U.PORTO
FLUP FACULDADE DE LETRAS
UNIVERSIDADE DO PORTO

MASTER IN ARCHAEOLOGY

Copper Metallurgy at Saruq al-Hadid (Dubai, UAE)

Tatiana Valente

M

2023

Tatiana Valente

Copper Metallurgy at Saruq al-Hadid (Dubai, UAE)

Master’s thesis submitted in fulfillment of the requirements for the degree of Master in Archaeology, supervised by Professor Francisco Reimão Queiroga.

Faculdade de Letras da Universidade do Porto | Faculty of Arts and Humanities of the University of Porto

2023

To Tiago

Content

Declaration of Honour

I hereby declare that I am the author of this dissertation *Copper Metallurgy at Saruq al-Hadid (Dubai, UAE)*, which has never been used in other course units or subjects at this or any other institution. All references to authors (statements, ideas, thoughts, quotes) have scrupulously met the applicable citation rules and are, therefore, referenced in the text and in the bibliographical references, in accordance with the referencing rules. I am aware that plagiarism and self-plagiarism is an academic offence.

Aveiro, June 30th 2023

Tatiana Valente

Acknowledgements

This Dissertation is the compilation of many years of work at Saruq al-Hadid, not only by me (the author of this Dissertation) but by many people who worked at this site and contributed to the results and interpretations presented here. Their efforts should here be praised and thanked for, not only for their expertise but for their spirit of camaraderie and resilience while working and living for several months each year at this site's remote and desert location.

Thus, I express my deepest gratitude to the members of the Sanisera Archaeology Institute, with whom I teamed up to research Areas 2A and G of Saruq al-Hadid, sharing long days of work and friendship. Thank you, in particular, to the director of this institute, Fernando Contreras, for always supporting my work since I was still a BA student 15 years ago. Thank you for your trust and recognition; without whom, I would not be where I am today, my dearest friend and boss.

Thank you especially also to Anna Zuber, Manuel González, Júlia Coso, Edurne Fernández and Marta del Mastro (from the Sanisera Archaeology Institute) and Hélène David-Cuny and her team (from the Saruq al-Hadid Archaeological Research Project) for how beautifully you illustrated the pieces and interpretations from the site, which I could now use to illustrate this Dissertation. Your shared vision of the site has helped highlight the importance of this site in Southeast Arabian history.

Thank you also to Anne Benoist, ceramic specialist joining the Sanisera Archaeology Institute, whose invaluable support and guidance will never be forgotten. Without your shared knowledge about the region's rich history and highlights of the social-ritualistic topics of the southeast Arabian Iron Age, none of the results and interpretations here presented could have existed. Thank you for recognising my value and introducing me to many colleagues working in the region, especially Carmen del Cerro, who has since become a dearest friend and counsellor on everything Iron Age. Her insights, support and encouragement to pursue the discussed topic will also be forever remembered.

The help, support, and collaboration from the SHARP team members (Saruq al-Hadid Archaeological Research Project, from the University of New England – Australia) must also be exalted. In particular, Lloyd Weeks, director of this team and specialist in southeast Arabian archaeometallurgy, without whom many of the topics here discussed and explored, especially under a ritual-economy theoretical lens, could not have been possible. Without his insights, advice and constructive reviews, this thesis would not be what it is. Furthermore, many of the proposed interpretations could not have been achieved without this team's work and archaeometric research of Saruq al-Hadid's material, in particular those of Kristina Franke, Ivan Stepanov, Claire Newton, Steve Karacic, Charlotte Cable and Hélène David-Cuny, which greatly contributed to the artefactual and paleobotanic assessment of the site. Their support and openness to collaboration will never be forgotten.

Thank you also for the support and effort from the Dubai Municipality team, particularly Mansour Boraik Karim and Hassan Zein. You were always there for me, in the good and the bad moments, helping in all imaginable ways for my success. You made all the logistics for this research possible and continue trying to help me have access to the archaeological materials from the Emirate of Dubai. Your insights and experience on how to excavate such a site with such difficult/different geomorphology were also invaluable. Thank you for always being there for me.

On behalf of everyone named and those who worked on this site, thank you also to HH Sheikh Mohammed bin Rashid Al Maktoum. Without your interest in archaeology and the rich heritage of the UAE, none of this work could have ever been possible. Thank you for financing all these research projects and providing all the logistic requirements for us to live and work on-site as comfortably as possible.

Last but not least, thank you to my Dissertation advisor, Francisco Reimão Queiroga, whose many expert insights and 'out-of-the-box' ideas were priceless to achieving the interpretations done. His teachings, advice and anthropological/ethnographic perspectives to analyse the data were fundamental to understanding much of the metallurgical evidence from Area 2A and have significantly shaped the way I theorised some sociological perspectives about this site.

Resumo

A metalurgia do cobre no sudeste da Arábia tem sido extensivamente estudada, focando-se na compreensão das dinâmicas de produção e comércio durante a Idade do Bronze. Investigações também se aprofundaram no período da Idade do Ferro, examinando evidências de mineração/fundição e possíveis locais de reciclagem de metais. No entanto, a descoberta de Saruq al-Hadid, um local autônomo exclusivamente dedicado à produção de objetos em ligas de cobre, oferece uma nova perspectiva sobre as dinâmicas de produção.

Este sítio fornece uma riqueza de evidências metalográficas, estruturais e contextuais que informam sobre os vários estágios da produção do cobre, incluindo fundição de metais, refinação e fabricação de objectos em materiais locais e importados por meio de técnicas em molde e respectivos acabamentos. Tais informações contribuem para o entendimento da produção metalúrgica em cobre da Idade do Ferro e das suas redes de comércio intra e extra-regionais.

Depósitos ritualizados de cobre e artefatos de prestígio em Saruq al-Hadid, semelhantes a locais de culto e assembleia encontrados na região, oferecem uma oportunidade notável para aprimorar a compreensão sobre a metalurgia do cobre e o seu papel social. Os contextos encontrados são sugestivos de atividades cultuais, sob a forma de deposições votivas a uma divindade 'serpente', sendo os artefatos em cobre componentes integrais de acções rituais, promovedoras de coesão social, e provavelmente legitimadoras da autoridade daqueles que controlavam tal produção.

A interpretação da organização e do significado da produção de cobre em Saruq al-Hadid pode ser alcançado através da lente teórica de uma 'economia ritual', fornecendo informações valiosas sobre a complexa interação entre tecnologia, dinâmica social e práticas culturais.

Palavras-chave: Idade do Ferro, sudeste arábico, metalurgia do cobre, coesão social, economias rituais

Abstract

Copper metallurgy in Southeast Arabia has been extensively studied, focusing primarily on understanding production and trade dynamics during the Bronze Age. Investigations have also delved into the Iron Age period, mainly examining evidence from mining/smelting and possible metal recycling locations. However, the discovery of Saruq al-Hadid, a standalone workshop dedicated to producing copper-alloyed objects, offers a fresh perspective on such production dynamics.

This site provides a wealth of metallographic, structural, and contextual evidence that sheds light on various stages of copper production, offering insights into production activities, including metal smelting, refining, and the fabrication of finished artefacts from local and imported materials through casting and working techniques. Such information contributes to understanding Iron Age metallurgic copper production and intra- and extra-regional trading networks.

Ritualized deposits of copper and prestigious artefacts at Saruq al-Hadid, akin to cultic and meeting places found in the region, provide a remarkable opportunity to enhance our understanding of copper metallurgy and its social role. The contexts of its assemblage are suggestive of cultic activities, particularly of votive depositions to a 'snake deity', and copper artefacts were integral components of ritual performances, fostering social cohesion and likely serving to legitimize the authority of those controlling the production.

Interpreting the broader organization and significance of copper production at Saruq al-Hadid could be effectively achieved through the theoretical lens of a 'ritual economy', providing valuable insights into the complex interplay between technology, social dynamics, and cultural practices.

Key-words: Iron Age, southeast Arabia, copper metallurgy, social cohesion, ritual economies

Introduction

The archaeological site of Saruq al-Hadid is located on the edge of the Rub al-Khali desert (in the Arabian Peninsula), on the southern border of the Emirate of Dubai in the United Arab Emirates (24º 39' 55'' N, 55º 14' 24'' E) (see Annexe 1). The black slag that covered much of the site made it visible in the active dunes and contributed to the discovery by H.H. Sheikh Mohammed bin Rashid al Maktoum, the ruler of Dubai, during a flight over the area in 2001. This metallurgical debris helped to characterise the site as a centre of copper metallurgy during the Iron Age II (c. 1100 - 600 BC) in southeast Arabia, as shown by the results of subsequent excavations (e.g., CONTRERAS *et al.*, 2017; VALENTE *et al.*, 2020; WEEKS *et al*., 2017b; WEEKS *et al*., 2019a).

In the regional panorama of Southeast Arabia, which comprises the territory of the United Arab Emirates and northern Oman, during the Iron Age (c. 1300 – 300 BC) (see Annexe 2a), the site of Saruq al-Hadid, with an intensive industrial component, comprising all metallurgical phases of copper production, from smelting to finished products, is unique. Only another singular example seems to exist within the Rub al-Khali landscape, ‘Uqdat al-Bakrah (YULE *et al.*, 2018), although it remains largely unexplored and has thus far revealed only final stages of object production. Throughout the Hajar Mountain Range, several mining and smelting sites from the same period have been identified. However, these sites tend to be relatively small in scale, focusing primarily on the initial phases of production, and are often situated in proximity to accessible ore deposits that justify their placement (GOY, 2019). In contrast, both Saruq al-Hadid and 'Uqdat al-Bakrah are detached from any known metal ore sources or settlement. While delving deeper into the subject, it becomes apparent that the positioning of these sites is more closely linked to ritualistic and economic considerations rather than the presence of natural resources.

Based on the findings obtained from research, it appears that Saruq al-Hadid may have had access to local water and fuel sources (WEEKS *et al*., 2015; WEEKS *et al*., 2016; WEEKS *et al*., 2017a). However, the necessary copper for metallurgical activities would have to be transported from ore sources located at least 100 km away in the Hajar

Mountains. In these mines, copper minerals underwent an initial smelting process before being distributed across the region. Upon reaching destinations such as Saruq al-Hadid, the copper had to undergo further smelting to eliminate impurities before being transformed into objects (GOY, 2019). This economic network that emerged during the Iron Age was likely facilitated by the domestication of the dromedary, which occurred towards the end of the Bronze Age (UERPMANN *et al*., 2002). The dromedary's ability to transport goods over long distances in the desert environment seem to have played a significant role in such production organization.

Simultaneously, as shall be discussed, the metallurgical “boom” that was observed during the Iron Age might have also been promoted by both technological and economic changes. The introduction of the falaj system allowed settlements to proliferate all over the region and oasis food supply to increase (AL TIKRITI, 2002; DEL CERRO *et al*., 2018), and from it, a population increase that might have required an increment in copper production. The exploitation of sulphidic ores (WEISGERBER, 1980; WEISGERBER, 1988) and trade increase with nearby regions (MAGEE, 1998a; MAGEE, 2002; MAGEE, 2004) seem to have also played a role in transforming this production organization and procurement as well as the SE Arabian social fabric. From new ritual cults to new ways of political and social organization (BENOIST *et al.*, 2015; BENOIST, 2010; MAGEE, 1998b; MAGEE, 1998c), to different forms of burial (VALENTE *et al*., 2023; GERNEZ *et al*., 2015; YULE *et al.*, 1988) and of controlling the territory (MAGEE, 1998b; MAGEE, 2004; MAGEE, 2007), all provide a glimpse of a society quite different from what existed before (POTTS, 1991; MAGEE, 2014).

The archaeological findings at Saruq al-Hadid not only shed light on the metallurgical production processes and organization but also valuable insights into the social dynamics underlying the emergence of such metallurgical sites. The unique characteristics of this site, including its detachment from known contemporary settlements, its seasonal nature (WEEKS *et al*., 2019a; WEEKS *et al*., 2019c; VALENTE *et al*., 2020), and the extraordinary abundance and diverse typologies of copper weaponry, jewelry, vessels, and prestigious objects discovered there (significantly surpassing quantities from other sites), suggest the possibility of multi-community occupation (VALENTE *et al*., 2020). Additionally, the identification of an assemblage associated with the "snake cult" at Saruq al-Hadid is significant. This cult, prevalent in the region during the Iron Age, has often been linked to metallurgical practices (BENOIST *et al*., 2015). These findings support the hypothesis that the selection of the site's location served primarily socio-ritualistic purposes, although economic and environmental factors inevitably played its role also.

Saruq al-Hadid served as a seasonal hunting site during the Bronze Age (WEEKS *et al*., 2019a; VALENTE *et al*., 2020), and similar sites with a hunting function existed in the broader region (CONTRERAS *et al*., 2016; VON DER DRIESCH *et al*., 2008; CARTWRIGHT, 1998). The central area of the site (Areas F and G) revealed signs of seasonal occupation, with numerous post-holes and fireplaces distributed throughout the site, and a significant lithic assemblage and associated accumulation of animal bones (ROBERTS et al., 2018; ROBERTS et al., 2019; MOORE et al., 2022). However, by the Early Iron Age, it transitions from hunting site to metallurgical centre, although reasons for it are yet to define. Nonetheless, despite the intensive metallurgical activities that will be observed during the Iron Age, Saruq al-Hadid maintained its seasonal nature. During this period, the site produced not only copper objects (though predominantly) but also a wide range of jewellery and ornaments made of gold, beads, and various stones, bones, and shells (SORIANO, 2018; WEEKS *et al*., 2019b; WEEKS *et al*., 2017a). Additionally, evidence of local and foreign trade was discovered, including weighing scales and imported materials such as iron, tin-bronzes (STEPANOV *et al*., 2020; VALENTE *et al*., 2020; WEEKS *et al*., 2017b; WEEKS *et al*., in press) and pottery vessels (BENOIST *et al*., 2017; KARACIC *et al*., 2018).

Within the realm of ritual practices, these objects were found in association with the snake cult, accompanied by incense burners, miniature weapons, and a variety of pottery, soft stone and copper vessels, and ladles. These findings bear similarity to those discovered in other cultic sites and communal buildings in the region, portraying commensality and political/administrative sharing (BENOIST, 2010; MAGEE 1998c).

The wealth of evidence uncovered at Saruq al-Hadid sets it apart from other sites in the region, indicating that it held a significance beyond being a mere production center. As the present study will explore in detail, the correlation between all evidence found points toward a place where people from all over the region could gather and produce the objects referred, either for utilitarian and/or prestige use and to be traded or offered as gifts (to the snake deity or among members gathered there). Notably, Saruq al-Hadid's location lies outside the sphere of influence of any specific political or administrative authority, reinforcing the notion that it was a place belonging to no entity in particular but accessible to all.

The Iron Age period witnessed a noteworthy phenomenon characterized by the fortification of settlements through the construction of defensive lines consisting of ditches and walls (e.g., MAGEE *et al*., 2017; PETRIE, 1998; CARTER, 1997). This previously unobserved practice in the region raised inquiries regarding the purpose of these fortifications and whether inter-community conflicts existed (BENOIST, 2010; MAGEE, 1998b). Although the available information on this topic remains limited, its correlation with the findings at Saruq al-Hadid, particularly its detachment from any documented settlement and the mentioned presence of cultic and communal artifacts, suggests a potential role for this site as a cohesive social hub. It likely served as a meeting place where communities could engage in peaceful trade, exchange goods and ideas, and possibly mitigate any existing tensions (VALENTE, 2023).

Despite the crucial importance of addressing these social inquiries to enhance our understanding of the region and the potential role of copper production, limited scholarly attention has been given to this topic. This Dissertation thus aims to address this research gap by focusing on the social implications of copper production in the region. Existing publications have primarily approached the subject on a site-specific basis. As a result, there is a lack of a comprehensive regional typological interpretation of metallic objects within the region's material culture, although some preliminary attempts to address these gaps exist (YULE *et al*., 2018). Furthermore, the available information regarding the economic and social aspects of copper is also limited. While notable studies by Julie Goy (2019) and Lloyd Weeks (2003) have explored technical and economic aspects of copper production, the focus on the social function of copper, both as a raw material and as finished product, has only recently begun to emerge.

This growing body of evidence primarily stems from excavations conducted at sites such as Saruq al-Hadid, Bithnah, Masafi, Mudhamar, and 'Uqdat al-Bakrah (BENOIST *et al*., 2015; GOY, 2019; GERNEZ *et al*., 2017; YULE *et al*., 2018). Hence, this Dissertation seeks to contribute to the field by offering a comprehensive examination of the social aspects related to copper production in the region.

In addition, it is worth noting that the majority of metallurgical studies conducted in the region have primarily focused on sites located in close proximity to copper extraction areas, in the Hajar Mountains. These studies primarily examine the abundant slag remains and the limited structural remnants associated with the copper smelting process. While considerable attention has been given to analysing the composition and formation processes of the slag, there is a significant dearth of research exploring the subsequent stages of object production, such as refining, melting and alloying techniques. A comprehensive understanding of these processes remains largely unexplored. Moreover, the region lacks extensive metallographic studies aimed at deciphering the techniques employed in producing the discovered copper objects. But once again, the unique nature of Saruq al-Hadid, with its wealth of archaeological data, offers an invaluable opportunity to conduct these essential studies, providing significant insights into the technical and economic aspects of copper production in the region.

This dissertation represents merely the initial steps on a long and intricate path towards comprehending the technologic, economic and social significance of copper, with the data from Saruq al-Hadid serving as a foundational starting point. The majority of the data presented in this study was collected by the author during her collaboration with the Sanisera Archaeology Institute during the excavations conducted from 2015 to 2019. However, it is worth acknowledging that crucial information, particularly concerning archaeometric data, was graciously provided by the SHARP team through their preliminary interim reports (WEEKS *et al*., 2015; WEEKS *et al*., 2016; WEEKS *et al*., 2017a) from their excavations at the site spanning 2015 to 2017. Nonetheless, it is important to emphasize that several of the interpretations presented herein are still preliminary and necessitate further examination and publication. As shall become evident, the primary objective of this dissertation was not to provide definitive answers but rather to discern the pertinent questions that should be posed in subsequent research endeavours.

A comprehensive and interconnected approach was adopted throughout this study to address the intricate and multifaceted research questions. Recognizing the complexity of the subject matter, the author established a contextual foundation by examining existing knowledge concerning copper production in the region. This involved identifying key production sites and their association with known mineral sources and technological processes, thereby shedding light on the underlying factors governing production organization. The presentation of this data follows a chronological framework, commencing with the inception of metallurgical production in the region during the 3rd millennium BC and extending to the Islamic period. By tracing the periodicity and distribution of copper in the region, particular attention is directed towards comprehending the significant surge in this industry during the Iron Age. It is apparent that this expansion was influenced by a combination of technological advancements, environmental conditions, as well as economic, social, and political dynamics.

Following the establishment of the industry's background, the author proceeds to examine the environmental and geophysical characteristics of Saruq al-Hadid, situating it within the diverse landscapes of the region. This investigation enables a deeper understanding of the factors that facilitated metallurgical production in a seemingly "desert" site. It was observed that neither the area was as deforested nor dune accreted as it is today, and fresh-water easily accessible through wells. Then, archaeological data from Saruq al-Hadid was carefully selected and correlated. As the author shall detail, since its discovery, the site was excavated by several archaeological teams. Some published or shared their unpublished reports with the author, although some did not. Despite potential limitations in data availability, the author worked to comprehend the site's stratigraphic sequence and accurately interpret the gathered information based on the available data.

The third section of this dissertation will focus on a comprehensive examination of the archaeological and analytical data pertaining to copper production at Saruq al-Hadid. A meticulous compilation of information regarding various aspects of the production process, including smelting, refining, casting, and smithing techniques, will be presented. Additionally, the primary copper alloys identified will be thoroughly discussed. By comparing these findings with both regional and interregional data, an exploration of the technical, economic, and social factors influencing the selection of specific production techniques and alloys will be undertaken. The analysis reveal a predominant use of local ores, with occasional instances of importing both raw materials and finished products, such as tin. It is worth noting that the chosen ore deposits were primarily of a sulphidic nature, necessitating the implementation of refining techniques to attain copper of sufficient purity. Furthermore, the recycling of metal scrap emerges as a notable economic practice during this period. Likewise, finishing techniques, specifically annealing and quenching, seem to have been employed to achieve objects of comparable strength and durability to tin-bronzes, though using local natural alloys (Cu-As-Ni).

The final section of this dissertation will focus on a comprehensive examination of the social aspects underlying copper production and the significance of Saruq al-Hadid within the broader socio-cultural landscape of the southeast Arabian Iron Age. The author embarks upon the identification of the individuals or groups responsible for the production, control, and consumption of the copper goods discovered. Although the available data may present challenges in attaining definitive conclusions, the study highlights evidence to increase the knowledge on these matters. Additionally, the author draws upon local and global examples for comparative purposes and propose avenues for future research.

Subsequently, a thorough discussion on the social power of copper and its ritualization is undertaken. The ritualized deposition of copper objects and prestigious artefacts at Saruq al-Hadid, reminiscent of similar findings in cultic and communal sites across the region, presents a remarkable opportunity to deepen our understanding of copper metallurgy and its social significance. To effectively interpret the broader organization and significance of copper production at Saruq al-Hadid, a theoretical framework rooted in the concept of a 'ritual economy' is employed. This lens allows for a comprehensive understanding of copper metallurgy within the socially constructed knowledge, beliefs, and practices of early Iron Age society in Southeast Arabia. By adopting this approach, valuable insights into the intricate interplay between technology, social dynamics, and cultural practices is gained, ultimately enriching our understanding of this complex phenomenon.

1. Copper production in southeast Arabia

Archaeological studies in Southeast Arabia began not long ago, mainly influenced by Mesopotamian archaeology. The “copper mountain of Magan” (PEAKE, 1928), recurrently mentioned in cuneiform texts as one of Mesopotamia’s copper suppliers in the 3rd and early-2nd millennia BC (e.g. MUHLY, 1985; WEISGERBER 1983), led many researchers to try to identify where it was located. The idea that Southeast Arabia could be the supplier began early in the twentieth century when a research commission was established to explore the origins of copper in assemblages discovered within Mesopotamia. Because some of these were copper alloys rich in nickel, considered a signature of Ultrabasic rocks in the Mountains of Oman, it was first suggested that the copper originated there (PEAKE, 1928).

Nevertheless, it was not until the 1950s that the initial archaeological expeditions were undertaken in this region, prompted by the quest to locate the enigmatic "Magan". Numerous prehistoric sites were unearthed during these investigations. Mainly tombs were discovered, easily spotted upon the landscape as circular above-ground monuments, but it was not long before evidence of settlements emerged in Al Ain (UAE), revealing artefact assemblages from the Bronze and Iron Age that bore resemblance to those discovered in the Mesopotamian and Iranian regions (e.g. FRIFELT, 1975a; DE CARDI *et al*., 1971; DE CARDI *et al*., 1975; DE CARDI *et al*., 1976). Subsequently, in the 1980s, there was a notable surge in research interest as more scholars became captivated by the region, now home to burgeoning petroleum sheikhs eager to invest in their historical heritage.

Significantly influenced by mineralogic research, the German Mining Museum also intensively surveyed the region, particularly the Hajar Mountains, during the 70s. In the 80s, the findings from these studies were consolidated and demonstrated through archaeometallurgical research that the region was in fact, the place of "Magan", with an established production of copper from as early as the Umm an-Nar period, which was distributed from Mesopotamia to the Indus Valley (e.g. WEISGERBER, 1980; WEISGERBER, 1981; WEISGERBER, 1983; WEISGERBER, 1987; WEISGERBER, 1988; WEISGERBER *et al.*, 1999; WEISGERBER *et al.*, 2003; HAUPTMANN, 1985; HAUPTMANN, 1995; HAUPTMANN *et al.*, 1980; PRANGE *et al.*, 1999). However, it is noteworthy that their studies primarily focused on extraction and ore smelting sites, with limited attention given to the organization of production and the manufacturing of objects.

Only later, in the early 2000s, L. Weeks (2003) tried to highlight archaeometallurgical information from copper objects found in the Bronze Age necropolis. His research revealed variations in metal acquisition patterns within the region, particularly regarding the mechanisms and routes employed for obtaining tin. Given the absence of tin in the local area, it must have been procured from external sources. Moreover, since the identified objects consisted of both nearly pure copper and tin-copper alloys, attempts were made to decipher the motivations behind the usage of either composition. It was observed that "*control over alloy composition was minimal, that recycling did not discriminate between alloy types, or that a wide range of tin-bronze alloys were produced for varying reasons*" (WEEKS, 2003, p. 128). It all pointed to a vast network of long-distance metal trade and technological development extending through the entire Middle East and Central Asia. Still, the proper outline of these trading dynamics remains understudied for lack of inter-regional data and information about other chronological periods; this study and others focused on the Bronze Age.

As research continues in the last two decades, more sites and information continue to appear, particularly about the region's Iron Age. Burial sites and settlements appear all over the region (MAGGE, 2018b; MAGEE, 2007), and recent metal studies such as that by J. Goy (2019), tried to identify the significant technological developments of metal extraction and smelting for the Iron Age period, and the social and economic choices behind the identified metal alloys. Drawing data from numerous Iron Age sites she was able to provide insights into this production *modus operandi*, distribution and consumption. However, Saruq al-Hadid, whose archaeometallurgical data is only now being prepared for publication, was mostly left out of her studies as she had not yet access to its results.

1.1. Mineralogical distribution of copper in Southeast Arabia

Copper ores in Southeast Arabia are found in the Hajar Mountains. This mountain range extends about 700 km long and 150 km wide, creating an arch averaging from 500-1500 masl from the Musandam Peninsula (in the north) to Ras al-Hadd (in the south). About 150 million years ago, active spreading ridges in the Neo-Tethys and South Atlantic Ocean created horizontal compressive forces that led to an eastward-dipping subduction zone. In turn, this led to the progressive formation of the Semail Ophiolite (a giant slag of oceanic crust made of volcanic and ultramafic rocks from the Earth's upper mantle) and the emplacement of Hawasina sediments. When horizontal compressive forces ceased, the uplifting of these areas began, emerging above sea level about 75 million years ago, and at 30 million years, the separation of Arabia from Africa and the collision of the Indian plate with Eurasia made the Hajar Mountains to slowly rise (GLENNIE, 1995).

Copper deposits found in the Hajar mountains (see Annexe 3a) formed during these processes and are mostly concentrated in the rocks of the Semail Ophiolite, of the mantle and crustal origin (LIPPARD *et al.*, 1986). These are massive sulphide deposits stratigraphically bound with the pillow lavas of the ophiolite and primarily comprised of pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and sphalerite (ZnS) and exhibiting well-developed gossans consisting of brightly coloured iron oxides, hydroxides, and sulphates. Secondary copper minerals such as malachite ($Cu_2CO_3(OH)_2$), azurite

($Cu_3(CO_3)_2(OH)_2$) and rare native copper are also present. Smaller vein-type deposits also occur throughout the Semail Ophiolite, frequently of high grade and containing significant quantities of chalcopyrite and pyrite, as well as secondary minerals such as brochantite ($Cu_4SO_4(OH)_6$), malachite, azurite and chrysocolla ($CuSiO_3.2H_2O$). Within the Hawisina rocks, similar massive sulphides and vein-type mineralization also occur, particularly at Al Ajal (near Muscat, Oman) and further north in the UAE.

1.2. Copper technology in southeast Arabia

1.2.1. Smelting evidence in southeast Arabia

In southeast Arabia, the first evidence of copper objects dates from the 4th/early 3rd millennium BC (as cited in GOY, 2019, p. 63-64), coming from the sites of Ra's al-Jinz where small fragments of metal were identified amongst lithic objects, and Ras al-Hamra (RH-10), from where a knife and fish hooks, as well as several other indistinguishable fragments, were identified. Similar objects were discovered at Ras al-Hadd (HD-6) (see Annexe 2b). However, from studies done on these objects, all were produced through mechanical work, not requiring the use of fire. Thus, we are not in the presence of reduction metallurgy. Furthermore, given the absence of evidence for these objects' production on-site and isotopic data, we cannot determine their origin.

The first proper reduction sites have been reported only from the second half of the 3rd millennium BC (HAUPTMANN, 1985; YULE, 1996) (see Annexe 2c). Thanks to work done by the aforementioned German Mining Museum Project in Oman, several extraction/smelting sites were mapped and dated to this period, including Maysar, al-Aqir, Bilad al-Maaidin, Raki, Hawqayn, and Ubaylah, to name a few (WEISGERBER, 1981; HAUPTMANN *et al*. 1988). All these showed a technology based on the selection of low iron sulfide (pyrite) and copper-iron sulfide (chalcopyrite), and high copper content ores of 5 to 56% such as malachite, chrysocolla and brochantite from areas of secondary mineralization, rich in nickel (Ni), arsenic (As) and cobalt (Co) (HAUPTMANN, 1985; HAUPTMANN *et al.*, 1988). These ores could be easily obtained at the surface.

The ores were smelted in furnaces 40-50 cm in diameter and approximately 40 cm in height, lined with clay and air supplied by tuyeres (WEISGERBER, 1983; HAUPTMANN, 1985). These were mixed with charcoal produced from local trees and shrubs (*Acacia*, *Prosopis* and *Ziziphus* (see annexe 3d)), and fluxes such as haematite and limonite were added to aid in removing intergrown silicious rocks from the copper ores (HAUPTMANN *et al.* 1988). No roasting prior to the reduction was observed, suggesting a "co-smelting" procedure (LECHTMAN *et al.*, 1999), where both copper and relatively pure matte were obtained. Studies of the slag indicate that temperatures ranged from 1150-1200^{o}C. However, viscosity was relatively poor and contained high levels of copper, meaning that the elements' separation was not ideal and required mechanical separation (HAUPTMANN, 1985; HAUPTMANN *et al.*, 1988; GOY 2019). After this, the separated copper lumps had to be remelted in crucibles for casting into planoconvex ingots at cavities dug in the floor (WEISGERBER *et al.*, 2003).

During the Iron Age (1st millennium BC)[1], in contrast, we observe the exploitation of massive sulfide deposits in underground mining using inclined galleries, shafts and pits, some up to 87.5 m in depth (WEISGERBER, 1980, p. 66-67; WEISGERBER, 1988, p. 286) (see Annexe 2e). Still, mixed iron and iron-copper sulfides and low-percentage copper mineralization in the gossans were exploited (HAUPTMANN, 1985). The reduction appears to be done in similar furnaces, and ores were reduced using the same co-smelting procedure (GOY, 2019, p. 335-336), requiring subsequent purification processes. Gangue, which surrounds the ores, is never completely removed to promote slag viscosity and separation of copper from impurities, and other rocks, minerals and shells are voluntarily added for the same purpose. In this case, iron oxides are crucial to reducing the excess silica that constitutes the gangue and promoting slag formation without increasing the temperature (GOY 2019, p. 336-341).

---

[1] Metallurgical evidence for the 2nd millennium BC is minimal (see Annexe 2d), perhaps by diminishing scale of production, destruction of deposits and/or simple lack of survey. However, it is speculated that it may have been done at the same places as those from the 3rd and 1st millennium and using similar technology to that observed for the 3rd millennium (VELDE, 2003, p. 109; WEISGERBER, 1988, p. 285).

From what J. Goy could observe from Iron Age slags from the region (2019, p. 54), during such co-smelting operations, the sulphur escapes in the form of gaseous SO_2, which allows the formation of matte, composed of copper and iron oxides. Depending on the amount of metallic copper in the matte, the roasting-reduction process can be repeated until an amount deemed sufficient is obtained. Since matte is a semi-metallic product, its appearance varies depending on the amount of metallic copper it contains. It will therefore have a morphology close to slag if it is composed of little copper or close to a mass of metal if it is rich in copper. The quality of the result will depend on the carbon dioxide available, temperature and contact between gas and solid material.

However, these will not continue to be purified near extraction/smelting areas but instead transported to workshop areas in settlements or metallurgical centres like Saruq al-Hadid and ‘Uqdat al-Bakrah (GOY, 2019). There these were purified (also referred to as secondary smelting). The furnaces for this process do not need to be closed, as this process does not need a reducing atmosphere. It can simply be a pit of pebbles and charcoal where a crucible is introduced. Airflow can be added with tuyeres or blowpipes. (GOY, 2019, p. 58-59).

Analysed slag from Qattarah indicates that it resulted from such secondary smelting rather than primary smelting (GOY, 2019, p. 461-462). Similar evidence, though not metallographically analysed yet, seems to exist in other settlements such as Rumeilah (BOUCHARLAT *et al.*, 1985), Al Thuqaibah (BOUCHARLAT, 1988), Muweilah (MAGEE, 1996b), Tell Abraq (WEEKS, 1997) and Kalba (CARTER, 1997, p. 144). However, some of these do not exhibit clear evidence of production at the site (as the existence of slags), but just the accumulation of such copper matte, resembling slags. Confirmation is required for secondary smelting on these sites, or simple hording as a source of wealth, or accumulation to be taken to other sites of actual production.

The amount of charcoal necessary for such an industry has also been discussed (ECKSTEIN *et al.*, 1987), particularly in a region without much vegetation cover. Data points to the use of mainly *Acacia* and other hardwood shrubs, although some authors suggest the use of dung as well (GOY, 2019, p. 341-342). However, although such has been attested in the archaeological record (e.g., MOHEN *et al.*, 1989), it might have only been used for the melting procedures (after the smelting), which does not require temperatures higher than 1000ºC. Furthermore, the high quantities of iron observed in the slags from this period suggest that metallurgists tried not to heat the furnaces too much, perhaps not to use as much fuel (GOY, 2019, p. 346). Favouring iron as flux, despite polluting the copper, would allow them to maintain lower furnace temperatures while facilitating metal segregation from slag. Although such would imply subsequent purification processes, the base co-smelting technique would already imply it (GOY, 2019, p. 347-348), thus not an issue.

For the following pre-Islamic period, again, data about metallurgic activities are almost non-existent, except for data coming from Mleiha (PLOQUIN *et al.*, 1999), 'Arja and Raki (WEISGERBER 1980; WEISGERBER, 1987; YULE, 1996) (see Annexe 2f). While comprehensive insights into this era are yet to be obtained, it appears that technology and production organization persisted in a similar fashion.

From the 9th and 10th centuries AD, however, metallurgical installations were discovered in close proximity to the same extraction and smelting areas observed in previous periods, including Lasail, 'Arja, and Madhab, thus supporting the hypothesis that the majority of mines in the region were consistently used through time, leading to the destruction and frequent mixing of evidence from preceding periods (WEISGERBER, 1983, p. 274). During this period, predominantly pyrite, chalcopyrite, and bornite ores were exploited from massive sulfide deposits, mirroring the practices of earlier periods. However, the ores were sourced from primary, unweathered deposits (HAUPTMANN, 1985, p. 107-108), requiring technological adjustments. These ores were of relatively low quality, require processes involving multiple stages of alternating roasting and smelting (WEISGERBER, 1987, p. 153). Co-smelting was no longer viable due to the insufficient oxide content in the ores. Near the extraction sites, the ores were roasted in stone and mortar-lined pits, approximately 1 meter in diameter, and subsequently smelted in relatively sturdy shaft furnaces that could be used for prolonged periods and reconstructed if necessary (WEISGERBER, 1980;

WEISGERBER, 1987). Following the initial smelting process, the copper matte had to be mechanically separated from the iron-rich slag for subsequent roasting and re-smelting. This procedure was repeated until the copper attained the desired level of purity for alloying and melting (HAUPTMANN, 1985).

For the remainder 12th to 19th centuries AD, archaeological evidence only has provided a few examples of copper mining at this time, being most smelting observed carried on from recycling earlier period slags with high matte content, iron oxides and secondary copper minerals recovered from refuse piles (HAUPTMANN, 1985, p. 103-104). For such, small bowl-shaped, clay-lined, smelting furnaces were built without a chimney shaft. Slag and matte were not tapped out and instead left to solidify inside, which resulted in large slag cakes with a copper matte “ingot” at their base. The structure had to be destroyed for its extraction and copper matte mechanically separated for re-smelting (HAUPTMANNM 1985, p. 104; WEISGERBER, 1987, p. 159).

1.2.2. Smithing evidence in southeast Arabia

The information about objects’ production phases is virtually non-existent in the region. From the late 4th millennium BC, objects begin appearing at middens and settlements on the eastern coast, such as Wadi Shab, Ra’s al-Hadd and Ra’s al Hamra (TOSI *et al.*, 2003; DURANTE *et al.*, 1977; UERPMANN, 1992), in the shape of small fragments of copper blades, fish-hooks and pins/awls, as well as evidence of metal working debris. However, most objects from this early metal production period appear in contemporary tombs, where besides the referred objects, rivets, tweezers, and long awls appear alongside bi-conical Jemdet Nasr pottery of Mesopotamian tradition that helped date these tombs (FRIFELT, 1975b; CLEUZIOU *et al.*, 2000). Still, despite much speculation, the actual copper origin of these earliest objects has not been demonstrated.

Throughout the 3rd millennium BC, the number of objects discovered in both settlement and tomb contexts increased, and adding to the referred type of objects, tanged or riveted knives, daggers, chisels, axe blades, spearheads, razors, finger, toe and earrings make their first appearance (FRIFELT, 1992; BENTON, 1996; CLEUZIOU et al. 2000; HAERINCK, 1991; VOGT, 1995). Metalworking of these objects is better attested at sites like Umm an-Nar Island (FRIFELT, 1995), where ingot fragments, clay moulds, processing residues and crucibles are found. Metalworking debris for secondary refining, melting and casting at other settlements, such as Hili 8, Ra’s al Jinz 2 and Tell Abraq (CLEUZIOU, 1989; CLEUZIOU *et al.*, 2000; WEEKS, 1997) are also attested, but again, remain largely understudied.

Throughout the 2nd millennium BC, although very few settlements are known for this period, and no object production is attested, objects abound in burial contexts. Adding to the type of objects mentioned from the previous periods, small swords, tanged arrowheads (often with incised decoration), and copper vessels make their first appearance in the region (CLEUZIOU, 1981; AL SHANFARI *et al.*, 1989; MAGEE, 1998d; VOGT, 1995; AL TIKRITI, 1989; VELDE, 2003). Again, very few studies exist about these objects, except for their composition (e.g. HAUPTMANN, 1995; HAUTPMANN et al., 1988; PRANGE *et al*., 1999; WEEKS, 1997).

The compositional analysis of objects dating back to the 3rd and 2nd millennium BC reveals that the majority of these artifacts were crafted using copper containing traces of arsenic and nickel, with the latter reaching levels as high as 4% or higher. This composition aligns with the elemental makeup of raw copper and ingots sourced from Maysar, Bahla, Umm an-Nar, and Ra's al Hamra, as evidenced by analytical studies (HAUPTMANN, 1995; HAUPTMANN *et al.*, 1988; CRADDOCK, 1981). This correspondence suggests that a substantial portion of these objects may have been locally produced using local ores. The presence of elements such as arsenic and nickel in the copper composition contributes to the inherent quality of the metal. Consequently, it is conceivable that the use of tin for alloying, as observed in other regions (MUHLY, 1985), may not have been necessary (EATON *et al.*, 1976; OUDBASHI *et al.*, 2020). The use of locally available ores could have provided a more cost-effective, readily accessible, and equally high-quality source of metal for the production of these objects.

Occasionally, however, some objects, particularly those of Tell Abraq (with over half of the objects analyzed), were of copper-tin alloy (WEEKS, 1997; PRANGE *et al.*, 1999). Such can suggest three different trading/production choices: import finished tin-bronzes, import tin to alloy with local ores, and/or recycle of copper-tin alloyed objects (WEEKS, 2003). Despite the observed preference for local ores, all are valid and possibly used in the region. The discrepancy of copper-tin alloyed objects observed at Tell Abraq may infer on this site relevant role as a Gulf trading post (MAGEE *et al.*, 2017). Nevertheless, research encompassing inter-regional dynamics and sociocultural factors is imperative for a comprehensive understanding of the motivations underlying these alloy preferences.

Technical details regarding the alloying, casting, and finishing of copper objects are, for all periods, largely understudied when compared to the smelting practices. Still, from the little so far observed, mainly from J. Goy's studies (2019, p. 59-60), techniques employed vary from casting into moulds to forging with hammering. Lost wax is also possible, which would require a bivalve mould, and case hardening, a patina operation to modify the appearance of the metal while maintaining internal properties, often used for copper-arsenic alloys. Finally, silversmithing was done for all welding, decoration and sharpening final processes.

1.3. Metallurgic periodicity in southeast Asia

As could be observed, significant blanks in the metallurgical record of the region deserve an explanation. Although lack of survey and/or destruction/mixing of previous extractive/smelting activities can provide an image somewhat distorted of the economic reality of each period, there is also an evident absence of studies focusing on post-smelting production stages that took place in either settlement or workshops dissociated from smelting/extraction sites. Social and environmental studies (i.e. BUDD *et al.*, 1995; STÖLLNER, 2008) on the factors that may have influenced technological and economic choices and thus influenced this production periodicity are also absent. Nevertheless, a few political, environmental, and economic factors, intra- and extra-region, have been pointed out and could explain such variations.

The environmental cost of large-scale copper smelting, especially on the amount of wood-charcoal necessary, may not just have depleted large, forested areas (ECKSTEIN et al., 1987) but also intensified erosion/aridification problems, already in place due to climatic changes observed throughout the Holocene (BRAY et al., 2004; LÉZINE et al., 2010; PARKER et al., 2006; PARKER et al., 2008). Air, soil, and water pollution inherent to this industry (as seen in, e.g. NOCETE et al., 2005; KNABB et al., 2016; CORTIZAS et al., 2016) (completely understudy in the region) may have also largely affected people's lives, which may answer questions of emplacement. Although purely transportation/environmental (water/fuel availability) logistics may be the reason for the location of smelting structures near the mining sites, the fumes produced during the smelting stages would also be a reasonable explanation (OTTAWAY, 2001). Consistent with this information is that no singular settlement exhibits evidence of smelting, only secondary smelting, and smithing.

From calculation studies made in the region between tons of slag, necessary charcoal, and inborn wood (WEISGERBER 1980; HAUTPMANN 1985; ECKSTEIN, 1987), it was concluded that even with a favourable assessment of tree stock and replenishment, the amount of copper produced at the peaks of its procurement, namely during 3rd and 1st millennium BC, would have stressed the vegetation and landscape, and such a situation, although requiring further research for confirmation, is reflected in the stratigraphic record of Saruq al-Hadid (WEEKS et al., 2016, p. 97-111; WEEKS et al., 2017a, p. 173-202; VALENTE et al., 2020), as we shall be discussed.

Thus, if we mirror this information with the metallurgical periodization observed, it is entirely plausible that over-production in specific periods led to the depletion of entire vegetation covers, thus forcing production halting in the subsequent periods (WEEKS, 2003, p. 35). Although production could shift to a different area (with still abundant vegetation) while the older one recovered, production would still decrease, compelling populations to explore alternative means of fulfilling their copper requirements, potentially resorting to recycling practices.

Copper recycling of slag and/or objects could have been an alternative to supplement the lack of copper extraction/smelting. Furthermore, this economical choice, often overlooked in the archaeological record but recurrent worldwide (e.g. FIGUEIREDO et al., 2010; MÖDLINGER et al., 2021), could have been an option in southeast Arabia (WEEKS, 2003, p. 35). Again, at Saruq al-Hadid, as shall be discussed, evidence for systematic copper recycling is attested in both Iron Age and Early- and Islamic levels (WEEKS et al., 2016, p. 248-254; WEEKS et al., 2017a, p. 425-470; VALENTE et al., 2020), in the shape of both scrap metal and slag recycling.

Several authors suggest that most metal for recycling would come from tomb-robbing (YULE *et al.*, 2018), particularly during the 2nd millennium BC where evidence of copper extraction/smelting is scanty, but copper objects in burial sites abundant (VELDE, 2003; CARTER, 1997; POTTS, 1991). Such contrasts with 3rd millennium evidence, where extraction/smelting evidence is abundant, but metal objects are not as much as should be expected (e.g. CLEUZIOU *et al*., 1983). Nevertheless, although many scrap-metal could come from tomb-robbing (despite social tabus, this may arise) recycling objects after daily disuse or damage was likely a reality. At Saruq al-Hadid, once more, the number of objects showing deformities and breakages (as shall be discussed) is significant and proves that melting of older objects into new ones was an economic solution as important as smelting new copper, whether in periods of copper scarcity or not. Future studies on this recycling economy, alongside other ones about stages of production, besides extraction/smelting, could provide further insights into this dynamic and adaptable economic network.

Foreign economic and political conditionings also played a role in the periodization of copper procurement, and both historical and textual data shed light on this matter. When copper production began in southeast Arabia, it was already well established in West Asia, particularly in neighbouring regions of Baluchistan and Iran (THORNTON, 2014). Such has led to suggestions that the copper technology of southeast Arabia was a foreign innovation, as much as early pottery production, attending to both stylistic and technological aspects of both productions, particularly when compared to contemporary ones from across the Straits of Hormuz (CLEUZIOU *et al.*, 2002; MÉRY, 1996). Although such aspects are indeed relevant and may indicate contacts and even the existence of groups of people living in the region that might have taught the basics of such productions, there is significant evidence, at least for the copper industry, that it developed through a phase of trial and error, as A. Hauptmann suggests (1985: 92) and observed in Maysar, which is inconsistent with the immediate adoption of a developed production. The "stimulus diffusion" theory proposed by L. Weeks (2003: 36), where only the idea of metal was brought to the region stimulating experimentation with local metal ores, fits better in the region evidence.

As copper production was perfected in the region, it could eventually enter the Middle Eastern commercial circuit, supplying the demand already in place during the Bronze Age. The demand from Mesopotamia, in particular, a centre of metalworking for the production of finished objects, but without evidence of mining and smelting (FRANKE, 2018), might have stimulated this impetus on copper extraction and smelting in southeast Arabia (EDENS, 1992). Contacts between both regions have been identified since the early Bronze Age, and the majority of textual resources mentioning the import of copper from Magan date to the 3rd millennium BC (POTTS, 1991; BEGEMANN *et al.*, 2010), exactly when production peaked. However, as L. Weeks (2003, p. 37) points out, reliable analytical links between regions and nearby ones, such as Dilmun and Meluhha, also hypothesized as consumers of southeast Arabian copper, are still scarce.

The decline in copper extraction/smelting observed during the 2nd millennium BC, despite the abundance of finished objects found, is an example of how poorly understood such an industry is. Although the economic dynamics of such production may have adapted due to environmental factors, shifting from primary sources of copper to simply recycling older objects as referred, several authors also suggest that instability in Mesopotamia and the demise of the Harappan civilization, at that time, could be the reason behind its decline (CRAWFORD, 1996), at least on the inter-regional circuit. Furthermore, Mesopotamian consumption of copper from other sources, such as Anatolia and Cyprus (e.g. CHEN, 2021; ÖZBAL *et al.*, 1999), may have also led to new exchange dynamics, perhaps more profitable at the time. However, although valid and most likely a contributor, it seems that such a simplistic theory demises the value copper may have had in the lives of those who extracted and produced it, as if external trade alone was the sole instigator of all economic demand.

Although the observed settlement demise (CARTER, 1997; CLEUZIOU, 1981) and change into a non-specialized production practice at multiple locations (at least of pottery and soft stone (MÉRY, 2000; DAVID, 1996)) may support the idea that at least both environmental and economic (external) factors altered distribution and consumption dynamics (CLEUZIOU *et al.*, 2002), this does not imply that metallurgic production has stopped. The mentioned large quantity of copper objects discovered in burial sites and analytical data from this period contradicts it (WEEKS, 1997). On the other hand, the already pointed out difficulty in chronologically dating slag heaps and the destruction that more recent extraction activities may have caused in older mines impedes us from accurately knowing if some, if not many, of the identified extraction/smelting sites, were not also used during the 2nd millennium BC.

Furthermore, already in the 3rd millennium BC and throughout the 2nd millennium BC, copper objects seem to be an essential social denominator expressed in their identification as burial goods (BENTON, 1996; POTTS, 2000; FRIFLET, 1992; FRIFELT, 1979; CLEUZIOU *et al.*, 2000; CLEUZIOU, 2002; RIGHETTI, 2015). Although the social meaning of metal objects is often understudied, given the difficulty of accessing such denominators, it has played an essential role in the impetus of such production.

From the end of the 2nd millennium BC until the mid-1st millennium BC, the impetus of copper production may have been directly related to internal demand of both economic and social pressures. On the one hand, we observe a tremendous increase in the number of settlements mirroring population expansion (DEL CERRO, 2004; MAGEE, 2007), likely facilitated by the introduction of the *falaj* irrigation system (AL TIKRITI, 2002; DEL CERRO *et al.*, 2018; DEL CERRO, 2007) which allowed a much more extensive agricultural production, thus supporting a larger population. In turn, this would have led to an inherent internal demand for copper, which allied to a regionally-specialized economy, reflected social needs, as these metal objects would have served as status objects used by newly emergent elites. The large quantity of copper weapons identified for this period (far more significant than previously) has even been hypothesized to reflect increased conflict between communities (MAGEE, 1998b; MAGEE, 1998c).

Nevertheless, external trade connections, particularly with Iran, still poorly studied, may have played a key role in this period also. The abundance of goods and cultural exchange between both regions is explicit. Both ceramic (MÉRY, 1996; MAGEE, 2005; MAGEE *et al.* 2007) and soft stone vessels (MAGEE *et al.*, 2005) are attested in both sides of the Hormuz Strait, as well as construction techniques, such as the production of similar mudbricks (KARACIC, 2019) and platform structures (LAMBERG-KARLOVSKY *et al.*, 1999). Stamp seals of both regions are also a commingling find (LAMBERG-KARLOVSKY *et al.*, 2001; KARIM, 2017), showing that both regions were in close contact. However, we cannot still understand the outlines of this exchange, particularly what pertains to metal exchange. Both had copper sources and were copper producers. However, due to the lack of a considerable number of isotopically analyzed objects, we cannot confirm if these were exchanged between regions, although stylistic evidence in southeast Arabia might suggest it (e.g. WEEKS *et al.*, 2017b, fig. 21), even if just in one direction, for the moment. The presence of iron weaponry in southeast Arabia, of likely origin in Iran (STEPANOV *et al.*, 2020), also points to this (at least) unilateral trade of metals.

The question of tin-copper alloyed objects in southeast Arabia is of even greater importance for this exchange of metals. Iron Age data from J. Goy (2019) shows that alloys have occurred randomly in southeast Arabia and already since the Bronze Age (WEEKS, 2003; WEEKS, 1997) alongside local As-Ni-Cu alloys. Most of the tin-copper objects are apparently the result of using recycled tin-copper, considering that their tin content is relatively low (below 4%). However, the pertinent question is, from where was tin (or tin-copper products) coming in the first place, considering that there are no sources of tin known in the region?

Through the same circuits of iron exchange, tin might have come to southeast Arabia from Iran. The copper mine of Deh Hosein in Iran, for example, which also contains stannite and cassiterite, has been isotopically linked to many of the Luristan bronzes from the 2nd millennium BC (NEZAFATI et al., 2009), which share stylistic traits with those found in southeast Arabia. Furthermore, several tin mines with mining evidence since the Bronze Age have been discovered in Central Asia, which has proven to be an essential contact zone between the Middle East, Western Asia and the Eurasian steppes (HAUPTMANN, 2020, p. 97-111; STÖLLNER *et al.*, 2020). Thus, tin likely did not come from only one source but from several, interconnected through a vast and dynamic network of metal exchange, to which southeast Arabia belonged. Still, attending to all evidence pointed out for the contacts between Iran and Southeast Arabia, it is possible that Iran was its primary (even if through secondary channels) supplier of metals.

The dynamics of this inter- and intra-regional metal exchange, allied to the observed new landscape adaptations and proliferation of settlements in southeast Arabian, may all have contributed to the observed social complexity and, thus, increment of copper procurement during the Iron Age period. However, this metallurgical “boom” will be short-lived.

During the following Pre-Islamic period, copper production will again decrease for unknown reasons. At burial assemblages (YULE *et al.*, 1988), it is evident that iron (at least in weaponry) slowly suppresses the presence of copper. However, copper will remain the metal to produce most utensils and jewellery, although iron swords, daggers, and arrowheads (of Iranian style) will become widespread. However, more is needed to explain the decrease in copper procurement. For example, although iron has become widespread at settlement sites like Mleiha and ed-Dur, copper-base objects are still produced at these sites (PLOQUIN et al., 1999; WEEKS, 2004; DELRUE, 2008). However, the employment of secondary smelting at these sites, including older slag and recycled material, suggests an economic effort in reusing sources of metal more readily available than mining itself. Unfortunately, not much else can be said because of a generalized lack of knowledge for this period at large (and subsequent ones), not just in terms of metal production but in most aspects of social and economic life.

1.4. Copper production organization

Again, information from prehistoric periods is much better known for copper production organisation than later ones. Evidence suggests that primary smelting was done near extraction sites during the Bronze Age. In contrast, the result of this first smelting, in the shape of ingots, would be transformed into objects at settlements (WEEKS, 2003). These ingots, produced at extraction/smelting sites, would also be the ones entering foreign trade, although trade of copper amorphous lumps and scrap should not be overlooked though understudied (HAUPTMANN *et al.*, 1980; WEISGBERBER *et al*., 2003). Moreover, despite this simplistic view of copper production organisation, not much evidence exists for the phases that would subdivide each set of production (e.g. mining, ore processing, smelting phases until pure copper, alloying, casting, annealing, hammering, polishing, and decoration).

Data regarding scale and duration of exploitation is also relatively diminishing as it relies solely on estimation calculations done at ore/gangue extraction, at Maysar, for example, and slag heap sizes (WEISGERBER,1980; WEISGERBER, 1981; HAUPTMANN, 1985), which can be quite misinformative as may not be from the same period. Although A. Hauptmann (1985, p. 95) hypothesized that slag amounts recorded at sites like Ubaylah were of large-scale production, there is no evidence to indicate how long they were in use, and if the slag belongs to the same period, and this goes for most slag heaps in southeast Arabia. Moreover, attending that studies have demonstrated that large slag outputs can be achieved by small groups operating under relatively simple production regimes (e.g., WHITE *et al*., 1996), we cannot measure the scale of production in the region until these slag heaps are excavated and measured following strict technological and chronological parameters (i.e. HUMPHRIES *et al*., 2016).

On the other hand, a couple of sites, Maysar (WEISGERBER, 1980; WEISGERBER, 1981; HAUPTMANN, 1985) and Wadi Hilo (KUTTERER, 2020), exhibiting buildings associated with the primary smelting phases of production, were excavated revealing a relatively small scale of production, though quite prolonged in time. At Maysar, the amount of debris was small, suggesting that copper production was taken as part-time, likely seasonal, and secondary to agricultural and pastoral activities. In the settlement, some buildings presented structures which might have been used as furnaces, however such has not been confirmed, and most smelting debris found was incorporated into the walls of these buildings (WEISGERBER, 1980, p. 88-89), thus possibly from somewhere else.

From the surveys carried out by the German Mining Institute in the 70s-80s, it was also observed that all smelting sites identified were located near water and arable land, which led authors to suggest that copper production was an integrated part of community life (HASTINGS *et al.*, 1975, p. 12), however, most of the sites where not dated, and on very few traces of settlement from prehistoric periods were found.

The site of Wadi Hilo, not far from known prehistoric settlements/burial sites such as Kalba (SCHWALL *et al.*, 2020; EDDISFORD *et al.*, 2009), Hatta (VALENTE *et al.*, 2022), Husn Awhala (PETRIE, 1998), or Qawr (PHILLIPS, 1997), provided evidence of extraction and smelting from the 3th millennium BC until the 1st millennium BC, with a production peak during the Umm an-Nar and Wadi Suq periods (KUTTERER, 2020, p. 68-76). The amount of slag found was relatively diminishing, which leads to believe that it was also a relatively small production site, likely seasonal (KUTTERER, 2020, p. 80), but consistent in time. The furnaces identified were located inside rooms in larger structures. Although it is impossible to know if all rooms were roofed or not, the authors indicate that some rooms were likely not, and some even open to the outside, with only three walls preserved (KUTTERER, 2020, p. 68-76). From pottery and ingots found in the remaining rooms, these were likely used for both living (while in production season) and storing the production at hand (KUTTERER, 2020, p. 50-78). Regarding areas for charcoal production, these were not identified on-site. Researchers theorize that charcoal could easily be brought in, considering its lightweight. At the site, mainly *Acacia* and *Prosopis* wood was used alongside bush and shrubs (KUTTERER, 2020, p. 82), as observed in other sites in the region. However, the location/process upon which charcoal was produced has never been identified, neither at this site nor anywhere in southeast Arabia. Finally, as expected, there are no traces of object production on site, as these stages of production would be carried out at settlement areas.

It is also interesting to note that this production could effectively supplement intra- and extra-regional trade, although of an apparent small scale. The economic articulation among the different productions (copper, pottery, soft stone, shells) and subsistence strategies (farming, fishing, herding) (CLEUZIOU, 2009) observed throughout the Bronze Age, with each community dedicating some time for activities that would bring them most output (attending to nearby resource conditionings), which could then be traded, thus seem to have created a perfect balance for supplementation between the region's communities. Enough was even produced to be traded to other regions at coastal sites like Tell Abraq and Kalba, as hypothesized (EDDISFORD, 2022). It was what can be entitled as "trade as subsistence activity" (CLEUZIOU *et al*., 1989; CLEUZIOU *et al.*, 2002) that seem to permeate the economic and social backgrounds of this entire region until today (LANCASTER *et al.*, 1992).

For the Iron Age, copper production is assumed to be larger than in the previous period, but this assumption is again based upon the size of slag heaps (WEISGERBER, 1987; WEISGERBER, 1988; WEISGERBER et al., 1999), large-scale mines (WEISGERBER, 1987), and the number of settlements for which copper processing was attested (COSTA et al., 1987), which as mentioned, cannot be the single denominators for such conclusions.

The noticeable increase in copper objects produced during this period can, on the other hand, infer the value of copper for this society. Let us consider the type of objects now produced in copper. We can hypothesize that this metal is now a much more readily available commodity that, although still reserved for the production of prestigious objects (as shall be discussed), will also be used for daily life objects such as vessels, hoes, needles, pins and fish hooks, not to mention diverse types of weaponry, namely arrowheads, daggers and axe heads that were now made in copper (YULE *et al.*, 2018); arrowheads, until recently, where of stone in southeast Arabia (MOORE *et al.*, 2022), when already of copper in most nearby regions. This fact can both reflect production increase and social change. It is the supplantation of stone by copper, which could only be possible if enough copper existed to slowly leave the "prestige" circuit to become a daily commodity (APPADURAI, 1986).

However, this took time to happen, particularly in Southeast Arabia. While in other regions, such as Mesopotamia and Iran, copper was already being replaced by iron (CUÉNOD, 2012) during the Iron Age, in southeast Arabia, copper was still seen as the most valuable metal (LOMBARD, 1985; BENOIST *et al*., 2015), although iron was occasionally starting to appear in some highly ritualized/communal contexts (MAGEE 1998a). Throughout the period, copper seems to remain a product of daily use, adoration, and status, representative of the entire society.

It seems thus secure that, considering both economic and social needs, copper procurement had indeed increased, and the organization of their production improved to be more dynamic and effective in both their control and distribution. However, nothing still points to large-scale production, remaining (apparently) a seasonal activity held by numerous communities of southeast Arabia. Nevertheless, the studies of J. Goy (2019, p. 225-265), showed that the organization of production phases did not change much, with first smelting still done near extraction zones. However, attending to the different types of ores that were now being smelted, both small secondary ore veins and large secondary sulphides, the scale of production presented itself in smaller or larger scatterings of metallurgical debris depending of the type of deposits. In the same way, smelting structures could either occur as isolated examples or in batteries. She goes further suggesting that sites exhibiting larger scale production, like Raki, for example, in areas of massive sulphide exploitation, could be exploited for longer periods, while smaller-scale exploitations near smaller secondary veins, such as in Bithnah, Hilo, Madhab, and those along the Wadi Qawr, would be depleted quickly, and thus produce less metallurgical debris (GOY, 2019, p. 273-276). Still both types of exploitation were done simultaneously during the Iron Age, though smaller ones could supply nearby communities, while in comparison, larger ones could be destined for larger trading ventures, supplying intra- and extra-regional exchange. However, further data (mainly isotopic) on such distribution patterns are necessary to prove such a theory.

The subsequent production phases of second smelting for copper purification, alloying and casting of objects that was done at settlement areas and, for the first time during the Iron Age, at seasonal specialized metal workshops like Saruq al-Hadid and 'Uqdat al-Bakrah, dissociated from any settlement, marking the striking difference from the previous period organization.

Nevertheless, essential to understanding how such a broad and dynamic distribution of copper exist, particularly in its distribution, was the domestication of dromedaries at the end of the Bronze Age (UERPMANN *et al.*, 2002). Until then, we observe a regional distribution of copper in its finished form (as objects, although as ingots were also relatively common) in most known Bronze Age settlements and burial sites. However, secondary smelting and production stages are only observed at a few settlements. From the Iron Age onwards, such are observed at most settlements instead, and sites like Saruq al-Hadid and ‘Uqdat al Bakrah, exhibit a large scale production (even if seasonal), likely thanks to the transportation dynamics that the dromedaries allowed in such a region. Still, other social dynamics that emerged during this period, such as the emergence of local elites (MAGEE, 1998b; MAGEE, 1998c; BENOIST, 2010), may have also favoured such copper production organization by the way communities interacted. Such dynamics are, however, still poorly studied.

The appearance of fortified enclosures throughout the region during the Iron Age may help us understand how such populations interacted, although information is still scanty. Perched upon hills, near *wadi* zones where copper was extracted, like those seen in Salut (AVANZINI *et al.*, 2018), Bithnah (BENOIST *et al.*, 2012b), Masafi (BENOIST *et al.*, 2012a), Lizq (KROLL, 2013), Husn Awala (PETRIE, 1998), to mention a few (see Annexe 2e), they seem to justify the necessity of controlling this resource. However, the construction of walled enclosures is not characteristic of the Hajar mountain settlements only. In the Piedmont and coastal areas, these are also found. This necessity of “protecting” a space appears only in the Iron Age and at sites which either exhibit some administrative/collective and/or cultic elements (at Muweilah, Rumeilah, Bida bint Sa’ud, Masafi, Bithnah, Tell Abraq, Kalba) (BENOIST, 2010; MAGGE, 2004; MAGGE *et al.*, 2017) or are within areas of copper extraction as mentioned.

Within such fortifications, structures like towers, bastions and storage units exist and commonly exhibit assemblages dedicated to storing food and metallic goods. It is pretty common to identify agglomerations of copper products (in both raw and finished state) (e.g. MAGEE, 1996; DEGLI ESPOSTO *et al.*, 2016; BOUCHARLAT *et al.*, 1985), but also large storage vessels that could contain stored food products (e.g. PETRIE, 1998; BOUCHARLAT *et al.,* 2001). Nevertheless, it is still impossible to confirm what such enclosures were 'protecting' and from whom. There is no clear evidence of conflict between the region's population, despite the enormous quantity of bellic material from this period (YULE *et al.*, 2018). Nevertheless, the location of these enclosures, particularly of those in the mountains, strategically perched near areas of copper extraction and fertile *wadis*, suggest that they had the function of controlling both territories and their resources. The fact that these *wadis* make the only possible passageways connecting the East and West plains of southeast Arabia could have also made these enclosures important points for controlling trading routes (SCHWALL *et al.* 2020, p. 330-331; YULE, 2019).

Furthermore, although settlement distribution boomed during the Iron Age relatively evenly through the region, permanent occupation of mountain *wadis*, for example, which until then were essentially just occupied seasonally for pastoral activities and procurement of copper ores, could from now on be "controlled" permanently by established populations. Although the Hajar Mountain territory is believed to have been organized amongst the different pastoralist populations that occupied it since the Hafit period, using for such territorial markers like the numerous observed tombs upon its landscape (CABLE, 2012; DEADMAN, 2014), is possible that the new settlements (and their elites) had from the Iron Age onwards a steadier control over that territory, and possibly, a more regular procurement of mineral resources, such as copper. The occupation (and fortification) of other territorial areas, those at coastal areas, for example, may have had, in turn, the purpose of controlling foreign trade (SCHWALL et al. 2020, p. 330-331), and with it, the distribution of copper extra-regionally, but also of importing other desired metals like iron and tin, the latter essential to produce the tin-copper alloyed objects found in the region.

From the periods that followed, from what was said previously, again not much is known, although we benefit from a few written sources that are worth mentioning. G. Weisgerber (1987, p. 158) comments on the existence of records, referring to the fact that each miner (and likely their kin) exploited his mine independently. Suppose this was the case and reflected past uses. In that case, it fits well in the pattern observed by J. Goy (2019), where smaller exploitations could represent local copper procurement, supplementing internal (local) markets. In the same way, other Early Islamic historical sources refer to the existence of fragmentary evidence about copper trade, contractual arrangements, taxes and administration (WEEKS, 2003, p. 54), which also fit well in the production organization pattern proposed for the Iron Age; controlled and administered by local authorities, who used central/fortified locations for controlling trade and resources (YULE, 2019).

2. Saruq al-Hadid: a site amidst Dubai desert dunes

After setting the context for copper production in southeast Arabia, it is time to move on to this Dissertation case study of Saruq al-Hadid. As previously referred to, this was an Iron Age metal workshop located in today's Dubai Emirate (UAE), which has the potential to further enlighten us about this production's technological, economic and social outlines.

The site's location from a nowadays perspective, seems quite inhospitable and devoid of any logical purpose for occupation besides grazing land for dromedaries, an economic activity in use until today. In truth, when we think of this entire region, only desert dunes, extreme heat, and lack of water come to mind. Dubai's technological attractions and skyscrapers also pops-up in our thoughts, thanks to the last fifty years of oil exploitation and foreign investment. Previously, population areas were sparse and distributed along the coast or piedmont zones where water and food resources abounded. Their society organized itself into sheikdoms that controlled both the economic and political dynamics of large communities, led by sheikhs who owed their legitimacy to the balance they could achieve in providing both protection and economic prosperity from the sparse but abundant existing natural resources (LANCASTER *et al.*, 1992).

Such political organization resulted from millennia of social and economic adaptation to this peculiar environment, where people learnt to dwell efficiently and profit from. However, how could this happen, and sites like Saruq al-Hadid - in the fringes of the Rub al-Khali desert – have been occupied? Understanding the climatic and environmental patterns of the region throughout the last millennia is crucial to answer this question.

2.1. Regional climatic setting

Southeast Arabian is classified as a "tropical desert" with a semi-arid climate influenced by two primary weather patterns: the Mediterranean regime, which brings modest rainfall and gentle winds in the winter, and the Indian Ocean regime, which brings heavy rain and winds from June to September (PARKER *et al*., 2008, p. 26). So, although the region experiences scorching temperatures during the summer due to its location, between 12° to 34° north of the Tropic of Cancer, there is still a considerable amount of rainfall, especially in the mountainous areas, with an average of 350mm per year and occasional snowfall above 3000 meters, which provides the necessary moisture to support a savannah-like landscape (LÉZINE *et al.*, 2002; GARCÍA ANTÓN *et al.*, 1998).

However, paleoenvironmental data suggest that its climate was less arid during prehistoric times. By examining data collected from the Awafi paleolake in Ras al Khaimah (UAE), with a similar landscape to that of Saruq al-Hadid, we can have an understanding of the region's environmental changes over the past 10,000 years (PARKER *et al*., 2008). Dune sediment sequences demonstrated that between 8,000 and 6,000 years ago, a significantly wetter period led to the formation of lakes in the area. These were surrounded by stabilized dune sediments, still relatively low, covered by a rich savannah-like grassland, which included elements such as *Acacia, Prosopis*, and *Tamarix*. Southeast Arabian Neolithic coincided with this period, characterized by nomadic societies exploiting marine resources and herding animals (e.g. VOGT, 1994; UERPMANN, 1992).

From 4.000 to 3.000 BC, the paleolake data suggests a peak of aridity, with aeolian flux and dune reactivation. It roughly coincides with the Hafit period, characterized by stone burial cairns built along the fertile *wadis* of the Hajar Mountains (CABLE, 2012; DEADMAN, 2017). Coastal sites continue to be exploited (CLEUZIOU, 2003; CLEUZIOU, 2007), although mountain *wadis,* where water abounds, seem to be preferred by for animal herding. Here, the first evidence of a settled population appears, as seen in Bat (FRIFELT, 1976) and Bisyah (ORCHARD, 1995). These represent proto-oasis settlements that take advantage of the palm-tree and abundant water to create complimentary subsistence strategies. Attending to the increased aridity felt in the region, it is possible that grazing lands between the coast and mountain areas diminished.

Afterwards, another wet period coinciding with the beginning of the Umm an-Nar period will follow until 2.200 BC, when another arid period begins, coinciding with Awafi Lake's desiccation and the beginning of the Wadi Suq period. These changes in the climatic conditions again expressed changes in this territory's occupation and subsistence strategies. During the Umm an-Nar period, territory occupation multiplied in coastal, mountain areas and piedmont areas. Hili 8 (CLEUZIOU *et al.*, 1980; CLEUZIOU, 1982) is perhaps the best example of this period of oasis settlements, greatly benefiting from water run-off and aquifer discharge from the Hajar Mountains. Nevertheless, in the following Wadi Suq period, the number of settlements will decrease (CARTER, 1997; VELDE, 2009), which led many authors to suggest that the increased aridity felt obliged to more dynamic and seasonal subsistence strategies (herding, hunting, fishing, recollection), evidenced in the shape of seasonal camp-sites and ephemerally constructed structures in both coastal and desert sites (CONTRERAS *et al.*, 2016; MAGEE *et al.*, 2017; VON DER DRIESCH *et al.*, 2008; WEEKS *et al.*, 2019a; WEEKS et al., 2019c).

Another short-lived wet period existed from the end of the Bronze Age until the beginning of the Iron Age. Then, the current climatic regime will be established, presenting increased aridity (PARKER *et al.*, 2006; BRAY *et al.*, 2004). However, due to innovations that occurred at this time, namely the *falaj* irrigation system (AL TIKRITI, 2002; DEL CERRO et al., 2018), dromedary domestication (UERPMANN et al., 2002), and a set of social and cultural changes already briefly mentioned, the number of known sites did not shrink but instead multiplied as never seen before (MAGEE, 2014).

2.2. Desert geomorphology and environmental setting

The increased aridity observed in the region from the Bronze Age onwards (even though mitigated by wetter periods) is much expressed in the dune pattern observed in the eastern Rub’ al-Khali desert, where Saruq al-Hadid is located. The dune pattern is oriented in the direction of the Shamal wind, persistent in a north-western direction, affecting the region during the summer months in the Indian Monsoon climatic regime. This pattern forms small, simple linear dunes, relatively symmetrical, without slip faces, and a pronounced northeast-southwest orientation (see Annexe 4a). In this area of Saruq al-Hadid, they are low, averaging 2 to 10 metres high only (KUMAR *et al*., 2011, p. 112-124).

From studies made by F. Preusser (2009, p. 628-629), it was observed that the Rub’ al-Khali dunes were formed during periods that coincided with glacial ages and low sea levels in the Persian Gulf, which provided the necessary sedimentary supply for aeolian accumulation at around 160-130.000 BP, 110.000 BP, 60-50.000 BP and 15-12.000 BP. However, information tells us that this dune accumulation happened from south to north, so the UAE, and thus the location of Saruq al-Hadid, only started dune accretion after 5.500 BP. From the information in the sedimentary sequence of the Liwa dunes (Abu Dhabi, UAE), it was identified that dune formation was very gradual at first, then suffered a very rapid accretion during 3.000 to 2.000 BP, and then stabilized without further deposition (BRAY *et al.*, 2004; GOUDIE *et al.*, 2000).

The dunes in Saruq al-Hadid, as in all the Rub' al-Khali desert, are predominantly quartzitic but contain secondary amounts of carbonate (either as calcite or dolomite)

(EL-SAYED, 1999) and rest on a cemented gypsum pavement – once an inland *sabkha*[2]. Just like in the referred Awafi Lake, in the northern UAE (PARKER et al., 2008), the Saruq al-Hadid *sabkha* may have formed during the mid-Holocene period (c.7500-4000 BC) (CASANA *et al.*, 2009) when Indian Ocean Monsoons brought heavy summer rains to the region that sustained lakes and streams, now completely gone. Upon these sediments, the first layer of sands and silts that contains the older archaeological remains found at Saruq al-Hadid were dated from 5821±282 BP (HERRMANN *et al.*, 2012).

After this period, the continued deposition of silt and sand over this deposit throughout the Bronze Age suggests that the site started receiving its first dune accretion but was still subject to periodic flooding, thus allowing human and animal occupation. An abundant quantity of fauna remains identified from this period (namely *Oryx leucoryx* and *Gazella* sp. (ROBERTS *et al.*, 2018)), and paleobotanic data suggesting an abundance of *Acacia, Prosopis*, and *Calligonum* (Weeks *et al.*, 2019a, p. 15) also support this theory. These may have allowed (and prompted) the seasonal occupation of the site during the mid-to-late-Bronze Age (Wadi Suq period) (Weeks *et al*., 2019a, p. 26-28; Valente *et al*., 2020, p. 172-173) (see Annexe 4c).

However, from the Iron Age onwards, as regional geomorphologic and paleoenvironmental data suggest, dune accretion intensifies (PARKER et al., 2008; BRAY et al., 2004; GOUDIE et al., 2000), and at Saruq al-Hadid's paleobotanic record, we can similarly observe that the previously identified taxa starts to disappears, likely promoting dune accretion (AL-MASRAHY *et al.*, 2013, p. 166-168). It is possible that in this area, mainly charcoal production necessary to supplement the metallurgic production depleted the area from the existing trees and shrubs. However, further studies are required to confirm this theory, including paleobotanic studies on a charcoal accumulation identified in Area 53 of Saruq al-Hadid (dated as from the Iron Age II period), whose results remain unpublished and understudied (see Annexe 4d).

---

[2] A coastal, supratidal mudflat or sandflat in which evaporite-saline minerals accumulate as the result of a semiarid to arid climate (EVANS et al., 1969).

Finally, as suggested by Liwa's evidence (BRAY *et al.*, 2004, p. 276-278), there was no considerable further accretion after 2.000 BP. Sand continued to move and shift from one position to another, following the Shamal wind pattern, but no considerable new deposits were formed afterwards. This also seems to have been the case at Saruq al-Hadid, where after the end of the Iron Age deposits, only about 50 cm of sand accumulated, when during the Iron Age, in some areas, over 2 metres accumulated.

The hydrological network upon which Saruq al-Hadid sits is also essential to understand this site's location. It sits on the eastern hydrological zone of the Hajar Mountains, where the dunes hide a still-high water table (RIZK *et al.*, 2003). Despite what the landscape may superficially suggest, water flows abundantly in aquifers that extend through the entire region, though replenished only when it rains, which requires careful water management since prehistoric times (Annexe 3c).

Based on personal communications from Hussain Qandil and Hassan Zein (in March 2016) (Members of the Architectural and Antiquities Department of Dubai Municipality), the groundwater can still be found here today at 3 to 4m below the surface. However, this water is brackish though suitable for livestock drinking, and easily accessed through wells (WEEKS et al., 2015, p. 322). Data collected at the site further indicates that groundwater was even higher during prehistoric times, as attested by the ancient wells here discovered, no deeper than 2,80 metres. Wells discovered in other sites from prehistoric periods indicate similar water tables (CLEUZIOU, 1989). However, attending that only one well could be securely dated as in use during the turn of the Late Bronze Age/Early Iron Age (VALENTE *et al.*, 2020, p. 172-173), we cannot confirm if all others were as well. However, they might be, as H. Qandil (personal communication in December 2016) mentions the discovery of Iron Age II pottery inside another of the wells discovered. Furthermore, the water in this area, attending to the decreasing density of the gypsum bedrock from the top-down (WEEKS *et al.,* 2015, p. 323), seems to have been sweet in prehistoric times, which would have facilitated the site's occupation.

Thus, the site gathers all conditions to sustain life, even a metallurgic production. Water was available and easily accessed through wells. Fuel was plenty, although depleted shortly after a few centuries of intensive metallurgic production. Food resources, such as animals for hunting when on-site, were also abundant. For the metallurgic production, only the metals had to be brought in from the Hajar Mountains, nearly 100 km away. However, transportation from that time onwards through dromedaries, as pointed out, made it possible.

2.3. The “possible” stratigraphic sequence of Saruq al-Hadid

Excavating sites like Saruq al-Hadid, where intensive human occupation is held on dunes, is challenging. The constant movement of the dunes by Aeolian actions disturbs the stratigraphic record greatly, impeding to obtain a precise stratigraphic sequence. The deposits are often found deflated by erosion actions and archaeological materials' weight. Furthermore, at Saruq al-Hadid, anthropic events for metal scavenging held through centuries disturbed its stratigraphy even further. Digging methodology had thus to be adapted to the site's geomorphology and the type of occupation we encountered – seasonal and persistent through millennia, without evidence of permanent occupation (WEEKS *et al.*, 2019a; WEEKS *et al.*, 2019c; VALENTE *et al.*, 2020).

As far as is known, the site extends for at least 4 km2, following agglomeration of artefacts exposed after strong winds. By the end of 2019, approximately 9.350 m2 had been excavated, and over 24.000 artefacts were recovered. Since its discovery in 2001, it has been excavated by ten different multi-disciplinary teams (see Annexe 4b) with their own research objectives. However, not all results were published or openly shared, which makes data assessment, logistically speaking, a true nightmare. Fortunately, thanks to the effort of some teams to collaborate and bring together their results, the site is finally being understood as a whole, and its potential to understand the dynamics of copper production and ritualization achieved.

Only the published results from two teams – the SHARP team excavating in Areas F/G and the SMS[3] team excavating in Areas 2A and G – will be detailed and correlated here to facilitate comprehension of this site chronostratigraphic phases.

2.3.1. Saruq al-Hadid chronostratigraphic phases

Following the chronological order of Saruq al-Hadid from the lower to the upper layers, we can observe that all deposits sit upon the cemented *sabkha* pavement formed after the desiccation of the paleolake that existed, as mentioned.

The first human occupation of Saruq al-Hadid relates to the referred 'humid' period, at roughly 2700 BC, that lasted until approximately 2000 BC. From AMS (Accelerator Mass Spectrometry) radiocarbon data collected (VALENTE *et al.*, 2020) from a hearth in this lower level in Area G, we know that the site was occupied by then (see Annexe 4c). Within this lower deposit ('Layer 9'), several post-holes, hearths, and an abundant lithic assemblage, along with a few sherds of pottery, were found. Covering this deposit, an abundant debris material was found from the carving of a well identified next to the dated hearth ('Layer 8'). Immediately above this debris, another hearth roughly provided a chronology from the beginning of the Iron Age II ('Layer 7'). This informed us that the well found in Area G, and possibly others found nearby, were carved and used, roughly between the Umm an-Nar/Wadi Suq period (2700-1300 BC) and used until the beginning of Iron Age II, when 'Layer 6' already intrudes the well, covering it completely. The chronological data for this intruding layer was obtained from another hearth dated through AMS radiocarbon and ceramic material corresponding to the Iron Age II period, which included a typical incense burner/chalice from this period (BENOIST *et al.*, 2012a, p. 155, fig. 15). Another AMS radiocarbon date from the Iron Age II was also obtained for the above 'Layer 5', and

[3] Acronym for Spanish Mission of Sanisera, although occasionally also appears referenced by the name of the institute: SAI (Sanisera Archaeology Institute).

containing pottery decorated with snake appliqués, also suggestive of this period (BENOIST *et al.*, 2015).

In matters of sedimentation, the lower 'Layer 9', as expected, was found very compacted, almost fused to the bedrock, presenting a rich silty content with high salinity levels. 'Layer 7', on the other hand, was less compact but still silty and saline, and with a low to moderate amount of mineralized stem roots. 'Layer 6', much sandier and less silty, still presented a higher salinity content but was even less compacted and had abundant mineralized stem roots. 'Layer 5' and above presented a completely sandy characteristic without any other contents. 'Layer 5', however, still presented low amounts of mineralized stem roots, but not the above layers. 'Layer 8' is anthropic, resulting from carving the well referred.

When comparing this information from the SMS team (VALENTE *et al.*, 2020) with that published by the SHARP team, it is clear that 'Layer 9' perfectly matches the sedimentary, material, and radiocarbon dates characteristics of their 'Horizon V' (WEEKS *et al.*, 2019c). The landscape was still dune-free at this time, providing a flattish surface over which people dwelled. Furthermore, although not much bone material was found by the SMS while excavating Area G, on the excavation squares of the SHARP team (Areas G/F), a significant accumulation of wild game remains – discarded after being hunted, butchered and prepared to be taken to their original settlements – was found (ROBERTS *et al.*, 2018). The squares excavated by the SMS were, apparently, part of the seasonal habitat for when these hunting activities took place. Besides the well, remains of hearths and post-holes from huts built with perishable materials were discovered there.

The mentioned traces of mineralized stem roots were also identified in the SHARP team at higher levels of 'Horizon V and IV' (WEEKS *et al.*, 2019c), which suggests a vegetation-prone environment (particularly during the Iron Age I) before pressing aridification conditions began in the Iron Age II. Dune accretion also seems gradual and relatively slow, with only about 50 cm of sediments accumulated since the bedrock (and through at least 3 thousand years) until that at the Iron Age II, they spike up over 2 metres within just a thousand years. However, this sand accumulation differs in all areas and varies with wind patterns and preceding surface conditions. Even today, it is customary to observe open areas of the *sabkha* amidst the dunes (see Annexe 3a), which was likely the case of Area 2A during the Iron Age II period.

Shifting our attention to Area 2A of Saruq al Hadid, we observe that immediately above the *sabkha*, the first stratigraphic deposit to be identified is that of the Iron Age II, corresponding to metallurgic activities and associated pit-combustion structures (see Annexe 4c). While Area G had accumulated considerable wind-blown sediments until the Iron Age II, Area 2A remained sand-free, likely because of the bone accumulation that created a natural barrier against sediments blown in that direction.

Thus, in Area 2A, only four deposits were identified, being the lower one a thin deposit (roughly 30-40 cm deep), designated as 'Layer 4'. This deposit is usually undisturbed and exclusively related to metallurgic production. Above it, 'Layer 3' (roughly 50 cm deep throughout) is associated with ritualized deposition and communal gathering events. Diagnostic artefacts and dated AMS radiocarbon charred material (CONTRERAS *et al.*, 2017) suggest that both layers correspond to the same period (Iron Age II – 1000-600 BC). However, it is complex to precise their correlation, as 'Layer 3' often appears to us mixed due to both natural and anthropogenic actions. However, after several spatial analyses done with GIS tools, we observe that most objects are primarily concentrated in a central area surrounded by pit-like combustion structures (see Annexe 11b). Dispersion to other Area zones happened due to anthropogenic and natural causes through time.

Returning to Area G, it is thus essential to refer that the Layers corresponding to this Iron Age occupation phase of Area 2A are 'Layers 5 and 3' (VALENTE et al., 2020), and 'Horizon III and II' from the SHARP team (WEEKS et al., 2019c), characterized by single occupation events where ritualized depositions were made (but not metallurgical ones). Between these and above ('Layers 4 and 2'), we find abandonment events where sterile sand was found.

Finally, above these Layers, in both Areas, 'Layer 1' (VALENTE *et al.*, 2020) or the 'slag layer' as is commonly known ('Horizon I' in the SHARP team nomenclature (WEEKS *et* *al.*, 2019c)), is found. 'Layer 1' is an accumulation of discarded material - mainly copper slag - with abundant metal scrap (copper, iron and gold), pottery, soft stone sherds, and numerous beads. Dating this Layer was done by the SMS team in Area 2A and by the SHARP team in Areas F/G, using both absolute and relative data that suggested a mix of material from the Iron Age II to the Middle Islamic period (CONTRERAS *et al.*, 2017; WEEKS *et al.*, 2019c). This large chronological frame hinders the interpretation of the site. However, it seems that after the site's abandonment as a metallurgical centre, the site became a location for scavenging reusable metal materials, thus creating this extensive slag cap that covers the entire site and is dissociated from the lower metallurgical practices. If we look at the site's name in Arab, this can already be suggested since it literally means "iron thief".

3. Saruq al-Hadid: a copper workshop

The site of Saruq al-Hadid holds the region's most extensive collection of metallurgical debris spanning through all the phases of production and the most extensive collection of copper-base objects as either finished or scrap metal. No other site in the region exhibits such a compendium of material in the same place, making it an excellent case study.

Nevertheless, it is important to stress that because the site has been excavated by multiple teams, as mentioned, the data here presented only represents the assemblage collected by the SMS and SHARP teams, which have been collaborating to publish the information as a whole. Nevertheless, it represents the most significant archaeometric information collected in Areas F/G and 2A. Both relative and absolute dating have been used by these teams to contextualize the data (WEEKS *et al.*, 2017b; WEEKS *et al.*, 2019a; WEEKS *et al.*, 2019c; CONTRERAS *et al.*, 2017; VALENTE *et al.*, 2020) and several archaeometric analyses (WEEKS *et al.*, 2015; WEEKS *et al.*, 2016; WEEKS *et al.*, 2017b) done by the SHARP team. Although most results are still preliminary and pending further analysis and publication, the most relevant information will be mentioned and discussed and correlated with research being done in other metallurgical sites of the region.

3.1. The smelting phase

The metallurgical slag that was found covering Areas F/G and 2A of Saruq al Hadid – commonly called the 'Slag Layer' (see Annexe 5a) – is not associated with any metallurgical structure visible and is distributed in the shape of large mounds that spread through the Areas by actions of deflation. While excavating these deposits, it is common to identify 'pockets' of denser accumulation of slag, which suggest that this waste was discarded in these spots forming small mounds. Continuous dump of this material over a long period covered a large portion of the site, forming two prominent large mounds (one in Areas F/G and another in Area 2A).

Although this material is concentrated in the above 'Layer 1' only, being dissociated from the metallurgical deposits ('Layer 4'), many (if not most) of this slag was produced during the Iron Age II, attending to chronologies obtained in the 'Horizon I' by the SHARP team from Thermoluminescence (TL) dates in technical ceramics (slagged furnace walls) (WEEKS *et al.*, 2019a, p. 26-29). However, it is hard to understand how it all agglomerated at the top of the stratigraphic sequence. The answer may be in the later chronologies identified by the SHARP and SMS teams (CONTRERAS *et al.*, 2017), which seems to result from later smelting activities. TL and AMS radiocarbon dates indicate that the site continued to be used for smelting metal during the Pre-Islamic and Middle Islamic Periods. However, even if substantial, given the amount of evidence from this period, pyrotechnological activities seem more sporadic (WEEKS *et al.*, 2019a, p. 26). Ceramic fragments from these later periods were also found among the slag deposit, indicating these slag mounds resulted from its dumping at this later occupation to recover scrap metal that could be reused/melted and slags further smelted to extract more copper—a common practice observed in the region (PLOQUIN *at al.*, 1999, p. 173).

Confirming the hypothesis that ‘Layer 1’ was formed by the dumping discarded materials recovered in lower Layers is the frequent inclusion of fragmented materials such as pottery and soft stone vessels (from the Iron Age II period), broken pieces of copper and iron objects, numerous miscellaneous beads, and occasional gold and copper wires (VALENTE *et al.*, 2020, p. 179-180). All these fragments appear randomly discarded among the slag without apparent care. Such an image of randomness is never observed in the lower deposits of the site. In those, the finds usually present physical integrity and are distributed orderly, even if sometimes geomorphological conditions may have slightly shifted them from their original location.

From all the slag identified in these mounds, there is thus no doubt that smelting activities occurred at Saruq al-Hadid. Supporting this hypothesis are the occasional fragments of technical ceramic from furnace walls, found both throughout ‘Layer 1’ and within copper prills agglomerations in ‘Layer 4’ of Area 2A (see Annexe 5b). There is no evidence of where these smelting activities happened on site. However, smelting furnaces could be installed directly on the sand. Moreover, if we consider that these structures often had to be destroyed to remove the ingots (GOY, 2019), then little evidence would remain of them.

Furthermore, although technical ceramics analyzed through Neutron Activation from Saruq al-Hadid could not be confidently assigned to a geochemical group that would indicate from where it was coming (WEEKS *et al.*, 2017b, p. 421), it shows similar inclusions to fabrics from the region (WEEKS *et al.*, 2016, p. 170), characteristically ‘sandy’, and well-tempered (for good refractory reaction to the smelting activity). The ‘sandy’ characteristic, with low clay content, was also observed in the technical ceramics of Wadi Hilo, which made fragments susceptible to water, disintegrating quickly, remaining only portions in contact with the slag (KUTTERER, 2020, p. 83).

Nevertheless, equality important as identifying how and where these smelting activities took place in Saruq al-Hadid, is to understand to which smelting phases this debris pertains. If from primary smelting activities (reducing ores to metal) or just secondary smelting for copper purification. Regional data suggest that primary smelting activities always occurred near extraction zones, being only secondary smelting carried on at settlement (GOY, 2019).

3.1.1. Types of slag

Two main types of slag are identified at Saruq al Hadid (WEEKS et al., 2017b, p. 449-456) as per macroscopic analysis. One is quite dense, nearly free of any copper corrosion on its surface, evidencing smelting activities in a tapping structure. In this process, the slag is tapped out of the furnace in its liquid state, which forms cakes 25 to 40 cm in diameter when cooled. This slag presents large air bubbles where fragmented and small amounts of trapped copper. Some also present sand or gravel attached, aiding in the conclusion that it was tapped out to an adjacent pit (HAUPTMANN, 2020, p. 233-236). However, some slags of this type also present a red or sometimes greenish surface colouration and some stone inclusions, suggesting different smelting phases. While the black homogenous slag may result from secondary/refining processes, the corroded, with inclusions, may relate to primary smelting phases (DOONAN *et al.*, 2014, p. 766). Still, this does not mean that it pertains to initial smelting phases (of ore reduction) because the use of sulphidic ores would imply several purification phases. So, we may be discussing consecutive refining stages happening at Saruq al-Hadid, since no ores have ever been found on site. Nevertheless, we have yet to determine how many smelting sequences in the extraction zones were necessary for the product to be deemed acceptable to be transferred to the workshop areas.

The second type of slag found is also dense but presents a more irregular and “flowy” texture, a higher amount of air bubbles, and often irregular surface texture. It is likely slag that cooled down inside the furnace (HAUPTMANN, 2020, p. 236-238), not presenting any evidence of fused sand, which would have happened if in direct contact with the ground. Some of these slags present evidence of the furnace shape, where c. 20 cm diameter slag blocks show a straight, sharp bottom line and a narrow rim. This impression supports the evidence that the bottom of the artefact was not formed on the ground, as in a pit, but on top of a second material. The copper metal would be below this slag, at the bottom of the furnace (WEEKS *et al.*, 2016, p. 175-181), and indeed copper metal is identified under some of these slag blocks. These are not yet ingots but rather intermediate products, which the SHARP team named ‘slangots’, as it comprises metal and slag. These ‘slangots’ often present traces of copper corrosion and non-fused or partly fused stone inclusions. These slags also present grey and rusty corrosion, suggesting the presence of metallic iron, which forms under too-reducing conditions in the furnace, typical of highly inefficient smelting processes which are common in early metallurgy of sulphidic ores (CRADDOCK *et al.*, 1987).

The difference between these two main types of slags has led the SHARP team to hypothesize if they could be from different kinds of smelting technologies, thus possibly representing different chronological periods (WEEKS *et al.*, 2017b, p. 456) – much possible if we consider the different chronological dates obtained for this debris in ‘Layer 1’. The presence of large, tapped slag cakes for the first type described is compatible with those pointed out by J. Goy (2009, p. 200-213) as representative of slags from the Early- and Islamic periods, while the Iron Age ones are smaller. However, we cannot base our conclusions on such a fact alone. Compositional data is required to properly subdivide these types, as they may pertain to different smelting phases, with the second type more befitting of the first smelting phases. In contrast, the first one is compatible with refining stages or even more superficial differences representing or not tapped slag.

3.1.1.1. WDXRF and optical microscopy results

Analysis of slag with Wavelength-Dispersive X-ray Fluorescence (WDXRF), combined with optical microscopy, shows the presence of four different groups of slag (WEEKS et al., 2016, p. 202-206). The majority is within the fayalite category, an iron-rich olivine that forms at about 1100^{o} to 1200^{o}C during smelting (HAUPTMANN, 2020, p. 258-261). Iron, part of the copper-iron-sulphide system, is extracted and rebound with silicate to form fayalite. This group shows high iron content combined with medium silica levels and low amounts of calcium and aluminium. Some specimens also exhibit the presence of forsterite, a magnesium silicate. Furthermore, the presence of metallic or oxidic copper trapped in these slags also shows that the efficiency of copper reduction can be described as medium to low (WEEKS et al., 2016, p. 211).

A second group shows lower silica but higher iron levels and falls in the group of wüstite. Wüstite is an iron oxide that can form during the smelting and refining phases. However, a clear differentiation between these two processes using optical microscopy showed evidence that several samples were refining slag (WEEKS *et al.*, 2016, p. 211). In these, the significant components are magnetite and, to a lesser degree, wüstite, being the first formed under mildly reducing conditions, while the latter requires strong reducing conditions (HAUPTMANN, 2020, p. 274). Magnetite is also a common mineral that forms during the reduction of sulphidic ores, especially those smelting in co-reduction processes to form sulphidic mattes, which was the primary process identified in the region during the Iron Age (GOY, 2019, p. 335-341). These would oblige to subsequent refining stages, thus the magnetite contents in slags originating from this process. In these resulting slags, fayalite is only present in minor levels or completely absent, and copper(-iron)-sulphides are similarly rare; metallic copper is often trapped in small to medium copper prills. (WEEKS *et al.*, 2016, p. 211).

A third group showed slags with low iron but high silica content, and optical microscopy showed that several fragments evidenced silica inclusion of small to medium-sized ‘stones’. Such inclusions can either derive from the gangue material (in the ores) or be added to the smelt as a flux to help in the formation of fayalite (mentioned in the first group) (HAUPTMANN, 2014, p. 91). Adding such fluxes is essential in reducing ores such as chalcopyrite, a copper-iron sulphide abundant in Oman. Such slags may thus inform us about the unsuccessful achievement of sufficient temperatures for such silica to react or that too much was added as flux. Either way, both point to the first smelting stages at Saruq al-Hadid.

The final group shows medium silica content with low iron and high calcium levels. As the previous one, this group can represent inadequate flux quantity or temperature during the first stages of a smelting process, but the reason for the high-calcium quantity remains to be explained. In some of the slags analysed by J. Goy (2019, 314-315), such high calcium was also observed, but it remains to be determined if it is from either mineral or fuel addition.

In short, most slags derive from primary smelting activities. However, the second group mentioned derives from refining phases, which indirectly suggests the production and handling of matte (WEEKS et al., 2016, p. 206). Most of this data correlates with what J. Goy (2019, p. 295-330) observed for slags within the region, primarily using sulphidic ores under a co-reduction technique, which led her to conclude that represent the nature of the ores and gangue added as flux, rather than any differences on reduction technique or production period, pointing out how difficult it is to even distinguish from first and secondary smelting phases, especially when so many repetitions of reduction stages are required to achieve a 'clean' copper ingot, and when reduction techniques seem still far from efficient. As temperature and airflow are essential components within smelting operations but are not always controlled to a similar degree within a single furnace and during the entire smelt, individual smelting slag fragments of different compositions do not necessarily derive from different smelting operations. Furthermore, J. Goy's (2019, p. 217-218) analysis to slag from different chronological periods also suggests the general appearance, colour, density and composition of slags from the Iron Age to the Islamic period, with slag sizes (and few associated chronological data) being the sole differentiator, which might also be the case at Saruq al-Hadid.

With WDXRF analysis done on these slag types from Saruq al-Hadid, it was also observable that alongside the significant components mentioned, medium components of sodium, potash, titanium, manganese and phosphorous, were also present, in addition to sulphur which is evident in most slags (WEEKS *et al.*, 2016, p. 207). Such naturally occurring elements improve the qualities of the copper itself. However, because the reduction processes were not efficient enough, small quantities of these elements were always lost to the slag. Mainly the loss of copper to the slags in the shape of Cu-(Fe)-sulphides (due to unsuccessful reduction to metallic copper) or as metallic copper prills (from non-ideal fluidity and viscosity of the slag) is observed in Saruq al-

Hadid, further confirming the inefficiency of the reduction process (WEEKS *et al.*, 2016, p. 207). Similar results came from other slags in the region (GOY, 2019, p. 298-300).

Arsenic and nickel contents also appear lost in these slags, but their values are generally low, being in most cases ≤ 1000 ppm for the latter and c. 100-700 ppm for As. Such suggests that both elements may have reached the copper metal (WEEKS et al., 2016, p. 208-209). Antimony and tin occurring only in negligible quantities in the ores from the region are, as expected, absent from the slags of Saruq al-Hadid. However, three samples still showed tin levels of c. 1000-3000 ppm (WEEKS et al., 2016, p. 208-209). The same results were observed in the slags from Qattarah, which led J. Goy (2019, p. 328) to hypothesise that these were the result of post-reduction processes; that is, final copper purification phases where tin-copper scrap metal was being melted alongside it. Finally, zinc was present on most slags analysed, though its range varied from 3 ppm to 2 wt% (WEEKS et al., 2016, p. 209). Again, J. Goy (2019, p. 321) also detected such variations in zinc content, suggesting that it resulted from using different deposits bearing such elements (equally attested throughout the region).

This additional information confirms a significant variation in the efficiency of smelting operations and that phases of primary smelting occurred on-site and not just secondary smelting, as observed in other settlement workshops. It was also observed that possibly different sources of copper from the region were used, attending to different trace elements identified on the slags (although variations in the smelting conditions might also explain this) and that slightly different technologies/furnaces (relating to different chronologies) may be present on site considering variations on slag morphologies/dimensions (this also requires further studies to be confirmed).

3.1.2. Smelting proceedures organization

To simplify what was learned from the information gathered at Saruq al-Hadid and other smelting sites in the region, a few paragraphs are essential to understand how this production phase was organized during the Iron Age. From what we knew until now, smelting stages were only executed near extraction areas, where ores were mined and separated from unwanted gangue material. Authors suggest this last operation could be done by non-specialized people, seasonally, although the identification of ore veins to exploit and the use of mining galleries (mainly underground ones) would have required specialized labour (even if still seasonal). The same goes for the subsequent smelting operations (GOY, 2019, p. 52-53).

Considering that sulphidic ores started being used during the Iron Age, a prior roasting operation would be required to remove intergranular water and crystallographic fixed OH- and CO2 from the ore, as well as sulphide and sulphate by oxidising them to SO2 gases. Such would be made in open pits at about 400-700oC and for several hours, or even days, allowing the ores to be crushed more efficiently and elements to separate easily in the furnace. This process would also desulphurise sulphidic intermediate products such as matte (HAUPTMANN, 2020, p. 298). However, although there are some claims that roasting structures were found in Oman (WEISGERBER, 1987), these seem from the Islamic period. Furthermore, J. Goy (2019, p. 335-336) identified that co-reduction was more likely for the Iron Age. During this operation, oxidic ores are smelted alongside sulphides, resulting in the precipitation of metal by roast reaction (HAUPTMANN, 2020, 298). For her, this would be a logical process. As top oxidic deposits were being exploited from the top of the gossans (since the Bronze Age), sulphidic levels would be reached and mixed in the furnace during the Iron Age. At this stage, sulphur escapes in the form of gaseous SO2, which allows the formation of a matte product composed of copper and iron oxides, consistently found in the analysed Iron Age slags of the region, including at Saruq al-Hadid (WEEKS et al., 2016, p. 213-215). In the subsequent phases of reduction/refining, this product would be reintroduced in the reduction furnace, and (depending on the amount of metallic copper present) the process would be repeated until an amount deemed sufficient is obtained. Such technique has been observed in other regions and experimented with (e.g. LECHTMAN *et al.*, 1999).

It is thus safe to infer that after the first ore smelting near the extraction sites, the product of this smelting, which would include matte and slag still rich in metals, could either continuously be there refined to produce copper ingots or immediately transferred to workshops such as Saruq al-Hadid. However, attending to the diminishing number of analysed slags for most sites in the region, we have yet to confirm it. Thorough study of slags from the region to differentiate between first and secondary smelting will be crucial to understand the organisation of this production.

Another critical study will be to understand if different sources supplied different sites. From Lead Isotopic analysis carried out by the SHARP team to the slags of Saruq al-Hadid, but also to ingots, waste/spill residues and finished artefacts, it is observed that most match isotopic data from nearest copper deposits and northernmost Oman, especially Wadi Jizzi and Rakah, instead of southern and foreign ones (although still identified) (WEEKS et al., 2016, p. 270).

3.1.3. Smelting furnaces

Although existing on-site, the fragments of technical ceramics are quite diminishing and most likely dissolved through time, attending to its 'sandy' characteristic as mentioned. Still, of the few existing and adhering to slag, several contributions can be made to understanding how the smelting structures were and how they were used. From the fragments of clay with adhering slag, it seems that these furnaces had an internal diameter averaging 20-30 cm (WEEKS *et al.*, 2016, p. 183-185). These measures are also consistent with the referred 'slangots' identified. The furnace lining remains are sometimes only 0.5 cm thin, although they might have been thicker (WEEKS *et al.*, 2016, p. 191-194).

Furthermore, from the two main types of slag described, the SHARP team also inferred that two kinds of smelting furnaces were employed on site, attending to the slag identified (WEEKS et al., 2016, p. 175-181). Both furnaces were quite similar, obeying standard models that would allow creating a reducing atmosphere for the reduction. Although there are no surviving remains of such examples anywhere in the region, they would share main characteristics (HAUPTMANN, 2020, p. 301-304) such as being semi-buried, with a stone and/or clay elevation (much like a chimney) that would allow the heat retainment while allowing the smoke to escape at the top. Construction materials vary attending to resources available, but those at Saruq al-Hadid seem to have been built entirely of stone-tempered clay. The main difference between the two furnaces, pointed out by the SHARP team, is that one would allow the slag to be tapped out, while the other would not.

Thus, the second described type of slag identified on site is consistent with closed furnaces where slag would accumulate above the metal, and only after it cooled down would the furnace be dismantled to remove the metal and slag. On the other hand, the first type of slag, evidencing tapping morphologies, was the product of tap furnaces, where slag would be progressively tapped out to an adjacent pit. This furnace could be recharged with more ore and fuelled several times, thus producing a more significant amount of metal and, thus, larger slag cakes. Only after the furnace reaches capacity it would be dismantled to access the metal.

Although these are valid suggestions, not enough data seems to exist to confirm the existence of both furnaces. The existence of tapped slag at Saruq al-Hadid seems evident. It is consistent with both Iron Age, Pre-Islamic and Islamic results from other sites in the region (GOY, 2019, p. 199-218), and the presence of the 'slangots'/furnace bottoms at Saruq al-Hadid does not necessarily means they were produced in closed furnaces. In fact, the metallic iron present in the slags could have resulted from both types of furnaces. Attending to the overall morphology of the slags present at Saruq al-Hadid, smelting technology observed in the region, type of ores used, and inefficient (unproperly controlled yet) reducing conditions during reduction processes, is most likely that we are simply in the presence of furnaces whose tap hole is above the furnace bottom (HAUPTMANN, 2020, p. 237), thus producing the evidence of both tapped slag and 'slangots' with variable quantities of metallic copper and iron.

Finally, two techniques could have solved the question of air supply to these furnaces. Small tuyeres and bellows could have been used to artificially introduce air (REHDER, 1994). These would be inserted in holes made at the lower portion of the furnace. At Saruq al-Hadid, evidence suggests that air was supplied by tuyeres which were inserted in 3 cm holes of which numerous examples are found (see Annexe 5b) (WEEKS *et al.*, 2016, p. 185-187), and similar to other examples found in the region

(GOY, 2019, p. 214). Unfortunately, there is no evidence of the actual tuyeres, neither at Saruq al-Hadid nor anywhere in the region. Nevertheless, attending to other ones found in nearby regions, they were likely made of clay (HAUPTMANN, 2007). Attending to what was said about the 'sandy' characteristic of local technical ceramic, it is understandable that they also had not survived the passage of time.

3.2. The refining and melting phase

Despite the abundant debris material from the smelting and refining phases at 'Layer 1' of Saruq al-Hadid, the vast majority of intact deposits from the refining process came from Area 2A at 'Layer 4'. Here, accumulations of the so-called "slangots", ingots and scrap metal were found throughout, often adjacent to structures (described in point 3.4) and dated to the Iron Age II period (CONTRERAS et al., 2017), where such metal could be refined and melted to produce copper objects. Although archaeometric data from these materials is still pending, morphologically similar ones (likely scavenged in later periods) were also found in 'Layer 1', which were analyzed by the SHARP team. Thus, although contextualized data from Area 2A cannot be provided yet, the results from the materials in 'Layer 1' already provides relevant information.

3.2.1. From 'Slangots' to ingots and casting spills

Amorphous 'slangots' were found abundantly throughout 'Layer 4' of Area 2A. Although we do not have any analysis of their composition, their morphology befits possible slag contents, both metallic copper and iron, as well as copper-(iron)-sulphides, considering morphological similarities with those analysed by the SHARP team in 'Layer 1'. Many of these present rounded-convex appearances, with diameters of up to 30 cm, which may be suggestive of furnace bottom dimensions, as mentioned above, although many present a large variety of sizes and shapes (see Annexe 6a-b), which parallels data from Masafi (GOY, 2019, p. 222-223), where it is suggested that more or less ventilation inside the furnace would potentiate (or not, respectively) the flow (and accumulation) of metal at the bottom, and thus, providing slightly different shapes for these 'slangots', although their composition is similar.

These 'slangots' cannot be used yet in the production of objects and thus must be submitted to one or more refining stages to remove any unwanted impurities, such as the remaining slag and iron. Such refining stages, however, do not need to be done in furnace structures anymore. To refine such 'slangots', they only need to be melted under a layer of charcoal by adding a flux such as sand (CRADDOCK, 1995, p. 203; MERKEL, 1990). Once the iron oxides are bound, they float to the top and skim off. The refining itself could be done in a small, lined pit or a crucible (TYLECOTE *et al.*, 1978), and evidence of such may have been found in Area 2A. Some small pit-combustion structures identified in the southern zone of Area 2A (further details in point 3.3.3.) could have served such a function. However, it is important to refer that there is no evidence of "proper" slag near these structures. However, it could have been removed to other site areas after each refining process, as done in later periods, forming 'Layer 1', to keep the processing areas clean.

Remnants of such slags, however, seem to have been found in Qattarah, identified as a secondary/refining smelting site (POWER *et al.*, 2011). On this site, similar amorphous 'slangots' and scrap metal were found, along with slag resulting from the purification and alloying of these materials. They presented a composition of low iron content and low percentages of arsenic and nickel. Tin was also present in these slags, which may result from mixing tin-copper scrap metal during this purification process (GOY, 2019, p. 347-348). Such might suggest that in this last refining stage, copper was ready (and alloyed) to be transformed into objects; otherwise, the mixing of scrap metal would not be done at this stage. As shall be discussed, a similar process seems to have occurred at Saruq al-Hadid.

3.2.1.1. Optical microscopy, SEM-EDS, pXRF and LIA results

The SHARP team analyzed several fragments of 'slangots', ingots and cast spills from 'Layer 1' through optical microscopy, Scanning Electron Microscopy with Energy-

Dispersive X-ray Spectroscopy (SEM-EDS), portable X-ray fluorescence (pXRF) and Lead Isotopic Analysis (LIA) that provide further insights and comparison with the data discovered in Area 2A and Qattarah. Most of these were shown to be composed of pure to almost pure copper with varying iron content and copper-(iron)-sulphides, although evidence for arsenical copper, zinc-copper, and tin-copper ingots was also found (WEEKS *et al.*, 2016, p. 216-246) that help us understand these stages of purification and transformation into ingots.

The (nearly)[4] pure copper showed to have varying contents of copper-(iron)-sulphides, which not only proves the proposed smelting technology of co-smelting of variable quality but also that these 'slangots' were subsequently refined until an acceptably low quantity of iron would not create brittle objects (MERKEL, 1990). Of the analyzed objects, only one presented an iron content of ≥ 30% and significant amounts of copper-(iron)-sulphides. Its microstructure showed it is a typical product of a primary smelting process that would oblige subsequent refining processes. Two other artefacts were shown to have an iron content of c. 10-20% and significant copper-(iron)-sulphides. Despite the diminishing amount of metallic iron, it seems that these were still the result of primary smelting processes, although probably produced under less reducing conditions than the first example (WEEKS *et al.*, 2016, p. 228).

Another analyzed group of fragments also revealed to be metallic copper with iron contents of ≤ 10% and copper-(iron)-sulphides. Some of these objects present more amorphous (and smaller) shapes than the previously described ones, which might, in turn, support that they result from ingots, copper spills or wastes (WEEKS *et al.*, 2016, p. 228). The microstructure of these objects and lower iron content seems to suggest, as opposed to the previous ones, the result of refined copper, and another step of refining would suffice to lower the quantity of iron to acceptable levels considering refining experiments by J. Merkel (1991) (WEEKS *et al.*, 2016, p. 230). Moreover, examples of this last step can be found in fragments containing only < 2% iron and

---

[4] Referred to as 'nearly' between parenthesis as it still has low values of minerals/metals ('impurities'), especially of arsenic and nickel, common in the Hajar mountains.

minor amounts of copper-(iron)-sulphides, which can be ascribed as proper copper (nearly) pure ingots (which would not alter the quality of the final products (MERKEL, 1990)). In one of these fragments, a small slag attached to the copper metal also indicates the presence of delafossite and magnetite, which suggest their refining in generally oxidizing conditions (WEEKS *et al.*, 2016, p. 232), thus supporting the use of crucibles for this process, as suggested.

An ingot of high arsenical copper identified by the SHARP team is also relevant (WEEKS *et al.*, 2016, p. 235-239). Although most ingots of (nearly) pure copper found at Saruq al-Hadid presented irregular to circular shapes, this one presented a plano-convex shape, which is already highly unusual for the Iron Age. Although typical for the Bronze Age period, Iron Age ingots usually present circular/oval flattish shapes from their production in simple imprints made on the ground (GOY, 2019, p. 224-228). Furthermore, it presented c. 12 wt% As, 1 wt% Fe, and c. 2 wt% S. Sulphur and iron levels are within the expected range. However, the arsenic level and absence of nickel are puzzling, as LIA done to this object indicated it was from the Hajar Mountains sources. Considering that arsenic levels from the region, although existing, are lower than nickel contents, the SHARP team has suggested that such specimens could have come from exceptionally rich sources of arsenic within the region, still unknown (WEEKS *et al.*, 2016, p. 239), although the possibility of being imported from nearby regions where such products are common, such as in Iran (OUDBASHI et al., 2020), needs to be considered. Such high arsenic levels in the ingots are not uncommon in the region and were observed in Masafi as well, some up to 18 wt%, and with variations of nickel from minimal or high percentages of up to 60 wt% which were quite disconcerting, and without any plausible reason for such high values (Goy, 2019, p. 374-382).

To understand such variations, further research on such types of objects is required, possibly analyzing more regional examples. As these ingots were melted, likely alloyed, transformed into objects, and those same objects recycled, progressive lower levels of arsenic and nickel are found in the objects, as shall be discussed in point. 3.3. Successive refining stages necessary to ‘clean’ the copper from unwanted properties may have also led to purer copper ingots, which can cause such variations. Understanding if the smelters/smiths would be aware of such variations will also be crucial. Different levels of nickel and arsenic would significantly change copper colour, casting and hardness properties, which were likely taken advantage of.

The other exciting find analyzed through pXRF by the SHARP team was a spill of a copper-zinc alloy containing 4 wt% zinc and associated 2 wt % arsenic, 1 wt% antimony, and 1 wt% iron. If this was an impurity or a deliberate alloy is still to be determined (WEEKS *et al.*, 2016, p. 239-243). Brass has been common in the Near East since the 1st millennium BC but only became widely used during the Roman period when its use also spread to southeast Arabia (HAUPTMANN, 2020, p. 373-377; WEEKS, 2003). Considering that the example analyzed had relatively low zinc, it was likely produced unintentionally, attending that zinc is also present in the ores from the Hajar mountains. Still, more research should be done in the future on such alloys, even if produced unintentionally. Already in the 3rd millennium contexts of the Umm an-Nar site (Abu Dhabi, UAE), several objects contained concentrations of zinc (FRIFELT, 1992), and this mirrors information from numerous sites all over southwest Asia which, although portraying objects likely produced as a natural-alloy, such copper-zinc ores may have been intentionally chosen for the golden colour and increased casting and hardness properties (THORNTON, 2007). We must consider that these, like the choice for rich nickel-arsenic copper ores, may have been intentional, even if the smelters/smiths were not completely familiarized with the chemical properties and thermodynamics necessary to alloy such metals effectively.

Finally, two rod fragments of tin-copper ingots were also identified in Saruq al-Hadid (WEEKS *et al.*, 2016, p. 243-248). Attending to the number of tin-copper objects also found on site (discussed in point 3.3.), the presence of such ingots is not surprising and more likely existed. However, they are the single examples found in the region. Despite the abundant quantity of bronze weaponry and jewellery since the Early Bronze Age, tin origin(s) still need to be answered (WEEKS, 2003).

One of these rods contained c. 11 wt% tin combined with minor amounts of lead, nickel, and copper sulphides. The other contained 7 wt% tin and low levels of sulphur and nickel. Considering the tin percentage contained in these ingots, it is safe to suggest they were intentional. The question that needs to be answered is if these alloyed ingots were imported as such or alloyed on-site. The first option seems more likely. Tin-copper objects in southeast Arabia, as we shall discuss in point 3.3., typically do not have such high percentages of tin, and such rod ingots were likely used to be alloyed with (nearly) pure copper to improve the colour and technical qualities of the objects under production.

3.2.2. The scrap metal

Regarding the abundant scrap metal identified along the 'slangots', ingots and spills in 'Layer 4' of Area 2A, the majority is either deformed or broken (see Annexe 6d). Many are folded once or several times, comprising complete artefacts and cut-off fragments. Similar discarded material was also mixed along the metallurgical debris of 'Layer 1' (WEEKS *et al.*, 2016, p. 249-255).

The deformation/breakage of such objects can be associated with two major activities. Either made them dysfunctional to mark them for reuse and recycling, although damage during use is quite likely also, or for symbolically "release" them of their original function (SWENSON, 2015). However, on-site, all artefacts from ritual contexts ('Layer 3' Area 2A and 'Layers 3, 5, 7' Area G) seem intact, without any apparent intentional deformation. Most likely, at Saruq al-Hadid, the deformed objects were for remelting, and the intentional breaking actions – including fragmenting in smaller pieces – were to facilitate their melting in crucibles (CLARKE, 2013).

Recycling of scrap metal has always been an important source within the economic spectrum of metal production and trade. Its regular use in metal workshops has been attested through archaeological contexts, ethnographic records, and archaeometric data. The role of scrap metal in metal trading circuits has also been attested. However, it still needs to be better understood, given the difficulty in tracing such circuits after metals have been melted repeatedly. Still, its use in every metal-producing society is secure (e.g. GALE, 1997; LAHIRI, 1995). At Saruq al-Hadid, such recycling has already been studied for the on-site iron metals (STEPANOV *et al.*, 2019). However, copper ones still need to be studied, especially concerning their provenance, importance in the regional economy, and use in the production chain.

Some authors have pointed out that tomb robbery to recover metal artefacts during prehistoric periods may have been a way to recover copper that could be recycled or hoarded as currency (YULE *et al.*, 2018). At Saruq al-Hadid, the abundance of metal weaponry found in 'Layer 4' provides such a possibility, particularly if we consider the presence of specific types of arrowheads which have been chronologically suggested as from the Wadi Suq/Late Bronze Age (e.g. YULE *et al.*, 2018, p. 54, fig. 4.11). However, the lack of proper regional typological studies on metal finds impedes us from knowing if such types of arrowheads, in particular, may have continued in use during the Iron Age period and thus still produced at Saruq al-Hadid. The absence of moulds on-site to produce these objects also hinders our knowledge about which ones were being produced here or not. Some examples (see Annexe 6e) were being produced there, as they were found unfinished. However, other examples may have been brought in to serve as votive offerings, trading items or scrap metal.

Nevertheless, as mentioned, numerous deformed and broken objects in 'Layers 1 and 4' tell us at least that many were to be recycled. In 'Layer 4', where these were found in their original contexts, these were often found agglomerated with other objects to recycle and even mixed with small ingot/'slangot' fragments and cast spills (see Annexe 6c). Many of such deformed/broken objects also exhibit marks of their intentional bending and cutting into small pieces, which were done by using sharp objects such as chisels (EVELY, 1993, p. 12), which were numerously found in 'Layer 4' as well (see Annexe 7b). Such cutting procedures would allow larger objects to be quickly melted in small crucibles. Arrowheads are usually melted whole, given their smaller size, unless they have already been broken from use.

Melted in the crucibles with these objects were also numerous examples of folded copper sheets, wires, and bands. Many also present cutting marks and hammering and heating evidence that would allow their folding. Many of these are sprues and other casting residues (and spills) that are saved to be remelted and reused. Larger wires (of circular and flat sections) found in 'Layer 4' of Area 2A (see Annexe 6e) seem to have been purposely made to be accumulated as such and later broken into smaller pieces and melted; it may have been a simpler way to have material ready to melt, instead of the ingots, which are much more challenging to break into smaller pieces. Some of the smaller ingots of (nearly) pure copper from this layer (attending to its morphology only as they were not submitted to the analysis yet) may have also been intentionally produced from recycled material and cast residues, as observed in other sites (e.g. Khirbat al-Hamri, Faynan (Jordan) (LEVY *et al.*, 2002).

However, despite this compelling evidence of metal recycling and organization of the melting production chain at Saruq al-Hadid, there is still no metallographic nor compositional analysis for these singular objects to help understand these processes better. In the future, priority should be given to the study of these ingots and scrap metal from Area 2A, as well as from other workshops in the region where such objects and stages of production were identified, such as at 'Uqdat al-Bakrah (YULE *et al.*, 2018).

3.2.3. Refining, alloying and recycling practice organization

A few paragraphs are necessary to resume and clearly define the refining, alloying and recycling practices held at Saruq al-Hadid.

The different iron content in copper ingots ('slangots') identified by the SHARP team testify for their purification on site, likely in crucibles, as provided data demonstrates that such melting in oxidizing conditions would suffice for the iron and sulphur impurities to be skimmed off from the top. Differences in iron content in these 'slangots' could be explained by differences in the thermodynamic conditions and fluxes added during their production, which were not well known/controlled by the smelters, as mentioned.

These ‘slangots’ were likely purified in small, shallow, pit-combustion structures identified in Area 2A. However, evidence of this has only been provided by numerous such ‘slangots’ accumulated adjacently to these structures (see Annexe 6i). Chronological and trace element analyses are still pending from these structures.

If crucibles were being used to purify such ‘slangots’, their presence near these structures has not been confirmed. However, a few fragments of crucibles might have been found near the larger pit-combustion structures in Area 2A and associated with the final stages of metallurgical production of copper objects (discussed in points 3.3 and 3.4.). These possible crucibles (see Annexe 6f) present remnants of fused copper in their interior, although they have not been analyzed yet. They are made of a sandy clayish material with a vegetable temper, which provides an exceptionally smooth touch, disintegrating easily. These are similar to examples identified by the SHARP team from ‘Layer 1’.

Many of the ones identified by the SHARP team (WEEKS *et al.*, 2016, p. 194-199) have relatively thin walls of 1 cm entirely preserved, significant amounts of organic temper, and no thick slag layer attached. Their interior shows a dark-coloured, bloated, vesicular fusion layer, likely copper and impurities residues. Diagnostic pieces show a small rim diameter of c. 10-12 cm. Such smaller dimensions (for easier manipulation and temperature control) and fabric are like other examples found in prehistoric crucibles for melting purposes (BAYLEY *et al.*, 2007). Furthermore, their temper and general appearance (burning colouration on the outside) contradicts the idea of being used inside a furnace, thus sustaining their use as melting crucibles to refine the ingots and scrap metal. Such processes could have been done in the smaller structures in Area 2A under a thin charcoal layer.

However, as the SHARP team has pointed out (WEEKS *et al.*, 2016, p. 197), different colourations in the crucibles they identified, from reddish/grey to beige/grey, might suggest that while some were used for the refining processes, others were only used for melting and alloying. The beige/grey colouration in some might suggest their use in reducing conditions, under a thicker layer of charcoal, to avoid metal oxidation and consequent metal loss. Such makes total sense, and the ones found near the larger structures in Area 2A, which contained large amounts of charcoal, presented such colourations from the reducing conditions they might have been exposed.

It is essential to stress that near these structures, only scrap metal, (nearly) pure ingots, and small copper balls (morphologically consistent with (nearly) pure copper as well) were found (see Annexe 6i). In the smaller structures, on the contrary, is where most of the 'slangots' were located. Thus, crucibles exposed to more oxidizing conditions could be used in these ones. The diminishing amount of charcoal from these structures, and their shallower shape, might also point to that. In fact, what we find in these structures is not real charcoal but simple ashy remains, consistent with results from higher temperatures and oxidizing conditions required for this process. The identification of artificial depressions at the edges of these pits might also have served the purpose of inserting bellows to create such conditions.

However, besides this additional evidence suggesting different structures and areas for refining and simple melting of copper, it is essential to remember that near the possible refining structures, not just 'slangots' were agglomerated near these and ready to use, but also ingots and scrap metal. Such might indicate that 'slangots' with relatively low levels of iron (<10%) could have been melted in the same crucible as these other (nearly) pure copper ingots and scrap metal. However, considering the oxidizing conditions reached in these structures, considerable metal loss may be expected, particularly of arsenic, nickel, and tin (present in the ingots and scrap metal). Such might explain the low levels of such metals in the identified alloys of Saruq al-Hadid's objects (discussed in point 3.3.). If the smelters/smiths knew about this fact, or if it mattered economically/technologically, it is hard to say.

3.3. Objects production

Many copper weaponry and jewellery types appear for the first time in Southeast Arabia during the Iron Age, as mentioned. However, besides numerous reports and publications about such objects and some contextual comparison with other sites, no regional typological studies exist from southeast Arabia. Such often creates chronotypological doubts about the contexts they appear and their use as votive, prestige or utilitarian objects, not to mention issues about their actual provenance, as many show apparent similarities with Luristan examples (OVERLAIT, 2003), thus creating doubts if some specimens were made locally (influenced by contacts with this region) or imported.

The diminishing number of compositional analyses of many of these objects, not to mention isotopic data, further hinders our knowledge about their provenance and uses, although studies conducted by J. Goy (2019) and L. Weeks (2000; *forthcoming*-a) are slowly starting to provide some insights about the alloys they are produced in and their origin. Metallographic data, on the other hand, to assess production techniques and uses (as well), still needs to be included in the region record, remaining a field completely understudied.

The material from Saruq al-Hadid, again, has the potential to provide important information about these questions, and exciting data have resulted from isotopic, p-XRF, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and macroscopical analyses carried-on on numerous objects from this site by the SHARP team (WEEKS *et al.*, 2017b, p. 425-480). These aimed to answer questions related to their provenance, primary alloys used in production (and reasons for their choices), and object production techniques (the first ones in the region).

Most of these analysed objects came from ritual deposits identified in Areas F/G by the SHARP team; the remaining materials from Area 2A are again pending analysis. Among the analysed objects were several types of different arrowheads, daggers, axe-heads, tweezers, razors, bracelets, and snake figurine.

3.3.1. Objects composition

At Saruq al-Hadid, three main types of copper-base alloys were identified in 35 analysed objects through ICP-MS. Most artefacts were of (nearly) pure copper (As-Ni-Cu), consistent with the natural alloys from the region. However, 4 contained arsenical levels >1wt% (2 have very low As ~1-2 wt%; 1 has c. 3.5wt%As, and one has ~13wt%

As), and 11 contained tin contents above >1wt% (with 8 having 'good' tin levels of >~5wt%).

The arsenical coppers identified with levels As >1wt%, may have, as mentioned, resulted from unknown Arsenide-rich sources in the region or, most likely, are imports. The tin levels observed could have resulted from intentional addition through tin ingots (not found on site), tin-copper rod ingots (two found on site), or the recycling of tin-copper alloyed objects. Since some tin levels are relatively low, these can be justified by the use of recycled material. During the alloying/recycling process, tin losses can occur by oxidation, dross formation, segregation, and by simple dilution (FIGUEIREDO et al., 2010; HAUPTMANN, 2007). However, the finds with levels above 5wt% must have been alloyed from tin (or tin-alloyed) ingots.

Such compositions thus reflect a preference for local natural alloys, although the use of recycled and imported material (with different metallic compositions) is not excluded. Such was also observed in other sites of regions (GOY, 2019: 387-404). However, objects made with (nearly) pure copper are relatively soft and lack mechanical properties such as increased hardness and strength. For example, daggers and axe heads of pure copper would be poor tools, as they would break and bend easily. Pure copper also results in less fluidity which would difficult the production of casted objects. Arsenic or tin levels, even if in low wt% as those observed in many of the objects from Saruq al-Hadid, would, in turn, improve such mechanical properties, making such objects much easier to cast, their melting point also lowers (which is vital to save fuel), and would enhance their tensile strength, and resistance to indentation and scratching (HAUPTMANN, 2020, p. 383-393, 398-400). It is thus crucial to understand the use pattern of such alloys since both pure and alloyed copper (with arsenic or tin) were identified in the on-site objects.

Furthermore, it is essential to understand if decorative choices were behind the choice of such alloys. Arsenic and tin-copper alloys increase the fluidity of the metal, allowing the production of highly decorated objects, as some in Saruq al-Hadid are. Those would require such alloys and expert craft skills (see Annexe 8). Arsenic or tin levels >5wt% also provides slight colour variations from the reddish copper colour to a progressively more golden colour if tin is added or silvery if arsenic (as well as nickel) is added (RADIVOJEVIC *et al.*, 2018). Thus, colour variations could have been perceived in pieces from Saruq al-Hadid, and alloy choices made to portray decorative and prestige purposes associated with wealth or status (HOSLER, 1995). Still, although such data has been abundantly discussed, there is no clear pattern observed for the Middle East. Although the mechanical properties of such alloys may have made their choice logical, their intentional colouration is subjective and difficult to access.

At Saruq al-Hadid, tin-copper alloys seem to have been regularly chosen for specific objects, namely tweezers, razors and chisels, blades and daggers (WEEKS *et al.*, 2017b, p. 428), as observed through pXRF analysis. The first ones, being tools, would improve their durability, as tin is more corrosion-resistant than arsenic. However, on hardness matters, both alloys create similar tools (considering the arsenic/tin levels observed) (NORTHOVER, 1989). The golden colour provided using tin, and the personal use of some of these objects (razors and tweezers), may, on the other hand, explain the preference for such alloys as symbols of status. However, such requires further data and the identification of a pattern for the broader region for confirmation. The same can be said for the daggers, perhaps status symbols, though given the diminishing number of such objects analysed, we cannot say this is the norm; several were also identified as being arsenical coppers.

The low levels of arsenic and tin observed also need to addressed from a technological perspective. High arsenic or tin contents increase brittleness when employing finishing techniques such as hammering, which seems to predominate at Saruq at Hadid (further details in point 3.3.2.). However, if such objects were submitted to annealing and quenching techniques intertwined with hammering, they would become excellent tools, mainly when containing only the observed low levels of tin and arsenic. Although extensive metallographic analysis is necessary for the objects of Saruq al-Hadid to understand if such techniques were used, they are a possibility considering what was observed from some metallographic data gathered from arrowheads.

In the case of arrowheads (WEEKS *et al.*, 2017b, p. 429-430), p-XRF indicates that most were of tin-copper alloy, although some arsenical ones exist. Limited access to tin may have created the necessity to use only natural alloys or recycled objects. Although further analysis is required to confirm if tin is more common in some arrowhead types than others, tin seems more significant in larger types; particular functions would perhaps require some types to be tin-bronzes. However, again, the lack of typological studies limits the access to object functionality and, thus, the understanding of such differences. Nevertheless, hammering techniques after the casting of arrowheads were observed (WEEKS *et al.*, 2017b, p. 431), which may have been employed for thinning and sharpening their edges, and/or to increase hardness within the hammered area (edge hardening).

If, in the future, further compositional and metallographic data is collected from objects such as axe heads, swords and daggers, the variability in their composition may reflect the aforementioned recurrence to recycling techniques, which allied to annealing and hammering techniques would provide them with the necessary tensile strength and resistance to indentation and scratching, without having to be alloys rich in neither arsenic nor tin. The identified values would suffice and, in fact, would facilitate the employment of such techniques. Higher contents would make such pieces brittle to hammering.

There is a similar irregular presence of tin and arsenic in rings and bracelets. Although such would not require any specific tensile or resistance treatment attending to their personal adornment characteristic, colour differences may, in turn, have affected alloy preference.

In turn, most vessels analysed are of (nearly) pure copper, except for one bowl type, alloyed with tin (WEEKS *et al.*, 2017, p. 435-437). Although the SHARP team suggested a specific function, perhaps ritualistic, for this bowl attending to its more golden colour, further data on such functionally and alloy patterns is required.

The copper snakes identified from numerous ritual deposits from Areas F/G were also analysed by the SHARP team (WEEKS *et al.*, 2017, p. 438). The majority is composed of (nearly) pure copper, and many revealed the presence of copper sulphides, indicating that these objects were produced from freshly cast copper (no recycling or remelting, which makes the sulphides to diminish). Such is interesting as it was only observed in such objects, providing clues about their ritualistic function and the intentional use of newly produced copper.

Some snakes, however, also present tin traces and copper sulphides, though in less percentage than others (WEEKS *et al.*, 2017, p. 443) and another presented traces of zinc below 7 wt%, so not actual brasses. As mentioned, zinc, naturally occurring in the Hajar mountains, is not surprising and is likely the result of such specific ores. Still, due to their zinc content, they would have presented a distinctive silver-red colour that might have been appealing. Although again, further data and analysis are required to confirm such hypotheses.

In short, the analysed objects from Saruq al-Hadid represent a preference for locally available sources, though the presence of arsenical copper and tin-copper alloys indicates that arsenic-rich and tin-copper rod ingots or finished products (recycled) of such alloys were also imported to the region and served the economic metal circuits of the region. The question, as mentioned previously, is from where such metals were coming from, especially tin – a matter of discussion for most tin-copper alloys identified in the entire Middle East (HAUPTMANN, 2020, p. 103-111; CRAWFORD, 1974; WEEKS, 2003, p. 165-195).

The low levels of arsenic and nickel are also not surprising and coincided with percentage levels identified for most of the analysed material from the Middle East. Such a range of values is consistent with the techniques employed and the organisation of the production chain proposed above for the refining, melting, and alloying of metals, where scrap metal was consistently employed also. Alloy composition identified by J. Goy (2019, p. 387-403) for the objects in Mudhmar, Masafi (both cultic sites) and 'Uqdat al-Bakrah (a metal workshop) also revealed similar compositions and suggesting similar production techniques. At these sites, no pattern of use associated with specific types of objects was also identified, even for those that could portray cultic functionality. This means that such alloy variation was either not important for the Iron Age society of the region or that not enough data exists yet. The latter option may be more likely. Continuously analysing materials from these sites, as well as settlement, administrative, and burial contexts will be fundamental to addressing this question. Such studies must also be combined with typological studies to address the functionality of such objects, as some may have been purposely made for votive or prestige contexts, while others for practical use.

3.3.2. Production techniques

Regarding production techniques for the production of objects in southeast Arabia, as observed, studies are almost entirely lacking, being some brief references for the Iron Age period made only by J. Goy (2019, p. 464-465) in her studies about the materials from Masafi, Mudhmar, and 'Uqdat al-Bakrah, although without recurring to any metallographic data, only simple object shape. She mentions that most objects, including weaponry, were cast into moulds. Depending on the type of objects, both simple and bivalve moulds could have been used. Moreover, attending to the shape of most weaponry found in the region, bivalve moulds must have been the primary technique employed. The identification of an unfinished axe head with its sprues at 'Uqdat al-Bakrah confirms it (YULE *et al.*, 2018, pl. B, n.82). Snake figurines found at Masafi and Mudhmar were also cast; however, these seem to have been produced in simple moulds. The undulating shapes of the snakes were drawn into the mould and linked together by small channels, which facilitated the flow of the molten metal. Much thinner and more delicate examples of such snakes than the moulded ones may have been hammered from thin metal sheets. Decorative elements, such as the snake eyes and scales, could have been entailed with chisels.

Regarding the moulds (simple and bivalve), these may have been made of stone or clay boxes and filled with sand, upon which the melted metal would be poured. Wood, ceramic, or soft stone moulds of the pieces under production could have been used to create the imprints on the sand, attending to the regularity of types identified throughout the region. However, due to the inexistent remains of such elements in the entire region, such a hypothesis cannot be confirmed.

At Saruq al-Hadid, sandbox moulds and object replicas were not identified, which greatly difficult our understanding of the final procedures for object production. The metallographic analysis done on some objects, although unprecedented in the region, has only been applied to a few examples. Still, quite interesting data was collected (WEEKS *et al.*, 2017b, p. 438-444).

Such methods, as previously mentioned above, when describing arrowhead composition, allowed us to understand that such objects were definitely cast in bivalve moulds and later hammered for edge-sharpening. From unfinished examples collected in Area 2A metallurgical deposits, it was also observed that these were produced in pairs, connected by their tang, and then separated as singular units using a chisel.

Most remaining weaponry may have also been produced in such bivalve moulds, as described; however, at Saruq al-Hadid, no clear evidence exists, like unfinished products with sprues (as the examples from 'Uqdat al-Bakrah). Nevertheless, the considerable amount of misshaped copper fragments, many suggesting being cut sprue fragments that were saved for subsequent recycling, may point in this direction.

Again, just like the snakes from Masafi and Mudhmar, the ones from Saruq al-Hadid (WEEKS *et al.*, 2017b, p. 438) are also shown through metallographic analysis to be worked from hammered strips, cut from sheets, which were bent into shape (see Annexe 8g). The hammering of the sheets is apparent within the microstructure because of the presence of deformed copper sulphides, which makes them look like elongated parallel units. In such hammered examples, the undulating shape of the snakes seems to have been made with a rod around the strip being pulled inwards (WEEKS *et al.*, 2017b, p. 444).

The production of objects with such hammering techniques was also observed in the anthropomorphic figurines identified in Area 2A (VALENTE *et al.*, 2019). Such finds were all made of copper that was cast into small bars (could be open face moulds on sand), which was then hammered, cut with chisels and folded with the help of rods to form the different figurine shapes, and finally incised with chisels for create anthropomorphic characteristics such as eyes and genitalia. Similar hammering, bending and decorative techniques, although not metallographic studied, may have also been employed in finds such as bracelets and rings of flat section.

Finally, it is also important to mention that the use of lost wax technology may have also been a possibility, already pointed out by J. Goy (2019, p. 407) about the production of elaborately decorated objects such as the bracelets from the Ibri/Selme hoard. Such may also be suggested for some finds discovered at Saruq al-Hadid. However, their local origin might be debatable, as they might as well be Luristan imports attending to their stylistic similarities (OVERLAET, 2003). However, although not from copper-base artefacts but from gold bead jewellery produced at Saruq al-Hadid also, we know that lost-wax, filigree and granulation techniques were known and employed for the production of jewellery (SORIANO *et al.*, 2018) (see Annexe 9). Thus pointing that lost wax techniques could indeed have been employed for a significant number of decoratively more elaborate objects.

Despite the general lack of metallographic data for the finds of Saruq al-Hadid, other pertinent evidence from the metallurgical deposits of Area 2A also provides further insights into these objects' production techniques and tools used. On-site, numerous copper vessels were found of different shapes (see Annexe 8c) and, as seen, of different alloy compositions. Moreover, in the metallurgical deposits, many of these were found broken and to be remelted, but also apparently, unfinished.

C. Clarke (2013, p. 31-35) thoroughly studied the raising of copper vessels. Although such a study used Minoan vessels as an example, techniques could be mirrored for those identified in southeast Arabia. She mentions that pure copper, although easy to hammer, is usually challenging to use in raising copper vessels, as its porosity might create cracks during the hammering process. Although adding arsenic or tin (of 6 to 7 wt%) makes the hammering process harder, it creates much more durable vessels and can be worked without cracking. However, she stresses that arsenic-copper alloys are unstable, and arsenic may dissipate with repeated heating, thus altering the alloy's characteristics. Attending that levels of arsenic in Saruq al-Hadid were mostly low it may confirm C. Clark's information and that arsenic levels may result from repeatedly being annealed and hammered to be produced. Tin-copper vessels, however, are more stable, allowing unlimited annealing. However, only a metallographic analysis of Saruq al-Hadid's materials would allow us to confirm such hypotheses.

Nevertheless, another critical evidence about the local raising of copper vessels at Saruq al-Hadid may be the common identification of small disc-shaped objects (quite thick) (see Annexe 7b), and frequent in the metallurgical deposits. These small discs are similar to those mentioned by C. Clarke (2013, p. 59-61) as cast disc billets from which copper vessels were progressively raised through subsequent annealing and hammerings processes until a vessel is formed with the help of a soft core (likely of wood) over which the vessel would be hammered and raised. Several different anvils, stakes and sinking hollows would help provide the different shapes to the vessel. Ethnographically, such materials and hammers used in raising copper vessels could be made of bronze, stone, wood, bone, or horn. However, only stone and metal ones survived in archaeological records (CLARKE, 2013, p. 78-88). Of such working materials, unfortunately, none of such was found on site. However, in 'Uqdat al-Bakrah, the presence of possible metal stakes is mentioned (although their actual function is not confirmed) – they seem too small for such purposes and show no use-wear (YULE *et al.*, 2018, pl.22, figs. 360-368). Furthermore, C. Clarke (2013, p. 61-62) also mentions the possibility of using bivalve and lost-wax moulds to cast vessels, and such a technique could indeed have been used at Saruq al-Hadid also, although again, such can only be confirmed through metallographic analysis.

Finally, about the vessel types from Saruq al-Hadid, it is essential to mention that although many are simple bowl types, many are spouted. Some of these spouts are quite long, indicating that these longer ones would have to be shaped from copper sheets (relatively abundant also in the metallurgical levels of Area 2A, although no large examples were found, only smaller ones) as separate elements. Such copper sheets would have to be hammered to create the spout's shape and then forged into the vessel. The same would be done for vessels, such as cauldrons with handles. In these handles, the hot joining's repeated hammering and forging procedures are visible, even to the naked eye.

In the metallurgical deposits from Area 2A, there were also several stone tools and copper objects that are still of complex assessment, as we have yet to learn what their function might have been, but which possible functions should be discussed. Many of these are stone tools, namely limestone and gabbro, which had to be brought in from the Hajar mountains, where they also abound (see Annexe 7a). Many of these are large and rectangular and could have served as working tables (anvils). These show hammering marks and depressions from repeated stress in the same areas. Other stone tools are smaller, elongated, and show smoothed depressions at their centre or towards the edges and could have been used as whetstones to sharpen blades. Several hand-size rounded stone tools could have been used as polishing stones or hand hammers. However, although these compare to examples described from other workshop sites (CLARKE, 2013, p. 78-91), we can only confirm their use once assessed microscopically.

Finally, some small chlorite tools are cylindrically shaped but thinned towards the edges. These are usually small, no bigger than 7 cm long and 1 cm thick at its centre. We have yet to understand what these tools are. However, attending to their shape, size, and abundance in the metallurgical deposits, they could have been used as rods or fitting implements to work on small copper/gold objects such as bead jewellery, rings, and bracelets. Still, this is entirely speculative as these do not compare to any objects ever published. Oddly, these tiny tools occasionally occur alongside votive deposits from Areas G and F, although many concentrate in the southern zone of Area 2A, along with the other identified stone tools. In this zone, primarily unfinished objects, metal scrap is observed.

Other unspecified copper objects discovered abundantly in the metallurgical deposits of Area 2A, especially around the large combustion structures, are some small objects, commonly called ‘clips’, whose function remains unknown. These are small, although of varied thicknesses and look like a clip (thus the name) (see Annexe 7b). Attending the location where they mainly concentrate, we have hypothesized that they could be clamps to close the bivalve moulds together. However, given the absence of such moulds, we cannot confirm it. It was also considered if they could be used as rivets to hot-join handles and other implements, but no clear evidence exists either.

Numerous copper 'spoons' - or what look like spoons - also appear constantly around the large combustion structures (see Annexe 7b). These are small (5-7 cm long) and had what appears to be the tang for a more extended handle (of wood, maybe), but no clear evidence exists; they could be as such. The context where they appear leads us to question if these could have been used for melting/hot-work small quantities of gold for beadwork. As gold has a lower melting point than copper, and most raw gold appeared on site as wires that would have melted quickly, these copper spoons could have served the effect. Trace elements analysis is nevertheless necessary to confirm it, but similar examples are also reported from Su Coddu-Canelles in Sardinia (as cited in DOLFINI, 2014, p. 484).

One last unknown artefact that is important to mention is the presence of shells with a greenish content (see Annexe 7b), randomly distributed in both metallurgical and ritual deposits. p-XRF analysis done by the SHARP team on these shells (WEEKS *et al.*, 2017b, p. 445) indicates that the greenish content was nearly pure copper with minor traces of arsenic and nickel, suggesting that these might have been pigment containers to stain bone and wood handles (SIDDALL, 2018), as these often exhibit such treatments on site. However, such has also been reported as cosmetic containers (TYLECOTE, 1992, p. 1).

Thus, considerable evidence in Area 2A is of complex assessment, particularly from the need for metallographic and microscopic analysis of the objects mentioned. However, it is hoped that these can still be done in the future, as this Area has a tremendous potential to help us understand the organization of objects production in southeast Arabia, including techniques and tools employed, still so poorly known for the region and overall, for the entire Middle East.

Even more poorly studied are decorations from these objects. Due to the burial conditions on site (highly saline), all copper objects present a thick corrosion patina that, although protective of the actual object, obscures all decorations the objects may have and, at times, even misinforms about its actual shape. This has been a constant problem throughout the entire region. The lack of conservation work on most copper materials from the region significantly impedes iconographic studies from accessing the symbolism and cultural significance of possible decorative motifs and imagery used on those copper objects, and subsequently impeding the interpretation of religious, mythological, or cultural themes representative of beliefs, values, and narratives associated with the Iron Age society of southeast Arabia. Furthermore, it impedes iconographic comparison with other regions to trace cultural connections, trade networks, and artistic influences. The deformed shape of some of these artefacts due to their heavy corrosion patina also impedes the assessment of artistic styles, techniques, and craftsmanship from the region, and even possible regional variations and individual artisans' styles (individuality). Furthermore, attending that many of these objects from Saruq al-Hadid came from ritualized/prestigious contexts of complex assessment (discussed in point 4), the lack of iconographic (and typological) data impedes us from understanding their actual function in this society and how they were used in rituals and ceremonies.

Still, from Saruq al-Hadid, of the objects that were possible to restore by Dubai Municipality, showed decorative iconography that will be important for future studies. Many revealed to have incised decorations done with chisels, although microscopic analysis to assess chisel types and techniques is still pending. Other objects revealed decorations done during casting, likely through the lost-wax technique, as mentioned above. Multiple handles of daggers and swords have also been inlaid with wood and bone inlays that were riveted to the handles. As mentioned, numerous bony fragments of such inlays presented greenish colouring (although we must consider tainting from the inlaid metal object and not intentional colouring – further is necessary).

3.3.3. The Combustion pits in Area 2A

The combustion pits found in Area 2A, attending to all that has been said about the material evidence surrounding them and the copper production technologies identified, are definitely structures integrating this production chain. The problem is understanding how they were used in the process and during which production phases. All of the collected samples from these structures still need to be analyzed, thus impeding us from confirming some of the theories proposed. Nevertheless, much contextual and stratigraphic information provided us with crucial data to understand many aspects of their distribution and possible use (VALENTE *et al.*, 2020).

A total of 29 combustion pits were found and excavated (Annexe 6g), 10 of them dated through AMS Radiocarbon from charcoal collected in its interior. Dating revealed they were used during the Iron Age II, most within 1000 to 800 BC, although the timeframe extends from roughly 1100 to 650 BC (CONTRERAS *et al.*, 2017). They are mainly concentrated in the northern excavated portion of Area 2A, and we know by the presence of charcoal deposits identified in the northernmost limits of the excavated squares that more exist further north and possibly east. All the pits are somewhat oval or rounded, between 100 to 200 cm in diameter (averaging 160 cm) and between 50 to 70 cm in depth. The exceptions are two rounded pits (13 and 24) with only 50 cm diameter and 30/40 cm depth, and the oval pits 25 and 31 with 120 and 90 cm length, and 35 and 15 cm in depth, respectively.

From excavating these pits, we also identified that they all contained the same composition, except pits 25 and 31 (see Annexes 6j). Approximately 30 centimetres of charcoal and burned sandstone slabs are always found at the pits' bottom, confirming their use as combustion structures. While the charcoal was used to feed the fire, the purpose of the sandstone slabs (ranging from 10-20 cm in size) was likely to maintain the heat inside the pits. Both materials for this combustion could be collected nearby, although the use of sandstone may not have been chosen for simple logistic reasons as these are known to be able to sustain (and maintain) extreme temperatures (up to 1500ºC) (REHREN, 2000, p. 22).

It is impossible to confirm what temperatures could be reached inside these structures. However, from evidence and experiments observed at other workshop sites, copper can be annealed at temperatures between 200 and 800°C. If the larger structures were used for such practices, for example, as well as for the simple melting of copper ingots and scrap metal, they could easily reach such temperatures with blowpipes or even with a simple breeze over the hearth if only lower temperatures are required (CLARKE, 2013, p. 78). However, if higher temperatures were necessary, as for the smaller structures (structures 25 and 31 in particular) suspected of being used for the purification and alloying of copper, bellows could increase temperatures up to 1600^{o}C (REHDER, 1994).

Furthermore, these charcoal and sandstone deposits are not limited to the pits' interior. Surrounding every pit, there is always an abundant quantity of this combustion debris that appears separated by intervals of fragmented gypsum and thin lenses of sand (see Annexe 6i). This seems to presuppose that these pits were at times cleaned from the debris in their interior, which is indiscriminately thrown out to their immediate surroundings. While doing so, part of the walls slightly crumbled, thus creating intervals between each cleaning action. On the other hand, the lenses of sand suggest that some time was allowed to pass until the next cleaning (the result of site abandonment until the next return). The exact time is, unfortunately, impossible to specify.

Nonetheless, the critical fact about this observation is that the slightly different sizes of pits might be justified by the number of cleaning actions they might have been submitted to. This may also have been the cause for the abandonment of a pit and the construction of a new one. If a pit became too large to maintain the necessary temperature requirements, it was discarded, and a new one was built. However, more chronological dating, and perhaps experimental archaeology, need to be done to prove such a hypothesis. So far, from the 10 pits dated, there was no direct relationship between size and chronology, nor between distribution and chronology. All we can say is that the pits were not all used simultaneously, as confirmed by the dating obtained and by the fact that some were covered by adjacent debris, suggesting that the covered ones were already in disuse. The reasons for its disuse, and even how far a new one was carved from the older ones seem random. No direct relationship between size, shape or location exists.

Randomly discarded was also how combustion debris was thrown out each time a combustion pit was cleaned. The accumulated charcoal and sandstone material around the combustion pits did not bother those using them or even the fragmented gypsum from the initial carving. Next to each pit, we always found below its combustion debris, the fragmented gypsum from its carving that often "fused" to the bedrock, forming (on average) a compacted mass of approximately 10 centimetres in thickness, dispersed around the pit (see Annexe 6i). Occasionally, this compacted gypsum deposit is also found above the debris of nearby pits – sometimes even intruding them – and thus indicating which pit is older and newer. The charcoal and sandstone debris thus did not affect production at those structures; however, inside, they were subjected to thorough and regular cleanings. The last combustion debris found inside each pit (used to date these structures) is the one they did not bother to clean because the structure would be disused.

It is also important to highlight pits 13 and 24 in particular. These are much smaller than any larger pits described so far, although they contain the same combustion debris inside (see Annexes 6j, middle). Their smaller size, however, might suggest other phases in the production chain that would require smaller structures, perhaps for the melting or alloying of metals in reducing conditions. If the copper was pure enough, or if simple scrap metal wished to be melted, their smaller size would facilitate their supply with the necessary draught to reach higher temperatures while at the same time preventing undesirable oxidizing conditions. Although the larger structures could sustain the conditions to melt and alloy, temperature and draught supply were likely more challenging to control. Those would be more effective for heating treatments, such as hot-hammering and annealing. Attending to the larger portions of some objects (namely swords and vessels there produced, for example), structures large enough to fit them under the layer of charcoal would be necessary. Such could not be done in the smaller structures.

The other two smaller pits mentioned – 25 and 31 – are, on the other hand, structurally and compositionally different from the other two and may not have been used exclusively for the purification of copper (see Annexes 6j, bottom). However, as mentioned previously, relatively pure copper and scrap metal could already be included in this stage. Although their size is not much different from the smaller structures, they are much shallower, and their content is slightly different. They contain much less sandstone material, and the charcoal material is more like ashy sediment consistent with activities that resulted in higher temperatures. They also had some artificial depressions that might have been used for the insertion of bellows to increase draught, not to mention the abundant quantity of unpurified copper found in their vicinities, as mentioned. These structures, as said, may have thus served mainly purification purposes.

Finally, from Area 2A is also essential to refer to the presence of several circular/oval depressions found throughout the gypsum floor, many within the overall dispersion zone of the pits (Annexe 6g). These are shallow depressions, no more than 15 cm deep and between 30 to 40 cm in diameter. They did not contain anything within, aside from the expected 'Layer 4' deposit that intruded them, and that could be composed of "clean" sand or charcoal if located close to a combustion pit. Although this is highly speculative, they could contain some containers, perhaps for water. Some large vessel fragments were found near one of these depressions. If the above reference to employing annealing and quenching techniques in these structures is correct, water nearby would be mandatory.

Throughout the whole of Area 2A, several postholes were also identified, much concentrated south of the pits zone, suggesting that some *barasti* structures may have existed there. Even so, no further evidence of how they might have looked exists. However, they could have provided shade to this southern zone where mainly metal accumulation was carried out and finishing of objects produced, as referred.

Considering the discussed information, and although more research is required in Area 2A, these combustion pits reasonably fit into the production chain observed from the metallographic data of the site. However, future analysis should be conducted, namely more metallographic data on the objects from this Area and trace elements analysis to the pits to confirm the hypothesis proposed. Experimental work could also be conducted to simulate the proposed production chain and confirm if these structures could sustain the temperatures suggested and be used in the purification, melting and alloying of metals. Ethnographic parallels should continue to be searched for, although so far, unsuccessfully. The only similar examples to these pits are the ones from ‘Uqdat al-Bakrah (YULE *et al.*, 2018).

At ‘Uqdat al-Bakrah, many such pits were identified, roughly exhibiting the same size, shape, and stratigraphic composition. Three types of combustion pits were also identified, though of slightly different sizes and shapes. Two types are quite like the larger and smaller ones identified in Saruq al-Hadid for melting/alloying and annealing. However, at ‘Uqdat al-Bakrah, some of these are considerably larger than all the others (and those at Saruq al-Hadid), exhibiting diameters of over 2 meters. These were interpreted as charcoal production pits, while the smaller ones were referred to as furnaces to recast disused objects. Although such seems a valid suggestion, in Saruq al-Hadid, the structures do not vary much in size except for those smaller ones mentioned. Also, charcoal production at Saruq al-Hadid may have been done in Area 53, excavated by the National Team from Dubai Municipality, where a large charcoal-rich mound was discovered, as mentioned. The third type of combustion pit from ‘Uqdat al-Bakrah, although not exactly like the smaller pits located in the southern zone of Area 2A for the purification of ‘slangots’, presents similarities in terms of size and stratigraphic content, although showing walls raised with stones and built as batteries close together. They are referred to as forging pits, where objects could be finished, and were associated with shaped stones that could have been used as sharpening tools, hammers, and anvils. These divergences of interpretation are also valid, thus demonstrating that much debate and research about such structures are required until conclusions can be reached.

3.4. Who produced these goods?

Although copper metallurgy has been developing in southeast Arabia since the 3rd millennium BC, and its products exported to nearby regions as previously discussed, it has been suggested that it was during Iron Age that an exponential craft specialization occurred, not only for the production of copper goods but also of other products such as soft stone and pottery vessels (MAGEE, 2014, p. 222-225). However, most of these conclusions come only from the apparent standardization of materials throughout the region – exhibiting similar types. Nevertheless, to discuss craft specialization, we must first identify the actors of the craft, how much energy they spend on it, why those goods are produced in the first place, and who owns that production (CLARK *et al.*, 1990). And so far, none of these questions have a clear answer.

There is a considerable increase in the copper products produced in the region, not only in numbers alone but in variety too. They seem to be equally distributed throughout the entire region; however, they appear primarily in burial and cultic sites (e.g. TAHA, 1981; GERNEZ *et al.*, 2017; YULE *et al.*, 1988). They appear in settlements also, but their spatial distribution has never been appropriately assessed, nor has their inter-site distribution/relationship. Furthermore, more data is needed to know who was producing these goods. As seen previously, most seem local, as produced from local ores, but the tin-copper objects identified might also mean that some were imported products. On the other hand, the technical artistry that many of the Iron Age products exhibit implies mastery and knowledge that would have to pass on for generations, likely between a single family of producers, as observed in other copper-producing regions (KIENLIN, 2014). Although some objects are suspected of being Iranian imports, especially bimetallic copper-base and iron weapons, as these are stylistically different from most southeast Arabian types (see Annexe 10) (OVERLAET, 2003), all others seem definitely local products. Such implies that local families specialize in the production of these products. However, we need to find out if they were entirely dedicated to this craft or if it was a simple seasonal activity.

Furthermore, we also need to find out if the smelters and the smiths were the same people. Most studies suggest that these were two different crafts requiring different sets of skills (KIENLIN, 2014, OTTAWAY, 2001). Ore procurement and first smelting was also a recurrently seasonal activity while producing copper products was a full-time task by expert smithers. In southeast Arabia, attending to the spatial distinction alone, there is a separation of smelting and refining/smithing sites (GOY, 2019, p. 451-452). However, this may result from copper ore distribution only in the Hajar mountains. There is no reason to discard the possibility that the same people would dedicate some of their time to collect and smelt the copper near the extraction areas (removing any unnecessary weight from impurities) and then transfer those products to settlement areas where they would be transformed into objects and commercialized, as observed in less complex societies and through ethnographic parallels (CHILDS, 2008). Furthermore, at Wadi Hilo, permanent structures were identified to reduce copper ores (KUTTERER, 2020) which might imply that such activities were more regularly procured and controlled. However, yet again, remains the question of who these people were.

The different typologies of copper objects identified in the region, especially of arrowheads (YULE *et al.*, 2018), suggest that these were done by different people (communities) with different stylistic and cultural preferences, thus producing slightly different specimens. However, the production of the same type of object in different styles might also reflect functional considerations, chronological variations, and social differentiation. Since regional typological studies on metal objects are lacking, little about this can be said. Some authors also pointed to itinerant artisans going from site to site to produce such objects (LINDUFF *et al.*, 2014). Although it is a valid suggestion, we cannot know for sure. At Saruq al-Hadid, for example, within the same type of arrowheads, we often observe slight variations that point to different artisans using the same type but applying their own individualities (moulds).

4. Saruq al-Hadid: a place of social cohesion

Following ethnographic parallels from the region and aforementioned social context for the Iron Age period, sites like Saruq al-Hadid, may have also served purposes of resolving conflict or for at least mediating trading relationships among groups. Tribal conflicts are until today resolved by respected tribal leaders who held influence within the community and often formed alliances or entered into treaties with each other to prevent conflicts. These agreements were often based on mutual interests, such as safeguarding trade routes, protecting grazing lands, or sharing resources (LANCASTER *et al.*, 1992), and celebrated through communal feasts and banquets, and accompanied by music, poetry recitals, and traditional dances, where a festive and joyous atmosphere was created, fostering a sense of unity and shared identity.

Gift-giving also played a significant role in celebrating agreements. Tribes exchange valuable gifts to symbolise goodwill and respect. The exchange of gifts was not only a sign of appreciation but also served to establish a reciprocal relationship between the tribes (RISSE, 2015). Moreover, the same goes for oaths and rituals, part of the celebration, where the leaders of the tribes involved would gather in a designated location and take solemn oaths, pledging their commitment to the terms of the agreement. These oaths were often accompanied by religious rituals, invoking the blessings of deities or seeking divine protection for the agreement.

All the material evidence found at Saruq al-Hadid, particularly from the 'ritual deposits', seems to point to these kinds of celebrations. Ritualized deposits on site appear either in the shape of small agglomerations in Areas F/G, between sterile deposits, or in successive, concentrated accumulations as observed in Area 2A (see Annexe 4c). But in addition to their different intensities and/or periodicities of deposition, Areas F/G and 2A also display differences in the types of objects incorporated, reflecting different types of rituals (WEEKS *et al.*, *forthcoming*-b).

4.1. Copper ritualization

In Areas F/G (see Annexe 10), we observe mainly copper-base weaponry dispersed through small, ritualized deposits, which include copper-base snakes and 'incense' burners in both copper and pottery – many snake-decorated (KARACIC *et al.*, 2017). Alongside these materials, alabaster, soft stone, iron and precious metal artefacts, finely crafted products in shell and bone, and pottery vessels (the majority in bowl form) are also constant. These deposits compare to several others found in Iron Age sites in southeastern Arabia, including Bithnah (BENOIST *et al.*, 2012b), Masafi (BENOIST *et al.*, 2012a), the ‘mound of serpents’ at Al Qusais (TAHA, 1981), Mudhmar (GERNEZ *et al.*, 2017), and Salut (AVANZINI *et al.*, 2018). Collectively, these sites seem to document a region-wide tradition of cultic/ritual activities related to a “snake deity” (CIAN, 2015; BENOIST *et al.,* 2015), with numerous examples of snake-decorated pottery and small copper-base figurines depicting this animal. The evidence for the burning of aromatics (probably incense) at each of these sites indicates its importance in cultic events in general (e.g. CARROLL *et al.*, 2003; KLETTER *et al.*, 2010).

Furthermore, the byproducts of metallurgical activity at Saruq al-Hadid were also incorporated into these ‘ritualised’ deposits. The variety of copper-base metallurgical residues in such contexts includes small amorphous copper lumps (including ‘slangots’) and raw copper ingots. This practice parallels contemporary sites, for example, at Masafi and Bithnah (BENOIST *et al.*, 2015), where metallurgical residues, including ‘furnace bottoms’ and ingots, were also found inside pottery vessels decorated with snakes or in pits. At ‘Uqdat al-Bakrah, several snake figurines are also known (YULE *et al.*, 2018).

Together, this evidence supports the theory that such materials are votive offerings to propitiate a snake deity associated with metallurgical knowledge and production (BENOIST *et al.*, 2015). The symbolism of the snake as a transformative and creative force, intertwined with fire and the craft of metalworking, can be found in various cultures across different regions. In ancient SW Asia, the snake had multiple aspects and associations, including healing, water and fertility. As a symbol of renewal and regeneration, in several cultural traditions, the snake represents the transformative powers involved in the creation and manipulation of metals (e.g., ROTHENBERG, 1972; MIROSCHEDJI, 1981; KOH, 1994).

Nevertheless, the social importance of copper-base objects in these rituals must also be considered alongside the presence and significance of production residues and raw copper. At Saruq al-Hadid, the variety of such finished objects is extraordinary – from simple tools such as pins/needles, hooks, and hoes to decorative items such as bracelets, rings, and vessels of different forms. However, by far, the most significant proportion of the finished objects comprises weapons, including axes, daggers, and especially arrowheads (see Annexe 8a). Elsewhere in the southeastern Arabian Iron Age, copper-base weaponry is particularly abundant in the cultic assemblages from Al Qusais (TAHA, 1981) and Mudhmar (GERNEZ *et al.*, 2017).

Miniaturised versions of weapons (and occasionally other object categories) are also common at these sites. Saruq al-Hadid has produced miniature bows, quivers, arrows, daggers, and axes, often made as skeuomorphs in copper-base or precious metal (see Annexe 8g). At ‘Uqdat al-Bakrah, miniature axes and daggers are also recorded (YULE *et al.*, 2018), and Mudhmar has a wide range of such objects, including miniature skeuomorphs of axes, arrows, arrowheads, bows, and quivers (GERNEZ *et al.*, 2017). Moreover, each of these sites is known for the presence of unfinished castings of copper-base weapons. These include both full-sized and miniature examples of socketed axeheads still with attached casting cup/sprues and flashing (GERNEZ *et al.*, 2017; YULE *et al.*, 2018), even though the latter does not exhibit any signs of metal production on site.

The prevalence of weaponry in cultic contexts is undoubtedly of cultural significance. However, identifying this practice’s specific nature and meaning for early Iron Age societies in southeastern Arabia is very challenging. At Mudhmar, the abundance of weaponry (especially archery-related artefacts) in votive contexts has been tentatively linked to their offering to a “*warrior deity…as key elements of specific social practices*” (GERNEZ *et al.*, 2017, p. 111). Beyond the religious realm, one can consider the possibility that the deposition of weaponry to a deity with a martial aspect mirrored the existence of a “warrior” ideology in contemporary society. Cross-culturally, such practices and beliefs have been linked to the emergence of warrior leaders or chieftains, who manipulated the materialised ideology of warriorhood to gain and maintain power, often through the control of relevant natural resources and/or industries, such as metallurgical production, and the exchange of these products and others considered “prestigious” (EARLE, 1997).

Other material categories from cultic sites/deposits emphasise this aspect. In particular, the presence at Saruq al-Hadid of iron swords (in Areas F/G only) alongside numerous bimetallic daggers is significant, as in other sites, including Mudhmar, Al Qusais and 'Uqdat al-Bakrah (STEPANOV *et al.*, 2020; WEEKS *et al.*, in press). Noting that there is no evidence of local iron smelting at any Iron Age site in the region, as well as the solid typological, technological and compositional parallels with contemporary material from Iran (STEPANOV *et al.*, 2019; STEPANOV *et al.*, 2020), it is highly likely that such artefacts were obtained through long-distance trading circuits. These votives are, therefore, profound exemplars of exotic and rare raw materials and craft skills. Not only symbols of a warrior identity but also material manifestations of the power to participate in and control the long-distance movement of exotic materials, likely the prerogative of a highly circumscribed, elite segment of society, as proposed. In Areas F/G, their deposition simultaneously served purposes both sacred and profane: propitiating a deity that was responsible for knowledge of fire and metallurgy while also demonstrating and legitimising the power of Iron Age community leaders (VALENTE, 2023; WEEKS *et al.*, in press).

4.2. Copper and its social power

To better understand this complex dynamic of belief, politics and economics, however, we must also consider the assemblage found in Area 2A, which, as noted above, is somewhat different from the one identified in Areas F/G. The assemblage from ritual contexts in Area 2A (see Annexe 11a) also contains offerings of copper-base snakes, weapons (miniaturized and regular), raw copper, and jewellery. However, unlike Areas F/G, incense burners have not been found there. As these seem to be a fundamental and persistent component of cultic rituals at Iron Age sites in southeastern Arabia, their absence in Area 2A suggests that more mundane "political ceremonies" in the shape of gift exchange and convivial festivity (BENOIST, 2010), characterized activities in this Area. Although votive offerings to a snake deity were still a component of the material remains from Area 2A, only agreements and exchanges between those who visited the site seem to have been celebrated here. Similar actions have been observed in other societies, where celebrations and ceremonies reinforced and legitimized ties between individuals and groups, providing recognition of authority, legitimacy and mutual obligations, particularly between actors at threat of conflict or simply between political entities within the same region who relied on each other economically or politically (LEVY, 1995; SWENSON, 2015; SWENSON *et al.*, 2022).

The ceramic assemblage found in Area 2A adds to our consideration of this hypothesis. Area 2A is dominated by grey ware jars and spouted vessels (BENOIST *et al.*, 2017), which parallel examples found in Rumeilah, Bithnah, Wadi al Qawr, and Muweilah (BENOIST, 1999; CORBOUD *et al.*, 1996; PHILLIPS, 1987; MAGEE, 1998c). As likely products of the extra-regional exchange circuits noted above, these vessels also had an enhanced material significance. Such vessels are comparatively rare in Areas F/G, which are instead dominated by sandy ware bowls and snake-decorated vessels of local production (KARACIC *et al.*, 2017). Steatite and copper vessels (many spouted), although produced locally (DAVID, 2002), also frequently occur in the Saruq al-Hadid assemblage, and parallel those of Iron Age contexts in the region (LOMBARD, 1985; GENCHI *et al.*, 2022; TAHA, 1981; VALENTE *et al.*, 2023). Finally, the presence of ladles is also attested on site, paralleling those found at Muweilah (MAGEE, 1998c). Collectively, such objects suggest a pervasive commensality at Saruq al-Hadid, resembling assemblages found in meeting and administrative buildings across the region, including the columned halls of Muweilah (MAGEE, 2007), Bida bint Sa’ud (AL TIKRITI, 2002), and Rumeilah (BOUCHARLA *et al.*, 2001), for example, which have been considered buildings for the meeting for the local elites.

Together, this evidence suggests that activities in Area 2A, while redolent with cultic imagery and characterized by the performance of offerings, took place within a context where people would banquet and celebrate; not only the craft production undertaken there but likely their gathering and what could come from it. On the other hand, Areas F/G seem to have a more ritually-oriented function, with a more direct connection with the snake deity.

It all thus suggests that copper technology was ‘ritualised’ at Saruq al-Hadid, as manifested through votive offerings to a snake deity who controlled metallurgical knowledge and production and who was venerated by the deposition of metal production residues and finished artefacts, especially weapons. However, it can be argued that ritualisation characterises not only the technology of copper production at Saruq al-Hadid but also its economic organisation.

Over the last two decades, archaeologists have worked to break down the pervasive, Western, dualistic conception of a (rational) sphere of economic action that can be contrasted with an (irrational) sphere of ritual action, particularly by deploying the concept of the 'ritual economy'. Such an approach explores how rituals can structure craft practices and craft goods' production, distribution and consumption (MILLER, 2015; MCANANY *et al.*, 2008; APPADURAI, 1986). Archaeological and ethnographic studies of ritual economies have highlighted, for example, societies in which the ritual cycle "*structures production and consumption…in a manner outside of the political control of any one group or individual. In this case economic interactions became embedded in the ritual cycle as a means to ensure peace and reciprocity while uniting groups outside of the bonds of kinship*" (MILLER, 2015, p. 125).

Although ritual economies have been explored as engines for the intensification of production in small-scale, non-centralised societies (MILLER, 2015; EVERHART *et al.*, 2020), the mutually constitutive realms of ritual and economy nevertheless provide many opportunities for ritual production to be co-opted in the exercise of power and the negotiation of (uneven) social relationships. Here, it can be argued that a perspective derived from the concept of "ritual economy" is valuable in understanding the organisation of copper production in early Iron Age southeastern Arabia, and its specific materialisation at sites such as Saruq al-Hadid.

A. Benoist (2010) has discussed authority and religion in the southeastern Arabian Iron Age, correlating data from several cultic sites and meeting places. Her review highlights the evidence for cultic activities, gatherings and festivity, but also the close association and importance of these activities for the management and sharing of resources, in a way that aligns well with the workings of a ritual economy. Although numerous sites evidence either one or another aspect of authority and religion (see Annexe 2e), Saruq al-Hadid's rich material assemblage, despite not yet providing any evidence for columned halls or cultic structures, shows it to be a place where members from communities across the region could gather for craft production, and while doing so, enact religious, social and political events that were fundamental to social reproduction and cohesion, as well as the negotiation of relations of power and prestige. Here, the liminal, desert locations of sites such as Saruq al-Hadid and ‘Uqdat al-Bakrah (YULE *et al.*, 2018) are not anomalous but rather a key criterion of their function: they represent a space *for* many communities but not *of* any specific community, and outside the control of any one group or individual. If we consider the Iron Age population of southeastern Arabia as experiencing an increased likelihood or threat of conflict – a suggestion supported by the fortification of many sites in the region during this period (BENOIST, 2010) and also the abundance of weaponry produced at this time – the need for places and rituals of social cohesion becomes clear.

If conflicts were occurring between the Iron Age communities of the region, or simply if every settlement had its own elite controlling and defending specific territories and resources, sites like Saruq al-Hadid and ‘Uqdat al-Bakrah may have been crucial to formalise and consolidate extra-community ties, and a sense of inter-dependency, as well as the authority of the elites who gathered there periodically (e.g., SWENSON *et al.*, 2022). P. Magee (1998c; 2002; 2007), has repeatedly stressed this idea and refers to the evidence supporting the existence of such elites. The referred characteristic assemblage found in columned halls – and at Saruq al-Hadid – comprises objects such as spouted vessels and ladles, symbolising the power of those who possess them. Similar claims can be made regarding the control of foreign resources such as iron (MAGEE, 1998a) or tin for copper alloying (WEEKS *et al.*, in press), or the grey ware vessels found at Saruq al-Hadid (BENOIST *et al.*, 2017) - noting that some could be local imitations. Many of these materials may be of Iranian origin or obtained via Iran (WEEKS *et al.*, in press), suggesting economic connections between elites in these areas responsible for controlling and distributing such products. Furthermore, the production of decorated shells buttons and beads of various materials attested at Saruq al-Hadid (WEEKS *et al.*, 2019b), stresses the idea that many forms of ‘prestigious’ production took place at the site, and were incorporated into its ritual economy.

Trading evidence found at Saruq al-Hadid also supports the idea of numerous groups coming together at the site to engage in exchange. This includes scale pans (see Annexe 8d), which indicate the weighing of items such as metal ingots, objects and scrap for exchange, as well as an extensive and diverse collection of stamp 'seals' found at the site (KARIM *et al.*, 2017), although noting that as yet there is no clear evidence for their use as administrative devices and they may rather have been personal markers of status or protective amulets. In fact, the entire paraphernalia observed in cultic and administrative or communal meeting structures in Iron Age southeastern Arabia, always charged with ritualised symbolic practices, appears to have been produced, offered and exchanged at Saruq al-Hadid.

Final considerations

This study has summarised the evidence for copper production and use at Saruq al-Hadid, alongside other crafting activities focused on elite or prestige goods, and outlined the details of an elaborate set of associated ritual practices directed towards a snake deity. It has been argued that this copper production – typically envisaged as a leading 'industrial' technology of its time that provided a major raw material for exchange – cannot be properly explored in purely technological and economic terms. Here, we have argued that the production and deposition of copper at Saruq al-Hadid can only be properly understood within complex, culturally-specific beliefs and practices, and with the recognition that aspects of a "ritual economy" shaped the nature of the Iron Age copper industry in southeastern Arabia.

Previously, Saruq al-Hadid has been conceptualised with the framework of "Arabian pilgrimage" (MAGEE, 2014, p. 239-240; WEEKS *et al*., 2019c, p. 173); a social practice that has been described as "*a constellation of gathering, sacrifice, and feasting at a sacred place to assemble and reify communities that are not coresident*" (MCCORRISTON, 2013, p. 608). While this model maintains its fundamental interpretive relevance for understanding a site such as Saruq al-Hadid, its explanatory power is enhanced when broadened to include the insights of studies of ritual economy; specifically, that such gatherings mobilised, and were mobilised by, ritualised craft production of copper and other materials.

Much work remains to be completed on the metallurgical remains from Saruq al-Hadid. This includes but is not limited to a fuller catalogue of metal artefacts from the site, followed by its subsequent typological study and distribution throughout the region and beyond. Only with such we can properly frame its role and capture the full complexity of the social contexts in which metallurgy developed in early Iron Age southeastern Arabia. Such can obviously not be completed without comprehensive archaeometric studies of metal extraction, composition, fabrication, use, and provenance. As observed, numerous questions relevant to properly understand why the identified alloys were chosen and how copper was processed remain unanswered. We still don't know the exact function of the structures identified on site, nor what were the dynamics of interactions and technological transfers between the various crafts attested on site.

Nevertheless, thanks to the concentration of metallurgical evidence at this site, this study provided relevant information on the organisation of its production chain, from first smelting procedures to refining copper and alloying with other metals and its transformation into objects. Metal recycling was also stressed here as much as possible to highlight its economic significance. The preference for natural local alloys of As-Ni-Cu was also confirmed in detriment of Sn-Cu alloys suggested. Arsenic containing copper, when manufactured under specific conditions (annealed and quenched), would provide as good tools as any tin-bronze even if in low quantities. Tin-bronzes, in turn, would have to be imported, which would result in more expensive alloys. However, their existence on site indicates that they were still desired alloys, as the difficulty of importing them would reinforce their owner's prestige/status. Nevertheless, "purer" (natural) copper was reserved for implements that would not require any tensile or strength improvement, especially votive objects, whose only function would be to appease the 'snake' deity for allowing its manufacture. In those, copper itself, as product, and shaped into weapons representative of those who control it, was the main element for which those people were thanked for.

Still, ethnographic studies to assess copper production in the region, which are currently lacking, would be extremely constructive to understand these dynamics and help interpret the archaeometric data available. On matters of social organisation, as has already been highlighted in this study, ethnographic data could also help define the dynamics of this 'ritual economy'. Social principles behind the tribal organisation in the Arabian Peninsula seem to have remained unchanged since immemorial times, and their interaction with peers, landscape, and resources is much unaltered (CABLE, 2012; LANCASTER *et al.*, 1992).

Lack of iconographic studies, as said, also hinders our understanding of this 'ritual economy' and, to a more considerable extent, its relationship with nearby regions. From the vast material collected of mostly Iranian origin, both regions seem to have shared close trading contacts but cultural styles and ideologies may have also been shared. However, we cannot verify the grade of such exchanges without such studies.

Nevertheless, much was already achieved with this study of Saruq al-Hadid, and hopefully, more it will bring with continued study. Its role in the region's copper production dynamics and socially cohesive function is slowly starting to be understood.

In the future, if Iron Age settlement pattern distribution continues to be assessed, more sites like Saruq al-Hadid likely exist. Sites like 'Uqdat al-Bakrah (YULE *et al.*, 2018), if further researched, may prove to have had a similar cohesive role as that of Saruq al-Hadid, and both (if not more) likely integrated a vast network of exchange that extended through the entire Arabian Peninsula. Current research is being developed to find more such sites in desert locations, and if those are found, it proves that a vast network of commercial and cultural relationships united (more than divided), such extensive region.

Bibliographical References

AL-MASRAHY, Mohammed; MOUNTNEY, Nigel - Remote sensing of spatial variability in aeolian dune and interdune morphology in the Rub' Al-Khali, Saudi Arabia. **Aeolian Research**. ISSN 1875-9637. Vol. 11 (2013), p. 155-170. doi: 10.1016/j.aeolia.2013.06.004.

AL SHANFARI, A.; WEISGERBER, Gerd - A Late Bronze Age warrior burial from Nizwa (Oman). **Oman Studies**. ISSN 0582-7906. Vol. 63, (1989), p. 17-30. ISSN 0582-7906.

AL TIKRITI, Walid - The excavations at Bidya, Fujairah: the 3rd and 2nd millennia BC culture. **Archaeology in the United Arab Emirates.** ISSN 0255-6782. Vol. 5 (1989), 101-114.

AL TIKRITI, Walid - The south-east Arabian origin of the *falaj* system. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 32 (2002), p. 117-138.

APPADURAI, Arjun - Introduction: commodities and the politics of value. In APPADURAI, Arjun, ed. - **The Social life of things. Commodities in cultural perspective**. Cambridge: Cambridge University Press, 1986. p. 3-63. ISBN 978-0-521-35726-5.

AVANZINI, Alessandra; DELGI ESPOSTI, Michele, eds. – **Husn Salut and the Iron Age of South East Arabia. Excavations of the Italian Mission to Oman 2004-2014.** Roma: L'Erma di Bretschneider, 2018. ISBN 978-88-913-1642-4.

BAYLEY, Justine; REHREN, Thilo - Towards a functional and typological classification of crucibles. In LA NIECE, S.; HOOK, D.; CRADDOCK, P., ed. - Metals and mining: studies in archaeometallurgy. London: Archetype, 2007. p. 46-55.

BEGEMANN, F. *et al.* - Lead isotope and chemical signature of copper from Oman and its occurrence in Mesopotamia and sites on the Arabian Gulf coast. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 21 (2010), p. 135-169. doi: 10.1111/j.1600-0471.2010.00327.x.

BENOIST, Anne - **La céramique de l'Age du Fer en péninsule d'Oman**. Paris: University of Paris I, 1999. PhD Thesis.

BENOIST, Anne - Authority and religion in South East Arabia during the Iron Age: a review of architecture and material from columned halls and cultic sites. In AVANZINI, Alessandra, ed. - **Eastern Arabia in the first millennium BC (Arabia antica 6).** [Online]. Roma: "L'Erma" di Bretschneider, 2010. p. 109-142. ISBN 978-88-91-31123-8. [Consulted 27 Jan. 2022]. Available in https://www.torrossa.com/it/resources/an/3176734

BENOIST, Anne; VALENTE, Tatiana - **Pottery from Area 2A of Saruq al-Hadid. Preliminary results from the last three seasons of excavations (2015-2017)**. [Interim Report]. 2017. Available in the Architectural Heritage and Antiquities Department of Dubai Municipality, Dubai, UAE.

BENOIST, Anne *et al.* - The Iron Age Occupation in Masafi: Report on two seasons of excavation. In POTTS, Daniel T.; HELLYER, Peter, eds. - **Fifty years of Emirates Archaeology. Proceedings of the Second International Conference on the Archaeology of the United Arab Emirates.** Abu Dhabi: Ministry of Culture, Youth and Community Development, 2012a. p. 146-159. ISBN 978-1-8606-3323-2.

BENOIST, Anne *et al.* - **La vallée de Bithnah au cours de l'Age du Fer**. Oxford: BAR Publishing, 2012b. ISBN 9781407311289.

BENOIST, Anne *et al.* - Snake, copper and water in south-eastern Arabian religion during the Iron Age: the Bithnah and Masafi evidence. In ARBACH, Mounir; SCHIETTECATTE, Jérémie, eds. - **Pre-Islamic South Arabia and its Neighbours: New Developments of Research**. Oxford: BAR Publishing, 2015. p. 21-36. ISBN 978-1-4073-1399-3.

BENTON, Jodie - **Excavations at Al Sufouh: a Third Millennium Site in the Emirate of Dubai.** Denmark: Brepols, 1996. ISBN 2-503-50503-1.

BOUCHARLAT, Rémy - Excavations at Al Thuqaibah Site, Al Madam Plain, 1987, by the Department of Archaeology of Sharjah: A Short Note on the Results. In BOUCHARLAT, Rémy, ed. - **Archaeological Surveys and Excavations in the Sharjah Emirate, 1988: A Fourth Preliminary Report**. Lyons: CNRS, 1988.

BOUCHARLAT, Rémy; LOMBARD, Pierre - The Oasis of Al Ain in the Iron Age: Excavations at Rumeilah, 1981-1983, Survey at Hili 14. **Archaeology in the United Arab Emirates**. ISSN 0255-6782. Vol. 4 (1985), p. 44–73.

BOUCHARLAT, Rémy; LOMBARD, Pierre – Le Bâtiment G de Rumeilah (Oasis d'Al Ain). Remarques sur les salles à poteaux de l'âge du fer en Péninsule d'Oman. **Iranica Antiqua**. ISSN 0021-0870. Vol. 36 (2001), p. 213-238. doi: 10.2143/IA.36.0.107.

BRAY, Helen; STOKES, Stephen - Temporal patterns of arid-humid transitions in the south-eastern Arabian Peninsula based on optical dating. **Geomorphology**. ISSN 1872-695X. Vol. 59 (2004), p. 271-280. doi: 10.1016/j.geomorph.2003.07.022

BUDD, Paul; TAYLOR, Timothy - The Faerie Smith Meets the Bronze Industry: Magic Versus Science in the Interpretation of Prehistoric Metal-Making. **World Archaeology.** ISSN 1470-1375. Vol. 27 N.1 (1995a), p. 133-143. doi: 10.1080/00438243.1995.9980297.

CABLE, Charlotte - **A multitude of monuments: findings and defending access to resources in the third millennium BC Oman**. Michigan: Michigan State University, 2012. Ph.D. thesis.

CARROLL, James; SILER, Elizabeth - Let My Prayer Be Set Before Thee: The Burning of Incense in the Temple Cult of Ancient Israel. **Studia Antiqua**. ISSN 0138-0575. Vol. 2 N. 2 (2003), p. 17-32.

CARTER, Robert - **Defining the Late Bronze Age in Southeast Arabia: ceramic evolution and settlement during the second millennium BC**. London: University College London, 1997. PhD Thesis.

CARTWRIGHT, Caroline – Seasonal Aspects of Bronze and Iron Age Communities at Ra's al-Hadd, Oman. **Environmental Archaeology**. ISSN 1749-6314. Vol. 3 (1998), p. 97-102. doi: https://doi.org/10.1179/env.1998.3.1.97

CASANA, Jesse; HERRMANN, Jason; QANDIL, Hussein - Settlement history in the eastern Rub al-Khali: Preliminary Report of the Dubai Desert Survey (2006–2007).

Arabian Archaeology and Epigraphy. ISSN 1600-0471. Vol. 20 (2009), p. 30-45. doi: 10.1111/j.1600-0471.2008.00306.x.

CHEN, Lucas - Sumerian Arsenic Copper and Tin Bronze Metallurgy (5300-1500 BC): The Archaeological and Cuneiform Textual Evidence. **Archaeological Discovery**. ISSN 2331-1967. Vol. 9 (2021), p. 185-197. doi: 10.4236/ad.2021.93010.

CHILDS, S.T. - Social Identity and Craft Specialization among Toro Iron Workers in Western Uganda. **Archaeological Papers of the American Anthropological Association**. ISSN 1551-8248. Vol. 8(1) (2008), p. 109-121. doi: 10.1525/ap3a.1998.8.1.109.

CIAN, Tracey - **Snake cults in Iron Age south eastern Arabia. A consideration on autochthonous developments and possible connections with other Middle Eastern traditions**. Qatar: UCL Qatar, 2015. Master Thesis.

CLARK, John; PARRY, William – Craft specialization and cultural complexity. **Research in Economic Anthropology.** ISSN 0190-1281. Vol. 12 (1990), p. 289-346.

CLARKE, Christina - **The Manufacture of Minoan Metal Vessels: Theory and Practice**. Uppsala: Åströms förlag, 2013. ISBN 978-91-7081-249-1.

CLEUZIOU, Serge - Oman peninsula in the early second millennium B.C. In HÄRTEL, H., ed. - **South Asian Archaeology 1979**. Berlin: Dietrich Reimer Verlag, 1981. p. 279-294. ISBN 978-3496001584.

CLEUZIOU, Serge – Hili and the beginning of oasis life in Eastern Arabia. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 12 (1982), p. 15-22. Available in http://www.jstor.org/stable/41219277.

CLEUZIOU, Serge - Excavations at Hili 8: a preliminary report on the 4th-7th campaigns. **Archaeology in the United Arab Emirates.** ISSN 0255-6782. Vol. 5 (1989), p. 61-87.

CLEUZIOU, Serge - Présence et mise en scène des morts à l'usage des vivants dans les communautés protohistoriques: l'exemple de la Péninsule d'Oman à l'âge du Bronze ancien. In MOLINOS, M.; ZIFFEREO, A., eds. - **Primi Popoli d'Europa. Proposte e**

riflessioni sulle origini della Civilta nell'Europa mediterranea, Florence: All'Insegna del Giglio, 2002. p. 17-31. ISBN 9788878142831.

CLEUZIOU, Serge - Early Bronze Age trade in the Gulf and the Arabian Sea: the society behind the boats. In POTTS, D.T.; AL NABOODAH, H.; HELLYER, P., eds. - **Archaeology in the United Arab Emirates**. London: Trident Press, 2003. p. 133–150. ISBN 9781900724883.

CLEUZIOU, Serge - Evolution towards complexity in a coastal desert environment: Early Bronze Age in the Ja'alan, Sultanate of Oman. In KOHLER, T.A.; VAN DER LEEUW, S.E., eds. - **The Model Based Archaeology of Socionatural Systems**. Santa Fe: School of American Research Press, 2007. p. 213–231. ISBN 9781930618879.

CLEUZIOU, Serge - Extracting wealth from a land of starvation by creating social complexity: A dialogue between archaeology and climate? **Comptes redus. Géoscience.** ISSN 1631-0713. Vol. 341 (2009), p. 726-738. doi: 10.1016/j.crte.2009.06.005.

CLEUZIOU, Serge; COSTANTINI, Lorenzo - Premiers éléments sur l'agriculture protohistorique de l'Arabie orientale. **Paléorient**. ISSN 1957-701X. Vol. 6 (1980), p. 245-251. doi: 10.3406/paleo.1980.4278.

CLEUZIOU, Serge; MÉRY, Sophie - In-between the great powers: the Bronze Age Oman Peninsula. In CLEUZIOU, S.; TOSI, M.; ZARINS, J., eds. - **Essays on the late prehistory of the Arabian Peninsula.** Rome: Istituto Italiano per L'Africa e L'Oriente, Serie Orientale Roma XCIII, 2002. p. 273-316. ISBN 9782002499945.

CLEUZIOU, Serge; TOSI, Maurizio - The southeastern frontier of the ancient Near East. In FRIFELT, K.; SMENSEN, P., eds. - **South Asian Archaeology 1985**. London: Curzon Press, 1989. p. 15-48. ISBN 9780913215500.

CLEUZIOU, Serge; TOSI, Maurizio - Ra's al-Jinz and the prehistoric coastal cultures of the Ja'alan. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 10 (2000). p. 19-73.

CLEUZIOU, Serge; VOGT, Burkhard – Umm an Nar burial customs. New evidence from Tomb A at Hili North. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421.. Vol. 13 (1983), p. 37-52. Available in http://www.jstor.org/stable/41222996.

CONTRERAS, Fernando *et al.* - Al-Ashoosh: a third-millennium BC desert settlement in the United Arab Emirates. **Antiquity**. ISSN 1745-1744. Vol. 90 354, e3 (2016), p. 1-6. doi: 10.15184/aqy.2016.219

CONTRERAS, Fernando *et al.* - Excavations in Area 2A at Saruq al-Hadid: Iron Age II evidence of copper production and ceremonial activities. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 47 (2017), p. 57-66. Available in https://www.jstor.org/stable/45163449.

CORBOUD, P. *et al.* - **Les tombes protohistoriques de Bithnah**. Mainz am Rhein: P. von Zabern, 1996. ISBN 9783805317375.

CORTIZAS, Antonio *et al.* - Early atmospheric metal pollution provides evidence for Chalcolithic/Bronze Age mining and metallurgy in Southwestern Europe. **Science of the Total Environment**. ISSN 0048-9697. Vol. 545-546 (2016), p. 398-406. doi: 10.1016/j.scitotenv.2015.12.078.

COSTA, P.; WILKINSON, T. - The hinterland of Sohar. Archaeological surveys and excavations within the region of an Omani seafaring city. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 9 (1987), p. 10-238.

CRADDOCK, P. T. - Appendix V. Report on the scientific investigation of metallurgical samples from the prehistoric site at Umm an-Nar, Abu Dhabi. In AL TIKRITI, W. - **Reconsideration of the Late Fourth and Third Millennium B.C. in the Arabian Gulf with Special Reference to the United Arab Emirates**. Cambridge: Cambridge University, 1981. p. 242-243. PhD Thesis.

CRADDOCK, P. T. – **Early Metal Mining and Production.** London: Trident, 1995. ISBN 0 7486 0498 7.

CRADDOCK, P. T.; MEEKS, N. D. - Iron in Ancient Copper. **Archaeometry**. ISSN 0003-813X. Vol. 29, N. 2 (1987), p. 187-204.

CRAWFORD, Harriet - The Problem of Tin in Mesopotamian Bronzes. **World Archaeology**. ISSN 2514-3956. Vol. 6 N.2 (1974), p. 242-247. Available in http://www.jstor.org/stable/124005.

CRAWFORD, Harriet - Dilmun, victim of world recession. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 26 (1996), p. 13-22. Available in http://www.jstor.org/stable/41223567.

CUÉNOD, Aurélie – Rethinking the Bronze-Iron Transition in Iran: Copper and Iron Metallurgy before the Achaemenid Period. Oxford: University of Oxford, 2012. Ph.D. Thesis.

DAVID, Hélène - Styles and Evolution: Soft stone vessels during the Bronze age in the Oman Peninsula. **Proceedings of the Seminar for Arabian Studies**. Vol. 26 (1996), p. 31-46. Available in https://www.jstor.org/stable/41223569. ISSN 0308-8421.

DEADMAN, William - Investigating the orientation of Hafit tomb entrances in Wadi Andam, Oman. **Proceedings of the Seminar for Arabian Studies.** ISSN Vol. 44 (2014), p. 139-152.

DEADMAN, William - **Early Bronze Age Society in Eastern Arabia: An Analysis of the Funerary Archaeology of the Hafit Period (3,200-2,500 BC) in the Northern Oman Peninsula with Special Reference to the Al-Batinah Region**. Durham: Durham University, 2017. Available in http://etheses.dur.ac.uk/12367/.

DE CARDI, Beatrice; DOE, D.B. - Archaeological survey in the northern Trucial States. East and West. ISSN 0012-8376. Vol. 21 (1971), p. 225–289. [Consulted 15 May 2023]. Available in https://www.jstor.org/stable/29755699.

DE CARDI, Beatrice; COLLIER, S.; DOE, D.B. - Excavations and survey in Oman. **Journal of Oman Studies.** ISSN 0378-8180. Vol. 2 (1976), p. 101–187.

DE CARDI, Beatrice; VITA-FINZI, Claudio; COLES, Anne - Archaeological survey in northern Oman, 1972. **East and West**. ISSN 0012-8376. Vol. 25 (1975), p. 9–75. Consulted 15 May 2023]. Available in https://www.jstor.org/stable/29756050.

DEL CERRO, Carmen - **Espacio arquitectónico y sociedad durante la Edad de Hierro en la Península de Omán (1300-300 a.C.)**. Madrid: Universidad Autónoma de Madrid, 2004. PhD Thesis.

DEL CERRO, Carmen – La Península de Omán: sociedad y usos del entorno en los oasis de la antigua Magan. ISIMU. ISSN 2659-9090. Vol. 10 (2007), p. 167-182. Available in http://hdl.handle.net/10486/12883.

DEL CERRO, Carmen; CÓRDOBA, Joaquín – Archaeology of a *falaj* in al Madam Plain (Sharjah, UAE); a study from the site. **Water History**. ISSN 1877-7244. Vol. 10 (2018), p. 85-98. doi: 10.1007/s12685-018-0210-0.

DELRUE, Parsival – **Archaeometallurgical Analyses of Pre-Islamic Artefacts from Ed-Dur (Emirate of Umm an-Qaiwain, U.A.E.).** Gent: Universiteit Gent, 2008. PhD Thesis.

DOLFINI, A. – Early Metallurgy in the Central Mediterranean. In ROBERTS, Benjamin; THORNTON, Christopher, eds. - **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 473-506. ISBN 978-1-4614-9017-3.

DOONAN, Roger *et al.* - Metals, Society, and Economy in the Late Prehistoric Eurasian Steppe. In ROBERTS, Benjamin; THORNTON, Christopher, eds. - **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 755-784. ISBN 978-1-4614-9017-3.

DURANTE, S.; TOSI, M. - The aceramic shell middens of Rays al-Hamra: a preliminary note. **Journal of Oman Studies.** ISSN 0378-8180. Vol. 3 (1977), p. 137-162.

EARLE, Timothy – **How Chiefs Come to Power. The Political Economy in Prehistory.** Stanford: Stanford University Press, 1997. ISBN 9780804728560.

EATON, E.; MCKERRELL, H. - Near Eastern alloying and some textual evidence for the early use of arsenical copper. **World Archaeology**. ISSN 0043-8243. Vol. 8 N.2 (1976), p. 169-191.

ECKSTEIN, D.; LIESE, W.; STIEBER, J. Wood supply in the prehistoric copper mining in Oman. **Naturwissenschaftliche Rundschau.** ISSN 0028-1050. Vol. 40 (1987), p. 426-30.

EDDISFORD, Daniel - Exchange networks of the Early Bronze Age Gulf: The imported ceramics from Kalba 4 (United Arab Emirates). **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 33 (2022), p. 23-48. doi: 10.1111/aae.12208.

EDDISFORD, Daniel; PHILLIPS, Carl - Kalbā in the third millennium (Emirate of Sharjah, UAE). **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 39 (2009), p. 99-112.

EDENS, Christopher - Dynamics of Trade in the Ancient Mesopotamian "World System". American Anthropologist. ISSN 1548-1433. New Series, Vol. 94, N.1 (1992), p. 118-139. doi: 10.1525/aa.1992.94.1.02a00070.

EL-SAYED, M.I. - Sedimentological characteristics and morphology of the aeolian sand dunes in the eastern part of the UAE: a case study from Ar Rub' Al Khali. **Sedimentary Geology**. ISSN 0037-0738. Vol. 123 (199), p. 219-238. doi: 10.1016/s0037-0738(98)00116-x.

EVANS, G. *et al.* – Stratigraphy and Geologic History of the Sabkha, Abu Dhabi, Persian Gulf. **Sedimentology**. ISSN 1365-3091. Vol. 12 (1969), p. 145-159. doi: 10.1111/j.1365-3091.1969.tb00167.x.

EVELY, D. - **Minoan Crafts: Tools and Techniques.** Göteborg: P. Aström, 1993. ISBN 9789170810091.

EVERHART, T.; RUBY, B. - Ritual Economy and the Organization of Scioto Hopewell Craft Production: Insights from the Outskirts of the Mound City Group. **American Antiquity.** ISSN 2325-5064. Vol. 85(2) (2020), p. 279-304. doi: 10.1017/aaq.2019.105.

FIGUEIREDO, Elin *et al.* Smelting and recycling evidences from the Late Bronze Age habitat site of Baiões (Viseu, Portugal). **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 37 (2010), p. 1623-1634. doi: 10.1016/j.jas.2010.01.023.

FRANKE, Kristina - **Metals without Ores. The Metallurgy of 3rd Millennium Upper Mesopotamia with Special Focus on the Jezirah**. London: University College London. PhD Thesis.

FRIFELT, Karen - On prehistoric settlements and chronology of the Oman Peninsula. **East and West**. ISSN 0012-8376. Vol. 25 (1975a), p. 329–423.

FRIFELT, Karen - A possible link between the Jemdet Nasr and the Umm an-Nar graves of Oman. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 1 (1975b), p. 57-8 1.

FRIFELT, Karen - Evidence of a third millennium town in Oman. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 2 (1976), p. 57–74.

FRIFELT, Karen - Oman during the third millennium BC: urban development of fishing/farming communities? In TADDEI, M., ed. - **South Asian Archaeology 1977**. Naples: Istituto Universitario Orientale, 1979. p. 567-588.

FRIFELT, Karen - **The Island of Umm an-Nar: Third Millennium Graves**. Aarhus: Jysk Arkæologisk Selskab, 1992. ISBN: 978-8772885612.

FRIFELT, Karen - **The Island of Umm an-Nar: Third Millennium Settlement**. Aarhus: Jysk Arkæologisk Selskab, 1995. ISBN: 9788772885773.

GALE, N. H. – The isotopic composition of tin in some ancient metals and the recycling problem in metal provenancing. **Archaeometry**. ISSN 1475-4754. Vol. 39 N. 1 (1997), p. 71-82. doi: 10.1111/j.1475-4754.1997.tb00791.x.

GARCÍAN ANTÓN, Mercedes; SAINZ OLLERO, Helios – Paleovegetación y su relación con la vegetación actual en la región de al Madam (Sharjah, Emiratos Árabes Unidos). **ISIMU**. ISSN 1575-3492. Vol. 1 (1998), p. 279-287. Available in https://revistas.uam.es/isimu/article/view/3762.

GENCHI, Francesco; TURSI, Giampiero - The softstone vessels assemblage from the Long Collective Grave 1 (LCG-1) at Dibbā al-Bayah (Sultanate of Oman): A preliminary assessment. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 33 (2022), p. 108-151. doi: http://doi.org/10.1111/aae.12209.

GERNEZ, Guillaume; GIRAUD, Jessica - Protohistoric graveyards in Adam (Oman). Preliminary report on the 2013 and 2014 seasons of the French Archaeological Mission to Adam. **Proceedings of the Seminar for Arabian Studies**. [Online] Vol. 45 (2015), p.

107–122. [Consulted 27 Jan. 2022]. Available in https://www.jstor.org/stable/43783626. ISSN 0308-8421.

GERNEZ, Guillaume; JEAN, Mathilde; BENOIST, Anne - The discovery of a new Iron Age ritual complex in central Oman: recent excavations near Ādam. **Proceedings of the Seminar for Arabian Studies.** ISSN 0308-8421. Vol. 47 (2017), p. 101-116.

GLENNIE, K. W. **The Geology of the Oman Mountains: An Outline of their Origin**. Beaconsfield: Scientific Press, 1995. ISBN 9780901360274.

GOUDIE, Andrew *et al.* - Latest Pleistocene and Holocene dune construction at the north-eastern edge of the Rub Al Khali, United Arab Emirates. **Sedimentology**. ISSN 1365-3091. Vol. 47 (2000), p. 1011-1021. doi: 10.1046/j.1365-3091.2000.00336.x.

GOY, Julie - **La Métallurgie du Cuivre à L'Age du Fer en Péninsule d'Oman: Organisations et Caractéristiques Techniques.** Paris: Université Paris 1, Panthéon Sorbonne, 2019. PhD Thesis.

HAERINCK, Ernie - The rectangular Umm an-Nar-period grave at Mowaihat (Emirate of Ajman, United Arab Emirates**). Gentse bijdragen tot de kunstgeschiedenis en oudheidkunde**. ISSN 0772-7143. Vol. 29 (1991), p. 1-30.

HAERINCK, Ernie - Excavations at ed-Dur (Umm al-Qaiwain, U.A.E.) – preliminary report on the sixth Belgian season (1992). **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 5 (1994), p. 184-197.

HAUPTMANN, Andreas - 5000 Jahre Kupfer in Oman. Band 1: Die Entwicklung der Kupfermetallurgie vom 3. Jahrtausend bis zur Neuzeit. **Der Anschnitt.** ISSN 2749-6449. Vol. 4. (1985).

HAUPTMANN, Andreas - Chemische Zusammensetzung von Metallobjekten aus der Siedlung Umm an-Nar. In FRIFELT, Karen, ed. - **The Third Millennium Settlement, The Island of Umm an-Nar 2**. Aarhus: Jutland Archaeological Society, 1995. p. 246-248. ISBN 9788772885773.

HAUPTMANN, Andreas - **The Archaeometallurgy of Copper. Evidence from Faynan, Jordan**. New York: Springer, 2007. ISBN 978-3-540-72237-3.

HAUPTMANN, Andreas - The Investigation of Archaeometallurgical Slag. In ROBERTS, Benjamin; THORNTON, Christopher, eds. - **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 91-105. ISBN 978-1-4614-9017-3.

HAUPTMANN, Andreas - **Archaeometallurgy – Materials Science Aspects**. New York: Springer, 2020.

HAUPTMANN, Andreas; WEISGERBER, Gerd - Third millennium BC copper production in Oman. **Revue D'Archeometrie.** ISSN 2802-1630. Vol. 3 (1980), p. 131-138. [Consulted 15 Dec. 2022]. Available in https://www.persee.fr/doc/arsci_0399-1237_1981_sup_1_1_1138.

HAUPTMANN, Andreas; WEISGERBER, Gerd; BACHMANN, G. - Early copper metallurgy in Oman. In MADDIN, R., ed. - **The Beginning of the Use of Metals and Alloys**. Massachusetts: The MIT Press, 1988. p. 34-51. ISBN 9780262132329.

HERRMANN, Jason; CASANA, Jesse; QANDIL, Hussein - A sequence of inland desert settlement in the Oman peninsula: 2008–2009 excavations at Saruq al-Hadid, Dubai, UAE. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 12 (2012), p. 50-69. doi: 10.1111/j.1600-0471.2011.00349.x.

HOSLER, Dorothy - **The Sounds and Colors of Power: The Sacred Metallurgical Technology of Ancient West Mexico**. Cambridge: MIT Press, 1994. ISBN 9780262526623.

HUMPHRIES, Jane; CAREY, Chris – New methods for investigating slag heaps: Integrating geoprospection, excavation and quantitative methods at Meroe, Sudan. **Journal of Archaeological Science**. ISSN 0305-4403. Vol. 70 (2016), p. 132-144. doi: 10.1016/j.jas.2016.04.022.

KARACIC, Steven et al. - Snake decorations on the Iron Age pottery from Sarūq al-Hadīd: a possible ritual centre? **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 47 (2017), p. 139-150. Available in https://archaeopresspublishing.com/ojs/index.php/PSAS/article/view/1225.

KARACIC, Steven *et al.* - Integrating a complex late prehistoric settlement system: Neutron activation analysis of pottery use and exchange at Saruq al Hadid, United Arab Emirates. **Journal of Archaeological Science: Reports.** ISSN 2352-4103. Vol. 22 (2018), p. 21-31. doi: 10.1016/j.jasrep.2018.09.007

KARACIC, Steven *et al.* - Another Brick in the Wall: Mudbrick Construction at the Iron Age II Site of Hili 2 (Emirate of Abu Dhabi, United Arab Emirates). **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 30 (2019), p. 199-212. Doi: 10.1111/aae.12150.

KARIM, Mansour *et al.* - Iron Age Seals at Saruq al-Hadid (Dubai, UAE). **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 47 (2017), poster.

KIENLIN, Tobias - Aspects of Metalworking and Society from the Black Sea to the Baltic Sea from the Fifth to the Second Millennium BC. In ROBERTS, Benjamin; THORNTON, Christopher, eds. – **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 447-472. ISBN 978-1-4614-9017-3.

KLETTER, Raz; ZIFFER, Irit - Incense-Burning Rituals: From Philistine Fire Pans at Yavneh to the Improper Fire of Korah. **Israel Exploration Journal**. ISSN 0021-2059. Vol. 60 N. 2 (2010), p. 160-187. doi: 10.2307/27927262.

KNABB, Kyle *et al.* – Environmental impacts of ancient copper mining and metallurgy: Multi-proxy investigation of human-landscape dynamics in the Faynan valley, southern Jordan. **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 74 (2016), p. 85-101. doi: 10.1016/j.jas.2016.09.003.

KOH, Sejin - An Archaeological Investigation of the Snake Cult in the Southern Levant: The Chalcolithic Period Through the Iron Age. Chicago: University of Chicago, Department of Near Eastern Languages & Civilizations, 1994.

KROLL, Stephan - The Early Iron Age Fort at Lizq, Sultanate of Oman. **Zeitschrift für Archäologie Außereuropäischer Kulturen.** ISSN 1863-0979. Vol. 5 (2013), p 159–220.

KUMAR, Arun; ABDULLAH, Mahmoud - An overview of Origin, Morphology and Distribution of Desert Forms, Sabkhas and Playas of the Rub' al Khali Desert of the

Southern Arabian Peninsula. **Earth Science India**. ISSN 0974-8350. Vol. 4(III) (2011), p. 105-135.

KUTTERER, Johannes - **The Archaeological Site HLO1. A Bronze Age Copper Mining and Smelting Site in the Emirate of Sharjah (UAE)**. Sharjah: Sharjah Archaeology Authority, 2020. ISBN 978-9948-25-729-5.

LAHIRI, Nayanjot - Indian Metal and Metal-Related Artefacts as Cultural Signifiers: An Ethnographic Perspective. **World Archaeology**. ISSN 1470-1375. Vol. 27 N. 1 (1995), p. 116-132. Available in http://www.jstor.org/stable/124781.

LAMBERG-KARLOVSKY, C.; MAGEE, P. – The Iron Age Platforms at Tepe Yahya. **Iranica Antiqua**. ISSN 1783-1482. Vol. 34 (1999), p. 41-52. doi: 10.2143/IA.34.1.519105.

LAMBERG-KARLOVSKY, C. *et al.* - **Excavations at Tepe Yahya, Iran 1967-1975. The Iron Age Settlement**. Massachusetts: Peabody Museum of Archaeology and Ethnology, 2004.

LANCASTER, William; LANCASTER, Fidelity - Tribal formations in the Arabian Peninsula. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 3 (1992), p. 145-172. doi: 10.1111/j.1600-0471.1992.tb00035.x.

LECHTMAN, H.; KLEIN, S. - The production of copper-arsenic alloys (arsenic bronze) by cosmelting: modern experiment, ancient practice. **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 26 (1999), p. 497-526. doi: 10.1006/jasc.1998.0324.

LÉZINE, Anne-Marie et al. – Mangroves of Oman during the late Holocene: climatic implication and impact on human settlements. **Vegetation History and Archaeobotany**. ISSN 0939-6314. Vol. 11 (2002), p. 221-232. doi: 10.1007/s003340200025.

LÉZINE, Anne-Marie *et al.* - Climate change and human occupation in the Southern Arabian lowlands during the last deglaciation and the Holocene. **Global and Planetary Change**. ISSN 1872-6364. Vol. 72 (2010), p. 412-428. doi: 10.1016/j.gloplacha.2010.01.016

LEVY, Thomas - Cult, Metallurgy and Rank Societies - Chalcolithic Period (ca. 4500-3500 BCE). In T. LEVY, Thomas, ed. - **The Archaeology of Society in the Holy Land**. Leicester: Leicester University Press, 1995. p. 226-244. ISBN 978-0718501655.

LEVY, Thomas *et al.* - Early Bronze Age metallurgy: a newly discovered copper manufactory in southern Jordan. **Antiquity**. ISSN 1745-1744. Vol. 76 (2002), p. 425-437. doi: 10.1017/S0003598X00090530.

LINDUFF, Katheryn; MEI, Jianjun - Metallurgy in Ancient Eastern Asia: Retrospect and Prospects. In ROBERTS, Benjamin; THORNTON, Christopher, eds. – **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 785-803. ISBN 978-1-4614-9017-3.

LIPPARD, Stephen; SHELTON, A.; GASS, I. - **The Ophiolite of Northern Oman**. London: Blackwell Scientific Publications, 1986. ISBN 978-0632015870.

LOMBARD, Pierre - **L'Arabie Orientale a l'Age du Fer**. Paris: Université Paris 1, Panthéon Sorbonne, 1985. PhD Thesis.

MAGEE, Peter - Excavations at Muweilah. Preliminarv Report on the First Two Seasons. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 7 (1996), p. 195-213.

MAGEE, Peter - New Evidence of the Initial Appearance of Iron in Southeastern Arabia. **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 9 (1998a), p. 112-117. doi: 10.1111/j.1600-0471.1998.tb00111.x.

MAGEE, Peter - Settlement patterns, polities and regional complexity in the Southeast Arabian Iron Age. **Paléorient**. ISSN 1957-701X. Vol. 24/2 (1998b), p. 49-60. doi: 10.3406/paleo.1998.4676

MAGEE, Peter - Cultural interaction and social complexity in the Southeast Arabian Iron Age. **Iranica Antiqua**. ISSN 1783-1482. Vol. 33 (1998c), p. 135-142. [Consulted 14 Jan. 2022]. Doi: 10.2143/IA.33.0.519127

MAGGE, Peter - The chronology and regional context of late prehistoric incised arrowheads in southeastern Arabia. **Arabian Archaeology and Epigraphy.** ISSN 0905-7196. Vol. 8 (1998d), p. 1-12.

MAGEE, Peter - The Indigenous Context of Foreign Exchange between South-eastern Arabia and Iran in the Iron Age. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 12 (2002), pp. 161-168.

MAGGE, Peter - The impact of southeast Arabian intra-regional trade on settlement location and organization during the Iron Age II period. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 15 (2004), p. 24-42. doi: 10.1111/j.1600-0471.2004.00022.x

MAGEE, Peter - The Production, Distribution and Function of Iron Age Bridge-Spouted Vessels in Iran and Arabia: Results from Recent Excavations and Geochemical Analysis. **Iran.** ISSN 2396-9202. Vol. 43 (2005), p. 93-115. doi: 10.2307/4300685.

MAGEE, Peter - Beyond the Desert and the Sown: Settlement Intensification in Late Prehistoric Southeastern Arabia. **Bulletin of the American Schools of Oriental Research**. ISSN 2161-8062. Vol. 347 (2007), p. 83-105. Available in https://www.jstor.org/stable/25067023.

MAGEE, Peter - **The Archaeology of Prehistoric Arabia: Adaptation and Social Formation from the Neolithic to the Iron Age** [Online] Cambridge: Cambridge University Press, 2014. ISBN 9781139016667. doi: 10.1017/CBO9781139016667.

MAGEE, Peter *et al.* - Sourcing Iron Age softstone artefacts in southeastern Arabia: results from a programme of analysis using Inductively Coupled Plasma-Mass Spectrometry/Optical Emission Spectrometry (ICP-MS/OES). **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 16 (2005), p. 129-143. doi: 10.1111/j.1600-0471.2005.00247.x.

MAGEE, Peter *et al.* - Tell Abraq during the second and first millennia BC: site layout, spatial organisation, and economy. **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 28 (2017), p. 209-237. doi: 10.1111/aae.12103.

MCANANY, Patricia A.; WELLS, E. Christian. - Toward a theory of ritual economy. **Research in Economic Anthropology**. ISSN 0190-1281. Vol. 27 (2008), p. 1-16. doi: 10.1016/S0190-1281(08)00001-2.

MCCORRISTON, Joy - Pastoralism and Pilgrimage: Ibn Khaldūn's Bayt -State Model and the Rise of Arabian Kingdoms. **Current Anthropology**. ISSN 0011-3204. Vol. 54 N. 5 (2013), p. 607-641. doi: 10.1086/671818.

MERKEL, J. – Experimental Reconstruction of Bronze Age Copper Smelting Based on Archaeological Evidence from Timna. In ROTHENBERG, B.; BACHMANN, H., eds. – **The Ancient Metallurgy of Copper: Archaeology – Experiment – Theory.** London: Institute for Archaeo-Metallurgical Studies, 1990. p. 75-122. ISBN 9780906183038.

MÉRY, Sophie - Ceramics and patterns of exchange across the Arabian Sea and the Persian Gulf in the Early Bronze Age. In AFANAS'EV, G. *et al.* - **The Prehistory of Asia and Oceania, Colloquium XXXII: Trade as a Subsistence Strategy. Post-Pleistocene Adaptations in Arabia and Early Maritime Trade in the Indian Ocean**. Forli: A.B.A.C.O., 1996. p. 167-179. ISBN 9788886712064.

MÉRY, Sophie **- Les Céramiques d'Oman et l'Asie Moyenne: une Archéologie des Échanges à l'Age du Bronze**. Paris: CNRS, 2000.

MILLER, G. L. - Ritual economy and craft production in small-scale societies: Evidence from microwear analysis of Hopewell bladelets. **Journal of Anthropological Archaeology.** ISSN 0278-4165. Vol. 39 (2015), p. 124–138. Doi: 10.1016/j.jaa.2015.03.005.

MIROSCHEDJI, P. - Le dieu élamite au serpent et aux eaux jaillissantes. **Iranica Antiqua.** ISSN 1783-1482. Vol. 16 (1981), p. 1-25.

MÖDLINGER, Marianne; TREBSCHE, Peter; SABATINI, Benjamin - Melting, smelting, and recycling: A regional study around the Late Bronze Age mining site of Prigglitz-Gasteil, Lower Austria. **PLoS One**. ISSN 1932-6203. Vol. 16(7) e0254096 (2021). doi: 10.1371/journal.

MOHEN, J. *et al.* - Ateliers métallurgiques dans l'habitat protohistorique du Fort-Harrouard. **Bulletin de la Société Préhistorique Française**. ISSN 1760-7361. Vol. 86 (1989), p. 404–408. doi: 10.3406/bspf.1989.9900.

MOORE, Mark *et al.* - Bronze age stone flaking at Saruq al-Hadid, Dubai, southeastern Arabia. **PLoS ONE**. ISSN 1932-6203. Vol. 17(7): e0270513 (2022). doi: 10.1371/journal.pone.0270513.

MUHLY, James - Sources of Tin and the Beginnings of Bronze Metallurgy. **American Journal of Archaeology**. ISSN 1939-828X. Vol. 89 N.2 (1985), p. 275-291. doi: 10.2307/504330.

NEZAFATI, N.; PERNICKA, E.; MOMENZADEH, M. Introduction of the Deh Hosein Ancient tin-copper mine, Western Iran: Evidence from Geology, Archaeology, Geochemistry and Lead Isotope Data. **Tüba-ar**. ISSN 2667-5005. Vol. 12 (2009), 223-236. doi: http://doi.org/10.22520/tubaar.2009.0018.

NOCETE, F. *et al.* - An archaeological approach to regional environmental pollution in the south-western Iberian Peninsula related to Third millennium BC mining and metallurgy. **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 32(10) (2005), p. 1566-1576. doi: 10.1016/j.jas.2005.04.012.

NORTHOVER, J. Peter - Properties and Use of Arsenic-copper Alloys. In HAUPTMANN, A.; PERNICKA, E.; WAGNER, G.A., eds. - **Old World Archaeometallurgy**. Bochum: Deutsches Bergbau-Museum, 1989. p. 111–118. ISBN 3921533422.

ORCHARD, Jocelyn - The origins of agricultural settlement in the al-Hajar. **Iraq**. ISSN 0021-0889. Vol. 57 (1995), p. 145–158. doi: 10.1017/S0021088900003041.

OUDBASHI, Omid *et al.* - Arsenical copper and bronze metallurgy during Late Bronze Age of north-eastern Iran: evidences from Shahrak-e Firouzeh archaeological site. **Archaeological and Anthropological Sciences**. ISSN 1866-9565. Vol. 12:231 (2020). doi: 10.1007/s12520-020-01182-3.

OVERLAET, Bruno – **Luristan Excavation Documents. Vol. IV. Early Iron Age in the Pusht-I Kuh, Luristan**. Gent: Peeters Publishers, 2003. ISBN 978-9042912434.

OVERLAET, Bruno – **Mleiha. An Arab Kingdom on the Caravan Trails. Discoveries in Sharjah Emirate – U.A.E.** Brussels: Sharjah Archaeology Authority, 2018.

PEAKE, Harold - Peake, H. The copper mountain of Magan. **Antiquity**. ISSN 1745-1744. Vol. 2 (1928), p. 452-457. doi: 10.1017/S0003598X00002520.

ÖZBAL, Hadi; MIEKE, Adriaens; BRYAN, Earl - Hacinebi Metal Production and Exchange. **Paléorient.** ISSN 1957-701X. Vol. 25, N.1 (1999), p. 57-65. doi: 10.3406/paleo.1999.988.

OTTAWAY, B. – Innovation, production and specialization in early prehistoric copper production. **European Journal of Archaeology**. ISSN 1741-2722. Vol. 4(1) (2001), p. 87-112. doi: 10.1179/eja.2001.4.1.87.

PARKER, Adrian; ROSE, Jeffrey - Climate change and human origins in southern Arabia. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 38 (2008b), p. 25-42. Available in https://www.jstor.org/stable/41223935.

PARKER, Adrian *et al.* - Developing a framework of Holocene climatic change and landscape archaeology for the lower Gulf region, southeastern Arabia. **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 17, N. 2 (2006), p. 125-130. Doi: 10.1111/j.1600-0471.2006.00261.x.

PETRIE, Cameron - The Iron Age fortification of Husn Awhala (Fujairah, UAE). **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 9 (1998), p. 246-260. doi: 10.1111/j.1600-0471.1998.tb00120.x.

PHILLIPS, Carl - **Wadi al Qawr, Fashgha-1: The excavation of a prehistoric burial structure in Ras al Khaimah (1986)**. Edinburg: Department of Archaeology, University of Edinburg, Paper n° 7, 1987. ISSN 0266-1799.

PHILLIPS, Carl - The pattern of settlement in the Wadi al-Qawr. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 27 (1997), p. 205-218. Available in http://www.jstor.org/stable/41223600.

PLOQUIN, A.; ORZECHOWSKI, S.; BRIAND, B. Paléométallurgie à Mleiha: une premiére approche. In MOUTON, M. - **Mleiha I: Environnement, stratégies de subsistance et artisanats**, Lyon: Maison de l'Orient méditerranéen, 1999. p. 171–190. ISBN 9782903264710.

POTTS, Daniel T. - **The Arabian Gulf in Antiquity.** Oxford: Clarendon Press, 1991. ISBN 9780198143901. Vol. I; ISBN 9780198143918. Vol. II.

POTTS, Daniel T. - **Ancient Magan**. London: Trident Press, 2000.

POWER, Timothy; SHEEHAN, Peter - Bayt Bin Ati in the Qattarah oasis: a prehistoric industrial site and the formation of the oasis landscape of al-Ain, UAE. **Proceedings of the Seminar for Arabian Studies.** ISSN 0308-8421. Vol. 41 (2011), p. 267–282.

PRANGE, M. *et al.* - Is Oman the ancient Magan? Analytical studies of copper from Oman. In YOUNG, M. *et al.*, eds. - **Metals in Antiquity**. Oxford: BAR Publishing, Archaeopress, 1999. p. 187-192.

PREUSSER, Frank - Chronology of the impact of Quaternary climate change on continental environments in the Arabian Peninsula. **Comptes Rendus. Geoscience**. ISSN 1778-7025. Vol. 341 (2009), p. 621-632. doi: 10.1016/j.crte.2009.02.003.

RADIVOJEVIC, M. *et al.* - Experimental design of the Cu-As-Sn ternary colour diagram. **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 90 (2018), p. 106-119. doi: 10.1016/j.jas.2017.12.001.

REHDER, J. - Blowpipes versus Bellows in Ancient Metallurgy. **Journal of Field Archaeology**. ISSN 2042-4582. Vol. 21 N.3 (1994), p. 345-350. doi: 10.1179/009346994791547562.

RIGHETTI, Sabrina – **Les Cultures du Wadi Suq et de Shimal dans la Péninsule Omanaise au deuxième millénaire Avant notre ére. Évolution des sociétés du Bronze Moyen et du Bronze Récent.** Paris: Université Paris 1 – Panthéon Sorbonne, 2015. PhD Thesis.

RISSE, Marielle - Generosity, gift giving, and gift avoiding in southern Oman. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 45 (2015), p. 289-296.

RIZK, Zein; ALSHARHAN, Abdulrahman - Water Resources in the United Arab Emirates. **Developments in Water Science**. ISSN 2542-646X. Vol. 50 (2003), p. 245-264. doi: 10.1016/S0167-5648(03)80022-9.

ROBERTS, James *et al.* - The role of wild terrestrial animals in late prehistoric societies of south-eastern Arabia: new insights from Saruq al-Hadid. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 29 (2018), p. 1-20. doi: 10.1111/aae.12112.

ROBERTS, James *et al.* - The exploitation of marine resources at Saruq al-Hadid: Insights into the movement of people and resources in Bronze and Iron Age south-eastern Arabia. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 30 (2019), p. 1-20. doi: 10.1111/aae.12137.

ROTHENBERG, B. - **Timna. Valley of the Biblical Copper Mines**. London: Thames & Hudson, 1972. ISBN 978-0500390108.

SCHWALL, Christoph; JASIM, Sabah - Assessing Kalba: new fieldwork at a Bronze Age coastal site on the Gulf of Oman (Emirate of Sharjah, UAE). **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 50 (2020), p. 321-332.

SIDDALL, Ruth - Mineral Pigments in Archaeology: Their Analysis and the Range of Available Materials. **Minerals.** ISSN 2075-163X. Vol. 8, 201 (2018). Doi: 10.3390/min8050201.

SORIANO, Ignacio *et al.* - Goldwork technology at the Arabian Peninsula. First data from Saruq al Hadid Iron Age site (Dubai, United Arab Emirates). **Journal of Archaeological Science: Reports**. ISSN 2352-4103. Vol. 22 (2018), p. 1-10. doi: 10.1016/j.jasrep.2018.08.030.

STEPANOV, Ivan *et al.* - Scrapping ritual: Iron Age metal recycling at the site of Saruq al-Hadid (U.A.E.). **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 101 (2019), p. 72-88. doi: 10.1016/j.jas.2018.11.003.

STEPANOV, Ivan *et al.* - The provenance of early Iron Age ferrous remains from southeastern Arabia. **Journal of Archaeological Science**. ISSN 1095-9238. Vol. 120 (2020), p. 105-192. doi: 10.1016/j.jas.2020.105192.

STÖLLNER, Thomas - Mining Landscapes in Early Societies - Imprinting Processes in Pre- and Protohistoric Economies? In BARTELS, C.; KÜPPER-EICHAS, C., eds. - **Cultural heritage and landscapes in Europe. Proceedings of the International Conference,**

Bochum June 8-10, 2007. Bochum: Deutsches Bergbau-Museum, 2008a. p. 65–92. ISBN 978-3-937203-36-2.

STÖLLNER, Thomas; GONTSCHAROV, Anton - Social Practice and the Exchange of Metals and Metallurgical Knowledge in 2nd Millennium Central Asia. **Metalla**. ISSN 0947-6229. Vol. 25(2) (2020), p. 45-76.

SWENSON, E. - The Archaeology of Ritual. **Annual Review of Anthropology.** ISSN 1545-4290. Vol. 44 (2015), p. 329-345. doi: 10.1146/annurev-anthro-102214-013838.

SWENSON, E.; BERQUIST, S. - Highland-Coastal Relations and Transformations in Dualistic Political Ideologies in Middle Horizon Jequetepeque. **Journal of Andean Archaeology.** ISSN 2051-6207. Vol. 42(1) (2022), p. 1-38. doi: 10.1080/00776297.2021.1878603.

TAHA, Munir – **The Iron Age in the United Arab Emirates with special reference to Mesopotamia**. Cambridge: Cambridge University, 1981. PhD Thesis.

THORNTON, Christopher - Of brass and bronze in prehistoric Southwest Asia. in LA NIECE, S.; HOOK, D.; CRADDOCK, P., ed. - **Metals and mining: studies in archaeometallurgy**. London: Archetype, 2007. p. 123–135.

THORNTON, Christopher - The Emergence of Complex Metallurgy on the Iranian Plateau. In ROBERTS, Benjamin; THORNTON, Christopher, eds. – **Archaeometallurgy in Global Perspective. Methods and Syntheses**. New York: Springer, 2014. p. 665-696. ISBN 978-1-4614-9017-3.

TOSI, Maurizio; USAI, Donatella - Preliminary report on the excavations at Wadi Shab, Area 1, Sultanate of Oman. **Arabian Archaeology and Epigraphy.** ISSN 0905-7196. Vol. 14 (2003), p. 8-23. doi: 10.1034/j.1600-0471.2003.140102.x.

TYLECOTE, R.; BOYDELL, P. - Experiments on copper smelting based upon early furnaces found at Timna. In ROTHENBERG, B., ed. - **Archaeometallurgy: chalcolithic copper smelting**. London: Institute of Archaeo-Metallurgical studies, 1978. p 27–49. ISBN 0906183006.

TYLECOTE, R. F. – **A History of Metallurgy**. 2nd ed. London: Maney Publishing, 1992. ISBN 1-902653-79-3.

UERPMANN, Hans-Peter; UERPMANN, Margarethe - The Appearance of the Domestic Camel in South-east Arabia. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 12 (2002), p. 235-260.

UERPMANN, Margarethe - Structuring the Late Stone Age of southeastern Arabia. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 3 (1992), p. 65-109. doi: 10.1111/J.1600-0471.1992.TB00032.X.

VALENTE, Tatiana - Saruq al-Hadid: a centre of metallurgic production and social cohesion. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 52 (2023), p. *in press*.

VALENTE, Tatiana *et al.* - Five seasons of excavations in Areas 2A and G of Saruq al Hadid (Dubai, UAE): Iron Age II evidences of copper production, workshop area and ceremonial activities. **ISIMU**. ISSN 2659-9090. Vol. 23 (2020), p. 169-195. doi: 10.15366/isimu2020.23.010.

VALENTE, Tatiana *et al.* - The Jabal al Yamh tombs (Hatta, Dubai, UAE): the architecture, spatial distribution, and reuse of prehistoric tombs in south-east Arabia. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 51 (2022), p. 413-431. Available in https://archaeopresspublishing.com/ojs/index.php/PSAS/article/view/636.

VALENTE, Tatiana *et al.* – The necropolis of Al Qusais (Dubai, UAE): preliminary results of the 2020 excavation and reassessment of the data from the 1970s and 1990s excavations. **Proceedings of the Seminar for Arabian Studies**. ISSN 0308-8421. Vol. 52 (2023), p. *in press*.

VELDE, Christian - Wadi Suq and Late Bronze Age in the Oman Peninsula. In POTTS, D. T.; AL-NABOODAH, H.; HELLYER, P., eds. - **Archaeology of the United Arab Emirates: Proceedings of the first international conference on the archaeology of the UAE**. Abu Dhabi: Trident Press, 2003. p. 102– 113. ISBN 1-900724-88-X.

VELDE, Christian – The Landscape of the Middle Bronze Age in the UAE – Where did people live? In **New Perspectives On Recording UAE History**. Abu Dhabi: National Center for Documentation & Research, 2009. p. 61-74. ISBN 978-9948-05-071-1.

VOGT, Burkhard - In search for coastal sites in Pre-Historic Makkan: mid-Holocene 'shell-eaters' in the coastal desert of Ras al-Khaimah, U.A.E. In KENOYER, J., ed. - **From Sumer to Meluhha: Contributions to the Archaeology of South and West Asia in Memory of George F. Dales, Jr.** Madison (WI): Department of Anthropology, University of Wisconsin, 1994. p. 113–28. ISBN 9780964399327.

VOGT, Burkhard - **Asimah: An Account of Two Months Rescue Excavation in the Mountains of Ras al-Khaimah, United Arab Emirates**. Dubai: Shell Marketing, 1995. ISBN 488581772.

VON DER DRIESCH, Angela *et al.* - The hunt for wild dromedaries at the United Arab Emirates coast during the 3rd and 2nd millennia BC. Camel bones from the excavations at Al Sufouh 2, Dubai, UAE. In **Archaeozoology of the Near East VIII. Actes des huitièmes Rencontres internationales d'Archéozoologie de l'Asie du Sud-Ouest et des régions adjacentes**. Lyon: Maison de l'Orient et de la Méditerranée Jean Pouilloux, 2008. p. 487-497. ISBN 978-2-35668-005-1.

WEEKS, Lloyd - Prehistoric Metallurgy at Tell Abraq, U.A.E. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 8 (1997), p. 11-85. doi: 10.1111/j.1600-0471.1997.tb00147.x.

WEEKS, Lloyd - **Early Metallurgy of the Persian Gulf. Technology, Trade and the Bronze Age World.** [Online] Brill Academic Publishers, 2003. ISBN 978-90-04-49544-9. [Consulted 01 Mar. 2022]. Available in https://brill.com/view/title/11126.

WEEKS, Lloyd - An analysis of Late Pre-Islamic copper-base artefacts from Ed Dur, U.A.E. **Arabian Archaeology and Epigraphy**. ISSN 0905-7196. Vol. 15 (2004), p. 240-252. doi: 10.1111/j.1600-0471.2004.00249.x.

WEEKS, Lloyd; PETRIE, Cameron - Iran and Arabia in the Iron Age: New Discoveries. In MUTIN, B.; ESKANDARI, N., eds. - **The Archaeology of the Southeastern Iranian**

Plateau Between the Neolithic and Achaemenid Periods. Turnhout, Belgium: ARWA collection / ARATTA, Brepols, in press.

WEEKS, Lloyd *et al.* ed. – **Saruq al-Hadid Archaeological Research Project (SHARP)**. [Interim Report 1]. 2015. Available in the Architectural Heritage and Antiquities Department of Dubai Municipality, Dubai, UAE.

WEEKS, Lloyd *et al.* ed. – **Saruq al-Hadid Archaeological Research Project (SHARP)**. [Interim Report 2]. 2016. Available in the Architectural Heritage and Antiquities Department of Dubai Municipality, Dubai, UAE.

WEEKS, Lloyd *et al.* ed. – **Saruq al-Hadid Archaeological Research Project (SHARP)**. [Interim Report 3]. 2017a. Available in the Architectural Heritage and Antiquities Department of Dubai Municipality, Dubai, UAE.

WEEKS, Lloyd *et al.* - Recent archaeological research at Saruq al-Hadid, Dubai, UAE. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 28 (2017b), p. 31-60. doi: 10.1111/aae.12082.

WEEKS, Lloyd *et al.* - Dating persistent short-term human activity in a complex depositional environment: late prehistoric occupation at Saruq al-Hadid, Dubai. **Radiocarbon**. ISSN 1945-5755. Vol.00, N. 0 (2019a), p. 1-35. doi: 10.1017/RDC.2019.39

WEEKS, Lloyd *et al.* - Worked and decorated shell discs from southern Arabia and the wider Near East. **Arabian Archaeology and Epigraphy**. ISSN 1600-0471. Vol. 30 (2019b), p. 1-26. doi: 10.1111/aae.12126.

WEEKS, Lloyd *et al.* - Saruq al-Hadid: a persistent temporary place in late prehistoric Arabia. **World Archaeology**. ISSN 1470-1375. Vol. 51, N. 1 (2019c), p. 157-182. doi: 10.1080/00438243.2018.1491324.

WEEKS, Lloyd *et al.* - Qarn al-Harf Metal Artefacts and Archaeometallurgical Analyses. in KENNET, D., ed. - **Excavations at Qarn al-Harf**. S.l: S.n., *forthcoming*-a.

WEEKS, Lloyd *et al.* - Iron Age Copper Production and the 'Ritual Economy' of Saruq al-Hadid (Dubai, U.A.E.). In **Archaeological Conference 2022. Advances in the UAE's Archaeology**. S.l: S.n., *forthcoming*-b.

WEISGERBER, Gerd - "…und Kupfer in Oman" Das Oman-Projekt des Deutschen Bergbau-Museums. **Der Anschnitt**. ISSN 0003-5238. Vol. 32, 2/3 (1980), p. 62-110.

WEISGERBER, Gerd - Mehr als Kupfer in Oman-Ergebnisse der Expedition 1981. **Der Anschnitt.** ISSN 0003-5238. Vol. 33 (1981), p.174-263.

WEISGERBER, Gerd - Copper production during the third millennium BC in Oman and the question of Makan. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 6 (1983), p. 269-276.

WEISGERBER, Gerd - Archaeological evidence of copper exploitation at 'Arja. **Journal of Oman Studies**. ISSN 0378-8180. Vol. 9 (1987), p. 145-172.

WEISGERBER, Gerd - Oman: a bronze-producing centre during the 1st Half of the 1st millennium BC. In CURTIS, J., Ed. - ***Bronzeworking Centres of Western Asia c. 1000-539 B.C.*** London: Keegan Paul International, 1988. p. 285-295. ISBN 978-0710302748.

WEISGERBER, Gerd; YULE, Paul - Preliminary report of the 1996 season of excavation in the Sultanate of Oman. In YULE, Paul, ed. - **Studies in the Archaeology of the Sultanate of Oman**. Rahden: Verlag Marie Leidorf, 1999. p. 97-118.

WEISGERBER, Gerd; YULE, Paul - Al-Aqir near Bahla' – an Early Bronze Age dam site with planoconvex 'copper' ingots. **Arabian Archaeology and Epigraphy.** ISSN 1600-0471. Vol. 14 (2003), p. 24-53. doi: 10.1034/j.1600-0471.2003.00003.x.

WHITE, J.; PIGOTT, V. - From community craft to regional specialization: intensification of copper production in pre-state Thailand. In WAILES, B., ed. - **Craft Specialization and Social Evolution: In Memory of V. Gordon Childe**. Philadelphia: University of Pennsylvania, 1996. p. 151-1 76. ISBN 9780924171437.

YULE, Paul. The 1995 German archaeological mission to the Sultanate of Oman. **Proceedings of the Seminar for Arabian Studies.** [Online] ISSN 0308-8421. Vol. 26 (1996), p. 175-176. [Consulted 27 Jan. 2022]. Available in https://www.jstor.org/stable/41223581.

YULE, Paul – Defence during the Samad Period – A First Attempt at an Archaeology of Conflict in South-eastern Arabia**. Journal of Oman Studies**. ISSN 0378-8180. Vol. 20 (2019), p. 143–176.

YULE, Paul; GERNEZ, Guillaume - **Early Iron Age Metal-Working Workshop in the Empty Quarter, al-Zahirah Province, Sultanate of Oman.** Bonn, Habelt: Universitätsforschungen zur Prähistorischen Archäologie, 2018. ISBN 9783774941120.

YULE, Paul; WEISGERBER, Gerd – **Samad ash-Shan. Excavation of the Pre-Islamic Cemeteries. Preliminary Report 1988**. Bochum: Selbstverlag des Deutschen Bergbau-Museums, 1988.