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Ancient agricultural landscapes in Southeast Arabia:

Approach and first results of an archaeological, geo-archaeological, and spatial study of the Masāfi Palm Grove, Emirate of Fujairah

Julien Charbonnier, Louise Purdue, Carine Calastrenc, Emmanuelle Régagnon, Thomas Sagory, Anne Benoist

Summary

Located in the northern part of the Hajar mountains (UAE), the oasis of Masāfi benefits from abundant copper and water resources and a strategic location at the crossroad between the western piedmont and the shore of the Gulf of Oman. Our project aims at reconstructing the dynamics and evolution of this oasis. An interdisciplinary approach was adopted for this purpose, based on a combination of archaeological, geoarchaeological, geomorphic, spatial, and botanical study. This article presents the methodology and the first results of our investigation in the southern part of the palm grove (Emirate of Fujairah) and more specifically: the mapping of the palm grove and the surrounding valley; the excavation of Iron Age hydraulic structures near the site of Masāfi-1; and the study of a test pit dug inside the palm grove. Thus, we will put forward first hypothesis on landscape use and evolution in the valley of Masāfi.

Keywords: Oasis, soil, irrigation, geoarchaeology, GIS

Fifty years ago, oases were still the main component of Southeastern Arabia's landscapes. Oases correspond to irrigated gardens characterised by intensive and mixed farming. Date palms, as well as underlying crops and associated irrigation systems – i.e. the network of canals delivering water to the gardens – were the keystone of this agrosystem (Figure 1). Under the

date palms, crops, protected from the sunrays, heat and evaporation thanks to flooding irrigation (Laureano 1998), are distributed vertically with generally fruit trees (lemon trees, fig trees...), cereals and then vegetables and legumes in the lower part (Tengberg 2012: 139-140). Cereals and forage crops can also be grown in open fields, located downstream or around the palm grove. Currently obtained by mechanical pumps, water irrigating the field was provided in the past by *qanāts* (locally called *aflāj*, sing. *falaj*), springs, wells and occasionally *wādī* floods.

When and how the oasis agrosystem developed is a still a topic of debate. Several scholars have assumed that oases appeared during the 3rd millennium BC and allowed for sedentary agricultural life. Until recently, understanding past agricultural landscapes in Arabia relied mainly on archaeobotanical studies and on the excavation of hydraulic structures. Therefore, the respective role of climatic oscillations and socio-economic dynamics on their development is still badly understood. However, understanding why oases were created is not the only question that needs to be raised. Indeed, oases are dynamic landscape entities and have existed for many millennia. It is their long-term evolution, structured around cycles of occupation and abandonment, which need to be reconstructed. Further pluridisciplinary studies at various spatial and temporal scales are therefore needed to understand their history.

Since 2011, the oasis of Masāfi project (Fujairah, U.A.E.) directed by Anne Benoist, ¹.

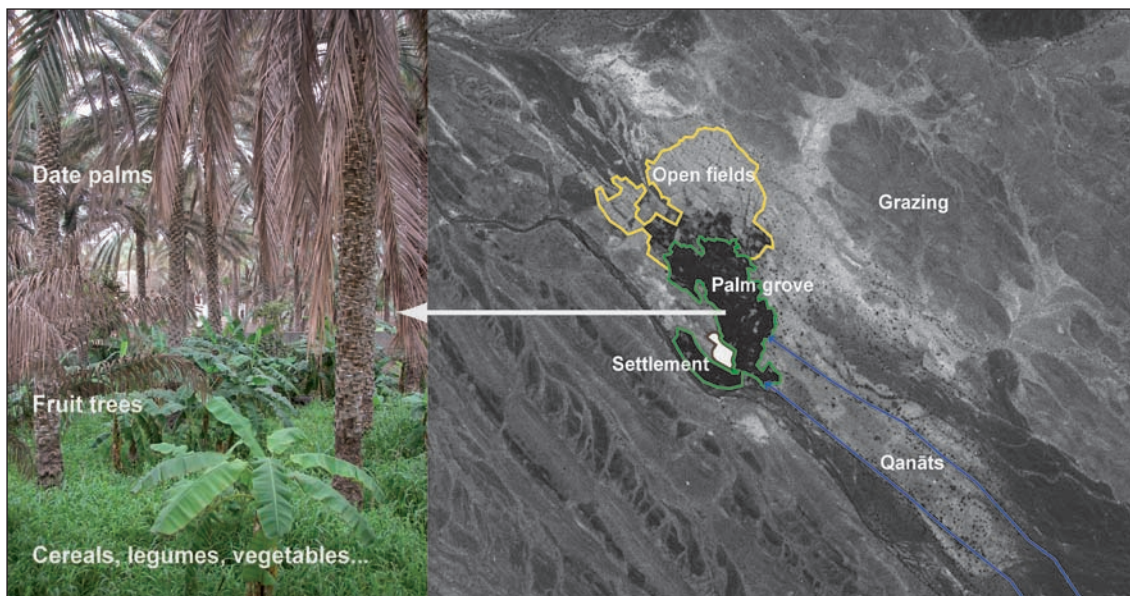


Figure 1: Spatial and internal organisation of Southeast Arabian oases (CAD Julien Charbonnier)

tries to fill this gap. Masāfi provides a relevant area of study for two reasons. First, this well-preserved palm grove is located in the northern Hajar Mountains (Figure 2), where studies, mainly conducted on the western and southern piedmonts of the mountains, are non-existent. Studying the formation and evolution of the palm grove will likely provide information on hydraulic technology and agriculture in these rough environments. Second, unlike other areas of the Peninsula, Masāfi benefits from abundant copper and water resources and a strategic location at the crossroad between the western piedmont and the shore of the Gulf of Oman. Reconstructing cycles of occupation and abandonment as well as the triggering factors for change will therefore prove of relevant importance at a regional scale.

The present article aims to introduce the interdisciplinary approach adopted, based on a combination of archaeological, geoarchaeological, geomorphic, spatial, and botanical study. We will also present the first results of our investigation in the southern part of the palm grove, which belongs to Fujairah emirate, and put forward first hypotheses on landscape use and evolution.

1. Oases in ancient Southeast Arabia: state of the art

1.1. Current theories concerning the development of oases

In our current state of knowledge, agriculture seems to have been introduced in Eastern Arabia during the Early Bronze Age (3200-2000 BC).

The first evidence for agriculture are the results of botanical studies conducted at Hīlī 8 in the oasis of al-'Ayn (U.A.E.) showing evidences of barley (*Hordeum vulgare* subsp. *distichum* and *Hordeum vulgare* subsp. *Hexastichum*), wheat (*Triticum cf. aestivum* and *Triticum dicoccum*), oat (*Avena* sp.) and peas (*Pisum sativum*) as well as date stones (Cleuziou & Costantini 1980) and wood fragments of date palm (*Phœnix dactylifera*) (Tengberg 2003: 232). The consumption of dates and cereals is also attested on several 3rd millennium sites: Rā's al-Jinz 2, Tell Ābraq (Costantini & Audisio 2001, Willcox & Tengberg 1995), Maysar 1 and Umm an-Nar (Tengberg 1998: 188f, Weisgerber 1981: 191-197, Willcox 1995: 257-259). Date stone remains dated to the Wadi Suq period (2000-1600 BC) have also been encountered in Nud Ziba and Tell Ābraq (Kennet & Velde 1995: 85; Tengberg 2003: 233). Similar cultivars (winter

cereals and date palm) are also attested during the Iron Age (c. 1300-300 BC) on several sites (Costantini & Costantini-Biasini 1986: 357-358; Tengberg 2003; Willcox & Tengberg 1995: 133).

The establishment of a regional exchange network based on the export of raw material (mainly copper) from Southeast Arabia to Mesopotamia, Iran and Indus, seem to have contributed to the adoption of agriculture in the former region (Cleuziou 1999: 99). Indeed, most of the crops cultivated in Southeast Arabia during the 3rd millennium BC originate from the Near East or Iran (Tengberg 2003: 235). Agriculture would have supported and strengthened the socio-economic changes as well as the demographic growth attested at that time (Cleuziou 2005: 144).

The evidences for the concomitant cultivation of date palm, cereals and legumes near settlements during the Early Bronze Age led Serge Cleuziou to suggest that the oasis agrosystem was already fully established in the 3rd millennium BC in Southeast Arabia. Cleuziou also assumed that: 1- oasis developed as an adaptation to arid conditions, population growth and regional exchange networks, 2- the agrosystem remained almost unchanged since then (Cleuziou and Costantini 1980; Cleuziou 1982: 19-20). This theory is now widely accepted among researchers working in Arabia (see Potts 1999: 36 or Tengberg 2003).

Another angle of approach is to consider that the development of oases is tightly linked to hydraulic technology. Denying Cleuziou's assumptions, Walid al-Tikriti proposed an alternative model. According to him, the development of oases would then be related to the introduction of *qanāt* technology during the Iron Age (al-Tikriti 2010: 240-243).

1.2. Limits of our knowledge on ancient oases

While we have now quite a lot of information regarding the assemblage of crops grown from the Early Bronze Age to the Iron Age, the hydraulic techniques as well as the organization of irrigation systems and agricultural plots themselves remain badly known.

Indeed, only wells are attested in several Bronze Age sites (Cleuziou 1989: 64-68; Frifelt 2002: 104; Weisgerber 1981: 203) but they were used for domestic activities and are not related to agriculture (Charbonnier 2015: 66). Numerous attempts have been made to date surface-water control devices. Some have been dated from the Bronze Age (see Brunswig 1989; Hastings, Humphries & Meadows 1975; Weisgerber & Yule 2003) but the evidences are questionable (Charbonnier in press). Some researchers suggested that *qanāts* were already used during the 3rd millennium BC (Cleuziou 1998: 61-62; Orchard & Orchard 2007: 150-151), but no structure has been properly dated from that period (Charbonnier 2015: 43-47). The oldest *qanāts* in Southeast Arabia seem to date from the Iron Age (al-Tikriti 2002, 2010; Córdoba 2013).

Hydraulic structures in oases are directly connected to agricultural plots and our knowledge of past cultivated gardens is even weaker. Iron Age gardens have only been excavated at al-Madām (Córdoba 2013), Hīl 15 (al-Tikriti 2002) and Qattārah, in the area of al-Ain where remains of cultivated trees were found associated to earth channels and wells dug into the limestone bedrock (Power & Sheehan 2011). The lack of systematic spatial, chronological, geoarchaeological and paleopedological studies prevents us from better understanding the construction, organization and abandonment of terraces and cultivated fields (were date palm cultivated on the same plots than cereals and vegetables during the Bronze and Iron Ages?). It also limits our knowledge of past agricultural practices and soil agrological properties (humidity, soil salinity / alkalinity, organic matter content), which are key to explain cycle of land use and abandonment.

2. The oasis of Masāfī

2.1. Environmental background

The oasis of Masāfī is located in a natural depression north of the Hajar Mountains, about 450m asl at the border between the emirates of Fujairah and Ras al-Khaimah (UTM coordinates: 40 R 415730 E 2798920 N) (Figure 2). The climate in this area is considered as semi-arid, with average

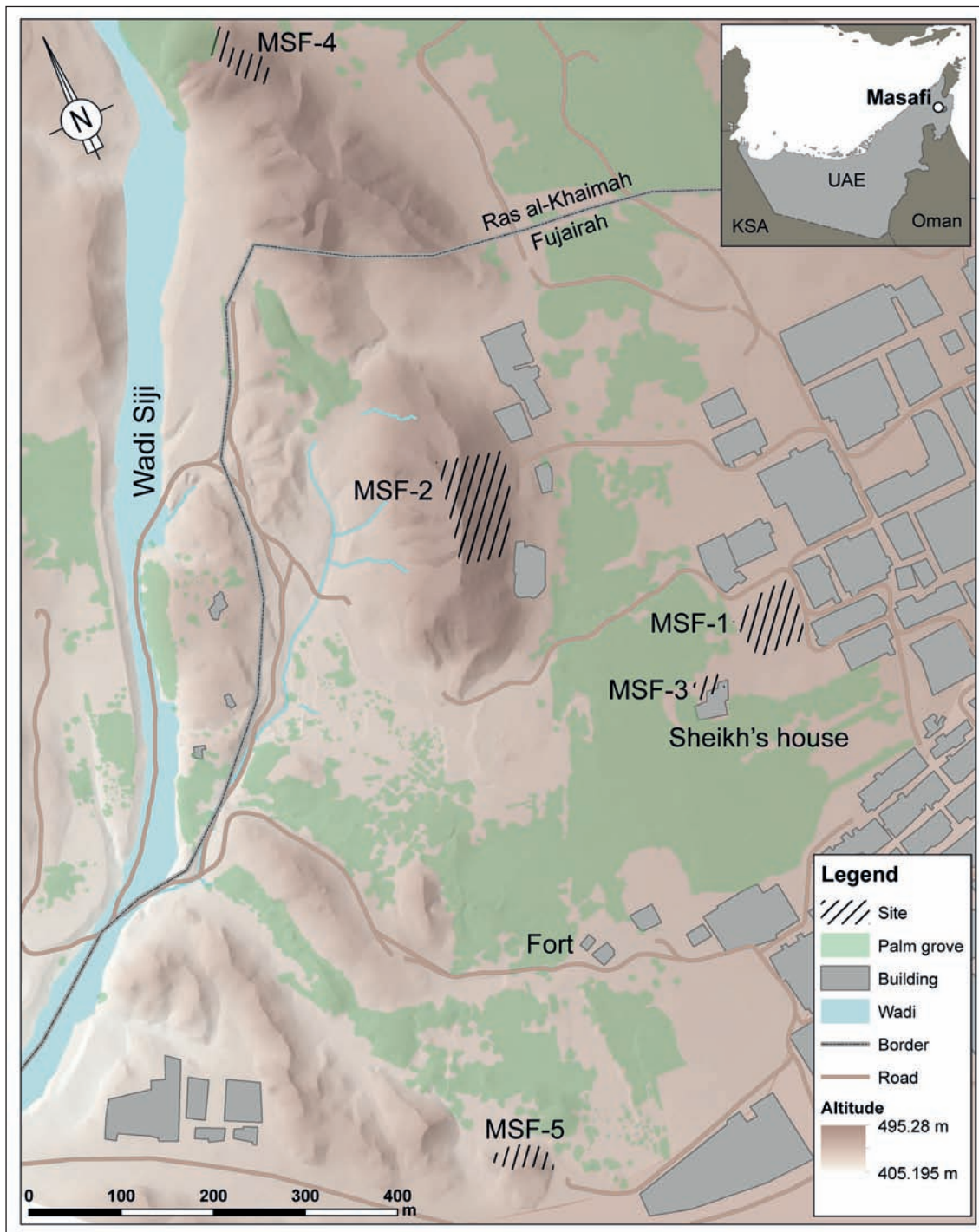


Figure 2: The Masāfi Palm grove with location of the 5 archaeological sites and our study area in the southern part of the palm grove (CAD Emmanuelle Régagnon and Carine Calastrenc)

yearly precipitation reaching 180 mm (1968-2004) with heavy rainfall in winter (Tourenq et al. 2009). The palm grove of Masafi is surrounded by basic igneous bedrock part of the Ophiolite complex, mainly gabbros and serpentinite with calcite veins. Lying on top of the bedrock are old quaternary deposits, comprised of boulders,

cobbles, gravels and sand, increasingly cemented in their lower part. Fractures in the bedrock to trap water and the transition from cemented to non-cemented deposits has allowed for underground water circulation and storage. This specific hydrogeological context explains why three wādī originate around Masāfi. Wādī Sidji runs west

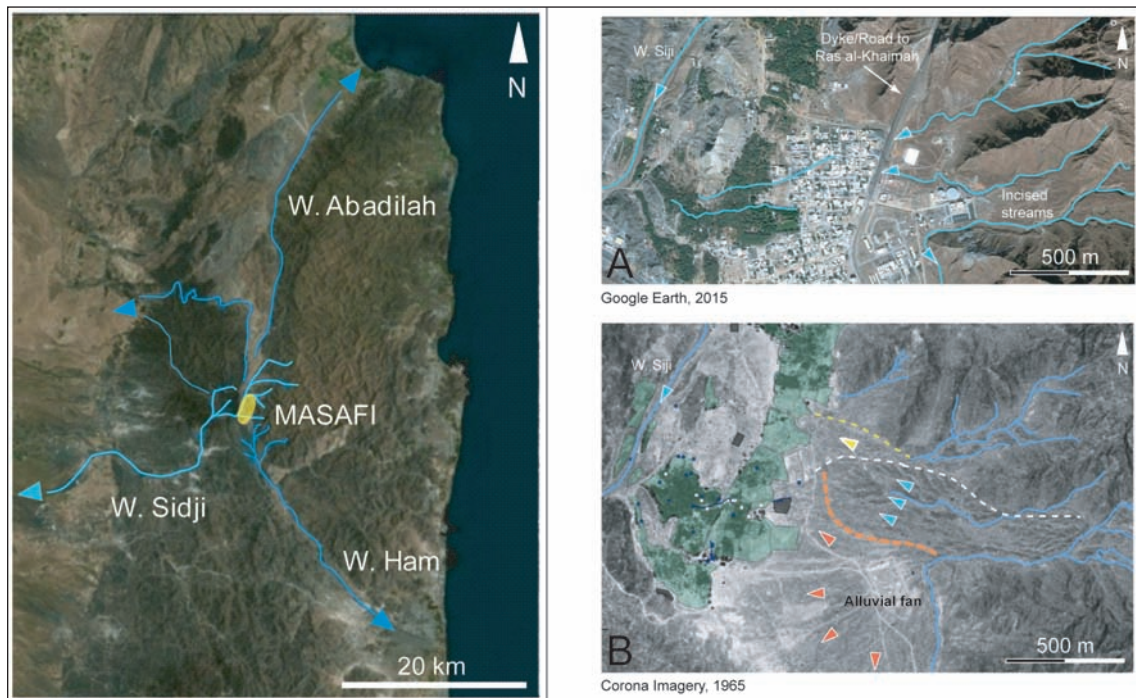


Figure 3: Hydrosystems around Masāfi: regional wādīs and local gullies (CAD Julien Charbonnier & Louise Purdue)

and dries up in the sand dunes on the shore of the Gulf. Wādī Abadilah flows to the north and reaches the small plain of Dibba while the valley of Wādī Ham, oriented north-west-south-east, leads to the city of Fujairah (Figure 3).

The present-day oasis covers about 50 ha and is organized in terraces that create horizontal surfaces adapted to irrigation (Figure 2). The eastern part of the palm grove is surrounded by high-sloped bedrock and quaternary alluvial fans, while its western part is composed of the deeply incised wādī Sidji. In the southern part of the oasis, which has been investigated by our team, terraces are distributed from east to west following the natural topography. Over the last decades, the groundwater level has significantly decreased (7-8m deep in the wādī) and water is pumped in order to irrigate the dominant date palms. Indeed, apart from a few mango and jujube trees, carrots and onions, traces of agriculture are scarce in the palm grove.

2.2. Archaeological background

Important water resources and a strategic location have favoured human settlement in Masāfi for the last four millennia. Masāfi-4, a Wadi

Suq period site, has recently been discovered and will be investigated in the next few years, while four other sites have been excavated (Figure 2). Masāfi-5 is located on a hill south of the palm grove and is dated from the Late Bronze Age (1600-1300 BC) – Iron Age I (1300-1100) (Degli & Esposti Benoist 2015). Masāfi-5 suggests main occupation during the second half of the 2nd millennium BC. In our present state of knowledge, the area is more densely populated during the Iron Age II (1100-600 BC) (see Benoist et al. 2012; Benoist 2013). To the north-west, a fortress erected on a rocky hill (Masāfi-2) included a dwelling made of houses built above a series of stone-faced terraces. A “U” shaped sanctuary (Masāfi-3) revealed many snake figurines in bronze as well as vessels, including incense burners, ornamented with snakes. Sixty meters to the north-east, a large building with a central pillared meeting room (Masāfi-1) was established at that same period. It was surrounded by a probable market, composed of barasti structures, and a rectangular podium that covered five small circular pits. North of the probable market and building, we recovered traces of irrigation canals (Figure 4).

In the present state of knowledge, the area of



Figure 4: Kite picture of Masāfi 1 (see Figure 2 for location) with an Iron Age building to the South and a network of canals to the North (Picture: Thomas Sagory, CAD Julien Charbonnier)

Masāfi seems abandoned after the end of the Iron Age II. During the late Islamic period, a mud brick fort was built south of the palm grove and the Sheikhs of Fujairah established their residence above the ruins of Masāfi-3. A *qanāt*, passing next to the Islamic fort, probably drained water southeast of the valley. Two complete vessels found at the bottom of the underground gallery suggest that it was in use around the 14th-16th Centuries AD.

3. Problematic and objectives

Archaeological fieldwork conducted for the last five years at Masāfi has provided us with data from the Wadi Suq period to the Iron Age and after the 15th century AD. There is a gap between the end of the Iron Age II and the Late Islamic period. The aim of our archaeological, geoarchaeological, and spatial study of the palm grove is to answer three distinct issues:

1. Was the agrarian area permanently cultivated

or did it witness phases of abandonment? Is the lack of data from the Iron Age to the 15th century AD linked to temporary phases of abandonment or reorganization of the palm grove? If so, what was the influence of resource availability (water and soils) and socio-economic factors on these changes?

2. Is the current configuration of the terraced palm grove a recent creation or does it reflect perennial past agricultural practices since the Iron Age?
3. Has the economic vocation of the palm grove evolved through time (shift from pluri-cropping to single cropping for export for instance)?

4. Approach and methods

To answer these questions, we aim to reconstruct the dynamics and evolution of the palm grove, considered in our approach as an

anthroposystem, i.e. an artificialized system, exploited and managed by human societies at various embedded temporal scales (from the event to long-term trends) and spatial scales (local to regional) (Lévêque et al. 2003). This system is structured around phases of stability, thresholds, social and/or environmental shifts, the impact of which is highly dependent on the society's resilience and capacity to change (innovation and development). To understand the formation and evolution of this anthroposystem, four steps are required, which we will present below in more details (Figure 5): 1- Study the settlement pattern on the long-term, 2- Reconstruct the regional, micro-regional, and local environmental dynamics (hydrosystem, climate, landscape organization), 3- Understand the agrosystem and its evolution including hydraulic technology, agricultural practices, and crops grown, 4- Build references on water management and agricultural practices.

4.1. Settlement pattern, exchange networks and socio-economic systems

The exploitation of the palm grove is directly connected to the population maintaining it. Phases of land abandonment should be visible through both the archaeological and demographic data. Therefore, we aim at comprehending population dynamics based on both the excavations within the study area and regional information on settlement pattern, showing the emergence or

abandonment of sites, their type and size, as well as information on trade and network. Indeed, the regional economic values of palm groves should not be neglected. The emergence of an intensive irrigated agrosystem with the production of crops dedicated to exchange and commerce is therefore directly tied with regional development. The opposite could also be true, but the identification of a decreasing regional exchange network in parallel with agricultural development within the palm grove could provide relevant information on land-use management and the development of local socio-economic strategies.

The evolution of exchange networks through time is currently being investigated: ceramic studies and ceramological analyses are being conducted in order to understand the origin of potteries from the Late Bronze Age and the Iron Age; metallurgical analyses are being carried out on copper ingots and artifacts discovered in the Iron Age sites of Masāfi so as to understand the flow of metal across Southeast Arabia (Goy et al. 2013). In parallel, surveys are being conducted in order to understand the local and regional settlement patterns (sites hierarchy, defense systems, trade routes, etc.) and the exploitation of raw material at the scale of the northern Hajar mountains (in particular the spatial distribution of copper mines and smelting sites).

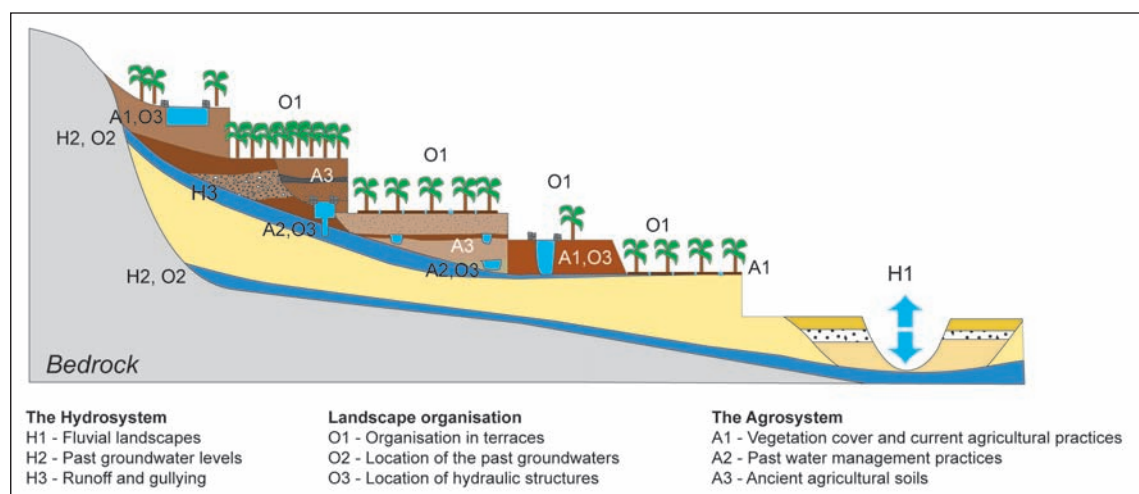


Figure 5: Approach and method adopted within the palm grove and its close periphery (CAD Louise Purdue)

4.2. The surrounding environment: landscape organization, the hydrosystem and climate

There are various scales of landscape reconstruction. As a base for further studies, it is necessary to understand the current spatial and vertical organization of the palm grove based on a cartographic and topographical study. This study has to be complemented with the mapping of archaeological structures, current and past hydraulic constructions (canals, wells, birkeh) as well as past traces of groundwater levels identified in the field in order to integrate temporality to the landscape analysis. Depending on the surface and the density of the vegetation cover, this complete survey was conducted using an experimental approach combining a Differential GPS, total station using a grip of points of about 10x10m, and a photogrammetric DEM (digital elevation model). Most of the palm grove was described using the DGPS (houses, plot boundaries, hydraulic structures, archaeological remains as well as lines of relief and slope breakings) but the dense vegetation cover in the central area prevented its use. Thus, altimetric data were obtained using the total station. In parallel, kite views were taken using a camera fixed on a kite. The vertical views, replaced in a geo-referenced frame located using the DGPS and/or Total Station, allowed to document the current excavations and build orthographic pictures and photogrammetric models using Agisoft Photo Scan Pro. Last, data was compiled and processed in a GIS software (Arcgis 10.2) in order to create the DEM of the palm grove.

Changing spatial scales, it is also necessary to reconstruct the micro-regional to regional evolution of hydrosystems. Indeed, the wādīs' lateral and vertical evolution is directly connected to surface and groundwater availability, indirectly climate, but will in any case influence water management in the oasis. The methods adopted are the ones of cartography (study of aerial photographs and their evolution), fluvial geomorphology, sedimentology and pedology on off sites alluvial archives, with a focus on signatures of landscape stability (paleosoil), downcutting events, episodes of fluvial accretion

as well as lateral river migrations. Once identified, they should be well framed chronologically. This information can be tied with 1- the identification of past groundwater levels in the palm grove, 2- the presence of gullies or sheetwash events, and 3- the study of deposits that fill irrigation structures and provide secondary information on hydrosedimentary dynamics prevailing during their use (such as direct traces of storms, floods and indirect traces of downcutting event leading to a decreasing groundwater level) (Berger 2000; Purdue & Berger 2015).

4.3. The agrosystem: agrarian practices, hydraulic technology and crops grown

4.3.1. The field approach

From a socio-environmental aspect, we aim at identifying 1) the nature of the crops grown based on the study of agricultural fields and the fill of adjacent canals/channels, 2) the characteristics of ancient agricultural fields and associated practices (fertility, manuring, evolution on the long-term, pollution, etc.) 3) the temporality and technology of hydraulic structures. The approach and methods adopted are the ones of rural geography, paleoecology, agronomy, geoarchaeology (physico-chemistry, soil micromorphology), archaeology, chronology, and taphonomy (Berger & Jung 1996; Purdue & Berger 2015).

Our field approach consists in opening test pits at the edge of the terraces and small trenches in the terraces (3-8 m²). This strategy proved efficient to locate archaeologically sterile layers in the palm grove, understand its spatial evolution from the Iron Age until today, and bring forward first hypotheses on the location of ancient hydraulic structures and technological evolution through time. The stratigraphy observed comprises agricultural soils, abandonment deposits, coarser sediments (gullies), canals, wells, and cisterns. Their texture, color, structure, stratigraphic boundaries, occurrence of anthropic and/or ecological inclusions, traces of oxidation/reduction, in situ burning, etc. are systematically described. Sediments are then sampled for chronological and paleoenvironmental analyses.

4.3.2. The laboratory approach

Chronology is the most required laboratory analysis to reconstruct diachronic dynamics. Hydraulic structures and cultivated horizons are preferentially selected and radiocarbon dated. Charcoal can be directly sampled in the profile when in situ burning events are visible. Often however, it is necessary to sample larger volumes of sediments, sieve them, and extract microcharcoal under a binocular. An alternative method, when organic material is not available, is Optically Stimulated Luminescence dating, which provides high resolution dates in shortly-used structures (Berger et al. 2004; Huckleberry & Rittenour 2013). We are developing this approach at Masāfī in collaboration with Durham University (Lisa Snape-Kennedy and Ian Bailiff).

Selected layers are also sampled for soil analyses such as grain size studies, physico-chemical measurements and micromorphology to characterize soil properties, estimate the impact of past agriculture on current soil fertility and identify specific agricultural practices. Much attention will be paid to the micromorphological method, which is the study of sediments under the microscope (Bullock et al. 1985; Stoops 2003) and has proven extremely relevant to understand sedimentary processes (environment of sedimentation, dynamic of flow, soil erosion), pedological and ecological dynamics (rhythm in water supply, soil development, vegetation cover, fire regime), human activities (slash and burn, manuring, irrigation), and dynamics related to soil climate (water stagnation/ evaporation) (e.g. Fédoroff et al. 1987; Courty et al. 1989; Kapur et al. 2008; Stoops et al. 2010), ². Last, bulk sediments (10 L) are also sampled for botanical (charcoal, seeds, phytoliths) and shell studies (molluscs, ostracodes).

4.4. Construction of references

The interpretation of past socio-environmental dynamics can only be understood if confronted to historic, modern and even current dynamics that control the evolution of agricultural and natural landscapes. Data recorded in modern or historic written archives (qualitative: types of crop grown; quantitative: temperature, rainfall,

etc.) can be confronted to data recorded on the field such as agricultural practices (soil studies) and water management (ethnographic studies). From an anthropic perspective, the construction of references also allows us to understand the adaptation of communities to various risks, such as the phreatic risk (hydromorphy, soil salinity) or the risk of erosion (gullying, soil erosion) (Arnaud-Fassetta 2008).

5. First results and interpretation

We will present here the results of the cartographic and topographical study of the southern part of the palm grove and its link with local geomorphology as well as our first results on the management of the palm grove since the Iron Age based on geoarchaeological, archaeological and micromorphological studies.

5.1. Environment and organization of the palm grove

5.1.1. Natural hydrological and sedimentary dynamics surrounding the palm grove

The palm grove is structured around its cultivated core but its dynamic evolution is highly dependent on microregional and regional environment and climate. As said in the introduction, Masāfī is the source of three wādīs (Figure 3) and first geomorphic surveys have shown that these wādīs are very entrenched (5 to 6 meters close to their source to 10-15 meters downstream). Downcutting events and fluvial accretion have led to the formation of one to three alluvial terraces, composed of gravels, cobbles and stone cemented in carbonates. No chronology was obtained but based on their pedological characteristics, we suspect that they are Pleistocene in age. More locally and on more recent periods, we believe that intense hydrosedimentary dynamics had an impact on the landscape. Current aerial pictures reveal the existence of numerous small entrenched wādīs east of the palm grove only, due to recent urbanization. Past aerial pictures, such as CORONA images from 1965, ³. (Figure 3), show that Masāfī was directly in the trajectory of

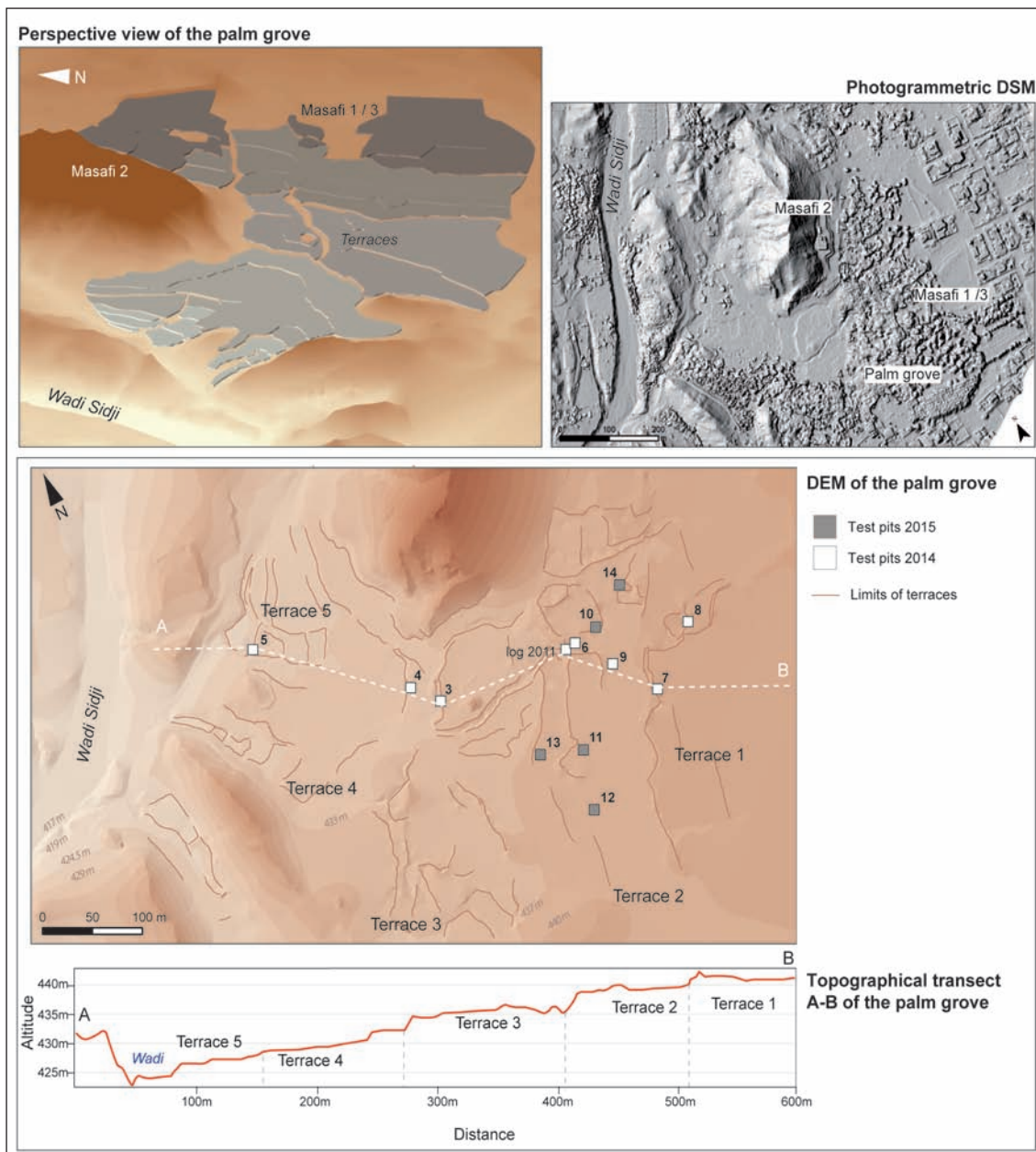


Figure 6: Some results of the spatial study (planar and vertical) of the southern palm grove: perspective view, digital surface model (DSM) and digital elevation model (DEM) with location of the geoarchaeological test pits (©Emmanuelle Régagnon, Carine Calastrenc & Thomas Sagory 2014)

gullies located at the terminal end of alluvial fans originating 1 to 1.5 km east. Three distinct detrital fans, undated today, seem to have crossed the palm grove (red and/or yellow arrows covered by darker colored deposits shown with blue arrows) (Figure 3). Surveys in this area show that these fans are composed on their surface of coarse gravels, stones and blocks of gabbro, as well as some finer white blocks of limestone that cover cemented gravels or blocks of gabbros. While channeling

some of these gullies could have supplied water for agricultural or domestic purposes, sheetflow erosion or uncontrolled water management could have led to soil erosion as well as the deposition of coarse sediments in cultivated areas of the palm grove. Stratigraphic units composed of these local coarse sediments could therefore suggest temporary land management issues or even land abandonment.

5.1.2. Reflection around the location of the groundwater table

Digging test pits in the palm grove and stratigraphic observation in wells have revealed that ancient agricultural deposits are no thicker than 4 to 4.5 meters. The easily identifiable substratum (or sterile layer) is very compact, composed of 20 to 50 cm of light grey to white carbonated silts, which turn bright green in the central part of the palm grove as a result of an ancient permanent water level. These carbonated silts are occasionally overlaid by light grey cemented gravelly silts (bright orange as a result of fluctuating water levels in other areas) (Figure 10). These two layers remind the fluvial deposits identified adjacent to the three wādīs as well as the ones noticed east of the palm grove, close to the detrital fans. Under these two layers, the stratigraphy examined in wells shows the occurrence of cemented stones and blocks of gabbro. The difference in compaction provided by the substratum and looser cultivated deposits is ideal for the circulation of groundwater, which

is confirmed by field observations (greenish and orange colors) and oral archives, suggesting that water overflowed in wells directly constructed in this perched water table. Today, the groundwater is located at a depth of 7 to 8 meters revealing the presence of a second groundwater table, maybe at the junction between the cemented gabbros and the bedrock itself.

5.1.3. Spatial organization of the palm grove

After two fields seasons, in 2014 and 2015, the team mapping the southern part of the palm grove obtained a topographic map (combination of GPS, total station and photogrammetry) and a DEM (Figure 6). The surface covered by this detailed mapping reaches 29 hectares and the resolution of the work ranges from 10 cm under the palm trees to 5 cm in open areas. The topographic map provides extremely relevant information on the current agricultural terraces, difficult to perceive under the palm grove. Five main terraces separated by more than 40 cm of elevation, and

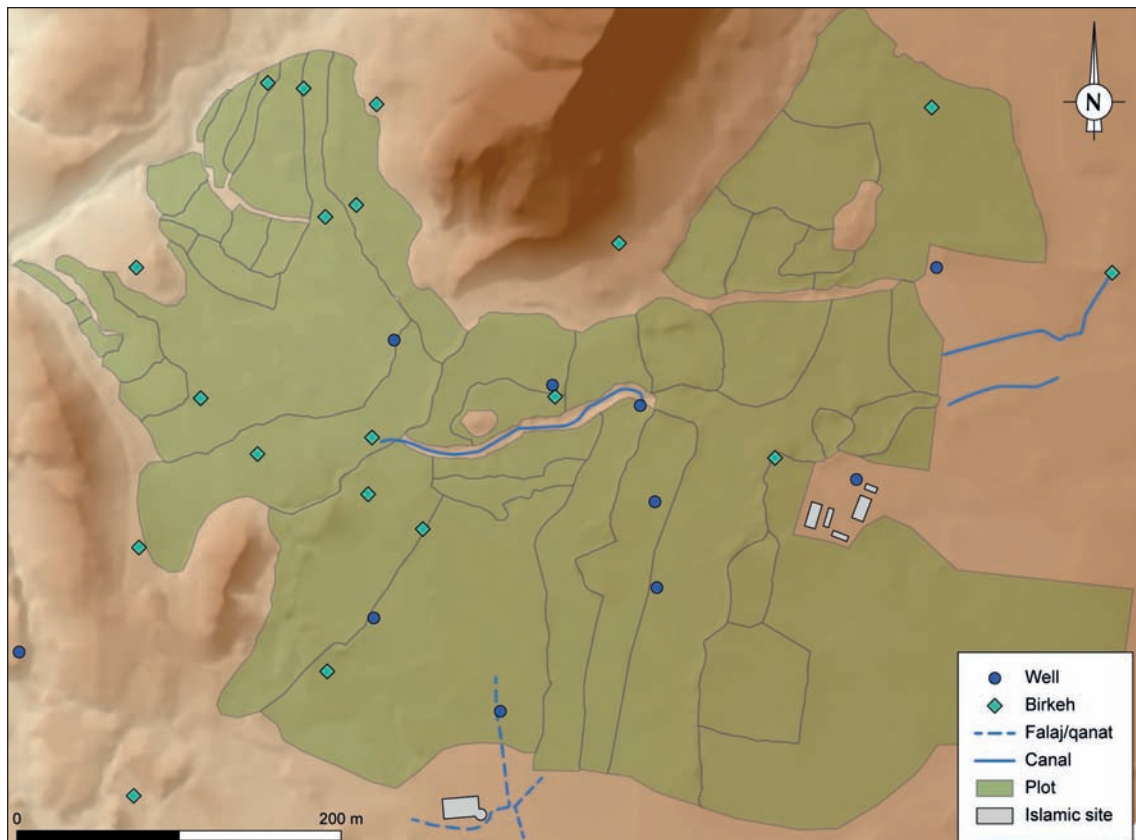


Figure 7: Location of the hydraulic structures in the palm grove (CAD Emmanuelle Régagnon, Carine Calastrenc & Julien Charbonnier)

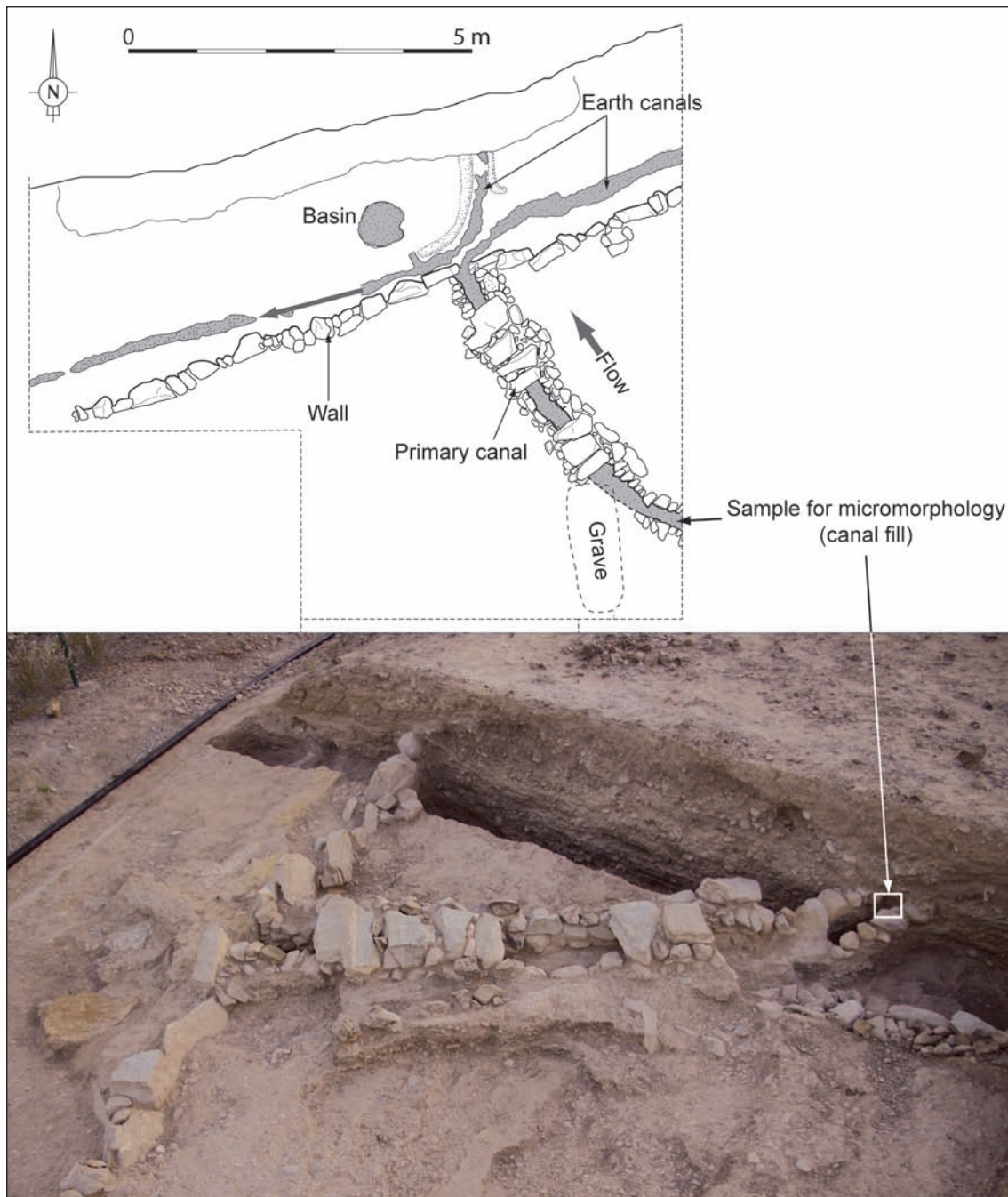


Figure 8: Zoom on the canal excavated at Masafi -I with location of the micromorphological sample obtained from its sedimentary fill (CAD Julien Charbonnier).

sloping to the west, were distinguished. Terraces T1, T2 and T3 on the eastern side present a more homogeneous surface: T1 lies at an elevation slightly above 440 m, terrace T2 around 437m and terrace T3 at 435m. The topography is more irregular on T4 and T5, with recent constructions of small terrace walls. The slope gently decreases from 433m (base of terrace T3) to 429m on terrace T4, and to 425m on terrace T5. The bottom of

Wādī Sidji, overlaid by terrace T5, lies 417m above sea level.

5.2. Water management and agriculture in the ancient palm grove

5.2.1. Location of hydraulic structures south of the palm grove

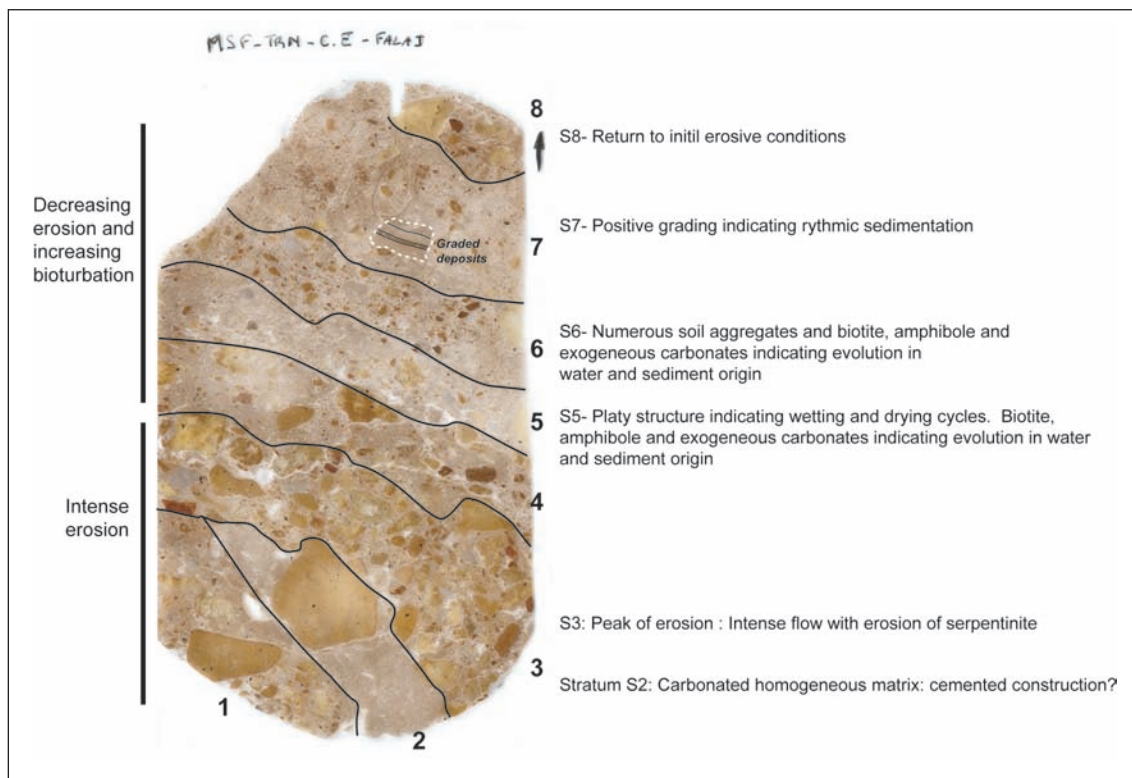


Figure 9: Synthetic description of a thin section sampled in the deposits filled the primary canal of Masafi (CAD Louise Purdue).

Visible hydraulic structures within these terraces highlight three distinct areas of activities (Figure 7). In the past and nowadays, the oasis of Masāfi was mainly irrigated thanks to wells. Wells are located on terraces 1, 2 and 3, and follow an east-west axis in the center and south of the palm grove. Most of them are dry and abandoned as the water table decreased during the last 30 years. These traditional wells are circular, 1.5 to 2 m in diameter, and are faced with stone blocks in their upper part. Currently, the palm grove is fed by deep wells located outside and east of the gardens.

Birkeh on the other side, are concentrated on terraces 4 and 5, mainly on the piedmonts of the geological outcrop of Masāfi 2 and 5. These cisterns are cemented and are currently fed by water pipes coming from the deep wells mentioned above. The only qanāt attested in Masāfi is Late Islamic in date and is located next to the fort. Although badly preserved, this structure could have, if we consider its altitude and slope, delivered water to the terraces 4 and 5 in the past. While some of

these hydraulic structures are still in use, some have been dated to the Islamic Period, while other still need chronological refinement.

5.2.2. An Iron Age irrigation system and its socio-environmental interpretation

The archaeological excavation of the site of Masāfi 1 (Figure 8), at the eastern edge of the palm grove, has allowed for the excavation of a primary canal connected to numerous small earthen ones, a few meters north of the building with the pillared room mentioned previously and dated to the Iron Age II (Charbonnier et al. In press). The subsidiary earthen canals, which were about 10 to 20 cm wide, were directly connected to light brown silts rich in charcoal, interpreted as an ancient cultivated layer. Microcharcoal sampled in this layer provided a date of 897-801 BC, ⁴, dating this exploitation and consequent water diversion to the Iron Age (Charbonnier 2015: 58). The cultivated layer and the subsidiary canals were located north of a low wall made of vertical stone slabs (Figures 4 and 8) that seems

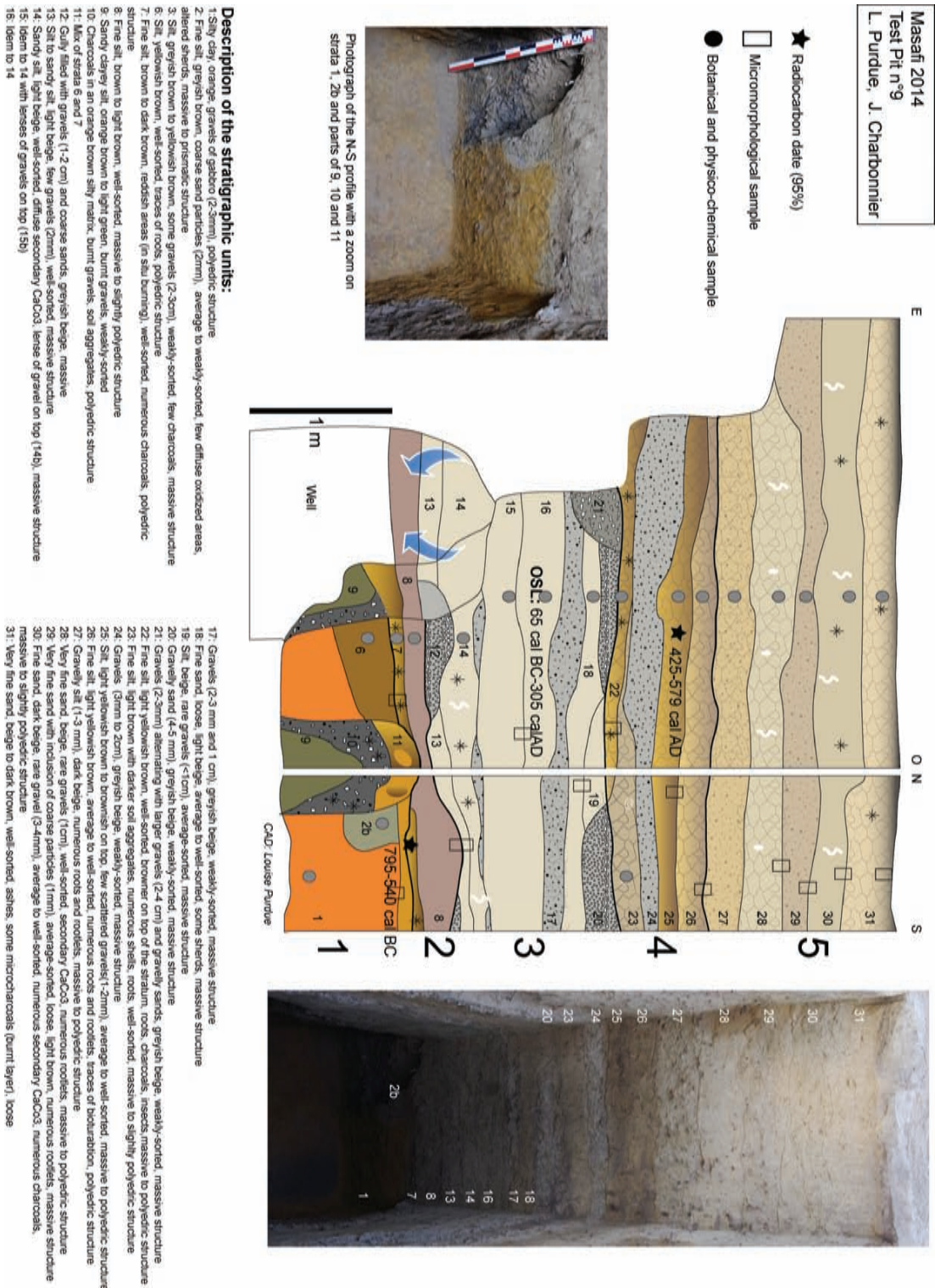


Figure 10: Stratigraphic description of Test Pit 9, terrace 2 (CAD Louise Purdue).

to have separated the space between the Iron Age building and the market from the gardens, located north of Masāfi 1. The latter are unfortunately not preserved as the area has been bulldozed in the last decade.

The primary canal contained nearly 15 cm of preserved coarse sediments. In order to link water management to environmental dynamics, we sampled these deposits to conduct a micromorphological study (see the section Approach and Methods) (Figure 8). Eight distinct episodes of deposition were identified (Figure 9). The first four are composed of coarse sediments with gravels of serpentinite (strata 1, 3, 4). Of interest is stratum 2 composed purely of cemented carbonates (water stagnation or cemented structure?). The upper deposits, strata 5 to 8, are composed of finer sediments rich in biotite, amphibole, exogenous carbonates and soil aggregates. Positive grading composed of four preserved laminae were identified in stratum 7. Uterior biological activity, favoured by reduced sedimentation, erased this syn-sedimentary signature.

The nature of the sediments suggests that runoff water was channelled north of Masāfi-1 during the Iron Age II. These results also highlight an initial intense water arrival with, possibly, the will to protect the primary canal from erosion (strata 1-4). This seems followed by an evolution in the origin of water supply (change in the mineralogical assemblage), and a more rhythmic sedimentation, maybe indicating seasonal water supply (Courty 1990) (Strata 5-7). This may testify of a change in the water catchment devices. This irrigation system is then abandoned. Changes in flow and sediment origin could result from a better management of runoff water supply or from a change in rainfall pattern (decrease of rainfall intensity). Why the system was abandonment still remains unknown however.

5.2.3. Agriculture and erosion since the Iron Age

As for today, fifteen test pits have been dug in the palm grove (Figure 6). The easternmost terraces, and mainly terrace 2, have preserved the deepest deposits. We will present here the

results obtained in Test Pit 9, the most well dated and studied test pit (Figure 6 and Figure 10). Test Pit 9 (1m x 3m) was opened directly in this second flat area and the substratum was reached at a depth of 4 meters. Thirty-one stratigraphic units were distinguished and are presented Figure 10. Within them, we encountered hydraulic structures, as well as ancient cultivated deposits, and small gullies. Numerous samples were taken for physico-chemical, micromorphological and botanical studies, which are still ongoing. Five different environmental and agricultural dynamics were identified and framed thanks to two radiocarbon dates, ⁵ and one OSL date, ⁶.

- **Phase 1:** The old groundwater level
The substratum is composed here of gravels and blocks of gabbro cemented in a carbonated green matrix indicating an ancient permanent water table.
- **Phase 2:** Iron Age agriculture and hydraulic technology (8th-6th century BC). The base of the test pit is composed of dark orange carbonated silts (Stratum S1: ancient limit of the groundwater level). A canal, 30 to 35 cm deep and filled with grayish silty clay (S2) was directly dug in this layer. The irrigation or drainage function of this structure is still debated but we put forward the hypothesis that the groundwater was close to the surface during this period. The canal is covered by fine dark brown silts (S7), rich in charcoal, probably corresponding to a past agricultural soil dated to 795-540 cal BC. A shallow circular well, 120 cm in diameter, in which Iron Age sherds were discovered, was dug on top of S7. The well is filled in burnt gravels and charcoals (S 9, 10, 11) and sealed by another cultivated stratum (S8).
- **Phase 3:** Temporary abandonment of the gardens (1st century BC- 3rd century AD)
This phase is composed of gravels and coarse sands (S 12, 14b, 15b, 17, 20, 21) alternating with light brown carbonated silts and fine sands (S 13, 14, 15, 16, 18, 19). While the bottom laminated coarse gravels indicate rhythmic flow in a gully (S 12), the coarser weakly-sorted upper ones suggest intense and uncontrolled flow (S 17, 20, 21), and discontinuous fine layers of gravels in

between suggest sheet flow deposition (S 14b, 15b). Iron Age sherds were identified in these deposits, but an OSL date obtained in stratum 16 suggests that this period occurred probably during the first three centuries AD. The finer deposits, very homogeneous and well-sorted do not present traces of past agriculture but could correspond to wind-blown deposits or sediments overflowing from abandoned canals.

- **Phase 4:** A return to agriculture (5th-6th century AD)

This period corresponds to a return to agricultural practices in the 5th-6th century AD as shown by the occurrence of probable ancient cultivated soils on nearly 50 cm (radiocarbon dated between 425-579 cal AD). S 22, 23, 25, 26 are composed of light brown fine silts rich in darker colored soil fragments in their upper part, originating from a past A horizon. Despite the reactivation of agricultural activities, traces of gullying and soil erosion are still visible with the occurrence of weakly-sorted gravels (S24).

- **Phase 5:** Historic and current soil use

The very distinctive deposits that compose phase 5 are comprised of 1.25m of beige bioturbated silts and sands, rich in small gravels (1-3mm) and secondary carbonates (S 27 to 31). While they do not seem to present as good agrological properties as the deposits of Phases 2 and 4, they are currently cultivated and disturbed by palm tree roots.

6. Conclusion

Our interdisciplinary methodology proved successful in mapping with many details the palm grove and identifying deeply buried past cultivation layers and hydraulic structures. In that way, it significantly differs from usual methods of landscape archaeology in Southeast Arabia, which most of the time consists in surveying and digging structures visible from the ground or located close to the surface. Combining archaeological excavation and soil studies has also provided complementary information

regarding the functioning and the evolution of the Iron Age canals in Masāfi-1.

The preliminary results of our project, and the detailed study of Test Pit 9, suggest that the oasis of Masāfi is structured in terraces that might have evolved through time and that the palm grove hasn't been continuously occupied over the last 4000 years. During the Iron Age II, gardens were partly irrigated by shallow wells thanks to a groundwater level close to the surface as well as canals diverting runoff water from the mountains to the east (canals north of Masāfi-1). The gardens seem then abandoned at the end of the Iron Age II (c. 7th-6th centuries BC) as shown both by the excavation of irrigation canals in Masāfi-1 and dating of cultivation layers in Test Pit 9. This is consistent with the archaeological data that shows an abandonment of the surrounding settlements (sites 1, 2 and 3) at the end of the Iron Age II. It also echoes the contemporary abandonment of several irrigation systems and associated settlements in other areas of Southeast Arabia (see Córdoba 2013: 148).

The reasons for this abandonment is however still unclear (environmental crisis and lowering of the water table?). Yet, the on-going environmental and archaeological analyses on samples and future test pits will enable us to clarify this question and to identify the relative influences of socio-economic, agricultural and environmental factors.

While in the available historical and archaeological documentation, the reoccupation of the valley does not seem to predate the Late Islamic period, Test Pit 9 points to an agricultural activity around the end of the pre-Islamic period or the beginning of the Islamic period. Contemporary dwellings are still to be found, unless they have already been destroyed due to the rapid urbanisation of the area.

Our combined archaeological, geoarchaeological and spatial approach is particularly relevant in studying ancient irrigation systems and gardens. In the coming years, we will continue to dig test pits in or around the palm grove in order to delineate the cultivated area and identify agricultural levels and hydraulic structures from the Bronze Age to current periods.

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Footnotes

(1) Within the framework of the French Archaeological Mission in the U.A.E. directed by Dr. Sophie Méry (CNRS, Rennes).

(2) In the field, blocs of 12x6x6 cm are usually carved in the deposits and wrapped in plaster bands to protect them. They are processed according to P.Guilloré's (1983-1987) method: samples are vacuum-impregnated with synthetic resin, cut with a water saw into 0.5 cm blocks, placed upon a temporary thin plate, flattened again, placed upon another thin plate, and finally polished to 30 to 40 μm). Observed using an optical polarized microscope, they are described using the terminology of Bullock et al. 1985.

(3) Mission 1019-1, 4 May 1965 (Courtesy of United States Geological Survey).

(4) Stratum 45, Microcharcoal, Poz-53975, 2680 \pm 30 BP, 2 σ calibrated date (95%): 897-801 cal BC (Reimer, 2013).

(5) Stratum 7, Microcharcoal, Poz-64517, 2520 \pm 35 BP, 2 σ calibrated date (95%) : 795-540 cal BC (Reimer, 2013) ; Stratum 25, Microcharcoal, Poz-64518, 1545 \pm 30 BP, 2 σ calibrated date (95%) : 425-579 cal AD (Reimer, 2013).

(6) Stratum 16, OSL, X 6677, Paleodose (G): 2.60 \pm 0.17, Dose rate (Gy/Ka): 1.22 \pm 0.07, OSL age estimate (years before 2015) : 2135 \pm 185 (ie: 65 cal BC-305 cal AD).

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