METALS AND METALLURGY :
USING MODERN TECHNOLOGY TO STUDY ANCIENT TECHNOLOGY

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My discussion of the general theme how modern technology has enabled us to reconstruct ancient metallurgical technology, will have to be limited to an examination of only three aspects of what is obviously a large and very complex topic, I will discuss in chronological sequence:

1. the beginnings of metallurgy in the Aegean, the first use of copper, gold, silver and tin.

2. the development of large scale, true industrial production of copper in the Late Bronze Age and the emergence of a trans-Mediterranean trade in copper, which was cast in the distinctive form of oxhide ingots

3. the transition from bronze to iron, from the Bronze Age to the Iron Age, a transition made possible (and desirable) because of the development of the technology that moved iron from an exotic, precious material, to a utilitarian everyday metal not only cheaper but superior, in many practical ways, to bronze.

The beginnings of metallurgy in the Aegean belong to what is best described as a trinket technology, involving the production of small beads and pins of copper. The earliest piece of metal from the Aegean, a tiny bit of copper from Dikili Tash, comes from the latter part of the Middle Neolithic period, now dated to ca 5300 BC. This find from Dikili Tash comes from what is now designated as Phase 3 of the Greek Neolithic. From Phase 4, the Late Neolithic (ca 5300-4700 B C), we have a slight increase in the use of metal, represented by nine copper pins from Dikili Tash, a single copper pin from the Kitsos Cave in southern Attica, and two small daggers from Ayia Marina in Phocis[1]

The real development of Aegean metallurgy, however, comes in Phase 5 , the Final Neolithic period (ca. 4500-3200 B.C.). Now we find metal usage spread over the entire Aegean, at sites such as Dikili Tash, Mandalo, Sitagroi in Macedonia, Sesklo and Pefkakia in Thessaly, Marathon, Thorikos and the Kitsos Cave in Attica, the Tharrounia Cave in Euboea, Kephala on Keos, Knossos and Phaistos on Crete, the Zas Cave on Naxos and Emporio on the island of Chios. Two aspects of this period are of special importance:

1 No longer does metallurgy mean just copper metallurgy. This is a polymetallic age, with a surprisingly extensive use of gold and silver as well as copper[2].

2 The Final Neolithic also brings to us the first evidence for actual metalworking in Greece, with crucibles and slags known from several sites, notably Sitagroi. My colleague, Philip Betancourt, has presented at this conference the exciting new evidence for copper smelting at Final Neolithic Chrysokamino, in eastern Crete.

All of this, especially the evidence for actual metalworking, even copper mining, and the extensive use of gold, has its exact parallel at contemporary sites in the Balkans. There is no time to go into all of the evidence here, but the Bulgarian site of Varna provides wonderful parallels for everything that we know from Final Neolithic Greece[3]. The logical conclusion is that we have, in Greece, a metal industry derived from the Balkans. What of the metal itself?

At present this question cannot be answered. Lead isotope research on early metal artifacts from the Aegean has only begun and the few objects that have been analyzed, especially a piece of copper slag, a piece of copper slag on a sherd, and a copper awl from Final Neolithic Sitagroi (Sitagroi III), plot in the Cypriot field, the Lavrion field and in a hitherto unknown field that is designated "the Sitagroi/Sesklo (S/S) source".[4] This could very well represent copper from the Balkans.

The question of copper sources in Greece itself is still a very controversial one. Although some scholars believe that Greece possessed many local copper deposits, small but certainly large enough to support an incipient metal industry, I remain sceptical about this, especially in regard to the major role now being assigned to copper from Lavrion. More about this later on. In my opinion Lavrion was a major source of lead and silver, but not of copper. Today one finds at Lavrion some 2,000 ancient mine shafts, some 1.5 million tonnes of slag and some 10 million tonnes of barren ore left on the surface, but all of this represents the by-product of the extraction of silver from argentiferous galena.[5] It has nothing to do with copper smelting.

Gold still presents serious problems for provenience study. Scientists in South Africa now claim that, through the use of mass spectroscopy, they are able to determine not only if the gold came from South Africa but even to connect South African gold with individual mines.[6] These are remarkable claims and such analytical work would obviously have a great impact upon archaeological research. We can only wait for future work to prove or disprove the claims being made today.

To my knowledge the early silver finds from the Greek Final Neolithic, especially those from the Alepotrypa Cave, have yet to receive any scientific examination. The work of Noel and Sophie Gale has shown that, by the Early Bronze Age, Siphnos was an important source of silver for the Early Cycladic metal industry.

The Belgian work at Thorikos suggests that the silver deposits of Lavrion were also being exploited by the mid third millennium B.C.[7] Other lead isotope research, carried out in Germany (Mainz and Heidelberg), has shown that silver from very old lead deposits, far older than anything known from Europe and the Mediterranean, was also being used in the Aegean, at least at the site of Poliochni. A double-spiral-headed pin from EB II Poliochni seems to be made of silver from Central Asia.[8] Unexpected to be sure, but not out of the question for, typologically, the pin has a parallel in a roughly contemporary pin (ca. 2800 B.C.) from the site of Mehrgarh, in southern Baluchistan.[9]

The Early Bronze Age also saw the first serious use of bronze. The sources of the tin used in making this bronze still remain a great mystery. A source in the Taurus mountains, in southeastern Anatolia, has received much publicity in the past few years.[10] Early Bronze Age mining activity certainly has been documented in the area, but I would still argue that this represents mining for gold and has no bearing on our search for Bronze Age sources of tin.[11] Nevertheless, the search for tin does seem to be geologically related to the search for gold. Both metals become prominent in the archaeological record at about the same time, the middle of the third millennium B.C.

International trade developed on a vast scale at that time, linking the north Aegeanwith lands as far away as the Persian Gulf, the Indian Ocean and the Indus River. Then disaster struck, triggered (according to some scholars) by a sudden deterioration of the climate ca. 2200 B.C.[12] The resulting decline in the level of culture in the Aegean is marked by the Middle Helladic period on the Greek mainland. It took some time for the area to recover. Only in the 14th-13th centuries B.C. do we have evidence in the archaeological record for an international cultural and commercial koine similar to what had existed some one thousand years earlier. It is in the 14th century that Cyprus became the dominant source of copper for the metal industries of the Mediterranean and the Levant. Major industrial centers developed on the island, notably Enkomi, Kition and Kalavasos-Ayios Dhimitrios, centers where elites acquired enormous wealth through control of the production of pure copper in raw ingot form.

These oxhide ingots (as they have come to be known due to their distinctive shape)[13] seem to have been produced only during a rather limited period, ca. 1400-1200 B.C., and, during that period, to have been shipped over much of the ancient world, from Sicily and the Lipari Islands in the west, to the Kassite capital of Dur Kurigalzu (near modern Baghdad) in the east.[14]

Our best evidence for the nature of this copper trade comes from two recently excavated shipwrecks, both discovered off the southern coast of Turkey. The Cape Gelidonya shipwreck, excavated by George Bass in 1960, produced the remains of the workshop of an itinerant metalsmith, including a number of copper bun and oxhide ingots and a full array of metalworking tools, all dated to ca. 1200 B.C.[15] The Uluburun ship, from ca. 1300 B.C., seems to have been carrying something of a royal cargo consisting of virtually all the materials involved in the international trade of the day, including elephant and hippopotamus ivory, Egyptian ebony, amber, blue glass ingots, tin ingots and some 10 tons of copper oxhide ingots.[16] That such a quantity of copper was being carried as but part of the cargo of a single ship indicates that we have here some of the raw materials for a very large-scale, industrial-scope metal industry. This is real metal production, metal usage on a vast scale, an industry with considerable economic impact and cultural significance.

The work of the Gales at Oxford has suggested that all of these oxhide ingots from Cape Gelidonya and Uluburun and, indeed, from every find spot save for the island of Crete, were made of Cypriot copper. The Gales now claim that virtually all the copper for these ingots came from a single mine, that of Apliki, a site now completely destroyed, by modern copper mining activity in the 1940's.[17] These conclusions are based almost entirely upon evidence supplied by lead isotope research, a technique that really looks at the geological age of the lead present as a trace element in the copper. The technique has revolutionized the study of sources of copper, lead and silver and the trade patterns based upon the results of those studies. Enormous sums of money have been spent supporting the work of the Isotrace Lab at Oxford and many, perhaps most Bronze Age archaeologists, have accepted without question the conclusions of the Gales, as presen-ted in an astounding number of published articles.

For the past 15 years I have urged caution and emphasized the need for critical evaluation, for what we are being told about Bronze Age trade makes no sense as Bronze Age history. Why would all Cypriot copper come from but a single mine, even the mine most distant from the main urban centers on the island. That objection is trivial compared to the presumed fate of all this Cypriot copper. To put it bluntly, it seems never to have been used. The problem is simple: all ingots are made of Cypriot copper but virtually all objects, according to the Gales, are made of Lavrion copper (and remember what was said earlier about Lavrion copper; it probably does not exist). This is true even when ingots and artifacts come from the same site, even from one and the same hoard deposit. Consider the Poros Wall hoard, excavated by George Mylonas at Mycenae. The ingots are of Cypriot copper, the artifacts are said to be of Lavrion copper. This makes no sense to me. We have ingots of Cypriot copper but very few artifacts. We have artifacts of Lavrion copper but not a single ingot. This defies logic; it makes no sense and, in my opinion, cannot be correct.

What is wrong? Have we wasted hundreds of thousands of dollars supporting a research program that provides nonsensical results? Some would say that yes, this is exactly what we have done. That cannot be correct. Lead isotope analysis is a proven scientific technique. The analytical results produced by the Multicollector thermal isonisation mass spectrometer at Oxford are extremely accurate and the basic technique has been used in geological research for several generations with excellent results. No, the fault cannot lie with the analytical technique but with the application of that technique in archaeological research. I have no answers, but before we can provide answers we have to recognize the existence of the problem.[18]

The end of the second millennium B.C. is associated with events that bear a remarkable similarity to what had happened a thousand years earlier.[19] For reasons that are still the subject of great controversy most of the ancient world at the end of the second millennium shifted from bronze (and stone) to the use of iron as the basic utilitarian, every - day metal. This shift marks the transition from the Bronze Age to the Iron Age and represents a major change in basic metalworking procedures. Copper and bronze could be cast in a wide variety of shapes and sizes, they could be hammered into sheets that could be shaped into bowls and jugs. Bronze was a versatile, beautiful metal that weathered well by forming a greenish patina. None of this was true of iron. It could not be cast, was difficult to hammer into intricate shapes, especially on a large scale, and, when exposed to the elements, corroded to a mass of oxide and rust. In every respect, metallurgically and aesthetically, iron seemed to be inferior to bronze. Why, then, did virtually all societies in the ancient world make the shitt from bronze to iron?[20]

Many attempts have been made to answer this question, going back at least to V. Gordon Childe's classic vision of iron as the democratic metal that came into prominence following the collapse of the elite-controlled palace economies and the monopolization of wealth and luxury goods within the narrow circle created by those elites. Access to bronze could easily be controlled, because bronze production depended upon access to costly imported raw materials, especially tin.

Iron, on the other hand, came from a far more widely available raw material, as almost every country of the ancient world had its own local deposits of iron ore. As international trade deteriorated during the course of the 12th century B C, stocks of bronze dwindled and there was massive recycling of scrap metal. A replacement for bronze was clearly desirable and iron, known since at least the third millenium B.C., was the logical candidate. But simple wrought iron, the product of a bloomery furnace, was far inferior to bronze. It was softer, could not be hardened by hammering and therefore quite unsa-tisfactory for any tool or implement requiring a sharp edge, and it had the unfortunate tendency to corrode into a heap of red rust.[21]

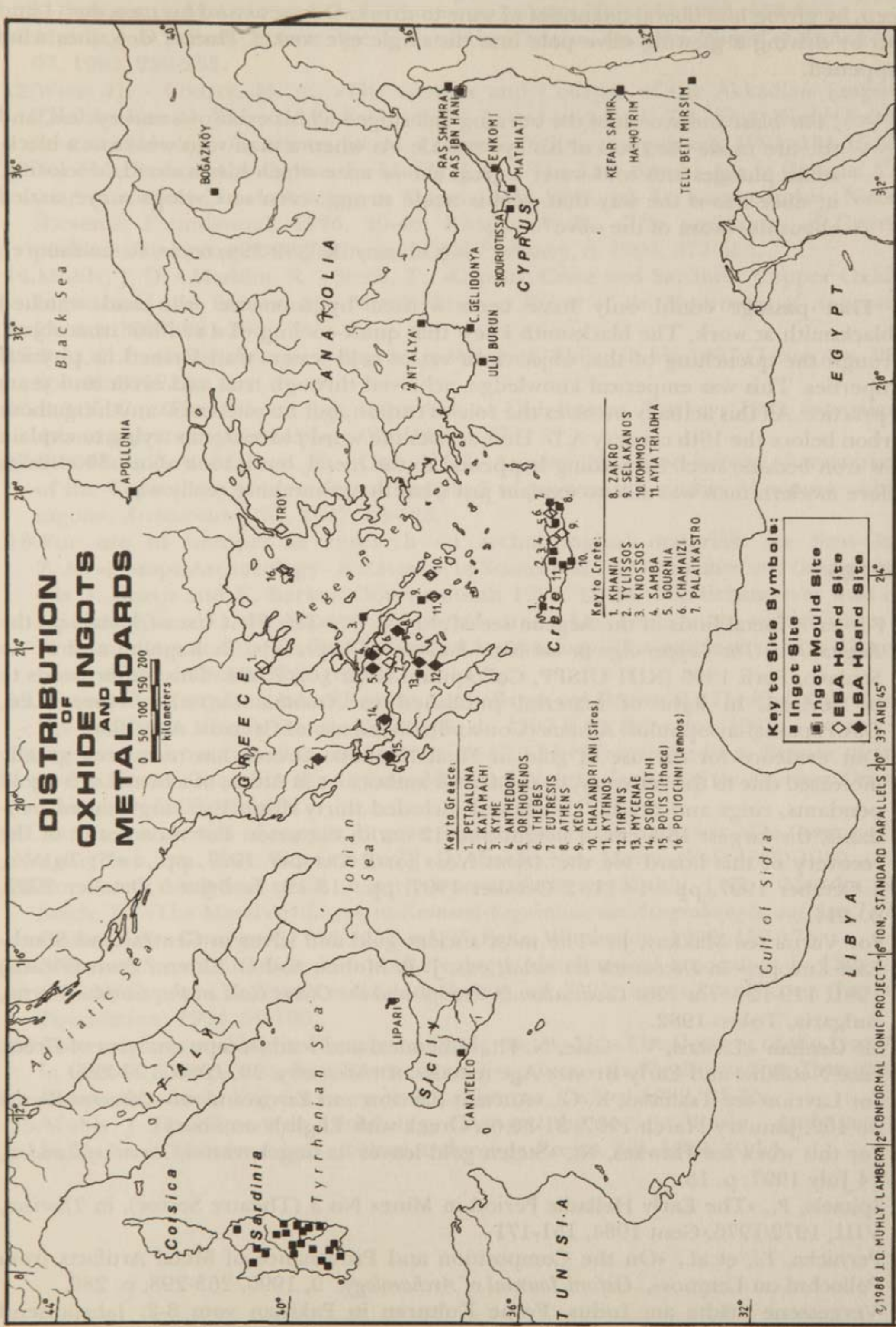
Before iron could play any serious role in human society this situation had to change. New technologies had to be developed, that could literally change the atomic structure of metallic iron, turning it into a metal actually superior to bronze in many important ways. The extraordinary thing is that, on the basis of our present evidence, these new technologies developed in a remarkably short period to time. Within the 12th century itself ancient metalworkers seem to have worked out the basic principles of iron and steel technology, thus being able to produce an object made of carburized, quenched and tempered iron, a metal now properly callecl steel.[22]

On the basis of the analytical evidence available to date, ironworking technology developed in the eastern Mediterranean, in Cyprus and in Palestine. Susan Sherratt has recently presented a catalogue of 12th century iron weapons and tools in the eastern Mediterranean. Of a total of 66 objects catalogued, 44, that is two-thirds of all known examples, came from Cyprus. One of these, knife number 106 from the settlement of Idalion, is the earliest known example of an iron artifact that had been carburized, quenched and then tempered. This knife represents a fully developed iron technology, a technology also seen in a remarkable iron (or steel) pick from the site of mount Adir in northern Galilee (Palestine).

Of the 66 objects that Sherratt presents in her catalogue 46 were knives or daggers. This is not accidental. The essential feature of a good knife is its sharp edge, as true today as it was in the 12th century B.C. Good quality steel made it possible for early Iron Age blacksmiths to put exactly such an edge on their iron knives. A particular type of iron knife, having a bone or ivory handle, often with a ring at its end and held in place with bronze rivets, seems to have been especially popular in the 12th and 11th centuries B.C. The magnificent example illustrated here comes from the Palestinian site of Tel Miqne, the Philistine city of Ekron, but such knives seem to have been a specialty of the Cypriot iron industry. Susan Sherratt even goes as far as to suggest that Cyprus developed technical superiority in the production of such knives, creating a position for itself as the "Silicon Valley" of the 12th - 11th century iron industry.[23]

Older scholarship maintained that iron technology came into Greece from the north, brought from Europe to the Aegean by Dorian invaders (along with cremation and Geometric pottery). All of this, we now realize, is completely wrong. Iron metallurgy developed in Greece through contact with the East, with Cyprus and the Levant. The development of the Greek iron industry is but one of the many products of the fruitful interchange between the Aegean and the Orient in the 12th and 11th and 10th centuries B.C.[24]

It is only appropriate, therefore, that the best literary description of ancient iron technology comes in one of the great products of this cultural interchange, the Odyssey



DISTRIBUTION OF OXHIDE INGOTS AND METAL HOARDS
0 50 100 150 200 kilometers
Key to Greece:
1. PETRALONA
2. KATAMACHI
3. KYME
4. ANTHEDON
5. ORCHOMENOS
6. THEBES
7. EUTRESIS
8. ATHENS
9. KEOS
10. CHALANDRIANI (Siros)
11. KYTHNOS
12. TIRYNS
13. MYCENAE
14. PSOROLITHI
15. POLIS (Ithaca)
16. POLIOCHNI (Lemnos)
Key to Crete:
1. KHANIA
2. TYLISSOS
3. KNOSSOS
4. SAMBA
5. GOURNIA
6. CHAMAIZI
7. PALAIKASTRO
8. ZAKRO
9. SELAKANOS
10. KOMMOS
11. AYIA TRIADHA
Key to Site Symbols:
Ingot Site
Ingot Mould Site
EBA Hoard Site
LBA Hoard Site
Black Sea
Adriatic Sea
Tyrrhenian Sea
Ionian Sea
Aegean
Gulf of Sidra
Corsica
Sardinia
ITALY
Sicily
LIPARI
CANATELLO
GREECE
Crete
TROY
APOLLONIA
BOĞAZKÖY
ANATOLIA
ANTALYA
C. GELIDONYA
ULU BURUN
SKOURIOTISSA
CYPRUS
MATHIATI
ENKOMI
RAS SHAMRA
RAS IBN HANI
KEFAR SAMIR
HA-HOTRIM
TELL BEIT MIRSIM
EGYPT
LIBYA
TUNISIA
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of Homer. The ninth book of the Odyssey describes the gruesome encounter between Odysseus and his men and the one-eyed giant Polyphemus. Having put the giant to sleep, by giving him liberal quantities of wine to drink, Odysseus and his men then blind him by driving a glowing olive pole into his single eye socket. Homer describes what happened:

> "The blast and scorch of the burning ball singed all his eyebrows and eyelids, and the fire made the roots of his eye crackle. As when a man who works as a blacksmith plunges into cold water a great axe or adze which hisses aloud, 'doctoring' it, since this is the way that steel is made strong, even so Cyclops' s eye sizzled about the beam of the olive"
>
> (Odyssey IX: 389-394; trans. R. Lattimore).

That passage could only have been written by someone who had watched a blacksmith at work. The blacksmith knew that quick-cooling of a red-hot iron object, through the quenching of that object in a vat of cold water, transformed its physical properties. This was emperical knowledge, achieved through trial and error and years of practice. All this actually involves the role of carbon, but no one knew anything about carbon before the 19th century A.D. Homer uses the word *pharmakos* in trying to explain how iron became steel. Something happened to the metal, but it took about 3000 years before modern man was able to explain just what that something really was.[25]

NOTES

1. For early metal finds in the Aegean see Muhly, J. D., «The First Use of Metals in the Aegean» in *The Copper Age in the Near East and Europe*, eds. B. Bagolini and F. Lo Schiavo, Forli 1996 (XIII UISPP, Colloquium XIX: 10), 75-84. This paper needs to be revised, in light of material published in *Neolithic Culture of Greece*, ed, G.A.Papathanassopoulos, Athens (Goulandris Museum of Cycladic Art) 1996.
2. Our evidence for the use of gold in Final Neolithic Greece has now been greatly increased due to the recovery, by the Greek authorities in Attica, of a hoard of 54 gold pendants, rings and beads. This hoard included thirty distinctive ring-shaped pendants, the largest 15,5 cm in height and 12 cm in diameter. For an account of the recovery of this hoard see the *Athens News* for 2 October 1997, pp. 1+3; *Τα Νέα*, 1 October 1997, pp. 1+11; 2 October 1997, pp. 18-19; *Το Βήμα* 5 October 1997, p. A44.
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5. For Lavrion see Tsaimou, K. G., «Ancient Lavrion and Environment», *Mineral Wealth* no 102, January-March 1997, 31-38 (in Greek with English summary).
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11.Muhly, J. D., «Early Bronze Age Tin and the Tauris», *American Journal of Archaeology*, 97, 1993, 239-253.
12.Weiss H. - Courty, M. A., «The Genesis and Collapse of the Akkadian Empire,: The Accidental Refraction of Historical Law», in *Akkad. The First World Empire: Structural Ideology, Traditions*, ed. M. Liverani, Padova (Sargon srl), 1993, 131-15.5.
13.For Late Bronze Age Cyprus see Muhly, J. D., «The Late Bronze Age in Cyprus: A 25 year retrospect», in *Archaeology in Cyprus*, 1960-1985, ed. V. Karageorghis, Nicosia (Leventis Foundation), 1985, 20-46; Knapp, A. B., «The prehistory of Cyprus; problems and prospects», *Journal of World Prehistory*, 8, 1994, 377-453.
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