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Modern Bedouin exposures to copper contamination: an imperial legacy?

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Abstract

The exposure of a modern Bedouin population living in the deserts and mountains of southwestern Jordan, to metal contamination was assessed via the analysis of sediments, plants, livestock, and foodstuffs. Exposure to copper is demonstrated to be a potential hazard. The Bedouin are shown to be vulnerable to contamination via several pathways, the most serious of which are familiar in the industrialized environments of the developed world.

Keywords: Bedouin; Copper; Exposure; Accumulation; Health

1. Introduction

The mineralized rocks of the Arabah rift system in the Faynan area of southwestern Jordan (Fig. 1) have been a source of mineral wealth, in particular copper, for millennia (Barjous, 1992; Rabb'a, 1994). Archaeological evidence indicates that they appear to have been utilized on an industrial scale from at least 2900 BP to 1400 BP (Hauptmann, 2000) and, indeed, were utilized on a smaller scale to produce jewelry from as early as 9000 BP. During this time, the copper resources fell variously within the realms of several Near Eastern empires, including the Assyrian, Babylonian, Egyptian, Roman, and Byzantine, in addition to local biblical kingdoms, such as Edom and Moab (Hauptmann et al., 1992; Pyatt et al., 2000). Industrial-scale exploitation of the copper appears to have ceased with the expulsion of the Byzantine administration from the area in the seventh century AD (Lewis, 1996).

In southern Jordan the center of these industrial activities appears to have been an extensive tell, known as Khirbet Faynan (Arabic: The Ruinsof Faynan), which is believed to have been the Roman city of Phaino, notorious in the Roman world for the dreadful conditions endured by the prisoners and slaves who were condemned to the mines(Eusebius, 1989). This ancient industrial center is located 70 km to the southeast of the Dead Sea at the eastern mountain front of the great Wadi Arabah rift valley in and adjacent to the Wadi Dana Nature Reserve (Fig. 1). The Dana Reserve contains a number of major wadis including Wadi Faynan and Wadi Ghuweir (Fig. 2), which drain into the Wadi Arabah. The rock strata in the geological sequence that are rich in copper are the Numaya Dolomite Limestone of the Durj Dolomite Shale Formation and the Umm' Ishrin Sandstone formation of the Middle and Lower Cambrian ages(Barjous, 1992; Hauptmann et al., 1992; Rabb'a, 1994). Geochemical analyses of the sedimentary rock of the study area have yielded values of 0.41–5.95% Cu. Soils in the study area are formed mainly from alluvium, colluvium, and eolian sediments sourced primarily in the complex escarpment geology and are thus composed of clay-to sand-sized particles, normally eroded from granite, sandstone, and limestone parent materials; in addition the metal content of the many soils are enriched by the redistribution by eolian and fluvial processes of mining and smelting wastes (Gee et al., 1997; Maskall and Thornton, 1998; Pyatt and Birch, 1994).

Today Khirbet Faynan is surrounded by massive heaps of black slag, estimated to total several hundred

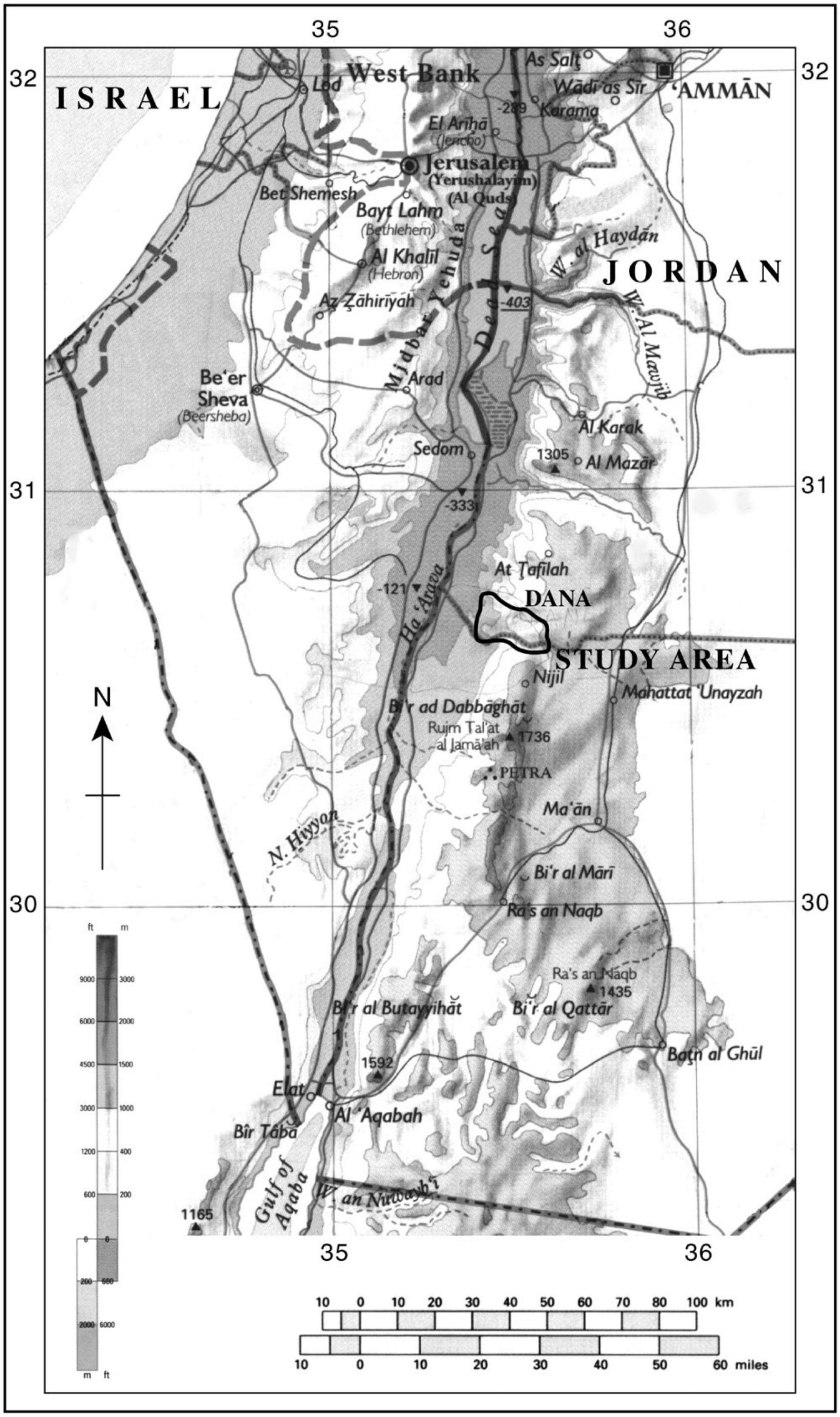

Fig. 1. Location of study area.

thousand tons, and less obvious industrial wastes in the form of metal-enriched soils derived from ore-proces-sing activities. The physical evidence for ancient industrial activities is extensive; dozens of abandoned mine adits and shafts may be visited, including the largest copper mine in the Roman Empire (Hauptmann, 2000). In Fig. 2 the ruined center of Khirbet Faynan is obvious as are extensive areas that are covered in slag and ash. Archaeological survey suggests that metal-processing activities occurred in many areas of this landscape, not just those apparently blighted by industrial wastes (Barker et al., 1997, 1998, 1999).

The living conditions endured by the workers who mined and processed the copper ores in ancient times were the subject of an earlier paper (Pyatt et al., 1999). This study explores the potential exposure of the modern Bedouin inhabitants to pollution which originated in ancient times via an analysIs of the copper concentrations of materials found or used within three Bedouin camp sites in this area. Site 1 was occupied in 1999, site 2 was occupied in 2000, and site 3 was occupied during the most recent field visit in 2001. Sites 1 and 2 were traditional campsites used every few years by families of the same Bedouin clan living in classic

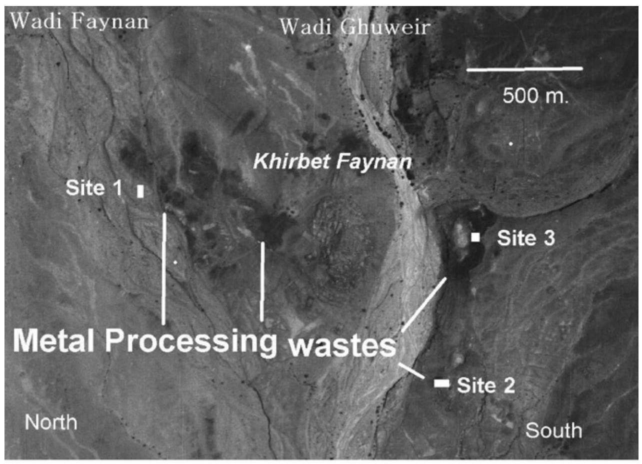

Fig. 2. Khirbet Faynan and location of sample sites.

black tents(Fig. 3), which were approximately 12 m long. There isno readily available information asto how long each of these campsites has been used, but decades if not centuries are not unreasonable estimates. Site 3 was a much smaller transient encampment, established recently and probably occupied by one or more goat herders. 2. Methodology

Materials which reflected a range of inputs into each camp site were collected and their copper contents analyzed. To determine whether copper was present in the Bedouin diet, bread made in site 2 was analyzed. Sediments were collected from the living floors of each of the three camp sites. To ensure coverage of the various activity areas in each dwelling, samples were taken at 1-m intervals along three parallel transects which were 1.3 m apart. Samples of sediment were also collected from the industrial complex closest to each dwelling site. Site 1 was 150 m from industrial wastes, site 2 was within 20 m, and site 3 was located within heaps of industrial waste (spoil and slag) next to a flat area where goatscould be conveniently tended. To act as a control, sediments were also gathered from freshly exposed Quaternary sediments in the Wadi Ghuweir (Fig. 2). All sediments were stored in clean glass tubes and air-dried at the Wadi Faynan field study center, which is maintained by the Council for British Research in the Levant.

Other potential inputs to the dwelling areas, such as fuels, foodstuffs, and unconsolidated industrial wastes were also collected and analyzed. Fuels used by the Bedouin include wood and animal dung, and samples of these were collected where possible. Finally, we were

Fig. 3. Traditional Bedouin black tent, Wadi Faynan.

Table 1 Copper contentsof tent floor sedimentsat Site 1 (mg/kg)

Locations	A	B	C	D	E	F	G	H	I	J	K
One Two	48 56	52 44	48 44	72 80	148 132	84 92	100 120	140 172	68 128	64 72	82 60
Three	40	56	44	92	160	100	112	168	84	94	91

Table 2 Copper contentsof tent sedimentsat Site 2 (mg/kg)

Locations	A	B	C	D	E	F	G	H	I	J	K
One	1360	680	1440	1440	1280	1760	1520	2320	1560	1720	2840
Two	1480	760	1280	1320	1280	1640	1800	2200	1760	1320	2400
Three	1200	760	1320	1360	1280	1640	2040	2440	1280	2000	2480

fortunate to be able to collect and analyze bread made at site 2. All plants, dung, and bread were stored in sterile glass tubes and air-dried at the study center before being sealed. Controls for the plant materials were obtained several kilometers from the sample sites, high in the mountains which fringe the Wadi Arabah. Controls for the flour and bread were obtained from Amman. Controls samples for the animal dung were not obtained.

Sediments were analyzed at the University of Wales, Aberystwyth and the biological materials were analyzed at the Nottingham Trent University. The plant materials were thoroughly cleaned using distilled deionized water and air-dried. All materials then underwent a standard acid digestion procedure and were subsequently analyzed by flame atomic absorbtion spectrophotometry (in Aberystwyth using a Perkin–Elmer 3110 instrument and in Nottingham using a Perkin–Elmer 1100 instrument). All results presented are the means of three replicates. Blanks were tested on both instruments and confirmed the accuracy of the analyses.

3. Results

3.1. House floors

The results of the analysis of the floor sediments of the tents at the three sites are presented in Tables1–3.At site 1, copper values range from 40 to 172 mg/kg sediment (Table 1). At site 2, copper values range from 680 to 2840 mg/kg sediment (Table 2). At site 3, copper values range from 1080 to 1720 mg/kg sediment (Table 3).

3.2. Quaternary sediments

The copper value obtained from the Quaternary sediments, which were used as a control, was 18 mg/kg sediment.

Table 3 Copper contentsof tent floor sedimentsat Site 3 (mg/kg)

Locations	A	B	C
One	1480	1480	1720
Two	1160	1200	1080
Three	1200	1360	1240

3.3. Bread

The bread made by the Bedouin at site 2 contained 364.37 mg/kg of copper. In contrast, the copper content of ‘‘Bedouin Bread’’ made in the traditional manner, but bought in Amman, was18.74 mg/kg bread. The copper content of proprietary flour, of the same brand as that used by the Bedouin in Wadi Faynan, was 13.87 mg/kg flour.

3.4. Plant material

Any plant which will burn may be used as fuel, but many of these grow in sediments derived from industrial activities. Acacia spp. wood collected from abandoned Byzantine-era fields to the west of site 2 contained an average copper content of 166.17 mg/kg wood. Acacia control samples obtained high in the mountains to the east had a copper content of 2.82 mg/kg wood. Oleander surviving close to site 2 had a copper content of 159.36 mg/kg dried plant stem. The copper content of Oleander control samples, collected at the head of Wadi Ghuweir, 5 km to the east, was 32.58 mg/kg dried plant stem.

3.5. Feces

Samplesof fresh goat feces were collected as they grazed between sites 2 and 3. Goat management in the desert may result in any goat herd walking over 15 km per day in search of grazing, and thus these analyses cannot be held typical of any specific area. The average

Table 4 Copper content of industrial wastes proximal to each Bedouin tent site (mg/kg)

Site	Copper
1	2600–2800
2	8000–16,000
3	4000–6000

copper content was150 mg/kg feces and thus is a potential source of copper into the Bedouin domestic environment and perhaps their food web.

3.6. Unconsolidated metal processing and mine wastes

Samples of these were collected from the wastes in the vicinity of each site (Fig. 2). Copper concentrations varied considerably, but in all cases were very high, ranging between 2600 and 16,000 mg/kg sediment (Table 4). Eolian processes ensure that these sediments represent an active source of environmental pollution across a wide area (Pyatt and Birch, 1994).

4. Discussion

The results obtained all indicate a significant risk of exposure to metals at each Bedouin camp site. At each location the floor sediments were enriched in copper above the concentrations detected in the unpolluted Quaternary sediments. The copper content of most of the tent floor sediments analyzed are higher than the copper concentrations found in the sediments of the Great Lakes of North America, which continue to cause great concern (Cusack and Mihelcic, 1999), yet here they are part of the Bedouin domestic environment. The copper content of the floor sediments derive from several sources. First, and most obviously, the copper content of the camp site sediments has been enriched as the result of ancient industrial activities long before the establishment of each Bedouin camp (Pyatt et al., 1999, 2000). Second, human activities may have introduced a range of materials which may have an enhanced copper content, mainly in the form of windblown copper-rich dusts from deflating spoil heaps, wood fuel (Gupta and Gupta, 1998) and animal dung (Pyatt and Grattan, 2001) which may be enriched in copper.

4.1. Metal distribution, enrichment, and trophic accumulation within the Bedouin camps

4.1.1. Distribution

Sites1 and 2 had been occupied by traditional Bedouin black tents(Fig. 3), where defined areas of the dwelling are traditionally used for specific activities. These areas are the public or men's area (the shigg) where tea is drunk, guests are welcomed, and the men may sleep, and the private or family area (the mahram) where cooking and food preparation takes place and which may be subdivided into separate sleeping areas. When necessary livestock are also stalled in the mahram, in particular throughout the winter months, which is warm but aromatic!

All the soil metal values at site 1 were at least double the concentrations found in the Quaternary sediments used as a control. This must reflect the site's proximity to Khirbet Faynan and extensive metal working wastes (Fig. 2). At site 1 (Table 1), within the shigg, copper concentrations ranged between 40 and 92 mg/kg sediment; in contrast, copper concentrations within the mahram reached 172 mg/kg sediment, much higher values than those found in the shigg, with notable enhancements apparent around the hearths(between 148 and 172 mg/kg sediment).

Site 2 was located on a flat area (Fig. 2), which had been previously cleared to grow watermelons, immediately below Roman-era industrial ruins and sediments associated with ore processing and smelting. Copper concentrations in the floor sediments are much higher than those observed for site 1, ranging from 680 to 2840 mg/kg sediment (Table 2). The domestic divisions of space within the tent appear to be reflected in the copper concentrations determined for the sediments which make up the tent floor. Within the shigg the average copper content of the floor sediment is 1216 mg/ kg, while within the mahram the average copper content is 1836 mg/kg. Despite these high values, the domestic divisions of the tent are again apparent in the metal concentrations observed in the vicinity of the cooking hearths(between 1640 and 2440 mg/kg sediment).

At site 3, which is located on a cleared flat area between mounds of black copper slag (Fig. 2), copper valuesin the sediments range between 1080 and 1720 mg/kg (Table 3). The entire structure was only 3 m square and as a temporary goat herder's shelter there are no subdivisions of use apparent within the area, nor was any hearth area obvious.

4.1.2. Enrichment

There are several apparent influences on the copper concentrations detected at each tent site. The primary influence is the background values for the soils at each location. All of these are above the copper concentration in the control sample and must reflect land use and proximity to industrial processing. Site 1 is within 150 m of industrial wastes, but is not directly built upon them. Background copper-concentrations at site 1 must reflect the redistribution of copper-contaminated sediments, most probably by eolian processes. Site 2 is within 20 m of obvious industrial structures, including a (long-empty) reservoir and a sluice, which may have powered a mill (Barker et al., 1999). The sluice looms above the field in which site 2 is located and water runoff may have introduced metal particles in solution and suspension into the soils. Site 2 therefore appears to have been sited upon sediments which may have been directly enriched with copper during ancient times and is very close to easily redistributed ancient industrial wastes.

The secondary influence is material introduced into the tents. Copper-rich dusts may be transported by eolian processes into the tents (Pyatt and Birch, 1994). This mechanism should be reflected in the general background values from the tent floors rather than as localized hotspots. Copper may also be introduced into the tents via combustion of woods gathered as fuel. It is clear from the analyses of trees growing in the area that the Acacia spp. and Oleander spp., which are frequently used as firewood, contain enhanced concentrations of copper and these will naturally be released into the tent environment in the form of ash and smoke. Each time the hearth is cleaned, the ash is distributed across the floor in the vicinity. The copper concentrations around the cooking hearths located within the mahram appear to have been enhanced by this practice. Finally, animal dung has been shown to contain high concentrations of copper, and these may be introduced both as fuel and as the consequence of animal stalling. It is clear from Tables1 and 2 that the floor sediments of the domestic areas of the traditional Bedouin tents contain higher concentrations of copper than the public areas and it is reasonable to propose that this may be the result of the use to which each area is put. This enhancement of the copper concentrations in the floor sediments of the domestic areas of the tent inevitably enhances the risks of exposure to potentially toxic concentrations of this metal. In particular, the concentration of copper in the sediments around cooking and food preparation areas may pose particular risks.

4.1.3. Trophic accumulation

It is clear that the Bedouin occupying this area are exposed to considerable concentrations of copper in their domestic environment and may accumulate these in their bodies via several pathways. The ingestion of copper through copper-contaminated food stuffs can be dramatically illustrated. The copper content of bread prepared at site 2 was 364.37 mg/kg; in contrast, the copper content of similar bread bought in Amman and used as a control was 18.74 mg/kg. The baking process therefore appears to have resulted in the 20-fold enhancement of the copper contained in the flour. The processes by which the copper may have been incorporated into the bread illustrate the risks involved here. Flour ismixed with water and kneaded into a dough; the dough is then handled vigorously until it has taken the form of a thin, roughly circular sheet. This sheet of dough is then draped over an upturned hemispherical cooking vessel, which is perched on stones over a wood fire and baked (Fig. 4a). Contamination of the bread may happen at several points in the process. First, the flour itself may be contaminated while in storage within the campsite by eolian copper-rich dust. Second, during baking, the dough may be exposed to copper dust from the floor of the tent and from the hands of the women engaged in the baking. Finally, the fire smoke may contain copper released in combustion, and the surface of the cooking vessel, covered in a black patina, may also be enriched in copper released by numerous previous fires Figs. 4a and b illustrate the nature of food preparation at site 2 and the potential for the accumulation of copper in the cooking process in this environment. In Fig. 4a, bread making is taking place at the cooking hearth. The copper in the floor sediments around the women reach 2440 mg/kg sediment and the risk of contamination is obvious. In Fig. 4b, two Bedouin women are engaged in food preparation. They are kneeling on the bare ground, there is no table, and the copper content of the sediments around them is 1440 mg/kg.

In the developed world, people are unknowingly exposed to toxic concentrations of copper in their home (Bluhm et al., 1992), a situation which is strikingly similar to that found in the deserts of southern Jordan.

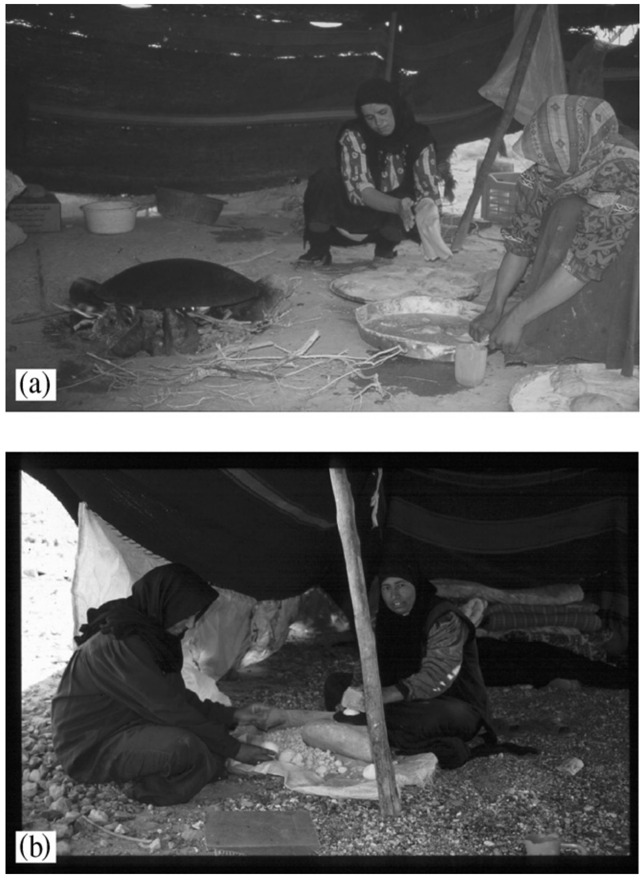

Fig. 4. Cooking activitiesat Site 2: (a) bread making (photograph by Carol Palmer); (b) food preparation (photograph by John Grattan).

In addition to eating, accumulation within the tent may come the inhalation of copper-enriched dusts. The classic pathway whereby polluted sediments are transported from the floor to the mouth via dust accumulated on the hands will obviously be active in both adults and children (Cotter-Howells and Thornton, 1991). Here, as in a home in the developed world, young children crawl on the floor and put their hands in their mouths.

4.1.4. Potential health risks

It is clear that the Bedouin living in Wadi Faynan and in the much wider area of southern Jordan exploited by ancient empires for the mineral wealth that it contained are exposed to high concentrations of copper in their domestic environments. While the biological half-life of copper from the diet is between 13 and 33 days, constant exposure may overwhelm the body’s excretory processes (Barceloux, 1999). Copper may be bioaccumulated by humans and is an essential trace element with a daily dietary requirement of 30 mg/kg adult bodyweight. Beyond trace values, however, exposure to high concentrations may have several severe health consequences. In excess quantities, copper accumulates chiefly in the blood, liver, and kidneys. Accumulation of copper in the human body may result in diarrhoea, nausea, hemmoragic gastritis, vomiting convulsions, coma, and death (Burch et al., 1975; Chuttani, 1965).

5. Conclusion

It is clear from the analyses presented here that the ‘‘Imperial Legacy’’ of enhanced concentrations of copper is an integral part of the modern environment in a wide area of southern Jordan. The copper wastes which are the result of many millennia of exploitation remain in the environment in a number of forms, in mine wastes, in ore-processing spoils, in slags, and in ashes, and all continue to release copper into the modern environment. Contemporary Bedouin are shown to be exposed to enhanced concentrations of copper in their domestic environment and it can be seen that through their own interaction with and management of their surroundings they actually enhance the already high concentrations of copper detected in the tent floor sediments of their dwellings. The situation described here is actually typical of a wide area of southern Jordan and many Bedouin families may be at risk. The Bedouin families, whose tent sites are the subject of this paper, have been advised of these results and have now moved 5 km to the west. The authors are now seeking the collaboration of the Jordanian health authorities to monitor the actual human exposure to copper.

This study demonstrates that the legacy of past industrial activity may persist into modern times and warrants careful investigation. Such ancient and historical industrial sites are common throughout the world, yet little attention is paid to any environmental hazard which may persist. The results presented here suggest that this confidence may be misplaced.

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