ARCHAEOMETALLURGY: THE STUDY OF ANCIENT METALLURGICAL PROCESSES

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ABSTRACT

The development of metallurgy is a significant achievement in the human career. Archaeometallurgy, the study of ancient metal production, gives a rare and enlightening glimpse into the lifestyle, culture, beliefs, science, and environment of the peoples involved. There exists copious evidence and remnants of such activity in the Chalcolithic age, an epoch from c. 4500-3500 BC. Crucibles, furnaces, ores, and slags, derived from the Abu Matar archaeological site in Israel, will be analyzed and evaluated through the use of illustrations and advanced microscopic representations of the artifacts in order to reconstruct the art of prehistoric smelting. In addition, the team will attempt to evaluate the artifacts within the context of the site as well as the broader cultural framework in order to understand the scientific and social aspects of ancient metallurgy.

INTRODUCTION

The field of anthropology can be defined as the study of the human experience. Within this vast discipline, the denomination of archaeology seeks to study and understand ancient societies and cultures. Archaeology is defined as the systematic study of past human life and culture by the recovery and examination of remaining material evidence, such as graves, buildings, tools, and pottery. Ancient cultures are best understood through experimental analysis, the study of similar cultures, and through ecological investigations regarding the materials and conditions in which the ancient people lived and worked.

In this project, the team of students sought to investigate the metallurgical processes prominent during the Chalcolithic Era which existed from roughly 4500 BCE to 3500 BCE. The Chalcolithic Era, which marked the commencement of the Copper Stone Age in Middle Eastern Asia, was an epoch of dynamic change, reform, and creation. Human societies increasingly grew more complex, leading to intricate relationships between man, environment, and technology. Such a promising milieu fostered demographic changes (population increases), economic ascension, and scientific advancement. During this time period, ancient populations first learned how to isolate precious metals from porous ores and stones through the process of smelting.

The ancient city of Abu Matar, which lies 1.5 km west of the ancient city of Beersheba and just north of the Beersheba valley, is one of the largest settlements of the

Ghassulian culture in the Northern Negev and the location of advanced metallurgical processes during the Chalcolithic Era. Abu Matar, which thrived in the fourth millennium BCE, spread over a gently rolling landscape surrounded by fields of grain, barley, and lentils. While the village maintained a small number of stone huts, rectangular mud-brick houses with stone foundations, and silos and hearths upon the surface, the vast majority of the village was comprised of subterranean bell-shaped pits linked by intricately connected galleries. These underground dwellings provided comfort and respite from the harsh climactic conditions which lent themselves to sweltering days, freezing nights, and torrential rains. The site, first discovered in 1952 and excavated in subsequent years by Jean Perrot, initially provided evidence of a single-step smelting process for Ghassulian copper. However, upon ensuing research in 1990/1991, findings revealed that the inhabitants of the ancient village had in fact engaged in multiple forms of metallurgy.

TEAM PROJECT GOALS

Within the Abu Matar site, many archaeological remains of the metalworking process were recovered, including: ore samples, furnace and crucible fragments, and slag. Utilizing these artifacts, the team aimed to determine the metallurgical objectives of the city's ancient inhabitants as well as more fully understand the physical and mechanical processes used during this era. In accomplishing these goals, the team sought :(i) to interpret all of the recovered artifacts in relation to the characteristic metallurgical process utilized during the Chalcolithic Era; (ii) to reconstruct the smelting process as existed during this ancient era based upon qualitative and quantitative analysis of the materials and their distribution at the site; and (iii) to understand the artifacts within the context of this Chalcolithic society. Phase I of the investigation entailed a basic understanding of the true nature of archaeology and the accompanying methodology. Phase II involved an expedition to an archaeological dig in progress to become familiar with the collection process of archaeology. Phase III demanded an in depth qualitative and quantitative chemical analysis of the artifacts from Abu Matar using the optical polarizing light and scanning electron microscopes. Phase IV required the documentation of the artifacts and conclusions in the form of illustrations, digital imaging, charts, and graphs.

METHODOLOGY

The analysis of the artifacts from Abu Matar required the use of various sophisticated equipment. These include the polarizing light microscope, digital camera imaging, and the scanning electron microscope. These instruments, combined with the traditional methods of hand-drawn illustrations of the specimens, allowed us to adeptly identify and analyze ores, crucibles, furnaces, and slag, so as to formulate a probable image of the life and metallurgical methods of the time period.

Artifact Assemblage

The artifacts examined in this project were from the German Institute of Archaeo-Metallurgy Bergbau Museum. The relics were originally collected and documented by the famed French archaeologist Jean Perrot in 1952 and subsequent years. During the analysis of the artifacts, special care was taken to avoid damage and contamination, the two largest problems when dealing with the handling of archaeological materials [8].

Digital Imaging of Artifacts

To digitally photograph the artifacts, a digital camera and a specially constructed staging area was used. The artifact was placed on a Picker International light box, surrounded with four light bulbs. A Kodak Digital Science Mega Pixel DC 120 Zoom was used to actually take the picture of the artifact. Most of the time, a Royal Red Stiffened Easy Felt was used as a backdrop to accentuate the object. When photographing the artifact, it was imperative to place a ruler or comparison of length by the object in order to preserve a sense of scale and size. A specific filing nomenclature was used to easily identify and categorize the pictures saved onto the computer to facilitate access in the future.

Optical Light Polarizing Microscope

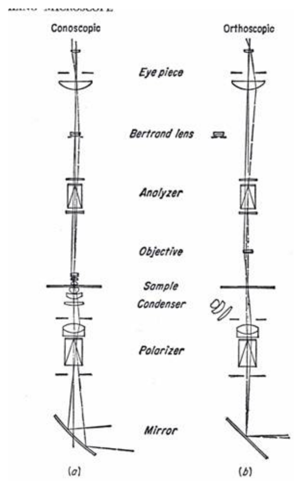
The specific polarizing microscope used for this project was a Leitz Wetzlar Microscope. It was hooked up to an Ernst Leitz G.m.b.H. Wetzlar Regel-Tranformator, capable of over 110 volts set between 50-60 Hz. To project the images from the microscope to the computer, an MDS system was used.

In order to use the light microscope, specimens must first be specially prepared. One way is to grind a mineral chip with a smooth flat surface which is broken or sawed off. The optimal size of the specimen is one inch square, 1/8 inch thick. The slide is polished on one side with 100, FFF, 600 carborundum, 302.5 American Optical Company emery. The unpolished surface is cleaved, dried, and mounted on a slide using Canada Basalm, Lakeside 70, or epoxy resin to secure. Another way to prepare slides is to cut to produce thin sections. The desired thickness of the slices is .03 mm. Precision-mounted diamond saws or diamond powder is used to produce these slices.

In addition to the polarizing microscope, other light microscopes include phase, reflecting, and binocular microscopes, all of which are used for specific and unique means. The polarizing microscope specializes in helping to view mineral fragments, grains, small crystals, and crystalline aggregates. It can be used to interpret textures, structures, and growth patterns of various minerals, ores, and other artifacts. In operation and function, it is very similar to the compound light microscope. However, it possesses several items which the former does not. It contains extra polarizing and analyzing devices, a more sophisticated rotating stage, and special Amici-Bertrand lenses. There are normally two polarizing devices, which combine to produce sharp, black distinction and well developed interference patterns in the specimen. The microscope usually yields a conoscopic observation. However, without the Amici-Bertrand lens, it yields the orthoscopic view of the specimen.

As its name suggests, the polarizing microscope polarizes the light into 2 beams with vibrations at right angles to each other. This strong polarization creates darkness and lightness in appropriate minerals, helping to identify the specimen. For instance, a more isotropic mineral like calcite would change from very bright to complete darkness as it is rotated on the stage, one of its distinguishing characteristics.

Figure 1: Diagram of inner column of the light polarizing microscope.



Scanning Electron Microscope (SEM)

The SEM is favored over the polarizing microscope because the shorter wavelength allows for less distortion and thus greater and clearer magnification. The essential principal to the SEM is to bounce electromagnetic radiation off the specimen and use lenses to focus that radiation. The microscope utilizes a voltage difference, normally set at 15 kilovolts, to shoot electrons down the “gun” at the specimen. The specimen is actually placed inside the “column” of the microscope, which contains, from top to bottom, the electron gun, magnets, lenses, condensers, astigmatism foil, and the stage itself which can be rotated on three axes. The bulk of the electron beam that gets shot into the microscope is actually grounded back into the microscope itself. This requires that the specimen be an electrical conductor, which can be made possible for nonconducting specimens by coating them with a metal such as iodine. A small portion of the electron beam is actually totally repelled in collisions with the nuclei of the sample and are bounced right back.

However, another smaller portion of electrons are deflected off the sample with lower energy, called secondary electrons, and these are what the microscope captures with magnets and focuses with lenses to produce an image for the observer.

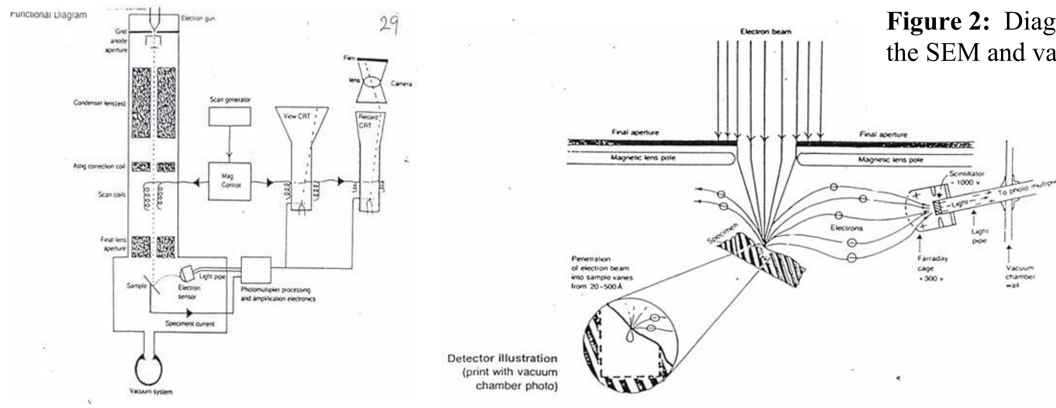


Figure 2: Diagram of the column of the SEM and various parts associated.

The deflected electrons float in the chamber of the column, and positively charged magnets pull them towards a sensor, then a screen where they will emit a light flash, then they proceed down a light tube, down a modifier tube, and finally the sensor at the end counts the flashes and creates a cohesive image. More electrons make brighter areas, and less electrons make darker areas. The resolution of the image can be adjusted by the diameter of the electron beam. A thicker beam will create a less-resolved image, while a thinner beam will result in a well-resolved image.

There is another convention in SEM technology where special sensors will detect the x-rays generated by electrons hitting nuclei. This is advantageous because each element and mineral has a unique x-ray emission and can be thus identified with this method. However, this technique was not utilized in this particular project.

Mineral Identification and Analysis

Two main characteristics of minerals are used when trying to identify them- form and aggregation. The tendency of a mineral to form or aggregate in a specific way is called the mineral's habit. A mineral may also be identified using incipient crystallization, which is the sudden arrest of crystallization. These produce various identifiable structures such as trichites, which are curved streaks in glass. Margarites are long streaks of globular form. Longulites are small and rod-like. Crystallites are minute nuclei of crystals, and microlites are needle-like in form.

Minerals can also be identified using fine aggregates, which are emphasized by the polarizing microscope. They are recognized by their radial and mosaic-like structures. Inclusions are when foreign objects are trapped during the crystallization, such as leucite often is, and can identify from whence the mineral came. Needle-like crystals may occur in other crystals, as well as other distinguishable crystals such as bladed crystals, twin crystals, isometric, hexagonal, orthorhombic, monoclinic, and triclinic crystals. The cleavage, parting, or fractures can also identify minerals. Finally, the orientation, which is the correlation between optical directions and crystallographic axes, and the index of refraction can determine the identity of a mineral [6].

METALLURGY

Generally, metallurgy is the process of extracting metals from their ores. Metal in its natural state is often found trapped within various ores or "host rocks." During the Chalcolithic Era, the method of extracting metal from the ores through the process of smelting was first derived. Smelting is the process by which a certain mineral is won from an impure ore. To accomplish this extraction, the impure ore must be first crushed up to increase surface area and thus the efficiency of the smelting process. The ore fragments are next placed in a crucible, along with fuel, which is then heated in a ceramic furnace within the ground. The furnace must be heated to very extreme temperatures, in the range of 1000-1200 degrees Celsius to successfully complete the separation. This temperature was reached by blowing continuous air onto the flame to create a more intense burn. With sufficient temperatures and proper atmosphere, the ore will melt and the mineral compounds will be reduced. Ideally, metal precipitates form an ingot, and liquid slag, a byproduct, composed of non-metallic materials, can be tapped. Evidence of slag is frequently found on samples of furnaces and crucibles excavated from digs. The main problem, however, facing the earliest smelters, whom are assumed to have inhabited Abu Matar at this time, is that the high intense heat was often not quite reached. Thus, the ores and metal could not completely separate resulting in metal with a high degree of impurities and slag fragments containing large amounts of the desired ore, namely copper in this case.

Archaeometallurgy is defined as the scientific investigation of archaeological metalwork, metal production, and manufacturing debris [2]. This process involves first the identification of the evidence of metalworking (i.e. crucibles, furnaces, ores, and slags) and secondly the structural and compositional analysis of these artifacts [1]. The results of this procedure are then used to explore the importance of metals in ancient societies, economies, and cultures, and to understand the process by which they were made, utilized, traded, and reused. These findings are also crucial in archaeologists' attempts to discover if and how these metals' properties were understood, and to find what processes were involved with their placement and survival in the archaeological record.

ORES

Ores are minerals that contain a valuable component, such as metal [7]. The copper ores we studied came from sedimentary ore deposits located at the mining sites of Faynan positioned in southern Jordan and Timna which is near the Gulf of Aqaba in Israel.

In terms of chemical composition, the ores found in Faynan and Timna are undistinguishable. However, ores can be differentiated from the site of origin by the texture. Ores typical of Faynan are tile and brecciated ores. Ores composed of malachite and copper sulfides also are distinct characteristics of the Massive Brown Sandstone mineralization found at Faynan. Other minerals found in Faynan are dolomite, limestone, and shale. Ores specific to Timna are cuprified plant relics that are easy to differentiate from Faynan ore due to their texture. It is believed that most of the ores that we studied came from Faynan because of their surface and specificity of certain mineral contained within the ore.

There are two main types of ores found within our archaeology sites, tile and brecciated ores. Tile ores are the most common ores located at both Faynan and Timna. Tile ores are composed of cuprite (Cu_2O) intergrown with iron-hydroxides, quartz, and pure copper sulfides. The most unique characteristic of tile ores is that they are self-fluxing, meaning that they melt easily in high temperatures. Since tile ore is self-fluxing, they may be smelted without adding any fluxing materials, therefore making smelting easier. Brecciated ores, while common in Faynan are less frequent in Timna. Brecciated ores are composed of cuprite and malachite, which have intergrown with each other. Like tile ores, brecciated ores contain quartz grains. However, unlike tile ores, brecciated ores contain calcite which results in a marble-like texture [5].

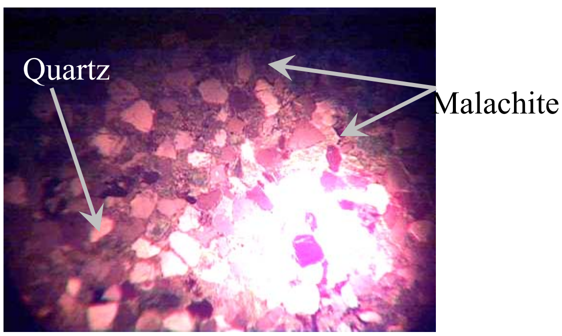


Figure 3 A sample of brecciated ore which is alleged to come from Faynan. The dark green is malachite and the red geometric shapes are quartz (both

Figure 4 An example of copper-rich malachite ore; it possibly came from Faynan.

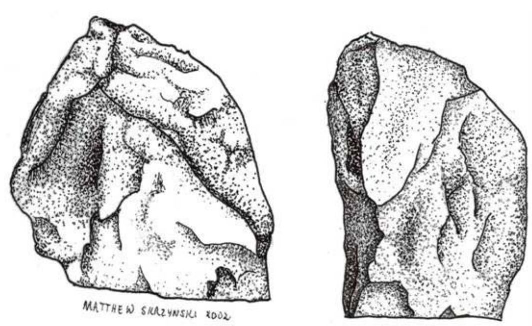


Figure 5 A drawing of the malachite ore above.

The ores found in both Faynan and Timna, while having different physical properties do have the same chemical composition. Cuprite, is a red cuprous oxide ore. Cuprite's chemical composition is Cu_2O, with 88.82% of the ore being copper, and 11.18% being oxygen. Cuprite, which is the most abundant source of copper is very rich in copper oxide resulting in its red color. Malachite, the ore that we studied primarily, is a bright green copper carbonate ore. Malachite is composed of $Cu_2(OH)_2CO_3$, with

71.95% CUO, 19.90% CO_2, and 8.15% H_2O. Azurite, is a blue crystalline carbonate of copper and is usually found with other copper ores. Azurite is composed of $Cu_3(OH)_2(CO_3)_2$, with a 69.24% composition of CuO, 25.63% of CO_2, and a 5.23% of H_2. Bornite is a reddish brown sulfide of copper and iron and its molecular formula is Cu_3FeS_4. Bornite is composed of 63.33% copper, 11.12% iron, and 25.55% sulfur. Chalcocite, Cu_2S is a sulfide of copper is a shiny lead gray color. Chalcocite is a principle ore of copper and is comprised of 79.86% copper and 20.14% sulfur. Chalcopyrite, which is also known as Copper Pyrite, is another sulfide of iron. The molecular formula is $CuFeS_2$, with 34.64% being copper, 30.42% iron, and 34.94% of sulfur. Chrysocolla is described as being a silver green copper silicon ore whose molecular formula is $CuSIO_3 \cdot 2H_2O$. Chrysocolla is 45.3% CuO, 34.3% SiO_2, and 20.5% H_2O. The host rocks are usually composed of quartz grains [3].

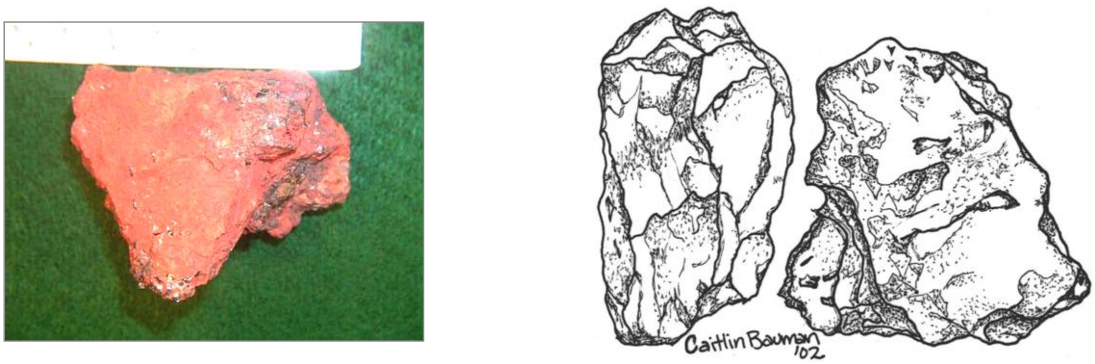


Figure 6 (left) A photograph of iron rich limonite/hematite. (Right) A pen drawing of the same ore.

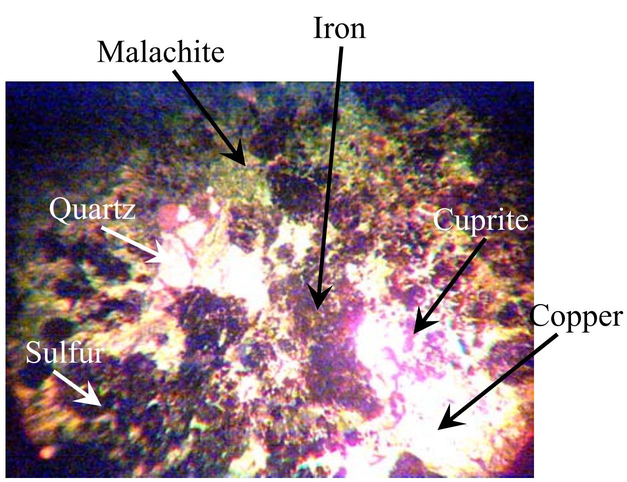


Figure 7 This sample ore is composed of quartz, which is distinguished by the red geometric minerals. The green is malachite and the light ret area is cuprite. The shiny gold color is noted as copper and the dark crimson region is iron. The black spots are sulfur.

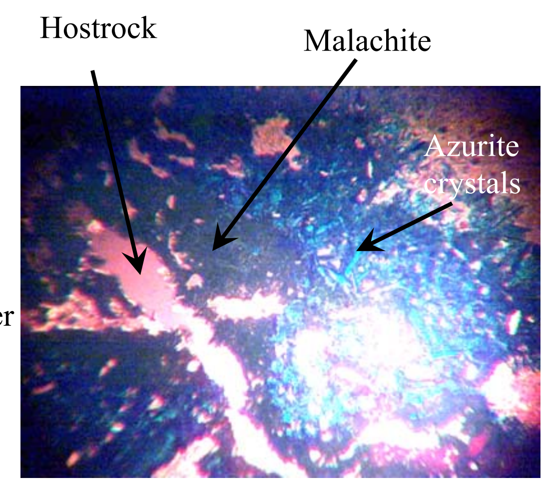


Figure 8 The bright blue sections are azurite crystals and the green part is malachite. The brown areas are rock sediments.

SLAG: WASTE THAT HAS MUCH TO SAY

Slag is a byproduct of several industrial processes in which high temperatures are obtained [9]. Specifically in this project we studied slag after the smelting process. When an ore, copper for instance, is smelted, the copper is extracted from the ore. What is left is the waste, the slag. We discovered that there are three different types of slag. One type is found on the walls of crucibles. Another can be deposited on the insides of furnaces. While these two types bind to walls of the apparatus, the third is a free fragment. The first two types demonstrate a more efficient smelting process because the slag had to be heated to a liquid state to facilitate separation of metals and waste [5]. Slag is a porous material, resulting in a relatively lighter weight compared to the ore from which it originated.

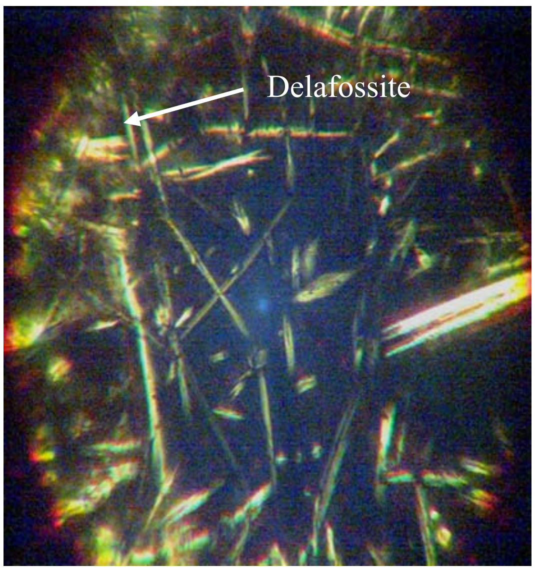


Figure 9 Delafossite needles on slag from furnace.

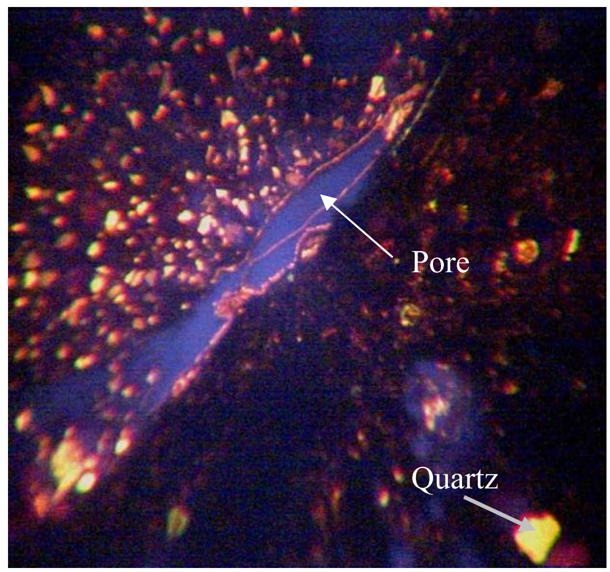


Figure 10 Quartz on slag from furnace.

We observed slag under the light microscope and the Scanning Electron Microscope. Figure **9** was a taken with a light microscope; it depicts structures called delafossite. Delafossite is a type of mineral composed of long needle-shaped crystals; they are evidence of the smelting process. In Figure **10**, quartz crystals are shown near a pore area. We can tell that these are quartz because when the slide is rotated, light causes it to change colors. If the quartz is very shiny and sharp edged, then you know that the ore was not heated to high enough temperatures. If the quartz is molten on the edges, it still probably was not heated high enough for it to melt all the way.

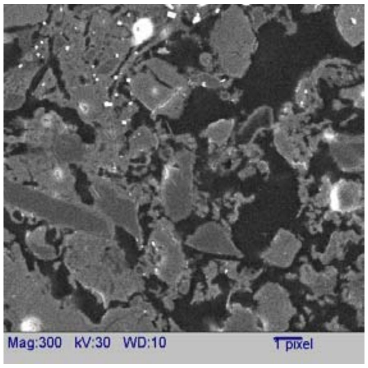


Figure 11 Porous slag with copper

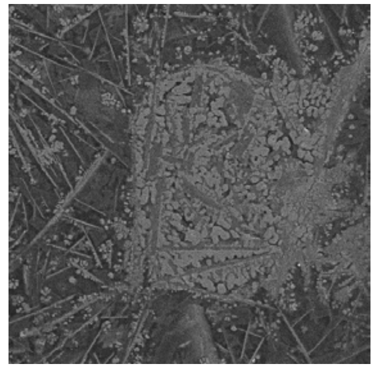


Figure 12 Transitional slag.

The two figures above were taken with the Scanning Electron Microscope. Figure **11** illustrates the porous nature of slag. The bright spots, copper, are evidence that smelting process was not complete. This might have been because the technology of the Chalcolithic people in Abu Matar was still in its primitive forms. In Figure **12**, the slag showed to be in a transitional stage. The delafossite surrounds a denser area, which may be slag that had melted and coagulated.

Table 1: Composition of Slag		
Name	**Chemical Formula**	**Abbreviation**
Metallic Copper	Cu	CU
Cuprite	Cu_2O	CUP
Delafossite	$CuFeO_2$	DEL
Hematite	-Fe_2O_3	HEM
Magnetite	Fe_3O_4	MAG
Quartz	-SiO_2	Q

CRUCIBLES

Crucibles are vessels that were and are used to heat substances at very high temperatures. Crucibles were used by the people of the Chalcolithic Period as containers in which the ores and/or the already extracted metal were melted in. The crucibles were mostly made out of clay and, depending on their uses, were usually undecorated. While crucibles were mostly composed of clay, they were sometimes mixed with quartz to make the crucible stronger. The sizes of the crucibles also varied. Depending on who was making and using the crucibles affected their size. If individual families were using the crucibles, the crucibles' sizes would reflect the family's needs, thereby being small. However, if the crucibles were being used by the "village smelter" the crucibles' sizes would be larger, reflecting the demand for his craft [4].

The artifacts that we analyzed from Abu Matar included crucibles used from both the smelting and melting processes. Crucibles that we studied that were covered in slag-like material were the crucibles that were used for the smelting process. The crucibles that we studied that were not covered by slag were the ones that were used solely for the melting process, or were perhaps not used at all.

MELTING CRUCIBLES

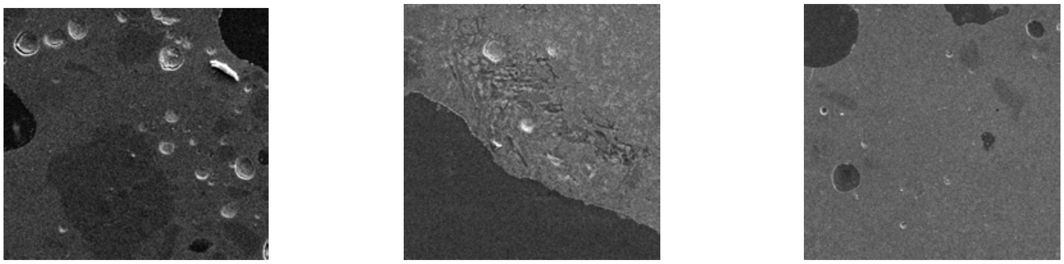


Figure 13 BAM 943.43. These photographs, taken with the SEM, display a crucible that was used only for melting. This can be deduced from the lack of slag on its surface.

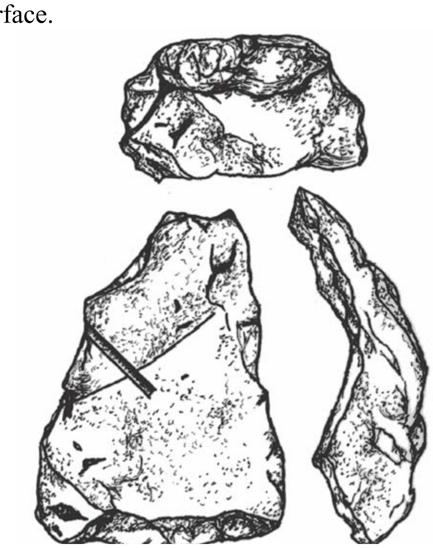


Figure 15 TAM 853.19. This is an illustration of the same crucible.

SMELTING CRUCIBLES

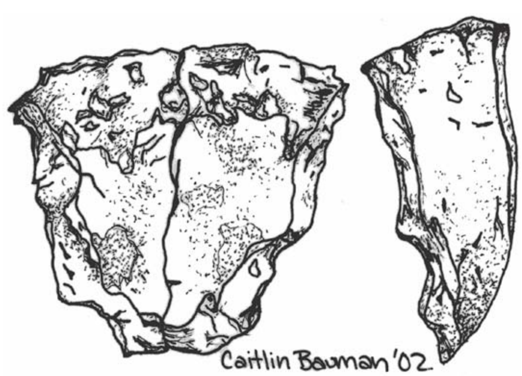


Figure 16 TAM 940.3 (Above) An illustration of the ventral and side views of the crucible.

Figure 17 TAM 940.3 This crucible was used for smelting. We can make this assumption because of the slag deposits found on the interior and exterior surfaces of the artifact.

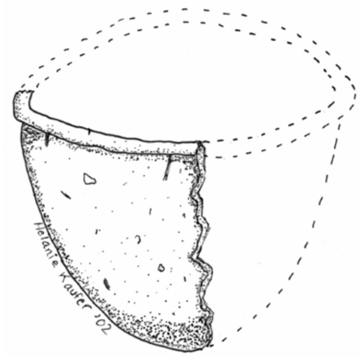
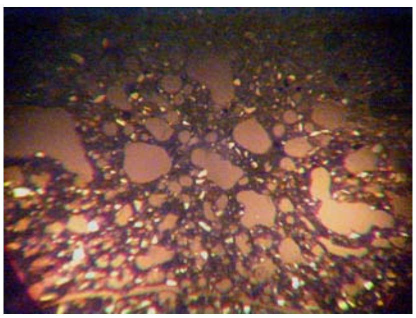


Figure 18 TAM 940.3 This picture is a model of what this crucible fragment would have looked like in its complete form. The artifact found at the archaeological site was only approximately 30% of the entire crucible. A reconstruction using this piece would result in a crucible about 10-11 cm. in diameter.

(Below) These photographs, taken through the use of the light microscope, illustrate crucibles that were used for smelting.



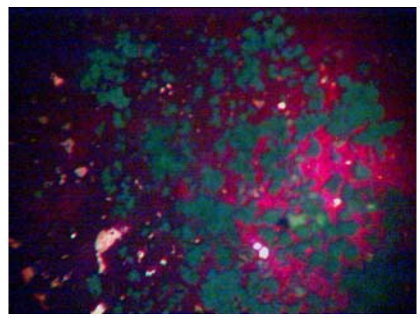


Figure 20 BAM L-244. This crucible contains quartz, malachite, and iron oxide, proving that it was used in the smelting process.

FURNACES

A furnace is an enclosure in which energy in a similar nonthermal form is converted to heat generated by the combustion of a suitable fuel. Chalcolithic furnaces were made of clay strengthened with quartz. Furnaces are an installation combining a "collar", "cylinder", and a pit. The furnace was used to reach the high temperatures required for smelting. The heat melted ores until it turned into two parts, metal and slag. It is believed that furnaces were installed in the ground for extra insulation. It is also thought that a crude lid was placed on top to hold the heat in. To raise the intensity of the fire, the people of the Chalcolithic era are thought to have used reeds encased in clay to blow air into the fire from the underside.

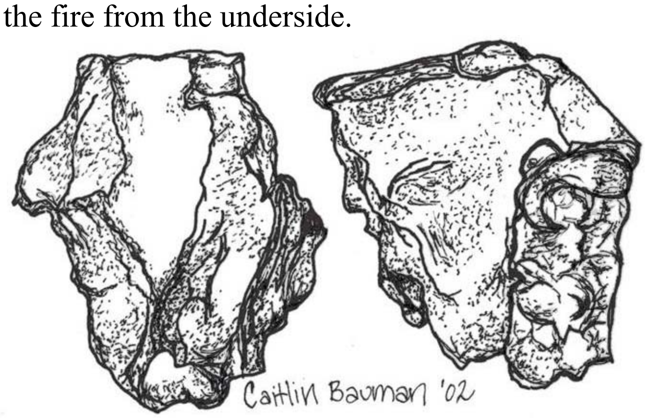


Figure 21

Observation of the various samples from Abu Matar was accomplished using the light polarizing microscope, scanning electron microscope, and various digital images. The digital imaging clearly showed a furnace and slag interface, the latter region being much darker than the former (figure **22**). Under the light microscope, we could distinguish several delafossite structures. Delafossite, CuAlO2, are identifiable by their unique needlelike, irregularly spaced, straight shapes (figure **23**). Delafossite suggests that some of the material, though not all, did reach the liquid state.

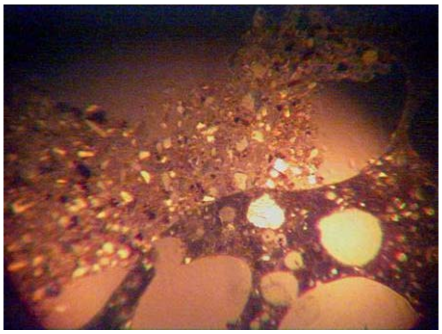


Figure 22 Light microscope slide of two defined portions – lighter portion is furnace, darker portion is slag.

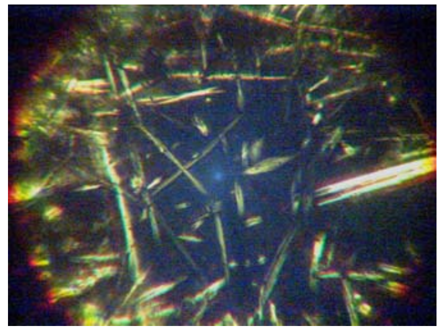


Figure 23 Light polarizing microscope slide of delafossite.

Based on these observations, various inferences can be made. Approximating the rest of the furnace structure by projecting from the fragment, it is believed that the furnaces were composed of a ceramic rim or "collar" about 30-40 cm. in diameter and 10 cm. in height. We can tell the structures were used for smelting because of the slag deposits that were found on the fragments, which are clearly delineated in the polarizing light microscope and SEM slides. Also, based upon their shape and configuration, the conclusion can be drawn that the furnaces had at least some parts installed in the ground, presumably for insulation purposes. Also, other artifacts were discovered that resembled the shape of a lid or cover for the furnace, which further suggests the smelting techniques the peoples of Abu Matar used [5]. However, these ideas are merely conjectures, and archaeologists can only hope to make as informed of a judgement as they are capable of. For instance, it is thought that the Chalcolithic peoples used long reeds encased in ceramic to blow oxygen into the furnace from below the actual structure in order to intensify the fire enough to reach the great temperatures needed to smelt ores.

Furthermore, observations made from the artifacts can be used to make general evaluations about the efficiency of the smelting process of the Chalcolithic era. Upon analysis of the slag composition, it was discovered to contain very high quartz content and even copper content (figure **24**). This implies that the methods that the inhabitants of Abu Matar applied were very inefficient, because a large percentage of the desired metal, copper, was still found in the excess slag. Aside from that, it can also be inferred that as time went on, they learned from their previous endeavors and would eventually be able to increase the purification efficacy. However, at the time of the discovery of the artifacts, the best prediction is that they were only experimental endeavors, but eventually became localized, specialized operations, even hinting at the possibility of specialization of labor at this early stage of human civilization.

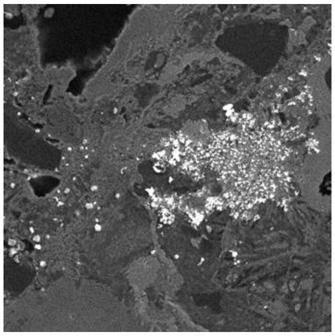


Figure 24 This slag contains copper showing the incomplete smelting process.

DISTRIBUTION OF ARTIFACTS

Figure 25

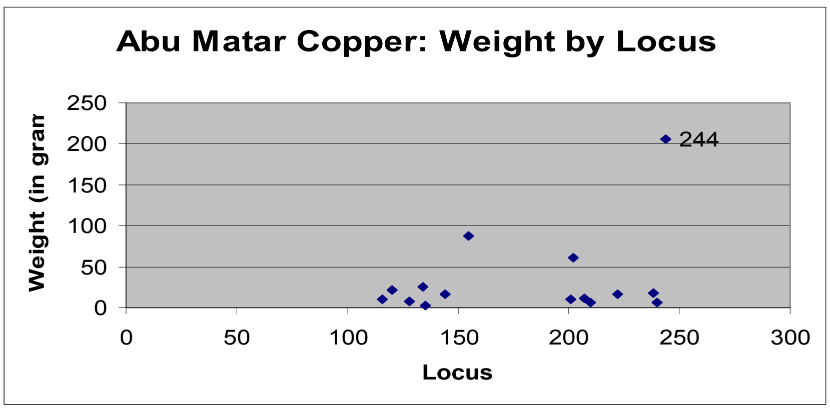


Figure 26

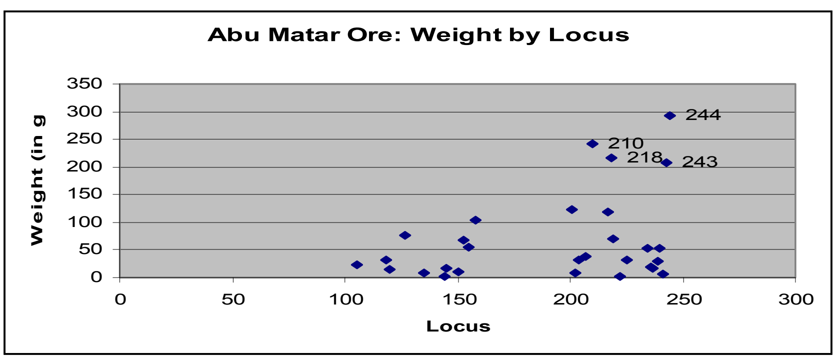


Figure 27

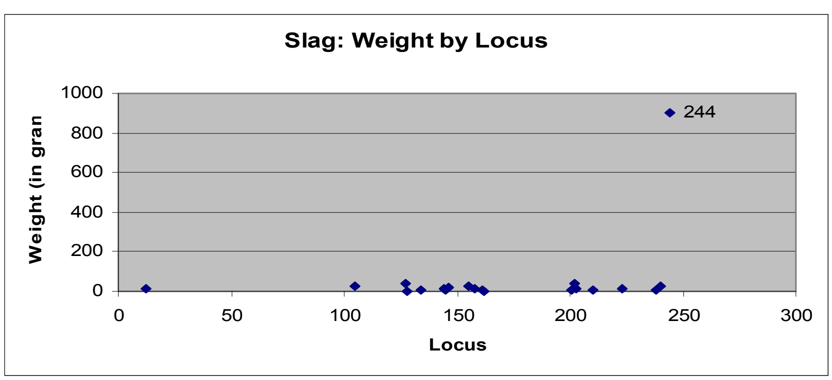


Figure 28

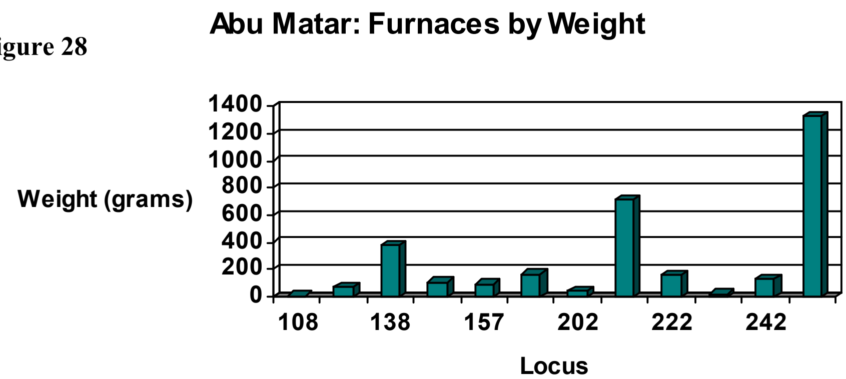


Figure 29

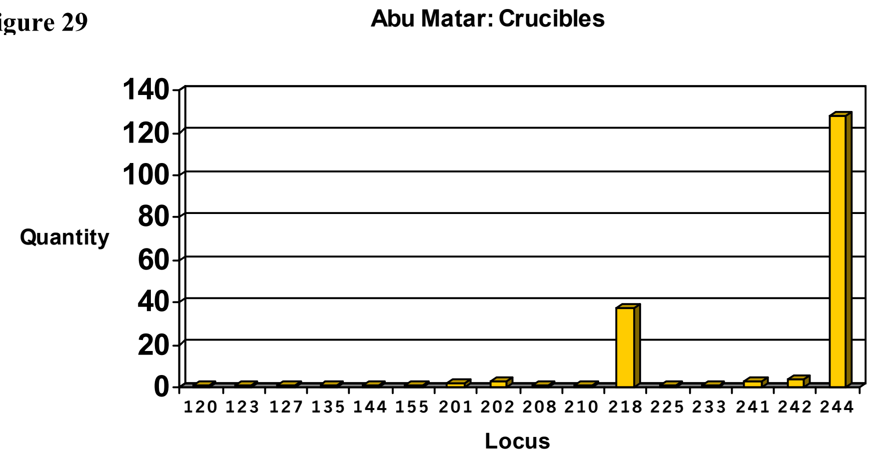


Figure 30

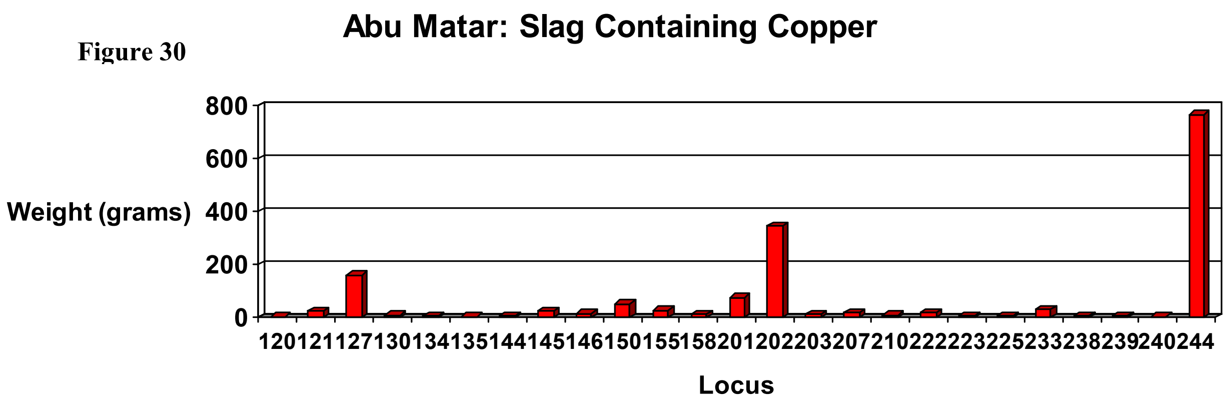
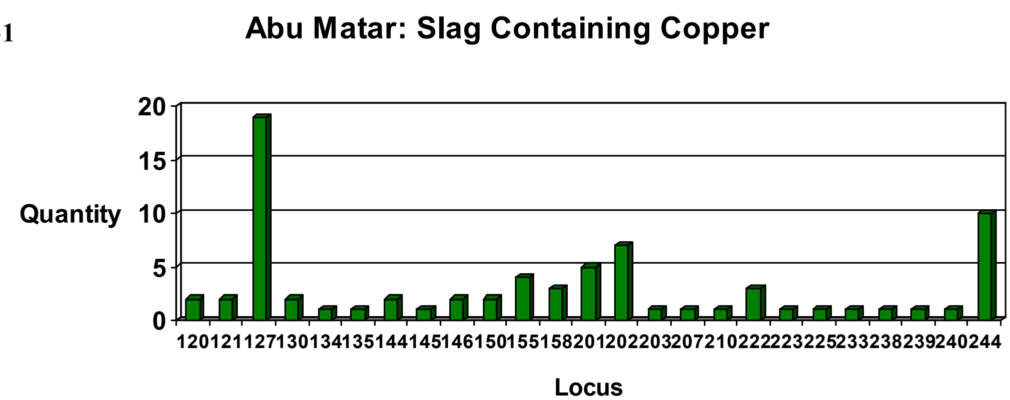


Figure 31



After examining the loci of the slag, copper, furnace, crucible, and ore artifacts through graphical analysis, we can attempt to gain insight into the lives of the Chalcolithic people. Figure 25 focuses on the copper. It represents the amount of weight of copper found on each locus. Clearly locus 244 is the site that contains the heaviest deposit of copper. We cannot, however, ignore that a relatively there are many different locations where a significant weight of copper was found.

Figure 26 represents the amount of weight of ores found at each specific locus. As shown on the chart, there is a good distribution of ores throughout the area. Loci 210, 218, 243, and 243 are the prominent loci for the weight of ore. This could mean that ores were gathered from these locations. The largest weight is still at locus 244, where the largest amount of copper was found.

Figure 27 conveys the slag distribution throughout the area. The largest weight of slag by far is at locus 244. There are small deposits at other loci, but none compare to the amount at locus 244. This could definitely be evidence that there was an organized system of smelting at this location. The other finds could just mean that people at this time were independently smelting copper, but at locus 244 it could have been more of a network and an industry. Also, the findings could be chronologically interpreted. They could show that at first there was just the self-sufficient practice and it later developed into more a division of labor at locus 244. Perhaps the industry was evolving into a full-fledged workshop.

Figure 28 represents the distribution of furnaces among the loci based on the total weight of the artifacts. The three loci with the greatest weight were 138, 206, and 244. As we have learned are situated in the ground and are generally larger than crucibles. From these facts we can infer that these loci were central locations for smelting during the Chalcolithic era. Although the furnaces are found at many loci, three locations show a much greater array in terms of weight.

Figure 29 depicts the distribution of crucibles by both weight and quantity. By comparing these charts we further our beliefs that locus 244 was a focal point in Abu Matar's societal life. Additionally, locus 218 appears to have held an important role in the development of technology. It is possible that locus 244 functioned as the main production site for copper whereas locus 218 might have been a satellite installation. Due to the lack of copper or slag found at locus 218 we can also conclude that this location was used for melting copper ingots, not smelting.

Figures 30 and 31 present an interesting view of the efficiency of the smelting process in Abu Matar at this time. The amount of copper found in slags is directly proportional to the rate of efficiency. As we have discovered earlier, more primitive forms of smelting left large quantities of copper in the slag. As the technology improved the smelters retrieved an increasing amount of copper from the ores. Figures 7 and 8 demonstrate that locus 127 and 202 were possibly more primitive sites due to the large amounts of slag containing copper.

Once again in terms of weight and quantity, locus 244 features a large amount of slag containing copper. This might be a result of massive operations occurring at that site: the more total slag produced the greater the amount of residual copper left in it.

DISCUSSION

Archaeometallurgy of the Chalcolithic Era, however, paints an important and unique picture of the lifestyle and culture of societies in the region. Copper was used not only for tools, but also for decorations, gifts, and tribute. Specifically, one of the economic implications of these new “compartmentalized” copper practices was the introduction of craft specialization and thus, trade. In fact, it is probable that the huge trade routes of Phoenicia and Egypt can trace their inceptions to these early Chalcolithic ventures. There seems to be direct evidence of trade between the Levant and Egypt. For example, gold rings were found in Palestine, yet the only supply of such raw material could have been obtained from Egypt. Trade fosters cultural interaction, wealth, and conquest.

Another important concept that arose from this metallurgical era was that of social class. By carefully assessing the quality of the artifacts, one can determine the social class of the owner. The pieces made from purer copper (retained in better condition) may have been owned by a chief or a Chalcolithic “entrepreneur” with a monopoly of the copper trade.

This principle of the “rich and powerful controlling the better metals” ultimately played a dominant role in the Bronze Age. In essence, the hierarchy of the Chalcolithic laid the groundwork for the rigid military aristocracy of the future ages. For example, only the richest Egyptians were able to afford and fight in the now famous bronze chariots that are usually depicted as copious in the media. The elitist military aristocracy then led to the concept of state-level governments, rulers, and of course the modern empire.

Perhaps the most striking evidence delineating the social classes are the copper artifacts found in elaborate, underground tombs.

Figure 32 Burial complex (note the complicated maze) at Nahal Qanah. Note the copper artifacts. Most likely, offerings were thrown in prior to the human burials.

Usually, citizens were buried under their homes, in the surrounding vicinity, cremated and placed into urns, or placed in public cemeteries. However, the presence of specialized "tombs" (or formal cemeteries) suggests that important members of the society were treated with more respect after death. These "tombs" were protected in huge, complex cave mazes. Copper gifts, artifacts (most likely thrown in before the actual human burial), and figurines were placed for additional protection.

Copper also shows evidence for power relations, especially labor relations. Copper production at Abu Matar was quite extensive with a more centralized workshop, rather than haphazard production. Copper was probably produced to be used immediately, with little competition between the producers. This evidence would probably support the idea that there was an elite-controlled industry smelting out the purest and most intense copper. The fact that simple copper tools or small goods were found in private courtyards also supports that hypothesis. Perhaps some individuals did not want to buy or associate with the capital copper industry. Also, some crucibles had much more slag on the sides than others. This could indicate that someone or some industry had perfected the smelting technique, as compared to a household venture. As chiefdoms began to form, the chiefs of villages probably imported copper from various places (using villagers to mine). However, the question of whether intense/large-scale production at Abu Matar was due to demand or an amalgam of regional activities cannot be answered definitively.

CONCLUSION

The different analyses of the samples of ores, slags, crucibles, and furnaces allow for certain conclusions to be drawn about Abu Matar and the people who lived there in the Chalcolithic period. The presence of the slag and metal traces on the surface of the furnace and crucible fragments definitely indicate that some form of metallurgical endeavors were undertaken at the site. Furthermore, the composition of the slag demonstrates the relative efficiency of the earliest smelting attempts by the people of Abu Matar. Slags were found to contain a high copper and delafossite content. The copper meant that the smelting endeavors succeeded in winning only a fraction of the desired copper metal from the original ore that was mined. The delafossite content suggests a reason for the relative failure to achieve maximum efficiency. Delafossites form when a sample is not fully converted to the liquefied state, and instead re-coagulates and thus forms needlelike, rigid, irregular crystals that were easily identified under the SEM and polarizing microscope. Furthermore, from knowledge of modern smelting methods, the slags found were not porous enough to be considered heated and purified to a sufficient degree. This further indicates that the earliest smelting attempts were grossly inefficient.

The crucible and furnace fragments found suggested that two separate operations were conducted at Abu Matar. Slags on crucibles containing a higher copper content indicate that smelting directly from ores was undertaken. However, the discovery of crucibles containing slag of much less copper content gives reason to believe that they were used instead for melting the more impure ingots taken from the initial smelting.

This could be an attempt to perhaps purify it even more or to produce various copper products.

The earliest attempts of smelting suggest that they were individually undertaken, instead of specializing and cooperating through a village-wide effort because the different crucible and furnace fragments were found to be relatively evenly distributed throughout the area. However, this could also mean that the village of Abu Matar was intentionally meant to be the metallurgical center of the area, because of the proximity of what is believed to be the major mining locations of Faynan and Timna.

The ores analyzed in this fashion were concluded to be primarily from the Faynan mining location. While the ores found in Abu Matar were similar in chemical composition to the ores of both Faynan and Timna, the physical and surface appearance of the ores of Abu Matar gives stronger evidence for Faynan as the origin of the ores. This lends further support to the theory that Abu Matar was a metallurgical stronghold of the region.

All the evidence and artifacts analyzed thus far allowed these conclusions to be drawn specifically about Abu Matar. However, in our own endeavors to recreate and understand the development of the people of this time, it is important to step back and analyze what Abu Matar meant to the rest of the Chalcolithic Age. The fact that Abu Matar was strictly used as a metallurgical center suggests that the people of this time had already established the practice of "specializations" where different people concentrate and specialize in only one area of production in a large-scale, coordinated effort. From an archaeological sense, it would be reasonable to assume that the people of Faynan and Timna were primarily engaged in mining the ores, then people managed to ship those ores from Faynan to Abu Matar where metal-smiths were waiting to receive their resources. These metal-smiths would then produce finished copper products. This specialization suggests that trade was occurring. This is important because it would then be the very origins and initial framework for the vast trading networks and routes throughout this region of Phoenicia and Egypt that would eventually come to form and become remembered for in ages to come.

This specialization also hints at the earliest development of social strata in society. The large effort put into the mining and winning of copper suggests that it was a prized mineral. Artifacts found at Abu Matar suggest that these finished copper products were actually meant as signs of status and wealth. The value of the copper could also mean that the copper was used in society to be bartered with and given as gifts or currency, in addition to its usage as tools or weapons. At this juncture, it must be pointed out that the softness of pure copper did not really lend itself to be used as tools or weapons, and instead it was used more in alloys such as tin or bronze which were much stronger and lighter. This suggests that copper products were used less by the average working man and more as symbols of wealth and stature.

Thus are the humble workings of Abu Matar, the Chalcolithic site that represented the earliest beginning and foundation of the Copper and Bronze ages. It evidenced the first attempts of men to mine and purify the metals that would eventually come to shape the infamously great empires and civilizations of history.

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