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RESEARCH AND EXCAVATION AT CHRYSOKAMINO, CRETE

1995–1998

I. INTRODUCTION

Chrysokamino is on the seacoast northwest of the town of Kavousi in the Mirabello Bay area of eastern Crete (Fig. 1).[1] It is on the southwest side of the hill of Chomatas, between Pacheia Ammos and Tholos Bay. The site consists of a metallurgical installation dating from the Final Neolithic (FN) to Early Minoan (EM) III, a habitation complex with Late Minoan (LM) I–III architecture and earlier pottery, a cave used from FN until EM III or later, several post-Minoan threshing floors and farm buildings, and many agricultural terraces. It is within the territory of the town of Kavousi, and the site is on public land. Chrysokamino is being investigated in a project sponsored by Temple University with the collaboration of the University

1. This preliminary report represents the work of several individuals and is divided into the following sections: I. Introduction (Philip P. Betancourt); II. Topography of the Chrysokamino Region (Lada Onyshkevych and William B. Hafford); III. The Geomorphology (William R. Farrand and Carola Stearns); IV. The Copper Smelting Workshop (Betancourt and James D. Muhly); V. The Stone Tools at the Metallurgical Site (Doniert Evely); and VI. Summary and Final Comments (Betancourt). The Habitation Site, under study by Cheryl R. Floyd, will be published at a later date.

The project worked under a permit issued by the Greek Ministry of Culture under the auspices of the American School of Classical Studies at Athens. Thanks are expressed to Nikos Papadakis, Director of the Ephorate for eastern Crete, and to the Directors of the American School, W. D. Coulson (1995–1997) and Muhly (1997–present). Financial support was given by the Institute for Aegean Prehistory, Temple University, the University of Pennsylvania Museum of Archaeology and Anthropology, and other donors.

The director of the project was Betancourt. Assistance was given by codirectors Muhly and Floyd. Other staff members included Farrand and Stearns, geologists (1995–1996), Mary A. Betancourt, *apotheki* supervisor (1995–1998); Onyshkevych, supervisor for the instrument survey and mapping team (1995–1998); Evely, stone tools specialist (1997); David S. Reese, faunal analyst (1997); and Polymnia Muhly, excavation consultant (1996). Trench supervisors included Eleni A. Armpis (1996), Brigit Crowell (1997), Barbara J. Hayden (1996), Katherine May (1996), Eleni Nodarou (1996–1997), Robert S. Powell (1996), Elizabeth Shank (1997), Evi Sikla (1997), Suzanne Stichman (1997), Stephanie M. Takaragawa (1997), and Tanya Yangaki (1996). Mark Hudson (1996) and Ann Schofield (1997) were present as archaeobotanists. The computer supervisor was Hafford (1995–1998). Artists included Lyla Pinch Brock (1996–1997), Ann Foster (1996), Stephanie E. Gleit (1995–1996), Laura A. Labriola (1996–1997), Shank (1998), and Ian Verstegen (1998). The conservator was Sari K. Uricheck (1996). Instrument survey and mapping team members were Jaime J. Alvarez (1998), Leigh-Ann Bingham (1995), Terrence P. Brennan (1998), May (1995), Powell (1996), Takaragawa (1996, 1998), and Jonathan Wallis (1995). Assistant cataloguers included Jane Hickman (1998), Gerardo I. Medrano (1997), and Shank (1996). Gayla Weng was administrative assistant (1998). Nodarou was soils specialist (1998).

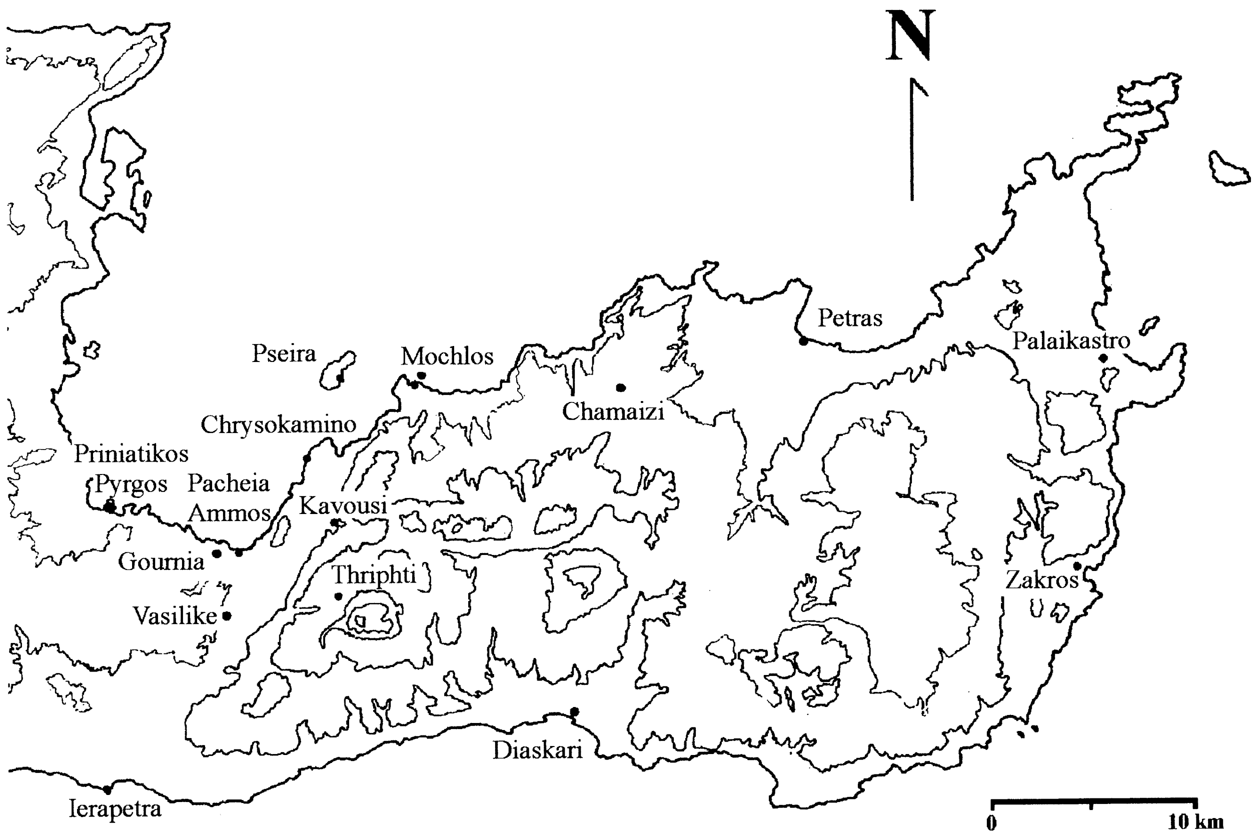


Figure 1. Map of eastern Crete

of Pennsylvania Museum of Archaeology and Anthropology. The site was surveyed with instruments in 1995, and excavation seasons were conducted in 1996 and 1997. In 1998, study was conducted in the INSTAP Study Center for East Crete.[2]

The site provides an opportunity to study the area of a Minoan estate with its surrounding farmland and an installation for metallurgy in the context of a greater region consisting of the land bordering on the southern and eastern parts of Mirabello Bay. For this aspect of the project we are greatly indebted to the previous survey work conducted in the Kavousi area by Donald Haggis, which forms the foundation for our understanding of the diachronic use of the Kavousi region.[3] The present study serves as a focused complement to this important earlier work.

Chrysokamino has been known to archaeologists since the end of the 19th century. The first mention in print of Minoan archaeological remains from the Chrysokamino territory is in an article by Harriet Boyd about the early excavations at Kavousi. Boyd reported Roman discoveries at Chordakia (east of Chrysokamino) and noted the presence of early architecture on top of the coastal hill.[4] The metallurgical site was first discussed in connection with the excavations at Gournia. According to Boyd Hawes, the local residents showed her a site called "Golden Furnace" in 1900, and she collected a few pieces of copper from the location. "Rock obtained from the adjacent cliff" contained traces of copper, according to her report, and she also noted that the ground was strewn with fragments of "an ancient furnace," but she offered no theory on the date of the remains.[5]

2. Thanks are extended to personnel at the Center, especially Thomas M. Brogan, Director; Katherine May, photographer; Westly Bernard, assistant photographer (1997); Stephania Chlouveraki, chief conservator; and Ann Brysbaert, conservator (1997). Thanks are also due to several persons for suggestions concerning the technology in use at the site, especially Harriet Blitzer and Paul Craddock.

3. Mook and Haggis 1990; Haggis 1992, 1996a, and 1996b.

4. Boyd 1901, p. 156 (called Choriodakia).

5. Hawes et al. 1908, p. 33.

Additional information concerning early visits to and opinions about the site was published by Angelo Mosso.[6] He reported that Joseph Hazzidakis visited the site twice, once in 1906 and a second time either before or later. Hazzidakis was then the Ephor-General for Crete. On his visits he collected a piece of metal and specimens of slag, and he also visited a nearby cave that Mosso regarded as the mine for the ore. Early Minoan pottery was collected from the cave, but no sherds aside from fragments of what Mosso regarded as "crucibles" were noted from the metallurgical location itself. Pieces of "scoria" were also found at the cave. The "crucible" fragments from Chrysokamino were clay pieces with pierced holes and with a glassy deposit adhering to one side.[7] One fragment was illustrated. Mosso analyzed the piece of metal and reported that it contained 45% copper.

Edith Hall and Richard Seager investigated the site in 1910.[8] They approached the headland by sea because they had visited Pseira first, and they had their boat stop at the coast near Chrysokamino later in the day. Hall regarded the site as "the place where they smelted their bronze [sic] in Minoan times." She returned for two days of excavation in the nearby cave, where she found human bones as well as ceramic remains. The results of her work were never published.[9]

Fritz Schachermeyr visited the site in the 1930s.[10] He reported finding a sherd of Vasilike Ware at the metallurgical location, which suggested an early date for the remains. No further research was conducted until the 1960s when the region was surveyed independently by Paul Faure and Keith Branigan. They both disagreed with the earlier researchers on several points.

Faure suggested that the ceramic fragments on the site were not from crucibles but from a single large furnace.[11] Based on the state of vitrification of the glassy waste products, the absence of soil accumulation, and his belief that the ore reduced was chalcopyrite, Faure regarded the site as "relativement récente." He suggested that the location held the remains of a smelting operation for copper using either charcoal or coal as fuel. He rejected the nearby cave as a mine.

Branigan thought that the site had been used for remelting copper, not for smelting, and he also assigned it a late date.[12] Based on analyses showing that a temperature of 1150° F had been reached in the slag and that calcium was present, he suggested that the site postdated the Roman period. He used literary sources to suggest the 12th to 13th century A.C. as the most likely date.

It is not surprising that by the 1960s the metallurgical site would be misinterpreted. The installation is unique for Crete and, in the course of sixty years of visits, all diagnostic pottery fragments had been removed from the surface. When Branigan reported that "the few coarse sherds from the site cannot be closely dated, but they are unlike any Minoan, Greek, or Roman pottery seen by the author in Crete,"[13] he was accurately assessing the situation. The pot bellows fragments from Chrysokamino are not like Minoan vessels from other sites.

Both Faure and Branigan used the nature of the slag and its highly vitrified condition to suggest a late date. In this conclusion, they were following established opinion.[14] They had no way of knowing that high

6. Mosso 1910, pp. 289–292 and fig. 164.

7. See the description of the furnace fragments, below.

8. Hall 1910; Becker and Betancourt 1997, p. 109.

9. A study of the pottery from Hall's excavations is in preparation by Betancourt and Floyd. Pottery from this excavation is preserved in the University of Pennsylvania Museum of Archaeology and Anthropology and in the Art Museum, Mount Holyoke College.

10. Schachermeyr 1938.

11. Faure 1966, pp. 47–48.

12. Branigan 1968, pp. 50–51; a remelting of copper was also regarded as the process by Tylecote 1976, p. 19, table 19.

13. Branigan 1968, p. 50.

14. Roman sherds on slag heaps with highly vitrified slags led to the mistaken impression that all such deposits were Roman or later, and slags were routinely dated from surface survey (without excavation) on the basis of their appearance (see, for example, the discussion of Cypriot slags in Koucky and Steinberg 1982, p. 156 and table 1).

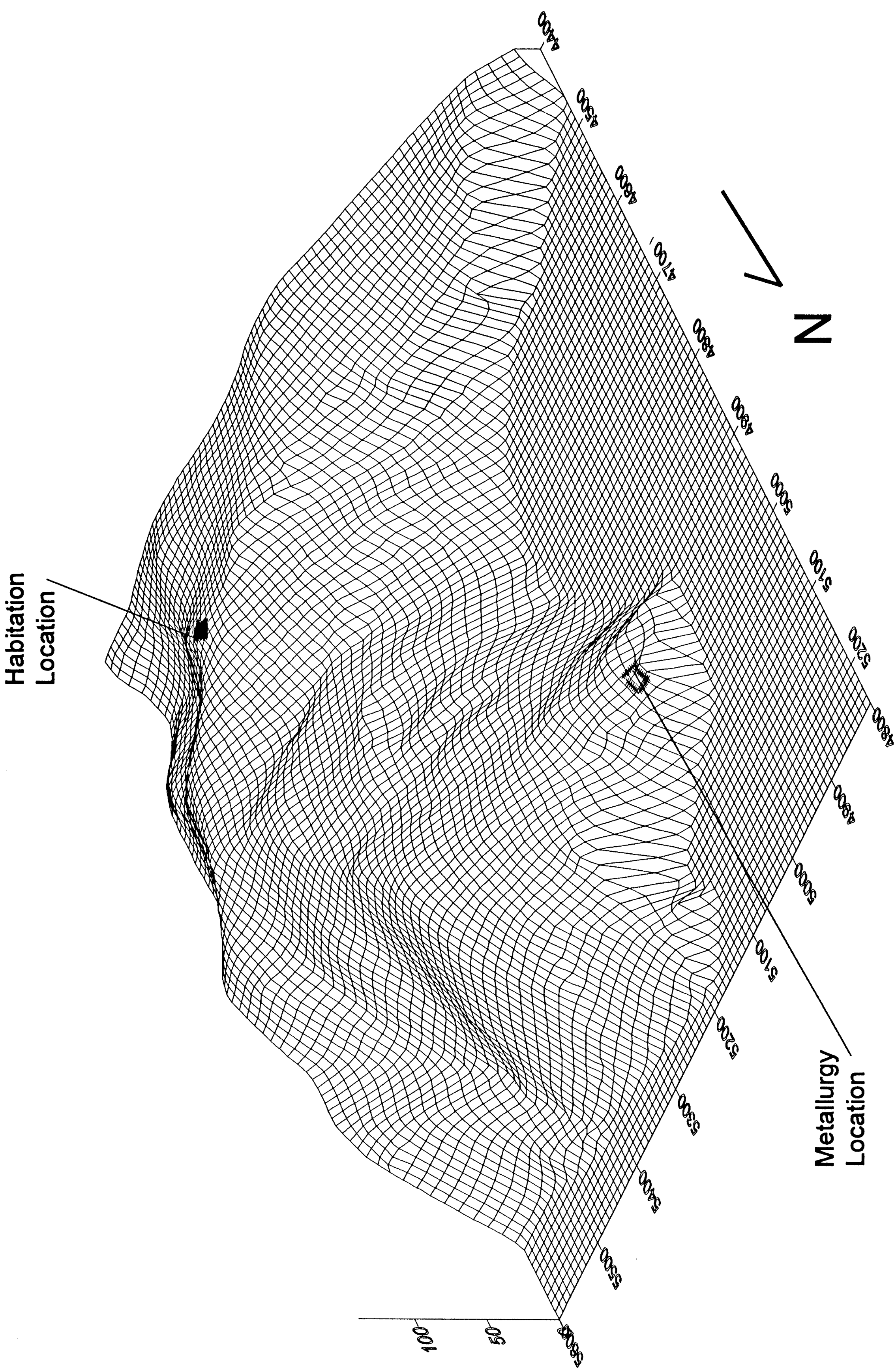


Figure 2. Three-dimensional view of the Chrysokamino region

temperatures could be reached by early metallurgists, or that the pot bellows had such an early history in Crete.[15]

In 1983 Noel Gale and Zofia Stos-Gale collected samples from Chrysokamino as a part of a larger archaeometric survey of metallurgy in the Aegean.[16] They collected ore, slag, and pieces of the industrial ceramics for scientific analyses of various types. The results of their analyses showed that the metallurgical site is extremely important for the early history of metallurgy in the Aegean Bronze Age. Thermoluminescent dates for the ceramics suggested a date of ca. 2700 B.C. The ore was copper ore (azurite and malachite), and the slag contained significant amounts of copper.

Three investigations of the region made as a part of the Kavousi Archaeological Expedition are especially relevant to Chrysokamino. Studies of the soils of the regions were made by Michael Timpson[17] and Michael Morris.[18] The study by Morris of the terra rossa–derived soils at Lakkos Ambeliou is especially useful to the present investigations. As noted above, the Chrysokamino area was also included in Haggis's regional surface survey,[19] which has provided invaluable information about the wider context into which Chrysokamino must fit. Having the regional survey of the area completed, so that the site can be placed within its cultural position in the Kavousi region, is a great aid to the new project.

Influenced by Faure and Branigan, most recent scholars have regarded the metallurgical location as later than the Bronze Age.[20] Chrysokamino has often been omitted from general discussions of Bronze Age metallurgy.[21] An exception to this pattern is an article by Georgia Nakou in which the site is correctly regarded as Early Minoan.[22] The most recent investigation of the metallurgical installation before the current project began was by Antonios Zois, who raised the possibility that the site was a modern lime kiln.[23]

The present project began with a preliminary season of work in 1995. The project's geologists, William Farrand and Carola Stearns, began mapping the exposed bedrock, and they examined its relation to human activity on the site. The topographic survey team members began their program of mapping the area with survey instruments, and they established a grid in preparation for archaeological excavation in future seasons.

II. TOPOGRAPHY OF THE CHRYSOKAMINO REGION

Chrysokamino is located in an area of terraced hillsides and steep cliffs overlooking the Gulf of Mirabello. Throughout the area, the ground surface is covered with dense, scrubby vegetation (maquis), occasional large thorny bushes, and a few lone olive trees.

Maps of the individual site areas, as well as of the larger region linked to them, were produced electronically in the 1995 through 1998 seasons.[24] Because of the dangerous slope and slipperiness of the coastal cliffs at Chrysokamino, most of the coastline could not be surveyed directly. The maps in Figures 2–4 were produced by digitizing the coastline and clifflines

15. The first pot bellows found in the Aegean, from Kommos, was discovered the first week of excavations in 1976 (Blitzer 1995, pp. 508–509).

16. Stos-Gale 1993, p. 124.

17. Timpson 1992.

18. Morris 1994.

19. Haggis 1992, loci 50 and 88; 1996a, pp. 380–381 and 401–403. In his system locus 50 is the Chrysokamino Habitation Site (Area Beta), and locus 88 is the metallurgical location (Area Alpha). See also Haggis and Mook 1993, pp. 287–288.

20. The current view is summarized in Haggis 1992, p. 170, locus 88.

21. For discussions of Aegean Bronze Age metallurgy that include Chrysokamino, see Fimmen 1921, pp. 17 and 120; Lamb 1929, p. 5; Forbes 1950, p. 364; Hutchinson 1962, p. 247; after the 1960s, the site was usually not mentioned (cf. Branigan 1974; McGeehan-Liritzis 1996).

22. Nakou 1995, p. 17.

23. Zois 1993, pp. 340–341. He was influenced by the calcareous white soil at the site, which is disintegrated phyllite, not lime (see Part III, below).

24. The team used a Topcon GTS 303 Electronic Total Station, a Gateway 2000 (486) laptop computer, and software including Easy Survey Plus (replacing PCAMP used in 1996), Surfer, and AutoCAD.

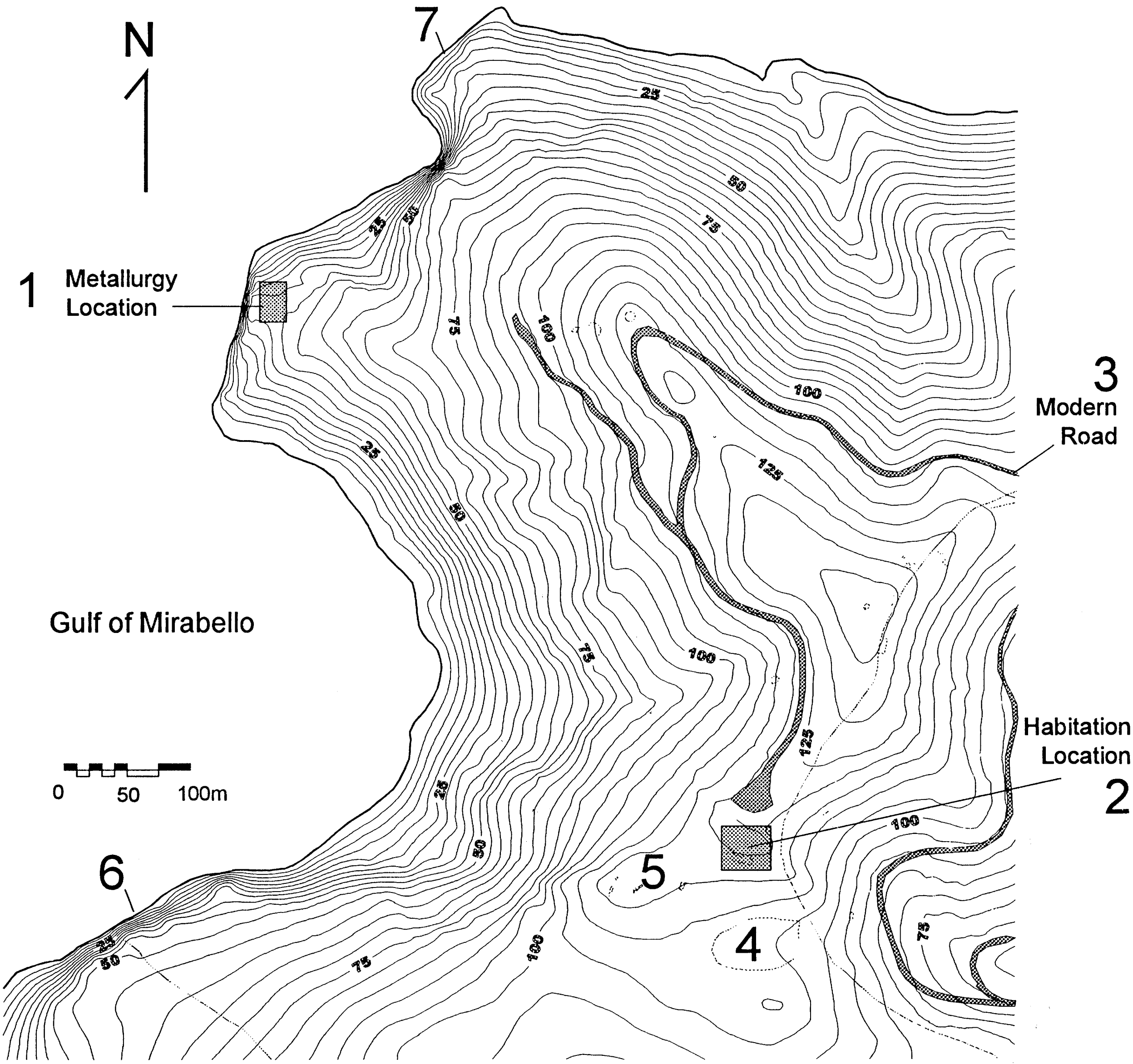


Figure 3. Map of the Chrysokamino region, with topographic contour intervals at 5 m. (1) XA, the metallurgical location; (2) XB, the habitation location; (3) modern gate into the Chrysokamino region, and beginning of modern road from gate; (4) large rubble ellipse, most likely a tumbled modern sheepfold; (5) fissures on rock outcropping; (6) cliffs; (7) Kolonospilia headland.

from an old Greek military map into AutoCAD and merging it with current electronically surveyed data in the Surfer and AutoCAD files. The military map, however, could not be precisely matched to topographic features and landmarks currently visible due to a number of factors; these factors include changes over the decades in the apparent line of the coast and in sea level, the older technology used, and the original purpose of these maps, which did not require the same level of precision as modern surveyed data. In merging these two bodies of data, some adjustments had to be made, including a slight rotation of the coastline axis west of north. Thus, the coastline cannot be regarded as having the same degree of accuracy as the rest of the topographic indicators. One exception, however, is the area of coastline immediately southwest of the metallurgical location (Fig. 3, no. 1), curving south and southeast into the bay below the Habita-

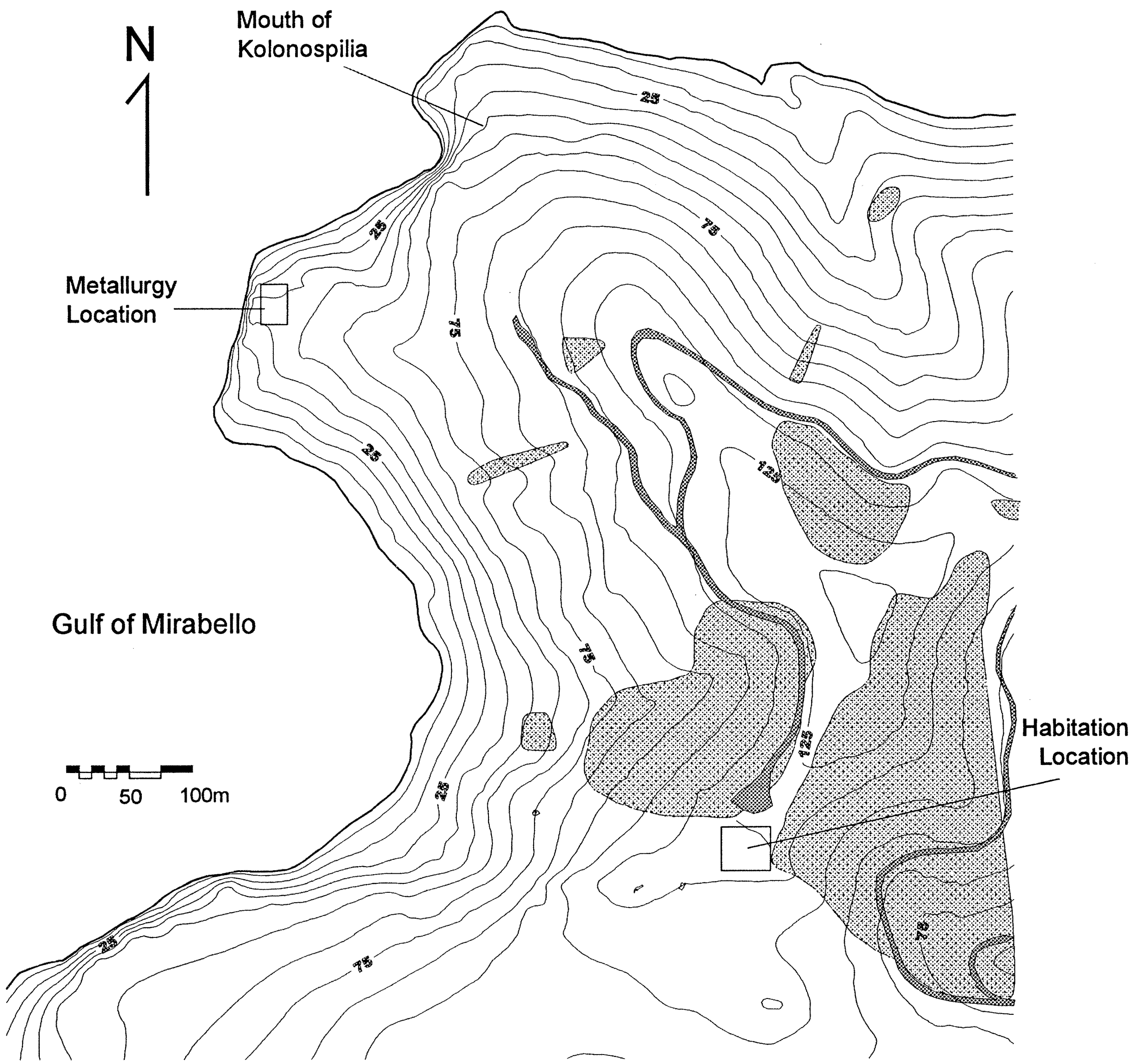


Figure 4. Topographic map of the Chrysokamino region (10-m intervals), with hatched areas indicating terraced locations, and XA (metallurgical location), XB (habitation location), and Kolonospilia cave indicated

tion Site (Fig. 3, no. 2); this area was accessible for survey purposes and was added to the map in the same way as the rest of the electronically surveyed data. This section of coastline was also used to align the military map's data and the electronically surveyed data. In addition, a number of coastal cliff areas that descended almost directly into the sea were accessible for surveying, and they yielded data consistent with the rotated coastline; these areas include the headland northeast of the metallurgical location (Fig. 3, no. 7) and the cliffs southwest of the Habitation Site (Fig. 3, no. 6).

In areas surveyed electronically, coverage averaged every 2 to 3 meters surrounding the excavated locations; areas farther away received sparser coverage, every 5 to 6 meters, because of the considerable extent of land needing to be surveyed. Areas that were very steep and slippery but just barely within the realm of accessibility (like the ravine opposite the gate to the Chrysokamino area, Fig. 3, no. 3, or the lower ravine area between the two excavated locations) in some cases could receive only sketchy coverage. This coverage consisted of a line of points taken along the highest ridge line and lowest ravine line; the data were sufficient for the topographic software to generate satisfactory topographic lines for those areas. As a result, even tiny man-made features were located and accurately positioned on the maps, so that their topographic relationships can be better understood.

The Habitation Site (Fig. 3, no. 2) is positioned below a small saddle south of the dome of the hill of Chomatas,[25] at an average elevation of approximately 120 m above sea level (masl). To the north and east, it is bordered by terrace walling, while a modern sheep fold (mandra) borders and overlays it to the south. The architectural complex itself slopes to the southwest at an average gradient of 0.14 (i.e., a distance of 1 m features change in elevation of 0.14 m). This slope continues to the southwest down to a fairly flat field (about 106 m in elevation), which contains terra rossa–derived sediment and a large ellipse of rubble walling, most likely an old sheepfold now tumbled down (Fig. 3, no. 4), up a small hill of about 110 m elevation, and then descending to a lower hill and down again until reaching a large basin filled with more of the terra rossa–derived sediment.

West of the Habitation Site is a rocky outcrop with two large fissures (Fig. 3, no. 5); another fissure, which may have been used as a spring, is located about halfway between the domestic complex and the rocky outcrop. The outcrop descends along a knobby ridge and rocky cliffs into a steep ravine, which continues down to the coastline. South of this ravine, the terrain descends along a gentler incline (with an average gradient of 0.16) to very steep cliffs that drop 44–50 m into the sea, at a gradient of 5.0 (Area 6 in Fig. 3). North and west of the Habitation Site, the terraced hillside steps down along a shallow ravine, and then at an elevation of approximately 80 m, drops in a steep and very slippery cliff and ravine, with a gradient of 0.53, to the seacoast.

Farther north, the modern dirt road (part of it created in the spring of 1996) extends from the Habitation Site along the terraced hillside onto the southwestern side of the same hill, one branch curving around the dome of the hill to the north side where the gate to the Chrysokamino area is located, and a lower branch (currently unusable) descending along the western side of Chomatas Hill and stopping abruptly. The southwestern side of the hill descends along a relatively bare and unterraced stepped ridge, down to a rocky headland above the sea. The metallurgical location (Fig. 3, no. 1) is positioned at a low saddle on this headland,[26] at an upper elevation of approximately 38 m, dropping sharply to the north at a gradient of 1.1, and sloping to the southwest at a gentler gradient of 0.65. The seacoast can be approached with relative ease along the southwestern descent, while the west, northwest, and northeast sides are too steep to allow access to the sea. Located about 222 m below the lower road, the metallurgical area itself requires a long and difficult climb for ascent or descent (gradient of 0.28). The direct distance between the metallurgical location and the Habitation Site is ca. 585 m.

25. Haggis 1992, pp. 163–164; 1996b, pp. 401–403, locus 50.

26. Haggis 1992, p. 170, locus 88; 1996b, pp. 380–381, especially note 22.

Around the curve of the cliff to the north and northeast of the metallurgical area (average gradient 5.0), another headland protrudes into the bay (Fig. 3, no. 7), descending to a rocky coastline at an average gradient of 0.21, before dropping in stepped cliffs to the water on the west and southwest (average gradient 1.0). The northern corner of this headland, however, steps down directly to sea level (gradient 1.75), although wide gaps between its ridges make it a difficult location for actual access to the sea. A cave is located 44 m above sea level on this headland (called Agriospelio, Kolonospelio, or Theriospelio).[27] The cave has a small mouth but a large interior (not mapped). The cave is separated from the metallurgical location by a direct distance of 230 m, and from the Habitation Site by a direct distance of ca. 610 m.

The region around these sites contains the remains of a number of relatively modern rubble structures as well as some features that probably marked the natural boundaries of the territory utilized by the inhabitants in the Bronze Age. The terraced hillsides immediately to the northwest of the domestic complex (see gray areas in Fig. 4) find parallels on the hills farther north, up to the modern gate to the Chrysokamino area (Fig. 3, no. 3), and to the northeast, where an olive grove currently thrives on the other side of the modern fencing. Although the terrace walls, built of schist or dolomite rubble, appear to be relatively recent in date, these terraced areas may have been used for grazing or agricultural purposes in the Bronze Age as well.

South of the Minoan Habitation Site, the two fields with terra rossa–derived sediment (see Fig. 3, no. 4, for the upper field) present the most likely candidates in the area for agricultural fields; currently, the large deposit of sediment derived from terra rossa in the low basin (Lakkos Ambeliou) is used by area residents as a "clay mine" for their gardens, as well as for a collection of beehives.

Access to the sea for this region was provided from antiquity onward by means of a major ravine[28] (mapped in 1998) that curves west of Lakkos Ambeliou, between two extremely steep cliffs, to a very small flat beach named Agriomandra; currently, this ravine is lined with relatively recent walls that support a path winding from one to the other cliffside for the length of the ravine.

Assuming that a combination of natural features and the overall regional settlement patterns delineate the outer boundaries of the region,[29] a total area of approximately 687,000 m^2 can be ascribed to the inhabitants of the territory, for agricultural, pastoral, manufacturing, or trade purposes.

III. THE GEOMORPHOLOGY

The metallurgical site at Chrysokamino is located on an isolated point of land, perched about 38 m above the sea with no immediately adjacent boat landing available, and backed by a sharp, but walkable ridge rising another 80 m without significant level areas. In times of nonviolent weather small ships could anchor in the cove just south of the point, but offloading would be difficult because of the steep slope up from the water. However, about

27. Haggis 1992, pp. 170–171; Becker and Betancourt 1997, p. 109 and note 24.

28. Haggis 1992, fig. 13.

29. The study of the probable boundaries of the estate, a complex matter involving many types of evidence, will be published elsewhere by Betancourt.

800 m southwest of the site, around a small but prominent rocky peninsula, a major ravine cuts through the local dolomite bedrock down to a small, but sheltered cove (Agriomandra), ideal for small ships. Moreover, this ravine provides relatively easy access to flat fields above. At present, remnants of a well-built road (a Turkish calderimi) are still visible through the ravine.

The metallurgical site sits on phyllite bedrock just a few meters away from the contact between the phyllite and the dark bluish gray Plattenkalk limestone. The phyllite exposed in the excavation trenches is mostly the white, very powdery (silty) calcium-carbonate-rich residue of weathering, so typical of most phyllite outcrops in this area. In addition, in several trenches a resistant carbonate ledge was exposed, angling diagonally across the trenches (strike N40–55E, dip 40–50S). In contrast to the orientation of this carbonate ledge, the Plattenkalk just west of the trenches strikes N70W and dips 35S. This discordance in orientation indicates that the phyllite was an overthrust sheet (nappe) from the north that overrode the autochthonous Plattenkalk some 30 to 40 million years ago (post–Late Eocene, pre-Miocene time).[30] In the cove extending 300 m south from the site, the complex nature of the phyllite series is abundantly illustrated by the chaotic nature of the included rock types—well-foliated phyllite, hard carbonate lenses, strongly sheared limestone masses, and gypsum—along with minor sandstone and conglomerate. Geologically, this is a melange.[31]

The Plattenkalk limestone forms the structural support of the Chrysokamino headland, as well as forming the impressive, near-vertical cliffs rising some 200 m out of the sea to the northeast of the site. It is thin-bedded, but solid, interlaced with conspicuous white calcite veins. To the southwest of the metallurgical site the Plattenkalk dips steadily down into the sea at angles of 25 to 35°, but on the north side of the excavated area the limestone drops precipitously some 38 m to the water.

Because of the obvious metallurgical interest of Chrysokamino, a search was made for possible sources of ore, but none was found. In fact, none of the local bedrock types seem obvious environments for mineralization. The calcite veins in the Plattenkalk limestone appear barren of any other minerals. Extensive coatings and fillings of the banded calcite formation called travertine are associated with outcrops of dolomite, especially in and near two large caves on the south side of the cove south of Chrysokamino, but no mineralization was seen. Also, a large outcrop of brilliantly white travertine occurs on the north side of the next cape about 300 m northeast of the Chrysokamino metallurgical site. It appears to be a filling of a major karstic cavity, mostly destroyed by coastal erosion, but no trace of metallic mineralization was obvious.

Other geologic raw materials are locally available, however. Two modest outcrops of gypsum (calcium sulfate) were noted, one along the coast about 250–300 m southeast of the Chrysokamino metallurgical site and the other high on the ridge about 600 m east–southeast of the site, both within the phyllite series. Abundant red clayey sediment fills an upland basin called Lakkos Ambeliou[32] at the head of the major ravine discussed above. This clay, which is redeposited terra rossa soil eroded from the surrounding

30. Wachendorf, Best, and Gwosdz 1975.

31. Wachendorf, Best, and Gwosdz 1975.

32. Sediment from the soil pedon at Lakkos Ambeliou is the subject of a study by Morris (1994).

Figure 5. Small promontory at Chrysokamino where the metallurgical workshop is located, looking west

dolomite slopes, appears to be a reasonable source of clay for ceramics. The deposit is at least 4 m thick in the center and covers some 25,000 to 30,000 m^2.

IV. THE COPPER SMELTING WORKSHOP

The metallurgical site (Area Alpha) is located in a small saddle ca. 30 × 60 m in size between exposures of bedrock. The lowest part of the saddle is at the north where it terminates at a cliff overlooking the sea (Figs. 2 and 5). Before excavation began, a low, wide deposit of slag and coarse industrial ceramic fragments covered the entire surface of the location. The original size of the deposit cannot be determined because it had partly eroded off into the sea. The slag was dark, vitreous, and highly ferrous, with small prills of copper in it. It was mostly in small pieces (under 2 cm in size), and much of it was pulverized.[33]

The excavation was laid out in grid squares of 2 × 2 m. The recovery strategy was designed to collect as full a record as resources permitted. Except for soil samples reserved for water-sieving and other purposes, all soil was dry-sieved. All artifacts, unusual stones (including all rounded stones), furnace fragments, and pieces of slag larger than tiny bits were collected. After collection, the material retained on the sieve was washed with fresh water to remove dust and improve visibility (revealing the green of oxidized copper products).[34] With the exception of samples taken for

33. A program of analysis of the slags is in progress by a team of investigators including the following: Yannis Bassiakos (Demokritos); Noel Gale and Zofia Stos-Gale (Oxford University); George H. Myer (Temple University); Charles P. Swann (University of Delaware); and Stuart Fleming (MASCA, University of Pennsylvania Museum of Archaeology and Anthropology).

34. In spite of this strategy, few objects other than furnace fragments and slag pieces were found. Many 10-cm-deep passes contained no sherds from vessels. Tens of thousands of furnace fragments and slag pieces were collected.

analysis, all of the vessel sherds and potential tools (including all rounded stones) were catalogued.

Copper ore at the metallurgical site has been found only as tiny pieces. The mineral species include malachite, azurite, and chrysocolla, all of which are secondary ores found in the upper levels of ore deposits where weathering has taken place. Pieces are all small (under 3 cm).

Other finds from the metallurgical location include furnace fragments, stone tools, fragments of pot bellows, one piece of a tuyere, and pottery. Remains of sea urchins and marine shells are present in small quantities.[35]

The Furnace Fragments

The industrial ceramic fragments are all in small pieces (Fig. 6, upper row). They consist of handmade pottery manufactured from a coarse fabric with abundant organic matter that includes impressions of grain and one impression of an olive leaf.[36] The clay has been fired to a red to black color. Fragments are from the walls and bases of tapering cylindrical objects with many perforations in their sides. The cylinders have diameters of between 20 and 45 cm, with open tops (see Fig. 6: **1**) and flat bases (Fig. 6: **2**). Cylinders have perforations spaced every few centimeters from the base to the rim. From the sizes and angles of the perforations, they could have been made by simply sticking the fingers or a stick through the wall while the clay was still wet. Because the lower parts of the interiors of the cylinders are covered with glassy deposits of slag containing small prills of copper, they have been identified as shaft furnaces.[37]

Catalogue[38]

1 Furnace, rim fragment Fig. 6

X 425. From Q 20-3. Diam. ca. 24. Coarse fabric with voids from burned-out organic matter (unevenly colored, from reddish yellow, 5YR 6/6, to black). Cylindrical furnace with straight rim; hole (Diam. 2.3 cm) 2.3 cm below the rim; rough interior and exterior (no slag on interior).

2 Furnace, base fragment Fig. 6

X 739. From N 20-3. Diam. not measurable; max. dim. 4.3. Coarse fabric with voids from burned-out organic matter (unevenly colored, from yellowish red, 5YR 5/6, to black). Furnace with flat base; rough interior and exterior; vitreous coating adhering to the interior.

3 Furnace, body fragment Fig. 6

X 140. From S 20-2. Diam. of furnace ca. 29. Coarse fabric with voids from burned-out organic matter (unevenly colored, from reddish brown, 2.5YR 5.4, to black). Cylindrical furnace with straight walls; many holes; vitreous coating adhering to the interior.

4 Furnace, body fragment Fig. 6

X 323. From R 20-3. Diam. of furnace ca. 27–30. Coarse fabric with voids from burned-out organic matter (unevenly colored, from light red, 2.5YR 6/6, to black). Cylindrical furnace with straight walls; many holes; vitreous coating adhering to the interior.

The Pottery

Most of the pottery from the metallurgical location dates to EM III, but the earliest sherds are Final Neolithic.[39] Examples are illustrated in Figures 6 and 7. One sherd from EM I–IIA (Fig. 6: **7**) and one sherd from

35. Faunal remains are being studied by David Reese, Field Museum of Natural History, Chicago.

36. The botanical remains are being studied by Glynis Jones, University of Sheffield. Most of the organic matter in the clay has been identified as chaff. The most common grain is barley.

37. These furnaces differ from the stationary furnaces seated in small hollows previously conjectured to have been used for smelting operations in Crete (Branigan 1974, pp. 68–69). Cylindrical shaft furnaces like those used for copper smelting in Niger (Bernus 1983) have been proposed for Early Cycladic metallurgy (Gale et al. 1985, pp. 85–86). The furnaces at Chrysokamino might be comparable.

38. Colors throughout the catalogue entries are in the Munsell system. Loci for finds are given by grid square. Measurements are given in centimeters.

39. Only a few hundred sherds come from the metallurgical location. They are being studied by Betancourt.

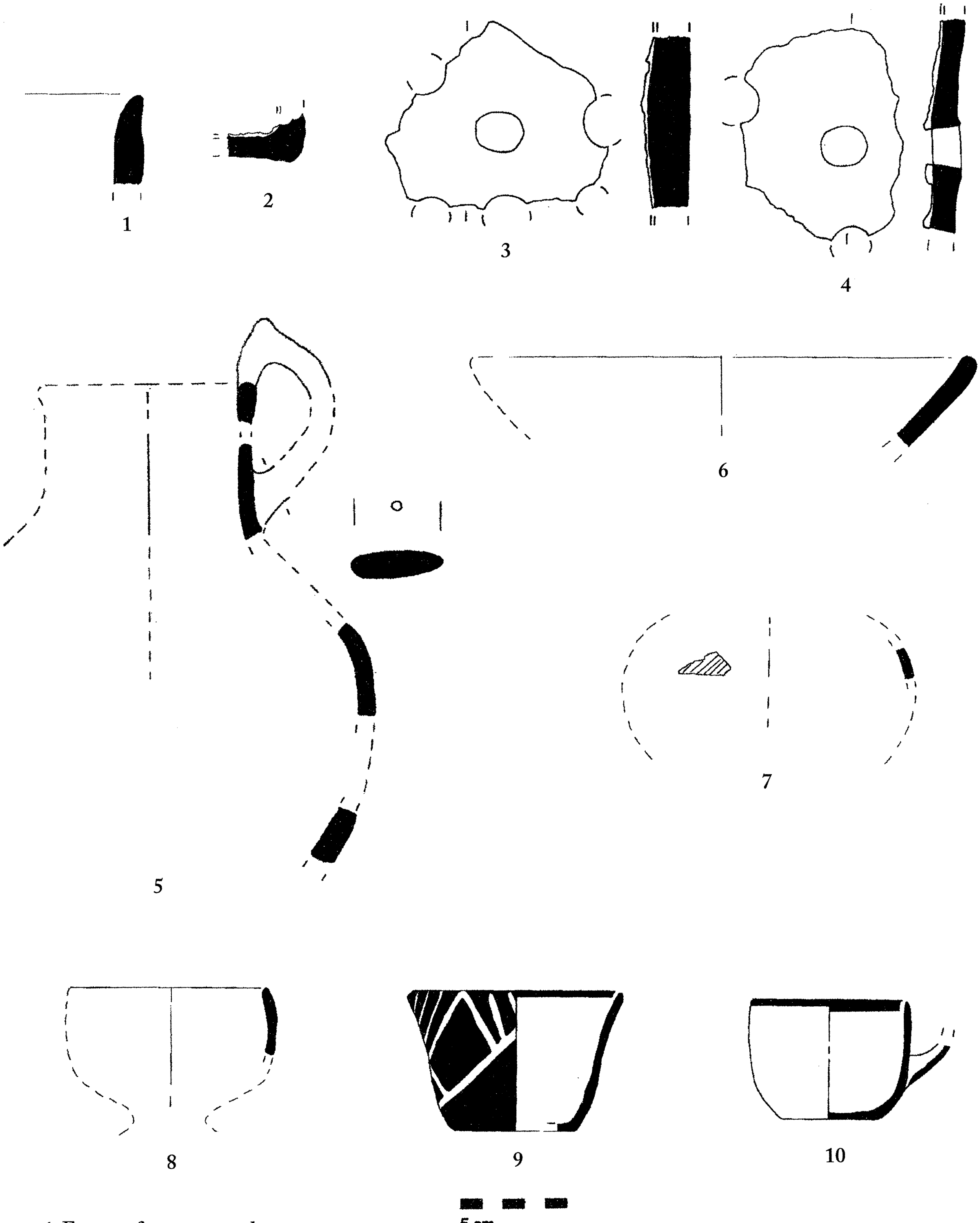


Figure 6. Furnace fragments and pottery from Chrysokamino

EM IIB (Fig. 6: **8**) come from the site. No Middle Minoan sherds are present. A selection of the pottery is presented in the catalogue. It is typical of the region, and it is all probably local to this part of Crete.

FN sherds are made from a dark, coarse fabric with thick walls. The clay is heavily burnished and fired to an uneven, dark color. Shapes include thick-walled open vessels as well as an interesting jar with a horn on the handle (Fig. 6: **5**). Similar dark-surfaced and burnished pottery is known from Vasilike,[40] Mochlos,[41] Sphoungaras,[42] and Pseira.[43]

The majority of the ceramics date to EM III. This ceramic phase, in which East Cretan White-on-Dark Ware is the predominant fine pottery, begins at the end of EM IIB[44] and lasts into a period that is contemporary with part of Knossian MM IA.[45] The period is a substantial phase in this part of Crete, with buildings known from Mochlos[46] and Pseira,[47] and with large pottery deposits suggesting a habitation phase at other sites.[48] The expanded EM III workshop at Chrysokamino, producing copper as a raw material for later remelting and casting into artifacts, would have provided at least some of the metal needed by these towns and villages.[49]

The chronology of the end of the East Cretan EM III phase is not completely understood, but there was probably a short local MM IA period before the introduction of the potter's wheel in MM IB. Decorated sherds were found on the floor of the small building discussed below, leaving no doubt about its date.

Besides the fine decorated pottery, the site includes examples of jars, bowls, and cooking dishes. Shallow bowls are common (**13–15**). The fabric for these coarse vessels is Mirabello Fabric.[50]

Catalogue

5 Jug, handle and body sherds Fig. 6

X 421, 671, 694, and 717. From L 17-2, O 20-2, and N 20-3. Restored H. ca. 25. Coarse, black fabric with an unevenly colored surface, mostly reddish brown (5YR 5/4); burnished on exterior. Closed vessel with one (or possibly two?) vertical handle(s); horn at top of handle; hole in base of handle.[51]

Final Neolithic.

6 Bowl, rim sherd Fig. 6

X 410. From R 20-3. Diam. of rim ca. 24. Coarse, black fabric with an unevenly colored surface, mostly dark reddish brown (5YR 3/3); burnished on interior and exterior. Open, shallow bowl.

Final Neolithic.

7 Pyxis, body sherd Fig. 6

X 460. From N 17-2. Max. dim. 2.4. Fine fabric (brown, 7.5YR 5/4). Globular pyxis with combed decoration incised into the exterior.[52]

Early Minoan I–IIA.

8 Goblet, rim sherd Fig. 6

X 750. From N 20-4. Restored Diam. ca. 9–10. Fine fabric (pinkish white, 5YR 8/2); slipped and burnished. Goblet with slightly inturned rim; Vasilike Ware.[53]

Early Minoan IIB.

9 Cup, rim and base sherds Fig. 6

X 167. From M 18-1, M 18-2, and M 18-3. Restored H. ca. 6.5–7.0, Diam. of rim ca. 10, Diam. of base ca. 5.5–6.0. Fine fabric (pink, 7.5YR 7/4); burnished. Conical cup. Dark slip on inside of rim and on exterior;

40. Seager 1904–1905, p. 212.
41. Seager 1912, p. 93.
42. Hall 1912, pp. 46–48.
43. Betancourt and Davaras 1990, tomb 2.
44. Examples of the characteristic white decoration applied over Vasilike Ware come from Myrtos (Warren 1972, lower stratum), Ayia Photia Ierapetras (Boyd 1904–1905, pl. 25, no. 2), and Vasilike (Betancourt 1983, p. 69, no. 236).
45. For discussions, see Zois 1968; Betancourt 1984; 1985, pp. 55–60.
46. For the Early Bronze Age town at Mochlos, see Seager 1909, p. 278; Soles and Davaras 1994, pp. 394–396; 1996, pp. 178–180.
47. Banou 1995a, pp. 19–20.
48. For Vasilike, see Seager 1906–1907, pp. 118–123; for Gournia, see Hall 1904–1905. Additional evidence, including the development from the end of EM IIB, is given in Betancourt 1984. The Pseira Survey shows that the countryside is definitely not deserted at this time.
49. For an alternative view, that Crete experienced a decline at this time, see Watrous 1994, p. 718.
50. For the analysis of the fabric, see Myer, McIntosh, and Betancourt 1995, pp. 144–146, with earlier bibliography.
51. For FN closed vessels with horns on top of the handle, cf. Vagnetti 1972–1973, p. 85, fig. 75, especially no. 8 (from Phaistos).
52. Small globular pyxides with stamped and incised decoration begin in EM I and persist into EM IIA. For EM I, see Xanthoudides 1924, pp. 34–36 (Koumasa); for EM IIA, see Wilson 1985, p. 305 (from Knossos). This example from Chrysokamino is probably from EM I.
53. The small goblet is one of the most common shapes in Vasilike Ware (Betancourt 1985, pp. 43–48). It has been discussed by Betancourt et al. (1979, pp. 42–45). The shape is distributed throughout Crete, but a large majority of the examples are from the Gulf of Mirabello area. This sherd is made of the typical fabric (Whitelaw et al. 1997, p. 268).

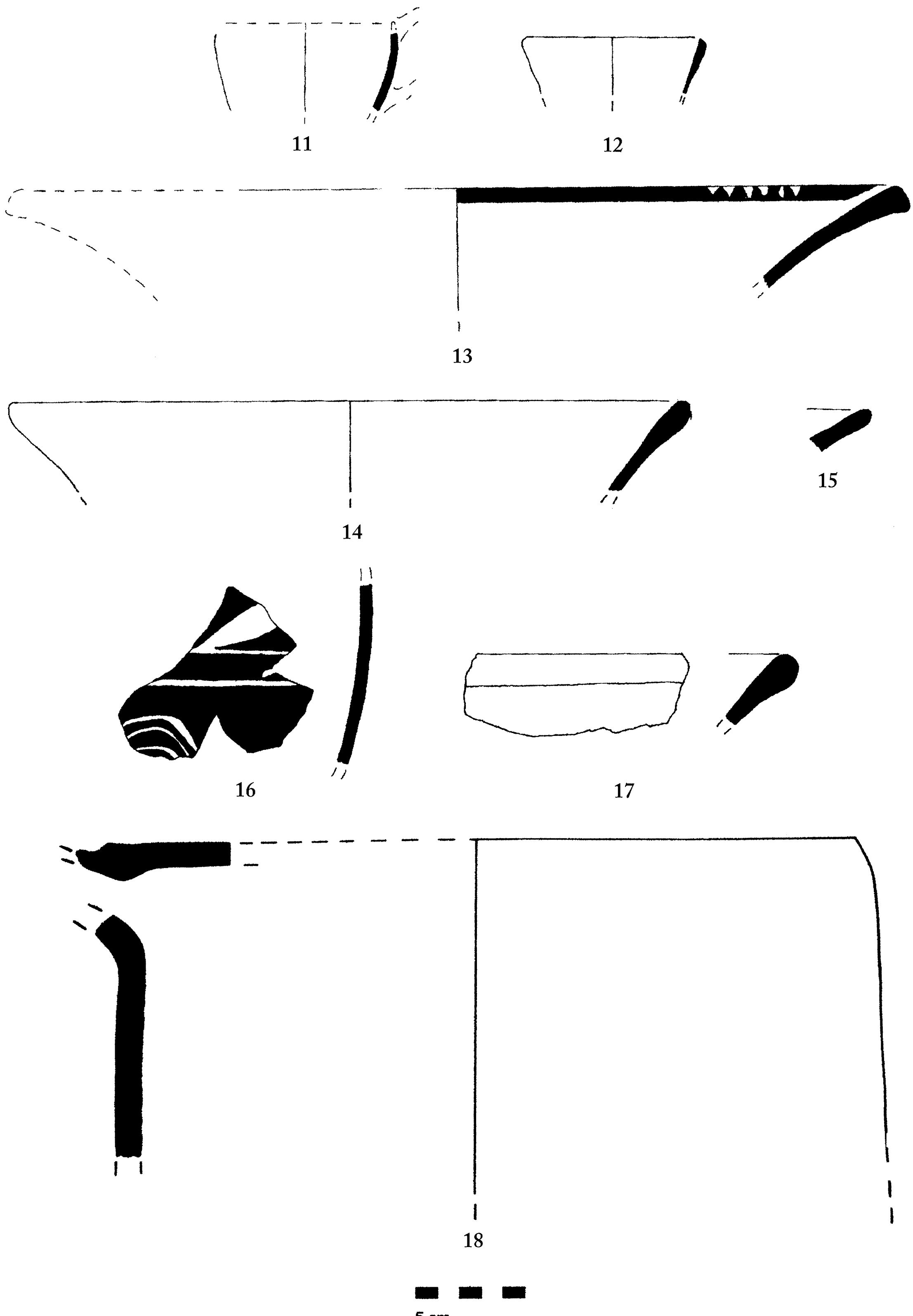


Figure 7. Pottery and pot bellows from Chrysokamino

added white paint: pendant triangles with hatched corners. East Cretan White-on-Dark Ware.[54]

Early Minoan III.

10 Rounded cup, fragmentary Fig. 6

X 210. From M 19-2B, M 19-3, and M 19-4. Diam. of rim ca. 8. Fine fabric (pink, 5YR 7/4). Rounded cup with one handle with circular section. Band on rim, inside and out; line on outside of handle. Several sherds burned.

Early Minoan III.

11 Rounded cup, body sherds Fig. 7

X 148. From M 19-3. Max. dim. (largest sherd) 4.4. Fine fabric (light brown, 7.5YR 6/4). Rounded cup; one handle with circular section.

Early Minoan III.

12 Rounded cup, body sherd Fig. 7

X 459. From N 17-2. Max. dim. 2.6. Fine fabric (light red, 10R 6/6). Rounded cup (?).

Early Minoan III.

13 Shallow bowl, rim sherd Fig. 7

X 168. From M 18-2 and M 18-3. Diam. of rim ca. 39–41. Coarse fabric (reddish yellow, 7.5YR 6/6, with a darker surface on the exterior and a paler surface on the interior). Shallow, open bowl. Dark slip on rim; added white paint: lines on rim. East Cretan White-on-Dark Ware.

Early Minoan III. Shallow, open bowls in White-on-Dark Ware are common in EM III. They are discussed by Betancourt and colleagues.[55]

14 Shallow bowl, rim sherd Fig. 7

X 150. From M 19-3. Diam. of rim ca. 25. Mirabello Fabric,[56] fine-grained (red, 2.5YR 4/6). Shallow bowl with straight rim.

Early Minoan III.

15 Shallow bowl, rim sherds Fig. 7

X 212. From M 18-3 and M 19-4. Diam. of rim ca. 20. Mirabello Fabric, fine-grained (reddish brown, 2.5YR 5/4). Shallow bowl with straight rim. Band in dark slip on rim, inside and out.

Early Minoan III.

16 Closed vessel, body sherds Fig. 7

X 181. From N 18-2 and N 19-2. Closed vessel, body sherds. Max. dim. of largest sherd 8.5. Coarse fabric (unevenly colored, mostly light brown, 7.5YR 6/4). Large closed vessel, most likely a bridge-spouted jar. Dark slip on exterior; added white paint: bands, spirals, diagonal lines. East Cretan White-on-Dark Ware.[57]

Early Minoan III.

17 Cooking dish, rim sherd Fig. 7

X 3. From M 22-2. Diam. of rim ca. 50–56. Coarse fabric (reddish yellow, 5YR 6/6). Thickened rim; pale fabric, not typical of cooking dishes in this region in later times.[58]

Early Minoan III.

The Pot Bellows

The pot bellows is a cylindrical clay artifact fitted with a flexible leather cover with one-way air flaps to allow air to be pumped out through a nozzle.[59] Fragments of a minimum of ten pot bellows come from Chrysokamino, and the best-preserved example is presented here (Figs. 7: **18**, and 8). The bellows from this site are drum-shaped cylinders with closed tops, with one or more large holes rather crudely cut in the flat upper surfaces. The shape of the lower edge (i.e., the open part facing down when the object was in use) is not certain, but rim sherds with straight rims may be from this shape. Diameters are between 28 and 48 cm. A nozzle is well preserved on bellows **18**. It is attached near the closed upper part of the

54. Decorated conical cups are common in East Cretan EM III, and the version with pendant triangles with hatched corners is one of the standard types. The vessel is discussed by Betancourt (1984, p. 39, shape 2A); for the motif, see p. 24, motif 2, nos. 3–5.

55. Betancourt 1984, pp. 38–39.

56. Day 1997, p. 225.

57. Large bridge-spouted jars in East Cretan White-on-Dark Ware are often decorated with spirals and other motifs; they are the most common fine pouring vessel in the period (for discussion see Betancourt 1984, pp. 45–46).

58. For the usual fabric of cooking dishes, which is fired to a red color, cf. Banou 1995b, pp. 113, no. ADC 42, and 116, no. ADC 74.

59. Davey 1979; Tylecote 1981.

cylinder. Deposits of fused mud are on the exteriors of several examples, always away from the closed top.

18 Pot bellows, large part of side and base and many nonjoining sherds Figs. 7, 8

X 143. From L 17-3, L 18-2, L 19-2, M 18-2, M 18-3, M 19-3, M 19-5, N 19-2, N 19-3, P 19-1, R 20-1, and locus E5050/N5016. Diam. of base ca. 37. Mirabello Fabric (unevenly colored, red to black). Cylindrical vessel with almost straight sides; one end closed (other end does not survive); nozzle at side, near closed end; rectilinear hole in closed end.

Early Minoan III.

Figure 8. Pot bellows 18, seen from above

A reconstruction of the use of the bellows has been suggested by Harriet Blitzer (Fig. 9). She proposes a leather bag with slits and flaps attached at the top, and the "rim" upside down and buried in the earth, sealed with mud to prevent air from escaping during use. Working the leather bag would force a draft of air through the nozzle, and it could be conveyed to a fire through a pipe or reed.

Figure 9. Reconstruction of a pot bellows. Drawing by L. Brock based on suggestions by H. Blitzer

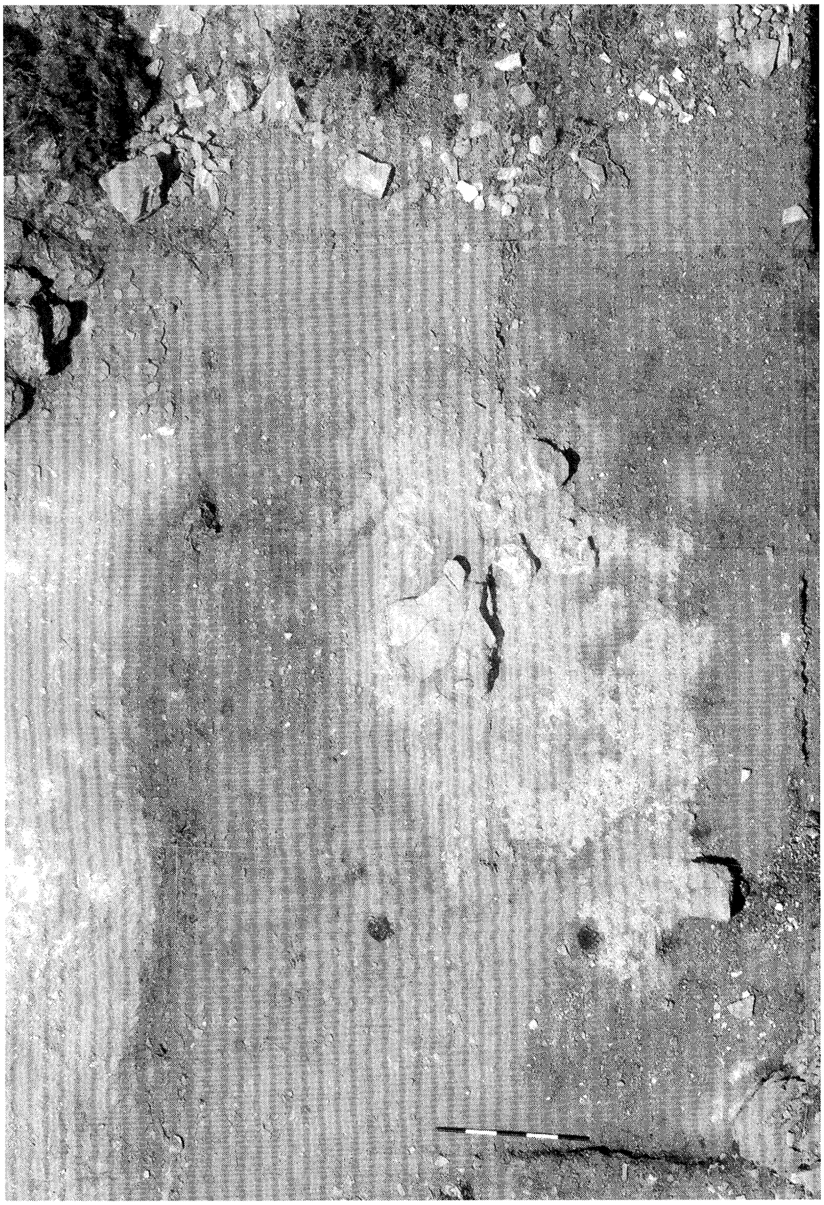


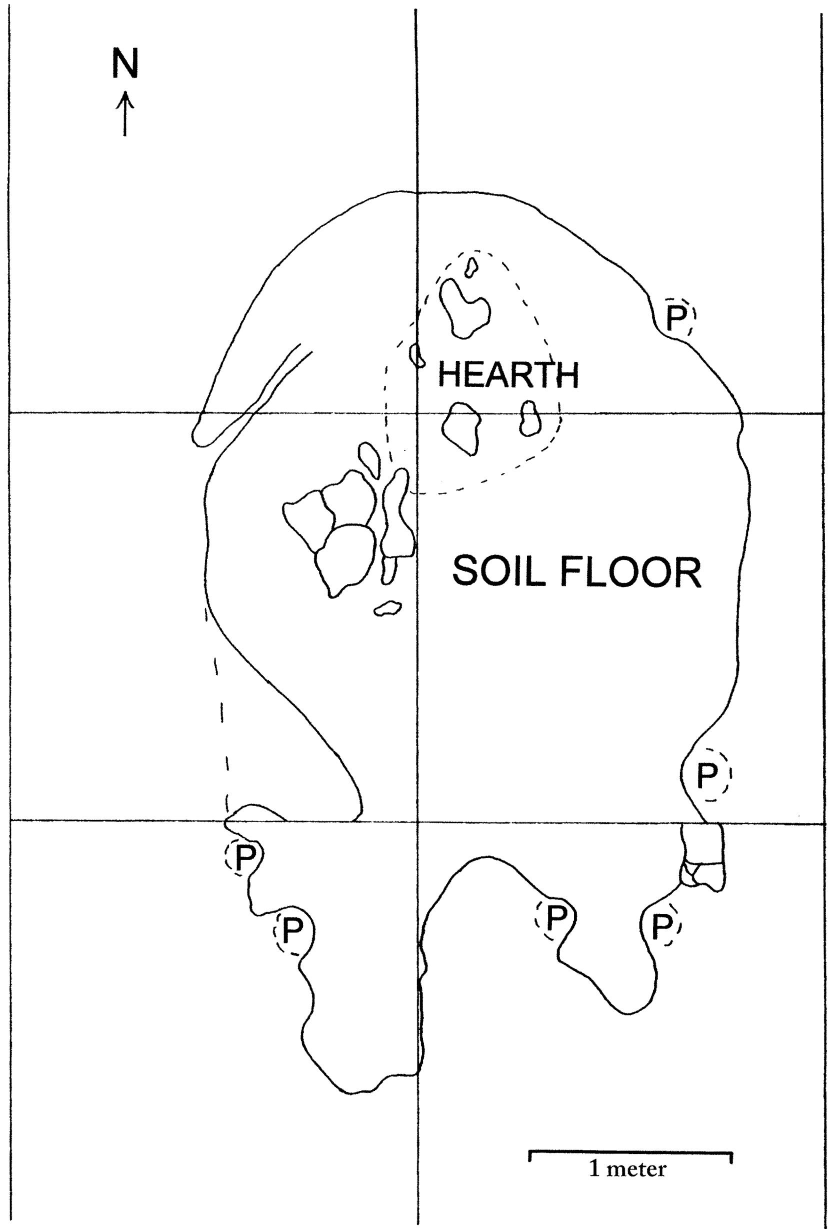
Figure 10. Aerial view of the apsidal building at Chrysokamino. Kite photograph by J. Driessen

The Apsidal Building

A small apsidal building was discovered on top of an accumulation of ca. 45 cm of slag and broken furnace fragments (Figs. 10, 11). It used wooden posts and other perishable materials for the walls and soil for the floor. It is possible the walls were of wicker or of interwoven branches. Three superimposed floor levels were found inside the structure.

The small building is oriented north–south, with the apse at the north. It is 2.60 m wide and 3.5 m north to south. At the south, three postholes could be distinguished, arranged in an east–west line with a wider spacing between the western hole and its neighbor to the east. The postholes could only be recognized because they were partly surrounded by the soil used for the floors, which was pale disintegrated phyllite that contrasted sig-

Figure 11. Plan of the apsidal building, with postholes (P) indicated



nificantly with the dark color of the slag pile on which the small hut was placed. Additional postholes could be seen at the sides of the building.

Three superimposed floors inside the building showed that soil was brought in and spread over the floor twice after the initial building of the structure. The lowest floor, which was very hard packed, was laid over the large deposit of slag and industrial ceramics. An area of red, burned soil near the north end of the floor indicated the location of a hearth. The hearth was very informal, without any clear boundary of stones.

No objects were found on the lowest floor in the hut. The second and third floors, however, had a number of sherds on them. The middle floor level, which was ca. 4–6 cm above the lowest one, was not as hard as the building's earliest interior floor surface. On it were fragments of cups, a cooking dish, jars, and basins. All the diagnostic sherds date to EM III.

Pieces of pot bellows were also on this floor. The hearth area, consisting of burned soil and stones, was farther back in the building than it had been on the lowest floor. Two flat stones, perhaps used as benches or platforms, were on this second floor. Neither one had any marks from use as a working surface. The area at the south, where the door must have been, was more worn than the floor inside the building.

That the soil was inside a building and not simply a lens over the slag pile in an area delineated by posts is proved by several pieces of evidence. The three superimposed floor levels were the same size, as if they had been limited by a wall. They ended with a sharp line at the place where the wall of perishable materials must have been. The situation was clear at the north, where the circumstances were very different inside and outside the structure. Sherds and soil were found in the interior up to the sharp line of the missing wall, with not a single sherd or small lens of soil outside it. The only scuffed area with soil spread in gradually diminishing amounts was at the south, where a gap between the postholes indicated the probable presence of the door. Artifacts were on the floor and scattered outside the doorway, but nothing was on the slag to the north of the edge of the floor, indicating that a solid wall prevented scattering in this direction.

Activities inside the hut obviously involved fire, because the burned area was a prominent feature in the room. It is not impossible that metallurgical activities were conducted here (bellows fragments were on the floor), but it is more likely that simple cooking was the main activity, and the hut was intended to provide shelter from the violent winds that sweep the small exposed promontory.

Reconstruction of the Smelting Operation

From the evidence excavated in 1996, a tentative reconstruction of the steps in smelting can be suggested. The absence of copper sources in the immediate vicinity indicates that at least some of the ore may have been brought to Chrysokamino by ship. Whether the source was in or outside Crete is not known.[60] From the beach, the ore needed to be transported ca. 2 km to the workshop area.[61]

The small number of tools at the site (see Part V, below) indicates that the ore was not crushed and prepared for the smelting operation there. This conclusion is confirmed by the complete absence of waste rock from the mining. Ore must have been crushed and sorted elsewhere and brought to Chrysokamino ready to be packed in the furnaces.

For the smelting operation, a furnace—a hollow cylinder perforated with many holes—would have been made by hand-forming techniques, perhaps from local clay, using chaff as a temper. Wood for fuel[62] was cut, and almost certainly made into charcoal, although evidence for this operation was not discovered. It was then packed into the small furnace along with pieces of copper ore.[63] The fuel would have been set on fire, aided both by a natural draft and by bellows (at least in EM III) worked by the smelters. After the ore was smelted, the furnace and its load were broken into small pieces to remove the prills of copper. This practice must have been standard for slags resulting from smelting operations with poor separation of the metal.[64]

60. For lists of copper locations in Crete and elsewhere in the Aegean, see Branigan 1968, pp. 51–53; 1974, pp. 59–66; McGeehan-Liritzis 1996, pp. 386–387.

61. The topography prevents a direct route.

62. As an alternative, the residue from olive pressing could have been used as fuel. The fire was extremely hot, consuming the fuel, and charcoal was not recovered from the water-sieving operation.

63. The possible presence of a flux is still under investigation.

64. The practice is well documented from later periods in Greece (Papadimitriou 1991, p. 119).

So far, no evidence has been found for any alloying of bronze or any melting, casting, or metalworking operation. The evidence suggests that, aside from the preparation and consumption of food, only smelting was conducted at the part of the metallurgical location excavated by this project.

Discussion

Chrysokamino changes many of our ideas about the nature of early copper smelting in Crete. On the one hand, those who have theorized about early smelting practices in Crete have envisioned a different type of operation,[65] and on the other hand, the site at Chrysokamino has been very badly misunderstood by those who have conducted surface surveys in the area.[66] Chrysokamino provides documentation for a Final Neolithic to Early Minoan workshop importing oxidized copper ores and achieving high smelting temperatures. Whether this process involved using a natural draft alone, or a combination of a natural draft and a forced draft using bellows, is still under study. Although the use of bellows for achieving a forced draft in smelting operations has been conjectured for sites as early as the Chalcolithic,[67] Chrysokamino provides the earliest examples of bellows that survive.[68] They cannot, however, be documented for Chrysokamino from before EM III, and the workshop was in use much earlier than this period (the EM III hut was built over 45 cm of accumulation of slag). The device may represent a technological advance at a site that had been using cylindrical furnaces and a natural draft for some time, or there may have been earlier bellows made of perishable materials.

The cultural connections of the site are both with the local Minoan settlements of this part of eastern Crete and with areas to the north of the island. That the workshop was firmly anchored in the local region is shown by its use of local resources. Almost all of the pottery is the common local ceramics of the eastern part of the Gulf of Mirabello region. The furnaces are made with chaff, suggesting a relation to the local agricultural economy. Use of local fuel, land, and access to markets implies the same conclusion.

The building type, however, is not local to Crete. Apsidal buildings with interior hearths are common in Anatolia and northern Greece.[69] Most known examples have stone foundations or even complete stone walls, but a few apsidal structures made of more perishable materials are also known.[70]

The best parallel for the technology comes from the Cyclades. Large deposits of slag located on cliffs in similar topographic situations are known from Seriphos and Kythnos.[71] Like that of Chrysokamino, their topographic situation maximizes the force of the north wind.

Preliminary lead isotope studies suggest that the Cyclades are a significant source of both copper and lead during the Early Minoan period.[72] Strong Cycladic connections occur at Ayia Photia, east of Chrysokamino,[73] and Cycladic influences have been noted in the Final Neolithic to Early Bronze Age tombs at Pseira,[74] which is just off the coast of Chrysokamino. Within this context of northern connections for this part of eastern Crete, the evidence from Chrysokamino suggests that the ties extend to metallurgical technology. Evidence for local connections is present as well. The workshop at Chrysokamino must have furnished copper to the inhabitants of the region, who would then have remelted it in crucibles and cast it into useful objects.

65. Branigan 1974, pp. 68–69.

66. For medieval to modern dates for the site, see Faure 1966, pp. 47–48; Branigan 1968, pp. 50–51; Haggis 1992.

67. For third-millennium B.C. India, see Hegde and Ericson 1985, p. 66; for Chalcolithic Israel, see Rothenberg 1985, p. 124. Presumably, these early bellows would have been of perishable materials.

68. For the history of the pot bellows, see Davey 1979; Tylecote 1981.

69. Werner 1993.

70. Renfrew 1986, p. 191.

71. Gale et al. 1985, pp. 83–86; Stos-Gale, Gale, and Papastamataki 1988; Hadjianastasiou and MacGillivray 1988.

72. Gale 1990; Stos-Gale and Macdonald 1991, pp. 264–269.

73. Davaras 1989, pp. 128–129; Day, Wilson, and Kiriatzi 1997.

74. Betancourt and Davaras 1990, pp. 28–36.

V. THE STONE TOOLS AT THE METALLURGICAL SITE

On a site where the breaking up of furnace slags to retrieve copper prills was a major component of the working cycle, one would reasonably expect to find a large number of stone tools with signs of percussive damage incurred during use. This is not obviously the case at Chrysokamino. Only 22 stone tools were found (Figs. 12, 13), and in several cases even their identification as tools is open to question. Eight examples are accordingly excluded from this discussion; of the remainder, none could be unequivocally assigned a function or use. Included here are three scraps of obsidian (including **19**), arguably derived from knapping obsidian on the site, but none in itself of a suitable size or nature for a tool. At the most generous level of interpretation, three tools could be considered pounders (including **20** and **22**), two could have been used in grinding work (**21** and **23**), and one (**24**) could have been a working surface or support. The remainder, and majority, are yet shrouded in uncertainty.

Why is this so? One major factor may be the uniformly poor state of preservation of the surfaces. This "degraded" condition may have resulted from natural weathering or from the corrosive effects of long exposure to hot materials in the functioning of the smelting processes, or a combination of both. The condition is manifested in the breaking down of at least the surface of the stone—sometimes being reduced to a somewhat powdery state, sometimes not, with consequent blurring and loss of detail. The presence of concretions only exacerbates the situation. Another reason for the scarcity of stone tools may be that when deemed exhausted they were slung down the slopes of the saddle and into the sea! However the set of circumstances arose, there are very few tools at the site.

Excluding the three pieces of (presumed Melian) obsidian, all the stone tools are of varying sorts of limestone and/or dolomite. Most tools are made of recrystallized gray limestone; with them are a coarser off-white to yellow limestone or dolomite (Fig. 13: **24**) and a few other carbonates. The first stone is well suited to the sort of percussive tools anticipated on this site. In terms of size and shape, tools made of this limestone could easily have been wielded by a single hand; they measure about 10–15 cm in length and weigh a half to a single kilo. All the stone tools had weathered in ravines or on the seashore until their angles were rounded and their surfaces worn down to an even texture. None seem to have been deliberately worked to create the tool's shape. The sole exception in the matter of size is **24**, whose shape—though also softened by the effects of water erosion—resembles that of a large boulder, split lengthwise by natural forces. This stone may have been intended to provide an immobile surface on which some working (but not pounding) was carried out. A suitable place for gathering the limestone pieces would have been the shore at the mouth of the short ravine running just west of the Habitation Site. All of these items, whether or not tools, were transported to the hilltop by the people working there; they do not occur naturally among the angular, slab limestones or the layered phyllites of the hillside.

To the extent that any pattern of wear from usage can be discerned,

19

Figure 12. Obsidian flake (19) with cortex on one side. Scale 1:1

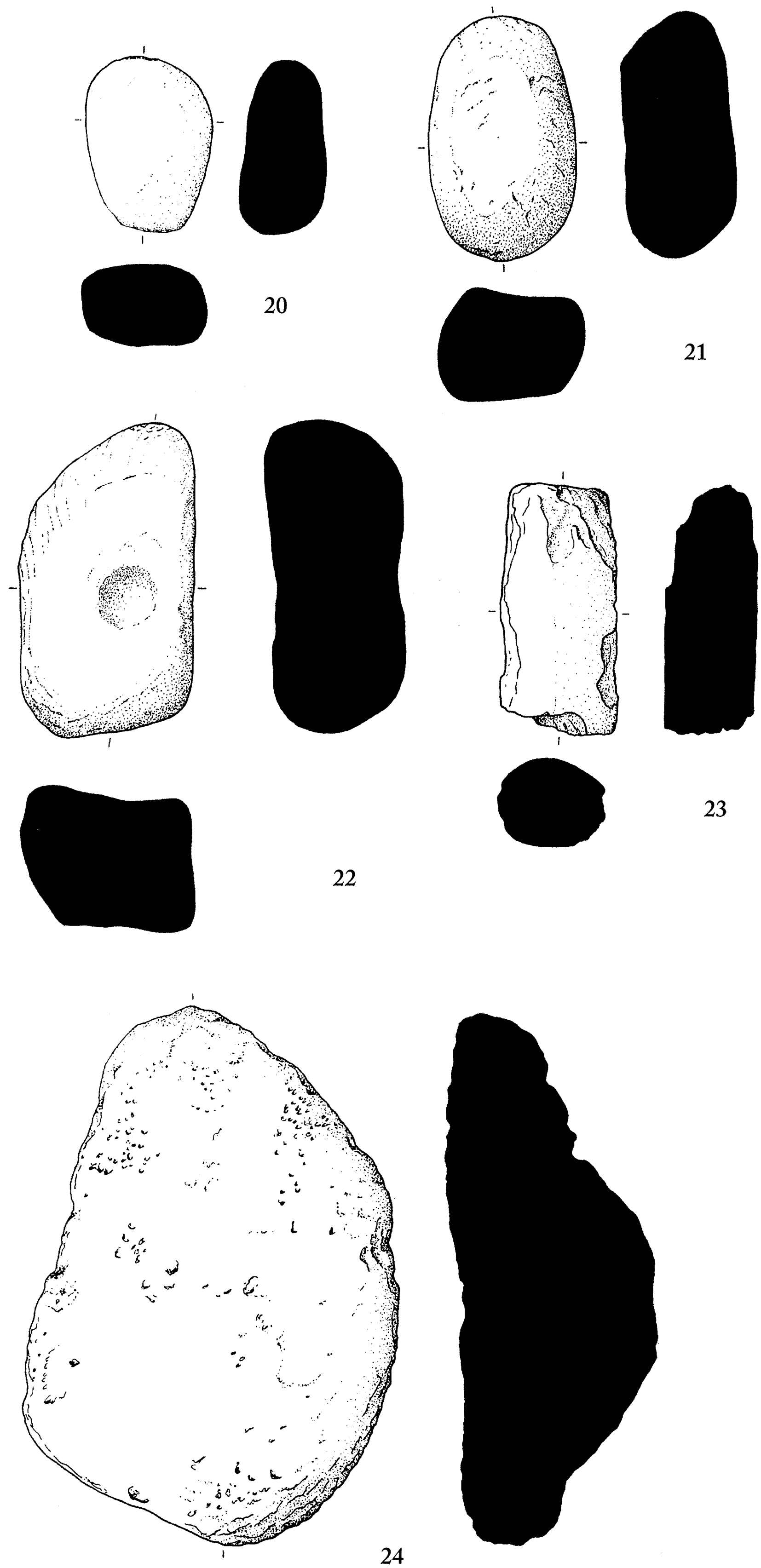


Figure 13. Ground stone tools (20–23) and a possible limestone support (24). Scale 1:3

the following observations can be made: (1) direct percussive action of the tool against an item of considerable hardness (slag would be hard enough) resulted in the loss of small surface chips; (2) as part of this process, larger flakes may have been accidentally removed from the working areas of the tool; (3) the act of grinding (combined with crushing?) resulted in a smooth, even surface, or one exhibiting a low grade of polish; and (4) occasionally scratches were left on the tool by the agitation of a hard and resistant material being worked.

Apart from more pounders and grinders, we might have expected to find items providing a firm and unyielding surface against which to break up the slag; the single support (**24**), as indicated above, could not have been used for this purpose. It is possible that the limestone on the hillside, with its natural slablike patterns of cleavage, would have supplied a ready source of suitable material, but why were no damaged pieces encountered? One possibility is that a pair of interconnected, shallow cup-depressions in the sloping bedrock were used instead; together, they measure 35 cm across and up to 7 cm deep. A series of such depressions could well have provided the support necessary to break up the slag. Only one pair has been found at the site, however, which suggests that the feature was not an integral part of the working cycle, because many more would have been required.

For the rest of the manufacturing processes, the same pounders, grinders, and (missing) working surfaces would have sufficed to prepare the imported ores, to break up charcoal fuels, and to demolish furnaces after firing. Sharper edges for cutting and slicing actions (i.e., obsidian or metal blades) or for chopping (axes, for cutting wood) had very minor roles to play in the industrial process as envisaged at Chrysokamino (though suitable for other daily events, such as preparation of foods). The clay and chaff mix used in vast quantities to form the furnaces was more likely to have been prepared outside the smelting site and brought to it in a condition ready for immediate use or short-term storage.

Catalogue

19 Obsidian flake, complete — Fig. 12

X 945. From J 18-1. L. 1.0, W. 0.9, Th. 0.5. Black, fairly lustrous. Cortex on one side, probably from the preparation process.

20 Tool (?), complete — Fig. 13

X 942. From J 18-surface. L. 7.5, W. 5.4, Th. 3.7, Wt. 208 g. Limestone, mid-gray. Wedge-shaped pebble; surface condition makes recognition of use damage very difficult. Traces of pounding may exist at either end (more on smaller end). Very worn/damaged surface, degraded.

21 Grinder (?), complete — Fig. 13

X 681. From O 20-4. L. 10.5, W. 3.6, Th. 4.9, Wt. 580 g. Limestone, very pale gray. Elongated cobble; two flat planes may be worked. Ends and sides show no sign of wear/damage. Faces are flat, not especially smooth. Poor surface; heat damage (?).

22 Pounder (?), complete — Fig. 13

X 712. From N 20-2. L. 13.4, W. 7.5, Th. 5.9, Wt. 1.220 kg. Limestone, pale mid-gray. Cuboid appearance, rounded angles; natural cobble. Possible ghosts of pounding damage on more pointed end; ill-defined hollow in center of one face (2.5 cm across; 0.3 cm deep). Even more indistinct hollow on other end. Surface in badly weathered condition.

23 Grinder/rubber (?), fragment Fig. 13

X 451. From N 17-2. L. max. 10.7, W. 4.9, Th. 3.9, Wt. 333 g. Limestone, mid-gray; layered. Rod, much battered; triangular in section. Two zones possibly modified through use: the flatter end is smooth; the angular end is somewhat so

24 Stone object/support (?), complete Fig. 13

X 453. From O 18-1 surface. L. 23.1, W. 16.1, Th. 7.1, Wt. 3.555 kg. Limestone or dolomite, off-white and yellow. Amorphous object: one surface flat and smooth; other surface uneven; no signs of use.

VI. SUMMARY AND FINAL COMMENTS

The metallurgy workshop at Chrysokamino provides new evidence for metallurgical operations in Early Minoan Crete. The earliest pottery is from the Final Neolithic period. Only a few sherds are present from EM I–IIB, but more pottery from EM III has been recognized, and the only building on the site, an apsidal hut with a hearth inside, is from this period. The site was abandoned near the end of EM III when East Cretan White-on-Dark Ware was in use.

The metallurgical operations carried out at Chrysokamino were restricted to a single part of the overall metallurgical process that began with ore and ended with finished products. Only copper smelting was conducted at Chrysokamino. The ore was mined elsewhere, and the removal of waste rock to produce a more concentrated ore for smelting also took place at another location. Remelting of smelted copper in crucibles and the casting of tools and other objects also occurred somewhere else. The workshop here must be regarded as a specialized aspect of a much larger operation.

The smelting process consisted of firing a charge of ore, fuel, and possibly flux in small cylindrical furnaces. A natural draft surely played an important role in the process, but bellows were available on the site by the end of the period of use (and possibly earlier, if they were of perishable materials). The bellows from the site are the earliest ones known, and they bear some unusual details, including holes cut in the pot bases, for use of the bellows upside down, in contrast to all other known bellows. This detail may be an early experiment in the use of the device.

The product of the workshop was a smelted copper. It was surely not very pure, because it must have been mixed with small amounts of the slag that was produced at the site in great quantities, so that it will have required remelting to produce tools and other objects. The copper would have been an important raw material to the early settlements in the vicinity, and the workshop must have made a significant contribution to the region during the Final Neolithic and Early Bronze Age. Its output could never have been very large, however, and it seems to have been dependent on a nonlocal source for the ore. It is not surprising that it was abandoned at about the time of the building of the Middle Minoan palaces when the base of the Cretan economy became more complex and more international.

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