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The Beginnings of Metallurgy: A New Look

Arguments over diffusion and independent invention ignore the complex metallurgic crafts leading to iron.

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It now seems that a complex technical logic rather than mere happenstance governed man's first ventures into the earth's crust for the diverse metallic and nonmetallic minerals scattered there. This conclusion has come to me and a number of fellow workers in ancient metallurgy as we have asked how men in the Neolithic made the seemingly abrupt transition from stone to metals. One must accept today that men "discovered" or "invented" the many significant new technologies of the Neolithic or early Bronze Age only through long preparation. They did so through cognitive conditioning by precedent technologies, through an expanding awareness of the imperatives laid on artisans by the materials themselves, and through a communicational revolution that entailed a diffusion of knowledge in time and space between centers of discovery and between linked technologies (*1*).

Simply to argue a series of independent inventions of "metallurgy" begs the fundamental question, how the multifaceted technical systems of the Neolithic came into existence (*2, 3*). For the case for the independent discovery of extractive metallurgy see (*2, 3*).

I have given my reasons in another article (*4*) for believing that all pyrotechnology became a coherent technical art in the zone of ancient Anatolia, Syria, Egypt, Mesopotamia, and Iran. By pyrotechnology we mean man's use of fire to fabricate plasters, ceramic pots and bricks, metals, and glazes and glass. Men were able to produce a temperature of 1083°C, the casting temperature of copper, probably no later than the sixth or fifth millennium B.C. They learned that under the right chemical conditions earthy gangues could be removed from metals as slags and ceramic products could be vitrified to glazes or glass. It is not coincidental that, in the fifth and fourth millennia, southwestern Asia produced evidences of the smelting of copper and lead and of the production of glazes. With such technical preparation, Anatolian and eastern Mediterranean peoples were able, about 2000 B.C., to engage in the mass production of copper from sulfide ores and to master the chemical and physical secrets of working iron. These accomplishments tell us much about their understanding of complex ore bodies, metals, impurities in metals, and glassy silicates.

In effect, men learned to tamper with and in many cases reverse the chemical processes by which the sulfide, carbonate, and oxide zones of metallic ores were originally laid down in the earth and surrounded with siliceous soils. Although the casting temperature of copper was a turning point in metallurgy and pyrotechnology, such absolute temperatures in the hearth or kiln merely made it possible for the artisan to come to terms with a wide variety of chemical and physical states in metals and slags which often seem to conflict with each other in their manifestations.

The first use of iron by pre-Hittite and Hittite peoples of Anatolia and Mesopotamia in the late third and early second millennium B.C. was thus the culminating moment in both early pyrotechnology and early metallurgy, as suggested in Fig. 1. Terrestrial iron was the offshoot of two "industrial" metallurgies, the large-scale smelting of copper from sulfide ores and the rendering of lead ores for silver (which also involved a partial invasion of the sulfide zone). Both metallurgies now seem to have been well established in the old Assyrian trading colony in Anatolia, centered at Kültepe-Kaniš during the years 1950 to 1800 B.C.

The underlying technical knowledge present at the various Assyrian *kārū* in Anatolia and Mesopotamia comes as no surprise. In these ghettos of often expatriate Assyrian merchants, metallurgy gave birth to entirely new arts of economics and communications. Kültepe and its satrapies witnessed the organized production of sulfide copper; the first large-scale trade in the rare metal tin and the fabrication of bronze by industrial methods; the output of silver; experimentation with iron; and the extensive use of such mechanisms of economic life as banking, credit, and the keeping of complex written records (*5*). Indeed four bodies of tablets, derived either from this period or just before it, now serve to document the emergent technical history of much of metallurgy and pyrotechnology: the texts of Ur III and Larsa in Babylon, the Kültepe tablets, the tablets from Mari in Babylon, and the Neo-Assyrian glass texts (*6*).

By about 1600 B.C. the metals trading area described in these tablets had extended deep into Europe and western Asia. Tin was perhaps the most elusive and intensely sought after metal, as Muhly (*7*) has shown, leading men possibly as far afield as Cornwall in England in the middle of the

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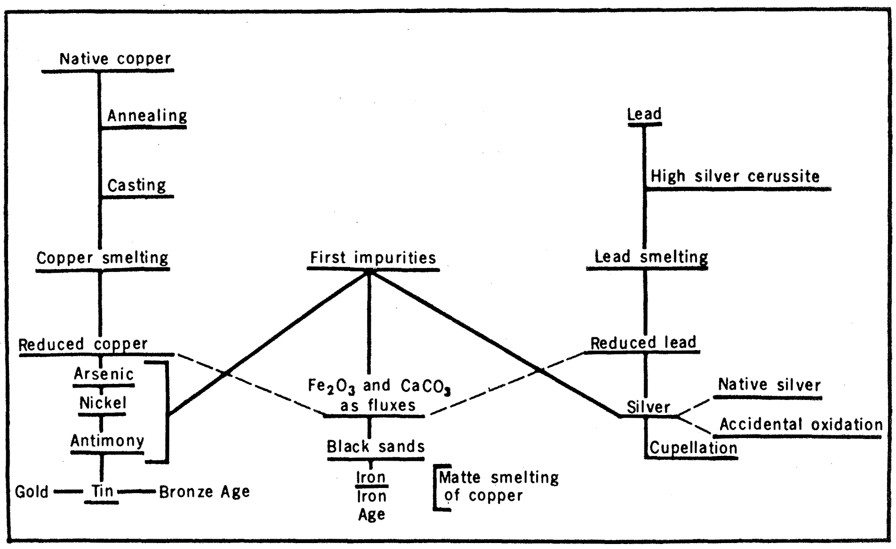

Fig. 1. Diagrammatic tree of metallurgy.

second millennium B.C. (*8*). Contemporaneously, Cypriot sulfide coppers became essential to late Minoan and early Mycenaean civilizations. The penetration of sulfide technologies to the copper deposits of Cyprus and Spain and the lead deposits of Greece marked the beginning of mass production of copper and lead (*9*). The copper billets of Cyprus in the shape of the hide of an ox are trademarks of this period (*7, 8, 10*). Both extractive metallurgy and casting technologies were fructified by a reasonably workable knowledge of impurities. The iron-containing ores hematite and jarosite, seashells, or silicates fluxed the smelting process. Arsenic, antimony, bismuth, tin, or lead affected the casting properties of copper. And "extraneous" metals such as silver, iron, gold, or zinc were offshoots of lead or copper production.

It would be a mistake, however, to see the earliest metallurgy as taking its origins in fire. Metals were first appreciated as stones. For most of the three millennia from 7000 to perhaps 4000 B.C., metallurgy centered on native copper. Figure 2 suggests that native copper in southwestern Asia was found in the heightened search for and trade in chert, obsidian, turquoise, lapis lazuli, and steatite (*11, 12*). Indeed, in the Sinai turquoise was exploited before its distant relative copper; and turquoise appeared as an object of trade in the middle of the seventh millennium B.C. (*13, 14*). But once copper metallurgy was coopted into pyrotechnology, as artisans discovered annealing and casting in the hearth, the baby swallowed its parent industries, whether of stone or fire.

The metallurgical revolution can be characterized as follows:

1) It first appeared in and was consummated in the upthrust plateaus and debouching river valleys formed at the eastern Mediterranean juncture of Europe, Asia, and Africa, where a variety of stones and metals was being experimented with even as domesticable plants and animals were being moved into new ecological niches.

2) Metallurgy was heir to 2 million years of man's experimentation in shaping solid materials such as stone, bone, and wood; and it was given a special impetus by the interlocking trade in stones that marked the late Neolithic.

3) As agricultural production grew and the cooking hearth came to assume a central role in village and tribal life, metallurgy became a benefactor and beneficiary of the revolution in food production.

4) Metallurgy represented the first serious penetration of the earth by men and fire. While ceramics offered economically more important pyrotechnic products at first, metallurgy introduced men directly to the science of the earth and its materials. It also lent itself directly to war, in a way that ceramics could not.

5) In short, metallurgy was a crucial ingredient or subsystem in the process of early urbanization, even leaving its imprint on the history of writing (Kültepe and the Sinai mines). It is instructive to scrutinize Ethiopia and northwest Kenya, two highland areas in which urbanization—and metallurgy—did not come to fruition at an early period, despite the long history of man's presence in the area, 150,000 years of the continuous working of and trade in obsidian, plant and animal domestication, and the appearance—in Turkana, Kenya, at least—of pottery around the middle of the seventh millennium B.C. (*15*).

The discovery of metals took place through a process of diffusion and multiple innovation, analogous to that described by Harlan (*16*) in his article, "Agricultural origins: centers and noncenters." A wealth of archeological and philological studies supports this conclusion (*7, 8, 11, 12, 14, 15, 17–21*). My main difference of interpretation with Harlan lies in my belief that extractive-casting metallurgy was probably discovered in only one center, southwestern Asia, and that secondary centers developed over thousands of miles through the search for minerals. Domestication (and urbanization) may have occurred independently in three or four main centers, although even this is still debatable.

The dating of the Ban Chiang bronzes in Thailand, which I viewed in the National Museum of Bangkok, poses the chief challenge to the thesis of this article and must in time be reconciled with it. The tentative assignment of fourth millennium for advanced Thai bronzes raises the question of the total cultural context of metallurgy in Thailand as well as the dating of the earliest bronzes in China. The issue is closely related to that of the still unknown tin sources for early bronzes in southwestern Asia. It could well be that the close juxtaposition of high-grade copper and tin resources in Thailand led men to an early and independent efflorescence of copper smelting and bronze making, although the weight of technical evidence presented here argues against this. Further metallurgical and pyrotechnological archeology from India to Japan is in order.

Nor have I tried to elucidate the many peculiarities of metallurgy in the New World, which may have their origins in the manner of transmission or invention of techniques as well as in the peculiarities of raw materials and of the esthetic tastes of Andean peoples. In any event this subject is being pursued by C. C. Patterson and H. Lechtman.

The argument for a logic in early metallurgy draws on a wide range of scientific studies now under way, with varying applicability.

1) A combination of techniques centering on metallography and the study of slags remains perhaps the most productive approach to early metals (*22, 23*).

2) Chemical analysis is still a standard way of determining major components of metals, especially of bronzes. Gettens' (*24*) work on Chinese bronzes provides a good example of its use, as do Caley's many studies (*25*).

3) Spectrographic analyses of Eurasian copper and bronze by scientists centered in Europe and inspired by Junghans and Sangmeister have provided useful groupings of such major impurities in copper as arsenic, antimony, bismuth, and tin (*26*).

4) The study of trace elements has begun to reveal inviting possibilities for those interested in trying to fingerprint coppers by neutron activation, atomic absorption, or spark source mass spectrometry. Rapp's group in Minnesota is beginning to define the geological source areas for certain trace elements in copper through neutron activation (*27*).

5) In Great Britain exciting new developments come under the general heading of archaeometry. Through analyses of metals segregated in the liquid and solid state, it has become possible to identify arsenic, lead, silver, and other impurities at the surface of metals and glazes. McKerrell of Edinburgh is studying the silvering effect of high arsenic in late third millennium bronzes with x-ray fluorescence. Charles and Oddy have used electron probe microanalyses on other elements such as mercury (*28*).

6) Isotopic analysis remains the best way to trace leads to their parent ores (*29, 30*).

7) Geophysics, geochemistry, and economic geology have substantially enlarged the understanding of ore formation. Are tin belts located at the juncture of tectonic plates? Are Cypriot pillow lavas and sulfide coppers an extension of those on the Anatolian mainland? How common are polymetallic deposits of copper, lead, and (say) iron? How frequently do native gold, silver, and copper appear in nature? What is the structure of an iron-copper gossan and how does it condition the attendant metallurgy? Does silver occur in cerussite as well as galena ores of lead (*31*)?

This article is both a summary of modern trends in studying early metallurgy and an effort to introduce balance into a subject that is too often the battleground of diffusionists and antidiffusionists interpreting the advent of technical civilization.

I shall proceed to the major metals and their impurities in historical order. Copper thoroughly dominated metallurgy from 7000 to 1500 B.C., remaining dominant in the pre-Columbian New World. True tin bronzes began to replace arsenic bronzes (copper-arsenic compounds) in southwestern

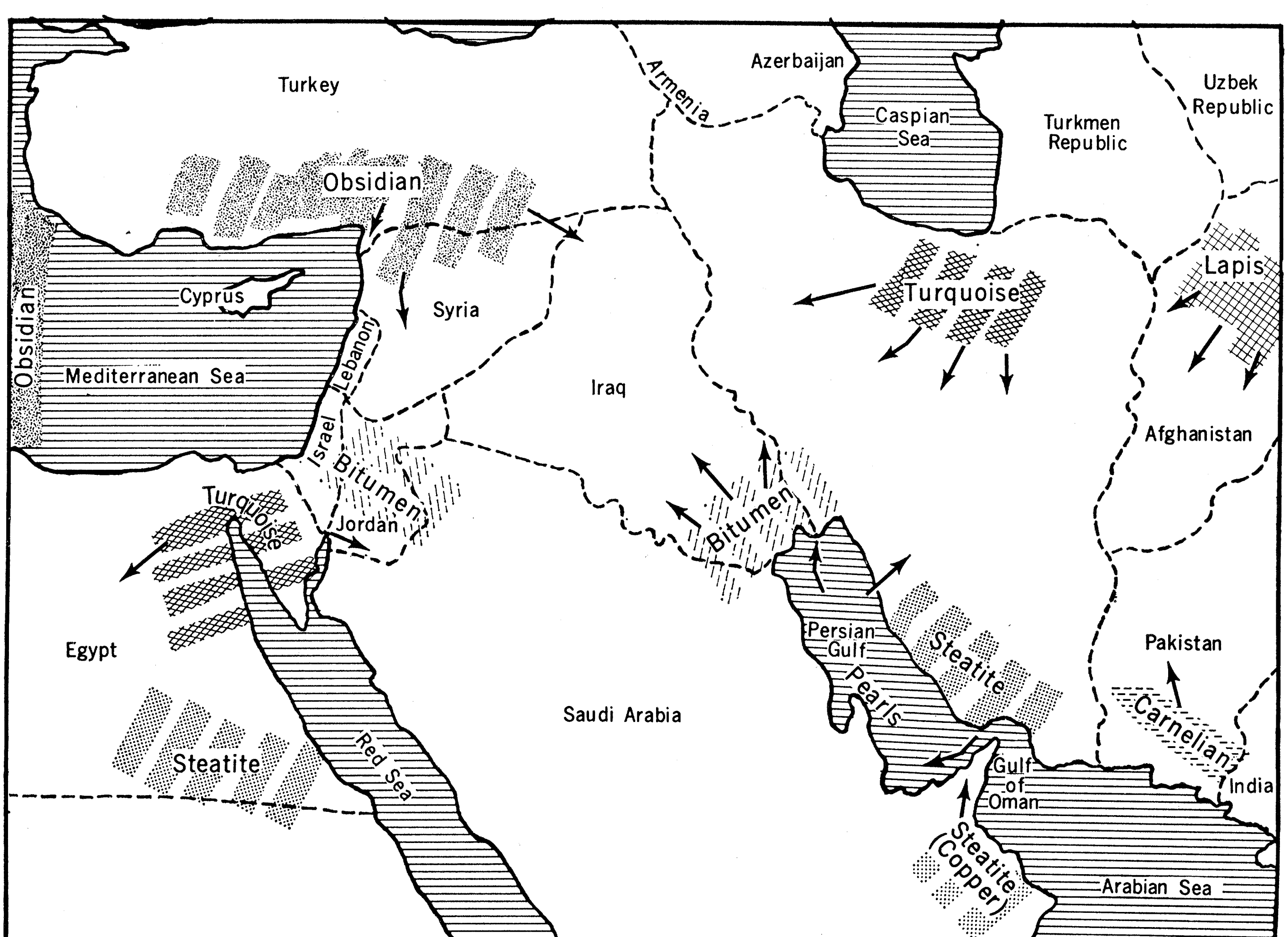

Fig. 2. The evolving trade in stones, jewels, and bitumen in the eighth to fourth millennia B.C. The overlapping circles of trade marked the appearance of settled life in the late Neolithic and set the stage for the discovery and movement of metals.

Asia during the middle of the third millennium B.C., and tin bronze turned up as far afield as southeastern Iran and Thailand in the early third millennium. Silver assumed major economic importance as a store of value in the early Bronze Age, at such sites as Susa (Iran), Ur III (Mesopotamia), and Kültepe (Anatolia). Lead had only secondary uses. Iron came into use as a major by-product of smelting processes for other metals, which revealed the existence of arsenic, antimony, bismuth, tin, and probably oxides of zinc.

Copper

Nearly everywhere, with the exception of parts of Africa and Greenland, native copper was the first metal to come into man's ken. There are a number of reasons for this. Copper minerals appear in bright, iridescent hues of blue and green in surface breaks in contact-metamorphic zones or in gossans. Copper is the most common native metal (a thousand times more common than gold) (*30, 32*). It migrates by chemical processes into crevices in the earth, often near the surface. It assumes the form of veins, nuggets, nodules, beads, or leaves. It is malleable and takes on an attractive orange-red color when hammered.

In Anatolia-Iran and in Yugoslavia-Hungary, surface occurrences of copper were crisscrossed by the trade routes in obsidian or other stones (which was not true, say, in southern Ethiopia) (*9, 11, 12, 15, 33, 34*). In the upper Great Lakes region of North America, native copper lay across the trails of Indian trade and migration (*35, 36*). Even today among the copper-working Indians and Eskimos of northern North

Table 1. Earliest occurrences of metals in southwestern Asia (seventh, sixth, and fifth millennia B.C.). [Courtesy of J. K. Bjorkman, University of Pennsylvania, Philadelphia]

City	Item	Assignment	Approximate date B.C.
	Turkey		
Cayönü Tepesi	Native Cu reamer and wire pins; malachite beads	"Past the fourth level"	7000
Suberde	Cu awl	"Lower level"	6500
Catal Hüyük	Pb and Cu beads	Level IX	6400
	Cu beads (from sheet Cu), finger rings, tubes; Pb beads and pendants	Levels VII and VI	6000–5700
	Cu "slag"	Level VI	5900–5800
Beycesultan	Hoard: 14 Cu tools and 1 Ag ring; chisel, possibly cast in open mold; the rest are Cu	"Second half of fifth millennium"	4500–4000
Hacilar	Cu beads	Levels IIa and Ia or Ib (Hassuna)	5400–5200
Can Hasan	Cu mace-head; Cu bracelet	Layer 2b, House 3 (Mersin XX-XXI)	5000
Mersin (Yümük Tepe)	Two Cu pins	Level XXII	5000
	Cu chisel, broad-faced; Cu ax	Level XVII	4600
	Cu stamp seal	?	?
	Six roll-headed Cu pins; Cu chisel, axes, adze, ore; polished metal tool or pin	Level XVI	4300
	Northern Syria		
Amouq	Worked stone with metal adhering	Phase B (Hassuna)	5500
Chagar Bazar	Cu bead	Level XII (Halaf)	4800
Tell Halaf	Cu fragments	Painted pottery levels; Halaf period	4800
	Northern Iraq		
Zawi Chemi	Piece of Cu (Cu mineral pendant)		8500
Tell Es-Sawwan	Cu beads, pieces, small knife	Level I and "below level II"	5600–5400
Samarra	Pieces of Cu	"Samarra"	5000
	Fe chisel-like implement, rectangular sectioned	"Samarra" (Halaf?)	5000
Arpachiyah	Piece of Pb	Halaf	4800
	Two fragments of Cu pins	Halaf (?)	4800 (?)
Hassuna	Fragment of galena	Level Ia	5700
Tepe Gawra	Small ring; chisel	Level XVII (northern Ubaid)	4000
	Iran		
Ali Kosh	Cu bead	"Ali Kosh phase"	6500
Tepe Giyan	Cu pins	Giyan VB	4500–4000
Sialk	Cu awls	Period I-3	5100
	Cu pin	Period I-4	4900
	Cu bracelet, pin, spatula fragment, button	Period II	4600–4100
	Cu pin, worked and annealed	Period I or II	5100–4100
Tepe Sabz	Cu	"Upper portions" (Bayat phase?)	4200 ?
Godin Tepe	Two Cu pins, "appear to be cast"	Period VI, Trench B, stratum 22	3300
Tal-i-Iblis	Puddle of hematite	"Early period"	4100
	Cu artifacts, ore fragments, a few crucible fragments; small Cu-smelting pit	Bardsir and Lalehzar (= Iblis 0)	4100
	300 crucible fragments with Cu slag adhering	Dump, Iblis I	4000
	Clay box, for cupellation?	Lalehzar	4100
	Subterranean furnace with deposit of white powder, possibly ceramic		3792 (^{14}C)

America are to be found remnants of an expert metal-working tradition in native copper that may have linked Siberia to Greenland in trade over much of the Christian era.

One finds striking evidences of early experimentation with several copper minerals at Cayönü Tepesi (near Ergani, Turkey) in a seventh millennium context (*37*). Mining of copper took place with stone mauls and birchbark baskets in the upper Great Lakes in the fifth millennium B.C. and with stone hammers and deer antlers at Rudna Glava in eastern Serbia in the fourth millennium B.C. (*33–36*).

In the area of upland southwestern Asia from central Turkey to the Persian Gulf, finds of early copper artifacts range from the late ninth or early eighth millennium in date to the late seventh or early sixth millennium B.C. (Table 1). Sites include Catal Hüyük, Suberde, Cayönü Tepesi, Zawi Chemi Shanidar, Tepe Zaghe, Chagha Sefid, and Ali Kosh (Fig. 3) (*11, 12, 14, 17, 37, 38*). Appearances in the sixth and fifth millennia are documented in south central or southeastern Iran (Sialk, Tal-i-Iblis, Tepe Yahya), and in Badarian (predynastic) Egypt (*13, 39–41*). The Old Copper Culture of North America came to technical flower in the fourth and third millennia (*35, 36*). So did the first copper workings in the Cernica culture of Romania and the Vinča-Pločnik culture of Yugoslavia (*33, 34*), as well as in Greece (Kitsos and Ale Potrypa caves, Sitagroi, and Sesklo) (*42, 43*). Metallurgy in Thailand (*20, 21*) now seems to be as old as in Afghanistan (Mundigak) or the Indus Valley (*44*).

By the end of the fourth millennium, the coppersmith was capable of producing such objects as a series of 10 copper crowns found at the cave site of Nahal-Mishmar, near the Dead Sea, along with 80 so-called scepters, 240 pear-shaped mace-heads, and 20 chisels or axes. The mace-heads and the majority of the ornaments were high in arsenic, sufficiently so to suggest an origin in the smelting of sulfide ores (*45, 46*). During the third millennium, bronze technology appeared throughout much of Europe and Asia, seemingly disseminated through trade and diffusion. The worth of copper as an industrial product, however, involved in an organized trade over thousands of miles, first fully manifested itself in the Bronze Age invasion of the sulfide zones in the early second millennium B.C.

I will briefly describe the following technical and historical phases of early copper metallurgy, before turning to polymetallism and metallurgy generally.

1) Native copper (hammering and annealing).

2) Evolution of casting and smelting.

3) Origins of bronze.

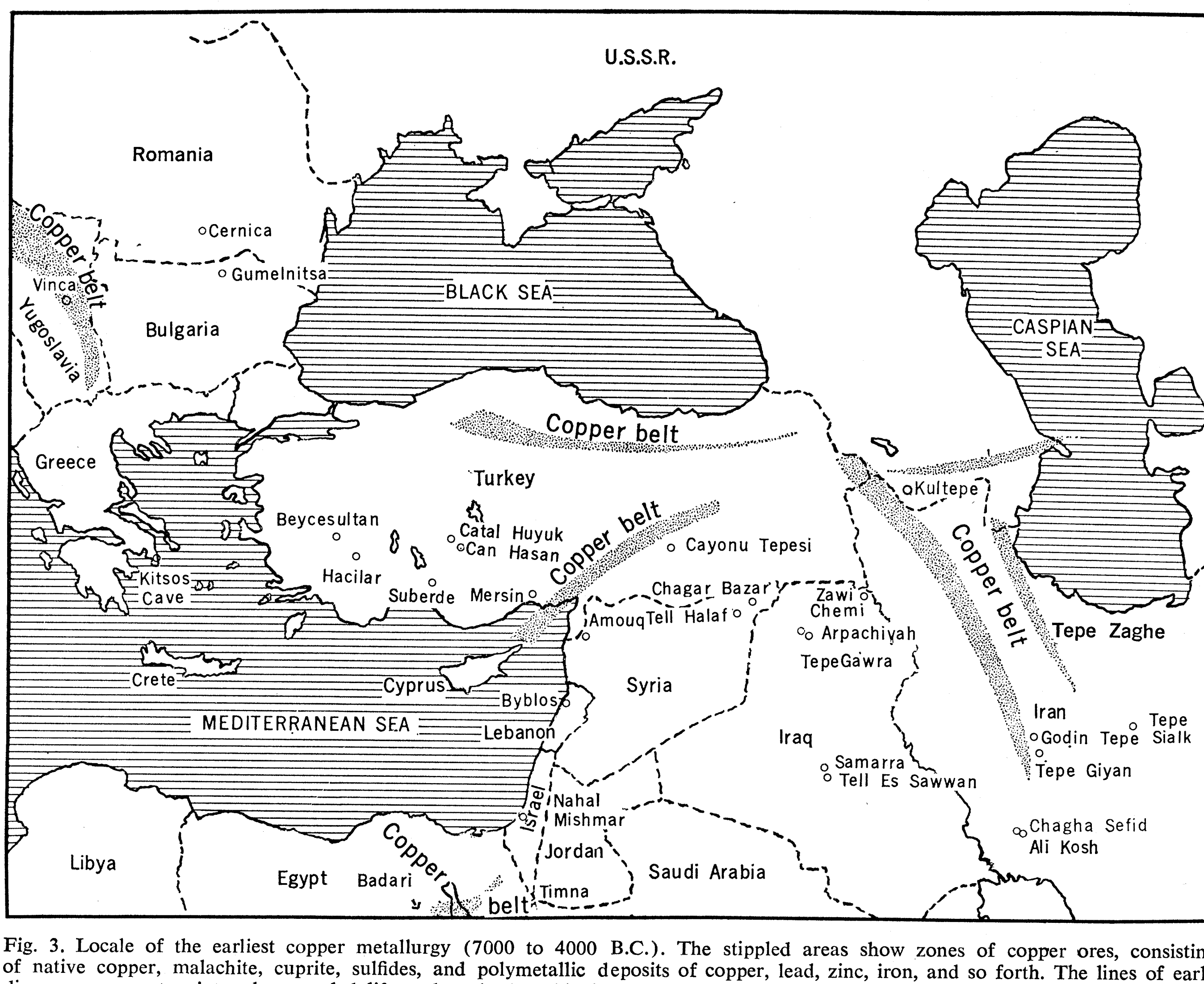

Fig. 3. Locale of the earliest copper metallurgy (7000 to 4000 B.C.). The stippled areas show zones of copper ores, consisting of native copper, malachite, cuprite, sulfides, and polymetallic deposits of copper, lead, zinc, iron, and so forth. The lines of early discovery were at points where settled life and trade (notably in obsidian) coincided with the occurrence of copper in visible form.

Native Copper

The monometallic or native copper phase varied in length and character from area to area. The Old Copper Culture of North America was seemingly untouched by other metals or by smelting or alloying, although in time native iron came into vogue among some Eskimos (*35, 36*). Two or three types of investigation have now combined to depict advanced Stone Age mining techniques leagued with a sophisticated metallurgy that reached to the threshold of the casting of native copper. Quimby's well-known survey of the native copper mines in the upper Great Lakes region pictures the Indians going as deep as 6 meters after the veins of pure copper (*35*). With the aid of fire and cold water as instruments for fracturing the native metal, they pounded the copper with beach boulders and pried it out with wooden levers, shaping it by techniques learned in the working of taconite and quartzite. In this fashion they removed at least 3000 and perhaps as many as 50,000 tons of copper. The Egyptians of the Middle Kingdom hardly did better in quarrying Aswan granite.

According to studies by Smith (*47*) and his associates Schroeder and Ruhl (*48*), the Old Copper Culture spearheads and knives evidence an advanced annealing and reworking technique (*49*). The annealing temperature of one object approached 1000°C, not far short of the casting temperature of copper.

At Solončene in Romania, as described by Tringham (*34*), annealing to a more modest 300°C has been found in an early copper fishhook. This likewise occurred in a monometallic setting, but one shortly to be invaded by techniques of smelting.

It seems virtually certain that the earliest native copper metallurgies everywhere were similar to the metallurgy of the Old Copper Culture Indians, except that in time annealing led to the casting of native copper (*50*). Metallurgy advanced because workers crossed the boundary of 1083°C and found themselves (inadvertently perhaps) engaged in the puddle casting of native copper—1083°C was the A.D. 1066 of metallurgy.

Casting and Smelting of Copper

Accumulated data on early metallurgy indicate that casting of native copper may have preceded smelting of copper from the ore (*2, 51–54*). Renfrew and Charles (*2*) suggest that Danubian shaft-hole axes came to be cast of native copper after having first been hammered therefrom. The transition occurred as the shaft hole was perfected.

Other archeological evidence is accumulating of the casting of native copper as a natural way of shaping it. A Ghandaran buddha from India of the second to fourth century A.D. is an example of cast native copper (*51*). It resembles Taxila statues of an earlier period in Pakistan. Moche copper cups in Peru from about A.D. 1000 were also cast of the native metal (*52*). Some of the earliest open-mold or bivalve mace-heads, hoes, or axes found at such diverse sites as Sialk and Susa (Iran), Arpachiyah (Iraq), Beycesultan and Mersin (Anatolia), and Thermi (Greece) from the fourth and third millennia B.C. may also have been in a transitional phase of casting of native copper; this no less than the Danubian axes examined by Charles (*28*) and by Jovanovič (*33*). According to Ottoway (*28*) the same appears to have been true of some Irish bronze weapons of the early second millennium B.C.

Members of the National Geographic–Smithsonian pyrotechnologic team in 1968 learned that native copper from Anarak (central Iran) has traditionally been melted and poured, rather than hammered, in the bazaars of Kashan and Yazd (close to Anarak). Tylecote (*22*) subsequently experimented with melting native coppers from Anarak, Ahaer (Iranian Azerbaijan), and Ergani (south central Turkey). In each case the native copper was more readily and handily cast than a smelted copper, but especially when accompanied by fractional quantities of impurities such as the arsenic found in the copper at Anarak.

In the fifth and fourth millennia, coppersmiths crossed the boundaries both to casting and to the smelting of copper from ores (a necessary adjunct to the expanding use of the metal). The most outstanding copper weapon of the period is a copper shaft-hole mace-head of about 4700 B.C., from Can Hasan in Anatolia, discovered by French (*55*) [although Brunton also found a large axhead in predynastic Egypt (*41*)]. Unfortunately, neither weapon has been analyzed.

Moorey (*53*) has outlined in elegant detail the evolution of cast copper weapons in Iran, beginning with Sialk III and Susa A in the early fourth millennium (contemporaneous with Arpachiyan axes). While most of the items analyzed fall within the second and first millennia B.C., several even at that late date appear to have been of native copper to which tin or arsenic was added in the casting process. Moorey cites a horse bit of Sialk B type (item 3), the mouthpiece of a horse bit (item 4), and a hilted dirk (item 37) as probable alloys of native copper and tin (Table 2).

Copper smelting in southwestern Asia is indicated by the widespread presence of arsenic, antimony, nickel, and bismuth in the metal (*26–28*). Selimkhanov (*56*) in Baku (Soviet Azerbaijan) has been most organized, perhaps, in trying to isolate the evolution of smelting and casting metallurgy by archeological strata at the site of Kültepe in Soviet Azerbaijan (*28*). From level I to levels II and III, native copper gave way to arsenical copper, whereas in levels III and IV tin bronze gradually appeared with manifestations of both the smelting of ore and casting of the metal.

At Non Nok Tha in Thailand, Bayard (*20*) found a socketed copper

Table 2. Analyses of Turkish and Iranian objects according to Moorey (*53*); in some cases the data show the melting of native copper. Blank spaces mean that the metal was not detected. In addition, Sb, Zn, and Au were not determined.

Item	Description	Cu	Sn	Pb	As	Ni	Bi	Fe	Ag
1	Horse bit	94.5	4.7	0.25	0.18	0.18	< 0.01	0.11	0.040
2	Horse bit	97.9	1.9			.086	< .01	.057	.026
3	Horse bit	92.1	7.9				< .01		.006
4	Horse bit	95.1	4.9			.041	< .01	.069	.0088
5	Cheekpiece	91.7	7.8	0.21		.19	< .01		.013
6	Horse bit	92.2	6.9	.51		.30	< .01	.078	.046
7	Horse bit	90.0	8.6	.55	.33	.55	< .01		.0099
37	Dirk	90.0	9.8					.055	.086

tool from the middle of the fourth millennium B.C. From its phosphorus and arsenic content he assumes that it may have had its origin in smelting.

There is little comfort in trying to deduce the origins of smelting directly from the pottery kiln or bread oven. Renfrew (*42*) has collected impressive evidences of the development of the pyrotechnic capabilities of the cooking hearth or bread oven in the Aegean, going back to the baking of clay figurines in Europe and the Middle East 20,000 years ago. In another article I try to show how ceramics and metallurgy were interrelated (*4*). There is little question that in the fourth millennium men came to understand the slagging of lead and copper (900° to 1100°C) as being connected to the vitrification of pottery. But metallurgy is not closely akin to pottery in technical method even where crucibles were used (*11, 40*). Its influence was felt more in the domain of glazes and glass.

Eastern Serbia today offers other evidences of the transition from native copper to smelting (*33, 34*). In the Rudna Glava mines, Jovanovič (*33*) has found pottery of the Vinča period (mid-fourth to mid-third millennium). These early Danubians probably first mined native copper, and later took recourse in ores of azurite, malachite, and cuprite through smelting. Serbian miners worked to the depth of 25 to 30 meters, using tools and methods not unlike those of the Old Copper Culture Indians in the United States. Jovanovič has independently concluded that the path to smelting of copper came through a phase of hot-hammering and then casting of native copper.

The best proof of smelting is, of course, the Bronze Age itself, when men organized the production of copper in a number of localities and chose among the merits of various impurities in lowering the casting temperature or improving the casting qualities of copper. The appearance of true tin bronzes was sporadic and masked by the fact that tin was replacing arsenic as the main impurity. High arsenic and high tin bronzes appear in the Royal Cemetery of Ur and at Kish and Khafajah by 2600 B.C. (*53–55*). The evidences for Syria and Anatolia are somewhat later; however, the earliest castings of animals and vessels from such sites as Alaca Hüyük and Mahmatlar project techniques of bronze casting so elegant as to be of some antiquity (*57*). The same may be said of the advanced hafted axes excavated by Bayard (*20*) in Thailand. These, together with Lamberg-Karlovsky's (*11*) bronze dagger found at Tepe Yahya in southeastern Iran and variously dated (*23*), push the Bronze Age in Asia back to the third millennium.

Origins of Bronze

Spectrographic analyses confirm that nearly everywhere tin was preceded as an alloying impurity by arsenic (which, unlike tin, forms a chemical compound with copper and which appears naturally in sulfide ores) (*26–28*). This was true in Anatolia, Soviet Azerbaijan, southern Europe, the Cyclades, Crete, Thermi, Israel, Iran, and the Indus Valley (*45, 53, 54, 58–60*). We may even speak of an era of "experimental alloying" in the fourth and third millennia B.C., during which men caught on to the fact that impurities of antimony, arsenic, or bismuth carried into the metal from the casting of native copper or the smelting of ores contributed to the ease of casting and of shaping the metal. Arsenic seems to have been the most consistent impurity before tin, ranging from less than 0.25 percent up to 3 to 4 percent, and occasionally reaching 10 to 12 percent (notably at Nahal-Mishmar). The proportion of arsenic generally seems to have diminished in bronzes as that of tin rose, suggesting that it was the impurity which first put men's minds to work looking for tin as a deliberate alloy. Despite its lethal qualities there is still a question as to why men replaced arsenic with the scarce tin. Increasingly, the term "Bronze Age" as signifying alloys of copper and tin appears to be a misnomer.

Arsenic became known to man in several ways, but mainly through the silvering effect that McKerrell (*28*) has identified in many Eurasian bronzes of the late third and early second millennia as the effect of surface segregation. It was present in cast native coppers from such sources as Anarak (which made Anarak native copper a superior cast product). It appeared in smelted coppers from a multiplicity of sites, because it is carried in solution from the ore to the metal. It is found in native form or as arsenopyrites at such sites as Erzerum in Turkey, Sises in Crete, and Rio Tinto in Spain and Portugal [where Sangmeister (*60*) believes the arsenical coppers of southern Europe originated] (*59*). How men came to identify it is no less a mystery than how they identified tin, which remains the enigmatic metal of the early Bronze Age. There is no known early Sumerian word for arsenic, for example.

Polymetallism as a Clue to Early Metallurgy

The Old Copper Culture Indians seem to have carried native copper metallurgy as far as it would have gone normally without inputs from other metallurgies. The transition from native copper to copper smelting and bronze casting in Romania, Serbia, Hungary, and northwestern Thailand was probably inspired by other metallurgies from other areas. Prospectors for tin must have been everywhere.

The implantation of smelting and the acceptance of tin bronze almost certainly occurred where several metals were under scrutiny, rather than just copper. Smelting seems to have gained its first foothold in a thoroughly polymetallic environment. When one looks at the monometallic cultures, he finds it impossible to explain the complex evolution of processes leading to the expanding production of bronze, silver, and later iron.

Polymetallism had three sources: complex ore bodies, especially sulfides and gossans; techniques of fluxing ores with each other; and the discovery of interacting impurities in the course of casting and smelting.

Multiple deposits of copper, lead, and iron (and often zinc, antimony, and nickel) are found commonly throughout Anatolia, Iran, and many of the metallogenic regions of the world (*30, 32, 61, 62*) (Fig. 3). The native copper deposits at Lake Superior, with pockets of up to 400 tons of pure copper, are very rare.

Copper occurs most commonly as sulfides. It appears in the context of hydrous ferric oxides, notably goethite (simply through the weathering of the gossan zone of sulfides). At Rudna Glava (Serbia) the copper-iron sulfide chalcopyrite has many accompaniments, but it is found in a setting of iron oxide magnetite, which miners avoided (*33, 34*). Magnetite and other ore impurities appear in the Ana Yatak ore body at Ergani (Anatolia) (*31*).

Anarak copper (Iran) was formed in the presence of ores of uranium, cobalt, lead, iron, and nickel (*63*).

By the same token, lead sulfides or sulfates appear in the context of copper, iron, and often zinc (early miners having first sought, as at Taerz in Iran, to avoid the zinc) (*64, 65*).

Not all gossan ore bodies have an oxidized capping, but those which do often show the brilliant orange characteristic of the Skouriotissa mines in Cyprus. Covellite (cupric sulfide) generally dominates in the upper oxidized zone. In close juxtaposition are the iron ores goethite, hematite, and jarosite; sulfur; and occasionally silica, gypsum, and kaolin, as well as sulfates of copper, iron, zinc, and lead (*61, 62, 65, 66*).

Oxide or carbonate copper ores on Cyprus are generally scarce, although they were ample enough to have been used in the prehistoric period, judged by the artifacts marking the period 2500 to 1600 B.C.

One finds at some points on Cyprus outcrops of gossan with a startling resemblance to ancient slags in both appearance and composition. Some limestones are so plastered chemically with the gossans as to persuade the viewer they are linings of ancient smelting furnaces. The gossan formation itself was the first clue to the chemical processes by which sulfides were weathered and by which the various elements in a sulfide formation might chemically flux each other in the fire.

Ancient mining was a study in the selection of compatible ores and fluxes and the avoidance of incompatible ores (such as magnetite with copper or zinc with lead). Indeed, I offer the truism that smelting began in most cases not as an exercise in reducing a single metallic ore but as an exercise in reducing several metallic ores in juxtaposition, with one serving to flux the others. For the incipient metallurgist who looked beyond native metals to the immediately surrounding ore bodies, the terms "metal" and "impurity" were at first meaningless ones, as witness the confusing terminology for the first metals (*5, 6*).

Iron was probably a by-product of both copper and lead smelting, since hematite or gossan were used as fluxes in smelting both metals, iron being yielded in the slag or the metal (*64, 65*). Silver mainfested itself as an impurity when lead was accidentally refined by cupellation. Arsenic must certainly have evidenced itself as spiegel or arsenopyrite in the context of copper deposits.

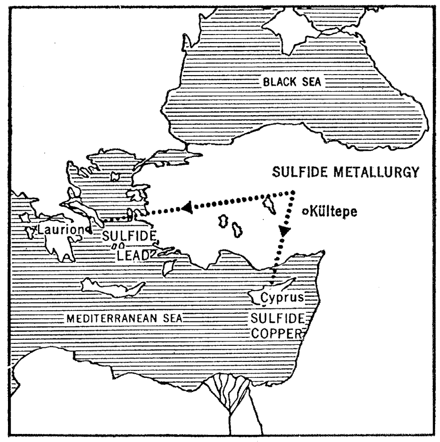

Fig. 4. Sulfide metallurgy was the outgrowth of new demands for metals during the Kültepe phase of the Bronze Age (early second millennium) and led to specialized metallurgies in Cyprus and Greece. It laid the chemical and geographic basis for the appearance of iron.

The history of polymetallism is best documented in Turkey and the Caucasus. Iron and silver metallurgies seem to have had a common origin along the Black Sea not far removed from copper; arsenic was mined in the Phrygian period; brass manifested itself in the second millennium; arsenopyrites or fool's gold (iron or copper pyrites) may have formed some part of the horde of Croesus; and platinum with iridium is occasionally found in the coins of the ancient Lydians (*68*). The Nahal-Mishmar copper hoards of the late fourth millennium may have been fashioned in some part from a rare sulfarsenate ore such as enargite or tennantite, which may be found only in Armenia (*45, 46*).

Sulfide Metallurgy

For reasons given above, the invasion of the sulfide zone of copper seems to have been a major turning point in metallurgical history after the initial discovery of native copper and of techniques of casting copper and smelting ores (Fig. 4). At such sites as Ergani in Turkey or Anarak in Iran it was directly involved in the first experience of copper smelting itself. Probably some small proportion of sulfides crept into the earliest smelting, simply out of propinquity, even though roasting removes most sulfur in the one (*31, 64–66*). The many impurities that appear in the first smelted coppers do not derive simply from the oxide or carbonate zone.

By 2000 B.C. the preparation of blister copper was established at Ergani as well as the *kārū* supplying the Assyrian headquarters of Kültepe-Kaniš with copper (*69*). Tylecote in 1968 analyzed several billets from Acem Hüyük and found that they were a blister or black copper (*22*); the same seems not to have been true of the oxhide bars of Cyprus, which are very pure (*67*). I have twice examined visually the tiny furnace of Maden Corüfü preserved at Alaca Hüyük, a supplying center in this period, and noted the typical billet, plus the slags of an interrupted heat. Pieces of iron fayalite slag are intermingled with those of copper. How iron smelting came to be so closely juxtaposed to copper smelting will require further study.

Sulfide metallurgy invaded Cyprus about 1600 B.C., a time pregnant for the three contesting civilizations that would play a hand in Cypriot history—the Hittites, the Minoans, and the Mycenaeans (*7, 8, 10, 62, 70, 71*). It reached Spain not much later. In both countries, tradition defines two salient periods of metallurgy: a Phoenician and a Roman period. In Cyprus, at least, the Phoenician era may more appropriately be termed Minoan-Mycenaean, judged by the pottery of those origins. The Roman era is marked by much darker and denser and more efficient slags than the gossan-like slags of the Phoenician and pre-Phoenician period. It began as a Greek period, if Skouriotissa mining timbers dating to the fourth century B.C. may be believed (*72*). The many mining adits of both epochs in the enriched zone bespeak the energy of the invasion. It was the era of the first mass production of metals, whose essential technologies have persisted until today with only few modifications.

The greatest anomaly of this period is perhaps the extent of metallic iron in copper slags: 29 to 37 percent in three slags from Yerasa and Petro Mutti in Cyprus (*62, 73*). The iron seems to have derived from the use of gossan as a flux. B. Rothenberg has shown me a gossan-like formation at Timna in Israel that was used as a flux in ancient copper smelting and appears as a form of "petrified" iron, possibly because of its long formation under water. C. Milton has discovered substantial amounts of metallic iron incorporated in the bits of copper in slags at Timna, invisible yet showing its presence through magnetism and its effects on the workability of the copper. I think that there may be a connection between the two phenomena.

Before turning to the other metallurgies that preceded iron, we may sum up the monometallic and polymetallic traditions that brought men in the zone of the Eastern Mediterranean, Persian Gulf, and Red Sea from native copper to the casting and smelting of several metals, to the invasion of the sulfide zone, and to the threshold of the age of iron. A single exfoliating strand of discovery led from copper metallurgy to the interconnected metallurgies of copper, lead, tin, and iron. A complex and sophisticated process of diffusion of knowledge and of trade played a constant role, ultimately extending metallurgy over much of Eurasia through multiple invention, and to the New World through trans-Pacific contacts, at least so far as the Eskimo was concerned (*36*).

1) Men came to know the stone called "metal" by working native copper through breaking it apart in the earth with fire and water and then cold-hammering it into small beads, tubes, or pins.

2) They introduced the further use of fire into the shaping of copper by annealing small intractable chunks, in some cases bringing the fragments to a temperature at which they melted and ran into the fire.

3) Smelting was probably discovered incidentally to the exposure of a variety of mutually fluxing ores of copper, lead, and iron to hearth fires, in some propinquity to work carried on in the annealing and casting of copper. This makes more sense than theories of the accidental discovery of copper smelting in a pottery kiln. As one contemplates the multiplicity of minerals present in a gossan zone, such a zone appears to have been a most likely spot for the early discovery of the chemical interconnection of minerals, particularly through visual means.

4) While the reduction of copper ores may have occurred later in time than the casting of copper metal, the two processes reinforced each other through the discovery of the impurities that alloy with copper—arsenic, antimony, bismuth, and tin. The advent of tin as an alloy can only be understood in terms of long prior experimentation with impurities that form chemical or mechanical compounds with copper, which have been demonstrated through archeology to have existed in artifacts everywhere.

5) The full-scale invasion of the sulfide zone during the Bronze Age in the third millennium B.C. in Anatolia appears to have been crucial in metallurgy, introducing mass reduction of ores and paving the way chemically and industrially for the acceptance of iron as the most economical metal.

6) Men became accustomed to slagging off silicates with the help of alkali fluxes and to working with materials at 1083°C, the melting point of copper. At this temperature and under the chemical conditions of slagging, it was natural that they venture in the fifth millennium into the arena of glazing. The end result was the nearly simultaneous ensconcement of iron and glass, between 2000 and 1500 B.C., as accepted pyrotechnic products.

Lead and Silver

The oldest known piece of lead is that discovered by Mellaart (*17*) at Catal Hüyük. Catal Hüyük may also boast the oldest piece of slag, if the analysis by Pittioni and co-workers (*74*) of a vitrified stone found there is correct. Even though the slag may be of copper, the juxtaposition of the two evidences, according to our theories, is not coincidental. Lead could only have been produced by smelting. Pieces of raw lead were also found in early strata at Arpachiyah (Iraq) and Anau (Iran) (*75*). In predynastic Egypt and at Hissar III, lead was being shaped into useful products (*41, 76*).

Silver made a debut in the fifth millennium B.C. at Beycesultan in Anatolia and at Sialk in Iran (*39, 77*). Does this appearance have any connection to that of lead? I believe it does, for reasons offered some years ago by Gowland (*78*) and the Hoovers (*79*). Although Patterson (*30*) speculates that the oldest silver artifacts were made of native crystals or of cerargyrite (silver chloride), it seems more probable that silver was discovered in the course of accidental cupellation of lead. Native silver is very rare (20 percent as abundant as gold and 0.2 percent as abundant as native copper), and generally occurs deep underground. Conophagos (*80*) has noted that ore at Lavrion occasionally had as much as 50 percent silver, standing out from the usual pattern of the lead ores cerussite and galena by its bright visibility.

The first convincing evidence of the production of silver from lead ores, however, is the cupel buttons found at Mahmatlar in the late third millennium B.C. and now in the Hittite Museum in Ankara (*81*).

In the third millennium B.C. silver became quite common, appearing at Thermi and Troy II in sumptuary products (*82*). At Susa, Ur III, and Kültepe it was the chief unit of exchange, setting the value of the shekel (*5, 6*).

If, in fact, lead was reduced from ore at the same time as copper, or even earlier, it was not because smelting it from the ore was much easier. Although it has a melting point of 327°C when pure, the reduction point of the ore is not much less than that of copper, in experiments of ours at Tal-i-Iblis going as high as 1300°C (*64, 65*). Furthermore, traditional metallurgists suggest that iron ores were a necessary flux, even in reducing cerussite. Lead smelting began in a highly polymetallic setting.

Since the best artifactual evidences for lead and silver are from ancient Anatolia, it is possible to surmise that a combined lead and silver metallurgy could first have occurred in the multiple ore bodies of lead, copper, and iron that ring the southern Black Sea coast, or in some of the numerous lead-bearing gossans of Anatolia and Iran.

Until the transfer of lead metallurgy to the Cyclades, Lavrion, and Spain, there does not seem to have been extensive invasion of the sulfide zone. Unlike the copper miner after about 2000 B.C., the lead miner in the Anatolian-Iranian highlands seems to have eschewed galena and to have concentrated his energies on the rare cerussites that are rich in silver (*64, 65*). This has been attested to by the miners, prospectors, and metallurgists on our expeditions: the mining of galena from below the water table and its smelting were far less rewarding than the working of cerussites. Even at Lavrion in the middle Bronze Age beginnings of silver working, there remains a possibility that smelting at first involved a mixture of cerussite and galena (*83*). And galena may never have been reduced for silver in the New World.

The penetration of the zone of lead sulfides and sulfates, as we have noted, was a function of the "Phoenician" and "pre-Phoenician" periods of metallurgy in Cyprus and Spain (although

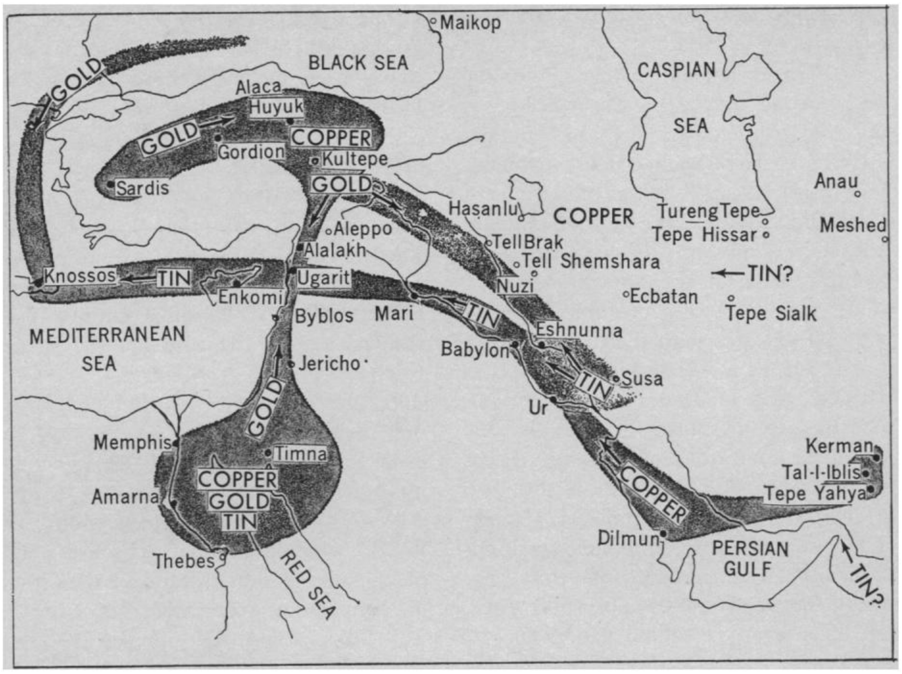

Fig. 5. Trade in metals grew apace during the millennium 2500 to 1500 B.C., bringing gold from Maikop to Crete and from Sardis to Byblos and Ur. Old routes opened up by obsidian and bitumen were in time filled by gold and tin, which became widespread, and copper, which stayed in more limited areas, except in the Persian Gulf region. Tin remains the mystery, having come in large amounts from unknown sources in the East.

lead seems not to have been mined in Cyprus). A review of the evidence by Salkfeld (*71*) suggests that lead smelting far outweighed copper smelting at the Rio Tinto mines (1 million tons of copper slag to 15.3 million tons of lead slag) (*62, 70, 71*). It is probable that the lead was a sulfate lying at the top of veins of galena, and derived from a plumbojarosite by weathering and leaching. As in the case of Cyprus, analyses of slag from Rio Tinto fluctuate between silica and iron. At Rio Tinto, silica was available in the gossan as an offsetting flux to the iron. Its use seems to have figured prominently in the working of the lead.

Tin

Tin remains the enigma of bronze metallurgy, simply because no one knows where the tin for the early and middle Bronze Ages in Anatolia, Mesopotamia, and Iran came from (*7, 8, 84, 85*) (Fig. 5). Moreover, we have as yet no real idea whether the first tin to be alloyed into bronze was stannite—the tin sulfide found with copper—or cassiterite—the tin oxide. Nor do we know where the first alloying occurred.

There is no shortage of evidence for the increasing presence of tin in early bronzes, although pure tin was relatively rare. We have already cited the almost universal indications of the replacement of arsenical bronzes by tin bronzes in the old Middle East in the third millennium, leaving arsenic an impurity to be reckoned with after 2000 B.C., mainly in Europe and the western Mediterranean. Philologists for a half century have been filtering the large documentary record on *annaku*, a logogram now generally accepted as meaning tin. Today they have little doubt that in the early second millennium B.C., a tin trade involving hundreds of kilograms was moving from Aššur in Assyria to Kaniš in Anatolia (*5, 7, 8*). Another set of documents describes the movement of tin from Susa up the Euphrates to Mari, and from Mari by way of Syria to a site putatively identified as Crete (*6–8*) (Fig. 5).

Muhly (*7*) has presented a convincing picture of this commerce in tin from eastern sources, notably Anšan and Susa in Elam, and its connections by way of Syria to the Minoan Bronze Age in Crete, which originated about 2500 B.C. He finds Mycenae and its satrapal cities in Greece turning toward Europe to Cornwall for their tin, utilizing trade routes down the Saône and Rhône rivers to the Mediterranean. The Mycenaean Bronze Age reached its apogee sometime after 1500 B.C.

The Bronze Age, in brief, developed in the ancient Near East and the Aegean, drawing on the evolution of industrial copper metallurgy which we have described. But until the advent of tin from Cornwall, there remains no inkling of tin sources, particularly those associated with Elam.

I have made four reconnaissances for early tin, aided by the geological surveys or minerals exploration institutions of Afghanistan, Iran, and Turkey, and provided with the essential skills of such geologists as A. Shekarchi, F. Klinger, and G. Rapp. As recently as October 1972, Muhly, Rapp, and I visited the Balikesir region of western Turkey with a Turkish metallurgist and the help of Turkish geologists to check out tin sources reported by Ryan. We did not find a single crystal of tin ore cassiterite in the pegmatites there.

So far, spectrographic traces of tin have been limited to the Mokur gold fields of Afghanistan, the black sands of the Caspian, and Turkish copper deposits at Arakli. Iranian geologists have found new and more definite evidences of tin this year in the granites of eastern Iran, near Meshed. We accept the implications of the Greek geographer Strabo (*86*) and the Arab geographers (*87*) that tin existed in Iran and was worked out. If there had been small deposits of tin in the watersheds of the Caspian or the Black Sea, one must presume that they were exhausted by the first bronze makers, much as the first gold deposits were exhausted.

The speed with which the Bronze Age found advanced bases in England and in Thailand (casting of advanced bronzes by 2800 B.C.) suggests that one must now look farther east for the tin for the early Bronze Age. Dilmun evidently was an entrepôt for copper from Kerman in Iran. Was there also a Persian Gulf entrepôt for tin? The records are negative, except for one reference noted by Muhly (*7*) to tin from Meluhha, which was in Iran (*88*). One finds no support from mineralogists in Thailand for positing the early movement of Thai tin to the Persian Gulf.

Tin is known to exist in Egypt, Nigeria, northwestern Italy, Spain and Portugal, Bohemia, Brittany, Cornwall, Thailand (Malaya), and at sites in Yunnan province and near Anyang in China. In 1971, Dayton (*84*) proposed a theory that the Bronze Age had its origins in copper and tin from regions of the Danube in central Europe and Bohemia, but there is no archeological or textual support for this (*7, 8, 85*). For the time being, a variety of techniques will have to be brought to bear on the tin problem, including further geological exploration; a study of routes by which metallurgical influences and products from Southeast Asia may have filtered west; and the development of isotopic and other means of fingerprinting tin.

Iron

Iron was the true beneficiary of the polymetallic ventures into the sulfide zone that occurred around Anatolia in the third and second millennia. The metal was already described in the Kültepe tablets of 1950 B.C. as a meteoric metal, interdicted for export (*5, 89*). The iron swords of Alaca Hüyük in the Hittite Museum in Ankara demonstrate that it was also known as a terrestrial metal. An analysis of these beautiful weapons, set in gold handles, shows a low nickel content, which is compatible with a nonmeteoric iron (*90*). The discovery of apparently isolated artifacts of iron at Tell Asmar (2500 B.C.), Tell Chagar Bazar (2440 to 2340 B.C.), and Alaca Hüyük (2100 to 1900 B.C.) no longer appears anomalous (*91*) (Table 1).

There were four paths to the identification of iron:

1) As meteoric or native iron, it was worked by Gerzean Egyptians of the fourth millennium B.C., Anatolian tribes of the third millennium B.C., Chou Chinese of the first millennium B.C., Hopewell Indians, and, more recently, Greenland Eskimos.

2) Gossans frequently suggest the appearance of nearly pure iron, in juxtaposition to copper and lead.

3) The smelting of lead ores with a hematite or gossan flux, which is nearly universal in traditional metallurgy in the ancient Middle East, sometimes yields a mass of unfused iron instead of the usual lead. This occurs under conditions of overapplication of charcoal heat and iron flux, producing too heavy reduction in the furnace (*64, 65*).

4) As analyses of copper slags from Cyprus show, the smelting of one of the copper sulfides covellite or chalcocite with a gossan flux occasionally yielded a pure iron (*62, 67, 73*). The high iron "Phoenician" slags of Cyprus often cannot be distinguished in appearance from gossans.

In view of the spread of smelting and casting technologies by 2000 B.C., one wonders why the earliest formal art of making iron seems to have been identified so largely with peoples of the Anatolian plateau and its environs. Some hypotheses are:

1) Anatolia was the seat of the first organized production of copper and silver (by the Assyrian colony) and the first known penetration of the sulfide zone.

2) Few other areas of the world were endowed with such a profusion of resources of copper, lead, iron, arsenopyrites, zinc, and so on. It is not coincidental that the area of the Alizones (near the historic Chalybes or Pamphlagonians) was called the birthplace of silver by Homer and the birthplace of iron by Xenophon, Herodotus, and Strabo (*92*). In this zone of the Black Sea mountains, for example, lead and iron smelting have taken place in close proximity at numerous surface deposits. But of equal interest is the fact that the southern Black Sea coast is lined with sands high in magnetite (up to 77 percent) that can be smelted at 900°C. Rich in olivine, they are self-fluxing.

3) A third factor comprises the vagaries of iron as a metal. Because of its absorption of carbon, it was virtually useless as a cast metal, and must therefore have been fabricated in the furnace as a sponge and then hammered and heat-treated. Only peoples with the very long metallurgical tradition possessed by the tribal peoples of Anatolia would have had the know-how and patience to experiment with iron. Economic necessity became important as richer copper resources were played out. As it was, a thousand years elapsed between the first experiments with iron and its acceptance as as industrial product. The great workshops at Gordion of the Phrygian period (eighth century B.C.) provide an example of the fulfillment of iron's possibilities as a metal (*93*).

The story of the consolidation of the Iron Age in Anatolia and its migration to the rest of the world is now being told by Pleiner (*94*) and a host of scholars who are currently studying the advent of metals in Europe, Asia, and Africa (*95*). Once the Hittite hegemony in iron was broken, in the 14th century B.C., technologies of iron appeared on the fringes of the Hittite empire, first in such places as Ugarit and Thrace, shortly thereafter in Crete, Palestine, and Egypt. The spread of iron may or may not have accompanied the fall of the Hittites. In any event it was prepared for by the spread of early sulfide metal technologies. The exception was that iron invaded Africa along with copper (both appearing in Ethiopia in the fourth century B.C.).

The vagaries of the metal—and its alloys with carbon—are such that iron came to be known to the Scythians as a metal to be forged (there are even a few instances of casting) and to the southeast Asians and Chinese as one mainly to be cast. Possibly through Persian influences, India became famous for its steel, derived by a process that is practically indistinguishable from Chinese techniques of making castings. However, once the vagaries became known, iron migrated rapidly, reaching Southeast Asia and China in the seventh century B.C., Hallstatt Romania about 750 B.C., and England between 500 and 400 B.C. It never jumped to the Western Hemisphere; but in Africa, whose Bronze Age was spotty at best, it found its true prehistoric home, reaching Meroë in Nubia about 300 B.C. and coastal settlements of northwest Africa through the Phoenicians by 1000 to 1250 B.C. It spread quickly to Ghana but much more slowly to west and south Africa (*19, 94, 95*).

Summary

In the 9 years since my first survey of early metallurgy appeared in this journal (*65*) metallurgy has become a major battleground between those who argue independent invention and those who argue diffusion in the evolution of urban civilization. In this new article I contend that:

1) The upland belt and debouching river valleys of southwestern Asia have a clear priority in the beginnings of copper metallurgy and extractive metallurgy generally, suggesting that the forces of urbanization contributing to the rise of metallurgy there were more massive, widespread, and better integrated than elsewhere.

2) The trend to polymetallism, against the background of pyrotechnology generally and the other important technologies of urbanism, established a necessary sequence to early metallurgy. This sequence was a prerequisite to the coming of the Iron

Age, which was uniquely contained at first within the environment of Anatolia and the eastern Mediterranean and spread outward from there.

3) The course of metallurgy and possibly of the other urbanizing technologies can best be understood through a process of diffusion and multiple innovation interrelating metallurgical evolution over much of Eurasia, but with the area defined by the Black Sea, the Caspian Sea, the Red Sea, and the eastern Mediterranean as its center. Only in this fashion can we place metallurgy in its proper role as an important subsystem in the rise of civilization.

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Domestication of Pulses in the Old World

Legumes were companions of wheat and barley when agriculture began in the Near East.

Daniel Zohary and Maria Hopf

Evidence is brought to bear on the questions as to which were the main legumes utilized in the early history of the Old World agriculture and where, when, and from what wild sources these cultivated pulses evolved. We have also attempted to evaluate the role that these food plants played in the development of Neolithic agriculture in the Near East and the rapid spread of this new technology west, north, east, and south.

Pulses accompany the cereals throughout the Old World Belt of Mediterranean agriculture. Where the old-type grain agriculture is still practiced, legumes like pea, lentil, broad bean, and chickpea are universal companions of wheats and barley. They constitute an essential element of food production and comprise an important ingredient in the peasant's diet. But while the mode of origin of the cultivated cereals was intensively studied both by archeologists and plant geneticists, and the fundamental role that these grasses played in the establishment of Old World Neolithic agriculture is now widely recognized (*1–4*), the Mediterranean pulses were relatively neglected. In the last few years a considerable amount of carbonized remains of legumes have been excavated in Neolithic and Bronze Age sites in the Near East and in Europe. Furthermore this archeological evidence was complemented by botanical and genetic examination of the wild relatives of the main legumes. In the cases of pea and lentil, the wild progenitors of the domesticated crops are already satisfactorily identified and their ecology and distribution surveyed (*5, 6*). More fragmentary information is at hand on several other Mediterranean legumes. Thus a critical assessment of the domestication of pulses in the Old World can be attempted on basis of the combined evidence from archeology and from the living plants.

This article aims at such a synthesis.

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Pea (Pisum sativum L.)

Peas make their appearance in the early Neolithic farming villages of the Near East (7000 to 6000 B.C.). Well-preserved carbonized pea seeds were discovered (Map 1) in aceramic Jarmo, north Iraq (*4, 7*), Çayönü, southeast Turkey (*8*), and in the prepottery B level in Jericho (*9*). Much richer remains of peas are available from somewhat later Neolithic phases in the Near East—from the sixth millennium B.C. Large quantities of carbonized pea seed accompany the finds of cultivated wheats and barley in Çatal Hüyük, 5850 to 5600 B.C. (*10*); Can Hasan (*11*); and Hacilar, 5400 to 5000 B.C. (*12*). The remains from the upper levels of Çayönü, Çatal Hüyük, and Can Hasan already show the smooth seed coat characteristic of domesticated peas.

Peas are common in the Neolithic agriculture settlements in Europe. Here again they are closely associated with the wheat and barley production. Rep-