Early Copper Production in the Polis Region, Western Cyprus

Paul Raber
Pennsylvania Historical and Museum Commission
Harrisburg, Pennsylvania

A region near the modern town of Polis in western Cyprus was chosen as the location for a program of archaeological survey and test excavation of metallurgical sites. Forty-nine metallurgical and related sites were located, recorded, and dated. These sites represent more than 2000 years of local copper metallurgy from the Late Iron Age to the Late Medieval period (ca. 8th century B.C. *to the 15th century* A.C.*).*

The analysis of resource use, copper production, and site distribution provides a picture of organizational patterns in the local copper industry through time. Three possible alternative models of the organization of the local industry are proposed and tested. Copper production in the Polis region was an essentially local enterprise based on part-time, seasonal production in a peasant economy. Changes in the political and economic contexts affected the patterns of distribution and consumption of copper products, but production remained relatively small in scale and locally organized throughout its 2000 year history in the Polis region.

Introduction

The archaeological questions that might be asked about early technologies fall into two broad categories: 1) those related to technological process and 2) those concerning the organization of the technology. In the first category are studies of raw materials, specific technical processes, the physical characteristics of products, and technological variation through time or by region. The second category includes studies of the social and economic contexts of technological development, innovation, raw material procurement, product distribution, labor requirements, and craft specialization. There is a noticeable contrast between the abundant literature of the first category and the more infrequent treatment of technological organization and development. With some notable exceptions, there have been few attempts by archaeologists to look in detail at local technological organization.

Much field and laboratory work on early technologies has focused on traditional culture-historical concerns: chronology, technological process, materials, technological products as cultural/chronological indicators, etc. Less effort has been made to consider technology in its relation to the environment and cultural setting, following the suggestions of Matson (1965) and others. Case studies examining specific technologies in a regional perspective over time are needed.

A recently-completed study of the Polis region of western Cyprus (FIG. 1) involved a consideration of both technological process and organization in the local copper industry during a period of about 2500 years (TABLE 1). A program of field and laboratory testing allowed the evaluation of hypotheses concerning the nature of the smelting process, the changing ways in which the industry was organized, and the relationship of technical and organizational factors through time.

The Polis Region Study

Cyprus has long been known as a source of copper and other metals, although its reputation in this regard probably far outstrips its actual contribution to the metals supply of the ancient Mediterranean. It was neither the earliest nor the largest supplier of copper in the region. Substantial production of copper and bronze seems not to antedate the later Bronze Age (late second millennium B.C.) (Merrillees 1978:3–4). Cyprus, however, possessed adequate resources of fuel, ore, and labor to make it self-sufficient in copper production. The island is without a source of tin, and the supply of tin for the manufacture of bronze remains an unresolved problem (Charles 1975; Maddin, Wheeler, and Muhly 1977; Muhly 1973, 1976, 1978).

Despite the widely recognized role of Cyprus in the metals trade of the early Mediterranean, there have been few efforts to systematically study copper production—its technology and organization—over the full span of recorded metallurgy. Steinberg and Koucky (1974), Koucky

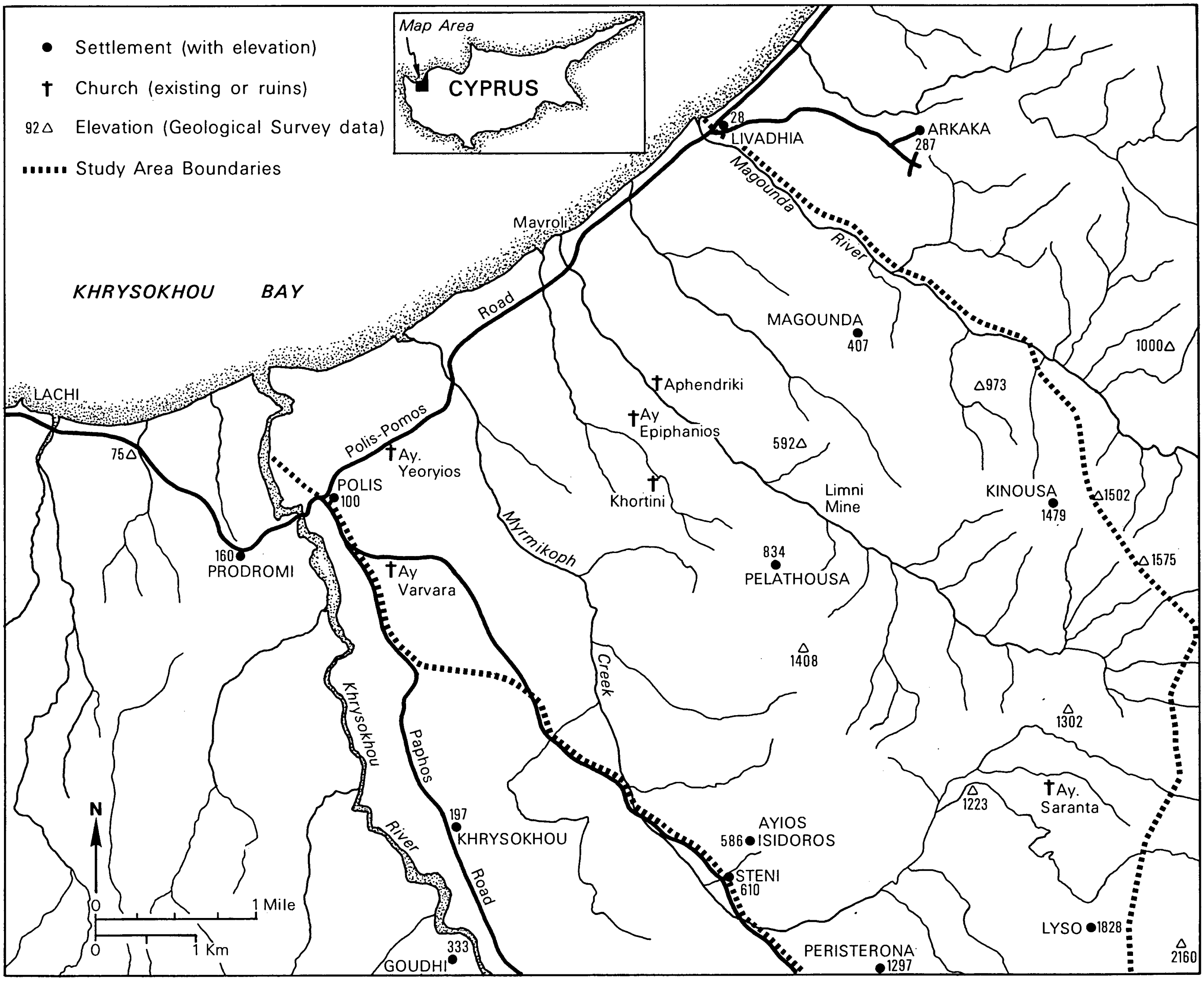

Figure 1. Polis region study area.

and Steinberg (1982), and Muhly, Maddin, and Karageorghis (1982) are notable exceptions. A broad geographical and chronological perspective on Cypriot and Mediterranean copper production and trade is needed.

As a preliminary step in a more comprehensive study of early Cypriot metallurgy, the Polis region study focused on a small, well-defined region of western Cyprus around the modern town of Polis, long known as a center of early mining and metallurgy (Cullis and Edge 1927: 24–28).

The study area is approximately 17 sq mi (44.7 sq km) and surrounds the modern mines at Limni and Kinousa. It is bounded on the north by the sea (Khrysokhou Bay); on the west by the town of Polis and the Khrysokhou River valley; to the south by a line through the villages of Ayios Isidoros, Steni, Peristerona, and Lyso; and to the east and SE by the Magounda river and the foothills of the Troodos, which rise sharply from the river valley (FIG. 1). The limits of the study area are somewhat arbitrary—evidence for early metallurgy occurs to the south and west—but they represent reasonable boundaries for the efficient transport of fuel and ores and a manageable area given the scope of the present study.

The Polis region has a well-established reputation as a copper-producing center of considerable antiquity. Early written sources from 5th century B.C. Athens mention the copper obtained from the city-state of Marion, the predecessor of the Hellenistic, Roman, and Byzantine center of Arsinoe and the modern town of Polis. Copper production continued under the British administration and through the period of Cypriot independence until 1980, when the Cyprus Sulphur and Copper Company closed its operations at Limni mine.

In common with the other copper-producing regions of Cyprus, the Polis region lies at the interface between the volcanic diabase mass of the Troodos Mountains and the pillow lavas surrounding the mountains (FIG. 2). Copper mineralization occurred during the Triassic and Cretaceous eras when hot mineral solutions invaded the pillow lavas along fault lines at the diabase/pillow lava interface. The resulting pyritic ores are the distinctive ore type of Cyprus. They resemble the pyritic ores of Asia Minor (e.g., Ergani Maaden) and stand in contrast to the oxide/carbonate ores of the Levant and Sinai (e.g., Timna). There is no indication that substantial quantities of the more easily-smelted oxidized copper ores were ever available in Cyprus.

Several environmental and topographic features are relevant to a consideration of copper production in the Polis region. Among the zones paralleling the coast are:

(a) a narrow (0.4 km) coastal plain, important as a focus of settlement and communication, consisting of Pleistocene and Holocene deposits;

(b) a wider (3 km) band of low, rolling hills dissected by streams trending NW;

(c) an abrupt rise in elevation to the Troodos foothills, an area strongly dissected by streams; and

(d) a second rise in elevation to over 600 m, marking the contact of the pillow lava with the diabase. This zone lies largely outside the study area, although its potential contribution to the fuel supply has been considered.

Also, there is an overall contrast between the volcanic zone of the Troodos foothills to the east and the sedimentary deposits (chalks, marls, alluvium) to the west. The bulk of the evidence for the mining and smelting of copper ores occurs in or near the deposits of the eastern volcanic zone although, as noted below, the smelting and refining of copper certainly occurred around the regional centers of Marion and Arsinoe.

Previous archaeological survey in the region has been sporadic, with no systematic settlement survey of most of the region. Stanley Price (1979) has summarized and sup-

Table 1. Chronological chart.

Period and approximate dates	*Sociopolitical developments*		*Mining and metallurgical technology*
	Cyprus	*Polis region*	
Late Bronze Age ca. 1600–1050 B.C.	Minoan and Mycenaean contacts; political centralization and growth of city-states; widespread trade; major cities destroyed in late 12th century B.C.	Little evidence of settlement in the Polis region.	Extensive metals trade through Cypriot ports; metallurgical-specialist quarters in several cities.
Iron Age Cypro-Geometric (CG) ca. 1050–700 B.C. Cypro-Archaic (CA) ca. 700–475 B.C. Cypro-Classical (CC) ca. 475–325 B.C.	Succession of local and foreign political control; ca. ten city-states; population decline in CG followed by growth; trade with Greece and the West.	Probable first settlement of Marion in CG (early tombs); trade with Attica; kings of Marion occupy palace at Vouni.	Increased export of metal; export of copper from Polis region; copper smelted near mines.
Hellenistic/Early Roman ca. 325 B.C.–A.C. 300	Ptolemaic military command; division into petty kingdoms follows weakening of Ptolemaic control; uniform Hellenistic culture; Roman province following annexation in 58 B.C.	Marion destroyed, Arsinoe founded nearby and becomes important Hellenistic center; developments under Roman administration uncertain.	Large-scale mining by state elsewhere on Cyprus; some copper smelting near mines in the Polis region during Hellenistic period; none apparent during Roman period.
Late Roman/Byzantine ca. A.C. 300–1200	Part of the Diocese of the Orient under control of Constantinople; 14 eparchies; population decline; conditions of general insecurity; Arab conquest in 653.	Arsinoe the chief city of the Khrysokhou eparchy and seat of a bishopric.	Widespread but small-scale metallurgy in the Polis region and elsewhere; copper smelted near coastal settlements in the Polis region
Late Medieval ca. A.C. 1200–1571	Feudal Frankish kingdom; stable population; conditions of general poverty and repression; Venetian annexation follows dominance of trade; Turkish conquest.	Arsinoe an ecclesiastical and administrative center; population shift to higher elevations reflects insecurity; modern town of Polis replaces Arsinoe.	Continued local mining and smelting in Polis region and elsewhere; vitriol rather than metallic copper may have been chief product.

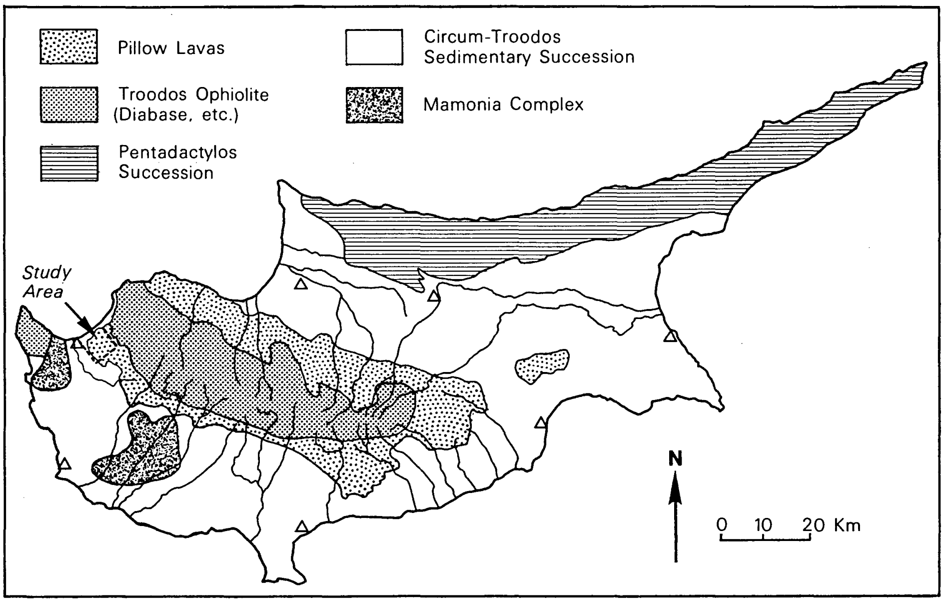

Figure 2. Geological map.

plemented the previous site locational data in his study of settlement patterns. Portions of the Khrysokhou River drainage have been systematically surveyed by Adovasio et al. (1975). That area lies largely to the west and south of the main metallurgical zone, however, and is thus outside the study area. Metallurgical sites in the region, primarily large slag heaps, have been noted by numerous observers, with some attempt at a survey by engineers and geologists interested in the reuse of old workings.

Steinberg and Koucky have summarized the available information on metallurgical site location throughout Cyprus (Steinberg and Koucky 1974; Koucky and Steinberg 1982), although no systematic survey of any single region has been undertaken. Previous generalizations about the size and organization of regional metallurgical industries, in the Polis region and elsewhere, have been based largely on impressionistic estimates of the visible remains (slag heaps, ore dumps, mine workings, etc.). These remains have often been erroneously regarded as all generally "Roman" or "Phoenician." The existence of a post-Roman (Byzantine or medieval) copper industry has been denied by some. The untested assumption about all of these industries has been that they are representative of large-scale, centrally-organized—that is, state-controlled—production.

The Polis region survey was planned to test this and other assumptions about the scale and organization of early copper production by systematically gathering information on the location, date, and size of all metallurgical sites within a defined region. The immediate goal was to characterize changes in the scale and organization of the industry over time; the ultimate goal was to evaluate several alternative models of metallurgical production.

To this end, all visible metallurgical sites within an area of roughly 40 sq km were located by a systematic surface inspection of transects and mapped on 1:5000 topographic maps obtained from the Cyprus Geological Survey. The fieldwork was carried out in June–October, 1980, primarily by the author, with the assistance of F. Koucky and S. McGuire. Diagnostic pottery associated with the sites, including several large, stratified slag heaps, was collected and assigned, when possible, to general time periods. Samples of slags and ores were gathered for later bulk and trace-element compositional analysis at the Pennsylvania State University.

Although the recording of settlement sites was not a primary concern of the Polis region survey, evidence of such sites was noted in the field. The boundaries of settlement sites were defined by the surface distribution of artifacts, the presence of features was noted, and a collection of all diagnostic pottery and a sample of non-diagnostic sherds was made. The settlement data were supplemented by reference to the Cyprus Survey Inventory, a compendium of sites located by previous surveys. Information from previous published surveys of the Polis region by Adovasio et al. (1975, 1978) and Stanley Price (1976, 1979) and from the unpublished surveys of Hadjisavvas and Nicolaou was incorporated into the survey data.

Estimates of the size of the slag deposits were made by calculations of the volume from surface area and height or by comparison with established estimates made by mining company geologists for several large and well-defined slag deposits in the area.

The dating of the sites presented some problems. Although pottery occurs frequently in association with slag deposits and in stratified contexts in some of the larger deposits, much of the pottery consists of local coarse wares that are undatable or, at best, can be dated only to very broad periods. Some datable fine and imported wares were collected, however, and these provided some chronological controls. Additional chronological control was established by checking the pottery dates against a provisional slag-dating scheme developed by Koucky and Steinberg (1982: 156–157). A detailed description of the sites and their dating may be found in Raber (1984: 355–427).

In all cases, precise dating was generally impossible and sites were assigned to broad chronological/cultural periods: Iron Age (Cypro-Geometric, Cypro-Archaic, Cypro-Classical), Hellenistic, Early Roman, Late Roman/Byzantine, and Late Medieval. It would, of course, be desirable to date the sites more precisely and thus provide a basis for a detailed analysis of both short- and long-term trends in production. For the purposes of the present analysis—the definition of the general character of the local industry and long-term trends—the assignment of the sites to broad periods was sufficient.

Models of Technological Organization

Three possible models of metallurgical organization were considered:

I. A state-organized, large-scale, full-time industry;
II. A local, village-based, seasonal industry; and
III. A transitional, mobilized, local industry.

All three models were based on historical and ethnographic cases. Although the information used to develop these models cannot be presented here in full (see Raber 1984), the chief characteristics and examples of each type of industry may be summarized briefly.

State-Organized, Large-Scale, Full-Time Industry

The centralized state-run industry is illustrated by Roman operations at Soli, Cyprus, and at Rio Tinto in Spain (Allan 1970: 9–13; Bruce 1937; Healy 1977: 112–133). At these copper production centers, slave labor was essential to the efficient operation of an enormous industry: several thousand tons of copper were produced each year. The chief characteristics of this type of industry are as follows:

1) The exploration and processing of ores occur on a large scale: an annual production of hundreds or thousands of tons is common.
2) Mining and smelting are full-time, specialized occupations.
3) Production centers are few, large, and located so as to minimize the cost of resource procurement and distribution, favoring a nucleated pattern.
4) The labor force is large and specialized. It includes full-time technical specialists, administrative personnel, and a large body of unskilled or semi-skilled laborers (slave labor in the case of Hellenistic and Roman production).
5) There is a large, centrally-organized support system providing fuel, roads and transport, storage facilities, etc.

The archaeological correlates of such an industry should be as follows:

1) The evidence should be concentrated in a few large sites, located near substantial ore and fuel supplies and with regard to transportation routes. The sites should be large in area and in the scale of their characteristic features: specialized architecture, mine workings, waste dumps, furnaces, etc.
2) The characteristic facilities of such large operations should leave distinctive traces: specialized architecture for storage, the processing of raw materials, and housing; specialized metallurgical facilities (permanent furnaces) and equipment (such as tongs, crucibles, and tuyères).
3) Extensive and patterned alteration of the landscape should be evident in the form of mine workings, quarries, deforestation, etc.

Local, Village-Based, Seasonal Industry

The local metallurgical industry is represented by numerous ethnographic cases as well as examples drawn from the historical literature on Europe and Asia. African examples are summarized in Cline (1937) and are too numerous to mention here. A particularly interesting example is 11th-century Chinese iron production described by Hartwell (1962, 1966), which strongly resembles medieval European peasant production (Nef 1952). The primary features of this type of industry include the following:

1) Production is small in scale and seasonal: total annual production amounts to several tons of metal.
2) Production sites are small, dispersed, and not associated with a settlement of full-time specialists but with a preexisting village or town.
3) The labor force is relatively small and composed of

part-time specialists primarily engaged in subsistence or other tasks.
4) There are few large or permanent facilities. A variety of techniques may be used but facilities are few, generally small, often temporary, and constructed from locally-available materials.
5) The industry is maintained by a local support system, eliminating the need for specialized housing, storage, and transportation.
6) Production is scaled to local consumption and scheduled according to local demand and the requirements of subsistence tasks. It is, therefore, seasonal or occasional.

Archaeological features associated with this type of industry should include the following:
1) There should be many small metallurgical sites located to exploit local ore deposits and within easy access of a village or town.
2) There should be little evidence of substantial or specialized architecture or metallurgical facilities. Furnaces will be small and simple and may not be evident, since old furnaces may be demolished after use or incorporated into the next season's construction.
3) Quantities of slag, gangue, and other waste or byproducts at any site will be small, reflecting the low level of production.
4) The evidence for distribution of metal, when present, should indicate primarily local consumption.

Transitional, Mobilized, Local Industry

The third type of industry is essentially a local industry mobilized for the purposes of a state or other central authority or through a market system. It differs from the state-directed industry in scale and from the local industry in the organization of production and distribution. This model is more speculative and poorly documented—in part, because it is transitional—but several examples may be proposed. The historical development of the previously-mentioned, 11th-century Chinese iron industry and the transformation of medieval European production seem to illustrate this type, as does the development of bronze production in the Benin kingdom of Nigeria (Bradbury 1957). In these cases, the mobilization of essentially local industries resulted from either direct interference or incorporation by the state, indirect interference through tribute or levy, or indirect interference through a market system.

The chief features of this type of production are as follows:
1) This is essentially a local industry, exploiting local resources and dependent upon a local support system, which has been incorporated or embedded into a larger system of control, demand, exchange, and distribution.
2) Production may be part-time or full-time, depending on the nature of demand and the extent of external control.
3) There should be many dispersed and relatively small production centers, located with regard to ore deposits and fuel supply, as in the local type of industry.
4) The labor force is skilled and specialized; it may be engaged in either part-time or full-time production, depending on demand.
5) The most distinctive feature is the linkage to a larger system. The resource base is local, but control and distribution of the products involve the industry in a wider economic and political sphere.

The archaeological correlates of this type of industry should be as follows:
1) The regional distribution of sites should be as in the local (Type II) industry: there will be many small, dispersed sites.
2) Archaeological evidence for metallurgical facilities will reflect the local base of the industry. A relatively small, local labor force will be housed in nearby settlements. There will, therefore, be no evidence of special housing or support facilities associated with the mining and smelting sites. Metallurgical facilities should be small in scale.
3) The quantities of waste, by-products, and metallurgical equipment should indicate a level of production intermediate between that of the Type I and Type II industries.
4) The scale of resource use (as evident in mine workings, slag heaps, deforestation, etc.) should be small, as in the local industry. The pattern of exploitation, however, should suggest planned rather than opportunistic exploitation of resources.
5) Metal produced should be widely distributed. Evidence for this may, however, not be available.

Tests of the Models

The field test of these models and the characterization of the Polis region industry involved a consideration of several lines of evidence: environmental constraints on the level of production; estimates of the average annual production of copper for each period; patterns of smelting site location and changes through time; technological characteristics of the local copper metallurgy.

Environmental Constraints on Production

The availability of raw materials for the smelting process imposes obvious constraints on production. Of the materials required for the process—ore, flux, fuel, and material for the construction of furnaces and other facilities—only fuel could conceivably have been a critical factor in the Polis region. Enormous quantities of fuel in the form of wood, or more typically charcoal, are consumed in the smelting of copper. Accounts by Classical authors attest to the severity of deforestation in the vicinity of metallurgical sites.

The reconstruction of the paleoenvironment is of obvious significance for a consideration of timber and fuel supply. The description of the early vegetation of the region is made difficult by the dearth of suitable palynological and paleobotanical evidence from archaeological sites, in the Polis region as elsewhere (Stanley Price 1979). For the period of concern in this study, however, some general features of the vegetation, especially the forest cover, can be inferred from the descriptions of Classical authors and the character of modern vegetation in undisturbed areas of the island.

The area has suffered from the pattern of deforestation, erosion, and desiccation common to the Mediterranean (Semple 1931; Bintliff 1977; Brice 1978: 141–147). Several factors are responsible (Hughes 1975: 68–75): the cutting of forests for fuel and construction materials, poor agricultural techniques which encouraged erosion, and overgrazing by sheep and goats. The problem is not recent: Plato, Strabo, and Livy mention the extent of deforestation since the Classical period and even within their lifetimes (see Semple 1931: 261–296; Cary 1949: 26, 164; Hughes 1983). References by early authors, Eratosthenes and Strabo for example, make clear that the island was once densely covered with forests. Clearance, according to Strabo (xiv. 6.5), was part of a deliberate policy of the Hellenistic-period governments, to which large-scale mining and shipbuilding greatly contributed. The requirements of domestic heating, local craft production, and construction added to the above factors. Although the extent of pre-modern forest clearance may have been significant (Hughes 1983), it seems likely that the present conditions of severe deforestation date to either the 18th or 19th century and are the result of the combined effects of overgrazing, overuse, and neglect on the part of the Turkish administration (Meiggs 1982: 397–399; Thirgood 1981: 124–125).

The forests that are now confined to the upper elevations of the region once covered a considerable part of the study area. Extant forests on the slopes of the Troodos and in undisturbed areas at lower elevations provide some idea of the original forest cover (Wilson 1959). This may be reconstructed for the mid-first millennium as follows. Oak (*Quercus lusitanica*) and poplar dominated a deciduous forest at the lower elevations, including the coastal plain and the sedimentary belt in the lower foothills. Above this, a mixed pine and oak forest (*Pinus brutia* and *Q. alnifolia*) was dominant, with patches of oak and poplar in well-watered areas. This forest continued to the upper limits of the study area, although *Q. alnifolia* was probably dominant in the upland valleys. Cedars (*Cedrus libanitica*) and cypresses (*Cupressus sempervirens*) were common throughout Cyprus and are likely to have been present in the study area.

A rough estimate, based on the reconstructed forest cover and the population distribution at this time, is that more than 50% of the lower elevations and 75% of the upper elevations were forested. An overall average of roughly 65% forest cover implies that about 11.5 sq mi (129.1 sq km) of woodland would have been available within the study area. Additional wood for charcoal could have been obtained from an even larger area (to include, perhaps, an 8-km-wide band around the study area) with little difficulty. The potential yield of wood from this larger area—considering the conceivable variation in the extent of forest, an average of 40 years for the replacement of the forest cover (Allan 1970), and the effect of competing uses for timber—may be estimated and the potential yield of copper, given certain assumptions about the copper content of the ore and the smelting process in use, calculated (TABLE 2).

Estimates of the availability of wood for fuel are necessarily approximate since there is often little precise information on the amounts of wood used in competing activities such as domestic heating, construction, and ship-

Table 2. Estimates of potential fuel supply and copper production in the Polis region.

Forest Cover	
maximum = 60 sq km, minimum = 18 sq km	
Available Wood for Fuel (40-year yield)	
maximum = 1,395,000 tons, minimum = 208,436 tons	
Potential Copper Production	
Matte smelting process	
maximum (8% copper ore)	= 386 tons copper/year
minimum (8% copper ore)	= 58 tons copper/year
maximum (12% copper ore)	= 579 tons copper/year
minimum (12% copper ore)	= 87 tons copper/year
Hydrometallurgical process	
maximum (8% copper ore)	= 1,020 tons copper/year
minimum (8% copper ore)	= 152 tons copper/year
maximum (12% copper ore)	= 1,530 tons copper/year
minimum (12% copper ore)	= 228 tons copper/year

Table 3. Estimated copper production in the Polis region.

Period	*Duration (years)*	*Slag (metric tons)*	*Total Copper Production* (metric tons)*	*Mean Annual Production (metric tons)*
Pre-Roman (CA to Hellenistic)	300	36,100	3,900	13.0
Late Roman/Byzantine	600	52,600	5,700	9.5
Late Medieval	300	21,600	2,300	7.7
Total	1,200	110,000	11,900	9.9

* Total copper production, rounded off to the nearest hundred, is estimated by multiplying the amount of slag by 1 ton copper/9.26 tons slag (conversion factor = 0.108).

building, for example. Rough estimates of the wood available for the smelting of copper during any period, however, suggest that fuel was never a critical or limiting factor in copper production in the Polis region (TABLE 2). Estimates of actual production (see below and TABLE 3) always fall far below (by one or more orders of magnitude) the potential production, given the estimated quantities of available fuel.

Estimates of Average Annual Copper Production

The calculation of actual copper production may be made in several ways. An upper limit on production might be calculated, as above, by considering available fuel. Secondly, the scale of copper production might be calculated from the number and size of known mines and an estimate of the volume of ore mined. Given a known volume of mined ore, the copper content of the ore, and the recovery rate of the smelting process, one could calculate the quantity of copper produced. This method presupposes that all or a significant part of the ancient mines are intact, archaeologically investigated, and datable. These conditions do not hold for the Polis region.

A third approach, adopted in this study, is to calculate copper production from the quantities of slag left by early smelting. Slag heaps are more often intact or partially preserved than are mine workings and may, therefore, provide a better indicator of the scale of production. There are several requirements for use of this approach: 1) the ability to estimate the quantities of slag at each site; 2) the ability to date slag deposits; 3) the calculation of a slag:ore ratio, dependent on chemical analysis of representative slags and ores; and 4) an estimate of the efficiency or recovery rate for the smelting process.

The Polis region study was able to address all the above conditions. Slag quantities were estimated from intact slag heaps or by reconstructing the size of disturbed heaps. Relative dating of the slag deposits was possible through the dating of associated pottery and correlating those results with a provisional slag-dating typology developed by Koucky and Steinberg (1982: 156–157). New and previously published analyses of ores and slags allowed a calculation of the slag:ore ratio. The efficiency of the smelting process was estimated from comparable published results (Healy 1977: 195; Jackson 1980: 23–25).

Estimates of the mass of slag from dated metallurgical sites yield the following figures for the production of slag at the sites of each period: approximately 36,000 metric tons from the Cypro-Archaic through Hellenistic periods; approximately 53,000 metric tons from the Late Roman Byzantine period; and approximately 22,000 metric tons from the Late Medieval period.

To estimate the amount of copper produced for each phase, it is necessary to first calculate a slag to metal ratio, or more precisely, both a slag to ore ratio and an ore to metal ratio. Usual estimates of the slag:ore ratio vary from 1:1 to 1:1.2 (Gordon-Smith n.d.; Healy 1977: 195), the ratio depending on the exact composition of the copper ore. The ore:metal ratio depends on the copper concentration of the ore and the efficiency of copper recovery in the smelting process. Because of the heterogeneous nature of copper ores, the copper concentration is highly variable. Values for the massive sulfide ores of Limni and Kinousa vary from around 0.5% to 10% or more, averaging around 1.5%. The ores from the zone of secondary enrichment likely to have been used by early miners (Koucky and Steinberg 1982: 162–164; Raber 1984: 204–212) were certainly richer, varying from about 8% to 30% copper. Gordon-Smith (n.d.), on the basis of assays of spill presumably from ancient workings at Limni, estimates that this ore may have averaged 15% copper, but Koucky and Steinberg (1982: 173) give a more realistic median value of 12% copper based on the mineralogy and presumed distribution of the enriched ores.

The efficiency of early smelting is, likewise, an inherently variable factor. Healy (1977: 195) assumes an 85% recovery rate for copper at Rio Tinto while Jackson (1980: 24) estimates a probable 90% recovery of copper in Bronze Age smelting in Ireland. Assuming that an 8–12%

copper ore was used by early metallurgists in the Polis region, the copper values of less than 1% obtained from most of the slags analyzed (Raber 1984: 278–282) suggest a recovery rate of greater than 90%. If we take 90% as a reasonable estimate and assume the use of a 12% copper ore, we obtain an ore:metal ratio of 9.26:1.

Using a slag:ore ratio of 1:1 and an ore:metal ratio of 9.26:1 we obtain a slag:metal ratio of 9.26:1. With this ratio it is then possible to calculate copper production from the slag quantities given above. The results of these calculations are presented in Table 3. Total production per period was divided by the approximate duration of the industry in each period to obtain a mean annual production figure for each period. Several points should be made with regard to these estimates.

1) The Polis industry was relatively small in scale during all periods. The estimates are liberal and could probably be adjusted downward. Even doubling or tripling the figures, however, produces production estimates that are still an order of magnitude or two less than figures for recorded production at Soli or Rio Tinto. During the period of peak production (pre-Roman: Cypro-Archaic to Hellenistic) the production amounts to roughly 10–20 tons of copper annually. Compare this to estimates of one ton/day at Soli and Rio Tinto (Allan 1970; Healy 1977) to gain some impression of the relative scale of the local industry.

2) Although production in the pre-Roman period is 37% to 69% higher than that for any later period, it is still nowhere near the production level that would be expected for a state-directed industry. Production for this period is consistent with a model of part-time production. The higher production figures suggest the association of copper smelting with the local city-state economy but are not indicative of full-time production.

3) Production estimates for all periods suggest part-time (seasonal or periodic) production. At the rate of 0.25 tons/day, for example, eight tons of copper could have been produced in about 32 days. Such production could easily have been scheduled around the demands of the agricultural cycle.

Site Distribution Patterns

IRON AGE

All the recorded metallurgical sites of this period occur in the upper reaches of the lower piedmont and in the upper piedmont in the vicinity of the modern Limni and Kinousa mines. Metallurgical activity at the time was evidently focused on the previously-unexploited ores of Limni and Kinousa. The settlement pattern (FIG. 3), however, is clearly centered on the city of Marion, although small agricultural settlements were located near the mines. The distribution of metallurgical sites and settlements suggests that copper smelting occurred near the mines, that all necessary facilities were located near the ore sources, and that labor was drawn from nearby agricultural villages. This pattern has been noted for this period elsewhere on Cyprus (Arthur Steinberg, personal communication).

HELLENISTIC/EARLY ROMAN PERIOD

A drastic decline in the local industry is evident in the drop in the number of recorded metallurgical sites. Total production for this period (300 years) was probably several hundred tons. As in the Iron Age, production occurred near the mines and the settlement system (FIG. 4) was centered on the new regional center of Arsinoe, which succeeded Marion in 285 B.C., after the destruction of the latter by Ptolemy I. The obvious sharp decline in local production for this period is correlated with the incorporation of Cyprus into the Hellenistic (Ptolemaic) economic and political system and the appearance of large copper-smelting centers elsewhere on the island. The overall pattern suggests that, with the ability to efficiently exploit the resources of the entire island, the Hellenistic and Roman rulers of Cyprus chose to locate their smelting installations with regard to convenience of supply and access. The relative isolation of the Polis region made it a poor choice for the location of a state-directed industry. Copper smelting in the Polis region remained a local enterprise, organized and maintained by and for the benefit of the local population.

LATE ROMAN/BYZANTINE

A major change in both the number of metallurgical sites and their distribution is evident in the period following the decline of Roman hegemony. This change takes the form of an increase in the number of smelting sites and the concentration of these sites on the coastal plain and in the lower foothills, although some smelting occurred, as before, near the mines. Not only is there an increase in the number of sites, but the number of larger slag heaps is greater as well. This apparent change in scale is, however, explained by considering the greater length of this period. Total production (an estimated 5700 tons) is greater, but average annual production is lower than that of the Iron Age and comparable to that of the succeeding period.

There are major changes in the settlement pattern (FIG. 5) as well. The number of recorded settlements declines, corresponding to the general depopulation of the island

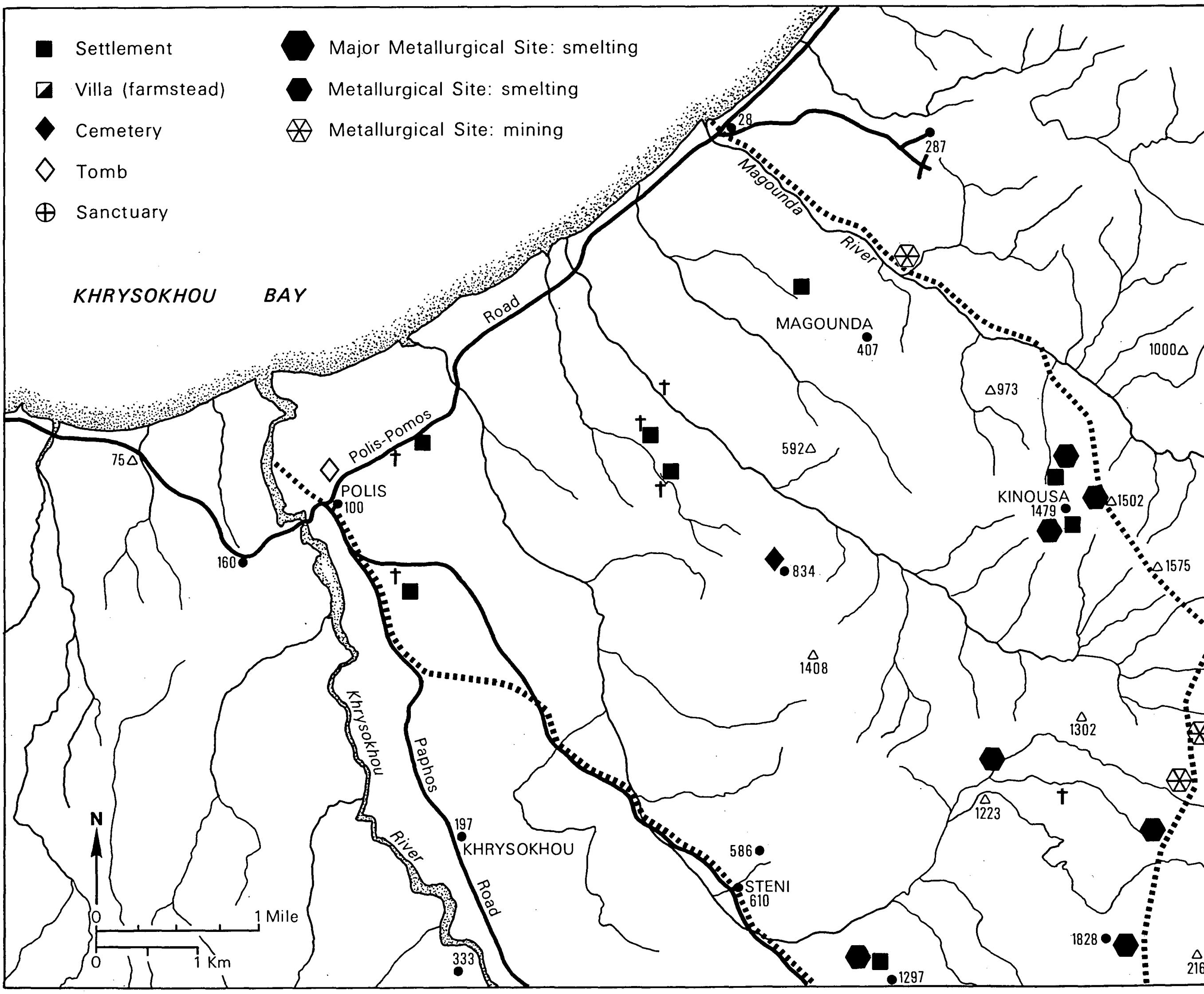

Figure 3. Iron Age site distribution.

as a whole. Arsinoe, the regional center, experienced a decline in size and importance and a more dispersed pattern characterized the distribution of villages. The appearance of upland sites suggests the widespread and historically-documented insecurity and absence of strong central government typical of this and the succeeding period.

The combined data indicate a distinctive mode of production for this period. Smelting sites were located near villages and the town of Arsinoe rather than near the mines, suggesting that relatively small quantities of ore were being mined and transported, a conclusion supported by the production estimates. Production was apparently adapted to local supply and demand rather than to external economic or political forces. A small-scale, seasonal or periodic production, using local labor and resources and oriented to a local market is indicated.

LATE MEDIEVAL

A change in the number of metallurgical sites and their distribution marks the next period. The number of sites decreases and, as before, metallurgical sites cluster around agricultural settlements rather than the mines (FIG. 6). Although total production for this period is lower, average annual production is roughly equivalent to that of the Late Roman/Byzantine industry. The shift in the location of metallurgical sites corresponds to a shift in the settlement system. The settlement of the upper piedmont con-

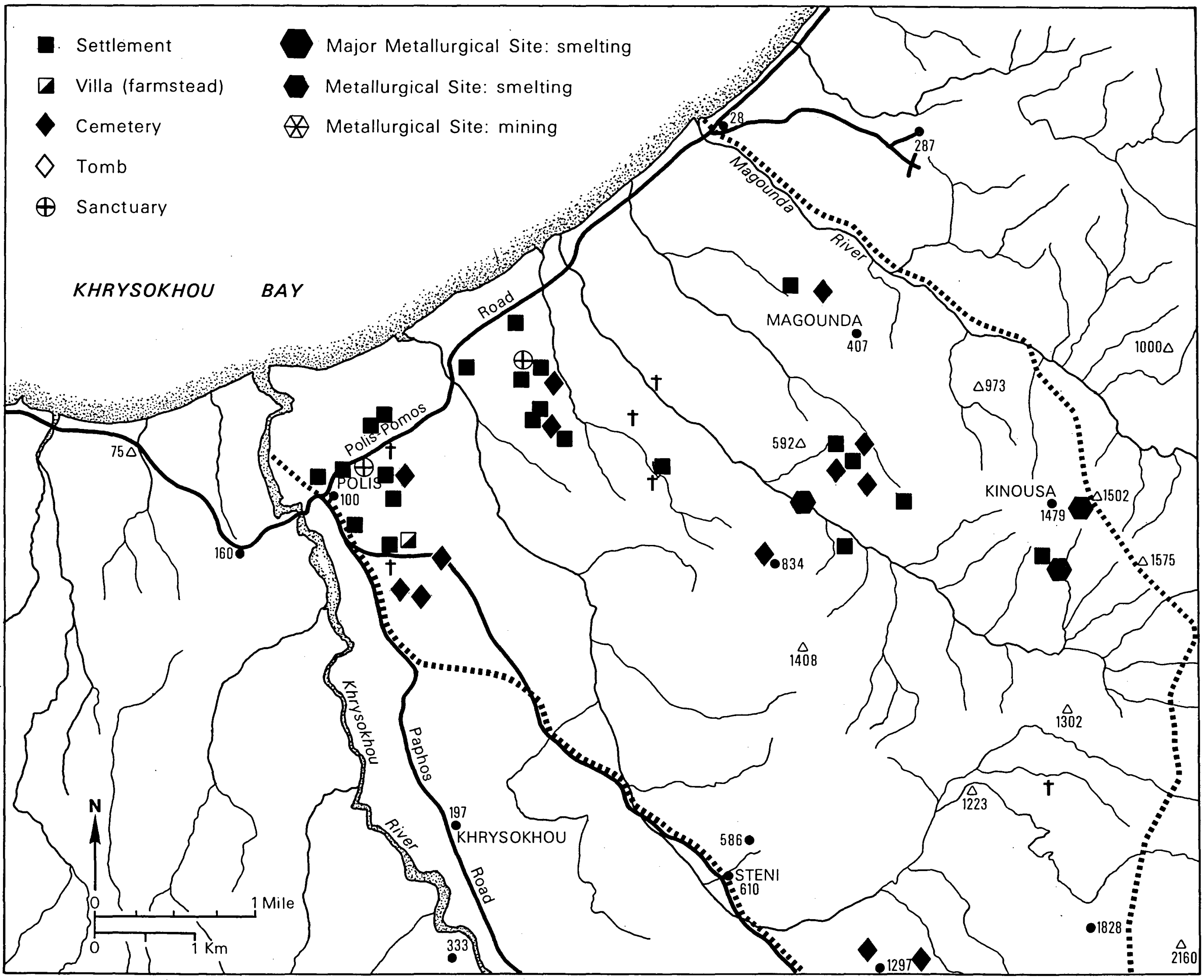

Figure 4. Hellenistic/Early Roman site distribution.

tinued, again suggesting conditions of general insecurity (e.g., piracy).

The map and production estimates again indicate a small copper industry, based on local resources and labor and producing for local demand.

Technological Characteristics of the Local Copper Industry

A full discussion of the technological characteristics of the Polis region industry is beyond the scope of this paper and will be addressed elsewhere. Of relevance here are the evidence for an alternative smelting technology and the implications of that technology for the organization of the local industry. The assumption in the literature has been that a matte smelting technique, analogous to that commonly used in modern and historical copper metallurgy, was in use from the earliest periods. The matte smelting process involves a complex and energy-intensive set of procedures including roasting to oxidize the ores and repeated heating to produce, first, a matte and, finally, metallic copper. An alternative procedure involves the leaching of copper sulfates from heaps of copper ore, the collection and drying of the leachate, and the simple heating and reduction of the sulfate salts to metallic copper. This hydrometallurgical or heap-leaching process is largely passive: the heaps of ore may be exposed to rain and the leachate collected over a period of weeks or months for

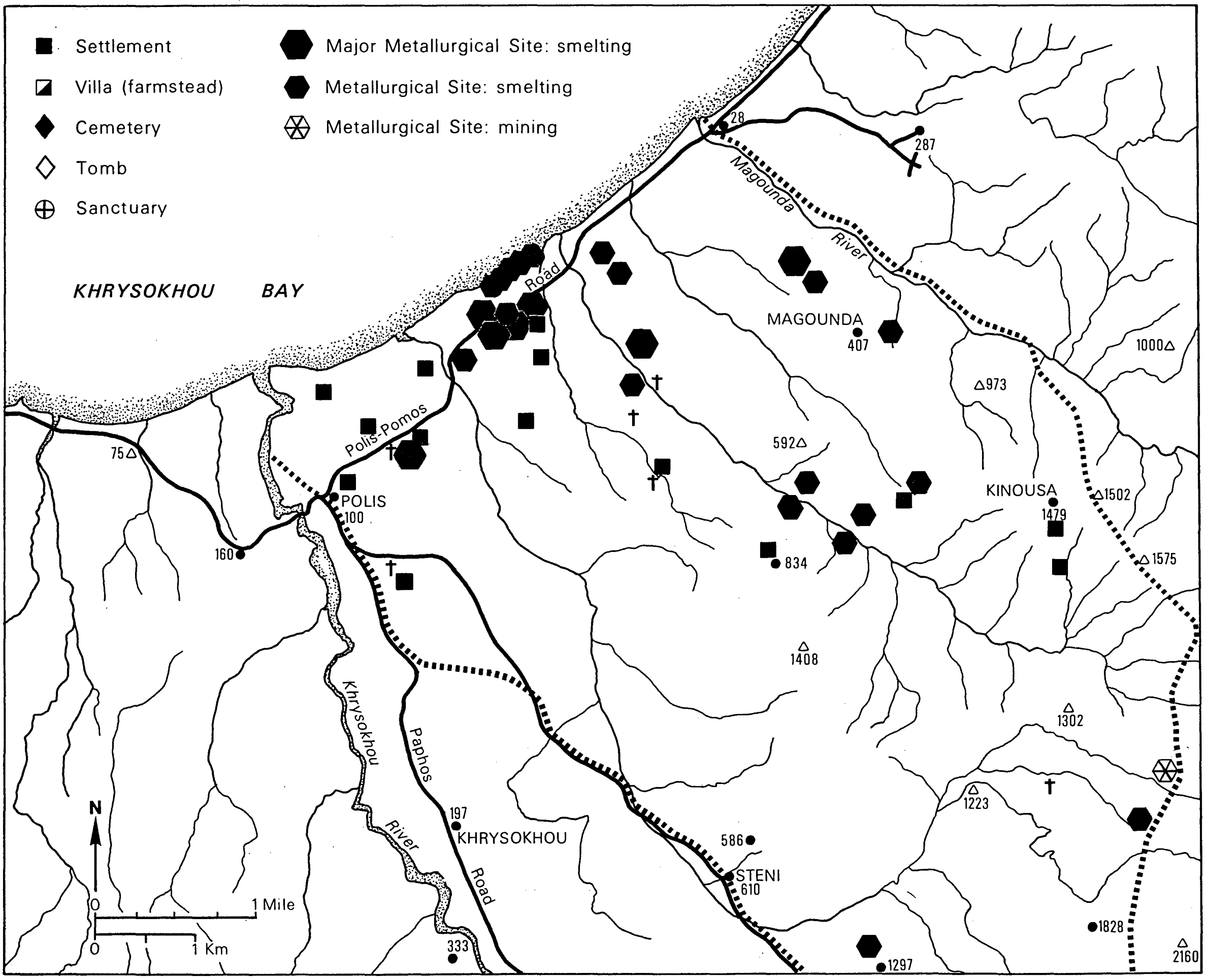

Figure 5. Late Roman/Byzantine site distribution.

periodic smelting. The hydrometallurgical process is clearly well-adapted to a part-time, small-scale industry of the type posited for the Polis region. All the necessary steps could have been easily scheduled with regard to the agricultural cycle. Field evidence and laboratory tests have provided support for this model of technology (see Raber 1984: 266–321).

Conclusions

Three models of the organization of the Polis region copper industry have been presented. Evidence from various sources—raw material supply, production estimates, metallurgical and settlement site distributions, and technology—has been considered in light of these models. A few generalizations may be made.

There is no suggestion in any of the data that the regional copper industry was ever a state-directed operation of the type known elsewhere in the Hellenistic and Roman periods. Neither the scale nor the organization, evident in the production estimates and site distribution patterns, are consistent with the characteristics of this type of industry. This conclusion is reinforced by the absence of any mention in the historical records of the Polis region industry or its products, but it stands in marked contrast to traditional assumptions about the organization of early Cypriot metallurgy.

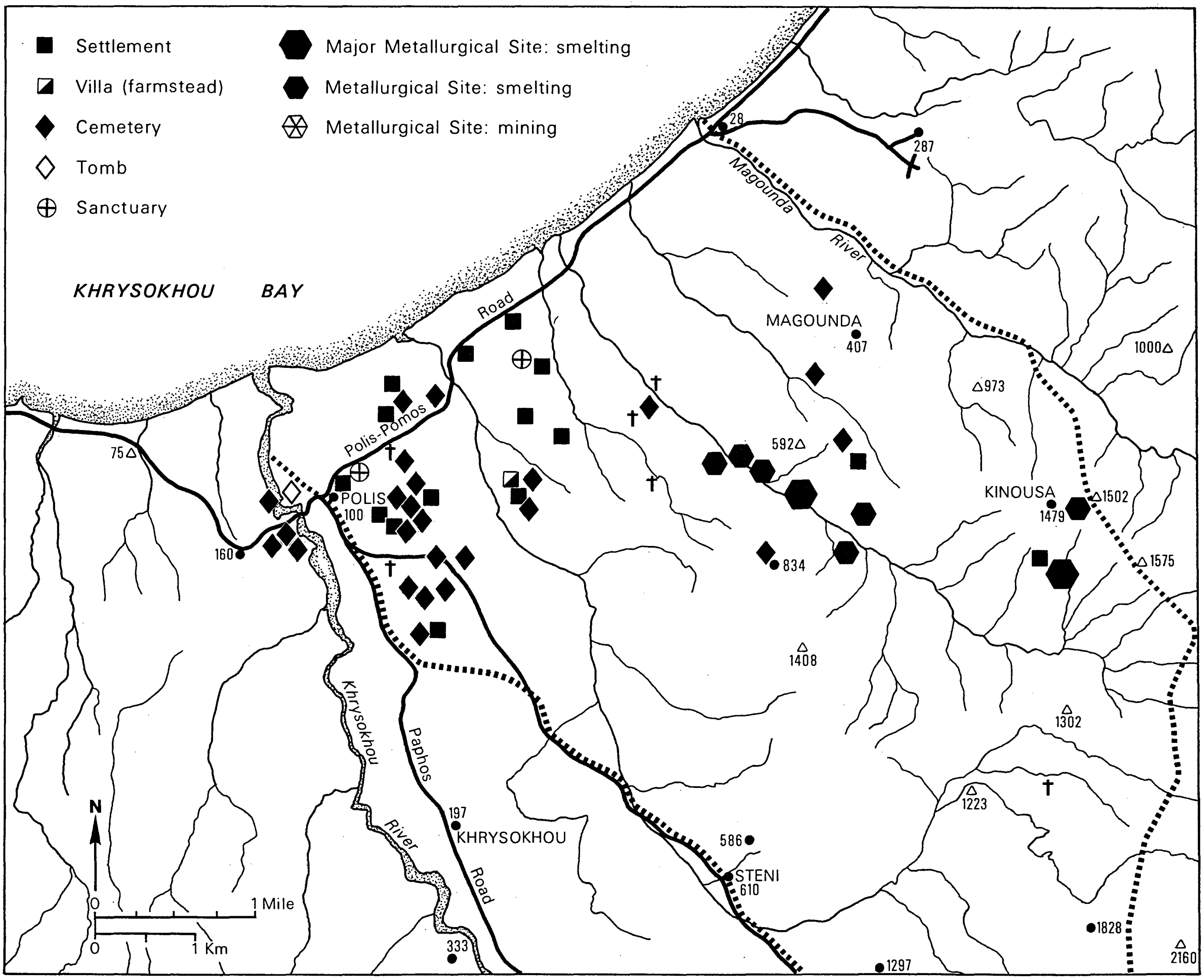

Figure 6. Late Medieval site distribution.

The industry associated with the Iron Age city-state of Marion seems to represent the Type III mobilized local industry. Essentially a local enterprise in origin and in certain aspects of its organization, it developed further in response to the demands of the local city-state. Although relatively small in scale and dependent on local resources and labor, the industry of this period was producing at least some metal for export (shipments to Attica in the 5th century B.C., for instance, are recorded; see above). Evidence for direct and complete control by a state, as at the large Hellenistic and Roman operations already noted, is absent and the scale of production is consistent with that posited for the Type III industry.

The production of copper at all other periods recorded (Hellenistic through late Medieval) seems to fit the Type II model and represents the output of a local village-based industry. The evident scale of production and the physical evidence from the smelting sites suggest that production was organized by the local population primarily for local demand. This is not to deny that some copper may have been traded to the rest of the island or beyond. The local population, however, was in control of production.

The production of copper in this type of industry is envisioned as occurring in the setting of Mediterranean village agricultural life. The general form of this life has probably not changed significantly in several millennia and many aspects may be inferred from ethnographic and historical studies (see, for example, Friedl 1962; Sanders 1962; Pierce 1964; Laiou-Thomadakis 1977). Assuming the use of the hydrometallurgical (heap-leaching) technology mentioned above, the following picture of the operation of the local industry may be drawn.

Mining and the forming of the ore heaps would have occurred during the winter or at any free period in the agricultural cycle, as would the gathering of wood for charcoal. Charcoal was burned during the slack period after the winter rains (March–April) or after the harvest (October–November). Copper salts were leached from heaps of ore exposed to the winter rains and collected as they accumulated. By the end of the wet season in February a sufficient quantity of leached copper sulfate salts was available for smelting during March and April or after the harvest in late October and November.

The conditions of ownership or rights over the ore deposits are unclear. Ore deposits may have been owned outright or controlled either individually or collectively by villagers. Under the stronger central authority of the Iron Age or the feudal system of the Late Medieval period, ore deposits may have been controlled by landlords who received rent or some portion of the product in return. All these forms of ownership and control are known from the ethnographic and historical literature (see, for example, Cline 1937; Nef 1952; Hartwell 1966).

Labor was provided by small groups of part-time village specialists working cooperatively in a manner well known in the ethnographic and historical literature on peasant societies (e.g., Nef 1952; Wolf 1966). Much of the work would have been occasional. Concentrated efforts were necessary only for short periods of the year and were scheduled for slack periods in the agricultural cycle.

Small quantities of copper were produced at several locations in the region and channeled through the regional center of Marion or Arsinoe. The mechanisms of distribution are unclear but certainly changed through time in response to local and external economic and political conditions. Although production remained based on the village economy, distribution may have been more or less controlled at various times by the urban elite or merchant classes.

The Polis region copper industry, as reconstructed above, appears to have been an essentially local phenomenon. Production was at all times based on the local village economy. External influence, when present, took the form of control of distribution.

The analysis of the regional copper industry presented in this paper should demonstrate the dangers of untested assumptions about both technology and the organization of technology. Analogies with modern technologies or with historical examples of technological organization may be very misleading unless treated as testable hypotheses. Such testing should be part of a regional and multidisciplinary study of technology and social organization.

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Paul Raber is an archaeologist with the Pennsylvania Historical and Museum Commission. He received his bachelor's degree from the Massachusetts Institute of Technology and his M.A. and Ph.D. in anthropology from the Pennsylvania State University. He maintains an active interest in the anthropological study of early technologies in both the Eastern Mediterranean and eastern North America. Mailing address: Pennsylvania Historical and Museum Commission, Box 1026, Harrisburg, PA 17108-1026.

Adovasio, J. M., G. F. Fry, J. Gunn, and R. Maslowski
1975 "Prehistoric and Historic Settlement Patterns in Western Cyprus," *World Archaeology* 5: 339–369.
1978 *Prehistoric and Historic Settlement Patterns in Western Cyprus: An Overview. Report of the Department of Antiquities, Cyprus.* Nicosia, Cyprus: Department of Antiquities.

Allan, J. C.
1970 *Considerations on the Antiquity of Mining in the Iberian Peninsula. Royal Anthropological Institute Occasional Papers* 27. London: Royal Anthropological Institute.

Bintliff, J.
1977 *Natural Environment and Human Settlement in Prehistoric Greece. British Archaeological Reports* 28 (*Supplementary Series*) (2 vols.). Oxford: B.A.R.

Bradbury, R. E.
1957 *The Benin Kingdom.* London: International African Institute.

Brice, William C.
1978 "The Desiccation of Anatolia," in William C. Brice, ed., *The Environmental History of the Near East Since the Last Ice Age*. New York: Academic Press, 141–147.

Bruce, J. L.
1937 "Antiquities in the Mines of Cyprus," in Einar Gjerstad, John Lindros, Erik Sjoqvist, and Alfred Westholm, eds., *The Swedish Cyprus Expedition*, Vol. 3. Stockholm: V. Petterson, 639–671.

Cary, M.
1949 *The Geographic Background of Greek and Roman History*. Oxford: Clarendon Press.

Charles, J. A.
1975 "Where is the Tin?," *Antiquity* 49: 19–24.

Cline, Walter
1937 *Mining and Metallurgy in Negro Africa. General Series in Anthropology* 5. Menasha, WI: G. Banta.

Cullis, C. C., and A. B. Edge
1927 *Cupriferous Deposits of Cyprus. Crown Agents for the Colonies Report*. London: Waterlow and Sons.

Friedl, Ernestine
1962 *Vasilika: A Village in Modern Greece*. New York: Holt, Rinehart, and Winston.

Gordon-Smith, J.
n.d. Untitled report on the Limni Mine, manuscript on file at offices of the Cyprus Sulphur and Copper Co., Ltd., Limni Mines, Polis, Paphos District, Cyprus.

Hartwell, Robert
1962 "A Revolution in the Chinese Iron and Coal Industries During the Northern Sung, 960–1126 A.D.," *Journal of Asian Studies* 21: 153–162.

1966 "Markets, Technology, and the Structure of Enterprise in the Development of the Eleventh Century Chinese Iron and Steel Industry," *Journal of Economic History* 26: 29–58.

Healy, J. F.
1977 *Mining and Metallurgy in the Greek and Roman World*. London: Thames and Hudson.

Hughes, J. Donald
1975 *Ecology in Ancient Civilizations*. Albuquerque: University of New Mexico Press.

1983 "How the Ancients Viewed Deforestation," *Journal of Field Archaeology* 10: 437–445.

Jackson, John S.
1980 "Bronze Age Copper Mining in Counties Cork and Kerry, Ireland," in P. T. Craddock, ed., *Scientific Studies in Early Mining and Extractive Metallurgy. British Museum Occasional Paper* 20. London: British Museum, 9–30.

Koucky, Frank L., and Arthur Steinberg
1982 "Ancient Mining and Mineral Dressing on Cyprus." in T. A. Wertime and S. F. Wertime, eds., *Early Pyrotechnology: The Evolution of the First Fire-Using Industries*. Washington, D.C.: Smithsonian Institution Press, 149–180.

Laiou-Thomadakis, Angeliki E.
1977 *Peasant Society in the Late Byzantine Empire: A Social and Demographic Study*. Princeton, NJ: Princeton University Press.

Maddin, R., T. S. Wheeler, and J. D. Muhly
1977 "Tin in the Ancient Near East: Old Questions and New Finds," *Expedition* 19(2): 35–47.

Matson, Frederick R.
1965 "Ceramic Ecology: An Approach to the Study of the Early Cultures of the Near East," in Frederick R. Matson, ed., *Ceramics and Man*. Chicago: Aldine, 202–217.

Meiggs, Russell
1982 *Trees and Timber in the Ancient Mediterranean World*. Oxford: Oxford University Press.

Merrillees, Robert
1978 *Introduction to the Bronze Age Archaeology of Cyprus. Studies in Mediterranean Archaeology*, Pocketbook 9. Göteborg: P. Aströms Förlag.

Muhly, James D.
1973 *Copper and Tin. Transactions of the Connecticut Academy of Arts and Sciences* 42. Hamden, CT: Archon.

1976 *Supplement to Copper and Tin. Transactions of the Connecticut Academy of Arts and Sciences* 46. Hamden, CT: Archon.

1978 "New Evidence for Sources of and Trade in Bronze Age Tin," in Jacqueline S. Olin, Alan D. Franklin, and Theodore A. Wertime, eds., *The Search for Ancient Tin*. Washington, DC: Smithsonian Institution Press, 43–48.

Muhly, J. D., R. Maddin, and V. Karageorghis, eds.
1982 *Acta of the International Symposium "Early Metallurgy in Cyprus, 4000–500 B.C."* Nicosia, Cyprus: Department of Antiquities.

Nef, John U.
1952 "Mining and Metallurgy in Medieval Civilization," in M. Postan and E. E. Rich, eds., *The Cambridge Economic History of Europe*, Vol. 2. Cambridge: Cambridge University Press, 429–492.

Pierce, Joe E.
1964 *Life in A Turkish Village*. New York: Holt, Rinehart, and Winston.

Raber, Paul A.
1984 *The Organization and Development of Early Copper Metallurgy in the Polis Region, Western Cyprus*. Ph.D. dissertation, The Pennsylvania State University. Ann Arbor, MI: University Microfilms.

Sanders, Irwin T.
1962 *Rainbow in the Rock: The People of Rural Greece*. Cambridge, MA: Harvard University Press.

Semple, Ellen C.
1931 *The Geography of the Mediterranean Region: Its Relation to Ancient History*. New York: Holt.

Stanley Price, N. P.
1976 "Patterns of Settlement in the Early Prehistory of Cy-

prus," unpublished Ph.D. dissertation, Oxford University, Oxford, England.

1979 *Early Prehistoric Settlement in Cyprus, 6500–3000 B.C. British Archaeological Reports* 65 (*International Series*). Oxford: B.A.R.

Steinberg, Arthur, and Frank Koucky

1974 "Preliminary Metallurgical Research on the Ancient Cypriot Copper Industry." In L. E. Stager, A. Walker, and G. E. Wright, eds., *American Expedition to Idalion, Cyprus*. Cambridge, MA: American Schools of Oriental Research, 149–178.

Strabo

1929 *The Geography of Strabo* (translated by H. L. Jones). Loeb Classical Library. Cambridge, MA: Harvard University Press.

Thirgood, J. V.

1981 *Man and the Mediterranean Forest: A History of Resource Depletion*. London: Academic Press.

Wilson, R. A. M.

1959 *The Geology of the Xeros-Troodos Area. Geological Survey of Cyprus, Memoir* 2. Nicosia, Cyprus: Geological Survey Department.

Wolf, Eric

1966 *Peasants*. Englewood Cliffs, NJ: Prentice-Hall.