



Investigation of a Copper-based Hoard from the Megalithic Site of al-Midamman, Yemen: an Interdisciplinary Approach

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In 1997, a hoard of copper-based objects was discovered at the megalithic site of al-Midamman, on the Red Sea Tihama coastal plain of the Republic of Yemen. Since there have been very few metal artifacts discovered in the lowlands of Yemen, and there was limited stratigraphy on the site, determining the time and place of production for these artifacts was difficult. A full investigation of the objects was deemed essential to determine their chronology and origin. Analysis included optical microscopy and scanning electron microscopy (SEM) for metallography, inductively coupled plasma spectrography (ICP) for bulk chemical composition, SEM to determine phase composition and corrosion products, and X-ray diffraction (XRD) to identify corrosion products.

The objects can be divided into three types of copper and copper alloy: pure copper, arsenic rich copper, and tin rich copper. The difference in composition appears likely to be deliberate and suggests that the objects were produced sometime during the Early Bronze Age through the Middle Bronze Age. Further investigation of any metal objects discovered along the Yemeni coast and along the Ethiopian/ Eritrean side of the Red Sea is obviously essential.

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Introduction

The report of an archaeological investigation into an hitherto largely unknown *menhir** culture in Yemen (Keall, 1998) highlights the question of how one may define the Bronze Age outside the

mainstream of the Near East. Can we rely on artifact typologies developed for different archaeological contexts in attempting to establish a chronology for a culture that we have only just begun to study in the Southern Arabia? If we excavate copper alloy tools for which there are visual typological parallels, from, for example, Tell Selenkihiyya in Syria *c.* 2400–1800 BC, how applicable is this date to our entire artifact assemblage when there are “non-Bronze Age” features present and when many of the other “Bronze Age norms” are not represented? This issue was first aired by de Maigret (de Maigret *et al.*, 1984: 426) when he

*In this paper, the term “monolith” is used to describe the use of a single piece of quarried stone, erected as a commemorative marker. “Pillar” is reserved for pieces of columnar basalt with sharp-cornered faces, sometimes with the classic prism shape that is characteristic of this naturally formed rock. “Megalith” simply means a giant version of the same thing. All of them may be judged to be “menhirs”, as originally upright stones with cultic meaning.

coined the term “South-Arabian Bronze Age”, distinguishing it from that of the Levant, because of the reported association in the Yemeni highlands of metal with what one might call an archaic lithic-tool industry.

The intellectual thrust of this article is to report the results of metallurgical and metallographic analysis conducted on copper-alloy tools which do in fact mesh with Syro-Palestinian EB/MB types (cf. Philip, 1989 (i), Figure 51). Typologically similar versions of some of the items have also been excavated by Zarins at Sihi, in south-western Saudi Arabia (for square-sectioned points, see Zarins & al-Badr, 1986: 48–49, & pl. 64, dated beginning *c.* 2100 BC), and reported by Vogt (Vogt & Sedov, 1998: cat. 76 [rivetted daggers], & 130 [square-sectioned point]), in a range of dates between the second half of the 3rd millennium—beginning 1st millennium BC. A most important observation in this regard is that, in the context of discussing daggers illustrated on statue-menhirs in the Hadramawt (south-eastern part of the Arabian peninsula), Newton & Zarins (2000: 159, & Figure 2) have identified actual artifacts (or illustrations from sealings) from both Syria and Iraq where their presence is judged to be “not common in the Mesopotamian repertoire”. They conclude (Newton & Zarins, 2000: 161) that this type of dagger was common, however, in the Arabian peninsula, and associate them with a Semitic-speaking pastoral society between 2500–1500 BC.

The purpose then, here, is to put forward the material from al-Midamman that has been excavated and analysed, so that others may have the benefit of the basic results, to contemplate the implications for mainstream Near Eastern artifacts. For the Canadian Project itself, metallographic and compositional analyses of the tools promises at least to develop clearer indications of with whom these unknown people interacted, as part of our search for their cultural identity.

Archaeological Context

The artifacts discussed here are from the Yemeni site of al-Midamman and were found during the March 1997 expedition of the Canadian Archaeological Mission* to the Red Sea coastal plain of Yemen, west of the city of Zabid (Pringle, 1998; Keall, 1998; see Figure 1).

A second season of excavations (in 2000) has helped define the cultural record at the site, and allows for the identification of two minor phases in the occupation—from Neolithic (5000–3000 BC) and medieval Islamic times (14th–15th centuries AD); and two

major periods of activity in the Bronze to Iron Age—the first around the turn of the 3rd–2nd millennium, and the second towards the turn of the 2nd–1st millennium. There is no sense of a hiatus between the two major phases, but the cultural activity is quite different.

Whether this represents hostile take-over, or at least outside influence, or whether it can be judged to be the evolution of cultural behaviour of the same people, is for future enquiry to address. Conclusions drawn from the results of both seasons of excavations were presented at the 1st and 2nd International Conferences on the Archaeology of the Ancient Near East, in Rome (1998) and in Copenhagen (2000). The Proceedings, however, of both conferences have yet to appear in print (cf. Keall, 2000; in press *a*).

The bulk of the metal objects analysed here come from the commemorative setting of a group of standing stones. They were excavated from the sandy matrix beneath the stones, consisting of an intact cache of copper alloy tools and an obsidian core (see Figure 2). Other isolated tools were also recovered from the same general context, though the conditions were disturbed by the falling of other formerly upright stones. Apart from the copper alloy tools and the obsidian, small fragments of pottery were found in the matrix beneath the standing stones, sufficient to reveal that the culture had a ceramic record. And intact grinding stones deliberately interred in commemorative acts at the same site, seemingly Wpoint to food preparation that was most likely agricultural in nature. Typological comparison suggests a date beginning *c.* 2400–1800 BC because commemorative pillars of this kind (for al-Rajajil, see Zarins, 1979: 76; for Hajar al-Ghaymah, (Wadi al-Hamili), see Bayles des Hermens, 1976: 5–37) are more usually attributed to the Chalcolithic era (say, 3500–2500 BC, it is proposed that the 2400 BC date is perfectly feasible for the al-Midamman finds.

A drastic cultural change occurred in the region of al-Midamman when many of the former standing stones were pulled down and dragged into position to form the footings of monumental buildings of stone. In one instance, the building’s footings were almost entirely constructed with pillars from an earlier menhir arrangement. Stone-lined tombs, which furnished a rich assemblage of whole vessels, allow this stone building settlement to be matched in time roughly with the Malayba-Subr culture (near Aden, 300 km distant), which is placed generally between *c.* the 14th–9th centuries BC (Vogt & Sedov, 1998: cat. 77–130).

The domestic settlement is characterized mainly through the presence of hearths that were presumably associated with ephemeral (and no longer visible) reed houses. The area is grossly deflated, but the extensive surface scatters of pottery are consistently intermixed with copper alloy tool fragments and obsidian microliths. The microliths have a reasonable parallel in the finds from Hajar al-Rayhani, in the Wadi al-Jubah (see Rahimi, 1987: 140), from the early Iron Age, around

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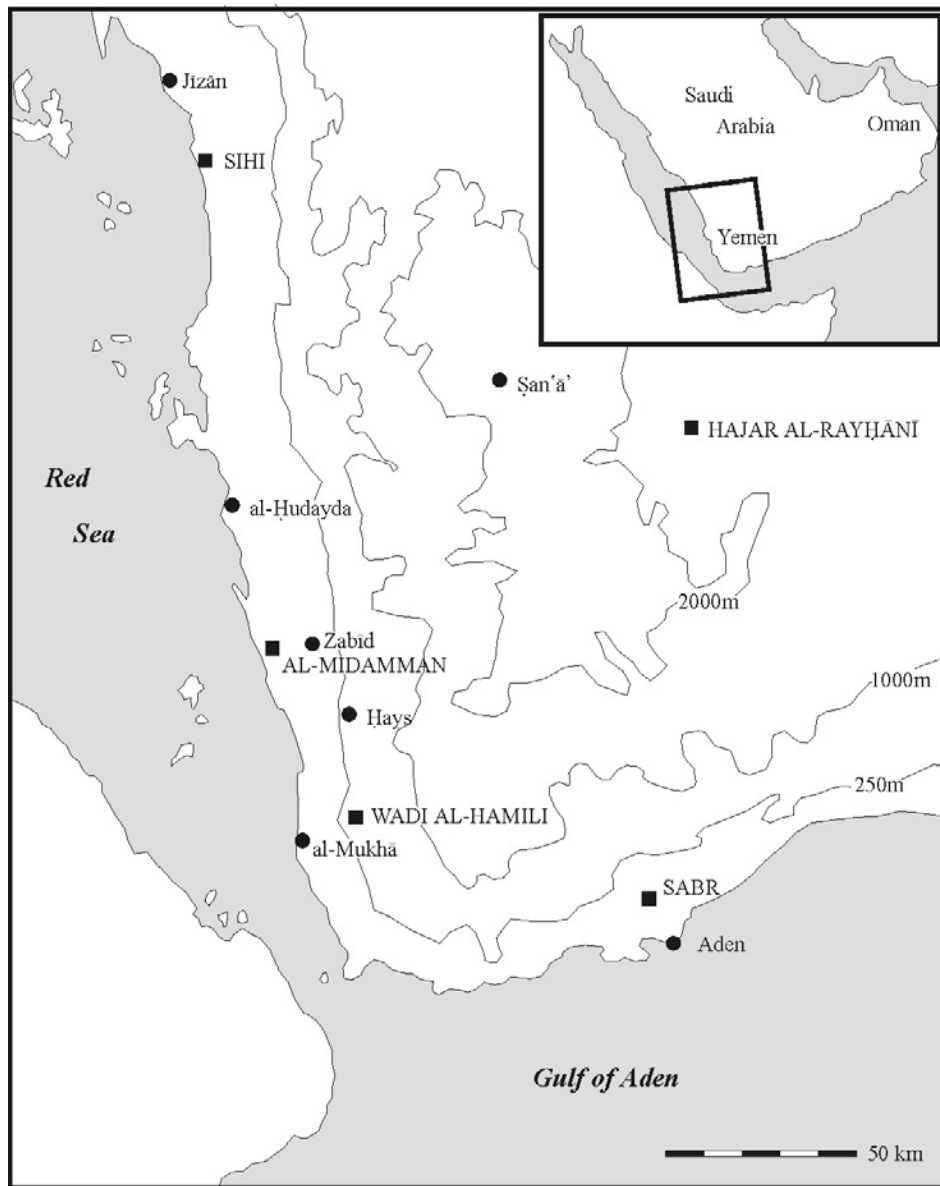


Figure 1. Culturally related sites in southern Arabia. E. J. Keall, ROM.

the turn of the 2nd–1st millennium BC. Obsidian microliths of the same character have also been recorded by the Canadian Mission on Dahlak al-Kabir, a large off-shore island on the Eritrean side of the Red Sea, at a latitude roughly 200 km to the north of al-Midamman. The most recent cultural record at al-Midamman comes in the form of a third building of stone, in which small fragments of shallowly scored decoration are to be equated exactly with those known from the northern highlands of Yemen (cf. Breton, 1998: 216). This gives us a date for the continued use of the settlement until around the 8th century BC. Terminal occupation of the site is marked by a volcanic ash horizon, though this event has yet to be dated successfully through laboratory analysis of the quartz-rich ash.

The main cache of metal artifacts was excavated in trench S1W1 at the base of the now-fallen granite monolith (see Figure 3). The cache consists of a cluster of copper alloy “tools”^{*} deliberately placed around a large cube of obsidian. The tools comprise an “adze” (ZP97.224), a “dagger” with double rivets below the tang (ZP97.232), a “razor” (ZP97.218), and two square-sectioned “points” adhering to one another (ZP97.231a,b). Excavated from a related, but slightly higher context was another group of artifacts which is, in all probability, part of the same cache. These comprise another “razor” (ZP97.110) and a “spatula”

^{*}The descriptive terms are given in quotation marks to impart some suggested sense of tool use, though no proof of actual function can be presented. Others, for example, have reported items like our spatula as a “spearhead”, and the tanged-points as “javelin heads”.

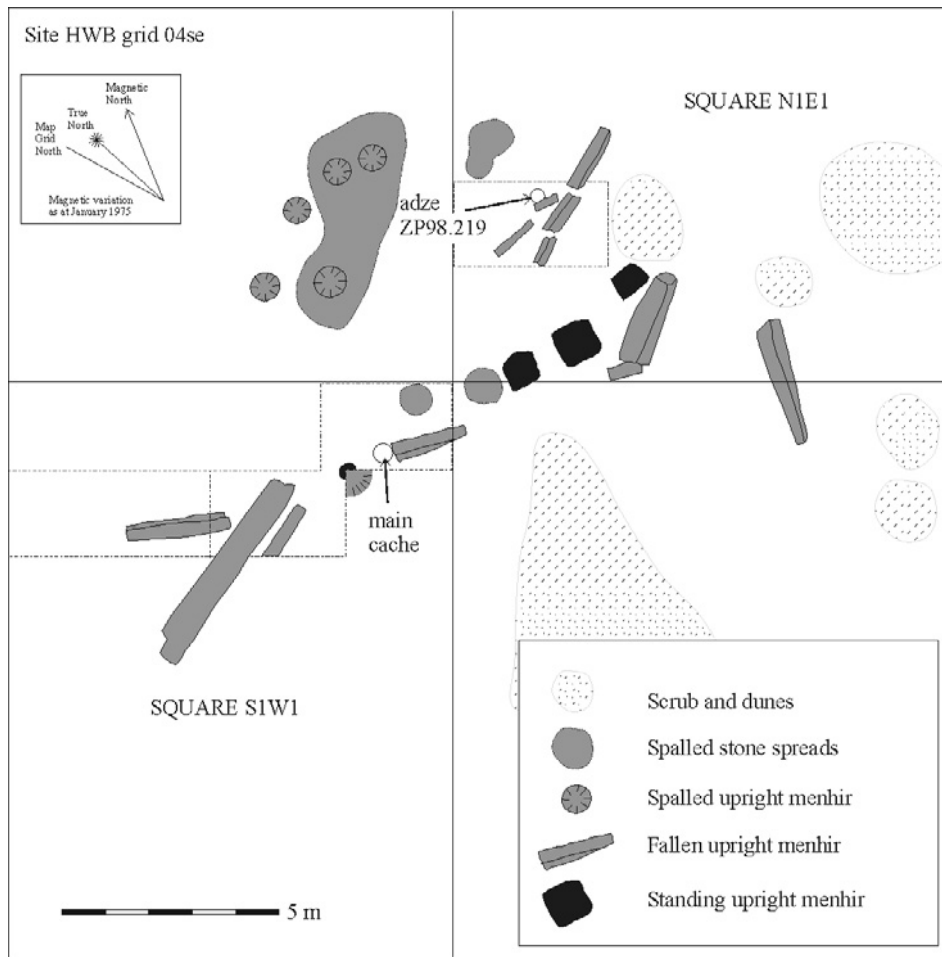


Figure 2. Excavation trenches around main menhir arrangement at site of al-Midamman. E. J. Keall, ROM, after Tina Mangieri.

(ZP97.111). The same contextual relationship applies to a third group of tools, which may have been disturbed from the main cache when the monolith fell. These consist of a “tanged point” (ZP97.237), a double-riveted “dagger” (ZP97.244), and a “spatula” (ZP97.236) (not illustrated). A second “adze” (ZP97.219) was excavated in the nearby trench N1E1, beneath a fallen basalt pillar. Another point (ZP97.216) was found near the surface west of the henge grouping. The entire assemblage is illustrated in Figure 4.

Scope of Study

Since little is known about the metallurgical tradition in Yemen in ancient times, analysis of the metal artifacts discovered at the megalithic site of al-Midamman, offered a unique opportunity to provide at least a few substantive facts about an otherwise little known tradition in the Southern Arabian Peninsula. A group of the metal objects, as listed in Table 1, arrived at the Conservation Laboratory of the Royal Ontario

Museum, Toronto (Canada) in early summer 1997 for cleaning, treatment for stabilization, and simple repair before being returned to Yemen. When questions arose as to the provenance of the material, conservation work was delayed until the objects could be sampled and analysed. To collect as much information as possible from the artifacts, analysis included optical microscopy and scanning electron microscopy (SEM) for metallography and to determine metallographic structure and corrosion products, inductively coupled plasma spectrography (ICP) for bulk chemical composition, and X-ray diffraction (XRD) to identify corrosion products.

Methodology

Initial visual examination showed that some of the objects—particularly the blade of dagger ZP97.244 and razor ZP97.110—were heavily corroded. However, because of their uniqueness, all finds were sampled to determine their chemical composition and their properties.

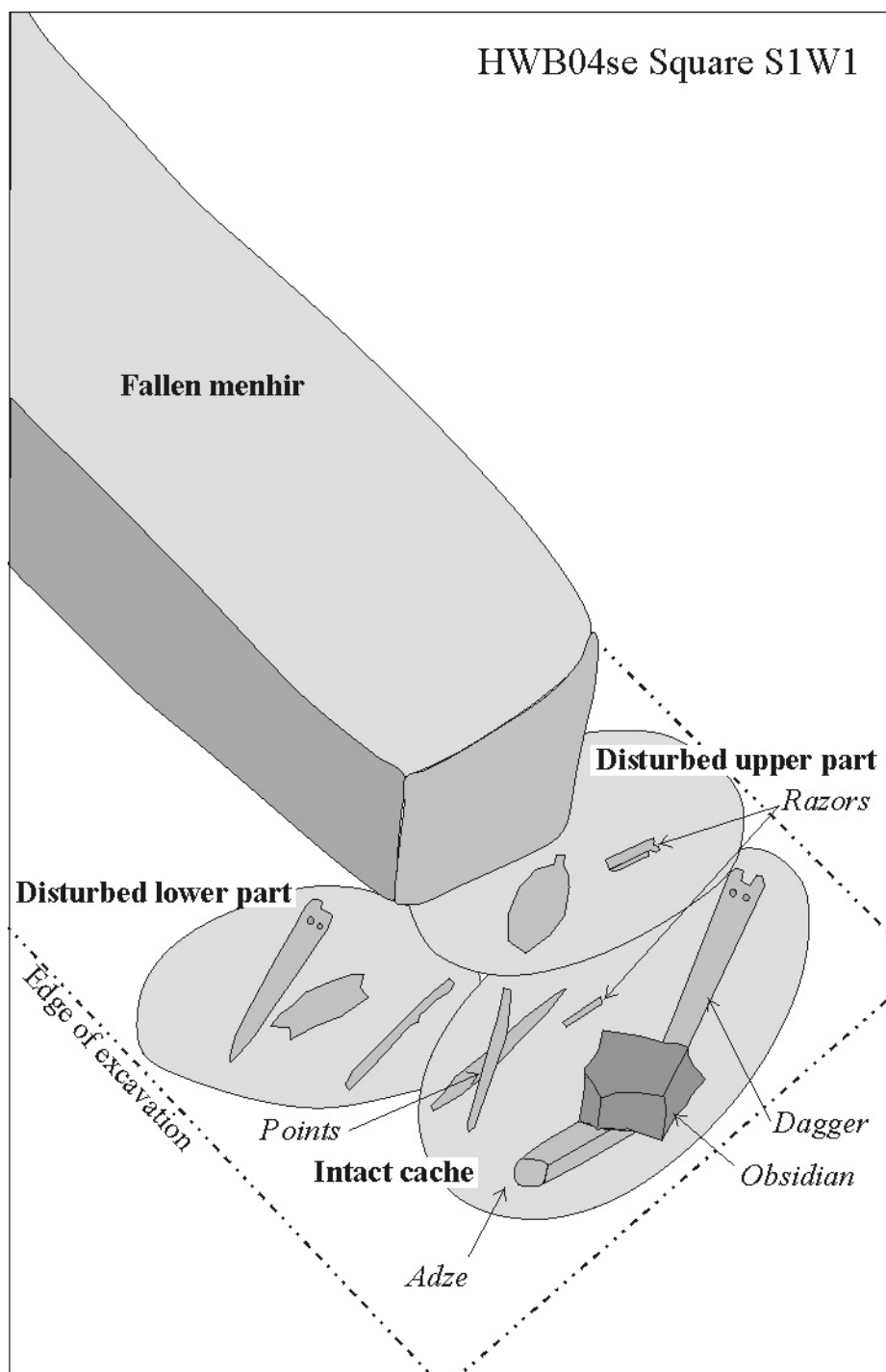


Figure 3. Cache of obsidian and copper/bronze artifacts interred beneath now fallen menhir. E. J. Keall, ROM.

Chemical characterization of the objects
ICP-AES analysis. The samples for ICP analysis were taken with a portable jeweller's drill using 0.8 mm drill bits. The first drilling from the corrosion layer was discarded and only metallic turnings were collected. The samples weight had a range of 9–15 mg. Subsequently, any corrosion that was visible under a microscope was

removed before weighing, however, unavoidably, because of intergranular corrosion, some amount of corrosion products was included in the samples. This is reflected in the low totals of the analysis results.

ICP-AES analysis is a well-established method for investigating the chemical composition of archaeological metal objects (Blades *et al.*, 1991; Segal *et al.*, 1994;

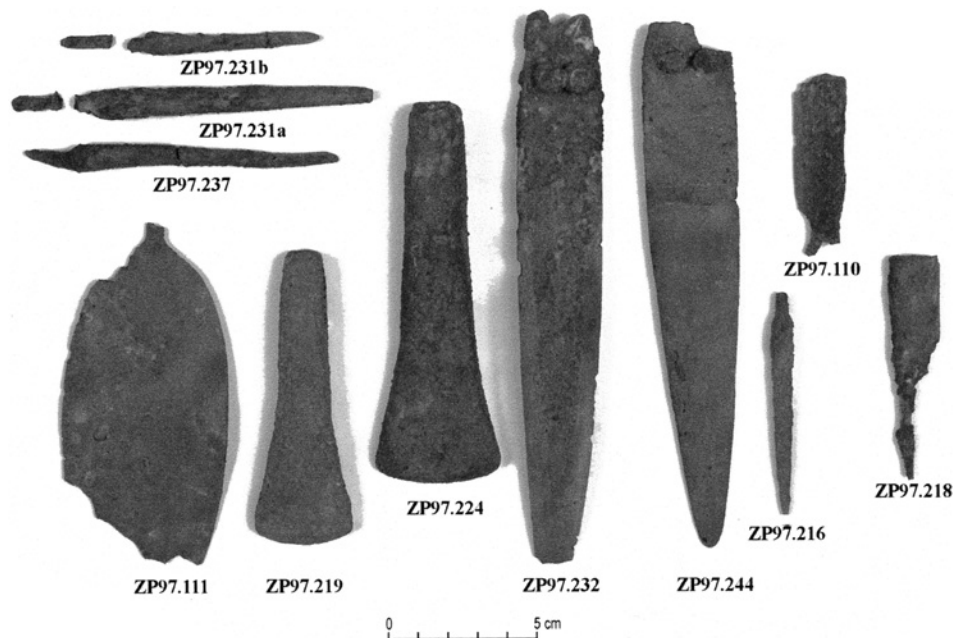


Figure 4. Photo of copper alloy artifacts from site of al-Midamman. Brian Boyle, ROM.

Tykot & Young, 1996). Analysis of the al-Midamman metal artifacts was performed on an OPTIMA 2000 Perkin Elmer simultaneous ICP spectrometer, in the labs of the Agenzia prov. per la protezione ambiente e la tutela del lavoro in Bolzano/Bozen (Italy), by applying a previously tested program especially developed for the analysis of ancient copper-based alloys. Sixteen elements were determined and quantified: Cu, Sn, Pb, As, Zn, Fe, Sb, Ni, Ag, Au, Bi, Cd, Co, Mn, P, S.

The results have a precision of about $\pm 1\%$ for Cu, $\pm 2\%$ for elements present at levels higher than 1%, and deteriorate to $\pm 50\%$ at levels around the detection limits, which are different for each element. The analytical results for all objects are given in Table 1. It should be pointed out that particularly the ICP results for the two most heavily corroded objects have to be considered as only semi-quantitative, since no pure metal was retrievable. Nevertheless, the analysis gives useful information about the nature of the material.

SEM analysis. Semi-quantitative chemical analysis by SEM was carried out on a fragment of corrosion from the blade edge of dagger ZP97.232 at the Wolfson Archaeological Science Laboratories, Institute of Archaeology, University College London (U.K.). A JEOL JSM-35 CF SEM equipped with an Oxford Link Pentafet energy dispersive X-ray analyzer (EDX) was used for the analysis. Elements quantified included Cu, Fe, Sn, As, Ni, Si, Cl, Ca, Sb, Pb, and S. A second investigation, limited to some inclusions in the metal of point ZP97.237, was carried out on a Cambridge/Leica Stereoscan 430i/Oxford Link SEM/EDX at the Department of Materials and Applied Chemistry for

Engineering, University of Trieste (Italy). Samples cut with a jewellers saw and mounted in epoxy resin and ground down on successive grades of silicon-carbide paper from p100–p1200. They were then polished with diamond paste on a polishing wheel down $\frac{1}{4}$ to micron and carbon coated in preparation for analysis. The SEM-EDX was run at 20 KeV at a working distance of 39 mm.

XRD analysis. At the Earth Sciences Department, Royal Ontario Museum (Canada), the X-ray powder-diffraction data were collected using Gandolfi cameras of either 114.8 or 57.4 mm diameter, with Cu $K\alpha$ radiation (Ni filtered). The films were scanned using an optical scanner calibrated for intensity and peak position using an external silicon standard. The data were then compared against the ICDD PDF-2 X-ray diffraction data sets using the search match routines of the JADE for Windows (3.0) programs.

Metallography

Three metallographic samples were taken for investigation by optical microscopy and SEM, one each from dagger ZP97.244, dagger ZP97.232 and point ZP97.237. The purpose of the investigation was to determine microstructure and the implications for production techniques employed for the objects. Investigative work was carried out on the Zeiss microscopes in the Metallography Laboratory, and on the SEM at the Department of Materials and Applied Chemistry for Engineering of the University of Trieste (Italy), and on the SEM-EDX at the Wolfson Archaeological Science Laboratories, Institute of Archaeology, University College London (U.K.).

Table 1. Results of ICP analysis of the copper artifacts from al-Midamman, Yemen

Alloy grouping	Sample number	Object	Exc. n.	Sample location	Cu	As	Sn	Pb	Zn	Fe	Sb	Ni	Ag	Au	Bi	Cd	Co	Mn	P	S	Total
Copper	1	adze	ZP97.224	narr. end	93.9	0.32	0.04	0.26	0.02	0.17	0.01	0.01	0.02	—	0.06	—	0.001	—	0.04	0.27	95.121
Cu	2	adze	ZP97.219	narr. end	94.6	0.16	0.03	0.11	0.01	0.21	—	0.01	0.01	—	0.02	—	0.001	0.001	—	0.05	95.212
Cu	10	point	ZP97.237	broad p.	87.5	0.25	0.01	0.08	0.01	0.09	—	—	0.41	—	—	—	—	—	—	0.12	88.47
Cu	12	point	ZP97.231b	tang	90.8	0.29	—	—	0.01	0.03	—	—	0.06	0.002	0.01	—	—	—	—	0.07	91.272
Cu	3	dagger	ZP97.244	blade	73.3	0.67	0.01	0.03	0.03	0.51	0.01	—	0.01	—	—	—	0.002	0.004	0.02	0.07	74.666
Copper/arsenic	4	rivet	ZP97.244	head	92.7	1.26	0.04	0.04	0.02	0.21	0.03	—	0.15	—	0.01	0.002	0.001	0.001	0.03	0.11	94.604
Cu/As	5	rivet	ZP97.244	head	69.4	1.19	0.03	—	0.06	0.93	0.03	0.01	0.09	—	—	—	0.001	0.011	0.03	0.35	72.132
Cu/As	9	point	ZP97.216	tang	88.6	2.21	0.01	—	0.01	0.41	—	0.01	0.09	—	0.01	0.001	0.002	0.001	0.02	0.12	91.494
Copper/tin	6	dagger	ZP97.232	blade	78.9	0.27	2.12	0.15	0.02	0.57	0.01	0.01	0.02	—	0.04	—	0.001	0.004	0.04	0.49	82.645
Cu/Sn	7	rivet	ZP97.232	head	78.7	0.18	2.82	0.38	0.01	0.23	0.01	0.01	0.02	—	0.07	—	0.001	0.003	0.02	0.18	82.634
Cu/Sn	8	rivet	ZP97.232	head	81.5	0.21	2.58	0.55	0.02	0.39	0.01	0.01	0.01	—	0.05	—	0.002	0.003	0.05	0.22	85.605
Cu/Sn	11	point	ZP97.231a	broad p.	94.8	0.17	1.46	0.37	0.01	0.07	0.01	—	0.02	—	0.05	—	—	—	0.15	0.39	97.5
Cu/Sn	13	razor	ZP97.218	handle	84.6	0.12	3.04	0.48	0.01	0.21	0.01	0.01	0.05	—	0.07	—	0.002	0.001	0.02	0.33	88.953
Cu/Sn	15	razor	ZP97.110	blade	78.1	0.17	2.15	2.44	0.03	0.17	0.01	—	—	0.001	0.06	—	—	0.002	0.09	0.25	83.473
Cu/Sn	16	spatula	ZP97.111	handle	73.8	0.15	3.31	0.42	0.03	0.21	0.09	0.01	0.01	—	0.05	—	0.001	0.002	0.04	0.19	78.313
Likely copper/tin	14	razor	ZP97.110	handle	50.1	0.02	0.18	0.01	0.39	1.71	—	0.01	—	—	—	—	0.005	0.012	0.05	1.96	54.447

The results given in the table have a precision of approx. $\pm 1-2\%$ for Cu, $\pm 5\%$ for elements present at levels greater than 1%, but deteriorating to $\pm 50\%$ at the respective detection limits.

Results

Quantitative chemical compositional analysis by ICP-AES

In discussing the analytical results we have to bear in mind that the total values are low because of problems with obtaining corrosion free metal. This will be mentioned and discussed below in the relevant paragraphs. ICP analysis revealed three main compositional distinctions within the group of objects: first, unalloyed copper; second, copper alloyed with arsenic; and third, a low tin bronze (see [Table 1](#)). Two adzes (ZP97.224 and ZP97.219), two of the points (ZP97.237 and ZP97.231b), and the handle of razor ZP97.110 were made of unalloyed copper. One dagger ZP97.244 and another point ZP97.216 were made of an arsenical copper, while the second dagger ZP97.232, the two razors (ZP97.218 and ZP97.110), the spatula ZP97.111, and the second point ZP97.231a were made of low tin bronze.

Semi-quantitative chemical compositional analysis by SEM. The SEM analysis of the corrosion fragment from dagger ZP97.232 gave the following results. The blade was found to be heavily corroded with alternating bands of cuprite and copper chloride, with a well defined surface encrustation (see [Figure 5](#)). Sulphur compound inclusions were also detected. The variation seen in tin and arsenic content is due to the technique of analysis, which incorporates spot analysis of individual phases, when averaged the amount of tin and arsenic detected are comparable to the ICP results (see SEM results in [Table 2](#)).

Metallographic investigation

Metallographic samples of dagger ZP97.244 and of point ZP97.237 were taken and examined under the optical microscope and under SEM. The metallographic structure of the samples from the dagger blades showed heavily elongated grains (i.e., [Figure 5](#)) and strain markings along the longitudinal section of the blade. A finely grained structure and some distorted annealing twins suggest that the dagger was functional and had a hardened edge. A fragment of the corrosion layer from dagger ZP97.232 examined by SEM gave similar results. The point ZP97.237 was also found to have been slightly worked by hammering. Faint striae are visible near the surface, while the core is in as-cast condition.

Conservation

The objects were examined using an Olympus SZ4060 stereo zoom (6–40×) microscope with a fiber optic light source. Peculiarities of the surface corrosion were noted, described and photographed. On many archaeological copper alloy artifacts, the original surface of the object remains as a pseudomorph (patina) composed of

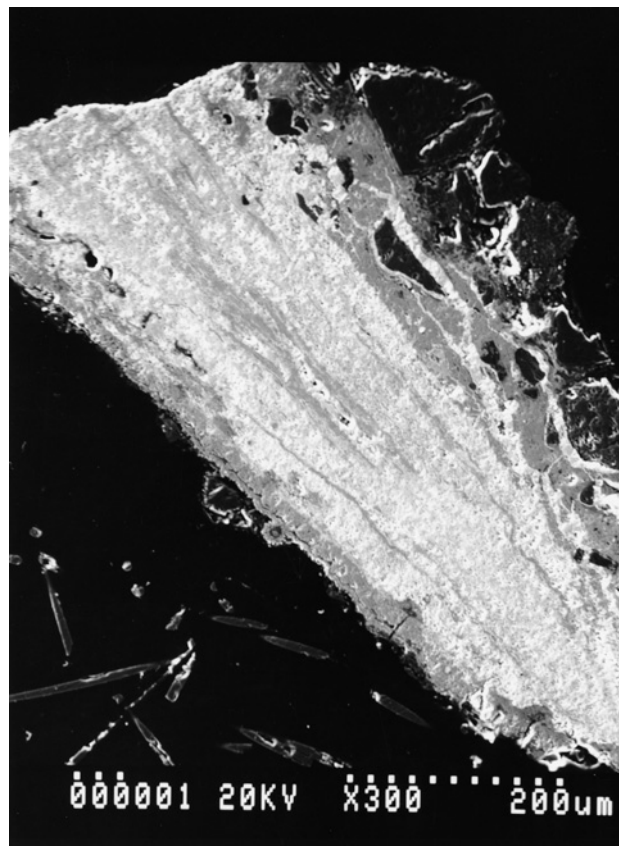


Figure 5. SEM micrograph of the blade edge of dagger ZP97.232. Alternate banding of copper chloride (dark lines) and cuprite (lighter lines) are clearly visible. Elongated grains are easily discernible and quite conspicuous. Surface encrustation is visible at edge. Aaron Shugar.

corrosion products within layers of massive corrosion. Mechanical cleaning is the optimum method to reveal this underlying layer ([Stock, 1999](#)). The choice of instrument to reveal such a surface will vary with the type of corrosion and the preference of the conservator. The metal artifacts were heavily encrusted with thick overlying corrosion products varying in colour from light to dark green, incorporating sand grains at various levels in the corrosion layer. The overall surface was non-uniform in a plastic way, with ebbs and flows of varying thickness.

The first test cleaning was performed in an area already opened (possibly by mechanical damage) in the corrosion on blade ZP97.232. A vibro-tool, Burgess Vibrograver Model 74, was used at high speed with a sharp tungsten tip for corrosion removal on all the material. It was hoped that one could follow the surface patina from this location by removing the corrosion products around it. However, the corrosion products proved to be extraordinarily thick, hard and tenacious, overlying an artifact that was thin and brittle, and (as discovered later) totally mineralized. This made corrosion removal very difficult and the patina was not discovered either here or at several

Table 2. SEM analysis of the corroded blade on dagger ZP97.232

Spot	Cu	As	Sn	Pb	Zn	Fe	Sb	Co	Mn	S	Cl	Ca	Al	Si	Total
1	74.53	0.8	3.66	0.27	n/d	0.76	0.21	n/d	n/d	0.23	0.66	0.1	0.35	0.7	82.27
2	76.89	0.32	1.58	0.24	n/d	0.51	n/d	n/d	n/d	n/d	1.41	0.06	0.15	0.43	81.59
3	57.01	n/d	n/d	n/d	n/d	0.31	n/d	n/d	n/d	0.12	11.07	0.41	0.22	2.15	71.29
4	66.64	1.14	5.81	0.45	n/d	1.11	n/d	n/d	n/d	0.1	1.62	0.17	n/d	0.49	77.53
5	83.08	n/d	n/d	n/d	n/d	0.14	n/d	n/d	n/d	n/d	0.09	0.15	0.17	0.08	83.71
6	47.97	2.44	8.48	1.32	n/d	1.68	0.46	n/d	n/d	0.05	8.46	0.21	n/d	0.42	71.49
9	82.9	n/d	n/d	n/d	n/d	0.08	n/d	n/d	n/d	n/d	0.23	n/d	0.14	0.07	83.42
Area scan 1	72.69	n/d	1.43	n/d	n/d	0.38	n/d	n/d	n/d	0.12	3.34	0.009	0.06	0.27	78.299
Area scan 2	70.02	0.68	2.16	0.28	n/d	0.54	n/d	n/d	n/d	0.33	3.39	0.13	0.12	0.79	78.44

n/d=not detected.

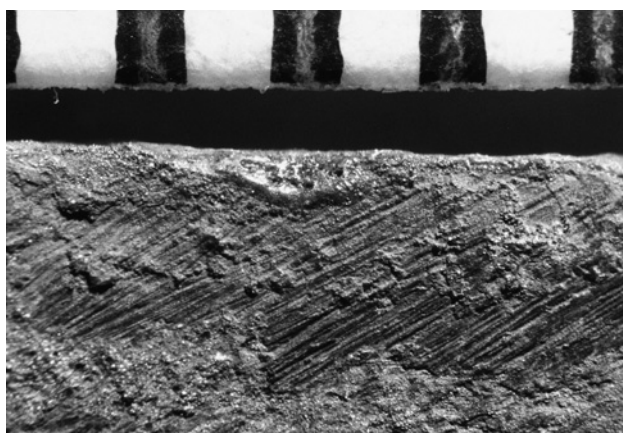


Figure 6. Mechanically cleaned section of point ZP97.237 showing working marks preserved in patina. Scale shown is in millimetres. Kathy David, ROM.



Figure 7. Mechanically cleaned surface of dagger ZP97.232 showing hair-line fracture. Kathy David, ROM.

other locations. A test area was then tried on adze ZP97.219. This object was very weighty, which suggested that it might be less mineralized than some of the other objects and might therefore provide an easier subject. However, the patina could not be located on this object either.

A further attempt at locating the patina on the dagger ZP97.232 proved successful. Of interest are parallel-working marks found preserved in this layer which can be seen to run under the corrosion layer (see Figure 6 and cf. Figure 7). Also revealed were hairline fractures in the surface of the blade (see Figure 7 and cf. Figure 8). These cracks are likely due to the weight of the monolith found resting on them. The blade is unusually thin. On another area of the blade, viewed macroscopically, was a group of crystals, which appeared to be cuprous chloride. The crystals' location above the cuprite layer made this identification logical, as the proximity of the site to the sea renders a high concentration of chlorides plausible. However, XRD analysis identified these crystals as gypsum, hydrated calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, for which the more likely source is the calcium rich ground water.

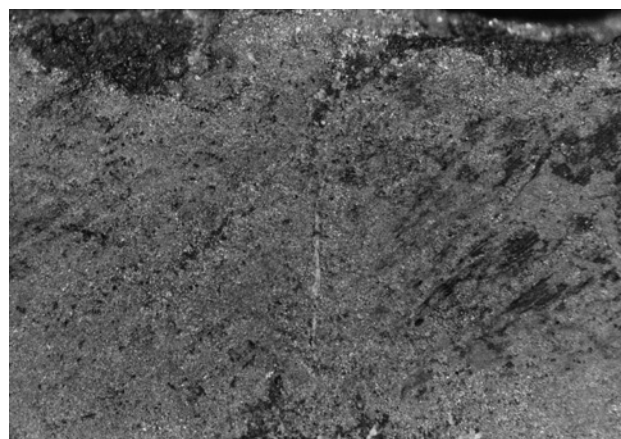


Figure 8. Hair-line fractures through point ZP97.237 running at right angles to length of point; now filled with lighter coloured corrosion products. Kathy David, ROM.

A test cleaning of point ZP97.237 was begun to compare corrosion/patina from a selection of objects from this excavated group. The polished break (see Figure 9) created while taking a section for

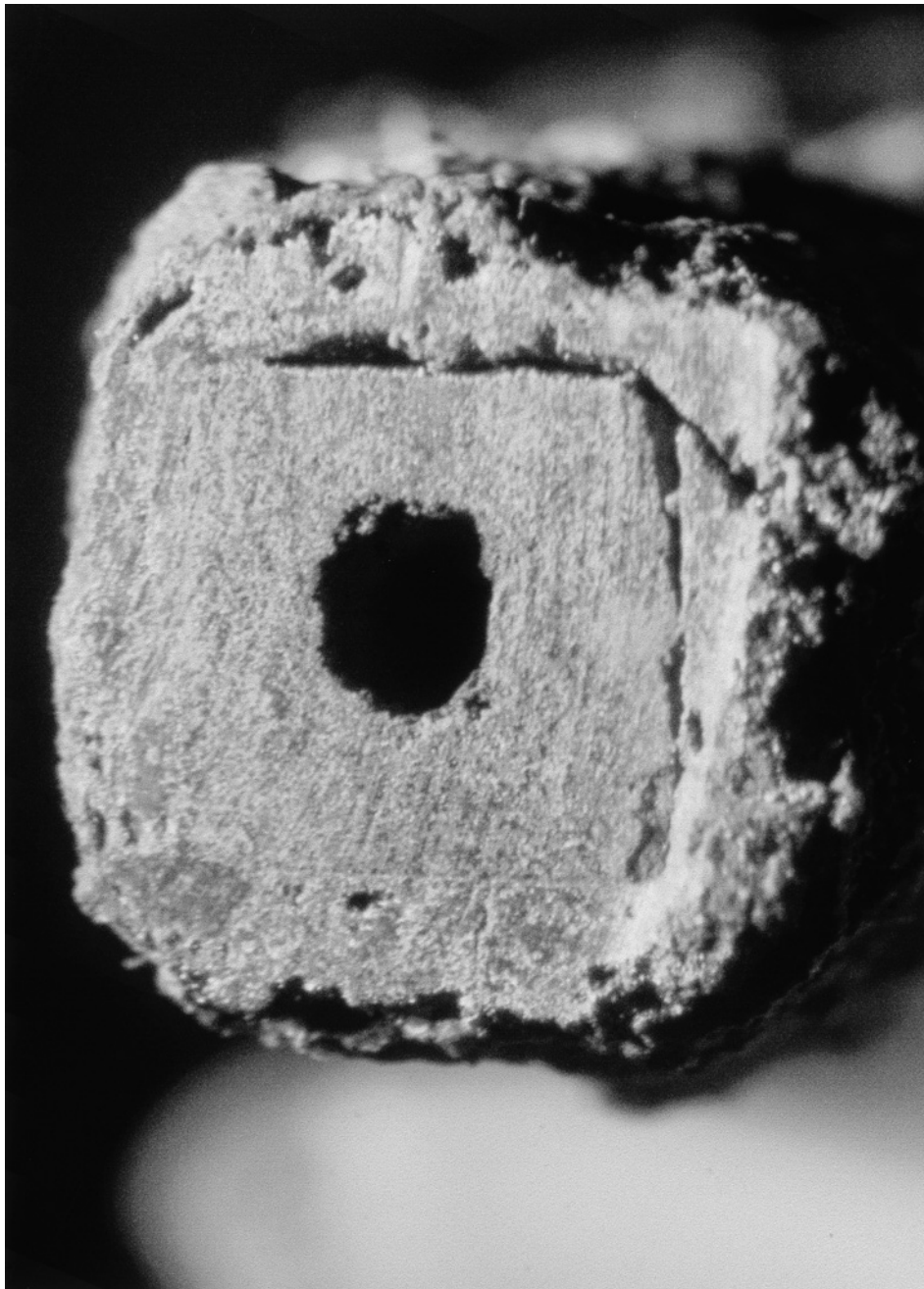


Figure 9. Polished cross section at break, mid-section, in point ZP97.237, showing actual square shape of object within massive corrosion products. Hole in center is location of sample drilling. Kathy David, ROM.

metallography and analysis showed an interesting cross section, indicating the relative thickness of the corrosion and location of the patina. Removal of the corrosion to a delicate patina revealed an object with a thin square profile, quite different from the impression of a “javelin point” that was indicated in its excavated state. This object is totally mineralized and therefore extremely fragile. As with the dagger, working marks were revealed in the surface patina (see Figure 6). They run at 45° to the edge of the pin and wrap around the

object’s edges. Superficial hairline cracks, as on the blade, can also be seen, running mainly at right angles to the edge of the pin (see Figure 8). These are unusual finds in a patina and may be stress cracks. In the absence of a metallurgical explanation, one hypothesis is that these cracks and those on dagger blade ZP97.232 were caused by the movement of the earth due to the weight of the monolith above, during or after burial. As the weight stabilized, the fissures then re-corroded together.

Of additional interest because they are rarely documented (Gettens, 1970: 63) are two unusual corrosion products identified by XRD analysis, conellite $\text{Cu}_{19}\text{Cl}_4(\text{SO}_4)(\text{OH})_{32} \cdot 3\text{H}_2\text{O}$ and buttgenschite $\text{Cu}_{19}\text{Cl}_4(\text{NO}_3)_2(\text{OH})_{32} \cdot 3\text{H}_2\text{O}$. Both are azure blue in colour. Various blisters in the corrosion, when opened during cleaning, showed dense crystals of cuprite, or colourless plates and crystals identified as gypsum. These crystallized formations on blade ZP97.232 and point ZP97.237 may indicate cycles of wet/dry and the slow evaporation of salts in solution after burial. The thickness and density of the corrosion products are similar to those seen on artifacts from contexts that have been exposed to periodic inundations. Conservation work is continuing.

Discussion

Arsenic

All copper-based objects excavated at al-Midamman contain measurable amounts of arsenic. The range is 0.12–2.21%. The presence of low levels of arsenic could be due to the use of copper ores in which arsenic was a relatively high impurity (Shugar, 1998). However, it could also be the remains of arsenical ores, such as realgar or orpiment (i.e., in sulphide form), previously smelted with copper ores to produce an arsenical copper alloy, which was then recycled several times. As arsenic is very volatile, some would have been lost in the form of vapor, in each re-melting of the metal. Another possible source could have been scrap arsenical copper, which was mixed with freshly smelted copper.

One of the two daggers (ZP97.244, samples 4 and 5, at over 1% As), and a point (ZP97.216, over 2% As) do contain higher arsenic levels than the remaining objects; however, even in this case, it is difficult to establish for certain whether the arsenic was deliberately added, as it can occur as a natural impurity even in rather pure copper ores. Lechtmann (1991, 1996) suggested that a level of arsenic of 0.5% was a recognizable intentional alloy for the metal smiths in the Andes. For the old world, Craddock (1976) suggested a level of 1% of arsenic as the border limit between accidental impurity and deliberate alloying, while Branigan (1974: 71–72) and Tylecote (1991: 215) suggested a level of around 2% As. Cowell (1985: 97–98) recommends a comparison of the arsenic to iron levels as a way of obtaining a better indication of the origin of the arsenic. Higher iron contents in the copper, in combination with the presence of arsenic, can indicate the use of unrefined (or not completely refined) copper. The iron levels in ZP97.244 (one of the daggers and its rivets) and in ZP97.216 (one of the points) are indeed slightly higher; however, the iron measurements may be enhanced because of corrosion problems.

An enriched Fahlerz-type ore tends to contain higher levels of many impurities, such as arsenic, antimony,

bismuth, nickel and silver. However the copper used for the finds from al-Midamman does not seem to have been reduced from this kind of ore, as these elements are quite low in all samples containing higher percentages of arsenic. Whatever the source, it should be stressed that the improved properties of the arsenical metal must have been evident to the metalworker. Arsenic acts as an excellent deoxidant for the metal, reducing its porosity and noticeably hardening the alloy. The relatively low arsenic content of dagger ZP97.232 (and its rivets) and point ZP97.216 could have resulted from its deliberate addition as a deoxidant (Northover, 1989: 113).

Arsenic, even at low levels, can change the colour of the metal giving a silvery appearance to the surface (Giumlia-Mair, in press *b*). In smelting experiments intended to replicate the production of arsenical copper found at Batan Grande, Peru, it was found that prills could be differentiated by their colour with arsenic contents as low as 2% (Merkel *et al.*, 1994: 221). It should also be noted that examples of similar daggers made of silver are also known (Primas, 1988: Figures 6, 2, 3). This raises the possibility that the arsenical copper objects from al-Midamman, and other objects of similar alloys from the Near East, were meant to look like silver. The possibility that this had specific cultural significance is discussed by Hosler (1994). Either one or both of these explanations may account for the use of arsenical copper for the rivets of dagger ZP97.244 and point ZP97.216. Further, the low total of the ICP results of the sample from the blade ZP97.244 (sample no. 3), which is due to corrosion problems, suggests that the arsenic content might originally have been higher and that the blade and the rivets were made of the same metal, most probably to obtain the same colour on all parts of the weapon. The general picture seems to indicate that in these objects the arsenic content is due to deliberate co-smelting of an arsenic ore (such as orpiment or realgar) and copper ore, with the aim of obtaining an alloy with better working properties, and possibly a different colour than unalloyed copper. However, some twinned crystals—the result of hammering and annealing—are visible on the metallographic sample of the dagger, and repeated annealing might have spoiled the silvery surface because of the high volatility of arsenic.

Tin

Objects with high arsenic levels do not contain appreciable tin and vice versa, objects which contain tin, show lower arsenic levels. This seems to confirm that we are dealing with deliberate additions of either arsenic or tin.

The low tin contents in dagger ZP97.232, one of the points ZP97.231a and the razors ZP97.218 and ZP97.110 (sample no. 15) are somewhat puzzling, as such low levels (2–3% Sn) have little influence on the properties of an alloy, particularly if compared with

the effect of the same amount of arsenic (Tylecote, 1979: 14–15; Cowell, 1985: 98). However, since mixed copper-tin ores do not normally occur in nature, copper-tin alloys of any composition are commonly considered an artificial alloy (as opposed to a natural alloy, for example of arsenical copper smelted by chance from mixed copper/arsenic ores). Possibly the smiths were still experimenting with tin, as a new alloying material, or they were recycling scrap bronze (Tylecote, 1991: 218). Similar copper items with low percentages of tin are known from several Bronze Age contexts (Bahat, 1976: 27–33; Bahat, 1975: 18–23, 117; Cowell, 1985: 98; Craddock, 1985: 99; Philip, 1991: 94; Shalev & Northover, 1993: 287–243; Stech *et al.*, 1985: 76).

The reason for employing low tin alloys could also be the wish of the artisan to keep the red colour of copper and to improve the casting properties of the metal. Tin deoxidizes, aids the fluidity of the molten metal (by reducing the melting temperature), and improves workability. In later times, for example, the coppery red lips and nipples of Greek statues or even details like the inside of elephant ears on a Roman triclinium ornament (Giumlia-Mair, *in press*) were made of such alloys, when a red colour and better working properties were required.

Lead

The lead present in the metal of razor blade ZP97.110 (sample no. 15) does not appear to be a deliberate addition, as it does not improve the functionality of the implement. This element might have been concentrated in the particular zone of the ore body from which the copper was smelted, or it may have been introduced in the flux added to the charge in the melting furnace. Lead percentages of up to around 2% can still be an impurity in copper (Giumlia-Mair, 1998a). Erratic amounts of lead are found in copper based objects by the Early Bronze Age, all over the Mediterranean (Craddock & Giumlia-Mair, 1988). By the Iron Age there is a clear correlation between the use of lead, the manufacturing process of the objects and their function (Giumlia-Mair, 1992, 1998a, b; Giumlia-Mair *et al.*, 1998).

Nevertheless, as pointed out by Cowell (1987: 98) and Philip (1991: 98–99), it seems that the deliberate addition of lead was practiced very early, possibly by the Early Dynastic period (Cowell, 1985: 98). The low level of lead in the blade of razor ZP97.110 (sample no. 15) has, of course, no practical function in a part of the artifact that had to be hardened by hammering. Lead is insoluble in copper and, if used in higher quantities, forms globules dispersed in the alloy, which weaken the metal and render it prone to cracking under the hammer. The level of lead in the razor could be due to a segregation phenomenon; however, the addition of lead (up to 2%) improves the fluidity of the molten metal. This alone could have been seen as a good

reason for the use of lead as an additive in this early period. The presence of lead in the razor raises again the extremely important and thorny question elucidated by Philip (1991: 101; 1995: 529) on the possibility of scrap metal having been used as the substantial bulk of supply in the metal trade at an early stage of metallurgy. This is particularly relevant in the discussion about lead isotopes. Obviously, this problem can only be resolved by evaluating large amounts of data, which are as yet, not available.

Regional Comparisons

The few existing analyses of objects from Anatolia and the Near and Middle East during the transition period, from the use of arsenic as an alloy to the preferred use of tin as an alloying element, seem to indicate that the simultaneous use of low tin bronzes, arsenical copper, and unalloyed copper lasted for over a millennium, from the Egyptian Early Dynastic Period to some point in the Bronze Age (Caneva *et al.*, 1985: 129 Figures 6–7; Frangipane & Palmieri, 1998: 140; Philip, 1991).

It is difficult to date the objects in this report typologically, because on sites as remote as al-Midamman, there is always the strong possibility of conservatism and archaism in the shapes. Furthermore the objects found buried in the main cache obviously reflect some form of ceremonial deposition, as practiced almost everywhere in early times (Cazeneuve, 1971: 72–75). In several instances, in different periods and with different cultures, objects were produced for ceremonial use only and were often not functional. The aim was a mere formal reproduction of the items for offerings, whose important features were the shape and the appearance of the metal, for example the colour (Shalev, 1995), rather than the alloy and its working properties. The alloy for this purpose would not have had any metallurgical significance and the smith may have used whatever cheap metal was at hand (Giumlia-Mair, 1998a). However, as already mentioned in the section on metallography, the tools found on the site are hardened and functional. Of course the evidence of hammering in these objects does not exclude the possibility of ceremonial deposition, but indicates that the objects were produced with the possibility of use in mind.

Typologically, the dagger can be broadly compared to some EB-MB period types (Philip, 1991: Figures 3, 7; Seligman & Yogev, 1993: 74 Figure 4 and note no. 4). The two adzes can be compared to other examples dated to the EB-MB periods (Shalev, 1994: 634, 5–6 for example of early pieces). The presence of the leaf-shaped object, listed as “spatula” in the table of results, links the al-Midamman hoard to tomb III at Ma’ayan Barukh, dated to EB IV, in which daggers and a similar object were present (Amiran, 1961; Dever, 1980). Tomb I at Tiberias, Israel, dated to MB I (Tzaferis,

1968: 15–19) has also been linked stylistically to Ma'ayan Barukh, Israel (Stech *et al.*, 1985: 80). Based on typological comparisons, a date range within the EB-MB periods seems to be the most probable.

The group of objects analysed is very small and it is not sufficient for a meaningful statistical comparison with other groups of objects. Nevertheless, it is interesting to note that the composition and the trace elements present in the objects do not seem to be comparable to those identified by Cowell (1985: 108–118) in Egyptian material or by Stech *et al.* (1985: 76) in the finds from Enan, which contain both arsenic and tin, nor to the ones identified in the material from the prehistoric tombs of Ras al-Khaimah (Emirates), which contain high percentages of nickel (Craddock, 1985). Anatolian material contains quite high levels of arsenic, nickel and antimony (Caneva *et al.*, 1985: 122–123; Frangipane, 1985: 215–218; Palmieri *et al.*, 1997; Riederer, 1987/88: 247). The unpublished Tell Abraq (Emirates) material (Richard Thomas, personal communication, 1997) and the material from Oman (Hauptmann, Weisgerber and Bachmann, 1988: 41–47) also seem to contain high percentages of arsenic and nickel; but this is not the case with the finds from al-Midamman.

From what we know so far, the shapes and the objects are very similar to the finds from the sites mentioned above, but the metal from the site at al-Midamman seems to be different, with the use of quite pure copper alloyed either to arsenic or to tin and, possibly, diluted with more unalloyed copper. The analysis of more objects could perhaps completely change our understanding; however the data we possess at present would seem to indicate a different origin for the copper. This could also mean that the settlement of al-Midamman belonged to a different sphere of influence than that of the maritime trading centers on the other side of the Arabian Peninsula. Perhaps a closer look at the civilizations on the Western side of the Southern Red Sea will provide more information on this matter.

Ancient Sources

The examination of several ancient texts provides insights into the relationships amongst different cultures around the Arabian Peninsula. Some cuneiform texts report that the son of Sargon, Manishtushu (2274–2260 BC) destroyed Awan/An Shan, the capital of Elam and overthrew the king of Magan, which was most probably today's Oman. For the identification of Magan as the "Legendary Land of Copper", see Weisgerber (1977: 192 and fn. 15).

The strong links between the cultures around the Indus, and in Elam and Mesopotamia, are well illustrated by the lapis lazuli trade from Afghanistan, down the Indus and up the Persian Gulf to Mesopotamia, Syria and Egypt (by sea) already in the third

millennium BC. A second indication of the vigorous trade between these regions are the tapered chlorite vessels, often with turquoise inlays, produced by eastern Iranians and exported to Syria and to the Indus valley (Carter, 1997: 325).

Yemen, on the other side of the Arabian Peninsula, seems to show more connections to the Ethiopian/Eritrean side of the Red Sea. Fattovich (1978: 352) connects the megaliths in Yemen (which he dates to the 2nd millennium BC "and possibly earlier") with the megaliths in the area of Harar, and the paintings and incisions on rocks in the Hijaz desert with similar artistic expressions in the Ogaden. He argues that people belonging to the same group lived on both sides of the Red Sea, and that they traded in incense and myrrh up to the Mediterranean by following three trade routes: the land route down the Nile valley, the land route along the Western Arabic Peninsula and the maritime route down the Red Sea.

The lists of Tuthmes III mention the trade with the Gnb-tjw and other contemporary texts mention the import of incense from still unidentified areas. Fattovich (1978: 353) interprets the Gnb-tjw as the inhabitants of Qataban and the land, where incense was produced, as Yemen. The different metals used on the western and the eastern coast of the Arabian Peninsula could reflect the existence of two different spheres of influence: one encompassing both coasts of the Red Sea and the second the countries around the Persian Gulf.

Conclusions

An interdisciplinary study was undertaken to fully investigate the copper hoard discovered at the archaeological site of al-Midamman, Yemen. The hoard was composed of objects which in composition and style strongly suggest that they were produced sometime during the EB-MB periods. But, it must be emphasized that the parameters used to date objects in other geographic locations do not necessarily apply in Yemen. In addition, the number of objects analysed is too small to be able to draw general conclusions, and to consider them exclusively distinctive to this culture. As such, the data should only be considered as indicative.

This study has shown that an interdisciplinary approach, including field archaeology, archaeometallurgy and conservation, can provide a worthwhile method of investigation. Our preliminary work provides some insight, however more field research is necessary on the Yemeni coastal plain, as well as in the Horn of Africa, together with metallurgical studies. During further research, possible influences from the Indian Sub-Continent should also be considered. In addition the obsidian finds should be compared with finds from other regions (in particular from Dahlak islands) to provide scientific evidence regarding the trade of this material.

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