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Classical Period Floodwater farming and quarrying at Jabal Hamra Arlbieg in the Jordanian desert: economic support for the Faynan Orefield

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Abstract

Recent research has shown that the Faynan Orefield was a scene of intensive metal production during the Classical Period, but the infrastructure supporting this activity is less well known. We present evidence for previously undetected floodwater-farming and quarrying at Jabal Hamra Arlbieg, which contributed to the economic life of the Faynan complex during Classical times. The site is located on an ancient route, south of the orefield. We describe the hydrological control features of the floodwater farm and a possible place of habitation. Pollen analysis suggests that olives and cereals were cultivated. Exposures of sediment sequences containing buried walls, and ceramics both within and upon these sediments, all indicate that the activity took place during Nabatean to Late Roman/Byzantine times. Two ancient quarried areas were distinguished from natural landforms by a combination of geomorphic properties and variations in the geochemistry of the Mn-Fe rich desert varnish on long-exposed and quarried rock surfaces. The site provided uncontaminated produce and building stone to the Faynan Orefield.

1. INTRODUCTION

Over the last 40 years, a series of projects have investigated the history and functioning of the great copper-production complex centred on the Khirbat Faynan, with its associated wall, channel and field networks mapped westward along the Wadi Faynan (Fig. 1; Barker et al., 2007; Hauptmann 2007). The Faynan Orefield (Figs. 1-3) was a key location of substantial Bronze Age into early mediaeval copper production (Adams 2002, 2003, Barker et al. 2007; Hauptmann 2007; Hunt et al. 2007; Hunt and el-Rishi 2010; Kind 1965; Knabb et al. 2016; Levy et al. 2001; 2002; 2003;

Weisgerber 2006) and a major source of environmental pollution (Grattan et al, 2007; 2016; Pyatt et al. 1999). The Faynan Orefield was one of the great, long-lasting industrial powerhouses of the ancient world, and its resource demand would have been substantial. Activities on the orefield were partially sustained by the organised development and exploitation of local ore, water, stone, plants, timber, animals and food. The orefield was, however, not self-sufficient: critical resources including charcoal and food were introduced along well-known routes from the inherently wetter and more biologically-productive Jordanian Plateau and from further afield. (Fig. 1: Baierle 1993; Baierle et al. 1989; Friedmann 2013; Horsfield and Conway 1930; Hunt et al. 2007; Hunt and el-Rishi 2010; Jouffroy-Bapicot et al. 2006; Rambeau 2010).

This account describes the nature, stratigraphy, palaeoecology, operation and economic roles of the newly discovered ancient runoff-harvesting floodwater farm and quarrying site termed here JHA, after the adjoining Jabal Hamra Arlbieg (also transliterated as Alrbieg and Arlbeig: 30º35´32"N 35º27´26"E). This site supported the metal mining and processing activity on the Faynan Orefield (Fig. 1, 2).

Fig. 1 and 2 hereabouts

2. LOCAL CONTEXT

The hinterlands of the Khirbat Faynan complex comprise three terrain types (Figs. 1-3). Eastward, the Mountains of Edom are arid, rugged, with a steep, fault-guided mountain front cut by deep gorges. The mountain-front has altitudinally-zoned vegetation. The vegetation zones are similar in many aspects to those reported nearby at the Jebel esh-Shara by Davies and Fall (2001). At high altitude there is dry, often rather open Mediterranean woodland characterised by *Pinus* (pines), *Cupressus* (cypress), *Quercus* (oak), *Juniperus* (junipers), *Pistacia* (lentisk/mastic tree), and *Olea* (oleaster) grading into shrub-steppe with *Artemisia* (wormwood), *Centaurea* (knapweeds), *Pistacia* and *Juniperus*. This passes downhill into Indo-Turanian steppe characterised by *Artemisia herba-alta* (wormwood). Some deeply-incised wadis contain spring-fed oases with Palmae (palms), *Salix* (willow), *Populus* (poplars) and Pteropsida (ferns), but in wadis with ephemeral flows there is sparse scrub of *Tamarix* (tamarisk), *Nerium* (oleander), *Retama* (broom) and *Phragmites* (reeds) (Bairle et al. 1989; Baierle 1993; Hunt et al. 2007).

A transitional terrain between the mountain front steppe and lowland deserts is characterised by very rapid changes of bedrock type, geomorphology, gradient, soils, runoff, vegetation and ecology. It contains massive Quaternary alluvial fans at the mouths of the gorges in the mountain front, and complex Pleistocene sequences associated with major wadis including the Wadi Faynan (McLaren et al. 2004). The Khirbat Faynan and many associated archaeological sites are located within this transitional zone (Barker et al. 2007). Vegetation is mostly highly-degraded steppe with ephemeral Poaceae (grasses), *Plantago* (plantains), Caryophyllaceae (sandworts), Asteraceae (thistles, ragworts and knapweeds) and some *Haloxylon* (Amaranthaceae) scrub.

A hyper-arid desertic lowland lies to the south and west of the transition zone, reaching far to the south in the Wadi Arabah. This terrain includes the Fidan Sand Sea, large wadis prone to violent floods, and isolated bedrock outliers surrounded by flatter terrain (el-Rishi et al. 2007; Raab'a 1994; Saqqa and Mohammed 2004). The desert lowlands are characterised by often very sparse Saharo-Sudanian vegetation of *Haloxylon* scrub and ephemeral desert grasses with very occasional *Acacia* (acacia) trees. Normally this vegetation supports a very limited agricultural economy; but grazing pressures can be locally intense (Mohammed 1999). Ancient arable agriculture in this zone has not been reported previously.

JHA lies on the margin of the transition zone and the hyper-arid lowland in steppe-desert with some ephemeral grasses, abundant *Plantago* and Caryophyllaceae and isolated *Acacia*. The catchment of the Wadi al-Mãk that runs past JHA is incised into the mountain-front.

Fig. 3 hereabouts

3. FLOODWATER FARMING

The role of water harvesting in supporting ancient and modern farming in arid lands is widely reported (e.g. Ashkenazi et al. 2012; Barker 2007; Barker et al. 1995; Beckers et al. 2012; Bruins 2012; De Vries 1987; Erikson-Gini 2012; Evenari et al. 1971, 1982; Gilbertson 1986; Gilbertson et al. 1994; Gilbertson and Kennedy 1984; Hunt and Gilbertson 1998; Kamash 2012; Lawton and Wilke 1979; Lüttge 2010; Oleson 2001, 2007; Ore and Bruins 2012; Oweis et al. 2012; Prinz 1996; Prinz and Malik 2002; Shanan 2000). Water-harvesting technology exploits ephemeral arid-zone runoff for arable agriculture, animals and people and has supported populations in drylands, sometimes for more than 5000 years.

With the exception of minerals, the distribution of potentially useful resources in the terrains around the Faynan Orefield is determined by the availability of water. Known local supplies of water (Barker et al. 2007) are shown in Table 1.

Table 1 about here

4. MATERIALS AND METHODS

Satellite-imagery was used to identify localities that could have supported ancient water-harvesting in the lowlands south and south east of the Khirbat Faynan complex. During the summers of 2009, 2011 and 2014 selective ground reconnaissance on foot and in vehicles covered approximately *ca*. 700 km^2 of these selected areas (Figs. 1-3). Once located, sites were mapped using dGPS. Exposures showing the stratigraphical relationships of walls were logged. Selected locations were excavated using single-context recording, drawn and sampled.

Desert varnish on exposed rock surfaces and sediment samples sieved at 2 mm were analysed chemically with p-XRF using a Niton XLt700 Analyser with low-power (1.0W) X-ray tube, Ag anode target and Peltier-cooled Si-Pin x-ray detector. Every effort was made to present the instrument perpendicular to the rock surface - the design of the instrument ensures a standardized working distance – and at least three replicate measurements using >30 second exposures at each sample point were made to allow for small-scale variation.

Samples for analysis of elemental composition were air-dried, disaggregated and sieved (<2 mm). Analysis of grain composition and major elements was carried out using a Phillips XL30 FEG SEM equipped with energy dispersive x-ray detector (Oxford Instruments X-Sight EDSATW). Sieved soil samples were mounted on carbon film-coated aluminium stubs. Images were collected using backscattered electron imaging (BSEI). Semi-quantitative information on elemental composition of individual grains was obtained using EDS. Trace element composition of soil samples was by ICP-MS following aqua-regia digestion. Blanks, duplicates and a certified reference material (CRM051) were used. Detection limits (ppb) of the ICP-MS were Pb 0.03, Zn 0.2, Cu 0.1 and Cd 0.05. High precision of the ICP-MS control standard is reported (3%) and recover rates for the CRM were between 95% and 103%.

Air-dry samples for granulometry were sieved at 2 mm to remove coarse particles, then disaggregated in sodium hexametaphosphate 0.5% solution. Replicates were analysed in a LS13320 Meritic laser granulometer until the trace stabilized, then a further five replications per sample were made and the means determined.

Palynological analysis used the method of Hunt et al. (2007). Samples of 5 mg dry weight were disaggregated by boiling in sodium pyrophosphate 5% solution for 20 minutes, sieved through 100 µm and on 6 µm nominal nylon mesh to remove coarse clasts, fines and solutes, then gravity separated using the swirling technique to remove silt. The residues were mounted in glycerin gel with an admixed safranin stain and examined at 400 and 1000x magnification on an Olympus BH2 microscope equipped with phase and Nomarski interference-contrast. All particulate organic matter including the pollen and spores were enumerated and pollen and palynofacies diagrams were drawn using TILIA software (Grimm 1991) and the conventions of Hunt and Coles (1988).

5. THE DISTRIBUTIONS OF WALLS AND CHANNELS IN THE DESERTIC LOWLANDS

Locations of ancient water-harvesting and utilisation technology and other features of interest are shown in relation to the geomorphology and surface geology in Fig. 3.

Fragments of walls or lines of boulders, sometimes curving, occur on prehistoric surfaces, upon and within Late Quaternary dunes NE of the ancient metallurgical site at Barqa el-Hatiye (BeH). These are visibly parts of prehistoric settlements (Figs. 2,3: Adams 2003; Adams et al. 2010; Hauptmann 2007). They are not appropriately adapted to the ancient topography to manage water.

Long low barrages across active wadi-braidplains were found immediately east of modern Faynan Village/Rashayadah and across the Wadi Abu Dhubban west of Barqa el-Hetye (Figs. 1-3). These are modern constructions.

Wall-and-channel networks identified previously west of the Khirbat Faynan complex have spatial and topographic properties associated with runoff-farming (Figs. 2, 3; see Crook 1999; 2009; Grattan et al. 2007; Hunt and El Rishi 2010; Newsom et al. 2007). Some areas were supplied by an aqueduct from the lower Wadi Ghuwayr (Fig. 3). The new survey (Fig. 3) indicates that these and other smaller wall-networks nearby are located on Late Quaternary alluvial fans and fluvial sequences (McLaren et al. 2004).

Low, isolated walls, or groups of walls, sometimes orientated oblique to the ground slope and possibly associated with rainwater harvesting, were located on satellite-imagery and confirmed by ground survey on the rocky lower slopes of Umm ʻIshrin Sandstones at six isolated jabal within the desertic lowlands. All were less than 5 km from the mountain front and located to the north and south of Wadi Burūs (Fig. 3). Apart from JHA, the most complex of these small wall networks is on the east side of the Jabal Burūs close to where Wadi Burūs leaves the Jabal. The network at Jabal Burūs is rectilinear in overall plan, but includes small curvilinear walls (or circular enclosures) frequently one course high. These walls were undateable. They might have formed hillside micro-catchments, but no water-storage features were identified. Such enclosures, if augmented by thorny branches, might be temporary gathering-points for animals grazing the marginal desertic lowlands during the winter vegetation-flush.

The clearest site of rainwater harvesting was detected at the foot of the north-facing slopes of the Jabal Hamra Arlbieg (Figs. 1 to 5). This hill is a geological and topographic outlier of the lower part of the Umm ‘Ishrin Sandstone Formation (Raab’a 1994) that characterizes the mountain front, from which it is separated by the Malqa Fault. This location is Site BLS 87 of the Barqa’ Landscape Survey (Adams et al. 2010).

6. FLOODWATER CONTROL AT JHA

Primary functional features of this floodwater farm are shown on Figs. 4-6 and Table 2. These are the characteristic properties of a floodwater diversion farm as defined by Beckers et al. (2012).

Table 2 hereabouts

Figs. 4-6 hereabouts

Various other walled enclosures, some very small, and of unclear origins and associations occur on the colluvium on the slopes that lead to the Jabal. Network 5 is an assemblage of fragments of walls and graves (GA-RC).

Bedforms in the flow routes shown in Fig. 4 indicate the wall-and-channel networks are still intermittently active. The locations and patterns of walls of wall-and-channel Networks 1, 2 and 3 and the outflow appear to reflect the distribution of part-buried fluvial bar-tops of likely Pleistocene or Early Holocene age (cf. McLaren et al. 2004). Alluvial sediments collected within distinct shallow sedimentary basins between these landforms and the Jabal, impounded by the wall-networks.

During the sustained heavy rainstorms of May 2014 (Farhan and Anbar 2014; Times of Israel Staff 2014, May 8) surface waters leaving this ancient floodwater farm through point 113 on Fig. 4 rejoined the flows within the unmanaged wadi-channels slightly to the north of the boundary wall. Their combined discharge was sufficient to create a very large lake covering ~40,000 m2 (with much deposited silt and fine sands) that accumulated temporarily at the modern earthern barrage in the Wadi Abu Dhubban, approximately 15 km further west (Fig. 2).

7. CERAMICS

The ceramics comprise more than 2200 sherds found across JHA. There are small surface scatters of sherds and debris of the Early Bronze Age and Iron Age. Most sherds were of Nabatean-Roman age. Across JHA, potsherds of Nabatean and Roman age occur upon and within a distinctive widespread sand body (facies 2L and 2) associated with the construction and use of the wall-and-channel networks. Network 4 provided significant quantities of Nabatean Fine Ware sherds; one sherd of Nabatean Painted Fire Ware Dekophase 4 that dates to the 2nd and 3rd centuries C.E., unpainted Nabatean pottery, one 1st to 2nd century C.E. flanged rim jug (Schmid 2000; Gerber 2001; 360 fig. 1:17); one body sherd of unguentarium; one triangular rim cooking pot with hooked rim; and one with bulbous rim of the 3rd and 4th centuries C.E. Surface finds at JHA were of Late Roman/Byzantine date (4th through 6th centuries C.E.); and some distinctive Early Islamic blue-glazed pottery (8th to 10th centuries C.E.). A few sherds of Late Islamic date (15th through to 17th century C.E) occur at the floodwater entrance to JHA at the Wadi al Mãk (Network 4) and near the final exit-point of this impounded water (112, Fig. 4). The main development and use of the farm was thus in Nabatean-Roman times, with some continuity of use into the Late Roman/Byzantine and sporadic activity thereafter (Adams et al. 2010. Holman unpublished).

Ceramic evidence for domestic occupation was only found at BAS (features 1 to 9 - Fig. 4) where the assemblage was dominated by Nabatean and Early Roman fine-ware - mainly cooking or storage vessels. These finds include one triangular ribbed necked jar manufactured in Petra during the 1st to 3rd centuries AD (see Gerber 2008; 336, fig 22.15). Most pottery was made in Petra, although some was “Aqaba Ware” of Dolinka (2003: 79-90) from Aila (modern ‘Aqaba).

8. STRATIGRAPHY AND SEDIMENTATION

Figs. 7-10 and Tables 3-6 summarise the lithostratigraphic and geochemical evidence at TR1 and TR3 (Network 1) and TR12 (Network 2: Fig. 4). The stratigraphy proved to be essentially similar in other trial trenches. Three widespread sedimentary facies (1, 2 and 3) and several more localised sub-facies were distinguished (Table 3).

Tables 3-6 about here

Figs. 7, 8 about here

The wall networks are partly built on the gravels of Facies 3 and the palaeosol 3r and thus postdate them. Some channels e.g. at 111 in Network 2 (Fig. 5) are cut into Facies 3 gravels. Sediments of facies 2, 2L and 2r abut some walls, but other walls were constructed on Facies 2 sands as they aggraded, for instance in TR1 and TR12 (Figs. 7-10, Tables 4-6). The channel-network is infilled with sediments of facies 2 and 2L. Facies 2 and 2L have granulometry and bedding suggestive of fluviatile deposition (Fig. 9, Table 3). They contain potsherds of Nabatean-Roman age e.g. TR5 at Q1 (Table 6), suggesting that the farm was built and added to during the Nabatean-Roman interval as Facies 2, 2L and 2r accumulated. The possibility of greater antiquity cannot be eliminated for parts of the wall-and-channel networks, and parts of facies 2L and 2.

Facies 1 drapes over walls and earlier stratigraphic elements and thus post-dates them. It contains no indication of local human activity. The mixture of aeolian and fluvial deposition in this unit indicates a complex history, but there is no dating evidence other than stratigraphic position. Similar deposition occurs today in the region (Hunt et al. 2007; Touchan and Hughes 1999).

9. SEDIMENTARY HEAVY METALS

Archaeological evidence of past metallurgical activity was not detected upon Jabal Hamra Arlbieg, nor upon or within the alluvial sequences and wall-and-channel networks of JHA. Very occasionally, small clasts containing veins of green copper ores occur in the alluvial deposits. These were likely introduced by floodwaters from upstream sources within the Umm ‘Ishrin Sandstone – this is also the situation today.

Detailed geochemical work in TR1 and TR3 sought to identify contamination from former local metallurgical activity (Figs. 9,10). Concentrations of heavy metals detected in Facies 3 are regarded as the local background because these coarse clastics are attributed to the Pleistocene or Early Holocene and pre-date the wall-and-channel network or any known ancient metallurgy in the area. Facies 2 and 2L, attributed to Nabatean-Roman times, also have low concentrations of metals. (cf.

Grattan et al. 2007, 2014, 2016). Facies 1 at TR1 had slightly higher, but still relatively low concentrations of cadmium, copper, lead, silver, tin and zinc. These concentrations are notably lower than those associated with Nabatean-Roman layers in the Faynan Orefield (Grattan et al. 2007, 2013, 2016 Knabb et al. 2016). Low concentrations of heavy metals in the alluvial sediments at JHA reflect natural processes. Plants and animals there would have been uncontaminated.

Fig. 9 hereabouts

Fig. 10 hereabouts

10. CROPS AND VEGETATION MANAGEMENT

The sediments at JHA are silty sands (Fig. 8) resulting from the application of irrigation waters. Analysis of major elements suggests predominance of Calcium, probably in the form of Calcium carbonate (Fig. 10). As such, the sediments would have accommodated considerable irrigation water, as long as drainage was impeded.

Pollen assemblages from TR3 (Fig. 11) are characterised by high frequencies of Caryophyllaceae (sandwort family), *Plantago* (plantains), and *Pinus* (pine) together with a wide diversity of herbs that are typical markers of the heavily-grazed dry steppe in the region today (Mohammed 1999; Hunt et al. 2007). These assemblages are consistent with intensive grazing in the past, as today.

Fig. 11 hereabouts

The pollen of plateau taxa remain broadly stable and in higher percentages than found in sites close to Khirbat Faynan (Hunt et al. 2007; Hunt and El-Rishi 2010). This suggests localised fuelwood extraction forest depletion for fuelwood on the plateau above the Khirbat Faynan did not extend as far south as JHA.

The percentages of *Olea* (olive) and *Cerealia* (cereals, barley where identifiable) are large enough to suggest that these were grown at JHA. Both taxa are relatively low pollen producers, so the regional signatures of steppe and plateau taxa are stronger than those of the cultivated species. Olives, with their deep root systems, are likely to have been well-suited to the alluvial deposits (cf. Gilbertson et al. 1994:235, Fig. 13.6). The cereals may have been grown on the clay/silt-rich colluvium at the edges of the Jabal. The pollen evidence is incompatible with the site being used to grow forage, as suggested for the field systems at Khirbat Faynan by Hunt and el-Rishi (2010). Animals might, however, have been fed on crop waste, as occurred elsewhere during the Roman period (Hunt et al. 2001). The rapidly-decreasing *Acacia* percentages suggest that this thorny tree may have declined over time around JHA. Perhaps its wood was used as fuel locally or at the Khirbat Faynan complex (Hunt et al. 2007; Miller and Marston 2012).

The similarity of assemblages suggests that Facies 3a was laid down during the same episode of farming and immediately before Facies 2, and that Facies 1 at TR3 followed without a significant hiatus. The very high percentages of thermally mature material, derived from combustion, are typical of regional Nabatean-Roman period assemblages (Hunt and el-Rishi 2010; C.O. Hunt, unpublished data).

11. QUARRIED ROCKFACES

The frequency of ashlar-built construction in and around the Khirbat Faynan indicates that the ancient quarrying of bedrock was common in this region, but sources are not well-known. Ancient quarried rock faces were identified at Q1 and Q2 on the east-facing slopes at JHA adjacent to wall-and-channel networks 1 and 3 (Figs. 5, 12-14). A flat area in front of the more extensive quarried rockface at Q1 is bounded to the east by a semi-circular wall (Fig. 5). Virtually all the pottery from within this bounded area was manufactured from 1st to 3rd centuries CE in Petra. There is one Nabatean fine ware low-ring jug of the 1st Century C.E. The pottery is consistent with quarrying occurring during the 1st to 3rd centuries CE.

Figs. 12-14 hereabouts

It is important to distinguish between quarried rock surfaces and those produced by natural processes of rock failure in this rugged terrain. Bedrock-failures occur common in this region, and slab failures, especially down-dip, happen on Umm ‘Ishrin Sandstone. Except for the major landslips mapped on such bedrocks in the Wadis Dana and Salawan by Barjous (1992), such events have not been observed at JHA, where bedding is ~horizontal. The differences between natural and quarried surfaces at Q1 are set out in Table 7, and Figs. 12 – 14.

Table 7 about here

At Q1, variations in the colour and extent of desert varnish (Cooke et al. 1993) led to the initial recognition of quarried rockfaces. The variations in the concentrations of Manganese (Mn) and Iron (Fe) are responsible for these colour differences – lighter quarried faces, and the dark un-quarried rock surfaces – are shown in Figs. 12-14). Petrological examination indicated that variations in colour and geochemistry did not reflect inherent variations in bedrock lithology. Natural hillslope rock surfaces, measured by p-XRF, varied between 6,385 to 17,543 ppm Mn and 8,812 to 18,839 ppm Fe. In contrast, vertical, pale-coloured quarried rock surfaces, where sandstone slabs had been prised away, had much lower concentrations (0 to 311 ppm Mn, and 2,820 to 8,903 ppm Fe). The volume of stone quarried from Q1 was estimated with the aid of a simple 3D model to be over 16,000 m^3. In antiquity, the closest destination would have been the Khirbat Faynan.

12. HABITATION?

Sites with stone-built evidence for former human habitation at JHA are rare. Apart from the BAS with its accumulation of pottery sherds, including cooking ware of Nabatean and Early Roman age (Adams et al. 2010), there were only the assumed “footings” of one (possible) cobble-hut (101), and a few small indeterminate features on the northwest summit of the Jabal. Within the through-valley to the ESE of the Jabal, at wall-and-channel Network 5 there were some long linear fragments of walls that might mark former enclosures, as well as two zones nearby of recently robbed graves (GA/GC) with pottery fragments that suggest the Bronze Age or possibly Iron Age (Figs. 3 and 4). A circular enclosure of large boulders with dark desert varnish found at 107 to the north-east of the Wadi al Māk (Fig. 5) appears to be much older.

13. DISCUSSION

The topography, the wall-and-channel networks and associated alluvial deposits at JHA (Table 2) constitute a flood diversion scheme in the typology of Beckers et al. (2012). The networks were intended to introduce, stabilise, store and use both water and sandy/silty sediments and seem to have been well-adapted to this location. Precise contemporaneity or the progressive construction of all of the functioning parts of the farm cannot yet be demonstrated. Nevertheless, the apparent overall hydrological coherence points to its walls, channels and topographic relationships having a unity of design and purpose. The pattern of modern fluvial activity across the site suggests that the general hydrological regime that sustained JHA in antiquity continues today, long after its abandonment, as occurs on many ancient floodwater farms (Hunt and Gilbertson 1988). An advantage of this form of water control is its flexibility - waters in a year with little harvested runoff could be concentrated by selective blocking of the major channels into small areas to support a viable crop. In a high-runoff year, water could be distributed widely and allowed to exit the system. This type of floodwater farming is remarkably rugged and resilient in the face of often very adverse environments (Frasier 1983; Prinz 1996).

The general design of the JHA system and its spatial relationships between local terrain, walls and water flow recall those initially termed the “Nabataean System” of floodwater farming (Evenari and Koller 1956; Evenari et al. 1982), although these are now understood often to be older in origin. Whilst there is evidence for earlier human activity in the general vicinity of JHA, all the present information suggests the complex operated from Nabatean to late Roman or Byzantine times.

Cultivation focussed on olives, with some cereals. This reconstruction contrasts with the suggestion by Hunt and El-Rishi (2010) that the WF4 flood-water farm adjacent to Khirbat Faynan may have been largely for forage, but it chimes with the phytolith evidence of Knabb et al. (2016) which suggests the presence of tree crops in their Unit 7. Olives are resistant to episodic drought and fluviatile erosion and can exploit deep soil moisture in coarser materials - impossible for herbaceous crops (Gilbertson et al. 1994). Tree crops would have provided essential shade for livestock in summer heat.

The site merits comparison with three other regional locations. In the Negev uplands, water management systems were often located within large through-wadis which contained significant water-retentive loessic soils. JHA differs with its impounded sandy alluvial infill sequences located among Pleistocene fluvial landforms in the distal parts of a massive alluvial fan, with very different topography and hydrology.

Qasr al-Tilah, 35-40 km further north, is also in transitional terrain – in this case where Wadi al-Tilah intersects with the northern end of the Wadi Arabah desert basin. This site is more elaborate that JHA, with an aqueduct, a reservoir, a fort or caravanserai, and a substantial network of raised agricultural fields on a grid pattern sustained by a network of water channels (now mostly destroyed by modern ploughing and bulldozing) but documented by early travellers and explorers, including Musil (1907: 209-214, Fig. 214 and 147ff); Frank (1934 213-215, Plate 29A and Plan 13); Alt (1935: 4); Glueck (1935: 12-17), more recently MacDonald (1992; SGNAS site 155). Although Hellenistic, Nabatean, early Roman and Byzantine pottery were collected from the site and its field system, most sherds dated to the Nabatean / early Roman period, as at JHA.

The floodwater farm at JHA has one (partial) parallel in the immediate area: wall networks WF4.1 and WF4.2 with “herring-bone patterns” near Khirbat Faynan (Fig. 2). Their modern land surfaces are likewise characterised by sherds of Nabatean - early Roman pottery (Creighton and Newsom 1999; Crook 1999, 2009; Gerber 1994; Kennedy and Bewley 2004; Newsom et al. 2007a). Nevertheless, the fundamental properties of their relationships with a far more subdued topography, different surficial geology, soils/sediments, hydrological regime and primary water supplies all differ. These Faynan networks had much greater longevity than that at JHA.

The comparative sites mentioned above all differ from JHA because they are much larger. JHA is relatively small and does not seem to have supported many people. It is likely that it exported produce and building stone, rather than being a net importer of food, as was the Khirbat Faynan complex (Hunt and el-Rishi 2010). Export of materials would have been possible via the ancient road connecting the Khirbat Faynan with the Umm al Amad mines, which runs adjacent to the farm (Fig. 1). Food from JHA would have been healthy because heavy metal contamination of the site was very low, unlike the levels of contamination in the WF4 farming system adjacent to Khirbat Faynan (Pyatt et al. 1999; Grattan et al. 2007; Hunt & el-Rishi 2010; Perry et al. 2010) - although the ancient communities in the Faynan orefield may not have been aware of this. Certainly, it can be hypothesised that the yields per hectare at JHA would have been better than at WF4, where metal contamination still leads to stunted plants (Pyatt et al. 1999). It can therefore be concluded that the JHA farm was an important part of the support network of the Khirbat Farnan industrial complex.

14. CONCLUSIONS

Exploration south of Khirbat Faynan examined >700 km^2 of hot desert lowlands and the lower slopes of the Mountains of Edom and discovered JHA, a floodwater farm of the flood-diversion type that extended ≥1200 m^2. No other unambiguous indications of ancient floodwater farming or water-harvesting were detected in the survey area. The farm was constructed adjacent to the Wadi al Mãk, from which it abstracted floodwaters. It was constructed in relatively sheltered topography at the foot of an isolated hill close to where Wadi al Mãk left its gorge in the mountain front.

The patterns of inlets, channels, impluvium, walls and outflow at JHA relate to the local topography and hydrology, which in turn reflect the local surficial and bedrock geology. The construction and use of (at least) parts of its main wall-and-channel networks appears to have essentially contemporary. Walls and channels were built between and/or upon coarse fluvial Pleistocene or Early Holocene sediments and are interbedded with – and appear to have confined - a distinctive and widespread stratum of waterlain sands. Within the irrigated area, olives were grown on the alluvium, especially where underlain by coarse clastics. Cereals may have been cultivated on finer-grained sediments/soils. The farm appears to have been constructed during Nabatean-Roman times, with a continuation of use into the Late Roman/Byzantine. There is minor evidence for habitation at the site, suggesting that produce was sent elsewhere for consumption. Two areas of Umm ‘Ishrin Sandstone quarried in antiquity were apparently associated with the Farm. It is possible that quarried ashlars went for construction at the Khirbat Faynan. The floodwater farm is immediately adjacent to an ancient route that links the Khirbat Faynan with the nearby copper mines at Umm al Amad in the Mountains of Edom. Both of these communities may have also been supported by the activities at JHA, as perhaps were transport and communications between them.

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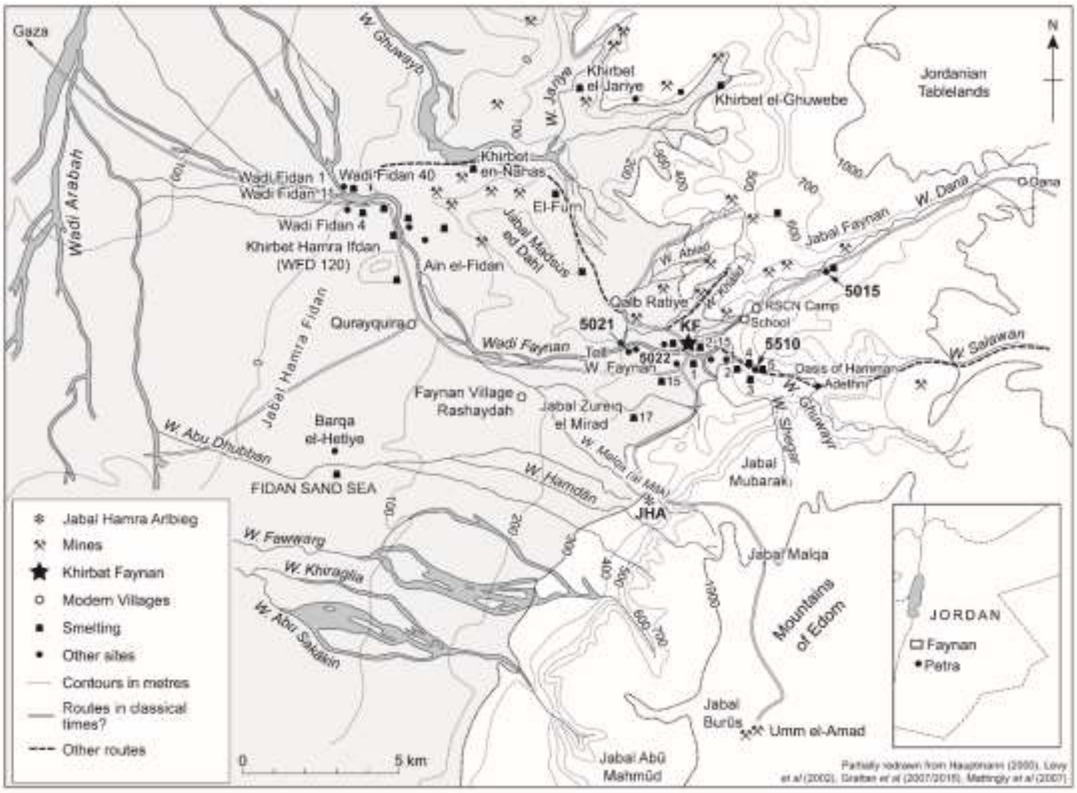
CAPTIONS TO FIGURES

Fig. 1. The location of the floodwater farm at Jabal Hamra Arlbieg (JHA), the principal archaeological sites in the study area, and important routes of Classical times (after Barker et al. 2007 and Bienkowski and Galor 2006) and key topographic relationships.



Partially redrawn from Hauptmann (2000), Levy et al (2002), Grattan et al (2007/2016), Mattingly et al (2007)

Fig. 2. Image derived from Google Earth showing location of Jabal Hamra Arlbieg and other key sites.

Fig. 3. Surface geological and geoarchaeological map, interpreted from satellite imagery and ground survey, Barjous (1992) and Raab'a (1994), showing the major floodwater farms and very small wall networks on isolated hills (outliers of mainly Cambrian bedrocks) in the desertic lowlands. This also shows (i) two modern barrages in the lowland desert drainage of the Wadi al Māk; and (ii) one across the Wadi Abu Dhubban that impounded a temporary lake >40,000 m2 floored with carbonate-rich silts and sands as a result of the sustained violent rainstorm of May 2014 – much of its the feeder water from the Mountains of Edom having travelled close to or (lesser quantities) through the ancient floodwater farm at JHA (see Farhan and Anbar 2014; Times of Israel Staff 2014).

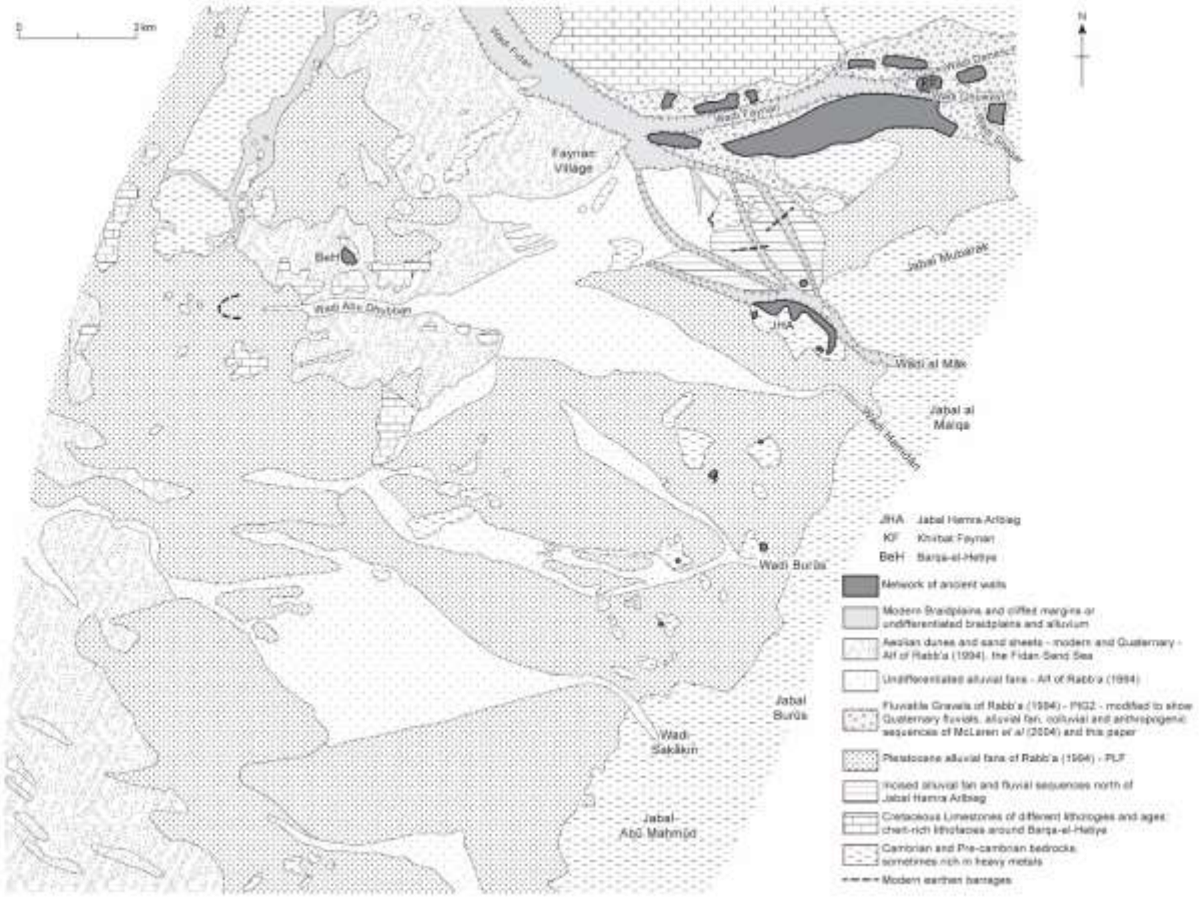


Fig. 4. The locations of the five wall-and-channel networks around Jabal Hamra Arlbieg (JHA) in relation to Quaternary alluvial fans, associated alluvial basins, major wadis, and major routes, interpreted from Google satellite imagery and ground survey, Barjous (1992) and Raab'a (1994).

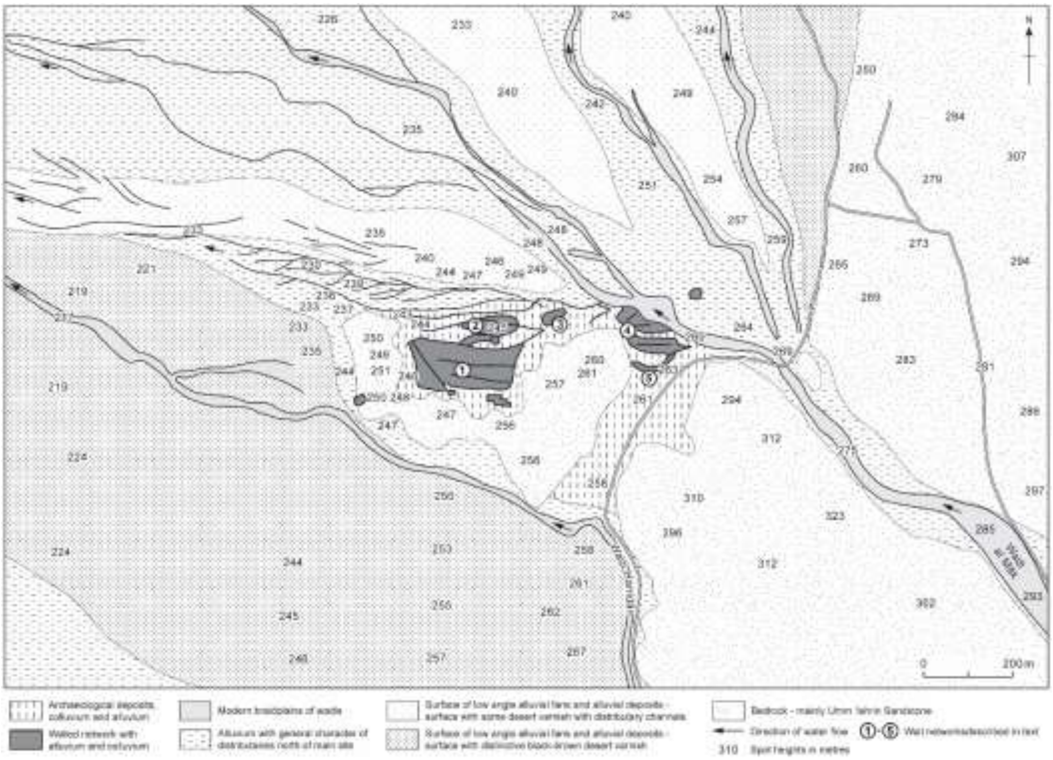


Fig. 5. Stone-built structures, walls, wall-and-channel networks, ancient bedrock quarries (Q1 and the smaller unstudied Q2), "modern" ephemeral stream channels, ancient controlled water flow pathways, surface heights (italicised) derived from Google satellite imagery, and our precise topographic surveys in relation to the adjacent wadis around Jabal Hamra Arlbieg: revised from initial survey by Adams et al. (2010). CS3 and CS4 are levelled survey transects.

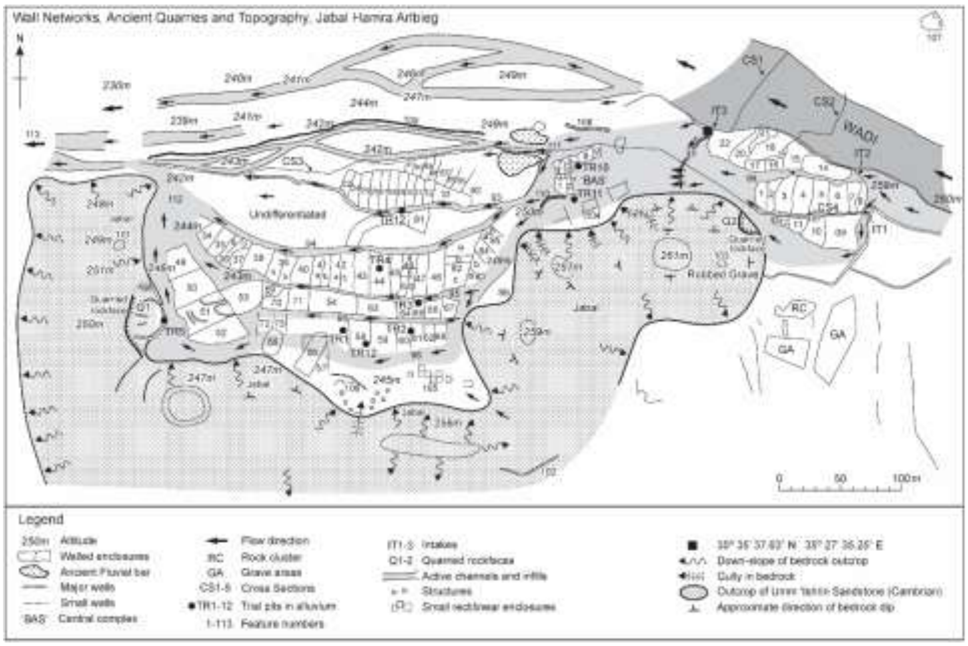


Fig. 6. The western part of floodwater farm JHA in a relatively sheltered basin on the northern side of the Jabal Hamra Arlbieg, photographed from immediately West of spot height 257 (metres above Jordanian Datum) on its northeast arm, looking West. The hilltop in the foreground is fractured Umm ‘Ishrin Sandstone, overlooking Network 2 (to the right) and Network 1 (to the left). Largely infilled linear conduits conducted water from the bottom right into the networks of rectilinear enclosures and to the hydrological exit into the adjoining desert. [Image 100-9206].

Fig. 7. Schematic summary of the stratigraphy at TR12. Here, a palaeosol and wall running along one side of a channel overlies gravels attributed to Facies 3 and these are overlain by Facies 1. On the other side of the channel, the wall is embedded in Facies 2, suggesting that this is broadly equivalent in age to the palaeosol.

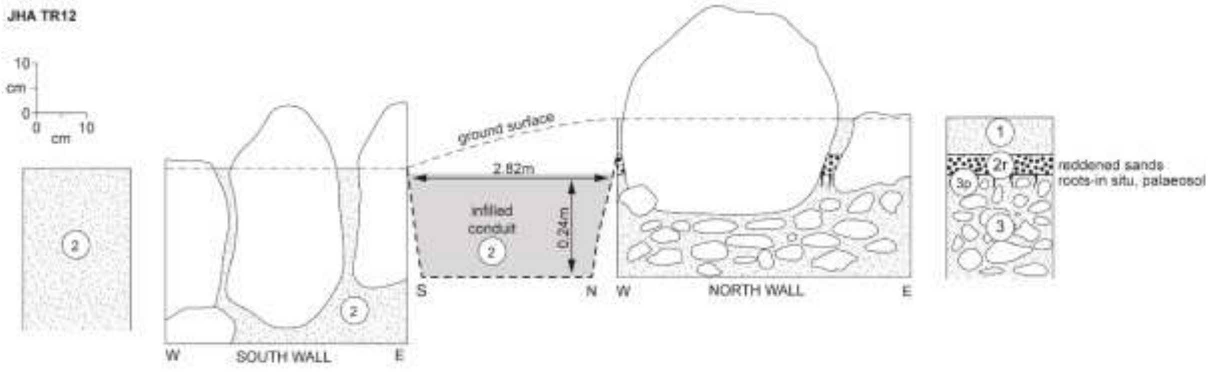


Fig. 8. Grain size analyses of sands from facies 3a, 2 and 1 at TR3. The strong peak in the medium sand is consistent with these sediments being locally derived from Umm ‘Ishrin Sandstone, while the grain size distributions as a whole are consistent with localised aeolian and/or fluviatile deposition (cf. Lucke et al., 2019).

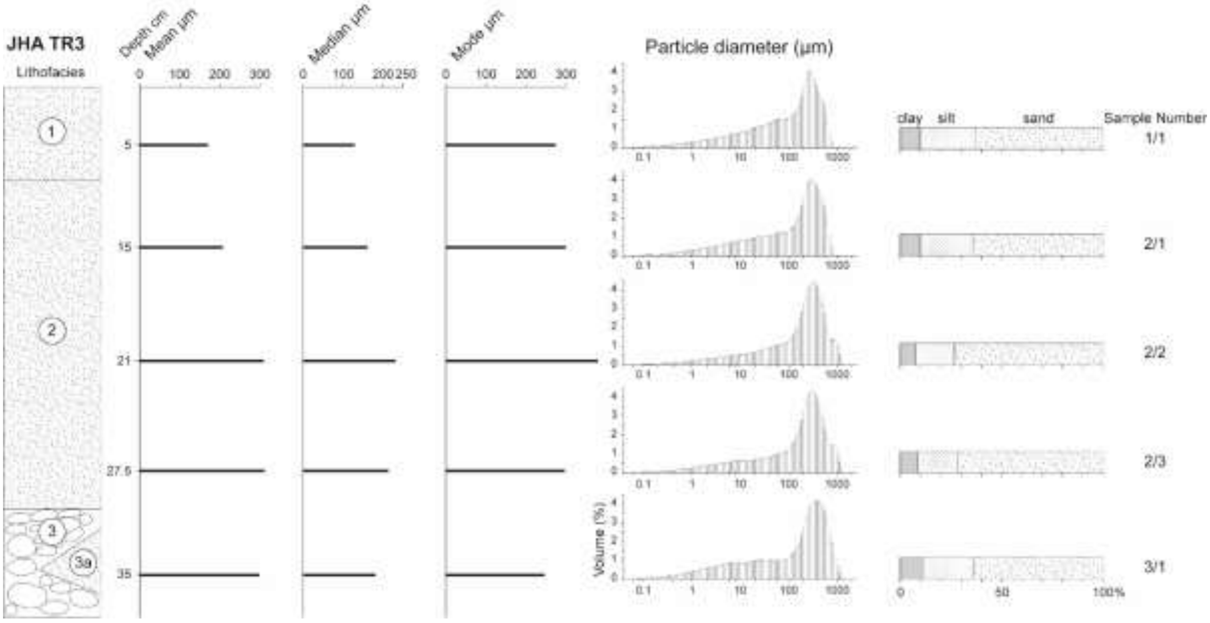


Fig. 9. Summary description of the alluvial lithostratigraphy at exposure TR1 and concentrations of selected heavy metals in the <2mm fractions of sediments, determined by p-XRF. Exposures TR2 to TR5 were broadly similar chemically.

Fig. 10. Major elements measured by EDS and heavy metals measured by ICP-MS at TR3.

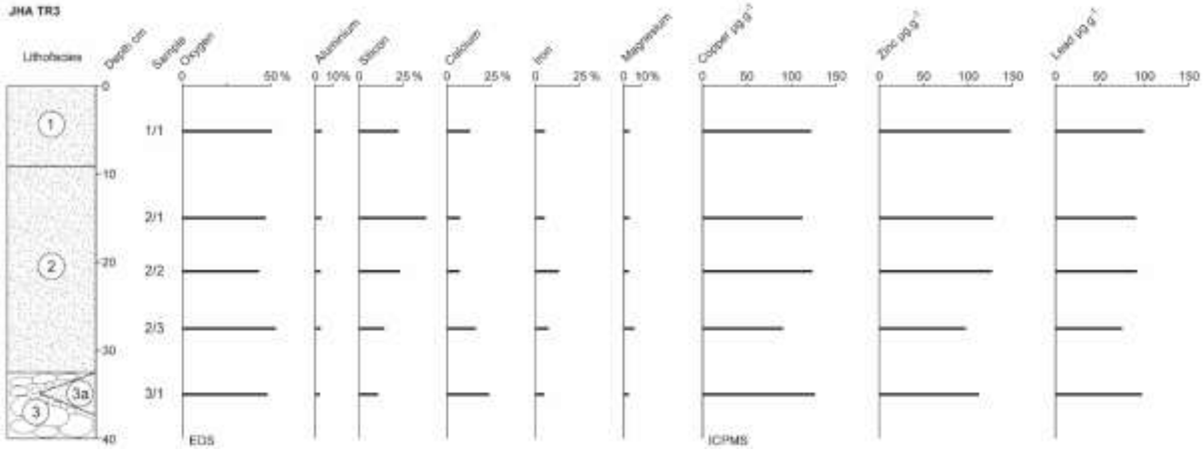


Fig. 11. Pollen and palynofacies analysis of samples from TR3. Pollen is calculated as percentages of total pollen. Palynofacies is calculated as percentages of total particulate organic matter.

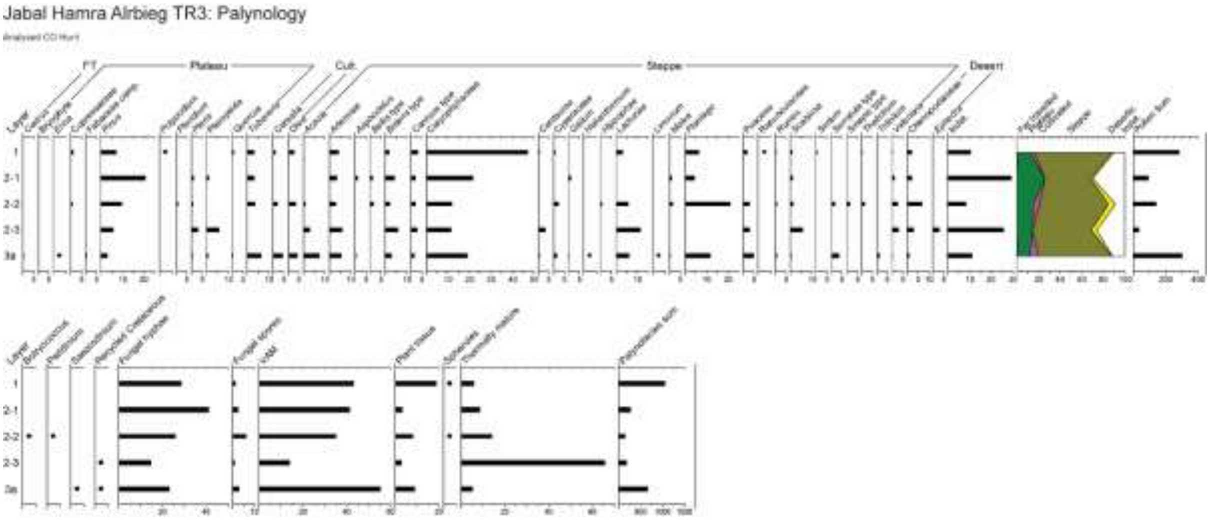


Fig. 12. Quarry Q1 in 2009 from the North. On the hillslope in the background the surface is fretted, with darker desert varnish and angular rock debris, while the quarried area (with the figures in the foreground) shows the pale brown colour of Umm ‘Ishrin Sandstone, with little desert varnish, distinctive morphology and possible tool marks. In 2014, Test Pit TR5 was ~3 m behind investigator on the left side of the image

Fig. 13. Quarry Q1, from the north. Measurements are ppm of manganese (Mn) measured with p-XRF. Surfaces with desert varnish have higher values of Mn than do quarried surfaces.

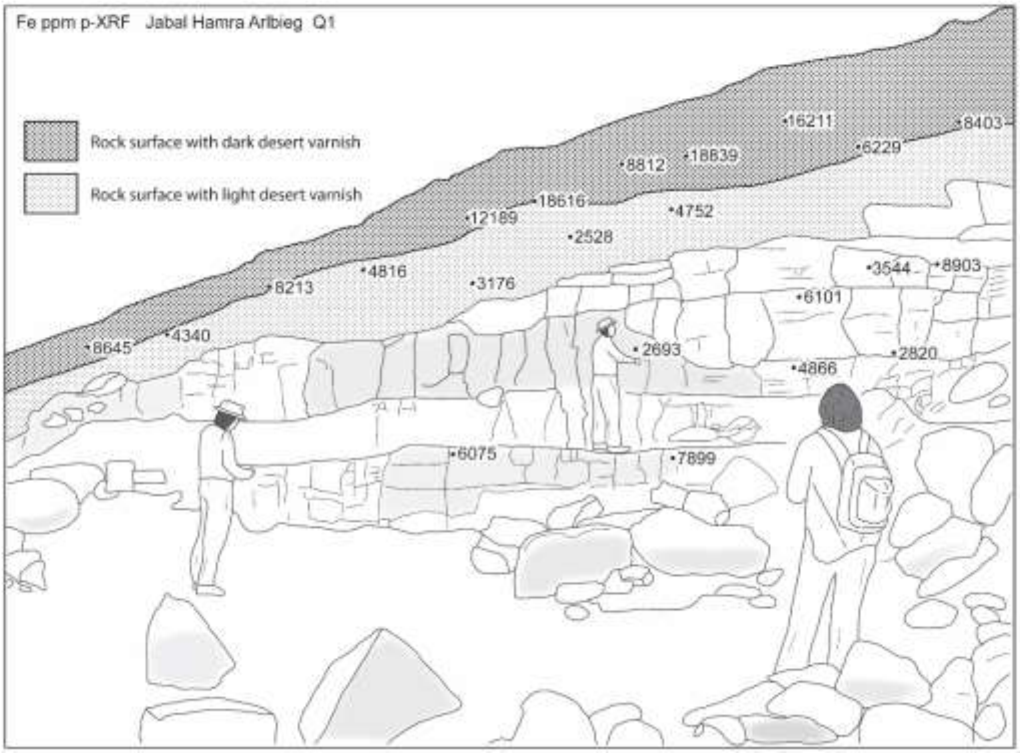


Fig. 14. Quarry Q1 from the north. Measurements are ppm of iron (Fe) measured with p-XRF. Surfaces with desert varnish have higher values of Fe than do quarried surfaces.

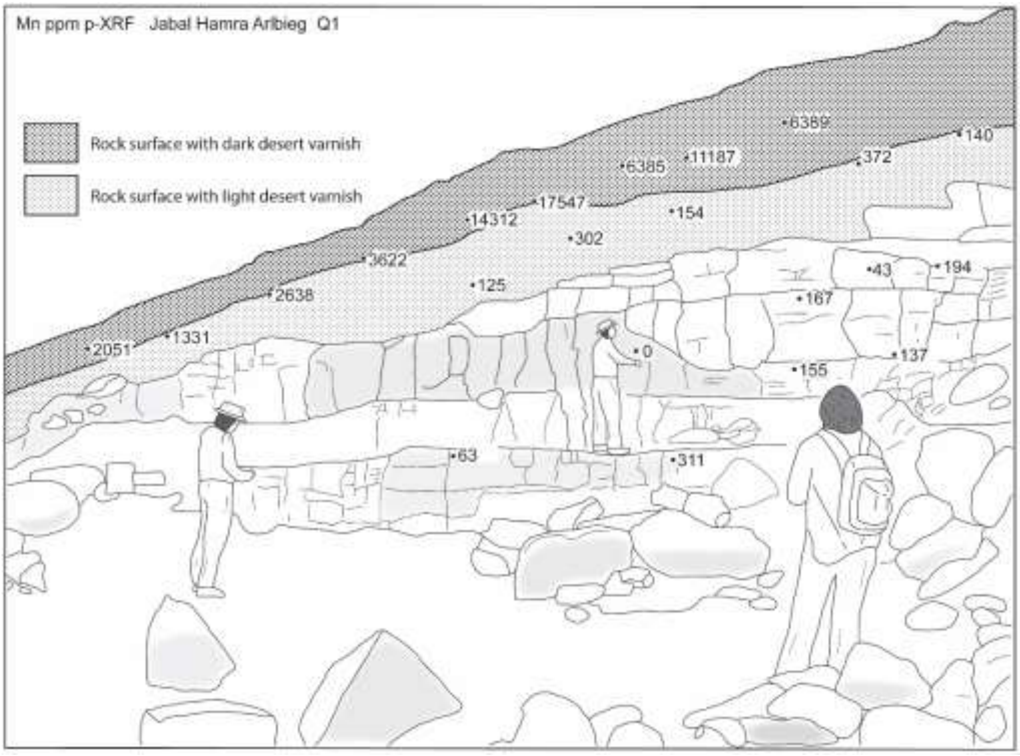


TABLE CAPTIONS

Table 1. Sources of water in the terrains around the Faynan Orefield (after Barker et al. 2007)

Oases, springs and perennial streams in the lower parts of gorges, sometimes with water conducted by aqueduct, and stored in reservoirs;
Occasional microcatchment rainwater harvesting systems which are elsewhere associated with Nabatean “stopping points” on long-distance routes across the desert;
Very large networks of walls and channels that managed surface runoff and stream flow for agriculture (Fig. 3).

Table 2. Functional features of the floodwater farm at Jabal Hamra Arlbeig

Characteristics
Networks 1-3 lie in a sheltered alluvial basin within the north pointing arms of the Jabal;
a long, substantial wall and flow route (108), often built on Pleistocene linear fluvial bar-forms, separates the walls/conduits and sediments of Networks 1 – 3 from the unenclosed desert terrain;
three robust water-intakes (IT1 to IT3) abstracted torrential waters at the edge of Wadi al Mãk (Fig.4);
channels (98, 99, 100) led flood waters into and through the more poorly defined, but also flood-scoured, wall-and-channel Network 4 (1-22);

water-impoundment area(s)/impluvia in wall networks walls and perhaps by a habitation site in Network 3 (98 and BAS/1-9) ponded water, allowing redistribution without inducing notable erosion;
onward distribution took place in robust channels with distinct cross-sections (93, 94, 95, perhaps 96), and a deliberately excavated flow route (111) through a Pleistocene fluvial-bar;
water and sediment would have been dispersed in larger and more elaborate wall-and-channel networks 1 (85-49) and 2 (23 – 92) sometimes with two inputs into an enclosure (70-87, 34-48). Presumably cultivation and/or grazing took place on the network alluvial infills. Excess water led (eventually) West-north west;
the outflow (112-113) into the lowland between the north-western arm of the Jabal and the end of the boundary wall (108). Such drainage is commonly considered to help mitigate any build-up of salts in soils/sediments or groundwater.

Table 3. Sedimentary facies identified at Jabal Hamra Arlbieg

Facies	**Characteristics**	**Interpretation**
3	Rounded to subangular sandy gravel, variably sorted, containing sandy lenses in places.	Braidplain sediments of later Pleistocene or early Holocene age (cf. Hunt et al. 2004; McLaren et al. 2004).
3a	Lenticular bodies of fine sands	Channel fills within braidplain sediments
3p	Reddened gravel with rootlet traces sometimes capping Facies 3	Pedogenically altered braidplain sediments
2r	Reddened sands with rootlets sometimes capping Facies 3.	Skeletal palaeosoil
2	Well-sorted medium-fine sands infilling shallow basins in the surface of Facies 3 and water distribution channels. Bioturbation, deformation structures and Nabatean-Roman potsherds are sometimes present	Waterlain sediments. Bioturbation suggests that in some locations plants have episodically grown in these deposits before being covered with further sand. Deformation structures might suggest localised slumping. The presence of potsherds in these sediments suggests they accumulated during the Nabatean-Roman interval
2L	Thinly laminated, well-sorted carbonate-quartz medium to fine sands, with thin laminations, sometimes containing pebbly lenses. Typically infilling channels. Sometimes passing up into Facies 2	Waterlain sands with laminations from spreading flow. In channels pebbly lenses reflect episodes of scouring flow.
1a	Sandy gravel layer infilling a 'v' shaped feature in Facies 2	Gully fill – fluvial lag
1	Fine sands and silts overlying Facies 3 and 2.	Sediments of wind-dominated deposition with occasional surface wash

Table 4. Stratigraphy of trench TR1

Layer	Depth (m)	Sediments	Interpretation
3	>0.42	Rounded and sub-angular partly-imbricated fine sandy gravel, variably sorted	Braidplain fluvial /colluvial sediments
2	0.42-0.10	Well-sorted medium-fine sands	Flood and aeolian sediments
1a	0.12-0.10	Thin sandy gravel layer infilling a 'v' shaped feature	Fluvial lag
1	0.10-0.0	Fine sands and silts	Wind-dominated deposition with occasional surface wash

Table 5. Stratigraphy of trench TR2

Layer	Depth (m)	Sediments	Interpretation
3	0.40-0.33	Rounded and sub-angular partly-imbricated fine sandy gravel	Braidplain fluvial /colluvial sediments
3a	0.37-0.33	Lenticular body of fine sands (3a)	Channel-fill within braidplain sediments
2	0.33-0.09	Well-sorted medium-fine sands	Flood and aeolian sediments
1	0.09-0.0	Fine sands and silts	Wind-dominated deposition with occasional surface wash

Table 6. Stratigraphy of trench TR5 adjacent to Q1

Layer	Depth (m)	Sediments	Interpretation
2	0.50-0.36	Well-sorted medium-fine sands, with on its surface sherds of Nabatean/Early Roman wares	Flood and aeolian sediments, with traces of human activity on its surface
1	0.36-0.0	Fine sands and silts	Wind-dominated deposition with occasional surface wash

Table 7. Criteria used distinguish between quarried bedrock faces and original terrain on Umm ‘Ishrin Sandstone at Jabal Hamra Arlbieg.

Criteria	**Untouched, natural rock surface**	**Quarried bedrock to 8m above base of slope**
Morphology	Rectilinear “gaps” typically only a few metres high or deep, associated with the particular strike and dip of the outcrop of a particular stratum, or small a group of strata.	Substantial arm-chair, basin-shaped, morphology with relatively steep sides, and steep and high backslope, and whose overall form bears only limited, if any relationship to thickness, strike and dip of the strata.
Slopes	Slopes of ~25°-35° throughout. There is no upper break of slope.	Slopes of 70° to almost vertical. The quarried face intersects with the original hillslope at a sharp angle.
Basal slope morphology	Basal slopes reduce rapidly in gradient at base, from *c.* 25°, to *c.* 5°.	The gradient remains near vertical, its base at the ground surface may be close to a right angle.
Basal slope materials	Basal slope formed of angular rock debris, typically with desert varnish, and fine-grained surficial sediments.	Exposure of bedrock, revealing ~horizontal to gently-dipping bedding planes and ~vertical joints.
Materials beyond the basal slope	Cobbles and boulders frequent and dipping downslope.	A quasi-horizontal surface often free of rock debris, of fine-grained alluvium, with isolated cobbles, stones, boulders, and angular slabs of bedrock that appear to have fallen from above on to the surface.
Desert varnish	Extensive desert varnish from dark brown to near black on 30-100% of rock surface and on some of the rock debris upon it.	Fresh rock surfaces, little or no desert varnish; where present brown to pale-brown.
Surface texture	Rock surface is fretted, rough, with pits or tafoni, with many sharp edges - the result of various forms of physical and chemical weathering. The micro-topography of the intersections between	Overall rock surface is often relatively smooth, but with a rectilinear “sharp” micro-topography where ashlars were removed, exploiting joints and bedding planes.

	bedding planes and the joint structure is frequently slightly rounded.	