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Prehistoric Human Ecodynamics in the Rub Al-Khali Desert: Results of Remote Sensing and Excavations in Dubai, United Arab Emirates

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PREHISTORIC HUMAN ECODYNAMICS IN THE RUB AL-KHALI DESERT: RESULTS OF REMOTE SENSING AND EXCAVATIONS IN DUBAI, UNITED ARAB EMIRATES

PREHISTORIC HUMAN ECODYNAMICS IN THE RUB AL-KHALI DESERT: RESULTS OF REMOTE SENSING AND EXCAVATIONS IN DUBAI, UNITED ARAB EMIRATES

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Environmental Dynamics

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ABSTRACT

Archaeological investigations in the Emirate of Dubai, UAE conducted by the Dubai Department of Archaeology and the University of Arkansas demonstrate that the desert inland of the Oman Peninsula was occupied not only during the Arabian Neolithic (8000-4400 BC), when the region experienced a moist period referred to as the Holocene Climatic Optimum (HCO), but also during the more arid millennia following the decline of the HCO into the Christian Era. During this period, desert settlement clustered near a band of oases, in contrast to the more widespread spatial distribution of remains of nomadic pastoralists from the Neolithic. Excavations at al-Ashoosh and Saruq al-Hadid, two sites at the southern end of the Emirate of Dubai, coupled with analysis of dune accumulation at Saruq al-Hadid through ground-penetrating radar, and a regional analysis of groundwater availability based on satellite imagery, reveal the varied landscapes that made desert settlement possible and provide a chronology of inland settlement and landscape transformation for a time and place that was not well documented before this study. Evidence presented in this dissertation suggests that these inland oases were dynamic environments that influenced patterns of desert settlement and land use, and in turn were shaped by the varied activities of prehistoric people. Periodic occupation at both sites began with seasonal encampments during a third millennium pluvial and resumed during arid phases in the second and first millennia. Late occupation was likely supported by shallow groundwater that was fed by orographic rainfall in the Oman Mountains, rather than by precipitation on the desert plain. Occupation during the first millennium BC was distinct from earlier periods in that is showed clear integration into a regional political and economic network, first in its incarnation as a cultic site in the Iron Age II period (900-600BC), and following that as a center for metal working at the end of the first millennium. A hiatus in settlement at Saruq al-Hadid following the

Iron Age II period and roughly coincident with the Iron Age III (600-300 BC) is marked by significant dune accumulation. The question remains whether this period of active sediment redeposition was a local or regional phenomenon, but the case is made here that it was a regional phenomenon triggered by the destabilization of sand dunes as natural vegetative cover was removed by growing herds of grazing animals and an expansion of agriculture in the Iron Age II period. These findings fill gaps in the histories of climate and settlement of southeast Arabia and more broadly, help to move us closer to understanding the complex exchanges between changes in climate, landscapes, and human activities in arid regions through time and worldwide.

This dissertation is approved for
Recommendation to the
Graduate Council

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Dr. Jesse Casana

Dissertation Committee:

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Dr. Marvin Kay

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Dr. Kenneth L. Kvamme

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Fieldwork would have been impossible without financial and professional support from Dr. Hussein Qandil, director of the Dubai Department of Archaeology, His Excellency Khalid bin Sulayem, Director General of the Department of Tourism and Commerce Marketing, and the generous support and encouragement of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Ruler of Dubai and Vice President and Prime Minister of the United Arab Emirates. By their grace, this research could not have been possible by support that came through the Dubai Department of Tourism and Commerce Marketing (DTCM). I must thank the DTCM for their ongoing support of the Dubai Desert Survey mission, and I owe much to the Department of Archaeology staff, including Hasan Zein, for their support, guidance in Dubai and the field, and for their hard work.

Many people volunteered their time and expertise to contribute to the Dubai Desert Survey research projects and intentionally or unintentionally, to my dissertation research. I am grateful to Dr. Katie Adlesberger, Dr. Sabrina Billings, Dr. Leslie Frame, Eric Jensen, Carlos Ochoa, and Dr. Jennifer Smith their work and companionship in the field during the 2007 expedition. My dissertation fieldwork in 2008 and 2009 benefitted from the help and expertise of Dr. Jenifer Smith and Dr. Jeffrey Szuchmann who assisted with excavation, survey and mapping in 2008 and Dr. Virginia Herrmann and Michael Fisher who excavated at Saruq al-Hadid in 2009.

There were many sources of financial support for this project. Initial support came from the Robert L. Stigler Jr. Scholarship through the Department of Anthropology and the Middle East Studies Program at the University of Arkansas. A Doctoral Dissertation Research Improvement Grant (#0820211) from the National Science Foundation, administered by Dr John Yellen, helped to cover a large part of the 2008-2009 field season and the processing of specimens collected in the field. The proposal process was guided by the helpful and patient people of Research Support and Sponsored Programs at the University of Arkansas. Optically-stimulated luminescence dating services was made possible by the Chicago Luminescence Award for graduate students granted by the University of Illinois at Chicago Luminescence Dating Research Laboratory directed by Dr. Steve Forman, who also provided me with guidance for collecting samples and interpreting the results. Former director Fred Limp and current director Jackson Cothren of the Center for Advanced Spatial Technology (CAST) at the University of Arkansas graciously provided access to field equipment and computing resources through the Center for Advanced Spatial Technologies at the University of Arkansas, and have supported the advancement of my career in tangible and intangible ways. Many other CAST employees served as sounding boards for ideas, and provided technical at various stages of this research, most notably Malcolm Willimason, John Wilson and Brian Culpepper who provided technical and logistical assistance. Research that relies on technical applications necessarily draw upon the support of many specialists, and for me this extends outside of CAST: I am very grateful to Dean Goodman of Geophysical Research Laboratory for his 'on-call' accessibility when I have questions while using GPR-Slice software.

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The members of my dissertation committee have provided me with much more than editorial help throughout my years as a student at the University of Arkansas, and each have provided lessons and inspiration in different ways which I will carry with me forever. One common strength that all three on my committee share is the ability to develop a strong research question that can be addressed through archaeological investigations. I hope to have acquired some of their skill. I owe much to Dr. Kvamme for providing training opportunities in the field and for serving as a role model for my style of inquiry and technical skill. As my master's degree advisor, Dr. Kay helped to provide a foundation for my academic career and has been an unfailing source of advice and support ever since I arrived on campus.

As the director of the Dubai Desert Survey, my primary adviser, Jesse Casana offered this project as an option for dissertation research and has worked closely with me providing guidance, assistance, access, and constructive criticism in this endeavor. Since I have known him, I have looked up to Dr. Casana as a role model for success in the field, and my association with him has been transformative. On a personal level, I have been able to go to Dr. Casana frequently for both professional and personal advice and have always come out better with his council. At the heart of it all, whatever past and future success I have or may experience as an archaeologist in the Middle East is owed in some part to Dr. Casana, who introduced me to the region, included me in some of his many research projects abroad, and allowed me the privilege of representing him and his projects and our research at professional conferences. These experiences are the foundation for my professional career and have already borne fruit in the form of research and employment opportunities. Dr. Casana's commitment and contributions to my personal success come from the type of patience and perseverance that one could expect from family.

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DEDICATION

For Henry and Virginia.

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In Prep. Herrmann, Jason T.
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CHAPTER 1

INTRODUCTION

The papers compiled for this dissertation represent the results of archaeological investigations at the sites of al-Ashoosh and Saruq al-Hadid, including an examination of the regional landscape of the western coast plain of the Oman peninsula. The two study sites, located in the dunes and desert pavements of the southern end of the Emirate of Dubai, are enigmatic in that they were occupied during times when the deserts were thought to be largely uninhabited and are not currently near any suitable hydrologic or other natural resources that could sustain occupation for any substantial amount of time. The circumstances surrounding the establishment and persistence of these sites through a series of environmental changes prompts a fascinating set of questions for archaeologists interested in the settlement patterns of the region and continues a longstanding tradition of inquiry of settlement patterns in semi-arid and arid lands. With respect to the regional focus, the presence of these sites suggests that models for settlement during the most arid periods in the history of southeast Arabia deserve some reconsideration. Moreover, results from this study add detail to the environmental history of the landscape of the desert interior of the Oman Peninsula in both the spatial and temporal dimensions.

This research was designed to build a foundation for an examination of the interactions between humans and their ancient environments by building chronologies of settlement and land use at the study sites and a chronology of environmental change at both local and regional scales. The rediscovery of Saruq al Hadid is credited to Sheikh Mohammed bin Rashid al Maktoum, who brought it to the attention of Dr. Hussein Qandil, then director of the Dubai Department of Archaeology in 2002. Qandil's assessment of the site and trial excavations (Qandil et al. 2005) were followed by five seasons of archaeological excavations led by the Jordanian Department of Antiquities from 2003-2008 (Al-Khraysheh and Nashef 2007). Research by the team from the University of Arkansas began in 2006 as part of a joint project with the Dubai Department of

Archaeology, the Dubai Desert Survey, which is dedicated to documenting the settlement and environmental histories of the region. In the 2006-2007 seasons, the Dubai Desert Survey conducted intensive surface survey within a 2km radius surrounding Saruq al-Hadid and including al-Ashoosh (Casana et al. 2009).

Most of this research has centered on Saruq al-Hadid whose prominence in the region can be attributed to two aspects of the site. First, is its material wealth; prior investigations at Saruq al-Hadid have produced abundant evidence for metal production and a vast collection of fine artifacts at the site, even though it is located 50-100 km from any known water, ore, or fuel sources. Despite a lack of evidence for direct access to materials necessary for metal fabrication, the site features a slag crust that covers a 1.5 hectare area, a record of intensive metal production that would have required the transport of large quantities of ore and fuel over long distances.

Aside from its impressive material wealth and puzzling location, Saruq al-Hadid is retains special status among archaeological sites in the Oman Peninsula as a stratified archaeological site located in a wasting environment. Documented portions of the site cover approximately one square kilometer and feature archaeological deposits up to seven meters in depth, from hearths carved into the desert pavement up to the modern dune surface, where a protective crust of copper slag has most likely slowed aeolian deflation. Stratified archaeological deposits like these are rare on the Arabian Peninsula, and documenting the sequence of occupation and sedimentation at the site was the priority of the excavations undertaken in 2009.

In Chapter 2 is a report of the results of the 2008-2009 excavations at Saruq al-Hadid, which while small in comparison to the area excavated by the earlier Jordanian project, have been nonetheless critical in developing a clear interpretation of the site. These investigations expanded the known history of settlement at the site to include third, second and late first millennium occupations in addition to the well-known Iron Age II phase. The results of these investigations also move the period of bronze and iron artifact production at Saruq al-Hadid to the late first millennium phase, which fits better with the regional chronology of metalworking technology. Importance of this site for understanding land use and settlement patterns in the deserts of the Oman Peninsula increases as the picture of occupation and land use at Saruq al-Hadid becomes clearer through tightly controlled excavations. The chronology of occupation outlined in Chapter 2 shows that Saruq al-Hadid likely began as an oasis site where nomadic pastoralists during the Umm an-Nar and Wadi Suq periods camped and took advantage of a relatively well-watered landscape. In contrast, the Iron Age II remains at the site do not bear any definite signs of settlement per se, instead, the material culture suggests that Saruq al-Hadid may have been one of a number of sites spread across the Oman Peninsula that were dedicated to a snake cult. The site is capped by waste from an intensive metalworking operation that appears to have taken place during the later first millennium BC. The remains from both the Iron age II and later remains from the site tie Saruq al-Hadid into a regional network of settlement and trade centers and suggest that, like the mountain piedmont and coasts, the sandy desert expanses of the Oman Peninsula held economic and ritual importance in the overall landscape.

A ground-penetrating radar (GPR) survey was conducted at Saruq al Hadid as part of the 2007 investigations with the Dubai Desert Survey A three-dimensional model of aeolian deposits interleaved with layers of cultural materials was created from the results GPR survey at Saruq al Hadid, and is presented in an article that comprises Chapter 3. Time slicing and the creation of isosurfaces show areas where artifacts are concentrated between layers of aeolian sands. Analysis of GPR facies permitted the creation of a three-dimensional model of the dune interior that separates major deposits by horizons. This sequence, paired with absolute dates from related excavations, shows that the phases of occupation and sediment accumulation recorded at Saruq al-Hadid are consistent with chronologies of environmental change and settlement proposed for the third through first millennia BC on the basis of other datasets. Results from this survey also provide some context for artifacts collected in prior excavations and offer valuable insight into the physical processes that shaped the present manifestation of the site. It is argued that the character of these sedimentary deposits may also constitute evidence for a period of environmental transformation at the end of the Iron Age II (1100-600 BC) that is yet only poorly attested in the known paleoenvironmental record of the region.

Chapter 4 provides some regional environmental context for the evidence of occupation document in test excavations at al-Ashoosh and Saruq al-Hadid. Al-Ashoosh (also Al Ashush (Qandil 2005)) is a scatter of cultural debris located on a lone, low dune that cuts across a broad inter-dune plain that takes its name from a nearby well which is now dry. The site was surveyed by the Jordanian expedition to Dubai and by the Dubai Desert Survey. The site is notable for the twenty-one hearths that have been found exposed across the surface of the dune, most of which were marked by thin lenses of ash and fire-cracked flint. At the center of the distribution of hearths stands a low mound of burnt bone and stone, interpreted as a midden and the presence of at least one tanour. Diagnostic ceramics indicated that the site was occupied during the Umm an-Nar period (Casana et al. 2009, 37; Qandil 2005, 126).

Chapter 4 makes use of satellite remote sensing data to examine the potential for upwelling freshwater in the mid Holocene that, at certain points in the prehistory of the region, likely breached the ground surface to create inter-dune lakes or oases. The chapter closes with a suggestion of how this persistent resource influenced settlement patters between occupation episodes.

After the close of this dissertation research in 2009, a new excavation effort was initiated at Saruq al-Hadid under the direction of Dr. Qandil and the Dubai Desert Survey, and that project has now uncovered a collection of artifacts comparable in size to those recovered by the Jordanian team. This effort, which is ongoing, is successfully generating an extremely rich record of Dubai's cultural history (Qandil et al. In Press). Detailed reports of the ongoing excavations and analysis of artifacts recovered from them will appear in future reports and will build on the chronological foundation established here.

CHAPTER 2

A SEQUENCE OF INLAND DESERT SETTLEMENT IN THE OMAN PENINSULA: 2008-2009 EXCAVATIONS AT SARUQ AL-HADID, DUBAI, UAE

By Jason T. Herrmann, Jesse Casana and Hussein Suleiman Qandil

Paper Published in *Arabian Archaeology and Epigraphy*

ABSTRACT
The 2008–2009 excavations conducted by the Dubai Desert Survey at Saruq al-Hadid, Dubai, have transformed our interpretation of the site from an Iron Age bronze production centre to a site with multiple occupations over the course of more than three millennia; they underline the importance of this site for understanding land use and settlement patterns in the deserts of the Oman peninsula. Saruq al-Hadid probably began as an oasis site where nomadic pastoralists during the Umm an-Nar and Wadi Suq periods camped and took advantage of a relatively well-watered landscape. In contrast, Iron Age remains at the site do not bear any definite signs of settlement per se; instead, the material culture suggests that Saruq al-Hadid may have been one of several sites in south-east Arabia that were dedicated to a snake cult. The site is capped by waste from an intensive metalworking operation that appears to have taken place during the later first millennium BC. Iron age and later remains from the site tie Saruq al-Hadid to a regional network of settlement and trade centres and suggest that, like the mountain piedmont and coasts, the sandy desert expanses of the Oman peninsula held economic and ritual importance in the overall landscape.

Keywords: archaeology, United Arab Emirates, Dubai, Iron Age, Wadi Suq, snake cult, ground-penetrating radar, optically stimulated luminescence

INTRODUCTION

This paper presents the results of archaeological investigations at Saruq al-Hadid, a large site located within a dune field in the desert of the Emirate of Dubai, UAE. Saruq al-Hadid is both enigmatic and spectacular, presenting a fascinating problem for archaeologists. While the site has produced abundant evidence for metal production and a vast collection of elite goods, it is located 50-100 km from any known water, ore, or fuel sources. Despite a lack of evidence for direct access to materials necessary for metal fabrication, the site features a slag crust that covers a 1.5 hectare area, a record of intensive metal production that would have required the transport of large quantities of ore and fuel over long distances.

Aside from its impressive material wealth and puzzling location, Saruq al-Hadid is notable, or perhaps wholly unique, in that it is a stratified archaeological site within the aeolian sediments of an active dune field (Figure 1). Documented portions of the site cover approximately one square kilometer and feature archaeological deposits up to seven meters in depth, from hearths carved into the desert pavement up to the modern dune surface, where a protective crust of copper slag has most likely slowed aeolian deflation. Stratified archaeological deposits like these are rare on the Arabian Peninsula, but at Saruq al-Hadid, deposits preserve a history of settlement now shown to span nearly 3000 years.

Saruq al-Hadid was first identified in 2002 by Sheikh Mohammed bin Rashid al Maktoum, who brought it to the attention of Dr. Hussein Qandil, then director of the Dubai Department of Archaeology. Qandil's assessment of the site and trial excavations (Qandil et al. 2005) were followed by five seasons of archaeological excavations led by the Jordanian Department of Antiquities from 2003-2008 (Al-Khraysheh and Nashef 2007). This paper presents the results of small-scale excavations at Saruq al-Hadid undertaken in 2008-2009 as part

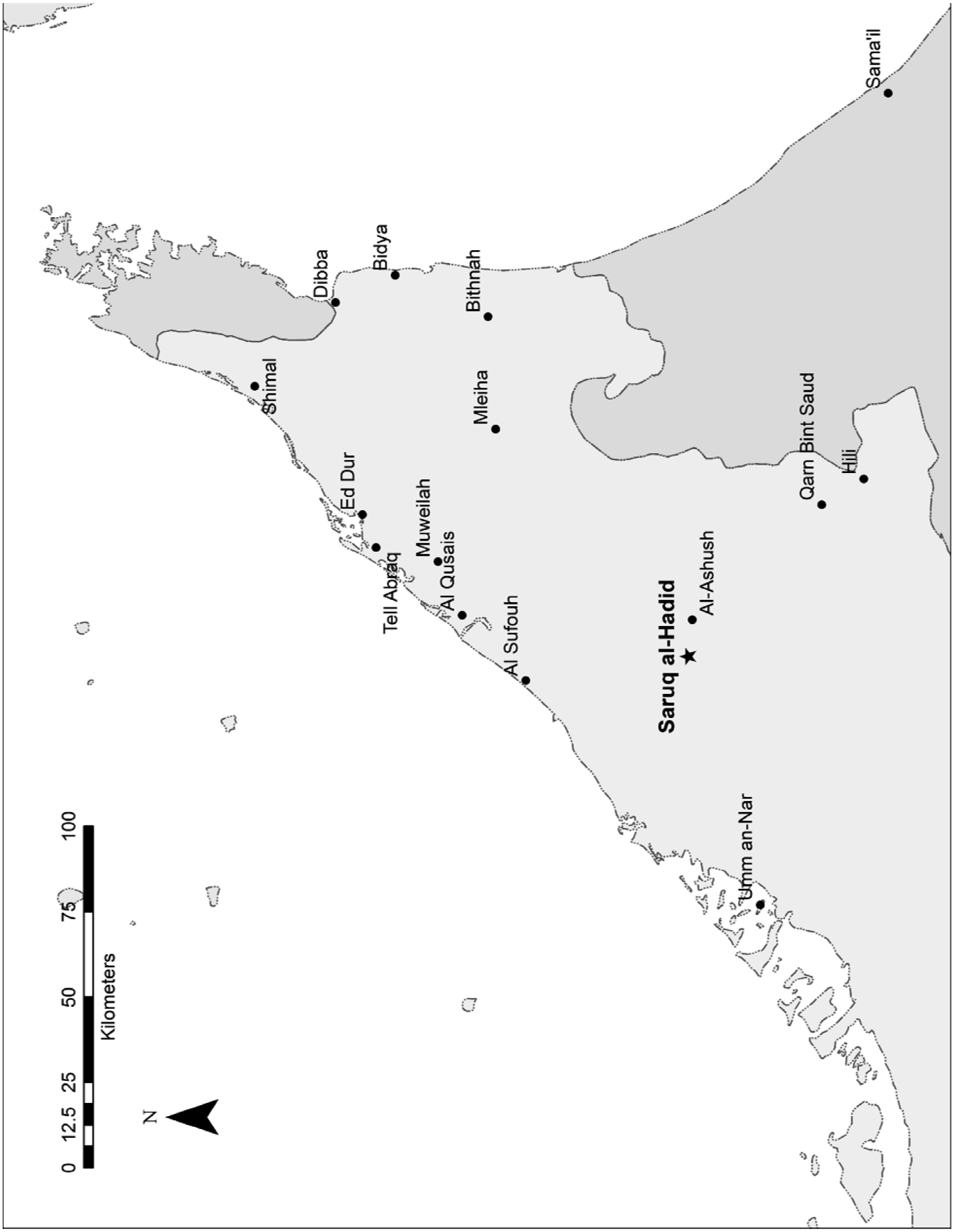

Figure 1: Location of Saruq al-Hadid and archaeological sites mentioned in the text.

of the Dubai Desert Survey, a joint project between a group of American researchers and the Dubai Department of Tourism and Commerce Marketing (Casana et al. 2008). Our goals in this effort were to recover a stratified sample of artifacts and sediments that could provide a series of absolute dates for the site. Our excavations, while small in comparison to the area excavated by the earlier Jordanian project and to that of the ongoing excavations by the Dubai Department of Archaeology, are nonetheless critical to the interpretation of the site, as they provide the best dating evidence yet recovered, showing occupation from the mid-third through the late first millennium BC. Following an overview of the environmental context and excavation history at Saruq al-Hadid, we present a detailed report on the excavations of 2008-2009 and our preliminary interpretations of the changing character of the site over its long occupational history.

Environmental Setting

Saruq al-Hadid lies in a field of quartzitic sand dunes (Goudie et al. 2000) in the southeastern end of the emirate, just less than a kilometer from the *de facto* border with the emirate of Abu Dhabi. Dunes in this area can sustain a very modest covering of seasonal grasses during the moist months of December and January, but are otherwise barren of vegetation, save for the very occasional Ghaf (*Prosopis cineraria*) tree anchored to deeper, hardened dunes or to the gypsum pavement that seems to underlie much of this dune field. According to their size and the persistence in the orientation of ridgelines and location, these dunes are best described as meso-dunes (Warren and Allison 1998). However, the effects of diurnal changes in wind patterns can be seen as constantly changing ephemeral surface formations, with sustained sandstorms resulting in more drastic reorganization. This dune field is protected on the north side by what could be interpreted as a deflated linear megadune, oriented more or less transverse to the northwesterly Shamal winds.

The site is likely located at the outer reaches of an alluvial fan that developed in the Pleistocene and during the wettest phases of the Holocene Climatic Optimum (HCO). The dunes at Saruq al-Hadid rest on a gypsum pavement that has captured stratified layers of sand pebbles that have been carried out from the Oman Mountains. These well-stratified sediments are cemented and sealed by a gypsum crust, indicating that the area was once an inland sabkha, created when the water table was within capillary reach of the surface and sediments accreted when trapped by surface water. The sediments in this layer have not been dated, but as with many sedimentary deposits in Arabia, this sabkha surface has likely been eroded by wind action to some degree after desiccation and before it was sealed with layers of aeolian sands. The first layer of sand, a thin light gray layer, has been dated to 5821 ± 282 BP through optically stimulated luminescence (OSL) (Brükner and Zander 2004), perhaps marking the commencement of dune accretion at the site.

The depth of the sands above the natural gypsum floor vary from a thin coating on exposed pan surfaces between dune ridges to the aforementioned seven meters, and evidence of dune mobilization that has resulted in the re-deposition and exposure of archaeological materials is found throughout the landscape surrounding Saruq al-Hadid. East of the central mound with the main slag deposit, several dense bone middens can be found deposited on the gypsum pavement or on what appear to be older, more stable dune surfaces.

Today there is no evidence of available fresh water in the area, although the modern water table is quite shallow, only two meters below the surface in some places. Several historic wells, notably the Al-Ashoosh wells just 8km to the southeast of Saruq, took advantage of this shallow ground water to provide water for camels traveling through the desert.

History of Archaeological Investigations

Following the discovery of Saruq al-Hadid in 2002, a two-meter square sounding was opened by Qandil (et al. 2005). The upper three meters of the excavation consisted of recent dune deposits, while cultural materials, identified as dating to the first millennium BC, were restricted to the lowest 50 centimeters of the excavation trench. These limited investigations produced an impressive inventory of objects including diagnostic ceramics, chlorite and soft-stone vessels, dozens of beads, and many copper or bronze artifacts including arrowheads, tweezers, axe heads, dipper handles, a fish hook, models of snakes, bracelets, rings, pins, knives and a spouted bowl (Qandil et al. 2005: 132).

A fence was erected in 2003 to protect the central slag-covered dune where exposed artifacts were most readily encountered. Investigations led by a team from the Jordanian Department of Antiquities began in 2003, kicking off a five-year project at Saruq al Hadid and other sites in the immediate area. A large excavation was opened on the slag-covered dune, along with three other excavation trenches on other parts of the site (Figure 2). By the time the project ended in 2008, the Jordanian team excavated an estimated 4,000m^3 of dune sands at depths of 5-7 meters terminating at the gypsum pavement, concentrating on the large slag mound at the site's core. Their work, published in a recent volume (Al-Khraysheh and Nashef 2007), produced an extraordinary collection of Iron Age artifacts, some of which are discussed below, perhaps only comparable in size and variety to the metal hoard at 'Ibri/Selme (Yule and Weisgerber 2001) or the grave goods from Qarn Bint Saud (Abu Dhabi Museum). This collection of artifacts has

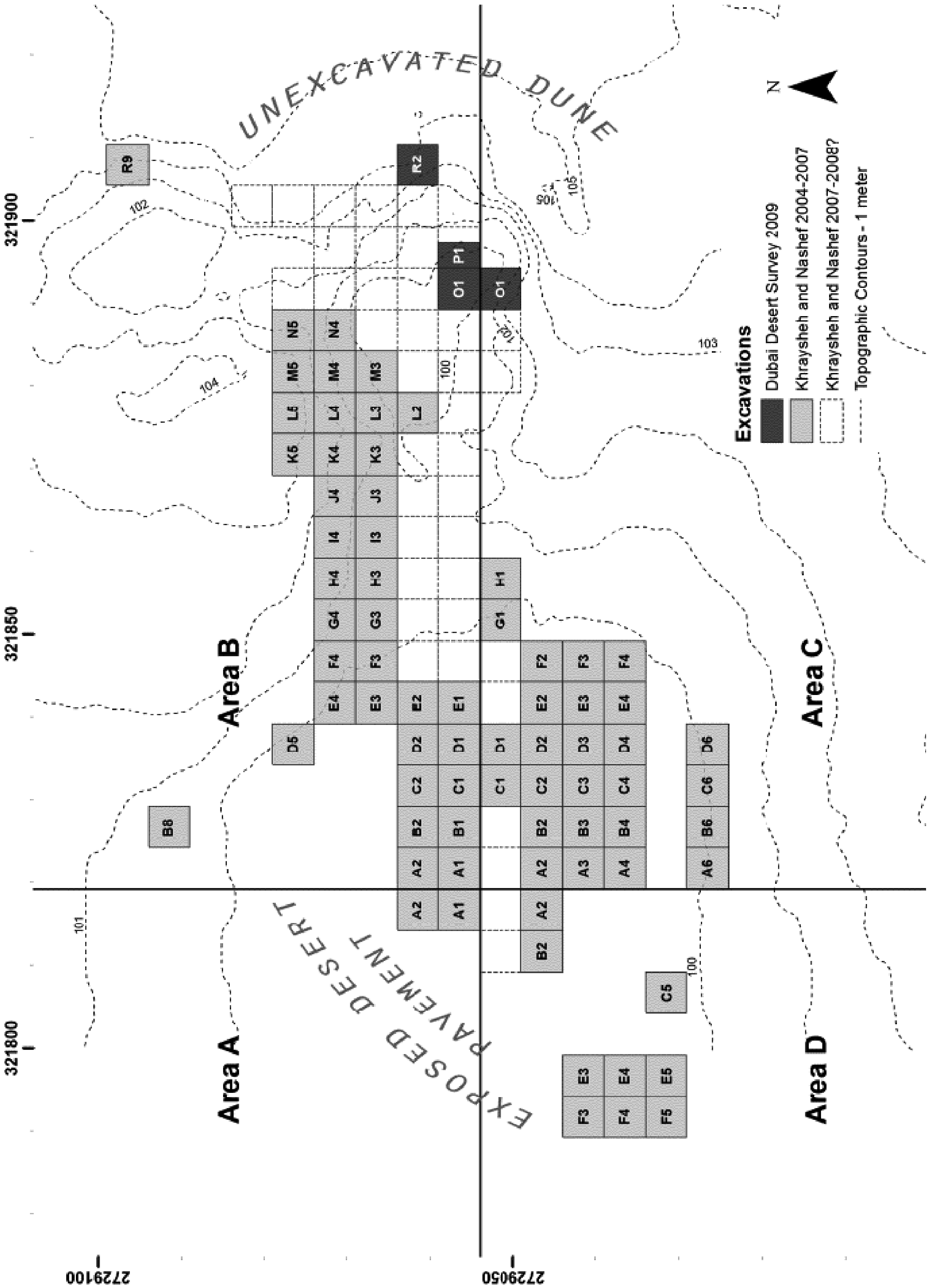

Figure 2: Plan of Saruq al-Hadid with locations of Jordanian Excavations described in Al-Khraysheh and Nashef (2008), the possible locations of excavations by the Jordanian Expedition conducted after 2007 and the locations of Dubai Desert Survey excavations.

spurred an effort to develop a museum dedicated to the site and has already led to discussions of its significance in secondary literature (e.g., Potts 2009).

In 2006, our team began a joint project, the Dubai Desert Survey, dedicated to documenting the settlement and environmental histories of the region. In the 2006-2007 seasons, we conducted intensive surface survey within a 2km radius surrounding Saruq al-Hadid and subsurface geophysical investigations on the unexcavated portions of the slag mound itself (Casana et al. 2008). Surface survey focused on inter-dune depressions that often bottomed out on a petrified dune deposit or desert pavement the site, and located many areas of more ephemeral occupation, ranging from scatters of artifacts to dense concentrations of heavily bleached animal bones, presumably the deflated remnants of piles or pits.

Ground-penetrating radar (GPR) survey at Saruq al-Hadid has been very successful in generating detailed images of sub-surface features. Following exploratory GPR survey in 2006, surveys in 2007 and 2008 covered more than a hectare of the site (Figures 2 and 3), focusing on the central slag mound and mapped sedimentary and archaeological anomalies at depths exceeding six meters (Herrmann, forthcoming). These data are detailed enough to show unconformities that mark buried dune surfaces as well as fine lamination of wind-blown sand deposits that appear between these surfaces (for another example see Bristow et al. 1996).

Following the close of the Jordanian team's excavations at Saruq al-Hadid, our team returned to the site in December 2008 and January 2009 during which time we undertook test excavations focused on the edges of the very large excavation trench left by the Jordanian project. Because cultural deposits are contained within dune deposits, any attempt to excavate the central portion of the site using vertical profiles quickly results in a slumped, eroded surface, which is what our team encountered when we arrived at the site in 2008. Our excavations began

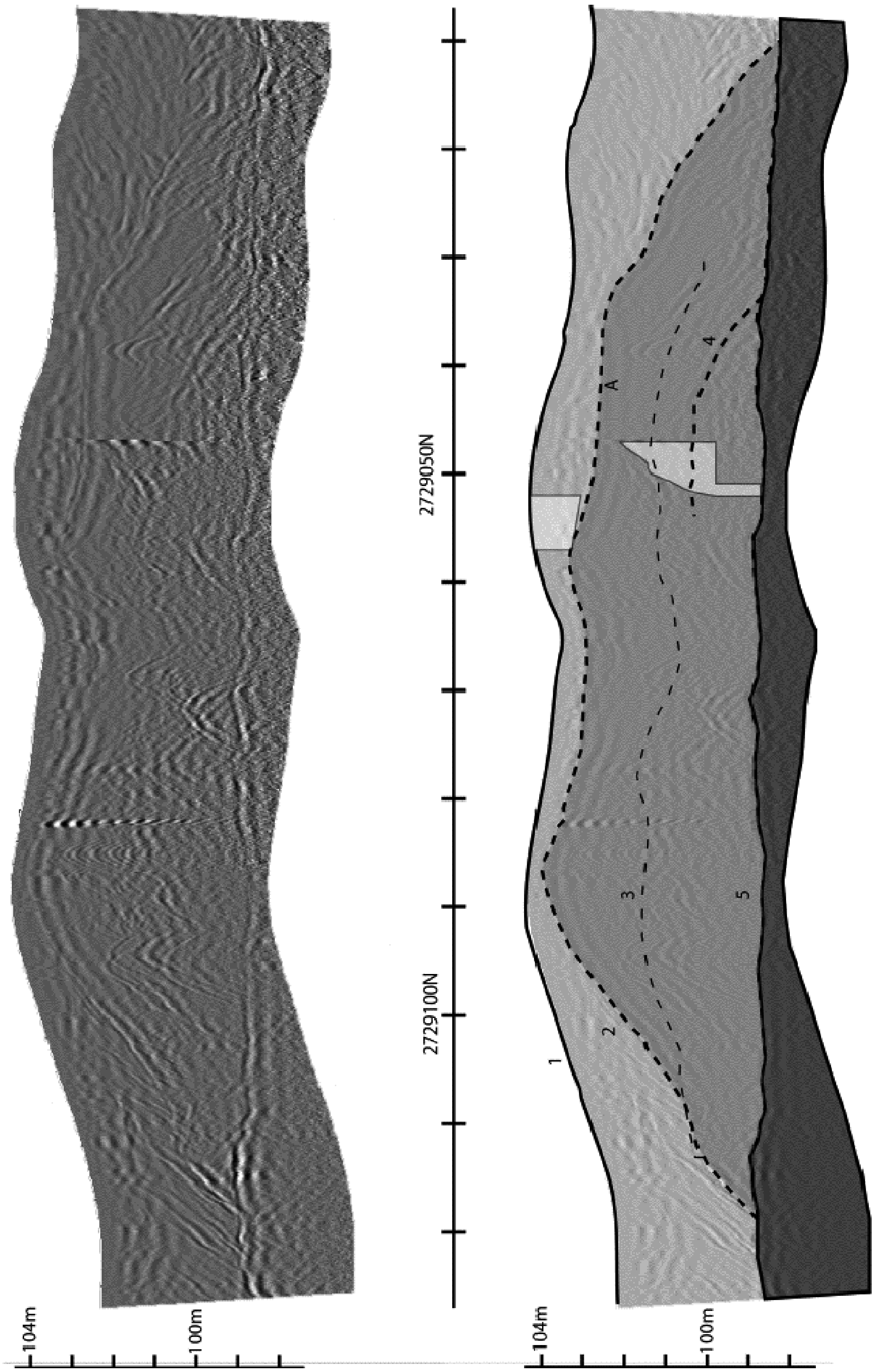

Figure 3: Top: Vertically-exaggerated 120-meter long radar profile. Bottom: Interpretation and approximate vertical locations of operations P1 and R2 and of AMS and OSL samples (see tables 1 and 2). 1) Dune surface. 2) Buried dune horizon. 3) Buried dune interface, Locus 5 signature. 4) Signature of Locus 3. 5) Gypsum desert pavement.

Figure 4: Overview of test excavations B-R2 (left) and B-P1 (right) in easternmost extent of Jordanian excavation trench. Photo taken from desert pavement level facing east.

with a section cleaning of the eastern portion of the Jordanian trench in an attempt to expose the stratigraphic sequence of the site (Figure 4). Following this work, we excavated two small, adjacent soundings at the top and bottom of the section in order to obtain datable materials and a stratified sample of artifacts, including faunal and botanical remains that had not been collected by the Jordanian excavations. This report primarily presents results of our team's investigations at Saruq al-Hadid through January of 2009.

After the close of our work in 2009, a major new excavation effort was initiated at Saruq al-Hadid under the direction of Dr. Qandil, and that project has now uncovered a collection of artifacts comparable in size to those recovered by the Jordanian team. This effort, which is ongoing, is successfully generating an extremely rich record of Dubai's cultural history (Casana and Qandil 2011). Detailed reports of the ongoing excavations and analysis of artifacts recovered from them will appear in future reports. Nonetheless, because our work in 2008-2009 provides the most secure dating evidence for occupation at Saruq al-Hadid, it remains essential to interpretation of the artifacts, the site as a whole, and desert settlement in southeastern Arabia more broadly.

FIELD METHODS

Stratigraphic Profile

The first operation our team undertook in December 2008 was to clear eroded and slumped deposts from a two meter wide section of the existing eastern trench wall, which was cleaned and mapped from the top to the bottom. Several buried dune interfaces were documented and organic samples were collected with the intention of submitting them for AMS dating. As clear exposure and documentation of intact deposits over such a large and unstable exposure proved to be quite difficult with this method, it was decided that traditional excavation trenches should be opened in the vicinity to obtain materials from more secure proveniences. The surface clearing did yield a number of small finds near the upper strata, which are mentioned below.

Operation B-R2

Operation B-R2[1] was placed to aid in mapping the upper layers of stratigraphy on the slag-covered dune (Figures 2 and 5). Two buried surfaces were detected beneath a sheet of clean, recently deposited windblown sand on the dune surface (Locus 1). The uppermost slag surface (Locus 2), which is only one or two slag pieces thick, is no more than ten centimeters in depth and slopes down from the northwest toward the southeast. The second buried surface (Locus 4) is separated from the uppermost surface by a lens of sand containing some slag and artifacts (locus 3). This second buried surface consisted of, besides another crust of slag, several clusters of small, fist-sized fragments of tabular limestone, measuring no larger than 30 cm in diameter. These stones, recorded as loci 5, slope down from the northeast to the southwest, in the direction opposite to the uppermost slag crust. Some stones showed evidence of burning or perhaps chemical weathering around the edges. Considering this, it is possible that these clusters of stone could be the remains of furnace installations or perhaps one furnace that has been scattered as the sands that supported it eroded away.

Beneath this surface lay more sand containing a moderate amount of slag, as well as many bronze arrowheads and small fragments of wood. The northern half (locus 9) of the trench in this lower level featured a significant concentration of bone, including a number of antler cores (Figure 6:h). The southern half of the trench (locus 10) contained noticeably less bone.

[1]Excavations were carried out using the recording system established by the Jordanian and Emirati expeditions at the site to create a dataset that can be integrated with data from previous investigations (Figure 2). All activities were also recorded in the Dubai Desert Survey coordinate system.

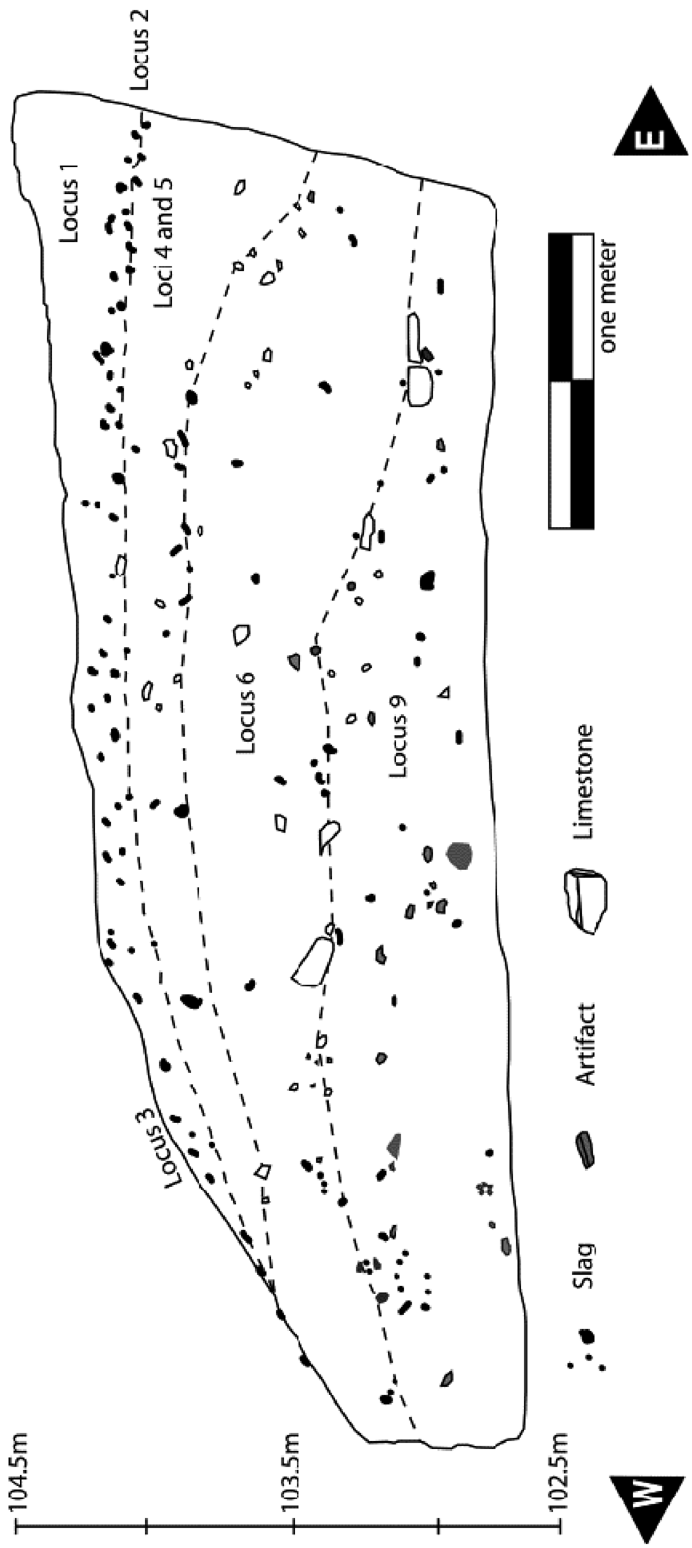

Figure 5: North profile of operation R2.

These remains have not been examined by a specialist, but the antler cores found here and in locus 9 seem to compare well to examples from Mleiha that were identified as oryx (oryx leucoryx) (Mashkour and Van Neer 1999; Mleiha DA-UF1212, photo 1 p. 127; also Stephan 1995, Hoch 1995, Van Neer and Gautier 1993, and Uerpmann 1993). Further excavation at the northern end of the trench revealed an incised ceramic sherd (Figure 7:FN 151). The eastern end of Locus 10 was quite productive in terms of artifacts, yielding several arrowheads and an abundance of large bones. At the lowest level reached in the north at approximately 1.2 meters below the surface (Locus11, circa 102.70masl), deposits of small fish and/or rodent bones began to be abundant. A second incised sherd was recovered from this level (Figure 7: FN213). Time constraints prevented further excavation in operation B-R2, but our success in identifying stratification in the slag deposits and horizontal and vertical distinctions in material distributions demonstrate that this context can produce useful data.

Operation B-P1

Operation B-P1 is a 3 by 5 meter excavation unit placed on a slope formed by erosion of the Jordanian excavation trench and was selected as a convenient access point from which we could stratigraphically excavate a thick layer of organic remains that had been identified through visual inspection of the trench section (Figures 2 and 8). This layer of very small and fragmented bones varies from 20 – 50 cm in thickness and stretches some 12 meters along the east section of the excavation trench left by the previous expedition. Work began from the north end of the excavation, where the slope from the eroding trench section was least steep and the overburden of sand above the top of the bone layer was shallowest. The first 1 x 1 meter of the trench on this

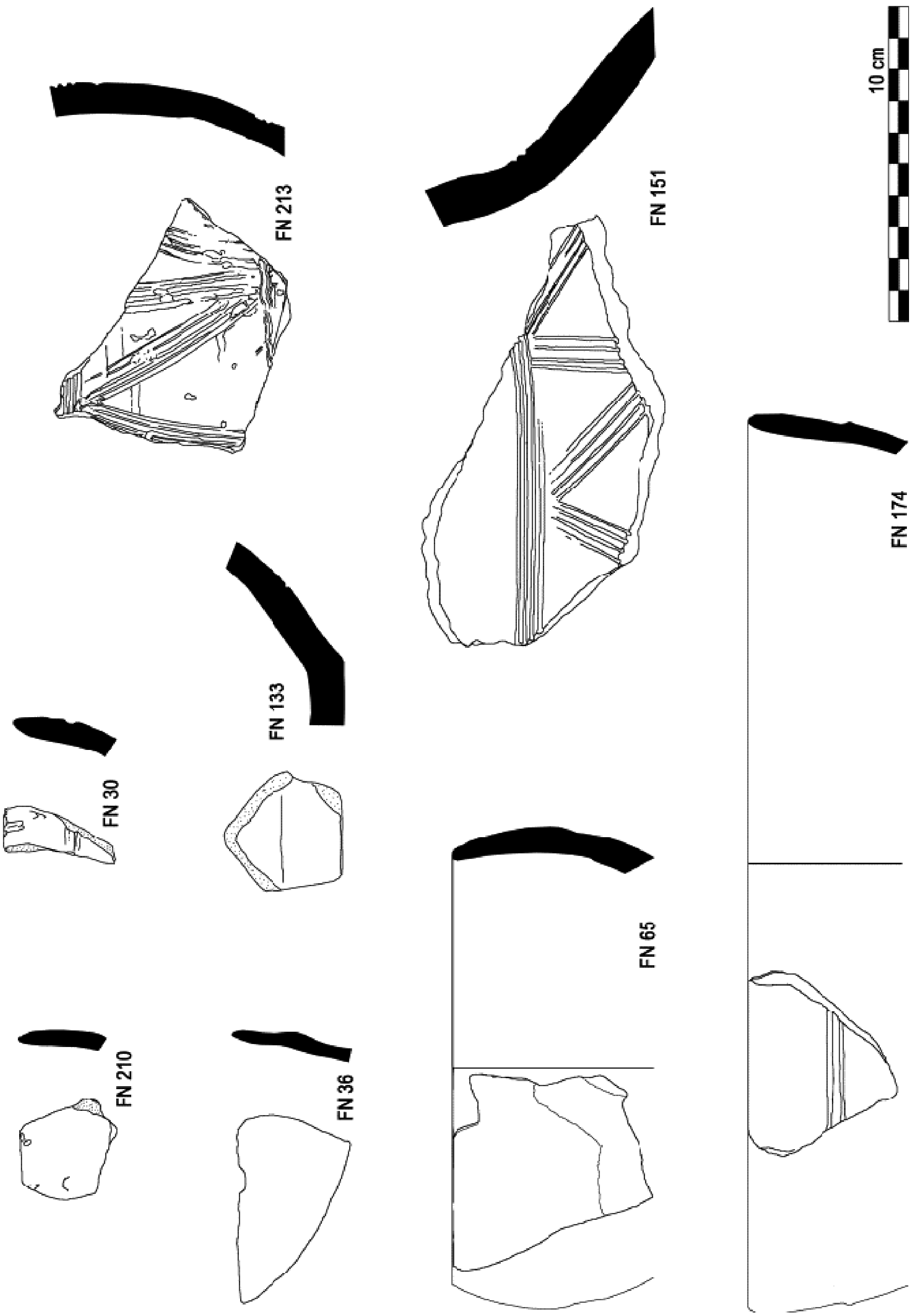

Figure 6: Ceramics from operation B-R2. See Table 3 for descriptions.

end served as a test area for our excavation method, here at the bottom of an eroding wall of sand. As we continued to excavate further south, the overburden above the bone layer became much thicker.

Like in Operation B-R2, the loose sand which is continually eroding from the sides of the larger excavation trench is designated as Locus 1. At this depth, this material is heavily peppered with artifacts eroded out of higher strata, including fragments of bone and iron, arrowheads, beads and ceramic sherds. Any stratigraphic context for finds recorded in Locus 1 is lost, but these are assumed to date to the Iron Age or later.

B-P1: Loci 2 and 4

The first harder-packed, intact layers of sand lying underneath the loose overburden were designated Loci 2 and 4. Locus 4 was found only in the higher, southern part of the operation, and most likely represents compacted earlier slopefall. It was nearly clean of artifacts, save for some very small pieces of slag and wood. It overlies Locus 2, which, however, was the uppermost preserved stratum in the lower, northern part of the operation. Locus 4 is separated from Locus 2 by a band of slag several centimeters thick in some places that denotes a buried dune slope. The continuation of this slag rich horizon is also visible in the section located to the south of operation P1 in an area excavated separately by Dubai Department of Archaeology staff. The slag lens at the interface of loci 4 and 2 slopes considerably down to the north, following the contour of the erosion slope above and is the source of many artifacts from the Iron Age, including two steatite bowls, a bronze bowl, other bronze fragments, stamp seals and several beads. These remains are all thought to eroded out of the slopes above the excavation trench.

B-P1: Locus 5

Locus 2 terminates on a plane trending downward from southeast to northwest, defined by several sizable chunks of limestone, which mark the top of Locus 5. While sands from Loci 2 and 5 were not visibly distinct from each other , the plane that separates them is well-defined by a diffuse scatter of artifacts and the unmodified tabular limestone chunks, similar to the ones described in Operation B-R2. These stones sheltered ash and charcoal deposits from the winds before Locus 5 was buried and samples of these were collected for radiometric age determination. Undisturbed sands from below one of the stones were also collected for age determination using optically stimulated luminescence (OSL) (Table 2: B).

Locus 5 produced a number of artifacts, including bronze fragments, several beads, iron blade fragments, bone and shell, but only two ceramic body sherds. These sherds including one with applique' snakes (FN 141, FN 136) are distinct enough to be securely dated to the Iron Age II (Figure 9)[2]. An upturned, complete steatite bowl (FN 108) was also collected from this layer, sheltering some charcoal and ash which was also collected and dated (FN 109). In all, three charcoal samples from this locus were submitted for radiometric age determination and found to date squarely in the Iron Age II, ca. 940 BC (Table 1: B,C and D) and in general agreement with the OSL date obtained from the sterile sands below (Table 2: B).

B-P1: Loci 3 and 6

Locus 3 is the uppermost surface of the layer of bones, artifacts and other materials that were left exposed by the Jordanian expedition and further revealed through the removal of Locus 5. The

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[2] Appliqué Snakes are a well-documented motif on Iron Age ceramics and are often decorated with circular impressions. Similar examples are known from al Qusais (Taha 2008), Period I at Rumeilah (Boucharlat and Lombard 1997), BB15 near Bisyah in Oman (Humphries 1974) and am-Dhurrah and Hili 14 (Lombard 1985).

Table 1: Saruq al-Hadid AMS dates

Reference Number	Sample number	Material	Op	Loc	Lot	PP/ FN	d13c	F	Error	14c BP	Error	Cal years mean BC	cal years sd
A	AA84596	Charcoal	R2	9	18	140	-21.7	0.6102	0.0035	3,968	46	2481	76
B	AA84590	Charcoal	P1	5	18	107	-10.5	0.7085	0.0035	2,768	39	915	50
C	AA84591	Charcoal	P1	5	19	117	-10.7	0.7047	0.0035	2,811	40	967	55
D	AA85670	Charcoal	P1	5	30	176	-10.8	0.7066	0.0041	2790	46	944	60
E	AA84589	Charcoal	P1	3	7	35	-10.5	0.7024	0.0035	2,837	40	1001	61
F	AA84593	Charcoal	P1	6	39	218	-23	0.6479	0.0033	3,487	41	1813	56
G	AA84594	Charcoal	P1	8	42	223	-11.4	0.6492	0.0032	3,471	40	1799	58
H	AA84595	Charcoal	P1	8	43	227	-13.8	0.638	0.0045	3,610	57	1976	85
I	AA84597	Charcoal	H 3				-10.8	0.6278	0.0075	3,740	96	2164	142
J	AA84598	Charcoal	H 4				-11.1	0.5836	0.0041	4,326	56	2972	80

Table 2: Saruq al-Hadid OSL Dates

Reference Number	Sample	Area	OP	Loc	Lot	PP/FN	OSL age	Age BC
A	UIC2477	C	O1	1	1		2430 ± 270	421 ± 270
B	UIC2481	B	P1	5	30	175	2,870 ± 490	861 ± 490
C	UIC2480	B	P1	7	40		3760 ± 395	1751 ± 395
D	UIC2476	B	P1	9	45		3400 ± 545	1391 ± 545

faunal remains here seem to be quite fragmented and have yet to be examined by a specialist, but it is apparent that there is quite a variety of remains represented here including fish, bird and mammal bones. One exception to the finely crushed and fragmented state of remains in this layer is the skull of a caprid that was observed in the same deposit jutting out from the section immediately outside of the excavation unit described here. There is a considerable amount of charred organic material mixed in with the larger pieces of animal bone here, but once again, there is otherwise no clear physical distinction between the sediments of the very top of the bone layer and the cleaner sediments seen in Loci 2, 4 and 5. This suggests that whatever remnants of a surface that has been detected here is the product of wind deflation and that materials from later, overlying strata that were not preserved may be mixed with the stabilized bone layer. This supposition is confirmed by the early first millennium BC (Iron Age) radiometric date from Locus 3 (Table 1: E). The top of the bone layer slopes down gently toward the south and features stones and artifacts on its surface.

Excavation into the bone layer began with Locus 6, which appears to be among the more stable deposits in the dune. At this point in the excavations, time constraints forced us to limit our work to a 1 x 1 meter square at the north end of Operation P1, since our goal was to create a

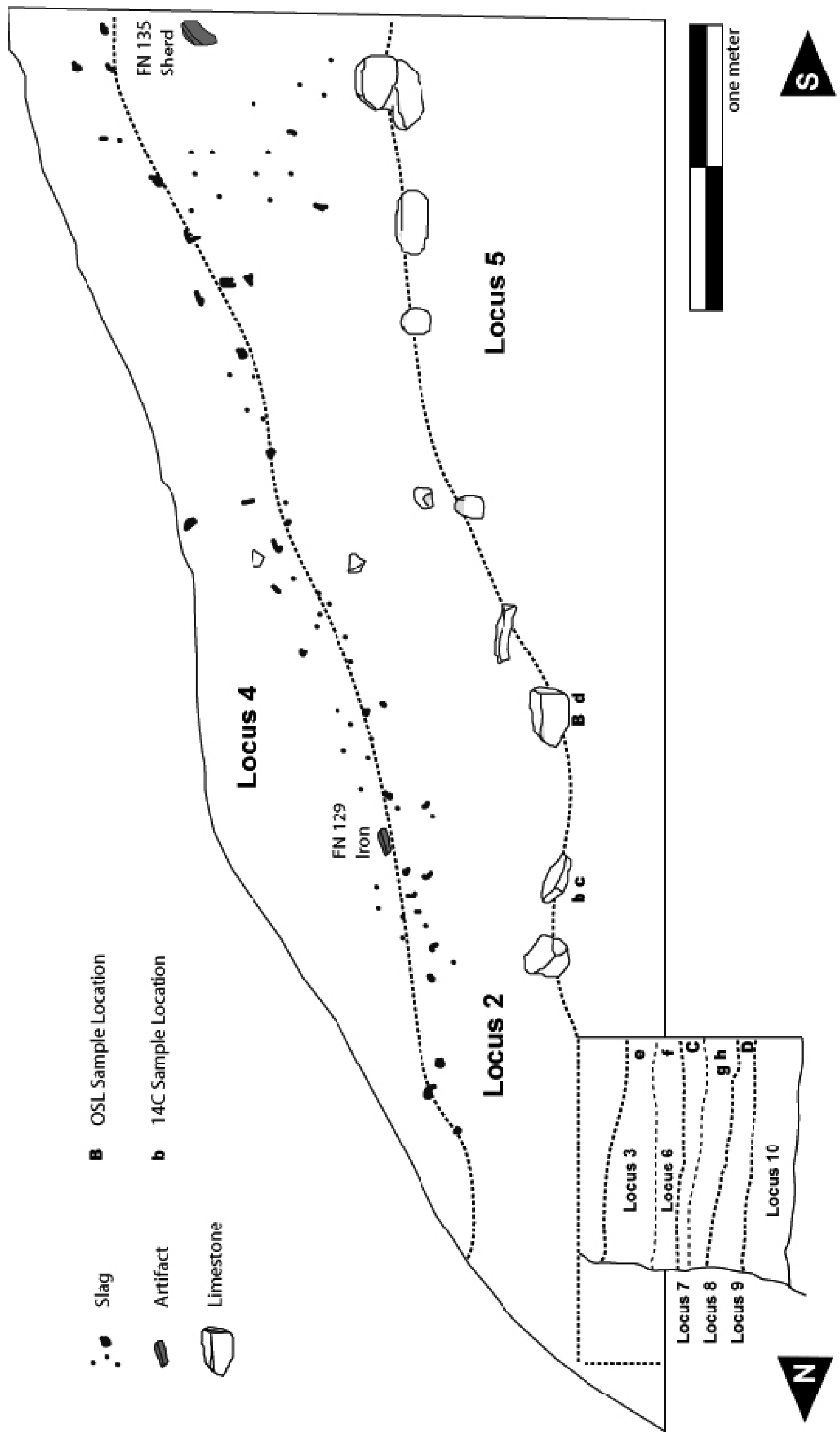

Figure 7: Section drawing of operation P1 showing locations of samples taken for radiometric dating.

stratigraphic column through the entire dune from the slag crust at the top down to the gypsum pavement. In the southwest corner of this probe, the bone layer was thickest at 40 cm, tapering to ca. 20 cm in the northeast corner. Locus 6 can be subdivided into three or four different layers (divided into separate lots during excavation), distinguished by their different proportions of bone and sand. The upper two layers are mostly bone, while the third layer is relatively clean sand with little or no bone present, save for small pockets of dense bone accumulation. We encountered more ashy sand and burnt bone than seen in the upper layers, and the bone was more fragmented at the bottom of Locus 6. The small concentrations of bone below the main layer could be the work of biological turbation.

The most interesting finds from the bone layer were encountered within its top 15 centimeters, where two areas of burnt sand and debris were also found, mixed into the bone layer. It was here that a whole, small steatite bowl (FN189, Figure 11), steatite vessel fragments, a complete bronze bowl, a bronze needle, and several diagnostic sherds were encountered. Ceramics from Locus 6 (Figure 10) appear to be very similar to red buff wares from phase H at Hili 8 (Figure 7: FN210, FN214, FN216) of the early second millennium (Cleuziou 1980: page 64:34). The steatite vessel fragment was exposed on the surface of Locus 3, therefore it is not clear whether it should be associated stratigraphically with Iron Age or earlier levels is not apparent. One steatite bowl fragment (FN 188, Figure 11) is quite similar to an example from Hili 2 (ur-Rahman 1980: 11, 18, fig. 7.1) which believed to postdate the third millennium but whose affiliation is yet unsure. AMS dating of the organic materials recovered from Locus 6 assign this layer to the beginning of the second millennium BC, a date that is consistent with the ceramic comparanda (Table 1: F).

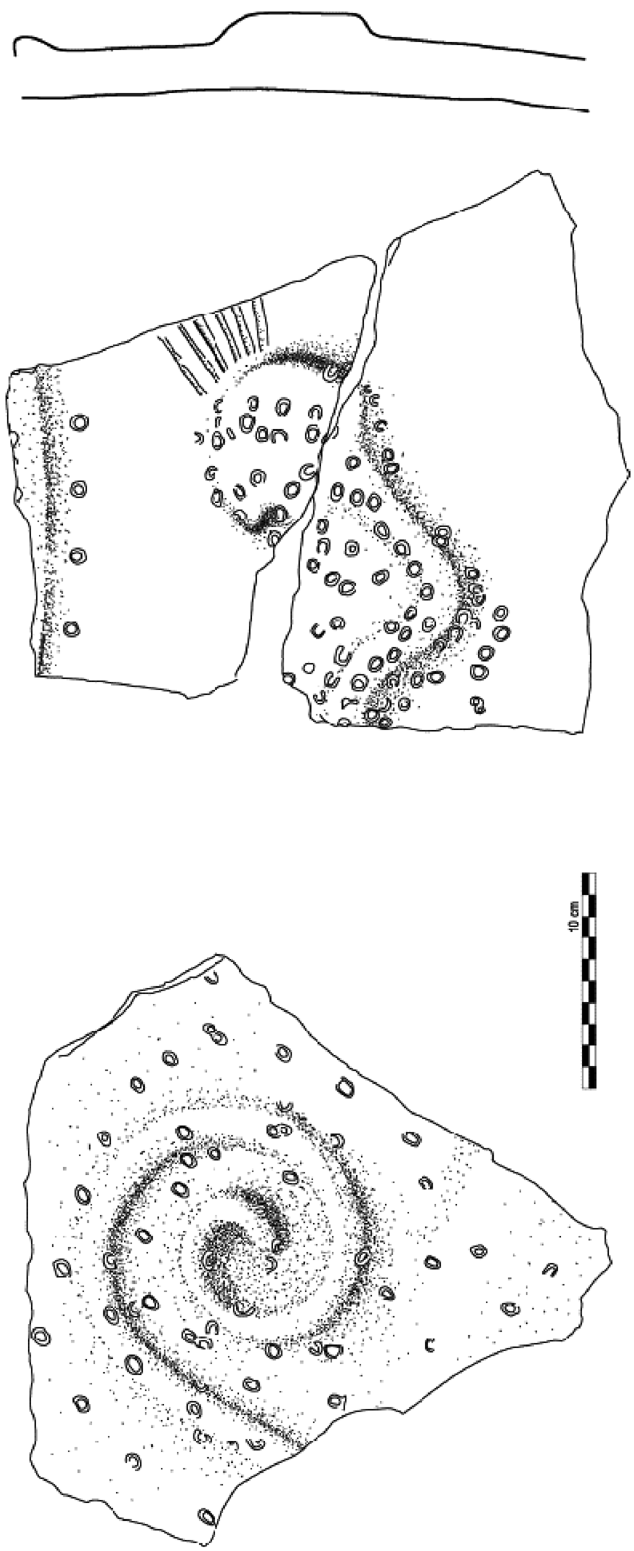

Figure 8: Iron Age ceramics from operation B-P1 (FN135, left) and B-R2 (Surface Find, right). Spiral relief snake with a parallel in Bourcharlat and Lombard 1985: 71:4. See Table 3 for descriptions.

B-P1: Loci 7 through 10

Locus 7 is a virtually sterile layer of sand located below the bone layer, with only the tiniest fragments of bones present. This stratum varies in thickness from 7 to 20 centimeters and sediments were collected from this stratum to date directly using OSL (Table 2: C). Locus 8, below Locus 7, is a lens of sand mixed with ash and bones, with charcoal scattered throughout and one patch of dark, burnt material which produced two samples that could be dated to the second millennium (Table 1: G and H). Locus 9, below 8, is a second layer of clean sand with small bone fragments and sediments from this locus were also dated with OSL (Table 2: D).

Locus 10 designates the consolidated sands that lie at the base of the dune deposits and are essentially fused to the gypsum pavement and is thought to be the same formation dated during the first investigations at Saruq al-Hadid (5821 ± 282 BP, Brükner and Zander 2004)

In short, this small exposure below the layer of dense organic remains, Locus 6, held stratified deposits but did not produce any ceramic sherds, though Loci 8 and 10 did contain non-diagnostic flint flakes. Charcoal and sediment samples were collected from each of these loci --in some cases in close association with artifacts--for radiometric age determination, producing results that did not differ from the early second-millennium BC dates obtained from the bone layer Locus 6 (Table 1: G and H).

The hearths contain large amounts of fire-cracked rock, ash and charcoal and show a baked crust of salt that probably formed as a result of the combination of high heat and pooling moisture in the gypsum pavement. One very large hearth, stretching some two meters from east to west, was partially exposed by the most recent Jordanian excavations. The entire area was clean of artifacts at the time of our investigation; however, we were able to collect some organic material from

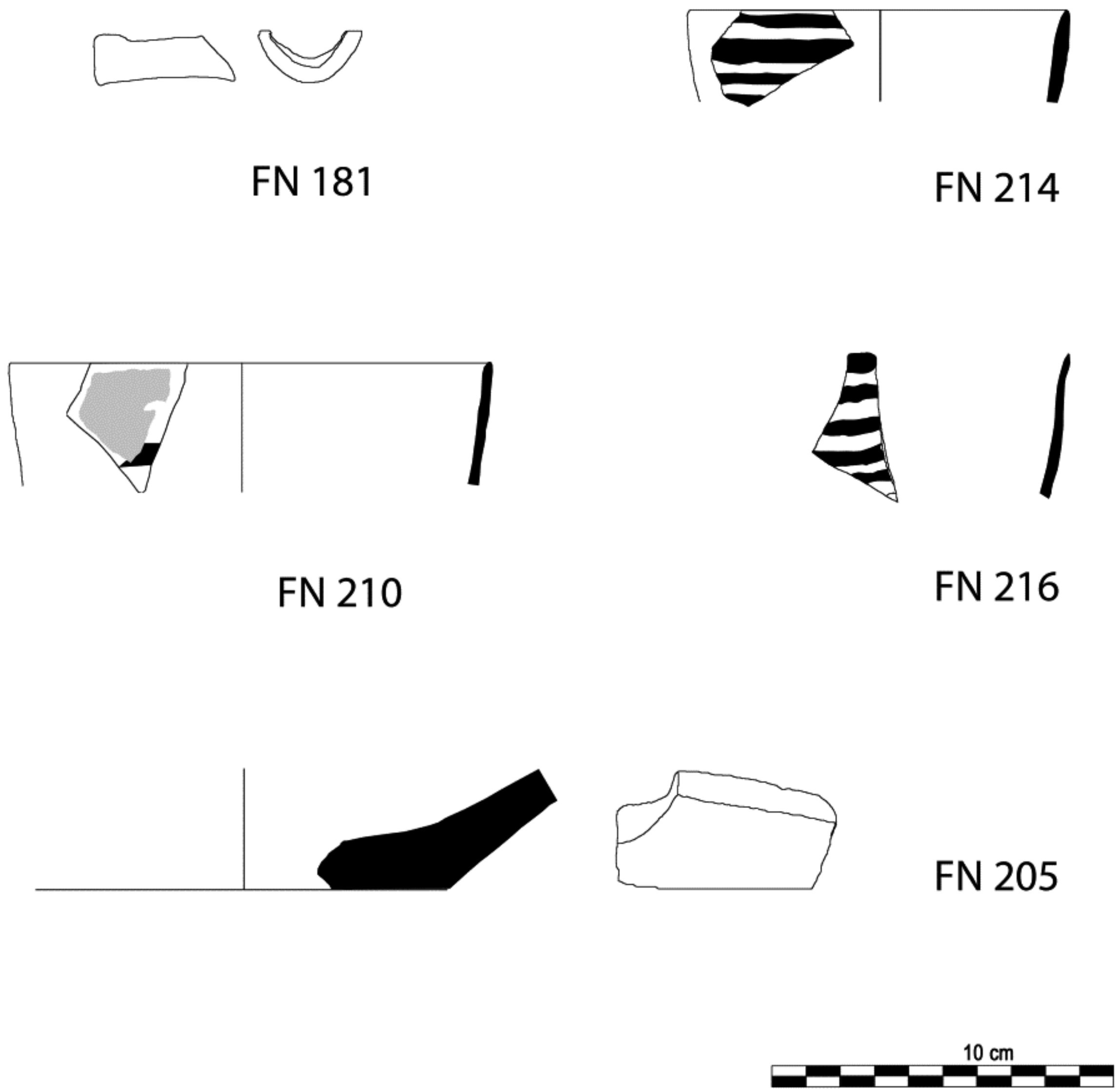

Figure 9: Wadi Suq ceramics from operation B-P1. See Table 3 for descriptions.

these hearths, two of which have been radiometrically dated. These dates bookend the third millennium BC (Table 1: I and J).

Summary of Operation B-P1

This excavation exposed several buried surfaces, all of which had been a product of slope erosion or deflation by wind. The earliest deposits are carved into the gypsum pavement and were covered by several layers of bone and ash alternating with clean, wind-blown sands that accumulated in the early second millennium BC. The thick, consolidated layer of bones, Locus 6, holds ceramics that have parallels from the Wadi Suq period, and is probably the result of a deflation event that occurred at the beginning of the Iron Age. A more substantial period of dune accretion follows this (Locus 5), during which Iron Age II artifacts were deposited. The plane of limestone fragments and artifacts between Loci 5 and 2 indicates another deflation episode. The uppermost interface investigated in this operation, the sloping band of slag between Loci 2 and 4, is made up of slope fall from above and masks the late first millennium period of dune accretion that was dated in an adjacent exposure. All of the deposits excavated in operation B-P1 that were found above the layer of bones, locus 6, seem to fall solidly into the Iron II period (Magee 1996), based on general agreement between absolute dates obtained through OSL and AMS and the material remains.

Operation B-O1/C-O1: Desert Pan

Our work finished with the mapping one small section of the evaporite desert surface adjacent to operation B-P1 that had been left exposed by the Jordanian excavations. This area, measuring approximately 5 by 10 meters and covering excavation blocks B-O1 and C-O1 (Figure 2), features five hearths, more than fourteen holes carved into the bedrock and one central depression that did not hold evidence of burning (Figure 12).

Figure 10: Steatite vessels from B-P1 Locus 3

ARTIFACTS AND SMALL FINDS

Finds from the 2009 excavations reported here are relatively few in number, but seem to be generally representative of the collections of artifacts found during the larger Jordanian excavations. Little or no contextual information is provided for most of the previously published objects (Al-Khraysheh and Nashef 2007). Linked with previously published finds, the examples described here provide some much needed stratigraphic and chronological context for the materials from Saruq al Hadid.

Metal Artifacts

The most remarkable aspect of the artifact assemblage at Saruq al Hadid is the amount and variety of copper or bronze[3] artifacts that were found at the site. The assemblage includes swords and daggers, arrowheads, axe heads, vessels, bracelets, pins, ornaments and fishhooks. Besides arrowheads, small and large vessels are perhaps the most common copper artifacts to be pulled from the sands of Saruq al-Hadid (Figure 6).

Only one small copper vessel was recovered during the 2009 excavations, a saucer that was encountered near the top of the bone layer in operation B-P1, much like those reported previously. Two main forms stand out: large, globular vessels and thin, shallow, undecorated, saucer-like dishes. The globular vessels often feature a slight shoulder and spouts of variable length (Al-Khraysheh and Nashef 2007:28). Rims are flanged, ledged, or carinated. Similar examples have been collected mainly from Iron Age tombs across the Oman Peninsula (Yule and Weisgerber 1991).

[3] Preliminary metallurgical analysis of metal artifacts using x-ray florescence suggest that the majority of what might commonly be called bronze objects are in fact relatively pure copper (Casana and Qandil 2011).

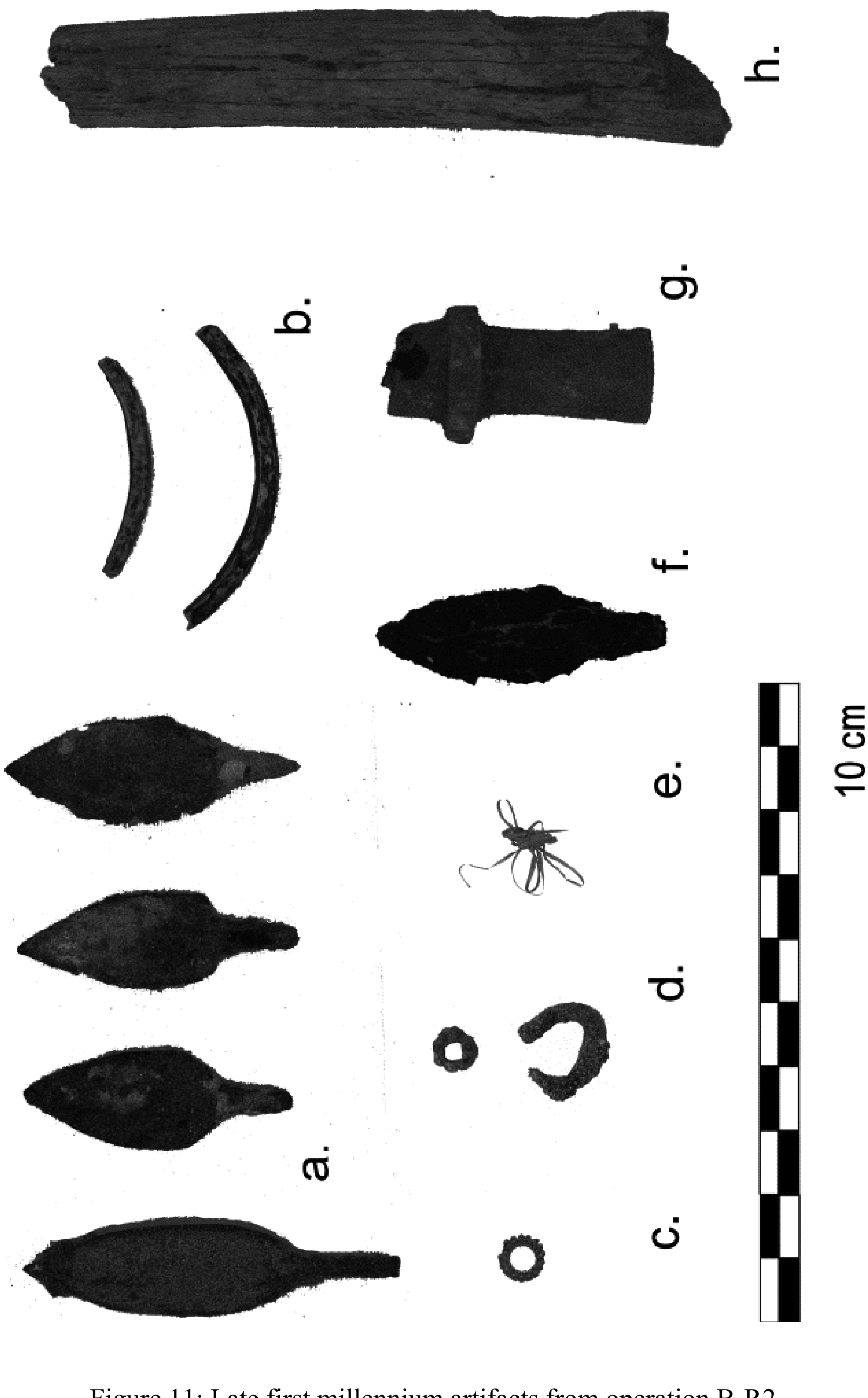

Figure 11: Late first millennium artifacts from operation B-R2

Almost a dozen swords and daggers have been recovered from Saruq al-Hadid (Al-Khraysheh and Nashef 2007:25), including two that feature a bronze handle with an iron blade (ibid.:175). Hundreds of iron blade fragments were also recovered at the site, and recent excavations have found two iron swords more than a meter in length (Casana and Qandil 2011). The 2008-2009 excavations did not produce any bronze swords or daggers but did uncover several bone fragments that were evidently carved to form the handle of a dagger or sword (FIGURE 6). Many of these fragments were stained a greenish-blue, resulting from the migration of copper alloys from a corroding object into the organic materials (Sease 1994). A copper ladle was found during the Jordanian expeditions to Saruq al Hadid, an artifact that is associated with ritual feasting (Moorey 1980, Stronach 1995, Magee 2003). This is one of the artifacts that may betray Saruq al-Hadid’s place in a network of international trade similar to that proposed by Magee et al. for Muweilah (1998a, 2003, and 2004).

While offering stands[4] are well attested at sites in the UAE and Oman, the stands collected at Saruq al-Hadid (Al-Khraysheh and Nashef 2007:71) seem to have no apparent parallels in the region (Potts 2009)[5]. Of the at least seven stands collected at the site by the time of our visit in 2009, four feature a tripod base supporting a long stem topped with a dish. Another is columnar in shape, supporting tiered platforms. Several of the stands are adorned with a crenellated pattern along the upturned lip that borders the edges of the dishes.

Bronze axes from Saruq al-Hadid (Al-Khraysheh and Nashef 2007:27) are similar to many other examples from tombs in the UAE and Oman (Rumeilah, al Qusais, Qarn Bint Sa’ud and‘Ibri/Selme: Yule and Weisgerber 2001: p. 19 Fig 9, Hili 8: Cleuziou 1980: p. 43 and p. 66,

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[4] These offering stands have been also described and interpreted as censers or incense burners.
[5] A bronze foot recovered in excavations at Mleiha (Boucharlat and Garczynski 1997 fig 27:10) bears a striking resemblance to the feet on the offering stand described by Potts (2010 also (Al-Khraysheh and Nashef 2007:71) and warrants a closer look.

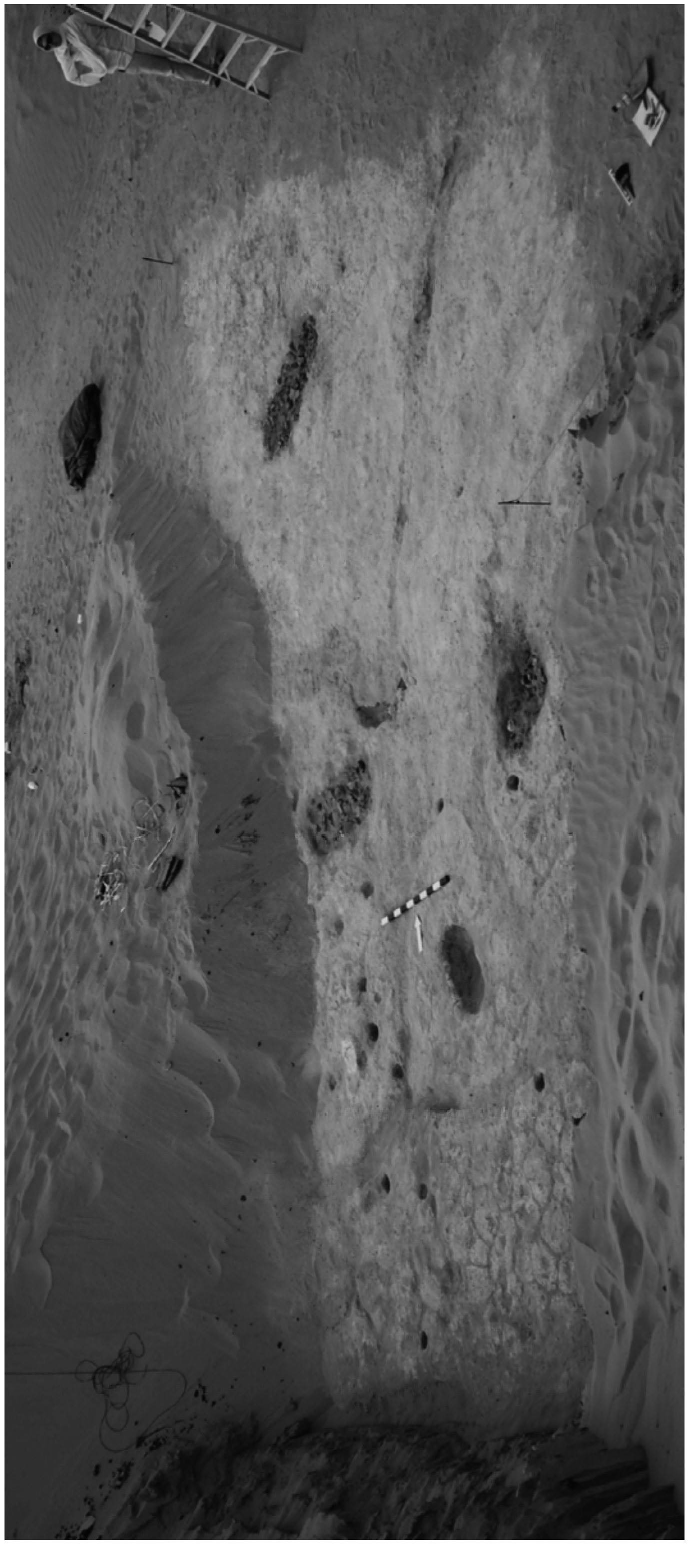

Figure 12: Postholes and hearths in gypsum pavement in squares B-O1 and C-O1 that were originally exposed by the Jordanian Expedition and later re-exposed by the Dubai Desert Survey Team

Fig. 40) and are regarded to be strictly ceremonial items, interpreted as a mark of nobility (Potts 1990). Other remarkable finds are a bronze ovate hoe with four known parallels in Arabia (Rumeilah, ‘Ibri/Selme) and a number of small wire fishhooks (Al-Khraysheh and Nashef 2007:70).

Bronze bracelets of various thicknesses appear in some abundance at Saruq al Hadid (Al-Khraysheh and Nashef 2007:70; Dubai Department of Archaeology inventory numbers JM.1830, JM.1842, JM.1843, JM.1848, JM.1857). Some of these specimens are corroded together and many are open on one end. Like many of the bronze artifacts here, are common finds in funerary contexts (Rumeilah, ‘Ibri/Selme Yule and Weisgerber 2001: p. 25 Fig 12). Also numbering among what are here provisionally classified as personal adornments are several heavy arm bracelets which may have served as a sort of armor (JM.1022). These are barrel-shaped thick bands with one flared open side, presumably for donning the object. Parallels have been found in Oman including in the metal hoard at ‘Ibri/Selme, (Yule and Weisgerber 2001: plate 4 35-37 class Bo3) and on the surface at Hili 8 (Potts 1990). Also present were long bronze straight pins. Bone finger rings and granulated gold beads connected in cylindrical clusters were also found, similar to those encountered at Dibba (Jasim 2006).

Pottery

The excavations during the 2003-2008 field seasons yielded ceramic remains that fit well with published Iron Age assemblages and the ceramics recovered in operation B-R2 and the upper levels of operation B-P1 echo their results. A number of complete or nearly complete, large storage vessels stand out, including some collar-rimmed and some necked jars similar to those found at Bithnah 44/50, (Benoist 2007; fig 13: 8 and 10). Several of these jars feature appliqué snakes, which are also represented on the other side of the Oman Mountains (Benoist

2009; fig 15 no 12). The great majority of potsherds that have been found represent large storage jars of this type, showing a very light red or orange paste with a dark red grog temper and an abundance of voids that betray a fugitive vegetal temper. Often, these sherds have a gray to black core and are interpreted here as having been fired at low temperatures.

There are fewer examples of other vessel types. At least three examples of bridge-spouted vessels are known from this collection, another form that is closely associated with the Iron II period, with the added implication of contact with people in Iran (Magee 2002). The bridge-spouted vessels, both complete examples and fragments, are painted with patterns similar to but not exactly like vessels reported from Muweilah (Magee 1998a, 1998b, 2001: Fig 12) and Rumeilah (Boucherlat and Lombard 2001:218 plates 50.1 and 50.2) featuring bands of rough horizontal striping that define a register decorated with curling wave patterns.

Operation B-P1 (Figure 10) yielded ceramics that are diagnostic to the Wadi Suq period, a phase that is previously unreported. These were found in the organic rich locus 6 and appear to be very similar to red slipped wares from phase H at Hili 8 (e.g. Cleuziou 1979: 36:1, 2, and 3).

Softstone Artifacts

The bone layer in Operation B-P1 held several steatite vessel fragments that were quite similar to vessels recovered from Tomb H at Hili 2 (Ur-Rachman 1979). Steatite vessels recovered (e.g. JM.0847) in the 2003-2008 investigations include both conical and round vessels with tapering sides (al-Shanfari and Weisgerber 1989, figure 4.4 p 24), forms common in the Iron Age. Rectangular compartment lids seem to start in the last quarter of the second millennium and continue through to the first millennium (Lombard 1985 fig 103 no 350) but the examples collected at Saruq al-Hadid have lost the careful decoration known from similar forms that are dated to the Wadi Suq Period.

Beads

A very large number of Beads were recovered in operation B-R2 of the excavations reported here as well as in previous investigations at the site, and a representative sample of the types and styles of beads are published in the report of the Jordanian expedition (Al-Khraysheh and Nashef 2007:p148-154). It should be noted that the materials and forms of beads recovered at Saruq al-Hadid share much with the assemblage from ed-Dur (de Waele 2007).

ENVIRONMENTAL CHANGE AT SARUQ AL-HADID

Certainly, one of the most obvious and vexing questions surrounding interpretation of Saruq al-Hadid is how the local environment changed over the millennia that the site was occupied. While we still lack direct evidence for environmental change in the vicinity of the site, we can infer some aspects of the trajectory of change over the Holocene. There is little question that the gravels found in the gypsum pavement below the site were probably carried out from the Oman Mountains during pluvial events in the Pleistocene (Juyal et al 1998; Harvey 2003), but the gypsum surface that seals these gravels, the remains of a desert lake of unknown age, could date to the Holocene, when there was enough moisture to sustain seasonal inter-dune lakes. If that is the case, the gypsum pavement could be a record of the moister environment that existed during the HCO in the period up to the fifth millennium BC, a record that has been protected from wind erosion by the thick covering of dune sands. The surface modifications in the form of postholes and hearths suggest that the regular inundation that created these deposits –from either groundwater or pluvial sources—were not a hindrance to the occupants at the site. This is consistent with the third-millennium BC dates recovered from the features cut into the pavement, which show that this occupation took place following the HCO, in a period that was much more arid, despite the minor resurgence in precipitation that is thought to have occurred in the third millennium (Parker et al. 2006; Doose-Rolinski et al 2001).

After this late third millennium wet period, there is evidence to suggest that inter-dune lakes persisted during the period from 4000 – 3000 BP, but conditions were probably not as humid as during the preceding moist period (Parker et al. 2006). The Wadi Suq period is understood as a time of social reorganization and population dispersal following the fluorescence of settlements during the Umm an Nar period. It is at this stage in the region's history that settlement is thought to have concentrated along the coastal margins (Carter 1997). The thick organic deposits of Loci 3 and 6 near the base of the dunes at Saruq al-Hadid show that there was inland occupation during the Wadi Suq Period.

The bone layer reveals Saruq al-Hadid's contains remains from fish, birds and mammals including what have been initially identified as gazelle and sheep/goat bones. The water table was undoubtedly very close to the surface here, suggesting that Saruq al-Hadid was part of an oasis belt that follows the al-Hajar Mountains from the northern emirates to the coast of Oman. Oases along this belt were fed from below by gravel fans that spread up to 100 kilometers out from the range and channeled water from the mountain wadis (Juyal et al. 1998). If Saruq al-Hadid was indeed located at an oasis, we could speculate that this lake may have persisted through to the Iron Age, attracting the people who brought the rich array of metal objects for which Saruq al-Hadid is known. At some point later in the site's history, a series of wells were dug in the gypsum pavement, three of which have been excavated. Artifacts surrounding these wells suggest that they date to the latest phase of settlement at the site, contemporary with the metal production, and thus may indicate that by this point all surface water was gone and the environment significantly more arid.

The first millennium is known as an arid period when dune sands were likely freed as stabilizing vegetation was lost to the drying climate (Parker et al. 2006). Dunes that accumulated during this period are not otherwise well attested in the UAE, for dune sands are frequently-re mobilized unless stabilized by some form of shielding. However, it is mainly during the first millennium BC that we see very rapid dune accumulation at Saruq al-Hadid (Figure 3), with substantial accretion at the site OSL-dated to have begun sometime near the start of the first millennium, continuing perhaps through sometime in the fifth century BC (Table 2: A and B). The debris of human occupation at Saruq al-Hadid may have helped to capture and protect sands from re-mobilization, shielding deposited sands and causing the site to rapidly accumulate some three or four meters in a five hundred year span. Thus the combination of human land-use practices and environmental change created the site as we see it today.

CHRONOLOGY OF SETTLEMENT AT SARUQ AL-HADID

The 2009 investigation confirms that Saruq al-Hadid contains third and second millennium occupations in addition to its substantial Iron Age component. The final phase of activity at the site, the period of metalworking that produced the extensive crust of slag, is not yet well dated. Our preliminary interpretation of these phases shows that the metallurgical activity is not necessarily connected to the phase during which the majority of copper and bronze cultic artifacts, for which Saruq al-Hadid is famous, were deposited. Despite this uncertainty, we know that the stratification of materials documented from its first occupation as a campsite, to its likely use a ritual center in the early first millennium BC, to its use as an intensive metal production site sometime in the late first millennium BC.

Saruq al-Hadid, the Campsite (Third-Second Millennia BC)

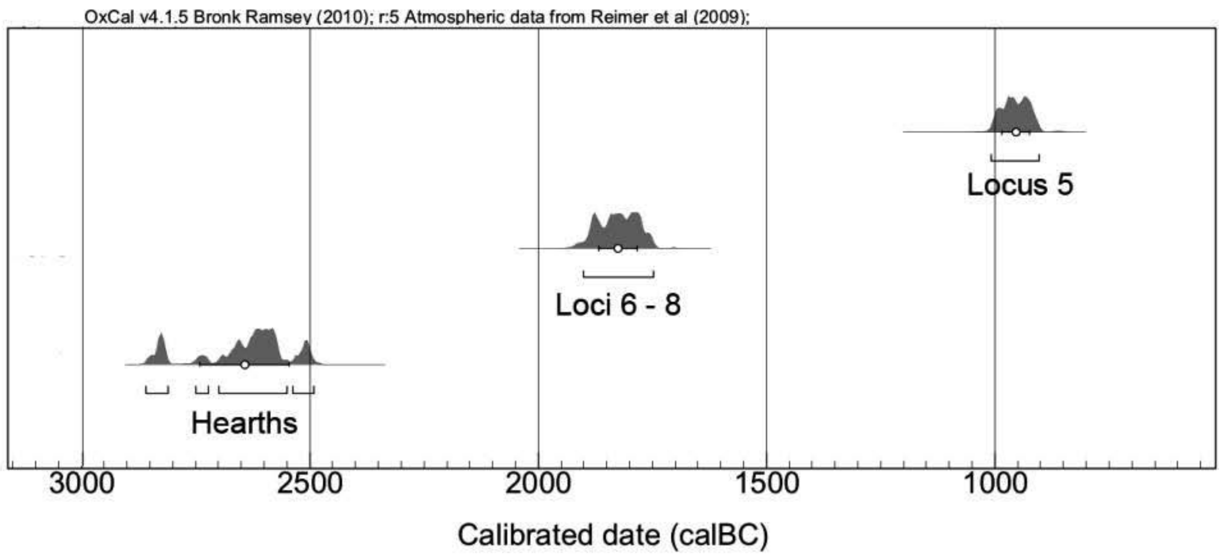

Figure 13: Summed probabilities of AMS dates from Table 1 grouped by context

The dating of what seems to be a third millennium component of the site is the most tentative, based only on dates retrieved from hearths that were uncovered by previous excavations (Table 1: I and J). From what we can see, the remains of this third millennium occupation are limited to the hearths and postholes carved into the gypsum pavement. Many examples of surfaces with dense concentrations of postholes and pitting can be found in archaeological contexts across the Oman Peninsula starting as early as the fourth millennium BC and continuing on through medieval times. Some examples of similar postholes in a firm substrate can be found in the fourth millennium layers from Ras al-Hamra 5, in the late third millennium at Ras al-Junayz 2, in the second millennium at Shimal and the uppermost floor level at Tell Abraq (Potts 1991: figs 37-38), in the later pre-Islamic era at ed-Dur and at Mleiha (Boucharlat and Mouton 1986: Plate VII; Boucharlat et al. 1997: figures 16, 18 and 35) and in medieval contexts at Julfar. Such postholes could have supported the frames of perishable structures similar to barasti huts, the likes of which were still being constructed in the Oman peninsula in the recent past, even after the discovery of oil and the socioeconomic transformations brought on by the expansion of the oil industry (Potts 1991).

The dense bone layer that lies less than a meter above the gypsum pavement (B-P1: Loci 3 and 6) and has been dated to the early second millennium presents a remarkable array of faunal materials and indicates that Saruq al-Hadid was once a resource-rich locale, probably in or very close to an oasis environment. The alternating layers of sterile sand and cultural materials that date to the third and second millennia suggest repeated occupation by nomadic pastoralists at Saruq al-Hadid, perhaps as part of a cycle of horizontal transhumance between the mountains and coasts connected to seasonal patterns of available precipitation or near-surface groundwater. Lake deposits at Awafi (Parker et al. 2004, Parker and Preston 2008) support a model of sporadic inter-dune lakes and oases scattered throughout grasslands in this period. Such a network could have supported the limited continuance of a nomadic pastoralist way of life beyond the Neolithic Period.

Further study of the faunal material from this deeply buried campsite phase of Saruq al-Hadid's history, as well as from the small Umm an-Nar period settlement of Al-Ashoosh located just 8 km to the southeast, will help to fill out the picture of settlement patterns, land use and environment during the second and third millennia BC. Al-Ashoosh is a small site, also investigated by the Dubai Desert Survey team (Casana et al. 2008), that covers about one hectare and features a series of small hearths and ovens surrounding a small mounded central midden that is filled with animal remains and hearth refuse.

The dense concentration of bones and artifacts that make locus 3 indicates that there was considerable deflation of sediments following the Bronze Age occupation of the site. This, coupled with the overlying sterile sands, suggest that there was a hiatus in occupation that lasted until the Iron Age II. For uncertain reasons, whether environmental or otherwise, the site lost its former appeal during the late second millennium BC.

Saruq al-Hadid, the Ritual Site (First Millennium BC)

The many valuable objects found at Saruq al-Hadid, including the array of copper and bronze artifacts that are thought to originate in the Oman Peninsula, as well as the objects with foreign associations like bridge-spouted vessels, link the site to regional trade networks of the first millennium BC. When considered with other developments such as the appearance of falaj water galleries and fortified structures and defensive walls at sites like Muweilah, these networks mark the Iron Age as a period of heightened cultural uniformity and economic strength in Southeast Arabia that saw the rise of local centers. How Saruq al-Hadid fit into this network remains unresolved. Was Saruq al-Hadid a desert campsite for nomadic pastoralists, as it seems to have been in the second and third millennia? Could it have been an oasis stop along a network of camel-borne trade that connected the coast with the Oman Mountain margins in this period (Magee 2004)? Alternatively, was it part of a constellation of special-use ritual sites that surrounded a center?

Evidence of ritual and ceremonial behavior during the Iron Age is limited for the most part to a handful of examples of formal architecture (large columned halls, see: Magee 2003; Boucharlat and Lombard 1997), as found at Rumeilah building G, Wadi Bahla and Bithnah, and to burial practices and grave goods documented at al Qusais (Taha 1983), BB15 near Bisyah in Oman (Humphries 1974) and perhaps from Am-Dhurrah and Hili 14 (Lombard 1985).

There is abundant evidence among the artifact assemblage from Saruq al-Hadid for another salient ritual symbol of this period, however. The snake motif that appears so frequently at the site has been recorded at numerous other sites elsewhere in the Oman Peninsula, at Tell

Abraq (Potts 1991), al Qusais (Taha 2009) and Bithnah 44/50 (Benoist et al. 2004: Fig 7, 9; Benoist 2007), as well as at Masafi (Benoist 2007), Rumeilah (Benoist 2002:21), ed-Dur[6] (Haerinck 2003: 92, Fig. 5.4), Bidya 2 (al Tikiriti 1989: Pl. 80:A), Muweilah (Magee 1998b: Fig. 4) and elsewhere in the gulf (e.g. Potts 1990:321; Benoist 2007). A snake cult with iconography similar to that found at Saruq al-Hadid is also well documented in Egypt, Mesopotamia, Elam, and the southern Levant.[7] In his dissertation, Koh (1994) shows that the snake had been a common feature of southern Levantine folk religion from the Bronze Age through the Iron Age. Considering that echoes of the snake cult can be found in place names connected with springs (Nehemiah 2:13), it is tempting to seek parallels between the Levantine and Southeast Arabian snake cults, given their common environmental and socioeconomic settings among semi-nomadic desert dwellers, as well as the well-documented trade relationships between the two regions.

In discussions of snake cults outside of the Oman Peninsula, the snake has been understood as a symbol associated with concepts such as fertility (Koh 1994: 133-138), soils, water, springs and groundwater (Dhorme 1949; de Miroschedji 2002; see discussions by Benoist 2007 and Potts 2007). Many of these snake representations in the Oman Peninsula and the Levant are found in an architectural context – for example, the ‘open air chapels’ at Bithna-44 (Benoist et al. 2004; Benoist 2007) or the Iron Age I altar at Timna (Rothenberg 1972:154) and later at Tel Beer-Sheeva (Aharoni 1975:154-156 plate 33). At Saruq al-Hadid, however, we have no evidence for standing structures.

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[6] Haerinck (2003) suggests the bronze viper found at ed-Dur could be Iron Age, but it exhibits a style and features, such as the suspension loop, not shared by Iron Age examples. It is possible that the ed-Dur example could date to the first or second century AD.

[7] See, for example, the clay cult stands with snake imagery from Iron Age I Timna (Rothenberg 1972: 154), Tel Beer-Sheva (Aharoni 1975: 154-156, Pl. 33), and Tel Beth Shean (Rowe 1940: Pls. XIV: 1, 4, and 5, XVI: 2 and 8, XVII: 3, XIX: 8, XX: 2, and LVIIIA: 3).

Saruq al-Hadid, the Industrial Site

Some uncertainty in the chronological sequence and environmental setting of copper, bronze and iron working activities at Saruq al-Hadid persists. Based on the material culture, it can be argued that the period of metal working came several centuries after the deposition of the Iron Age II materials. Many finds from slag layers both on the surface and buried, such as gold jewelry, green glazed ceramic sherds and vessels and the abundance of iron artifacts, suggest that metalworking activities at Saruq al Hadid took place after 300BC and possibly as late as the first century AD, based on parallels excavated from periods of major occupation at well-documented sites such as Mleiha and Ed-Dur. For example, an example of granulated gold jewelry of the style found at Saruq al-Hadid (Al-Khraysheh and Nashef 2007:27) is attested in the Iron Age at Rumeilah (Boucharlat and Lombard 1985 pl 73:10), but this form seems to persist beyond the Iron Age at Samad (Yule 2001: T 95:1:1 and T 175 10.5) and into the first century AD at sites like ed-Dur (Haerinck 2001: Pl E1:4, Haerinck 2007: fig 24) and Mleiha (Boucharlat and Garczynski 1997:64). Several yet-unreported examples of green glazed pottery from Saruq al-Hadid resemble vessels of a well-documented style known to have been current toward the end of the first millennium (Jasim 2006; Haerinck et al. 1993) have been collected during investigations at Saruq al-Hadid, including at least one entire vessel. The proliferation of iron blade fragments throughout the surface layers of the dune at Saruq al-Hadid (Casana et al. 2008; Al-Khraysheh and Nashef 2007:61-62) is another line of evidence that supports some temporal distance between the top slag deposits and the deeper Iron II materials. Incidences of iron artifacts in Iron Age II contexts in the Oman Peninsula are known to be extremely rare, and very few examples have been dated as early as the Iron Age III period (Magee 1998b:113). Finally, it can be argued that the period of metal working at Saruq al-Hadid followed the deposition of many of the Iron Age artifacts since this rather substantial crust of slag for the most part overlays the Iron Age cultural material, some of which is buried under three meters of sediments and separated from the slag by a layer of sterile sands. An OSL date on sediments taken from this layer of sterile sands located near the top of the dune, but below the main slag crust, gives a date 421BC±270 (Table 2: A), providing a rather broad *terminus post quem* for the deposition of the slag.

The slag layers, however, also hold diagnostic Iron Age ceramics, such as the bronze arrowheads and Iron Age sherds excavated in Operation B-R2; some featuring appliqué snakes (Figure 6). This indicates that either we are seeing an early adoption of iron forging, dating to the Iron Age or that the Iron Age and later (third century BC – first century AD) deposits have been mixed through erosion or human action. Deflated sites are the norm on the Arabian Peninsula, and distinct layers could have conflated over time. One anthropogenic genesis for what are likely mixed contexts in the surface layers of the dunes at Saruq al-Hadid could have been the installation of smelting furnaces in the soft sands (if the clusters of limestone exposed in the upper part of the dune are indeed the remains of furnace installations), a method that has been observed elsewhere (Weeks 2003). Despite being a deflated surface that may have resulted in a mixing of archaeological contexts, we ultimately have the slag crust of the dune to thank for shielding the underlying stratification from more extensive wind erosion.

The exact timing of the metalworking activities at the site will become clearer as we collect more datable materials from the slag layer itself, including direct dating of slag via thermoluminescence. Results will be of great significance because surprisingly little is known about copper production during the Iron Age in the Oman Peninsula, due to a dearth of metalworking sites that date to this period. If metalworking is shown to have been practiced during the Iron Age II, it would force us to reconsider the possibility of iron use in the Oman Peninsula during the Iron Age. If it is shown to have postdated the Iron Age and preceded the Islamic Era, it would alternatively offer an interesting exception to the observation that copper processing was not widespread in the Oman Peninsula during the late pre-Islamic periods (Weeks 2003:35), although metalworking is somewhat well represented at Mleiha (Ploquin et al. 1999).

Whatever the precise date of smelting operations prove to be, the intensive metal production at the site must have had a significant impact on the local environment. Ancient smelting depended on four resources: an ore source, a fuel source, water, and human labor. At the outset, only one of these resources, human occupation, appeared to have been available at Saruq al-Hadid. It is possible that ancient metal workers were drawn to the site by the presence of fuel resources, perhaps a stand of ghaf or acacia supported by a shallow water table. In an arid area like the Rub' al-Khali desert, the demands of metallurgical production for fuel would have required considerable stands of trees to support a smelting operation for any amount of time. The felling of large numbers of trees or the removal of other types of vegetation for fuel could have set off a local environmental change resulting in the de-stabilization of dunes, the loss of understory vegetation, and higher evaporation rates. The amount of slag that had been removed during excavations by the Jordanian expedition resulted in a mound with a volume of approximately 50 m^3 and there is little doubt that the harvesting and burning that would have been required to produce this quantity of waste would have had an enormous impact on the fragile desert environment. The environmental degradation that follows ore smelting operations elsewhere could have been what pushed the metalworkers of Saruq al-Hadid into such an improbable location in the first place; leading them to transport the ore a considerable distance from its source in the Hajar Mountains as has been suggested in later periods (e.g. Stokes et al. 2003)[8].

CONCLUSION

The sequence of occupation at Saruq al-Hadid that was identified during the 2008-2009 excavations has transformed our interpretation of the site. What was once perceived as an Iron Age center of bronze production has been revealed to be a multi-period site with distinct site functions spread over more than three millennia. Our results underline the importance of this site for understanding land use and settlement patterns in the deserts of the Oman Peninsula. Saruq al-Hadid may have begun as an oasis site where nomadic pastoralists during the Umm an-Nar and Wadi Suq periods camped and took advantage of a relatively well-watered landscape. In contrast, Iron Age remains at the site do not bear any definite signs of settlement per se, instead, the material culture reflects ritual activities and suggests that Saruq al-Hadid may have been one of a number of sites spread across the Oman Peninsula that were dedicated to a snake cult. Remains of this period not only tie Saruq al-Hadid into a network that included settlement and trade centers like Muweilah (Magee 2003), Rumeilah and al-Thuqaiba (Cordoba 2003), but also suggest that, like the mountain piedmont and coasts, the sandy desert expanses of the Oman Peninsula were regarded to hold economic and ritual importance in the overall landscape. If Saruq al-Hadid is indeed proven to have been a primarily ritual site during the Iron Age II

[8] Animal bone is one possible alternative fuel that could have supported metalworking operations -iron forging in particular- at Saruq al-Hadid. The upper strata in Op. B-R2 included some charred bones which could have served as a fuel source. Examples of concentrations of butchery waste documented in the Islamic layers of al-Basra, Morocco (Benco et al. 2002), and Tell Tuneinir, Syria (Loyet 1998:30-31), and at medieval sites in Europe (in York, England: Bond and O'Connor 1999) have been found in close association with metallurgical waste. Benco et al. point out, however, that as a fuel, faunal material would only be suitable for forging metals but not for smelting ores (2002:9).

period, this shift from its use for periodic settlement to a more specialized function would mark a significant departure from the land-use strategies of earlier periods. The site is capped by the waste from an intensive metalworking operation that is yet to be dated with confidence, but appears to have taken place during the later first millennium BC. The precise date of metalworking at the site and broader trends in environmental change and settlement in the Oman Peninsula will become clearer as excavation continues at the site through the analysis of the wealth of artifacts of interest to archaeologists and art historians and through further examination of the of faunal remains and sedimentary deposits.

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Table 3: **Ceramic Descriptions**

Trench	FN	Locus	Lot	Description
B-P1	135	4	17	Body sherd with raised spiral design (1.1cm wide snake) and incised/impressed circles/ovals all over exterior; 1.4-1.7cm thick; pink exterior, interior and fabric (5YR7/4), gray core (5YR6/1); smoothed on interior; moderate fine, medium and large red and dark-brown grit.
B-P1	181	3	32	Neck or spout sherd. 0.6cm thick; exterior concretions. Stroke of weak red paint (10R5/4) on exterior and interior; fabric light reddish brown (2.5YR7/4); some fine dark-brown and red grit.
B-P1	205	6	37	Base sherd; body 1.3cm thick, base 1.5cm thick; exterior and interior are reddish yellow (7.5YR6/6) and gray (5YR6/1) interior fabric. Some fine white grit, occasional medium red and dark-brown/black grit.
B-P1	210	6	37	Vertical-walled cup rim sherd of thin red-ware; 0.3-0.4cm thick; reddish brown (2.5YR4/4) on exterior and interior. Dark brown slip or paint on exterior (5YR3/1), reddish brown fabric (5YR6/4) with fine white and red temper.
B-P1	214	6	37	Rim sherd of black-painted thin red ware, incurving rim goblet; 0.4cm thick; Horizontal bands dark reddish gray (2.5YR4/1) paint at and below rim; Exterior and interior. red-brown slip (2.5YR5/4); fabric light reddish-brown (5YR6/4); some very fine red and gray grog.
B-P1	216	6	39	Rim sherd of thin-walled painted vertical cup or goblet, slight s-curve; 0.3cm thick; interior and fabric very-light red (2.5YR6/8), exterior very light brown (7.5YR6/4) with gray (7.5YR5/1) painted horizontal stripes, connected by vertical strokes or drips; moderate very fine and fine brown/black grit; rare red grit.
B-R2	30	4	6	Red slipped interior and exterior; light reddish brown (2.5YR6/4); highly fired; Rare fine red, some very fine, fine white inclusions.
B-R2	36	6	7	Rim sherd with gray (2.5Y6/1) exterior, and darker slipped gray interior (2.5Y5/1); 0.45cm thick; abundant very fine white inclusions.

B-R2	65	6	11	Plain, rounded rim sherd from bowl. Dark gray eroded slip (10YR4/1) on exterior and interior. Fabric (5YR7/3) has some very fine and fine black grit; occasional fine white and red grit.
B-R2	133	9	18	Base sherd, faded black slip or paint on exterior and interior appears gray (5YR5/1); flat base; body 0.7cm thick, base 1.1cm thick; exterior, pink interior fabric (7.5YR7/3); some fine black and reddish-brown grit.
B-R2	151	9	20	Large shoulder-sherd incised on exterior-3 horizontal grooves at meeting of neck and shoulder; below this large triangles formed of 4 grooves (3 ridges); 1.5cm thick; Exterior ranges from very pale brown (10YR7/4) to light reddish brown (2.5YR7/4). Medium-gray core (10YR5/1); abundant fine, medium, dark reddish brown grid (5YR3/2).
B-R2	174	10	23	Bowl rim, red-slipped interior and exterior (2.5YR4/3). Low ridge on exterior; exterior and interior very pale brown (10YR7/4), fabric light reddish brown (2.5YR6/4); some fine red grit.
B-R2	210	11	28	Rim sherd exterior and interior weak red (10R5/4) with fine red and gray grit.
B-R2	213	11	27	Body sherd with incised pattern-triangles; 1.2cm thick; exterior, interior and fabric pink (7.5YR7/4); weak red slipped (10R5/3) on exterior over incisions; some fine to large red grit.
Surface Find		7	9	Body sherd with raised snake head and body (1.1cm wide) on it (snake) and incised/impressed circles/ovals all over exterior; 1.4-1.7cm thick; pale yellow exterior and fabric (2.5Y7/3),smoothed very pale brown interior (10YR7/3); moderate fine, medium and large black grit.

CHAPTER 3

THREE-DIMENSIONAL MAPPING OF ARCHAEOLOGICAL DEPOSITS AND ENVIRONMENTAL CHANGE WITH GROUND-PENETRATING RADAR AT SARUQ AL-HADID, DUBAI, UNITED ARAB EMIRATES

By Jason T. Herrmann

For submission to *Archaeological Prospection*

ABSTRACT

A three-dimensional model of aeolian deposits interleaved with layers of cultural materials was created from the results of a ground-penetrating radar (GPR) survey at Saruq al Hadid, a multi-period archaeological site located on the eastern fringe of the Rub al-Khali desert in the United Arab Emirates. Time slicing and the creation of isosurfaces show areas where artifacts are concentrated within the dune deposits. The analysis of GPR facies permitted the creation of a three-dimensional model of the dune interior that separates major deposits by horizons. This sequence, paired with absolute dates from related excavations, shows that the phases of occupation and sediment accumulation recorded at Saruq al-Hadid are consistent with chronologies of environmental change and settlement proposed for the third through first millennia BC on the basis of other datasets. Results from this survey also provide some context for artifacts collected in prior excavations and offer valuable insight into the physical processes that shaped the present manifestation of the site. It is argued here that the character of these sedimentary deposits may also constitute evidence for a period of environmental transformation at the end of the Iron Age II (1100-600 BC) that is yet only poorly attested in the known paleoenvironmental record of the region.

Keywords: Ground-penetrating radar, GPR Facies, Arabia, Iron Age, Sand Dunes

INTRODUCTION

Ground-based remote sensing strategies within archaeological research projects are most often designed to locate and, when possible, identify evidence of human activity such as buried architectural elements, activity areas, evidence for earth-moving, and very occasionally, individual artifacts. These technologies are used less often to explore the stratigraphic "architecture" that supports the cultural materials of interest and thereby understand site formation processes, with several notable exceptions (Ruffell et al. 2004; Chadwick and Madsen 2000). This is not an indictment of investigators who use ground-based remote sensing in archaeology- the pursuit of such a goal requires that there be some advantage to revealing stratigraphy through remote sensing rather than through direct observation via excavation. If, however, the sedimentary matrix surrounding archaeological materials is of interest to the investigators, and excavation is not a viable solution, then the remote sensing technology that is selected for investigation also needs to be capable of generating data that has vertical depth at a spatial resolution sufficient for to delineate sedimentological features of interest. Moreover, the sensing technology that is employed must be suited for the environment and sensitive to contrasts in the physical properties of the sediments of interest, which is sometimes not the case at all.

The research questions and environment at Saruq al-Hadid are suited for an approach that examines the relationship between cultural materials and the surrounding sediments. Saruq al-Hadid is a stratified oasis site located in the southern end of Dubai Emirate, United Arab Emirates (Figure 14). The earliest archaeological layers at Saruq al-Hadid have been dated to the third millennium BC and the archaeological levels reflect a pattern of periodic occupation at the site at least through the first millennium BC and possibly as late as the third century AD

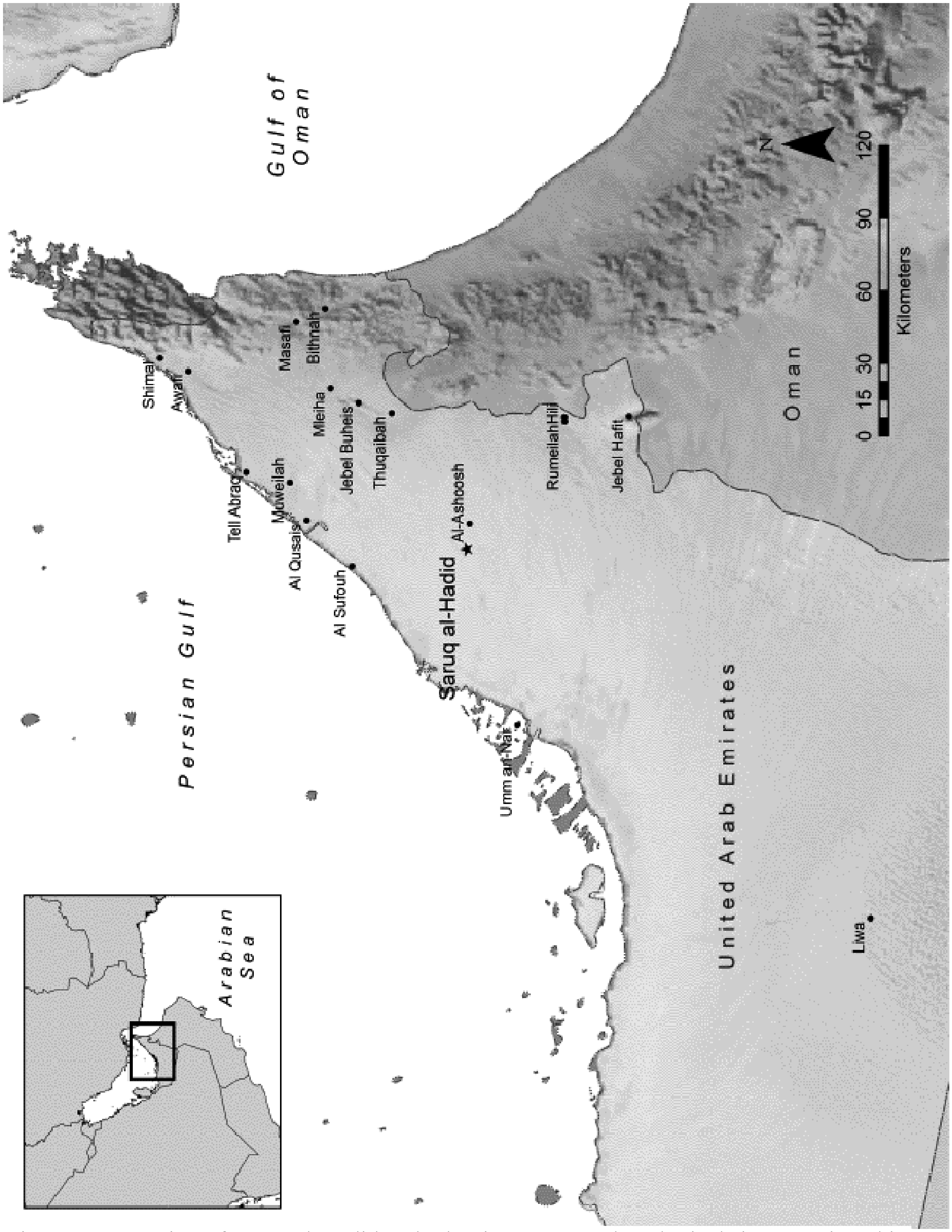

Figure 14: Location of Saruq al-Hadid and other important archaeological sites mentioned in the text.

(Qandil 2005; Casana et al. 2009; Qandil et al. In Press; Herrmann et al. 2012). An integrated program of ground-penetrating radar (GPR) survey and archaeological excavation that produced radiometric dates from both cultural and aeolian deposits has enabled the creation of a three-dimensional model of subsurface deposits for an important portion of Saruq al-Hadid, along with a chronology of their development. Radar facies analysis (Ruffell et al. 2004; Jol and Bristow 2003, 24; Bristow, Chroston, and Bailey 2000), here applied in the form of horizon mapping, was used to create maps of the three-dimensional arrangement of subsurface features recorded by this GPR survey. The resultant maps have helped the development of excavation strategies in unstable sand dunes, helped to establish a sequence of prehistoric activity at the site, and advanced our understanding of the arrangement of subsurface deposits by tracing horizontal variation as mapped in radar profiles. This final point is the focus of this article: how the analysis of the arrangement of windblown sediments as seen in the GPR data can be used to understand the changing environments at Saruq al-Hadid and in the surrounding region.

In recent years, widespread access to remote imaging applications and the new capacity to directly date the burial of sediments via optically stimulated luminescence (OSL) within a reasonable margin of error have revolutionized the study of dune systems. The analysis of aerial and satellite images have enabled a better understanding of dune morphologies and landform transformation in deserts shaped by winds (Breed and Grow 1979; Breed et al. 1979). Ground-based remote sensing techniques, and ground-penetrating radar (GPR) in particular, have helped researchers to understand buried stratigraphic architecture over large areas without excavation (Bristow, Pugh, and Goodall 1996). Until fairly recently, periods of dune building could only be deduced from gaps in the record of humid events as recorded in organic remains from lacustrine and fluvial contexts. OSL dating has given geomorphologists a way to date the burial of dune deposits that does not rely on the presence of organic materials which can be rare in arid environments (Atkinson, Thomas, Goudie, and Bailey 2011; Atkinson, Thomas, Goudie, and Parker 2011; Lancaster et al. 2002). Stratified wind-driven sediment deposits dated via OSL can serve as an independent indicator of past environmental conditions that complement organic moist-period proxies, as dune building is generally not attested during moist climate phases (Bray and Stokes 2004; Fleitmann et al. 2007). Episodes of aeolian deposition that are dated using OSL and that have been mapped with GPR can be used to trace spatio-temporal trends in aridity over large areas. It should be noted, however, that dune accumulation does not represent a complete record of phases of sediment mobility or aridity, for what exists today in the sedimentary record has likely only been preserved by a subsequent stabilizing event, such as a period of increased moisture and/or vegetative cover (Stokes and Bray 2005; Goudie et al. 2000; Bray and Stokes 2004; Singhvi and Porat 2008).

Radiometric dates collected from excavations or stratigraphic columns in sand dunes that have been mapped with GPR strengthen the interpretive power of sediment profiles: strata observed in excavations can be identified in GPR survey profiles, and then extrapolated across the profiles to become components of a three-dimensional map of the dune interior (Lancaster 2008). In this article, reflections in the GPR data that represent buried natural and archaeological layers were digitized to create a series of surfaces that were then used to produce a three-dimensional visualization of the dune interior. The generation of digital representations of buried surfaces is a very useful, but seemingly under-employed, product of GPR surveys, despite having been a central part of some of the landmark archaeological applications of GPR (Conyers 1995). More often, these types of models are used by geomorphologists to understand dune development and migration (Bristow, Lancaster, and Duller 2005; Girardi and Davis 2010). At

Saruq al-Hadid, GPR facies represent a sequence of dune accumulation episodes that occurred between periods of occupation, and the radiometric dates that were originally intended to help to reconstruct the sequence of occupation can also be used to understand how the landscape and environment changed in the vicinity of Saruq al-Hadid and across the Oman Peninsula during the three thousand year history of the site.

Saruq al-Hadid and the Surrounding Environment

Investigations at Saruq al-Hadid commenced soon after the site was discovered in 2002. Initial surface analysis and test excavations revealed that the site had a significant Iron Age component with a very rich assemblage of ceramics, soft-stone vessels, copper and iron artifacts and small finds that included both semi-precious stones and precious metals (Qandil 2005, 132). A five-year Jordanian expedition (Al-Khraysheh and Nashef 2007) made a substantial impact on the site and our knowledge of it, when up to 3000 square meters of archaeological deposits were uncovered through excavations and produced a collection of artifacts that are of sufficient quantity and quality to spur interest in creating a museum dedicated to the site. Following the Jordanian excavations, a cooperative effort between the Department of Archaeology and the University of Arkansas was formed with the mission of reconstructing the settlement and environmental history of the site. This collaborative project began in 2006 and included the GPR survey and test excavations in 2007 and 2009 that are described here.

Saruq al-Hadid is located (Figure 14) in a field of meso-dunes that are 3 - 5 meters in depth (Warren and Allison 1998) that are composed of a mix of quartzite and carbonate sand grains (Goudie et al. 2000; White et al. 2001). This dune field is protected on the north side by a deflated linear megadune aligned to the northwesterly Shamal wind. The effects of regular light westerly winds can be seen in the near-constant reworking of these meso-dunes, with sustained

Figure 15: GPR survey at Saruq al-Hadid

sandstorms resulting in more drastic reorganization. Some winters, these dunes feature a very modest covering of grasses but are otherwise mostly barren of any sort of vegetative cover (Figure 15). The wider landscape is dotted by the occasional Ghaf tree (*Prosopis cineraria***)** that is anchored by a deep root system to an aeolianite or desert pavement substrate that underlies much of this dune field.

Most of the dunes at and immediately surrounding Saruq al-Hadid rest on a gypsum marl that is mixed with pebbles derived from slope wash at the end of one of the alluvial fans that spill out from wadis in the Oman Mountains. This gypsum crust was likely formed following the Pleistocene deposition of these gravels in a period when the groundwater breached the surface and was later partly eroded by exposure. The white gypsum evaporite is only visible in narrow inter-dune spaces and absent in the large exposures of desert plain located to the east and south of this dune field. The dunes to the west of Saruq al-Hadid cover undulating surfaces of weathered aeolianite instead of sitting on the desert pavement plain.

Test excavations at the site in 2009 included the cleaning of the trench floor from the Jordanian Expedition and revealed the gypsum substrate that is dotted with postholes and hearths. Dated charcoal from some of these hearths puts them in the third millennium BC (Herrmann et al. 2012). The marl is covered with a thin layer of cemented sands whose relationship to the postholes is uncertain. These remains from the Umm an-Nar period (2500-2000 BC) indicate that Saruq al-Hadid's occupants erected reed structures here in seasonal encampments. Covering this layer is evidence for repeated occupation of Saruq al-Hadid during the Wadi Suq period (2000 – 1300 BC), when inhabitants left behind substantial deposits of bones from birds, fish and mammals, suggesting that the region surrounding Saruq al-Hadid was rich with exploitable flora and fauna at this time, likely as part of an oasis system fed from shallow freshwater aquifers (Herrmann In review, forthcoming).

The subsequent Iron Age II period in southeast Arabia is marked by an unprecedented level of construction, the adoption of unique agricultural techniques, the expansion of agricultural installations, and evidence for widespread regional and international trade. While the early levels of cultural deposits at Saruq al-Hadid described above suggest a pattern of regular, possibly seasonal occupation by nomadic pastoralists, the later deposits are dramatically different in that they do not include signs of domestic or subsistence activities. Instead, the assemblage of Iron Age II dated materials suggests that residents of the site focused on ritual activities associated with a cult distinguished by the frequently repeated appearance of snake iconography (Herrmann et al. 2012). This makes Saruq al-Hadid one of several sites spread across the Oman Peninsula that seem to have been dedicated to such a 'snake cult' (Benoist 2007). These Iron

Age II levels, which in some places remain protected by clean dune sands, produced a number of well-preserved copper and ceramic artifacts, some of which may have been imported from afar (Potts 2009).

Any discussion of Saruq al-Hadid would not be complete without some description of the abundant copper and iron working waste that seems to have shielded much of the site from erosion by wind. This surface layer is what led to the site's discovery in 2002 (Qandil 2005), and sits above the Iron Age II level, with some intermixing. The plentiful evidence of metalworking consists of large amounts of copper slag, ingots of smelted copper, abundant iron blade fragments, and remains of ceramic crucibles, tuyères, and some unmodified copper ore. The waste from metalworking is also interspersed with ceramics, faunal remains, gold and silver wire, and abundant beads from semiprecious stones (Al-Khraysheh and Nashef 2007). The date of deposition for the uppermost cultural deposits has yet to be determined with precision, but they likely represent several conflated episodes of activity that, based on the latest material evidence and a single OSL date, occurred no earlier than the late first millennium BC (Herrmann et al. 2012, 5–6).

The material evidence found at Saruq al-Hadid for repeated, but diverse use of the site over at least three millennia prompts the obvious question: what resource consistently drew people to a place that is today so far removed from water and plant life, as well as the ore and fuel that were clearly used there in the site's latest phase? In order to approach an answer to this question, we used text excavation, GPR and absolute dating techniques to develop an environmental history of the different phases of occupation at Saruq al-Hadid.

METHODS

Ground-penetrating radar data are a record of the intensity with which microwave energy is reflected back to the sensor by contrasts in the electromagnetic properties of buried materials. Most often, radar data represents the distance of contact boundaries between sediments or other materials with contrasting electrical properties from the sensor. Differences in dielectric permittivity and conductivity result primarily from differences in water content within the stratigraphic column (Davis and Annan 1989), which is influenced by the grain-size and porosity of the sediments. Changes in the properties of subsurface materials cause some of the energy to reflect back toward receiving antenna at the surface, while the remaining radar energy balance continues away from the antenna either to be reflected off of additional contrasts or to be attenuated into the medium. The two-way travel time of the radar wave, from transmission to reflection to reception, is a function of the velocity of the electromagnetic wave as it moves through the sediments and differs for each matrix. The velocity of the radar wave is determined by the relative dielectric permittivity (RDP) of a material. The depth of anomalies seen in radar data can be estimated from the two-way travel time by using the RDP to convert time to depth.

At a site like Saruq al-Hadid, a non-invasive subsurface mapping strategy offers enormous benefits. The site is located in dry and active aeolian sands, and archaeological materials are set in very fragile contexts. The very loose sediments, while physically easy to dig, also make stratigraphic excavation very difficult. Perhaps the greatest challenge of archaeological investigation in this environment is the constant reworking of the dunes by wind, which can obscure the floors and walls of excavation trenches and compromise the strength of any baulk in short order. The problems continue after excavations are finished. At Saruq al-Hadid, windborne sediments are most active at the eastern end of the large, open excavation trench created by earlier investigators that lies at the end of a large exposure of desert pavement. This east-west trench channels and concentrates the velocity of westerly winds onto the eastern baulk of the excavation, rapidly eroding the central ‘slag dune’ that is considered to be the site’s core, and redepositing windborne sediment at the top of the excavation trench. By contrast, GPR survey has produced extremely clear profiles, similar to ‘snapshots’ of the dune interior, that will persist after the site has been excavated by archaeologists or eroded by wind. These data serve as a guide to the internal structure of the site, offering clues to the organization of sediments and cultural materials encountered through earlier and ongoing excavations.

Remote sensing of the subsurface in Arabia has traditionally been the domain of mineral and petroleum interests; however, some near-surface prospection has been carried out for purely academic aims in the fields of archaeology and geology. Ground-penetrating radar and other near-surface remote sensing techniques (geomagnetic survey at al-Madam (Carbó et al. 2000), Muweilah (Blau et al. 2000), Julfar (Herrmann et al. 2011) and Al-Ashoosh (Casana et al. 2009) and electromagnetic conductivity in Bahrain (Frohlich and Lancaster 1986) are emerging as effective tools in mapping subsurface deposits in the arid environments of southeast Arabia. Among these technologies, ground-penetrating radar has been shown to be an effective tool for depth-sensitive mapping in dunes owing to the high resistivity of aeolian sands that allows better-than-average penetration by radar waves where larger sedimentary structures within dune deposits can be clearly seen (Bristow and Jol 2003, 2). Ground-penetrating radar is particularly valuable for revealing the stratigraphy in dunes that are too large to be excavated. The geometry of dune bedding is often used to reconstruct ancient wind regimes (Bristow, Pugh, and Goodall 1996). Geological applications of ground-penetrating radar are particularly effective and widely employed in arid aeolian deposits for mapping stratigraphic architecture in profiles or to trace lateral change and continuity in buried deposits Ground-penetrating radar surveys has only been reported for a handful of archaeological sites in the UAE, most notably at Muweilah where GPR survey was successful in identifying the horizontal distribution of buried architectural remains across broad sections of the site in time slices, and the vertical distribution of features is clearly evident in radar profiles (Ryz Evangelista, Magee, and Wedepohl 2002; R. Evangelista and Wedepohl 2004). More recent archaeological research that has employed GPR have focused on historical resources and include survey at Dalma Island (Frohlich and Lancaster 1986) and an ambitious effort to identify historical features in downtown Sharjah (Blue et al. 2012).

GPR Data Acquisition

A GSSI SIR-3000 was used to collect GPR data transmitted and recorded via a monostatic 270 MHz frequency antenna equipped with a survey wheel. The 270 MHz antenna has a lower frequency than those usually employed in archaeological surveys in southeast Arabia (R. Evangelista and Wedepohl 2004) and elsewhere, but lies on the high-frequency end of the norm for sedimentological studies in sand dunes (Bristow, Pugh, and Goodall 1996). This frequency antenna was selected in order to achieve a greater depth of penetration, with the trade-off being that it would theoretically yield lower-resolution results than studies that use a higher-frequency antenna. To test the efficacy of this antenna, three long GPR profiles were collected on the central slag dune of Saruq al-Hadid during a short visit in 2006. This test produced encouraging results in that the profiles clearly revealed dune-bounding surfaces and the vertical positions of artifacts (Casana et al. 2009, fig. 11).

Following this initial assay, an intensive GPR survey was undertaken in 2007 to map the vertical distribution of sediments and cultural layers in the central slag dune of the site. The two hundred and thirteen profiles that were collected were organized into 40-meter square blocks of north-south transects that were spaced one meter apart (Figure 16). In the end, a total of 8292 meters of GPR data were collected. A total station was used to establish the survey area from the Saruq al-Hadid site datum, which had been placed by a surveying team in the employ of the Emirate of Dubai. Passage along survey transects was guided by fiberglass measuring tapes, and the scan rate was controlled using the GSSI survey wheel, which was set to collect 40 scans per meter. The survey squares were placed as close to the edge of the open excavation trench as possible in an attempt to capture the heaviest concentrations of cultural remains that had been the target of the earlier excavations. In some cases, particularly in the survey area south of the open excavation trench, transects were truncated to avoid the steep drop into the trench or to avoid piles of debris that had been placed on the dune surface by the excavators from earlier expeditions.

Additional blocks of GPR profiles were collected by the author at Saruq al-Hadid in December, 2008, and most recently by another surveyor as part of Dubai Desert Survey activities in February, 2012. The results of these surveys will not be presented here, however, as they do not exhibit such dense concentrations of artifacts, and the strata they represent have not been investigated through test excavations.

Data Processing

Ground-penetrating radar data were processed for display and analysis using GPR-Slice 7.0 ground-penetrating imaging software by Geophysical Archaeometry Laboratory. GSSI .dzt format data were imported into GPR-Slice, regained, and subjected to DC drift removal. Profiles were bandpass filtering to remove low amplitude noise below 128 MHz and high amplitude noise above 835 MHz. This window was chosen following a visual analysis of the distribution of

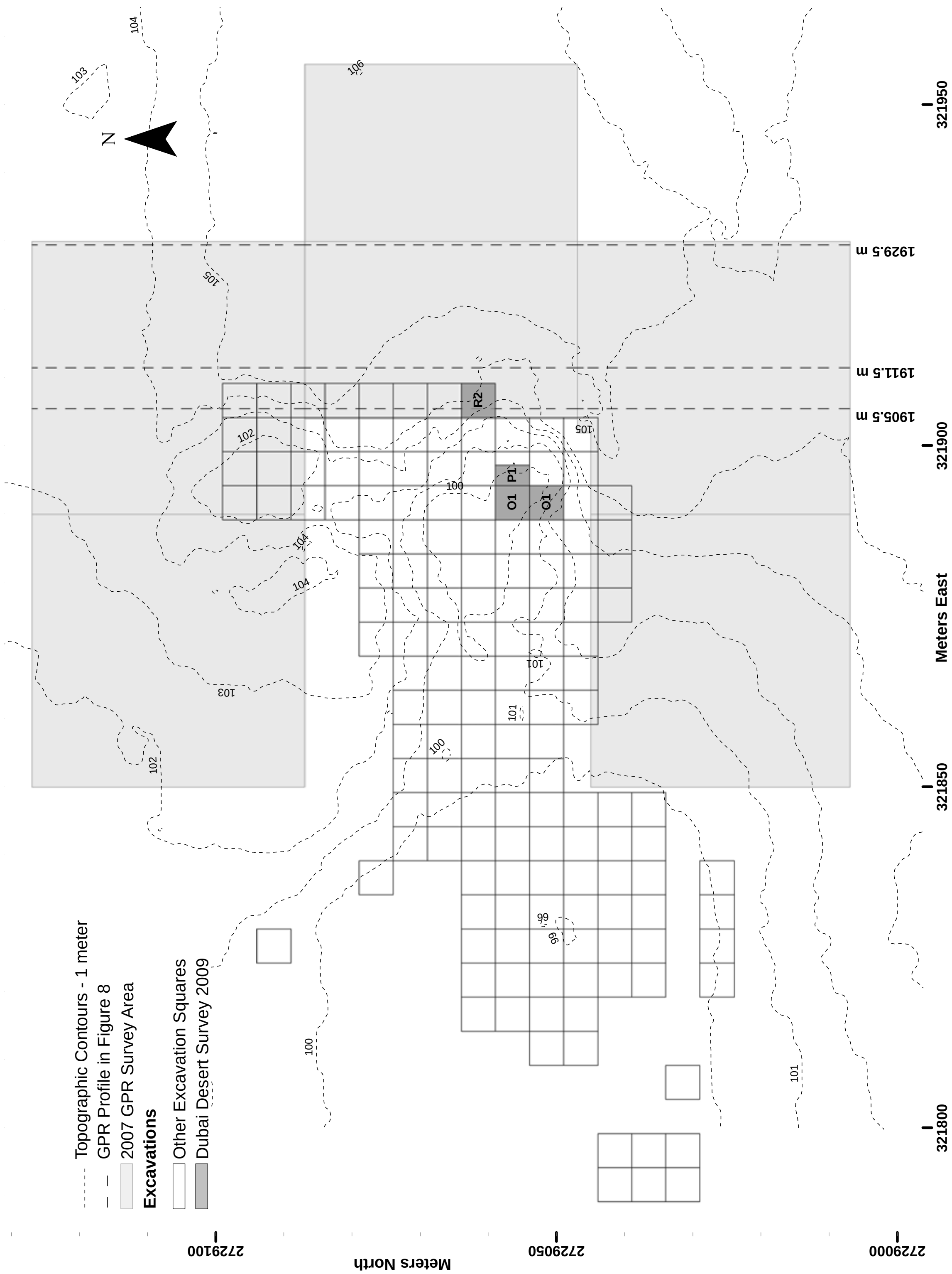

Figure 16: Map showing GPR survey area at Saruq al-Hadid, locations of 2009 excavation trenches, and locations of profiles in figures 5, 6 and 7.

signal return frequencies in the data in a histogram, only a slight adjustment from the prescribed bandpass window of 1/2 and 2 times the center frequency. In this case, the high pass filter at 128 MHz was particularly useful in filtering out some low-frequency noise from an unknown external source which affected transects in the southeast corner of the survey area. The average background values across scans on the horizontal axis were removed with little fear of removing contact boundary signals since none were parallel with the surface topography. The surface wave was cropped from the radar profiles in order to remove the effects of the "skin" from the surface wave that would appear in time slices that were corrected for topography. Migrated and Hilbert-transformed (Goodman and Klein 2011, 181; Turner 1994; Yilmaz 2001; Conyers 1997) data were used for horizontal time slicing and the creation of three dimensional displays of anomalies, but most radar profiles were easily interpretable with minimal background filtering, thus unmigrated profiles are used for illustration to emphasize anomalies (Conyers 1997, 129).

Wave velocity was determined through hyperbola fitting, a method applied to dozens of clearly apparent hyperbolae that appear in profiles across the survey area. Velocity was generally consistent throughout the dataset and centered on an average of 0.151 m/ns with a relative dielectric permittivity (RDP) of 3.95. The average velocity measured below the gypsum pavement was only slightly slower at 0.127 m/ns, giving the matrix an RDP of 5.5. Both values are within the expected range for dry and damp sands (Davis and Annan 1989; Baker, Jordan, and Pardy 2007). Using the prescribed upper and lower bounds for resolution based on ¼ and ½ the wavelength, the limits for horizontal resolution lies between 0.138 and 0.27 meters (Jol and Bristow 2003, 12; Sheriff and Geldart 1982), well above the 40 scans/m (0.025 meter) step size set during data collection.

Because the surface of the dunes is being reworked continually by wind action, data from subsequent GPR surveys at Saruq al-Hadid or in active dunes elsewhere should only be corrected with surface information that is collected in the same field season, and ideally at the same time as the GPR survey. An alternative to topographic correction based on surface data is to trace a reflection in the radar profiles that is known to represent a flat plane and then create a surface from it that is inverted to 'back correct' the horizon to be flat and shift the samples vertically (Goodman and Klein 2011). For this dataset, this latter method was found to be preferable to topographic correction using surface data since the surface model generated from field data did not produce a flat substrate following topographic correction, even though the gypsum layer that supports the dune is in reality very flat and level, except where it is pocked with hearths, pits, and postholes. After the contact boundary representing the gypsum surface at the site was rendered to a horizontal plane in the data, it was possible to expose the locations of these anthropogenic features and emphasize cultural features that sit at or near the base horizon through time slicing.

Automatic detection of horizons created a starting point for horizon editing. In many cases, dense concentrations of high-amplitude anomalies that represent reflections off of buried artifacts and stones tended to obscure the signal response of buried dune interfaces and therefore hindered the automatic horizon detection offered by GPR-Slice software. At the deepest point of the dune, the signal was attenuated to a degree where the horizon was not detectable through automated means. Following automatic detection, horizons were edited by hand in each of the 213 radar profiles, beginning with the interface between the gypsum pavement and the overlying sand dune and working upward.

Absolute Dating of Deposits

Samples for radiometric dating were collected during the 2009 excavations at Saruq al-Hadid from both cultural and natural deposits (Herrmann et al. 2012). Organic carbon samples consisting of charcoal that was found in hearths or protected by artifacts or materials that are known to have been brought in by humans were subjected to 14C dating. During excavation, we found that the cultural strata were often separated by layers of clean sand that were free of cultural materials. In order to strengthen the chronology of occupation and site formation determined through 14C dating and artifact analysis, therefore, sediment samples were collected for age determination through optically-stimulated luminescence (OSL). As described above in the introduction, the use of OSL dating of aeolian deposits as a tool for environmental reconstruction has ballooned in recent years (Bray and Stokes 2004; Goudie et al. 2000; Preusser 2002; Atkinson, Thomas, Goudie, and Bailey 2011; Atkinson, Thomas, Goudie, and Parker 2011) and complements proxy data derived from cultural, fluvial, and lacustrine contexts.

GPR SURVEY RESULTS

The GPR survey at Saruq al-Hadid generated results at a resolution fine enough to map multiple buried bounding surfaces and individual artifacts with extreme clarity. The quality of results is attributable to the highly resistant dry sand deposits that maximize signal propagation, as well as the strong dielectric contrast between the material characteristics of the ceramic, stone, and metallic cultural materials and the sand matrix in which they are suspended. The distribution of buried contact boundaries between deposits and the locations of many cultural materials are visible in both the individual radar profiles and the horizontal time slices at Saruq al-Hadid.

GPR Facies

Analysis of the radar profiles resulted in the identification of four distinct reflections below the surface of the dune that represent contact boundaries between four distinct episodes of deposition within the dune. These reflections are a result of a change in the velocity of the radar wave as it passed through sediments with surfaces that have slightly different amounts of moisture than the surrounding matrix, which is related to the contrasting lithologies of the layers of sand and their interfaces. It was observed through excavation that the bounding surfaces often contained small fragments of slag, bone, stone, and other artifacts, as well as a small amount of clay or evaporite, indicating that there was some deflation of sediments. Moreover, dune surfaces and contact boundaries tend to have finer particles on these surfaces (Bristow, Pugh, and Goodall 1996, 43). The combination of these two factors tend to make contact boundaries within sand deposits them good reflectors of radar energy (Bristow, Pugh, and Goodall 1996). The four sedimentary facies described here were verified and dated in the test excavations in 2009 and form the basis for the reconstruction of the environmental and settlement histories of the site. The series of reflectors was used to create digital surfaces that represent the topography of the buried strata, resulting in a three-dimensional model of the dune's interior.

Apart from the boundary between the gypsum substrate and the dune itself, the uppermost reflection below the dune surface (Reflector 1) is the most readily apparent and continuous contact boundary in the radar profiles. Reflector 1 is a convex, high-amplitude anomaly that rises almost to reach the dune surface in the center of the survey area and falls away to meet the gypsum substrate at the edges of the survey profiles (Figure 17). This reflection is relatively easy to pick out from the image since it is both near the surface where it has a strong signal to return to the sensor and is rather unobscured by reflections from strata above and below it. The sands that rest above this contact boundary on the north and south slopes show bedding that slopes toward the north. Based on the limited perspective of these north-south oriented profiles, the orientation of the bedding suggests a northward progression of dune movement over Reflector 1. On the south end, the reflections suggest bedding that follows the contour of the underlying dune surface in some places or is truncated at the edge of the buried dune surface in other places. The reflector separates strata that are now understood to be the proto- or prehistoric dune deposits (below it) and the archaeological remains from the historic phase of the site plus more recent sands (above it).

Reflector 1 forms the lower boundary of the historical-period facies at Saruq al-Hadid, and it is known from excavations that where this reflection reaches the top of the dune surface at the center of the survey area, it is part of what is referred to as the 'slag crust.' It can be seen in some of the radar profiles that artifacts, including some very strong reflectors that are almost certainly metallic, can be found along this reflector where it dips below the dune surface. An OSL date from sediments taken from the sands directly below Reflector 1 gives an end date for the older deposit below at 2430 ± 270 BP (Table 5, Figure 17). The deposits in the historic-period GPR facies, which includes also the most recent emplacement of sands on the very surface of the dune, must thus have been deposited at the earliest in the late first millennium BC. The date for these levels is corroborated by analysis of artifacts from the dune's artifact crust (Herrmann et al. 2012).

At the very north end of Reflector 1, there is evidence for a series of slip faces that appear to be below the contact boundary and angle downward roughly parallel with the reflector. Otherwise, there are no clear patterns of stratification or bedding in the radar profile below Reflector 1; instead, we see a weak repeating signal that continues for approximately 10 nS downward. This area is interpreted as a layer of clean, undifferentiated sand that is relatively free

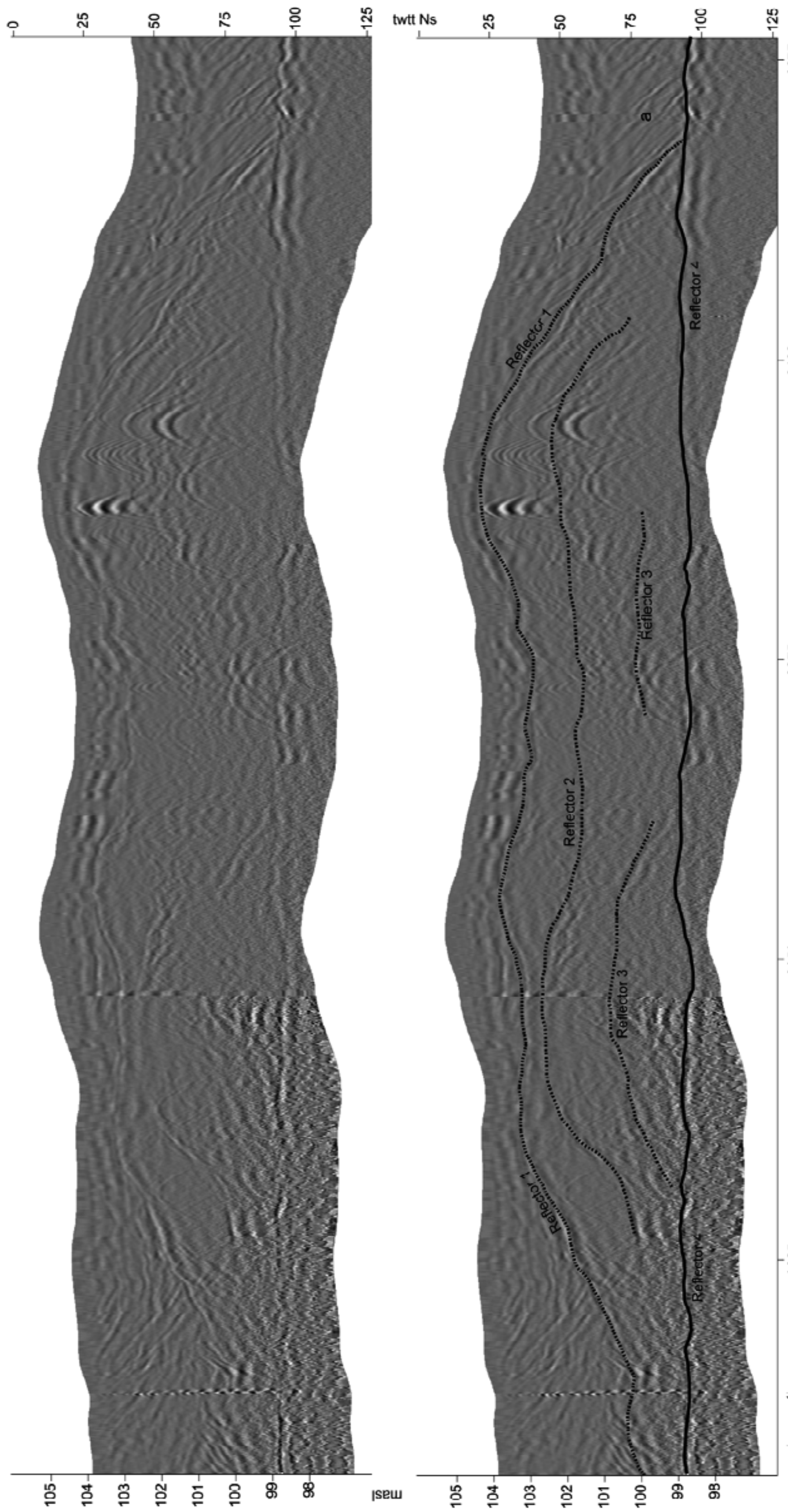

Figure 17: GPR Profile at 1905.5 meters east

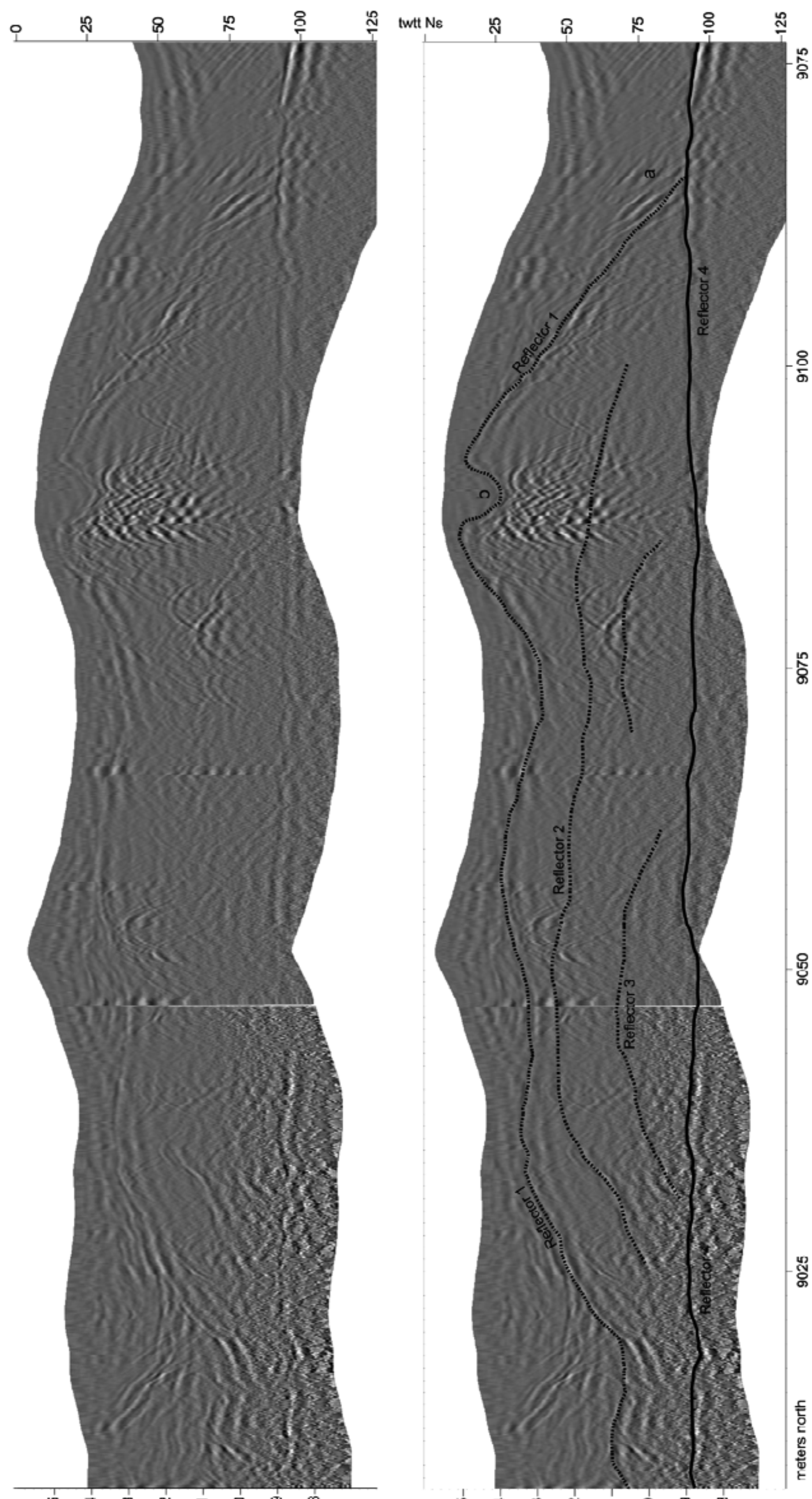

Figure 18: GPR Profile at 1911.5 meters east

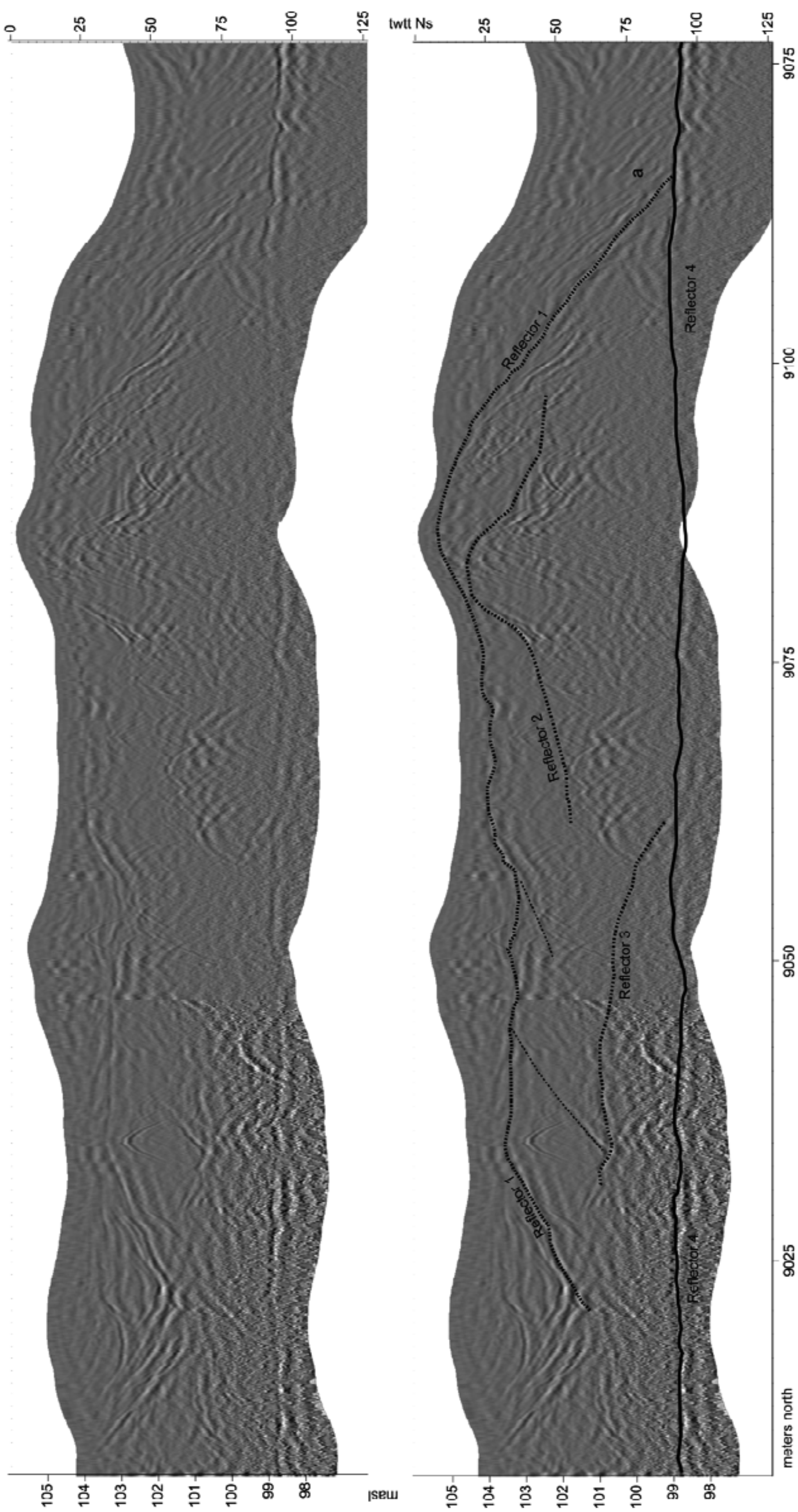

Figure 19: GPR Profile at 1918.5 meters east

of cultural material until the top of Reflector 2 (Figure 17: a).

In the profile aligned at 1911.5 meters east on the site grid, an anomaly appears that may represent a pit dug into the facies below Reflector 1 (Figure 18: b). This may be an example of the kind of installation that mixed archaeological contexts and led to the inclusion of artifacts of different periods on the Reflector 1 dune surface. Instead of a feature dug from above, however, an alternative interpretation of this anomaly would be that it represents a structure that extends vertically from Reflector 2. This high-amplitude anomaly is also represented in the time slices, which are discussed below.

Reflector 2 is a concentration of high-amplitude hyperbolae that are distributed horizontally within the buried dune defining a horizon surface (Figures 17 - 19). Based on what was recorded in the University of Arkansas excavations in 2009, these reflections can be attributed to cultural materials, as concentrations of tabular limestone and clusters of sizeable metal and ceramic artifacts that date to the Iron Age II period were found at this level. The strong repeating signatures of a very large cluster of moderate-amplitude and very high-amplitude reflections visible in Figure 18 below the possible pit or standing feature, for example, suggest the presence of metallic objects in addition to some tabular limestone.

The clean sands that were observed above the layer of Iron Age II artifacts are a sedimentary facies that represents some 300-500 years of sand emplacement, temporally bounded on the one hand by the OSL date acquired at the top of the formation (discussed above) and on the other hand by a series of 14C dates collected from the Iron Age II artifact horizon (Table 4: samples AA84590, AA84591, and AA85670) (Herrmann et al. 2012, 57). This timing and age of this deposit corresponds roughly to the Iron Age III period in southeast Arabia.

Reflector 3 is the signature of a deposit that was identified in the 2009 test excavations that is particularly compact and rich in organic remains (Figure 17) and represents a deflated deposit that predates the first millennium BC Iron Age II period and caps the second and third millennia BC deposits (Herrmann et al. 2012, 57–58). This stratum is referred to as the 'bone layer' in the excavations and is from a context where increased moisture content was observed in sediments, however, a measurable change in velocity from shallow to deep sediments was not detected in an analysis of wave velocity through hyperbola fitting. This reflector includes the deepest reflections on the radar profile that are still within the sand dune, but it is poorly resolved in this dataset since it happens to lie under the tallest sections of the dune. The distance from the sensor and the increased moisture and organic content in these deposits may very well have resulted in increased signal attenuation.

During humid phases in the past, southeast Arabia had a more hospitable environment than its current state as a hyperarid sand sea that generally receives less than 50 mm of precipitation per year. Moister times are recorded in materials recovered from alluvial fans (Al-Farraj and Harvey 2000), lacustrine environments (McClure 1976; Lézine et al. 1998), and speleothems (Burns et al. 1998; Burns et al. 2001; Fleitmann et al. 2003; Fleitmann et al. 2004). The flat base of evaporite salts on which the sands of the study area rest is evidence of Saruq al-Hadid's moist past, when groundwater breached the desert surface and supported shallow lakes here, perhaps as late as the Neolithic, but certainly before features were carved into the gypsum and the deposit of dune sands above. Since this gypsum substrate is considerably denser than the sands above it, it generated the most robust reflection of all of the stratigraphic horizons (Figures 17-19). This is Reflector 4, a continuous high-amplitude signal that formed the basis of the topographic correction as described above. In places where this reflector was not beyond the sensory depth, the radar wave could penetrate and detect features below the gypsum crust, though few, if any, anomalies below the gypsum crust can be attributed confidently to an anthropogenic origin. This substrate's high salt content and capacity to preserve moisture present a more conductive matrix that contributes to faster attenuation of the radar energy.

Time Slicing and Three-Dimensional Modeling of Deposits

Time slicing was performed on radar profiles that had been corrected for topography and antenna tilt. The tops of the GPR profiles were trimmed in order to remove the surface reflections from the time slice models and filtered by removing the mean value of each line to remove contrast between parallel transects. The near-circular signature of the buried slag-covered dune surface as it dips away from the center of the survey area is the most noticeable anomaly to appear in time slices of the dune (Figure 20: late first millennium dune surface, Reflector 1). The shape of the dune defined by reflector 1 is clear in three-dimensional representations of the dune interior (Figure 21). There are several persistent anomalies that occur through many of the time slices (not shown); these are the repeating signals of metallic reflectors, usually found on the surface or near the Reflector 1 horizon.

Some of the anomalies located below the Iron Age III facies seem to be organized in orthogonal patterns that are oriented on a southwest-northeast axis. These signatures in the time slices correspond to the levels of the Iron Age II deposits that were found during excavations, described as Reflector 2 above, which appear to be near-horizontal in the radar profiles. The distribution of these anomalies are represented as isosurfaces for high-amplitude reflections in Figures 8 and 9, and are confined to an area defined on the top by Reflector 1 and terminate in a relatively horizontal pattern which define the Iron Age II surface, Reflector 2. The orthogonal patterns suggest that these anomalies represent the foundations for a group of rooms that are

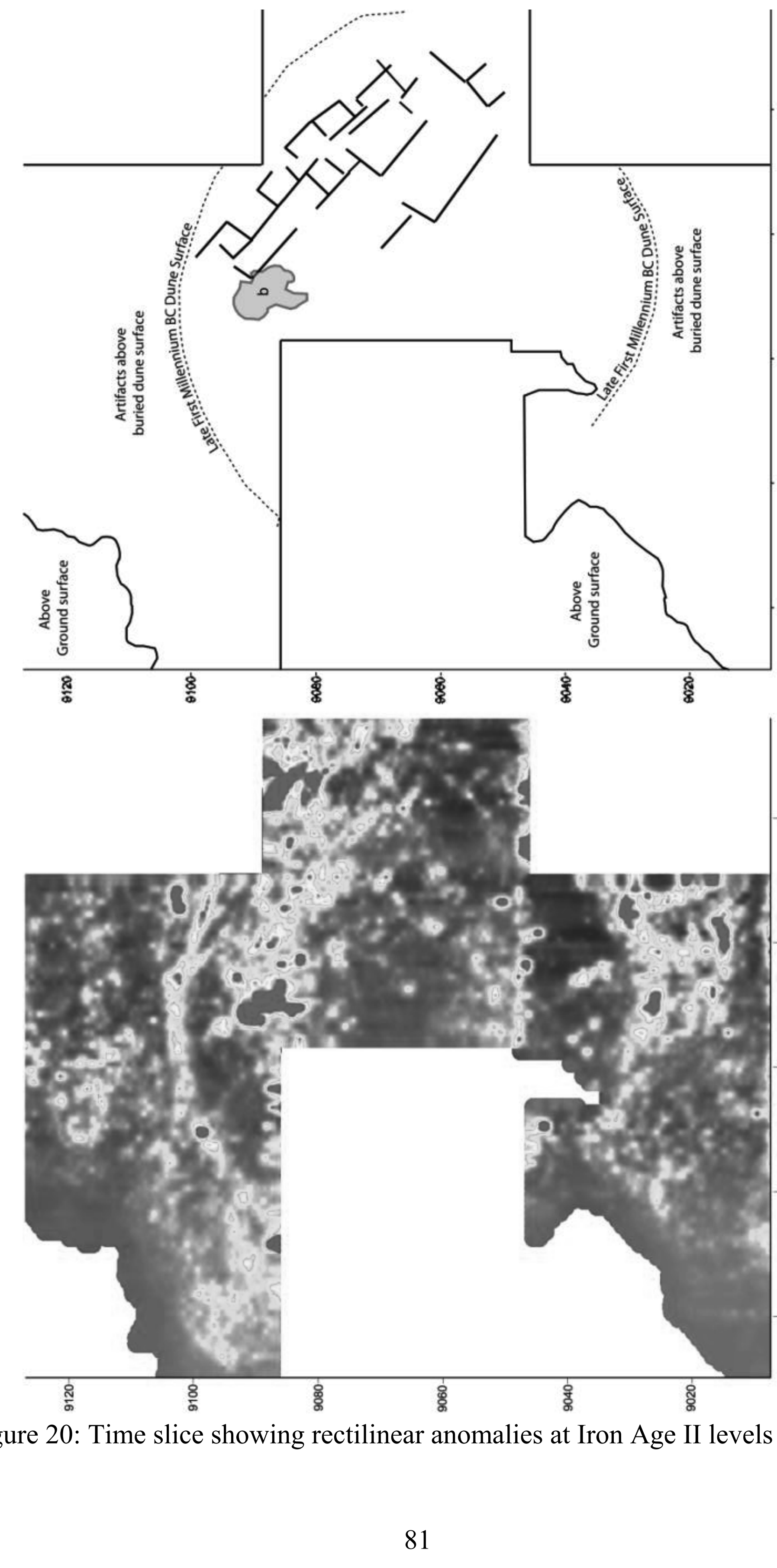

Figure 20: Time slice showing rectilinear anomalies at Iron Age II levels in dune.

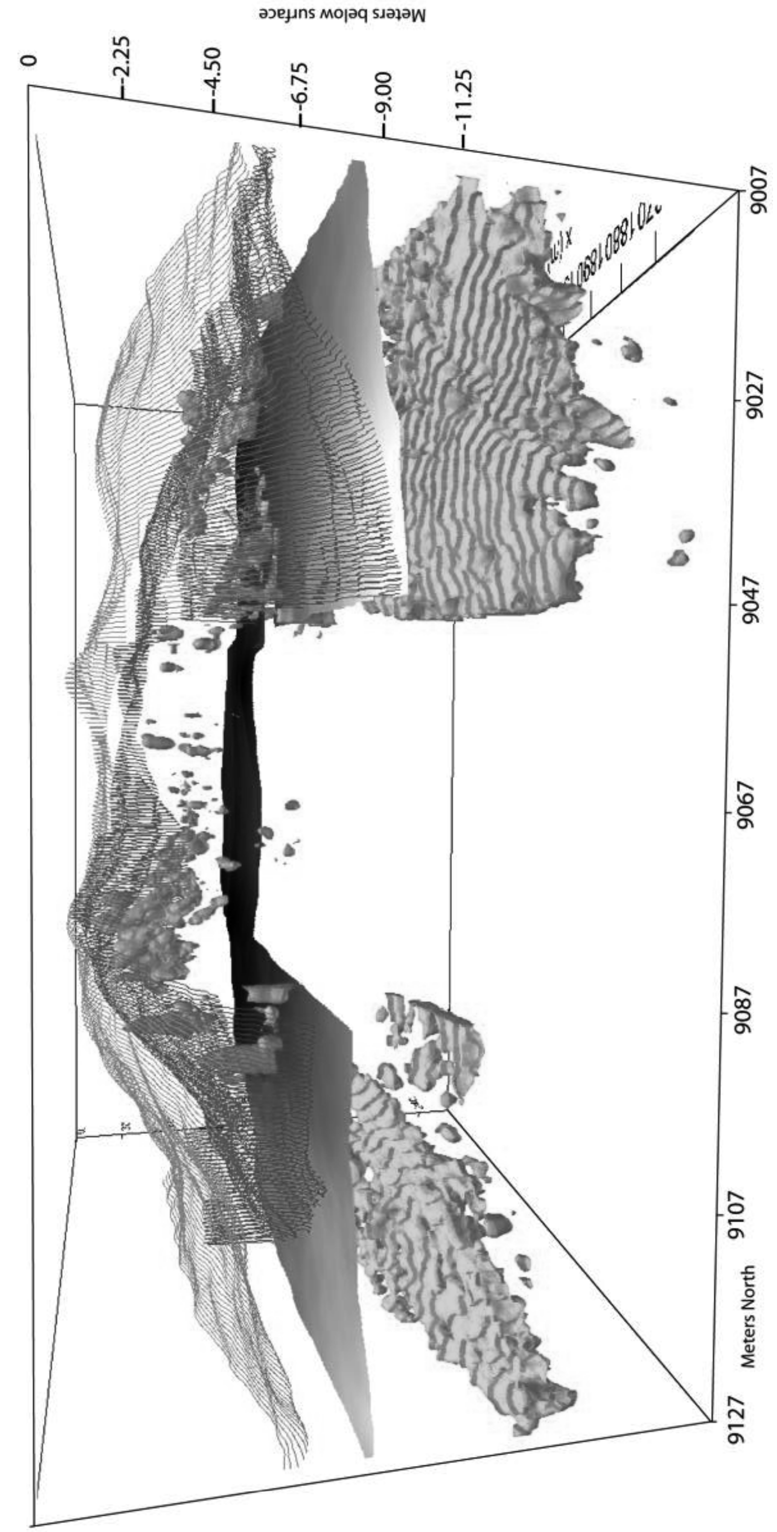

Figure 21: Three-dimensional representation of the dune interior at Saruq al-Hadid. Dune surface in yellow, reflector 1 in green mesh, high-amplitude reflections are green solid isosurfaces and gypsum pavement is the solid gray gradient surface.

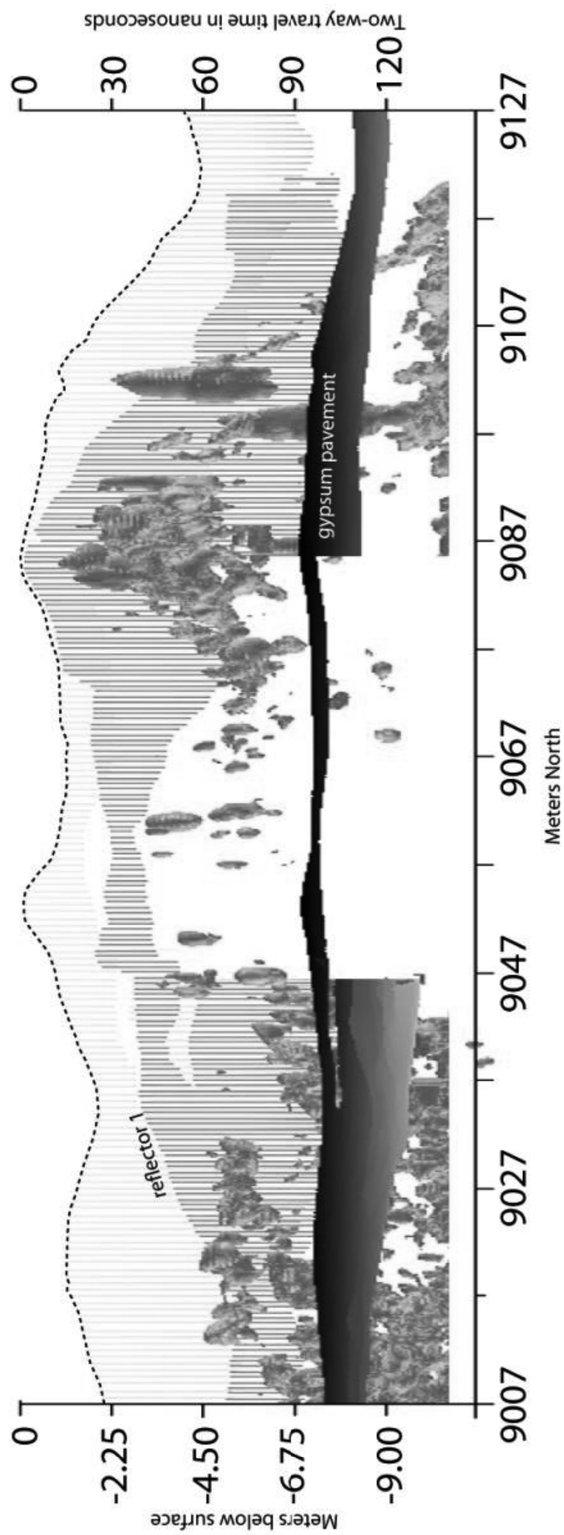

Figure 22: Dune profile as viewed from grid west. Area under reflector 1 in green. Isosurfaces of predominately Iron Age II reflective anomalies in green

approximately 5-7 m square. This is surprising, since a horizontal surface is unlikely to be preserved in these active dunes, one possible explanation is that these materials were rapidly covered and capped, preserving their horizontal arrangement. The blocks seem perhaps to surround a courtyard space that lies close to the western boundary of the survey limits in the center of the survey area. Based on some alignments of tabular limestone uncovered in test excavations in 2009, these room blocks, if they exist, are likely only preserved as lines of stone used as foundations for huts with temporary superstructures that were made of woven palm leaves (*areesh*) in order to provide shade and allow a breeze to pass through. The northern extent of this cluster has the strongest anomalies, which appear clearly in three-dimensional isosurface maps of the dune interior (Figures 21, 22). As discussed above, these may be interpreted as either a vertical extension of the features that are associated with the Iron Age II 'foundations' at Reflector 2 or an installation dug into the ground from the surface above Reflector 1.

DISCUSSION

The discovery of a possible plan for a structure or group of structures that is located approximately midway through the dune was an unexpected result of the GPR survey. This deposit, recorded as reflector 2 in the GPR profiles, corresponds to levels where excavators found most of the Iron Age II bronze and ceramic vessels that included a snake motif that were part of ritual activity related to a snake cult (Herrmann et al. 2012; Benoist 2007; Potts 2007). When artifacts with the snake motif are found in abundance like at Saruq al-Hadid, the snake cult sites normally include some structures, including what is interpreted as an open-air altar that is two to five meters across (Benoist 2007). This could be one interpretation for this vertically-stacked cluster of anomalies that seems to be integrated into the orthogonal plan of the foundations and that is visible in profile in the three-dimensional isosurface map of the site. To

Speculate further, the plans of buildings that are seen to spread across the rest of the dune could include open-air chapels, which are recorded to be two to five meters on their longest side, sometimes arranged around central offering areas, which could explain the absence of strong anomalies near the center of the dune. The true purpose and appearance of these anomalies can only be verified through archaeological excavation.

Most of the alternating cultural and natural strata layered within the central sand dune at Saruq al-Hadid are relatively thin and somewhat deflated, exhibiting evidence for some conflation of deposits on the top of each stratum that suggests a period of wasting when it was exposed on the surface. Reflector 1, consisting of a crust of artifacts that is exposed on the present surface near the middle of the survey area, exemplifies this pattern. This crust is very rich in cultural materials primarily from the late first millennium occupation, when the production of copper and iron goods seems to have been the principal activity in this part of the site. Materials that date to different periods and suggest other activities also appear in this layer and represent some mixing of archaeological layers, occurring perhaps when furnaces for smelting or forging were installed into the dune (Herrmann et al. 2012, 65).

Reflector 3 is another example of a deflated surface, consisting of a thick layer of artifacts, faunal materials, and other evidence of human activity found in a densely packed deposit of sands. This deflated layer caps a sequence of deposits that were likely the result of seasonal visits by nomadic pastoralists in the early second millennium BC (Herrmann et al. 2012, 57).

The exception to this pattern of stratified, yet deflated deposits is the layer of clean sand deposited between approximately 950 and 400 BC that is delimited by Reflectors 2 and 1 and accounts for almost half of the volume of the buried prehistoric dune. At the base of this deposit lies what is interpreted as Iron Age II building foundations, probably with some bronze and ceramic vessels that were likely part of ritual activity there. While a few Iron Age II sites, such as Rumeilah and Tell Abraq, persisted through to the second half of the first millennium BC, on the whole there was a marked decline in the number and density of settlements in the Oman Peninsula in the following Iron Age III period. The collapse of Iron Age II society and the vastly reduced cultural signature on the landscape during the Iron Age III observed by archaeologists has been attributed to the degradation of agricultural or freshwater resources resulting from a combination of an ongoing regional trend toward aridification since the end of the third millennium BC (Parker, Goudie, et al. 2006; Atkinson, Thomas, Goudie, and Bailey 2011) with the consequences of environmental over-reach during Iron Age II expansion (Magee 2000, 36).

Could the sand deposit that seals the Iron Age II remains be evidence for an environmental shift in southeast Arabia at the end of this period? The possibility of a natural or anthropogenic environmental change that coincided with the end of the Iron Age II in southeast Arabia has not received much treatment from those interested in the ancient environments of the Oman Peninsula. While sea cores also indicate increasing aridity at this same time (Lückge et al. 2001), on the whole, dune deposition is poorly attested elsewhere in the Oman Peninsula for this period. In Liwa Oasis, however, Stokes and Bray (2005) report the accumulation of approximately 40 m of homogeneous windblown sediments during the first millennium BC. The accumulation and preservation of approximately 2 m of windblown sand at Saruq al-Hadid following the deposition of the Iron Age II artifacts indicates that sands were active in this area as well, but it is not yet understood how widespread and intense this episode was.

The rapid expansion of desert settlement and agriculture in the Oman Peninsula in the Iron Age II has been cited as a potential factor that promoted the reactivation of windborne sediments (Magee 2004). While rainfall in Arabia during the early Holocene exceeded current amounts, it should be remembered that at no time in the past has there been sufficient moisture in the region to support dry farming in most of the Arabian Peninsula (Potts 1993), with the exception of the highlands of Yemen (Parker, Goudie, et al. 2006) where precipitation amounts were enough to irrigate lowland and mountain terraces (Harrower, Oches, and McCorriston 2011). Remarkably, many of these ancient water management systems were sturdy enough to still be used by locals today (Wilkinson 2003). In the Iron Age II, however, the introduction of the *falaj* system that watered fields at the base of the mountains via subsurface channels permitted agriculture on a scale that had not been practiced before. The adoption of *falaj* irrigation is credited as one of a handful of innovations that supported the rise of regional polities and a population explosion even in a time of diminishing precipitation and a dropping water table (Potts 1990, 392; Magee 1998, 51–52).

Could the extensive agricultural land-use and adoption of new grazing domesticates (see below) have compromised the land-cover dynamics of the region, and to what degree? Archaeologists have identified anthropogenic deforestation or removal of surface vegetation as a driving influence on environmental degradation in the Near East and in drylands elsewhere. In the Oman Peninsula, the Abassid period has been identified as a time when surface vegetation was removed past a threshold of sustainability (Goudie et al. 2000). Grazing, wood-cutting and metalworking in Bronze Age, Roman, and Byzantine Wadi Fayan, Jordan, resulted in disastrous and long term environmental degradation that influenced the appearance of the landscape today (Barker 2002; Barker, Gilbertson, and Mattingly 2007). In the desert southwest of the United States, too, land-use practices were responsible for environmental degradation (Kohler and Matthews 1988).

In addition to or instead of the expansion of agricultural lands, it is possible that an expansion of grazing animals and pastures could have triggered a reactivation of dune sands. Herds of sheep, goats and cattle could have grown with the human population and put new stress on the grasses that covered the dunes. The appearance of the domesticated camel in southeast Arabia at the beginning of the Iron Age II (H.-P. Uerpmann and Uerpmann 2002) could have tipped the balance toward a degrading environment. The domestic camel is recognized as having had a significant, if not central, role in the development of the social and economic infrastructure that sets this period apart from earlier periods. Magee (2007) posits that the uniform culture that spread across the Oman Peninsula at this time would only have been viable through the centralized control of trade and resources from different environments, and this management of transportation and goods was only possible using the camel.

The environmental impacts of the appearance of the domesticated camel are not yet understood. It is difficult to estimate the size of the domestic camel population in southeast Arabia during the Iron Age II period partly because there is an unsatisfactory faunal sample and also because it is difficult to distinguish domestic camel remains from those of the wild population which existed and was still being hunted at this time (H.-P. Uerpmann and Uerpmann 2002, 257). The impact of grazing animals, specifically domestic camels, on desert cover in southeast Arabia, is much better understood, however. An interest in contemporary desert ecology has prompted a series of studies on the effects of grazing in desert environments in the UAE, and the results clearly show that camel grazing is significantly more detrimental to species diversity, plant density, and the survival of perennial plant species than native antelope and oryx herds in both the dunes and gravel plains (El-Keblawy, Ksiksi, and El Alqamy 2009; Gallacher and Hill 2006).

The configuration of dunes in the Rub al-Khali is the product of a complex sequence of environmental changes that includes shifting winds at both the regional and local scales, variable rates of precipitation, and changes in groundwater levels. Therefore, accurate interpretation of dune chronologies is dependent on an understanding of the effects of sediment reworking/removal as well as sediment deposition (Telfer et al. 2010). Most of the aeolian record consists of deposits that have been preserved by a subsequent stabilizing event such as a period of increased precipitation or an increase in groundwater levels (Stokes and Bray 2005). Thus, we must ask the question: what landscape transformation stabilized the thick layer of post-Iron Age II sediments at Saruq al-Hadid? In most cases, it is the spread of vegetation, supported by an increase in precipitation, that shields the surfaces of aeolian deposits, and this is also the most likely scenario for Saruq al-Hadid. Even without direct rainfall on the dune itself, precipitation in the mountains could have been carried into the stretch of desert occupied by Saruq al-Hadid and its neighboring sites via bedrock fractures and near-surface aquifers (Ghoneim 2008; Herrmann In review). Vegetation with deep roots or that could be supported by moisture brought up by capillary action through the sand dune could have covered the dune and stabilized the sediments.

An environment that was relatively rich in vegetative cover could have been what attracted metalworkers of the late first millennium BC to Saruq al-Hadid. While vegetation may have played a role in the initial stabilization of the Iron Age dune deposits at Saruq al-Hadid, it was the subsequent toxic and destructive activities at the site that preserved them for us today. The deposition of this heavy crust of copper slag mixed with a wide array of artifacts formed a shield that has undoubtedly kept winds from removing sediments on the site and preserved this rare archive of late Holocene environmental change in the inland deserts of the UAE.

SUMMARY AND CONCLUSIONS

GPR survey at Saruq al-Hadid has generated images of the interior structure of dune deposits at a resolution fine enough to map multiple buried bounding surfaces and individual artifacts with clarity. In addition, the location of a possible structure or cluster of structures that likely dates to the Iron Age II period has been identified. The vertical distribution of buried contact boundaries has allowed a reconstruction of the stratigraphy of the archaeological deposits across the unexcavated portion of the central dune. This GPR survey, combined with temporal information from 14C dating of organic materials and OSL dating of clean sediments collected in test excavations, has helped to identify four facies anchored to southeast Arabian culture periods that can guide interpretations of the results from past and future investigations at Saruq al-Hadid.

The four sedimentary episodes identified through this research were separated from each other by reflections that represent deflated surfaces containing large quantities of cultural remains. The uppermost facies covers the late first millennium BC/early Christian era materials with abundant evidence for metalwork identified as Reflector 1. These levels have not been dated with any precision yet, but we know from an OSL date acquired below the surface of facies below that accumulated at the earliest in the fourth century BC. This gross sedimentological unit also includes the most recent wind-blown deposits.

The second facies from the surface (below Reflector 1) represents a post-Iron Age II abandonment of the site and suggests a period of active dune emplacement from approximately 950 to 400 BC. It is argued here that this period of aridity could have been triggered by the destabilization of dune cover due to increased herd sizes and the introduction of the domestic camel to southeast Arabia during the Iron Age II period.

This facies is bounded on the bottom by a horizon consisting of many anomalies that represent the positions of stones or artifacts (Reflector 2). Time slicing suggests that this horizon may be partly defined by the placement of foundation stones for structures, in addition to the debris of other human activity, but this has not yet been verified through excavations. This horizon has been dated to the Iron Age II with some confidence by three well-clustered 14C dates and is the likely source of the bronze vessels and offering stands that may have been associated with the ceremonial activities of a snake cult that has been recorded at several other sites in the Oman Peninsula and elsewhere in the ancient Near East.

Little is known about the next facies, which includes the sands below the Iron Age II materials of Reflector 2 and terminates either on the desert pavement surface or the second millennium deposits, which are poorly represented in the GPR data. During excavations, the fourth and deepest facies was found to be made up of artifact-rich compacted sands that contained very large amounts of faunal remains. These appeared in the GPR profiles as Reflector 3, but could not be traced across any significant area with confidence.

The gypsum surface, Reflector 4, that supports the dune was also modified by ancient humans and was dated to the Umm an-Nar period in the late third millennium BC. The GPR data was somewhat effective at detecting the locations of hearths and pits that had been carved into its surface.

The broader contribution of this research is in the identification of an accumulation of windblown sediments during a period when an environmental change was suspected to have taken place in southeast Arabia but for which environmental proxy data were lacking. While I have presented here only a single dated sequence of accretion from a deposit where sediments may have been trapped and protected from redistribution by a surface shield of cultural materials or by other means, these data are part of a growing corpus of paleoenvironmental proxies which are helping to develop a fine-scaled regional model of environmental change in pre- and protohistoric southeast Arabia. In order to reconstruct how the history of dune accretion at Saruq al-Hadid fits into regional trends, however, a systematic sampling of dunes in this dune field and of dunes from the surrounding area would be needed. Whether here or elsewhere, the methods and results of this study could serve as a model for further investigations that use a combination of GPR profiling and OSL age determination to map and date the internal structures of archaeological sites in dry sediments or aeolian deposits in order to build a history of climate and landscape change.

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Table 4: Saruq al-Hadid AMS dates

Reference Number	Sample number	Material	Op	Loc	Lot	PP/ FN	d13c	F	Error	14c BP	Error	Cal years mean BC	cal years sd
A	AA84596	Charcoal	R2	9	18	140	-21.7	0.6102	0.0035	3,968	46	2481	76
B	AA84590	Charcoal	P1	5	18	107	-10.5	0.7085	0.0035	2,768	39	915	50
C	AA84591	Charcoal	P1	5	19	117	-10.7	0.7047	0.0035	2,811	40	967	55
D	AA85670	Charcoal	P1	5	30	176	-10.8	0.7066	0.0041	2790	46	944	60
E	AA84589	Charcoal	P1	3	7	35	-10.5	0.7024	0.0035	2,837	40	1001	61
F	AA84593	Charcoal	P1	6	39	218	-23	0.6479	0.0033	3,487	41	1813	56
G	AA84594	Charcoal	P1	8	42	223	-11.4	0.6492	0.0032	3,471	40	1799	58
H	AA84595	Charcoal	P1	8	43	227	-13.8	0.638	0.0045	3,610	57	1976	85
I	AA84597	Charcoal	H 3				-10.8	0.6278	0.0075	3,740	96	2164	142
J	AA84598	Charcoal	H 4				-11.1	0.5836	0.0041	4,326	56	2972	80

Table 5: Saruq al-Hadid OSL Dates

Reference Number	Sample	Area	OP	Loc	Lot	PP/FN	OSL age	Age BC
A	UIC2477	C	O1	1	1		2430 ± 270	421 ± 270
B	UIC2481	B	P1	5	30	175	2,870 ± 490	861 ± 490
C	UIC2480	B	P1	7	40		3760 ± 395	1751 ± 395
D	UIC2476	B	P1	9	45		3400 ± 545	1391 ± 545

CHAPTER 4

SHALLOW ALLUVIAL GROUNDWATER AND PREHISTORIC SETTLEMENT PATTERNS IN THE OMAN PENINSULA

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ABSTRACT

In semi-arid and arid zones, changes in prehistoric settlement patterns are generally understood to be connected to trends in available moisture from precipitation or rivers and streams. In this article, I attempt instead to connect spatial and temporal patterns of prehistoric desert activity in the deserts west of the Oman Mountains to fluctuations of available groundwater that, at certain points in the prehistory of the region, breached the ground surface to create inter-dune lakes or oases. Three strands of evidence connect episodes of desert occupation to periods when inter-dune lakes may have been present: 1) the results of archaeological investigations in the southeastern corner of the Emirate of Dubai, UAE; 2) modern drainage patterns of orographic moisture from the Oman Mountains as seen in MODIS and LANDSAT satellite data; and 3) trends in Persian Gulf sea levels in the Early and Mid-Holocene. Finally, I explore how the use of and attitudes toward this persistent resource changed between occupation episodes.

Keywords: Southeast Arabia, Oasis Settlement, Saruq al-Hadid, Al-Ashoosh, Bronze Age, Umm an-Nar, Iron Age, MODIS, Sea Level

INTRODUCTION

In his report on the first seasons at the Iron Age site of Muweilah, UAE, Magee (Magee 1996, 211) challenges archaeologists who have an interest in settlement patterns of southeast Arabia to confront an environmental bias in the interpretation of ancient settlement patterns and establishes the goal of explaining the how and why of prehistoric settlements that are located in the desert plain west of the Oman Mountains, far from the relatively fertile coastal zones or oases tucked into active wadis that descend from the mountain heights. While further research at the site has shown Muweilah to be a complex economic center with demonstrable international ties and an arguably coastal orientation, the discovery of two archaeological sites that lie further into the arid interior approximately midway between the Persian Gulf coast and the Oman Mountains has now renewed Magee's challenge to understand prehistoric land use in truly arid environments. These two sites, Al-Ashoosh, which dates to the third millennium BC (Qandil 2005; Casana et al. 2009), and Saruq al-Hadid, which hosted human activity sporadically from at least the third through first millennia BC, with evidence for intense metalworking sometime in the first millennium , are located far from today's reliable sources of water. A problem central to understanding human activity at these prehistoric sites—and other possible sites that may lie undiscovered in the desert plain of Arabia—is the question of the origin of the moisture that must have supported biological resources, now absent, that made these locations attractive to prehistoric people. A related question is how the appearance of desert oases influenced patterns of settlement during the Umm an-Nar and Iron Ages in southeast Arabia.

With a few exceptions, the idea that environmental conditions had a dominating influence on prehistoric social and cultural trajectories has met with considerably less skepticism in southeastern Arabia than in other parts of the Middle East. One perhaps problematic reason for this is that southeast Arabians did not establish an historic record until much later than their counterparts in Mesopotamia and the Levant, with the result that native independent strains of evidence that would provide alternative explanations for sociopolitical change and temper environmentally deterministic interpretations are unavailable (Crumley 1994; Paulette 2012). However, the extreme marginality of the landscape from the perspective of human requirements means that we must take environmental factors into account in reconstructions of ancient societies. The complete lack of perennial surface streams and extremely low levels of precipitation have made dryland farming an impossibility for much of the region, and even up to modern times settlement has been tightly clustered around easily identifiable hydrologic resources, such as perennial wadis, active springs, and other groundwater sources.

This article makes the case that occupation at of Al-Ashoosh and Saruq al-Hadid relied on the availability of groundwater from shallow alluvial aquifers that supported oasis environments at these desert sites well into the Iron Age. A brief review of the environmental history of the region is followed by a report of fieldwork at Al-Ashoosh and a summary of results from investigations at Saruq al-Hadid (covered in greater depth in (Herrmann et al. 2012; Qandil et al. In Press)(Herrmann et al. 2012; Qandil et al. In Press)(Herrmann et al. 2012; Qandil et al. In Press)(Herrmann et al. 2012; Qandil et al. 2013). The potential for alluvial groundwater to reach into the central desert plain where Al-Ashoosh and Saruq al-Hadid reside is demonstrated with thermal infrared images captured by satellite that show land-surface temperature. The relationship of these shallow aquifers to fluctuations in climate and sea-level during periods of occupation at the two sites is then considered. Finally, looking at the variation in the activities attested during different periods at Saruq al-Hadid and Al-Ashoosh, we return to the question of how the desert reaches of the Oman Peninsula, and the oases that might have existed there, fit into the changing economies and conceptions of landscape of prehistoric people in southeast Arabia.

Present and Past Environments of the Oman Peninsula

The image of an arid, unforgiving landscape dominates traditional ideas of Arabia, in its past or present state. It is true that the landscape of the Oman Peninsula is challenging to humans for a number of reasons. Foremost is its aridity: southeast Arabia receives on average less than 100 mm of rainfall per year, and not necessarily on a regular cycle. Rainfall in the UAE lowlands is annually below 50 mm and is supplied either by westerly winter storms that originate in the Mediterranean Sea or by the Indian Ocean Monsoon that is blown parallel to the southern coastline of Arabia and occasionally breaches the Oman Mountains to cause thunderstorms (Glennie and Singhvi 2002). In the summer, temperatures in the Oman Peninsula can surpass 50º C. The Oman Mountains, which form the spine of the Oman Peninsula and separate the country of Oman from the United Arab Emirates, do capture orogenic rainfall that is delivered to the bordering lowlands via wadis, but the limited flow has only been sufficient to sustain relatively limited agricultural efforts. Some of this water is transported below the surface to rise further into the desert at inter-dune oases, but their irregular appearance and tendency to be rather brackish, as well as the general rarity of soils of any kind on the western side of the mountains, have generally stymied the establishment of sizeable settlements. An exception is the Batinah coast, strung between the Arabian Sea and the Oman Mountains on the eastern side of the peninsula. It features a more humid environment with steep wadis that feed and promote more arable soils. A history of correspondingly more intense occupation in this area has been attributed to the presence of these resources (Magee 2000). The coastlines on both sides of the peninsula once hosted rich estuarine environments featuring mangroves, a landscape that gradually disappeared as the climate changed, save for a small part of the Arabian Sea coastline near Kalba in southern Oman (Glover 1998).

The landscapes of the Oman Peninsula have played a major role in reconstructing the chronology of human societies and settlement, with particular landforms serving as the source of important resources, hazards, as avenues or barriers to mobility and expansion. The landforms of the Oman Peninsula are also key players in the environmental history of the region with the sea, desert plain, and mountain ridge, all influencing climate dynamics on short and long term timescales. The region can be divided into three environmental units that run in roughly parallel north-south strips: the desert plain that runs to the coast, the gravel plain on the margins of the mountain range, and the Oman Mountains themselves. The coastal plain includes part of the Rub' al-Khali sand sea that reaches eastward from the central Arabian Plate toward the coast and runs between the Oman Mountain range and the Persian Gulf, as far north as Sharjah Emirate. In the northern emirates, the dune fields of this desert are primarily made up of branching parallel linear dunes that are oriented SSW – NNE and are relatively stable due to the sparse vegetation that covers them (Goudie et al. 2000). As one moves inland, however, these dunes tend to be taller, hold less vegetation and be more active. More dynamic dune fields may feature secondary dune forms that are oriented NW to SE (Goudie et al. 2000). The sizes of dunes are a good indicator of their age: the largest linear dunes have been dated to 18000 to 9000 BP, while lower dune fields that are prone to more rapid recycling of sands through wind action are rarely older than 6000 years (Parker and Goudie 2007).

Tidal action on the low Persian Gulf shoreline has formed coastal sabkhas, where seawater is trapped between low dune ridges and left to evaporate and create marine sediments and brines. Farther inland, dune ridges are separated by stony plains, which are varyingly referred to as gravel mantles or desert pavements. In the northern emirates, including the study area surrounding Saruq al-Hadid and Al-Ashoosh, these remarkably stable landforms (Laity 2011) make up the surface across which dunes slowly move. The desert pavements commonly stretch some two kilometers transverse to wind direction between the linear dune fields and are understood in the past to have hosted groundwater-fed interdune lakes and inland sabkhas (Glennie and Singhvi 2002). The latter are similar to desert pavements or plains and develop in areas that receive little precipitation, have sparse or no vegetative cover, and that are prone to deflation (Goudie and Wells 1995). In active sabkhas, the elevation of the water table exceeds the elevation of the surface where it is not overrun by eolian deposits, so that brines and evaporites can form at the surface (Johnson et al. 1978). Salt accumulation in sabkhas discourages protective vegetative cover and promotes further deflation, thus enhancing the salt pan (Goudie, Livingstone, and Stokes 1999). Modern sabkhas could indicate the locations of prehistoric lakes that formed in periods when annual precipitation rates and the water table were higher.

In some places in the east, sand dunes terminate at the very base of the Oman Mountains, covering the broad, rocky alluvial fans that buffer the western edge of the mountains. The mountains extend in an arc from the northeast coast of Oman, with elevations reaching 3000 m at Jebel Akhdar and constitute the modern border between the United Arab Emirates and Oman. The ophiolite exposure in these mountains is the largest and most studied in the world and is rich in copper resources, particularly sulphide ores (Glennie 1995). Ancient mining and copper-working sites were initially rediscovered by geologists and engineers seeking to establish modern mining operations; ancient sites in this area are telltale signs of a buried ore deposit

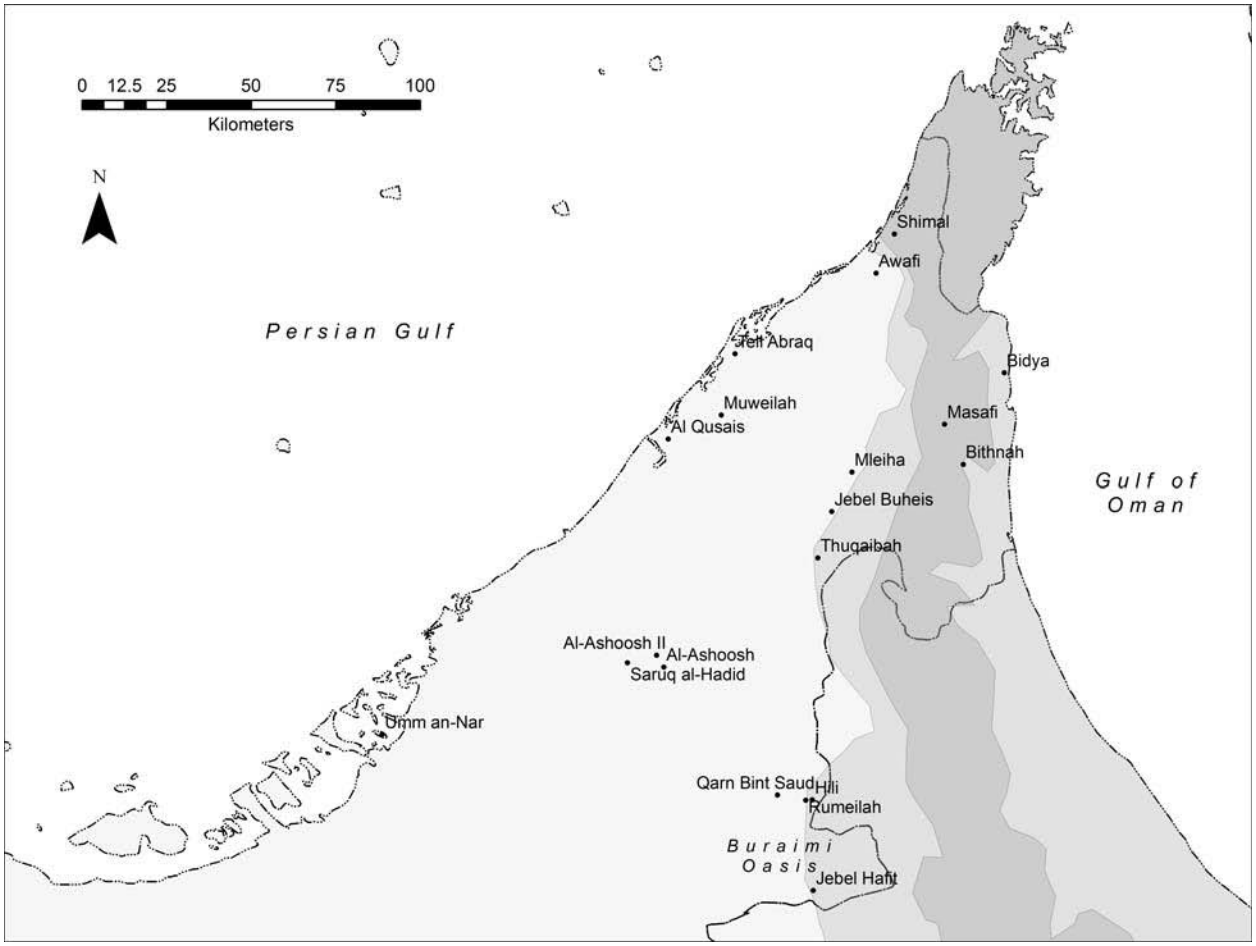

Figure 23: Map of the Oman Peninsula with study sites, other important archaeological sites mentioned in the text and broad environmental zones

(Weisgerber 1978; Hauptmann 1985). It is copper that made the Oman Peninsula known to Mesopotamian kings, scribes, and traders; texts reveal that this region, known as Magan, was at certain points the main supplier of copper to Mesopotamian peoples. The remains of pre-Islamic mines are certainly less common than evidence of later mining operations, but this is perhaps due to the extensive destruction that was part of Islamic period mining (Wilkinson 2003). Still, a few early mining sites have been located (Weeks 2003).

In other places in the east, sand dunes give way to vast gravel plains that slope upward toward the mountains. These alluvial fans are comprised mainly of silts, clays and gravels, though some of the only developed soils in southeastern Arabia are found along the wadis that drain the Oman Mountain range. The alluvial fans occupy two geographic areas, separated by the mountain range from which they originate. On the eastern flanks of the Oman Mountains, on the Batinah coast, the wadis and alluvial fans traverse a narrow strip of land to reach all the way to the Arabian Sea. The alluvial plain on the west side of the Oman Mountains in the northern UAE is called the al-Madam plain. Like the Batinah coast, this area is crosscut by a number of wadis draining the mountains. For the rest of the mountain chain, from the Emirate of Sharjah south to Ra's al-Jinz, Oman, the alluvial fans drain inland and are often partially covered by mobile sand dunes. These fans can vary from two to sixteen kilometers wide and for much of the mountain range and have merged to create what is an essentially continuous gravel plain that stretches along the base of the mountain chain, extending up to 200 kilometers away from the mountains. The alluvium in these landforms generally consists of poorly-sorted dolomite, limestone and flint gravels intermixed with silt. The volume of these gravel fans and the wadis that feed them along the Oman Mountains, the oldest of which began to accumulate sometime around 300,000 BP, is evidence for moister conditions during the early Pleistocene (Juyal, Singhvi, and Glennie 1998), at a time when the Arabian Peninsula was much more humid and covered with vegetation. Some of these older wadis on the Batinah coast on the east side of the Oman Mountains had meandering channels, suggesting thicker alluvial deposits. After that period, wadi gravels were deposited during other humid phases, during interglacial periods, and during sporadic heavy rainfall events that occurred during arid periods. In the northern part of the UAE, where these fans reach the sea, relative dating techniques have identified three discrete episodes of fan development, with the oldest deposits toward the beginning of the late Pleistocene (~100,000

BP) and later fans closer to the Pleistocene - Holocene interface at approximately 12,000 BP (Harvey 2003).

Today, the wadis that once carried these massive amounts of alluvium are only seasonally active, drawing from orographic moisture captured by the Oman Mountains, and only one wadi in the UAE delivers water to the Gulf (Wadi Lamhaj in Ras' al-Khaimah), while all others terminate in dune fields. The paths of some wadis as they cross the coastal plain are, however, still visible in satellite imagery (e.g., Wadi Dhaid and Wadi Hamman) (Parker and Preston 2008).

Besides the alluvial fans and wadis, a number of relict lakes that are spread over the Arabian Peninsula comprise the remainder of the ancient hydrologic features known to the region and continue to be fruitful sources of paleoclimate proxy data (Goudie and Parker 2010). They most often come from closed basins where lake levels are controlled by a balance between water accumulation from precipitation and loss from percolation and evaporation, making them particularly sensitive to changes in the water balance of the region. In the UAE, they are found at Awafi in Ras al-Khaimah (Parker et al. 2004; Parker, Goudie, et al. 2006; Parker, Davies, and Wilkinson 2006; Parker, Preston, et al. 2006) and in Al Ain (Gebel et al. 1989), in Oman in the Wahiba Sands (Radies et al. 2004) (Gardner 1988), in Yemen in the Dhamar (Wilkinson 2005) and al Hawa regions (Lézine et al. 1998) 2007), in southern Saudi Arabia at Munfadan (McClure 1976), and in northern Saudi Arabia in the Nafud (Garrard, Harvey, and Switsur 1981). The paleoclimate data produced from these sources, supported by high-resolution climate records from speleothems (Fleitmann and Matter 2009) and sediment cores from the sea floors (Lückge et al. 2001) have been used to produce the following reconstruction of the region's climate history in relation to its history of occupation.

The Neolithic inhabitants of southeast Arabia enjoyed humid weather in a relatively lush landscape, a product of the northward reach of the Indian Ocean Monsoon system (IOM) that brought enough precipitation to support a savanna type environment across the Oman Peninsula between 8500 and 6000 BP. During this time, nomadic pastoralists shepherded flocks of cattle, sheep, and goats across dunes stabilized by grasses and between interdune lakes (Parker et al. 2004). The annual influence of the monsoon moved gradually southward to its current position sometime around 6000 BP, and southeast Arabia dried out considerably as a result (Fleitmann et al. 2007).

Southeast Arabia was particularly arid during the "Dark Millennium" that followed, and archaeologists have documented a resulting population dispersal (M. Uerpmann 1992). Peak aridity is recorded for 5900 and 5200 BP (Parker, Preston, et al. 2006, 472), and during these dry episodes, phytolith ratios from lake sediments indicate that woody vegetation nearly disappeared in the northern emirates (Parker et al. 2004). Precipitation from a source other than the IOM returned to southeastern Arabia in the early third millennium, as indicated by lake sediments at Awafi, and persisted until about 2200 BC (Parker, Preston, et al. 2006). This moist period was contemporary with the emergence of the Umm an-Nar culture, a Bronze Age leap in social complexity that featured the creation of monumental structures and international ties with Mesopotamian and Indus Valley cultures (Potts 1990). The end of this moist period coincided with Bond Event 3, a period of intense aridity that affected the entire Middle East and North Africa (Bond et al. 1997; Gasse and Van Campo 1994) and is famously associated with the collapse of the of the Akkadian Empire institutions (Weiss et al. 1993, 1002), although the effect on the daily life of the general population of Mesopotamia is still in question (Paulette 2012, 183).

The following second millennium BC marked the beginning of a long trend of aridity and dune reactivation that was only briefly interrupted by sporadic episodes of increased precipitation. Despite continuity in the occupation of some earlier sites, such as Abraq (Potts 1990), Shimal (Vogt and Franke-Vogt 1987), and Kalba (Carter 1997), there was an overall decrease in the number of settlements at the beginning of the second millennium in the Oman Peninsula. During this phase, known as the Wadi Suq, the inhabitants of southeast Arabia are thought to have generally returned to pastoral nomadism (Cleuziou 1981) and marks the beginning of a long trend of aridity and dune reactivation that is only briefly interrupted by sporadic episodes of increased precipitation.

Despite the ever-increasing aridity in the first millennium BC, this period saw a great expansion in the number, size and complexity of settlements across the Oman Peninsula with its peak in the Iron Age II (1100-600 BC) (Magee et al. 2002; Magee 2003b; Magee 2003a). The Iron Age III (600-300 BC) is marked by evidence for a period of dune accumulation again coincides with a much sparser archaeological signature. The arid conditions established at this time have persisted through to the present day, with an additional phase of intense dune accretion and aridity recorded for the period around 1000 AD (Parker, Preston, et al. 2006).

ARCHAEOLOGICAL INVESTIGATIONS

Al-Ashoosh and Saruq al-Hadid were initially recorded as part of an archaeological survey conducted by the Dubai Department of Archaeology in 2004 (Qandil 2005). They were excavated in the years following by two separate expeditions, one directed by a team from the Jordanian Department of Antiquities (Al-Khraysheh and Nashef 2007) and another overseen by the Dubai Department of Archaeology (Qandil et al. In Press). A third Group from the Dubai Desert Survey, A joint project between the Dubai Department of Archaeology and a group of

American researcher, undertook surface survey, geophysical investigations, and test excavations at the two sites in concert with other activities in the region (Casana et al. 2009; Herrmann et al. 2012; Qandil et al. In Press). Ongoing investigations include archaeological survey, excavation, materials analysis and ground-based remote sensing and contribute to developing histories of occupation and environmental change at each site.

Al-Ashoosh

Al-Ashoosh (also Al Ashush (Qandil 2005)) is a scatter of cultural debris located on a lone, low dune that cuts across a broad interdune plain in the southwest corner of the emirate of Dubai near its border with Abu Dhabi (Figure 23). This site, which takes its name from a nearby well that has fallen into disuse sometime in the last two decades, was originally visited by a Jordanian expedition between 2004 and 2007. The site was later in 2007 surveyed by the Dubai Desert Survey expedition (a joint effort of the University of Arkansas and the Dubai Department of Archaeology), which mapped twenty-one hearths exposed across the surface of the dune, most of which were marked by thin lenses of ash and fire-cracked flint (figure 24). At the center of the distribution of hearths stands a low mound of burnt bone and stone, interpreted as a midden (Figure 25). Diagnostic ceramics indicated that the site was occupied during the Umm an-Nar period (Casana et al. 2009, 37; Qandil 2005, 126).

The Dubai Desert Survey undertook a brief follow-up expedition at the site in 2008 with the goal of enhancing our picture of activities at the site and collecting materials from secure contexts that could produce an absolute date. A surface collection produced a dozen diagnostic artifacts in close proximity to the hearths, including some diagnostic ceramics and a cluster of

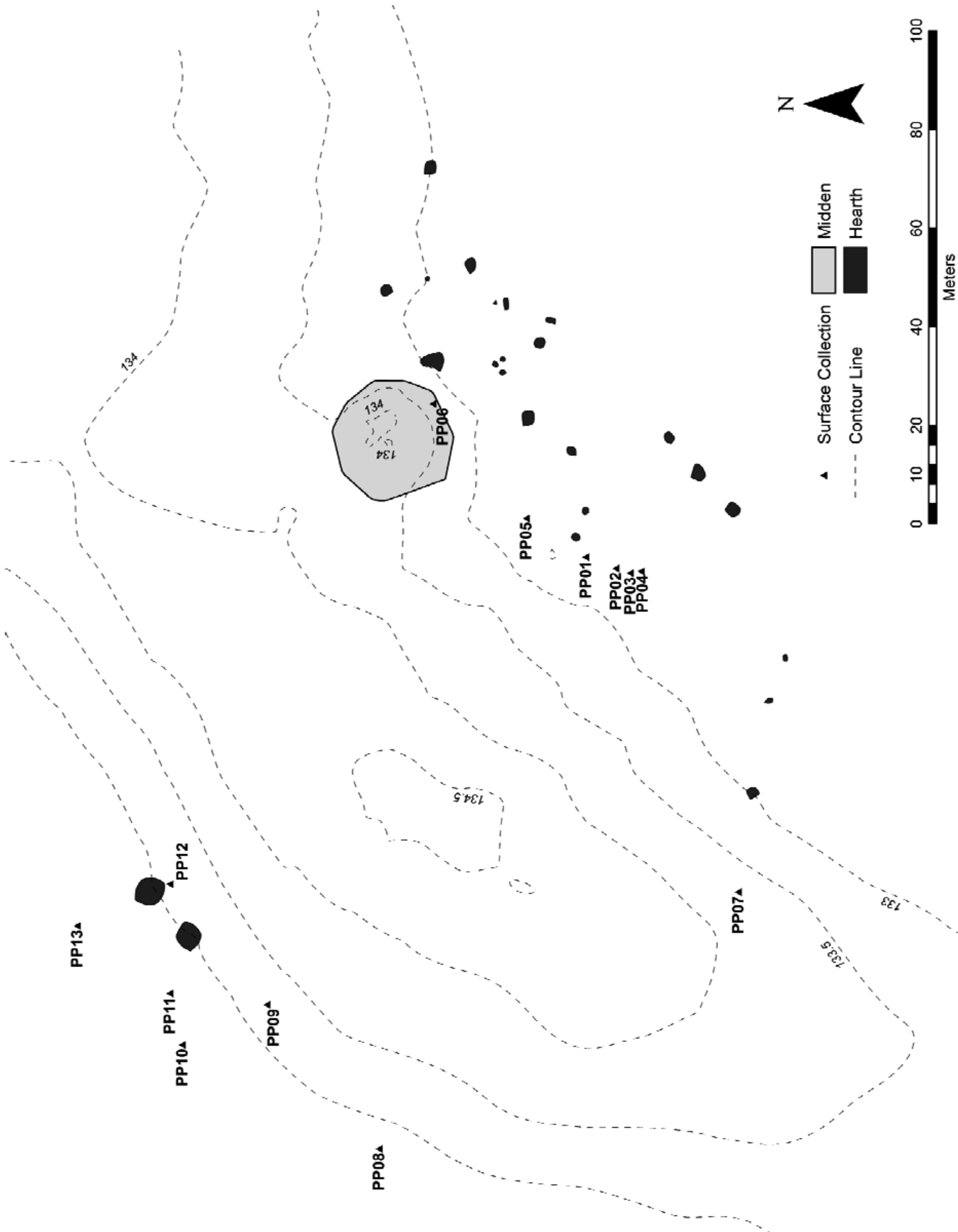

Figure 24: Map of Al-Ashoosh

Figure 25: Landscape at Al-Ashoosh

Figure 26: Excavated tanour at Al-Ashoosh

terebrailia palustris shells, which indicate some connection with the mangrove-lined estuaries of the Persian Gulf coast (figure 27).

Two test excavations accompanied the surface collection. A 1 by 2 meter test trench (TT3) was placed on the north side of the central midden, the surface of which is littered with a substantial amount of fire-cracked flint and animal bone. Ash deposits were detected here just below the sheet of sand that covers the surface. Two particularly dark and dense ash deposits intermixed with sand and stone were documented in this trench. These deposits were much darker, denser concentrations of charcoal than were found in the other hearths documented on the dune surface at the site, and as their association with such a dense concentration of bone and fire-cracked rock would suggest, they likely resulted from some intensive processing of an unknown organic product. One carbon sample retrieved from the uppermost ash layer was dated by 14C radiometric age determination to 2148 ±92 BC (calibrated) (Table 2).

A hearth ring featuring hand-pressed mud bricks that had been recorded on the surface during the initial Dubai Desert Survey visit (Casana et al. 2009) was excavated and found to be a tanour (Figure 26). The loose sand deposits surrounding this oven showed evidence of several ephemeral surface hearths nearby. The oven is oblong in shape, with its interior measuring approximately 110 by 80 cm. The mud-brick and pisé walls measured from 15 to 25 cm thick where exposed. The inside walls of the oven were smoothed and show signs of high heat in the form of discolored, very friable areas of clay plaster on the interior of the oven. The tanour was filled with sand mixed with ash and charcoal and produced several body sherds. The bottom of the oven was found approximately 45 cm below the surface and covered with approximately 10 cm of hand-formed brick fragments and fire-cracked rock. The burnt mud brick is interpreted as having fallen from the superstructure, with the assumption that the tanour walls continued above surface level. The concentration of brick and stone at the bottom of the oven was bisected and three carbon samples extracted from the lowest layers yielded calibrated dates of 2163 ±87, 2310 ±80, and 2246 ±75 BC (Table 7).

Reexamination of the geomagnetic survey results from Al-Ashoosh (Casana et al. 2009, fig. 8) has suggested the presence of a second tanour located some 20 meters north of the excavated one and very near the midden. Tanours are often found in pairs at other third millennium sites in southeast Arabia (Potts, Dalongeville, and Prieur 1990, 37; Frifelt 1975, fig. 54; Magee et al. 2002, 148), and are thought to have had been dedicated to bread baking and cooking meat separately. Therefore, while the two tanours at Al Ashoosh do not appear in such close spatial association as the pairs at other sites, it is possible that they were contemporary ovens that served complementary purposes. For future investigations, the heavy ash deposits that remain in the central midden, the tanours, and the various hearths present the opportunity to reconstruct desert interior flora in the third millennium BC.

Saruq al-Hadid

The important site of Saruq al-Hadid (also Sarouq al-Hadeed, (Qandil 2005) has been the focus of archaeological activity in the Emirate of Dubai since its discovery in 2002 and is best known for the vast array of metal artifacts retrieved by several expeditions. The large-scale joint excavations by Al-Khraysheh and Nashef (Al-Khraysheh and Nashef 2007) from 2004 to 2008 produced a collection of hundreds of objects, including evidence of copper processing in the form of tools, ore, slag, and furnace fragments, along with daggers, swords, and vessels of copper/bronze, fishhooks, offering stands (Potts 2009), and other copper/bronze implements, softstone vessels, gold, silver and bone objects, stamp seals and thousands of stone and shell

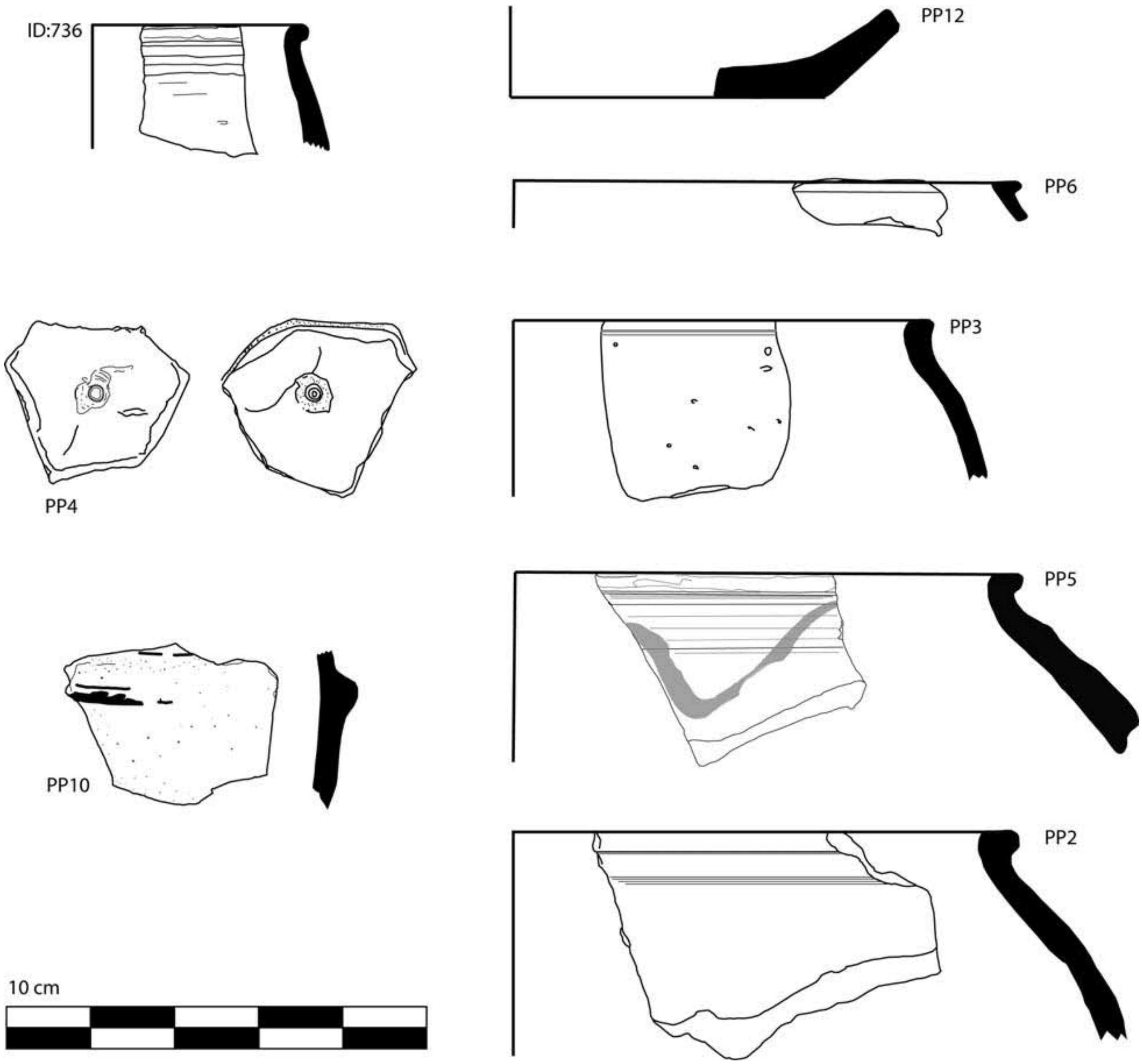

Figure 27: Diagnostic ceramics from Al-Ashoosh. See Table 6 for descriptions.

beads. The more recent investigations of the Dubai Desert Survey have focused on developing the chronology of deposits at Saruq al-Hadid and have discovered that there is more to the site than the artifact-rich Iron Age component from which it has derived minor fame(Herrmann et al. 2012a). In fact, it is an extremely rare example of a stratified desert site that hosted repeated and varied activities over three millennia.

Most of the cultural materials at the site come from a single stratified sand dune that rises over six meters above a gypsum substrate (Figure 28). The dune is protected from deflation by a crust of copper slag interspersed with other artifacts. The earliest dated occupation at Saruq al-Hadid took place in the third millennium BC, roughly contemporary with occupation at Al-Ashoosh. A number of postholes, basins, and hearths were carved into the evaporite pavement that supports the central dune (2012a, fig. 12), and their arrangement suggests repeated, periodic occupation during that period. This natural pavement has been protected from wind action by the overlying sand dunes of the site and may thus be a better-preserved version of the scoured and deflated surface that now appears as a stone mantle covering the inter-dune plains beyond the Saruq al-Hadid dune field. It is likely that the human activities of this period took place on a thin layer of sand covering the pavement and that the features were carved into the gypsum below through this sand layer.

Three wells that are carved into the gypsum and gravel substrate have been explored in separate investigations. They are 2.0-2.5 meters deep and feature a rim that is lined with rough sandstone blocks. Like the hearths and postholes, the rims of the wells are carved into the gypsum pavement, but this does not mean that these features were contemporary, or that they did not continue in use during later periods of occupation. One well was reported as dating to the Iron Age in the initial publication of the site (Qandil 2005). This highlights a significant

Figure 28: Landscape at Saruq al-Hadid

difficulty of excavating a multi-period desert site: because of the unpredictable ways the sand dunes have shifted, eroded and even been modified by humans at every stage of their existence, it is even more challenging than usual to ascribe a date to features whose stratigraphic relationship to reference deposits is unclear, such as those in non-contiguous dune deposits and disconnected surface features like the wells.

Second and third millennium components are confined to deflated but stratified deposits in the bottom meter of sediments in the 2009 excavations by the Dubai Desert Survey. A test trench excavated by a team from the University of Arkansas shows that the oldest and deepest dune strata above the evaporite pavement are a series of 10-20 cm thick layers of sand that contain lithic materials and evidence of burning. Dated carbon and sediments from these layers indicate that the deposits were laid down in the early to middle second millennium BC, as was a dense, deflated layer of organic materials, primarily animal bones, that caps them. This 30 cm thick layer of bones was only exposed in a 3 x 5 meter excavation trench, but it can be seen extending for some distance in both directions in the eroded baulks of prior excavation trenches. This layer of organic materials also produced artifactual remains, including some fragments of Wadi Suq beakers (Herrmann et al. 2012, fig. 10; cf. Magee et al. 2009, fig. 9; Cleuziou 1978, fig. 64:34; Potts 1991, fig. 49:3), softstone vessels, and a copper/bronze pin (Herrmann et al. 2012). This layer needs further exposure and organics deserve be investigated further, but this midden indicates that the area surrounding Saruq al-Hadid was quite rich with life.

The vast majority of sediment accumulation at Saruq al-Hadid took place during the first millennium BC. A buried dune surface that lies no more than one meter above the second millennium deposits produced a number of artifacts that can be securely connected to Iron Age II material culture and yielded 14C carbon dates and OSL dates of buried sediments that support this assessment. This layer is the probable source for the majority of the Iron Age II ceramic vessels that feature snake iconography reported by al-Khraysheh and Nashef (2007) as the snake symbol also appears frequently in the assemblage collected from this level by the 2009 University of Arkansas excavations. This symbol as objects such as bridge-spouted vessels also found at Saruq al-Hadid, have strong associations with ritual practices (Magee 2003a). Considering that no evidence of domestic contexts from the Iron II period have been encountered at Saruq al-Hadid, it has been proposed (Herrmann et al. 2012) that this part the site, if not the entire site, was a ritual center similar to the snake cult centers that have been identified at Bithnah-44/50, Al Quasis, and Masafi (Benoist 2007).

Several meters of clean sand overlie this Iron Age II level. This layer features banded sand deposits, at the top of which is a clear interface containing small bits of carbonate. This interface is interpreted as the end of an accumulation event that seems to have occurred during the Iron Age III (Herrmann et al. 2012, fig. 3). Above this interface are several further poorly-organized cultural layers. The large amounts of copper-working accoutrements encountered at this level, including furnace fragments, burnt stones, and slag, as well as numerous iron blade fragments, bits of precious metal, and thousands of beads of various materials, mark this phase as an industrial period in the history of Saruq al-Hadid. Artifacts that could be of Iron Age II origin are encountered in these levels, but with less frequency and in close association with other artifacts of a most certainly later date, calling into question earlier assessments of the connection of the items associated with a snake cult to a phase of intensive metalworking (Herrmann et al. 2012, 65). This latest deposit has yet to be securely dated, as it is difficult to untangle the deflated erosion surfaces at the top of the Saruq al-Hadid sands. However, based on an OSL date from the sands immediately under this horizon (421 ± 270 BC) and the character of the assemblage from these levels, including large numbers of iron artifacts (which only appear very late into the "Iron Age" elsewhere in southeast Arabia), semi-precious beads, and gold jewelry, it is likely that this layer is contemporary with Achaemenid control of the region or even Parthian activity at Mleiha and Ed-Dur (Mouton 1999; Benoist, Mouton, and Schiettecatte 2003; Haerinck 2011).

GROUNDWATER IN THE PREHISTORIC DESERT INTERIOR

As mentioned above, it is difficult to understand the presence of substantial human activity at these two sites deep in the dunes of the Rub' al-Khali, especially the repeated occupations and intensive activity over thousands of years documented at Saruq al-Hadid, without hypothesizing the presence of much more extensive biological resources than are evident today, and the moisture needed to support them. This section discusses the possibility that alluvial groundwater was once available in the central desert plain where Al-Ashoosh and Saruq al-Hadid are found.

Scarce and highly variable patterns of annual precipitation produce minimal surface flow from the wadis that drain the mountains and leave groundwater as the most reliable water source in the UAE, both today and in the past. Consequently, the distribution, quality and recharge of groundwater resources have been a high research priority for geologists, hydrologists, agriculturalists and city planners in the UAE, mostly to accommodate the rapid population growth and urban expansion that the region has experienced in the last few decades (Ghoneim 2009). Access to groundwater has also been the subject of considerable interest for investigators interested in understanding the patterns and practices of prehistoric populations in southeast Arabia. The major focus of groundwater-related research, however, has been the varying degrees of availability within or at the mouths of wadis or in the large oases that lie at the very base of the Oman Mountains. In these locations, an elevated water table fed by orographic precipitation is easily accessed through wells and appears seasonally, if not more often, on the wadi surface. Investigations at Hili have traced the construction of wells in the oasis and shown how the third millennium BC populations at the oasis reacted to a rapidly dropping water table, likely resulting from the decrease of precipitation following the so-called 'little pluvial,' by digging progressively deeper wells (Jorgensen and Al-Tikriti 2003; Cleuziou 2009, 730). The study of ancient water management practices is not restricted to well depths—evidence for a water table close to the surface is the basis for interpretations of intensive landscape manipulation at Hili 14 (1985, 65), where the level of agricultural fields was lowered over time starting in the third millennium BC to chase deeper groundwater.

The *falaj* system, in which water is transported from wadi mouths and subterranean streams to arable fields via a subsurface channel, is perhaps the most celebrated innovation attributed to the pre- and proto-historic populations of southeast Arabia and any discussion of water management in southeast Arabia would be incomplete without a few words about it. It is widely recognized as one of a few Iron Age adaptations that allowed a population explosion in this period even at a time when precipitation and groundwater levels dropped below the threshold necessary to support dryland agriculture at the base of the mountains and in wadis (Potts 1990, 392; Magee 1998, 51–52). Boucharlat (2003) identifies two types of *aflaj*: what he cites as the original, true *qanāt*/*falaj* that draws from a deep stable aquifer, and the type of *falaj* that is more relevant here, the *ghaili aflaj* (also known as the *quanāt-e havabin*), which taps into a shallow water table, often in alluvial fans, and has irregular, seasonal flow. Only one possible *falaj* has been documented in an area away from an alluvial fan or wadi surface water: a water gallery reported near Muweilah (Mouton 2001), whose status as an actual *falaj* and Iron Age date have yet to be confirmed (Magee et al. 2002, 150).

Even though Al-Ashoosh was occupied during a period that is thought to have experienced increased precipitation (Parker, Preston, et al. 2006), we can assume that the populations at Al-Ashoosh and at Saruq al-Hadid must have also relied to some degree on groundwater resources, especially considering that the site of Al-Ashoosh is named for nearby Tawi Al-Ashoosh (Qandil 2005). At Saruq al-Hadid, the four known wells (with possibly more hidden beneath the unexcavated dunes) point even more directly to the exploitation of prehistoric groundwater resources. None of the wells near the two sites are in use today, but recent and active sabkha remains exist nearby. This was discovered during survey surrounding Al-Ashoosh II, a Neolithic site identified by the Dubai Desert Survey in 2007 just 4000 meters to the north-

northwest of Al-Ashoosh, when the existence of a large moist depression was revealed (Casana et al. 2009, 34–35). This depression is very similar in appearance to that described by El-Sayed (1999, 227) in his survey of desert landscapes in the Liwa Oasis region in the southern part of the UAE.

Shallow Desert Aquifers and Oases

Even at some distance from the mountains, short-term recharge events can enhance the availability of groundwater, albeit not to the degree that they can in wadi courses or piedmont oases. Following rain events, water can be transmitted to the shallow aquifer in the alluvial fans as it percolates through dunes after rainfall, flows from streams running down from the mountains, and is forced through bedrock fractures from the Oman Mountain aquifers into the cemented gravels or onto the desert surface. In all three of these scenarios, the shallow aquifer is held in desert gravels that are on average 60 meters thick and drain toward the gulf(Imes and Wood 2007, 1308). The modern depth from the ground surface to the water in this aquifer decreases significantly as one moves away from the mountain piedmont and is less than 10 meters below ground surface level for most of the desert plain (Imes and Wood 2007).

Ghoneim (2008) and Ahmad (2010) both favor the idea that groundwater is transmitted into the desert plain by way of bedrock faults and fractures and have tested this hypothesis through analysis of satellite imagery and geophysical survey results. The short-term effects of aquifer recharge from precipitation in the form of upwelling in the western desert plain of the Oman Peninsula can be seen in thermal anomalies in images collected daily by Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite. In arid regions like the desert plain of the UAE, solar energy can quickly raise ground surface temperature, and when the ground surface is wet, the water vapor that rises from it results in areas of detectable cooling. The relatively small and infrequent precipitation events in the UAE dry up quickly, but moisture that is trapped in the near subsurface keeps an area moist (and cooler) longer, presumably because the water is being recharged from below. In the studies mentioned above, several summer rain events were selected for examination in MODIS images to find where water that falls as rain in the mountains and is carried toward the sea by alluvial fans drains in wadis or emerges as springs. The thermal anomalies identified are thought to appear too soon after recent storms to be direct runoff. Instead, it is proposed that they result from groundwater breaching the surface of the desert in very shallow basins when the balance of the aquifer is upset by the addition of precipitation in the mountains (Ahmad 2010, 72–79). This hypothesis works well with the findings by Imes and Wood (2007) that show that recharge from precipitation directly on the desert plain or in wadi flow is simply not possible because the high evaporation rates prevent the meager amount of precipitation that falls on the desert of the UAE from reaching the aquifer and instead suggest that waters in the shallow aquifer are transferred upward from a deeper source.

Ghoneim's analysis of the northern emirates identified cool, persistent anomalies in the vicinity of Jebel Buheis in Sharjah (Ghoneim 2008). These anomalies may comprise the northern extent of a chain of oases where groundwater channeled by faults in the bedrock tends to breach the surface in times of increased precipitation. Areas of heightened groundwater flow, just south of Ghoneim's study area in Abu Dhabi emirate, have been identified by Imes and Wood (2007, fig. 3 and 7). One of these roughly crosses the Dubai Desert Survey study area, along the border

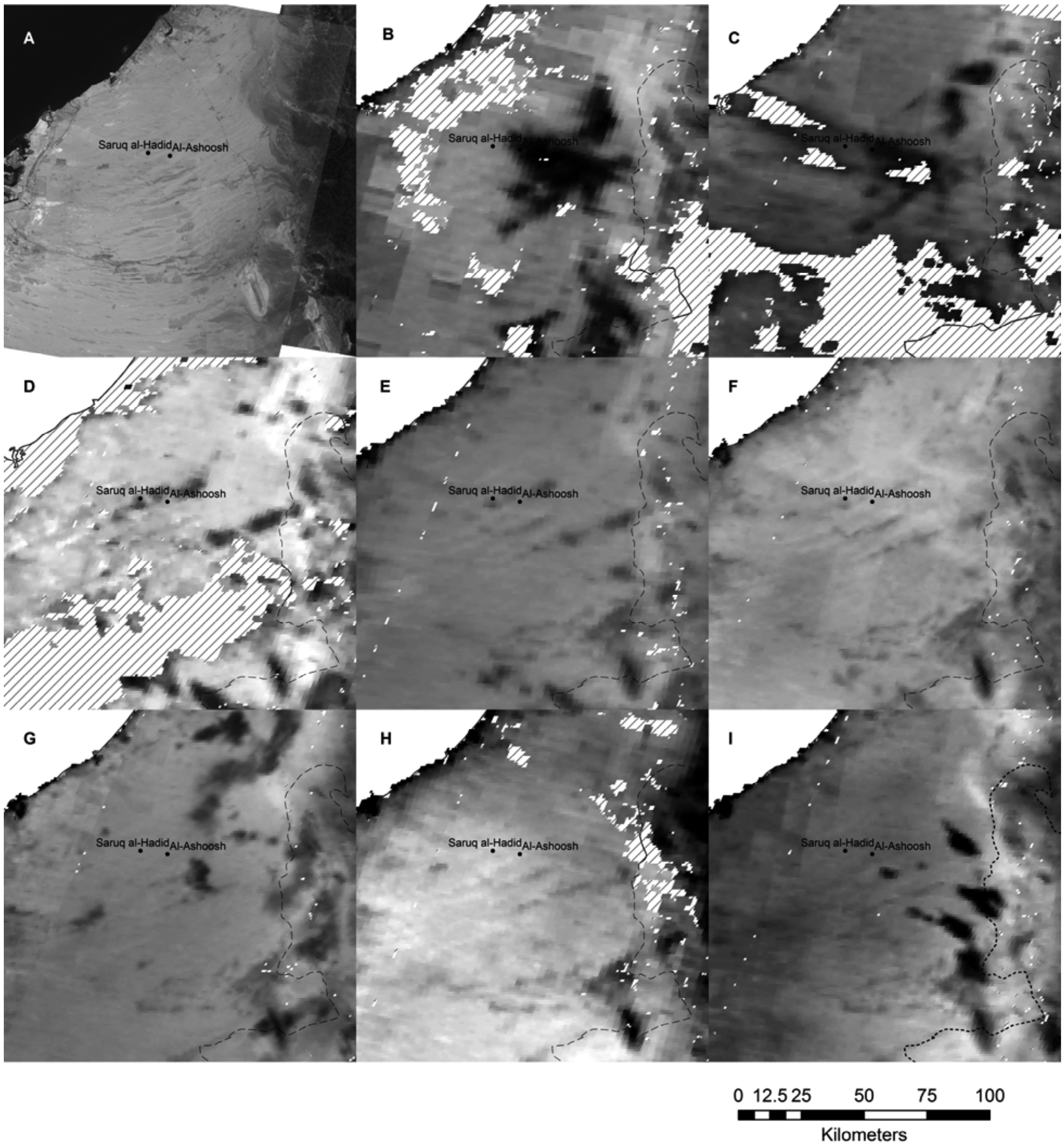

Figure 29: Top Row: A) LANDSAT image of the desert plain surrounding the Dubai Desert Survey study area. MODIS land surface temperature reflectance images record the lingering effects of a July 30, 2008 summer storm recorded in Ali Ain as is appears in the desert plain on B) July 31, 2008 and C) August 1, 2008. Second Row: thermal anomalies in the vicinity of the study sites following a storm on D) May 30, 2011, that persists through E) May 31, 2011 and F) June 1, 2011. Bottom Row: Thermal anomalies in the desert plain following a storm on G) July 12, 2011. H) is the desert on September 10, 2011 just before a storm that I) leave thermal anomalies on September 11, 2011 that indicates the direction of mountain runoff.

as summer and later summer storms that were notable for the amount of precipitation at points along the Oman Mountain chain near the city of Al Ain, UAE. The satellite images already hold one obvious clue to where groundwater is more readily available- the sites of modern agricultural installations, which are visible on recent LANDSAT images as a series of rectangular plots between Dubai and Abu Dhabi emirates, and it is shown here that this area is also prone to exhibit a cool thermal anomaly following rain events. Figure 29 shows the appearance and persistence of thermal anomalies in the desert plain following four rain events documented in the vicinity of Al Ain. These rain events were selected following open plains close to the mountains between dunes at the southern end of the frame (e.g., Figure 29A). Figures 29B and 29C show the location of a rather expansive cool land surface anomaly that appeared following a rainstorm on July 30, 2008 (Kazmi 2008). Note that the cloud cover in Figure 29C corresponds with the channels for groundwater flow in this area hypothesized by Imes and Wood (2007, fig. 3 and 7), and it is possible that the cloud cover that prevented the acquisition of land surface temperature caused by thermal anomalies from the evaporation of surface moisture. The shape of the surface temperature anomaly in the Dubai Desert Survey study area in Figures 29B and 29C, as well as that following a rain event on July 12, 2011 (Figure 29G), can also be seen as a southern continuation of the patterns revealed by Ghoneim's analysis of the northern emirates, particularly the thermal anomaly recorded for her ar-Rafiah basin (Ghoneim 2008, fig. 10). A rainstorm on May 30, 2011 (Figure 29D) shows persistent cooler anomalies (Figures 29E, 29F) that roughly fit the exposures of desert pavement between the dunes in the study area. Figures 29H and 29I show the desert before and after a rainstorm on September 10, 2011 that caused cool anomalies to appear in the gravel plains close to the mountains.

Sea Level and Settlement

These satellite images show the shallow aquifers of the Peninsula can be recharged by rain events in the Oman Mountains, and still do water the desert to some degree, however, output in the past would need to have been greater in order to overcome the high evaporation rates and to allow enough surface or near-surface water to persist to support the types of resources we associate with the activities recorded at Al-Ashoosh and Saruq al-Hadid. Two possible factors could have enhanced output at these locations. First, increased precipitation would obviously promote upwelling in the desert oases. The amount of precipitation was certainly greater during the HCO and it is generally accepted that there was a period of increased precipitation at the end of the third millennium BC, roughly coincident with the Umm an-Nar period (Parker, Preston, et al. 2006).

The second influence on groundwater upwelling in the desert plain would be the level of Gulf waters. Having a current average depth of just 35 meters (Purser and Seibold 1973), the Persian Gulf has seen very dramatic changes in sea level. Some of the most notable and important changes in sea level in the Persian Gulf took place in the years between the Late Glacial Maximum (LGM) and approximately 6000BP when the Persian Gulf trench went from being a wide valley accommodating the Ur-Schatt river system to the shallow sea that we are familiar with now (Lambeck 1996). It was only until 12000 BC when ocean waters breached the Strait of Hormuz to enter the Persian Gulf floor plain and the archaeological implications of an open Gulf basin have long been considered for human populations in the Holocene, and are now beginning to be realized for earlier populations (Armitage et al. 2011; Rose 2010).

The Persian Gulf experienced fluctuations in sea level later in the Holocene that were considerably less dramatic. While the overall trend is for gradual regression of sea level after 6000 BP, a later sea level high stand is indicated by relict shorelines appearing as beachrock and

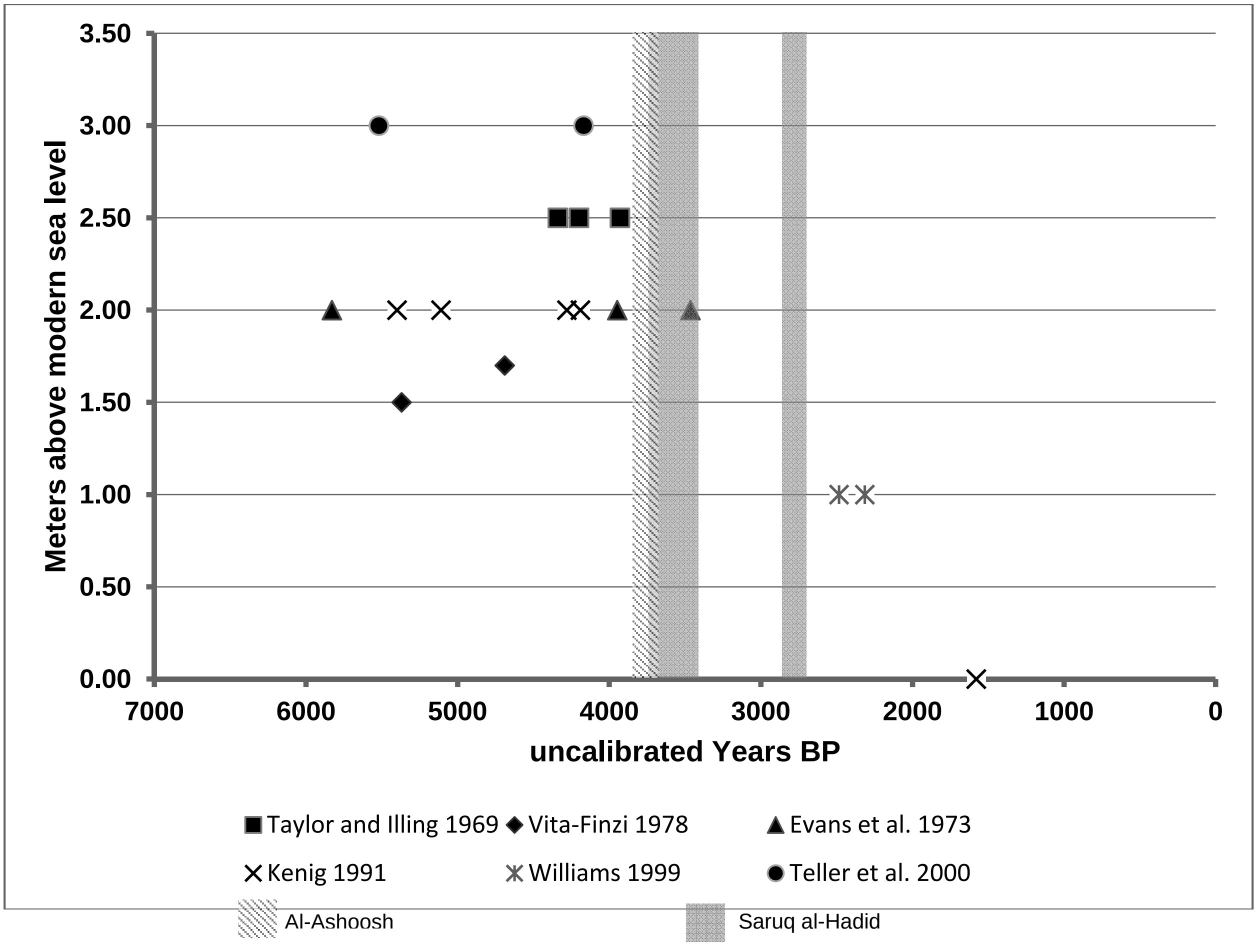

Figure 30: 14C dates from gulf sea level high stands and periods of occupation at Al-Ashoosh and Saruq al-Hadid

cemented beach sands that sit far inland from the coast and coastal sabkhas in Qatar and the Oman Peninsula. There is only broad agreement among sea level estimates, but a trend is clear (Figure 30): sea level peaked at approximately two meters higher than it is today around 5500 BP, and then dropped to its present levels by 2300 BP (Williams and Walkden 2002, 381). The late rise in sea level has, in the past, been attributed to wind and storm surges, enhanced tides and tectonic uplift (Lambeck 1996; Wood et al. 2012) but an elevated sea level is recorded outside of the Persian Gulf basin on other Indian Ocean shores and elsewhere at this time (Williams and Walkden 2002, 381).

These slight changes in the relationship between the ground surface, sea level, and, freshwater lenses surely influenced the appearance of interdune lakes on the low western coastal plain of the UAE. A rise in sea level would cause the incurring sea water table to also rise and elevate any freshwater lenses that may be above it, creating groundwater spring oases which can often be attractive habitats for animals and humans in arid regions. The dated layers of occupation at Al-Ashoosh and Saruq al-Hadid roughly correspond to the high stand of the gulf, and the period of dune accumulation follows. Dropping sea level and reduced recharge of fresh water lenses from diminishing rainfall in the mountains may have meant the end of the rich flora and fauna in these environments.

CHANGING DESERT SETTLEMENT STRATEGIES

The influence of the environment on ancient societies and settlement patterns has been a point of philosophical contention for archaeologists and anthropologists for decades, and this debate has only intensified as more earth and natural sciences specialists become involved in archaeological investigations with the rise of interdisciplinarity. Regardless of individual preference for either a straightforward connection between environmental degradation and societal change, either in the form of collapse (Weiss et al. 1993) or advancement (Brooks 2006; Cleuziou 2009), or for an approach that avoids environmental inputs in interpreting transformations in culture and settlement patterns and instead looks to political and economic factors, two essential facts cannot be set aside: 1) that environmental change influences human activity, and 2) that the response of ancient humans to environmental change is a product of, and only interpretable through the cultural filter of the group in question.

In arid environments like southeast Arabia, the study of human population distributions has even been used to predict the availability of water, treating ancient humans as “sensitive indicators of past climate and living conditions" (Kuper and Kröpelin 2006, 803). The reality that settlement patterns are influenced by the availability hydrologic or other natural resources should not be controversial, particularly in such an arid environment. However, such generalizations effectively describe settlement patterns at only the broadest scale, and do not explain the types of activities that took place in moist zones or how these settlements fit into political or economic networks or migratory patterns.

The results of archaeological investigations at Al-Ashoosh and Saruq al-Hadid show several distinct strategies for occupation at desert oases. More paleoenvironmental investigations are needed to acquire a fuller picture of what these oases looked like, what types of resources they offered, whether they appeared seasonally or persisted for years at a time, and how their appearance likely changed through time. Similarly, much remains to be done in terms of archaeological fieldwork. Nonetheless, it is clear, despite the small amount of controlled excavation and analysis to date, that the ideological and economic approaches of prehistoric people toward these oases were not uniform throughout the history of their occupation. The differences in land use strategies that we see over time at these sites can be attributed to a tendency toward a dispersed or nucleated settlement pattern and the existence or type of social and political institutions that backed the occupants of these sites. Occupations at Saruq al-Hadid and Al-Ashoosh can be divided into two rough categories, the prehistoric pastoralist oasis settlements and the later oasis outposts.

Oasis Settlements of the Second and Third Millennia BC

As a relatively small site located in the desert dunes midway between the mountains and the Gulf waters, Al-Ashoosh belongs to a segment of the Umm an-Nar site-type spectrum that is underrepresented in the literature. It does not seem to possess the kind of cultural material and installations that make the Umm an-Nar lifeway so distinct and sophisticated compared to preceding periods despite its continued political fragmentation (Potts 1986), such as collective burial architecture built on Hafit traditions (S. Méry et al. 2001; Blau 1996) (Cleuziou and Vogt 1983; Frifelt 1991; Benton 1996; Blau 2001; Kennet and Velde 1995), the production of high-quality pottery (Sophie Méry 1997; Cleuziou, Méry, and Vogt 2011), the establishment of complex settlements or settlement networks (Cleuziou 1980; Cleuziou 1989; Brunswig 1989), or evidence of an Mesopotamian trade connections (Weisgerber 1983, 2007a, 2007b, (Potts 1990, 119–125; Weeks 2003; Tengberg 2002).

The mounded midden of fire-cracked stone, bone, and ash suggests that the occupants of Al-Ashoosh processed wild floral and faunal resources, and only the presence of two possible tanours suggests some degree of permanence at the site. At most, Al-Ashoosh is part of a widespread network of modest communities like those identified at Wadi Andam (Al-Jahwari 2009) or the Abu Dhabi Airport (Beech, Kallweit, and Hellyer 2004; de Cardi 1997), but it is unlikely that desert soils (or the lack thereof) could have supported actual agriculture. The assertion that the propagation and harvesting of wild resources around Al-Ashoosh is likely to have been the site's purpose, can only be tested through analysis of the rich deposits of carbonized remains in the hearths and midden. Though the presence of *Terebralia palustris* shells at the site indicates a connection to the Arabian littoral, either through a network of mobility or trade, Al-Ashoosh cannot be connected through its material culture to a particular Umm an-Nar center, which is consistent with the apparent fragmentation of the social and political landscape in this period.

The Umm an-Nar and Wadi Suq remains at Saruq al-Hadid cannot be attributed to anything more than household-level subsistence activity by nomadic or semi-nomadic pastoralists. Here too, however, there is evidence for a coastal orientation—there are what appear to be crab shells and claws in the deflated faunal layer at Saruq al-Hadid, along with remains of many other species, including sheep/goat and possibly camel. As mentioned above, in the second millennium Wadi Suq period, there is a general reduction in evidence for occupation in the region, with some continuity of occupation at earlier Umm an-Nar centers like Tell Abraq, Shimal, and Kalba (Magee 2000). The imbalance between the large numbers of Wadi Suq tombs in the mountains compared to the paucity of contemporary habitation sites makes this phase of southeast Arabian prehistory rather mysterious. The common explanation for the lack of settlement sites is that lifeways tilted even more toward nomadism following a decline of oasis polities in the Umm al Nar period, perhaps related to the drying climate (Brunswig 1989; Carter 1997).

Oasis Outposts of the First Millennium BC.

The framework for a new level of complexity was forged in the Late Wadi Suq/Iron Age I interface as a social and political reorganization signaled by the construction of large ceremonial platforms that are interpreted as symbolic or administrative centers at Nud Ziba (Kennet and Velde 1995), Kalba, and Bida'a (Carter 1997). We also witness the reappearance of imported materials at the end of the Wadi Suq. Access to exotic goods such as Iranian ceramics and cylinder seals is interpreted as a 'material manifestation of power and authority' by local elites (Magee and Carter 1999). In the Iron Age proper, the heterarchical organization and regional fragmentation that has been hypothesized for third and second millennium societies of the Oman Peninsula gave way to an unprecedented scale of human activity and complexity of social organization. The establishment of large fortified settlements (Boucharlat and Lombard 1985; Magee et al. 2002), public architecture such as columned halls (Magee 2003a; Boucharlat and Lombard 2001), the development of *aflaj* that permitted intensive agriculture (Magee 1998), evidence for widespread regional and long-distance trade networks (Magee 1999; Magee 1998; Magee 2005; Tengberg 2002), and the corroboration of these international ties by foreign texts (Potts 1985a,b 1986).

Looking through the lens of the first millennium BC remains at Saruq al-Hadid, we no longer see pastoral nomads, but instead the guiding hand of regional institutions of control. The Iron Age II deposits uncovered during the Dubai Desert Survey excavations paired with evidence strongly suggest that Saruq al-Hadid was a site devoted to the snake cult (Herrmann et al. 2012), one of a handful scattered across the Oman Peninsula and part of a tradition that is recorded in the southern Levant, Mesopotamia and Iran. Associations for this cult are many and varied, but in southeast Arabia it is believed that the cult is tied to concepts of fertility, soils, groundwater and perhaps even bronze working (Benoist 2007, 45 for Bronze working; Potts 2007; Koh 1994). It has been proposed that snake cult sites like Bithna-44 may have been destinations for pilgrims. Since they are manifest as devotional sites closely associated with springs and wells, it would be interesting if the snake cult constituted some form of resource management strategy. The idea that there was reverence for relatively scarce natural features or particular segments of the landscape warrants further investigation, particularly during of this period of intensive land use and population expansion.

Despite clear linkages to regional social networks in both late phases, there is a significant contrast between the ritual orientation of the Iron Age II period and the industrial

Figure 31: Stamp seal from Saruq al-Hadid

pursuits evident during the latest occupation at Saruq al-Hadid. This change in material orientation follows an overall decline in evidence for settlement in the in the UAE which has in the past been attributed to the degradation of agricultural or freshwater resources, interpreted as an environmental over-reach during the agricultural expansion seen in the Iron II period (Magee 2000, 36). This manufacturing outpost that hosted a variety of specialized activities, according to the diversity of the material remains from this layer. The materials worked at this site include bone, iron and copper brought from afar, and precious stones and metals transferred from perhaps even further afield. Is the mix of regional and international goods at Saruq al-Hadid evidence for external control of the Oman Peninsula in this period? The earliest proposed date for the late phase of occupation at Saruq al-Hadid is Iron Age III when the region came under the control of Achaemenid kings in Iran, a shift seen in economic texts (Potts 1990, 394–398) and in the material culture of the region (Magee et al. ceramic analysis).

It is important to note that the progression of occupation types in these Dubai oases somewhat resembles that recorded at Mleiha, which is located in the same zone of oasis upwelling in Sharjah emirate. There, settlement began in the third millennium BC and continued through to the third century AD. The third and second millennium BC settlement consisted of light, seasonal structures, as indicated by the numbers of postholes carved into the marl. Part of the site is sandy, and disorganized groupings of stones and artifacts are found in the sandy portions of the site (Mouton 1999). The shift from the semi-nomadic phase to a sedentary phase is not gradual or continuous, as the next major occupation of the site occurred in the early Christian era, but the remains from this period show an even greater intensity than that found in the late phases of Saruq al-Hadid. Unlike Saruq al-Hadid, this phase at Mleiha features substantial architecture, but there is similar evidence of craft specialization at both sites (Herrmann et al. 2012).

SUMMARY

Based on these archaeological investigations in the emirate of Dubai, it is clear that the desert plain between the Gulf coast and the Oman Mountains occupied an important place in the cultural and economic landscape in the relatively arid millennia following the Holocene Climatic Optimum. This is a revision of the early presumption that the desert landscape was abandoned in arid periods. It is also clear that the long-term drying of the region was not linear or uniform over the entire landscape of southeast Arabia. Instead, a picture of fragmented and varied landscape transformations in both spatial and temporal dimensions is beginning to emerge. These inland desert plains remained a mosaic of microclimates that included inter-dune oases of the kind that are hypothesized to have supported activities at Saruq al-Hadid and Al-Ashoosh. Inter-dune lakes and marshes were periodically recharged by precipitation that fell on the Oman Mountain heights and was channeled into the desert either through porous alluvial fans or more likely from below via a network of bedrock fractures. The interaction between the tails of the gravel fans and tension from sea water incursions pushed alluvial groundwater up to the surface in the desert as far as 30-50 kilometers from the base of the mountains, and this upwelling can still be observed in the northern emirates of the UAE in sensitive satellite imagery today. This oasis belt would have stretched along the Oman mountain chain. If the organic remains from Al-Ashoosh and Saruq al-Hadid are any indication, this oasis belt supported enough flora and fauna to attract a range of prehistoric activities that varied through time.

The archaeological sequence represented at Al-Ashoosh and at Saruq al-Hadid shows that the orientation of inland desert economic strategies changed from a focus on local resource extraction and subsistence-supporting economies at the household or small group level to settlements that were tied to institutional networks that stretched across the Oman Peninsula and beyond. In the early phases, nomadic pastoralists hunted, harvested and processed local resources for subsistence. In the later periods, symbols of external organization and control appeared in the form of religious iconography, stamp seals (Figure 31) and exotic goods. Though the purpose of the site was transformed from a ritual to an industrial focus during the course of the first millennium BC, the activities at Saruq al-Hadid throughout this era were specialized and relied on regional and international trade networks. The desert oases were thus not static loci, always serving only as convenient campsites and isolated from more widespread developments. Rather, in all periods they were part of a broader landscape, integrated into widely-shared social and economic worldviews, and the changing character of settlement and activities at these oases was a product of political, social, and economic transformations at the regional level.

As the corpus of paleoclimate proxy data becomes denser in the dimensions of both space and time, we approach the potential for truly high-resolution social and environmental reconstructions of southeast Arabia, of which the distribution of groundwater-fed oases in the deserts of the UAE is one important part. The findings described here provide a framework for future paleoenvironmental prospection with the goal of identifying areas with high potential for prehistoric upwelling of alluvial groundwater and give some hope for the existence of additional undiscovered archaeological sites hidden in the desert sands. Continued research on the ancient groundwater dynamics and patterns of settlement on the dunes and plains of the desert zone will help to further demystify prehistoric desert land use in Southeast Arabia.

Table 6: Descriptions of Ceramics from Al-Ashoosh collected 2008.

ID	Collection Type	Operation	Locus	Lot	Date	Type I	Count	Description
	Piece Plot	PP2			12/12/08	Sherd	1	Rim. Blackish, severely abraded slip, light red (2.5YR6/6) fabric with sparse white medium grit temper. Light reddish brown interior (2.5YR7/4)
	Piece Plot	PP3			12/12/08	Sherd	1	Rim. Reddish yellow (5YR6/6) body with large sub-angular white grit temper.
	Piece Plot	PP4			12/12/08	Sherd	1	Perforated body sherd. Light reddish brown exterior (2.5YR6/4) with white grit and unidentified inclusions at interface between exterior and interior layers. Pink interior (5YR7/4).
	Piece Plot	PP5			12/12/08	Sherd	1	Rim sherd, partially burnt. Reddish gray (2.5YR6/1)
	Piece Plot	PP6			12/12/08	Sherd	1	Rim sherd with a very pale white slip (7.5YR8/1) and faint light gray paint decoration (7.5YR7/1) over a pink paste (2.5YR8/4)
	Piece Plot	PP10			12/12/08	Sherd	1	Body sherd with black pain or slip over a gray paste (7.5YR6/1). Slightly burnt and reddish on the interior with mixed black and white grit temper.
	Piece Plot	PP12			12/12/08	Sherd	1	Charred base sherd. Gray (7.5 YR6/1) paste with white sub-angular medium temper. Similar to PP10
723	Piece Plot	PP13			12/12/2008	Sherds	4	4 sherds, 2 body, maybe 2 base, 0.7-1.4cm thick; Ext. & int. light orangish-tan; fabric very light brown; some very-fine to medium white grit
710	excavation unit	TT3	1	2	12/11/2008	Sherd	1	Body sherd, 0.8cm thick; Ext. & fabric light gray, int. dark gray with white concretion(?); occasional very-fine & fine dark-gray grit
711	excavation unit	TT3	1	2	12/11/2008	Sherd	1	Small body sherd, 0.4cm thick; Ext., int. & fabric light brownish-gray; occasional very-fine black & white grit

718	excavation unit	TT3	2	1	12/11/2008	object?	1	Pinched piece of fired clay; 1.8 by 1.0cm
716	excavation unit	TT3	2	1	12/11/2008	Sherd	1	Very small body sherd; 0.7cm thick; Ext., int. & fabric medium-gray; ext. & int. a little browner; ext. smoothed; occasional very-fine white grit
736	excavation unit	TT4		4	12/11/2008	Sherd	1	Rolled everted rim sherd, small jar?; 0.65cm thick; Int. & fabric light orangish-brown; Ext. medium reddish-brown (slipped?); possibly single horizontal band of dark paint below rim on ext.; occasional very-fine & fine white grit & voids
758	excavation unit	TT4		4	12/11/2008	Sherd	3	3 small body sherds, 0.5-0.7cm thick; traces of brown paint or slip on ext. of 2 of the sherds; Ext., int. & fabric light pinkish-orange; occasional very-fine black & white grit; 1 sherd shows traces of burning on one sherd-edge
750	excavation unit	TT4		4	12/11/2008	Sherd	1	Body sherd, brown paint(?) on ext.; one thicker band and then a thin wash; 0.5cm thick; Ext., int. & fabric very light brown; rare fine white grit; some fine voids
751	excavation unit	TT4		4	12/11/2008	Sherd	2	2 body sherds, 0.5cm thick; one has 2 rills on int.; Ext., int. & fabric very light grayish-brown; abundant very-fine, some fine black & gray grit; occasional very-fine red grit
752	excavation unit	TT4		4	12/11/2008	Sherd	4	3 small body sherds, 0.6cm thick; Ext., int. & fabric light reddish-brown; some very-fine & fine dark-brown & white grit
753	excavation unit	TT4		4	12/11/2008	Sherd	2	2 small body sherds, 0.3cm thick; Ext., int. & fabric very light brown; 1 has thin incised groove on ext.; abundant very-fine & fine brown, white & red grit
754	excavation unit	TT4		4	12/11/2008	Sherd	1	Coarse body sherd, 1.1cm thick; Ext., int. & fabric very light grayish-brown; abundant very-fine, fine & medium red, brown &

								white grit
757	excavation unit	TT4		4	12/11/2008	Sherd	1	Small body sherd; 0.65cm thick; Int. & fabric very-light grayish-brown; Ext. light orangish-brown; some very-fine & fine black & white grit
755	excavation unit	TT4		4	12/11/2008	Sherd	2	2 small body sherds, 0.3-0.5cm thick; Ext., int. & fabric very light orangish-brown; occasional very-fine & fine brown & white grit
756	excavation unit	TT4		4	12/11/2008	Sherd	1	1 Base sherd? & 1 body sherd; 0.6-0.8cm thick; Ext. & int. light grayish-brown-body sherd has medium gray core; fabric very light gray; occasional very-fine & fine black & white grit
722	excavation unit	TT4		5	12/12/2008	Sherd	1	Small body sherd, 0.6cm thick; Ext., int. & fabric light grayish-brown; medium-gray core in one part; some very-fine red grit & voids
721	excavation unit	TT4		5	12/12/2008	Sherd	1	Small Body sherd, 0.5cm thick; Int. & fabric light brownish-gray; Ext. slipped(?) medium gray; occasional very-fine black & white grit
720	excavation unit	TT4		5	12/12/2008	Sherd	1	Small Body sherd, 0.8cm thick; Int. & fabric very light brown; Ext. light pinkish brown; rare very-fine black & white grit, occasional fine voids

Table 7: 14C dates from Al-Ashoosh

Sample Number	**Op**	**Loc**	**Lot**	**d13c**	**f**	**error**	**14c BP**	**error**	**Cal BC**	**Cal sd**
AA84586	TT3	2		-24.60	0.6279	0.0046	3738	59	2148	94
AA84587	TT4	2	5	-25.90	0.6270	0.0040	3750	52	2163	87
AA84588	TT4	2	6	-27.10	0.6200	0.0032	3840	42	2310	80
AA85671	TT4	2	6	-26.40	0.6230	0.0031	3802	40	2246	75

CHAPTER 5

SUMMARY AND CONCLUSIONS

The preceding chapters report the results of coordinated archaeological and remote sensing investigations at and surrounding two archaeological sites, Saruq al-Hadid and Al Ashoosh, that were occupied during the last three millennia before the Christian era. The results and conclusions contribute new information for the archaeological and environmental histories of an underexplored region of the Oman Peninsula, the inland desert plains. This research shows that the desert plain between the Gulf coast and the Oman Mountains occupied an important place in the cultural and economic landscape in the relatively arid millennia following the Holocene Climatic Optimum. This stands in contrast to the early presumption that the desert landscape was abandoned in arid periods. It is also clear that the long-term drying of the region was not linear or uniform over the entire landscape of southeast Arabia. Instead, the results presented here paint a picture of fragmented and varied landscape transformations in both spatial and temporal dimensions is beginning to emerge. These inland desert plains remained a mosaic of microclimates that included inter-dune oases of the kind that are hypothesized to have supported activities at Saruq al-Hadid and Al-Ashoosh.

The sequence of occupation at Saruq al-Hadid that was identified during the 2008-2009 excavations, and is reported in the article that is submitted as Chapter 2, had the most to contribute to the developing settlement history of the region. Saruq al-Hadid was previously only thought to have been an Iron Age center of bronze production, but we now know it is a multi-period site where each phase of occupation reflects a distinct pattern of settlement. Saruq al-Hadid begun as an oasis site where nomadic pastoralists of the Umm an-Nar and Wadi Suq periods took advantage of a relatively well-watered landscape, leaving behind waste in the form of animal bones and artifacts. In contrast, the Iron Age remains at the site do not bear any definite signs of settlement or subsistence per se, instead, the material culture reflects ritual activities and suggests that Saruq al-Hadid may have been one of a number of sites spread across the Oman Peninsula that were dedicated to a snake cult. The final phase of occupation at Saruq al-Hadid is characterized by a substantial amount of waste from metalworking operations sometime during the last three centuries of first millennium BC into the first two centuries of the Christian era. Remains from both the snake cult and metal working phases tie Saruq al-Hadid into a network that included regional settlement and trade centers and indicate that, like the mountain piedmont and coasts, the sandy desert expanses of the Oman Peninsula were regarded by ancient peoples not as wastelands bereft of resources that exist only as an obstacle to travel, but as landscapes with economic and ritual importance.

The results of the test excavations at Saruq al-Hadid anchor the results of a GPR survey that is reported in Chapter 3. Data from the GPR survey produced images of the interior structure of dune deposits at a resolution fine enough to map buried bounding surfaces, the locations of possible structure foundations, and individual artifacts with clarity. In addition, the facies identified in the radar profiles have allowed the stratigraphy of the archaeological deposits and temporal information from 14C and OSL dating to be extrapolated across the unexcavated portion of the central dune. One of the most intriguing findings from the GPR survey is a substantial layer of windblown sediment that alludes to a post-Iron Age II hiatus in activity at the site and suggests a period of active dune emplacement from approximately 950 to 400 BC, during the Iron Age III period. It is argued in Chapter 3 that this period of aridity is a regional event that could have been triggered by the destabilization of dune cover due to increased herd sizes and the introduction of the domestic camel to southeast Arabia during the Iron Age II period.

Interpretations of the archaeological investigations at Al-Ashoosh in Chapter 4 are interpreted in the context of an analysis of the availability of shallow groundwater during the third, second and first millennia BC. Thermal infrared imagery of the ground surface show that the exposed desert pavements in the coastal plain where Al Ashoosh and Saruq al-Hadid are located become cooler following precipitation episodes in the mountains. This indicates that during periods of increased precipitation possible for inter-dune lakes and marshes to have persisted in the deserts of the UAE beyond the Holocene Climatic Optimum as these basins were periodically recharged when precipitation fell on the Oman Mountain heights and was channeled into the desert via shallow bedrock fractures. Upwelling groundwater would have fed an oasis belt that stretched along the Oman mountain chain, and if the organic remains from Al-Ashoosh and Saruq al-Hadid are any indication, this oasis belt supported enough flora and fauna in the study area and perhaps elsewhere to attract a wide range of prehistoric activities over several millennia.

The sequence of occupation determined through investigations at Al-Ashoosh and at Saruq al-Hadid shows that the orientation of inland desert economic strategies changed from a focus on local resource extraction and subsistence-supporting economies at the household or small group level to settlements that were tied to institutional networks that stretched across the Oman Peninsula and beyond. In the early phases, nomadic pastoralists hunted, harvested and processed local resources for subsistence. In the later periods, symbols of external organization and control appeared in the form of religious iconography, stamp seals and exotic goods. Though the purpose of the site was transformed from a ritual to an industrial focus during the course of the first millennium BC, Iron Age and later period activities at Saruq al-Hadid were specialized and relied on regional and international trade networks. The desert oases were thus not static loci, always serving only as convenient campsites and isolated from more widespread developments. Rather, in all periods they were part of a broader landscape, integrated into widely-shared social and economic worldviews, and the changing character of settlement and activities at these oases was a product of political, social, and economic transformations at the regional level.

Accumulated windblown sediments were also identified, mapped and dated in this research and fill a spatial and temporal lacuna in the environmental history of Southeast Arabia. Only a single dated sequence of dune accretion -where sediments may have been trapped and protected from redistribution by a surface shield of cultural materials or by other means- is presented here, but as part of a growing corpus of paleoenvironmental proxies in the region, these findings add focus to a regional model of environmental change in pre- and protohistoric southeast Arabia. It is the hope of the author that the chronological frameworks established here, including the sequence of occupation at Saruq al-Hadid and the sequence of dune accretion will continue to be built upon with new discoveries in the inland deserts of the western coastal plain of the Oman Peninsula.

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Wilkinson, Tony J. 2003. "The Organization of Settlement in Highland Yemen During the Bronze and Iron Ages." In *Proceedings of the Seminar for Arabian Studies*, 157–68. 33.

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Wood, Warren W., Richard M. Bailey, Brian A. Hampton, Thomas F. Kraemer, Zhong Lu, David W. Clark, Rhodri H.R. James, and Khalid Al Ramadan. 2012. “Rapid Late Pleistocene/Holocene Uplift and Coastal Evolution of the Southern Arabian (Persian) Gulf.” *Quaternary Research* 77 (2) (March): 215–220. doi:10.1016/j.yqres.2011.10.008.

Yilmaz, Özdoğan. 2001. *Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data*. SEG Books.

VITAE

JASON T. HERRMANN

EDUCATION

University of Arkansas	Anthropology MA	2004
University of Cincinnati	Anthropology BA	1999

PUBLICATIONS and REPORTS (* *peer review*)

2012 Herrmann, Jason T., Jesse Casana and Hussein Suleiman Qandil
*A Sequence of Inland Desert Settlement in the Oman Peninsula: 2008-2009 Excavations at Saruq al-Hadid, Dubai, U.A.E. *Arabian Archaeology and Epigraphy*. 23/1: 50-69.

2010 Casana, Jesse and Jason T. Herrmann.
*Settlement History and Urban Planning at Zincirli Höyük, Southern Turkey. *Journal of Mediterranean Archaeology*. 23.1 p. 55-80. DOI: 10.1558/jmea.v23i1.55.

2009 *Casana, Jesse, Jason T. Herrmann and Hussein Qandil.
Settlement History in the Eastern Rub al-Khali: Preliminary Report of the Dubai Desert Survey (2006-2007). *Arabian Archaeology and Epigraphy*. 20: 30–45. DOI: 10.1111/j.1600-0471.2008.00306.x

2008 Casana, Jesse, Jason T. Herrmann and Aaron Fogel.
*Deep subsurface geophysical prospection at Tell Qarqur, Syria. *Archaeological Prospection* 15, 207–225. DOI: 10.1002/arp.335

2006 Herrmann, Jason T.
Product Review: IDRISI Andes Edition Enhances Modules, Adds Land Change Modeler. *Earth Imaging Journal* 3: 6. pp. 40-41.

2005 Kay, Marvin and Jason T. Herrmann.
Report on Archaeological Survey at Pea Ridge National Military Park, Arkansas, and Wilson's Creek National Battlefield, Missouri, 2001-2004. Report to U.S. Department of Interior, National Park Service, Midwest Archeological Center, Cooperative Agreement No. CA611500047. Lincoln, Nebraska.

2004 Herrmann, Jason T.
Interpreting Leetown through the Integration of Aerial and Ground-Based Remote Sensing Techniques. Report submitted to the Midwest Archaeological Center, National Park Service, Lincoln, Nebraska.

CONFERENCE PRESENTATIONS

2012 Herrmann, Jason T. and J. David Schloen.
Spatial Data and Mapping in OCHRE: case study from the Neubauer Expedition to Zincirli. Paper to be presented at the American Schools for Oriental Research Annual Meeting in Chicago, Illinois.

2011 Herrmann, Jason T. Duncan P. McKinnon, Jason L. King and Jane E. Buikstra.
Summary of Three Seasons of Remote Sensing at Mound House (11GE7), Greene

County, Illinois. Poster Presented at the Midwest Archaeological Conference, La Crosse, Wisconsin.

2011 Buikstra, Jane E., Duncan P. McKinnon, Jason L. King, Jason T. Herrmann, and Mary Ann Vicari.
The Kampsville Experience: Education in the Lower Illinois River Valley. Poster presented at the Southeastern Archaeological Conference Meeting, Jacksonville, Florida.

2011 Herrmann, Jason T, Robert Carter, Katie M. Simon and Christine Markussen.
Poster: Geomagnetic Survey at Julfar al-Mataf, 2010. Poster presented at the Seminar for Arabian Studies, British Museum, London.

2010 Herrmann, Jason T. and Jason L. King.
A Resistance Survey of Mound 1 at Mound House, Illinois. Paper presented at the Midwest Archaeology Conference, Bloomington, Indiana.

2010 McKinnon, Duncan and Jason T. Herrmann.
Exploring a Cultural Landscape: A Multidisciplinary Approach to Understanding the Spatial Layout of the Confederate Cemetery in Fayetteville, Arkansas. Paper presented at the Southeastern Archaeology Conference, Lexington Kentucky.

2010 Herrmann, Jason T.
Evidence for Desert Occupation and Environmental Change at Three Sites in Dubai, UAE. Paper presented at 7ICAANE meetings, British Museum, London.

2009 Herrmann, Jason T.
Site Formation at Saruq al-Hadid, Dubai and Implications for Environmental Change in Southeast Arabia. Paper presented at the American Schools for Oriental Research Annual Meeting in New Orleans, Louisiana.

2009 Herrmann, Jason T.
Digital Dunes: Site Structure as seen in GPR from Saruq al-Hadid, UAE. Paper presented at the 37th annual international conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Williamsburg, Virginia

2009 Herrmann, Jason T. and Jesse Casana
Geomagnetic Survey at Zincirli Höyük, Turkey. Poster presented at the 37th annual international conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Williamsburg, Virginia

2009 Casana, Jesse, Hussein Qandil and Jason T. Herrmann
Archaeological Investigations at Saruq al-Hadid: An Iron Age Metalworking site in Dubai's Inland Desert. Paper Presented at the 2nd International Conference on UAE Archaeology, Abu Dhabi, UAE.

2008 Casana, Jesse, Jason T. Hermann and Eric R. Jensen.
Settlement History and Urban Planning at Zincirli Höyük, Southern Turkey. Paper presented at the 2008 Society for American Archaeology Meetings, Vancouver, British Columbia.

2008 Hermann, Jason T. and Jesse Casana.
Climate and Settlement Dynamics at Three Sites in the Rub' al-Khali Desert, UAE. Paper presented at the 2008 Society for American Archaeology Meetings, Vancouver, British Columbia.

2008 Herrmann, Jason T.
Human Ecodynamics at Three Sites in Dubai, UAE. Paper presented at the American Schools of Oriental Research Annual Meeting, Boston, Massachusetts.

2007 Herrmann, Jason T., Eileen Ernenwein, Michele Koons, Dan Aylward, and Duncan McKinnon.
Geophysics at Tiwanaku: Results from the 2006 Field Season. Poster presented at the 2007 Society for American Archaeology Meetings, Austin, Texas.

2006 Herrmann, Jason T.
Non-invasive Survey Techniques in Cultural Landscape Investigation. Paper presented at the Society for Historical Archaeology 39th Conference on Historical and Underwater Archeology, Sacramento, California.

2006 Herrmann, Jason T.
A GIS Approach to Evaluating Prehistoric Seasonal Land Use Strategies at Pea Ridge National Military Park, Arkansas. Poster presented at the 2006 Society for American Archaeology Meetings, San Juan, Puerto Rico.

2006 Herrmann, Jason T., Jesse Casana and Aaron Fogel.
Geophysical Prospection and Three Dimensional Modeling of Buried Archaeological Features at Tell Qarqur, Syria. Paper and poster presented at the American Schools of Oriental Research Annual Meeting, Washington DC.

2003 Herrmann, Jason T.
Preliminary Report on Upland Archaeological Investigations at Pea Ridge National Military Park. Paper presented at the 61st Plains Anthropological Conference, Fayetteville, Arkansas.

2001 Scarborough, Vernon L., Richard Hutchinson and Jason T. Herrmann. Evolution of a Maya Landscape: La Milpa and its Immediate Hinterlands. Paper presented in session in Honor of R.E.W. Adams' Contributions at the Sixty-Sixth Annual Meetings for the Society for American Archaeology, New Orleans, Louisiana.

INVITED LECTURES

2011 Archeology Day, Center for American Archeology.

2010 “Site Formation at Saruq al-Hadid, Dubai: Implications for Environmental Change in Southeast Arabia” Environmental Dynamics/Geosciences Colloquium, University of Arkansas.

2009 “Archaeological Investigations in Dubai's Interior.” Presented to the Abu Dhabi chapter of the Emirates Natural History Group.

GRANTS, FELLOWSHIPS and AWARDS

2008 National Science Foundation Doctoral Dissertation Research Improvement Grant #0820211 ($14,999.00)

2008 American Schools of Oriental Research Travel Grant for travel to the 2008 American Schools of Oriental Research Meetings, Boston, Massachusetts. ($250.00)

2008 King Fahd Center for Middle East and Islamic Studies Student Research Grant for archaeological fieldwork in at Zincirli Höyük, Turkey. ($1800.00)

2008 Chicago Luminescence Award to support luminescence dating of sediments for dissertation research ($5000.00)

2004-2008	University of Arkansas Doctoral Academy Fellowship ($10,000.00/year-4 years)
2006	Robert L. Stigler Jr. Scholarship for archaeological fieldwork in Dubai, UAE. ($1482.00)
2006	King Fahd Center for Middle East and Islamic Studies Student Research Grant for archaeological fieldwork in Dubai, UAE ($1800.00)
2006	American Schools of Oriental Research Travel Grant for travel to the 2006 American Schools of Oriental Research Meetings, Washington DC ($250.00)
1998	University of Cincinnati Globalization Travel Grant for studies in Southern Mexico. ($500.00)
1997	University of Cincinnati Charles Phelps Taft Undergraduate Enrichment Award for archaeological fieldwork at La Milpa, Belize. ($1400.00)

TEACHING EXPERIENCE

2013	Archaeology of the Ancient Near East, Anthropology, Dartmouth College
2010-Present	Instructor, Arizona State University Field Program in Geomatics at the Center for American Archeology, Kampsville, Illinois
2011	Instructor, UCLA Field Program at Amarna in Archaeological Geophysics, Amarna, Egypt
2009	Instructor, Introduction to Raster GIS, University of Arkansas
2009	Guest Lecturer: Approaches to Archaeology, University of Arkansas
2008-2009	Instructor, Approaches to Archaeology Lab, University of Arkansas
2007	Workshop: Introduction to high-density scanning for archaeologists. Workshop at the 2007 Society for American Archaeology Meetings. Austin Texas. With Christopher Goodmaster, W. Fredrick Limp, Director.
2005	Guest Lecturer: Archaeological Remote Sensing, University of Arkansas

SELECT FIELD PROJECTS

2007-Present	Spatial Data Coordinator/Archaeo-Geophysics Specialist, University of Chicago Neubauer Expedition to Zincirli Höyük, Turkey.
2010-Present	Geomatics Instructor, Center for American Archaeology, Illinois.
2011	Director, Tell el-Amarna Geophysical Survey, Egypt
2010	Archaeo-Geophysics Specialist, Julfar, Ras al-Khaimah, United Arab Emirates.
2006-2009	Archaeologist, Dubai Desert Survey, United Arab Emirates
2006-2007	Archaeo-Geophysics Specialist, Tell Qarqur Expedition, Syria.
2005-2006	Archaeo-Geophysics Specialist, Tiwanaku Geophysical Survey, Bolivia.
2002-2005	Graduate Assistant, Battlefields Archaeological Survey, Pea Ridge National Military Park, Arkansas and Wilson's Creek National Battlefield, Missouri.
1997-1998	Excavator, Ancient Maya Water and Land Use in Northwest Belize Project, Belize.

PROFESSIONAL EXPERIENCE

2012	Neukom Postdoctoral Fellow – Department of Anthropology, Dartmouth College.
2011-2012	Research Project Professional - Photographer, Persepolis Fortification Archive Project, Oriental Institute, University of Chicago.
2010-2011	Research Project Professional, Neubauer Expedition to Zincirli Höyük, Oriental Institute, University of Chicago.

2007-2008 Research Assistant, MEST Supported Archaeological Activities, King Fahd Center for Middle East and Islamic Studies, University of Arkansas.
2006-2007 Research Assistant, Center for Advanced Spatial Technologies, University of Arkansas.
2003-2004 Principal Investigator, Development of Leetown Hamlet Interpretation through Geophysical Methods, Pea Ridge National Military Park, Arkansas.
2002-2004 Research Assistant, Battlefields Archaeological Survey and Predictive Modeling Project, University of Arkansas.
1999-2002 Field Technician & Technical Specialist, Gray & Pape, Inc. Cultural Resource Consultants, Cincinnati, Ohio.
1997-1999 Laboratory Technician, Ancient Maya Water and Land Use in Northwest Belize Project, University of Cincinnati

PROFESSIONAL SERVICE
2011 Reviewer – Computer Applications in Archaeology.
2008 Archaeology Brown Bag Lecture coordinator, University of Arkansas.
2007-2008 Vice President – University of Arkansas Student Chapter of American Society for Photogrammetry and Remote Sensing.