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Living at the wadi – integrating geomorphology and archaeology at the oasis of Qurayyah (NW Arabia)

Laura Hüneburg[a], Philipp Hoelzmann [a], Daniel Knitter [b], Bernd Teichert[c], Christiane Richter[c], Christopher Lüthgens[d], Abdullah S. Alsaud[e] and Marta Luciani [f]

[a]Physical Geography, Institute of Geographical Sciences, Freie Universität Berlin, Berlin, Germany; [b]Department of Geography, Physical Geography, Landscape Ecology and Geoinformation, Christian-Albrechts-Universität zu Kiel, Kiel, Germany; [c]Faculty of Spatial Information, University of Applied Sciences Dresden, Dresden, Germany; [d]Institute for Applied Geology (IAG), University of Natural Resources and Life Sciences Vienna, Vienna, Austria; [e]Director General of Research and Archaeological Studies, Saudi Commission for Tourism and National Heritage (SCTH), Riyadh, Saudi Arabia; [f]Department of Prehistoric and Historical Archaeology, University of Vienna, Vienna, Austria

ABSTRACT

The archaeological site Qurayyah, situated in the NW of the Tabuk Province of Saudi Arabia, has been repeatedly described as one of the largest and most significant oases of Northwestern Arabia. Human occupation in the oasis started at least from the early Holocene and continued to the Nabatean, Roman and late Byzantine period. The hydrologically favored position results from its specific geomorphological location where the plateaus fade towards the east and the landscape opens towards the Tabuk Basin so that a balanced water supply was ensured. We present a geomorphological map (1:20,000; main map) based on the interpretation of a high-resolution satellite image and detailed control in the field. The map integrates archaeological, hydraulic and natural features in order to show how the people at Qurayyah structured their landscape and developed water management strategies in relation to prevailing geomorphological processes during the incipient phase (Bronze Age) of the oasis.

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Geoarchaeology; geomorphological map; water management strategies; Bronze Age / early Iron Age; NW Arabia; remote sensing

1. Introduction and background

The archaeological site of Qurayyah (28°47'N/36°E) is situated 70 km north of the provincial town Tabuk and 26 km west-south-west of Bir Ibn Hirmas in the NW of the Tabuk Province of Saudi Arabia (main map, preview map). No open water, near-surface groundwater or active spring is available at Qurayyah. However, in the near vicinity within the larger wadis groundwater is presently pumped for center pivot irrigation. On the northern slopes of the 'Rock Plateau', traces of formerly active fracture springs were identified, which are probably related to a karstic groundwater system developed within the sedimentary rocks forming the mesa. This points to near-surface groundwater resources. However, to date, it remains unclear if the site of Qurayyah provided direct access to open or flowing water in the past, although it has been repeatedly described as one of the largest and most significant oases of Northwestern Arabia (Al Al-Ghabban, 2010). Undoubtedly, it must be regarded as one of the oldest and widest-spread architectural landscapes and thus an artificial, man-made oasis. Al-Ghazzi (2010) proposed an association with the capital of the Midianites, a people mentioned in the Bible, Classical sources and the Qur'an, due to the size, location and the presence of second millennium BCE pottery material on the surface of Qurayyah. However, this is not borne by archaeological data.

A new Austrian-Saudi joint archaeological research project, led by the University of Vienna (Prof Dr. Marta Luciani) and the Saudi Commission for Tourism and National Heritage (SCTH, Dr. Abdullah S. Alsaud), started in 2014 to conduct systematic multi-disciplinary investigations on the site for the first time (Luciani, 2014, 2016; Luciani & Alsaud, 2018; Luciani, Binder, & Alsaud, 2018). The site has been fenced by the SCTH to avoid uncontrolled access by humans or grazing animals. However, as in many other instances throughout the country, the area around the site and its off-site locations are at risk of being endangered by human looting.

Archaeological research has confirmed the presence of human occupation in the oasis starting at least from the Pre-Pottery Neolithic B (PPNB) (Luciani & Alsaud, 2018). Human presence continued into the third to second millennium BCE, the Early, Middle and Late Bronze Ages (twenty-seventh to early twelfth centuries BCE, Luciani & Alsaud, 2018), the second half of the first millennium BCE down to the Nabatean, Roman and late Byzantine period (Ingraham, Johnson, Rihani,

CONTACT Philipp Hoelzmann phoe@zedat.fu-berlin.de Physical Geography, Institute of Geographical Sciences, Freie Universität Berlin, Malteser Strasse 74-100, 12249 Berlin, Germany

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& Shatla, 1981; Luciani, 2016; Parr, Harding, & Dayton, 1970). While our preliminary data confirm that the site is a palimpsest of different occupation periods and we have not yet carried out a complete survey of the entire ruin, the large majority of the pottery found on the surface is clearly recognizable and belongs to the Bronze Age. Four out of five of the excavation areas opened so far contain exclusively Bronze Age remains.

While we have reason to suppose that the settlers in Qurayyah belonged to the local population of the Tabuk region, we do not yet have any positive evidence for their relationship with the human groups attested in the country and in Northern Arabia in general (from Jubbah to Rajajil to the Wadi Sharma) in previous epochs (Neolithic to Chalcolithic).

One of the major research questions concerns establishing a chronology and investigating the modalities of the formation of a permanent settlement in the oasis of Qurayyah, its extensive agricultural area and its water-harvesting and irrigation system, possibly among the earliest of the entire Arabian Peninsula and the Levant (Masry, 1977; Parr et al., 1970). A fundamental premise for clarifying the above research questions is an understanding of the functioning of water management strategies during the incipient phase of the oasis (most likely Bronze Age). Moreover, elucidating the geomorphology and human interventions will enable a better understanding of the formation processes that led to the establishment of a permanent settlement with monumental architecture and an agricultural area extending over several hundred hectares.

With this publication, we provide a geomorphological map of the archaeological settlement site of Qurayyah and its surroundings (Main Map). The map highlights the interrelation of archaeological, hydraulic and natural features and shows how the people at Qurayyah structured their landscape and water management strategies in relation to the prevailing geomorphological processes.

2. Methodology

No accurate, geo-referenced mapping of either the natural or the archaeological features of the site existed before this project started. Therefore, our first step was to prepare a series of maps of the site and its surroundings at a scale of 1:2,000 based on ESRI-World Imagery. In the field, 42 points throughout the entire site were measured by means of a differential GPS (DGPS) as WGS 84/UTM 37N coordinates using Leica Geosystems equipment including two antennas ATX 1230, two controllers RX 1210 T, and two receivers GTX 1230.

14 Ground Control Points (GCP) were identified in order to rectify the GEOEYE-1 satellite image. Furthermore, a fundamental network consisting of 23 points was determined (Hatton, 2016). Five points of the local grid were measured in order to transform the existing local coordinate system into the WGS 84/UTM 37N coordinate system. After the GCP-measurements, the size of the section from the satellite image was enlarged in the northern and western part for scientific reasons. Therefore, the GCP measurements are not equally distributed over the entire satellite image.

The geomorphological mapping is mainly based on the interpretation of information provided by a GEOEYE-1 satellite image. The spectral resolution covers the visible range with the channels red, green, blue and near infrared. The image was pansharpened by using the Modified IHS (Intensity-Hue-Saturation) algorithm so that the spatial resolution resulted in 0.5 m per pixel. The satellite image has the following parameters:

Region:	Qurayyah, Saudi Arabia
Area:	44 km^2
Spectral Resolution:	R-G-B-NIR, Pan
Resolution PAN:	0.5 m (resampled from 0.41 m)
Resolution MS:	2.0 m (resampled from 1.65 m)
Coordinates:	WGS84, UTM (Zone 37N)
Color depth:	16-bit
Recording Date:	2015-09-15
Recording Time:	08:29 CET
Cloud Cover:	0.000%

In order to improve the geo-rectification, the 14 measured GCPs were used in combination with a SRTM1 scene.

The remote sensing based mapping was complemented by information derived from Corona images (U.S. Geological Survey, 1967), geological maps (Bramkamp, Brown, Holm, & Layne, 1963) and other visible range remote sensing products provided by Bing maps and Google Earth, as well as photos taken by an unmanned aerial vehicle (UAV) (Hüneburg, 2016). The detected geomorphological categories and features were ground-truthed during field campaigns in November 2016 and 2017.

The geomorphological map follows the guidelines published by Leser and Stäblein (1975) as far as these covered the ensemble of relief features observed in the investigation area. For geomorphological features not covered by this guideline, new categories were implemented and dedicated signatures created that follow previously published geomorphological maps of arid and semi-arid areas (e.g. Pachur, 1974; Perego, Zerboni, & Cremaschi, 2011; Zerboni, Perego, & Cremaschi, 2015). The resulting geomorphological map mirrors different scales of surface features, and corresponding layers contain large-scale geomorphic structures, geomorphic processes and anthropogenic structures.

The larger scaled geomorphodynamics of the area and the local characteristics of Qurayyah and its immediate hinterland, topographical and hydrological

analyses of the terrain were assessed using digital elevation data as supplied by radar satellite images (SRTMGL3; NASA JPL 2013 with a spatial resolution of 1-arc second, i.e. approx. 30 m). The four scenes covering the wider surroundings of the research area (N28-N29E035, N28-N29E036) were merged and reprojected to a metric coordinate system (UTM 37N). Based on this digital elevation model, the watershed basins surrounding Qurayyah were calculated (Main Map).

3. Geology, hydrology, climate and anthropogenic features

The Arabian Peninsula is divided geologically into the Western Arabian Shield, which is part of a Precambrian crustal plate, and the Arabian Shelf, which consists of eastward thickening sediments (Alsharshan, Rizk, Nairn, Bakhit, & Alhajari, 2001). Following peneplanation of the crustal plate in the late Precambrian, the surface was covered by lower Palaeozoic (Cambrian to Devonian) basal sands that discordantly overlie the Precambrian crystalline basement and slope gently towards the northeast. Petrographically the Palaeozoic (at Qurayyah mainly Ordovician) sediments are described as fine-grained, cross-bedded, only slightly consolidated sandstones interbedded with clay (Alsharshan & Nairn, 1989).

The Hisma is a broad plateau east of the Northern Hijaz region (Ingraham et al., 1981). It is characterized by weathered Palaeozoic sandstones and clays that are deeply dissected by wide wadis where silt, gravel and associated fine sediments of quaternary age were deposited. Qurayyah is located in the eastern part of the Hisma Plateau in a region of sandstone mesas and buttes of between 700 and 1000 m. This is the transition zone, where the landscape opens towards the Tabuk Basin to the east.

The Tabuk Basin is a large endorheic basin that is bounded by the Hisma to the southwest and to the northeast by ranges of flat-topped hills. It comprises the Saq Formation (middle Cambrium to early Ordovician) and the Tabuk Group (early Ordovician to early Silurian) that represent continental to marginal marine and alluvial to fluvial environments (Alsharshan and Nairn, 1989; Laboun, 2013).

The two largest wadis of the investigated area drain from the Hisma Mountains with a confluence directly NW of Qurayyah. As joint courses, they run northeast towards the Tabuk Basin and end ca. 7.5 km northeast of Qurayyah in a playa-like depression. At present these wadis are ephemeral but during Late Pleistocene and Holocene phases of wetter conditions (Hoelzmann et al., 2004; Engel et al., 2012; Rosenberg et al., 2011; Enzel, Kushnir, & Quade, 2015; Breeze et al., 2016) they probably served as at least seasonally active drainage systems for the highlands in the west. It is open to debate whether the wetter conditions during the early Holocene indicate a stronger influence of winter rains (Mediterranean cyclones) (Schulz & Whitney, 1986) and/or a slight inland expansion of the North African summer monsoon rains across the Red Sea accompanied by the uplifted moist air of this monsoon (Enzel et al., 2015). At Tayma, situated in the Tabuk Basin 280 km southeast of Qurayyah, a minimum early Holocene annual precipitation of 150 ± 25 mm is assumed – the threefold of the recent precipitation rate (Engel et al., 2012).

There is also evidence for former local spring activity at the Qurayyah site. The mesa located in the southwestern sector of the site is composed by layers of the Tawil sandstone member (Bramkamp et al., 1963) that belongs to the upper Tabuk Group of Silurian to early Devonian age (Laboun, 2010). While the top of the inselberg is characterized by the occurrence of massive layers of sandstone, ductile layers of silt and clay predominantly form the base of the structure. This has resulted in the development of a complex system of cracks and fissures within the rocks. The fact that these rocks are at least partly carbonaceous likely resulted in the development of a karstic groundwater system within the bedrock of the inselberg. On the northern slopes of the mesa, remains of flowstones that had developed on the rock surface were identified, providing clear evidence of at least minor former spring activity in the area of the less permeable silt and clay layers forming the base of the inselberg. Field evidence indicates that these springs may have been closely related to fractures channelizing the groundwater flow.

The Tabuk region of NW Saudi Arabia belongs to the hot desert climate (BWh) of the Köppen–Geiger climate classification system (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). The annual average temperature is 22°C with highest temperatures in July (up to 46°C) and lowest temperatures in December (down to −6°C). Precipitation (46 mm/a) occurs sporadically and locally mainly between October and April. Westerly winds dominate during winter, when the jet stream is displaced to the south placing Qurayyah in a leeward situation.

The archaeological site Qurayyah is an oasis structured in two different units. In the southwest a 50 m high, 1.2 km by 350 m inselberg (called the ‘Rock Plateau’; Figures 1 and 2) exhibits two rows of high-standing stonewalls (Figure 3) with built-on towers running across it, one freestanding tower and several graves. Immediately to the northeast, there extends a ca. 300 ha. area encircled by stone-and-mud-brick walls. This wide extension of the site includes both a circular-ogival, mud-brick-walled, smaller ‘Residential Area’ (ca. 5 ha; Figure 4) in the south and an ample layout of fields and channels throughout. This extended, walled area in the northeast spreads out over the alluvial plain of the local wadis in a fan geometry covering

Figure 1. View to the north of the south-eastern edge of the 'Rock Plateau'. The two N-S stone wall lines ('a' and 'b') and a tower ('c') on the eastern part of the plateau are visible.

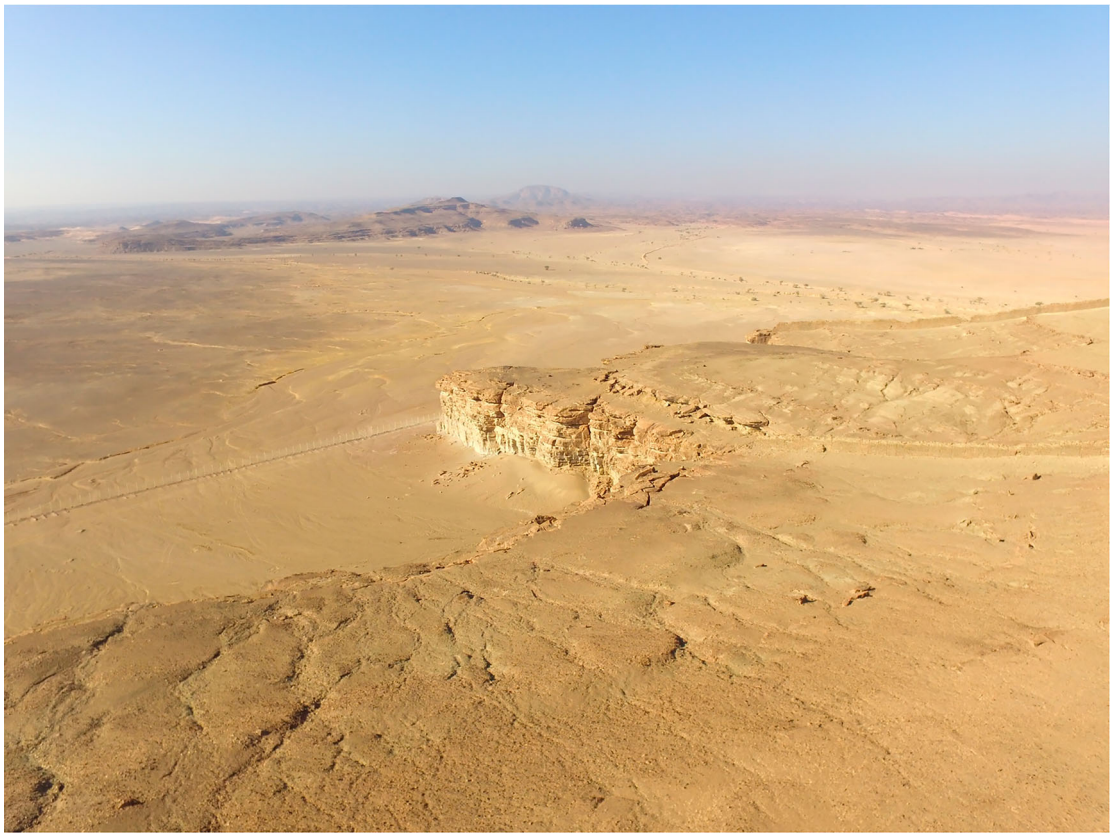

Figure 2. View from the 'Rock Plateau' to the north-west (compare with Figure 1). In the foreground the western escarpment of the Rock Plateau and surface drainage lines on the plateau are visible.

several hundred hectares (Figure 5). An expanse of ca. 150 ha. outside of the walled site displays similar fields partitioned by low-lying stone walls (Figure 6). An additional similar area that may equally well belong to Qurayyah is located ca. 5 km SE of the site, thus bringing the entire agricultural catchment of the site to ca. 600 ha.

Figure 3. Drone photo of the southern segment of the eastern stone wall ('arrow') standing on top of the 'Rock Plateau'. Viewed from the north and looking south to the Wadi Ghubai ('WG').

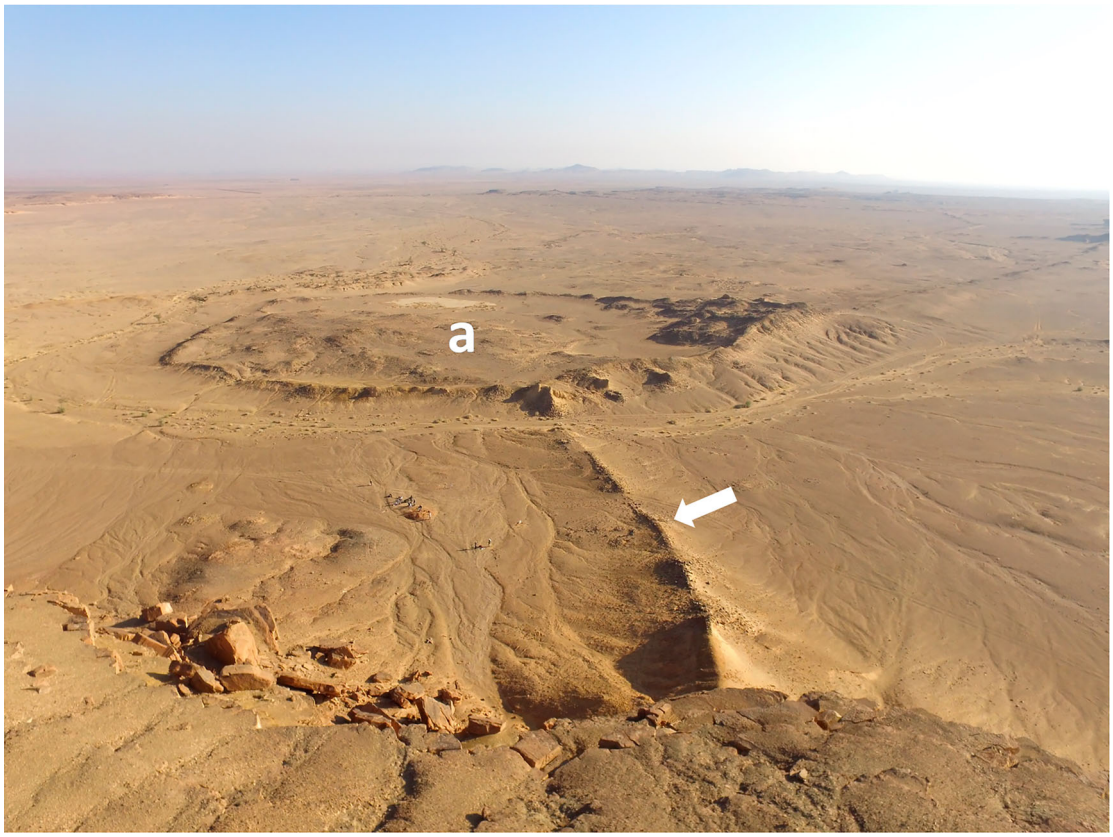

Figure 4. The stone-and-mud-brick walled, ogival-shaped 'Residential Area' ('a') in a view from the eastern tip of the 'Rock Plateau' looking to the NW. Stone-and-mud-brick Wall (arrow, black B on inlet map) is visible as a feature connection the foot of the 'Rock Plateau' to the 'Residential Area'.

On the site, there are seven major categories of anthropogenic features visible with clear distinctive functions: major linear features; minor linear features; hydraulic linear features; standing architectural structures; productive installations; circular stone structures and depressions (see Section 4.2 for details).

Figure 5. (a) View of the main wadi that runs through the archaeological site (arrow shows the flow direction). (b) View to the wadi banks (arrow) that consist of gray substrate that show signs of hydromorphic mottling (oxidation-reduction) and that were used as agricultural fields.

Figure 6. The area of the fields in the northern extension of the site, with visible stone partition walls and canals (arrows), viewed from the NE corner of the city walls to the West.

4. Geomorphological units and anthropogenic structures

4.1 Large scale geomorphic structures and processes

The settlement Qurayyah is located in a specific geomorphological position at the transition between two different landscapes. The plateaus that dominate in the southwest form a tableland that overtops the surroundings, and decrease in elevation from south (900 m) towards the northeast (800 m). At the site of Qurayyah the plateaus fade towards the east and the landscape opens to form the transition towards the Tabuk Basin. The archaeological site Qurayyah is situated near the confluence of two supraregional wadis – Wadi Harif and Wadi Ghubai – in a hydrologically favored but geomorphologically sheltered position to the lee-side of the 'Rock Plateau'.

Whereas the category *plateau* indicates the rough top of a hill, the flat categories of *plateau remains* and *level plateau* could have served as secure bases for a settlement itself. *Level plateaus* exhibit visible denudation whereas *plateau remains* are dominated by denudation.

Material from the plateaus accumulated primarily by rock fall or, to a lesser degree, by slope wash in the direct vicinity of the escarpments forms talus cones of varying size. These talus cones are cut by wadi courses or form a gradual transition to areas dominated by denudative processes (Figure 7). The break of slope marks where the slope toe begins and gradually merges with the ground line. These slopes are characterized by denudational processes and often show sheet wash in the surface run-off direction.

The wadis – as river valleys with episodic discharge – are incised in the bedrock within the interior or tableland of the plateaus. In the lower part of their course and where the wadis leave the plateau, their bottom is flat and occupied by fluvial sediments. These wadi areas include remains of linear and braided palaeo run-off that show a clear drainage direction. This is a common landscape feature of arid and semi-arid landscapes that experienced wetter palaeo-climates and supports the thesis of a more frequent water supply in the past (Pachur, 1974).

The settlement is situated at the confluence of the Wadi Ghubai and Wadi Harif, where remains of buildings, walls and fields can be found in the wadis' courses. Whereas most of the remains are located close to the outstanding 'Rock Plateau', single walls have been detected across the course of the wadi. These seem to control floodwater and prevent it from becoming disruptive. Likewise, the small walls in the area of former fields can be interpreted as similar control-features due to their perpendicular orientation in relation to the wadi course.

The wadi floors are generally flat and filled with fluvial deposits (sand and gravel) from previous flash flood events. At the leeward side of the plateau these fluvial deposits are partly covered by a thin layer of aeolian sand that has been mobilized by the current dry climate. Vegetation occurs occasionally in the palaeo

Figure 7. View from the 'Rock Plateau', towards south-west to Wadi Harif ('WH') that enters from the plateau of the Hisma Mountains ('HM' east of the 'Rock Plateau') the transition zone where the landscape opens to the west.

run-off channels and is concentrated at the confluence of the two larger wadi systems west of the settlement (Figure 8). This concentration, in addition to the presence of center pivots, indicates that the water mostly passes this region instead of following the natural course of the Wadi Ghubai. Small fluvial fans are present in the south where flash floods have washed alluvium down from the nearby plateaus.

4.2. Anthropogenic structures

In the frame of the geomorphological mapping, seven different groups of anthropogenic structures on the surface of the site were identified from satellite images and surface surveys conducted on foot. These are (cf. plan of the anthropogenic features, inset on the main map):

1. **Major linear features**: [A] high-standing stone and [B] mud-brick-and-stone walls.
   [A] The former are visible in two N-S stone wall lines, erected ca. 200 m apart from each other and partitioning the entire expanse of the plateau (ca 20 ha) in three different areas. The total length of the northern and southern segments of the W wall is 430 m and of the northern and southern segments of the E wall 230 m, respectively (Figure 3).
   [B] Mud-brick-and-stone walls extend to encircle the entire lower part of the settlement (300 ha) with an approximate length of 8 km. Within this larger expanse, the so-called 'Residential Area' (5 ha) features an extra mud-brick-and-stone enclosure (0.9 km in total length, Figure 4).
2. **Minor linear features**: low-standing, short stone walls visible in the lower town of the settlement that seem to partition the agricultural land and possibly function as sediment retainers (Figure 6).
3. **Hydraulic linear features** (blue lettering):
   [A] One stone-block dam, built 2.5 km upstream from the site regulating the flow of the Wadi Ghubai (cf. blue 'A' on the main map).
   [B] Inside the site: numerous stone-built canals and watering structures for the agricultural fields, including the so-called 'Roman site' (Parr et al., 1970): a 9.5 ha, major water reservoir located in the central part of the lower town.
   [C] At least one stone-block-structured opening in the SE city wall and an identical one in the N city wall, both coinciding with the bed of the major wadi and characterized as the 'Inlet' and 'Outlet' of the surface hydraulic system.
4. **Standing architectural structures** (black lettering):
   In the lower town:
   [A] Towers along the wall encircling the lower town;
   [B] The so-called 'Nabatean Building 1', and 'Nabatean Building 2' (Parr et al., 1970);
   [C] Several stone-built buildings, likely dwellings in the 'Residential Area'.
   On top of the plateau:
   [D] Six towers lining the W stone wall;
   [E] One large circular tower connecting the northern and southern segment of the E wall;
   [F] One free-standing tower at the eastern end of the mesa.

Figure 8. View of the Wadi Ghubai before the confluence with Wadi Harif. The wadi walls are up to 4 m high. Note the white jeep for scale in the upper left corner.

5. **Productive installations** (red lettering):
   [A] In a ca. 1 ha area, located between the NE foot of the 'Rock Plateau' and the walls of the 'Residential Area', a high scatter of slag and a number of mounds indicating pottery (and possibly also metallurgical?) kilns are well recognizable (one early Late Bronze Age pottery kiln has been excavated, Luciani & Alsaud, 2018);
   [B] Several rows of fine-sediment circular basins extending in Y-shaped lines outside and west of the city walls and one large ditch inside the site, likely used as clay production installations;
   [$C_{1\text{-}3}$] An elongated (190 m×70 m) water (?) basin in the NW part of the site (C_1); a 500 m long, 37 m wide ditch with consistent large pebble deposits in the central part of the site just N of the 'Residential Area' (C_2); and a small circular water (?) basin in the SE part of the site (C_3).
6. **Circular stone structures**: a number of circular stone structures, most likely cairns, were identified in different locations within the site and in its outskirts. They are of different sizes (diameters range from 20to 70–80 m), which may indicate different functions and dates.
7. **Depressions**: half a dozen round depressions, possibly used as graves and one large square, stone-lined pit feature filled with human bones. Both are on top of the 'Rock Plateau'. Several depressions, likely to have been graves, can also be observed in different locations in the lower town, especially in its southeastern area.

While some patterns in the association of specific geomorphological and functional units may be observed (see Section 5 below), the surface survey of these structures cannot currently provide any chronological information; for the time being this anthropogenic landscape must therefore be considered a palimpsest.

5. Conclusions

The geomorphological map of Qurayyah illustrates many aspects of a profound background of knowledge of the founders of this man-made oasis. The site made use of the hydrologically favorable location at the confluence of two supra-regional wadis, as seen in the remains of water-harvesting measures encompassing the entire site. On the other hand, the sheltered position to the lee-side of the 'Rock Plateau' indicates the risk awareness of the inhabitants concerning occasional flooding and erosive events within striking distance of the larger wadis. Moreover, the size and complexity of the anthropogenic landscape reveal a deep knowledge of the geomorphology of an extended micro-region, resulting in the conceptual design of a settlement with agricultural fields covering several hundred hectares and extending many kilometers beyond the walled site. The residential and funerary areas of the settlement were located on higher flood-free positions. The mud-brick-walled 'Residential Area' in the center of the site overlooked the artisanal areas in the southwest and benefited from direct water accessibility without the risk of flooding. The agricultural fields occupy transitional areas just above the linear or braided run-off of smaller tributaries and often anthropogenic regulated wadis. Therefore, artisanal areas were out of reach of erosive heavy rainfall floods but profited from fertile alluvial substrates distributed during non-erosive or even tamed flooding events.

Observation of the hydraulic features listed above (3. [a] dam upstream of the site, [b]numerous canals and one major reservoir in the area of agricultural fields, [c] water 'Inlet' and 'Outlet' on the city wall) have prompted us to develop the hypothesis that the dam [a] on the Wadi Ghubai regulated the major surface water intake on the site of Qurayyah. This water flow had access to and was drained from the site through the major water 'Inlet' and 'Outlet' [c] in the S and N parts of the site. Water storage and distribution followed through internal canals and the 'Roman Site' [b]. Additional water-harvesting measures were managed through ditches and water (?) basins.

This hypothesis will need to be checked through specific, intensive ground-truthing. In order to verify the chronology of the different hydraulic features, OSL samples have been taken at specific locations of the system ([a] dam; [c] water 'Inlet' and 'Outlet'; [b] canal). They are currently being analyzed by the University of Natural Resources and Life Sciences Vienna, Austria. Five new radiocarbon dates (Luciani, in press and Luciani & Alsaud, 2018) show that the construction of monumental stone walls on top of the Inselberg can now be firmly dated to the third millennium BCE. Four dating samples originating from the base of a canal at the foot of the 'Rock Plateau' provide additional information. These samples were analysed using the OSL signal of quartz stimulated at 125°C and applying a double SAR (single aliquot regeneration) protocol following Banerjee, Murray, Bøtter-Jensen, and Lang (2001). First results point towards a deposition of the sampled sediments during the third millenium BCE and may corroborate the construction of the canal within that period (personal information of the Vienna Laboratory for Luminescence dating, VLL). These OSL ages are preliminary as these are the first obtained dates of a suite of 15 samples for OSL dating from Qurayyah that are currently under investigation. The fortification and walling of outcrops and plateaus is a known phenomenon in the third millennium. BCE Southern Levant (Philip, 2003). The other major oasis in Arabia Tayma' was also encircled by a city wall in the early third millennium BCE (Hausleiter, 2018).

The Qurayyah evidence, while still preliminary, provides strong indications that the wall system encircling the entire site and the enclosed agricultural fields and canals dates back to the formative stage of the oasis. The coherence and homogeneity of the whole wall complex along with the finding of Bronze Age pottery scattered throughout the site seem to support this hypothesis.

This means that water-management skills in the Hejaz allowed the organization of a vastly extended cultivation area and the establishment of a major permanent settlement, which displayed 'urban' characteristics from its inception in the late Early Bronze Age. The exact terms of what 'urbanism' involved in the desert are not yet well-defined (Luciani forthcoming, Faust, 2017), and therefore we use the word within quotation marks. However, the monumentality and magnitude of the stone constructions and irrigation system, and the development of copper and ceramic production, indicate a more complex social organization than one would expect at the village level.

A more detailed understanding and a more precise chronological determination of this incipient phase of the oasis will be needed to unravel the origins, duration and collapse of this complex watering and agricultural system, possibly one of the earliest of this magnitude in the entire Arabian Peninsula.

Software

For the GPS computations, the software products Leica Geo Office (LGO) and Trimble Business Center (TBC) were used and the rectification of the satellite image was undertaken in Erdas Imagine. All the processes following rectification were conducted using freely available open source software. Merging of the SRTM scenes was performed using the GDAL tool (GDAL 2017). Reprojection was conducted in R (R Core Team 2017) using the projectRaster function of raster package (Hijmans 2016). The DEM analysis was conducted in GRASS GIS v. 7.2 (GRASS Development Team, 2017) using r.watershed. Digitizing of features and on-the-fly blending of remote sensing imagery provided by Microsoft (bing maps) and google (Google Earth) was conducted in QGIS version 2.18 (QGIS Development Team 2017). The Sentinel-2A scene (GS2A_20151125T081252_002220_N02.04) was resampled, mosaiced and subsetted using SNAP software (SNAP 2017).

The following data and software were used to produce the geomorphological map of Qurayyah:

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ORCID

Philipp Hoelzmann http://orcid.org/0000-0001-8709-8474
Daniel Knitter http://orcid.org/0000-0003-3014-4497
Marta Luciani http://orcid.org/0000-0002-3105-2212

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