Environment and Land Use in the Wadi Faynan, Southern Jordan: the Third Season of Geoarchaeology and Landscape Archaeology (1998)

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This report describes the third season of fieldwork by an interdisciplinary team of archaeologists and geographers working to reconstruct the landscape history of the Wadi Faynan in southern Jordan over the past 200,000 years. The particular focus of the project is the long-term history of inter-relationships between landscape and people, as a contribution to the study of processes of desertification and environmental degradation. The geomorphological and palaeoecological studies have now established the outline sequence of landform changes and climatic fluctuations in the late Pleistocene and Holocene. The complex field system WF4 has now been recorded in its entirety in terms of wall construction, surface artefacts, and hydrological features, as well as most of the outlying field systems. From these studies, in combination with the analysis of the surface artefacts, an outline sequence of the water utilization and management strategies they represent can now be discerned. Ethnoarchaeology is also being used to investigate the present-day populations of the study area, their interactions with their landscape and with neighbouring socio-economic groups, in part to yield archaeological signatures to aid the interpretation of the surface remains being gathered by the archaeological survey. Palynology is showing that Roman/Byzantine agriculture and mining severely impacted on the landscape in terms of deforestation; and geochemistry that Roman/Byzantine mining severely polluted the landscape, the effects of which are still apparent in the modern ecology of the study area.

Introduction: background and research objectives (GWB)

The project is a study of the 'archaeological history' of Wadi Faynan in southern Jordan by an inter-disciplinary team of archaeologists and geographers, our principal focus being the relations between people and landscape through time, especially in the context of understanding processes of desertification. Much has been written about desertification history by historians, geographers, ecologists, and archaeologists, with the respective roles of climate and people being much debated. The archaeological evidence for apparently intensive phases of settlement in what are now dry and degraded environments is frequently brought into such debates, with theories proposed that people played a significant role in the process of desertification through their actions, for example by developing irrigation systems that caused salinization, stripping the landscape for fuelwood, allowing their livestock to overgraze the vegetation, and so on. However, contempory ecological theory indicates that many dryland environments can in fact be remarkably resilient, recovering relatively quickly from over-intensive exploitation. Despite the frequency of speculation about the long-term role of people in desertification, there have been remarkably few modern scientific studies of the problem. Landscape archaeology, integrating the methodologies of archaeology and geography, has the potential to document the relationship between people and landscape over long timescales with the necessary precision to contribute significantly to the desertification debate (Barker *et al.* 1996). This is the aim of the present study.

The Wadi Faynan forms as a series of tributaries that dissect the steep scarp on the western edge of the upland plateau (principally, from north to south, the Dana, Ghuwayr, and Shayqar) and flows westwards into the Wadi Arabah, a total distance of some 30 km. Today the main wadi presents a bleak landscape, arid and largely denuded of vegetation, though the tributary wadis are in places well watered and comparatively well vegetated from ground springs. The northern side is part of the Dana Reserve of Jordan's Royal Society for the Conservation of Nature, and a few bedouin families are allowed to graze their goats there under controlled conditions. Other bedouin families graze the main wadi, and in recent years its southern side was used for vegetable growing with water piped from the Ghuwayr spring, though this practice has now been abandoned.

Before our project began, the Wadi Faynan and its tributaries were known to be rich in archaeological evidence for past settlement. The principal ancient settlement in the wadi, long known to early travellers, is Khirbat Faynan (WF1 in the survey record), a major site of Nabatean, Roman, and Byzantine date (at least) located at the head of the Wadi Faynan near the confluence of the Dana, Ghuwayr, and Shayqar tributaries. A preliminary survey by a team from BIAAH had located a broad suite of Nabatean, Roman and Byzantine sites down the main wadi to the west of Khirbat Faynan, mostly on the edge of a substantial field system of rubble walls (WF4 in the survey record), its surface pottery indicating a broadly similar date. Excavations had begun on an early (pre-pottery neolithic) farming settlement in the Wadi Ghuwayr, (Wadi Ghuwayr 1: Simmons and al-Najjar, 1996), and a later neolithic settlement in the main wadi had been excavated some years previously (Tell Wadi Faynan: al-Najjar *et al.*, 1990). The BIAAH survey also located a number of other prehistoric sites within and around the field system, including a substantial early bronze age settlement (WF100). Given the scale of the WF4 field system and the diversity of settlement evidence in and around it, therefore, the Wadi Faynan seemed ideal for a detailed investigation of the development of arid-zone farming techniques in the Near East.

Wadi Faynan and its environs are also characterized by rich mineral deposits, and from the work especially of the Bochum Mining Museum the history of copper exploitation here is well documented (Hauptmann and Weisgerber 1987; Hauptmann *et al.* 1985, 1992). Although Faynan copper was used by neolithic and chalcolithic societies, the first intensive exploitation seems to date to the Early Bronze Age (*c.* 3500–1900 BC). There was a second significant episode in the first part of the first millennium BC, the Edomite Iron Age. Copper was then extracted on a major scale in Nabatean, Roman and Byzantine times, with Khirbat Faynan identified as the Phaino to which Christians from Palestine and Egypt were transported in the third and early fourth centuries AD to work the copper mines under its control. The character and extent of copper extraction in Islamic times are not clear, but in recent years Jordan's Natural Resources Authority has been prospecting the ancient workings to assess the feasibility of renewing extraction. The Wadi Faynan is therefore a particularly attractive location for investigating the nature and scale of human impacts on a desertic landscape, given the millennia of industrial and agricultural activities that have characterized human settlement here.

Given the overall aims of our project, our specific objectives have been identified as follows: (1) to construct a geomorphological and palaeoecological sequence for the study region, establish its chronology, and determine the respective roles of natural and human processes in its development; (2) to establish the nature, chronology and functioning of the ancient field systems; (3) to establish the nature, chronology and character of the surface archaeology outside the field system; and (4) to integrate all these geographical and archaeological data in a model of landscape development. The 1996 and 1997 seasons of fieldwork (Barker *et al.* 1997, 1998) successfully established an outline sequence of geomorphological and palaeoecological change, including evidence from a preliminary pollen analysis of sediments behind a barrage at Khirbat Faynan indicating considerable landscape degradation in Roman and

Byzantine times (Hunt and Mohammed 1998). The archaeological survey of the eastern half of the WF4 field system and initial studies of the artefacts collected from it allowed us to propose preliminary models for the character of initial spring-based farming and for the development and character of floodwater farming in later prehistory and iron age/Nabatean/Roman/Byzantine times.

The objectives of the 1998 season of fieldwork (March 31–April 25 1998) were therefore as follows: (1) to evaluate and refine the previous geomorphological work in the study area on Pleistocene and Holocene environmental change; (2) to complete the survey of the WF4 field system, advance the study of the surface material collected from it, to refine its chronology, and evaluate and refine the hydrological models proposed from the earlier seasons; (3) to investigate in greater detail the environmental impacts of ancient agriculture, pastoralism, mining and smelting; and (4) to introduce an ethnoarchaeological component to the project, to establish the relations between people and landscape today and to determine the archaeological signatures of different forms of settlement and land use to aid the interpretation of the data collected by the archaeological survey within the field systems in 1996–1998 and to be collected outside the fields systems in 1999 and 2000.

Pleistocene and Holocene environments

Introduction (DDG)

The preliminary geomorphological map of the study area established by the 1996 field season (Barker *et al.* 1997) and revised in 1997 (Barker *et al.* 1998) has been further revised by the 1998 fieldwork, but the principal findings of the original study remain valid. Furthermore, a programme of OSL and ^{14}C dating is providing an outline chronological sequence. One OSL date indicates that the Ghuwayr Beds were forming in the order of 150,000 years ago. The relationship of the Shayqar Beds is not yet clear, but it still seems likely that they post-date the Ghuwayr Beds, and were followed by the accumulation of the Faynan Beds, which our OSL dates suggest formed some 50–20,000 years ago. These deposits generally reflect environmental conditions characterized by powerful streams, but they were overlain by windblown silts formed in cold and dry conditions, which have a late glacial date *c.* 16,000 BP. As described below, we have also established a sequence of inter-linked terrace formations in the Wadis Dana, Ghuwayr and Faynan, and that there is clear evidence in both the Wadi Dana and the Wadi Faynan for a significantly wetter environment in the early Holocene, though the chronology and nature of the aridification that succeeded it are not yet established in detail. As this sequence of environmental change is confirmed, and its chronology refined, however, it will be possible to establish correlations at the regional scale regarding climatic and environmental change, as well as determining in detail the respective roles of natural and anthropogenic processes, particularly given the striking evidence that is emerging (discussed later in this report) for major episodes of pollution impact in the past from smelting activities that are still in evidence in the flora and fauna of the study area.

Terrace stratigraphies (JPG, SJM)

Our aims in the 1998 field season were to develop and confirm our understanding of the Pleistocene and Holocene terrace stratigraphy, to check their relative altitudinal position and to collect appropriate material for OSL dating. The objective was to establish the relationships, if any, between the terrace sequences mapped in the Wadi Dana and the Wadi Ghuwayr, to determine their relationship with the terrace sequence of the Wadi Faynan and to resolve further the geomorphological maps published in our earlier reports (Barker *et al.*, 1997, 1998).

In the Wadi Dana, in this field season, we have established the existence of at least five Pleistocene fluvial terraces. The uppermost was at least 126 m. above the current wadi floor. The fourth terrace in the sequence, 40–50 m. above the present wadi floor, which we have termed the Fass Yad terrace, contained an *in situ* hand axe of middle palaeolithic type (Fig. 1). The other terraces were at (very broadly defined) approximately 20–30, 11–14 and 4–6 m. above the present wadi floor. We established that the altitudinal relationship was consistent throughout the lower Wadi Dana.

In the Wadi Ghuwayr, we continued our exploration of the impressive fluvial terrace units identified in the 1997 fieldwork, and resolved their relationship with the Ghuwayr Beds and with the terrace units of the Wadi Dana. In the Wadi Ghuwayr we identified and mapped four fluvial terrace units which extend upstream from the Ghuwayr Beds mapped on the flank of Khirbat Faynan to the confluence of the Wadi Nahil and Wadi Hamam, and continuing into the Wadi Hamam. Our unpublished field observations indicate that these terrace units were securely located within the stratigraphy of the Ghuwayr Beds. We have therefore amended the

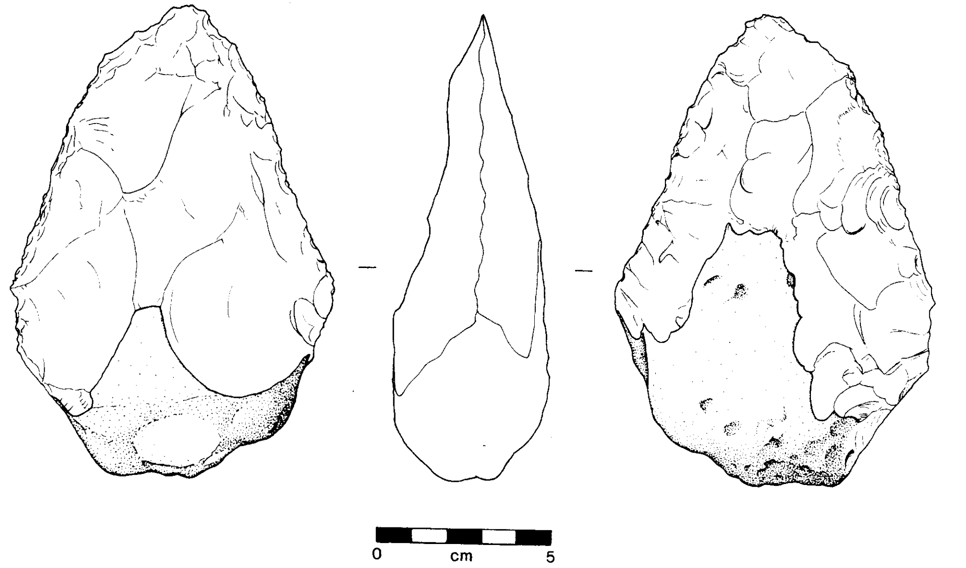

Figure 1. *Middle palaeolithic handaxe from the Fass Yad terrace, Wadi Dana. (Drawing: M. Pearson).*

geomorphological map in the vicinity of the South Cemetery (WF3). Our present hypothesis is that the Pleistocene fluvial terraces and adjacent alluvial fan development (Rabb'a 1992) of the Wadi Ghuwayr were perhaps in part contemporaneous. We established the altitude of each terrace in a series of transects. The altitudinal relationship of each terrace unit was observed to be consistent, although such observations obviously need careful interpretation in what might have been a tectonically active area in the late Quaternary. In addition, several substantial deposits of probable Holocene age were identified, described and sampled for further analysis. An extension of the highest identified fluvial terraces was identified in the Wadi Faynan, where it is draped over a bedrock ridge at the boundary of the Shayqar and Ashaiar Beds (see Barker *et al.* 1998: fig. 1).

Our 1998 fieldwork has indicated that the Pleistocene terrace units of the Wadi Dana and the Wadi Ghuwayr were similar in number, in altitude above the present wadi floor, and respective relationships to each other. We conclude provisionally that they were deposited in synchronous response to relative changes in base level. We have also confirmed that the terrace units of the two wadis continue downstream into the Wadi Faynan. Further samples for OSL dating were collected from the Ashaiar Beds, from the Fass Yad 'hand-axe terrace', from the sands deposited behind the Khirbat Faynan barrage, and from an outcrop of interbedded fluvial gravels and aeolian sands near the modern settlement of Grigorah at the western end of Wadi Faynan.

Holocene palaeoenvironments (HAM, COH)

This season's programme was designed to test our emerging models of Holocene vegetational history and valley alluviation. The main objectives were: to refine and develop models and chronologies of Holocene sedimentation; to extend the palynological sampling programme commenced in the 1996 season in order to refine chronologies of vegetational history; to 'calibrate' the palynological results by sampling modern analogue environments; and to test palynological and sedimentological results using molluscs as indicators of environmental change.

A total of 23 sites of Holocene age was sampled; two of these sites were previously known, the rest were new sites located by survey.

Of particular note is the accumulating evidence for a significantly wetter environment in the early Holocene. Previously (Barker *et al.* 1997), we reported the evidence of the sediments contemporary with and below the neolithic settlement at Tell Wadi Faynan indicating an environment of perennial streams by the settlement *c.* 6500 years ago 8–9 m. above the present wadi floor. (Since then, moreover, our data have been augmented by the identification of frustules of the diatom Navicula, a freshwater organism: F. B. Pyatt pers. comm.). We have also identified deposits in the Wadi Dana 10 m. above the present floor containing flint artefacts of broadly neolithic type (T. Reynolds pers. comm.), water-snails and organic residues, with a radiocarbon date of (uncalibrated) 7240 +/–90 BP (Beta 11121). It seems likely that this wet phase ended *c.* 6000 years ago, as the river began to cut down towards its present floor.

We also have important pollen evidence from sediments at three locations sampled in the 1998 season for the nature of chalcolithic and bronze age environments in the Wadi Faynan. (This work is part of the doctoral research by HAM.) The three sites were: WF24 (also given the geomorphological code 5051), a circular catchment just south of the WF4 field system outside unit WF4.8 (illustrated in Barker *et al.* 1977, fig. 14); WF148, an oval catchment in the south-west corner of unit WF4.13 in the WF4 field system, the unit containing the early bronze age settlement WF100 being excavated by Dr Karen Wright (Wright *et al.* 1998); and one of her 1997 excavated trenches, Operation 3, in the north-eastern sector of WF100. Standard laboratory methods (boiling in potassium hydroxide to disaggregate, sieving on nominal 7 mm. nylon mesh to remove fines and swirling on a clock glass to remove silt and sand) were used to extract the pollen (Hunt 1985). The samples were stained with safranine, mounted in Aquamount and examined under transmitted light and UV-fluorescence. The fluorescence spectra were mostly very dark red, suggesting coherent assemblages and relatively simple taphonomic pathways for the pollen. Our provisional view is that the absence of bright colours suggests that intrusive pollen are not a problem in these samples. The pollen diagrams are drawn using the conventions of Moore *et al.* (1993) and the palynological diagram follows the conventions of Hunt and Coles (1988).

WF24

WF24 is a circular cistern fed by a catchment system of boulder walls. A similar boulder wall attaches it to a small building of similar construction a few metres away that contains abundant potsherds and lithics of chalcolithic/early bronze age type, and its catchment is truncated by the erection of later walls of Nabatean/Roman date, so whilst the dating of the cistern remains uncertain, there is a reasonable case that it is chalcolithic/early bronze age. The cistern appears to have been used as an impoundment to hold water from the catchment either for human consumption, or watering stock, or for releasing into adjacent fields (Hunt and Gilbertson 1998). The cistern filled with sediment and was emptied at least once at some time in the past, since there is a large

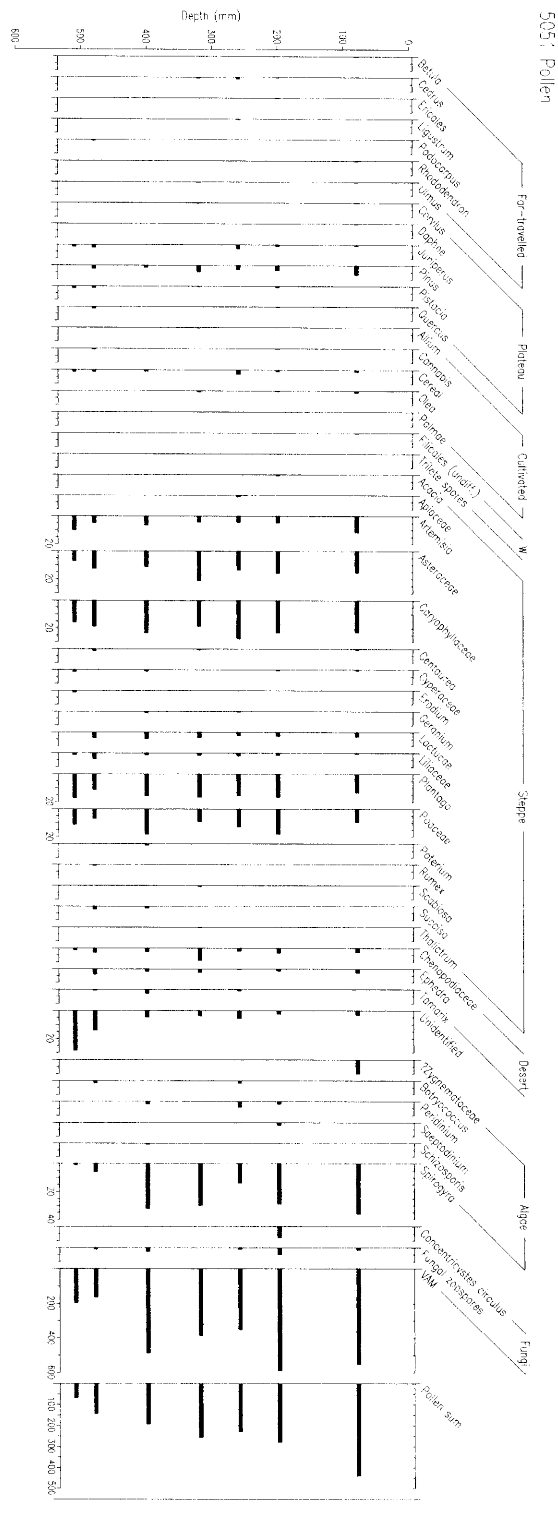

Figure 2. *Pollen diagram for the ?bronze age catchment WF24 (geomorphological site 5015), calculated as percentage total pollen and spores.*

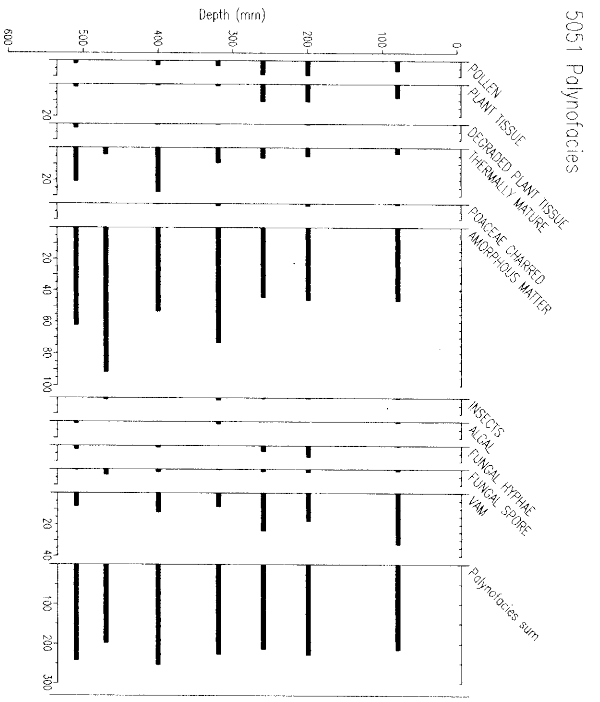

Figure 3. *Palynofacies diagram for the ?bronze age catchment WF24 (geomorphological site 5015), calculated as percentage total particulate organic matter.*

adjacent spoil heap. The ground around the cistern is now very deflated and there are areas of bare rock and elsewhere boulders up to 0.25 m. across lie on a reg pavement. Many of the rock outcrops and larger boulders are patinated with dark brown desert varnish, but only on their uppermost surfaces, suggesting that considerable ground lowering, probably in the region of 0.2 m., has taken place in the past. Coring in 1996 and excavation in 1998 both gave a maximum depth of 0.53 m. for the cistern. The fill consisted of 0.17 m. of greyish-orange (10YR7/4) coherent clayey silty sand overlying 0.36 m. of dark yellowish-orange gravelly silty sand. Landsnails of Theba type were found in the base of the fill in 1998; this type of landsnail appears to be associated with fairly well-vegetated steppe in the region today.

The pollen diagram (Fig. 2) is characterized by high counts of Caryophyllaceae (15 to 25 per cent) and Asteraceae (6 to 22 per cent). Also important are Poaceae (6–19), Lactuceae (1–6), *Artemisia* (5–12), *Plantago* (15–19), *Ephedra* (1–4), Chenopodiaceae (2–8), Liliaceae (1–4) and some other species which occur occasionally, including *Centaurea*, *Geranium*, *Poterium*, *Succisa* and *Rumex*. All the above mentioned species are characteristic of steppeland. Fairly sparse tree pollen are present, including *Pinus* (0 to 6 per cent), *Juniperus* (1–3) and *Quercus* (0.5–1), *Olea* (1–2 per cent) and *Pistacia* (1–3). These probably reflect Mediterranean forest on the plateau lands above the Wadi Faynan. Desertic vegetation is rare and represented by Chenopodiaceae (2–8), *Ephedra* (1–4) and *Tamarix* (1–4). *Tamarix* can also be a waterside plant. In addition, cultivated species are present, mostly Cereal (1–3 per cent), but also *Allium* type and *Cannabis* type. The *Olea* pollen discussed above may also have come from cultivated plants. Occasionally Palmae are present and these may reflect springside vegetation, either natural or cultivated.

The depositional environment was clearly waterlain, since algae are common. These include planktonic types like *Peridinium* (1 to 4 per cent) and *Botrycoccus* (2–3). The presence of these types suggests that standing water was present in the cistern regularly for periods of several months. More common are the benthonic algae *Spirogyra* (7–38) and other Zygnemataceae (0–10). These are commonly known as pondslime and are typical of shallow eutrophic (nutrient-enriched) sunwarmed waters.

Soil fungi are present including Fungal zoospores (1 to 8 per cent) and huge amounts of VAM (Vesicular Arbuscular Micorrhyzae). VAMs are fungal symbionts on the roots of plants, usually of herbaceous type, and the presence of these and fungal zoospores in large numbers in waterlain sediment is strongly suggestive of soil erosion (Hunt 1994). The *incertae sedis* known as *Concentricystes circulus* (0–9 per cent) may also be of fungal origin, since its preservational and staining characteristics are extremely similar to palynomorphs of known fungal origin. It is known from damp calcareous soils and is typically incorporated into waterlain sediments by soil erosion

The results of palynofacies analysis can be seen in Figure 3. The core is characterized by high levels of amorphous matter, especially in the lower part of the core but decreasing upward. Amorphous matter is commonly generated in soils, especially in areas of intense human activity (Hunt and Coles 1988). Thermally mature material is concentrated mainly at the lower part of the core (21–30 per cent) and this percentage decreases upward (6 to 4 per cent). This material is the product of charring. Some of the charred material is most probably of monocotoyledonous origin and may be charred grass or cereal straw. In most natural environments, thermally mature material is very rare (less than 2 per cent), so the high count in the lower half of this borehole probably reflects human activity. Pollen is present in low percentages (2–4 per cent) in the lower part of the core from the bottom and then increases progressively upward (8–9 per cent). Plant tissue is rare in the lower part of the core and then progressively increases upward (10–12 per cent). Fungal hyphae and insects and fungal spores are occasionally present. In the upper part of the borehole the pollen percentage increases and the thermally mature and amorphous matter decreases, probably due to the termination of local human activity after the abandonment of the cistern. The high rates of VAM in the upper part of the core are consistent with soil erosion.

WF148

Site WF148 is an oval catchment structure at the south-west corner of WF4.13 similar in construction to the fragmentary boulder walls in this part of the field system which we believe are likely to be of early bronze age date (see DJM below: the bronze age landscape in WF4.13). A soil pit was excavated in 1998, the fill consisting of 0.1 m. of compact mid-brown (10YR5/4) sandy silts overlying 0.42 m. of compact mid-brown (10YR5/4) stony sandy silts. One sample (5518.1) was taken from the base of the fill. The assemblage extracted from it is too small to be easily or reliably interpreted, but is of a generally steppic aspect. The very small number of grains in the sample suggests dilution of the pollen by a very large clastic input – in other words, by soil erosion (though no VAMs or other soil fungi were found, suggesting that topsoil had already been removed locally). The presence of the peridinioid dinoflagellate cyst *Saeptodinium* is, however, consistent with the structure having contained relatively deep and permanent standing water.

Table 1. *Pollen counts from sites 5516 and 5518.*

Species	**5516.3**	**5518**
Pinus	1	0
Juniperus	4	0
Corylus	0	1
Rosaceae	0	1
Olea	1	0
Caryophyllaceae	2	1
Cyperaceae	1	0
Poterium	2	0
Poacae	6	1
Cereal type	2	0
Plantago	1	2
Chenopodiaceae	3	1
Asteraceae	1	8
Lactuceae	1	0
Saeptodinium	0	1

WF100, Operation 3

Three samples were taken from *in situ* early bronze age deposits in the wall of one of Dr Wright's trenches (Operation 3: Wright *et al.* 1998) with her assistance. Of the three samples two, from layer 1240, of clayey material, possibly mud bricks, contained no palynomorphs. A small assemblage was recovered from layer 1235, a sandy, gravelly deposit with EB I sherds, described here as geomorphological sample 5516.3. The assemblage is very small (Table 1). Steppic taxa such as Poaceae, Asteraceae, *Plantago*, *Poterium* and Caryophyllaceae are consistent with steppeland, though the count for Chenopodiaceae points to more dessicated conditions than in 5015. The trees – *Pinus* and *Juniperus* – probably reflect plateau vegetation. *Olea* and cereal pollen might reflect cultivated or wild plants.

Discussion

Though the dating of the WF24 and WF148 catchments remains insecure, there is a consistency between the preliminary results from their sediments and from the more securely-dated sediments in WF100 Operation 3 suggesting that the significantly wetter environments of the early Holocene were probably succeeded by a relatively diverse steppic landscape by the fourth and third millennia BC (the Early Bronze Age), with some degradation perhaps developing through time. The use of structures such as WF24 and WF148 to store water for considerable periods is confirmed by the finding of algal microfossils consistent with relatively permanent water. It seems clear that, whereas neolithic people farming the Wadi Faynan had access to perennial water, later prehistoric farmers had to develop strategies for coping with more arid environments. Furthermore, the large spoil heap beside the WF24 cistern and the finding of very large numbers of recycled soil fungi in the WF24 sediments are consistent with very strong soil erosion during and after the use of this structure. Such erosion could result from poor land management techniques by the agricultural population, or of aridification removing the steppic vegetation cover, or a combination of factors. However, given the notorious resilience of steppic vegetation, our present inclination is to place more emphasis on climatic change as likely to be the more significant factor, suggestive of a major environmental deterioration through the last two millennia BC.

The steppic landscape indicated for the Bronze Age contrasts strongly with the very degraded steppeland present by Nabatean times in the later first millennium BC and the even more degraded desertic environments present later, as evidenced by the sediments cored behind the Khirbat Faynan barrage (Hunt and Mohammed 1998). A major component of the 1998 season was the re-sampling of the Khirbat Faynan barrage sediments to give greater precision to the findings of the initial study: 132 samples were taken at close intervals to provide a high-resolution record of (on the evidence of initial radiocarbon dates from the 1996 augered sample) the last 2500 years. In total, 204 stratified samples were taken in the 1998 season. Twenty samples were taken for radiocarbon assay, and six bulk samples were taken for molluscan analysis from key contexts. A total of 31 analogue samples was also taken from well-characterized modern environments. The results of this sampling programme will only be available when the radiocarbon assays, pollen and molluscan analyses have been completed, but from this work should then emerge a robust and refined model of the pattern, causes and chronology of Holocene sedimentation and vegetational change, including an evaluation of the respective roles of climate and people in shaping the Faynan landscape over the past 10,000 years.

Environmental impacts of ancient mining and smelting activities: initial EDMA studies
(DDG, JPG, FBP)

The spoil and slag tips from past mining and smelting activities, especially those of the 'climax phase' of the Nabatean, Roman and Byzantine periods, still occupy large areas of the Wadi Faynan and its region, and represent potentially highly dynamic and polluted systems. Heavy metals such as copper and lead, in particulate form or in solution/suspension, can be mobilized by processes including sheet and gully erosion, atmospheric erosion (Pyatt and Birch 1994) and leaching, and can thus continue to contaminate the atmosphere, pedosphere, and hydrosphere. The application of Energy Dispersive X-ray Micro-Analysis (EDMA) is allowing us to measure the changing scale of environmental pollution caused by past mining and smelting activities, and the legacy these activities have left in the landscape today.

EDMA: methodological considerations

The Energy Dispersive X-ray Micro-Analysis (EDMA) described here sought to establish rapidly the proportions present of elements above Sodium in the Periodic Table. EDMA is ideal for preliminary studies of this nature in that the results obtained are broadly representative of the pollutant concentrations present and allow later studies to be carefully focussed. The geochemical trends reported below have now been confirmed by more geochemical analyses using an Inductively Coupled Plasma Spectrometer. The speed and reproducibility of EDMA enable it to characterize rapidly the elemental characteristics of sediments; the proportions of one key element – Copper – are readily determined, and the method also provides information on the proportions of Calcium, Magnesium and Silicon present. Ca and Mg are likely to reflect, in large part, the quantities of carbonate materials that were derived from the Mesozoic and Cenozoic limestones which crop out in the upper Dana valley. Silicon has numerous local sources: important sources are volcanic and plutonic bedrocks, as well as Cambrian and Ordovician bedrocks that crop out below the limestones through the region, and as a result, information on these elements provides a measure of the throughput of materials eroded in the Wadi Dana and its associated wadis. These data suggest the extent to which the heavy metal load of archaeological sediments in the Faynan may reflect general levels of soil and rock erosion and transportation, as opposed to the consequences of mining and smelting in the study area. Further key interpretative information is provided by the two geological monographs for this region (Barjous 1992; Rabb'a 1994).

In general, EDMA has been shown to have an accuracy of ±10% of the figure given (Goldstein *et al.* 1984; Pyatt and Lacy 1988). In this study the accuracy may be less than this figure. In addition, there are several other limitations that are the consequence of working with archaeological materials that must temper subsequent interpretation. The proportions obtained by EDMA are not the concentrations of the element in that sample, but reflect the abundance of that element relative to elements that can be measured. Because the electron beam of the Scanning Electron Microscope is used as a source of energizing radiation, there may well be a surface sensitivity present which is not generally suitable for bulk samples, and heterogeneity results from the small volume of the sample being analyzed relative to the bulk samples. Fully accurate and precise analytical data can only be obtained if the electron beam is impacting upon a flat and polished surface – properties which cannot exist in the materials studied. This accuracy limit has meant that the results from this technique cannot easily be applied to (essentially isolated single) samples from archaeological deposits, because it is difficult to interpret the information gained. Nevertheless it is possible to employ this approach by using many samples taken through complex sediment bodies, when the study employs the multiple sampling of each sample, and when the resulting data are not over-interpreted. In this study, each estimate of elemental proportions is an average of five replicate studies of that sample.

In sediment sequences like those studied here, which are likely to have complex histories of heavy-metal pollution, it is clear that the estimated proportions of pollutant metals might, on occasion, change rapidly with respect to one another, as one element increases, or another declines. The fluctuations can be difficult to interpret. Nugget effects can occur – an unexpected super-abundance of an element. These may be the consequence of the chance analysis of an area particularly rich in a particular element. Typically, variations in the abundance of the element gold can vary notably through this effect. In common with many other palaeoecological approaches, this feature is managed by ensuring attention is given to seeking wider and sympathetic patterns of change within the whole data body.

In this type of study, information on the actual concentrations of pollutant metals present in a standard body of sediment would also be useful. This information cannot be obtained from EDMA: ICP-MS or similar approaches are needed. However, these apparently more reliable analyses also require additional information for reliable interpretation: it is important to be able to sustain key assumptions concerning the approximate equivalence of rates and styles of accumulation represented by samples, assumptions which are often over-looked because of the difficulty of establishing the nature and rate of sedimentation in appropriate detail. This work is presently underway.

Study locations

The first location studied is the section exposed at Tell Wadi Faynan: there is a continuous sequence of windblown sands and silts here, which accumulated several kilometres downwind of the key metal-smelting areas around Khirbat Faynan (Barker *et al.* 1997, fig.6). These sediments have yielded radiocarbon- and archaeologically-dated materials which demonstrate that they were of late neolithic antiquity at their base and Roman/Byzantine age at their surface (al-Najjar *et al.* 1990). Extrapolation from al-Najjar *et al.* (1990) suggests that the sediments from 0–45 cm. were late neolithic, 45–60 cm. were chalcolithic, whilst from 60–140 cm. they ranged from bronze age to Roman/Byzantine. The uppermost sediments from 115–140 cm. are inter-bedded with Roman/Byzantine sherds and metal-smelting wastes and are overlain by field walls thought to be of approximately this age. In common with all such surficial sequences in this area, the sediment body evidences desiccation cracks and bioturbation. Nevertheless, field inspection revealed no evidence which would nullify an assumption of the essential stratigraphic integrity of the sequence.

The second location is the accumulation of slopewash and windblown materials in a reservoir behind a barrage at Khirbat Faynan. As discussed by Hunt and Mohammed (1998), this deposit probably represents a more or less continuous sequence of sediments spanning the past 2500 years, that is, from approximately Nabatean times to the present day. This sequence was sampled using an Edelman coring head on an Eijkelkamp auger.

Results and discussion

At Tell Wadi Faynan, Ca and Si dominate the composition of the largely wind-blown sediments (Fig. 4). Although fluctuations in the proportions of one are (not surprisingly) reflected in the proportions of the other, the proportions of each remain much the same throughout the profile, suggesting that there have been no dramatic changes in the provenance or general character of these sediments during their accumulation. Re-plotting these data on a log-scale (Fig. 5) enables fluctuations in other elements associated with pollution to be examined, without the swamping effects that stem from changes in the proportions of the abundant Ca and Si. Comparison of the changing proportions of the elements indicates that there are no particular associations between fluctuations in Ca or Si, and heavy metals such as Cu, Ag, or Zn. In consequence, there are no grounds for believing that the variations in these heavy metals are the result of natural fluctuations in the rates of transport and depositions of metal-bearing sediments from upstream in the catchment – they appear to reflect enhancement due to mining and smelting. These data suggest that significant pollution began after the Late Neolithic and reached extremely high levels in the Roman-Byzantine period, a pattern which corresponds with both wider patterns of Cu emission to the atmosphere postulated for the northern hemisphere by Hong *et al.* (1996), and the industrial history of the Faynan region proposed by Hauptmann (e.g. 1989, 1992, 1997; Hauptmann *et al.* 1992).

There is a reverse sequence in the sediments behind the Khirbat Faynan barrage, with extremely high levels of heavy metal pollution at the base and lower levels further up (Figs 6 and 7). Ca and Si indicate both the overall preponderance, and the essential constancy of provenance, of the carbonate-

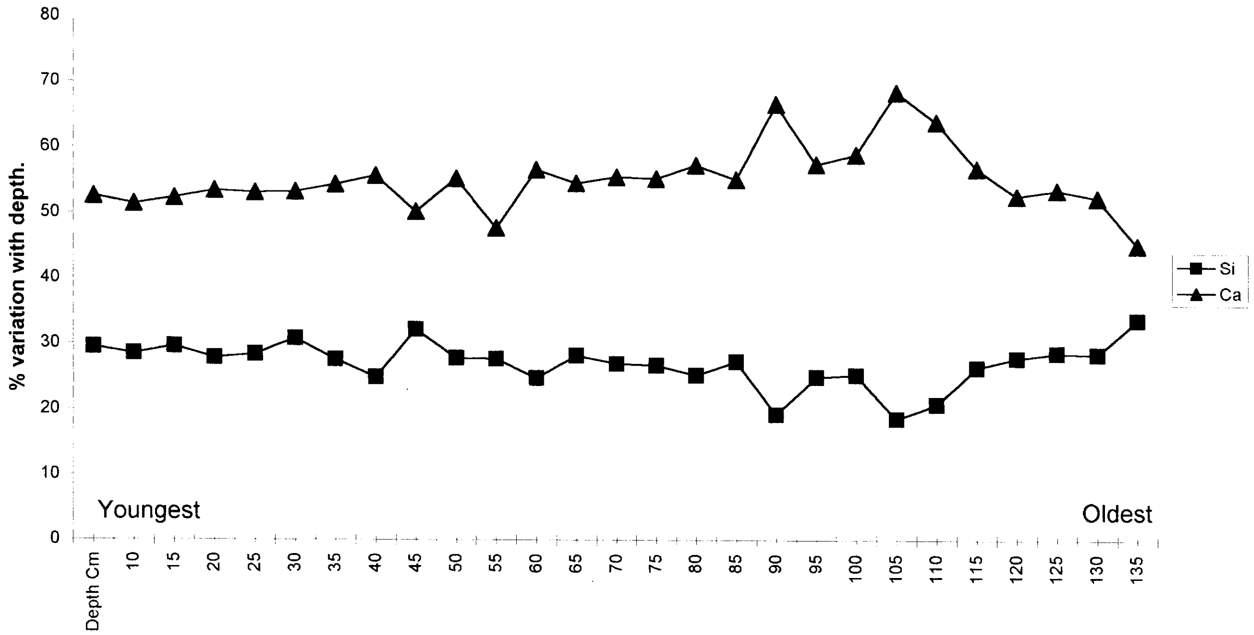

Figure 4. *Proportions of Silicon (Si) and Calcium (Ca) determined by EDMA from the aeolian and water-washed sequence at Tell Wadi Faynan. The base of the sequence is Late Neolithic to approximately 45 cm., the upper part from 120 to the surface at 140 cm. is Roman/Byzantine.*

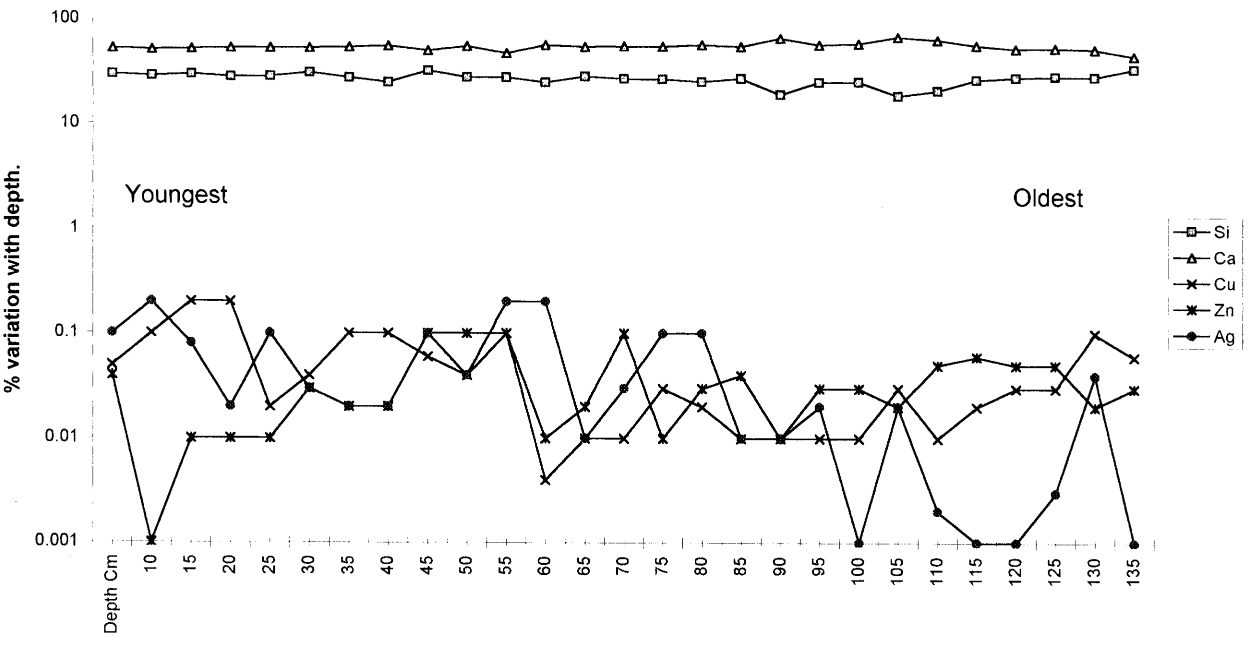

Figure 5. *Proportions determined by EDMA of Silicon (Si), Calcium (Ca), Copper (Cu), Tin (Sn) and Silver (Ag) plotted on a log scale at Tell Wadi Faynan. The base of the sequence is Late Neolithic to approximately 45 cm., the upper part from 120 to the surface at 140 cm. is Roman/Byzantine.*

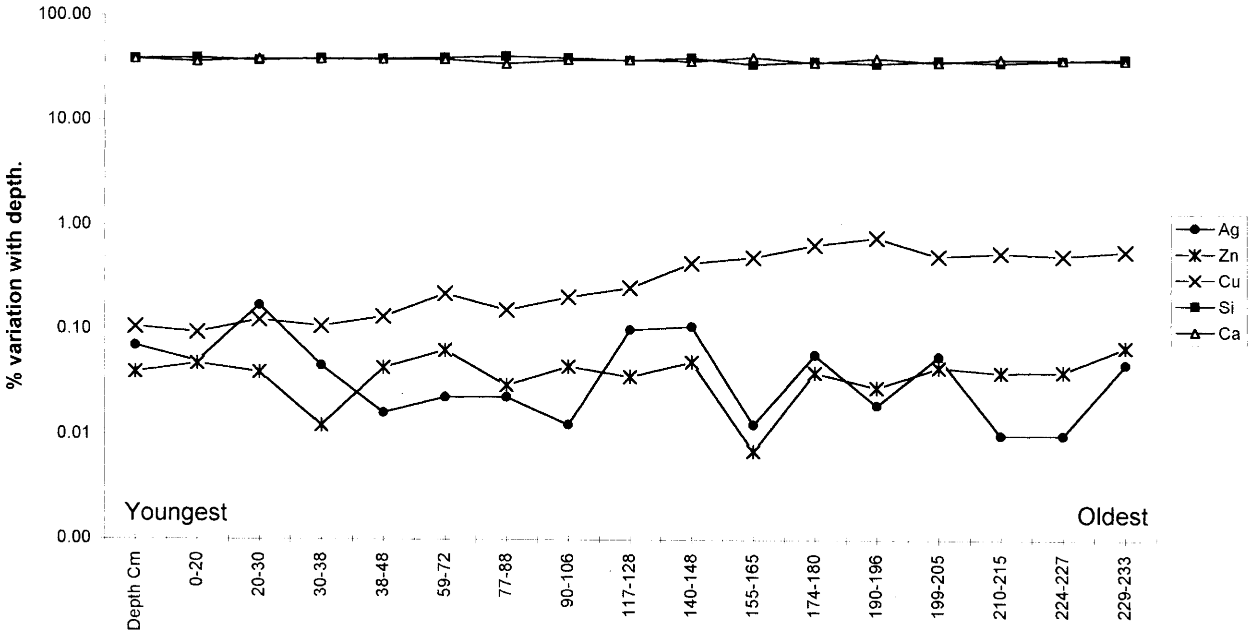

Figure 6. *The proportions of Calcium (Ca), Silicon (Si), Copper (Cu), Zinc (Zn) and Silver (Ag) determined by EDMA through the Khirbat Faynan reservoir-infill deposits – these are assumed to date from the Nabatean/Roman period at the base 229 cm. and to be modern at the surface at 0 cm.*

rich and quartz-rich fine sands which accumulated behind the barrage. It is evident that the proportions of selected heavy metals through the profile bear little relation to variations in Ca and Si, again suggesting that these pollutants reflect human activities, not variations in overall sediment input. Very polluted sediments are indicated below 140 cm., with notable proportions of pollution from Cu and Sn. There appears to be another area of very polluted sediment at and above 50 cm., but by this time Cu had become relatively unimportant. Overall, the proportions of Cu decline upwards from about 77–99 cm., suggesting a diminution of metal-working and smelting. The proportions of Co, Ag and Zn present are very low, and it is difficult to interpret fluctuations in them. Nugget effects are probably apparent in the small proportions of gold detected. The uppermost sediments are still very enriched in copper, a feature which appears to reflect the modern environment with its legacy of ancient metalliferous slags (see below), but still almost an order of magnitude lower than those in the lower parts of the barrage infill.

The systematic nature of the trends evidenced in the more abundant elements such as Cu through these two bodies of sediments suggests the essential reliability of EDMA studies when carried out in the manner described and the interpretive caution advocated. Much further work is needed on the sources of these metals, the mechanisms by which they were released, as well as their transport, deposition and stability in this environment. Nevertheless, it seems clear from the proportions of copper detected in both the upper Tell Wadi Faynan sequence and in the basal Khirbat Faynan sequence that there were high levels of environmental pollution caused by copper processing in the Nabatean, Roman and Byzantine periods, concentrations which coincide, of course, with the plentiful archaeological evidence that these periods, the Roman and Byzantine in particular, witnessed intensive copper mining and smelting.

Environmental pollution today

Alongside the study of the archaeological sediments, the present-day ecology of the area was investigated (by FBP) in particular to determine the impact of metalliferous pollutants today from the past mining and smelting activities. It was found that the vegetation of the spoil/slag tips was limited in diversity and that generally the biomass and cover values of plants were reduced in such contaminated areas. Species which had successfully colonized and survived in these areas included *Asphodelus fistulosa*, *Ephedra alte*,

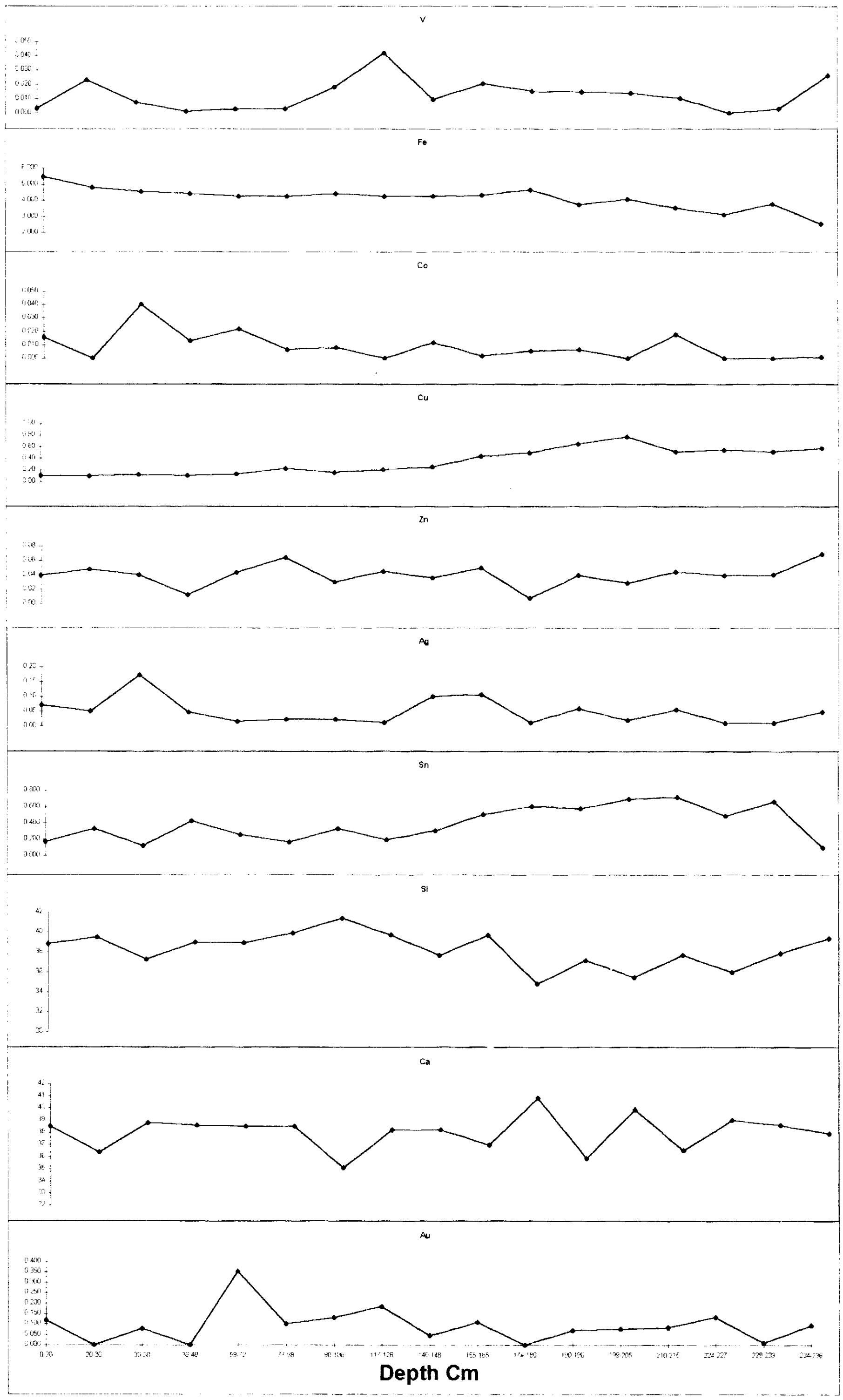

Figure 7. *The proportions of metal elements determined by EDMA through the Khirbat Faynan reservoir-infill sediments: Vanadium (V), Iron (Fe), Cobalt (Co), Copper (Cu), Zinc (Zn), Silver (Ag), Tin (Sn), Silicon (Si), Calcium (Ca), and Gold (Au). The base of the sequence is at 234 cm.*

Gymnarrhena micrantha, and *Urginea maritima*. These species are also present in sites distant from the spoil/slag tips, and it is conceivable, but currently unproved, that ecotype formation may have occurred in the polluted areas. The organic increment in the polluted areas was extremely limited and often found trapped in small pockets by micro-topographical features; consequently, pattern is imposed on plant distribution as a response to factors of both the biotic and abiotic environment.

A series of animal and plant samples was taken from sites within the area, both control sites away from the spoil/slag tips and contaminated sites on or around them. Initial analysis by atomic absorption and X-ray microanalysis is indicating bioaccumulation together with the transfer of cations through trophic levels. Such movement of cations through food webs was reflected in the preliminary values of copper in the faeces (10 parts per million) and urine (5 ppm) of the present-day sheep population, and in the milk (3 ppm in samples from two herds) of goats. Analysis of wild barley plants sampled on a transect also indicates that biomass and cover values deteriorate with increasing metal pollution. It is clear that the mining and smelting residues of the Faynan landscape are having notable pollution impacts even today, and it is conceivable that the local bedouin may be the recipients of enhanced copper body burdens. Further analysis of plants and herbivores is clearly important to develop this aspect

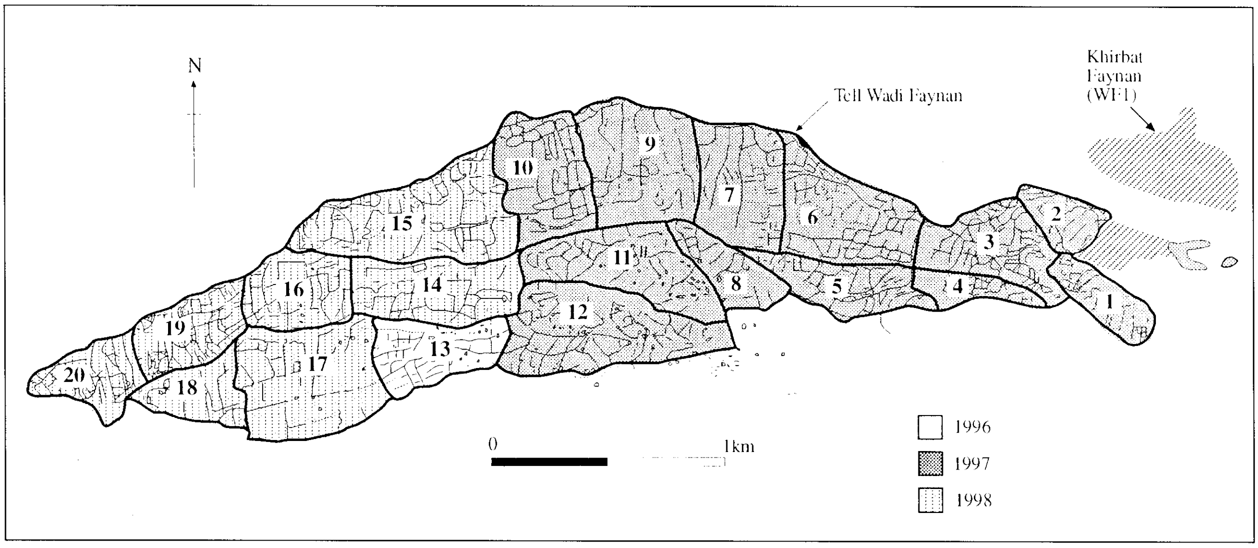

Figure 8. *The main field system in Wadi Faynan (WF4), showing areas surveyed in the 1996, 1997 and 1998 seasons.*

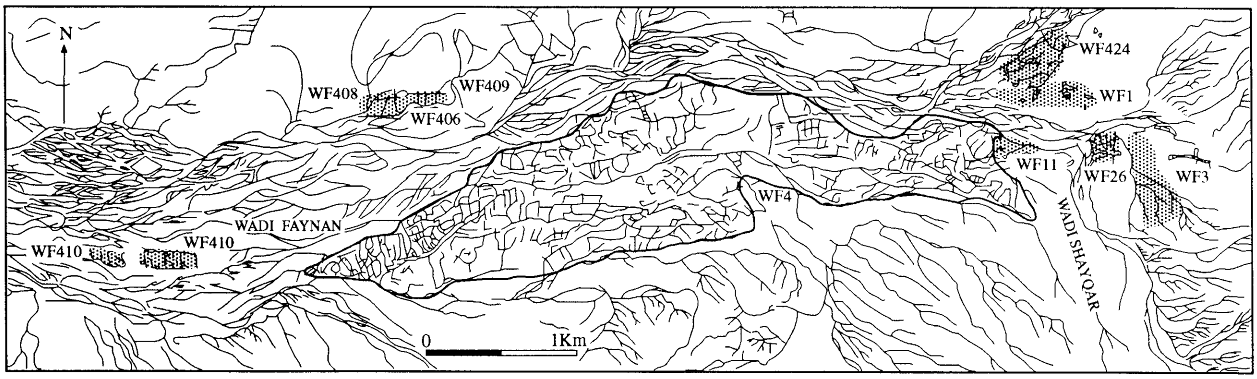

Figure 9. *Ancient field systems in the Wadi Faynan, showing the units surveyed in the 1998 field system outlying the main field system WF4.*

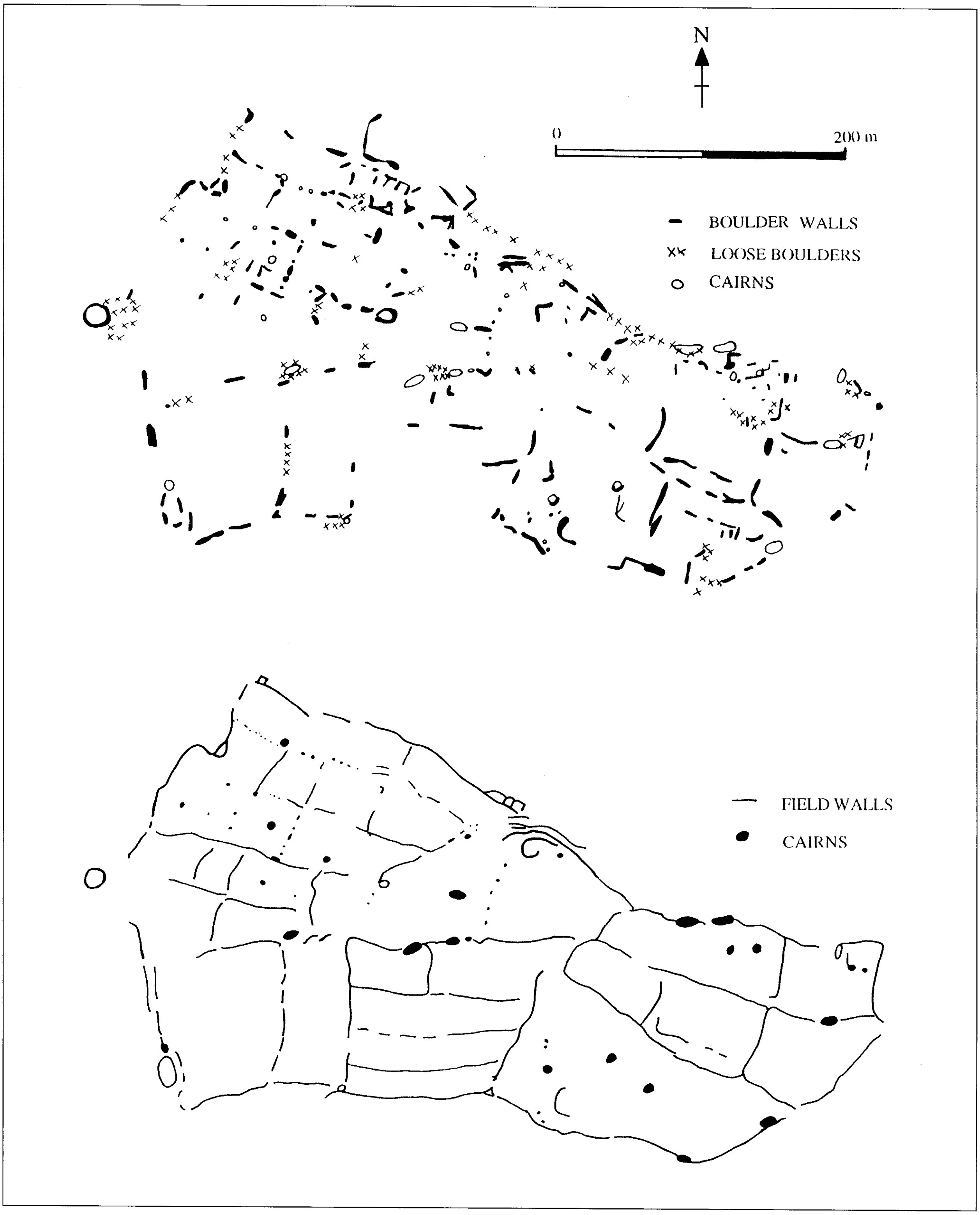

Figure 10. *Survey unit WF4.13, showing (above) the early bronze age and (below) the classical landscapes.*

of the programme and its implications for future as well as present systems of land use.

The comparison between the scales of metalliferous environmental pollution today and in the Nabatean/Roman/Byzantine periods suggests the likelihood of severe effects on human health in those periods of antiquity as a consequence of inhalation, skin contamination, and bioaccumulation from animal and plant foods. Livestock would surely have been affected from grazing polluted vegetation, as the sheep and goats still are today. On the evidence of the modern barley transect, plant productivity would also have been impaired. The implications of these preliminary findings are clearly exciting, and it is intended in the future to investigate the effects of environmental pollution on past Faynan populations through the analysis of human and other animal skeletal material.

The field system survey

Introduction (OC, PN)

The 1998 field season saw the continuation of artefact pickup and wall recording across the field system WF4, completing the programme begun in 1996. By the end of the 1997 season, 12 of the 20 units into which the field system had been divided had their fields recorded and samples of surface artefacts collected. Hence the priority of the 1998 season was to record and collect material from the outstanding units of the major field system WF4, that is, WF4.13 to WF4.20 (Fig. 8). Of these units, WF4.13 had already had surface artefacts collected from it in the pilot scheme in 1996, so only required the walls to be recorded. The recording of walls and the collection of surface material in the remaining areas constituted the initial phase of fieldwork. Subsequently this phase was supplemented by the recording and photographing of structural features within the fields or field walls considered to be of special interest or significance. Such features included: large cairns; clear examples of water management structures such as sluices, baffles and spillways; buildings, burials and large boulder structures; and long continuous lengths of parallel walling. This operation was completed successfully within the first three weeks of the month-long season (Fig. 8), leaving the final week free to commence the recording and sampling of the vestiges of smaller field systems beyond WF4 (Fig. 9). The 1998 studies, of both the WF4 field system and the field systems beyond, have considerably enhanced our understanding of the chronology and functioning of the ancient floodwater farming systems in the Wadi Faynan.

The bronze age landscape in WF4.13 (= site WF100) (DJM)

Further investigation of the field systems and other structural evidence in area 13 of field system WF4 revealed important information about the landscape evolution in this area. The excavations carried out in 1997 by Dr K. Wright (Wright *et al.* 1998) provided the key to interpreting and separating out the early bronze age and later landscape features (Fig. 10). This unit comprises a well-defined terrace containing 30 fields demarcated by walls of probable Nabatean and later date, while a dense spread of early bronze age pottery had indicated, even before the start of the current fieldwork, that a substantial settlement of the Early Bronze Age existed beneath. The essentially hydraulic function of the classical field system was clear from close examination of surviving drop-structures (spillways) and from a microtopographical analysis of the system as a whole. Water flowed through this system over a succession of low terraces running from east to west. The 1997 excavations had confirmed that the main series of field walls that we see today were of Nabatean and later date, but that numerous features of bronze age date were also surviving, in part incorporated, in part destroyed, in part buried below the later walls. Many of the walls in this area contained a mixture of construction styles, the main contrast being between, on the one hand, double-faced terrace walls of roughly coursed blocks and, on the other, lines of large boulders set orthostatically. The latter style of wall foundation appears, from the excavated evidence, to be a particular feature of the bronze age structures of WF 100. The Nabatean terrace walls typically are wider and have a distinctive core of small stone and mud packing, even when they are reusing boulders from dismantled early bronze age walls or building over the top of sections of early bronze age foundations *in situ.*

A record was made of over 60 features in this unit. Many of these numbers were allocated to boulder lines breaking the surface and indicating the presence of underlying bronze age walls or structures (Fig. 11). In the clearest examples, it was apparent that bronze age rectilinear buildings had been incorporated directly into later field walls. In a number of cases where the boulder walls were traced in the centre of later fields, the boulders were scored by numerous vertical lines, interpreted as evidence of ploughing (Fig. 12). The plough marks suggest that there has been up to 20 cm. of soil deflation in this part of the field system since antiquity, supporting the sediment and palynological evidence for soil erosion during and/or after the Bronze Age discussed

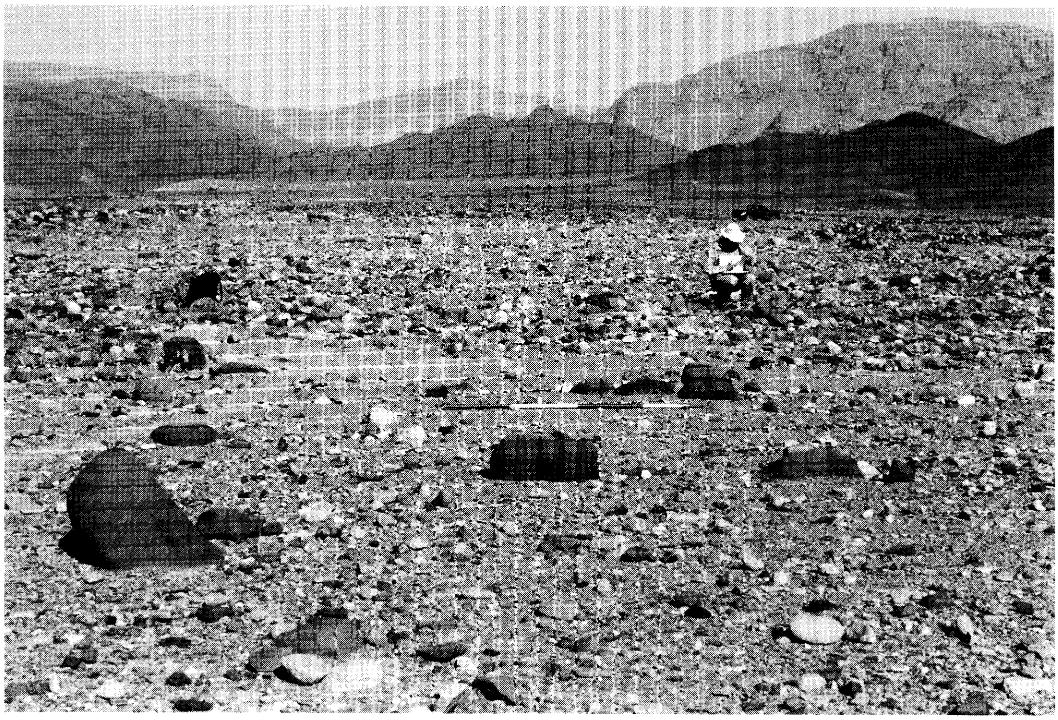

Figure 11. *Boulder structures probably of bronze age date in WF4.13. Scale 2 m. (Photograph: G. Barker).*

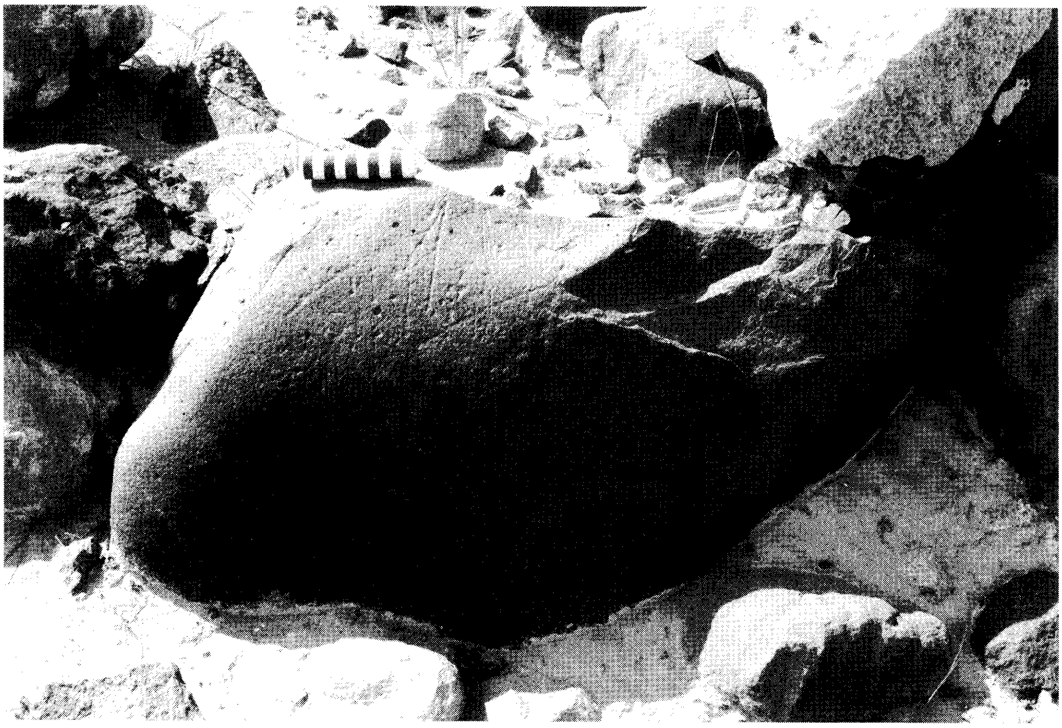

Figure 12. *Scratchmarks on ancient boulder walls in WF4.13, presumably ploughmarks, indicating soil deflation since the period of their construction. Scale 10 cm. (Photograph: G. Barker).*