

• *Date palm – Falaj – Irrigation – Settlement archaeology*

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Settlement History of a Mountain Oasis in Northern Oman – Evidence from Land-Use and Archaeological Studies

*Siedlungsgeschichte einer Bergoase im Nordoman –
Untersuchungen zur Landnutzung und Archäologie*

With 6 Figures, 3 Tables and 4 Photos

Little is known about the functioning and history of the rapidly decaying ancient mountain oases in Northern Oman. In the *Wadi Bani Awf* with its head oasis *Balad Seet* hydro- and pedological measurements were combined with archaeological surveys to derive a series of comprehensive settlement hypotheses. The main driving force for the dynamic development of this exemplary selected watershed at the northern foot of the *Hajar* mountain range was the availability of an abundant and stable flow of springs. The likely construction of a spring-based *aflaj* irrigation system and of elaborate terraces in the first millennium BC allowed an increasingly efficient water use for the production of dates, wheat and alfalfa. The scarcity of land and water might have been two major driving forces for the development of this mountain oasis over its three millennia of existence.

1. Introduction

Situated at the eastern edge of the Arabian Peninsula (*Fig. 1*), the Sultanate of Oman has experienced a very rapid modernisation process since the early 1970s. Following the political opening and the rapid infrastructural changes triggered by the oil-driven economic boom, desert oasis agriculture – once the backbone of the country's economy, together with fisheries and trade – has undergone major changes. Due to the aridity of its climate (from 0 to 240 mm annual precipitation compared to a potential evapotranspiration of >2000 mm) agriculture in Oman heavily depends on irrigation.

At present about 2% of Oman's total land surface, equivalent to 150,377 ha, is cultivated (Agriculture Statistics 1995). Of this area, about 74% is irrigated by modern sprinkler systems drawing subsurface water from wells (mostly situated in the flat northern coastal area, the Batina region, and intensively cropped with modern technologies), 14% by ancient *falaj* systems, 0.4% by springs and the remainder by a combination of the former methods (*Ibrahim 1999*).

The basic irrigation infrastructure of the complicated, partly underground *falaj* (pl. *aflaj*) systems, a canal that conveys groundwater from the foot

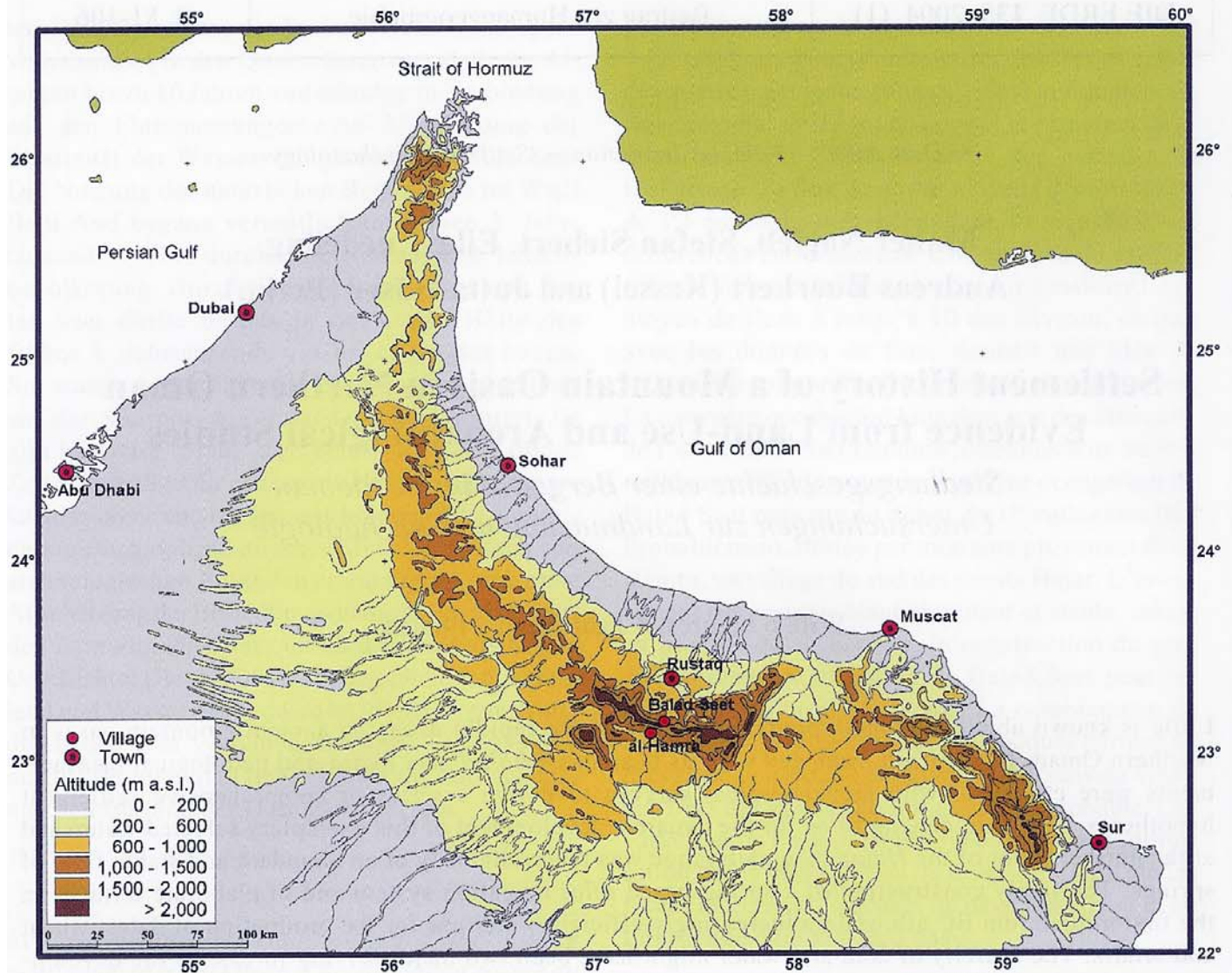


Fig. 1 Relief map of northern Oman showing the major mountain ranges, important towns and villages and the research site of Balad Seet (modified after Gebel 1988) / Höhengschichtenkarte des Nordoman mit den wichtigsten Bergzügen, Städten und dem Untersuchungsstandort Balad Seet (modifiziert nach Gebel 1988)

of a mountain or another impermeable layer to a distant oasis, has been investigated by several authors (Costa 1983, Dutton 1986, Norman et al. 1998, Omezzine and Lokman 1998, Wilkinson 1974). However, little is known about how these systems have developed over time and how their development may relate to the settlement history of a site. In a recent paper on the regional development of these irrigation systems, which are also known as *qanat* in the Persian zone of influence, Boucharlat (2003) differentiates the *aflaj* according to their catchment types. These range from

typically deep, underground water-draining galleries for the true *qanat* to shallower wadi bed collection systems and also comprise systems that merely convey the water above-ground from a spring to the fields. It is this latter type that is referred to in the following study.

Research is needed to unravel the settlement history of northern Oman, and clearly the development of the oasis settlements has to be seen in the broader context of cultural development. The earliest oasis settlement in this region is thought to be

Hili 8 in the modern oasis of Al Ain in the United Arab Emirates, which was dated to the early 3rd

millennium BC (Cleuziou 1998, Costantini 1980). It was concluded from charred date stones and im-

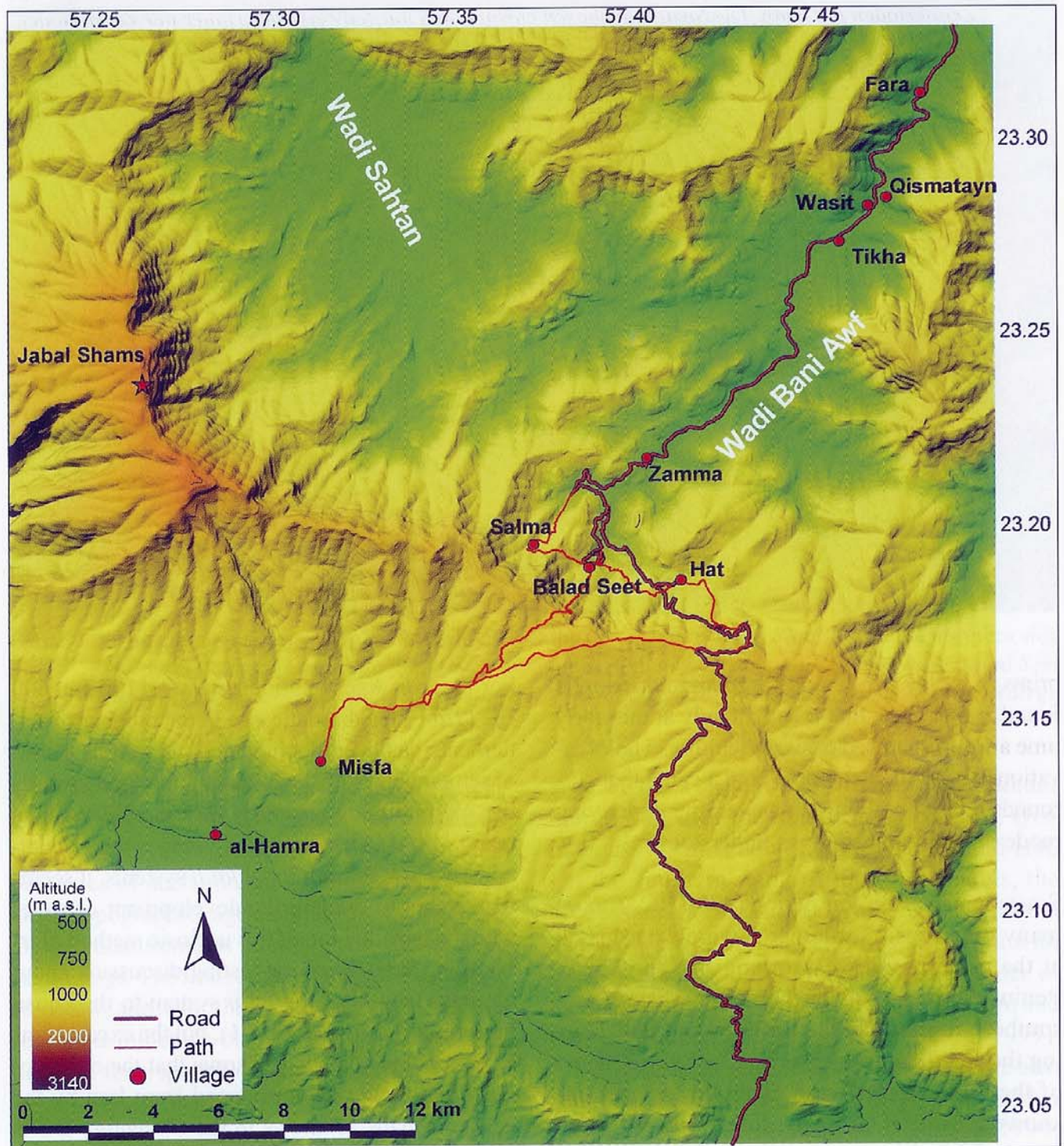


Fig. 2 Relief map of the study area with the Wadi Bani Awf, the Hajar mountain range and the al-Hamra area comprising the modern roads and ancient trading paths. Data from Russian military maps (1:100,000), own GPS measurements and aerial photographs / *Reliefkarte des Untersuchungsgebietes mit dem Wadi Bani Awf, dem Hajar Gebirge und dem Gebiet um al-Hamra. Die Daten für das der Karte zugrundeliegende Höhenmodell stammen aus russischen Militärkarten (1:100 000), eigenen GPS-Messungen und Luftbildaufnahmen.*

Tab. 1 Sequence of settlement phases at Balad Seet in the context of archaeological and historic time periods in Oman. The settlement phases partly overlap with the duration of the time periods. / *Abfolge der Siedlungsphasen in Balad Seet im Vergleich zu den archäologisch und historisch belegbaren Zeitperioden in Oman. Die Siedlungsphasen entsprechen nur teilweise der Dauer der Zeitperioden.*

Time period	Duration	Settlement phase
<i>Hafit</i>	3,100–2,700 BC	(1)
<i>Umm an-Nar</i>	2,700–2,000 BC	(1)
<i>Wadi Suq</i>	2,000–1,300 BC	(1)
Iron Age I	1,300–1,100 BC	(1)
Iron Age II	1,100–600 BC	(2) (3)
Iron Age III	600–300 BC	(3)
Late Iron Age (<i>Samad</i>)	300 BC–630 AD	(3)
Early Islamic	630–1,055 AD	(4)
Middle Islamic	1,055–1,500 AD	(5)
Late Islamic	1,500–1,930 AD	(6)
Sub-recent	1,930–1,970 AD	(7)
Recent	1,970–today	(8)

prints of barley, wheat and sorghum in dried mud found at this place that it had already at this early time a well-organised oasis agriculture. The excavations at Al Ain also uncovered a canal that surrounds a large building; however, the underlying mode of irrigation is not yet understood.

Since the *Umm an-Nar* period (2700 BC, *Tab. 1*) many other oasis settlements were established at the eastern and western coast of the Oman Peninsula as well as at the south-western and southern foreland of the Hajar mountains. During the *Wadi Suq* period around 2000 BC, most of the inland oases were given up for still unknown reasons. During the following 900 years some of the older settlements at the coast were still in use, but in most areas one can only find faint traces of settlements. The many large cemeteries that were discovered, however, provide convincing evidence that these areas were not completely abandoned (*Carter 1997*).

For the Iron Age II period between 1100 and 600 BC (*Tab. 1*), a dramatic rise in the number of settlements has been documented, as well as a shift of settlements from the mountain foreland towards the mountainous regions (*Magee 1999*). Since many of the new established villages were situated very close to traditional *falaj* systems, it seems reasonable to explain the development of oases with the introduction of this intrinsic method of irrigation. There is a long-lasting discussion about the introduction of the *falaj* system to the Oman Peninsula (*Boucharlat 2001*), but the excavations of the last ten years have shown that the old theory of that they were introduced from Iran by the Achaemenians as late as in the 6th century BC is no longer convincing. Still, it remains open to further discussion whether the *falaj* system came from outside or whether it was developed in Oman.

To fill existing gaps of knowledge in the settlement history of oases in northern Oman, an interdis-



Photo 1 The mountain oasis of *Balad Seet* situated at the upper end of *Wadi Bani Awf* on the northern side of the *Hajar* range of the *Jabal Akhdar* mountains, Oman / *Die omanische Bergoase Balad Seet am oberen Ende des Wadi Banif Awf und am Nordrand des Hajar-Zuges im Jabal Akhdar Gebirge*

plinary study engaging archaeologists and agriculturalists was initiated. Its aim was to elucidate the natural and historical bases for the transformation processes of such ancient systems based on detailed topographic, agricultural and hydro-pedological measurements as well as on archaeological findings. The first results of this study, presented below, allow for the development of hypotheses for the millennia-old development of oasis agriculture for a specific section of northern Oman.

2. Materials and Methods

2.1 Experimental area

The study area comprises the *Wadi Bani Awf*, a catchment area (watershed) on the northern

side of the *Hajar* range of the *Jabal Akhdar* mountains with the small oases of *Fara*, *Qismatayn*, *Wasit*, *Tikha*, *Zamma*, *Salma* and *Hat*. On the southern flank of these mountains, the area extends as far as to the villages of *Misfa* and *al-Hamra* (*Fig. 2*). For centuries *al-Hamra* with its *sheikh* was the traditional political center of the region and a market place for goods from and into the *Wadi Bani Awf* (*Ribbeck et al. 1999*). The strong contacts across the mountains are also reflected by families living at *al-Hamra* but also owning fields at *Balad Seet* (*Mershen 1999*; *Nagieb* personal communication).

Within this area the central observation unit for the agronomic research is the mountain oasis of *Balad Seet* (23.19° N, 57.39° E; 996 m a.s.l.), situated at the upper end of the watershed in a

small valley at the foot of a 1000 m high cliff and surrounded by mountains (*Photo 1*). In the middle of this valley is a major rocky outcrop, which contains most of the village buildings. The surrounding rock formation consists of highly permeable carbonates (dolomites and lime stones of the *Mahil* formation) resting over impermeable, red-greyish-green silt- and clay-stones of the *Muaydin* formation. The silt-stones have very little fracture porosity and act therefore as an aquifuge, whereas the carbonates above are highly fractured and karstic which allows the groundwater to be stored and to migrate over long distances (*Weier*, personal communication; *Fig. 3*). Next to Balad Seet and at the foot of the same cliff is the slightly smaller oasis of *Hat* with three springs that drain into the same watershed. The lower part of the wadi contains the oases of *Zamma*, *Tikha* and *Fara* which are much smaller than Balad Seet. They derive their water partly from the drainage flow of the two head-oases filtrating through the rocky valley and partly from smaller local springs.

2.2 Recording of topography, agro-infrastructural features, available water and soil properties

At Balad Seet the measurement period started in April 2000 and comprised the establishment of a three-dimensional digital base map of the oasis within a Geographical Information System (GIS). First, the topography of the rugged surrounding mountains was digitised from Russian military maps (1:100,000, Joint Stock Company SK-IMPEX, Moscow, Russia) with 40-m altitude lines. Subsequently, all major features governing the oasis agriculture were mapped using a differential Global Positioning System (GPS; Trimble Pathfinder, Sunnyvale, CA, USA) with decimeter precision. Those features comprised the position of the 12 springs, the 14 shallow wells that have been dug into the wadi sediments to allow irrigation water to be reused, the canals conveying the spring water to the fields (*aini-afraj* or shortly called *afraj* below), the terraces as well as the position of the date palms (*Phoe-*

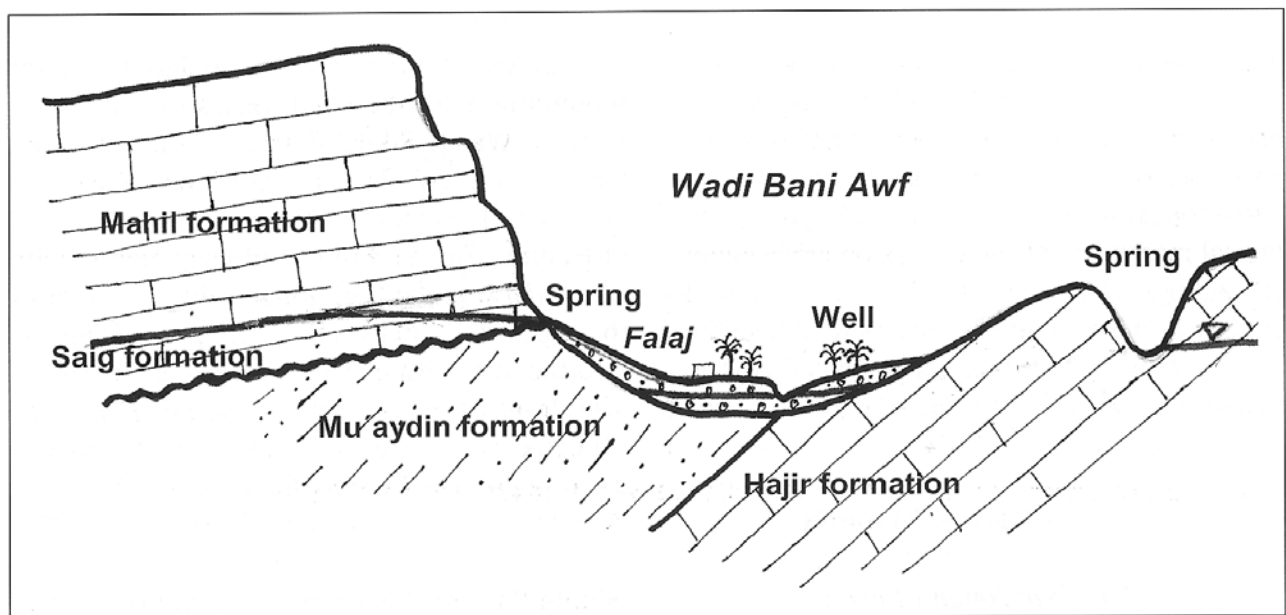
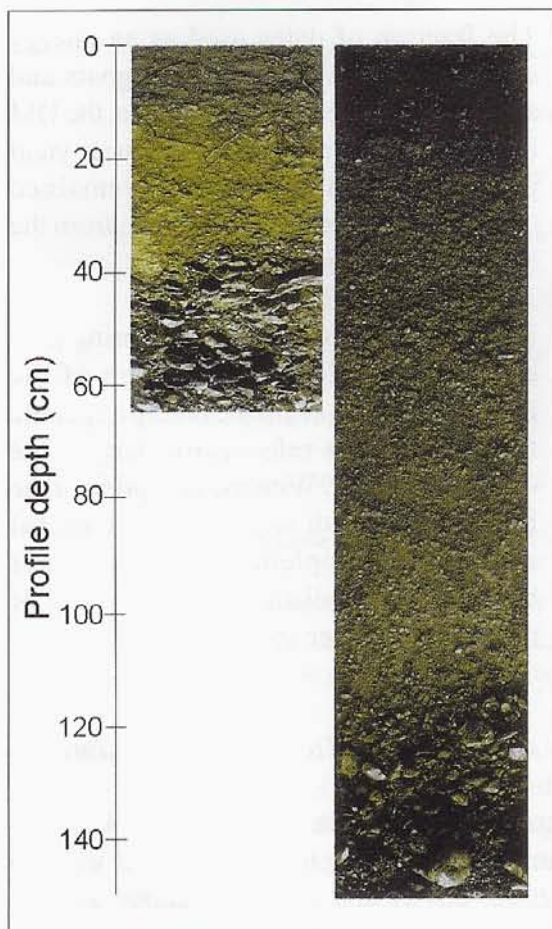


Fig. 3 Schematic cross-section of the geological setting at Balad Seet in the upper Wadi Bani Awf, Oman (approximately in NW-SE direction) / Schematischer Querschnitt durch die geologische Schichtung des Wadi Bani Awf bei Balad Seet (ungefähr in NW-SO Richtung)

nix dactylifera L.), foot paths and roads. The borders of the plots in the six terrace systems of the oasis and the houses were digitised from aerial photographs taken with a remotely controlled camera from a helium-filled balloon (Buerkert et al. 1996). Additionally, 3-D measurements of the terraces were taken with an electronic tachymeter at ± 0.01 m (Leica-Geosystems TPS300, Leica GmbH, Switzerland).

Between November 2000 and April 2003 monthly flow measurements of all springs at Balad Seet that convey their water into four major *aflaj* systems, were taken with a hand-operated barrel system to determine the total influx of irrigation water and the relative contribution of each system to this total over time. Additionally daily precipitation data were collected to observe the response of spring flow to rainfall.



In November 2002 and January 2003 selected springs in Balad Seet and *Hat* were sampled to determine the age of the water stored through the tritium/³helium ratio and concentration of the anthropogenic trace gases sulphurhexafluoride (SF_6) and chlorofluorocarbohydrides (CFC) according to methods described by Aeschbach-Hertig et al. (1998) and Beyerle et al. (1999). The purpose of these water measurements in the context of this paper was to show the relative importance of the different *aflaj* as water sources and the “elasticity” of their water flow during the extended period of drought experienced during the measurement period. Given the constancy of the geological properties of the springs’ parent rocks, insights into the “elasticity” of the water supply are an important basis for subsequent hypotheses about any pre-historic settlement of the oasis system under study.

In October 2002 two soil pits were dug in the palm grove area and the cropped portion of the *Mazra* terrace system. A lacquer peel technique (modified after Hähnel 1961) was used to conserve and study the structure of the anthropogenic profiles (Photo 2). In the second pit soil samples were taken at four depth intervals (0 to 0.2 m, 0.2 to 0.4 m, 0.4 to 0.6 m

Photo 2 Soil profile of the shallow upper part of the *Mazra* terrace system in Balad Seet (Oman) planted with palm trees (left) and the lower part planted with annual crops and alfalfa (right). In the latter note the difference between the gray, silt-rich upper layers of this man-made profile with their high water-holding capacity and the lower portion with its reddish, stony and rapidly draining structure. / Lackprofil des oberen, mit Dattelpalmen bestandenen, flachgründigen Teils des *Mazra* Terrassensystems in der omanischen Bergoase Balad Seet (links) und des unteren, tiefgründigen Terrassenteils, der mit annuellen Kulturen und Luzerne bestanden ist (rechts). Klar erkennbar ist die Differenzierung zwischen den grauen oberen Schichten des künstlichen Profils mit seinem grauen, schluffreichen Substrat, das durch eine hohe Wasserhaltekapazität gekennzeichnet ist und dem unteren Teil mit seiner rötlichen, steinigen Drainageschicht.

and 0.6 to 0.9 m) to determine the particle size distribution and hydraulic properties of the different layers. About 0.2 m below the plough layer at 0.45 m depth, this profile also contained a small piece of charcoal, which could be used for ^{14}C -dating through accelerated mass spectrometry (AMS) at the Institute of Physics at the University of Erlangen-Nürnberg, Germany. In the same pit, a single green glazed pottery sherd was found that allowed a typological age determination.

2.3 Agricultural production and carrying capacity

To estimate the agricultural production, the carrying capacity for small ruminants and the size of the farming community at Balad Seet over time, the following eight assumptions were made (Tab. 2):

- (1) The average water flow of the springs in the valley of Balad Seet has remained unchanged over long periods of time and thus present day flow rates can be used as a proxy.
- (2) Potential evapotranspiration in the valley may be calculated according to *Priestley and Taylor* (1972) modified by *Shuttleworth* (1993). The necessary input data (global radiation and air temperature) came from an automatic weather station established at Balad Seet from Dezember 2002 to April 2003. Crop coefficients were taken from *Allen et al.* (1998).
- (3) Date yields and energy levels from unfertilised local palms genotypes have remained largely unchanged over time. Present day yield levels (10-20 kg DM tree⁻¹ year⁻¹, *Nagieb* personal communication) are in close agreement with data reported from Oman prior to modernisation (FAOSTAT 2003).
- (4) The germplasm for wheat (ancient landraces of *Triticum aestivum* and *T. durum*,

Al-Maskri et al. 2003), sorghum (*Sorghum bicolor* L. Moench) and alfalfa (*Medicago sativa* L.) has remained unchanged over time. Therefore yield levels prior to 1960 (FAOSTAT 2003) and energy contents of crops are representative for previous periods. Human energy consumption for a farm-working adult has also remained constant over time.

- (5) The largely genetically determined ratio between crop residues and grain yield, also known as harvest index, has remained constant over time and may thus be taken from present-day measurements in the oasis.
- (6) The construction of the access road in 1980 led to a large increase in the cropland grown with alfalfa as the basis for feeding the oasis's herd of small ruminants.
- (7) The fraction of dates used as an energy supplement for the nutrition of goats and sheep grazing the desert mountains, the DM intake of these animals and the meat yield per slaughtered animal have remained constant over time and were taken from the literature (*George* 1987).
- (8) The usable fraction of the total spring flow can be calculated as a function of the irrigation system available during a specific time period. This refers particularly to the constructed *aflaj*. With the exception of the likely oldest wadi well, major additional amounts of supplementary well water became only available with the arrival of motor pumps after 1980.

2.4 Collection of archaeological data

An archaeological survey totaling 14 weeks was undertaken during three campaigns in 1999 and 2000. Given that the study aimed at a re-

Tab. 2. Listing of input variables used to model the carrying capacity of the mountain oasis of Balad Seet (Oman) through time. The approximate duration of the settlement phases does not always correspond to the time span of the archaeological and historic time periods.

Eingabegrößen, die für die Modellierung der Landnutzungskapazität der Bergoase Balad Seet (Oman) im Zeitverlauf verwendet wurden. Die ungefähre Dauer der Siedlungsphasen stimmt nicht immer mit der Dauer der archäologisch und historisch belegbaren Zeitperioden überein.

	Settlement phase	1	2	3	4	5	6	7	8
		3,100- 1,100BC	1,100- 900BC	900BC- 630AD	630- 1,055AD	1,055- 1,650AD	1,650- 1,930AD	1,930- 1,970AD	>1,970
Approximate duration									
Input data									
Energy content of mutton and goat meat (kJ kg ⁻¹)	8,360	→							
Energy content of dates (kJ kg ⁻¹)	6,530	→							
Energy content of cereals (kJ kg ⁻¹)	12,130	→							
Human energy demand (kg ⁻¹ (head x day) ⁻¹)	7,530	→							
Fraction of cropping area cropped with alfalfa	0.3	→							0.84*
Fraction of dates used as food	0.8	→							
Ratio crop residues DM [†] / grain yield	3	→							
Date yield (kg tree ⁻¹)	18.8							20	32.5*
Wheat yield (kg ha ⁻¹)	1,400	→							6,000*
Sorghum yield (kg ha ⁻¹)	3,000	→							18,000*
Alfalfa yield (kg DM ha ⁻¹)	15,000	→							33,600*
Livestock DM demand (kg DM (day x head) ⁻¹)	2	→							2*
Meat yield per slaughtered animal (kg head ⁻¹)	15	→							15
Usable fraction of spring flow	0.01	0.1	1.0	→					
Water pumped from wells (m ³ day ⁻¹)	0	→							63*

[†] Dry matter, data assumed to remain unchanged for prior periods, * actual measurement

gional appraisal of settlement patterns, only surface material was collected and no excavations were undertaken. During the survey Balad Seet received the registration number 63 and its 18 sites were sub-numbered

from 1-18. In the following description only these sub-numbers are used.

The surface material consists – with few exceptions – of pottery sherds, which after compari-

son with a previously established pottery typology, allow a provisional dating of the archaeological sites. However, the chronological scheme for Oman's history is still vague and therefore the dating spans of the different periods are broad (Tab. 1). This certainly has major effects on the precision with which the settlement development can be interpreted.

Additionally, the pottery may allow insights into the functional context of the sites, as in many cases it was possible to distinguish between the remains of domestic items and grave wares. Furthermore, pottery sherds can indicate trade connections between different sites and areas.

Since typological studies of the pottery in Oman are rare, especially for the Islamic periods, it was decided to collect all pottery sherds, rather than only a subsample as was previously done in other surveys of the Near East. However, this was only possible because the number of finds was relatively small at all archaeological sites. Upon completion of the field collection, all pottery was processed typologically and with an archaeological seriation technique (The Bonn Seriation and Archaeological Statistics Package, Version 4.0).

In addition to the pottery, all built ancient structures such as houses, towers, shelters, protection walls and tombs were mapped and described. This mapping was made with the help of a GPS and aerial photographs at the scale of 1:20,000 (National Survey Authority, Sultanate of Oman, 1985). From selected oases aerial photographs were taken with a helium-filled balloon, as described above, to obtain a better overview of the architectural remains of the sites.

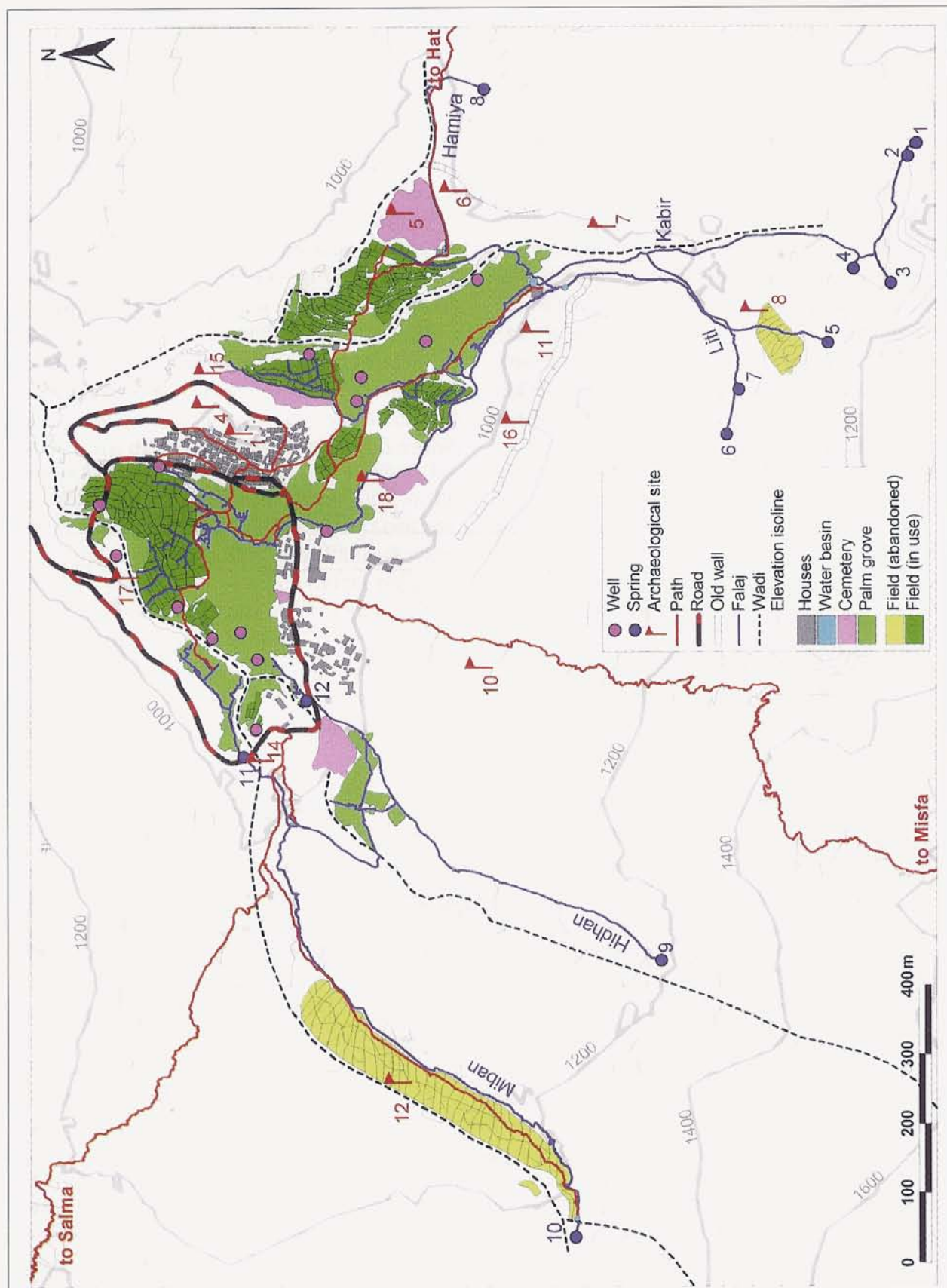
3. Results

3.1 Settlement and agriculture in Balad Seet

In early 2001, the oasis system of Balad Seet comprised 650 inhabitants distributed in 80 households who rented land in and out. About 2,800 date palms comprising 14 varieties cover 8.8 ha of terraced land. The 385 fields of the oasis are divided into six terrace systems totaling 4.6 ha. These comprise Mazra with 145 plots and a total area of 2.03 ha, Zahir with 137 plots and 1.27 ha, Khaw with 53 plots and 0.54 ha, Libsi with 58 plots and 0.47 ha, Rud with 19 plots and 0.25 ha and Khtawi, a small private terrace system with 6 plots and 0.06 ha. Average plot size is 110 m² with a variation between 7.5 and 593 m² (Fig. 4). The terraces contain traditional wheat landraces (*Triticum aestivum* L. and *Triticum durum*; Al-Maskri et al. 2003), sorghum (*Sorghum bicolor* Moench s.l.), barley (*Hordeum vulgare* L. s.l.), oats (*Avena sativa* L.), alfalfa (*Medicago sativa* L.), garlic (*Allium sativum* L.), onion (*Allium cepa* L.), lime (*Citrus aurantiifolia* [Christm. et Panz.] Swingle) and banana (*Musa* spp.) in rotation or in interplanted cropping systems. The analysis of the land-use pattern across the year (winter compared to summer months) also shows a characteristic fluctuation of used and unused plots. In the cooler winter months, the fallow rate is only 15-20% and has a larger variation of crops compared with the summer months, when the total proportion of fallow plots is 50-70%, and cultivation consists of mainly drought-tolerant crops such as sorghum.

A major proportion of the farm income is derived from the up to 200 small ruminants (sheep and goats) fed mainly alfalfa, immature barley and crop

Fig. 4 GIS-based map with the agricultural features and archaeological sites of the mountain oasis of Balad Seet, Oman / GIS-gestützte Karte der landwirtschaftlichen Infrastruktur und der archäologischen Fundstätten in der omanischen Bergoase Balad Seet



residues at home in addition to a minor amount of forage browsed during two 3-hour herded grazing periods per day in the oasis rocky neighbourhood. On separate grazing grounds in the surrounding mountains and at altitudes above 1,300 m, small ruminants are also herded by semi-nomadic families commonly referred to as *shawawi*.

Until the early 1980s when an unpaved road was built across the Wadi Bani Awf to connect it with Rustaq, most trade occurred with al-Hamra which was connected to Balad Seet by two ancient trade routes. The major 27 km long donkey trade path connected the two places via Hat, and a 19 km long footpath allowed travelers to climb the cliff above Balad Seet partly by rock stairs.

3.2 Rainfall, runoff and hydrological features

With only one major rainfall event in July 2001, the total *aflaj* flow declined from 30.0 m³h⁻¹ in November 2001 to 22.3 m³h⁻¹ in March 2003. It recovered within 4 days after two long expected rainfall events on 15 and 17 April 2003 with 20 and 44 mm precipitation, respectively, to 31.3 m³h⁻¹ (Fig. 5). During the prolonged drought period, the total flow of all springs decreased at a monthly rate of about 3%. However, there were clear differences for the different *aflaj*. The springs in the eastern part of the oasis which joint their water into the *falaj* Kabir (with a flow rate of 24.7 m³h⁻¹ on 20 April 2003),

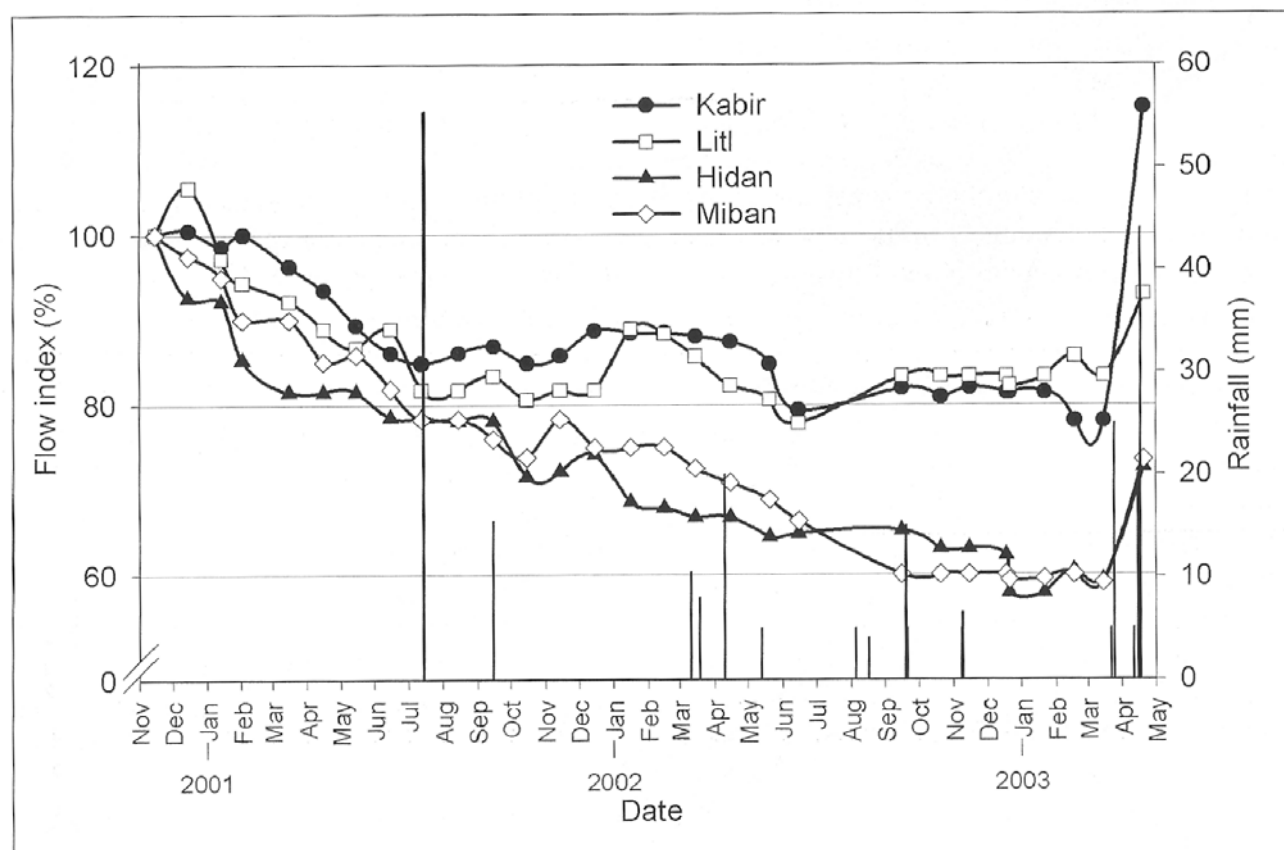


Fig. 5 Relative flow of the four major *aflaj* and rainfall at Balad Seet. Flow rates were set to 100 at the onset of the measurement period on 15 November 2000. No rainfall measurements were taken before January 2001. / Relative Schüttung der vier Hauptbewässerungskanäle und Niederschläge in Balad Seet. Die Schüttungen wurden relativ zu denjenigen am 15. November 2000 (Messbeginn) angegeben, die Niederschlagsmessungen begannen erst im Januar 2001.

Litl ($1.7 \text{ m}^3\text{h}^{-1}$) and Hamiya ($0.2 \text{ m}^3\text{h}^{-1}$) showed a much slower decline in their flow over the prolonged drought period than the springs in the south (Hidan with $2.0 \text{ m}^3\text{h}^{-1}$) and west (Miban with $2.9 \text{ m}^3\text{h}^{-1}$) indicating a more buffered hydrological reservoir with a larger water storage capacity (Fig. 5). In winter months, the oasis farmers of today's Balad Seet draw in addition to the springs' flow up to 63 m^3 of groundwater per day by motor pumps from 14 wells which have been dug into the wadi sediments. In summer months, however, seepage is too low to allow the extraction of substantial amounts of water from these wells.

The first results of the isotopic analyses of the water's age indicate a range of 2 to 10 years for the percolation from the mountain tops to the springs feeding Balad Seet. Given the karstic nature of the parent rock, it is most likely that the age of the apparently younger waters reflect a contact between water and air at some point of the flow path through the rocks. Therefore, the average water age is probably at the upper end of the determined range, with substantial scope for variation between individual springs.

3.3 Soil analyses

The analyses of the soil profiles indicate that the cropped, man-made terrace soils of Mazra are made up of three successive top layers in total 0.9 m thick and with pH 8.4, 12–15% clay, 48–54% silt, 34–38% sand and an organic carbon (Corg) concentration of 23 g kg^{-1} . The very high Corg levels reflect the regular application of manure at rates up to $10 \text{ t ha}^{-1} \text{ year}^{-1}$. They form the basis for the high fertility and productivity of these oasis soils despite high C turnover rates (Wichern et al. 2003).

The ^{14}C dating of the charcoal in the Mazra terrace system revealed an age of 911 ± 43 years or an origin between 1,027–1,212 AD at a 95% prob-

ability. This corresponds well to the age determination of the sherd which dates back to the Early Islamic period probably between 800–1,000 AD.

During the period of terrace construction, the large amounts of silt needed were likely collected from wadi sediments after heavy rainfalls, as there is barely any other soil material available in the rocky surroundings of the oasis. Below the upper layers there is a clearly differentiated fourth stratum with 9% clay, 27% silt and 64% sand and an increasing number of big stones. This clear stratification of horizons allows the storage of water and nutrients in the upper 0.9 m of the terrace soils and a rapid drainage below, thereby avoiding the typical build-up of toxic salt concentrations with irrigation in many arid environments. The upper, shallow soils planted to date palms have a similar structure, but reach the coarsely weathered bedrock at only 0.4 m.

3.4 Archaeological findings

The most important archaeological place of Balad Seet is situated at the steep eastern slope of the outcrop, where the modern settlement is located (Site 4 on Fig. 4, Photo 3). A total of 785 pottery sherds of different periods, but no architectural structures or tombs were discovered there. The sherds covered the entire period from the Iron Age II period (Tab. 1) to modern times. The fact that only ceramic sherds were found at the bottom of the eastern slope indicated that, over time, this part of the outcrop was the rubbish dump of the settlement above. It may thus be hypothesized that the site was continuously inhabited since the Iron Age. As there are no architectural remains older than the Late Islamic period in the village itself, the archaeological findings did not allow estimation of the extension of the settlement nor the size of population for these early periods. The fact that all Iron Age II sherds (579 pieces) are from domestic wares, and no grave pottery has been found, precludes the possibility that they come from tombs situated at the top of the outcrop.



Photo 3 Balad Seet from the east. The white arrow marks the rubbish dump with pottery from different periods. / *Balad Seet von Osten. Der weiße Pfeil kennzeichnet den Müllplatz mit Tonscherben aus den verschiedenen Siedlungsphasen.*

Twenty-one out of a total of 38 sherds of the same archaeological period were collected on Site 5 (*Fig. 3* and *Fig. 4*), situated at the eastern edge of the fields. This area is covered with an Islamic cemetery. The graves were constructed inside the remains of stone-built house foundations (*Photo 4*). Three rooms or houses were distinguishable but the area was very disturbed, which made it impossible to determine whether there once was a small settlement or only a few individual houses. Because the stones of the foundations are laid out carefully, it may be assumed that they were not from stables but from homes. The determination of the age of these house foundations is as difficult as that of the remaining sherds

on Site (5): 21 sherds were of the Early Iron Age, 10 of the Early Islamic period and 7 of the Middle or Late Islamic period (*Tab. 1*). Since the Islamic graves were built inside the house foundations, the former must be older than the latter. If the graves are Late Islamic, the houses could be of the Early Islamic or Late Iron Age period.

A local story in Balad Seet refers to an ancient settlement (Site 8) called *madina qadima* (old city) in Arabic. Its inspection revealed a number of very dilapidated terrace fields with remains of a *falaj* system. These are situated at a slope south-east of Balad Seet close to Spring 5 (*Fig. 4*). Here 45 of the 47 discovered pottery sherds are of the

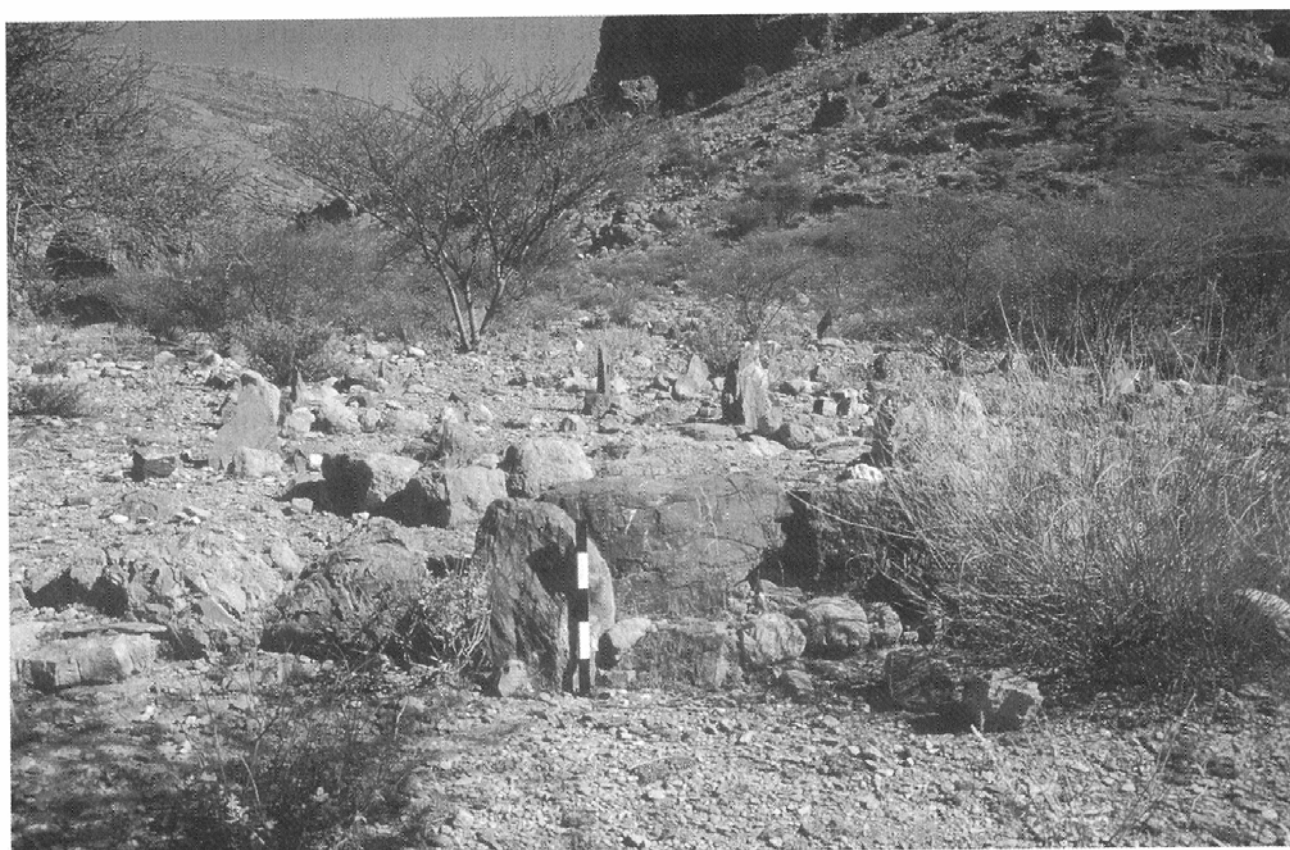


Photo 4 Islamic cemetery with graves inside the remains of stone-built house foundations. The graves may be of the late Islamic period (1,500–1,930 AD) and the houses of the Iron Age II period (1,100–600 BC) or the Early Islamic period (630–1,055 AD, *Tab. 1*). / *Islamischer Friedhof mit Gräbern innerhalb den Resten steinerner Hausfundamente. Die Gräber könnten der Spät-islamischen Periode (1500–1930 n. Chr.) entstammen und die Häuser der Eisenzeit II (1100–600 v. Chr.) oder der Frühislamischen Periode (630–1055 n. Chr., Tab. 1).*

Iron Age II. It is unclear whether they really allow for dating the terraces, because they also could have been carried with manure from other places to this site. However, the physical state of these terraces and the fact that the residents of the village did not remember their function and interpreted them as remains of an ancient settlement indicated that they were abandoned a long time ago.

Besides the former *madima qadima* terraces there is a second area of abandoned terrace fields in the situated south-western part of the village (Site 12, *Fig. 4*). However, it is much better preserved. The old men of the village remember that these fields were abandoned about 70 years ago due to a successive shortage of water. According to oral records

after the abandonment of these terraces, a smaller system was built together with an access *falaj* to allow the flow of Spring 10 (*Fig. 4*) to reach these structures that are planted with date palms. In the immediate surroundings of these fields the remains of a few scattered enclosures were identified on Site 14 (*Fig. 4*). They appear to be former camp sites of the *shawawi* and their livestock. The four pottery sherds found inside these enclosures are of Iron Age and very Late Islamic date. Some further remains of stone built houses are scattered south and south-east of Balad Seet. Given their architectural layout these houses are probably also of the Late Islamic period.

South and east of the oasis two long and massive walls were erected. The southern near Site 16

(Fig. 4) stretches parallel to the slope over 440 m. It was built of undressed stones, about 1.5 m high, and its width varies between 0.6 and 1.0 m. The eastern wall near Site 6 (Fig. 4) was also built of undressed stones, but is more massive than the first one. It also extends parallel to the slope and ends near the eastern wadi. No findings were discovered near these walls, and today's inhabitants of Balad Seet have no records of who might have built them. They explain their purpose as part of a fortification system, but their position on the steep rocky slope makes this very unlikely. Walls of a similar type have been found elsewhere in Oman and are often interpreted as boundaries, but with unclear functions.

Near Site 4 (Fig. 4), two Islamic cemeteries were found: one at the eastern foot of the outcrop with the modern village (Site 15, Fig. 4), the other one south of the village (Site 18, Fig. 4). The latter one is still in use, whereas the former is overgrown with bushes and littered with rubbish. In contrary to the cemetery of Site 5 (Fig. 4), no findings were discovered on the latter cemeteries. Presumably, they belong to the Late Islamic and recent settlement phases.

In contrast to other parts of Wadi Bani Awf, Wadi Hat and al-Hamra where tombs of the *Hafit* period were discovered, no such structures were found at Balad Seet, nor were there any settlements from this period. Presumably, during these early times the population lived from herding goats and sheep, and their dwellings have completely vanished. Wherever identified elsewhere, such early tombs were located in clearly visible positions, marking long axes. This gave raise to the hypothesis that they not only served as burial sites but also as landmarks pointing to important features in the landscape (Siebert et al. 2005). As Balad Seet is topographically a dead end and the mountain crests nearby could only be crossed on a steep footpath unsuitable for animals, there may have been no cause for the construction of early tombs as landmarks.

The settlement history during the following periods (*Umm an-Nar* period, *Wadi Suq* period and Iron Age I period, Tab. 1) is even more difficult to determine for the area as only a few graves were found in Wadi Bani Awf and al-Hamra and none at Balad Seet.

At al-Hamra two settlements of the Iron Age II period were identified, similar to Balad Seet, and there are also several cemeteries of this period. Two additional small Iron Age cemeteries were discovered in the Wadi Bani Awf between Zamma and Tikha. Since there are no remains of Iron Age tombs at Balad Seet, it remains open to further debate, where the deceased of Balad Seet may have been buried.

The following periods of the Early Iron Age and the Late Iron Age are only represented by some tombs and faint traces of a wall at al-Hamra, but not in the Wadi Bani Awf. The latter also preserved only very few remains of the Early Islamic period.

In the 11th/12th century AD, a slight increase of settlement activities in the Wadi Bani Awf as well as at al-Hamra was observed. At al-Hamra these sites are sometimes close to the former Iron Age settlements. Pottery of this period was also found at Hat and in Wadi Bani Awf at the junction to Bi'r. The last mentioned oasis was probably abandoned already in the Middle Islamic period or in the early phase of the Late Islamic period.

A dramatic change in the settlement history of the wadi was observed for the Late Islamic period. All now-existing oases were established by then. This was conclusively shown by the appearance of the so-called *Bahla* ware, the typical glazed pottery for this period, that was found at all settlements. Two additional sites, now abandoned, were established during this period. At al-Hamra a new *falaj* was built which provided the basis for erecting a much larger settlement.

4. Discussion

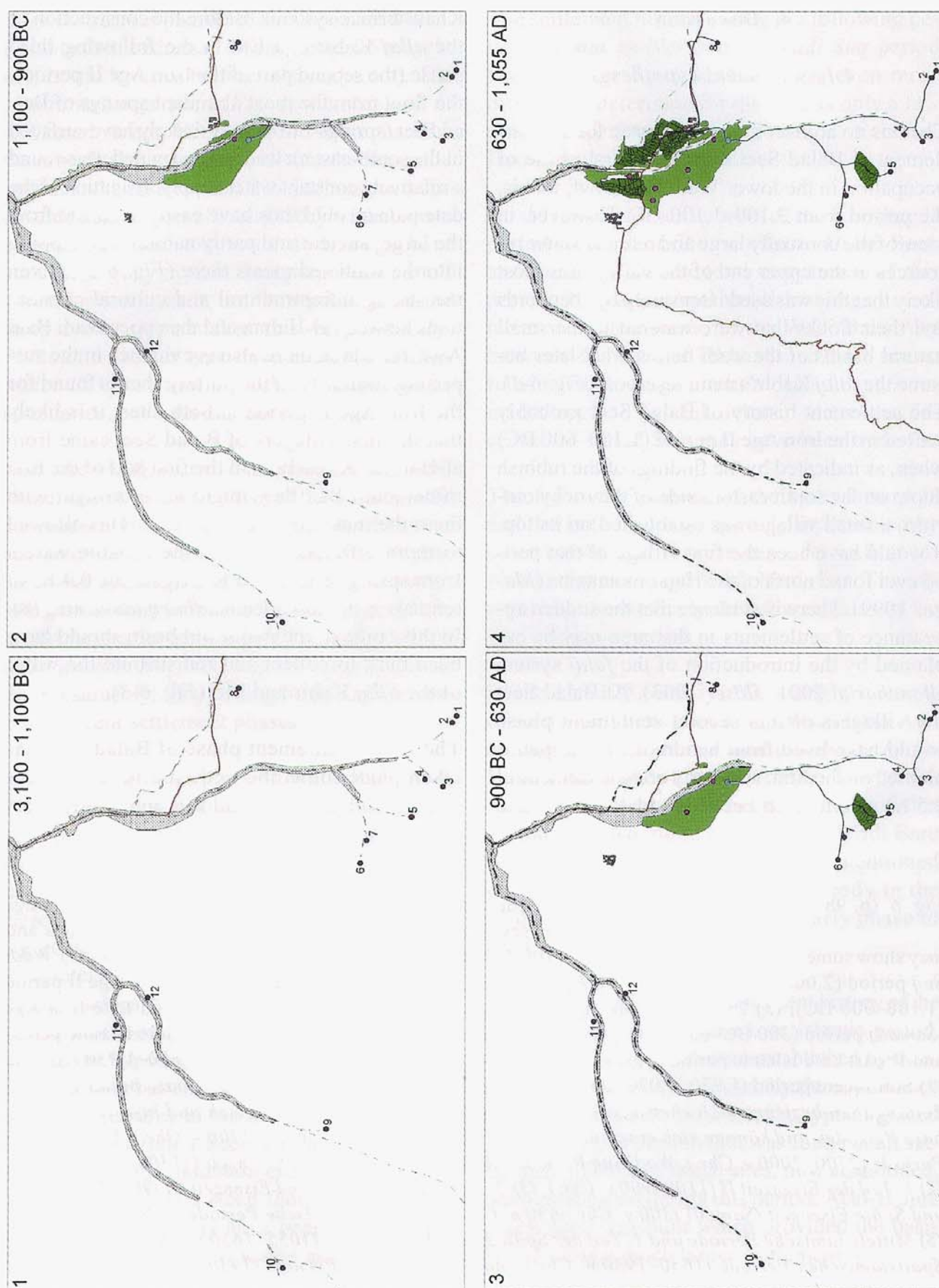
4.1 Settlement hypotheses

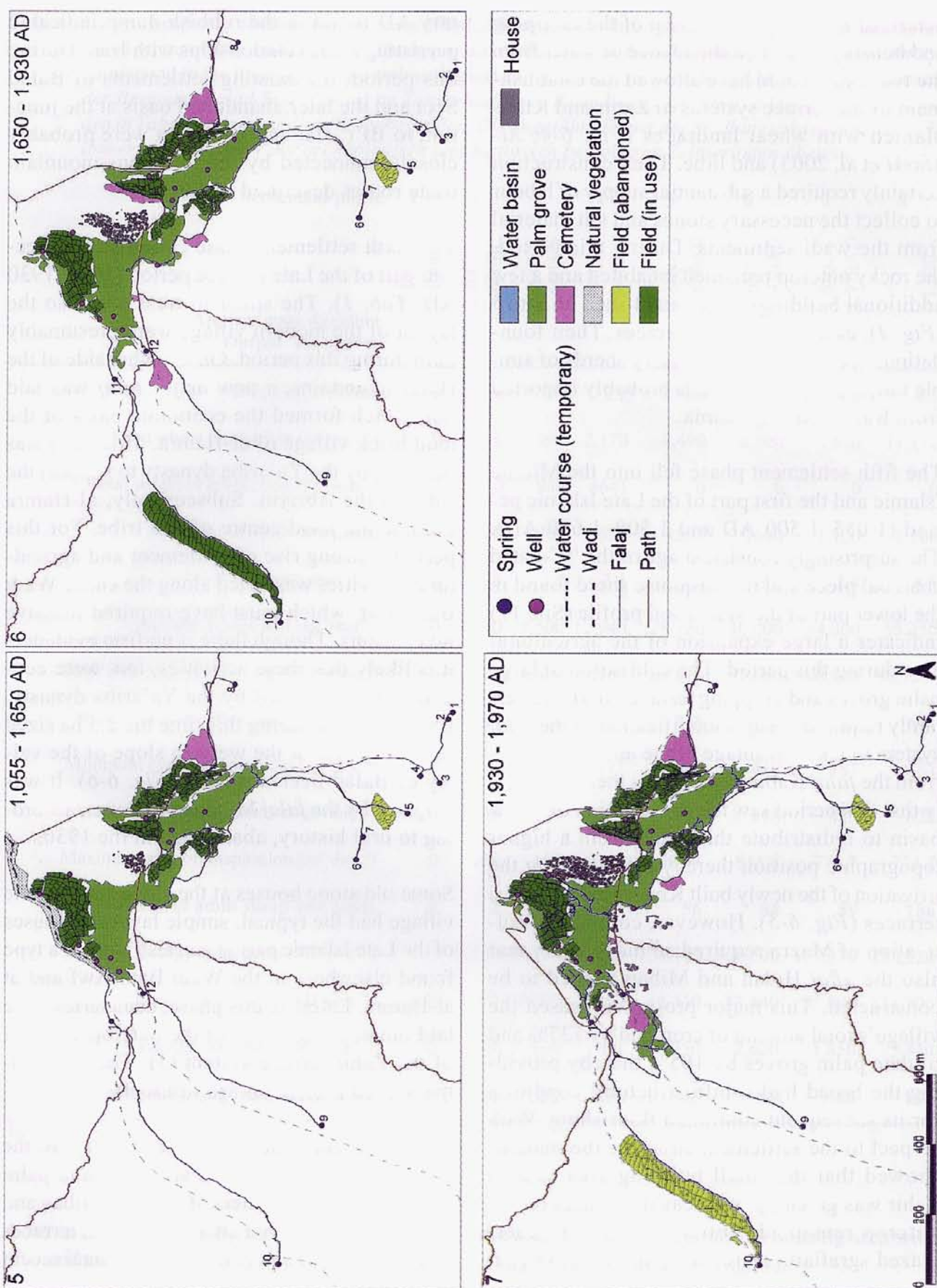
There is no archaeological evidence for any settlement at Balad Seet during the first phase of occupation in the lower Wadi Bani Awf, that is, the period from 3,100–1,100 BC. However, in view of the unusually large and reliable water resources at the upper end of the valley, it is most likely that this was used intensively by shepherds and their flocks that were watered in the small natural basins of the wadi below what later became the *falaj* Kabir's main reservoir (Fig. 6-1). The settlement history of Balad Seet probably started in the Iron Age II period (1,100–600 BC) when, as indicated by the findings of the rubbish dump on the south eastern side of the rocky outcrop, a small village was established on its top. It would have been the first village of that period ever found north of the Hajar mountains (Maggie 1999). There is evidence that the sudden appearance of settlements in this area may be explained by the introduction of the *falaj* system (Boucharlat 2001; Häser 2003). At Balad Seet the villagers of this second settlement phase would have lived from hundreds of date palms planted on the first, relatively archaic terraces of 2.5 ha size located between today's Zahir and

Khaw terrace systems. Before the construction of the *aflaj* Kabir and Litl in the following third phase (the second part of the Iron Age II period), the flow from the most abundant springs of Balad Seet (springs 1 to 4) would likely have surfaced in the south-eastern wadi and provided year-round a relatively constant water supply. Irrigation of the date palms could thus have easily occurred from the large, ancient and partly natural well tapping into the wadi sediments there (Fig. 6-2). Given the strong infrastructural and cultural connections between al-Hamra and the upper Wadi Bani Awf, for which there also is evidence in the surprising similarity of the pottery sherds found for the Iron Age II period at both sites, it is likely that the first villagers of Balad Seet came from al-Hamra. As early as in the first half of the first millennium BC, they might have brought with them the innovative *falaj* system. This allowed to more efficiently exploit the reliable waters from springs 1 to 4 and to irrigate the 0.4 ha of terraces in the so-called *madina qadima* area (8). In this context, the major old basin should have been built to collect and redistribute the water of the *aflaj* Kabir and Litl (Fig. 6-3).

The fourth settlement phase of Balad Seet has taken place sometime in the Early Islamic period (630–1,055 AD) and was apparently char-

Fig. 6 (p. 98-99) Settlement phases of the mountain oasis of Balad Seet (Oman). Timings relate to settlement phases rather than to archaeological and historic periods and may show some overlap: (1) Hafit period (3,100–2,700 BC), *Umm an-Nar* period (2,700–2,000 BC), *Wadi Suq* period (2,000–1,300 BC) and Iron Age I period (1,300–1,100 BC), (2) 1st part of Iron Age II period (1,100–900 BC), (3) 2nd part of Iron Age II and Iron Age III period (900–300 BC) and Late Iron Age (*Samad*) period (300 BC–630 AD), (4) Early Islamic period (630–1,055 AD), (5) Middle Islamic period and 1st part Late Islamic period (1,055–1,650 AD), (6) 2nd part Late Islamic period (1,650–1,930 AD) and (7) Sub-recent period (1,930–1,970 AD) / *Besiedlungsphasen der omanischen Bergoase Balad Seet. Die Zeitangaben beziehen sich eher auf die Siedlungsphasen als auf archäologisch und historisch belegbare Perioden und können sich etwas überlappen: (1) Hafit Periode (3100–2700 v. Chr.), Umm an-Nar Periode (2700–2000 v. Chr.), Wadi Suq Periode (2000–1300 v. Chr.) und Eisenzeit I (1300–1100 v. Chr.), (2) 1. Teil der Eisenzeit II (1100–900 v. Chr.), (3) 2. Teil der Eisenzeit II und Eisenzeit III (900–300 v. Chr.) und Späte Eisenzeit (Samad) (300 v. Chr.–630 n. Chr.), (4) Frühislamische Periode (630–1055 n. Chr.), (5) Mittelislamische Periode und 1. Teil der Spätislamischen Periode (1055–1650 n. Chr.), (6) 2. Teil der Spätislamischen Periode (1650–1930 n. Chr.) und (7) Subrezente Periode (1930–1970 n. Chr.)*





acterised by a large expansion of the cropping and housing area. The abundance of water from the two *aflaj* should have allowed the establishment of the terrace systems of Zahir and Khaw planted with wheat landraces (*Fig. 6-4*; *Al-Maski et al.* 2003) and lime. Their construction certainly required a substantial supply of labour to collect the necessary stones and silt material from the wadi sediments. During this period, the rocky outcrop remained inhabited and a few additional buildings were established on Site 5 (*Fig. 4*), east of the Zahir terraces. Their foundations are still visible and carry sherds of simple turquoise glazed vessels probably imported from Iran or Mesopotamia.

The fifth settlement phase fell into the Middle Islamic and the first part of the Late Islamic period (1,055–1,500 AD and 1,500–1,650 AD). The surprisingly consistent age of the ¹⁴C-dated charcoal piece and the turquoise sherd found in the lower part of the Mazra soil profile (Site 17) indicates a large expansion of the agricultural area during this period. The cultivation of large palm groves and cropping terraces at Mazra certainly required a major modification of the *aflaj* system to take advantage of the abundant water from the *falaj* Kabir system. It is therefore likely that this period saw the construction of a new basin to redistribute this water from a higher topographic position thereby also allowing the irrigation of the newly built Khaw, Rud and Libsi terraces (*Fig. 6-5*). However, continuous cultivation of Mazra required so much water that also the *aflaj* Hidan and Miban needed to be constructed. This major project increased the village's total amount of cropland by 137% and of date palm groves by 105% thereby providing the broad hydro-infrastructural condition for its subsequent continued flourishing. With respect to the settlement structure the remains showed that the small building area east of Zahir was given up, whereas the houses on the outcrop remained. Pottery sherds of underglazed sgraffiato wares from the 12th/13th cen-

tury AD found in the rubbish dump indicated persisting trade relationships with Iran. During this period, the existing settlements of Balad Seet and the later abandoned oasis at the junction to Bi'r, Hat and al-Hamra were probably closely connected by the two trans-mountain trade routes described earlier.

The sixth settlement phase comprises the second part of the Late Islamic period (1650–1930 AD, *Tab. 1*). The small fortress and also the layout of the modern village were presumably built during this period. On the other side of the Hajar mountains, a new major *falaj* was laid out, which formed the economic basis of the mud brick village of al-Hamra. This *falaj* was financed by the Ya'ariba dynasty to support the tribe of the Abriyin. Subsequently, al-Hamra became the local centre of this tribe. For this period a strong rise of settlement and agricultural activities was noted along the entire Wadi Bani Awf, which must have required massive investments. Though there is no firm evidence, it is likely that these activities, too, were economically supported by the Ya'ariba dynasty. It is likely that during this time the 2.5 ha sized terrace system at the western slope of the valley of Balad Seet was built (*Fig. 6-6*). It was irrigated by the *falaj* Miban until it was, according to oral history, abandoned in the 1930s.

Some old stone houses at the slope south of the village had the typical, simple layout of houses of the Late Islamic period and also were of a type found elsewhere in the Wadi Bani Awf and at al-Hamra. Latest in this phase, cemeteries were laid out east and south of the outcrop and east of the Zahir terrace system (5). The two last-mentioned cemeteries are still in use today.

The sub-recent settlement phase (*Tab. 1*) saw the construction of the 1.2 ha sized Hillhila palm grove to which the waters of the *aflaj* Miban and Hidan were conveyed after the western terraces had been abandoned (*Fig. 6-7*). The final recent

Tab. 3 Carrying capacity of the mountain oasis of Balad Seet (Oman) through time. All output estimations are based on input data from Table 2. The approximate duration of the settlement phases does not always correspond to the time span of the archaeological and historic time periods. / *Landnutzungskapazität der Bergoase Balad Seet (Oman) im Zeitverlauf ihrer Besiedlung. Alle Output-Größen beruhen auf den in Tabelle 2 dargestellten Eingabegrößen. Die ungefähre Dauer der Siedlungsphasen stimmt nicht immer mit der Dauer der archäologisch und historisch belegbaren Zeitperioden überein.*

Settlement phase	1	2	3	4	5	6	7	8
Approximate duration Output estimation	3,100- 1,100BC	1,100- 600BC	900BC -630AD	630- 1,055AD	1,055- 1,650AD	1,650- 1,930AD	1,930- 1,970AD	>1,970
Cropping area (ha)	0	0	0.4	2.2	4.6	7.0	4.6	4.6
Total wheat production (kg year ⁻¹)	0	0	390	2,170	4,490	6,900	4,540	11,110
Total sorghum production (kg year ⁻¹)	0	0	840	4641	0	0	0	0
Number of adult date palms	0	400	400	690	1535	1600	1,700	1,700
Palm grove area (ha)	0	2.5	2.5	3.1	7.0	7.6	8.8	8.8
Total date production (kg year ⁻¹)	0	7,500	7,500	12,940	28,780	30,000	34,000	55,250
Total fodder production (kg DM [†] year ⁻¹)	0	0	1,800	9,950	20,610	31,680	20,840	90,730 [†]
Water available (minimum) (m ³ day ⁻¹)	4	44	438	442	538	538	538	601
Minimum evapotranspiration (m ³ day ⁻¹)	0	138	138	171	383	419	487	487
Medium evapotranspiration (m ³ day ⁻¹)	0	138	149	234	513	618	619	622
Maximum evapotranspiration (m ³ day ⁻¹)	0	138	163	308	667.3	855.8	774.7	774.7
Number of adult sheep and goats	0	2	11	29	56	84	59	186
Energy from dates (MJ year ⁻¹)	0	39,130	39,130	67,490	150,140	156,500	177,370	288,220
Energy from crops (MJ year ⁻¹)	0	0	14,930	26,250	54,410	83,640	55,000	134,700
Energy from meat (MJ year ⁻¹)	0	60	350	900	1,750	2,620	1,850	5,840
Number of adults living from agriculture	0	14	20	34	75	88	85	156

[†] Dry matter

phase is characterised by the renovation of the *aflaj* and of many houses, using cement, and by

the establishment of a southern housing area with a large school building (Fig. 4).

4.2. Agricultural production and carrying capacity over time

The previously described sequence of *aflaj* and terrace construction and the amounts of food and fodder likely produced from these terraces allowed the drawing of a sketchy, yet surprisingly convincing picture of the agricultural activities at Balad Seet over the millennia of its existence (Tab. 3). It appears as though the cropping area steadily increased between the 3rd and 6th settlement phase and declined again only after the western terraces of size 2.5 ha had been abandoned in the 1930s. Thereafter, the 2.9 m³ water flow h⁻¹ of the Miban *falaj* was used for date production in the 1.2 ha of the Hillhila palm groves. Wheat production likely followed the expansion and shrinkage of the cropping area, with the exception of the present period when the arrival of mineral nitrogen and phosphorus fertilizers allowed doubling of the grain yield per unit area. The presented settlement hypotheses allow the postulation of an interesting infrastructure-driven swing between periods of water limitation and those of land limitation. This can be exemplified by the assumed production of sorghum, a heat-tolerant typical summer cereal. It might have expanded several-fold during the 4th settlement phase when water should have abounded year round after the construction of the Kabir *falaj* system, and before the large expansion of land following the subsequent construction of the Mazra terrace system. A steadily increasing production of dates over the centuries seems very likely to reflect both an expansion of the palm grove area, and during the modern period, the intensification of the palm production by manure application to the trees. The latter was a consequence of the larger herd sizes maintained at Balad Seet (Tab. 3). The road construction in the 1980s with the subsequent large influx of food commodities from external markets should have led to a reduced area dedicated to wheat and a major conversion of the former "food land" into "fodder land". This would have allowed an increase of the herd size of sheep and goats to the present levels of up to

200 head, and herewith, much above the drought-limited carrying capacity of the marginal grazing grounds in the surrounding ecosystem. In an increasingly market-oriented economy, the animals are sold at premium prices on regional markets or are eaten by the farmers' extended families when returning to their village of origin on occasion of religious feasts such as Ramadan and *Id*.

The number of settlers at Balad Seet may have always substantially exceeded the agriculture-based carrying capacity of the upper Wadi Bani Awf. Revenues from trade may have allowed the import of grain from villages like al-Hamra with larger land resources. The large difference between today's calculated carrying capacity of 156 adults and the four-fold higher actual village population, however, is the result of the revenues from the flourishing secondary (trading) and tertiary sector (education and administration) of the modern economy which is based on oil and gas revenues. These allow large quantities of calories and plant nutrients in the form of mineral fertilizers to be imported into the oasis and may finally lead to the conversion of the agriculturally exploited resource base into an increasingly vacation-oriented setting. Such transformation processes have been taking place in many oases of Oman and can presently be observed in its final stages at al-Hamra, Balad Seet's presumed mother village.

5. Conclusions

Despite the scanty finding situation in the study area, the combination of topographic, agricultural, hydro-pedological and archaeological data allowed the establishment of conclusive settlement hypotheses for the Wadi Bani Awf with a focus on its head oasis Balad Seet, a likely early offspring of al-Hamra. The main driving force for the settlement dynamics at Balad Seet was the availability of an abundant and stable flow of springs at the northern foot of the

Hajar mountain range. This triggered the early construction of an interrelated infrastructure of *aflaj* and terraces for the sustainable and increasingly efficient production of dates, limes, annual crops and meat. The scarcity of land and water and their eventual optimisation by the immigrant settlers of Balad Seet might have been the major driving force for the development and apparent relatively stable wealth of this oasis over the millennia.

The absence of settlements of the 3rd millennium BC in the area of this study leads to the hypothesis that the earliest oases of Oman may not have been established in the mountainous regions of the Hajar range, but instead concentrated in its foreland and at the coast. The reasons for the choice of settlement areas are still poorly understood. The emergence of the first mountain settlements between 1100 and 600 BC confirm the existing theory on the one hand, but provide new hints to the strong correlation between the rise of settlements at this period and the introduction of the *falaj* system. The origin of the *falaj* irrigation system remains open to further debate. The discovery of an Iron Age settlement at Balad Seet, an oasis on the northern side of the Hajar mountains which was connected with al-Hamra on its southern side is a major surprise. It contradicts the conclusion of Magee (1999) who argued that the Hajar range formed a cultural barrier. The findings of this study rather indicate that a political, and presumably also economical, frontier went right through the Wadi Bani Awf. For the first time, this study shows the existence of the Early and Middle Islamic settlements that were not based on trade such as in Sohar, or on metal resources such as in Arja and Wadi Safafir, but on agriculture alone. The apparently uninterrupted inhabitation of Balad Seet during periods of major crisis and revival at other sites in Oman reflects the role of oasis agriculture for the settlement history in this arid country. As such, oasis agriculture certainly merits further interdisciplinary research.

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Summary: Settlement History of a Mountain Oasis in Northern Oman – Evidence from Land-Use and Archaeological Studies

To unravel the settlement history of oases in northern Oman, data on topography, the agricultural setting, water and soil parameters and archaeological findings were collected in the Wadi Bani Awf with its head oasis Balad Seet. Data collection lasted from April 2000 to April 2003 and was based on the establishment of a 3D-georeferenced map of the oasis comprising all its major infrastructural and agronomic features. At today's Balad Seet, a total of 8.8 ha are planted to 2,800 date palms and 4.6 ha are divided into 385 small fields dedicated to wheat, barley, sorghum, oats, alfalfa, garlic, onion, lime and banana. Radiocarbon dating of charcoal in the lower part of the main terrace system determined its age to 911 ± 43 years. Monthly flow measurements of four major *aflaj* systems showed a total maximum flow of $32 \text{ m}^3 \text{ h}^{-1}$ with the largest *falaj* contributing 78% of the total flow. During drought periods, average water flow decreased by 3% per month, however, with significant differences between the spring systems. The analysis of the tritium/³helium ratio in the water led to an estimated water age of up to 10 years. In combination with the flow data, this provided insights into the elasticity of the spring flow over time. The use of the natural resources of the Wadi

Bani Awf by a pastoral population started probably in the early 3rd millennium BC. The first permanent settlement might have been established at Balad Seet during the first part of the 1st millennium BC. Presumably it was initiated by settlers from al-Hamra, a village at the southern foot of the Hajar mountains. Given an abundant and stable flow of springs, even in periods of drought, the construction of Balad Seet's first irrigation systems may have occurred at this early time. The combination of topographic, agricultural, hydro-pedological and archaeological data allowed assessment of the carrying capacity of this oasis over the three millennia of its likely existence. The changing scarcity of land and water and the eventual optimisation of their use by different *aflaj* constructions have been major driving forces for the development and apparent relatively stable existence of this oasis.

Zusammenfassung: Siedlungsgeschichte einer Bergoase im Nordoman – Untersuchungen zur Landnutzung und Archäologie

Ziel der vorliegenden Untersuchung war die Entschlüsselung der jahrtausendealten Siedlungsgeschichte von Oasen im Nordoman am Beispiel des Bani Awf Tales mit seiner Kopfoase Balad Seet. Dazu wurden zwischen April 2000 und April 2003 topographische, landwirtschaftliche, hydrologische und pedologische Messungen sowie archäologische Geländeaufnahmen auf der Grundlage einer dreidimensionalen Geländekartierung durchgeführt. Die Analyse zeigte 2800 Dattelpalmen auf 8,8 ha Fläche und 385 mit Weizen, Gerste, Sorghum, Hafer, Luzerne, Knoblauch, Zwiebeln, Limetten und Bananen bestandene Kleinparzellen mit einer Gesamtfläche von 4,6 ha. Das Alter der Hauptterrassen konnte mittels ¹⁴C-Datierung von Holzkohle in einem Bodenprofil auf 911 ± 43 Jahre bestimmt werden. Monatliche Wasserflussmessungen der vier wichtigen Quellkanalsysteme ergaben eine maximale Gesamtwassermenge von $32 \text{ m}^3 \text{ h}^{-1}$, woran das größte Kanalsystem einen 78%igen Anteil hatte. Während einer längeren Trockenphase nahm der Wasserfluss monatlich um durchschnittlich 3% ab, wobei allerdings deutliche Unterschiede zwischen den vier Kanalsystemen festgestellt werden konnten.

ten. Die Bestimmung des Tritium/³Helium-Isotopenverhältnisses in den Quellwässern ergab deren Alter mit bis zu 10 Jahren und erlaubte in Verbindung mit den Flussmessungen eine Abschätzung der Elastizität der Wasserverfügbarkeit über die Zeit. Die Nutzung der natürlichen Ressourcen im Wadi Bani Awf begann vermutlich im frühen 3. Jahrtausend v. Chr. durch eine nomadische Hirtenbevölkerung. Die dauerhafte Besiedlung von Balad Seet dürfte bereits in der ersten Hälfte des frühen 1. Jahrtausends v. Chr. eingesetzt haben. Sie wurde vermutlich von Siedlern aus al-Hamra auf der Südseite des Hajar-Gebirges initiiert. Es gibt Hinweise darauf, dass bereits zu dieser frühen Zeit in Balad Seet die ersten einfachen Bewässerungskanalsysteme entstanden sein könnten. Die Kombination von biophysikalischen Messergebnissen und archäologischen Befunden erlaubte auch eine erste Abschätzung der Besiedlungsdichte dieser Oase über den Zeitraum ihrer vermutlich dreitausendjährigen Geschichte. Die wechselnde Knappheit von Ackerland und Wasser sowie deren letztliche Optimierung durch den Bau verschiedener *aflaj*-Kanalsysteme dürften wesentliche Triebkräfte für die Entwicklung und den Bestand der Oase gewesen sein.

Résumé: Histoire de l'établissement d'une oasis de montagne au Nord Oman – Recherches d'usage du terrain et d'archéologie

Pour révéler l'histoire de l'établissement d'oasis du Nord Oman, des mesures biophysiques et des recherches archéologiques ont été conduites dans l'oued Bani Awf et son oasis amont, Balad Seet. La collecte des données s'est déroulée d'avril 2000 à avril 2003. Elle repose sur le lever d'une carte de l'oasis en 3 dimensions comprenant les principaux aménagements agricoles et hydrauliques. De nos jours à Balad Seet, 2800 palmiers dattiers sont plantés sur une superficie totale de 8,8 ha et 4,6 ha sont subdivisés en 385 petites parcelles vouées aux cultures de blé, orge, sorgho, avoine, luzerne, ail, oignon, citrons verts et bananes. Une datation au ¹⁴C d'une pièce de charbon prélevée à la base du

principal système de terrasse établit son âge à 911 ± 45 ans. Les mesures mensuelles des flux de sortie des quatre principaux canaux (*aflaj*) indiquaient un flux maximal de 32 m³ h⁻¹ auquel le principal *aflaj* contribue pour 78%. Au cours des périodes de sécheresse les flux de sortie moyens décroissaient de 3% par mois avec, cependant, de significatives différences entre sources. Une analyse du rapport tritium/³hélium de l'eau conduisait à estimer l'âge moyen de l'eau à jusqu'à 10 ans environ, ce qui, avec les données de flux, donnait une idée de l'élasticité temporelle de l'écoulement des sources. La première occupation humaine, par des éleveurs, de l'oued Bani Awf remonte probablement au 3^{ème} millénaire BC alors que la première occupation de Balad Seet remonte au début du 1^{er} millénaire BC. Probablement, initiée par migrants provenant d'al-Hamra, un village du sud des monts Hajar. L'écoulement des sources étant abondant et stable, même en période de sécheresse, la construction du premier système d'irrigation de Balad Seet peut remonter à ces premiers temps. La combinaison de données archéologiques et biophysiques permettait d'évaluer la capacité de charge de l'oasis au cours des trois millénaires de son existence probable. Les variations du manque de terre et d'eau et leur optimisation par la construction de divers *aflaj* ont été les forces directrices majeures du développement et de l'existence continue de l'oasis.

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