ARCHAEOZOOLOGY OF THE NEAR EAST VI

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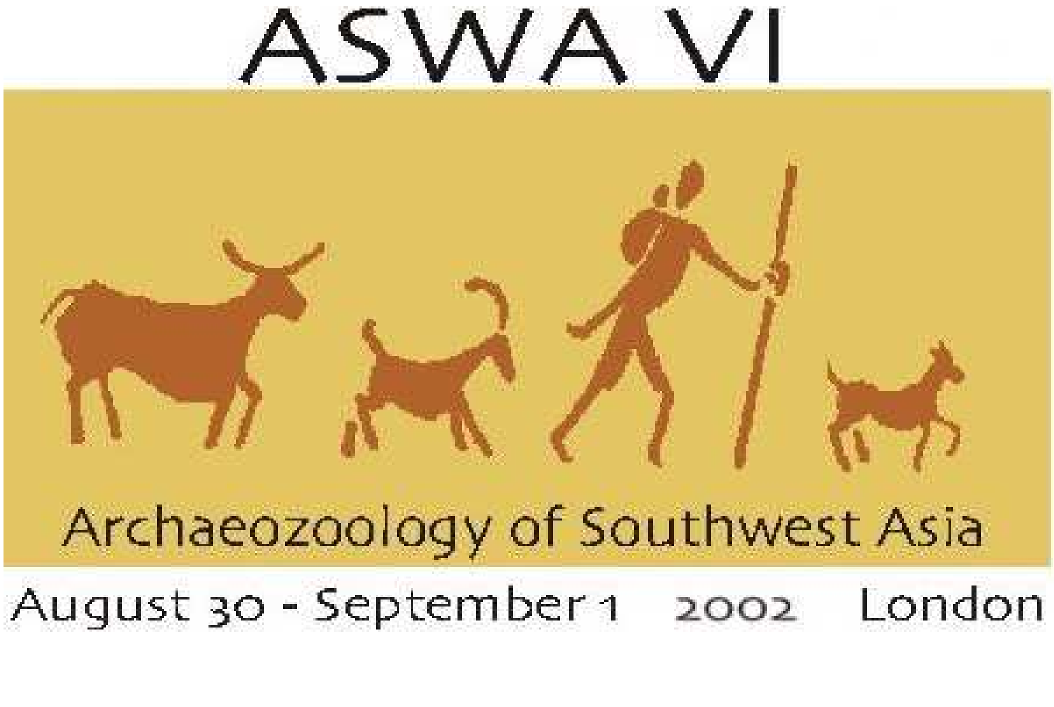

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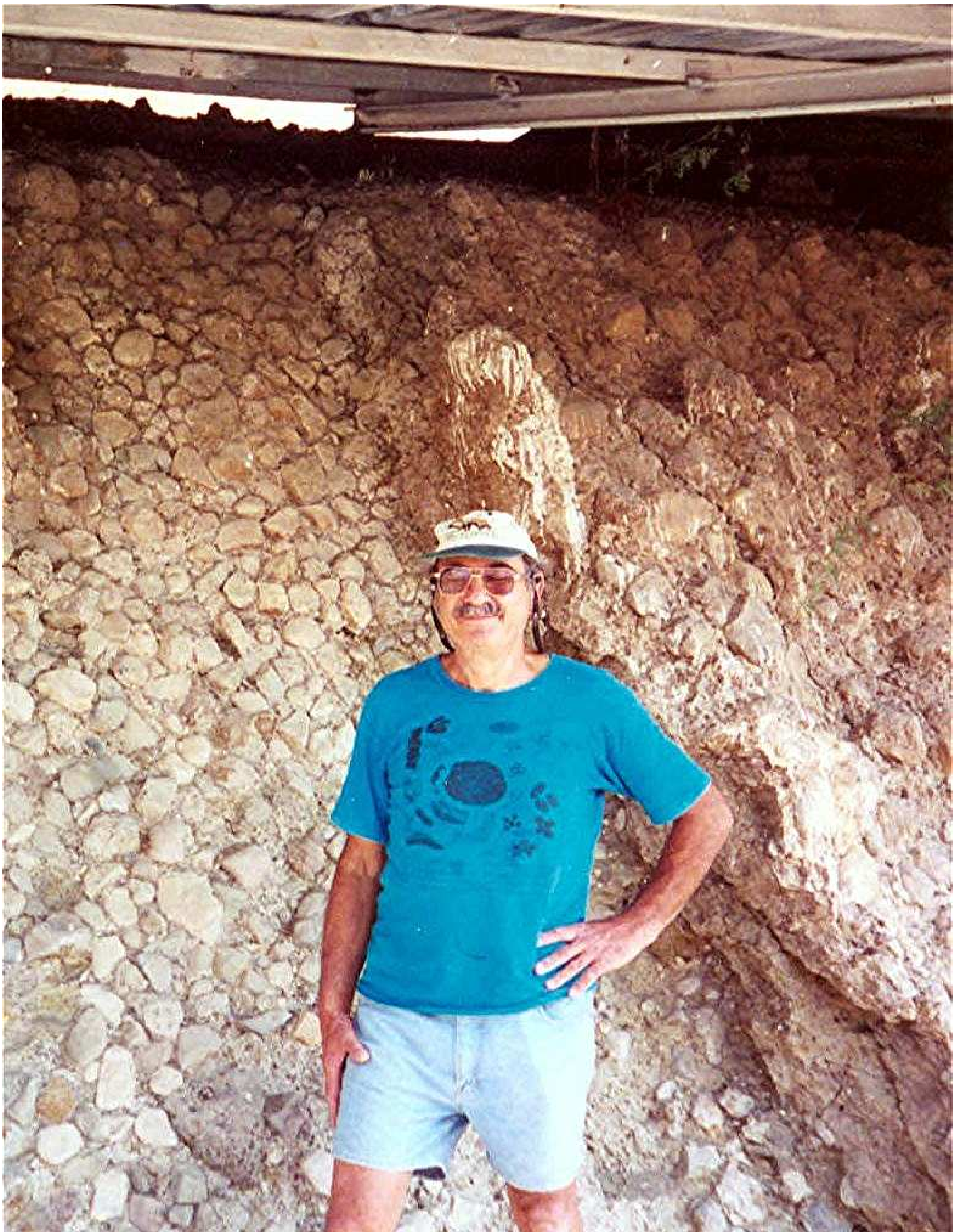

Prof.Dr. Eitan Tchernov

This volume is dedicated to the memory of Prof. Dr. Eitan Tchernov, in fond memory of his enthusiasm and support to many in the field of archaeozoology**.**

Preface

The ASWA VI meeting was held at the Institute of Archaeology, University College London, from 30th August-1st September 2002, timetabled to follow on the heels of the ICAZ meeting in Durham, UK. Over 55 participants attended the meeting, travelling from 13 countries, bringing the latest research results from our field. As usual, it was a pleasure to see so many doctoral students presenting their research – a sign for a very healthy future for zooarchaeology in south west Asia. It is still unfortunate, however, that colleagues from some Middle Eastern countries were unable to attend due to financial and political constraints.

Presentations were organized into the following six themes, which highlight the scope of the ASWA membership: Animals in Palaeolithic and Epipalaeolithic Levant; Neolithic Patterns of Animal Use; Animals in Neolithic Anatolia; Animals in the Chalcolithic and Bronze Ages; Iron Age, Nabatean and Roman Patterns of Animal Use; Animals in Ancient Egypt. There was also a poster session, and contributors were invited to submit papers to this volume.

As always with the ASWA forum, the meeting served to welcome new scholars to the group, but was also very much a reunion of old friends and colleagues who have been sharing new information and discussing issues of joint interest for many years now. In this vein, it is a great sadness that ASWA VI was the last international meeting attended by Prof. Eitan Tchernov, an original founder of the group and mentor and inspiration to so many. For many of us, it was the last time we saw Eitan, and experienced his usual incisive comment, unstoppable enthusiasm for the subject, and warm friendship. He will be greatly missed.

ASWA VI was supported by the Institute of Archaeology, UCL, who provided facilities and financial and administrative help. In particular, the organizing team was aided greatly by the administrative assistance of Jo Dullaghan at the Institute. ARC bv (Archaeological Research and Consultancy, Groningen, The Netherlands) once again shouldered the finances of the publication of the proceedings, and we are extremely grateful for their continuing support. Many thanks are also due to the postgraduate student helpers from the Institute of Archaeology who made the meeting run so smoothly: Banu Aydinoğlugil, Jenny Bredenberg, Chiori Kitagawa, Peter Popkin, and Chris Mosseri-Marlio (who also produced the logo reproduced on the frontispiece of this volume).

Many thanks to all the participants for making the meeting such a success!

Louise Martin
London 2005

Participants of the 6th ASWA Conference, held at the Institute of Archaeology, University College London.

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Preface

SHEPHERDS TAKE WARNING: CHRONIC COPPER POISONING IN SHEEP

Chris Mosseri-Marlio[1]

Abstract

Copper can represent a serious threat to sheep health under certain environmental conditions, a fact well known within modern veterinary practice. This paper investigates chronic copper poisoning as a new and as yet undiscussed variable in understanding ancient animal husbandry practices. Some of the subjects considered here are the etiology of the disease and its environmental requirements, the possible use of the site of Kalba, UAE as a case study, the results of the soil sample tests taken from Kalba, as well as ethnographic, archaeological and environmental parallels.

Resumé

Le cuivre peut représenter une menace sérieuse pour la santé des moutons sous certaines conditions environnementales, un fait qui est bien connu dans les pratiques vétérinaires modernes. Cet article examine le cas d'empoisonnement chronique, comme une nouvelle variable non encore discutée pour la compréhension des pratiques d'élevage dans le passé. Quelques-uns des sujets débattus ici sont relatifs à l'étiologie de la maladie et de ses exigences environnementales, la possibilité d'utilisation du site de Kalba aussi bien que les parallèles ethnographique, archéologique et environnementale.

Keywords: United Arab Emirates, Sheep, Copper poisoning, molybdenum, environmental toxicology, Zooarchaeology.

Mots Clés: United Arab Emirates, mouton, empoissoner à cuivre, molybdenum, empoissoner d'environnement , zooarchéology.

Introduction

Our understanding of early animal husbandry systems has centred on the integration of a number of fields such as biogeography, animal ethology, transhumance, seasonality and the domestication process to name a few. This paper adds another tool to the toolbox of zooarchaeologists: it examines how the geochemistry of any given biotope can affect the animals—and by association the humans—that lived in it. It is well-known in veterinary science that sheep, unlike the other domesticates, are very sensitive to surplus dietary copper (Cu), and here we examine the factors that govern this disease as well as the possibility that it may have influenced animal husbandry practices at the Bronze and Iron Age site of Kalba, UAE. The paper begins with a description of chronic copper poisoning (CCP), its etiology and physical manifestations. The geochemical requirements for an environment favourable to CCP will then be discussed, followed by a description of the local Kalba environment and the faunal remains from the site. Ethnographic, archaeological and environmental parallels are then drawn. The results of the chemical analysis on bone samples from Kalba will be given, and discussed in light of recent research into the problem of diagenesis. These arguments will be brought together and discussed in relation to our understanding of the effects of the environment on ancient livestock.

Chronic copper poisoning in sheep

A description

There are two types of ovine copper toxicosis: chronic and acute. The former, which happens over a period of time due to intake of dietary copper, is described here. Acute copper poisoning only occurs when animals are subject to a short episode of excessively high copper consumption, such as might

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occur in modern flocks if the wrong type of feed supplements are given. Acute copper poisoning is therefore not discussed here.

Unlike the other domesticates, sheep are highly susceptible to an excess of copper in their diet (Bruere & Wesl 1993; Kimberling 1988; Merck 1979; Radostits *et al* 1997). Trace amounts of copper are essential for many biological functions in both vertebrates and invertebrates, and for the mammals copper is required for normal iron metabolism, soft tissue production and the health of the nervous system (Merck 1979; Radostits *et al* 1997). For sheep, however, an excess can prove fatal, and thus they have a relatively narrow range of copper intake acceptability. As an example, pigs can take up to 250 ppm of copper in their feed as a supplement for optimum health and cattle 100ppm; sheep can experience toxic levels with as little as 10ppm of copper in their feed (Church & Pond 1988; National Research Council 1980). Although toxic levels for copper have not been established for goats (Humann-Ziehank *et al* 2001) they can safely tolerate the copper intake levels of swine (Solaiman *et al* 2001). Some mild sensitivity in kids has been observed (Bruere & Wesl 1993). Why the sheep should be so sensitive to copper while its fellow domesticates are not, remains unknown at this time. The much referred to handbook *Veterinary Medicine* (Radostits *et al* 1997: 1601) describes sheep as "*peculiar in the way in which copper is handled (by them) metabolically*". Humans are not susceptible to copper poisoning at the levels we are discussing here, as we have a much more efficient mechanism for excreting copper than sheep

Copper is taken up by sheep through herbage, drinking water and soil ingestion. Because the sheep lacks an efficient system with which to shed excess copper through faeces and urine, the copper is stored in the liver on a cumulative basis. It remains there until the critical toxic threshold is reached. During the copper loading phase, which may take several months or longer, the animal can appear quite normal, with no outward signs of being unwell. Excess copper is stored in the liver where it remains until a stress trigger causes it to be released into the animal's system. Typically in modern sheep populations CCP is initiated by circumstances relating to heat, dietary stress, haulage, predators or even breeding.

Once the critical stage has been reached, the animal experiences an acute haemolytic crisis and dies within one to two days (Bruere & Wesl 1993; Kimberling 1988; Merck 1979; Radostits *et al* 1997). Because the animal's red blood cells rupture as a result of the concentration levels of Cu in circulatory system, insufficient oxygen is present to supply the soft tissues, and therefore sick and dying sheep initially display signs of anaemia. Within days the mucous membranes of the mouth and eyes are jaundiced and yellowish. Any urine passed at this point is a very dark red wine colour. An autopsy on a sheep that has succumbed to copper poisoning will reveal an organ cavity markedly discoloured. The liver and spleen are swollen and the kidneys have a dark gunmetal colour. There is an unpleasant metallic odour that permeates the meat on the animal (John Martin pers. comm.) It is important to note that during the chronic phase, the animal appears quite normal. The outward signs of anemia, discolouration of mucous membranes and lack of energy would only be apparent once the haemolytic crisis had begun, after which death could be expected within 24–48 hours. Thus, to the shepherd with no specialist knowledge, the animals would appear quite normal for a certain period and then, once the critical levels had been reached, catastrophic flock deaths could occur.

Copper in the environment

The heavy metals exist in colloidal, particulate and dissolved phases in the environment. Water chemistry is an essential factor in understanding the bioavailability of metals. The mobility and availability of copper in the biomass is related to soil texture, drainage, acidity and organic matter. Acid soils have more mobile copper in them than alkaline soils. Salinity also plays a role in the concentration of heavy metals. For instance where there is an increase in groundwater salinity, metals are desorbed by the associated sediments, increasing the metal concentrations in groundwater (Osmond *et al* 1995). Most of the research into copper uptake in plants in relation to CCP has centred on the leguminous plants such as lupins and clover, neither of which are central to this discussion. However, it was shown that in these types of plants, copper is most concentrated in the tender shoots (Bruere & Wesl 1993). The copper content of wild plants growing on the spoil tip of the ancient mining site of Khirbet Faynan in Jordan showed an opposite trend, with a greatest concentration of copper in the roots of plants, although the content in the leaves was also considered high (Pyatt *et al* 2000). Plant species vary in their ability to take up micronutrients in the soil (White & Zasoski 1999).

The important role of Molybdenum in ovine copper toxicosis

The heavy metal molybdenum (Mo) is a trace element found throughout the world, largely in igneous deposits. As a general rule, heavily weathered soils will be poorer in Mo than those which are not, and alkaline and wet soils will produce herbage with higher concentrations of Mo than acidic and more arid soils (Adriano 2001). As with copper, the bioavailability of Mo is dependent on soil alkalinity and moisture content. Unlike most other heavy metals, molybdenum reaches its greatest bioavailability under alkaline conditions, and is least available in acid soils.

The role of Mo in copper toxicosis in sheep is a complex one, and remains poorly understood, since the underlying metabolic relationship between Mo and Cu is still unknown (National Research Council 1980). This heavy metal acts as an uptake modifyer for copper, fixing itself to the copper molecule to create an insoluble copper/molybdenum complex which is excreted in the animals' faeces and urine (Merck 1979, Bruere & Wesl 1993). If insufficient copper is available in the diets, the Mo complex molecule will cross into the animal's circulatory system, searching for copper to bind with. In regions where Mo is bioavailable (or as in the case with modern sheep flocks, where Mo supplements are given) the risk of copper poisoning is greatly reduced and indeed in the case of supplements is removed entirely.

The mechanism by which Mo binds itself to Cu is so efficient than in areas with considerable bioavailable Mo levels, copper *deficiency* is a problem not only for sheep but also cattle (Erdman *et al* 1978; Hidiroglou *et al* 1990; Radostits *et al* 1997; Thornton, 2002). Known as molybdenosis in cattle, and enzootic neonatal ataxia in sheep, these conditions can be fatal to livestock and are both treated by supplementing the animals' feed with the missing trace element - copper. The very complex nature of the molybdenum-copper relationship has only been described in its most basic terms here. It is perhaps more useful to consider CCP in terms of both copper and molybdenum, since it requires a marked absence of Mo as much as a surplus of Cu in order to manifest itself. Geochemical analysis of grazing areas has recently been the focus of a study by Thornton (2002) that seeks to highlight environments potentially toxic, on the basis of heavy metal surplus and deficiency, to both wild and domesticated animals.

Kalba: an archaeological case study for CCP

The micronutrient environment around the multi-period site of Kalba

Given that the micronutrient content of the soils in any environment has a role to play in the consideration of animal husbandry and management, how might this be best recognised in the archaeological record? It is proposed here that the multi-period site of Kalba may provide an example. Kalba is located on the northern coast of the Gulf of Oman (Fig. 1), with the settlement site located some two kilometers from the present shoreline, at the northern limit of the al-Hajar mountains. This mountain range is within the allocthanous Semail ophiolite complex, a mineral-rich area that extends from the Musundam Penninsula in the north to the Masirah Islands in the south. The area has a wealth of copper and other minerals and has supported copper extraction since the third millennium (Hauptmann 1985), a fact that has played a key role in the development of settlements in Southeast Arabia in the past. Kalba lies between the piedmont and the coastline, in the alluvial fan of the Wadi Ham, and would have benefited from the high mineral content of water runoff from the al-Hajar mountains. While there is no evidence of copper mining within the immediate site, there is evidence for copper processing, as well as the manufacture of stone vessels (Phillips & Mosseri-Marlio 2002).

Tests carried out on soil samples from mud bricks, deep soils and surface soils showed a pH neutral to slightly acidic environment ranging from 7.0 – 6.5. Three soil samples were tested for nine different heavy metals (arsenic, cadmium, cobalt, chromium, copper, molybdenum, nickel, lead, zinc). These results have been published elsewhere (Phillips & Mosseri-Marlio 2002), and since then further tests have been done on soil samples, this time only on four heavy metals. For purposes of clarity, all

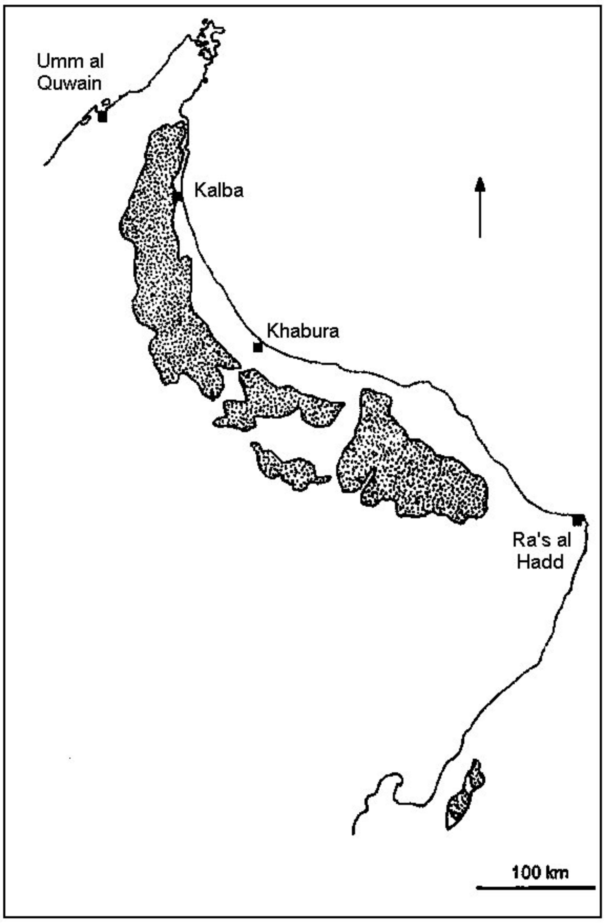

Fig.1. Oman semail opholite; the micronutrient environment at Kalba.

results are reproduced in Table 1. The copper levels shown here are considered high by agricultural standards (John Martin pers. comm.). The chromium and nickel concentrations, though they do not play a role in this discussion, were also strikingly high.

Kalba: an inhospitable environment for sheep?

The composition of the parent materials comprising the al-Hajar mountains would have provided for a mineral rich environment at the foot of the alluvial fan, which is evidenced by geological reports of the area (Hauptmann 1985; Graham 1980) as well as samples from both deep and surface soils shown above. In terms of copper, the range of 28-83ppm exceeds the levels of a known sheep antagonistic environment in Canada, which has levels averaging 25 ppm (John Martin pers. comm.). As previously stated, however, the bioavailability of heavy metals depends on many factors such as soil pH and ground water chemistry, and mineral concentration values in and of themselves do not tell the full story about the toxic potential of the environment. Radostits and colleagues (Radostits *et al* 1997: 1600) state: "*In fact either copper deficiency or copper poisoning can occur on soils with apparently normal copper levels, the syndrome depending on the particular conditioning factors present*". Groundwater and rainfall also effect copper concentrations in the biomass, with levels rising as much as 10% after rainwash from upland areas (Marchand 2003). There should therefore also be a consideration of possible seasonality to the toxicity in the environment around the site. Molybdenum, which as already mentioned has a mitigating action on the effects of copper, was not detected in any of the samples, nor does it appear in any of the geological maps of the area and studies consulted.

It would appear that there is, based on the results of the soil analysis, toxic potential for sheep living in the Kalba area. The question is, does the archaeological evidence bear this out?

Table 1. Mineral content of soil samples[1] from Kalba, UAE

Sample	Arsenic	Cadmium	Cobalt	Chromium[2]	Copper	Molybdenum	Nickel	Lead	Zinc
Wadi Suq[3]	ND[4]	ND	23[5]	95	83	ND	352	ND	26
Iron Age 1	ND	ND	27	112	36	ND	390	ND	31
3rd Mill	ND	ND	23	90	28	ND	350	ND	25
Surface 1	[6]			93	41	ND			24
Surface 2				88	66	ND			25
Iron Age 2				69	32	ND			20
Wadi Suq 2				91	48	ND			18

[1] Soil was tested using an inductively coupled plasma-optical emission spectrometer at the Animal Health Laboratory, University of Guelph, Ontario, Canada.
[2] The chromium shown in these samples is the naturally occuring, trivalent, non carcinogenic variety. Hexavalent chromium is associated with environmental pollution resulting from fossil fuel combustion and steel production.
[3] Samples were taken from datable mud bricks
[4] ND = Not detected
Detection thresholds:
a. As, Mo <1.0 µg/g
b. Cd < 0.5 µg/g
c. Co < 2.5 µg/g
d. Cr, Cu, Ni, Pb < 5.0 µg/g

[5] All values given in parts per million (ppm)
[6] After the first tranche of tests, soils were only tested for chromium, copper, molybdenum and nickel. Blank spaces indicate no test taken.

Metal criteria for soils from Ontario[1]

Mean content of uncontaminated soils	Cobalt	Chromium	Copper	Nickel	Zinc
	5	15	25	16	55
Maximum permissable metal content in Ontario soils	Cobalt	Chromium	Copper	Nickel	Zinc
	20	120	100	32	220

[1] These figures provided by the Ontario Ministry for Agriculture and Food

Table 2. Faunal remains from Kalba, UAE.

Total number of identified specimens	2330[1]
Total Number small ruminants	1221[2]
Total Number identified as *Capra*	257
Total Number identified as *Ovis*	45
Ratio of sheep:goats	1:5.7

[1] The faunal analysis for this site is not complete. This represents the data for the part of assemblage that has been analysed. This number represents all the phases of the excavation as the stratigraphy is not yet complete.
[2] This figure contains a small number of gazelle

And just as crucially, is there any modern, historical or ethnographic evidence for the poor performance of sheep in the area? Before any of these questions are addressed, it is important to remember that CCP is not something that happens from one day to the next, and the effects of it on any given herd could easily be mitigated by a number of factors: the trade of other animals from outside the mineral catchment area, the birth of lambs who may attain slaughtering age and still be in the pre-crisis stage of the illness and the use of fodder produced using water sources outside the catchment area. In terms of an archaeological assemblage, one would expect to find a perhaps proportionally small number of sheep bones to signal that sheep husbandry was attempted but never entirely successful. A final word of caution on animals succumbing to CCP: because of the tainted and inedible nature of the flesh, the carcasses would never end up in midden deposits as waste from food consumption. The likelihood of recovering bones from animals that died of CCP would therefore be very low in a midden setting.

The sheep:goat ratio from Kalba

The multi-period site of Kalba can be considered a "coastal oasis", a well-watered coastal site, exploiting a number of environmental niches, with an economy that extended to support inland communities as well as being in maritime trade contact with other areas in the Indus Valley and Arabian Gulf. The subsistence economy was based on both domesticated animals and plants as well as a wild species, both terrestrial and marine. Throughout the life of the site these trends are well established. So far, there is nothing in the environmental evidence to suggest that the economy changed from one based more on wild foods, and hunting and fishing, to one based more on domesticates over the life of the site. Domesticated animals appear in the assemblage from its earliest levels, and fish bones molluscs are omnipresent throughout. This unique biotope, which lies at the conjunction of coastline, piedmont, sabkha and mangrove, provided a wealth of foods.

Throughout the life of the site, sheep are always outnumbered by goat, with an average ratio of nearly six goats to one sheep (Table 2). There are many reasons why a community finds one domesticate preferable to another. These include secondary product economies, environmental adaptation and cultural preferences (Redding 1984; Lancaster and Lancaster 1988). While the sheep:goat ratio is not surprising considering the current environment, it does differ from other sites in the Arabian Gulf area, where sheep were frequently the domesticate of preference (Uerpmann & Uerpmann 1994; Uerpmann & Uerpmann 1997; Uerpmann 2001). This is particularly the case at Tell Abraq, where the economy was quite similar to that of Kalba because of its dependence on marine foods as well as terrestrial ones, both wild and domesticated (Uerpmann 2001). Both a large and a small variety of sheep were found there; out of nine phases identified at the site, sheep outnumber goat in six. At Muweilah sheep were also an important aspect of the economy (*ibid*). These examples show a sheep and goat economy quite different from that at Kalba.

Modern animal husbandry in the Kalba catchment area

On a local level, two types of animal husbandry are practiced today. Small flocks of goats are kept by local farmers who range over an area of a few square kilometers, moving on in the course of the day to find more forage. It is the personal experience of the author after six seasons working in the Kalba area that sheep are only rarely included in this type of localized opportunistic flock management, seen only on very few occasions. An unofficial "animal graveyard", an open pit near the site used by local farmers to dump dead animals, was seen over the years to have a very small number of sheep in, compared to a very large number of dead goats and some cattle. Of the dead goats observed, those that were in an advanced state of decay enough to allow the skin to split and peel away frequently showed very large bowel obstructions resulting from continuous consumption of the ubiquitous blue plastic shopping bags.

The second type of animal husbandry is the more large scale industrialized approach, such as the al-Rugailat Farm and the Fujairah Farm, both cattle farms in Fujairah, and both of which depend entirely on industrially produced feedstuffs. The sheep that nowadays are slaughtered locally to provide meat are all imports. Indeed the port of Fujairah is one of the UAE's largest livestock holding stations. Thus the livestock that actually consumes food from the environment (i.e. browsed) is quite small in number, and within this type of husbandry, sheep are only very rarely present. The copper and other heavy metal-rich browse is therefore consumed most frequently (and successfully) by goats.

Ethnographic, Archaeological and Environmental Parallels

The Khabura Project

The University of Durham's Khabura Project (Dutton 1999) conducted a study into the rural systems of an area in Oman between Khabura, located on the coast west of Muscat, south into the highlands to the town of Ibri. The study, which was part of a larger project to investigate the human and natural resource base of the country just as it was on the cusp of major economic reform, focused on such issues as agriculture, hydrology, natural resources and livestock management. Considerable attention was given to the study of animal husbandry and land use, and an attempt was made to integrate the better aspects of traditional agriculture and pastoralist methods with modern technology in order to preserve the unique culture of the area.

Sheep and goat management formed part of the study, particularly in relation to the differences between lowland and upland flocks and herds. In terms of its relevance to this research, it should be noted that both of the small ruminants were kept in the area under study, with sheep slightly outnumbered near the coast and almost absent in the uplands. This absence of sheep reflects a terrain and vegetation largely unsuitable for sheep.

The Khabura project does not make a good comparison with Kalba for the following reasons. Firstly, most of the area under study does not lie within the copper rich area shown in Figure 1, despite its proximity to Kalba. In the absence of a localized geological profile, it is impossible to determine to what extent the soil chemistry there is similar to that of Kalba. While there is no doubt that there will be some copper in the environment due to the project's location near the ophiolite belt, the presence or absence of Mo cannot be predicted. Because of its relative economic insignificance in standard concentrations, molybdenum is frequently omitted from geological maps.

Secondly, the animal husbandry methods are described on the project as "intensive or semi-intensive", and sheep in all areas were receiving fodder from local sources as well as from outside their catchment area. It is impossible to derive a relationship between animal—or indeed human—health and micronutrients in soils unless a local origin of foodstuffs can be assured (White & Zasoski 1999). Louis Kwantes, a veterinarian associated with the fieldwork, noted that animals received dietary supplements from vets and para-vets working in the area. On rare occasions, copper deficiency was a problem; this was treated with copper supplements. As noted above, molybdenum is frequently the cause of copper deficiency in ruminants, therefore it is possible that this mineral is present in the soil further south in Oman.

Further observations made at Khabura concern a preference by pastoralists for goat over sheep (Louis Kwantes pers. comm.). One reason for this is the susceptibility of sheep to fly-strike, a potentially fatal condition arising from insects whose lifecycle depends on egg laying in the wooly coats of sheep. There is also a local preference for goat meat as a feast food on the grounds that "goat tastes better", and that as such it has a higher prestige value in a feast setting. Strikingly, it was the opinion of Kwantes that "in almost every respect from a health point of view and regardless of location, Omani sheep were more vigorous than goats". This is a good example of a "folk preference" for one domesticate prevailing over the practical evidence. In the coastal environment further south at Ra's al-Hadd, the goat functions as a "mobile desalination plant" (Lancaster & Lancaster 1988), drinking local brackish water and producing in return milk with a low enough salt content for human consumption.

Archaeological and environmental parallels

Clearly, the sheep has been one of the most successful domesticates, frequently in areas of the Old World that are known for their copper-rich soils as well as copper mining activities. Recent work into environmental toxicity around an ancient copper mining in the Wadi Feinan site in southern Jordan has opened up the discussion about the interaction between micronutrients in the soils around ancient settlements and animal husbandry (Grattan *et al* 2002; Grattan *et al* 2003; Pyatt *et al* 1999; Pyatt *et al* 2000). This environmental study of a heavily polluted ancient copper mining area included the testing of plant materials to determine the toxic uptake in livestock as well as the potential for providing food crops for the local work force. The work is important because it is one of the first to explore the relevance of those parts of the environment that are not immediately visible, i.e. the soil chemistry. While the work focuses mainly on the effect of the mining waste pollution to humans, the implications for livestock are clear. There are no faunal analyses available yet on assemblages abutting this area, although both goats and sheep have been observed grazing around the spoil heaps described. At this point no further comment can be made about the Wadi Feinan copper mining area with regards to CCP, although it may well prove a fruitful avenue for further study in the future.

It is important to remember that an environment that is toxic to animals should not necessarily be expected to show a clear *lack* of faunal remains, since the mechanisms behind that toxicity will not have been understood by the local population. Also, as mentioned previously, it is likely that any animals dying from CCP would be largely invisible in the faunal record. Therefore there will never be a well-defined linear relationship between toxic or polluted environments and bone assemblages. Nonetheless, in the case of CCP we can still look at mineral profiles in an attempt to establish which areas appear safe (low concentrations of metals available biologically in the environment) and which areas *cannot* be ruled out as *unsafe* (high copper concentrations but unknown molybdenum concentrations). This can best be illustrated using Table 3, which examines a number of areas within the ophiolite Peri-Arab Crescent, a copper-rich geological formation which encompasses an area from Cyprus to Oman (Fig. 2).

Table 3. Known Copper Mining Areas.

Location	Copper	Molybdenum	Toxic Potential for sheep?
Cyprus, Limassol Forest	Yes (Panayiotou 1977, Pyatt, 2000)	Yes, but rare (Panayiotou 1977)	Possible
Central Turkey	Yes (Piskin *et al* 1990)	Yes (Piskin *et al* 1990)	Not likely
Kerman, Iran	Yes (Shahabpour 1991)	Yes, abundant (Shahabpour 1991)	Not likely
Wales	Yes (Thornton 2002)	Yes, abundant (Thornton 2002)	Not likely *
Wadi Feynan, Jordan	Yes (Pyatt *et al*)	Unknown	Possible
UAE	Yes	No	Likely

*Molybdenum is present in high enough levels in Wales to induce molybdenosis in cattle.

Discussion

A modern case study?

Much time and effort was put into locating a modern example of CCP that would have occurred as a result of an unfavourable environment. No reports of the disease occurring spontaneously as a result of grazing in unfavourable soils could be found in the recent literature. This may seem to cast doubt upon the hypothesis about Kalba and CCP, for it might be argued that if this is indeed a problem in environmental pockets throughout the world, there would be evidence of it. Therefore, the following observations can be made.

Veterinary science in general is relatively new, having only been established as a separate field of study at the beginning of the twentieth century. The biological role of copper and molybdenum in higher organisms is also something that does not have a long history: the relationship between the two metals in animal diet was published as late as 1938 (National Research Council 1980) and the identification of copper as the culprit in CCP as late as 1945, the latter being reported in Australia. It has not been possible to determine when large scale addition of dietary supplements for the prevention of deficiencies/toxicosis for livestock became the norm. It seems likely that both of these papers were written during a time when any sheep succumbing to the illness were doing so as a result of environmental conditions, and not through the consumption of copper-rich cattle feed, for instance. Thus,

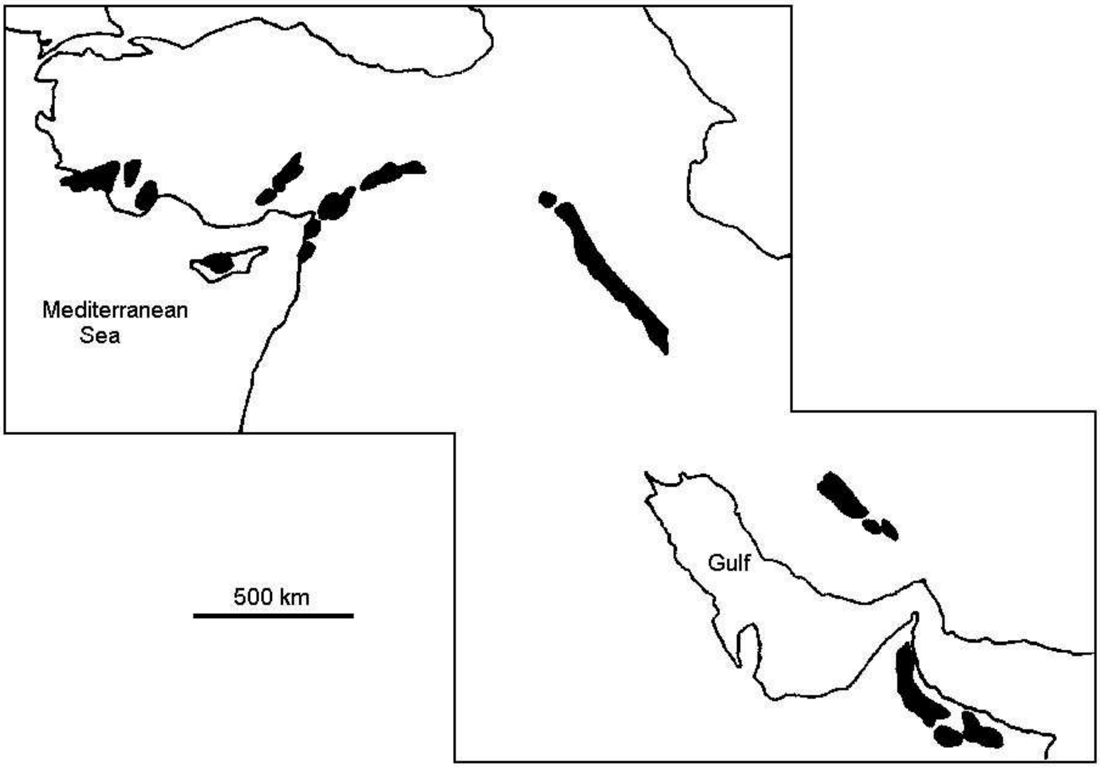

Fig. 2. Copper distribution in the Peri-Arab Crescent.

from a standpoint of modern veterinary science, CCP occurs as a result of improper use of feed and supplements, and not toxic landscapes. The practicing veterinarian, confronted by a copper toxicity problem, will deal with the immediate concerns and suggest treatments, because to delve into the underlying causes is time consuming and thus, expensive[2]. It is only the private or government consultant who can spend the time to understand the whole picture and recommend remedial actions. Modern industrialized sheep management relies on feedstuffs and feed supplements to an extent that the browsing environment plays only a partial role in the health of sheep.

There are well-known sheep-antagonistic areas in the world today in Canada, the United States and Australia. For the reasons outlined above, such as the automatic inclusion of molybdenum in supplemental sheep feeds, CCP poses little problem. Modern industrialized farming methods make the problem of environmental hazards to flocks relatively small. These examples come from the New World, where large flocks of animals were introduced into the landscape without having a long history of being "tried", either by local pastoralists or a local wild sheep population. What about the areas of the world where domesticated animals have played an important role in subsistence economies for thousands of years? It is proposed here that where there are localized conditions that favour one domesticate over another, a certain folk knowledge is developed over time. This leads pastoralists to make decisions that are environmentally influenced but perhaps ascribed to other cultural factors. As the suite of domesticates were introduced into Southeast Arabia, it is easy to see how goats might have come to be favoured if sheep did not prosper at Kalba.

CCP at Kalba

The low ratio of sheep:goat at Kalba highlighted a need to explore the reasons why this site might have had a different approach to animal management than others in the area. The simple answer is

[2] John Martin of the Ontario Ministry of Agriculture and Food estimates that in order to get to the bottom of any localised environment-based CCP problem would require a minimum of 500 hours of work.

that today sheep are rarely seen there, and so for whatever reason, it is simply not a "sheepy"area. The next question is why, given that other areas have plenty of sheep? The suggestion that CCP might be the answer to this question remains for the time being merely that—a suggestion. Because the hypothesis cannot be tested, we have to rely on supposition and soil sampling.

It is not hard to imagine that Kalba, as an important trade community that was receiving and dispatching goods from local areas as well as Makkran (the Indus valley), Dilmun (Bahrain) and Mesopotamia (Phillips & Mosseri-Marlio 2002), was also trading livestock. The identification of a pig bone at Rafaq (currently under study by the author), in the interior to the southwest of Kalba, attests to the fact that animals were being traded within the Arabian Gulf and beyond. The arrival of sheep as trade items could easily have bolstered small stocks that may have been desirable for cultural reasons even if they did not prosper on Kalba soils. Yearly monsoons that brought rains in the spring might have added additional mineral wash, as mentioned earlier in this article. The sheep present in the Kalba faunal assemblage do not necessarily have to be the remains of animals that were either locally raised or all imports. It is likely that the truth will lie somewhere between. If sheep were not entirely successful for herders, their numbers could easily have been bolstered by imports.

Results of tests on archaeological and modern bone from Kalba

When this paper was first presented at the ASWA VI conference in London 2002, results were given for analyses of 17 bone samples taken from both archaeological as well as modern bone from the site at Kalba. The bones of sheep, as well as other species such cattle, goat, gazelle, dolphin (in order to highlight any differences between land and marine animals), dog (as occupying a high trophic level) were tested. Also included were controls from a known copper-poor environment in Canada as well as a sample each from a nearby mountainous area and a coastal site on the Arabian Gulf. It was hoped at that time that any biogenic uptake of copper in sheep might be visible in the bones (Appendix 1).

While the results of these tests are available at the end of this paper as a footnote—they may for instance be useful at a later date for some other purpose—they were not considered to be useful in light of recent investigations into the diagenetic processes associated with mineral transfer from soils and surrounding matrix into buried bone (Pike & Richards 2002). Fresh animal bones have been proven to exhibit significant uptake of copper ions in solution (Al-Asheh *et al* 1999). In addition, mice living in an abandoned copper mine were shown to have greatly raised levels of copper in their tissues (Laurinolli & Bendell-Young 1996). Whereas it appears that biogenic copper levels in bone might be a good indicator of environmental conditions at the time of death, diagenesis muddies the picture to too great an extent to make this analysis useful in interpreting the zooarchaeological record. We do not need the archaeological bone to tell us whether heavy metals were present during the lives of humans and animals in the past. The soil samples speak amply for themselves.

Conclusion: Redefining the "environment" in "Environmental Archaeology"

It has been the aim of this paper to introduce micronutrients in the soil as an important aspect of the environment that supported humans and animals in the past. Whereas our definition of environment generally includes factors such as rainfall, climate, topography, seasonality etc., what is unseen - soil chemistry - plays just as significant a role. Chronic copper poisoning in sheep has been used as an example to illustrate how soil chemistry may have had an immediate impact on animal management at Kalba, and to encourage us to consider other factors that may have had an influence over animal management. The focus here has been on CCP, but there are other conditions equally toxic to livestock that influence modern land use for ruminants: molybdenosis, as already mentioned, as well as iodine deficiency problems which can have a drastic effect on live animal births. Areas with iodine deficient soils are classified as "goiter belts", and livestock managed in these areas must receive iodine supplements to survive. The area covered by the ASWA conference is one with a very rich mineral profile, one that would be well taken into account as we continue our research into the relationships between humans and animals in the past.

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