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Coping with desertification: 5000 years of farming and mining in the Wadi Faynan, southern Jordan

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Introduction

Much has been written about desertification - about how and why desert landscapes have developed - by historians, geographers, ecologists, and archaeologists. 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, or stripping the landscape for fuelwood, or 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, at variance with the linear models of human impact frequently proposed by archaeologists and historians for the past. Despite the frequency of speculation about the role of people in desertification in the past, and the potential of landscape archaeology to contribute significantly to the debate, there have been remarkably few modern scientific studies of the problem attempting to bring the the appropriate range of disciplines together within a single integrated

research framework (Barker *et al.* 1996). This is the aim of the project discussed in this paper.

The Wadi Faynan is situated about 40 kilometres from Petra, the world-famous capital of the Nabatean kingdom that flourished in the last few centuries BC before the Roman conquest of the region. The study area for our project embraces the catchment of the wadi, forming a transect about five kilometres wide running for some fifteen kilometres westwards from the rim of the Jordanian plateau *c.*1500 metres above sea level to the floor of the Wadi Arabah rift valley, here at about sea level. The main wadi today is a bleak landscape, arid and largely denuded of vegetation, but the three main tributary wadis of the Wadi Faynan that dissect the plateau scarp, (from north to south) the Dana, Ghuwayr and Shayqar, are in places well watered and comparatively well vegetated from ground springs.

The principal archaeological monuments of the Wadi Faynan, long known to early travellers, are the Khirbet Faynan, a major settlement of Nabatean, Roman and late-Roman (Byzantine) date located at the head of the Wadi Faynan near the confluence of the three tributaries and, nearby, an aqueduct, reservoir and water mill of Roman/Byzantine date. To the west of this complex is a substantial (*c*.5-kilometre long) field system of rubble walls, its surface pottery indicating primary use contemporary with that of the Khirbet Faynan settlement. Before our project began, reconnaissance surveys had also located a variety of neolithic, chalcolithic and bronze age sites both in the main wadi and in its tributaries, some of which are being excavated by other teams.

Wadi Faynan and its environs are also characterized by rich mineral deposits, and from the work especially of the Bochum Mining Museum (Germany) the history of copper exploitation here is comparatively well documented (Hauptmann 1992; Hauptmann and Weisgerber 1987; Hauptmann *et al*. 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, and especially Roman and Byzantine times: it is generally agreed that Khirbet Faynan must be the settlement of *Phaino* mentioned by classical writers as the place to which prisoners such as Christians from Palestine and Egypt were transported in the third and early fourth centuries AD to work the copper mines under its control.

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. The methodologies of the team include: geomorphology and

palaeoecology; archaeological survey of the field systems and hydraulic structures; archaeological survey of the settlements, cairns and other surface archaeological evidence both within and outside the field systems; the collection and analysis of associated surface artefacts; ethnoarchaeology; and GIS analysis. This paper is based on the preliminary findings of the first three seasons of fieldwork of what is scheduled to be a five year project, and encorporates the work of researchers from a dozen research institutions (Barker *et al.*, 1997, 1998, and in press).

Climate and environment

A geomorphological sequence of landform changes and climatic fluctuations has been established by the project for the past *c.*200,000 years and given a preliminary chronology with a series of OSL and C14 dates. The late glacial environment was cold and dry, and there is then strong and widespread evidence from sediment sequences and the fauna and flora within them for a significantly wetter environment in the early Holocene, probably lasting until *c.*6000 years ago. This was replaced by a relatively steppic landscape by the fourth and third millennia BC. There is evidence for strong soil erosion during and after this period, through the second and first millennia BC. By the later first millennium BC the landscape consisted of very degraded steppeland, and this degradation then accelerated significantly through the first millennium AD with a collapse of the steppic component in the pollen diagrams along with the disappearance of olive cultivation and a drastic reduction in cereal cultivation - the flora at this time was analogous to the modern pollen rain in the Dead Sea. The desertic environment has persisted to the present day, though there is evidence for an episode of even greater aridity in the period *c.*AD 1600-1850.

Settlement systems

Most of the lithic evidence for the presence of Natufian foragers c.10,000 years ago has been found in the upper tributaries, though some Natufian lithics have been found throughout the main wadi. The same holds true for the Pre-Pottery Neolithic period - the main settlements were in the upper tributaries: a PPN 'A' site of simple rubble shelters and pits currently being excavated by Bill Finlayson and Steve Mithen (Finlayson and Mithen 1998), and a substantial PPN 'B' settlement of well-built stone houses being excavated by Alan Simmons and Mohammed Najjar (Simmons and al-Najjar 1996), are a few hundred metres apart in the lower Wadi Ghuwayr at the junction between the mountains and the main wadi. By the sixth and fifth millennia BC, the zone of principal settlement had expanded out into the main wadi: excavations a few years ago, for example, revealed a late neolithic/early chalcolithic settlement of simple rectangular drystone houses at Tell Wadi Faynan, a kilometre

west of Khirbet Faynan (Najjar *et al.*, 1990). By the fourth and third millennia BC, during the Early Bronze Age, the primary settlement zone seems to have shifted into the main wadi, and expanded throughout it: our survey has revealed a series of discrete zones of bronze age settlement, both on the southern side of the wadi within the area demarcated by the later classical field system and in the small tributary wadis on the northern side. One zone of the classical field system encompasses the most substantial of these settlements, where excavations by Dr Karen Wright have revealed evidence for irregularly-built drystone structures together with enclosures, middens, pits and storage bins (Wright *et al.* 1998).

By the early first millennium BC, the iron age landscape was dominated by a single substantial settlement (WF424 in our survey record), built immediately below its successor Khirbet Faynan at the strategic centre of the Faynan region, the point where the three major tributary wadis come together to form the Faynan. We have also found zones of iron age settlement along the southern margins of the field system, and on the northern side of the wadi. The evidence suggests that the iron age settlement system consisted a few large and discrete habitation units, probably organized hierarchically, with WF424 the dominant site, though recent work in the neighbouring Wadi Fidan suggests that there may have been other more ephemeral settlement forms as well (Levy *et al.* in press).

The Nabatean system in the last three centuries BC was also dominated by one central settlement, Khirbet Faynan. However, the excavations by Wright *et al.* (1998) found small buildings of Nabatean and Roman date in the area of the bronze age settlement within the classical field system, and we have noted a variety of structures with similar pottery elsewhere within the field system. Also, though the systematic recording and analysis of the archaeology outside the WF4 field system only begins in 1999, we know of a series of larger farmsteads of broadly Nabatean date on the southern slopes overlooking the classical field system. The indications are, therefore, that the Nabatean landscape consisted of a series of adjacent settlement units, organized in some kind of hierarchicall relationship with respect to Khirbet Faynan.

In Roman and Byzantine times most of the satellite settlements were abandoned, leaving Khirbet Faynan as the single dominant settlement, the *Phaino* of the classical sources. The nature of the Islamic and later settlement system following the eventual abandonment of Khirbet Faynan remains unclear, but it is at least evident from our survey work so far that it was not characterized by a renewal of substantial settlement within the field system zone, though there are indications of ephemeral settlements on the surrounding slopes akin to the sites of recently abandoned Bedouin encampments.

Farming and water management

Like the Natufian foragers before them, the first agricultural communities in the wadi clearly preferred the well-watered upper tributaries for their primary settlements, though lithic scatters indicate other activities throughout the main wadi, presumably hunting and pastoralism. The spring-side locations of the PPN A known in the Wadis Dana and Ghuwayr are typical of many early farming sites in the Near East - like the well known site of Beidha, for example, on the plateau 30 kilometres away near Petra - presumably because the springs provided naturally-irrigated land for cereal fields and animal pasture (Bar-Yosef 1995). Our geomorphological investigations show that, when later neolithic farmers settled at Tell Wadi Faynan, there was a more or less perennial stream by the site - the sediments contain, for example, frustules of the diatom *Navicula*, a freshwater organism - and the pottery and mortar from the site contain a mixture of reeds and grass as well as straw. The likelihood is that the primary settlement zone was able to expand from the tributaries to the main wadi floor at this time, when the environment was signficantly wetter than before or afterwards, because farmers could exploit the seasonal floodwaters of the main wadi for their crops with methods akin to those used by the earlier neolithic farmers in the upper tributaries.

In the area of the early bronze age settlement within the classical field system, we have been able to recognize a series of boulder walls within and underlying the later field system which appear to be vestiges of bronze age structures and field boundaries, some of the latter terraced. They are associated with circular or oval cisterns 30-50 centimetres deep, fed by short feeder walls. The northern settlement zones include sequences of roughly-built terrace walls and check dams built across the shallow floors of tributary wadis, with pottery in associated sediment sequences indicating a bronze age date. The indications are, therefore, that, whereas neolithic farmers in the Wadi Faynan were able to exploit well-watered locations, bronze age farmers were having to develop strategies for coping with the more arid environments evidenced for the fourth and third millennia BC, strategies that included building walls to collect and trap seasonal floodwaters in storage cisterns and in terraced fields laid out along the direction of water flow.

The principal iron age settlement beside Khirbet Faynan was associated not only with a field system of boulder-built walls, often set orthostatically, but also with substantial boundary walls built upstream of these fields along the junction between the hill and the wadi floor. These boundary walls collected water from the surrounding slopes and guided it along to particular exit sluices above the terraced fields, so that maximum water flow could be directed down the central part of the field system. Similar boundary walls enclosed iron age field systems on the northern

side of the Wadi Faynan, and in part at least they had a water-diversion function. We cannot be sure of the dating of these boundary walls because the field systems which they enclose, which we believe are of iron age date, are invariably overlain by classical fields. However, the fact that we have only found these boundary walls enclosing field systems with significant iron age material, and the constructional similarities between the walls and the fields they enclose, suggest an iron age date is the most reasonable hypothesis on the present evidence. If ths theory is correct, it implies that, whereas bronze age farmers built terrace walls at right angles across wadi beds to check floodwater flow and try to spread it laterally over surrounding fields, and small catchments to collect water in cisterns, iron age farmers in Faynan had learned to construct substantial and rather sophisticated walls to divert the flow of floodwaters sometimes hundreds of metres from their natural line, so that far greater quantities of water could be collected and sent down a field system than was possible with bronze age technology.

The technology of floodwater farming was further refined by Nabatean farmers in the latter centuries of the first millennium BC. The focus of their wall-building activities was especially a series of small tributary wadis that run parallel to the main wadi along its southern side. Water was dammed as it issued from the adjacent hills, diverted westwards by boulder walls along the contour of the slope, and then through simple sluices (gaps) and spillways (stepped structures) onto terraced fields below. Nabatean technology on the southern slopes may also have included channels formed by parallel walls that fed water directly into the fields on either side through sluice gaps.

It seems increasingly likely from the studies of field layout and construction, and of the surface material, that the entire agricultural landscape was managed as a more or less integral system in the Roman and Byzantine periods. Systems of long parallel walls were built to divert water from the main wadi into adjacent fields on low-elevation terrain, and from the southern tributary wadis. Further down these tributary wadis, similar channels were built at *c.*45^{o} to water flow to collect any water that had by-passed the higher diversion walls or drained back into the wadis from the higher terraced fields, to force it once more onto adjacent cultivable land. The effectiveness of the system is in part explained by the uniformly low levels of water infiltration we have found at sample sites from the upper slopes to the lowest fields, but organizational factors were also important. The field evidence supports the hypothesis of cooperation between areas of the field system fed by the parallel channels: rather than farmers with land upslope having exclusive access to the floodwaters of particular wadis at the expense of other farmers with land further down the direction of flow, the internal linkages between the system imply that water

resources were shared down the length of the field system. The construction of major parallel channels to carry floodwater through the system demonstrates the same engineering skills in moving water relatively long distances over gentle gradients as are displayed by the Roman engineers who designed the rock-cut feeder channel that brought water several kilometres from the Wadi Ghuwayr spring to the aqueduct feeding the reservoir near Khirbet Faynan.

Mining and smelting and their environmental impacts

Nuggets of surface copper were collected by neolithic (and probably earlier) people in Wadi Faynan, presumably for ornamental purposes, and Faynan copper was exploited by chalcolithic people and traded with the surrounding region. However, the first clear evidence for the systematic mining of the copper ores and their processing at Faynan settlements is in the Early Bronze Age, a period of major transformations in social complexity throughout the Levant (Adams and Genz, 1995; Hauptmann, 1989; Wright *et al.* 1998). At first, ores visible at the surface were mined by open-cast methods and then smelted in smple crucibles in the settlements, but as demand increased, deeper ores were mined by galleries and then smelted in smelting ovens located on the windward side of ridges near the settlements. By the Iron Age, deep ores were being mined extensively in the hills and then smelted at major settlements such as the one below Khirbet Faynan, where we found thick deposits of slags, charcoal-rich unlike the bronze age slags, suggesting experimentation with new technologies to deal with the far larger quantities of ore being processed.

By the Roman period, the hills around Faynan were honeycombed with deep mine shafts, and the quantities of ore being smelted by the *Phaino* labour gangs have left kilometre-long spreads of tap slag on the ridges above Khirbet Faynan. One of the most exciting results of our project is geochemical evidence from sediments sampled near Tell Wadi Faynan and Khirbet Faynan and analyzed by EDMA (Energy Dispersive X-ray Micro-Analysis) that appears to record changing levels of heavy-metal pollution in the atmosphere caused by the copper smelting. The initial results suggest that this pollution was small-scale in the Chalcolithic and the Early Bronze Age, significantly greater in iron age and Nabatean times, and enormous (lethal in terms of modern pollution criteria) in Roman/Byzantine times, with further smaller impacts later.

Discussion and conclusion

Although our focus to date on the field system evidence, and not yet on the archaeology of the surrounding hills, means that the relations between agriculture and pastoralism through time remain uncertain, the initial results of our project indicate

complex non-linear sequences of environmental change, settlement systems, and agricultural and industrial activity.

First, in terms of environmental change, after the early Holocene wetter phase we can discern a principal trend of progressive aridification and degradation, culminating in extremely degraded landscapes by the mid first millennium AD. However, though the partial nature of the record needs to be emphasized, and its chronological imprecision, it is already clear that the trend was not constant in its progression, and that it contains oscillations.

Second, in terms of land use, from the Late Neolithic onwards a number of increasingly sophisticated systems of water control can be discerned, but again it is clear that there is no simple progression in land use from simple to complex. Whilst early bronze age (and perhaps late chalcolithic) farmers developed systems of floodwater farming to cope with increasing aridity in the fourth and third millennia BC, the nature of settlement and land use in the second millennium BC remains unclear (as indeed throughout the region), though a switch to forms of land use dominated by pastoralism is usually proposed within the context of the collapse of early bronze age polities. From excavations in the neighbouring Wadi Fidan (Levy *et al.* in press) there are suggestions of pastoral groups on the fringe of the agricultural units there in the Iron Age, and there are indications of a similar archaeology of pastoralism in our own area in the Iron Age and Nabatean periods. There is striking evidence for large-scale and highly organized - coordinated - systems of floodwater farming in Roman and Byzantine times. The likelihood is that the degraded landscapes of the post-Byzantine period have only supported systems of land use like those of the Bedouin in the region today.

Third, another complex non-linear sequence is emerging regarding the impact of people on landscape. The expansion of farming down the wadi in the Later Neolithic appears to have had no significant impact on the landscape, but it is possible that the erosion we can detect during and after the Early Bronze Age, whilst probably mainly a response to aridification, partly reflects poor land management techniques. Given the evidence of the geochemistry for the beginning of smelting pollution at this time, wood-cutting for metallurgical processing may also have been a factor. However that may be, it is clear that the demands of Nabatean and in particular Roman/Byzantine mining activities (the latter probably state organized), in parallel with the intensive agricultural practices developed to feed the workforce, had an ultimately devastating impact on the landscape. Our pollen evidence for the dramatic reduction in vegetation cover in Roman/Byzantime times is supported by charcoal analysis from smelting sites suggesting that by this period timber for the furnaces had to be brought down from the plateau because none was available locally (Engel 1993;

Hauptmann 1992). We have also found widespread evidence that the classical farmers were trying to combat the effects of wadi-downcutting in their alterations to the floodwater-farming systems. These were ultimately ineffective - the main wadi now flows at least five metres below the parallel channel systems that diverted the Faynan floodwaters into the ancient fields. Whether or not climatic change was also a factor, it is clear that stripping the landscape of vegetation must have made it extremely vulnerable to erosional trends.

The geochemical evidence also demonstrates that industrial processing at this time caused enormously high levels of environmental pollution. The effects of this are still felt today - our ecologists have found that the milk, urine and faeces of the Bedouin's goats today have significant levels of heavy metals from grazing the polluted ground, and that cereal growth is also badly affected around the smelting sites. Hence there is a strong possibility (still to be tested by skeletal analysis) that the health of the classical populations in particular was directly affected from inhalation, skin contamination, and bioaccumulation of polluted animal and plant foods. Whilst the collapse of intensive farming and mining in Roman and Byzantine times no doubt in part reflects changing economic relations between Faynan and the wider world, it seems inescapable that the activities of these farmers and miners had a profound impact on their landscape from which it has still not recovered, and probably directly on their own well-being.

Our project has succeeded so far in establishing the principal components of the environmental and settlement sequences in the Wadi Faynan: what we can tell so far of their inter-relationships indicates something of the potential complexity of the interplay between long-term, medium-term, and short-term processes that is likely to emerge as the project develops. However, the richness of the data also suggest that, especially through GIS, we should be able to integrate our findings on how the landscape has changed, and the role of people in this, to investigate also how different populations in the past perceived their changing landscape and their place within it. It should be possible, for example, to model the spatial characteristics of air pollution at different distances from the major smelting settlements, and its different effects on surrounding populations. There is much still to be learned about the extent to which farmers using the field system operated independently or collaborated, and in the latter case, whether by cooperation or coercion. And how did the sacred and the secular relate to one another in different periods? There is intriguing evidence, for example, that whereas bronze age people kept their cemeteries and fields apart, classical farmers deliberately constructed water diversion systems so that they encorporated burial cairns at key nodal points. Reconstructing landscape histories needs natural scientists to analyze changing forms of landscape, and archaeologists to

analyze changing settlement morphologies and systems. We hope that the effective partnership of disciplines in our project will allow us ultimately not just to describe these two landscape histories for Faynan but also to understand their interactions, including in terms of the perceptions and choices that underpinned human actions in this landscape, and shaped the latter with ultimately devastating consequences.

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