The Archaeological Site HLO1
A Bronze Age Copper Mining and Smelting Site in the Emirate of Sharjah (U.A.E.)

Dissertation
der Mathematisch-Naturwissenschaftlichen Fakultät
der Eberhard-Karls-Universität Tübingen
zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer. nat.)

vorgelegt von
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Tübingen
2013

Tag der mündlichen Qualifikation: 13.02.2014
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1 Acknowledgments

The present dissertation would not have been possible without the interest and encouragement of Dr. Sabah Jasim, Director of Antiquities of the Emirate of Sharjah, who offered to include the site HLO1 in the Joint Project between his Department and the Institute of Pre- and Protohistory of Tübingen University. The Sharjah Government generously supported the excavations in every respect.

Particular thanks are due to the supervisors of this thesis, Professors Ernst Pernicka and Gregor Markl for their constant advice and support regarding access to laboratories, instruments and equipment. Special thanks go to Gregor Markl and his working group for many stimulating discussions. Thanks are also due to professor Thilo Rehren. During a Marie Curie Host Fellowship at the Institute of Archaeology in London, he provided valuable archaeometallurgical advice.

Discussions with the late Gerd Weisgerber during his visit to Wadi Hilo were most helpful and inspiring. The same is true for Eisa Abbas from the Sharjah Directorate of Antiquities who shared his profound knowledge of the area with me. Discussions with Christian Velde during several visits at the site were also very stimulating. Special thanks are due to Lloyd Weeks for his help with the interpretation of the data. For the analyses of the pottery from HLO1, I would like to thank Christina Neureiter. Also of great help were discussions with my friend Bastian Asmus who gave a lot of practical advice with regard to smelting and founding techniques during the Bronze Age. He contributed a great deal to the completion of the present thesis. Last but not least I want to express my gratitude to the Fritz Thyssen Foundation for providing a doctoral stipend and funding of the laboratory research.

2 Preface

During the short history of archaeology in SE Arabia, the Bronze Age has been the most eminent phase. Archaeological research in this area began some fifty years ago, with the Danish excavations at Umm an-Nar near Abu Dhabi. This site provided the eponym for the Early Bronze Age in the wider area. A great deal of archaeological effort was invested into Bronze Age research both in the United Arab Emirates and the Sultanate of Oman. While research in Oman provided a lot of insight into copper mining and smelting, this was not the case in the United Arab Emirates, where the focus was on the further processing of copper, the production of bronze, and the manufacture of metallic objects.

The excavations at HLO1 in Wadi Hilo were a first step towards closing the gap between the smelting of copper and the melting of bronze. A combination of refined excavation techniques and archaeo-metallurgical research gave insight into the processes, from ore-extraction to the production of pure copper. Detailed stratigraphical observations and extensive radiocarbon dating provide a time frame for these activities from the end of the 4th millennium BC to the Iron Age.

Considerations with regard to the ecological, geological and geographical setting of HLO1 indicate a conscious regional selection of the site. It is situated in one of the most fertile parts of the northern Hajjar Mountains, close to several surface exposures of copper ore, and it is easily accessible from the major Bronze Age settlements in the area.

3 Introduction

3.1 History of the Wadi Hilo project

The site HLO1 became of interest when an exchange of territories between the Emirate of Fujeirah and the Emirate of Sharjah brought the upper Wadi Hilo under the responsibility of the Sharjah Directorate of Antiquities. Surveys on the slag field of HLO1 (Fig. 3.1) yielded a fragment of Umm an-Nar pottery, which was interpreted as an indication that the slag might derive from Early Bronze Age copper smelting. The low mound just north of the Islamic watchtower also attracted attention, as it was suspected to contain an Umm an-Nar grave. Because of its importance, the site was included in the Joint Project between the Sharjah Directorate of Antiqities and the Institute of Pre- and Protohistory of Tübingen University. Subsequently, the author, as a doctoral candidate of Ernst Pernicka and Gregor Markl, took over the management of the field work at the site, which became an important constituent of this doctoral thesis.

The first season of excavations at HLO1 was carried out in 2007. Excavations were continued in 2008, 2009 and 2011. The most recent season was carried out in the autumn of 2012 (see Fig. 3.2). Like the earlier seasons, it lasted six weeks. During all the seasons, well-trained workmen of the Directorate of Antiquities carried out the actual digging. Trench supervisors during several seasons were archaeologists from Armenia, Austria and Germany (Iren Kalantaryan, Suren Kesedyan, Artur Petrosyan, Robert Ghukasyan, Christina Neureiter, and Katja Thode). In regular visits, Sabah Jasim and Hans-Peter Uerpmann gave invaluable advice and directions for the excavations. As important specialists, Gerd Weisgerber from the Mining Museum at Bochum and Ernst Pernicka from Tübingen University visited the excavations in 2009 and 2008, respectively.

Metallurgical investigations for this project were carried out by the author under the supervision of Ernst Pernicka and Gregor Markl at the Institute for Archaeological Sciences and at the Department of Geosciences of Tübingen University. Further investigations took place at the Curt Engelhorn Zentrum for Archaeometry in Mannheim, supervised by Ernst Pernicka, and at the University College in London, supervised by Thilo Rheren. Apart from the constant assistance of the Sharjah Directorate of Antiquities in the Emirates, the research for this thesis was supported by a Marie Curie Host Fellowship for Early Stage Research Training (EST) and by the Fritz Thyssen Foundation. Two preliminary reports have already appeared in the *Proceedings of the Seminar for Arabian Studies* (Kutterer and Jasim, 2009; Kutterer et al., 2013).

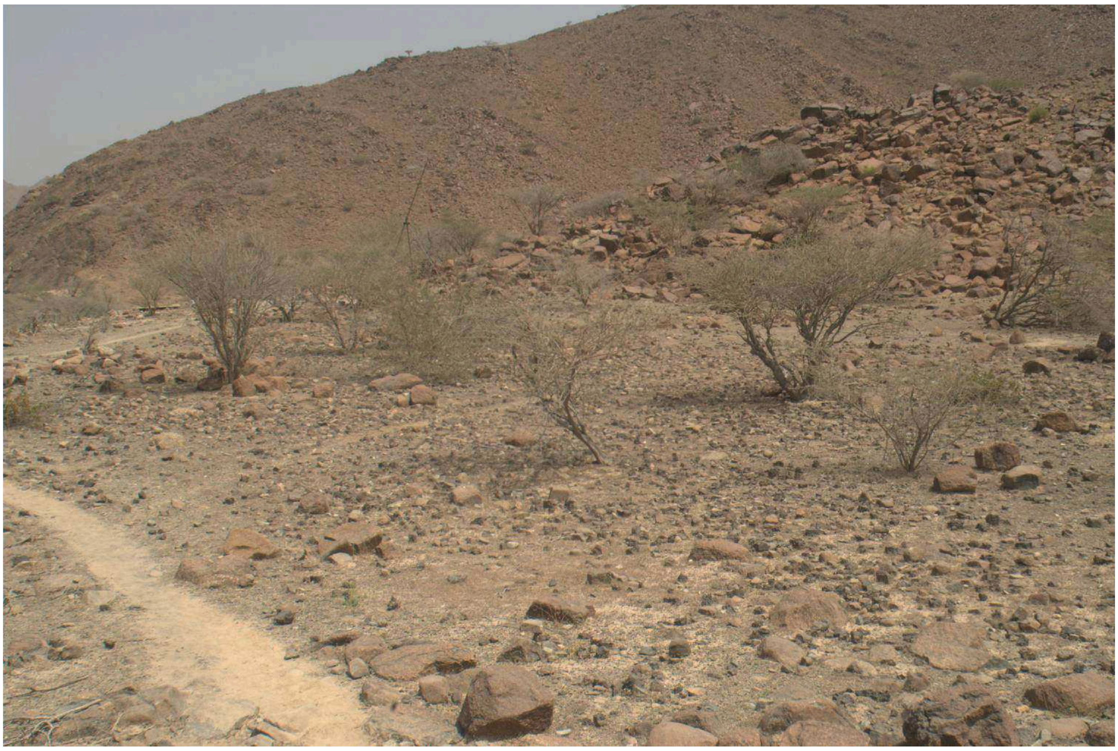

Figure 3.1: Slag concentration in the center of HLO1.

3.2 State of Bronze Age metallurgical research in SE Arabia

In spite of the fact that all periods from the late Stone Age to the Islamic period have left their traces at HLO1, the Bronze Age is the main focus of this thesis. This phase was an essential step in the prehistory of SE Arabia. Within the UAE, there are several important Bronze Age sites, for instance, Umm an-Nar near Abu Dhabi (comp. Frifelt, 1995; Potts, 2012), which has given its name to the Early Bronze Age in the whole area, and which is an anchor point for its chronology. Generally, the Bronze Age phases in SE Arabia have been named after the important sites discovered early on in the history of its archaeological research. Thus, the period preceeding the "Umm an-Nar" period is called "Hafit" period after the graves at Jebel Hafit near Al Ain (Potts, 2012; Boehme, 2011), which yielded datable pottery imported from Mesopotamia. The phase succeeding the Umm an-Nar phase has similarly been named the "Wadi Suq" period after sites in the Wadi al-Suq east of Al Ain (Cleuziou, 1981). This phase was recently subdivided into a Wadi Suq phase in the proper sense and a "Late Bronze Age phase" (Velde, 2003).

The copper ore deposits in the Hajjar Mountains of the Emirates and Oman must have been a major reason for the strong development of the Bronze Age in SE Arabia. A cuneiform inscription of the Ur III period mentions the land of *Magan* as the origin of copper. Actually, the search for the "Land of Magan"

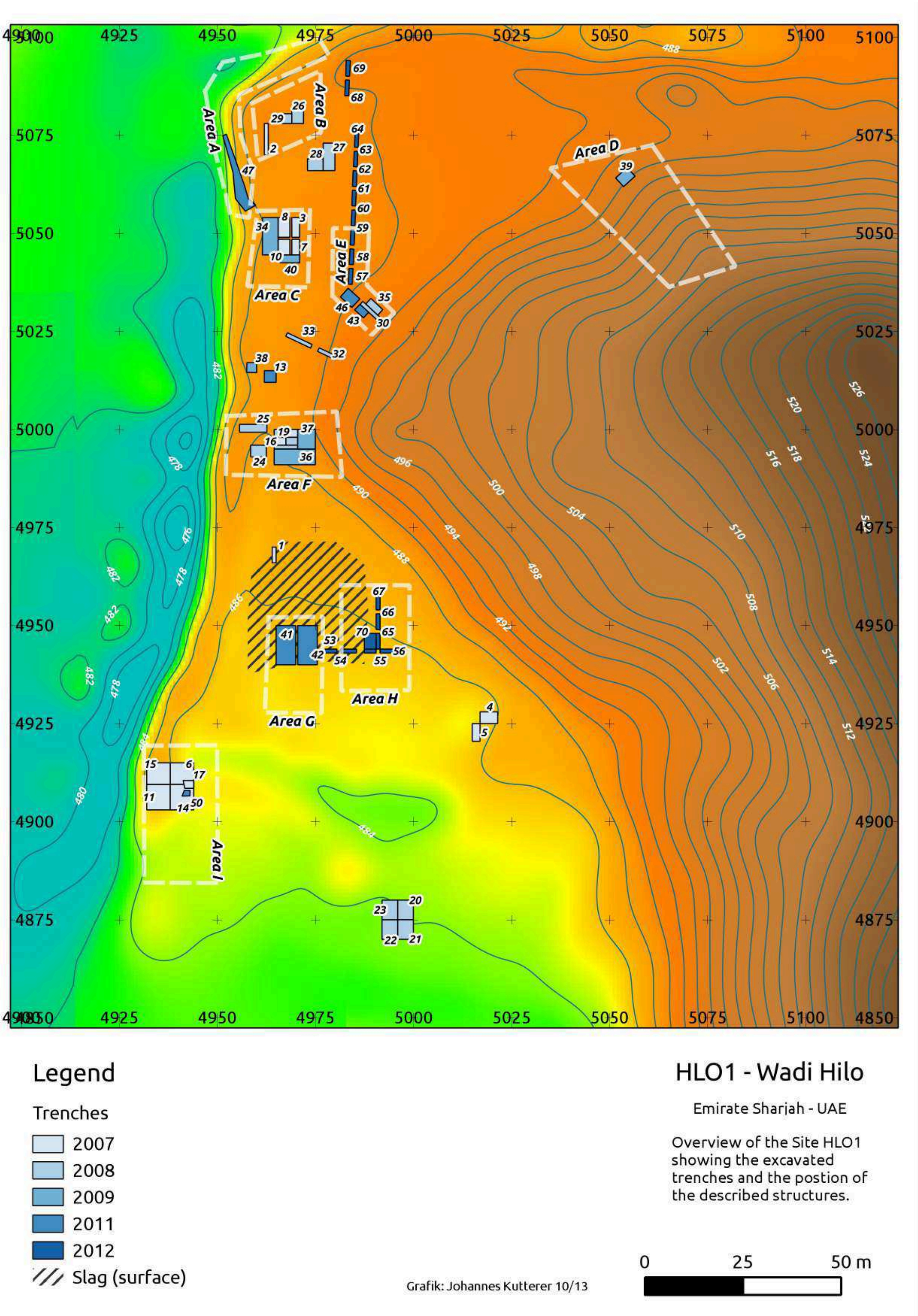

Figure 3.2: Overview of the site.

was a major impetus for the beginning of archaeological research in SE Arabia some sixty years ago (Potts and Hellyer, 2012). However, the assumption that Magan might have been the Oman Peninsula precedes archaeological research in the area by far: the first chemical analyses of metal artefacts from Ur, Kish, and al-Obeid, indicated a high nickel content which is characteristic of the copper from SE Arabia (Peake, 1928). Almost all cuneiform inscriptions mention the toponyms Magan and Dilmun (Potts, 1994). In the meantime there is general agreement that the toponym Magan means the Oman Peninsula, i.e., northern Oman and the United Arab Emirates. The name Dilmun, which in later periods was only used for the island of Bahrain, seems in earlier periods to have also been extended to the neighbouring coasts of the Arabian Peninsula (Potts, 1990a; Weeks, 2003; Edzard et al., 1977; Cleuziou and Tosi, 2012). However, there are no copper sources in that area. Therefore, Dilmun only seems to have had the role of a trans-shipment centre for the metal coming from Magan.

Finding the actual sources of the Maganic copper mentioned in the cuneiform texts was one of the major aims of a project of the "German Mining Museum" in Bochum (Germany) (Hauptmann, 1985). Towards the end of the 1970s and in the beginnings of the 1980s, several surveys and excavation campaigns were conducted by the Bergbaumuseum under the direction of G. Weisgerber. The excavations were mainly concentrated at the site of Maysar in central Oman. Subsequent archaeo-metallurgical research (Prange, 2001) created a broad base for further research in the wider area (Weisgerber, 1981; Hauptmann, 1985; Yule et al., 2001; Weisgerber and Yule, 2003; Begemann et al., 2010). The merit of this project is the accumulation of profound knowledge about copper mining and the smelting technology of copper metal from ore on a large scale. Another important contribution was the work of Weeks (Weeks, 2003) with its focus on the techniques of transforming raw copper into completed objects in settlements, which found a network of exchange between mining sites, settlements, and long-distance trade. Apart from analyses of metal artefacts (Weeks, 2003), there was no equivalent research in the United Arab Emirates. HLO1 is the first copper production site in the Emirates to be investigated systematically.

3.3 Research objectives to be addressed by the research at Wadi Hilo and the evaluation of finds and findings from HLO1

Research into Bronze Age finds and findings was the main topic to be addressed at HLO1. However, the site presents more archaeological features (Fig. 3.3), which required documentation and explanation prior to the inevitable interference caused by the excavations. In particular, the later occupation of the area had to be documented in detail in order to prevent the loss of historic evidence which might become of interest for future research or restoration. This mainly applies to the historic and protohistoric ruins and graves which were the most evident features at HLO1 prior to the excavations. These features were mapped together with the remnants of prehistoric buildings. The ruins of a rural settlement in the northern part of the site were evident protohistoric features. These ruins had obviously been exposed to continual decay and would necessarily be partly disturbed by the excavations. Therefore, some effort seemed necessary to document their present state of preservation, even though this was not connected to the main focus of this dissertation. No further effort was spent, however, on detailed research with regard to these features.

The usual problem of any surface site is its integration into the existing knowledge of the prehistory of its area. This was first addressed by the study of surface finds of pottery, which cover the periods from the Early Bronze Age to the Medieval period. This large a time span required further research into the chronological order of the individual findings. Recovery of materials for dating was of prime importance. However, the known limitations of radiocarbon dating, due to the inevitable plus/minus ranges of potential error, also required particular care concerning the stratigraphical observations of the finds. Their documentation was a problem to be dealt with both during the excavations and during their evaluation. The development of the appropriate excavation techniques for obtaining well stratified evidence at a site with a low rate of sedimention thus became a major incentive of the work at HLO1.

The most interesting feature of the site, apart from the tons of slag, were the traces of prehistoric stone structures visible at the surface. They promised results with regard to the functional units of the site. At an obvious smelting site, these could have been areas where ore processing took place, where smelting furnaces were located, and where the metal obtained was further processed. The slag, as the remnant of the smelting process, had a major potential for elucidating that process in detail. This was one of the main objectives of the work at HLO1. Of course knowledge about the final products was also very important.

Finding the exact location of the potential mining area(s) in the Hajjar Mountains, renowned for their wealth of copper ore, was another prime research objective. This required engaging in geological and mineralogical descriptions of the ore and of its source rock. The mining procedures and the preparation of the ore were also of interest, as well as the distance and potential routes between the locations of the mining site and the smelting area. Information on the available means of transportation was expected from a study of animal bone remains. They also have potential for yielding conclusions about the subsistence strategies of the inhabitants. In the end, this expectation was not fullfilled because of the scarcity of bonefinds at HLO1. Nevertheless, some bone-remains of potential beasts of burden could be identified.

Considerations about the location of the site in relation to its natural environment and to known centers of Bronze Age life in the area were important for understanding the role of the site within the exchange network of that period in the northernmost part of the Oman Penisula. This finally leads to expectations

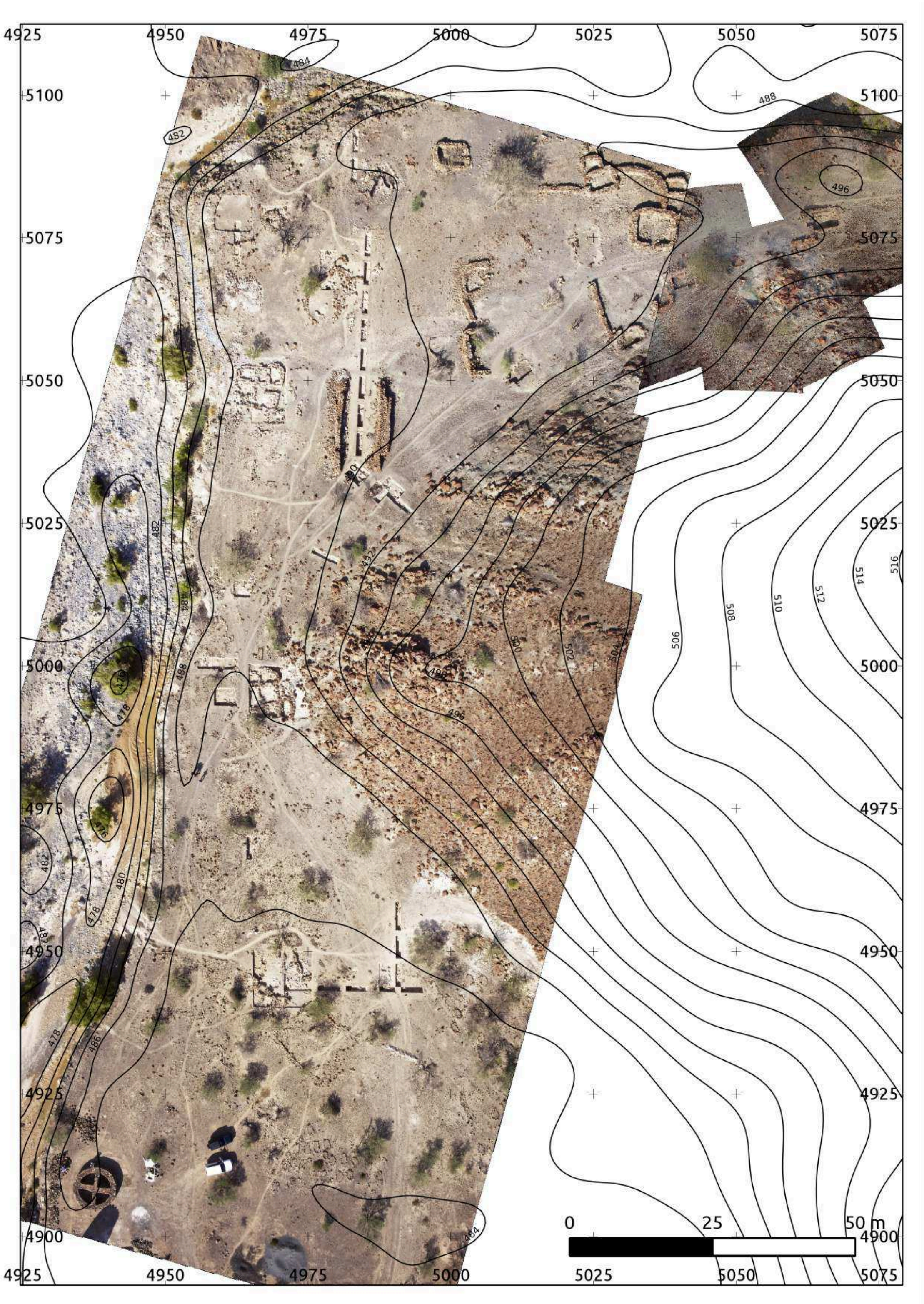

Figure 3.3: Aerial photo of the site (Foto: Oliver Jackson).

with regard to understanding the role of Wadi Hilo within a developed natural and cultural landscape that could, at least partly, be achieved by the presented topograhic and geographic research.

3.4 Methodology

3.4.1 Excavation methods and techniques applied at HLO1

A low rate of sedimentation, resulting in a slow and shallow accumulation of archaeological layers, required particular excavation techniques. In order to obtain stratified evidence, it was necessary to apply methods mainly developed for paleolithic excavations, where all finds and findings are recorded 3-dimensionally before they are removed from the soil. This was achieved by using a theodolite equipped with a laser device for measuring the exact 3D-position of the object indicated by the laser point. The respective coordinates are immediately recorded in a field computer connected to the theodolite together with an individual find number of the object generated automatically by the field computer. Each object was then packed in an individual zip-lock plastic bag labelled with the find-number of the object. From the field computer, the find numbers and their coordinates were later transferred into a database where all information for the find were stored for evaluation.

In the computer, the three dimensional mapping of the particular categories of finds or findings at variable scales and angles allows for the recognition of stratigraphical distributions even where the differences in altitude are small and where the inclination of the ancient surfaces raise difficulties for recognizing the stratigraphical positions of individual objects and findings or of particular categories of finds in relation to others. Within important architectural features, for instance, the workshop in Area F, the 3D-information of the finds allows for a reconstruction of walking horizons otherwise obscured by the inclination of the respective layers.

Photographs of particular surface features, such as walls, fireplaces, or slag concentrations, etc., were taken from a photo crane (Fig 3.4). Such photographs, marked with reference points related to the general coordinates of the site, were rectified into ortho-pictures and transferred into a geographical information system (GIS) for horizontal documentation (see Fig 3.5 and Uerpmann et al. (2006, p. 75–76)). Structures and other surface findings were also measured and recorded with the total station and imported into the GIS database. This procedure also allowed for documentation of minor intermediate steps of excavating particular features, which later could be evaluated within the GIS.

All the data recorded during the excavations were stored in a database. For this purpose, the opensource database PostgresSQL was used (www.postgresql.org). The coordinates of the finds and findings could be included through the additional use of PostGIS (http://postgis.org). These data could be directly evaluated with

Figure 3.4: Camera crane used at HLO1.

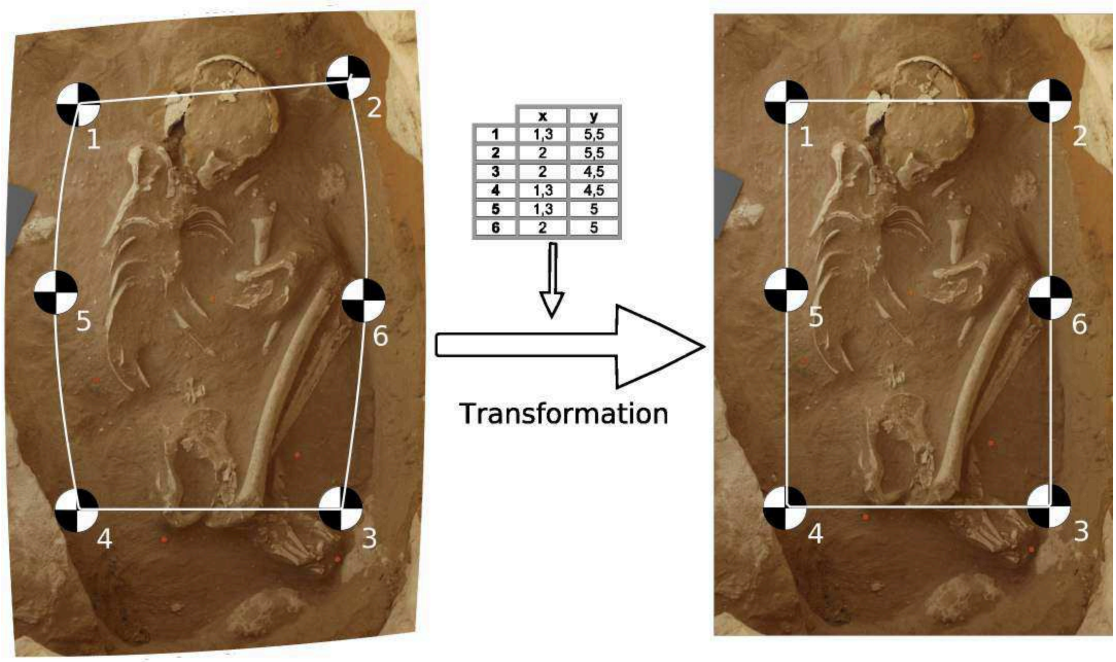

Figure 3.5: Schematic presentation of the process of ortho-rectifying of excavation photographs.

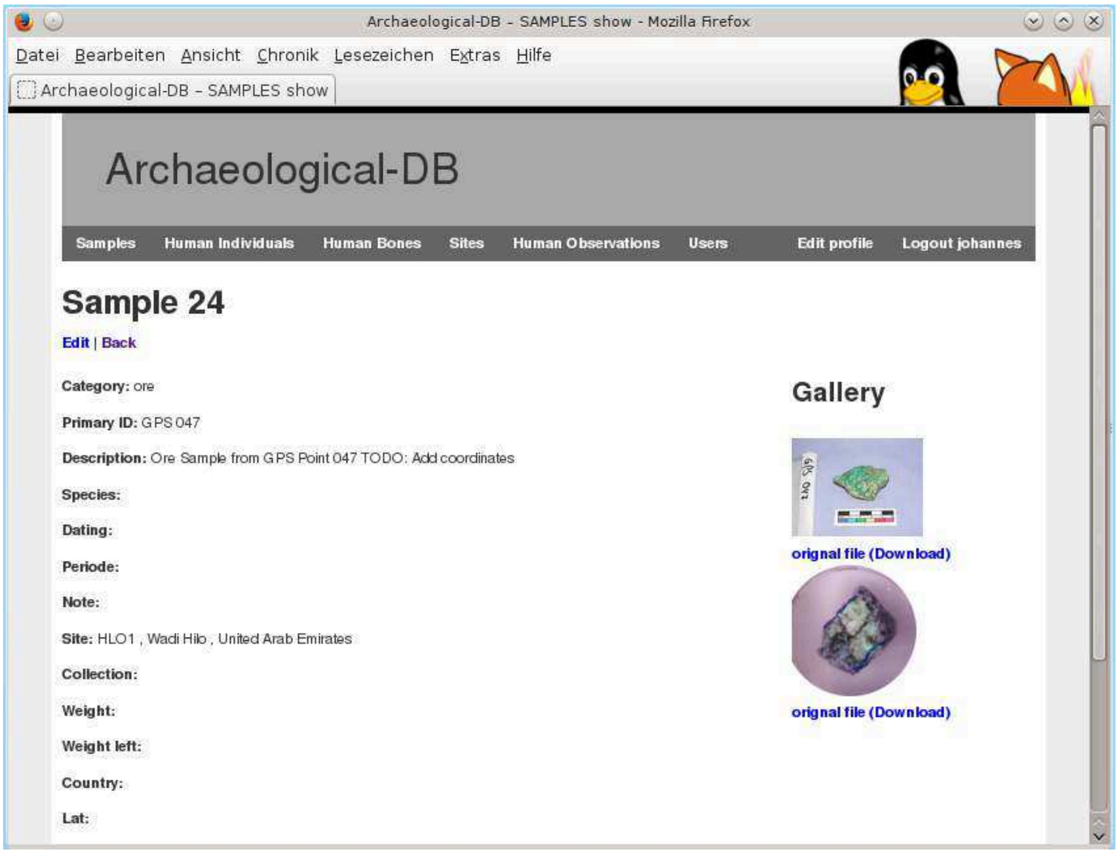

Figure 3.6: Sample screenshot of the webdatabase.

the free GIS software packages QGIS (QGIS Development Team, 2013) and GRASS (GRASS Development Team, 2012a).

For the organisation and management of the samples taken for further investigations, a web-based database was developed (Fig 3.6). If, for example, a polished micrograph was produced from an ore sample, it would automatically be given a new sample number and registered in the database. A web-site would store all relevant information, data and pictures for the sample. This database is also based on PostgresSQL and was developed in the programming language "Ruby on Rails" (http://rubyonrails.org).

4 Geography and geology of the region around the site HLO1

The site “Hilo 1” (HLO1) is situated in the Hajjar Mountains (= “Rocky Mountains”) in the Eastern Region of the Emirate of Sharjah (UAE) at an altitude of c. 350 m NN. It is located 6 km north of the township Wadi al-Hilo, the modern administrative center of the area. The archaeological site occupies a flat area on a geologically old wadi terrace extending along the base of the western slope of the major chain of the Hajjar Mountains. With elevation around 1000 m this mountain ridge is a major geographical barrier between the coastal lands along the Gulf of Oman, the central areas of the Emirates, and the coast of the Arabian Gulf to the west.

In the area of the site, the Hilo river flows North–South just west of the highest ridge of the Hajjar Mountains. It originates at an altitude of about 600 m some 9 km NNW of the archaeological site and flows south from there in a fairly straight line, passing the site HLO1, towards the modern township of Wadi al-Hilo. There it turns east and cuts through the mountain chains in order to reach the coast of the Gulf of Oman beyond the present borderline between the Emirates and Oman. Following the local usage of the name “Wadi al-Hilo” it will in the following only be used either for the riverbed itself or the whole valley, depending on the context. Under the present climatic conditions, the river bed is dry through most of the year, but it frequently becomes a strong torrential river during the rainy season.

The gravel terrace on which the site is situated is cut by the al-Hilo river along its western edge. As the terrace itself consists of geologically old and strongly cemented wadi gravel, a vertical cliff, up to 10 m high, is formed all along the edge of the terrace towards the wadi channel. To the north, this terrace is delimited by a small side wadi, which collects runoff water from the western slope of the main mountain chain. It cuts the northern end of the terrace in order to join the Wadi al-Hilo at the level of its main channel. However, the eroding power of the side wadi is not strong enough to maintain a vertical terrace edge at this northern border of the archaeological site.

Towards the south there is no visible natural boundary of the terrace. This area is now a large garden, confined by a wall and fence, clearly visible in Fig. 4.1. It was bulldozed before the archaeological site was found north of it. No archaeological observations were made in the area of this garden when it was prepared. Its northern fence is the southern limit of the protected archaeological area.

Figure 4.1: Site HLO1 (seen from the west). The site is situated on the wadi terrace in the background. In the center the ruins of a large building are seen, apparently an aristocratic center in sub-recent times. In the far background there is the main ridge of the Hajjar Mountains extending north to south.

The lower ground on the western side of the wadi channel is covered by small gardens and fields surrounded by low walls built of large wadi pebbles. Some small houses extend along the base of the western slope of the valley. Opposite the archaeological site there is an old mosque which is still used from time to time. South of the mosque and on the other side of the modern road there are the ruins of an obviously important historic building (Fig. 4.2). According to local informants the eminent buildings south of the road were used well into the 20th century by a local potentate. The size of the two-storey building alone indicates the importance of its former residents. There are remains of an outer wall with fortifications. The watch-tower on the other side of the wadi at the entrance to the archaeological site also seems to belong to this context, as well as the fortified look-outs on the adjacent mountain ridges. Where the road turns south again there is a modern garden, which delimits the archaeological area. In the background there is the main mountain ridge of the Hajjar Mountains.

Figure 4.2: Ruins of the eminent sub-recent building which, according to local informants, was in use until some 50 years ago. The walls are built of unhewn wadi pebbles and plastered with clay. There are two storeys and the staircase is partially preserved.

4.1 Situation in the landscape and ecological setting of HLO1

The site HLO1 is situated about 1 km north of the main motorway connecting Sharjah City with Kalba. The road to the site connects to the motorway at the point where it starts to make its western ascent towards the tunnel through the main mountain ridge.

The exact geographical position (WGS 84) of the archaeological site is:

Northern Latitude = 24.991561
Eastern Longitude = 56.218719
Elevation above sea level c. 350 m

Before construction of the motorway it was difficult to reach the area of the site, either from the east coast or from the western lowlands. Because of this difficult access from all sides, the question comes up concerning the accessibility of the copper producing site of HLO1 from contemporary sites and harbors in the larger area.

As local topography determines human movements in the mountains, using the elevation data measured by the Shuttle Radar Topography Mission (SRTM) of NASA was tried for calculating the optimal routes between HLO1 and the major Bronze Age sites as mentioned above. NASA provides a Digital Terrain Model (DTM) obtained from the radar data with a resolution of 3 arc-seconds (approximately 90 m) (Farr et al., 2007). This resolution is sufficient for dealing with the large-scale questions discussed above. For the following analysis, the opensource GRASS program was used (GRASS Development Team, 2012a).

In an initial step, the SRTM data provided by NASA for the area of Wadi Hilo were used to calculate a "cost surface" originating at HLO1 by using the function "r.walk". This function calculates an anisotropic cumulative cost surface. The function not only takes into account slope gradients, but also walking times which differ according to upward and downward movements (GRASS Development Team, 2012b, raster processing: r.walk). Based on this cost surface and the function "r.drain" it is then possible to calculate the optimal pathways between HLO1 and the Bronze Age sites mentioned above (GRASS Development Team, 2012b, raster processing: r.drain). As a limitation, it should be mentioned that with the DTM being used as the only database, other parameters, such as, for instance, the availability of water or the limitations of walking speed according to the underground and other surface parameters, could not be taken into accounted.

The first approach was calculating pathways towards the east coast (Fig. 4.3). A known archaeological site on that side of the peninsula is Kalba (Eddisford and Phillips, 2009). The other endpoints of the calculated routes were randomly selected. As expected, the calculated routes mostly follow the Wadi Hilo. Only for the southernmost point does the route leave the valley at the present township of that name and cross a low ridge in order to reach the next larger wadi farther south. All other routes follow the Wadi Hilo to the point were it leaves the higher parts of the mountains. This is even the case for a route to the area north of Fujairah. Merely looking at the map one might come to the conclusion that the easies route would go up the Wadi Hilo and cross the main mountain chain over one of the saddles into Wadi Hel leading down to Fujairah. But even for the northernmost point on the map, the program calculated that the southern route was more cost effective.

To apply these analyses to routes leading to other important Bronze Age localities in the Emirates, sites were selected which are distributed over the whole area (Fig. 4.4). These are Kalba (Eddisford and Phillips, 2009) on the east coast, Shimal in the north of the west coast (Velde, 2009, p. 65), Tell Abraq in its centre (Potts, 1990b,a), and Umm an-Nar (Frifelt, 1975, 1995) in the south. Hili was selected as a site at the south-western edge of the Hajjar Mountains (Frifelt, 1975; Cleuziou, 1980), and in the inland basin, closer to HLO1, Mleiha was chosen with its large Umm an-Nar Grave. The geographical distribution of these sites also allows for a judgement with regard to other sites as well, both in the Emirates and in the north of the Sultanate of Oman.

The routes towards the west also follow the Wadi Hilo to the township of that name, and thus take the same routes as the modern streets (Fig. 4.4). However, from there the most cost effective walking way does not follow the modern motorway going west. It rather turns south into a side wadi in order to reach the next larger wadi. There the route turns west and passes not far from the Umm an-Nar grave at Munaih (Phillips, 1997, p. 208), from where it crosses a low pass to Wadi al-Ghor which opens into the Inland Basin about 5 km north of the modern road from Dubai to Hatta.

Where the route reaches the Inland Basin, it starts to divide. For the closest destination, the Umm an-Nar grave at Mleiha, the route simply continues in a straight line over the open plain until it reaches the base of Jebel Faya. The route to Shimal in the north follows the eastern edge of the plain along the foot of the Hajjar Mountains. The same is true for the route towards Hili in the south. Interestingly, this is the same route taken by traders of fresh fish transported on camels between Ra's al Khaimah and Al-Ain until the middle of the 20th century (personal communication with the former Sheikh of Fili, Sharjah).

The route towards the west coast continues along the main wadi, which changes its name from Wadi al-Ghor to Wadi Yudaidah (or Idayyah) where it leaves the mountains. It proceeds north-west to al-Madam and from there along the west side of Jebel Buhais and Jebel Faya before it enters the sand dunes of the northern extension of the Rub al-Khali. Eventually it reaches the coast between the cities of Sharjah and Ajman. Again it is interesting to note that this also was the route of the first motorable road from Dubai and Sharjah across the peninsula and towards the Omani coast.

Where Wadi Yudaidah leaves the dune area, the calculated route splits into a northern branch towards Tell Abraq and a southern branch which reaches the coast

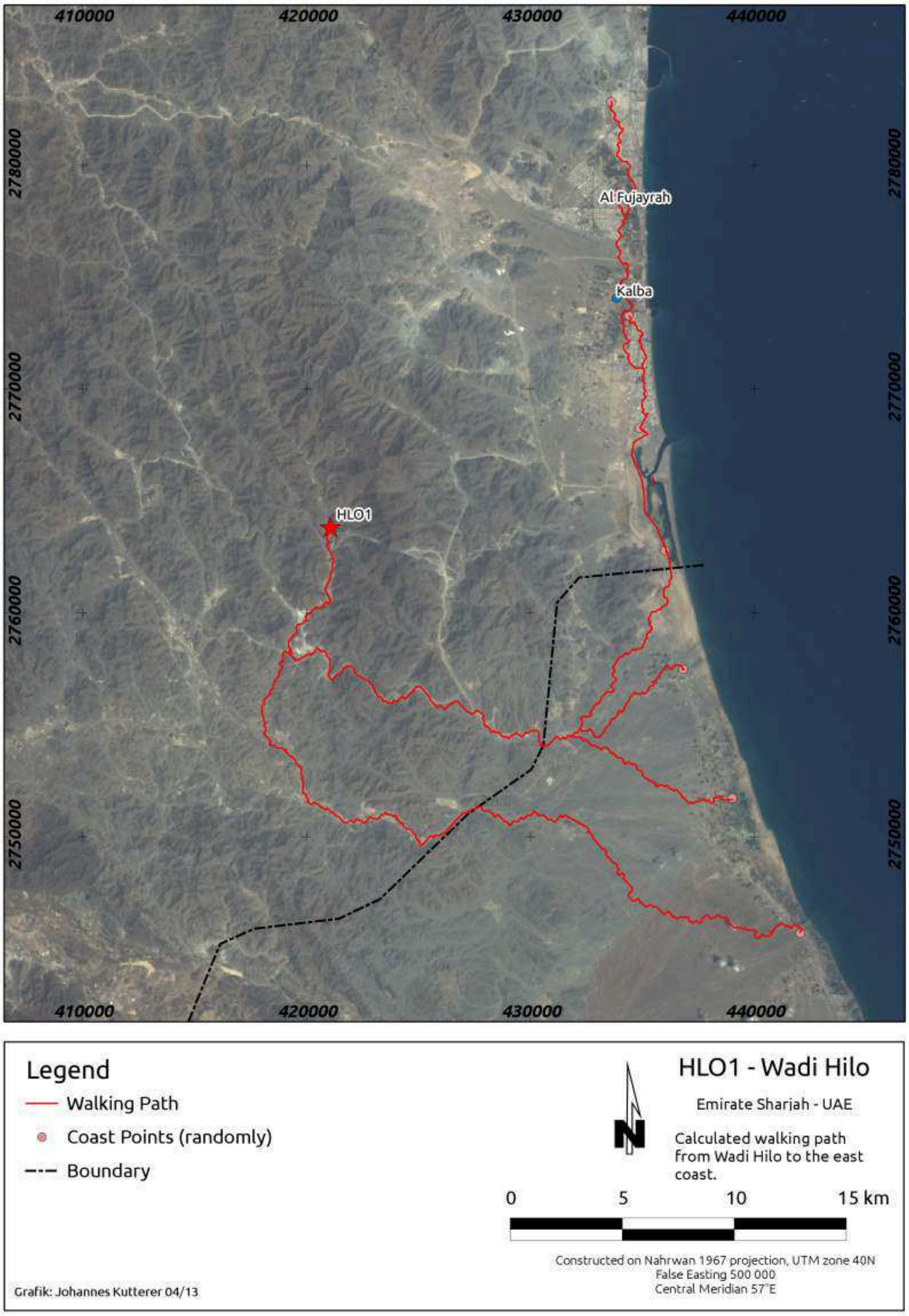

Figure 4.3: Map with pathways from Wadi Hilo to the east coast calculated in GRASS with the "r.drain" function (GRASS Development Team, 2012b, raster processing: r.drain).

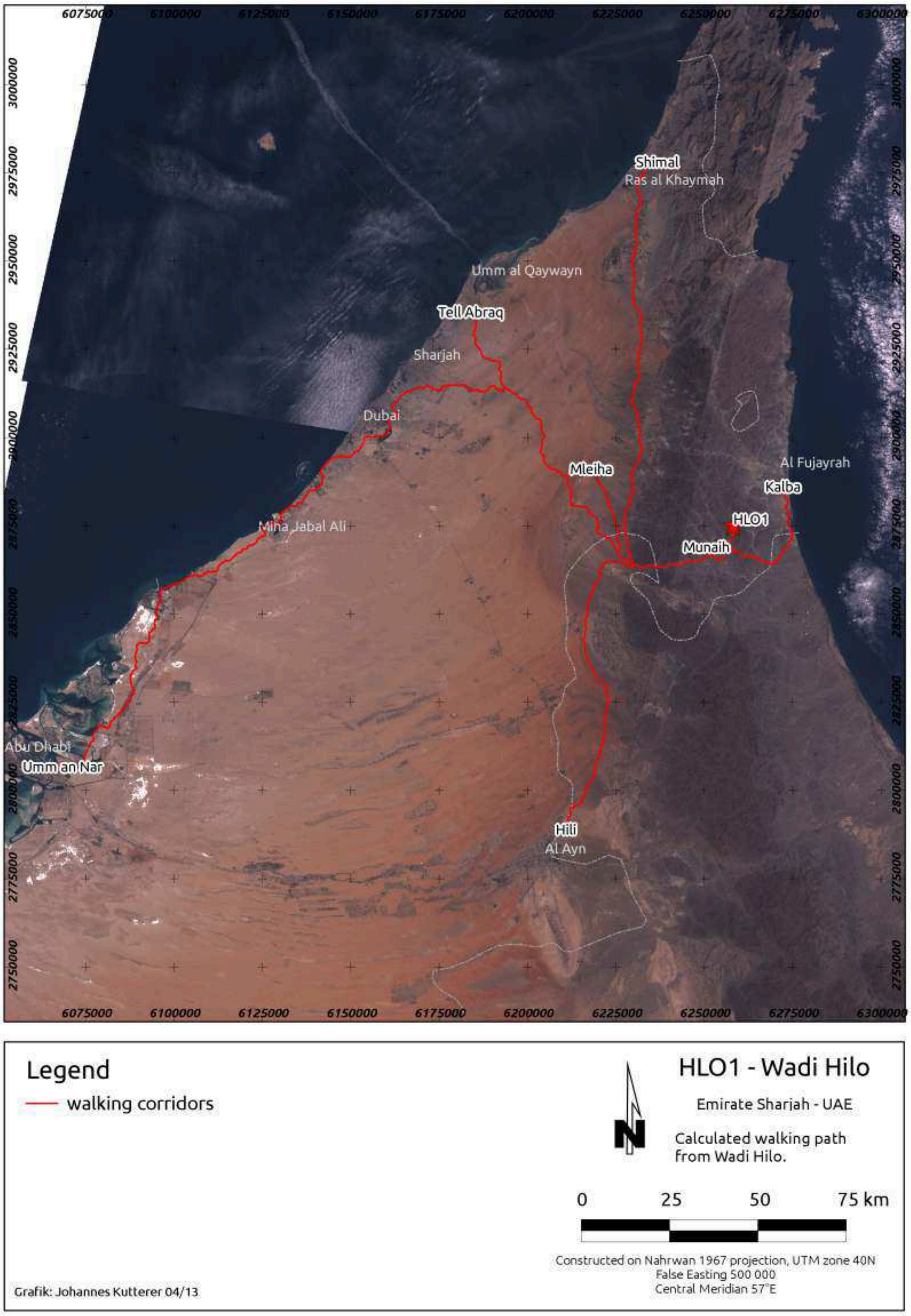

Figure 4.4: Map with pathways in the UAE calculated in GRASS with the "r.drain" function (GRASS Development Team, 2012b, raster processing: r.drain).

between Sharjah and Dubai. From there it follows the coastline until it reaches Umm an-Nar, which today is a part of the city of Abu Dhabi.

Although the calculated pathways are only based on the topograghy, there are other aspects in favour of these routes. For crossing the dune area, the wadi bottom is much more suitable than an up-and-down path on soft sand across the dunes. Water supply will also have been easier in the wadi, where potholes and accessible groundwater remain long after the occasional rains.

As a pack animal, the donkey is known to have been available during the Bronze Age. This is known from osteological evidence, also available at Wadi Hilo, and demonstrated by a relief on one of the Umm an-Nar graves at Hili (al-Ain), which shows a rider on a donkey (Frifelt, 1975, Fig. 51). Cattle could have been used as draft animals. Both donkeys and cattle are hoofed animals which have difficulties walking on sand, thus making gravel filled wadi beds a much better path for them. Camels, which would not have had this problem, only became available during the Iron Age (Uerpmann and Uerpmann, 2012).

The name of the valley in which the archaeological site of HLO1 is situated already gives a first hint to its ecological situation: حلو (hilu) means “sweet” in Arabic. Increased rainfall along the western slope of the main mountain chain is collected in the valley, where it flows off to some extent, but where it is also a rich source of phreatic water. Therefore Wadi Hilo is intensively used for various forms of agriculture. Probably the river itself was dry for most of the year. The old wells, which are encountered everywhere in the upper parts of the valley, indicate a high level of ground water. Only during the last few years has the groundwater level gone down remarkably, probably because of excessive water consumption. Nevertheless, some deep wells still provide large amounts of water.

During the historic period, the water level seems to have been some 10 to 12 m below the present surface. This assumption is based on depth measurements of old wells (Fig. 4.5 and 4.6). Correlated with the rich water supply in Wadi Hilo, there are a lot of trees in the present vegetation. Since there was less agricultural activity during the Bronze Age, there may have been even more trees and other vegetation which could be used as fuel.

Figure 4.5: Masoned well shaft south of the archaeological site HLO1. The shaft is preserved to a depth of about 10 to 15 m.

Figure 4.6: Ramp at another historic well south of HLO1. Probably the ramp was used for draft animals which had to pull water buckets to the surface. The depth of the well shaft and the length of the ramp are about 10 to 12 m.

4.2 Geological environment of the site HLO1

Most parts of the Hajjar Mountains consist of the so-called "Semail-Ophiolite", formed by oceanic crust. The Semail ophiolite is considered the largest and most accessible old ocean floor in the world (Coleman 1977, p. 182, Glennie 1995). As such, the Hajjar Mountains of the Oman Peninsula are part of the Peri-Arabic ophiolite belt, which is also called the Zagros belt. It extends from northern Oman through south-western Iran and south-eastern Turkey to the island of Cyprus in the eastern Mediterranean (Prange, 2001, p. 15).

Where exactly the ophiolite originated some 96 Ma ago is still under discussion. It seems obvious that it formed at an oceanic spreading center. Whether this was a mid-oceanic ridge or the axis of a marginal basin is not clear (see e.g. Dilek and Flower, 2003). A more detailed description of the geological situation in the Omani part of this belt and of the ore deposits connected to this geological formation is found in Hauptmann (1985, p. 15-33) and Weeks (2003, p. 7-14). In the UAE the Hajjar Mountains are dominated by the **Omani–Emirati Ophiolite Complex**. This complex is one of seven geological units into which the Emirates can be subdivided (see Fig 4.7).

The northern tip of the SE-Arabian Penisula consists of carbonatic shelf sediments belonging to the Arabian continental rim. They are referred to as the **Hajjar Supergroup** and date from the Middle Permian to the Upper Cretaceous (Phillips et al., 2006). In the south, the "Hajjar Supergroup" is delimited by the **Dibba Fault Zone**. Like the **Hatta Fault Zone**, this unit consists of deformed sediments (limestones and associated deepwater sediments). They are interstratified with smaller tectonic units of metamorphous rock (Phillips et al., 2006; Styles et al., 2006).

On the western rim of the Hajjar Mountains, there are **calcareous sediments** which were deposited during the Late Cretaceous and into the Palaeogene period. Probably this happened in a foreland basin of the Thetis Sea (Farrant et al., 2006, p. 13). Farther to the west and also parallel to the western border of the mountains, there are three other major geological units, which evolved during the Quaternary. These are **fluvial gravel fans** along the mountain-slopes, **aeolian sand dunes** and **coastal deposits** (Farrant et al., 2006, p. 13). A more detailed description of the geological situation in the vicinity of the archaeological site in Wadi Hilo will be given in next section, where the copper ore deposits will be described.

4.3 Indications for local copper production at HLO1

4.3.1 Geology and the occurrence of copper ore in Wadi Hilo

The geology of the larger area around Wadi Hilo has already been treated above. The whole area is dominated by the Ophiolite complex. Apart from that, there are only younger sediments in the form of sub-recent wadi fill and quaternary

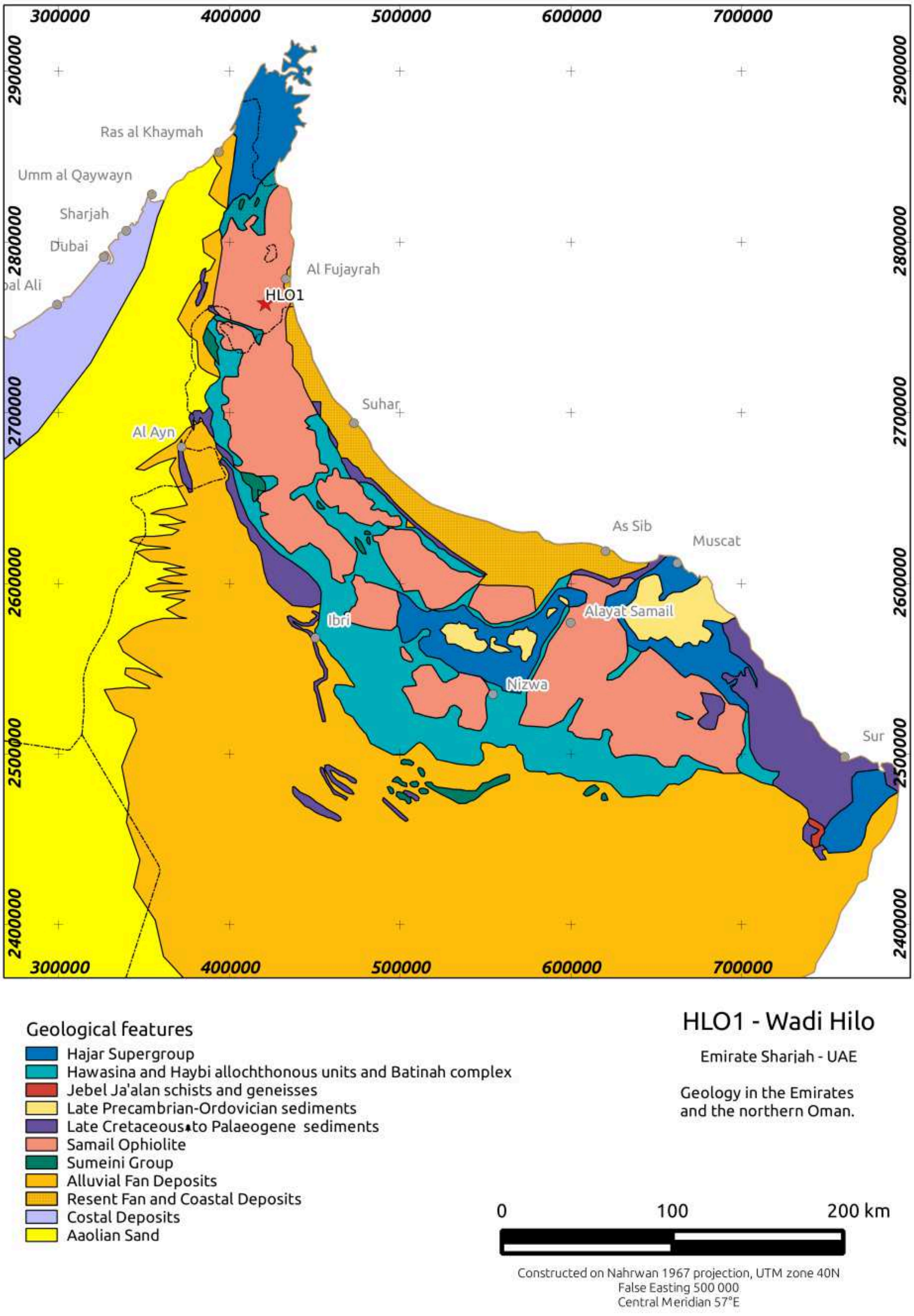

Figure 4.7: Overview of the geology of the UAE and northern Oman (modified after Kusky et al., 2005, Fig. 2).

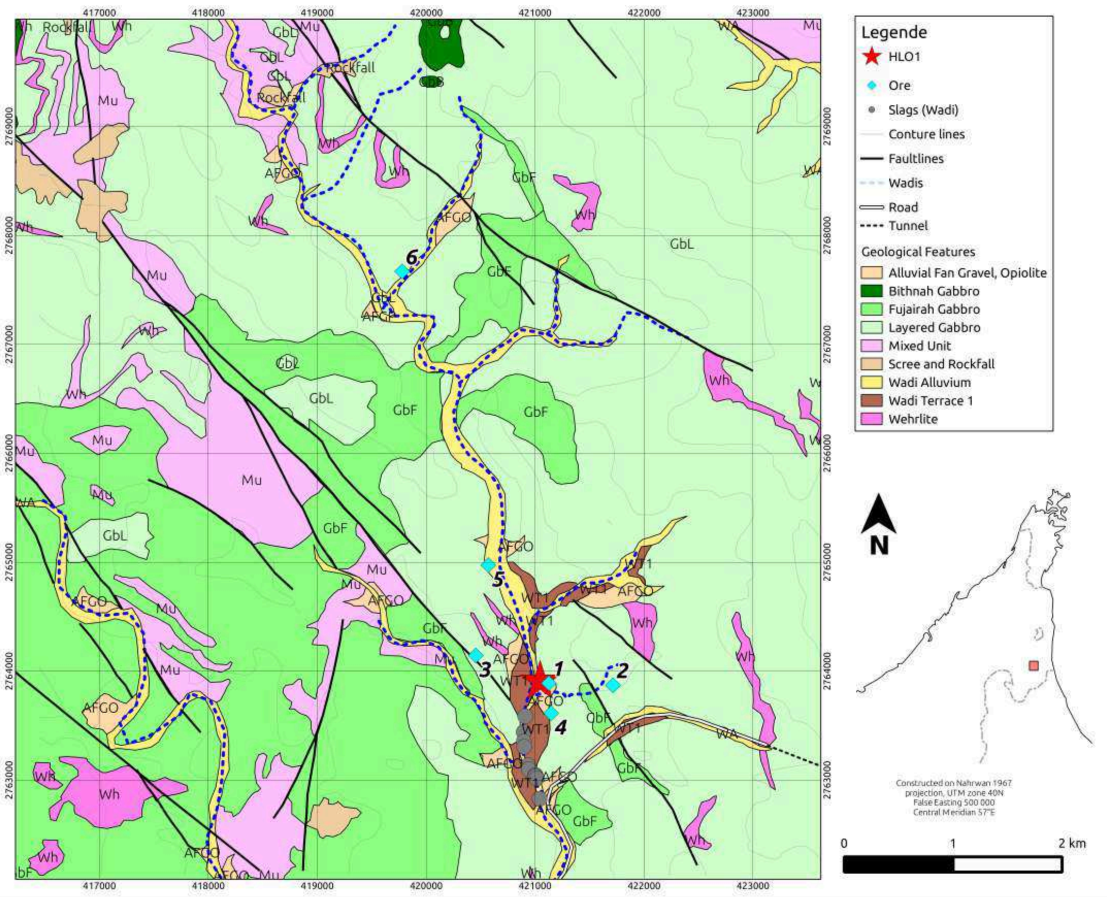

Figure 4.8: Geology of the Wadi Hilo (modified after Styles et al., 2006).

terraces. The prehistoric site is situated on one of these terraces (WT1). Such terraces originated when older gravel fill of the wadi bottom was later dissected again by flowing water. The terrace at HLO1 consists of almost unsorted gravel, containing large boulders with well rounded edges and all sizes of other rounded pebbles. The sandy matrix is also not well sorted. Like many other terraces in the area, the terrace of HLO1 is firmly consolidated by calcareous, hydromagnesitic, and silicate cements (Styles et al., 2006, p. 52). The ophiolite bedrock in the area of the archaeological site HLO1 is represented by five different units (see Fig. 4.8 und Table 4.1).

The oldest crustal rocks in the area of the site are represented by **Layered Gabbros** (GbL). These are situated above the **"Moho Transition Zone"** which is made up by the **"Mixed Unit"** and **Wehrlite**. The mantle rocks below them (Harzburgite and Dunite) do not crop out in the area of the site. Apart from Wehrlite and the Mixed Unit the **"Later Magmatic Suite"** also contains the **Fujairah Gabbro** and the **Bitnah Gabbro** (Styles et al., 2006).

The Layered Gabbro forms the base of the crust and has intrusions of younger ultramafic rock. In weathered form, the Layered Gabbros are dark brown. Usually

Table 4.1: Geological units accessible in the area around HLO1.

Scree, Rockfall	Slope deposits	Superficial deposits	Quaternary to Recent
Alluvial Fan Gravel	Alluvial fan deposits		
Wadi Terrace	Wadi deposits		
Wadi Alluvium			
Bitnah Gabbro	The later magmatic suite	Oman–UAE ophiolite	Late Cretaceous, Cenomanian to Turonian
Fujairah Gabbro			
Mixed Unit			
Wehrlite			
Layered Gabbro	The early crustal section		
Dunite	The Mantle section		uncertain
Harzburgite			

they are coarse grained. Their major components are three groups of minerals: amounting to 20%-50%, clinopyroxenes (diopside to diopsidic augite) are the most important constituents. Partially serpentinised olivines occur at up to 15% and are second in importance. Plagioclase (bytownite) and associated opaque minerals form the rest (Styles et al., 2006, p. 28).

The "Mixed Unit" is a very complex zone belonging to the Later Magmatic Suite. As mentioned before, it forms the "Moho Transition Zone" together with Wehrlite and the deeper Dunites as described by Boudier and Nicolas (1995). Above the Mixed Unit there is the Wehrlite which also belongs to the "Later Magmatic Suite". In the area of HLO1 it is only visible at the surface in small areas.

In the surroundings of the site the "Later Magmatic Suite" is mainly represented by the "Fujairah Gabbro". To the north there is also a small outcrop of "Bitnah Gabbro". The Fujairah Gabbro is very heterogeneous. With regard to its grain size, it varies from coarse grained to microgabbro. It occurs in the form of patches or veins (Styles et al., 2006, p. 41). The slope behind the archaeological site of HLO1 consists of Layered Gabbro in the lower part. The upper slope consists of Fujairah Gabbro.

The question **"from where did the ore come?"** is most important for the issue of the local copper production at HLO1. Various geological surveys during the last decades (Greenwood and Loney, 1968; Styles et al., 2006; Thomas et al., 2006) have indicated that there are small occurences of copper ore in the area which are not worthwhile for modern mining. They occur mainly in the "high-level gabbros" which are associated with fault zones (Styles et al., 2006; Thomas et al., 2006). Surveys in the Omani Mountains indicate that outcroppings of ore occur in all lithological units (Hauptmann 1985, p. 25, Weeks 2003, p. 12-13). According to the chief of police at Wadi Hilo, a survey for copper ore was conducted south of HLO1 some 20 years ago. In 2007 several graded terrace steps were visible near the base of the slope (see Fig. 4.9). However, ore extraction in this area was apparently not considered worthwhile.

Figure 4.9: Old prospecting terraces south of the site HLO1.

Reconaissance surveys during the excavations led to the discovery of a number of small outcroppings of ore in the vicinity of the archaeological site. At some of them, there were indications of early ore extraction (see Fig. 4.8). The occurrence No. 1 in Fig. 4.8 is the metalliferous vein directly adjacent to the archaeological site. As pointed out in the section on the features of the site (see Section 4.3.2), the excavations in this area yielded clear indications of ancient mining. The ore remnants found in this area are secondary copper ores, such as, for instance, chrysokolla or malachite.

Indications of another former occurence of ore (no. 2) were found east of the site, about 500 m up the small side wadi. At the south slope of this side wadi a larger depression extends upwards (Fig 4.10). It seems that this depression was left behind by open-cast mining. Downslope, a quartz pebble was found containing a very small piece of a mineral which probably is chalcopyrite.

Another ore occurrence (no. 3) is also within sight of HLO1. It is situated in a mountain saddle up-slope on the west side of the main wadi (Fig. 4.11). This ore occurrence is also well differentiated from its surroundings by a lighter (partly almost white) colour of the rocks. (Fig. 4.12). Similarly to the other potential prehistoric mining sites, only some few pieces of secondary ore were found on the present surface at this place during our survey. There are, however, obvious traces of former ore extraction, for instance an artificial step in the rock displaying traces of fire-setting. At the base of the slope below this ore vein, that is, on the other

Figure 4.10: Potential open-cast mining at ore-vein 2.

side of the main wadi bed from HLO1, there is a small slag field where some of this ore may have been processed.

Number 4 in Fig. 4.8 indicates an outcropping of ore which was the reason for modern prospecting, as mentioned before. On the graded uppermost terrace (see Fig. 4.9) some secondary ore was found (Fig. 4.13). Because of the disturbance caused by the modern survey, potential traces of prehistoric mining were destroyed. As this shallow outcrop could probably be realized at the former surface, and as it is quite close to the ancient smelting site, the place was most likely also used for ore extraction during the Bronze Age.

The ore occurrence no. 5 is situated in the main wadi, only a little more than 1 km north of HLO1. Again, the light coloured rocks at the outcropping of ore are easily recognized (Fig. 4.14). On the west side of the riverbed there is a rubble cone of these white rocks. Fragments of secondary ore were found in this area. Because of continued erosion near the wadi bed, it was impossible to find traces of prehistoric mining.

The last occurrence of copper ore near HLO1 (No. 6 on the map) was exposed by a new street which was built near the upper end of the wadi, leading up to a mountain crest. Again it contains secondary copper ore, apparently in low quantity. According to our observations, all veins of ore in the near vicinity of the prehistoric smelting site are small occurences of secondary copper minerals. It is remarkable that all local occurrences of copper ore are in light coloured rocks

Figure 4.11: Mountain saddle west of HLO1 with a white outcropping of quartz.

Figure 4.12: Open-cast mining in the mountain saddle west of HLO1 (occurrence no. 3).

Figure 4.13: Copper ore on the uppermost terrace of the modern survey area.

which are conspicuous in the landscape. Usually they are found close to geological disturbances. Secondary copper ores fill cracks in these rocks or are visible as small veins.

Figure 4.14: Ore vein no. 5.

Figure 4.15: Ore vein seen from the north-west corner of the site with the arrow indicating the extent of the lodes.

4.3.2 Ore veins and mining at HLO1 (Area D)

At the entrance to the side wadi NE of the known archaeological features of the site, a geological anomaly is exposed in the form of lodes of white quartz, which are well visible within the weathered dark brown surface of the local gabbro (Fig. 4.15). Already during the first visits to the site in 2006, blocks of quartz with green-blue inclusions were found, indicating the local occurrence of copper ore (Fig. 4.16).

In 2011 an excavation trench (trench 39) was opened in this area at the base of the slope. It was aimed at uncovering the lower parts of the quartz lode by removing the talus sediments and obtaining a section parallel to the slope. As expected, this section (Fig. 4.17) provides clear evidence for open-cast mining activities in this area. The ore-rich central part of the lode was removed to a depth of about 1.5 m (pit 1 in Fig. 4.17 and Fig 4.18), where the dark-brown ophiolite-gangue was exposed. To the west of the lode, the section reveals another large pit (pit 2), which may have been aimed at exploiting weathered parts of the lode, or may have had technical reasons with regard to access to the lode or downslope transportation of the ore, e.g., by a chute. In any case, the exposed area indicates complete removal of the ore-rich central part of the lode. The debris of these activities refilled the already exploited lower parts of the mining

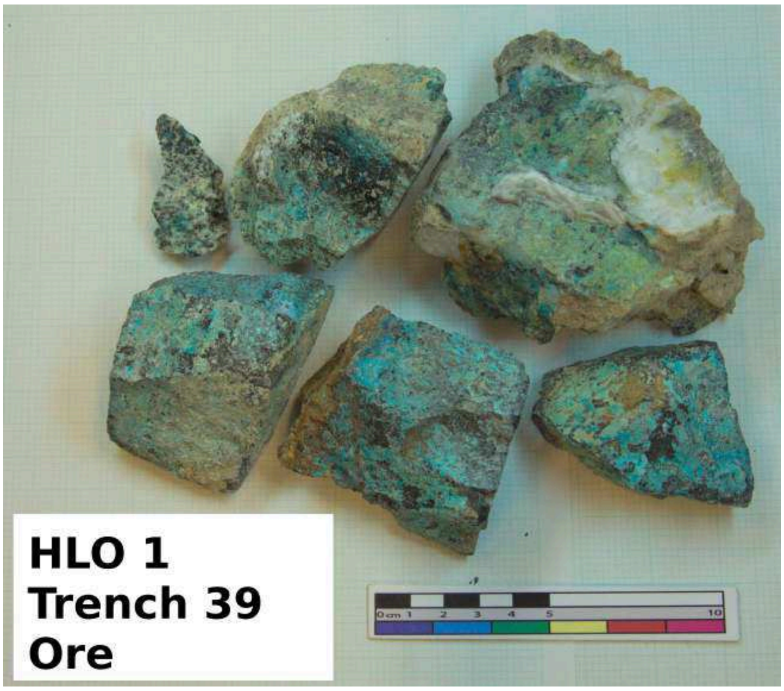

Figure 4.16: Ore samples.

area and extended over the adjacent parts of the slope. They are visible at the present surface in an area extending over some 40–50 meters of the slope above the excavated trench (see Fig. 4.15). In addition to local ore extraction at this part of the site, other outcrops of similar ore in the vicinity were most probably exploited as well (see Sec. 4.3.1). In conclusion it is obvious that, together with the ecological advantages of the whole area, the local occurrence of copper ore was the main reason for choosing the area of HLO1 as a site for copper production in prehistoric times.

Figure 4.17: Section through two exploitation pits at the ore vein.

Figure 4.18: Close-up of exploited ore vein (pit 1 in Fig. 3.17).

5 The Bronze Age at HLO1

5.1 Workshop (Area F)

A large stone built structure was encountered at the foot of the slope in the area where the wadi terrace is only about 20 m wide (Fig. 5.1). A first sondage was dug here in 2007 where a 'U' shaped structure (wall *a*) was visible at the surface. This area was considered promising because an increased rate of sedimentation was expected at the base of the slope.

As a first assumption, the 'U' shaped structure was considered as part of a smelting furnace, because the surface scatter of copper slag seemed to originate from this area. Trench 12 was outlined in a way that it cut the 'U' shaped structure in half, thus providing both horizontal and stratigraphical information about the nature of the structure. Trench 16 connected to trench 12 at one corner. Thus, a combination of the sections of the two trenches provided a stratigraphic section through the whole structure visible at the undisturbed surface. Trenches 18 and 19, excavated after the first two trenches, exposed the complete northern part of the structure, while trenches 24 and 25 explored the western limits. During later seasons of excavations, trenches 31, 36, and 37 were excavated in order to reveal the total area of this complex building. Apart from delimiting its horizontal N/S extension, the excavations yielded clear evidence for the time-depth during which this structure was in use, including the whole Bronze Age and the Iron Age. It was therefore most challenging to establish a chronological sequence of construction of the individual walls and of the rooms enclosed by them. These rooms were numbered *1* to *6* in the sequence of their exploration (see Fig. 5.1).

As it turned out when looking at the junctions of the walls, room *1* was a later addition to an already existing building. Wall *a* as the outer circumference of room *1* was built against walls *c* and *e* which enclose rooms *2* and *3*. Room *3* seems to be separated from room *4* by the well built wall *f*. However, the northern part of wall *f* does not seem to have been higher than the floor level of rooms *3* and *4* at the time when these rooms were used. As this wall continues north below wall *d*, it seems to be a remnant of an older building and appears to be the oldest wall in the whole area. In its southern part, a thicker and less regular package covers wall *f*. This package connects to wall *g*. It seems possible that the well built part of wall *f* continues under this package and passes below wall *g* in order to reappear on its southern side as wall *i*. A functional interpretation of the old walls *f* and *i* is not possible within the exposed contexts. The broader and more coarsely set southern part of wall *f* may have been a later working platform within the large room *3/4*.

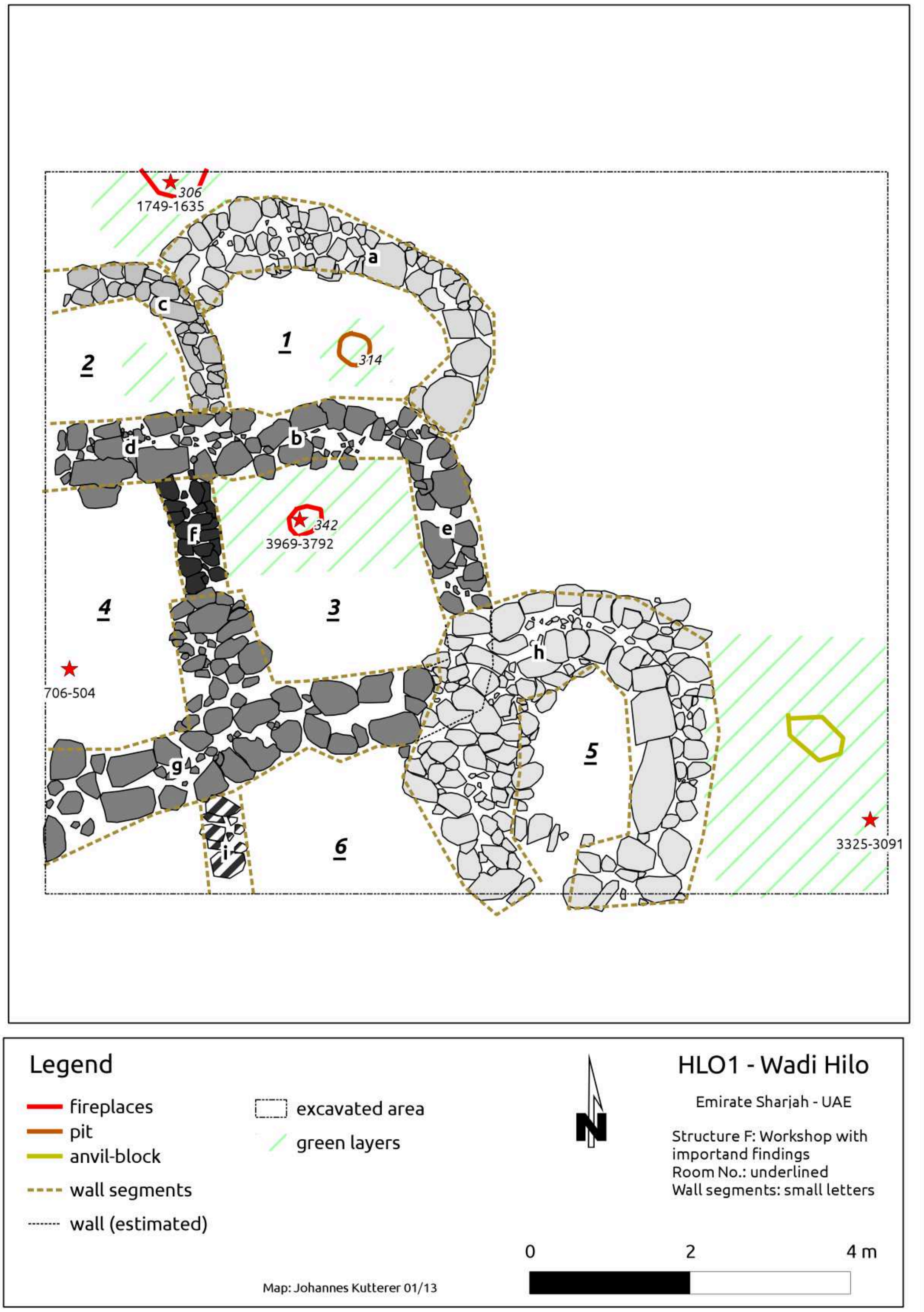

Figure 5.1: Map of the workshop (Area F).

Apparently this room was the central part of the Bronze Age workshop, to which room *2*, and later room *1*, were added as separate annexes.

The almost circular wall *h* around room *5* is clearly set on top of the remnants of the earlier walls *e* and *g*. Thus, room *5* is the latest addition to the whole complex. As will be shown later, this happened during the Iron Age.

For the sake of being systematic, the individual rooms will, in what follows, be described following the sequence of their room numbers, which follows the sequence of their discovery and not the sequence of their construction.

5.1.1 Room 1

This room is situated at the NE corner of the whole building complex. It has an open space of about 4 m^2 and is delimited by 3 wall sections, referred to as *a*, *b*, and *c*.

Wall a is a dry wall built of rounded natural boulders measuring up to c. 70 cm in diameter. The wall forms a slightly irregular semi-circle. On the west side it is built against *c* and in the south against wall *b–e*. Consisting of up to six layers of stones wall, *a* is the best preserved wall of the whole complex. From east to west, the number of preserved stone layers decreases to only three layers at the connection with wall *c*. Obviously the floor of room *1* was dug into the sloping natural surface at the transition of the flat terrace towards the slope in the east. The base of wall *c* comprises only one inner line of slightly smaller stones set against the exposed soil. The outer line starts from the natural surface upwards and partly consists of large natural boulders.

Wall b also consists of an outer and inner mantle. It connects walls *d* in the west and *e* to the east. Although the junctions with these walls appear somewhat disturbed, the three of them obviously form a functional unit as the northern and eastern walls of room *3/4*. Difficulties in recognizing this functional unit in the plan result from bad preservation of the inner mantle of wall *b*. It seems possible that this wall is a remnant of an older circular building which was incorporated into the wall around the later room *3*.

Wall c is of uniform appearance. Large pebbles from the terrace sediments were used for its construction. Only the lowest two or three layers of stones are preserved. The wall is set against the northern face of wall *d* and is therefore a later addition to the whole complex.

Wall d has two distinct mantles consisting of large flat blocks. They stand upright to a height of up to 1 metre. The space between the mantles is filled with smaller pebbles. As said before, wall *d* was built before wall *c*, but it is younger than wall *f* (Fig. 5.2).

Figure 5.2: Contact between walls d *and* f. *Wall* f, *beginning in the right lower corner of the picture, is built of regularly set pebbles. Wall* d, *however, consists of very large blocks and visibly crosses above wall* f.

5.1.2 Room 2

The western extension of room *2* is unknown as it extends beyond the limits of the excavated trench. There are no particular observations for the excavated part of the room.

5.1.3 Room 3

Room *3* is the central part of the excavated workshop area. To the north, it is delimited by wall *b*, to the east by wall *e*, and to the south by wall *g*. On the west side are the remnants of wall *f*, which probably was not much higher than the floor level of the adjacent rooms and may have acted as a sort of sill between rooms *3* and *4* at the time when these rooms were used in the form described here. The interpretation of the southern part of wall *f* is difficult. It might have been a partial division between rooms *3* and *4* or a sort of working platform. Unfortunately neither this southern part of wall *f* nor wall *g* are well enough preserved to reveal the chronological relation between these two parts of the building.

In the northern part of room *3* a radiocarbon date was obtained from the sediments of fireplace 342 underneath the floor level of the room. As this fireplace is pre-Bronze Age, it will be discussed separately.

5.1.4 Room 4

Only the eastern part of room *4* was excavated. Its western limit may be under the baulk or might reach as far as a row of stones uncovered in the eastern part of trench 24. Wall *f* as a (partial?) separation from room *3* was already discussed above. A shell of *Anadara* cf. *ehrenbergi* from the fill of room *4* yielded an Iron Age radiocarbon date (see below).

5.1.5 Room 5

Room *5* is a circular structure in the south-east of the workshop complex. It partly extends onto the slope to the east. Wall *h*, which encloses this room completely, has an inner and outer mantle and is partly built of very large boulders. This applies in particular to the east side where the blocks reach diameters of more than 1 m. The rest of the wall is built of smaller unhewn stones. Wall *h* was built over the respective parts of walls *e* and *g*, and is therefore a later addition to the workshop complex.

5.1.6 Room 6

It is not clear whether room *6* really is a room or whether it is an outside space. It appears to have been subdivided (or enclosed on the west side) by wall *i* which, as a potential part of the old wall *f*, may no longer have been functional during the use of room/space *6*. The access to this room or space must in any case have been from the south.

5.1.7 South-East Area

Outside the southeastern part of the workshop there is an open space which obviously was part of the workshop complex because it yielded interesting finds and findings related to metal working. In its centre there was a large block of about 65 x 50 x 50 cm (Fig. 5.3). Its surface indicates hammering and some greenish staining is visible on parts of it. Apparently raw pieces of copper ore were crushed on this anvil in order to separate the gangue from the pure ore. Obviously this happened repeatedly over a time long enough for the accumulation of sediment around the base of the block.

Early on during the excavations it became clear that old floor levels were preserved at the base of this block. Therefore only a sub-square to its SW was dug deeper in order to obtain sections through the sediments surrounding the block (Fig. 5.4). These sections revealed several fine-grained greenish layers ("green carpets") interchanging with layers of small gravel. A complex fireplace with a large ash layer was found in the SE corner of the excavated area, which was sampled for radiocarbon dating.

Figure 5.3: Anvil block after cleaning the area around its base.

Table 5.1: Quantities of ceramic finds from the workshop area.

Periods	Quantities (n)
Islamic	3
Islamic?	1
Iron-Age	136
Iron-Age?	33
Wadi Suq	74
Wadi Suq?	25
Umm an-Nar or Wadi Suq	31
Umm an-Nar	64
Umm an-Nar?	11
undefined	121

5.1.8 Chronology

Contextual dating within the workshop area is largely based on pottery finds. On the whole, Bronze- and Iron Age pottery is represented in equal numbers within the workshop (see Table 5.1).

With the exception of room *5* and its surrounding wall *h*, only Bronze Age pottery was found in the layers related to the rooms and walls of the workshop area (Fig 5.7). In contrast, Iron Age pottery was found in the sediments above the

Figure 5.4: Sections at the base of the anvil block.

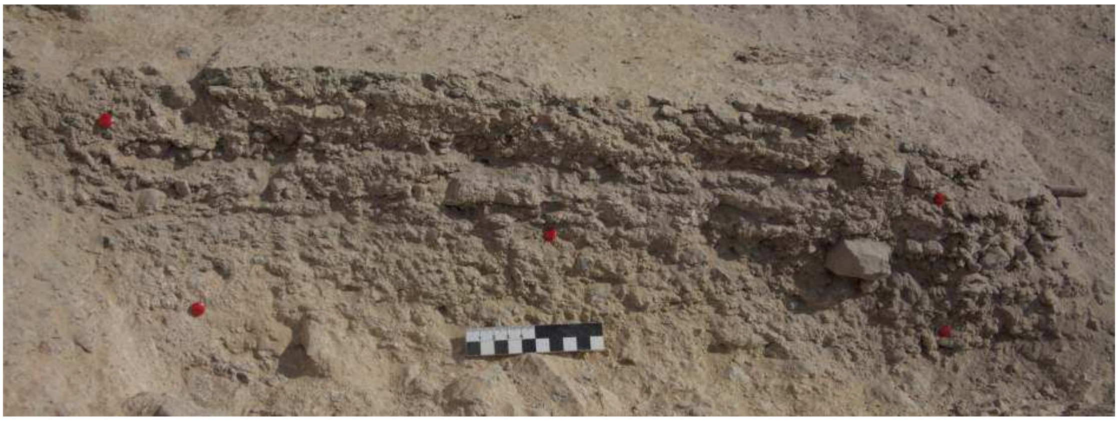

Figure 5.5: Detail of the section south of the anvil (eastern view) with the "green carpets".

wall remnants (Figs 5.8 and 5.6). There, the Iron Age pottery is associated with the horizon of the pitted stones (*Näpfchensteine*) (Fig. 5.9), which also contains the densest concentration of slag. In the lower horizons, the amount of slag decreases, although it remains present among the finds down to the lowest excavated levels.

5.1.9 Particular finds and findings

At the base of wall *a* in room *1* a plano-convex copper ingot was found (see Fig. 5.11). It weighs 4.6 kg and its diameter is 14.7 cm with a height or thickness of 6 cm. The surface was corroded but the convex side indicated the typical roughness caused by sand casting (see Fig. 5.12). After cutting the ingot in the middle, an air pocket of about 4 cm width became visible near the round base of the ingot. Some small air pockets are included near its even surface (see. Fig. 5.13). An overall chemical analysis indicated that the ingot consisted of almost pure copper (see Table 5.5 and chap. 5.5).

Figure 5.10 represents the distribution of all metal finds within the workshop area. These are mostly small and thin sheets. Polished sections of some of them indicate a silvery shine. SEM analysis showed that they consist of copper sulfide (see Chapter 5.5.4).

About 50 cm south of the copper ingot, a pit was found with a diameter of c. 40 cm at the surface (finding 314), which was dug down c. 25 cm below the level of the ingot. The walls of the pit were slightly consolidated, probably due to heating. The sediment inside the pit was greenish and contained two animal bone fragments which were not burnt but also greenish in colour. As far as they were preserved, the walls of the pit are steep down to a depth of c. 18 cm below the assumed floor level of the room. The slightly concave bottom of the pit has a depth of about 25 cm (Fig. 5.15).

A green horizon is an important stratigraphic marker inside room *1*. This horizon has a thickness of 2–7 cm and consists of fine sandy sediment. It is also observed outside of the room, to the north of wall *a*. There it extends below the radiocarbon-dated fireplace 306 and must therefore be older than c. 1700 cal BC. However, the greenish sediment does not extend throughout all of room 1. Nevertheless, pit 314 has its upper limit at the same level, and the copper ingot comes from this horizon as well.

Another green horizon was exposed in room 3. Unfortunately there is no absolute evidence for contemporaneity with the green horizon in room 1. However, the two horizons are at the same level in relation to the modern surface. Hearth 342 is just below the green horizon in room 3.

Greenish sediments also occur in the area east of room 5 outside the building. This area is already part of the slope behind the workshop and can therefore not be correlated stratigraphically with the layers inside. From an ash lens within this outside layer, a remarkably early radiocarbon date of c. 3200 cal BC was otained from the ashy sediment sample (12260).

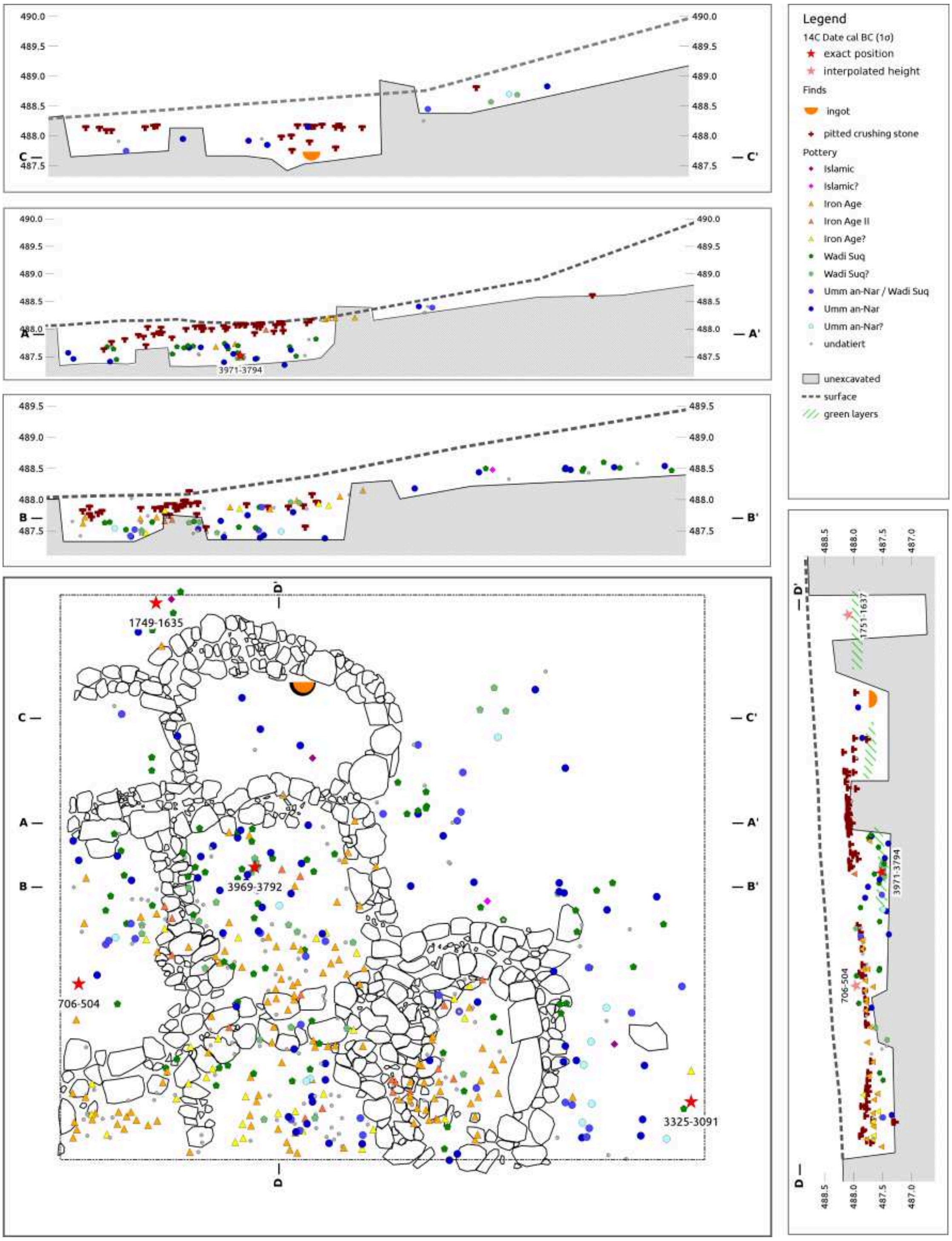

Figure 5.6: Section plots through the workshop with the distribution of ceramics and pitted crushing stones (letters on the rim of the map indicate positions of the sections).

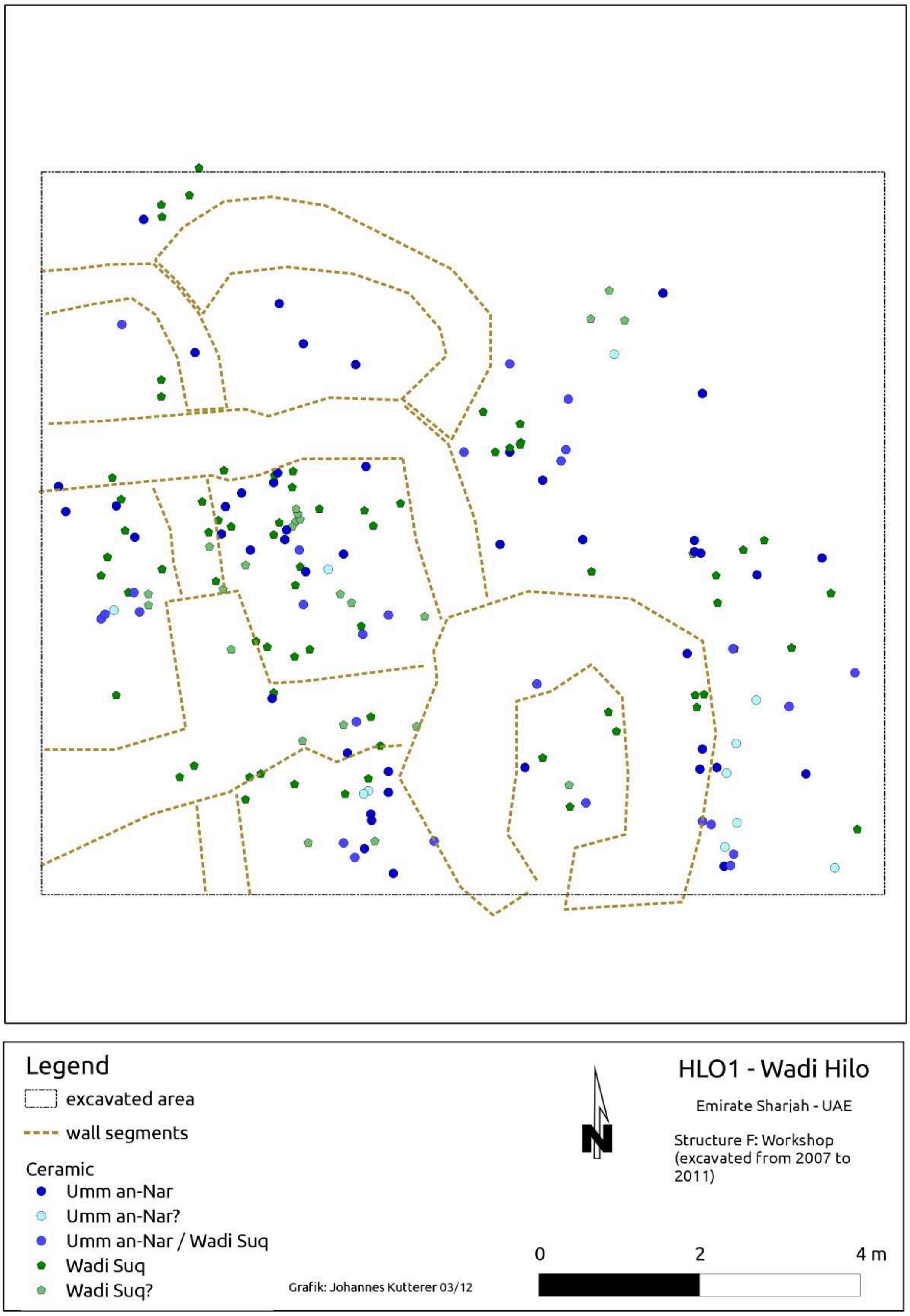

Figure 5.7: Distribution of Bronze Age ceramics.

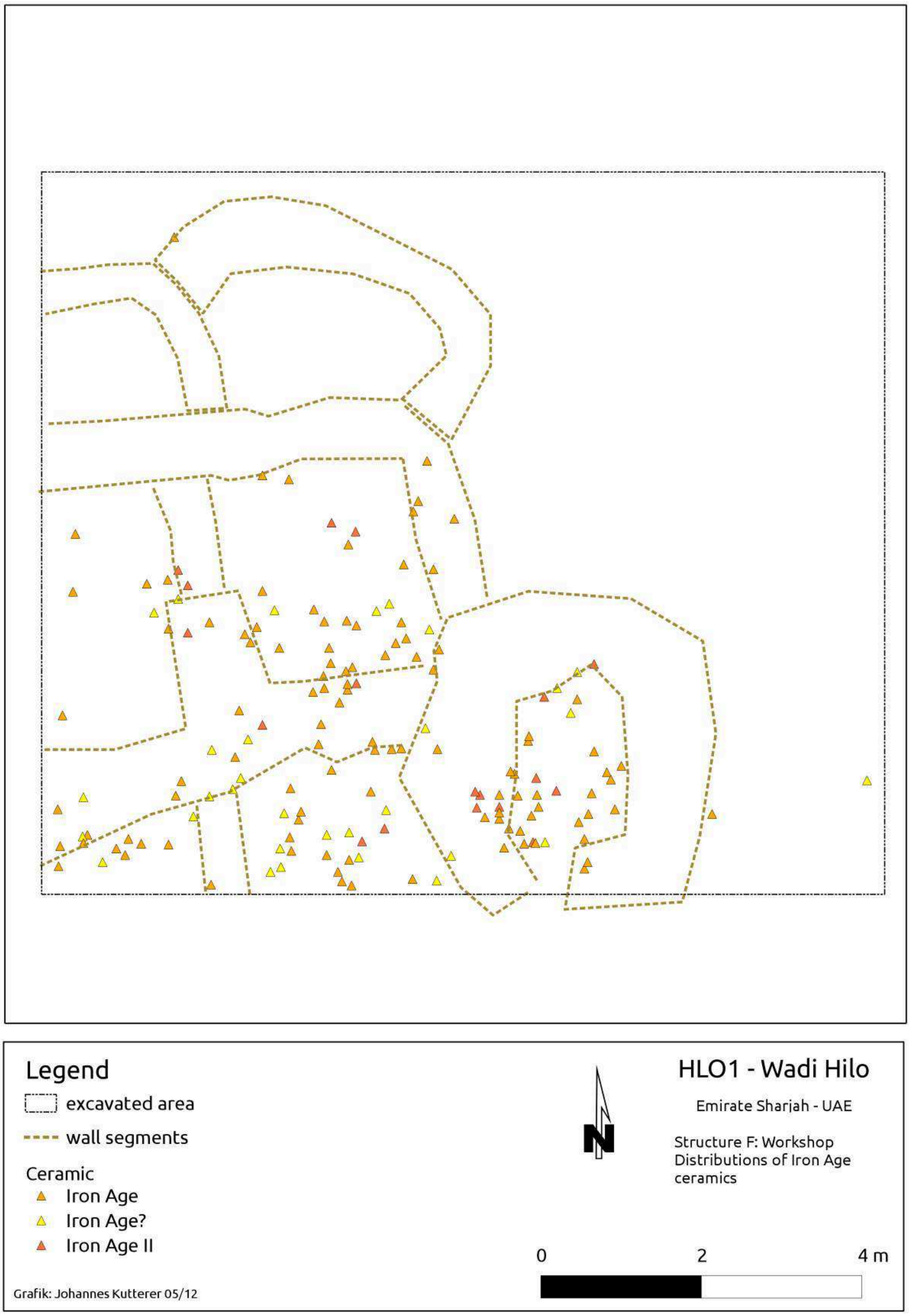

Figure 5.8: Distribution of the Iron Age ceramics.

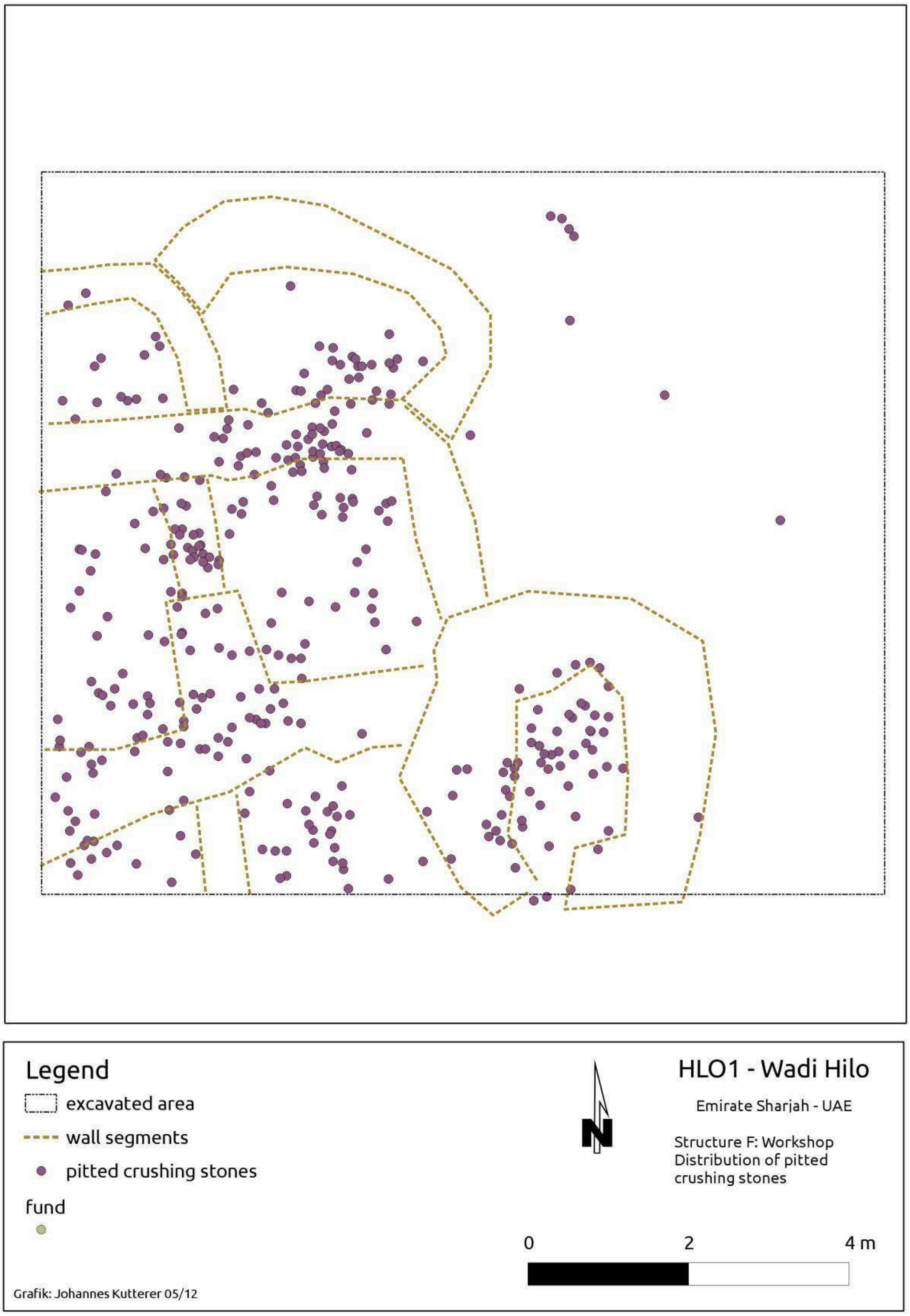

Figure 5.9: Distribution of pitted crushing stones.

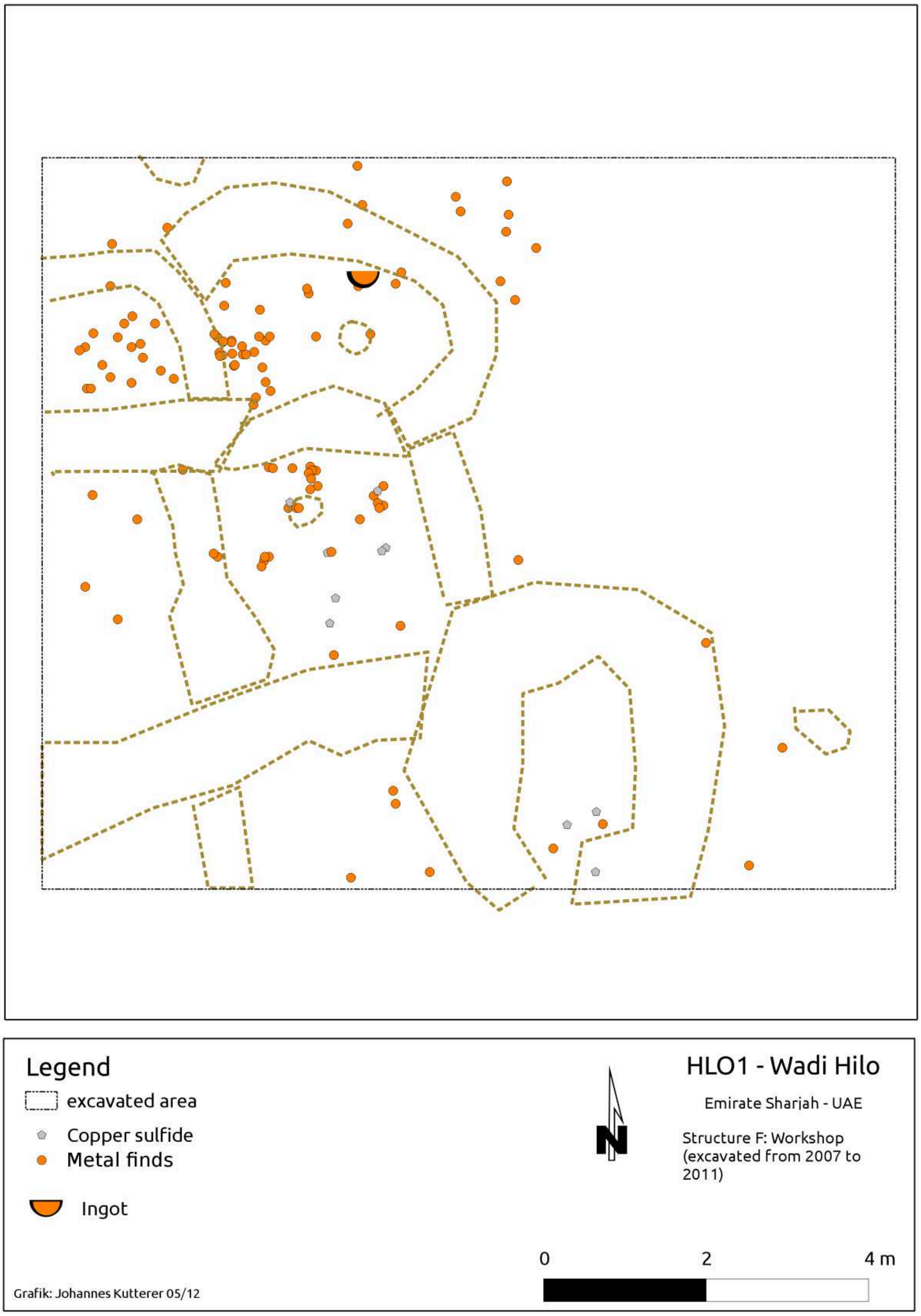

Figure 5.10: Distribution of metal finds.

Figure 5.11: The ingot (circle) in situ.

Figure 5.12: Ingot

Figure 5.13: Section of the ingot.

Figure 5.14: Casting pit before excavation.

Figure 5.15: Section of the casting pit.

In order to determine the copper contents of the greenish sediments, three compressed RFA pellets (sample-IDs 107, 113 and 117) were produced. They were analysed at the Geoscience Department of Tübingen University. For comparison, a sediment sample (sample ID 141) from the nearby wadi was also analysed. This last sample had a copper content just above the detection limit. In contrast, samples 107 and 113 from the workshop floor had a copper content of more than 5 wt.%. Sample 117 from an only slightly greenish layer in trench 46 also had a copper content clearly above that of the wadi sample (141) (see Table 5.2). The samples from the workshop are a clear indication for an enrichment step of copper ore in the workshop. Presumably the raw ore was crushed and sorted there in order to further separate clean ore from gangue.

Table 5.2: X-Ray fluorescence (WD–XRF) analysis of green sediment (107,117,133) and wadi sediment (141) from HLO1, Method: Multi_res Vac34. Normalised. Pressed powder pills. Total represents analytical total in wt-%.

Main and minor elements in wt-%											
No.	Find-No	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
107	12150	40.7	0.50	9.7	12.7	0.12	7.2	24.6	0.00	0.90	0.38
117	12412	32.9	0.29	12.4	24.3	0.13	14.9	15.3	0.00	0.28	0.11
133	11223	37.7	0.38	10.5	9.5	0.13	7.9	30.0	0.00	0.64	0.42
141	9001	44.5	0.56	11.0	7.7	0.14	9.3	25.1	0.53	0.82	0.13

Trace elements in mg/kg																				
No.	Sc	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Sn	Pb	Cs	Ba	La	Ce	Nd	Hf	Ta	S
107	1300	220	1600	690	6.5%	-	20	550	10	40	-	10	-	1900	10	100	30	270	1600	1400
117	70	150	1100	690	0,2%	30	20	340	10	20	10	-	24	100	20	-	-	-	-	460
133	1100	200	1200	770	5.4%	-	10	620	0	10	0	0	-	1700	10	90	30	220	1300	1100
141	20	190	1100	490	80	90	40	460	10	70	10	0	30	220	40	100	20	20	-	620

Figure 5.16: Green layer in room 1 of the workshop in area F.

5.1.10 ^{14}C-dates

From within the structures in Area F, two sediment samples from the hearths and a mollusc shell could be radiocarbon dated (see Table 8.1). The sediment sample from the hearth within the northern section yielded a ^{14}C-date of 1751–1637 cal BC (1σ, Hd27743), indicating that this fire burnt during the Wadi Suq period. The shell, found in Iron Age layers, provided a date of 835–777 cal BC (1σ, Hd29111).

The lowest ash lens 324, however, provided a date of 3971–3794 cal BC (1σ, Hd28956). This may indicate that the area of the site was already used before the Bronze Age. Slow sedimentation during this time, due to the dry climate and the lack of mining activities, explains why this hearth was found almost immediately below the Bronze Age findings.

Another early radiocarbon date of 3326–3092 cal BC (1σ, MAMS-15104) was obtained from a sediment sample of another hearth in the south-eastern part of the workshop. Interestingly, this fireplace is situated in the area of the greenish sediments around the base of the anvil block (see Fig. 5.3, 5.4 and 5.5). It seems that ore crushing on this block had already begun during the Hafit period at the very beginning of the local Bronze Age. One problem that can arise when wood is used for radiocarbon dating is that sometimes the wood of slow growing, old trees is dated, leading to too old dating results. This "old wood" problem must be taken into account when interpreting radiocarbon dates. However, in the case of HLO1, the samples which were measured were taken from sediments out of fire-places and thus represent an average of the burnt wood-material. Therefore this effect is less problematic as in cases where single charcoal pieces are dated. Delayed use and reuse of old hardwood is also unlikely since the decay of dead wood in the area occurs fast and the general scarcity of wood very likely meant that every available material was promptly used by the inhabitants of the area.

5.2 The house and workshop in Area C

A major stone structure (Area C) was found in the north-west of the site, approximately 2.5 m off the edge of the terrace (Fig. 5.17). It has an extension of c. 9 x 9 m. The eastern part of the walls were visible at the surface before excavation. In 2007 a first sondage (trench 3) indicated the existence of a large building with several rooms. In spite of its exposed position near the edge of the terrace, and the low rate of sedimentation in this area, the foundations of the walls were relatively well preserved. In the following campaigns the building was completely exposed by several trenches (7, 8, 10, 34, 40) covering an area of more than 70 m^2.

In the northern part of the building there are three rooms (1, 2, and 3). Their external walls are more or less curved and do not form clear corners. The interior sizes of the rooms vary between 1.9 m^2 and 4.2 m^2. A fairly straight wall separates these rooms from the southern part of the building. South of it is an area enclosed by a rectangular wall. It appears to be divided by another wall into rooms 4 and 5. The southwestern corner of the building is badly preserved and the outer face of the southeastern corner is completely missing. In general, the western and southern walls are built of larger blocks than the walls of the northern part of the house. This might indicate several phases of building and re-building.

The individual rooms were almost entirely filled in by collapsed stones (Fig. 5.18). For this reason, the excavation was slowed down considerably. It had to be clarified for each single stone as to whether it belonged to the collapse or to a preserved wall.

5.2.1 Room 1

Room 1 is in the northeastern corner of the building. Its extension is 3 m from north to south and 1.7 m west to east. Its interior space is around 4.2 m^2. The entrance was from the central corridor in the south. Another doorway connected rooms 1 and 2. This second door was intentionally raised to a higher level during a later phase of use of the building (see below). Apparently the floor level of room 1 was lower than the natural surface outside the building, because its inner wall still has three layers of stones while the outer side has only two layers. The walls of this room are the best preserved ones of the whole structure.

5.2.2 Room 2

The middle room, room 2, is the smallest room of the house. It measures 1.1 x 1.9 m. Like room 1, it has an entrance from the central doorway (Fig. 5.19). As mentioned before, another doorway connected room 2 to room 1 on the original floor level. In a second phase of use, the floor of room 2 was raised 20 to 30 cm by an infill of soil. The doorway connecting rooms 1 and 2 was raised correspondingly with flat stones (Fig. 5.20). The raised floor of room 2 is interpreted as a working

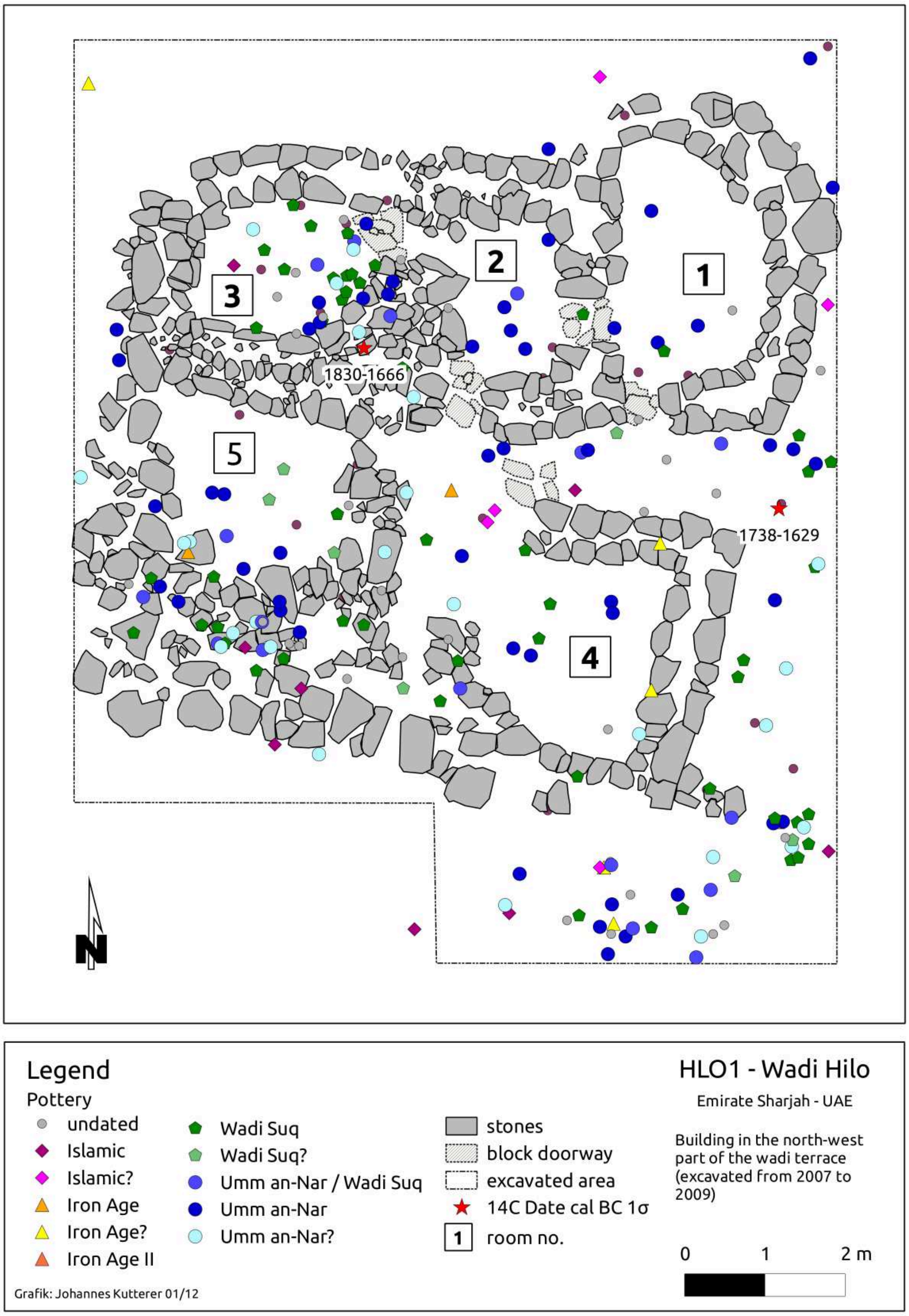

Figure 5.17: Layout of the house and workshop in Area C with locations of radiocarbon dates (cal BC; 1σ) and pottery distribution.

Figure 5.18: Room 1 during excavation.

platform, indicating the later use of the room as a workshop. The raised workshop floor level consisted of small stones and pebbles in a fine-grained sediment. Fragments of furnace wall were retrieved on top of this level. In order to partially preserve that platform while nevertheless obtaining further information about its function, excavtions continued only in the southern part of the room. Apparently, the platform was used as a base for a furnace (Fig. 5.21).

The wall separating rooms 2 and 3 is not well defined due to its state of preservation. Apparently this wall was taken down in the context of transforming this part of the building into a workshop. *In situ* stones could only be separated from collapse in the deepest level below the working platform. Obviously only the edge of the working platform separated rooms 2 and 3 during this second phase of use of the building.

5.2.3 Room 3

Room 3 is in the north-west of building C. It has an extent of 2.8 m^2 and measures c. 2.1 m by 1.6 m. The outer wall in the west is less well preserved due to the erosion towards the terrace edge. The thick wall in the south is remarkable. Unlike the other walls of the building, it is built of three rows of stones (Fig. 5.24) which, however, are smaller than those of the other walls. This might indicate that it was constructed later, potentially during the restructuring mentioned above for room 2 when this part of the building was transformed into a workshop. Unlike room 2, the floor level of room 3 was not raised during this process. Instead, a sandy living

Figure 5.19: Entrance from the doorway to room 2.

Figure 5.20: Raised doorway connecting room 1 and room 2.

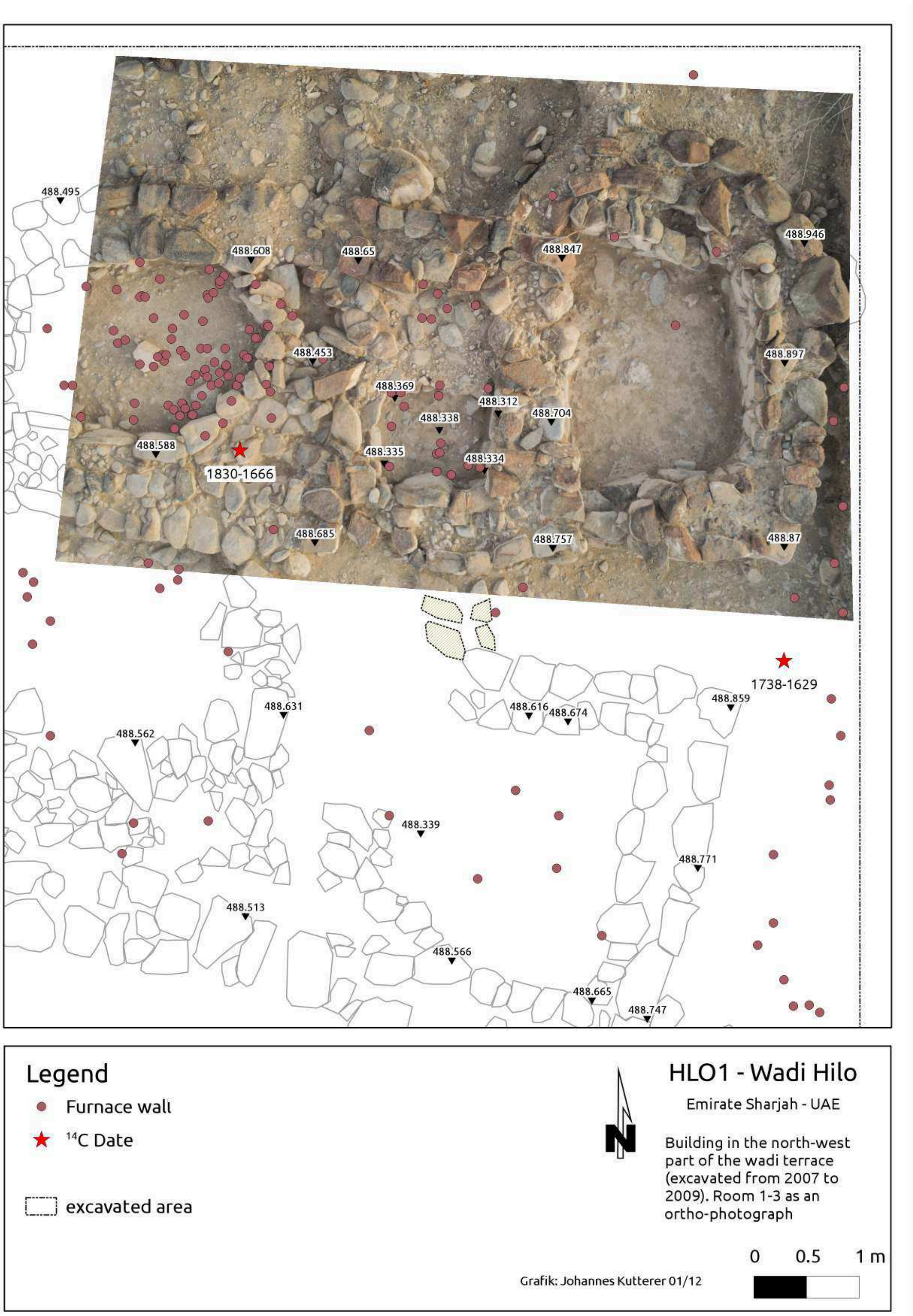

Figure 5.21: Ortho-rectificed picture of rooms 1, 2 and 3 with the distribution of furnace wall fragments.

Figure 5.22: Furnace wall fragments

floor was observed in room 3 below the collapse of the walls. It was found directly above the *in situ* wadi gravel of the terrace. Ceramic finds from this floor mostly belong to the Wadi Suq period. Some Umm an-Nar sherds were found in the fill of the walls. Fragments of furnace wall (Fig. 5.22 and 5.23) were found both in rooms 2 and 3, which apparently were connected during the later phase of use.

5.2.4 Rooms 4 and 5

The southern part of the building indicates a partition into two rooms (4 and 5). In contrast to the northern rooms, the outer walls are straight with rectangular corners. From the east there is a c. 2 m long "corridor", probably the entrance to the whole building from the middle of its eastern side. In this part there are relatively few collapsed stones. The walls there are also comparatively well preserved. In the west the preservation of the walls is much worse. A large number of collapsed blocks in this area makes the interpretation of the original situation and its reconstruction difficult.

A living floor (feature 425) is indicated in room 4. It consists of loamy sand. Probably this horizon originated simply by using the room—a process often observed on our pathways during the excavations. Below the floor level, the undisturbed wadi gravel of the terrace was found. This floor contained pottery fragments of the Wadi Suq and Umm an-Nar periods. Apart from small remnants of the floor, room 5 did not contain any describable features.

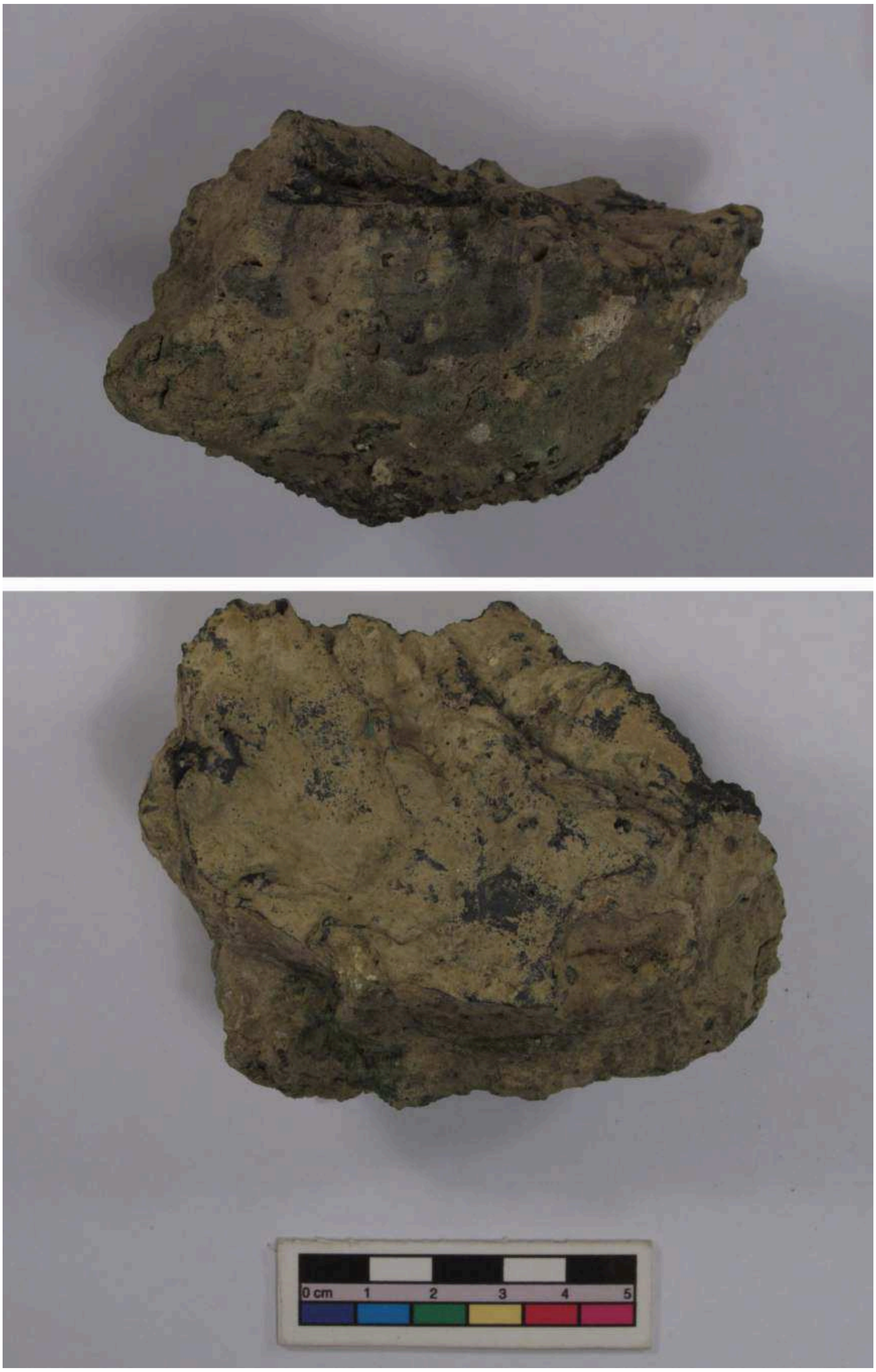

Figure 5.23: Furnace wall fragment from room 2 of house and workshop in Area C (top: Section; bottom: Slag-coating).

Figure 5.24: Central wall built of three rows of stones.

The straight walls of this southern part of building C represent a different architectural conception, probably indicating a later addition of these rooms to the whole complex. This may also have happened during the restructuring of rooms 2 and 3 during the Wadi Suq phase of the site.

Judging by the thickness of the wall between rooms 3 and 5, a height of about 3 m can be assumed. A common roof over rooms 3 and 5 seems possible. The other rooms may have had independent roofs and the corridor from the entrance in the east may not have been roofed, like a sort of "light-well".

A mollusc shell of the species *Cyprea*, find number 16343, was retrieved from the remnants of the dividing wall between rooms 2 and 3. It yielded a ^{14}C-date (Hd-29112 = 3958±24 bp) which is calibrated to between 1830 and 1666 BC (1σ) or 1901 and 1594 BC (2σ) against the marine curve (Reimer et al. 2009) with a reservoir effect of 200±50 years. As the shell was encountered inside the wall behind the 3rd row of stones; this is most probably the date of a restructuring of the building, as described above.

A further radiocarbon date could be obtained from a sample of ashy sediment (find no. 6138) from the entrance area of the building (Hd-27744 with 3383±39 bp), yielding a calibrated date of 1738–1629 BC (1σ) or 1770–1534 BC (2σ). This is slightly younger than the shell date, and probably derives from the time of use of the building. A thick package of collapse from building C sealed the dated material. It is highly probable that the ashy sediment is not from an *in situ* fireplace but derives from the cleaning of a fireplace inside the building. Its position in the

Table 5.3: Quantity of ceramic finds from the house and workshop in Area C.

Period	Quantity
Iron-Age	3
Iron-Age?	8
Islamic	18
Islamic?	8
Umm an-Nar	136
Umm an-Nar?	47
Umm an-Nar / Wadi Suq	35
undated	44
Wadi Suq	88
Wadi Suq?	20

entrance area anyway suggests that the building was already in existence at the time of deposition of the ash.

The chronology of the pottery finds clearly indicates that the building was constructed during the Bronze Age. Although there are younger pot-sherds, about 80% of the ceramics belong to this period (see Table 5.3). The observd living floors exclusively contained Bronze Age pottery. However, Wadi Suq pottery and Umm an-Nar sherds could not be stratigraphically separated. It should nonetheless be noted that rooms 1 and 2 almost exclusively yielded Umm an-Nar pottery, whereas in room 3 there are clearly more Wadi Suq sherds.

5.3 Western slope area

Already in 2007 other concentrations of copper slag were discovered during survey activities on the western side of Wadi Hilo opposite to site HLO1 (Fig. 5.25). They were close to the modern road at the base of the slope. Farther up the slope there are several structures which appear to be Bronze Age graves.

5.3.1 Trenches 48 and 51: The Workshop

In 2011, three exploration trenches were opened in this area. Trenches 48 and 51 were situated within the slag concentration, while trench 49 opened one of the oval structures presumably containing a Bronze Age grave. Copper slag occurred in trenches 48 and 51 already at the surface. Lined stones at the surface indicated a potential structure. Actually the two trenches revealed an oval structure with an extension of 2.8 x 3.2 m (Fig. 5.26). Its interior contained a large amount of slag in a sandy to stony matrix. Unfortunetaly no pottery or other diagnostic finds could be discovered within this structure. Its basic similarity with the workshop in Area F of HLO1 may indicate that this structure on the opposite slope of the wadi was also a Bronze Age workshop.

Figure 5.25: West side of the wadi. In the foreground there is a concentration of slag (dark brown area) near the road.

5.3.2 Trench 49: A Bronze Age grave?

The roundish structure, measuring about 5.5 m in diameter (Fig. 5.27). is preserved to a height of more than 1 m above the surrounding surface. It consists of large stones arranged in the form of a "false vault" with some preserved long and flat slabs partially covering the gap remaining along the center of the vault (Fig. 5.28).

Based on the observed architecture and the resulting assumption that this structure might have been a Late Bronze Age grave, the northern part of its interior was excavated and a west–east section of the assumed grave-fill was prepared. However, only Islamic pottery was found in this trench inside the structure.

As the architecture of this structure is characteristic of the Wadi Suq period, it seems likely that it was emptied and used for domestic purposes during Islamic times. The complete disappearance of indications for its original use is no wonder if this later use had the intensity indicated by the amount of finds from the Islamic period (pers. comm. Christian Velde). Nevertheless, based on observations in the early Islamic village at the northern end of HLO1, it is not totally impossible that the whole structure was built in historic times.

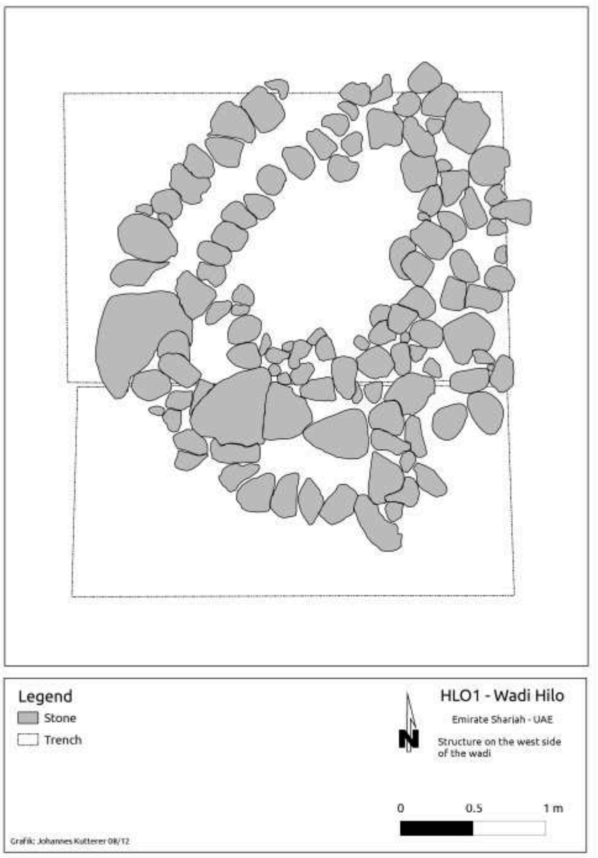

Figure 5.26: Map of trenches 48 and 51.

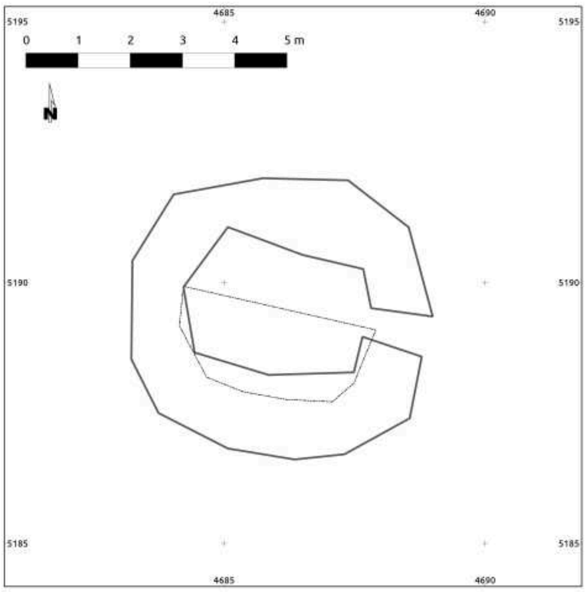

Figure 5.27: Drawing of the grave structure.

Figure 5.28: Grave structure after excavation.

5.4 Traces of smelting at HLO1

5.4.1 Slag

The most conspicuous left-overs of ancient copper smelting at HLO1 are large slag accumulations on the present surface (Fig. 5.29). The slag concentration in the centre of the site measures ca. 2800 sqm (see also Kutterer and Jasim, 2009; Kutterer et al., 2013). Excavations in this area indicate that this is not a continuous heap of slag. The amount of slag per surface unit varies a lot from about 10 to 100 kg per square meter. Calculated for the whole site, this is between 50 and 200 metric tons. Based on an estimated relation between slag and metal of about 5 : 1 to 10 : 1 (Hauptmann 1987, p. 108 and Weeks 2003), one may assume that the amount of copper produced at the site was between 5 and 40 metric tons. However, estimation of the real amount of slag produced at the site is even more difficult. Towards the water-course of the wadi, the site has a vertical cliff. A lot of the slag may have been dumped over this cliff into the wadi bed where it was washed away with the next major flood. Actually, a surprising quantity of slag was found superficially on the wadi gravel up to 2 km downstream of the site. Some of the pieces weighed several kilograms (see Fig. 4.8). As no other smelting sites are known in this part of the valley, the slag, together with an unknown quantity inside the wadi gravel, must have come from HLO1.

In comparison to other sites in the region (e.g., Maysar in Oman) the amount of slag is relatively small. Therefore HLO1 was one to the smaller metal producing sites. These are quite common in the Emirates but none of them has been excavated so far.

5.4.2 Ore processing

Another category of archaeological finds, which is typical for copper production sites, are pitted crushing stones and hammer stones. In the area where slag is concentrated, hundreds of these crushing stones are found at the surface. Some larger stones with pits or grinding surfaces were used as headstones for some of the Islamic graves in the area of the site (see Fig. 5.30). A large quantity of crushing stones were also found in the excavated layers of the workshop areas. Obviously they were used for crushing the raw pieces of ore before separating the pure ore from the gangue. Some grooved hammerstones were found as well, but their function may have been different (Fig. 5.31).

"Green carpets", thin greenish floor layers inside the workshops, are another indication of pretreatment of copper ore. Chemical analysis of these layers indicated copper contents of 5% or more. In normal sediments inside the buildings, copper contents are below 100 mg/kg (Table 5.2). Apparently the greenish layers originated during the enrichment process of the ore before smelting. In this process, the ore coming from the mining site(s) was crushed in order to separate the clean

Figure 5.29: Slag concentration in the central part of HLO1.

Figure 5.30: Selection of pitted crushing stones (left) and a pitted anvil used as headstone in an Islamic grave (right).

Figure 5.31: Grooved hammer stone

ore from the gangue by hand picking. Small ore fragments and dust of the ore will slowly have accumulated on the floor of the area where this process took place.

5.4.3 Charcoal

The question of the provision of fuel for the smelting process is fairly unproblematic at Wadi Hilo. Today the wadi bottom is used for intense production of vegetables and dates, but even now there are large stands of acacia and prosopis trees together with big bushes and shrubs. In the past, the woody vegetation was probably even richer than today. More than in other parts of the Hajjar Mountains, there must have been enough fuel for smelting copper from the local ore. Large fire pits filled with charcoal at the southern border of HLO1 were first interpreted as places for the production of charcoal. However, radiocarbon dating of the charcoal revealed that these pits were Neolithic. In fact, producing charcoal at the smelting site is much less effective than producing it at the places where the trees grow. Whole stems, in particular the dense wood of acacias, are much heavier than charcoal. Thus, charcoal was probably not produced on-site but brought in from other parts of the wadi.

5.4.4 Furnaces

It is difficult to answer the question concerning the furnaces used at HLO1 for copper smelting. Compared to the large amount of slag found at the surface of the site, it is astounding that there are almost no fragments of furnace walls or furnace linings. This is in strong contrast to descriptions of sites in Oman. Hauptmann refers to masses of furnace wall fragments at Bronze Age sites in Oman (Hauptmann, 1985, p. 91). According to Gerd Weisgerber (pers. comm. during his visit to HLO1), the proportion of slag to furnace wall was around 1 : 1 at Maysar in central Oman.

A closer look at the few pieces of furnace wall found at HLO1 immediately reveals why there are so few finds of furnace wall at the site: the specimens from HLO1 are very sandy and have a low proportion of clay. Because of this, even well-fired pieces of furnace wall disintegrate when they come in contact with water. Preserved fragments tend to be quite small, heavily fired, and coated with a layer of slag on the inside, which provided some stability.

The bad quality of the clay can be explained by looking at the local geological conditions. For several kilometers up and down from HLO1, the bedrock along Wadi Hilo only consists of Semail-Ophiolite. Within 20 km around the site there are no rocks, in particular no limestone, that produce clay when they get weathered. In contrast, there are such fine-grained clay sediments in the immediate vicinity of the site of Maysar in Oman (Hauptmann, 1985, p. 91). This explains the differences in the quantity of furnace wall fragments.

Because of bad preservation, only a single furnace structure could be recognized and excavated at HLO1: in trench 13, some 15 m north of the workshop (Area F)

(Fig. 5.32). Already visible at the present surface, there was a concentration of furnace wall fragments and a comparatively large amount of big pieces of flow slag around it.

Excavation of this area yielded a clay platform which was surrounded by set stones. Residues of the clay lining had stuck to some of these stones and were partly covered by slag. Large quantities of slag and further fragments of furnace wall were found in this trench. Again, these finds were of bad quality, although the firing was obvious. The material contained a large amount of sand and little loam or clay. The inner diameter of the whole structure was c. 50 cm and thus comparable to furnace structures at Maysar 1 (Fig. 5.33) (Hauptmann, 1985, p. 91).

As no pottery for comparative chronology and no charcoal for radiocarbon dating was found in this area, a fragment of furnace lining, which was covered with slag on one side, was used for thermoluminescence (TL) dating. During preparation, neither quartz nor feldspar could be extracted. Because of the basaltic geology and the lack of clay minerals in the area, this is not astonishing. Nevertheless, the material yielded a date of 6400±1400 years. The relatively large statistical error is caused by the low concentrations of radioactive elements in the sample.

Based on the measured date, the furnace could be quite early (Final Neolithic or Chalcolithic). Although some copper finds are known from the 4th millennium BC shell middens on the Omani coast (Uerpmann and Uerpmann, 2003, p. 7), and there are very early indications for copper production at HLO1 (see Sec. 5.1), the TL date for the furnace wall can only indicate that it is an "early" furnace, which was definitely in use before the beginning of the Iron Age at 1200 BC.

5.4.5 Wind as a resource

Wind must also be considered an important resource for copper smelting. This is well known since the work of Juleff (1996). The geomorphological setting of the site HLO1 must therefore also be considered with regard to its exposition to air movements in the valley. The whole site is exposed to the wind by its high position relative to the wadi bottom. This is also indicated by a sub-modern threshing platform that exists at the north-western corner of the site (see Fig. 11.4).

The furnace mentioned above is situated at a place where the north wind, which regularly blows at HLO1 in the late morning, is channeled and reinforced by the projecting slope to the east (see Fig. 3.2). It hits the furnace directly and may have been reinforced by organic mats arranged as funnels which would not have left archaeological traces.

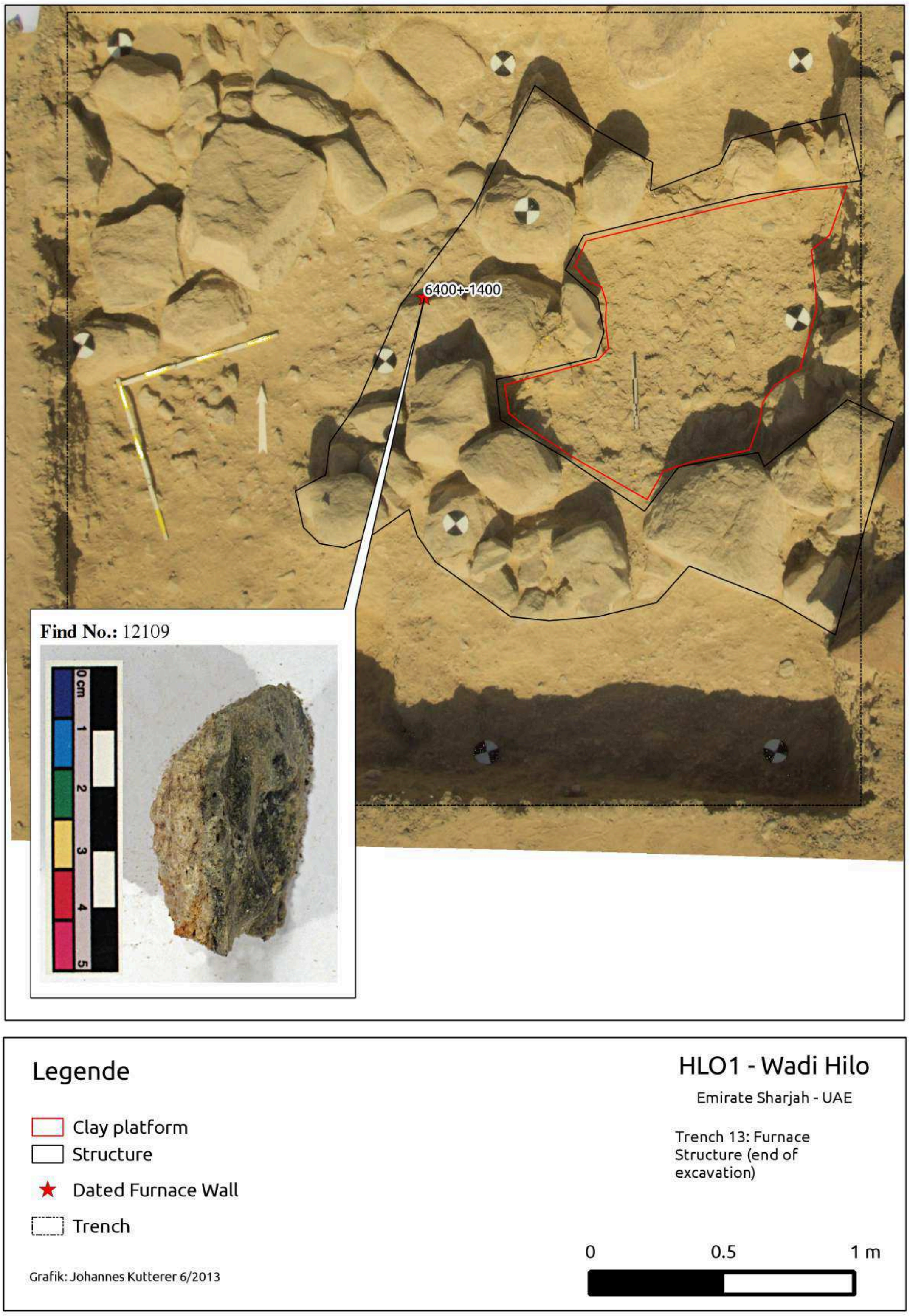

Figure 5.32: Furnace in trench 13 after excavation.

Figure 5.33: Furnace in Trench 13 during the excavation. The inner diameter of the structure made by stones is c. 50 cm.

5.5 Archaeometric analyses

5.5.1 Copper isotopes

The idea that the natural variation of copper isotopes could be useful in archaeometallurgy was already discussed during the 1990s. Initially there was hope that it might provide a direct clue to the origin of the respective objects. This would have replaced the indirect method based on the lead that occurs in copper ore, as an indicator for the geographical origin of a copper artefact (Gale et al., 1999).

As early as the 1950s it was assumed that the variation of copper isotopes might be correlated with the origin of the copper ore (Walker et al., 1958). However, during the last years it has become obvious that Cu isotope ratios cannot be used to determine the geographical origin of copper artefacts. Instead they provide evidence for the origin of the ore within a particular ore deposit. As Markl et al. (2006) writes in his last chapter,

> "Thus, copper isotopes cannot be easily used to track down a specific source of copper, be it in archaeological, geological or biological contexts, based on a single analysis of an artefact, a mineral or a biological sample." (Markl et al., 2006, p. 4227)

However, statements are possible with regard to the kind of ore from which an artefact was produced. Thus, copper isotope ratios are clearly different between low-temperature copper hydrocarbonates and copper sulphides (see e.g. Markl et al., 2006). Copper isotopes are indicated as ^{63}Cu and ^{65}Cu in relation to δ^{65}Cu. The delta-value is calculated as follows:

$$\delta^{65}Cu = [(^{65}Cu/^{63}Cu)_{sample}/(^{65}Cu/^{63}Cu)_{standard} - 1] \times 1000$$

Copper isotopes of the large ingot from HLO1 were measured at the School of Earth Sciences at the University of Melbourne (AUS) with a NuPlasma mass spectrometer. Sample preparation followed Li et al. (2009) with slight modifications. The solution used for measuring had a concentration of c. 450 mg/kg and was provided through a peristaltic pump. The mass bias was corrected by Standard Sample Bracketing against the NIST SRM 976 Standard. The measurement itself was conducted in time resolved mode. Iolite Software was used for the data analysis. 30 sec. were integrated for background analysis and ca. 90–120 sec. for the sample signal itself. Two samples of the copper ingot were analysed: one for the metallic copper from the inside of the ingot and the other from its corroded outer surface. The results are shown in Table 5.4.

Table 5.4: Copper isotope ratios of the large ingot from HLO1.

Description	δ^{65}Cu (in ‰)	s
Ingot (corr.)	-0.46	0.23
Ingot (metal)	-0.65	0.10

The value for δ^{65}Cu of the metallic core of the ingot was measured to be -0.65, while for the corroded outer surface, it was insignificantly higher, at -0.46. Including the measurement error, the two values can be considered identical. As there are no other copper isotope analyses from SE Arabia, the possibilities for their evaluation and interpretation are quite restricted. Their potential, once comparative measurements will be available, for particular questions is described for instance in an article by Klein et al. (2010).

As mentioned above, copper isotopes provide indications for the type of source of the copper. Thus primary sulphide copper ore has values from about -0.4 to 0.3 permil. Values larger than 0.3 permil occur in hydrocarbonate ores (e.g. malachite, azurite). Values below -0.4 occur in supergene sulphides (Klein et al., 2010, Fig. 6). However, these values are only applicable when the ore deposit did not originate from recycling of copper from an older ore deposit. Recycling would lead to another fractionation of the copper isotopes and to selection against the heavier isotope (see Markl et al., 2006). Looking at the δ^{65}Cu values for Wadi Hilo from this point of view indicates a preference for smelting supergenic sulphides. However, primary copper ores cannot be ruled out. It is, however, unlikely that oxidic copper ores, such as malachite and azurite, were smelted at the site.

5.5.2 Analyses of the metal finds

Comparative sites evaluated with regard to their metal artefacts

Metal artefacts from three other sites in the wider area around HLO1 were included in the present study for comparative reasons. Two of these sites are collective graves that were excavated by the Sharjah Directorate of Antiquities, partly under the local supervision of the present author within the context of the Joint Tübingen/Sharjah archaeological project. The sites excavated by the author have the numbers BHS 88 and BHS 89, where BHS stands for "Jebel al-Buhais" and the numbers for the particular sites. In both cases, the sites are collective graves with a typical Bronze Age architecture.

The site **RH 1** is situated in the Sultanate of Oman and was examined during archaeological explorations directed by Hans-Peter Uerpmann in the late 1980ties for one of the maps of the "Tübingen Atlas of the Middle East". A description of the site is found in Uerpmann and Uerpmann (2003). The site is a shallow shell midden situated on the Ra's al-Hamra promontory in the costal area of Muscat, the capital of Oman. There are several other shell middens on this promontory which were explored by an Italian mission directed by Maurizio Tosi. Most of these shell middens were occupied during the late and final parts of the Neolithic period. RH1 is exceptional, however, because it appears to represent a transitional phase between the final Stone Age and the Bronze Age. The site is aceramic like the earlier shell middens at Ra's al-Hamra, but its ashy layers, exposed by animal burrows, yielded small fragments of metal objects, probably fish-hooks. According to their green surface color, they consisted of copper or bronze. Some few pieces were collected for analytical purposes and exported to Germany with permission of the local authorities.

The metal finds from RH1 are of particular interest in the context of early metallurgy because they predate the Early Bronze Age in the usual sense (see Uerpmann and Uerpmann, 2003, p. 73; Fig. 5.2). A radiocarbon date obtained from a shell found together with the fish-hooks yielded a result of 4755±20 bp (Hv 12977). Calibrated against the marine curve, it indicates an age of 2935–2621 BC (1 sigma, Marine curve, $\Delta R = 200 \pm 50$). As indicated by their aceramic context, these metal objects are older than the Umm an-Nar period of the Early Bronze Age. Layers containing finds of this "Aceramic Bronze Age" were also found east of Muscat, at Bandar Jissa, and farther south-east at Wadi Shab (Tosi and Usai, 2003, p. 20). Bandar Jissa has given its name to the "Bandar Jissa Facies" comprising the transition from the Stone Age to the Bronze Age. Radiocarbon dates for this period are in the range of the date from RH1 (Uerpmann, 1992, p. 86). Sites of the Bandar Jissa Facies had not yet been discovered in the UAE, but the green layer at the base of the anvil block in area F of HLO1 falls in this period and might indicate that the copper for the metal hooks and pins found on the Omani shell middens may have been produced locally in the Hajjar Mountains at sites like HLO1.

Figure 5.34: Needle (Sample No. 68) from Grave BHS 88 in the al-Buhais area.

BHS 88 is situated in the plain west of a chain of rocky hills which connect the north-western corner of Jebel al-Buhais in the south with Jebel Aqaba in the north. The grave was built of unhewn local limestone directly on the pediment plain of these mountains. Less than 1 km west of the site, large dune fields begin, which are part of the north-eastern extension of the Rub al-Khali desert.

BHS 88 is a characteristic circular grave of the Bronze Age. Typologically it can be classified as as an early subdivided Umm an-Nar grave (Jasim, 2012, p. 263), indicating its construction in an early phase of this culture. During later prehistoric times, the grave was re-used for another interment. An iron sword was discovered with this later burial.

Below the level of this secondary burial, remains of the Bronze Age interments were excavated and evaluated in 2010 (Kutterer and Kutterer, 2012a). During these excavations, conducted by A. Kutterer and the author, a metal needle (Fig. 5.34) was found which could be used for analysis.

The site **BHS 89** is situated a few hundred meters northeast of BHS 88 in a saddle between high rocky peaks belonging to the chain of mountains mentioned above. Its elevated position allows for a wide view over the dune fields in the west and the Mleiha Madam plain in the east. Typologically it can be classified as transitional between the Hafit phase and the Umm an-Nar phase. A marine shell was found in the entrance to this grave, which was artificially blocked. A radiocarbon date of 4555±20 bp was measured on this shell (MAMS 12987). Calibrated with a reservoir effect of $\Delta R = 230 \pm 20$, this date corresponds to an age between 2668 and 2334 BC. As the shell was found in the sediments blocking the entrance, this might rather be a date for the end of use of this grave.

As mentioned above, pottery and other finds from the grave indicate a date in the transitional phase between the Hafit and Umm an-Nar periods. A prolonged use during this transitional period is also indicated by the stratigraphical positions of particular burials and grave goods (Jasim, 2012). While excavating the skeletons,

Figure 5.35: BHS 89: A child burial with anklet during the excavation.

several metal objects were found which could be sampled for chemical analyses. Among them is a bronze anklet from a child's burial in the upper part of the grave fill (Fig. 5.35 and 5.36). Two further metal artefacts can not be attributed to a particular skeleton. A needle and a small bracelet were found on or just above the native soil (Fig. 5.37).

Metal artefacts from HLO1, BHS 88 and BHS 89, as well as the finds from RH 1 in Oman, collected for analysis by M. and H.-P. Uerpmann in 1983 (Uerpmann and Uerpmann, 2003, p. 73f), were analysed by ED-XRF at the Curt Engelhorn-Zentrum Archäometrie. Results for the samples from HLO1 are presented in Table 5.5. Table 5.6 contains the data for BHS 88, BHS 89 and RH1.

The plano-convex ingot with a weight of more than 4 kg is certainly the most conspicuous metal artefact from Wadi Hilo. It was sampled in the upper, middle and lower parts of the section through the middle of the ingot. A fourth sample was obtained from the outer oxidized layer. The three samples from the inner part of the ingot do not differ significantly. The ingot consists of almost 100% pure copper. The value for iron (Fe) of the uncorroded part is in the range described for the Umm an-Nar period (Weeks, 2003, Table 4.7). Compared to other finds, the value for the Wadi Hilo specimen is very close to the median of ingot finds from the Early Bronze Age of SE Arabia (Weeks, 2003, Table 4.8). The higher value of 3.5 from the corroded part of the ingot is most probably caused by corrosion, leading to an uptake of iron from the surrounding soil (Weeks, 2003, p. 78).

The values for arsenic (As) and tin (Sn), which are interesting with regard to alloying, are below the detection limit. This is also true for lead (Pb). Low values

Figure 5.36: Detail of the anklet (sample no. 67), BHS 89.

Figure 5.37: Needle (sample no. 74) and small bracelet (sample no. 73) made of copper from BHS 89.

for lead are also recorded in the literature for the Emirates and Oman (Weeks, 2003, Table 4.22). Cobalt (Co) is far below the detection limit (<0.01), as are zinc (Zn, <0.2), selenium (Se, <0.005), antimony (Sb, <0.005), tellur (Te, <0.005) and bismuth (Bi, <0.01). The values for the trace elements are not significantly different within the corroded outer layer.

A different situation is indicated by sample 95, which is a needle. Apparently this needle was brought to Wadi Hilo as a finished product. Its composition is completely different from that of the ingot. With a content of 93% copper, 2% arsenic and 2% tin, it can be called a *bronze* needle. The values for lead (Pb=0.47%) and antimony (Sb=0.3%) are also significantly different from metal objects originating from northern Oman and the Emirates. These usually have lead contents measured in ppm (Weeks, 2003, p. 92). The value for Sb is also an order of magnitude higher than usually found in materials from SE Arabia (Prange, 2001, Table 5). This is a strong indication that the metal of the needle was imported from outside the region (see Sec. 5.5.3).

Sample no. 93 is a metal droplet found in a piece of slag from HLO1. Its nickel content is also higher than that of the ingot, but still in the known range of nickel in metal artefacts from Arabia (cf. Weeks, 2003, Table 4.12).

Sample 97 is from a fairly solid piece of metal. It might be an elongated ingot and is only slightly different in its chemical composition from the large ingot. Thus its composition is quite inconspicuous.

Two other samples (94 and 99) are matte (see Sec. 5.5.4). In a polished section they are white to silvery. In Table 5.5 their values are extrapolated to show their metallic composition.

The finds from BHS 88 and 89 fall in two groups when considering their chemical composition: the anklet (no. 67) is made of tin bronze with 87% Cu and 11.6% Sn. Ni and As are higher than in the samples from HLO1. The three other samples from graves BHS 88 and 89 have a copper content of 96%–98%. Two needles (68 and 74) indicate a higher content of Ni. Arsenic is also higher in all samples from Jebel Buhais, with values around 1%. The other trace elements do not differ much from the values for HLO1.

One of the fish-hooks (142) from RH 1 consists of 99% copper. Compared to HLO1, only the values for Ni and As are slightly higher. Otherwise its chemical composition is identical to the samples from HLO1 which are connected to metal production. This is of particular importance insofar as the finds from the RH1 shell midden are among the oldest metal artefacts in SE Arabia, coming from an aceramic context of the Final Neolithic.

Table 5.5: XRF-analyses of metal objects from HLO1.

ID	Object	Cu	Fe	Co	Ni	Zn	As	Se	Ag	Sn	Sb	Te	Pb	Bi
93	droplet	84	15.4	0.26	0.60	< 0.2	< 0.01	0.01	< 0.002	< 0.005	< 0.005	< 0.005	< 0.01	< 0.01
95	needle	93	0.78	0.02	1.00	< 0.2	2.45	0.01	0.02	1.69	0.3	< 0.005	0.47	< 0.01
97	metal frag.	100	0.29	0.02	0.01	< 0.2	0.01	0.01	< 0.002	< 0.005	< 0.005	< 0.005	< 0.01	< 0.01
94	metal frag. *	99	0.50	< 0.01	0.05	0.2	< 0.01	0.28	0.00	< 0.005	< 0.005	0.04	< 0.01	< 0.01
99	metal frag. *	99	0.20	< 0.01	0.02	< 0.2	0.01	0.34	0.01	< 0.005	< 0.005	0.07	< 0.01	< 0.01
96	ingot middle	100	0.22	< 0.01	0.09	< 0.2	0.05	0.01	0.02	< 0.005	< 0.005	0.02	< 0.01	< 0.01
97	ingot top	100	0.17	< 0.01	0.10	< 0.2	0.04	0.03	0.01	< 0.005	< 0.005	< 0.005	< 0.01	< 0.01
98	ingot bottom	100	0.21	< 0.01	0.08	< 0.2	0.05	0.02	0.01	< 0.005	< 0.005	< 0.005	< 0.01	< 0.01
99	ingot corr.	96	3.50	0.013	0.16	< 0.2	0.18	0.01	0.02	< 0.005	< 0.005	0.008	0.06	< 0.01

* Coppersulfid; extrapolated to metal compostion

Table 5.6: XRF-analyses of metal objects from BHS88, BHS89 and RH1.

ID	Site	Object	Cu	Fe	Co	Ni	Zn	As	Se	Ag	Sn	Sb	Te	Pb	Bi
67	BHS89	anclet	87	0.19	0.02	0.35	< 0.2	0.39	0.02	0.009	11.6	0.008	< 0.005	< 0.01	< 0.01
68	BHS88	needle	98	< 0.05	< 0.01	1.20	< 0.2	0.96	0.04	0.009	< 0.005	0.038	< 0.005	< 0.01	< 0.01
73	BHS89	brace	98	0.69	< 0.01	0.13	0.3	0.61	0.05	0.015	0.085	0.013	0.009	0.15	< 0.01
74	BHS89	needle	96	0.06	< 0.01	1.71	< 0.2	1.94	0.02	0.059	< 0.005	0.043	0.006	0.07	< 0.01
142	RH1	hook	99	0.18	< 0.01	0.23	< 0.2	0.30	< 0.005	0.008	< 0.005	0.007	< 0.005	0.01	< 0.01

Discussion of the results regarding the metal composition

The chemical composition of the large plano-convex ingot from HLO1 is inconspicuous with regard to what is known about other copper ingots from SE Arabia. It fits into the existing image derived from other ingots found in this part of the world. The same is true for a metal droplet out of a slag from HLO1, which in its trace elements fits other metal finds from the Omani Mountains. Its high iron content is due to the melting process's leading to the formation of the slag which englobed the droplet. As iron is soluble in liquid copper, the enrichment of iron is due the gravitational subsidence of copper during the smelting process (Craddock, 1995, Fig. 4.6).

An important question regarding the chemical composition is that of the bronzes. Tin bronze is already known from Early Bronze Age contexts of SE Arabia (Weeks, 2003, Table 4.24). Bronzes are usually differentiated into *arsenic bronze*, *tin bronze* and *tin-arsenic bronze*. According to present knowledge there is no natural occurrence of tin ore in SE Arabia (Prange, 2001, Table 5). Therefore is has to be assumed that the tin, or copper alloyed with tin, must have come from outside this area. A bronze object with a tin content of more than 0.5% must either have been imported or produced by recycling imported metal (Weeks, 2003, p. 121).

Arsenic, nickel and cobalt should be considered together when dealing with early metallurgy in SE Arabia. Arsenic was one of the first components used for alloying. As copper and arsenic are often associated in the same rocks, it can be difficult to decide whether an alloy was produced by accident or consciously (see Lechtman, 1996). Part of the ophiolite complex is rich in arsenic, nickel, and cobalt, together with the occurrences of copper. A comprehensive discussion of these elements is found in Weeks (2003, p. 109–120). Among the metal artefacts from HLO1, only the needle (Sample 95) has a high content of arsenic. In order to explain this observation, it makes sense to consider the ratios of As/Ni and Co/Ni. These should range from 0.1 to 1.0 for copper from Oman (Begemann et al., 2010). The samples from RH1, BHS88 and BHS89 are in this range of the As/Ni/Co ratios.

In Oman and the UAE, tin bronzes already occur in the Umm an-Nar phase of the Early Bronze Age starting just after 3000 BC. As tin sources do not occur in this area, the question arises of where the tin came from. And as the second question, how did it enter the area? One possibility is that pure tin was imported in order to be alloyed with local copper. The other explanation could be that the bronze itself was imported. For the needle from HLO1, there are indications from the trace elements lead (Pb) and antimony (Sb) that the copper itself had come from outside the area, indicating that the whole object was imported. The Iranian highlands, e.g., the copper-tin mines at Deh Hosein, are the closest known source of tin, which might have been the source of tin for SE Arabia in the Early Bronze Age. The lead isotope ratios of that mining site match some of the bronze artefacts found at Tell Abraq (Nezafati et al., 2011). A more extensive discussion of tin bronzes in SE Arabia is found in Weeks (2003).

5.5.3 Lead isotope analyses (LIA)

The analysis of lead isotope ratios (LIA) was introduced into archaeometallurgical research during the 1970s. The techniques used until then for determination of the origin of metal finds were mainly based on quantitative chemical analyses. However, the chemical composition of metal changes during smelting. Therefore, chemical analyses were of little value for the determination of the origin of a particular sample. For that reason, it is no wonder that LIA raised high expectations in the beginning (Gale and Stos-Gale, 1982) and was used by archaeo-metallurgists in Europe (e.g. Pernicka et al., 1984) and elsewhere.

The potentials and limitations of LIA were the subject of controversies during the 1980s and 1990s (e.g. Budd et al., 1996; Tite, 1996; Scaife et al., 1999; Pernicka, 1992). This led to severe insecurities among archaeologists, who were on the one hand not acquainted with the procedures of scientific analyses, but on the other hand wanted reliable results from the new technique. This is clearly expressed in, for instance, a 1994 editorial by Chippindale in *Antiquity* (Chippindale, 1994).

The introduction of new analytical procedures, such as inductively coupled plasma mass spectrometry (ICP-MS), over the last years allowed for more precise and almost non-destructive analyses (Cattin et al., 2009; Stos-Gale and Gale, 2009; Baron et al., 2013). In addition, the methods used for the evaluation and interpretation of the data have advanced considerably during the last 20 years. The amount of available data has increased tremendously, and with that has come new approaches to their interpretation. To some extent such data can nowadays easily be obtained through the Internet (Stos-Gale and Gale, 2009).

Basics of Lead Isotope Analysis

LIA was first used by geologists in order to determine the age of the Earth. Another application used early on was for estimating the age of metalliferous deposits. For this purpose, four stable lead isotopes are used. These are ^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb (Pollard, 1996, p. 302). Actually ^{204}Pb is not really a stable isotope. However, as it has an extremely long radioactive half-life of 1.4 x 10^{17} years, it is treated as a stable isotope (Audi et al., 2003).

Unlike the stable isotopes of other elements, which are quite evenly distributed over the surface of the Earth, the isotopes of lead differ strongly from region to region. This is mainly due to the fact that three of the four isotopes are the end products of a radioactive series. Thus, ^{206}Pb is produced through several intermediate stages out of ^{238}U (uranium). ^{235}U decays into ^{207}Pb. The last radioactive series, leading to ^{208}Pb, starts from ^{232}thorium (Pollard 1996, Fig. 9.1, Faure 1986, Fig. 18.1–18.3).

As mentioned before, the radioactive series from uranium and thorium to lead were first used by geologists to determine the age of the Earth, and of meteorites and rocks (see Allègre, 2008, pp. 193–200). This was based on the following values of radioactive half-life after Pollard (1996, p. 312). Summaries of geological methods for dating with the help of uranium, thorium and lead are found in Faure (1986) and Allègre (2008). The following equations indicate the half-life of each radioactive series (Pollard, 1996, p. 312):

$$
\begin{aligned}
{}^{238}\mathrm{U} &\longrightarrow {}^{206}\mathrm{Pb}: & \mathrm{T}_{\frac{1}{2}} &= 4.468 \times 10^9 yr \\
{}^{235}\mathrm{U} &\longrightarrow {}^{207}\mathrm{Pb}: & \mathrm{T}_{\frac{1}{2}} &= 0.7038 \times 10^9 yr \\
{}^{232}\mathrm{Th} &\longrightarrow {}^{208}\mathrm{Pb}: & \mathrm{T}_{\frac{1}{2}} &= 14.01 \times 10^9 yr
\end{aligned}
$$

Because of the complex processes during the cooling of the Earth and the formation of the core, mantle and crust, the distribution of lead isotopes differs largely from unit to unit (Pollard, 1996). This also includes the formation of ore deposits, where the disparities in isotope proportions become differentiated even further. As copper ore always contains a small proportion of lead, which is transferred to the finished products of copper metallurgy, the geographical and geological differences in lead isotope abundances have the potential to be used by archaeologists in order to determine the origin of copper ore (Weeks, 2003, p. 130). Following this chain of thought, various deposits of copper ore must have different ratios of lead isotopes, which could be called their isotopic "fingerprints". This fingerprint should also be reflected by the metal objects produced from the ore. As copper often contains traces of lead ($< 1\%$), the "fingerprint" can also be traced in finished copper artefacts. Usually this assumption works when the traces of lead derive from inclusions within the copper ore. However, with ongoing research it became obvious that lead isotope values often overlap. Statements regarding the origin of a particular metal object may therefore be ambiguous. Pernicka concisely summarized this problem more than 20 years ago:

> "We are in the very ungratifying situation that more measurements lead to more ambiguity! On the other hand, negative statements are always possible with certainty. Thus, if the isotope abundance ratios of lead in an artefact do not agree with those of a given ore, the artefact cannot possibly have been derived from this particular ore." (Pernicka et al., 1990, p. 278)

Normally, lead isotope data are measured and cited as ratios of two isotopes. Today, isotope ratios are generally reported as separate ratios of four isotopes: ${}^{207}\mathrm{Pb}/{}^{206}\mathrm{Pb}$, ${}^{208}\mathrm{Pb}/{}^{206}\mathrm{Pb}$ and ${}^{206}\mathrm{Pb}/{}^{204}\mathrm{Pb}$. For graphical representation, two plots are used, where the x-axis always is ${}^{207}\mathrm{Pb}/{}^{206}\mathrm{Pb}$. The two y-axes are ${}^{208}\mathrm{Pb}/{}^{206}\mathrm{Pb}$ and ${}^{206}\mathrm{Pb}/{}^{204}\mathrm{Pb}$ (Stos-Gale and Gale, 2009, pp. 202–203). As mentioned above, the methods of LIA were continually developed further during the last 30 years. It soon became clear that for its use in archaeology, two primary assumptions must apply:

1. Isotope ratios must not have been changed during the smelting and associated processes.

2. Recycling or mixing of metal from different sources must be excluded.

Detailed research was undertaken with regard to the first point (see Stos-Gale and Gale, 2009). According to these analyses, there are no indications for fractionation during anthropogenic metallurgic processes (Stos-Gale and Gale, 2009). Treating the second point is more difficult, and is mainly based on the assumption that large scale recycling did not occur during the Early Bronze Age. In SE Arabia, this may have started during the Wadi Souq Period or the Iron Age. Mixing of ore or raw copper from different deposits may, however, be assumed with some probability. For a detailed description of LIA in archaeology and a discussion of its methodology, cf. Weeks (2003, pp. 131–133).

LIA data from HLO1 and comparative sites

Lead isotope values of metal objects from HLO1 were measured at the Curt Engelhorn Center in Mannheim with the help of a multi-collector ICP-MS (MC-ICP-MS). More information on ICP-MS is found in Pollard et al. (2007).

For comparison, the following geological data were used: Chen and Pallister (1981), Calvez and Lescuyer (1991), Stos-Gale et al. (1997), Gale et al. (1981). Archaeological data for comparison with the HLO1 results were taken from Weeks (2003), Prange (2001) and Begemann et al. (2010). Further archaeological data for comparisons derive from excavations of the Directorate of Antiquities of the Sharjah Emirate, which were carried out by a team from Tübingen University directed by the author. The sites BHS 88, BHS 89 and RH 1 were described above (see Chapter 5.5.2). Three metal artefacts from BHS 89 derive from the Early Bronze Age (transitional period from the Hafit Phase to the Umm an-Nar Phase) (Kutterer and Kutterer, 2012b; Jasim, 2012). A needle from grave BHS 88 (see above) is from the early Umm an-Nar phase (Kutterer and Kutterer, 2012a; Jasim, 2012) (see Section 5.5.2). The following tables, Tables 5.7 and 5.8, contain the LIA data from HLO1, RH 1, BHS 88 and BHS 89. They are presented and compared with further data from the literature in Fig. 5.38.

Table 5.7: Lead isotope data for objects from HLO1.

No.	Object	Major Elements	$^{207}Pb/^{206}Pb$	2σ abs. error	$^{208}Pb/^{206}Pb$	2σ abs. error	$^{206}Pb/^{204}Pb$	2σ abs. error
96	ingot	Cu	0.84813	0.00006	2.08930	0.0004	18.420	0.006
97	metal frag.	Cu	0.84250	0.00002	2.08160	0.0001	18.566	0.002
99	metal frag.	Cu	0.84336	0.00030	2.08460	0.0003	18.553	0.006
95	needle	Cu-As-Sn	0.83629	0.00003	2.07140	0.0001	18.742	0.001
100	ore	–	0.84448	0.00004	2.08450	0.0001	18.509	0.005
105	ore	–	0.85073	0.00011	2.09130	0.0001	18.285	0.001
102	slag	–	0.84419	0.00004	2.08040	0.0001	18.526	0.002
103	slag	–	0.84575	0.00003	2.08480	0.0002	18.474	0.003
104	slag	–	0.84588	0.00003	2.08430	0.0001	18.460	0.001
93	droplet	Cu-Fe	0.85030	0.00008	2.10470	0.0003	18.428	0.001

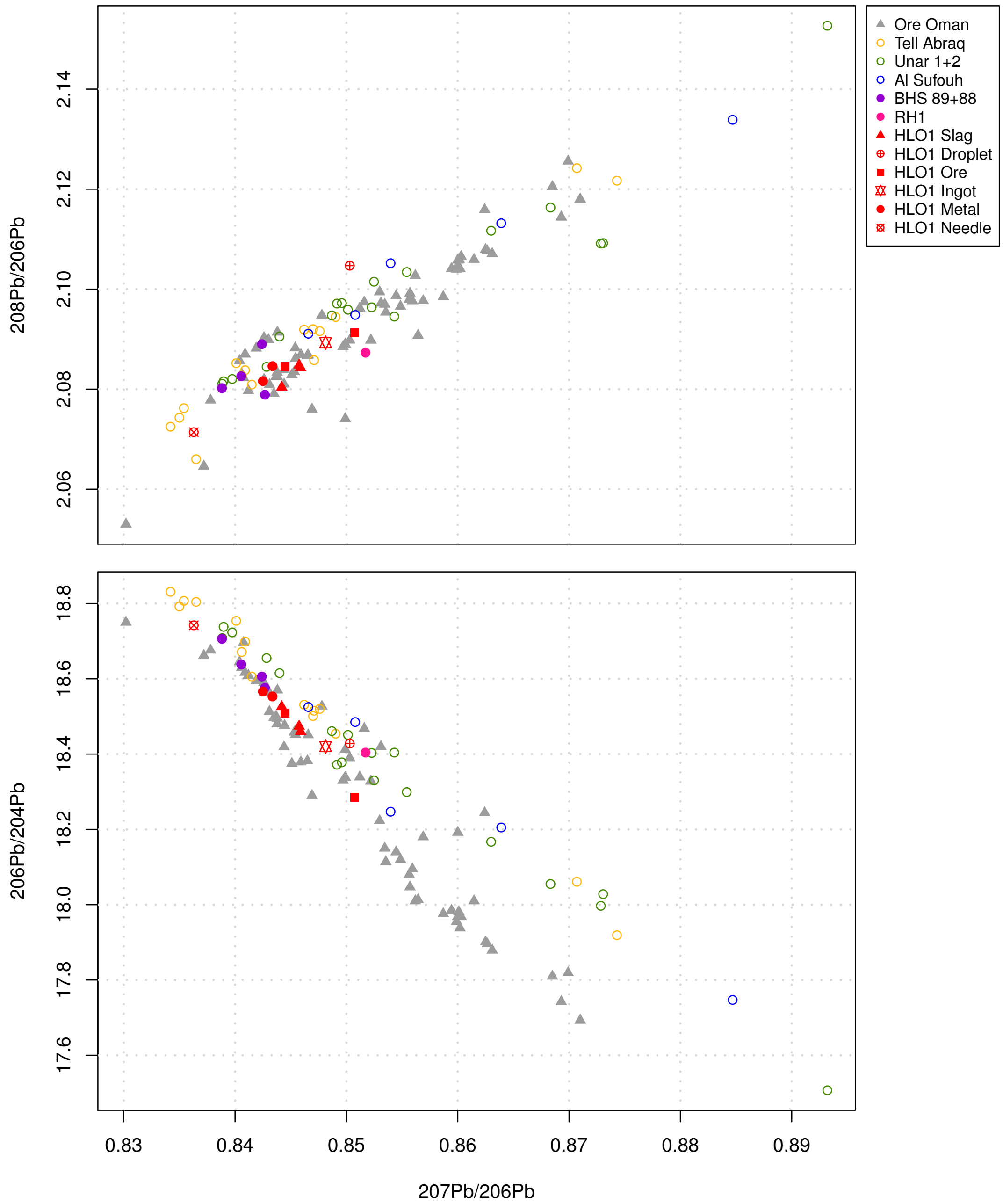

Figure 5.38: Plot of the LIA data from HLO1, BHS 88/89 and RH 1 in comparison to data taken from the literature (Begemann et al., 2010; Calvez and Lescuyer, 1991; Chen and Pallister, 1981; Gale et al., 1981; Prange, 2001; Stos-Gale et al., 1997; Weeks, 2003).

Table 5.8: Lead isotope data for objects from sites BHS 88, BHS 89 and RH 1 (for figures of the samples see Fig. 5.35-5.37).

No.	Site	Object	Major Elements	$^{207}Pb/^{206}Pb$	2σ abs. error	$^{208}Pb/^{206}Pb$	2σ abs. error	$^{206}Pb/^{204}Pb$	2σ abs. error
68	BHS88	needle	Cu-As	0.84241	0.00002	2.0890	0.0001	18.606	0.005
67	BHS89	anclet	Cu-Sn	0.84268	0.00002	2.0789	0.0001	18.576	0.002
73	BHS89	bracelet	Cu	0.84056	0.00003	2.0826	0.0001	18.638	0.006
74	BHS89	needle	Cu	0.83882	0.00003	2.0802	0.0001	18.706	0.002
142	RH1	hook	Cu	0.85172	0.00003	2.0873	0.0002	18.404	0.003

Fig. 5.38 indicates that the samples from HLO1 (red dots), which derive from finds connected to copper production at Wadi Hilo (copper ore, slag, small metal fragments and the large ingot), are concentrated in one part of the diagram. The ratios of $^{207}Pb/^{206}Pb$ are concentrated between about 0.84 to 0.85, while the ratios of $^{208}Pb/^{206}Pb$ is from 2.08 to just above 2.10. The third ratios ($^{206}Pb/^{204}Pb$) has a distribution from ca. 18.3 to 18.6. Thus, these values are all in the range of other known copper ore occurrences (gray triangles) within the Omani Mountains.

In Fig. (5.38), the large copper ingot is situated in the centre of the signatures for copper ore, a copper droplet from a piece of slag, and of the slag samples. This suggests that the ingot represents the average of the LIA signals of HLO1. The other metal samples from Wadi Hilo, which are marked by the red circle, are also concentrated in this part of the diagram. Most of these samples consist of small pieces of copper sheet. Sample 99 is matte (copper sulfide). Its position in the diagram indicates that this find also is a direct remnant of local copper production.

Only the Pb ratios of one sample from HLO1 are clearly separated from the other finds of HLO1. This sample is from the needle mentioned before (circle with an X, no. 95). The ratio $^{207}Pb/^{206}Pb$ has a value of 0.83, which is clearly lower than in the other samples from the site. The ratios of $^{208}Pb/^{206}Pb$, with a value of 2.07, and $^{206}Pb/^{204}Pb$ (18.74) are lower or higher than those of the other samples.

The graph also contains samples from the two Bronze Age graves at Jebel al-Buhais described above. These four samples (violet circles) are not within the distribution of the HLO1 samples, but are clearly within the distribution of the whole of the copper ore region in the Omani Mountains. It is remarkable that the four samples are fairly close to each other.

The sample from RH 1 is also within the range of the Pb isotope relations from SE Arabia. This is most interesting, because the find—a fish-hook from an aceramic shell midden in Oman—is among the earliest metal finds from SE Arabia. According to the LIA results, it seems to have been produced out of ore deriving from the Hajjar Mountains. This indirectly confirms the assumption that the early radiocarbon date from the base of the anvil block in area F of HLO1 may actually be related to the earliest known metallurgy in SE Arabia.

Interpretation of the results from HLO1

Considering the isotope data of the by-products of smelting, such as ore, slag, and a copper droplet from a piece of slag (samples No. 93, 99, 100 and 102–105), which represent materials directly connected to copper smelting at HLO1, it is obvious that they are very close to the values of the ingot (no. 96). Actually, the values for the ingot are separated by values of only a single digit per mill from the calculated mean of the other HLO1 samples mentioned above. This must be considered a strong indication for an origin of the ingot from the local ore of Wadi Hilo.

However, the values of the needle (no. 95) clearly indicate that this find was brought to the site as a finished product from somewhere else. The lead isotope ratios even suggest that it may have been imported from outside the region. This is also indicated by the results of chemical analysis, which shows relatively high proportions of antimony (Sb) and lead (Pb). These are untypical for copper deriving from the ophiolithic ore deposits in the Omani Mountains (see Table 5.5) (cf. Prange, 2001, Table 5).

Isotopic comparisons with other Bronze Age objects from the UAE

For comparison, data from other sites of the region were included in the graph (Fig. 5.38). They stem from Unar 1 and 2, al-Sufouh, and Tell Abraq. The data was taken from a publication by Weeks (2003). The runaway values (TA1614, TA699, TA107 and M10-17) were not included, because they correspond to values which are usually dealt with as “radiogenic”: indicating that ore with a high content of uranium and/or thorium was smelted. This is not the case for ores from the Omani Mountains (Weeks, 2003, p. 145).

Considering the isotopic values of the ingot from HLO1, and thus the mean for metal production at that site, it is conspicuous that this value is consistent with “cluster 3” (Weeks, 2003, Fig. 7.2) This cluster includes five objects from Tell Abraq. They come from grave- and settlement contexts and contain various alloys including copper, Ni-copper, copper-low-tin, tin bronze, and a tin ring (Weeks, 2003, p. 149). This means that copper from HLO1 may have been transported to Tell Abraq to be further treated and alloyed in order to produce the above mentioned objects.

It is interesting to see that the needle, which is foreign to the other copper objects from HLO1, falls in cluster 1 of Tell Abraq (Weeks, 2003, Fig. 7.2). This cluster consists of objects made of tin bronze. The only difference is that the HLO1 needle has a lower percentage of tin (1.69%).

The LIA data indicate that the metal production of Wadi Hilo must be seen within a larger network of exchange between the Bronze Age sites in the wider area. On one hand, HLO1 seems to have produced copper for other Bronze Age sites in the area, such as Tell Abraq, Kalba, Unar 1/2, and others, but on the other hand finished products (exemplified by the needle) were brought to Wadi Hilo. Apparently the alloying with tin did not happen at the smelting site itself

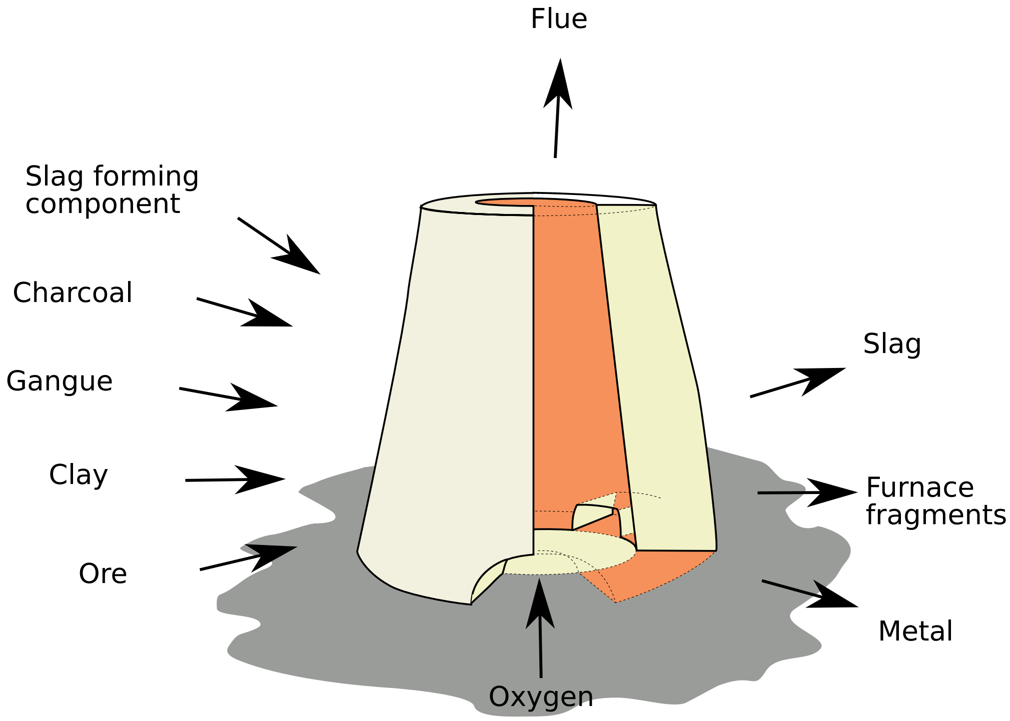

Figure 5.39: Schematic depiction of the furnace which must be considered the "reaction vessel" for transformation of the raw materials (left) and the products of the smelting process (right) (modified after Asmus, 2012, Fig. 4.1).

but probably in the larger centres on the coast, where the tin was available after being imported from outside the Oman Peninsula. Thus, the needle is an indication that HLO1 was part of a much larger exchange network which not only included SE Arabia but most probably the northern shores of the Gulf as well.

5.5.4 Copper production at HLO1

Residues of copper production left at a smelting site are the most important source of information about Bronze Age procedures and techniques of copper smelting at HLO1. The most conspicuous of these residues is the large amount of slag. Other categories of finds providing evidence for smelting technology are the wall fragments of furnaces, drops and fragments of metal, as well as copper stone. Remnants of ore, left behind in the smelting area, also need to be considered.

Raw materials and products which are important constituents of copper production are depicted in Fig. 5.39. The furnace is the reaction vessel for the components on the left side of the figure, which are transformed in the furnace into the wanted metal. Slag and furnace wall fragments are waste products of this process (see Asmus, 2012, p. 53). The following chapter will deal with these categories of finds.

Copper slag

Slag is the most frequent remnant of metal production. As it is usually quite noticeable at the surface of archaeological smelting places, it serves as a major indicator for this kind of sites. Slag tends to be well preserved, to occur in large quantities, and to be readily available for further inspection without excavation. Therefore it has become a major source of information about historic and prehistoric smelting procedures. The density of slag is usually lower than 3.5 g/cm^3 (Goldenberg, 1996).

Slag derives from smelting processes and usually consists of various silicates. Dissolved within these silicates there are diverse oxides, e.g. Al_2O_3, FeO, MnO and CaO. Apart from these melted residues there are unmelted compounds, like ore remnants, furnace wall fragments, and charcoal, which may be found in the slag.

Slag is an inherent result of the process of copper smelting, which, on the other hand, is influenced to a large extent by the slag production. Therefore the slag has to comply with certain requirements of the whole smelting process. The most crucial property of slag is that it should not retain much of the metal, which is the wanted product of the whole process. In order to achieve this aim, the slag should be highly fluent at the temperature which needs to be reached in order to separate the metal from the unwanted constituents of the ore. The slag must be fluent to the extent that the molten metal can gravitationally sink down to the bottom of the furnace. This process must be optimized to the extent that a maximum of metal can be extracted from the ore with a minimum of fuel in order to achieve operating efficiency (Hauptmann, 1985, pp. 37–38).

Macroscopic assessment of the slag

The macroscopic assessment of the slag from Wadi Hilo follows Hauptmann (1985). As mentioned, the large amount of slag on the surface was the first indication for early metal production at the site HLO1. The slag was found in varying density all over the surface of the old wadi terrace. Apart from the large amount of slag at the site itself, another surface concentration, which was cut by the road, occurred on the other side of the wadi. Sondages 48 and 51 were made in order to explore these slag accumulations. The differences between the slag from the west side of the wadi and that of the main site will be dealt with after a detailed description of the latter.

Fragments of *large flow slag* (*große Fließschlacken*), of type A according to Hauptmann (1985, p. 38), form the majority of slag found at HLO1. The colour of this slag ranges from dark brown and dark grey to black. In contrast, the surfaces of old breaks are usually light brown. The thickness of large pieces of flow slag mostly ranges from 6 to 8 cm (Fig. 5.40). The lower side of the depicted piece of slag shown in Fig. 5.40 is rough, indicating that it flew from the furnace onto a sandy surface. In contrast, the upper side displays cushion-like flow structures. It seems that the "slag cakes" had diameters between 20 and 35 cm. Today they are preserved as mostly fist-size fragments. The estimated weight of the largest "slag cakes" was up to 15 kg. Breaks and cross-sections indicate air bubbles in their upper parts, ranging from c. 3 mm to 2 cm in diameter. In the lower 0.5 cm there are only very small air bubbles (<0.5 mm), which may have originated secondarily by weathering. Hand samples look homogeneous and microcrystalline. This type of large slag is mostly found on the wadi terrace at the main site.

The other type of flow slag is flat (*plattige Fließschlacken* = Type B Hauptmann (1985, p. 38)), and, with a thickness of 3–4 cm, thinner than type A. The surface has bulging flow structures and burst blisters (Fig 5.41). The lower side is sand-rough as well. This slag is full of gas bubbles with diameters from 0.5 to several centimetres. The estimated outer diameter of this slag is 20 cm at a maximum, which is much less than in the other type of flow slag. The colour ranges from dark brown to black. In comparison, this type of slag is predominant on the western side of the wadi, but does occur in low quantities on the main site HLO1 as well.

The third type of slag, Type C according to Hauptmann (1985, p. 38), is *thin flow slag* (Fig. 5.42). This type of slag is less than 3 cm in thickness. The lower side is rough as in the other types of slag. The upper side has flow structures comparable to the "skin" on hot milk. The colour is mostly dark brown to black. This type does not form large slag cakes like those originating from tapping the furnace. Probably they were formed as "runnels" from a furnace.

The last type of slag is drop- or cord-like slag (type D) (Hauptmann, 1985, p. 38). The surface is usually cord-like, comparable to Pahoehoe Lava (Fig. 5.43). There are sporadic air blisters and some sand-rough surfaces. Apparently the cordlike slag originated at the rims of larger pieces of flow slag from which it broke off later (see Fig. 5.44).

The two last types of slag described above occur at both slag concentrations in Wadi Hilo. Nevertheless, in detail there are macroscopic differences between the slag from the two concentrations. First, there are differences in colour: the slag from the main site mostly varies from dark grey to black, while those from the western concentration are mostly black both on the upper and lower side. Secondly, their broken surfaces are brownish and weathered. Apart from that the individual pieces are smaller on average than those from the main site.

Chemical composition of the slag

Overall chemical analyses with regard to main and trace elements in the slag was done by wavelength dispersive X-ray fluorescence (WDXRF) (Hahn-Weinheimer et al., 1984). Samples were ground to powder in an agate mill. Six grams of the sample were mixed with 1.2 g Lenco-Wax and then pressed with a pressure of 300 kN/m^2 in order to form a powder pill. These samples were then analysed with a Bruker AXS S4 Pioneer X-ray spectrometer (Rh-tube with 4 kW excitation) at the Department of Geosciences in Tübingen and measured by Multi_res Vac34 without standard and then normalized to 100%. The results presented in Table 5.9 derive

Figure 5.40: Large flow slag (Type A). The upper picture shows a large flow slag with fluxion texture and burst gas bladders. The picture in the middle shows the same slag in cross-section. Large gas bubbles are visible in the upper part. In the lower picture, the bottom side of the slag is depicted with its sandy roughness.

Figure 5.41: Flat flow slag (type B).

from two series of measurements of selected slag. Details about the samples are documented in Table 5.10. The first series of analyses was measured in 2007 and contained samples of large flow slag from the first season of excavations at the main site. Large pieces of flow slag were cleaned of loose sediment with water. They were then broken with a jaw crusher and ground to powder in an agate mill. As some of the samples contained larger droplets of copper, which might have caused problems when pressing the pellets, they were cleaned with the help of a magnetic separator. Therefore the copper values of the first series of measurements (2007) are to be used with caution. For the second series of measurements (2011), the weathered outer surfaces were eliminated with a stone saw. Thus, samples from inside the slag were obtained and analysed. This excluded the possibility that the analyses were influenced by contamination or weathering.

All slag samples have a content of SiO_2 of about 40%. Iron oxide is lower by an order of 10. Al_2O_3 is present in the slag with contents between c. 5.5% and 17.5%. MgO, and with the CaO remaining below 10%. The values for copper, as the wanted product, ought to be as low as possible, and range within the first four samples (where the larger copper droplets were separated before analysis) are around 2%, which is a little less than in the other eight samples, which contain c. 2.5% Cu as a mean value. Based on these results, the slag from Wadi Hilo can be classified as silicate slag with the main constituents iron oxide, manganese oxide, calcium oxide and aluminum oxide. Because of the relatively low contents of FeO they cannot be considered as pure fayalite slag.

Figure 5.42: Thin flow slag (type C).

Figure 5.43: Selection of drip- and cord-like slag.

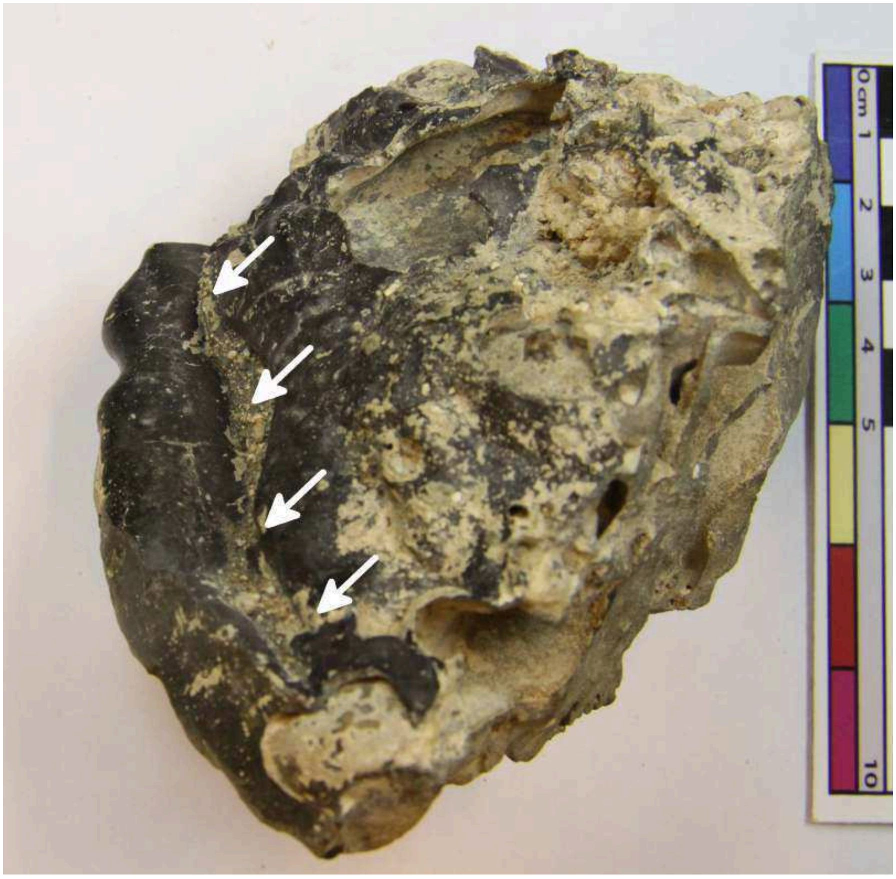

Figure 5.44: Large flow slag with cordiform rim. The assumed break line is marked by arrows.

Table 5.9: X-Ray fluorescence (WD–XRF) analysis of tapp-slag from HLO1, Method: Multi_res Vac34. Normalised totals represent analytical totals in wt-%.

Main and minor elements in wt-%												
No.	Find-No	SiO_2	FeO	Al_2O_3	MgO	CaO	MnO	Na_2O	K_2O	P_2O_5	TiO_2	Cu
Sampleset 1												
128	1019	40.6	27.7	11.1	12.5	5.3	0.20	0.00	0.29	0.06	0.22	1.66
129	1077	35.6	34.0	10.4	6.7	10.4	0.09	0.00	0.19	0.02	0.20	1.99
130	1183	37.0	32.6	11.0	9.9	6.1	0.12	0.00	0.13	0.03	0.18	2.52
132	291	40.1	40.7	5.5	6.6	4.4	0.07	0.00	0.21	0.05	0.14	1.93
Sampleset 2												
82	6124	41.4	24.0	17.5	4.5	9.3	0.08	0.20	0.26	0.04	0.17	2.34
83	7329	40.6	28.2	12.8	6.9	9.2	0.11	0.09	0.28	0.00	0.11	1.47
84	7400	41.7	27.2	12.6	4.2	10.3	0.07	0.15	0.25	0.00	0.11	3.26
85	7140	40.5	24.2	16.0	5.9	11.0	0.12	0.23	0.25	0.00	0.15	1.51
87	16440	44.4	19.7	14.3	11.6	5.2	0.00	1.02	0.30	0.00	0.15	3.14
88	10481	46.9	20.5	13.1	8.1	7.5	0.10	0.11	0.28	0.03	0.29	2.92
89	16440	40.9	22.7	16.3	9.9	7.4	0.00	0.42	0.31	0.04	0.31	1.47
90	16400	45.7	20.8	13.4	7.9	7.6	0.06	0.19	0.24	0.00	0.11	3.87

Trace elements in mg/kg																				
No.	S	Sc	V	Cr	Co	Ni	Zn	As	Sr	Y	Zr	Pb	Ba	La	Sm	Eu	Hf	Ta	U	Cl
Sampleset 1																				
128	110	350	220	1000	340	530	0	0	500	10	0	4	350	0	0	0	60	70	0	168
129	280	410	260	950	190	280	0	60	460	10	0	9	460	10	0	0	70	110	0	209
130	510	510	220	1100	210	460	0	50	400	0	0	9	520	0	0	0	90	130	0	105
132	190	370	210	900	230	440	0	50	470	0	0	8	410	10	0	0	70	70	0	610
Sampleset 2																				
82	110	-	290	630	150	92	0	-	750	-	40	-	-	-	-	-	-	-	-	350
83	0	-	170	730	280	300	4	-	500	-	20	-	-	-	-	-	-	-	-	0
84	70	-	300	610	310	130	0	-	430	-	20	-	-	-	-	-	-	-	-	340
85	240	-	200	1100	250	190	10	-	470	-	20	-	-	-	-	-	-	-	-	0
87	0	-	0	800	480	650	30	-	310	-	10	-	-	-	-	-	-	-	-	0
88	90	-	0	100	190	370	0	-	570	-	20	-	-	-	-	-	-	-	-	0
89	130	-	208	750	500	560	40	-	410	-	20	-	-	-	-	-	-	-	-	0
90	0	-	92	416	210	200	0	-	800	-	40	-	-	-	-	-	-	-	-	0

Table 5.10: General information on the sampled slag.

Sample	Find No.	Type of Slag	Colour (surface)	Level	Context
Sampleset 1					
128	1019	Large flow-slag	dark gray	0	West Side
129	1077	Large flow-slag	dark gray	0	Structure F
130	1183	Large flow-slag	dark gray	2	Structure F
132	291	Large flow-slag	dark gray	2	UaN-Tower
Sampleset 2					
82	6124	Large flow-slag	dark gray	0	Tobacco-shed
83	7329	Large flow-slag	dark gray	0	Furnace
84	7400	Large flow-slag	dark gray	1	Structure F
85	7140	Large flow-slag	dark gray	0	Furnace
87	16440	Large flow-slag	brown/black	0	West Side
88	10481	Large flow-slag	brown	4	Structure F
89	16440	Large flow-slag	dark brown	0	West Side
90	16400	Thin flow-slag	brown	4	Structure C

The chemistry of the slag directly influences its physical properties during the smelting process. The influence of the main constituents on the properties of the molten mass can be summarized as follows:

Quartz (SiO_2) in the slag at Wadi Hilo most likely derives from the gangue associated with the ore. There is no indication of an anthropogenic admixture of quartz to the melted mass as a flux. At high contents of SiO_2 and fast cooling, the slag tends to form amorphous glass without a defined melting point. This is called undercooling. When cooled slowly, a crystalline structure develops (Goldenberg, 1996).

The slag from Wadi Hilo has relatively high contents of quartz (SiO_2). For instance, the slag from Maysar 1 (Oman) only contains 29.5% quartz on average (see Hauptmann, 1985, Table 4) compared to 41.2% on average at Wadi Hilo.

Iron oxide (FeO) is among the major constituents of slag and is already found in slag from early metallurgical sites (Goldenberg 1996, p. 38, Craddock 1995, p. 137). During the smelting process it acts as flux, making the slag more fluid. Often iron oxides occur naturally as gangue in ore minerals and are therefore readily available for smelting operations. In addition, iron-silicate slag has a low melting point of about 1100°C–1200°C. A disadvantage of this slag is its comparatively high capacity to dissolve copper sulfide (Cu_2S). This leads to a loss of pure copper and an enrichment of copper in the slag (Goldenberg, 1996). At Wadi Hilo the content of iron oxide is 27% on average, which is considerably lower than the content of iron oxide (FeO + Fe_2O_3) in the slag from Maysar 1 (Hauptmann, 1985, Table 4).

Calcium oxide (CaO) is, along with FeO, among the major oxides found in slag. Unlike iron oxide, it lowers the solubility of Cu_2S in the slag. However, above a certain content, it raises its melting point and its viscosity. Up to 25 wt-% of CaO is considered useful (Goldenberg, 1996). At Wadi Hilo the content of CaO is 7.8% on average. A similar value was found at Maysar (Hauptmann, 1985, Table4).

Magnesium oxide (MgO) is comparable to CaO in its properties with regard to copper smelting. However, from a certain point upward, it increases the solubility of copper in the slag (Goldenberg, 1996). Similar to the value for CaO, the average MgO content is about 7.8%, which is again very similar to the value determined at Maysar (Hauptmann, 1985, Table 4).

Aluminium oxide (Al_2O_3) should occur in slag at a concentration of less than 10%. Once the percentage is higher, this leads to a very ropy condition of the slag. Aluminium oxide usually derives from clay minerals. If combined with a high percentage of silicium dioxide (SiO_2), both elements usually derive from the furnace lining (Goldenberg, 1996). The charge of the furnace and the lining of its wall thus create a self-mixing melt composition which melts at a comparatively low temperature (Kronz, 2000). The high contents of quartz ($SiO_2 = 41.2\%$) and aluminium oxide ($Al_2O_3 = 12.8\%$) in the slag from Wadi Hilo actually are an indication that the furnace lining was an important constituent of the smelting process. Together with the charge of the furnace, it created an equilibrium between a comparatively low melting temperature and an acceptable viscosity of the melt. In comparison, the content of aluminium oxide at Maysar (Hauptmann, 1985, Table 4) was less than one-half of that observed at Wadi Hilo.

Conclusions with regard to the smelting process

Based on the chemical composition of slag, an assessment of the smelting temperatures is possible. This allows an approximate determination of one of the most important parameters of the whole smelting process. Slag does not have a fixed melting point, but rather an interval of "softening". This interval depends on the chemistry of the individual phases of the slag. The liquid state is reached as soon as the last crystalline compound melts. The corresponding temperature can be determined by deduction from various phase diagrams (see Hauptmann, 1985, p. 62).

For a first assessment of the melting temperature of the slag from Wadi Hilo, the three most frequent components were chosen for a phase diagram. These are FeO, Al_2O_3, and SiO_2. However, for a meaningful result, the three components together should comprise a major part of all components. This is not the case for the choice of components mentioned above, which only sum to 80% of the slag. In order to anyway use this kind of diagram, the proportions of MgO, CaO and MnO were added to the iron oxide. This addition increased the mixed components so that more than 95% of the main components were represented in the phase diagram. Given a certain insecurity caused by the artificial increase of the iron oxide by more than 15%, the result of the triangular plot can only be used as an approximate determination of the melting temperature.

Fig. 5.45 represents two series of measurements of samples from Wadi Hilo. Sample set 1 (red dots) is based on earlier measurements and was published before, in (Kutterer and Jasim, 2009). However, in the already published graph, one dot is misplaced: the rightmost dot should be within the range of the other dots for sample set 1.

The blue dots represent sample set 2. The majority of these dots indicate a range of the melting temperature up to 1200°C. Three outliers, however, are in the range around 1300°C. It is conspicuous that the cleansed samples are farther to the right in this diagram, indicating a slightly higher smelting range. This might, however, be an artefact of the calculation process because it could have to do with the described inclusion of magnesium-, manganese- and calcium oxide with the iron oxide.

As the results of this first phase diagram are not completely satisfactory, a further phase diagram will be discussed in the following: as described above, the problems derive from the fact that the samples from Wadi Hilo cannot simply be reduced to three main components. As calciumoxide is quite frequent in the samples, another phase diagram was sought, which would include calcium and be appropriate for slag. As an alternative, Bachmann (1982) describes a phase diagram for $FeO–SiO_2–CaAl_2Si_2O_8$. In mineralogical terms, $CaAl_2Si_2O_8$ is anorthite.

Fig. 5.46 indicates that 7 of the 12 samples are in the range below 1250°C. Two of the non-purified samples are on the line 1300°C. Three more of the purified samples cluster in the tridymite area. Unlike the diagram of Fig. 5.45, the two sample sets are no longer separated. The samples in the area at or above 1300°C may not be indicated correctly by this system. They are included for completeness but should not be used in further interpretations.

In conclusion, it seems acceptable to assume that the slag from Wadi Hilo was liquid at temperatures between 1150°C and 1250°C. This is coherent with observations for slag from Oman (Hauptmann, 1985, pp. 62–64). With regard to the parameters described above, the differences between the types of slag from the two separate sites at Wadi Hilo (HLO1 and "west side") or from different contexts at the main site are not significant. On the whole the ranges of the different types of slag are identical (see Table 5.10).

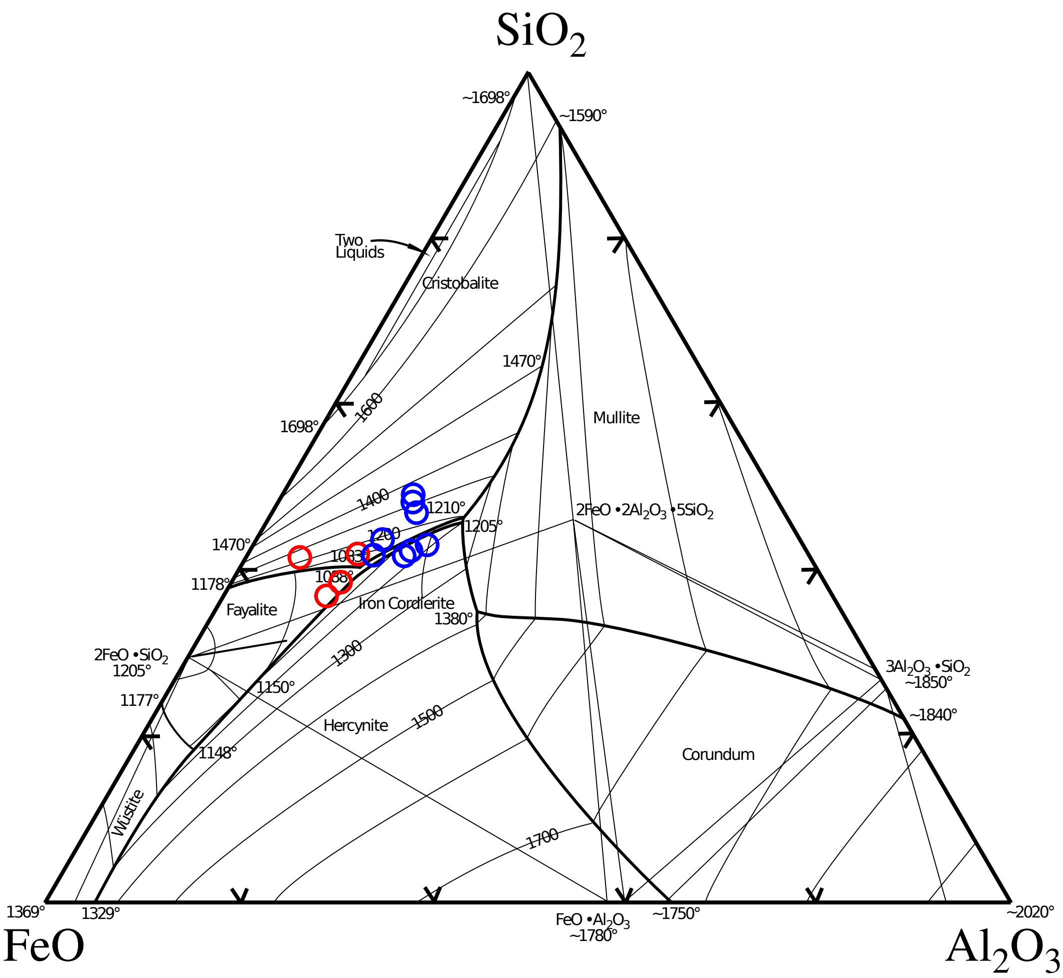

Figure 5.45: *Phase diagram showing the slag from HLO-1 in the ternary diagram of FeO–Al_2O_3–SiO_2 The red circles represent the uncleaned slag (sample set 1); the blue dots stand for the cleaned slag of sample set 2. The amounts of MnO, MgO, and CaO are added to the amount of FeO (modified after Osborn and Muan, 1960).*

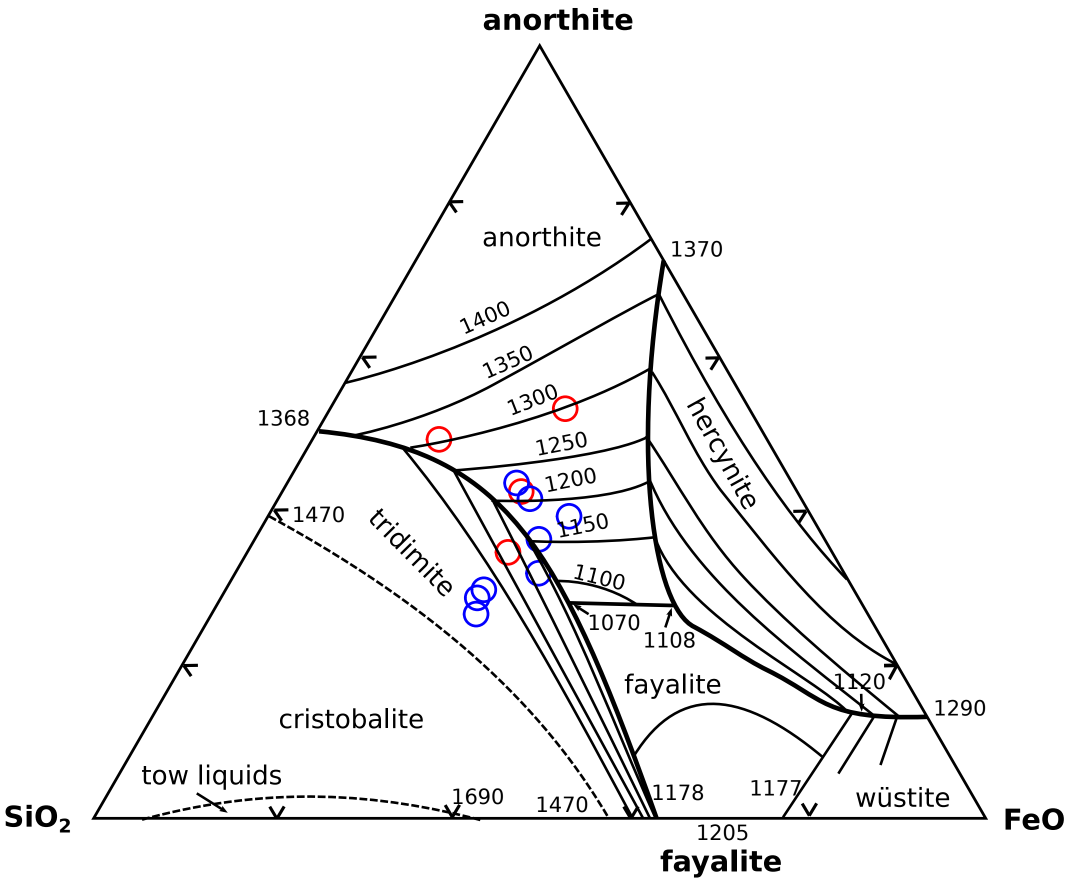

Figure 5.46: Phase diagram showing the slag from HLO-1 in the ternary diagram SiO_2–FeO–Anorthite. The red circles are uncleaned slag (sample set 1) and the blue ones are the cleaned slag from sample set 2. The amounts of MgO have been added to the amount of FeO (modified after Bachmann, 1982; Costagliola et al., 2008).

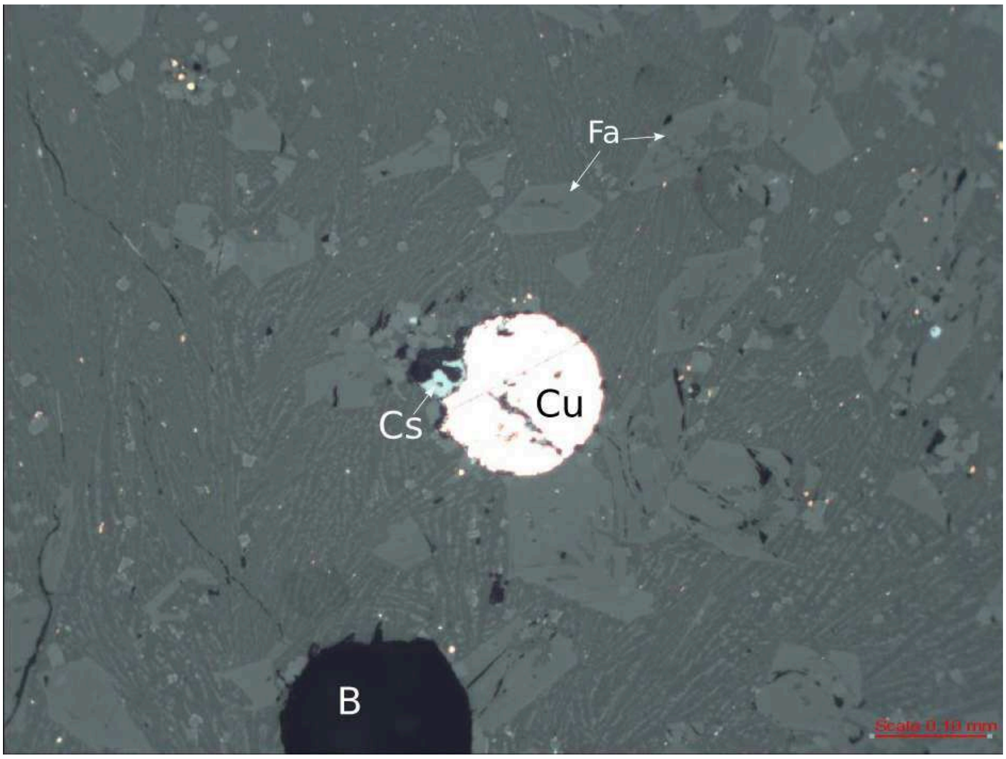

Figure 5.47: Microscopic image of a large flow slag (sample 77): Fayalite crystals (Fa) are included in a glassy matrix with some air blisters. In the centre, a copper droplet (Cu) can be recognised which is connected to a small droplet of copper matte (Cs).

Microscopic examination of the slag

In order to obtain further information on the slag from Wadi Hilo it was examined with the help of an optical microscope (OM) and a scanning electron microscope (SEM). Polished blocks were prepared by embedding samples of slag in resin which were then cut, ground, and polished. In a first step these samples were examined by OM in order to determine the individual phases. Some of the samples were then examined by SEM-EDS at the University College, London.

Large flow slag (Fig. 5.47 and 5.48) usually indicates well discernible crystaline fayalites embedded in a vitreous matrix. This indicates fast cooling outside the smelting furnace. Apart from that, air blisters as well as small droplets of copper and copper-sulfide were observed.

The slag of type C indicates a composition similar to that of the large flow slag (types A and B). Thus, sample 79 shows fayalite crystals under an optical microscope (Fig. 5.49). It is conspicuous, however, that the crystals are noticeably longer, potentially indicating slower cooling. A macroscopic depiction of the same slag is shown in Figure 5.42.

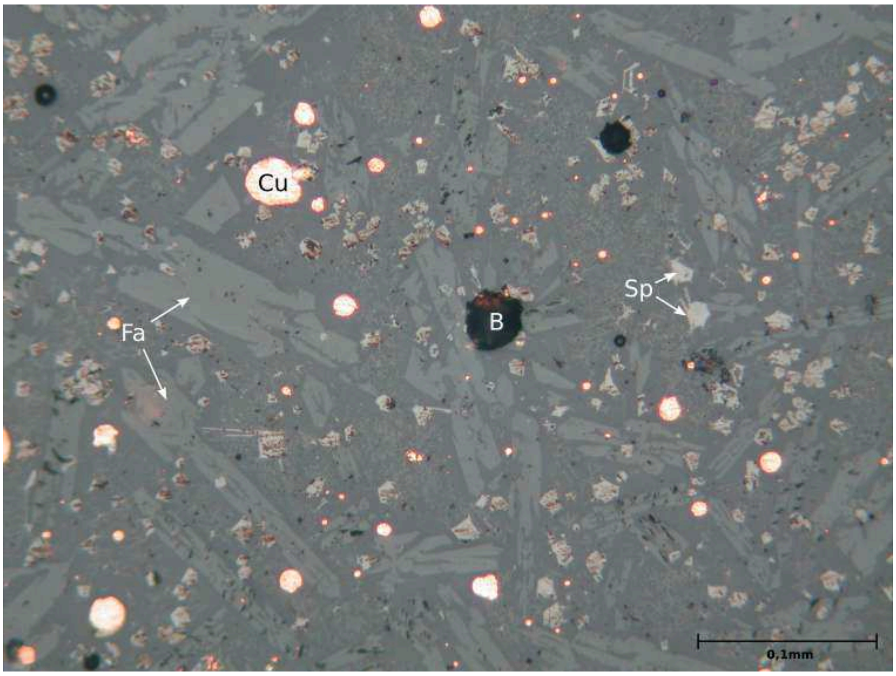

Figure 5.48: Large flow slag (sample 13) with long fayalite crystals (Fa) in a glassy matrix. Apart from air blisters (B) there is a large number of copper droplets (Cu) of variable size. Light-grey spinel crystals (Sp) can also be recognized.

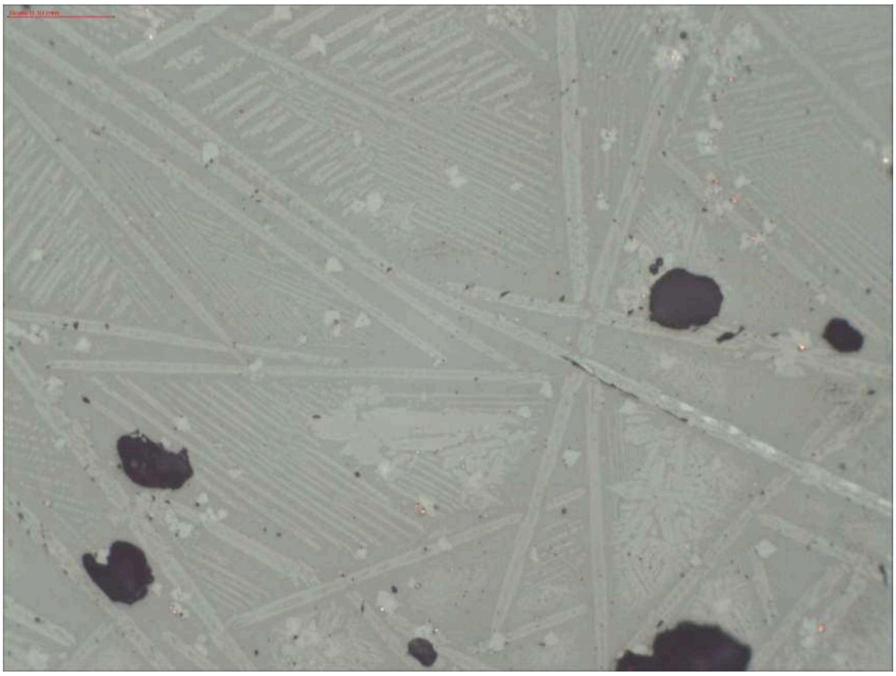

Figure 5.49: Thin flow slag (cf. Fig. 5.42) with needle-like fayalite structures in a glassy matrix with some few tiny copper droplets.

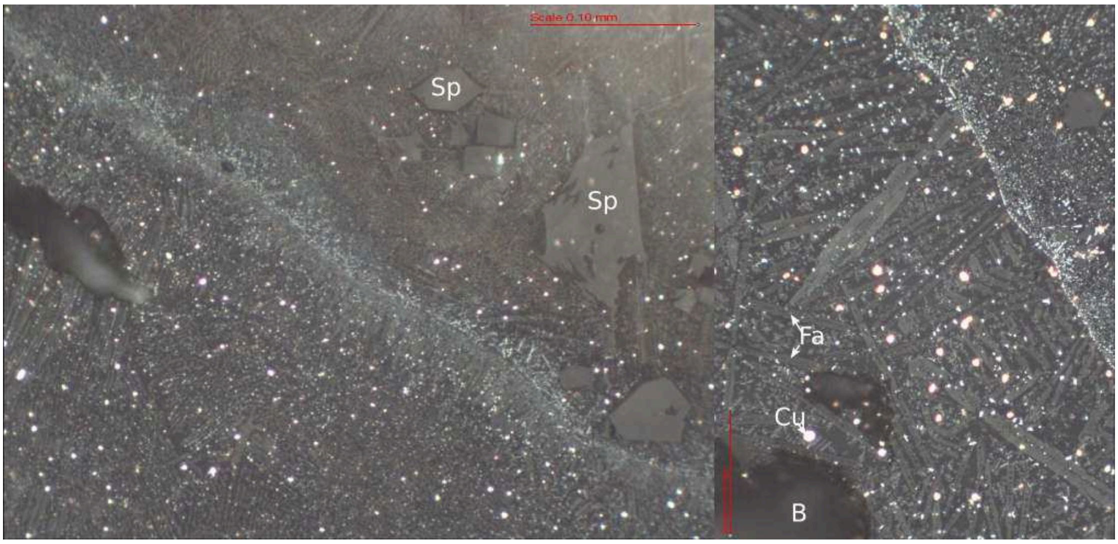

Figure 5.50: Small cordiform slag (Sample 80, see 2nd from left in Fig. 5.43) with a diagonal boundary resulting from overcast. From the left side needle-like fayalite crytals (Fa) reach the boundary surface. To the right the texture at first displays small crystals and only develops longer fayalite crystals at a certain distance from the boundary line. In addition, some spinels (Sp) are visible in the right half of the picture. Throughout the picture there are many copper droplets (Cu) and some air blisters (B).

Unlike types A–C, the slag of type D (2nd slag from the left in Fig. 5.43) indicates a much less homogeneous composition. A clear boundary is visible in Figure 5.50, where an already solidified piece of slag was overflown by liquid slag. The already solidified slag has much larger fayalite crystals, indicating slower cooling. Faster cooling on top of the already cold slag led to the formation of small crystals in the contact zone. Only at a certain distance from the contact zone was cooling slower again, leading to the growth of more needle-like fayalite crystals.

Copper matte

As described above, the occurrence of matte within the slag could be proved. Matte is a sulfur-containing phase, which originates when sulfuric copper ore is smelted. There are three kinds of matte: normal matte contains more iron than copper (pyrite, FeS, bornite). In contrast, "enriched matte" contains more copper than iron (bornite Cu_5FeS_4, chalcocite). The "white metal" (*Spurstein*) is practically free of iron and includes only copper and sulfur (chalcocite Cu_2S). To some extent matte can be consider as consciously produced as an intermediate product during copper smelting (Goldenberg, 1996, p. 40).

Apart from traces of matte within the slag, there is another exceptional form of this mineral at Wadi Hilo (Fig. 5.51). At first sight it appears as small, sometimes

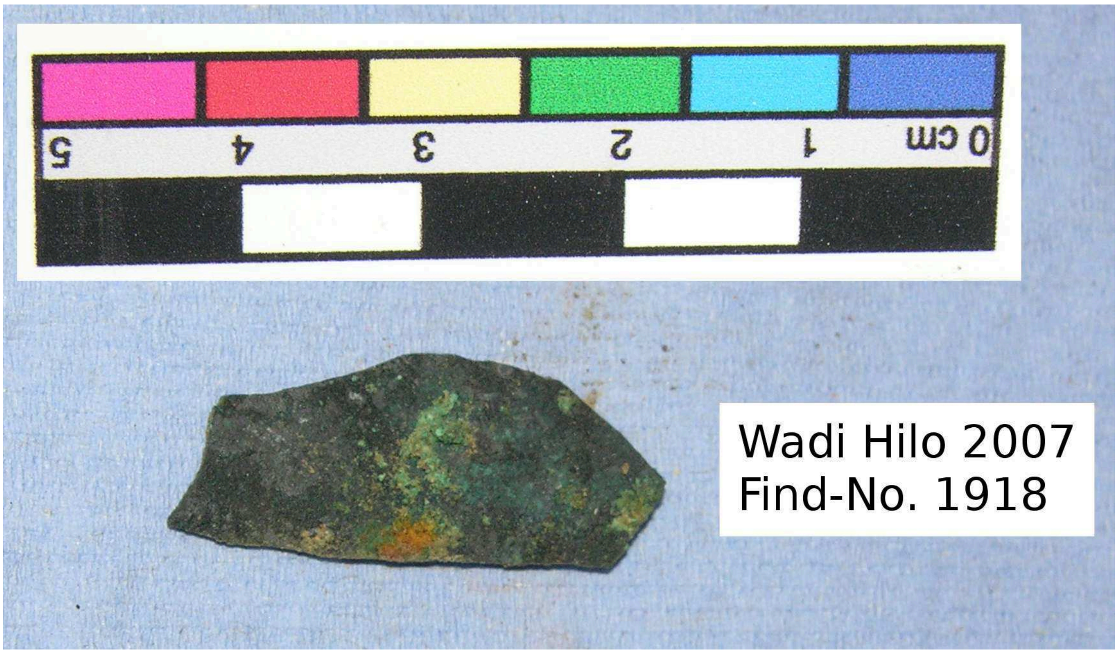

Figure 5.51: Copper matte found at HLO1 in 2007 (sample 11, find no. 1918).

vaulted leaflets, which look like copper foil. However, in a fresh section, their colour is blue to silvery (see Fig. 5.52). This form of matte was also described at Maysar 1 and Bilad al-Maaidin in Oman (Hauptmann, 1985, p. 78). The different phases of copper sulfides can not be differentiated under the optical microscope. Sometimes a thin layer of matte sticks to a layer of slag.

Table 5.11 provides the results of an SEM analysis of a polished section of matte (Fig. 5.53). This analysis indicates that the material consists mainly of copper (ca. 70 wt-%) and sulphur (ca. 23 wt-%). Traces of iron are present in the sample as well. The copper contents vary in three spectra between $Cu_{1.55–1.59}S$. This indicates that the samples probably are geerite.

As already assumed by Hauptmann (1985, p. 78), the matte sheets may be a waste product. During smelting, matte settles between the slag and the metal (Thornton et al., 2009). This could indicate that a thin layer of matte developed under particular conditions. Afterwards, it broke into small fragments. There are indications that matte was processed further in SE Arabia. A fragment of "white metal" (="*Spurstein*") was cast in a small crucible at Bilad al-Maaidin (Hauptmann, 1985, pp. 78–79).

Remnants of the furnace lining

The internal lining of the furnace wall is also an essential constituent of the smelting process and takes part in the reactions inside the furnace (cf. Kronz, 2000). Therefore polished sections of a number of wall fragments were prepared, which were mostly still covered by a layer of slag. One of these samples will be discussed

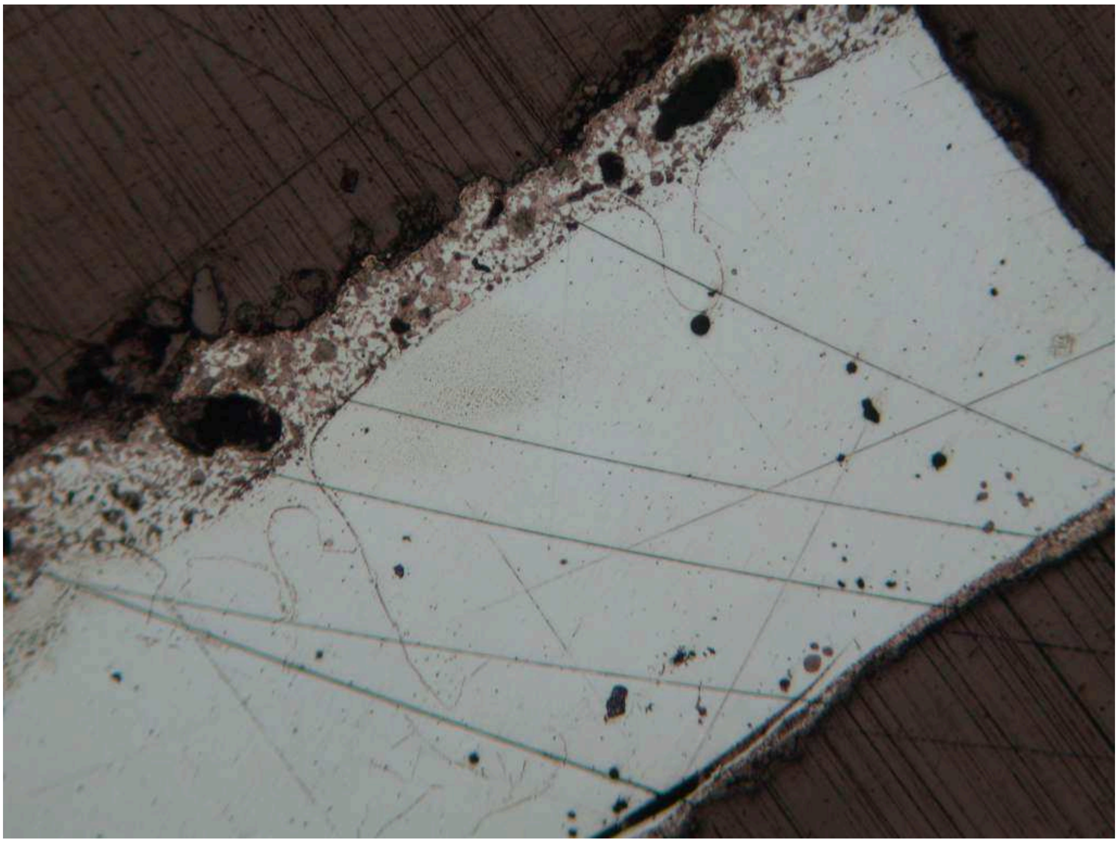

Figure 5.52: Copper matte under optical microscope; Sample 11 (Find No. 1918), width = 2 mm.

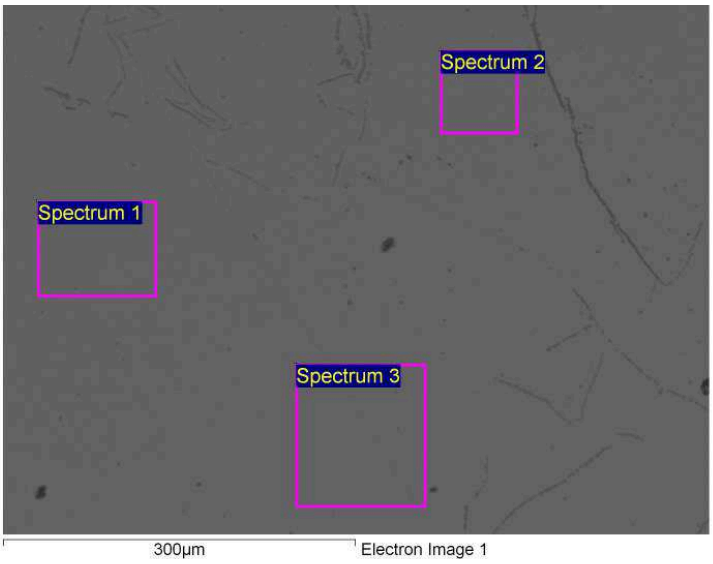

Figure 5.53: SEM image of copper matte (Sample 11, Find No. 1918). For chemical analyses of the phases, see Table 5.11.

Table 5.11: Matte piece from HLO1. Sample ID 11 (Find No. 1918) normalised wt.-% SEM-EDS. Total refers to the analytical total of the spectrum (Fig 5.53).

	S	Fe	Cu	Total
Spectrum 1	23.3	0.5	73.6	97.4
Spectrum 2	23.6	0.4	73.0	97.0
Spectrum 3	22.8		70.2	93.0

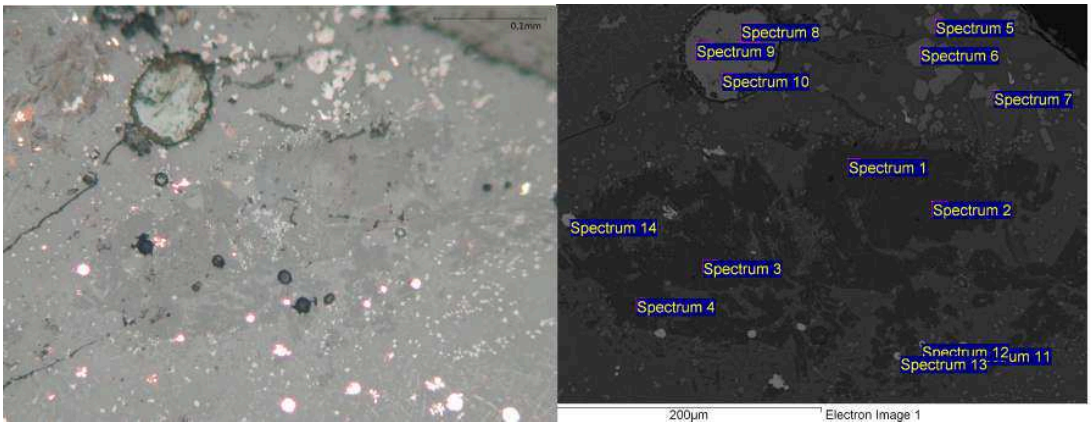

Figure 5.54: Left: Furnace lining coated with slag. Right: Measuring points of the SEM analyses shown in Table 5.12.

in detail: the analysed piece of furnace lining consists of sandy clay and was covered with a layer of slag on the inside. Only the first millimeters below the slag layer were well fired, while the rest was less consolidated and crumbled easily. The polished section indicated that the morphology of this sample was clearly different from the samples of pure slag (cf. Fig. 5.54), which usually contain obvious fayalite phases. In contrast, the furnace lining sample is inhomogeneous and indicates quite variable constituents. Phases are present which do not occur in normal slag samples. For example, Fig. 5.54 shows a grey mineral which is “cordierite”. SEM analysis (Spectra 1–4) indicates Si contents of c. 22 wt%, Al c. 20 wt%, and Mg c. 9 wt%.

Another well recognizable phase is spinels. These can be classified as “magnetites”, as indicated by the spectra 5–7. In addition, the sample contains corrosion products of metallic copper (spectra 8–10).

Many copper droplets are also easily recognized. Chemical analysis indicates that they partially contain a fairly high amount of iron. Such droplets were even found in parts where the structure of the original furnace lining is still visible.

The results obtained from this sample clearly demonstrate that the furnace lining took part in an exchange reaction with the contents of the furnace. Thus, it is quite likely that the high amounts of aluminium in the cordierite of this sample

Table 5.12: Furnace wall fragment coated with slag (sample 2). Totals refer to the analytical total of the SEM/EDS-spectrum in wt% (see Fig 5.54).

	O	Mg	Al	Si	Cl	K	Ca	Cr	Fe	Cu	Br	Total
Spectrum 1	55.6	8.8	20.1	22.3				0.6	3.6	0.7		111.7
Spectrum 2	56.7	6.3	20.5	24.5		0.2	0.2		3.1	1.1		112.7
Spectrum 3	53.5	7.8	18.5	23.3					4.4	1.2		108.7
Spectrum 4	53.6	8.3	19.5	23.0					4.1	1.2		109.7
Spectrum 5	35.3	3.4	4.2					0.4	61.5	2.8		107.7
Spectrum 6	34.1	3.2	4.5						61.8	2.6		106.2
Spectrum 7	34.6	3.7	5.3					0.8	57.6	3.5		105.4
Spectrum 8	26.8			0.4	17.6				1.2	56.9		102.9
Spectrum 9	27.5			1.4	17.1				1.4	55.1		102.4
Spectrum 10	25.8			0.7	17.1				1.3	55.1	0.9	100.9
Spectrum 11	2.9		0.5	1.4					1.7	91.3		97.8
Spectrum 12	46.5	2.0	7.7	26.3		0.5	4.4		4.3	15.0		106.9
Spectrum 13	44.8	1.9	6.9	27.0		0.8	3.4		4.1	18.8		107.8
Spectrum 14	4.2		0.9	2.1					2.7	94.3		104.3

derive from a reaction between the molten slag and the furnace lining. On the whole, the sample leaves the impression that the represented slag was relatively ductile. Probably more oxygen was available in the area near the furnace wall than in the reaction zone itself.

In the area of the sample where slag is predominant, there are also small fayalite needles and in addition zonated spinels (see Fig. 5.55). In the early stages of the smelting process more Mg, Al and Cr were incorporated into the spinel. During cooling their concentration was more and more reduced. Therefore the concentration of these elements became lower and lower in the outer parts (cf. Table 5.13).

Table 5.13: Zonated spinel (sample 2). Totals refer to the analytical total of the SEM/EDS-spectrum in wt% (normalised) (see Fig 5.55).

	O	Mg	Al	Si	K	Ca	Cr	Fe	Ni	Cu	Total
Outer Area											
Spectrum 1	51.4	3.3	9.4	17.7	0.3	2.1	-	33.8	-	3.5	121.4
Spectrum 2	46.1	2.2	7.9	13.2	0.3	1.4	-	41.6	-	3.0	115.7
Spectrum 3	41.9	2.5	7.5	8.0	-	0.7	-	47.6	-	2.5	110.7
Inner Area											
Spectrum 4	38.8	4.8	11.0	-	-	-	4.8	45.0	0.7	1.1	106.1
Spectrum 5	38.7	4.7	10.8	-	-	-	3.5	44.2	0.6	1.1	103.6
Spectrum 6	38.6	5.0	11.0	0.5	-	-	4.2	45.0	-	1.2	105.6

Copper Ore

The occurrences of copper ore in Wadi Hilo were described in Section 4.3.1. A polished section was prepared of one of the collected ore samples. As a hand rock sample, this piece indicated obvious green ore minerals which were secondary copper ores like malachite and chrysocolla. The ore was embedded into the quartz as very fine veins. Therefore examination under the light microscope was not a

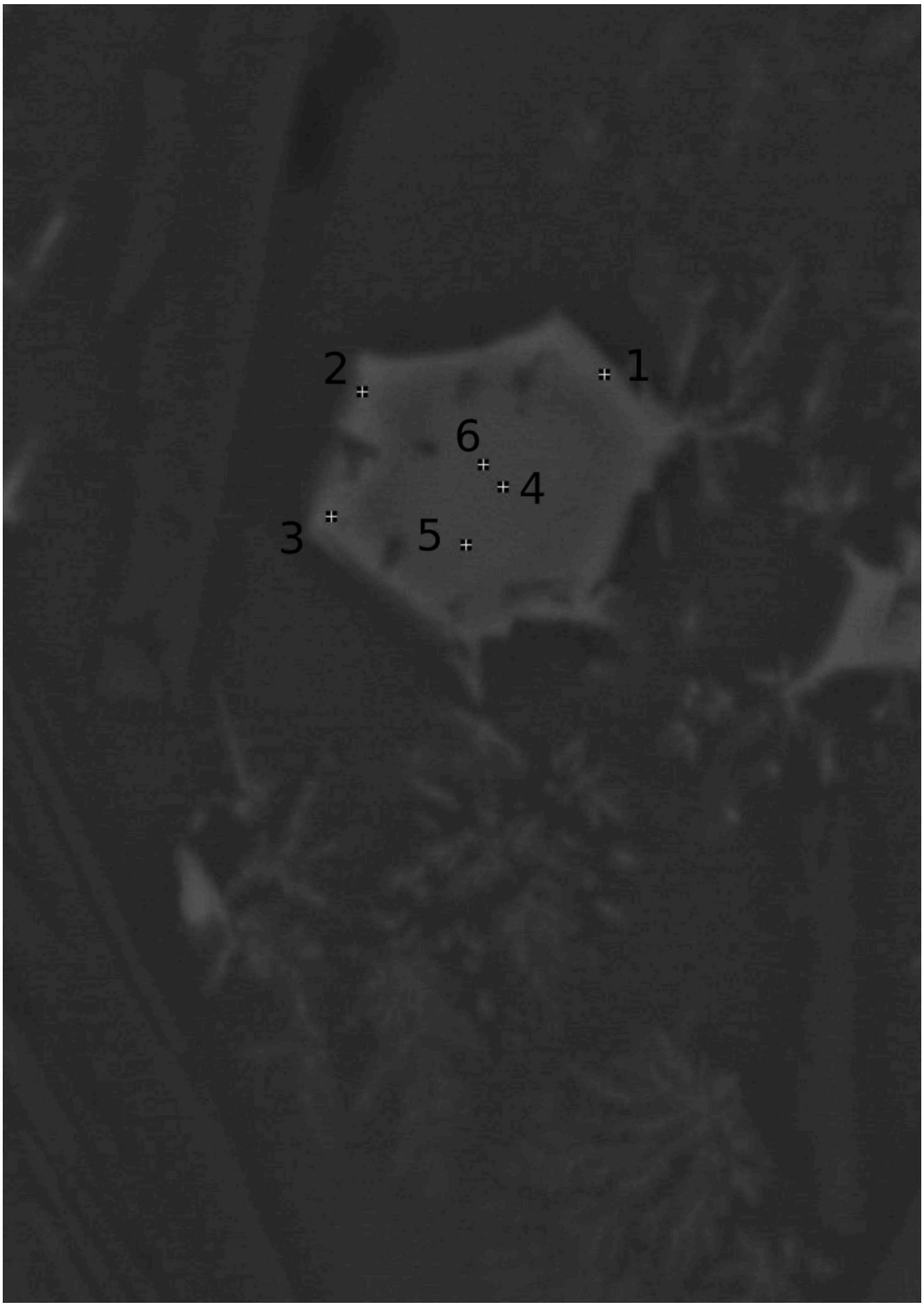

Figure 5.55: Zonated spinel: SEM picture (measurements in Table 5.13).

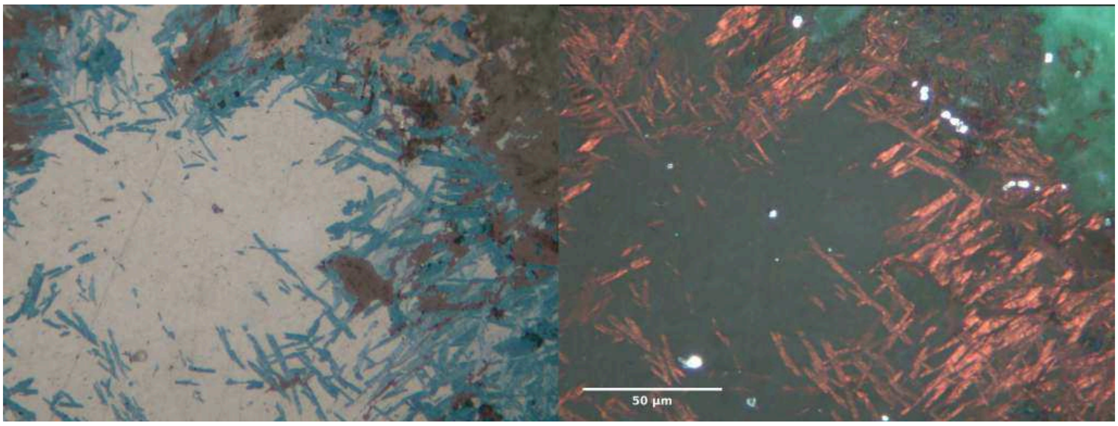

Figure 5.56: Copper ore under the optical microscope; right: reflected light image under plain polarised light (PPL); left: same image with crossed polarisation (XPL). The blue mineral under PPL is covellite which appears red under XPL. The extended grey-blue phase probably is chalcocite.

simple task, as surface weathering often causes rapid destruction of the veins. A freshly broken piece was selected for preparation of a polished section.

A light blue and a dark blue mineral can be recognized under the ore microscope (Fig. 5.56). These are the secondary copper ore minerals mentioned above. Red internal reflexes visible with crossed polarisers indicate that the dark blue mineral is covellite (CuS). This creates a corrosion cortex covering the light-blue mineral, which is most probably chalcocite.

Reconstruction of the smelting process

As described above, the smelted ore came from small occurrences found throughout the upper Wadi Hilo. They provide secondary copper ores, like chrysocol, chalcocite and malachite, which are embedded in the copper-bearing quartz veins within the ophiolithic bedrock. The ore was mined in open pits. Most probably the extracted ore was handpicked from the rubble, leaving behind the unworkable adjoining rock. Transportation to the smelting site may have made use of donkeys as beasts of burden.[1]

At the smelting site, the pre-sorted ore was crushed further with hammerstones and sorted again. Research in Oman (Hauptmann, 1985, p. 91) indicates that the ore could thus be enriched to about 30 wt%–50 wt% of copper. Nevertheless, a lot of silicates remain with the ore because of the tight association of copper ore and quartz. For this first on-site step of the copper smelting process, a radiocarbon date of the Hafit period (late 4th millenium BC) was obtained at HLO1.

[1] As demonstrated by a relief on an Umm an-Nar grave at Hili, donkeys were available in SE Arabia as beasts of burden already in the Early Bronze Age.

Roasting of the ore, as the next potential step in copper smelting, did not leave any recognizable traces at the site HLO1. There are also no indications for Bronze Age production of charcoal. Hauptmann (1985, p. 93) postulates that charcoal was used for the smelting process. However, it may be assumed that this process would also work with well-dried Acacia wood (Timberlake, S., Asmus, B., Radivojevic M. in prep.).

Unfortunately, precise statements on the construction of smelting furnaces at HLO1 are not possible. The fragments of furnace walls are badly preserved because of the lack of good clay in the wider area around the site. Therefore, the furnace linings were probably made of sandy mud, left behind in the wadi by the occasional floods. The proportion of fragments of the furnace lining in relation to slag is extremely low at HLO1. This is in contrast to the site of Maysar, where furnace wall fragments are a major constituent of the metallurgical evidence from the site (see Hauptmann, 1985). The badly preserved floors of some furnaces have diameters of about 50 cm. One may assume that the furnaces were pear-shaped and comparable to the furnaces described by Hauptmann (Hauptmann, 1985, p. 92). It is impossible to provide statements about the sizes of the tap holes, nor about the number, size and position of the wind pipes.

The numerous finds of large flow slag are clear evidence for a process temperature in the furnaces above the melting point of slag. Thus, temperatures around 1200°C were generally reached inside the furnaces. The form and structure of the flow slag indicate that the slag did not solidify inside the furnace but rather was tapped in order to form large slag cakes in the open.

5.6 Other Bronze Age features

5.6.1 The Umm an-Nar watchtower (Area I)

Already during the first visits to the site, a conspicuous and apparently pre-modern feature was observed close to the Islamic watchtower, which is the prominent landmark of the whole area. It was a low mound just north of the watchtower, which seemed to contain a prehistoric grave. Therefore it was selected as a prime object for excavations during the first field season in 2007.

In order to obtain both horizontal and vertical documentation of the findings, the mound was divided into four quadrants (trenches no. 6, 11, 14 and 15). When laying out these trenches, it became obvious that walls were preserved in the centre of the mound. A peripheral round stone structure with an outer diameter of 7.7 m and an inner diameter of c. 5.1 m (Figs 5.60, 5.58 and 5.57) became visible after removal of the surface rubble. The round structure was divided into four quadrants by crossed walls orientated N–S and W–E.

Excavation started in the north-eastern sub-square (trench 6). While its western limit was the N/S dividing wall, the southern limit was about 20 cm north of the W/E dividing wall. Thus, a section through the fill was retained there after almost complete excavation of the N/E Quadrant (=room 1) of the tower. The fill of room 1 consisted of big pebbles and large pieces of metal-smelting slag, with only a small amount of fine matrix between them (Fig. 5.59). This fill reached down to the base level of the dividing walls inside the tower.

The deeper sediments inside the tower were completely different. They consisted mostly of coarse-grained sand without any larger components. This sandy fill was c. 20 cm deep and rested on the surface on which the outer wall of the tower was erected. Below this surface the sediment slightly changed again, becoming coarser and containing more stones. It appeared to be like the natural surface sediment of the surrounding wadi terrace.

In this sub-square (trench 6) of the tower, the circular outer wall is preserved to a height of about 1 m. The inner cross-walls measure up to 1.15 m at their highest part. The building stones are unhewn boulders, obviously selected to fit each other in thickness and shape. They seem to have been set in horizontal layers of more or less consistent thickness. The cross-walls were built against the inside of the outer wall. Obviously they were erected in a second step (as also indicated by the above mentioned sand layer on the original floor level).

The opposite SW quarter of the tower was dubbed “room 2” and excavated as trench 11. Here the outer wall is less well preserved and much lower. Like room 1, the upper part of room 2 was filled with a mix of rubble and slag—the last component being less frequent than in room 1. Below this fill, the sequence of sediments is identical to that of room 1. The other two quarters of the tower (room 3/trench 15 in the NW and room 4/trench 14 in the SE) are quite similar in finds and findings to rooms 1 and 2.

Figure 5.57: Mound before excavation in 2007 (view from NE).

Outside of the tower, the blocks that had fallen from the wall were removed from the surface on which they had dropped. These blocks were later (2011) used for the protective reconstruction of the tower (see below).

Apart from removing the fallen blocks, another trench (no. 17) was opened on the east side at the outer base of the tower. The purpose of this trench was to clarify the stratigraphic context of the building in relation to the surrounding surface. By chance, this trench cut a shallow fire pit, which was dug into the natural surface at the outside of the tower wall (Figs 5.60 and 5.61).

The black ash layer in this pit yielded a radiocarbon date in the early second millennium BC (Hd-26446, conventional age BP 3470±34; cal BC 1886–1692 (2σ)), i.e., in the early Wadi Suq period. This fire pit does not extend underneath the structure, but was obviously dug against it. Thus the tower already existed when the fire was burning. The radiocarbon date is therefore later than the construction of the tower.

According to Gerd Weisgerber, the excavator of the smelting site at Maysar in Oman (personal communication during a visit to HLO1), such small towers are known features at sites of the Umm an-Nar phase in the Omani Mountains. They are considered to have been watchtowers—probably with an elevated and protected platform well above ground level, comparable to the nearby historic watchtower (Fig. 5.64)

Figure 5.58: Umm an-Nar watchtower after excavation (photo taken from the modern tower south of it).

Figure 5.59: Section through the fill in the north-east chamber of the UaN Tower seen from the north. The round outer wall is seen in the foreground. The straight wall to the right divides the N–S wall, which is set in regular layers of stones of similar height. The section (in the shade) indicates an oblique layering of fallen large stones both from the outer and from the dividing wall. In the trough between them, there are smaller stones, mostly deriving from the inner fill of the two walls (visible within the outer wall in the foreground).

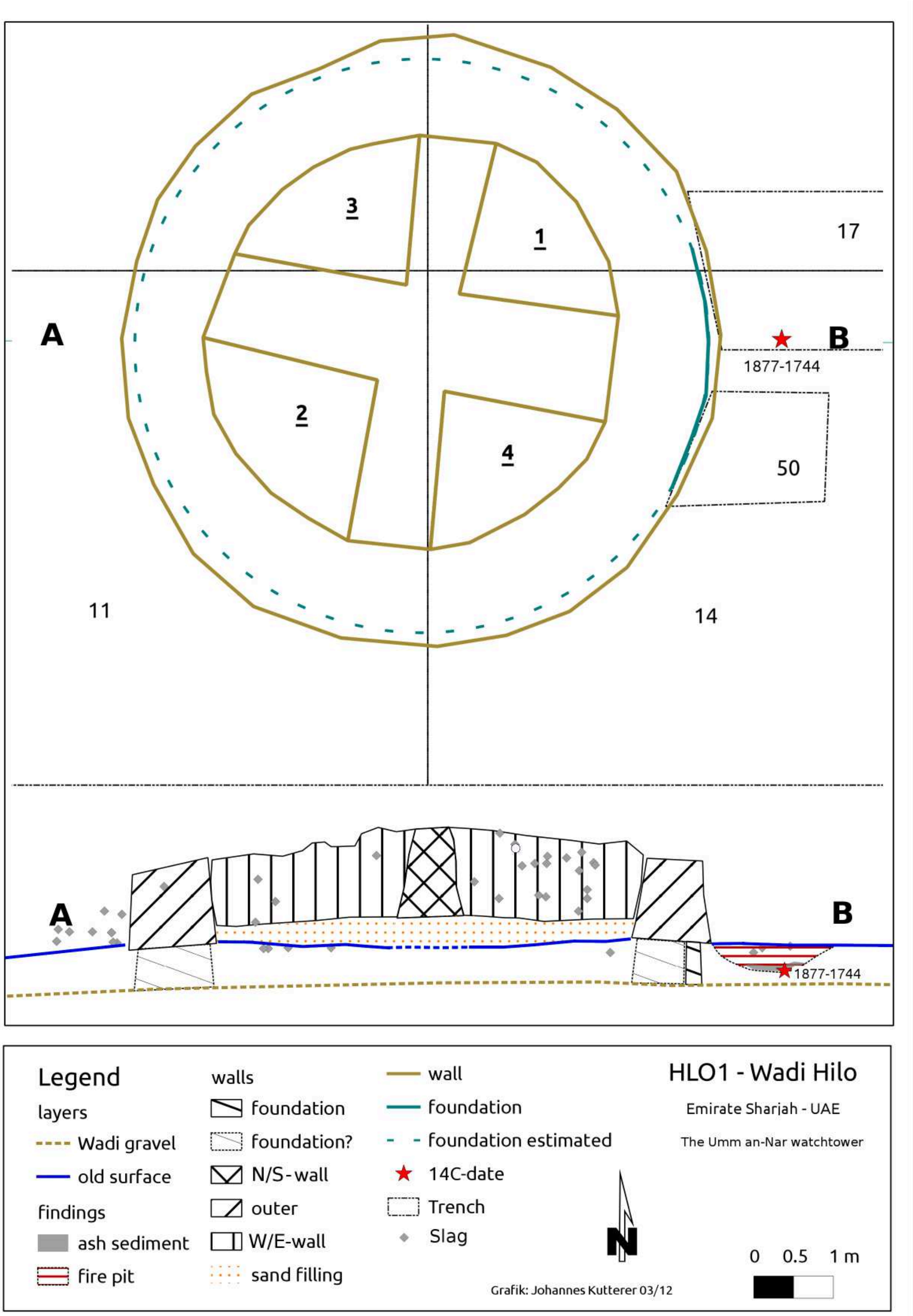

Figure 5.60: Upper part: Horizontal plot of the UaN tower. Lower part: E–W section of the preserved base of the tower.

Figure 5.61: Section of trench 17 with radiocarbon-dated ash layer in a fire pit. The pit was dug against the base of the tower which already existed when the pit was made.

Trench 50, dug just south of trench 17 in november 2011, revealed the existence of a below-ground foundation of the tower wall. The diameter of this foundation is some 10–20 cm smaller than that of the base of the tower at ground level. As a large-scale exposure of this foundation would have endangered the stability of the tower wall itself, trench 50 was kept as small as possible. The foundation also became visible in trench 17 when it was slightly extended below the standing outer wall. A computer aided reconstruction of the curvature of the foundation indicates that it was built as a stone circle directly below the tower wall with a diameter slightly smaller than that of the tower itself.

In order to protect the remnants of the tower from further destruction, its original walls were partly reconstructed during the excavations in 2011 (Fig. 5.63). Flat light-grey wadi pebbles were used to visibly separate the undisturbed base of the tower from the reconstructed upper part. Reconstruction of the rising structure made use of the fallen blocks which surrounded the base of the tower as rubble and which were exposed during the excavations in 2007. Both the round outer wall and the cross-walls inside the tower were reconstructed in 2011 to a height of about 1.5 m above the present ground level.

Figure 5.62: Foundation wall in trench 17. The radiocarbon-dated ash layer is visible in the section on the left side of the trench.

Chronology

For the time being, an absolute date for the construction of the tower cannot be given. In any case, it was built before c. 1700 BC when a fire was burning in a pit dug against the outer wall. However, the sequence of findings provides a relative chronology: obviously the wall considered as the foundation of the outer wall is the oldest part of the whole structure. Unfortunately, it is impossible to clarify whether this underground wall was really built as a foundation or if it could be the remnants of an older tower at the same place.

In a second step, the outer wall of the tower was erected on top of the assumed foundation. The base of the thicker outer wall starts from about 10 cm below the present surface outside the tower. As a third step, again at an unknown time during or after the construction of the outer wall, some 20 cm of sandy sediment was deposited inside the tower. The internal cross-wall was built on top of this sand. The last observed phase of construction of the tower is the filling of the internal chambers divided by the cross-wall with a mix of stones and slag. Unfortunately, the upper part of the tower is not preserved. Thus, its real function cannot be determined. It is also not possible to narrow down the time span during which the tower was used. This might be one or more of the phases during which the site of HLO1 was inhabited. The only indication for a certain time depth of the construction phases and use of the building can be derived from the large amount of slag deposited inside the tower after the internal cross-wall was built. This slag

Figure 5.63: The UaN tower after partial reconstruction in 2011. The grey wadi pebbles separate the original wall from the reconstructed part above. Reconstruction appeared necessary in order to protect the preserved basic structure of the Bronze Age building.

must have been available in sufficient quantities at the site—indicating that copper smelting already had gone on for quite a long period of time.

The collapse of the upper part of the tower is the last step in its history which left its traces in the archaeological record. The rubble of the collapse, together with fine-grained windblown sediment, formed the hill which led to the recognition of the whole structure at the surface of the site.

Interestingly enough, another tower was erected during the Islamic period only about 15 m south of the Bronze Age tower. Apparently the ruin of the old tower was not any more recognizable at that time. Otherwise either its base or at least its stones would probably have been re-used for the new tower. Its diameter is smaller than that of the old tower and mortar (instead of dry masonry) was employed in its construction. However, like the old one, the new tower does not have an entrance at ground level. As visible in Fig. 5.64, the entrance to the tower is some four metres above ground on the west side of the building. The lower part of the tower is completely filled with rubble, creating a floor level at the height of the entrance. On this level a central column was erected which carried the upper platform constructed of wood (Fig 5.65). A more detailed description will be given below in the chapter on the findings of the historic periods (Chapter 11.1).

Figure 5.64: West side of the modern tower with the elevated entrance.

Figure 5.65: Column inside the modern tower.

Figure 5.66: NW corner of the HLO1 terrace seen from the north. A small side wadi comes from the left (east) and the main wadi passes the site flowing south in viewing direction.

5.6.2 Northern fortification

The discovery of the small Umm an-Nar tower (see 4.6.1) at the southern edge of the site gave rise to the question whether a large tower of this period (Potts, 1990a, pp. 101–102), suitable as a fortified living structure for a larger number of inhabitants, as known from Tell Abraq (Potts, 1991, p. 22), Hili (Cleuziou, 1996, p. 161), Bat (Frifelt, 2002, p. 107), or Maysar 25 (Weisgerber, 1981, p. 200), might have existed at Wadi Hilo as well. This was obviously not the case. However, the nature of the site itself provided a natural fortification in the form of the vertical and up to 8 m high terrace edge along the western side of the site (Fig. 5.66). To the east, the steep slopes of the main ridge of the Hajjar Mountains would also not have allowed easy access for enemies. Only the southern flank was open for aggressors, and it was secured by the small watchtower (see 4.6.1).

A minor potential for an attack was in the north, because the small wadi coming from the east does not have a vertical cliff towards the settlement area of the site. Apparently this northern flank was protected by a wall consisting of large blocks, erected in several steps from the wadi bottom up to the height of the terrace (Fig. 5.70, 5.71, 5.72, 5.73 and 5.74). Not much archaeological effort has been invested up to now in the exploration of this structure, but its existence is obvious

Figure 5.67: Deviation of the water flow in the side wadi with the help of rows of large blocks.

in several areas of the northern slope. The wall in the north might not only have had a defensive function but could also have been a necessary protection against erosion of this flatter part of the terrace by torrential floods coming down the eastern side wadi during heavy rains. The floods of the main wadi endanger the existence of the site even today. Therefore, protective measures may already have been taken in the Bronze Age by laying out rows of large blocks deflecting the water towards the middle of the valley (Fig. 5.67). Several such rows are still visible, but their building date is not known.

Two steep stairways can be recognized in the centre of the northern fortification. These stairs may have been used as access to water holes at the bottom of the side wadi. Indications for the existence of a flatter ramp leading down from the settlement area on the terrace to the bottom of the main wadi are visible at the north-western corner of the site (Fig 5.66, 5.68, and 5.69). This ramp, named "structure A" during the excavations, must have been an essential northern gateway for the whole site, which is otherwise only accessible from the south. The architecture of the ramp is directly connected to the fortification structures along the northern edge of the site, which indicates that they were constructed together.

Figure 5.68: Ramp at the north-western corner of the site allowing passage of people, animals and goods to and from the northern part of Wadi Hilo (upper end at arrow A). Arrow B marks the side wall of the upper ramp (see Fig. 5.69).

Although no evidence for direct archaeological dating of this structure is available at present, there is little doubt that it belongs to the Bronze Age occupation of the site. It is not only a northern exit and entrance but also provides access to contemporary installations on the west side of the wadi, including graves and a small smelting area indicated by slag heaps as well as another ore outcrop on the western slope.

The ramp is still in use today as a footpath, particularly frequented by the local goat-herds, something which contributes to its erosion. It leads down from the terrace to the wadi bottom over a length of c. 20 m and is built into the steep western cliff starting at the terrace edge near the north-west corner of the house and workshop in Area C. The end is at the point where the side wadi meets the main channel. At the upper entrance, which is formed as a shallow incision into the terrace edge, it has a width of c. 2 m. Farther down it narrows to c. 1.3 m, but this mainly seems to be due to erosion, which obviously took away much of the supporting wall structures. These are, nevertheless, still recognizable, in particular in the upper part. Although there is no direct archaeological evidence for its dating, its inclusion into the northern fortification and its topographic context with the house and workshop in area C strongly supports a Bronze Age date for its construction (see also chapter 4.6.6).

Figure 5.69: Side wall of the upper ramp before reconstruction (situated at arrow B in Fig. 4.68).

Figure 5.70: Big blocks at the wadi edge.

Figure 5.71: Upper end of the drainage channel.

Figure 5.72: Draining channel seen from the slope.

Figure 5.73: Remnants of the fortification at the northern edge of the wadi terrace.

Figure 5.74: Reconstruction of the fortification.

5.6.3 Area E

Based on the experience that sedimentation was strongest near the base of the slope, another exploration trench (T30) with a width of 1 m was opened at the slope south of the walls of the subrecent tobacco-shed. While the up-slope south-eastern part of the trench only revealed slope sediments without finds or findings, a wall was found in the lower part. On both sides of this wall there were prehistoric finds, including Bronze Age pottery and metal objects. Therefore this part of the trench was widened on both sides (T43 to the west and T35 to the east). In 2011 another trench (T46) was opened in prolongation of T43 and T30, reaching into the gap between the standing walls of the tobacco shed (Fig. 5.75).

Trenches 30, 35 and 43

The wall found in T30 extends along the base of the slope from NE to SW. It is preserved with two lines and two to three layers of stones which are partly deranged. At its northern end, there were many fallen stones. Only Islamic pottery was found above the wall remnants. Lower down, from spit 5 onwards, there were only prehistoric finds (pottery, metal, slag, grinding stones, shells etc.). Some few sherds are from the Iron Age, but most are from the Bronze Age.

Trench 46

Trench 46 is separated from trenches 30 and 35 by a baulk which could not be removed because of a local path which passes there between the slope and the tobacco shed. Trench 46 also revealed remnants of a wall, of which three layers of stones are preserved. It is parallel to the wall observed in trenches 30, 35 and 43 and has the same structure. We may therefore assume that it belongs to the same building, which could, however, not be explored further because of the foot-path and the ruins of the tobacco shed.

It should be mentioned that a curved wall is attached to the straight wall, starting from the same level, but not preserved to the same height. In front of this wall (to the north-west) there is another small area of green-coloured sediment (see the workshop section above). Most probably the architectural remains found in these exploration trenches indicate another workshop area for metal production (Fig. 5.76).

The distribution of pottery finds is similar to that in the workshop area farther south. In the upper layers, only Islamic pottery was found. A post-hole, lined with stones, was found in the middle of the trench. It obviously belongs to the sub-recent tobacco shed and held the southern centre-post for its roof (Fig. 5.77).

Below the Islamic surface layers, other finds only appeared in spits 8–11. The pottery is from the Bronze Age exclusively. In the northern corner of the trench, a fireplace was found in spit 10. Its ash yielded a Neolithic radio-carbon date (^{14}C age BP: 6153±28, cal BC 1σ: 5205–5047; MAMS-15104). The construction level

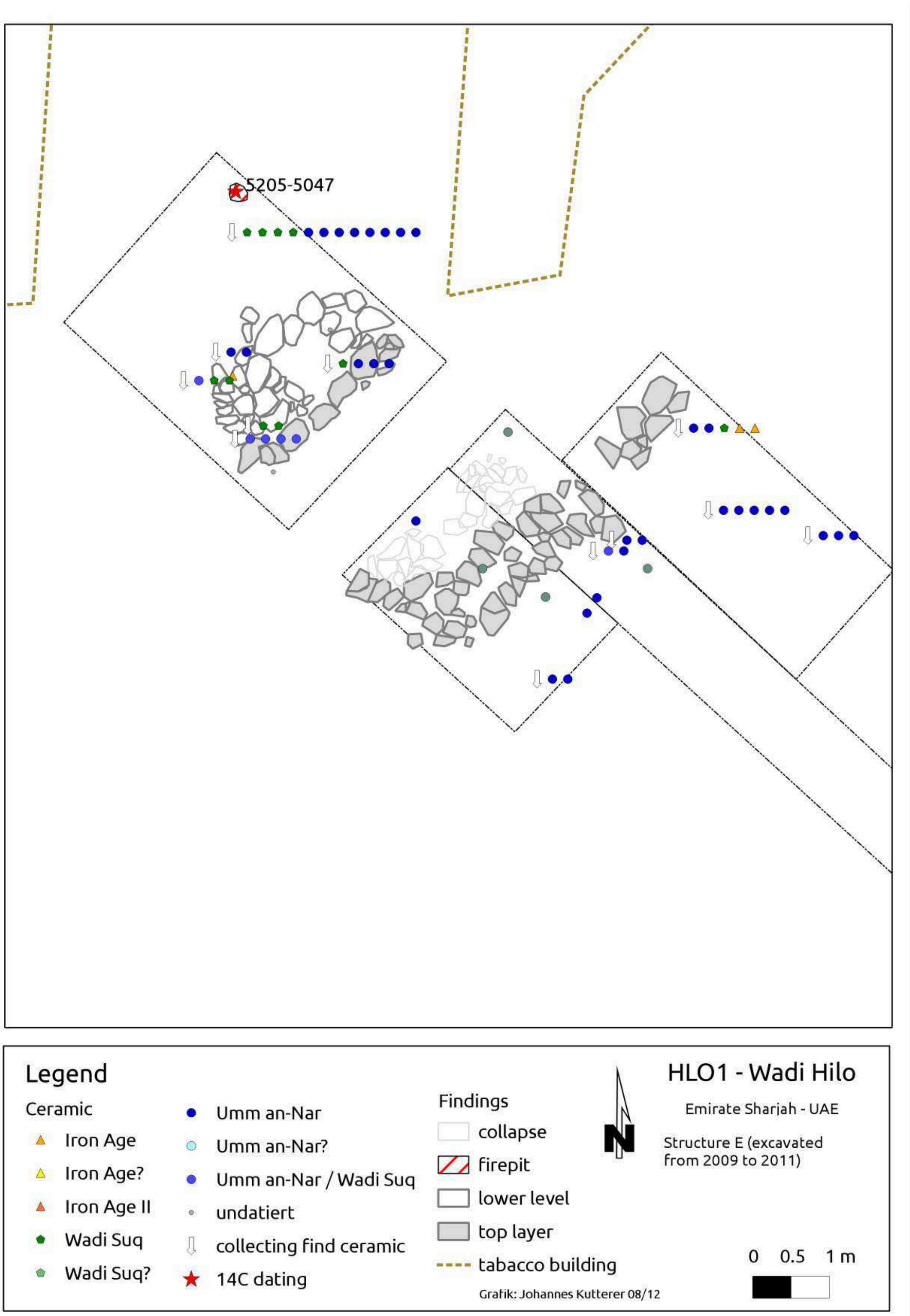

Figure 5.75: Map of structure E.

Figure 5.76: Green sediment in trench 46, level 10. The dated fireplace can be seen in the background at the base of the left corner of the trench. The copper content of the green sediment visible in the foreground is c. 0.2% (sample 117; Analyses in Table 5.2).

Figure 5.77: Posthole in levels 1–2 belonging to the "Tobacco shed".

of the rounded structure is several centimetres above the corresponding ash layer (Fig. 5.78).

Figure 5.78: Wall remnants in the southern part of trench 46 (levels 10–11).

5.6.4 Trenches 41 and 42

South of the large concentration of slag, several stone structures are visible at the surface. One of them is a large square (feature 148), others are rows of stones (feature 339, Fig. 5.92), which begin at the terrace edge and extend towards the slope in the east. In order to explore these structures, trenches 41 and 42 were opened. Trench 41 extends across feature 339 and reaches the slag concentration in the north. Trench 42 extends north from the NE corner of feature 148.

Features in levels 0–2

After removal of the surface in trench 41, several wall structures became visible in the south of the trench and another one in the NE corner. Parts of the structures in the south belonged to feature 339 and were already visible at the surface. As a working hypothesis, it was first assumed that wall 339 was part of a defence system at the southern edge of the site. However, soon it turned out that wall 339 was not massive enough and that it belonged to a building containing several small rooms. The walls did not extend much below the present surface and consisted of only one to two rows of stones. Pottery finds from the area are quite mixed and contain specimens from the Bronze Age to the Islamic period (Fig. 5.79).

In the SW corner of trench 42 there was part of a wall (723) belonging to wall 701 of feature 339 in trench 41. In the SE corner, however, parts of a larger structure 148 were cut (feature 725). In the northern part of the trench there are some remnants of walls, presumably belonging to others found in the NE corner of trench 41. They might represent one or two rooms of a larger building.

As in trench 41, all the remnants of walls found in trench 42 are restricted to removals 1 and 2 and are not seen in deeper layers (Fig 5.80). This observation, together with the late pottery found there, indicates a fairly recent (post Bronze-Age) date of the structures.

Features in levels 3–4

Below the walled structures, from removal 3 downwards in trench 41, several large hearths became visible. One of them (721) appeared below wall 712 (Fig. 5.82). The number and the size of these hearths or fire places increased considerably throughout removal 3. Within removal 4 there were some 10 partly overlapping fire pits, some with diameters up to 1.3 m and a depth of c. 20 cm. Their fill was deep black and full of large pieces of charcoal (Fig. 5.81).

Intact pieces of charcoal were only found in this part of the excavated area of the whole site. Other hearths discovered at HLO1 were much smaller and only contained ashy sediments with fine-grained black particles, but not real charcoal.

In trench 42 there are fewer hearths and their occurrence is restricted mainly to the NE corner. They are also markedly smaller and their colour is less dark. Hearth 730 is an exception, however (Fig. 5.83). It is walled with stones of fairly equal size and has a diameter of about 60 cm and a depth of c. 15–20 cm. Probably

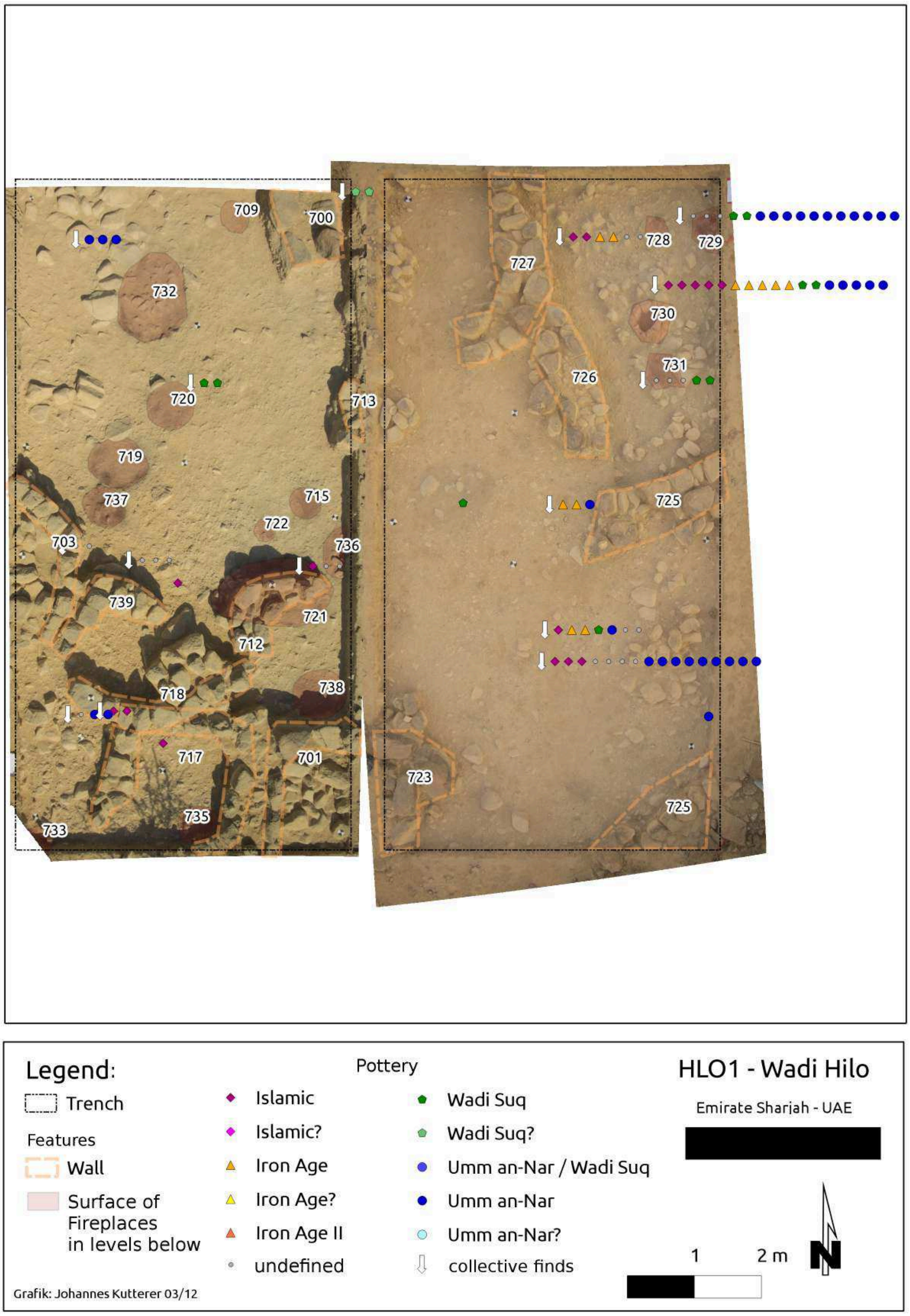

Figure 5.79: Map of trenches 41 and 42: Levels 0–2.

Figure 5.80: Trench 41: Section of part of wall 701 and stratigraphic separation from levels 3 and 4 (gravel).

it belongs to the building surrounded by walls 725–727. Pottery finds of level 3 in these trenches (41+42) are from the Bronze Age exclusively. Apart from two fragments of Wadi Suq pottery, all other finds are from the Umm an-Nar period. In the transitional level below, only three pot-sherds were found.

Most of the hearths mentioned above appear to have been dug from this transitional zone into level 4. Thus, the hearths are not associated to levels with pottery. No archaeological finds whatsoever were encountered in level 4: neither within the hearths nor in the layers around them. Thus, the only way of obtaining a date for these features was radiocarbon dating of the ashes. Four of the ash lenses encountered in level 4 (two each in trenches 41 and 42) were radiocarbon dated. Their ages range from the 9th to the 4th millennium BC (see Table 8.1) and thus indicate a Neolithic occupation of the site. A discussion of these Neolithic features is to be found in the next chapter, Chapter 7.

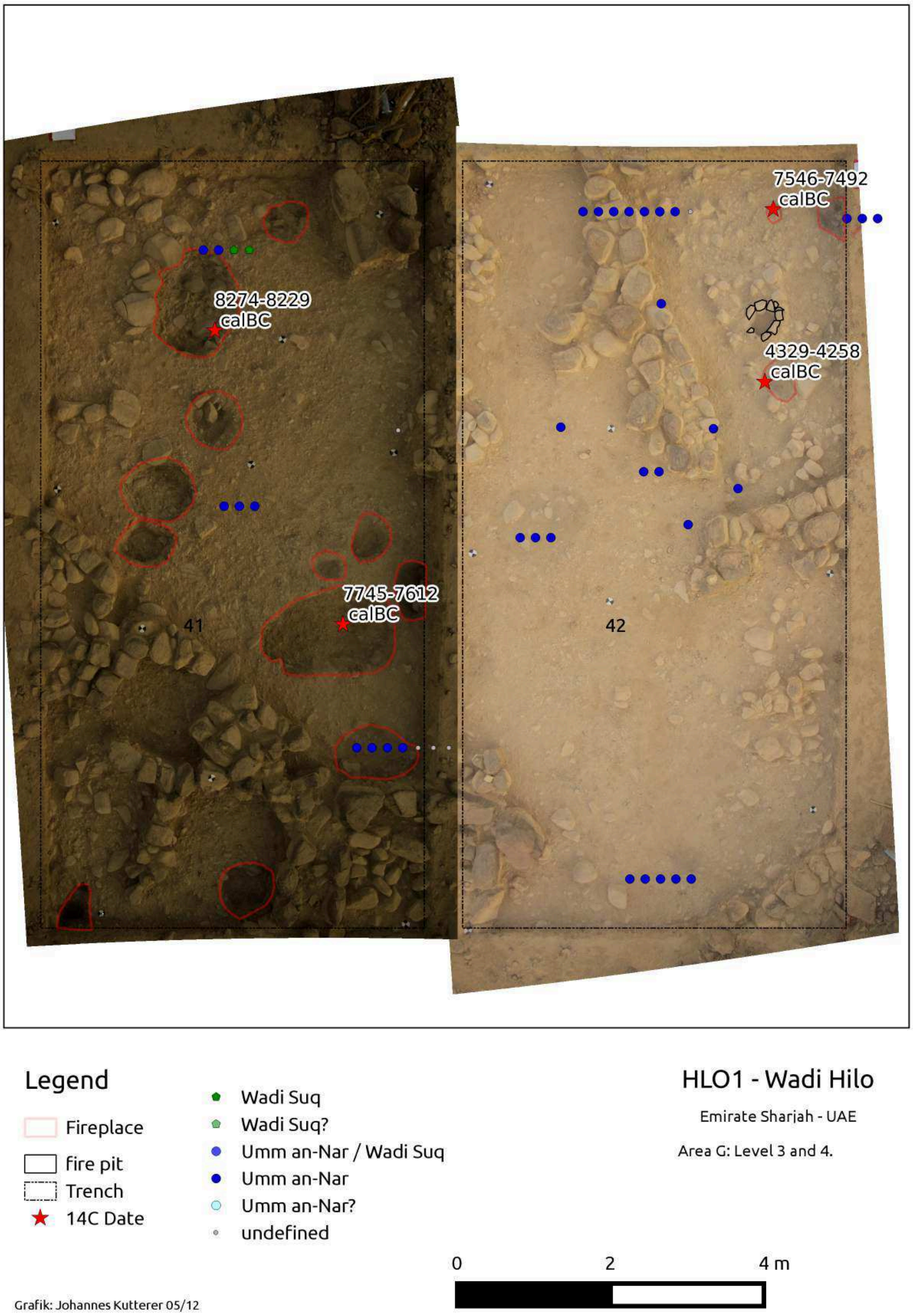

Figure 5.81: Trenches 41/42: Pottery finds of level 3 and surface of fire pits in level 4.

Figure 5.82: Wall 712 above fire pit 721 indicating clear stratigraphic separation of the two features.

Figure 5.83: Walled hearth 730 within structures 725–727.

5.6.5 Further structures at HLO1

This section deals with findings and structures which either cannot yet be fully described and understood because the excavated areas are still too small, or which have only been identified at the surface and can thus not completely be interpreted with regard to their function and chronology.

Bronze Age levels in trenches 65–67

Trenches 65, 66, and 67 were excavated in 2012 in the south-eastern part of the site near the base of the slope in order to find *in situ* Neolithic contexts (see Chapter 7). Because of their geomorphic position there is a lot of sediment accumulation in this area, comparable to the situation around the workshop some 40 m farther north (see 5.1).

Bronze Age levels were reached in these trenches at a depth of 20 to 50 cm below the surface. They are mainly characterized by the occurrence of bronze slag and pottery fragments, which were easily recognized. In addition to these finds, small pieces of copper ore occurred in trenches 66 and 67. Apparently this part of the site still belonged to the workshop area. This is corroborated by finds of slag and findings of stone settings, which can be interpreted as the base of furnace structures. These rounded structures consist of small and large wadi pebbles and reach diameters around 1 m. Small pebbles (< 10 cm) seem to have been used for paving the area before a round furnace base was built on it of large stones. These findings indicate that a larger area along the base of the slope was part of the Bronze Age smelting installations.

At the northern end of trench 67, black sediment could be retrieved that yielded a radiocarbon date of 2133–2035 cal BC (MAMS-17623, see Table 8.1). This hearth is at a level corresponding to the potential furnace structure mentioned before. Its date is from the final Umm an-Nar period and provides further evidence for Bronze Age smelting activities in this area.

Bronze Age layers and structures in trenches 57–64

Throughout trenches 57–59 a grey level was encountered which only contained Bronze Age pottery (see also Chapter 7). Within these layers there are also smaller structures—for instance, a paved fireplace in trench 57 (Fig. 5.86). In trench 58, a walled post-hole was found, which again most probably belongs to the Bronze Age (Fig 5.87).

In the southern part of trench 57, a fireplace could be radiocarbon dated, yielding a date of 2473–2350 cal BC (MAMS-17624, see Table 8.1). In absolute terms, this Bronze Age fireplace is situated deeper than the Neolithic fireplace in the neighbouring trench 46. This is explained by an inclination of the layers in this area close to the slope. It nevertheless indicates a low rate of sedimentation in the 4th millennium BC, caused by the dry climate during this period (Uerpmann, 2003). The lowermost part of the level with pottery is also dated by two other

Figure 5.84: Furnace in trench 67.

Figure 5.85: Last excavated level in trench 67 (north is to left side).

Figure 5.86: Fireplace in trench 57.

fireplaces in trench 57 (MAMS-17625, see Table 8.1) and trench 60 respectively (MAMS-17626, see Table 8.1). These three fireplaces in trenches 57 and 60 are all on the same level: indicating that the Bronze Age surface in this part of the site was horizontal and parallel to the present surface. The Neolithic level was only a few centimetres deeper.

In trench 59, the Bronze Age layer is less deeply buried and cannot so easily be recognized. This is due to the lower rate of sedimentation at this distance from the slope. Practically no findings were encountered in this trench, while some slag and pot-sherds still occurred. Farther to the west, trenches 60–61 were practically sterile. The geological underground of the wadi terrace was encountered here at a depth of only 10–20 cm. The same is true for trenches 62–64. The only finding in this area was a potential wall in trench 61. It seems to have been built of two rows of stones with small pebbles in between (fig. 5.88). The function, extension, and dating of this wall could not be clarified because of the narrow width of the search trench.

5.6.6 Trenches 68 and 69

These two trenches at the northern border of the site were laid out in order to clarify the situation at the edge of the terrace towards the side wadi where the existence of a fortification was assumed (see Chapter 5.6.2). It is conspicuous that

Figure 5.87: Post-hole in trench 58.

Figure 5.88: Wall in trench 61.

Figure 5.89: Trench 69 after removal of the surface layer (north is to the right).

Figure 5.90: Post-hole under large blocks in trench 69 near the northern terrace edge.

particularly large blocks were encountered at and just below the present surface in trench 69 and towards the northern end of trench 68. Such blocks were not observed near the present surface in other parts of the wadi terrace. They may actually derive from the collapse of the uppermost parts of the assumed fortification wall along the northern wadi edge (Fig. 5.89). Therefore this observation must also be discussed in that context. Actually, there is archaeological evidence for a late accumulation of the large blocks: below some of these blocks in trench 69, a post-hole was encountered which was mounted with stones. This clearly indicates that the large blocks fell onto a settlement surface. Thus, they cannot be part of the geological context of the wadi terrace, but must derive from a collapsed man-made structure. This observation corroborates the evidence from T 69 for a fortification along the northern border of the site (see chapter 4.6.2 and Fig 5.90).

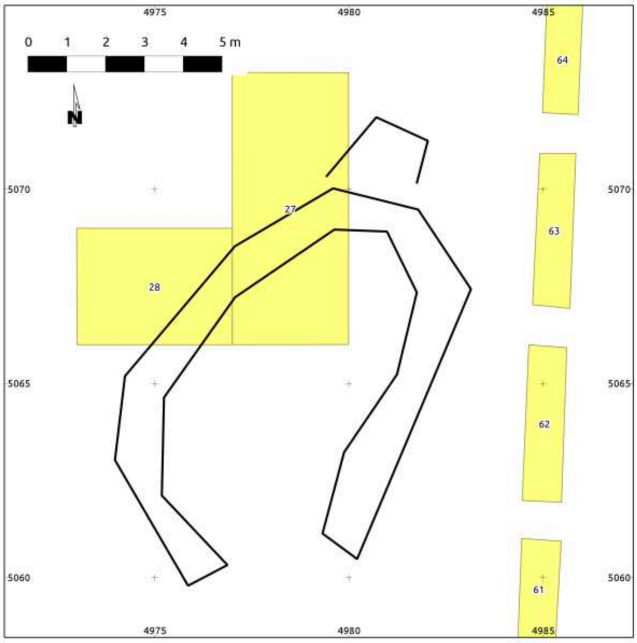

Figure 5.91: Plan of structure 23.

Structure 23

Structure 23 is a round platform with a diameter of about 10 m delimited by a circle built of selected natural stones (see Fig. 5.91). It is situated east of the threshing area in the north-western corner of the site (see paragraph: 11.2).

Unfortunately, the state of preservation is so bad that only the delimiting row of stones can be clearly recognized. Neither do finds from the excavated quadrant of the structure provide a date. As the preservation is worse than in the case of the Islamic buildings farther east, one is tempted to consider structure 23 as older. However, within the larger context of the Islamic village structure, 23 could make sense as the base of a small watchtower comparable to the reconstructed one in the south of the site.

Structure 148

Structure 148 is the base of a quadrangular building of c. 10 x 10 m. It consists of a double wall around a plain surface. A small niche, built of stone, is situated in the south-east. The structure was already visible before excavations started (Fig. 5.92). In the north it was cut by trench 42, indicating that only one layer of stones is preserved. It sits more or less on top of layers containing Bronze Age pottery. Neither a function nor a more precise dating could be derived from the observations in trench 42. Given the fact that no habitation structures of the Iron Age have yet been identified at HLO1, one might assume that this presumably post Bronze-Age building might represent that period.

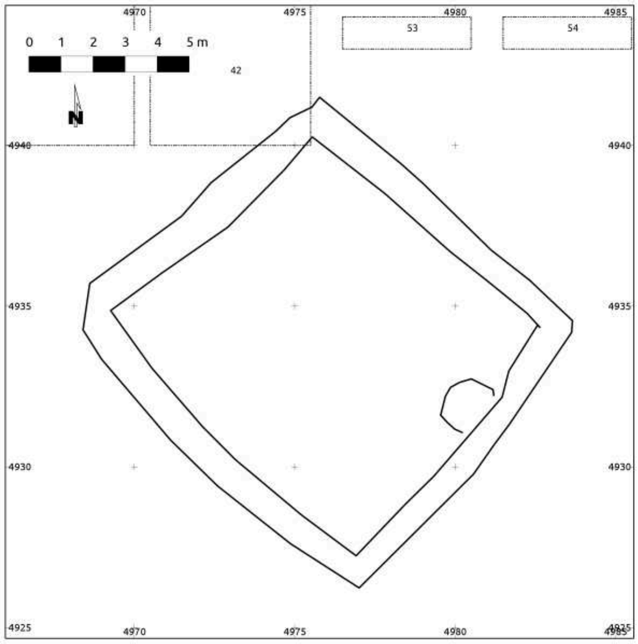

Figure 5.92: Plan of structure 148.

Figure 5.93: Photo of structure 148.

5.7 General conclusions with regard to the Bronze Age period at HLO1

The Bronze Age has left the most obvious traces of an intense occupation of HLO1. According to the present state of archaeological exploration of the area on the old wadi terrace, there seem to have been separate activity areas. Most obvious is the area along the base of the slope south of the excavated workshop. There are indications for further metallurgical activities in this part of the site which indicate that this area was dedicated to copper production.

In area C, however, there may first have been a living quarter as indicated by the house found near the edge of the terrace and close to the upper end of the ramp leading down to the wadi bed and further towards the upper Wadi Hilo. Later on this house was transformed into a workshop, potentially at the shift from the Umm an-Nar to the Wadi Suq phase. It is a pity that up till now no clear remains of living quarters have been found at HLO1. These might be hidden below the sub-modern settlement in the north of the site or under the present village on the other side of the wadi. Indications in that direction are the graves at the western slope and the western smelting area.

Fortifications, most obviously in the form of the Umm an-Nar watchtower at the southern access to the site, indicate the economic importance of the site. Although badly preserved, the assumed fortification wall at the northern wadi edge appears to have been even more labour-intensive than the watchtower. The effort invested in these constructions is an indirect measure of the importance of the site during the Bronze Age. But in spite of these indications of a certain importance, it was certainly minor in comparison to sites like Maysar in Oman. This most probably has to do with the productivity of the local sources of copper ore. Future research will have to clarify whether this also was the case at other sites in the area, indicating that large smelting sites could not exist in this part of the Hajjar mountains.

One important result of the research at Wadi Hilo is the fact that this small scale metal production seems to have been more environmentally sustainable than the smelting at the large scale sites like Maysar. In this region the availability of wood is the limiting factor for the production of metal. In Maysar the the metal production ceased sometime during the Bronze Age because of the lack of trees (personal communication G. Weisgerber). But HLO1 metal was produced from the beginning of the Bronze Age to the Iron Age.

Dating of the metallurgic evidence turned out to be complicated. A first attempt to find charcoal included within the slag failed completely. Several hundreds of crushed fragments of slag did not yield a single piece of charred wood. Another possible way to date slag is described by Haustein (2001) and Haustein et al. (2001, 2003). This approach is based on the luminescence of grains of quartz included in the slag. However, the slag at HLO1 was melted completely and, while cooling, it solidified like glass without a crystalline structure. Thus, no quartz grains could be extracted. According to Haustein and Krbetschek (2002), direct dating of glassy slag is not possible. However, as described above, a piece of furnace wall covered with slag could be dated by thermoluminescence and yielded a Bronze Age date. Another direct date was obtained by radiocarbon dating of one of the green layers ("green carpets") in the workshop area (see Sec. 5.1) . The date is quite early (Hafit period) and thus indicates metallurgic activities at HLO1 during the very beginning of the Bronze Age in SE Arabia. This possibly suggests a very early beginning of the occupation and use of the site. This already included metallurgical activities, starting during the Hafit period of the very early Bronze Age. This is most important with regard to the metal finds from aceramic shell middens along the coast of the Gulf of Oman. The finds from HLO1 are the first evidence for potential local smelting of the pure copper used for these fish-hooks.

Apart from pottery finds, there is no direct date for Late Bronze Age metallurgy at HLO1. In principle this is also true for the Iron Age, but there is at least stratigraphical evidence from the workshop in Area F, in the form of many pitted crushing stones, for metallurgical activities during the Iron Age, at a time when the walls of the Bronze Age workshop were already eroded. The Islamic period is also represented by pottery finds, but no evidence for metal production during that time has yet been discovered.

5.8 Animal remains from HLO1

5.8.1 Mammal bones from HLO1

Preservation of animal bones at HLO1 is generally poor. The few bone fragments which could be recovered are quite small. The better preserved ones were identified by Margarethe Uerpmann. Most of them probably represent small ruminants without further indications as to which of the five species of this group occurring in the area (domestic sheep and goat, gazelle, thar, and wild goat) they belong. Two jaw-bones represent small domestic ruminants (sheep or goat). In one of them, the third molar is erupting while the other has abraded premolars indicating advanced age. Some bones, coming from the "green horizons", are better preserved because they are impregnated with "copper".

There are only few finds from larger animals. From structure C there is a cattle tibia. The Bronze Age layer at trench 67 yielded a second phalanx of a donkey. In spite of their singularity these two finds are most important because they indicate that large domesticates were available at the site for transportation purposes. Unfortunately, because of the small amount of animal remains it is impossible to draw further conclusions, e.g., with regard to a seasonal utilization of the site.

5.8.2 Molluscs from HLO1

More than 200 shells and shell fragments of molluscs were discovered during the excavations at HLO1. The mollusc finds of the seasons from 2007 to 2009 were identified by James Nebelsick (Tübingen). Their diversity is quite low and comprises the marine gastropod *Terebralia palustris*, some oysters, a few other marine bivalves, and one scaphopode. In addition, there were two coral fragments. Oysters and terebralia, which close their lids firmly when out of the water, were probably brought to the site as food. The nearest occurrence of both species is on the east coast. Therefore they indicate connections in that direction. From there they could be carried fresh to HLO1. However, both species occur on the west coast as well, but if brought to HLO1 from there only the shells and not the flesh would have reached the site. The consumption of molluscs is also indicated by traces of fire on one of the terebralia shells. Apart from the marine species there is a large number of shells from small terrestrial gastropodes which occur naturally on the site. They do not belong to the anthropogenic remains.

6 The Iron Age at HLO1

The site HLO1, and Wadi Hilo itself, was also used by the Iron Age population of the larger area, whose presence at the site is indicated by finds of pottery and by radiocarbon dating. There are about 200 pieces of identified fragments of Iron Age ceramic, which is about one-half the amount of the Bronze Age pottery found there. It is clear that, according to current knowledge, the Iron Age inhabitants used the same structures at HLO1 as the Bronze Age occupants.

6.1 Iron Age use of the workshop in Area F and of the house in Area C

As described in previous chapters, the workshop in area F was used from the Hafit period onwards. The lower sediments in this area yielded nothing but Bronze Age pottery. A second phase of use is indicated by Iron Age pottery. This pottery is found together with a large number of pitted crushing stones. A detailed description, also with regard to the Iron Age, is found in the general workshop chapter (see Chapter 4.1). The use of the workshop in the Iron Age is corroborated by a radiocarbon date of 704–504 cal BC, Hd-29111, see Table 8.1). The addition of a new room to the workshop (room 5; see Section 4.1) is the only well documented evidence for Iron Age architecture at the site. A fireplace in trench 55 in the south of the site also yielded an Iron Age radiocarbon date of 510–409 cal BC (MAMS-17622).

As in the case of the workshop in Area F, the house in area C was built in the Bronze Age and used again, with some modifications, in the Iron Age. A description of the history of the house in area C is found in Chapter 4.2.

6.2 Copper smelting in the Iron Age

The horizon of pitted crushing stones in the workshop (Area F) is an indirect confirmation of Iron Age smelting activities at HLO1. However, it is impossible to exclude the possibility that the Iron Age inhabitants did not (exclusively) smelt the local copper ore, but rather used the Bronze Age copper slag as raw material by extracting the copper inclusions of the old slag. This sort of "mining" old slag has been described for Maysar (Hauptmann, 1985). Because of the missing archaeological evidence for metallurgical activities of the Iron Age, such as furnaces or dated slag concentrations, a more detailed evaluation of Iron Age metallurgy at Wadi Hilo is not possible.

6.3 Conclusions with regard to the Iron Age at HLO1

Archaeological evidence for Iron Age activities is only found sporadic at HLO1 in certain areas. Up to now, the excavations have indicated that buildings of the Bronze Age were re-used. Possibly some structures visible at the surface in the south of the site are exclusively from the Iron Age (e.g., structure 148 in area G). However, this will remain an assumption as long as no further data are available.

7 The Neolithic occupation at HLO1

The Neolithic is discussed here after the younger periods because it is not related to ore extraction and metallurgy, which are the main focus of this dissertation. Its discovery was unexpected because no hints about this period were discovered at the site before the excavations. Radiocarbon dates on black ash from large fireplaces in the southern part of the site HLO1 yielded firm evidence that the site had already been visited during the Neolithic period (see Table 8.1). They clearly extend the time range, initially known from a single date in the north of the site (trench 46), which indicated that HLO1 was already visited during the Neolithic period.

The Early Holocene radiocarbon dates from the large fireplaces in trenches 41 and 42 (see Chapter 5.6.4) are first indications that Neolithic people might have lived at the site for quite some time. In order to further explore this potential phase of settlement at HLO1, four search trenches (trenches 53–56) were dug during the 2012 season of excavations and laid out between trench 42 and the slope to the east. As expected, the rate of sedimentation was higher towards the slope. Therefore further trenches (65–67) were opened. A curved stone structure appeared in the assumed Neolithic stratum of trenches 55, 56 and 65. In order to further explore this structure (H), trench 70 was opened at the junction of the two trench lines. The exposed area indicates that the structure may have been a paved platform (see below).

Another radiocarbon date indicating an occupation of HLO1 during the 5th/6th millennium BC came from trench 46 in the northern part of the site. Therefore trenches 57–64 were laid out in order to explore the stratigraphic context of this early date. As in the south, the Neolithic layers are not easily differentiated from the layers above and below. A major difficulty arises from the extreme rarity of anthropogenic finds in the obviously aceramic layers.

7.1 Neolithic layers in the south of the site

The Neolithic layers corresponding to the radiocarbon dated fireplaces in trenches 41 and 42 are separated from the Bronze Age layers above them by only a few centimetres of fairly fine-grained sediments. The lack of pottery finds, which characterise the Bronze Age layers, was nevertheless a useful stratigraphic indicator.

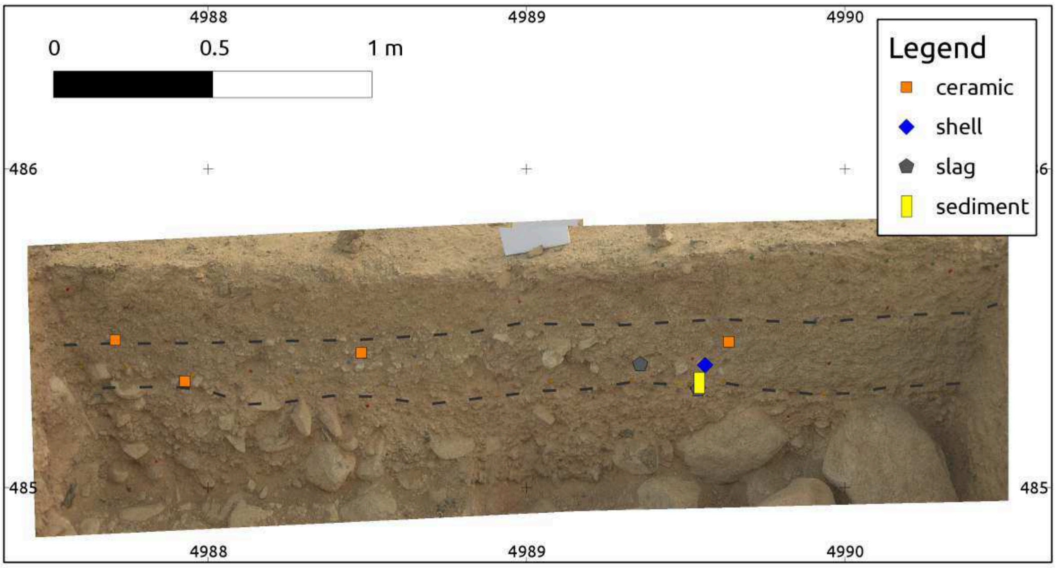

Figure 7.1: Northern section of trench 55. The dashed lines indicate the layer with pottery. The stones at the base of the trench are part of the Neolithic structure.

Below the Neolithic layer there are the old sediments of the wadi terrace, mostly consisting of fairly large well rounded wadi pebbles within a sandy to gritty matrix.

With increasing rates of sedimentation towards the slope in the east, the separation of the Neolithic layers from those of the Bronze Age becomes easier. In trench 56, about 70 cm of younger sediment were observed above the Neolithic layer. In addition, the Bronze Age layer has a marked greyish colour in trenches 54 and 55, which is also visible northwards in trenches 65–67.

Below this grey stratum, there is a reddish layer. Apart from two hearths in trench 56 and structure H (see below), there are almost no finds or findings from trenches 54, 55 and 70. This can be recognized in Fig. 7.1 showing the southern section of trench 55. From the modern surface to a depth of c. 20 cm, there are no finds. Presumably this layer was formed after the Bronze Age when this part of the site was not intensly used by people. Below these surface deposits, there is a layer with some few pottery finds. In addition, there is a fireplace in the western section. Its ash produced a radiocarbon date of 2411±18 (MAMS17622, see below and Table 8.1). The Neolithic layers start below this feature. They contain very few finds but include parts of structure H, which is clearly a man-made feature.

7.2 Structure H

Structure H already became visible in search trenches 55 and 56, where a number of large stones were observed in a fairly fine-grained matrix. They created the impression of belonging to a rounded structure, which stratigraphically was clearly below the Bronze Age horizon. This upper horizon was distinctive in colour and contained pottery. For clarification, trench 70 was opened in order to see a larger part of this structure (see Fig. 7.2).

Pottery and slag were also found in the upper three removals of trench 70. Removal 4 did not produce any finds, while removal 5 again made stone structures visible at the same depth where they were found in the search trenches. They consist of curved settings of small to medium-sized wadi pebbles. In the south there seems to be a thick wall. A single flint artefact was found on this "platform", which is consistent with a Neolithic date. However, apart from being an artefact with several negatives of removed flakes, the find is not characteristic at all. It was found near the black and white marker in the centre of the trench. A closer view is given in Fig. 7.3 together with a picture of the flint find.

7.3 Eastern part of trench 56

The eastern and southern sections of trench 56 cut through two interesting ash lenses. One of them is dug in from the gray layer. A few centimeters below there is another ash lens which clearly is stratigraphically older (Fig. 7.4). The upper ash lens in the south section has a radiocarbon date of 2431–2243 cal. BC (MAMS-17621). The second ash lens, some 5–6 cm lower in the eastern section, yielded a date of 3012–2926 cal. BC (MAMS-17620; see Table 8.1). These fireplaces are situated at the base of the slope where the rate of sedimentation is higher than farther away from the slope. It was around 5 cm in 500–800 years, as an estimation based on the radiocarbon dates. Towards the flat area in the west this rate is much lower.

7.4 Neolithic layers in the northern part of HLO1

Neolithic layers were also encountered in the northern area of the site. Already in 2011, an ash lens was encountered in trench 46, which yielded a 6th millenium BC radiocarbon date (Fig. 2.58 and Table 8.1; MAMS-15105). As in the southern part of the site, the natural accumulation of sediments is most pronounced in this area close to the base of the slope. Thus, the Neolithic ash lens is buried here under c. 1 m of younger sediments. Interestingly, the texture of the layers in this part of the site is similar to that in the southern area: the Bronze Age layers are grey-coloured and contain pottery, whereas the Neolithic layers are yellowish and aceramic. They could easily be followed in the search trenches 57–59, which were opened northwards from the northern corner of trench 46 along the axis of the sub-recent "Tobacco shed" (see Chapter 11).

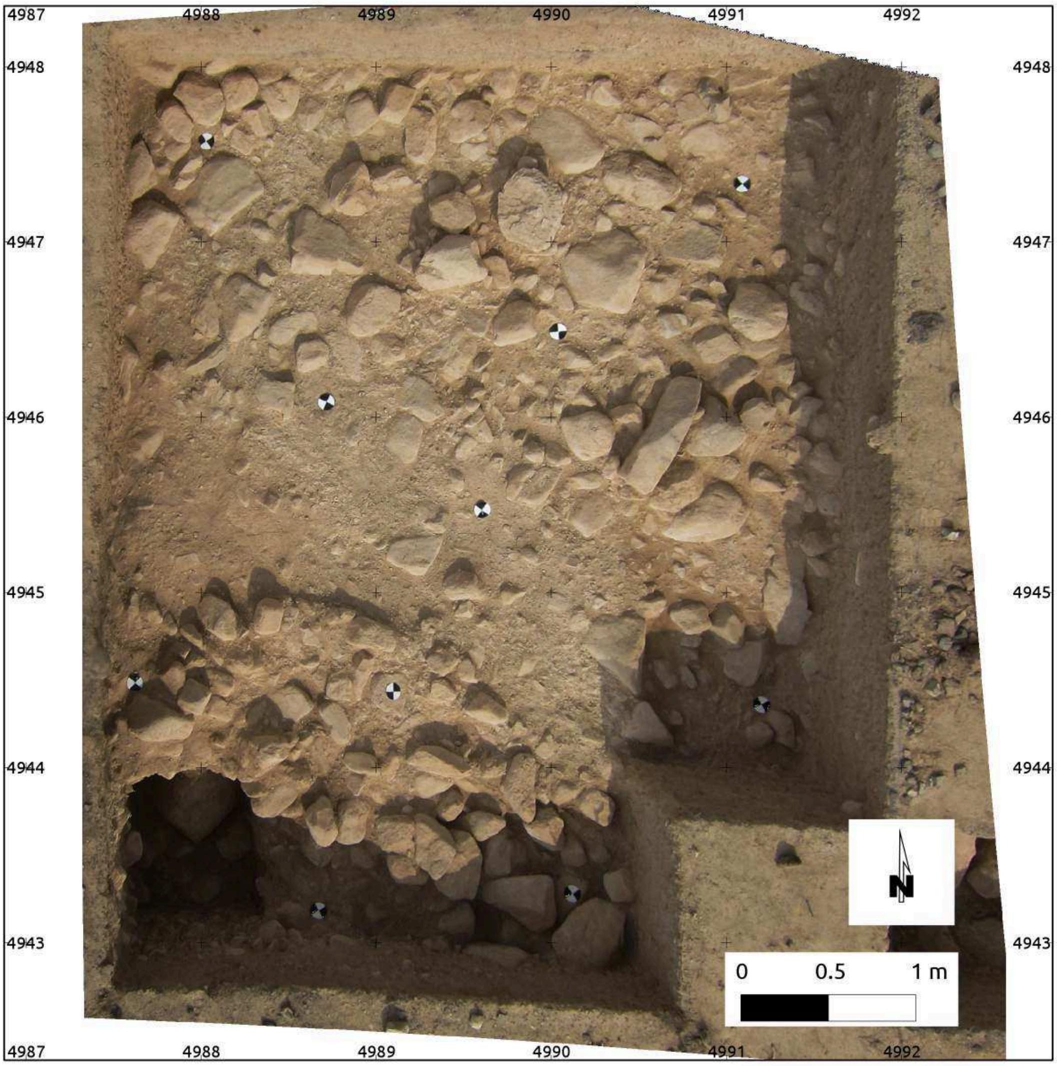

Figure 7.2: Neolithic structure in trenches 55, 65 and 77.

Figure 7.3: Flint artefact and its find spot seen from the east side of the trench.

Figure 7.4: Two radiocarbon dated fireplaces in trench 56 seen from north.

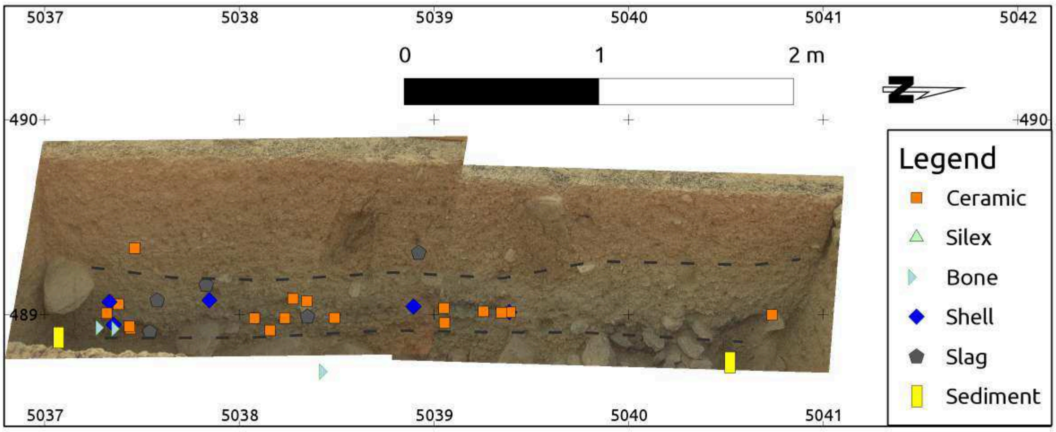

Figure 7.5: East section (mirrowed) of trench 57.

7.5 Conclusions with regard to the Neolithic period at HLO1

The Neolithic contexts discovered at HLO1 are clearly distinct from other Neolithic sites in the wider area. Generally, these are characterized by large amounts of flint artefacts, like for example FAY-NE15 in the Central Region of the Sharjah Emirate (Uerpmann et al., 2012). This site is directly connected to the natural occurrence of rich flint sources in the respective areas (e.g. Uerpmann et al., 2008). Such ressources do not exist at Wadi Hilo nor in the wider neighbourhood. Flints, as the most important raw material during the Neolithic, must have been brought to the area from far away. It will have taken at least a day's journey from Wadi Hilo to reach the nearest known flint sources at Jebel Rawda near Hatta. The assumption that this material was quite precious at sites within the ophiolithic parts of the Hajjar Mountains is a probable reason for the scarcity of flint finds in the Stone Age layers at HLO1.

Judging from the large fireplaces and the stone structures described above, it is unlikely that the small amount of flints indicates an only ephemeral use of HLO1 during Neolithic times. The *in situ* stone structures found in the southern part of the site and the chronological depth of the Neolithic radiocarbon dates are clear evidence for an intense use of the area during the first millennia of the post-glacial period. This is to be understood within the framework of palaeo-economic considerations on the SE Arabian Neolithic: based on the findings at BHS18 (Uerpmann and Uerpmann, 2008), Neolithic subsistence in this area was based on pastoral nomadism without agriculture. The mountain areas must have been important for this nomadic population as they provided water and pasture during the hot season. This even may have been the case during the 4th millennium BC, when the desert areas in the interior became inaccessible to the Neolithic herders and when known human presence in this part of Arabia was restricted to the coastal areas along the Gulf of Oman (Uerpmann, 2003). The observations at Wadi Hilo may actually be of more general importance insofar as they could indicate the presence of many more Neolithic sites in the Hajjar Mountains of Oman and the Emirates, which have not yet been recognized because of the very low density and the uncharacteristic nature of the artefacts left behind by this population.

One clue for the frequent use of the site HLO1 in the Neolithic period may be the big fireplace filled with very dark sediment. The size and colour of the hearth shows that it was used not only once but rather frequently. HLO1 surely was a good place to stay, and it might also be the case that the fireplace was used during ritual procedures. This was also the case at the Neolithic site BHS18, some 40 km west of HLO1.The fireplaces there are associated with a spring and a graveyard with hundreds of human burials. Around the graveyard, many rather huge fireplaces with such dark sediments, quite similar to the fireplace in HLO1, were excavated (Uerpmann and Uerpmann, 2008).

As a final conclusion, it should be pointed out that these far-reaching conclusions on the early history of the whole area only became possible through systematic radiocarbon dating of fireplaces as indicators of human activity, even if they were not directly connected to other findings. The other important conclusion about the origins of metallurgy in the area is the potential evidence for population continuity from the Neolithic to the Bronze Age, which has to be discussed in the conclusions of this dissertation.

8 Radiocarbon dating of HLO1

A total of 18 radiocarbon dates were measured for the site of HLO1, based on 16 sediment samples and two marine mollusc shells (Table 8.1). The sediment samples were taken from black ash from fireplaces whereas the shells came from archaeological layers. As they were of marine species, their presence at the site had to be due to transportation by the inhabitants. The samples were measured by Dr. B. Kromer, first at the radiocarbon laboratory of the University of Heidelberg and later at the Klaus Tschira Laboratory in Mannheim.

The program OXCAL 4.2 (Ramsey, 2013, 2009) was used to calibrate the measured ^{14}C-values. The ash samples were calibrated with the calibration curve IntCal09. For the marine samples, the curve Marine09 (Reimer et al., 2009) was used. For marine samples, it is important to take into account the reservoir effect of the marine environment (see Uerpmann, 1990; Uerpmann et al., 2013a; Zazzo et al., 2012). As remarked by Uerpmann, shell dates from eastern Arabia are generally older than charcoal dates from the same archaeological contexts in spite of using the marine calibration curve (Uerpmann et al., 2013a). This is due to a particular reservoir effect of the northern Indian Ocean, which depends on the varying strength of the Indian Ocean Monsoon (IOM). Whereas this reservoir effect can be up to 400 years at peak times of the IOM, it decreases during periods with lower monsoon activity. For the shell dates from HLO1, a reservoir correction of ΔR 200±50 was applied. Table 8.1 also contains the uncorrected shell dates to allow for re-calibration once a more precise correction value becomes available.

The radiocarbon ages for HLO1 span the time from c. 8000 to 500 cal BC, although with large gaps. Nevertheless, they include the Neolithic period, the Bronze Age, and the Iron Age. The distribution of the ^{14}C dates from HLO1 is shown in Fig. 8.1. Up till now, HLO1 is the only Neolithic site in the Hajjar Mountains. Probably this is due to the lack of archaeological research in the mountain areas of NE Arabia. So far, the most complete sequence of Neolithic habitation in SE Arabia was explored in the Central Region of the Sharjah Emirate, indicating human presence in this area from the 9th to the very beginning of the 4th millennium BC (Uerpmann and Uerpmann, 2009). According to the available evidence, the Neolithic populations were nomads, depending on their domestic cattle, sheep, and goats on the one hand, and on gathered vegetables on the other. It was implicitly assumed that the mountains were part of their seasonal migrations, but the anthropogenic radiocarbon dates from Wadi Hilo are the first proof of this assumption, in particular because their sequence already starts in the early Holocene and appears to be more or less continuous until the Bronze Age. Problematic ^{14}C dates which can occur when people used wood that is not

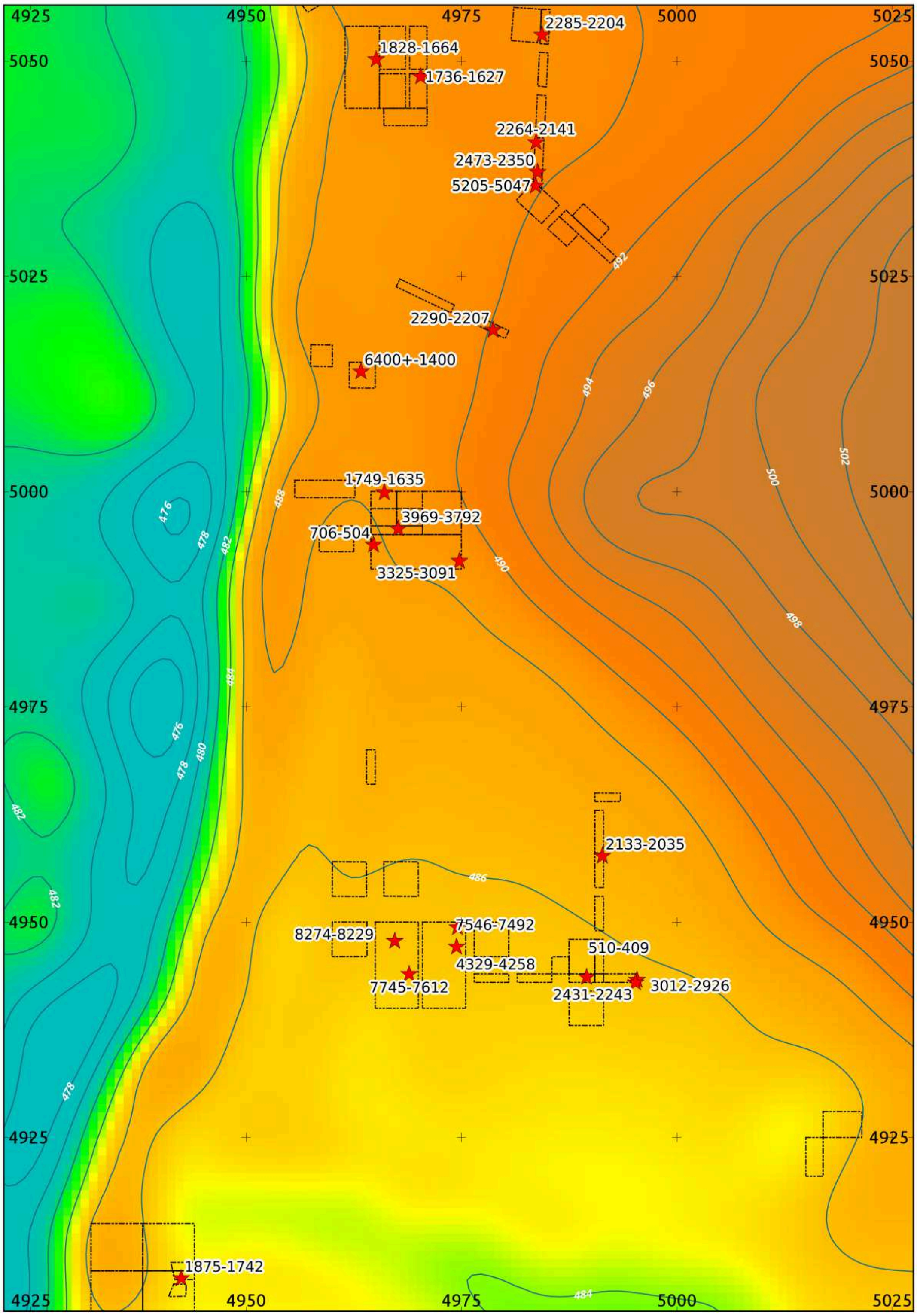

Figure 8.1: Distribution of the radiocarbon dates from HLO1.

Table 8.1: ^{14}C-dates from HLO1. The calibrated shell dates are corrected with ΔR 200±50

Lab. No.	Find No.	^{14}C age BP	δ^{13}C	cal BC	
				1σ	2σ
Sea shells (ΔR 200±50)					
Hd-29111	11056	2992±24	-16.0	704-502	738-404
Hd-29112	16343	3958±24	-9.2	1828-1664	1899-1592
Sediments					
Hd-27744	6138	3383±39	-21.5	1736-1627	1768-1532
Hd-27743	7283	3408±41	-22.1	1749-1635	1875-1610
Hd-26446	1603	3470±34	-24.6	1875-1742	1884-1690
Hd-27591	6263	3824±15	-25.6	2290-2207	2335-2200
Hd-28956	8742	5094±82	-35.7	3969-3792	4048-3669
MAMS-15102	17167	9002±36	-4.1	8274-8229	8291-7998
MAMS-15103	12141	8709±32	-8.8	7745-7612	7815-7599
MAMS-15104	12260	4471±26	-30.3	3325-3091	3335-3026
MAMS-15105	12422	6153±28	-19.1	5205-5047	5209-5015
MAMS-15106	17156	8441±33	-11.5	7546-7492	7576-7478
MAMS-15107	17171	5420±28	-28.4	4329-4258	4336-4237
MAMS-17620	18241	4373±20	-25,2	3012-2926	3082-2916
MAMS-17621	18218	3855±19	-23.0	2431-2243	2460-2209
MAMS-17622	18054	2411±18	-27.6	510-409	716-403
MAMS-17623	18393	3693±19	-19.0	2133-2035	2141-2025
MAMS-17624	20073	3928±19	-19.3	2473-2350	2476-2344
MAMS-17625	20186	3768±20	-21.3	2264-2141	2284-2064
MAMS-17626	20207	3805±19	-26.2	2285-2204	2297-2147

contemporary but already old when they burn it in their fires, can be excluded because of the very poor preservation of wood in the Emirates due to insects which feed on dead plant material and climatic factors (pers. comm. H.-P. Uerpmann).

Detailed descriptions of the locations and contexts of the samples are given in Section 5.

Table 8.2: Historic periods after Begemann et al. (2010); Uerpmann et al. (2013a); Velde (2003).

Period	Date
Early Islamic	c. 800–1100 AD
Iron Age	c. 1250–500 BC
“Late Bronze Age”	c. 1600–1250 BC
Wadi Suq (Middle Bronze Age)	c. 2000–1600 BC
Umm an-Nar (Early Bronze Age)	c. 2600–2000 BC
Hafit (Chalcolithic)	c. 3000–2600 BC
Final Coastal Neolithic	c. 3900–3000 BC
Neolithic	c. 9000–3900 BC

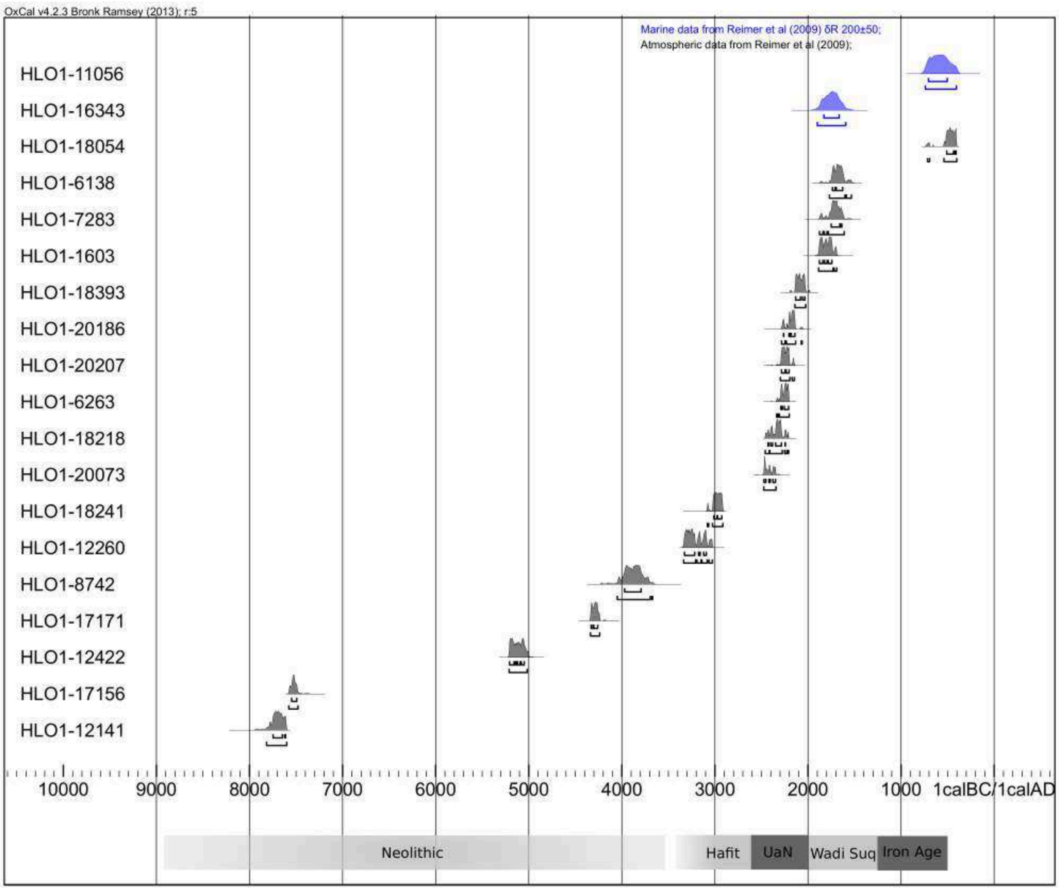

Figure 8.2: Radiocarbon dates for HLO1.

9 Pottery-finds from HLO1

Pottery finds are most important for chronological assessments, both during the excavation where they support stratigraphic interpretations, and during the evaluation of the materials, where they help to separate "clean" from mixed horizons. Ceramic finds from the seasons 2008, 2009 and 2011 were analysed by Christina Neureiter. The classification of the finds followed established pottery descriptions (see Rice, 1987; Barker, 2002). A summary of the results is included in Kutterer et al. (2013) and will also be presented below.

As a means of stratigraphic control during the excavations, a first classification of ceramic finds was entered into the database when the coordinates of a potsherd were recorded in the field computer. The categories used in the respective field of the database were "Umm an-Nar" for the Early Bronze Age and "Wadi Suq" for the Middle Bronze Age or "Umm an-Nar/Wadi Suq" for specimens which could not be identified further. Three finds were classified as "Late Bronze Age" (sensu Velde, 2003), representing the badly known period between the Wadi Suq phase and the Iron Age. Iron Age pottery was not subdivided further. Probably most of it belongs to the Iron Age II. All pottery finds thought to be younger than the Iron Age were entered as "Islamic". This is based on the fact the finds themselves do not provide characteristics for a subdivision, and on the observation that nothing indicates the presence of finds from the periods between the Iron Age and the early medieval period.

The spatial period of the pottery finds within particular structures was described and discussed for the individual structures in Chapter 5. A chronological summary of pottery finds is given in the following Table 9.1. Most of the pottery is fine ware and made on a potter's wheel. About one-tenth of the finds are painted pottery. Drawings of a selection of the pottery finds are found at the end of this chapter.

The total number of pottery finds is 1650, which is very low in comparison to other excavated sites of the same periods. This might indicate that the living quarters of the people working at the smelting site were not included in the excavated areas.

Table 9.1: Total amounts of pottery finds according to period

Period	Quantity (n)
Islamic	345
Islamic?	36
Iron Age	194
Iron Age?	65
Late Bronze Age	1
Late Bronze Age?	2
Wadi Suq	206
Wadi Suq?	48
Umm an-Nar / Wadi Suq	83
Umm an-Nar?	64
Umm an-Nar	336
unkown	270

9.1 Documentation of the pottery

The drawings of the ceramic finds from HLO1 were produced by Susanne Stöckl.

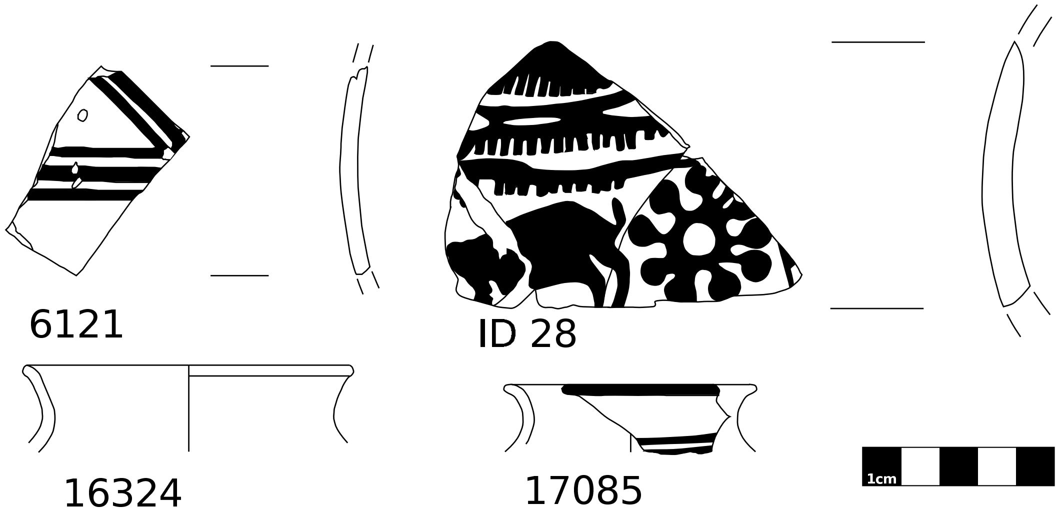

Figure 9.1: Umm an-Nar pottery from HLO1.

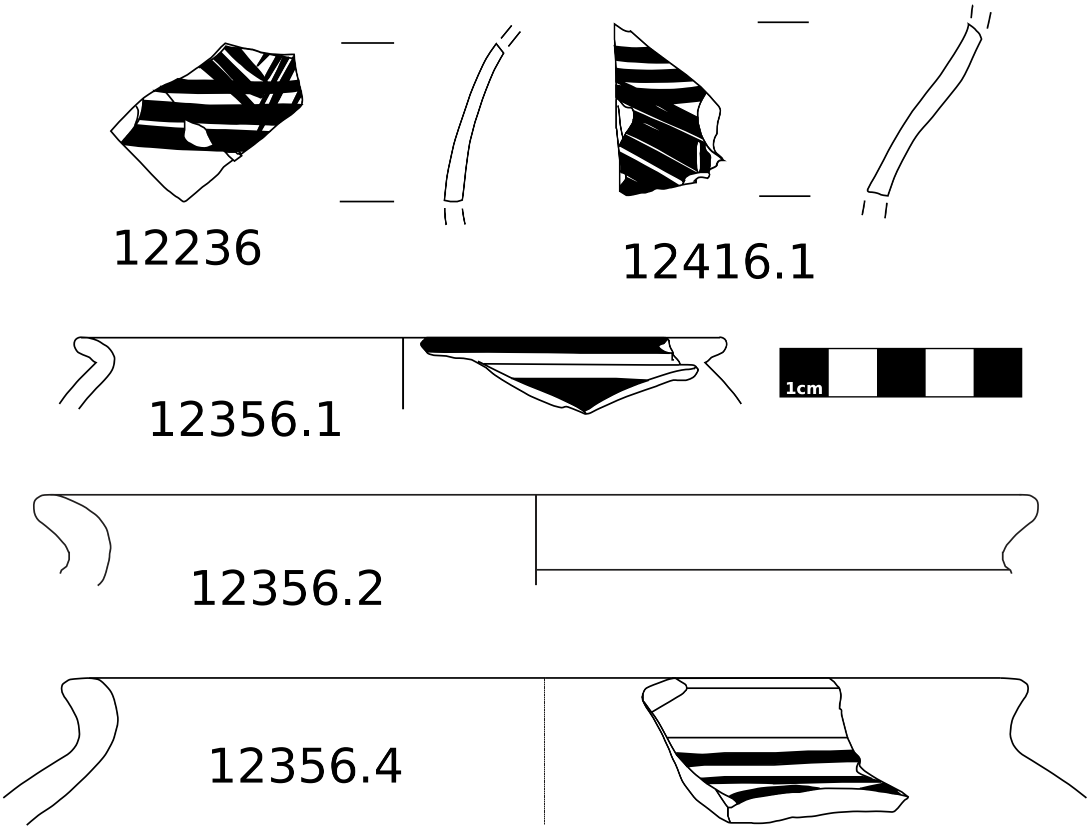

Figure 9.2: Umm an-Nar / Wadi Suq pottery from HLO1.

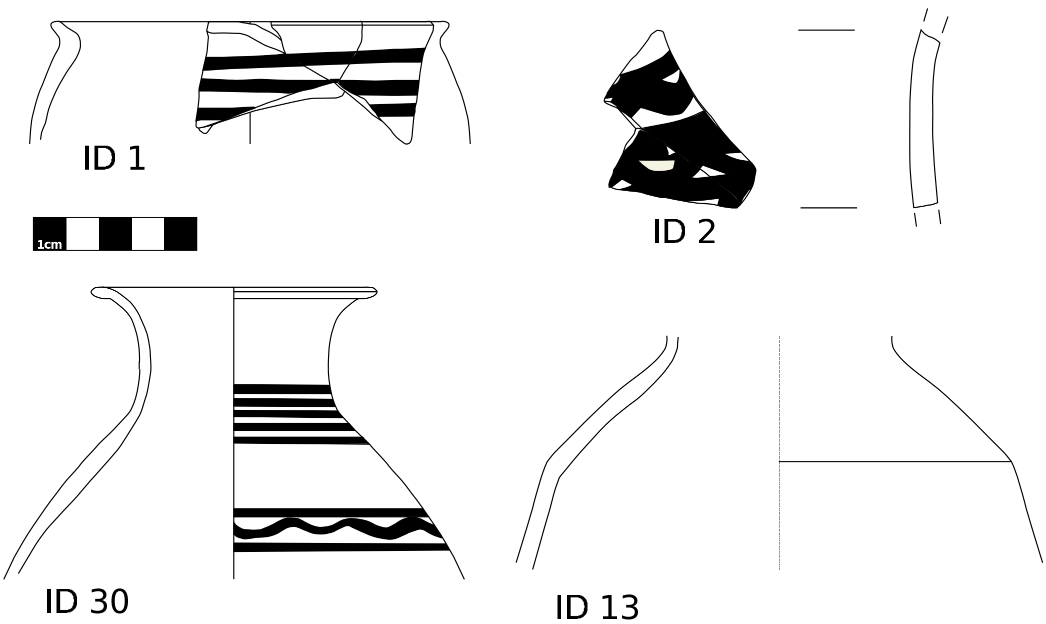

Figure 9.3: Wadi Suq pottery from HLO1.

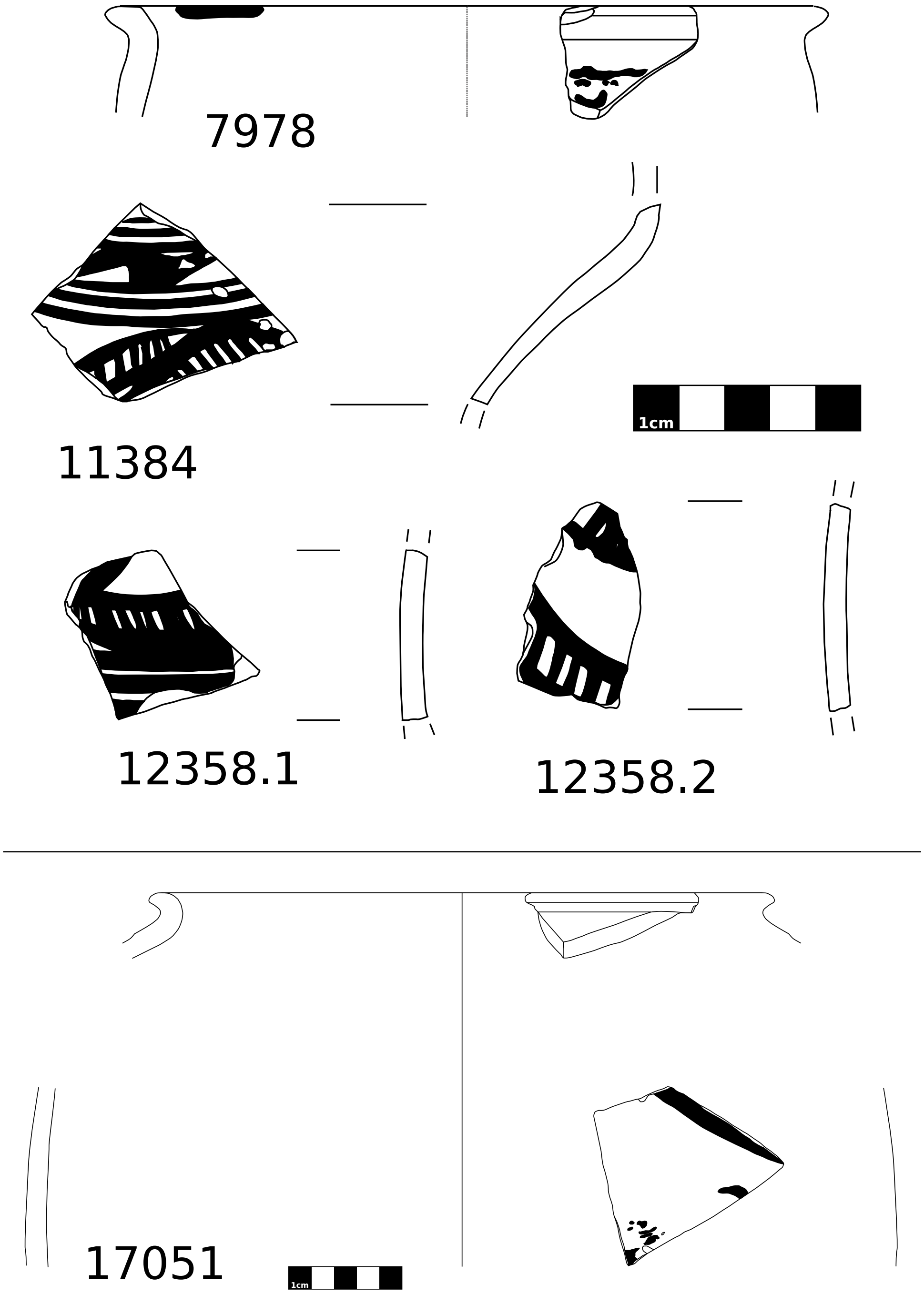

Figure 9.4: Wadi Suq pottery from HLO1.

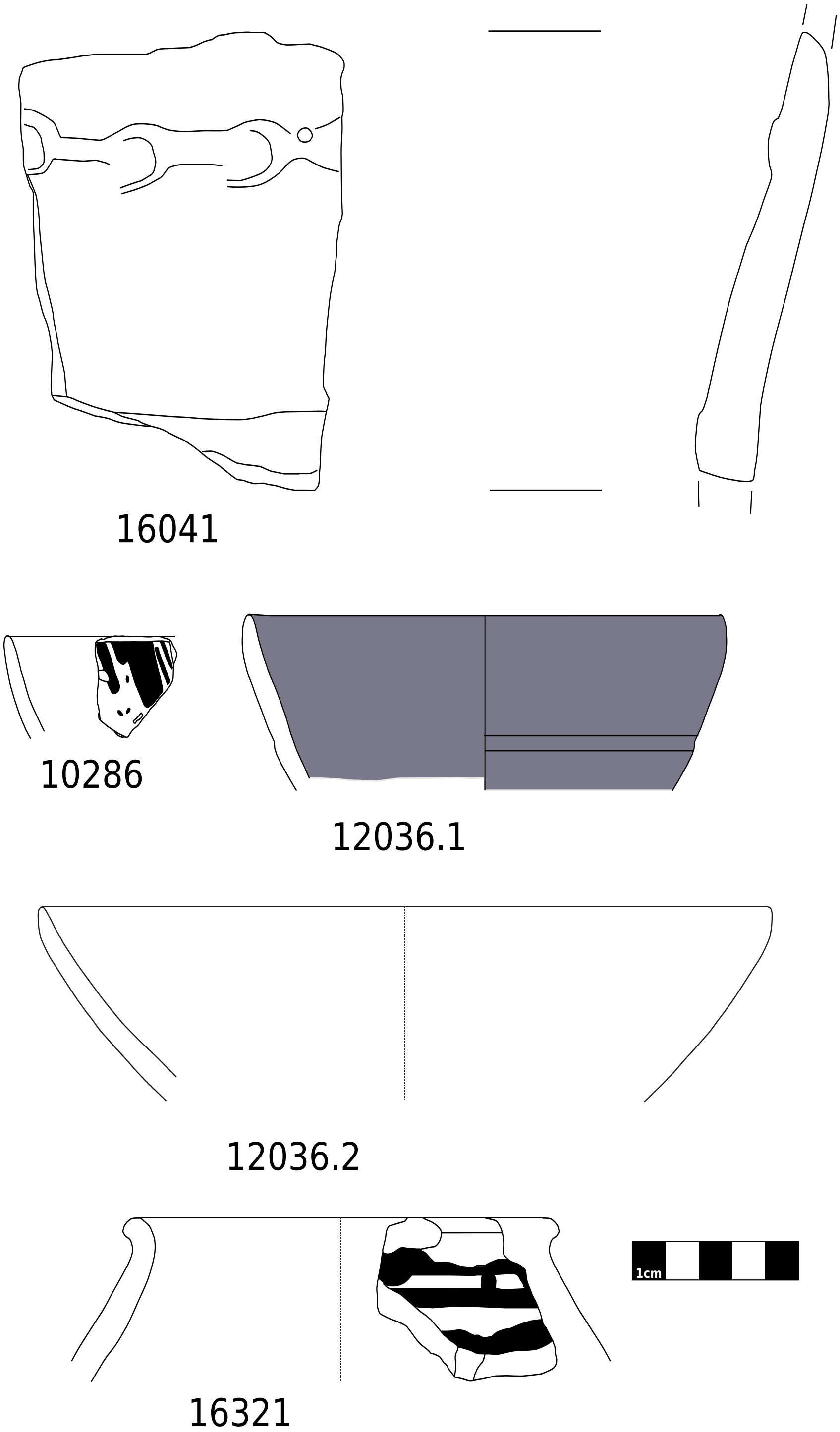

Figure 9.5: Iron Age pottery from HLO1.

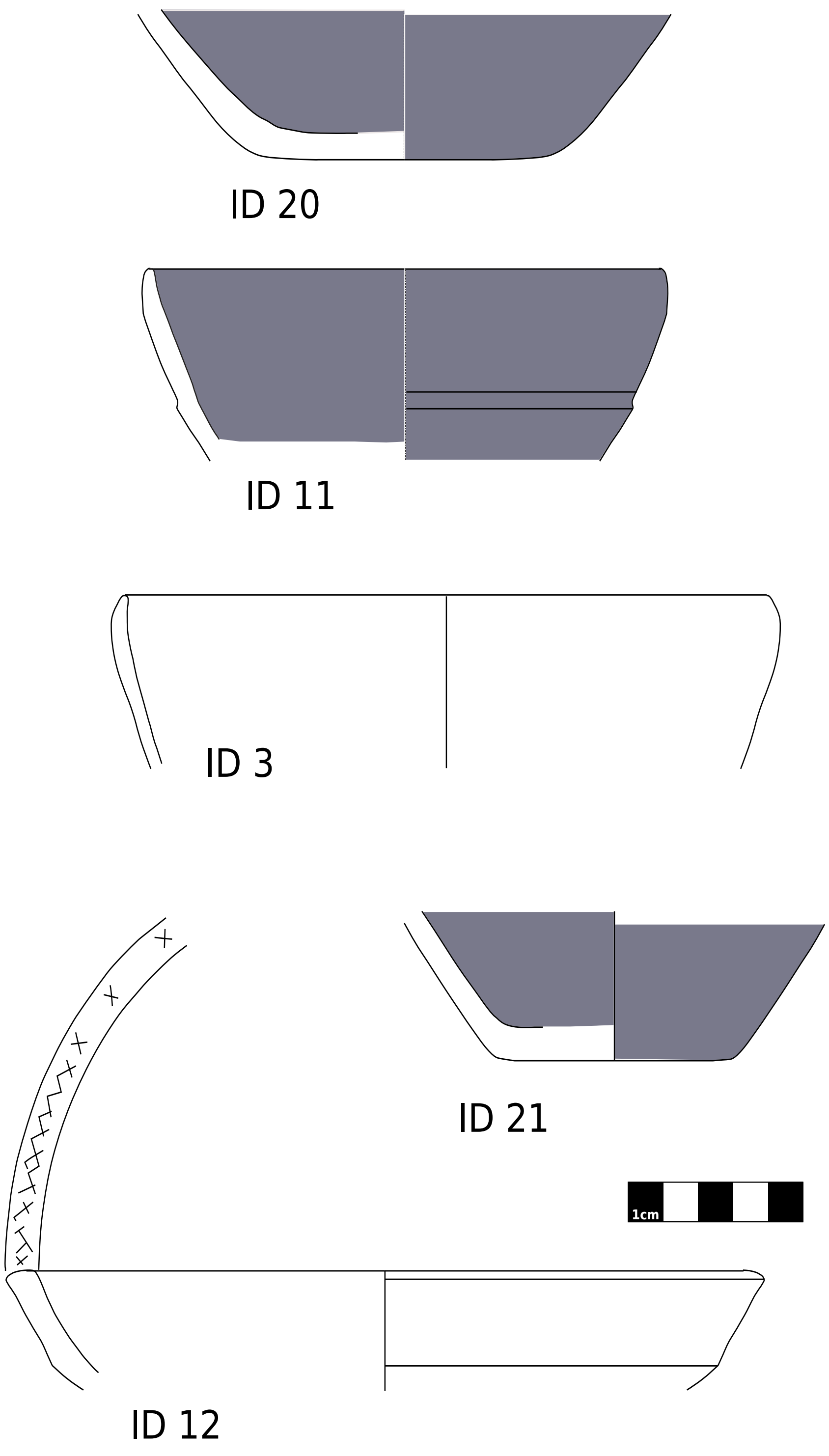

Figure 9.6: Iron Age pottery from HLO1.

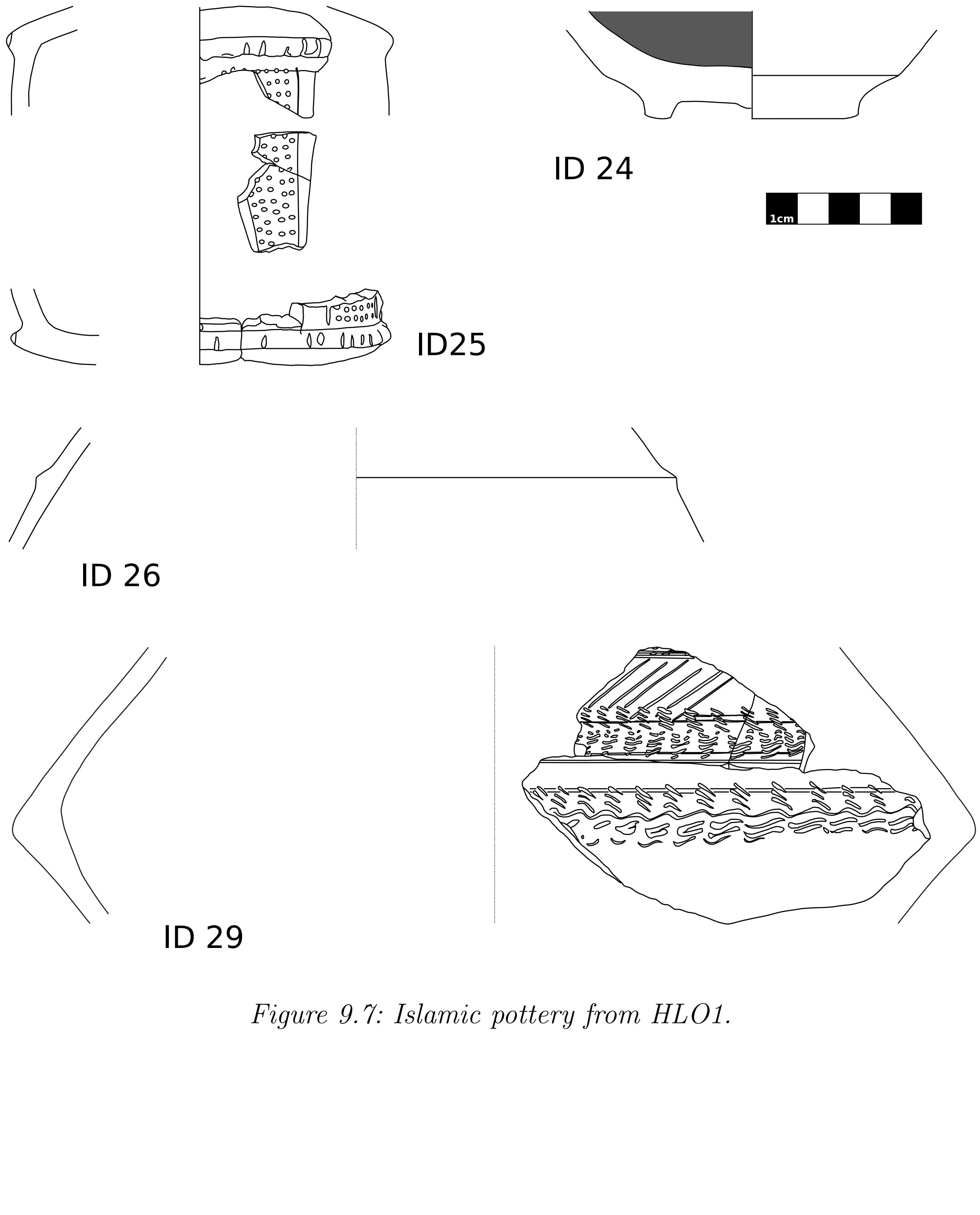

Figure 9.7: Islamic pottery from HLO1.

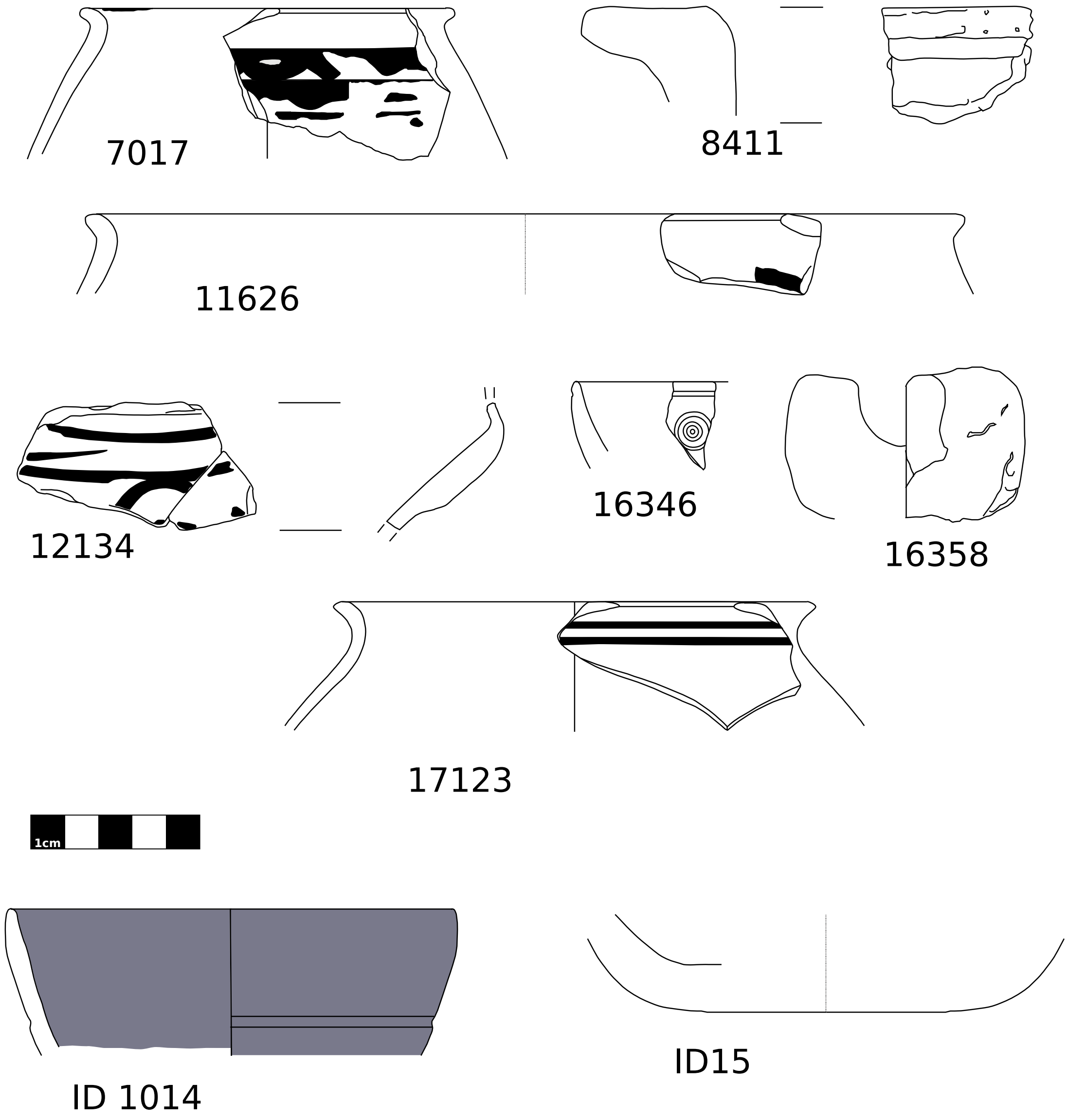

Figure 9.8: Undated pottery from HLO1

10 Results for the prehistoric periods

Excavations at HLO1 yielded unexpected results insofar as human presence at the site was not only discovered for the Bronze and Iron Age and the historic period but also for the transitional time from the Neolithic to the Bronze Age and for the Neolithic itself. Obviously, the favourable ecological conditions provided a base for human subsistence during most of the time since the end of the last Ice Age. This is reflected in the radiocarbon dates obtained at HLO1.

For the Neolithic period in particular, human presence at the site is only conceivable when considering the radiocarbon dates. They reach from the 8th to the 4th millennium BC. The large fire-pits, filled with ash and charcoal, indicate repeated periods of use during the 8th millennium BC. This goes well with assumptions about a nomadic way of life of early Neolithic herders (Uerpmann et al., 2010, 2013b; Uerpmann and Uerpmann, 2003), which did not leave much traces at particular sites. However, the rounded stone pavement discovered at HLO1 apparently belongs to this period, but does not provide insight into its functions. The same is true for the few flint artefacts from pre Bronze-Age levels. None of them allows chronological or functional conclusions. Nevertheless, the lack of flint artefacts in this area is an important observation. Obviously it is caused by the lack of flint resources in the Hajjar Mountains, which explains why surveys and other archaeological activities in this area up till now never provided evidence for the occurrence of Stone Age sites.

A radiocarbon date of 3325 to 3091 BC (1σ, see Table 8.1) for a layer which indicates processing of copper ore, is to date the oldest indication of metallurgical activities in SE Arabia. It might indicate that the earliest finds of copper artefacts in the area, fish-hooks found on shell middens in Oman, were produced locally. As assumed by Uerpmann and Uerpmann (2003), such coastal populations seasonally used the adjacent mountain areas for grazing their herds. The findings from HLO1 are a first indication that this assumption is correct. Based on these observations, one might speculate that people with an intimate knowledge of the mountains behind their coastal sites may have directed early prospectors to occurrences of copper ore within the ranges of their seasonal movements. This is also important for the question concerning the origin of the copper used during the Hafit phase of the Early Bronze Age. The findings at HLO1 indicate that this copper could have derived from local production in the Hajjar Mountains.

Generally the findings of the Bronze Age at HLO1 are evidence for large-scale copper production happening throughout the Umm an-Nar and Wadi Suq phases.

There is no indication for a major Bronze Age settlement at or in the vicinity of the site, although it seems likely to have existed. Some structures at the west slope of the wadi, opposite to HLO1, might be Bronze Age graves. The fortifications at HLO1 also argue in favour of a permanent presence of people at the site during the Bronze Age. The lack of evidence for living structures might be due to a predominant use of wood for domestic housing, which would not have left archaeological traces that could be recognized in the sediments of the site without applying special excavation techniques.

Seen from the archaeo-metallurgical point of view, the site certainly contributed to the provision of copper in the greater area. Lead isotope analyses of a large copper ingot found at HLO1 indicate that bronze artefacts from other sites could have used this copper for alloying. Probably pure copper was exported from HLO1 in the form of ingots and not alloyed or further processed at the site. Apart from evidence of ore or slag processing, the Iron Age has not left much of a trace at HLO1. Therefore no further results can be provided for this period in the present state of research at the site. During the historic periods, the site was used as a settlement and graveyard area. This period was not in the focus of this dissertation, which nevertheless provides general documentation of these findings.

11 Features of the historic period

When approaching the archaeological site of HLO1, small fortifications are visible on the surrounding mountain ridges, and a well preserved (and meanwhile restored) old watchtower gards the entrance to the area of the site. On the opposite side of the wadi there are the ruins of a major building of mudbrick and stone, indicating that this part of the valley was sort of a "central place" during early historic times as well. Although not belonging to the prehistoric periods, these historic features will be described here as well in order to document them. This applies in particular to those remains which were to some extent disturbed during the excavations. An overview of the historic features is given in Figure 11.1.

11.1 Watchtower

The most obvious historic feature is the watchtower dominating the entrance area of the site (Fig. 11.2). Apart from the internal constructions of wood, this tower is preserved completely. In 2008 it was restored by the Directorate of Heritage of the Sharjah Emirate. It is built of large wadi pebbles set in mortar which originally also covered the outside grooves. These grooves are now filled with white gypsum. The tower's diametre at the base is 4.7 m (Fig. 11.3).

The tower does not have an entrance at ground level. As visible in Fig. 5.64, the door to the tower is some 4 m above ground on its west side. The lower part of the tower is completely filled with rubble, creating a floor level at the height of the entrance. On this level a central column of stones and clay is erected: obviously for supporting an upper platform constructed of wood, which is not preserved today (Fig . 5.65). The upper platform did not have a roof. It is surrounded by the castellated crown of the tower wall. Towards the slopes in the east and north-east, this wall is higher than on the other sides—probably for protection of the defending crew against gunfire from the mountain. There are no loopholes in the wall of the upper plattform. Instead, the top of the wall has merlons, and there are indications of a raised wooden construction from which the defenders could shoot through the gaps. An interesting construction is a triangular "nose" projecting out of the wall at the level of the upper platform. It has a small downward opening at floor level, which may have served as a toilet for the defenders of the tower in the case of a siege. This function is also indicated by the fact that the massive wall around the foot of the tower merges with the base of the tower below this opening. The "droppings" from the assumed toilet would thus have accumulated outside the defended courtyard. There is no loophole on the lower level of the tower in the

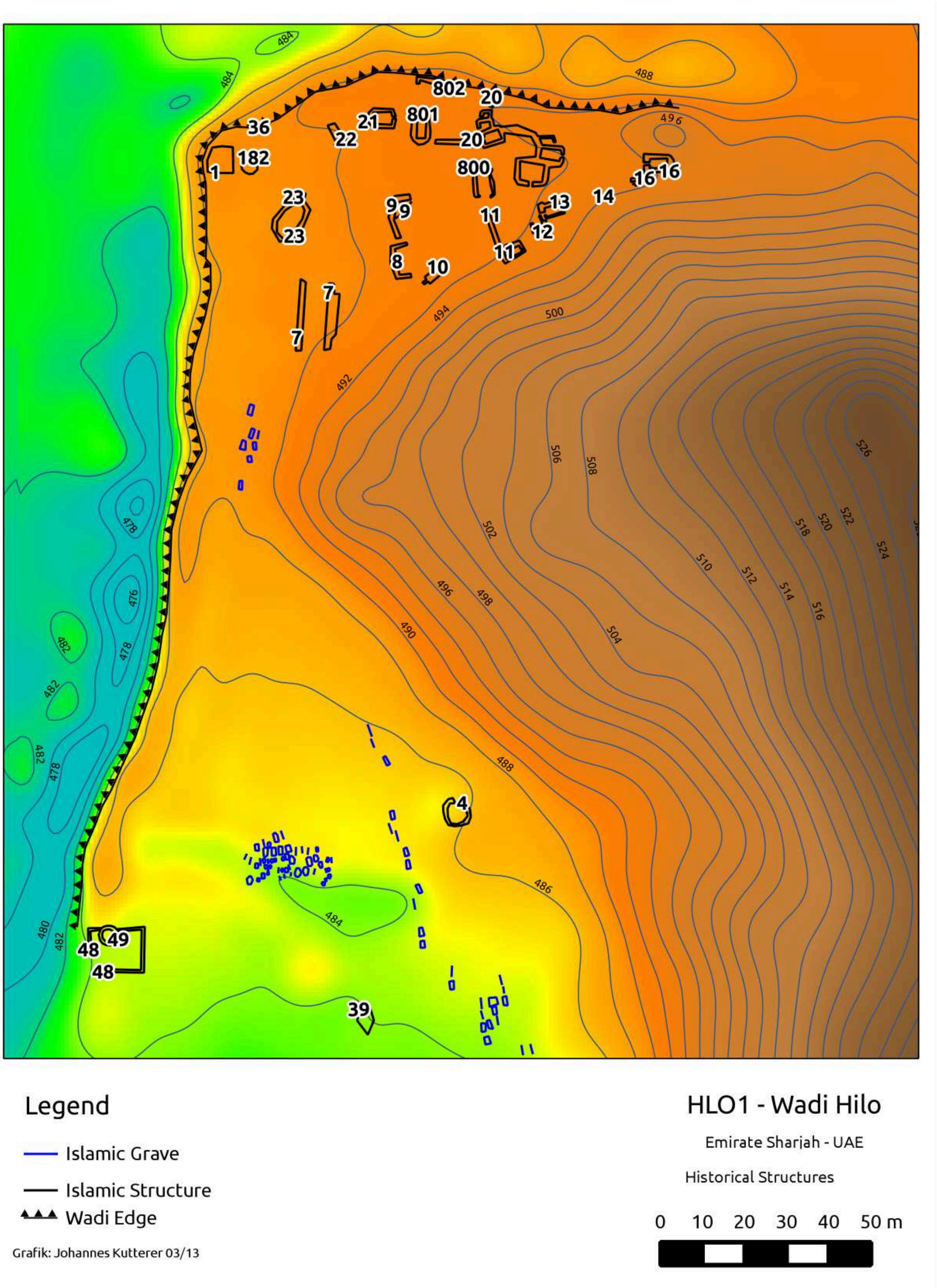

Figure 11.1: *Overview of the historic buildings in the northern part of the terrace, the graves along the slope and in the centre of the southern area, and the watchtower in the south-west.*

Figure 11.2: Tower at the entrance of the site.

drip-line of the "nose". Nevertheless, the area below the "nose" could be defended by shooting through its hole. At the level of the lower platform there are narrow loopholes all around the tower, except for the part in the west where the entrance is. The base of the tower is surrounded by a rectangular court of c. 10 x 12 m, which is delimited by an enclosing wall with numerous loopholes and a height of c. 1.5 m. There is an entrance at the western wall of the court.

11.2 Threshing area (feature no. 1)

Another well preserved and obviously man-made feature of the site, situated right on the north-western corner of the terrace, is a plain square area of c. 6 x 6 m paved with small pebbles. It is dug into the slightly sloping terrace in order to prepare a levelled surface. The two edges towards the unaltered terrace surface are fixed by rows of flat stones, densely set. According to a local informant, this structure was used for threshing and winnowing of cereals. Obviously the wind-exposed situation at the terrace corner favoured this kind of use of the place well into subrecent times (Fig. 11.4 and 11.5).

11.3 Feature 182

Feature 182 is a round stone construction with a diametre of c. 4 m directly east of the threshing area. After cleaning the surface, it looked like a solid construction (see Fig. 11.6). Going deeper into the northern half revealed an inner ring of stones at base level. The internal diametre of the stone circle is about 3 m (Fig. 11.7).

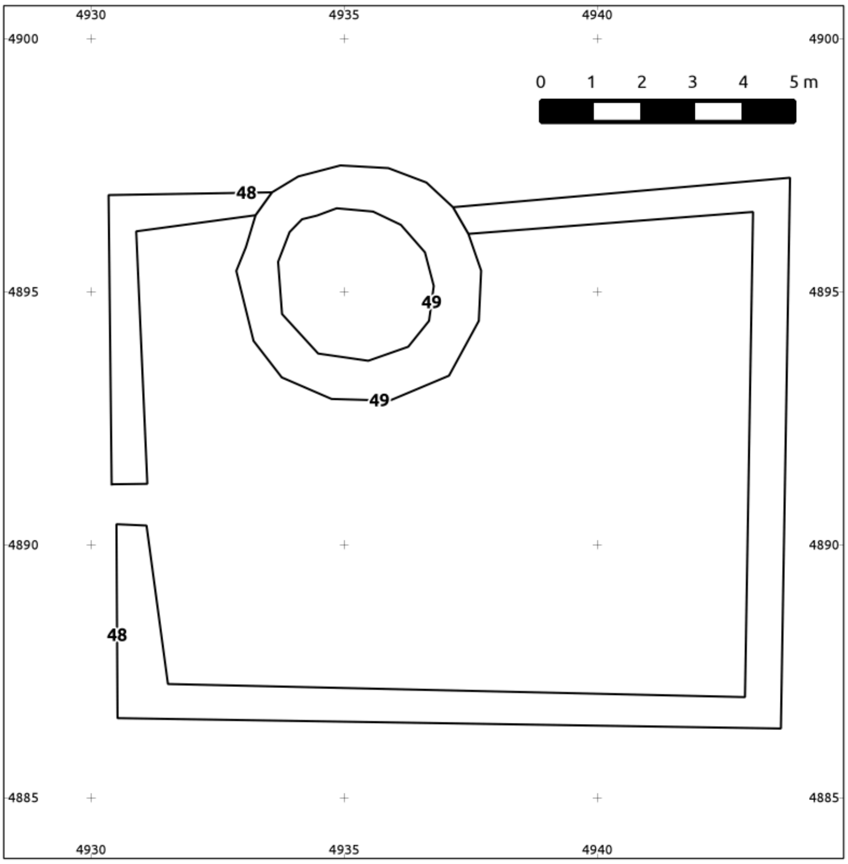

Figure 11.3: Map of the modern tower.

Figure 11.4: Threshing area.

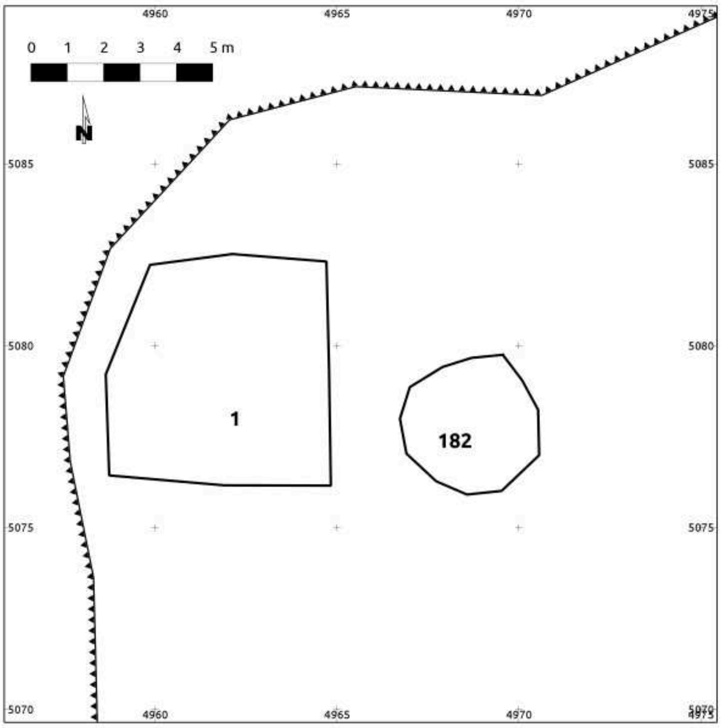

Figure 11.5: Map of features 1 and 182.

There were no other finds or findings. An archaelogical dating of the structure was therefore not possible. Judging from the whole context, feature 183 might have been the base of a small watchtower for the Islamic village to the east.

11.4 Feature 7 – "Tobacco shed"

The apparently most recent ruin, perhaps apart from the watchtower and the threshing area, is interpreted as a shed for drying and processing tobacco leaf. This "Tobacco shed" is one of the most obvious ruins in the flat northern part of the site. It consists of 2 parallel double-lined walls preserved to a height between 1.1 m and 1.9 m with a length of 15.5 m and a distance from each other of 5.3 m (Fig. 11.8). Both are more than a metre thick at the base and get thinner towards the top (see Fig. 11.9). The eastern wall is collapsed towards the interior near its southern end, the western wall is collapsed to the outer side at its northern end. During the 2012 excavations, four post-holes, lined with stones, were discovered right below the present surface on the central line between the two walls. They indicate that a wooden roof existed over the room between the two walls.

According to Aissa Abbas (personal communication) the upper Wadi Hilo was a local centre of tobacco production in the 20th century. In this kind of building, tobacco leaves were dried. For this purpose, the space between the two walls

Figure 11.6: Feature 182 at the beginning of the excavations.

Figure 11.7: Feature 182 after excavation (north is upwards).

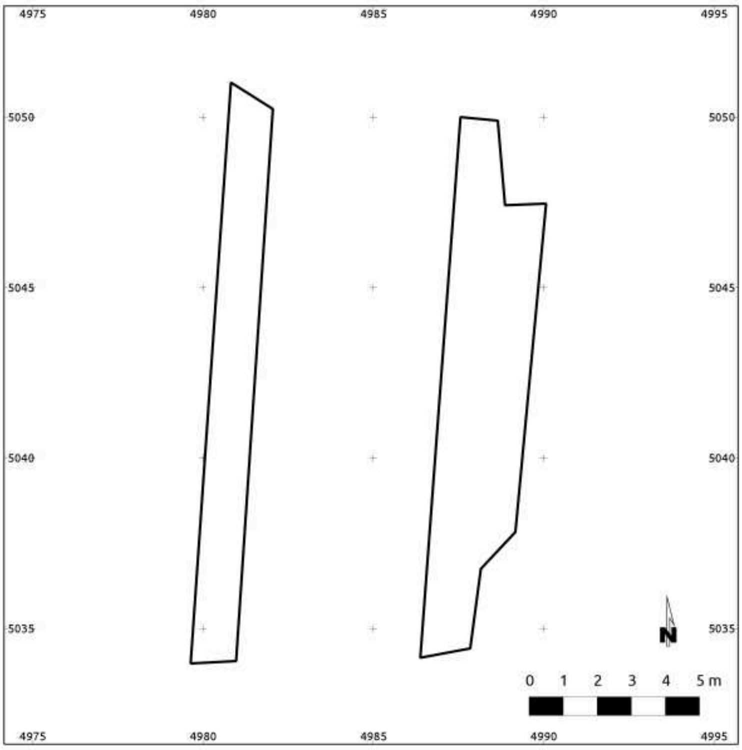

Figure 11.8: Outline of the "Tobacco shed".

Figure 11.9: View through the space between the standing walls of the "Tobacco shed".

Figure 11.10: Tobacco shed with partially preserved roof in an adjacent village in Wadi Hilo.

was covered with a roof made of date palm leaves. A similar building with its roofing still preserved can be found farther down the valley (see Fig. 11.10). The postholes between the two walls of feature 7 confirm a reconstruction according to this example.

11.5 The "Islamic Village"

As mentioned before, a large number of Islamic graves and the ruins of semi-subterranean houses indicate the existence of a protohistoric Islamic village in the area of the prehistoric copper smelting site, particularly in its northern part. Besides houses for the human inhabitants, there are structures which appear to have been stables and sheds. For some other architectural remains, more or less plausible interpretations will be proposed or cannot be provided at all. Nevertheless, all of the presumably protohistoric findings will be documented in the following section.

Feature 10: Semi-subterranean house Building 10 is the sub-structure of a semi-subterranean house, consisting of a walled rectangular room with an inner space of 2.2 x 3.8 m. Its horizontal floor is situated 70-90 cm below the slightly sloping surface. The entrance in the centre of the NW-wall is flanked by two slabs of flat rock and has a width of 60 cm. Two stone-steps lead down into the room.

Figure 11.11: Feature 10: Semi-subterranean house with entrance from the north-west.

Figure 11.12: Feature 10: Entrance bordered by two large slabs.

Feature 11: Partially subterranean house This structure is partly dug into the slope at its southern side. There are two conspicuous niches in the southern and eastern subterranean wall. From the north-western corner a 11 m long low wall extends northwards onto the flat area.

Features 12 and 13: "Farm-sted" (house and stable) Features 12 and 13 seem to form an "economic unit" with no. 13 (Fig. 11.16) being the living space for the humans and structure 12 (Fig. 11.17) sort of a stable for the animals. No. 13 is east of no. 12 and is a semisubterranean house with its entrance in the west. Its walls are comparatively well preserved and built of fairly regular stones. Below ground level, they consist of 1 row of stones while the above-ground part of the northern wall still has two rows of stones.

There is only a narrow corridor between feature 13 and 12 which forms an angled southern entrance-way to the house from where a doorway also connects the two structures. No. 12 is a U-shaped wall, still standing quite high, with the open side to the north. It is slightly dug into the slope to the south. Most probably it had a pent-roof and was a shelter for animals.

Feature 16: Semi-subterranean house Feature 16 is the easternmost building of the Islamic village and well separated from the other structures. It consists of a house with the present floor being not much lower than the surrounding surface. The internal space measures 4.2 x 2.2 m and has its entrance from the west. From west to east the entrance narrows from c. 75 cm to 65 cm. It is built of large blocks.

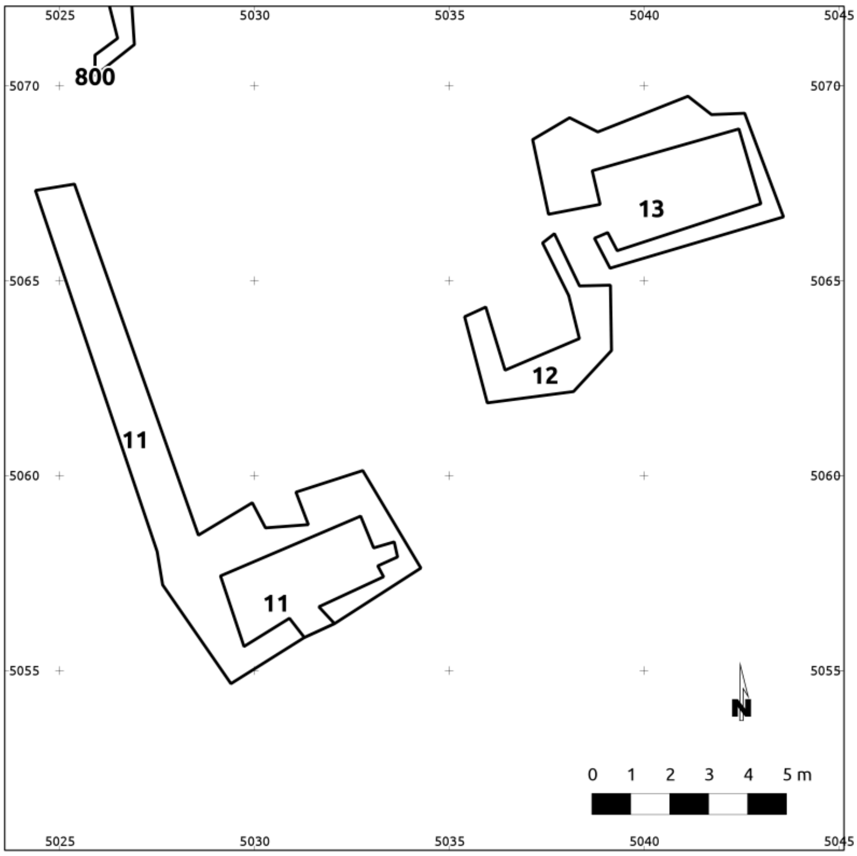

Figure 11.13: Outlines of structures 11-13.

Figure 11.14: In the foreground there is the badly preserved semi-subterranean part of structure 11. In the background there is the outer wall extending northwards.

Figure 11.15: Internal view of structure 11 with the eastern niche.

Figure 11.16: Feature 13, western part and entrance.

Figure 11.17: U-shaped structure no. 12. To the left there is the entrance to house no. 13.

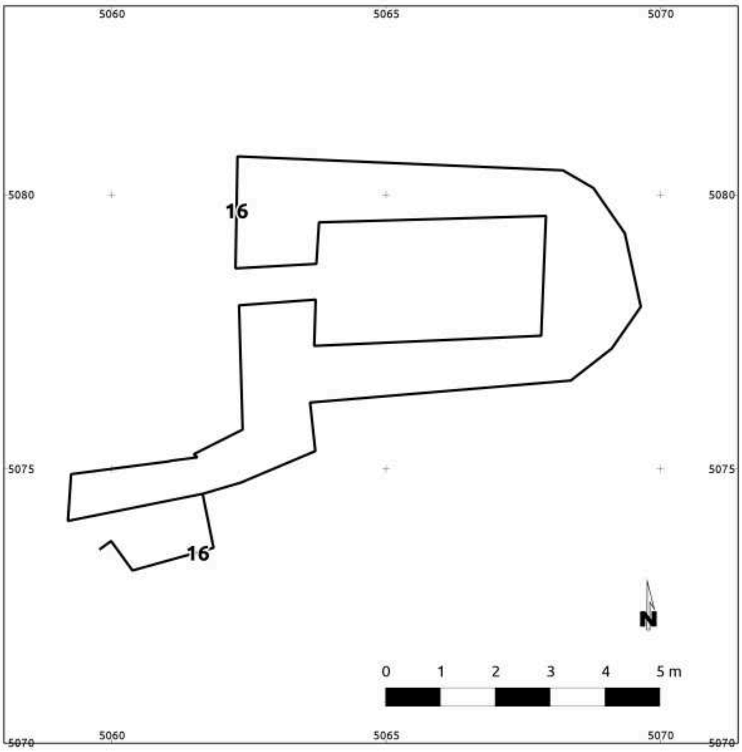

Figure 11.18: Outline of structure 16.

A south- and westward extension is added to the front-wall of this house, which still stands higher than the walls of the house (Fig. 11.18, 11.19 and 11.20). The wall of this annex has a 50 cm wide window in the middle, which seems to have looked into a small room built against the wall from the south with a narrow entrance from the west. The chronological relation to structure 16 and its function is unclear.

Feature 21: House Feature 21 is a fairly well preserved rectangular house built upon the natural surface. It measures 5 x 6.5 m (Fig. 11.21) and has a double wall consisting of small boulders in various shapes, often with rounded edges indicating that they were collected in the wadi bed. The wall stands up to 1.6 m high. The entrance is to the east. Window-openings are not visible (Fig. 11.22).

Feature 22: Semi-subterranean house Feature 22 is a badly preserved building dug into the terrace surface (Fig. 11.21 and 11.23). The narrow entrance is from the south. Below ground-surface the walls are better preserved. Above ground the walls, consisting of large wadi pebbles, have mostly fallen into the building. The preserved part of the walls had only one stone-mantle.

West of the building there is a small annex interpreted as a stable for lambs (Fig. 11.24). It may have been built later than the house 22.

Figure 11.19: Feature 16: Wall with a window connected from south-west to the semi-subterranean room.

Figure 11.20: Feature 16: Semi-subterranean room.

Feature 20: Large above-ground house With an extension of about 20 x 30 m structure 20 is the largest preserved building of the Islamic village (Fig. 11.25), consisting of several rooms. Its walls are preserved up to a height of 1.5 m. The largest and southernmost room has an entrance from the south and is built of irregular wadi boulders. North-east of this room there are 2 smaller rooms with doors from the east. Their back-walls are part of a more or less circular wall which continues in a westerly direction where it joins the back wall of another room. The entrance to this room is from the west. From this entrance a long straight wall extends farther to the west. To the north two other rooms with entrances from the west continue the north-western series of rooms belonging to structure 20. A short wall closing the gap between structure 20 and the edge of the terrace seems to be a functional part of this building, forming an eastern border of a large courtyard between structures 20, 801 and 802.

Feature 800: Large above-ground house or shed Feature 800 consists of the remnants of a badly preserved rectangular building with an entrance from the south. Like the other buildings of the Islamic village this structure is built of large wadi pebbles. Its arrangement fits the layout of the surrounding structures, but nothing can be deduced with regard to its function (Fig. 11.26).

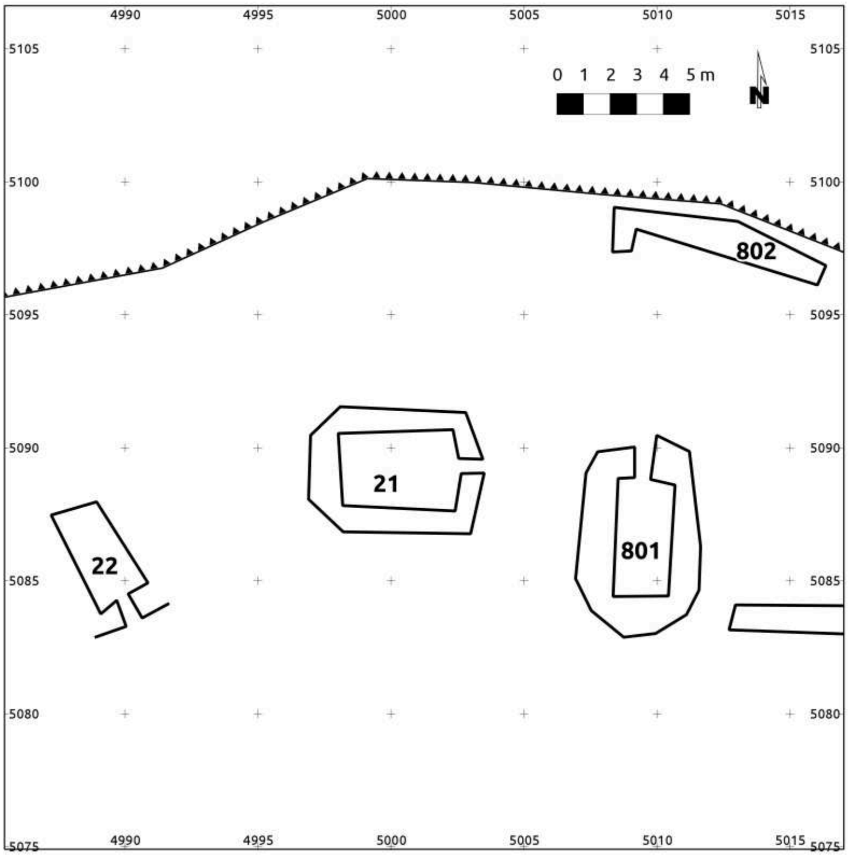

Figure 11.21: Map of structures 21, 22, 801 and 802.

Figure 11.22: Feature 21: Remnants of the building as seen from the east.

Figure 11.23: Feature 22 seen from the south.

Figure 11.24: Lamb-stable west of house 22.

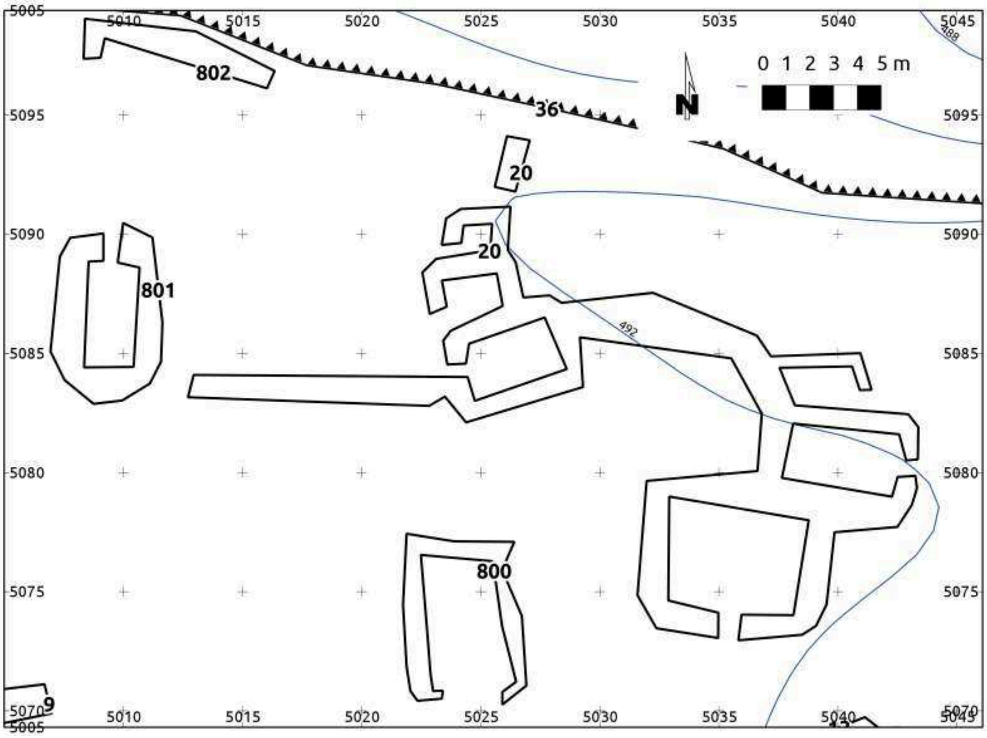

Figure 11.25: Map of structures 20, 800, 801 and 802.

Figure 11.26: Remnants of feature 800.

Figure 11.27: Feature 801.

Feature 801: Semi-subterranean house The floor of feature 801 is only slightly deeper than the surrounding surface. The wall has 2 rows of stones and consists of selected wadi boulders which are set carefully. The entrance is from the north and has three steps (Fig. 11.21 and 11.27). Its south-eastern corner comes close to the end of the long wall extending westwards from building 20, forming sort of an entrance between the two buildings. Together with the wall 802 along the northern terrace-edge and the western parts of house 20 structure 801 surrounds a court-area similar to the one between houses 11, 13, 800 and the large southern room of house 20.

Feature 802: Feature 802 is a wall along the edge of the northern wadi which seems to delimit a large courtyard in the functional context of buildings 20 and 801. The lower row of stones consists of large blocks with rounded edges. West of it there might have been a drain or a passage leading down into the northern wadi (Fig 11.21 and 11.28).

11.6 Further structures

Feature 8: Feature 8 consists of a U-shaped wall enclosing a space with a width of 6.2 m and a "depth" of 2.7 m (Fig. 11.29). The double-lined wall is preserved to a height of 1.4 m. The outer line of the north-south wall is bulging outward in the middle. Walls and corners are eroding towards the inner space. This kind of 3-sided building can probably be reconstructed with a pent-roof of twigs supported by wooden beams. Such buildings are often used as animal-shelters.

Feature 9: Feature 9 (Fig 11.32) is an angled wall which has to be seen in a functional connection with feature 8. The gap between the two features may

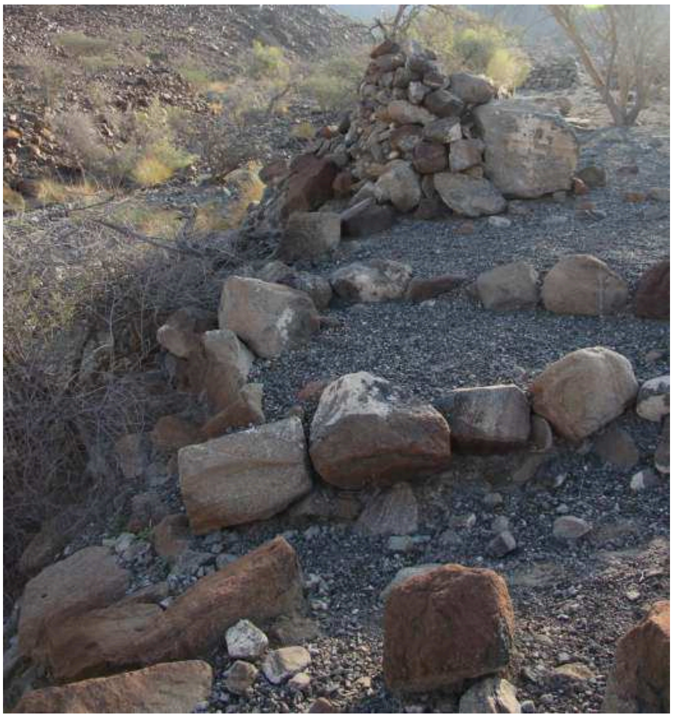

Figure 11.28: Feature 802 with drain in the foreground.

have been an entrance to a court-yard east of these two features. A curved wall separating the northern corner of feature 9 from the open space seems to be a later addition to this structure. The mostly collapsed walls of this feature are preserved to a height of up to 0.8 m. Like feature 8 this wall most likely was part of an animal shelter (Fig. 11.29).

Feature 17 – Fox-Trap? Feature 17 is a small and well-preserved structure in the eastern side-wadi outside the Islamic village and slightly beyond the north-eastern corner of the mapped area (Fig. 11.1). It looks like an oval heap of stones with a height of c. 60 cm. It is hollow, however, with a small entrance from the east (Fig. 11.33 and 11.34). According to the interpretation of the locals it was a fox-trap. The entrance had a "shutter", i.e. a flat stone which fell into the gap when a supporting stick was moved out of its place. Foxes and other carnivores endangering the smaller domestic animals may have been kept away from the village by this gadget.

Feature 14 – Lamb coves: Feature 14 consists of two small chambers built of big wadi pebbles and covered with large flat stone slabs. According to Aissa Abbas (pers. comm.) such structures were used as "cages" for small lambs or kids which were too small to accompany their mothers when these left the village for grazing. Their bleating would help to bring the mothers back to the village in the evening (Fig. 11.35).

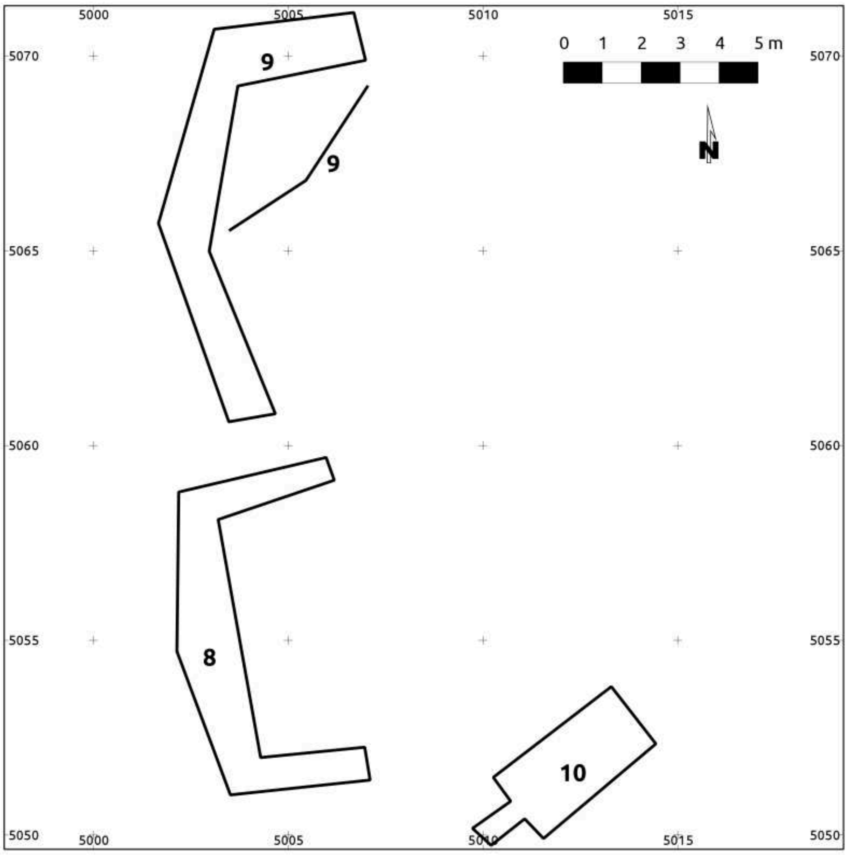

Figure 11.29: Feature 8-10: Outline of the structures.

Figure 11.30: Feature 8: NS-wall from south-west.

Figure 11.31: Feature 8 – tilted part of the wall.

Figure 11.32: Feature 9 – Curved wall in prolongation of feature 8.

Figure 11.33: Feature 17 – Entrance of the “Fox-Trap” from east.

Figure 11.34: Feature 17 – “Fox-Trap” from north with the entrance on the left side.

Figure 11.35: Feature 14 – Lamb coves.

11.7 Other features of the historic period

Feature 4: Sondages early on during the work at HLO1 were made at a roundish structure at the base of the slope (Fig. 2.62), more or less in the middle of the long row of Islamic graves along the base of the slope. The stone circle has a diameter of about 4 m and an entrance from the north (see Fig 11.36).

Sondages quickly revealed that the structure only consisted of the stones visible at the present surface. From the outer wall smaller stone circles extended into the interior of the structure (Fig. 11.37). Excavations on its outside were not possible due to the nearby Islamic graves. Apart from the fact that the structure is situated on the present surface, it was impossible to derive chronological or functional interpretations from the few finds and findings.

Feature 39: Near the southern border of the area of HLO1 some architectural remnants were observed during the first season (2007) of our work at the site. The most remarkable above-ground observations were long stone slabs protruding more or less vertically from the modern surface (see Fig. 11.38). The oval structure measures c. 4 x 6 m.

A trench made in 2008 through this structure indicated a very bad state of preservation of what seems to have been a building. It was not possible to obtain archaeological indications of its chronology. Judging from knowledge gathered

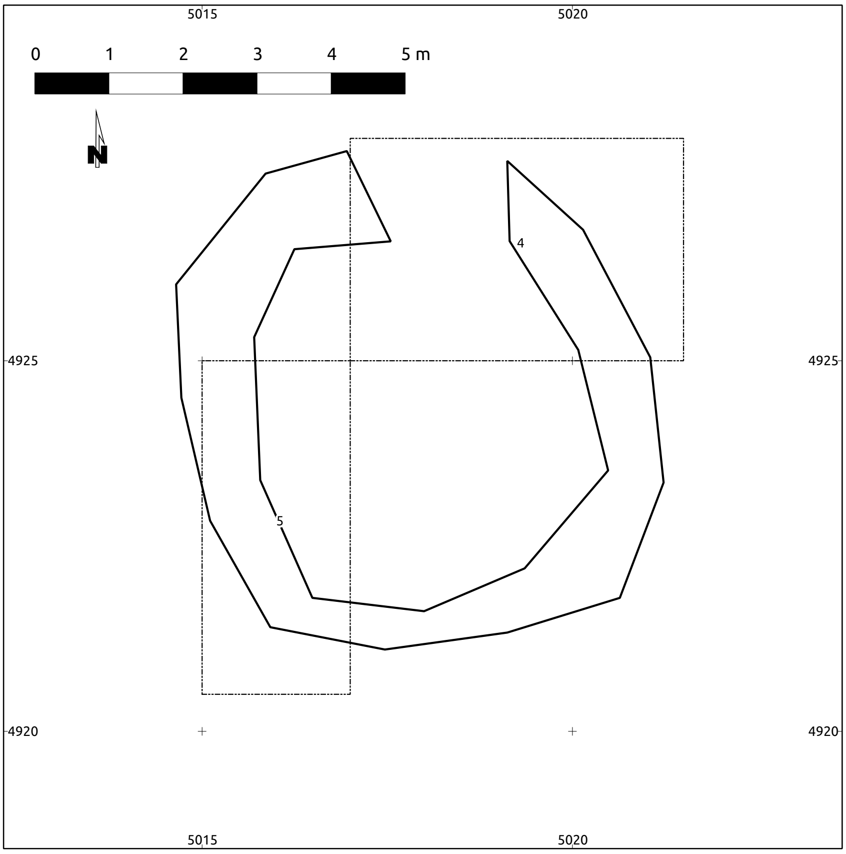

Figure 11.36: Map of feature 4.

Figure 11.37: Outer wall of feature 4 with internal “appendix”.

Figure 11.38: Structure 39: Elliptic house (?) in the southern part of HLO1 before excavation.

during later seasons, it seems most probable that Feature 39 represents a semi-subterranean house of the Islamic period. As observed on the western side of Wadi Hilo and in old villages farther up the wadi, houses with roofs constructed out of long flat stone slabs were still in use there as sheds or stables.

11.8 Islamic graves

In the southern and middle part of the site, there are more than a hundred Islamic graves visible on the surface (Fig. 11.1). Three local concentrations can be distinguished: the northern group, closest to the village described above, consists of seven graves situated in the area of the Bronze Age workshop (structure F) in the narrowest part of the wadi terrace. These graves are delimited by stone slabs and usually have headstones: sometimes consisting of old mill-stones. They are oriented north–south. More than 100 similar graves are found farther south-east in a long row along the base of the slope. Because of the trees in this area not all of them could be mapped in Fig. 11.1. Their orientation is NNW to SSE. The third group consists of about 50 graves in an irregular roundish concentration in the middle of the flat area NE of the watchtower. According to the locals, it is no longer known to whom these graves belong.

11.9 Conclusions with regard to the features of the early eistoric occupation of HLO1

The early historic ruins in the NE of the site obviously represent a "socio-economic" unit and are therefore of particular interest. Its obvious centre is building 20, with its central court and its two "wings" north-west and south-east of it. Structures 800, 11, and 13 form a protected unit to the south of the central court with a large yard enclosed by the buildings and a long wall. North-west of building 20, there is a similar unit surrounded by walls and by buildings 801 and 21. Buildings 10, 8 and 9 are sort of an outer border of the whole complex towards the area in the south-west, while buildings 21 and 22 flank the "entrance area" on the north side. The round platform 182 might actually have been the base of a small watchtower protecting the western entrance to this lightly fortified village. Its well-planned arrangement might indicate that this was the early historic "central place" of the upper Wadi Hilo.

12 Summary

The site **HLO1** in the Wadi al-Hilo, which means "Hilo river valley", in the Emirate of Sharjah, UAE, has been excavated since 2007 by a Joint Project of the Directorate of Antiquities of the Government of Sharjah and the Institute of Pre- and Protohistory of Tübingen University under the direction of Sabah A. Jasim from the Sharjah side and Margarethe Uerpmann and Hans-Peter Uerpmann from the Tübingen side. The author was in charge of the actual excavations at the site from 2007 to 2012 and, under the supervision of Ernst Pernicka and Gregor Markl, of the evaluation of finds and findings presented in this dissertation.

The site is situated near the upper end of the valley. Its name translates as "sweet valley", which is due to its fertility and the rich supply of fresh water in its alluvial underground. Geologically, the area is dominated by Gabbro of the Oman–UAE Ophiolite, which contains small occurrences of copper ore. Some of them indicate traces of surface mining, including a locality at the northern periphery of the archaeological site.

Indications for copper smelting at the site begin during the transition from the Neolithic to the Bronze Age. At present, this is the earliest proof for metallurgy in SE Arabia. Indications for continued occupation of the site during the Bronze and Iron Ages exist in the form of typical pottery from these periods. Direct and indirect evidence for metal production was found in the form of smelting furnaces, workshops, and traces of ore processing. An ingot of pure copper with a weight of 4.6 kg—which, according to the lead isotopes, was produced from local ore—is direct evidence for on-site metallurgy. Isotope analyses of artefacts from other Bronze Age sites indicate that HLO1 is a potential source of copper for a larger area of SE Arabia.

The economic importance of the site and its products is indicated by traces of fortifications. The most obvious is the base of a watchtower of the Umm an-Nar period excavated near the southern access to the site. Traces of a fortification wall were found along the northern border of the site. The stone foundations of a house with several rooms are the only indication for potential domestic buildings. This house was later transformed into a workshop. Presumably, wooden huts, which have left no traces, served as housing for the prehistoric population.

An additional outcome of the excavations at HLO1 is the evidence for a Neolithic occupation of the site. Unfortunately, the only evidence for that period are five radiocarbon dates for fireplaces which span the time from the 9th to the 4th millennium BC. Based on stratigraphy, a partly excavated stone structure also belongs to this period. Some few flint artefacts from the corresponding levels are insufficiently characteristic for a typological characterization.

Obvious ruins indicate human presence during the historic period in the form of fairly well preserved rural buildings in the north of the site. They seem to form a "socio-economic unit", which as such seemed deserving of detailed description before their state of preservation deteriorates further.

A large number of presumably Islamic graves were spared from excavation. A well preserved Islamic watchtower at the southern entrance of HLO1 and the ruins of a noble house on the other side of the wadi indicate that the ecological advantages of the area attracted people at all times.

13 Zusammenfassung

Die Fundstelle **HLO1** im Wadi Hilo (Emirat Sharjah, VAE) wird seit 2007 von einem gemeinsamen Projekt des Instituts für Naturwissenschaftliche Archäologie der Universität Tübingen unter Leitung von Margarethe und Hans-Peter Uerpmann und des Antikendirektorats des Emirats Sharjah (VAE) unter Leitung von Sabah A. Jasim untersucht. Der Autor dieser Dissertation hat die Grabungen an der Fundstelle HLO1 von 2007 bis 2012 geleitet. Die Auswertung von Funden und Befunden unter Anleitung durch Ernst Pernicka und Gregor Markl sind Gegenstand der vorliegenden Dissertation.

Die Fundstelle liegt am oberen Ende des Wadi Hilo auf einer alten Wadi Terrasse am Ostrand des Tales. Sein Name bedeutet „Süßes Tal“, was sich auf seine Fruchtbarkeit und den Reichtum an Wasser in seinem alluvialen Untergrund bezieht. Geologisch wird die Gegend durch Gabbro-Formationen des Oman-VAE-Ophioliths bestimmt, der kleine Vorkommen von Kupfererz enthält. Einige davon zeigen Hinweise auf einen obertägigen Abbau, darunter auch ein kleines Vorkommen nahe der Fundstelle.

Hinweise auf Kupferverhüttung am Fundplatz beginnen am Übergang vom Neolithikum zur Bronzezeit. Derzeit sind dies die ältesten Spuren metallurgischer Aktivitäten in Südost-Arabien. Eine Besiedlung des Fundplatzes von der Bronze- bis zur Eisenzeit wird durch charakteristische Keramik-Funde dieser Perioden belegt. Direkte und indirekte Belege für die Erzverhüttung liegen in Form von Schmelzöfen, Werkstätten, Schlacken und Spuren der Erz-Aufbereitung vor. Der Fund eines Barrens aus reinem Kupfer mit einem Gewicht von 4,6kg – der nach Ausweis der Blei-Isotopie aus lokalem Erz gewonnen wurde – ist ein klarer Beleg für Kupfergewinnung vor Ort. Isotopenanalysen an Bronzefunden anderer Fundstellen weisen darauf hin, dass HLO1 eine potentielle Produktionsstätte von Kupfer für größere Gebiete in SO-Arabien gewesen ist.

Die ökonomische Bedeutung der Fundstelle und ihrer Produkte ergibt sich aus den Spuren einer aufwendigen Befestigungsanlage. Ihr auffälligster Bestandteil ist der Stumpf eines Turmes, der in die Umm an-Nar Phase der Frühen Bronzezeit datiert. Er liegt auf der Südseite der Fundstelle und kontrolliert den dortigen Zugang. Weniger gut erhaltene Spuren einer Befestigungsanlage wurden entlang der Nordseite gefunden. Grundmauern eines Hauses mit mehreren Räumen sind die einzigen Spuren potenzieller Wohnbauten. Dieses Haus wurde später zu einer metallurgischen Werkstätte umgebaut. Vermutlich hat die prähistorische Bevölkerung in Holzbauten gelebt, die keine archäologischen Spuren hinterlassen haben.

Ein zusätzliches Ergebnis der Ausgrabungen sind die klaren Hinweise auf eine Nutzung der Fundstelle im Neolithikum. Leider besteht der Nachweis für die

Periode nur aus fünf Radiocarbon-Daten, die den Zeitraum vom 9. bis ins 4. Jahrtausend v. Chr. belegen. Auf Grund der Stratigraphie gehört auch eine partiell ergrabene Steinstruktur zu dieser Periode. Einige Silexartefakte aus den zugehörigen Schichten sind zu uncharakteristisch um eine typologische Zuordnung zu ermöglichen.

Augenfällige Ruinen belegen die menschliche Anwesenheit in historischer Zeit. Diese liegen am Nordrand der Fundstelle. Da sie die sozio-ökonomische Struktur der Ansiedlung widerspiegeln, rechtfertigten sie eine detaillierte Beschreibung und Dokumentation bevor sie weiter zerfallen.

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