The Genesis of Oases in Southeast Arabia: Rethinking Current Theories and Models

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Abstract In South East Arabia (Sultanate of Oman and United Arab Emirates), oases are irrigated gardens characterised by intensive and mixed farming: date palms form a canopy under which other crops are protected from the sun's rays and the heat. The origin of this agrosystem and its impact on the historical trajectory of Arabian populations are still much debated issues. Some scholars have suggested that oases developed as soon as agriculture was introduced into the region, at the beginning of the Early Bronze Age (3200–2000 BC). The intensification of trade with neighbouring civilisations of Mesopotamia, Iran and Indus seems to have ignited the spark for the adoption of agriculture in Southeast Arabia. According to the existing theories, oases then emerged rapidly and were a means of adapting agriculture to the arid environment of this region. This agrosystem remained unchanged in its fundamental principles until the present day. This theory, however, denies the diachronic dimension of Southeast Arabian landscapes. The present chapter therefore aims to re-evaluate the data and reassess current theories of an Early Bronze Age origin for oases. An alternative development model, based on the available data, will be proposed. It is suggested that the development of oases corresponds to a long process with several steps resulting from environmental changes, technological innovation and socio-economic factors.

Keywords Oasis · Arabia · Protohistory · Archaeobotany · Palaeoclimatology · Hydraulic

> 'Is this Arabia,' we said, 'is this the country we have looked on heretofore as a desert?' Verdant fields of grain and sugarcane, stretching along miles, are before us; streams of water, flowing in all directions, intersect our path; and the happy and contented appearance of the peasants agreeably helps to fill up the smiling picture. The atmosphere was delightfully clear and pure. (James Wellsted's travel account cited in Hogarth 1904: 138–139).

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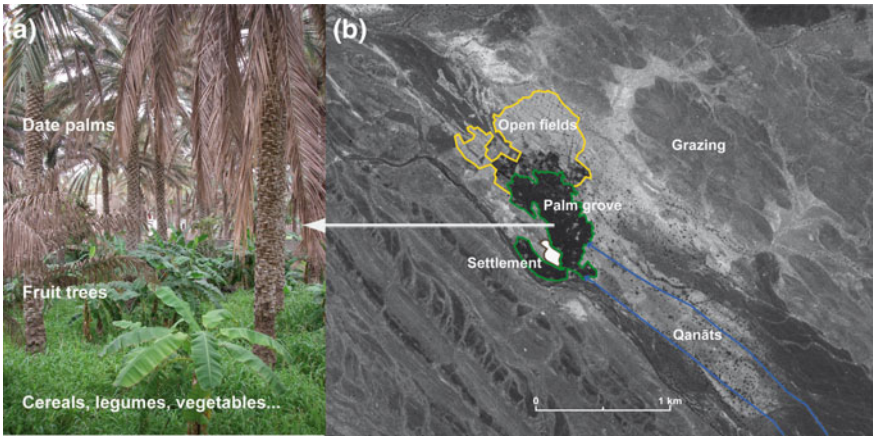

Fig. 1 Spatial organisation of an oasis (**b**) and vertical distribution of crops in the palm grove (**a**)

In Arabia and North Africa, the oases correspond to irrigated gardens characterised by intensive and mixed farming. The date palm is the keystone species of this agrosystem, also called "*bustān*" in the scientific literature. Palm trees form a canopy under which other crops are protected from the sun's rays and the heat in these arid regions (Fig. 1a). The temperature is always lower in the palm grove than in the surrounding areas. Evaporation from canals and the surface of flooded plots is also greatly reduced (Laureano 1998). Under the date palms, crops are distributed vertically; two to three layers can be distinguished: from top to bottom: date palms, fruit trees (lemon trees, fig trees, etc.), cereals and then vegetables and legumes (Tengberg 2012: 139–140). When a plot is irrigated, water feeds the palm trees, the other fruit trees and also annual plants. All the crops therefore benefit from permanent moisture in the soils. Wild plants and animals are also attracted by the oasis and contribute to the formation of soils. Fields are rarely left fallow and can provide one harvest of dates and other fruits and several harvests of cereals and vegetables annually. Apart from the palm grove, the other components of an oasis are the irrigation system, the open fields and the settlements (Fig. 1b). Cereals and forage crops can be grown in open fields, located downstream or around the palm grove. Hydraulic structures extract water from the ground or divert surface run-offs in order to feed the oasis and keep it green all year long. The last element, a key component of an oasis, is intangible: it consists of the rules and the organisation adopted by a community of people to share water and maintain the irrigation system.

Established in the piedmont area, on coastal plains, or terraced on mountain slopes, oases are landmarks of Southeast Arabia (i.e. the Sultanate of Oman and the United Arab Emirates). Located between the Persian Gulf and the Gulf of Oman, this area is characterised by an arid climate. However, moderate rainfall occurs during winter on the Hajar Mountains, which separate the coastal plain from the inland desert (Sanlaville 2000: 49). Large floods, which form after rainfall events, dry out on the piedmonts surrounding the mountains and recharge the underflows.

The region also benefits from fossil aquifers. Water resources are traditionally exploited with the help of hydraulic devices locally called *aflāj* (sing. *falaj*). This term actually refers to several types of structures. On the piedmont of the Hajar Mountains, most *aflāj* correspond to *qanāts*, tunnels draining groundwater to the surface, while in the mountain valleys, *aflāj 'ayni* usually tap springs. The term *falaj ghayli* is used for systems diverting floodwaters.

The study of water management techniques and oases is crucial to understand the historical trajectory of local societies in the second half of the Holocene as irrigation was essential to sustain agriculture. The development of new agrosystems and new hydraulic techniques may have had a deep impact on the settlement pattern, population growth and trends towards specialisation or the increase in hierarchy. Some scholars have suggested that they developed as soon as agriculture was introduced into the region, at the beginning of the Early Bronze Age (3rd millennium BC).

The present chapter is devoted to the question of the development of this agrosystem in Southeast Arabia and aims to re-evaluate the data and reassess current theories of an Early Bronze Age origin for oases. An alternative development model, based on the available data, will be proposed. The main objective of this paper is thus to show that there is still an open debate on this question. Finally, it will be argued that further progress on this issue will depend on multidisciplinary approaches and the excavation of palm groves.

1 The "3rd Millennium BC Oases" Theory

During the Umm an-Nar period, Southeast Arabian societies underwent significant changes. Sites were integrated into a regional exchange network with the export of raw materials—mainly copper—to Mesopotamia and the Indus valley (Cleuziou 1999: 99). Ceramic technology and monumental stone and mud brick architecture appear for the first time in this region (Cleuziou and Tosi 2007: 128). Collective burials, built above ground, could reach several metres in diameter and were sometimes made of standing stones. Massive circular or subcircular "towers", sometimes surrounded by ditches, were built on the main sites. Their function is still debated, but they required a considerable investment. At that time, society was characterised by social stratification with a concentration of wealth in the hands of the few although it seems that many decisions might have been taken collectively. In addition, this period witnessed demographic growth, hence the need for agriculture to sustain the population (Cleuziou 2005: 144).

The most widely accepted theory concerning the emergence of oases in Southeast Arabia was developed by Serge Cleuziou, who was responsible for the study of the Early Bronze Age (3200–2000 BC) site of Hīlī 8, in the oasis of al-'Ayn, UAE (Fig. 2). During the excavation of Hīlī, numerous remains of wheat, barley and date stones have been found bearing testimony to the practice of agriculture since the first half of the 3rd millennium BC (Costantini 1979; Cleuziou and

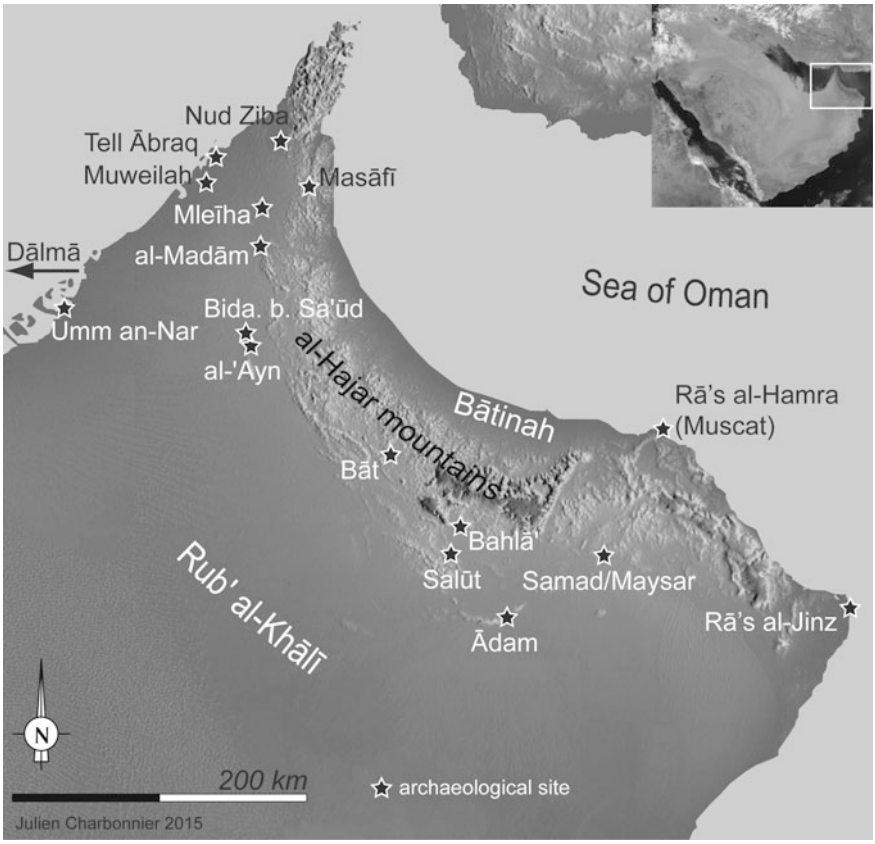

Fig. 2 Map of Southeast Arabia with sites mentioned in the text

Costantini 1980). Later, Cleuziou made the assumption, based on the archaeobotanical discoveries in Hīlī and other contemporary sites, that the oasis agrosystem already existed during that period: the cereals would have been cultivated under a date palm canopy (Cleuziou 1982: 19–20, 1997: 391–392, 2009: 730). Based on the identification of the charred remains and imprints of sorghum from Hīlī 8, Cleuziou also suggested that annual crops were cultivated throughout the year (i.e. wheat and barley as winter cereals harvested in spring and sorghum as a summer crop harvested in autumn) as in present-day oases (Cleuziou 1997: 401). This idea was taken up by other researchers such as Potts (1999: 36), Méry (2013) and Magee (2014: 2390). Margareta Tengberg, an archaeobotanist, also suggested that the oasis agrosystem was already underway in the 3rd millennium BC owing to the simultaneous presence of cereal, vegetable, legume and date stone remains on Bronze and Iron Age sites (Tengberg 2003; 2012).

Cleuziou later suggested that the first stage in oasis development was the establishment of "small palm tree gardens" during the first half of the 3rd

millennium BC, based on Jessica Giraud's results of a survey in the Ja'alan region, east of Oman (Cleuziou 2009: 734; Giraud 2007: 191). Concerning the Hafit period (3200–2700 BC), Giraud noticed that the cairn graves, which are highly visible in the landscape because of their prominent positions, were often located close to areas near present-day palm gardens. She suggested that Hafit graves were established in the past near small oasis settlements (Giraud 2009: 747–748).

Contacts with Mesopotamia, Iran and Indus would have ignited the spark for the adoption of agriculture as the cereals cultivated might have been introduced from these regions (Tengberg 2003: 235). Cleuziou thinks that the oasis is an indigenous and original response to these stimuli, i.e. that this agrosystem was invented locally in order to adapt agriculture to the arid environment of Eastern Arabia.

In Cleuziou's view, this agrosystem then remained unchanged until the present day. Therefore, the agricultural landscape has never really changed: "By analogy with the present-day oases of the Oman Peninsula, we may imagine that some plants were grown in the shades of these palm trees" (Cleuziou 1982: 19). Walid al-Tikriti shares the same vision when he assumes that "the landscape of the oases cannot have been very different from what it was before the recent oil-boom era" (al-Tikriti 2002: 137). For al-Tikriti, however, the oases developed in the first millennium BC, in parallel with the development of *qanāt* technology (al-Tikriti 2010: 240–243). Cleuziou, in contrast, considers that *qanāts* could have been already used in the 3rd millennium BC and were sustaining the oases from the beginning (Cleuziou 2009: 731).

Clearly, Cleuziou does not claim that oases have no historical trajectory. On the contrary, he is aware that the evolution of climate and water resources could have led to the abandonment or the spatial evolution of some oases. For instance, the lowering of the water table has led to the lowering of the *qanāts* and gardens in order to maintain gravity-fed irrigation, as observed during the twentieth century AD (Bisson 1989: 183; Costa 1983: 248–249; Weisgerber 2005: 75–78). However, he implies that the agrosystem remained the same because it was adapted to the arid climate of Arabia from the beginning.

Nevertheless, the theory of Cleuziou can be discussed and criticised in the light of climatic, archaeobotanical, sedimentary and archaeological data. Were the landscapes of the Bronze and Iron ages really similar to the present-day one? When and how did palm groves develop?

2 Climate Change During the Second Half of the Holocene in Arabia

The Holocene moist phase, lasting until the 5th millennium BC, was characterised by wetter climatic conditions (Fleitmann and Matter 2009: 640) resulting in the development of lakes and a savannah-like landscape in Arabia (Parker et al. 2004, 2006). There were more wild animals, and grazing was facilitated. During the

so-called Neolithic period in Arabia, populations were therefore mainly hunter-pastoralist. Along the coasts, groups specialised in fishing, gathering shells and exploiting mangroves (Biagi and Nisbet 2006; Cleuziou 2005: 134). With the retreat of the monsoon towards the south, summer rains ceased to reach Southeast Arabia from the 5th millennium BC (Fleitmann and Matter 2009: 640); peaks of aridity then occurred at the beginning and end of the following millennium. The 4th millennium BC corresponded to a slightly moister period that was interrupted by an arid event around 3200–3000 BC. The climate became slightly wetter again, but remained arid during the 2nd millennium BC (Parker et al. 2006: 472–473). Aridity increased around 1000 BC: during the Iron Age, the climate was as arid as it is today (Fleitmann et al. 2007: 180).

Relatively little is known about the evolution of groundwater in Southeast Arabia during the Bronze and Iron ages. During the Umm an-Nar and Wadi Suq periods, it is clear that the water table retreated in al-'Ayn from two wells that were excavated at Hīlī 8. The first one, dating from the first half of the 3rd millennium BC, was about 4 m deep, while the second one, used from *c.* 2700 to *c.* 1800 BC, reached 8.50 m in depth (Cleuziou 1989: 64–68). This suggests that the groundwater was quite close to the surface at the beginning of the Umm an-Nar period and that it dropped around 4.5 m over 1000 years. Similar processes seem to have taken place during the 1st millennium BC, as some *qanāts* were abandoned during or at the end of the Iron Age. The *qanāt* AM-2 excavated in al-Madām was probably abandoned after the local population desperately tried to lower the tunnel and the channels (Córdoba 2013: 148; Córdoba and Del Cerro 2005: 525).

3 Crops Cultivated During the Bronze and Iron Ages in Southeast Arabia

According to the recent studies, wild date palms (*Phoenix dactylifera*) were growing along the Persian Gulf and could have been domesticated locally (Gros-Balthazard et al. 2013: 17–19 and 24). The oldest remains of date stones found in this region come from the island of Dālmā (Abu Dhabi emirate, UAE) and have been radiocarbon-dated to the end of the 6th/beginning of the 5th millennium BC. They were recovered during the excavation of the Neolithic site Dālmā 11. The archaeobotanists who studied these two charred stones were unable to tell whether they corresponded to wild or cultivated dates (Tengberg 2012: 142). They suggested they could have been gathered in the region or imported from Mesopotamia (Beech and Shepherd 2001: 87–88). If reference is made to the above-mentioned study, it seems to me likely that these dates grew locally, maybe not on Dālmā Island but somewhere in Southeast Arabia. As regards the Neolithic period, data concerning the exploitation of date palms are therefore limited.

When it comes to the 3rd millennium BC, there are far more charred remains and evidence for the cultivation of date palms. At Hīlī 8, plant remains have been found in the oldest layers, dated by Cleuziou to the Hafit period, and hundreds of charred

date stones in the Umm an-Nar levels (Cleuziou and Costantini 1980). Numerous charred stones have also been recovered in 3rd millennium layers in Rā's al-Jinz 2 (RJ-2, Oman) and Tell Ābraq (UAE, Costantini and Audisio 2001; Willcox and Tengberg 1995). There is also evidence of dates on the sites of Bāt (Oman, charred remains and impressions on mud bricks), Maysar 1 (Oman, charred remains) and Umm an-Nar (UAE, impressions on mud bricks) (Tengberg 1998: 188f; Weisgerber 1981: 191–197; Willcox 1995: 257–259). Margareta Tengberg notes that stem tissue remains of date palm have also been identified in Hīlī, which seems to indicate that this species was cultivated locally (Tengberg 2003: 232). On the whole, it is very likely that given the great quantity of date stones discovered and their presence in many excavated Umm an-Nar settlements, even coastal ones such as Tell Ābraq and RJ-2, date palms were already cultivated at that time in Southeast Arabia, especially since this species seems to have been endemic to the Gulf. Date palms probably grew next to inland sites, such as Bāt and Hīlī, and may have been brought to coastal sites in exchange for some goods (Cleuziou 1999: 98–99).

In comparison, there is little information about the Wadi Suq period (Middle Bronze Age, 2000–1600 BC). Date stones were discovered in Nud Ziba (UAE, Kennet and Velde 1995: 85). This fruit was also part of the diet, along with cereals, in Tell Ābraq (Tengberg 2003: 233). More recently, jujube and date stones were collected during the excavation of a Late 2nd millennium site (1400–1200 BC) at Masāfī, in the UAE (Degli Esposti and Benoist 2015: 65).

The range of crops attested during the Umm an-Nar period is quite limited. Bread wheat (*Triticum* cf. *aestivum*) was present in Bāt, Umm an-Nar, Tell Ābraq and Hīlī 8. In the latter site, there were also charred remains of emmer (*Triticum dicoccum*), oat (*Avena* sp.), two-rowed barley (*Hordeum vulgare* subsp. *distichum*), six-rowed barley (*Hordeum vulgar*e subsp. *hexastichum*) and peas (*Pisum sativum*) (Tengberg 2003: 232). Impressions of six-rowed barley were found in Bāt and Umm an-Nar. Charred remains and impressions from seeds of sorghum (*Sorghum bicolor*) were initially reported in Hīlī 8 by Costantini (Cleuziou and Costantini 1980), but this identification was seriously questioned later (Rowley-Conwy et al. 1999, Tengberg 2012: 145).

There is little information concerning the consumption of fruits. Charred seeds of melon (*Cucumis melo*) were found in Hīlī 8, while many charred remains of jujube (*Ziziphus spina-christi*) were discovered during the excavations of Hīlī 8, RJ-2 and Bāt (for an overview, see Costantini and Audisio 2001: Table 6). Jujube tends to be collected from the wild, so the trees were not necessarily cultivated. It was already being consumed during the 5th and 4th millennia BC, as demonstrated by finds in the Neolithic sites of Rā's al-Hamra 5 and 6 (Oman, Biagi and Nisbet 1992).

The agrosystem of the Bronze Age was therefore limited compared to that of the present day. Only winter cereals and pulses, originating from the Near East, seem to have been cultivated during the Umm an-Nar period (Tengberg 2003: 232). Not many fruit trees were exploited at that time: only date palms were cultivated with any certainty.

In the Iron Age, dates were an important part of the diet. Thousand five hundred charred stones were recovered at Muweilah (UAE), along with more than 1300

carbonised dates (Tengberg 1998). Analyses carried out on teeth from pre-Islamic graves in al-Maysar (Oman) showed that caries were rare in the Early Bronze Age and became more common during the Iron Age, which suggest that the proportion of dates in the diet increased during the 1st millennium BC (Kunter 1981; Potts 1990: 127–132). Impressions of free-threshing wheat (*Triticum aestivum/durum*) and barley (*Hordeum vulgare*) were identified in Rumeilah (al-'Ayn, UAE) and Tell Ābraq (Costantini and Costantini-Biasini 1986: 357–358; Willcox and Tengberg 1995: 133). A recent palynological study led in Salūt (Oman) has identified the presence of sesame (*Sesamum* sp.) in the Iron Age layers. The pollen amount in some levels could indicate the use of this plant for oil or flour production (Bellini et al. 2011: 2785).

During the Late pre-Islamic period (PIR, third century BC–third century AD), excavations at Mleīha (UAE) reveal that dates, winter cereals (barley, *Hordeum vulgare*, and wheat, *Triticum durum* or *aestivum*) and pulses (lentils, *Lens culinaris*, broad beans, *Vicia faba*, and grass peas, *Lathyrus sativus*) were the basis of the diet before the advent of Islam (Pena-Chocarro and Barron Lopez 1999: 64–68; Mouton et al. 2012: 214). Caries seem to have been common at that time, probably due to the high consumption of dates (Nelson et al. 1999). Fleshy parts of grapes (*Vitis vinifera*) and pomegranates (*Punica granatum*) were recently found in a building dated between the second and the mid-third century AD at Mleīha (Mouton et al. 2012: 214). They could have been cultivated locally, but this has still to be confirmed.

4 Soil Studies of Oases

There is a clear lack of pedosedimentary data concerning oases in Southeast Arabia. Soil studies of palm groves are almost non-existent. A recent micromorphological analysis of a naturally exposed crosscut in *wādī* al-Sharsā, near Bāt, suggests that floodwaters were used from the 4th millennium BC in this area. Before that date, the *wādī* was an active floodplain, which then became less active. A subsequent gradual silting of the plain, interspaced with episodes of rapid flooding, testifies to anthropic flood diversion, i.e. fields were irrigated with *wādī* flows. Irrigation seems to have started in the second half of the 4th millennium BC and then became more intensive with evidence of tillage in the 3rd millennium BC (Desruelles et al. 2016).

5 The Pre-Islamic Hydraulic Techniques in Arabia

All oases depend on irrigation systems that collect run-offs or floods or tap groundwater. As already mentioned, a recent study in Bāt seems to indicate that floods were already diverted towards the fields during the 4th millennium BC in

wādī al-Sharsā. Although dikes and dams are used today, only one can be dated to the Bronze Age with certainty. It is a 300-m-long low wall that closes a small valley in the region of Bahlā' (Oman). It could have been used to retain water and sediments for agriculture or grazing. Several ingots and anthropomorphic figures made of bronze have been recovered from its masonry. The plano-convex ingots are generally dated to between the 3rd and 2nd millennia BC. The figures are similar to some others found in occupation layers from the same period at Rā's al-Jinz (Weisgerber and Yule 2003: 48–51).

Two possible dams were also reported by a German mission in wādī Samad (Oman), where many Bronze and Iron Age sites have been identified, some of which have been excavated. These two small levees of stone blocks are located next to a *wādī* channel and near an Umm an-Nar settlement, which is why they have been interpreted as Bronze Age diversion dams. It has been suggested that they were used to trap water and sediments (Hastings et al. 1975: 11). These structures are therefore poorly dated. The same remark applies to a series of walls near Bāt, located at the bottom of a slope and perpendicular to a *wādī* bed. Unfortunately, no OSL or radiocarbon analysis has been carried out in the surrounding layers. An Umm an-Nar sherd, recovered at the bottom of one of the walls and partly slid up under it (Brunswig 1989: 22–25), only provides a *terminus post quem*. The function of these structures is unknown, but it seems they are unlikely to correspond to diversion dams as Brunswig and Frifelt suggested (Frifelt 1985: 99). Indeed, unlike most diversion dams, they are not slanted compared to the *wādī* bed and they are too close to each other.

In the recent past, groundwater was extracted through wells and *qanāts* (Fig. 3). The oldest recorded wells in Southeast Arabia date back to the 3rd millennium BC. As already mentioned, two of them have been excavated at Hīlī 8. They were located inside Umm an-Nar buildings and are accurately dated, but they were probably not used for irrigation (Cleuziou 1989: 64–68). Wells have been discovered in many Early Bronze Age settlements such as Bāt (Frifelt 2002: 104), Salūt (Degli Esposti 2011) and *wādī* Samad (Weisgerber 1981: 203). During the Iron Age, they were used to provide water to cattle and humans (al-Madām-1, UAE, Córdoba and Del Cerro 2005: 519–520), for manufacturing mud bricks (al-Madām workshop, Córdoba 2013) and for irrigation. Two wells associated with channels

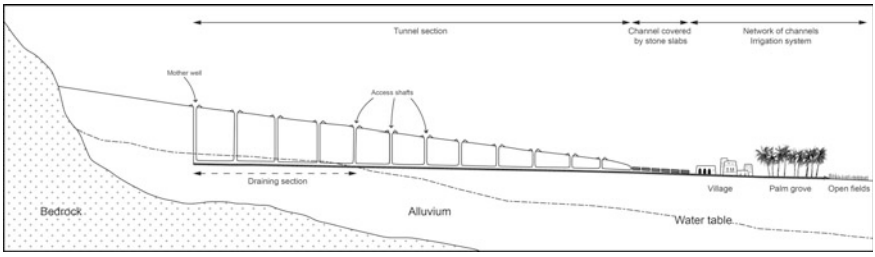

Fig. 3 Section of a *qanāt*

were found during a rescue excavation in Qattārah (al-'Ayn, UAE), while another was associated with tree pits. These structures come from a stratified context and could be dated with certainty to the Iron Age II (Power and Sheehan 2011: 272–273). One well was excavated in Mleīha in area B, which could be dated to the Late pre-Islamic period (Dalongeville 1999: 43). Michel Mouton thinks that wells were used in this plain to irrigate garden crops and date palms (Mouton 1999: 272).

The development or introduction of *qanāt* technology in Southeast Arabia is still debated. Some scholars have suggested that *qanāts* were already in use during the Early Bronze Age. A partly excavated *qanāt* in the region of Bahlā' has been dated to the 3rd millennium BC (Orchard and Orchard 2007: 150–151), but the arguments of the excavators have proved insufficient (see Charbonnier 2015). Cleuziou has also argued for the use of *qanāts* at Hīlī 8 where some ditches and channels were lowered several times. He suggested this was related to the lowering of the *qanāt* tunnel in response to the retreat of the water table during the 3rd millennium BC (Cleuziou 1998: 61–62, 1999: 90, 2009: 731). However, no remains of Bronze Age *qanāts* have been found so that Cleuziou's idea remains an assumption.

It is now agreed among scholars working in Southeast Arabia that *qanāts* were used from the beginning of the Iron Age II. Ancient *qanāts* have been excavated at Hīlī, Bida Bint' Sa'ūd and al-Mādam (al-Tikriti 2002 and 2010; Cordoba and Del Cerro 2005; Cordoba 2013). Others have been reported after surveys (al-Tikriti 2002; Schreiber 2007: 136; Weisgerber 1981). I have argued elsewhere that only the al-Mādam *qanāt* (AM-2) was well dated to the Iron Age, thanks to the excavation of the tunnel and the associated surface channels and fields. A radiocarbon date around the beginning of Iron Age II was also obtained on a gastropod shell that appears to have lived in the channels (Córdoba 2013: 147–148). There are still some doubts concerning Hīlī and Bida Bint' Sa'ūd, because their dating relies mainly on their proximity to Iron Age settlements and the discovery of pottery sherds during their excavation, whereas there are very few elements that confirm the age of the surveyed structures (Charbonnier 2015).

Data concerning pre-Islamic hydraulic structures are still fragmentary, as there is no information regarding the 2nd millennium BC. Floods and run-offs could have been used from the end of the 4th or the 3rd millennium BC. Wells were dug during the Umm an-Nar period and throughout the Iron Age. *Qanāts* were probably not introduced before the 1st millennium BC.

6 Water Management in Southeast Arabia

In arid regions, water from irrigation systems is very often shared among a community. There are no data about the pre-Islamic hydraulic communities, as the Bronze and Iron ages are prehistoric in nature, so we have to look at water management during modern times to try to understand the impact of hydraulic structures on societies and landscapes.

From a management perspective, there are broadly two categories of hydraulic structures: those that can be built at an individual or familial level and those that have to be built by a community or political entity. Although wells can be beneficial to a community, they fall into the first category (Wilkinson 1977: 97). A family can dig them, especially if the water table is located a few metres below the surface as was the case during the Early Bronze Age in some areas (cf. Hīlī 8). Garden plots tend to be clustered around each well and are fed by a radial network of channels extending outwards, as was the case in the Bāṭinah region (Costa and Wilkinson 1987: 43–53). Plots and dwellings are not necessarily grouped but can be scattered (Wilkinson 1977: 97).

Digging a *qanāt* or diverting floods requires much more labour investment (Beaumont 1989: 27; Costa and Wilkinson 1987: 37). In Southeast Arabia, *qanāts* belong to communities of people. The digging and maintenance (cleaning underground galleries and channels) are funded by all shareholders. One person—*wakīl*—is generally responsible for supervising these tasks, coordinating the work and collecting the money. This person is generally a prominent member of the oasis population, as he also settles the quarrels concerning the access to water. The water distribution can be managed by the shareholders or by a supervisor (*'arīf*). In Oman, UAE, Saudi Arabia and eastern Yemen, water shares from *qanāts* generally correspond to a period of time that is distributed along a water cycle. Indeed, the flow cannot be interrupted and must be shared day and night. In Oman, during the daytime, sundials were traditionally used to measure water shares, while stargazing was used at night (Al-Ghafri et al. 2004; Charbonnier 2014; Dutton 1989; Nash 2011).

The use of *qanāts* entails grouping the gardens as water must reach all of them and moves constantly from one field to another inside the palm grove (Charbonnier 2014: 92). To reduce the travelling time for water, fields must be as close as possible to each other. Thus, it seems important to group the fields as shareholders must be able to check whether the shares are being respected. In Ādam, people would come regularly to the sundial to see whether everything was all right concerning the water distribution. Numerous quarrels still arise showing the importance of discussion and transparency in the day-to-day management of community irrigation systems.

7 Discussion: Challenging Previous Views Concerning the Emergence of Oases

During the discussion, I will try to demonstrate three things: (1) agriculture emerged during the Bronze Age in Southeast Arabia, (2) Cleuziou's oasis theory is not firmly established and (3) the available data can be used to propose another model for the development of the oasis agrosystem in this region.

7.1 Bronze Age Agriculture in Southeast Arabia

Domesticated crops (wheat, barley, etc.) imported from the Near East have been present since the 3rd millennium BC in Southeast Arabia. At that time, local societies had closer contacts with Mesopotamia, Iran and the Indus valley, which explains their presence. As we have seen, archaeological evidence suggests that at least part of the population had adopted a sedentary lifestyle and society had become more stratified since at least the Umm an-Nar period. Archaeobotanical evidence suggests that annual crops and date palms were cultivated in Southeast Arabia at that time, i.e. cereals and dates were not imported from abroad. Indeed, cereal husks were also present on the sites as they were used as temper for mud bricks, which suggests that grains were threshed locally (Willcox and Tengberg 1995).

Al-Tikriti has suggested that *Phoenix* was not cultivated before the Iron Age in the region; dates would have been imported from abroad (al-Tikriti 2010: 243, footnote 23). In my view, this is unlikely, as large quantities of date stones have sometimes been found. Besides, archaeobotanists have demonstrated that the presence of stem tissue points to the local cultivation of date palms (Tengberg 2003: 232). This idea would also be strengthened by an indigenous origin of the date palm (Gros-Balthazard et al. 2013).

7.2 The 3rd Millennium BC Oases: A Questionable Hypothesis

Although agriculture seems to have been established during the 3rd millennium BC, the same does not apply to the "multi-storied" oasis agrosystem. Only archaeobotanical evidence has been used to demonstrate its existence, which, in my view, is not sufficient. As already noted by al-Tikriti, the discovery of cereals and date stones in an archaeological context does not prove that the former were cultivated below the latter (al-Tikriti 2010: 243, note 23). It only demonstrates that these crops were cultivated at the same time. Date palms and annual crops could also have been cultivated in separate fields, adjoining or spatially separated.

I will go even further by saying that nothing in the archaeobotanical data shows that the vertical distribution of plants typical of the oases existed at that time. On the contrary, the range of crops cultivated in the 3rd millennium BC and up to the Late pre-Islamic period was limited: it only included cereals, some legumes and date palms. Cultivated fruit trees are absent from the documentation until the Late pre-Islamic period, with the exception of jujube trees that do not require the protection of date palms to grow. This proves that, at best, the hypothetical pre-Islamic oases were composed of only two layers and not three or four as in the present day.

Besides, the annual plants attested during the Bronze and Iron ages are all winter (wheat, barley, oats and peas) or spring (oats) crops, which means that they could

not be cultivated all year long as in present-day oases. Unless our data are incomplete, this means that the agrosystem of the Bronze and Iron ages was not as intensive as it is today. Furthermore, winter cereals do not have to be cultivated under date palms as they are grown during the coldest season, and in fact, they are generally cultivated in the open fields surrounding the palm groves. This allows me to hypothesise that date palms and annual crops were spatially separated until at least the Iron Age.

7.3 A Dynamic Landscape and the Gradual Formation of the Oases: An Alternative Model

Based on the available data, I propose an alternative, albeit hypothetical, model for the development of the oases in Southeast Arabia. I suggest that oases formed gradually following many changes in the landscape and the social structure. These changes were also enabled by the development or introduction of new hydraulic techniques.

(1) At the end of the Neolithic, populations were already taking advantage of wild plants (Tengberg 2003: 232). The date stones found at Dālmā are likely to correspond to the exploitation of wild date palms, as it is now highly probable that these were growing along the shores of the Persian Gulf.

(2) From the second half of the 4th to the beginning of the 3rd millennium BC, data from Bāt suggest that floodwater was already diverted at the foot of the Hajar Mountains. This still has to be confirmed, but as Fouache et al. (2012) have noted, it would show that the development of agriculture in this region predated the development of contacts with Mesopotamia and Iran in the 3rd millennium BC. However, the crops cultivated at that time have not yet been recognised. The floods could have been used only to cultivate winter crops, as there was already a winter rainfall regime. An interesting outcome of floodwater irrigation would have been the development of arable land. In arid regions, soils are sometimes as rare as water and *qanāts*, unlike surface water irrigation systems, do not provide much sediment to the fields. The areas where sediments brought by the flood irrigation accumulated could have been reused to install oases fed by *qanāts* in some places.

Agricultural practices are therefore not confirmed during the Hafit period, but if data from Bāt are correct, they are likely to have occurred in some valleys of Southeast Arabia. It has been suggested that Hafit graves, located in prominent positions, marked the territory of nomadic pastoral populations when they were absent (Deadman 2012: 33). It is likely that many groups in the 3rd and even in the 4th millennium BC maintained this lifestyle, but this does not exclude the possibility of the existence of agricultural communities in some areas, for example the water-rich mountains, or of semi-nomadic groups practicing irrigation or rainfed agriculture in addition to pastoral activities. In parallel, it is

known that coastal populations had a halieutic economy. Date palm domestication has yet to be understood, but these trees could have been exploited since that time. Battesti (2005) mentions the existence of semi-nomadic groups in Sahara who own palm gardens but do not irrigate them. The trees take advantage of groundwater relatively close to the surface. Date palm roots seem to be able to reach water up to 17 m below ground (Peyron 2000: 12). In fact, feral palms can grow on *wādī* banks or near springs. Only a few members of the group stay next to the gardens all year long. They only carry out pollination, harvest and vegetative propagation (by planting suckers). Such practices are attested in Chad and Sudan (Battesti 2005: 24). These non-irrigated palms are less productive but require less labour investment. Semi-nomadic groups, at the end of the Neolithic and at the beginning of the Bronze Age, might well have exploited such palm gardens.

(3) During the Umm an-Nar period, agriculture seems established but not the multi-storied oasis agrosystem. No Bronze Age irrigation system in relation to date palm plantations has yet been found in Southeast Arabia. I suggest that in some areas, such as Hīlī, date palms could have grown without a water supply due to the proximity of the water table. Their roots could have easily reached the shallow groundwater, especially along *wādī* banks. Wells are attested and could also have been used to water the palms, as well as other crops, in other areas. Cereals and legumes had to be irrigated at that time because of the scarcity of rainfall. They would have been cultivated outside the palm grove, in open fields, during the winter season.

As already noted, individuals or families can own wells as the labour investment to dig them is generally limited. Consequently, water drawn from them does not have to be shared among the community and gardens do not have to be clustered: they are distributed in space along the aquifer (Costa and Wilkinson 1987: 43–53). The Bronze Age of Eastern Arabia was perhaps characterised by such agricultural plots spread across the landscape.

Unfortunately, there are no data from the arid event at the end of the 3rd millennium BC to the end of the 2nd millennium BC, and it is not known whether agricultural practices evolved during this period.

(4) The Iron Age saw an increase in arid conditions and, possibly, the development of a hydraulic technique enabling the exploitation of groundwater: the *qanāt*. Although the dating of several *qanāts* from the Iron Age is still debated (Charbonnier 2015), this technology seems attested in some places. In parallel, it is very likely that wells were still used during the 1st millennium BC. Alternatively, other scholars have suggested that *qanāts* were introduced only during the Islamic period (Power and Sheehan 2012: 303). In any case, the main point I wish to emphasise is that the introduction or development of *qanāt* technology must have had a profound impact on both the social organisation and the agrosystem:

- It led to the formation of cohesive groups bound by the management of a common resource. The water of a *qanāt* must be shared permanently, day

and night, and year-long. It also needs constant maintenance, which means that more members of the group had to adopt a sedentary lifestyle.
– Fields had to be clustered to facilitate water transport and the control of sharing.

I wonder whether the need to cluster gardens and fields, in order to share the water of *qanāts*, was one of the main factors leading to the formation of palm groves. In order to maximise the use of this shared water, populations would have started to cultivate crops under the date palms. The oasis agrosystem would thus have been an outcome of this process. It offered benefits in an environment that became even more arid after 1000 BC.

However, it is not certain when summer crops were imported into Southeast Arabia; archaeobotanical data suggest that only winter crops were cultivated at that time. The introduction of summer crops might have been facilitated by palm grove agriculture as it offered shade during the hot Arabian summers.

(5) Throughout the Late pre-Islamic and Islamic periods, the oasis agrosystem was enriched by the gradual importation of new cultivars (summer crops and fruit trees).

8 Conclusion

As Tim Power and Peter Sheehan have noted, hypothetical Bronze and Iron Age oases are often "retrospective projections of the present date-palm oasis onto the past" in the minds of Western scholars (Power and Sheehan 2012: 296; see also Giraud 2007: 190). More broadly, this approach to Arabian oases fits into the "timeless" vision of Arabia, its inhabitants and its landscapes, which is common to many Westerners from the first travellers to contemporary scholars (Magee 2014: 367 and 463).

The theory proposed in this article, although hypothetical, tries to consider the oasis-*bustān* agrosystem as the product of a long history and several feedback processes, from the domestication of date palms (local?) to the appearance of multi-storied crops related to the need to group gardens to share the water of *qanāts*. Clearly, a large variety of sources must be taken into account to understand the history of the oases and the evolution of landscape in South Arabia. Until recently, studies have mainly focused on archaeobotanical data and the excavation of hydraulic structures. The context of the latter is generally not well understood. A multidisciplinary approach is needed to fill this gap and should include soil and environmental studies. A recent project led by Louise Purdue and the author in Masāfī (UAE) is heading in this direction: test pits have been dug in the palm grove in order to reconstruct its evolution, and analyses (in micromorphology, pedology, archaeobotany, etc.) are on-going (Charbonnier et al. in press).

This appears fundamental to comprehend the genesis of oases as this agrosystem, which improves land and water use, most certainly had a profound impact on the settlement dynamics in arid regions of Africa and Arabia. It will also raise the question of the adaptation of human populations to the aridification process in the second half of the Holocene.

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