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A critical mineral through ages: traces of modernity in late bronze age cypriot copper

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Copper influenced the history of civilization and nowadays is playing a growing role in the transition to a climate neutral economy. Its ability to signal turning points in economy is long-standing: in the past, physical and chemical properties promoted the technical revolution of Copper Age and the article shows that the value chain of copper in Late Bronze Age (LBA) Cyprus anticipates traits of modernity: several parallelisms are found with Chile, the major copper producing country today. A description of copper extraction in LBA Cyprus is reported highlighting type of ores, smelting process, social and commercial development, importance of oxhide ingots, and final transition to the Iron Age.

KEYWORDS: COPPER, CYPRUS, OXHIDE INGOTS, LATE BRONZE AGE, ARCHAEOMETALLURGY

Navigare necesse est, vivere non necesse

INTRODUCTION

The red metal, one of the first known elements with a unique reputation as economic indicator, strongly influenced the history of civilization. In the year 1800, the breakthrough invention of the battery by Volta inaugurated the age of the electricity and nowadays copper is playing a growing role in the transition to a climate neutral economy: the new energy sector accounts for a minor share but in the future around three-quarters of demand will come from solar photovoltaics, electric vehicles, wind turbines, and batteries (1). Its ability to signal turning points in economy is long-standing: in the past, physical and chemical properties (color, ductility, corrosion resistance, alloying properties) promoted the technical revolution of Copper Age and these notes evidence that the value chain of copper in Late Bronze Age Cyprus anticipates traits of modernity. The island lent the metal its name: the Italian word "rame" derives from the late Latin "aeramen", which in turn is an evolution from the classical "aes" (bronze), but in several European languages the word for copper is derived from the Latin "cuprum" from Aes Cyprium (Cypriot copper), used by Pliny the Elder

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to describe the pure metal (2). Until the Byzantine era, the mines of the island were the main producer in the Mediterranean area and the eponym "cuprum" eventually signified copper (3). Natural resources, technical skills, commercial entrepreneurship, and the location between three continents explain sectorial predominance for centuries, and recent archaeological studies supported by experimental archaeometallurgy and spectroscopic techniques shed light on its role (4-6).

THE ORES

Despite several advantages Cyprus was a relatively late player on the scene. Pliny's statement that copper was discovered there was unfounded, but the celebrity of the island's deposits predated by over a millennium the time of the naturalist. The cradle of copper metallurgy began to swing in the Near East around 10,000 years ago and by 7000 BC there is evidence for the annealing of native copper, successively leading to the discovery that the metal could be melted and poured into molds at its fusion temperature of 1,084°C (7). The scarcity of native copper in the Near East led from the late 5th millennium BC to exploitation by smelting of secondary minerals such as the hydro-carbonates. Since the fabrication of bronze by alloying copper with tin around 3000 BC, technical and commercial exchanges of metals contributed to shape the Mediterranean communities (8).

Earliest small-scale copper production on Cyprus dates from the late 4th to mid-3rd millennia BC and concerned native copper and oxide ores. Mining took place in the 3rd millennium BC, probably following contacts with tradesmen and metalworkers from Anatolia, the Levant, and the Aegean islands where copper metallurgy was already established: even in the case of Chile, major copper producer with around 25% of global output, foreign influence led to the first large-scale copper mining projects at the beginning of the 20th century, before a lengthy nationalization process (9). Besides other industrial minerals, the Mediterranean island still hosts some of the richest copper ores per surface area in the world and several million tons of slag (the by-product of an estimated 200,000 tons of copper metal produced during antiquity) spot the landscape at the foothills of the Troodos Mountains, the mining basin occupying the southwestern part of the island (10) (Fig.1). The lower slopes are ringed by so-called pillow lavas, which hold copper deposits ranging in size from less than 50,000 tons to more than 20 million tons with metal content between 0.3-4.5 wt%: mined deposits today have lower grade (0.3-1.0 wt% copper) and larger tonnage (often greater than 1 billion tons). Copper is geochemically scarce: it stands for around 0.006% of the earth's continental crust and, as a typical chalcophilic element, sulfides are the main natural occurrence and the dominant ore (11). Also Cypriot deposits are in this form and extraction from their minerals (e.g., chalcopyrite $CuFeS_2$, covellite CuS, chalcocite CuS_2) was developed later than the technology from the hydro-carbonates such as malachite $[Cu_2CO_3(OH)_2]$ or azurite $[Cu_3(CO_3)_2(OH)_2]$ due to complex treatment first involving roasting to convert the sulfides to oxides, and then multiple melting stages to obtain refined copper metal. The genesis of Cypriot deposits occurred by a complicated geological process: primary minerals mostly including pyrite (FeS_2), chalcopyrite ($CuFeS_2$) and sphalerite (ZnS) reacted with rainwater, forming a sulfuric acid solution with various amounts of sulphates of iron, copper, and zinc. As a result of successive dissolution and precipitation processes caused by weathering, an "iron hat" (gossan) of red and yellow iron oxides and hydroxides was formed above zones of copper enrichment, where content may reach 25 wt% (12).

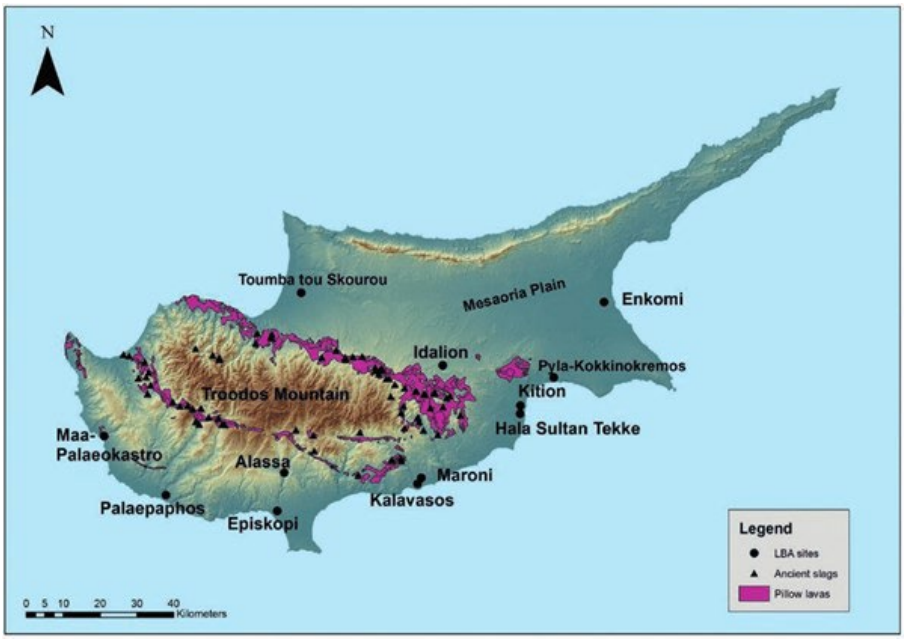

Fig.1 - Map of Cyprus indicating LBA cities, ancient slags and pillow lavas sites / Mappa di Cipro con le città nella tarda Età del Bronzo, siti di antiche scorie e lave a cuscino

Courtesy by Artemis Georgiou (2017) with digital data of Cyprus Geological Survey Department
https://www.moa.gov.cy/moa/gsd/gsd.nsf/dmlIndex_en/dmlIndex_en?opendocument

THE SMELTING PROCESS

After roasting the copper-rich sulfide under oxidizing conditions, early in the 2nd millennium BC Cypriot metalworkers succeeded to smelt the pyritic ore by burning the local timber for the roasting process and the production of charcoal, used as reducing fuel. Partial details of the process are inferred by the residual findings of mining and smelting operations. In summary, copper smelting was executed in a cylindrical furnace capable to reach a temperature sufficient to melt the ore and separate the metal from the slag, exploiting the different densities of copper and slag. The goal was to oxidize with air sulfur and iron from the mineral to produce a copper-enriched molten sulfide phase, the matte, with successive thermal treatments for conversion into black copper, an iron and sulfur rich metallic copper, and final refining of copper metal. During the Middle Bronze Age (MBA, 2000-1650 BC) the Cypriots laid the ground for dominance in copper supply by advancements in smelting technology and manufacturing innovative ceramics with improved heat and thermal shock resistance (13,14).At the beginning of the Late Bronze Age (LBA, 1650-1050 BC), the adoption of bellows and tuyères (nozzles) in clay furnaces allowed to achieve higher temperatures with an efficient fluxing for separation of the slag without significant metal losses (15).

A reliable energy supply is an asset of the Chilean mining industry: also contemporary technology employs a pyrometallurgical route for copper metal production from sulfides, with tuyères essential to regulate temperature and atmosphere. The matte smelting process involves the fusion of sulfide minerals concentrate with a flux resulting in the production of the sulfide melt, the matte, while the gangue associated with the starting sources passes into the slag.

The reaction can be sketched as:

sulfidic source concentrate + flux = matte + slag + gases

Operatively, sulfide ore concentrate is roasted in air at 1,200-1,300°C to give the matte with a copper content of about 50–70% and the matte is oxidized by dry air flowing above the melt. Iron sulfide is transformed into iron oxide and combines with the slag, while copper sulfide gives molten copper (99% purity) called blister, due to evolution of sulfur dioxide producing blisters on the surface. Successive melting and casting into anodes of rectangular shapes takes place before final electrorefining

to high purity metal (16).

THE SOCIETY

Little is known about the internal social and political organization due to the lack of readable indigenous sources. Cyprus importance peaked during the LBA, when economic and cultural prosperity originating from copper trade promoted evolution of considerable centers: the cities of Enkomi, Kition, and Hala Sultan Tekke developed great commercial ports to support commercial activities (17). Similarly, copper made an impressive contribution to the Chilean economy via export income during the past century and in the early '90s the country witnessed a period of growth, in which the mining sector played a significant role as a result of trade agreements with major economies. The main port of Enkomi, located in the gulf of Famagusta on the East coast, served as an export hub and an emporium of luxury goods and specialized products (e.g., metals, ivory, jewelry, and pottery) imported from the commercial city of Ugarit, an "international" trade center at one day's sail on the Syrian coast (18,19). In Enkomi several metal working quarters were excavated and a building, the so-called "Fortress", was operative during the 17th-12th centuries BC with its western part occupied by metallurgical workshops. The coastal centers of the island show evidence of metallic copper re-smelting and refinement activities: bronze, the most important copper alloy, was vital for manufacturing weapons, tools, and luxury items, and ruling classes of exporting and importing countries exercised control on its bulk circulation. Due to the market leadership of an indispensable strategic metal, Cyprus established par relations with the powers of the time, turning mineral wealth into an instrument of policymaking.

Cultural changes went with the economic progress: a still undeciphered writing system appeared for the first time on the island (20,21). It was called by early epigraphers "Cypro-Minoan" due to similarity to Linear A of Crete, and its signs were identified on trade items such as Cypriot and Mycenaean pottery and ingots. Textual and iconographic evidence from neighboring regions such as the Aegean palaces at Knossos (Crete) and Pylos (Messenia), the Syro-Canaanite cities of Ugarit and Alalakh, tablets from Ebla in Syria, the Amarna letters as well several temples' representations in Egypt describe a palatial control of bronze production and the existence of interrelated networks for transport and commerce over long distances. Most of metals distribution was conducted by sea with bulk cargoes: Chile owes its leading position not only to its vast mining resources but also to an efficient domestic and export-oriented transport infrastructure: copper transfer takes place by sea routes and, due to port locations, meteorological conditions can occasionally limit shipments with disruptions in delivery (22,23). The discovery in modern times of shipwrecks off the Turkish coast along old seaways elucidated the Cypriot origin of the past copper traffics with the decisive support of spectroscopic techniques, in particular trace elements and lead isotope analyses (LIA) connecting the mineralization to finished metal products (24). The Uluburun vessel, detected in 1982 after sinking in the late 14th century BC, held exotic goods including ivory, ebony, amber, one ton of tin ingots, and almost ten tons of copper ingots, mostly oxhide-shaped. LIA allowed to confirm the copper provenance from Cyprus, thus proving that local workshops could supply a single cargo potentially capable to yield 11 tons of bronze, a scale sufficient to provide weapons for an entire army (25).

THE OXHIDE INGOTS

If information concerning the organization of copper production and trade remain scarce, oxhide ingots constitute an interesting investigation object of Cypriot copper technology and distribution during 1400-1100 BC, standing for a sort of standardized commodity brand in the period of their production. Metal purity was over 99% and the shape was not of Cypriot origin: first examples appeared in Crete during the Late Minoan I period (16th-15th centuries BC) with some ingots made of copper extracted from still unidentified mines (26-28). Slightly changed over time, oxhide ingots are rectangular plates (usual length 60 cm, width 40 cm and thickness 4 cm) with extremities at each corner probably for transport necessities: the name is due to resemblance of the shape to the stretched leather of an ox and weight is generally 25-30 kg (Fig.2). Also known are the plano-convex, or bun, ingots with a typical mass of a few kilograms each. Oxhide ingots are like blister copper: the top surface is roughened, while the bottom surface shows cavities owing to gas evolution.

Fig.2 - Oxhide ingot / Lingotto oxhide

Courtesy of Neues Museum, Berlin (Germany),
https://www.smb.museum/en/museums-institutions/neues-museum/home/
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The first specimen was found in Sardinia in the nineteenth century and LIA determined that the overwhelming majority of oxhide ingots found across the Mediterranean area was made of Cypriot copper: for example, export to Crete took place as early as the 16th century BC contemporarily to its appearance in Scandinavian rock art, although no ingot has been found on Cyprus at a stage when copper production was directed towards foreign consumption (29). Also in the case of Chile today, nearly all of the copper production is destined for export and the purity issue is strategic: Chile's copper exports mainly relate to refined copper, which consists of cathodes of 99.99% purity, and to concentrates containing just under 30% copper, to be melted and refined elsewhere. The export proportion is balanced today but increasing share of concentrates raises concerns due to missing contact with end customers and lower added value of the product (30). In the 14th century, both production and export intensified as attested by archaeological discoveries and textual evidence, such as the letters from Alashiya (a name referring to the island of Cyprus) found in the archive of the Egyptian city of Tel el Amarna, where shipment was recorded of a total of 897 ingots of copper, corresponding to nearly 30 tons of pure metal in a time span around two decades (31).

The preparation of oxhide ingots was executed by pouring several batches of fused metal into a mold at a temperature above its melting point. It is possible that sand casting methods were used: only one limestone oxhide ingot mold was discovered at one of Ugarit's ports, but its use for the specific purpose is questioned (32). The similar weight, shape, and purity of the oxhide ingots suggest a metallurgical chain organized according to the principles of competence subdivision under control of a central authority. Following the extraction and primary smelting phases conducted on-site inland by mining workers, secondary smelting and refining processes probably took place on the coast, where standardized oxhide ingots were ready for distribution and shipment. Incised and impressed marks appear on the surface and the same impressed signs also appear on ingots of other metals, a proof of the advanced technical level of the commercial organization (33,34). Production and export peaked in the 13th century BC when oxhide-shaped ingots were present throughout the Mediterranean and central Europe: to the period date both the only primary smelting site of Politiko

Phorades so far known (discovered in 1996) as well as the mining settlement of Apliki, found in 1938 before destruction by modern mining operations.

The importance of copper for the society is stressed by the presence of oxhide ingots on different objects setting a relationship between metalwork and cult. Among the most symbolic, the statuettes of the Ingot God and the "Bomford" Goddess, bronze four-sided stands (Fig.3), miniature copper ingots, and stone seals with inscriptions in Cypro-Minoan interpreted as votive offerings (35,36). The association of metallurgy and religion established by the elites as an instrument of authority was not unprecedented, but at the same time the specific shape was transformed into an icon with identifying and cognitive reference to the place of origin, thus explaining the findings of miniature ingots in Egypt, the Levant and Anatolia (37). A collection of oxhide ingots of the period was retrieved from the shipment in the wreck of Cape Gelydonia discovered in 1960 in southwest coast of Turkey. The ship carried 34 intact oxhide ingots, 20 plano-convex ingots, copper fragments, and a large amount of bronze scrap. LIA indicates that the mentioned oxhide shaped ingots were probably made of copper from the Apliki mine: although many of the contemporary copper objects found on the island came from other sites, this origin might show that the productive control for export was still supervised by a central authority (38). Still today, an important share of copper production in Chile is controlled by a state-owned company and a specific legislation sets the rules for profits re-distribution, stressing the importance that mineral wealth plays for the national economy: for the last two decades, around 10% of national GDP came from copper mining (39).

Fig.3 - Fragment of a bronze four-sided stand / Frammento di un supporto quadrilatero in bronzo

Courtesy of Royal Ontario Museum, Toronto (Canada), rom.on.ca

Even the sustainability issues were well known by a society who understood the impact of mining on labor, energy, and transport: the issue of recycling was relevant and scrap metal use is attested in hoards findings (40). Cypriots were also active in trading other metals associated with the bronze business, thus integrating the commercial offer: by the Middle Bronze Age tin superseded arsenic as the preferred alloying metal to produce bronze and, although the silvery-white metal had to be imported from distant continental places, several tin ingots carried by the Uluburun and Cape Gelydonia ships were inscribed with symbols identified as Cypro-Minoan (41).

CONCLUSIONS: THE TRANSITION

In the 12th century BC, the complex commercial network of the Late Bronze Age began to collapse, as urban

centers in the Aegean, Anatolia, Syria, and Palestine were destroyed. This period, corresponding with the transition to the Iron Age, is generally termed the "Crisis Years": whether climate changes, warfare, or plagues, the exact causes remain uncertain (42). In Cyprus, several important settlements were abandoned, albeit production and trade of copper in the form of oxhide ingots continued through the century (43). Cypriot trade turned westward in search of new markets and suppliers: around 40 oxhide ingots found in Sardinia confirm exchanges with the Nuragic culture both in term of products (e.g., ceramic wares) and metallurgical know-how: the Italian island was rich in silver and tin, two metals whose traditional Cypriot supply had been disrupted (44,45). The passage to the Iron Age was accompanied by political and cultural changes, including the migration of Aegean populations, which introduced Greek language in Cyprus. Kition (today's Larnaca) enjoyed a further period of prosperity in the South coast, linked to the establishment of the first Phoenician trading post with an eye to the local mining capabilities. The Cypro-Minoic script evolved into the Cypriot syllabary, which already since the 11th century BC was used to express the Greek language. The advent of the Iron Age didn't preclude the use of copper, particularly for manufacturing weapons and armors: the contemporary technologies could not reach the melting temperature of iron and therefore iron objects were made by forging, limiting the range of feasible products. The local smiths were among the first in in the Eastern Mediterranean to develop iron processing, but a large demand for copper persisted and Cyprus, which owned the largest deposits in the Eastern Mediterranean as well as the specialized workforce, continued production and export although abandoning the oxhide ingot that constituted its trademark of origin. The geopolitical center of history had shifted and, under the spell of "the paradox of plenty", local elites progressively lost the strength of unity, leaving traces for posterity.

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Un minerale critico attraverso le epoche: tracce di modernità nel rame cipriota della tarda età del bronzo

Il rame ha influenzato la storia della civiltà e oggi svolge un ruolo crescente nella transizione verso un'economia neutrale dal punto di vista climatico. La sua capacità di segnalare punti di svolta nell'economia è di lunga data: in passato, le proprietà fisiche e chimiche hanno promosso la rivoluzione tecnica dell'Età del Rame e l'articolo mostra che la catena di valore del rame nella Cipro della tarda Età del Bronzo anticipa i tratti della modernità: si trovano diversi parallelismi con il Cile, il principale paese produttore di rame oggi. Viene riportata una descrizione dell'estrazione del rame nella Cipro della tarda Età del Bronzo, evidenziando il tipo di minerali, il processo di fusione, lo sviluppo sociale e commerciale, l'importanza dei lingotti oxhide e la transizione finale all'Età del Ferro.

KEYWORDS: RAME, CIPRO, LINGOTTI OXHIDE, TARDA ETÀ DEL BRONZO, ARCHEOMETALLURGIA

TORNA ALL'INDICE >