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# Nabatean Archaeometallurgy at Petra, Jordan

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## Abstract

Since the establishment of the Nabatean capital city ca. 300 B.C, stone craftsmen must have needed immense quantities of metal tools to carve the many and huge monuments of Petra. Though many researchers agreed that large metal consumption relates to the carving of the rock city, the enigma about the source of the metal and metal tools is still never fully understood. Surveys at the central area of the world cultural heritage site of Petra in Southern Jordan revealed evidence of what may be the first known metal smelting locality or workshop associated with the Nabatean occupation of Petra. In an area close to the famous Sextius Florentinus tomb, a thick layer on the surface testifying debris with ash, charcoal, slag, and junks of raw material related to smelting activities was found. Surface mapping and analyses of the exposed wall structures indicate a special construction in this area that is different from the regular habitation areas in the site. Samples from the site, potential raw material sources, and finished objects from excavations were analyzed using mainly Scanning Electron Microscopy (SEM) and Electron Beam Microanalysis Energy Dispersion (EDS) to produce valuable elements for samples comparison. Other methods like X-ray radiography, XRF, XRD analyses and general metallographic studies, were employed too. The mineralogical structure of the slag indicates medium to high furnace temperatures. Elements present in the analyzed samples indicate that the ore used was probably mined from the nearby hematite and manganese rich layers and veins of the local sandstone rocks at Wadi Al Mataha at the ancient city's fringes.



*Keywords:* Nabatean, archaeometallurgy, Petra, slag, EDS, XRF;

## 1. Introduction

Metalwork was well known by the inhabitants of southern Jordan since late prehistory as known through the analytical studies of metallurgical findings from broad archaeological exposures in Wadi Faynan [1,2]. Analytical studies of metal samples from two oases in Northwest Arabia, Qurayyah and Tayma concluded that arsenical copper mainly of tin bronze and leaded tin bronze was processed at both sites [3].

Researchers in the Nabatean history believed that since the early days of the city's establishment (ca. 5th century B.C), the Nabatean must have searched for hard metal to carve their enormous rock-cut architectural monuments on the sandstone rocks, especially, during the sudden expansion and urbanization of Petra city at the end of the 1st century B.C.

Even with these logical needs, the question about these needs has never been well answered in the Nabatean archaeological research. Local sources and manufacturing were not proposed.

Since 1999, a systematic survey was carried out by the Hashemite University at Petra and the adjacent Nabatean settlements which sought to document and clarify the archaeological and architectural monuments and their geoarchitectural characteristics. The survey attempts to produce a database about the archaeological monuments and their deterioration conditions for conservation [4]. During the undergoing survey Dr. Khrisat came across the unusual surface scatter of metal slag concentrations resting over dark grayish sediments in spatial association with a southwest facing masonry construction located northeast of the famous Sextius Florentinus tomb at Wadi Al Mataha area (also known as Tomb number 763 according to Brunnow and Domaszewski survey (Fig, 1)[5]. Several studies have used slags as a source of information on ancient metallurgical processes [6,7,8,9,10].

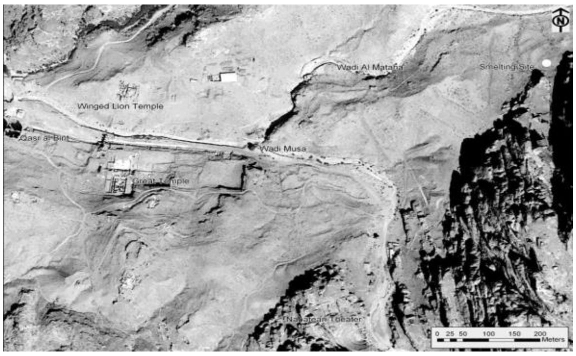


**Figure 1.** An aerial photo showing the major monuments in the central area and the smelting site

Our evidence is the first of its kind relating to metalworking in Petra. The term metalworking however, in the Nabatean archaeological context, inevitably conjures to a commercial or trade exchange practices of the Nabatean culture rather than a great metallurgical competence of the Nabatean themselves.

Easily recognized tooling marks are seen all over the rock-cut facades and stone-quarry areas of Petra. A limited number of metals, especially iron tools and weapons that were recovered from the archaeological investigations at Petra. According to Hammond, the evidence of a Nabatean iron tool kit transmitted to us by the different excavations revealed that copper and iron were used in building for both domestic and public structures at Petra [12]. During the excavation of the main theatre, Hammond found that metals were employed in its construction in which iron and copper fixtures were used to attach moldings. Additionally, iron nails keyed the plaster to the walls, and metal tools such as picks were used in carving the sandstone seats and entrance ways. At the Nabatean theatre, a possible iron dagger was found and is believed to date to 100 B.C [12]. Similarly, the excavations at the temple of the Winged Lions provided clear evidence that the Nabateans used copper and iron nails to key plaster elements in this temple and in the domestic structures adjacent to the temple, in addition a cube of iron was found in a ca. 200 B.C. grave at the same temple [13]. Other iron objects such as nails and knives were recovered from the residential area in Az-Zantur in the central area of the site, which is believed to go back in time to about 50 B.C. [14,15]. Tombs at Petra in the Wadi Sabra area revealed iron finger rings dated to around 50 B.C [16]. On the other hand, remains of metalworking sites or furnaces were never been unearthed or reported from the site.

Hence, the source of metal technologies and of the metals used as well by the Nabatean at the site has been always explained as being imported [5,17,11,18]. The general opinion is that the Nabatean strong trade and commercial relations with many contemporary cultures made it easier for them to obtain the metal objects through trade than maintaining over metal industries, especially during the urban expansion of the site in the second century B.C. The discovery of slags in a high concentration, and the results of our analysis of some of the slag samples [19,20] suggested an *in-situ* byproduct of metalworking which lead us to think about more realistic explanations for solution to these intriguing Nabatean technologies.

## 2. The Finding

During our survey, slag concentrations have been observed at three places in Petra; Wadi Sabra, Wadi Numair and Wadi Al Mataha. At this stage of our research, we are investigating the materials that have been collected from the slag concentrations in Wadi Al Mataha. The findings' location lies about 800 m northwest of the ancient center of Petra city (Fig. 1). From the exposed stratigraphy by natural erosion of the site sediments, a surface scatter includes material from several stages of the smelting process found in a spatial context with a southwest facing Nabatean masonry construction located northeast of the famous Sextius Florentinus Tomb number 763 (Fig.2) is attested.

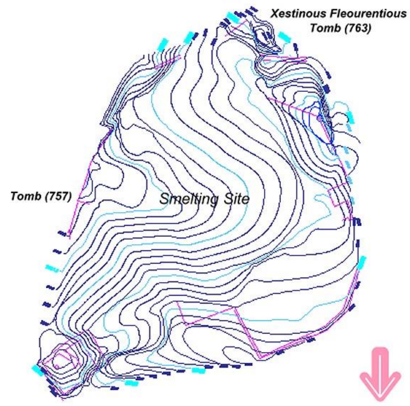


**Figure 2:** Smelting Site Map of Wadi Al Mataha, Petra.

Here, the slag bearing sediments cover about sixty square meters area and are about 60 centimeters thick in their middle parts. The archaeological remains fall by about some few centimeters along the slope, towards Wadi Al Matah to the Northwest. The mound of debris shaped as semicircular and enclosed by a construction of crudely worked sandstone blocks. The deposit measures approximately 15 to 20 meters in north south by 45 meters in east-west directions. This anthropogenic sediment formation is a result of distinct special activities superimposed on architectural debris, slags and charcoal rich midden deposits.

The erosion of the fine sediments concentrated the large stones and slag fragments on the surface. Large portions of the exposed slag and other materials have recently been damaged and moved as the site is close to a major tourist track to Petra through Wadi al Mudhlim, and also due to increased tourism at Petra.

At the northern slope of the location and towards Wadi al Mataha sediments and the slag fragments are very loosely packed and mixed with other Nabatean cultural debris which suggests their contemporaneity. Moreover, cyclic dumping formed the heap at the slope by over a quite long period. The incorporated cultural material, especially the pottery indicates a date of the Nabatean/ Roman time; it cannot be a colluvial mixture from various deposits.

Thus, the material in the deposit must be considered as representing one specialized operation that is different from the other deposits in the surroundings of the material, especially the slags quantities that suggest the state of being the product of one or of a very limited number of furnaces.

Apart from few small holes dug by looters, there is no record of any excavations at the location. The location of the site refers to the major wind direction (i.e. southwest/northeast) at the foot of al-Khubtha mountains which served to help furnacing. The high amount of charcoal within the site's sediments indicates an abundant availability of this fuel to the Nabatean during their smelting.

## 3. Sampling and the Analytical Procedure

After a detailed surface mapping and the demarcation of the different sectors of the site that is to be analyzed, sample selection was executed. A total of sixteen samples was documented, collected and analyzed. The samples included finished Nabatean iron and copper objects obtained from archaeological excavations, *in situ* fragments of what look like a copper ore and slag fragments that represent the residue of the ancient Nabatean smelting activities (Fig. 3). The samples also included some potential iron or sources collected from rock formations within the location vicinity.

**Figure 3:** Some of the fragments selected for the scientific investigations

The analytical procedures were achieved by utilizing mainly the scanning electron microscopy (SEM) and electron beam microanalysis energy dispersion (EDS) to produce quantitive and qualitative valuable elements for samples comparison [19,20,21]. Such methodologies have been already applied in studying the homologous findings as they provide the analytical composition of each phase forming the sample [22,23]. Other methodology like X-ray radiography, XRF, XRD analyses coupled with a preliminary optical examination provides a general idea of the method of manufacture on a macroscopic level. General metallographic studies can give a thorough picture of the history of an object and a much deeper understanding of the metallurgical processes employed.

## 4. Experimental Work and Results

A variety of schematic examinational techniques were employed. All samples were preliminarily checked under the optical and scanning electron microscope (SEM) to singularize areas of different morphological phases, and to be analyzed by microanalysis (EDS). To accomplish this, some of the samples were cut, cast in epoxy-resin and hand-polished. The mounted samples were then machine-polished to one quarter of a micron and etched by Nital acid solution to observe the metallografic structure. Finished metal artifacts samples, such as the ancient coin or the nail, were surface examined to avoid their destruction and to get their analytical information on their chemical composition and mode of making.

In total more than sixteen samples were collected from different archaeological contexts. Some were obtained from regular excavated sections, while others were taken from the exposed Nabatean sediments of the site and from the expected raw material sources. Here, we summarize the main results of some of the key investigated samples of metallic consistence (Table 1), and incorporate new discoveries made and acquired during the investigations, which have provided us with information and helped in concluding about the iron-making and the metallurgy technologies in the city of Petra to add further understanding of the Nabatean early metal production.

**Table 1.** List of Petra's Key analyzed samples

| S. No | Location | Date | Description |
|---|---|---|---|
| 1 | Site No. 1 (Wadi Al Mataha) | Nabatean | Slag fragment found incorporated within the site sediment |
| 2 | Site No. 2 (at Wadi Numair on surface) | Nabatean | Slag fragment found incorporated within the site sediment |
| 3 | Site No. 1 (Wadi Al Mataha) | Nabatean | Slag fragment found incorporated within the site sediment |
| 4 | Found along the vein at Wadi Al Mataha | Geologic Late Cambrian | Hematite deposits (Iron Ore?) |
| 5 | Site No. 1 (Wadi Al Mataha) | Geologic Late Cambrian | Possible copper ore found in abundance within the site sediments |
| 6 | From the excavation of Winged-lion temple | Nabatean | Iron Nail with square section |
| 7 | From the excavation of the erosional section of the Winged-lion temple | Nabatean | Nabatean Coin possibly Bronze |

The analysis results of the key samples (in the following they will be quoted by their serial number of first column of Table 1) can be summarize as follows:

## 5. Sample 1

The slag sample shows a smooth compact frontal surface, with glassy luster, and is mostly homogeneously colored. The dorsal part shows a rough surface with many air vascular and has a metallic luster (Fig. 4)

**Figure 4:** digital photo Sample 1

To allow a very accurate quantitative determination of the micrometric areas, some very small parts of the sample were mounted in epoxy resin and smoothly leveled and had been cut them with a jeweler saw and polished to 400 mesh alumina and finished with colloidal silica. The samples were all etched with Nital acid solution (Fig 5-A). Then the sample was observed under the SEM-detector (Fig 5-B).

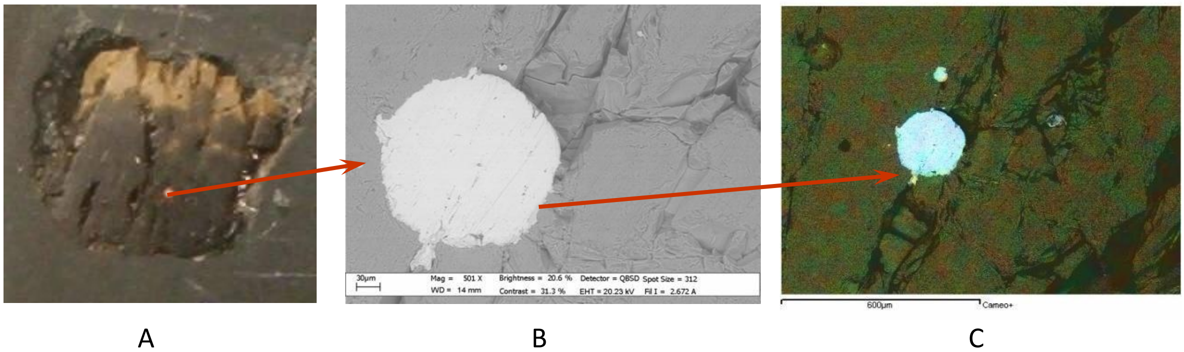


**Figure 5. A -** Fragment of sample 1 cast in epoxy-resin, **B** - and enlargement zone of copper inclusion, C – x-ray mapping shows the difference of distribution: Cu (blue) Mn (green), Si (yellow) and O (red).

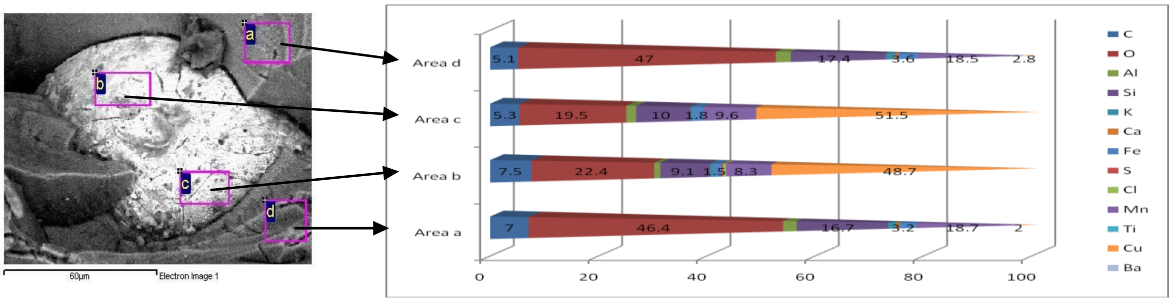


**Figure 6.** Analyses of the areas investigated by EDS (data in wt% ± 0.2)

By this way, it has been possible to foresee the existence of two phases through the atomic contrast from the use of the detector for the backscattered electrons. EDS punctual analysis detects Cu as a unique element constituting the round particles, and Mn, Si, O as those constituting the sample matrix, this is also evident through the x-ray mapping which shows the inclusions and the different elements distribution (Fig -C).

The composition determinations of the selected micro-areas are presented with their EDS values (Fig. 6) which allow to distinguish better the copper rich phase and the compact matrix that constituted by manganese-silicon compounds phase. Other elements are present in traces and at this stage it is impossible to assign a well determinate percentage values as the instrumental resolution is 0.2%, but their presence could give indications for further scientific investigation with higher resolution methodologies.

The sample indicates a slag product from a copper rich manganese sandstone raw material such as those exposed in the neighboring Wadi Faynan area.

## 6. Sample 2

The slag sample was collected from a naturally exposed section with incorporated Nabtean sediment at Wadi Numair (Table 1). The part of the sample represented in figure 7 is formed by a homogeneous material well-structured in a lamellar phase. The average elemental composition in EDS is presented in Figure (8) in which the presence of manganese as a principal component is evident.

**Figure 7**. Slag fragment sample number 2

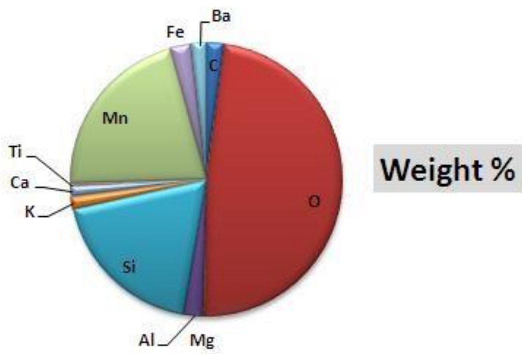


**Figure 8.** Elemental composition in EDS (data in wt% ± 0.2)

The manganese predominance is well evidenced in the pseudo colours x-ray mapping in the enlargement of analyzed area, Fig.9 Mn (blue) Al, Si (green) O (red)

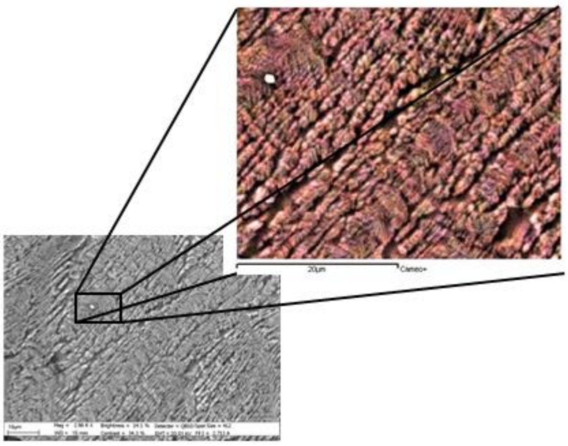

**Figure 9.** Enlargement zone with Mn presence

In other areas of the same fragment, a radial structure is present. The analytical composition indicates again a compound among Mn, Si, O, but also Al is present at a constant concentration.

Different modes of elements dispersion "visualization:" was made to "visualize" the copper inclusions in a homogeneous matrix (Fig. 9). The sample was characterized by the dominant presence of Mn. Other elements were not traceable even after reaching the resolution limits of the instrument.

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The continuation of the analysis of each sample areas presenting some differences in the microstructures; it is not possible to get constant value of elements composition for the complexity of the present phases. Punctual analyses combined with X-ray imaging led us to understand the nature of the investigated sample formation system (Fig. 10).

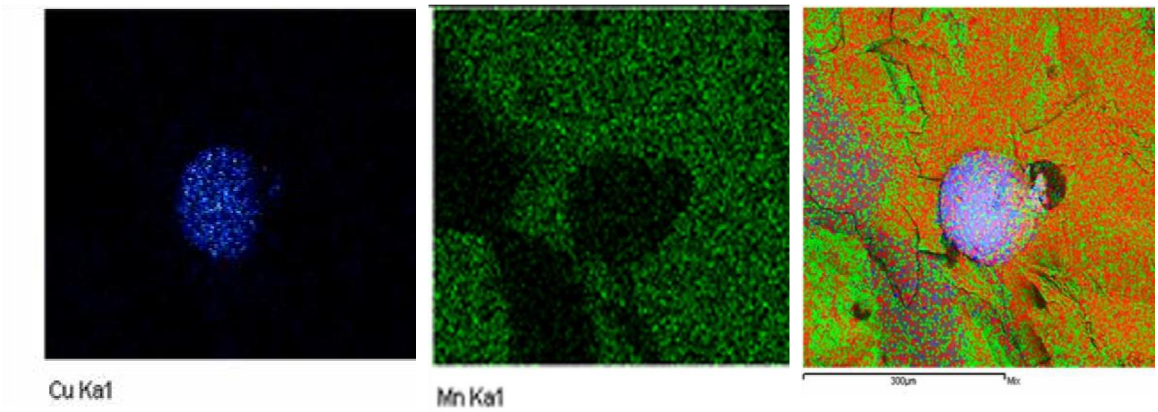



**Figure 9**: Different dispersion "visualization modes; **a –** copper inclusion (blue)**, b** - x-ray imaging of an inclusion in a homogeneous matrix characterized by the presence of Mn (green), **c** - an imaging showing Cu (blue) Mn (green), Si (yellow) and O (red) of an inclusion in Sample 2

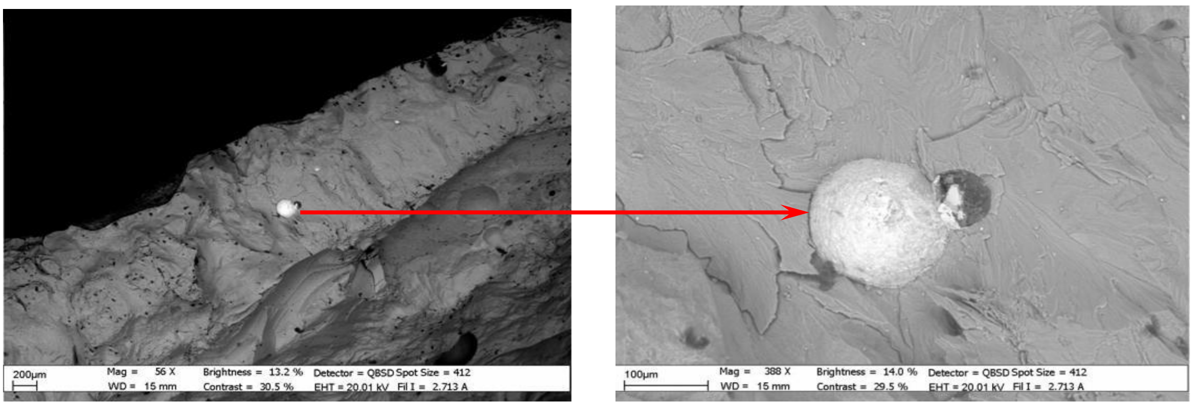



**Figure 10.** Enlargement zone with copper inclusion

Nevertheless, the spectrum (Fig.11) and the values reported in the chart, obtained from the areas marked in the SEM image (Fig.12), also show higher values only for the same elements.

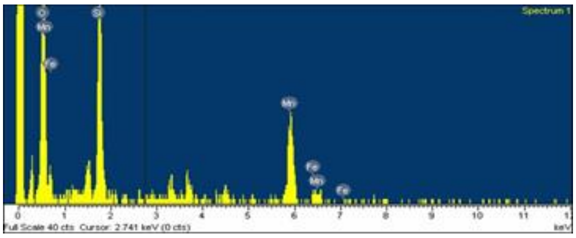


**Figure 11.** X-ray diffraction spectrum of Sample 4 showing the dominance of Fe, Mn, Si, and O.

## 7. Sample 3

It represents a slag collected from natural eroded section of site No. 1 at Wadi AlMataha (Fig. 13).

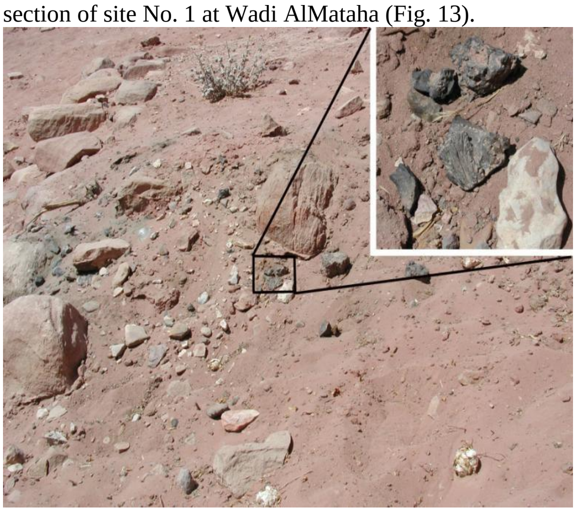


**Figure 13**. Natural exposed section of site No. 1 with the slag sample 3

The body of the sample mainly consists of a compact mass with glassy surface especially in some parts (areas a, c) of the analyzed fragment of the sample. At higher magnification, some evident change of morphology is represented by an oriented crystal growth appearance (area d). This might have been caused through the interaction with the sounding matrix. In the area "a" (marked by a black frame) a regular dotted morphology is observed (Fig. 14).

The morphological analysis led us to assure that strong thermal stresses followed by slow cooling processes had developed.

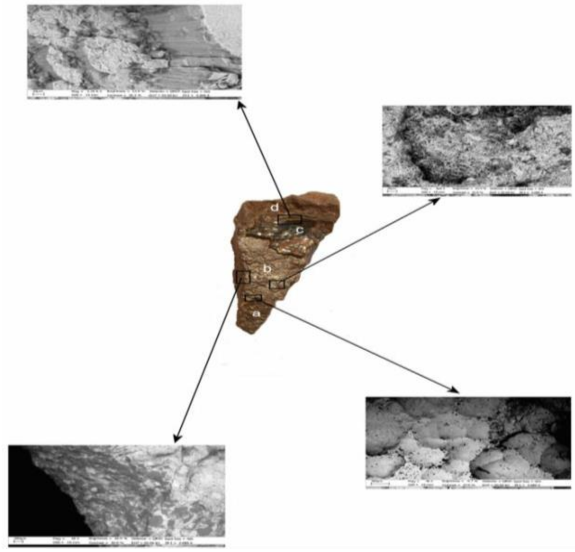


**Figure 14:** Sample 3 shows the different microphotos of analyzed areas a,b,c, and d The overall composition of the sample is mainly formed by iron and oxygen. To eliminate the doubt of a physiological superficial oxidation process, determinations on spots along a line from the inner part to the surface have been carried out (Fig. 15).

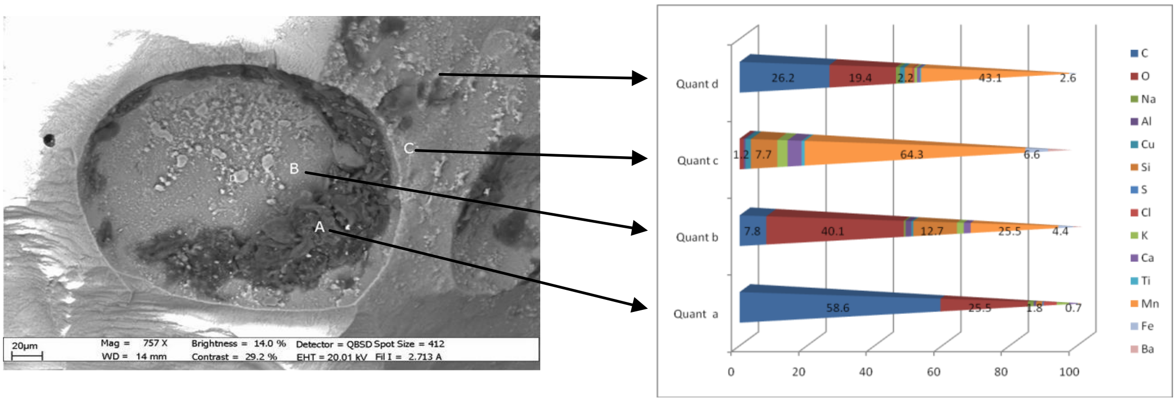



**Figure 12:** Microphoto of the investigated areas A,B,C & D and their EDS analysis result.

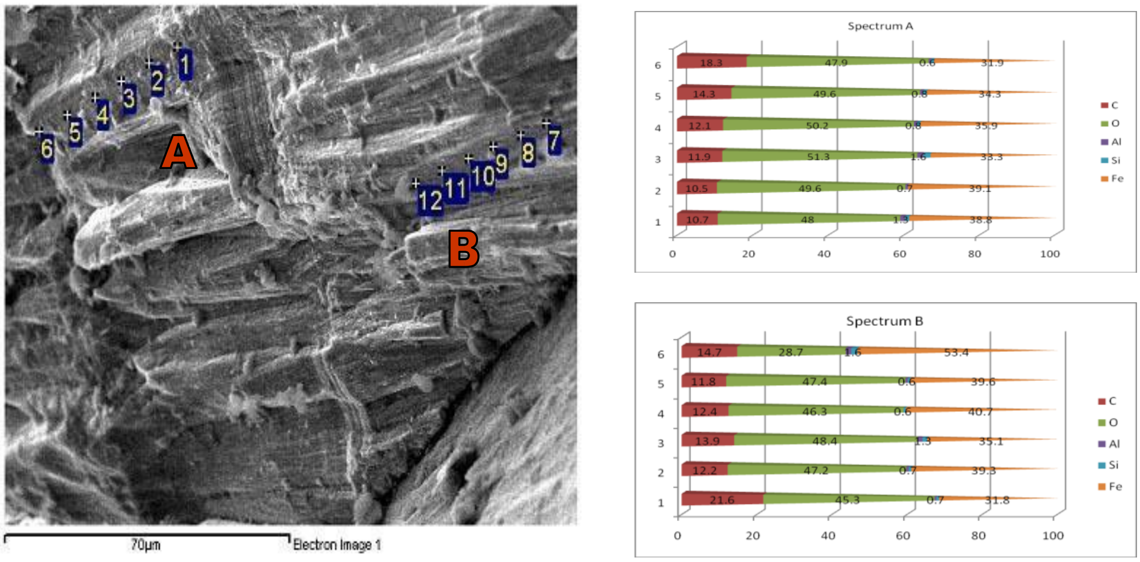



**Figure 15:** Microphoto of the investigated lines and the EDS analysis for each spectrum An increasing trend of the values of the iron is opposed to decreasing oxygen. The spectrum and the values reported in Fig. 15 Spectrum A & B which is obtained from the areas marked in the SEM image Fig.15.

| Element | Zone A | | | | | | | A-B | A- B crystals | B | C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A1 | A2 | A on ridge | A on bottom | average zone 1 | average zone 2 | average zone 3 | | | | |
| C | 4.5 | 4.7 | 6.5 | 4.9 | 4.1 | 5.7 | 9.5 | 3.2 | 3.4 | 6.2 | 5.8 |
| **O** | **44.0** | **40.4** | **33.7** | **39.3** | **37.0** | **29.7** | **39.9** | **43.9** | **35.8** | **32.4** | **18.7** |
| Al | | 1.3 | 0.8 | 0.8 | 1.1 | 0.8 | 0.7 | 1.1 | 2.1 | 1.0 | 0.4 |
| Si | 0.8 | 1.8 | 0.9 | 0.7 | 1.8 | 1.1 | 0.8 | 4.2 | 6.3 | | 0.8 |
| P | | | 0.2 | 0.2 | | | | 0.2 | 0.3 | | |
| Cl | | | 0.3 | 0.27 | | 0.2 | 0.2 | 0.1 | 0.1 | | |
| Ca | | 0.4 | 0.27 | 0.2 | 0.6 | 0.2 | | 0.3 | 0.6 | | |
| **Fe** | **50.7** | **50.6** | **56.6** | **53.3** | **55.1** | **61.9** | **48.8** | **46.9** | **50.4** | **60.5** | **74.4** |
| Mg | | 0.3 | | | | | | | 0.5 | | |
| Na | | 0.3 | 0.4 | | | | | | | | |

**Table 2.** Different areas investigated by EDS analysis, all the results are reported so to point out also trace elements at the limit (or under) of the instrument resolution.

Other analyses carried out in different micro-areas did not reveal any significant element that could be associated to any trace element specific for a possible ore (Table 2). Apart from Fe and O, all the elements seem to constitute soil, and from the ratio of their concentration it would be possible to establish only comparisons and hypotheses

Analyses on restricted areas with a particular microstructure are reported in order to furnish further comparative elements in the charts and the EDS values of the areas indicated in microphotos (Figs. 16, 17 and 18):

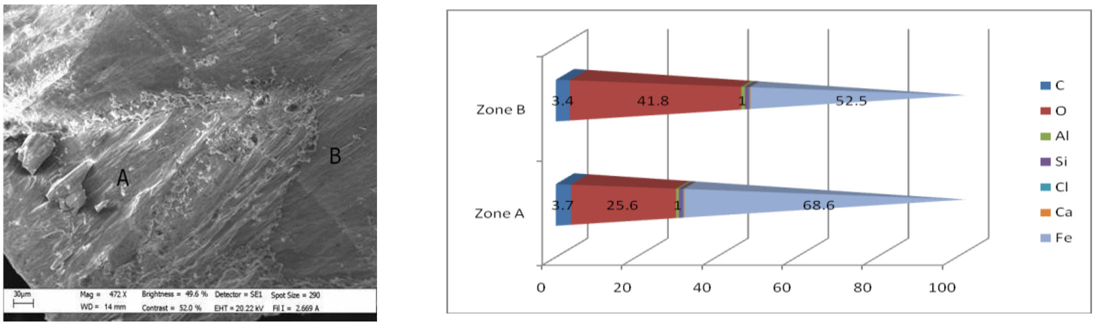



**Figure 16** The investigated micro-areas and the EDS analysis values for each spectrum

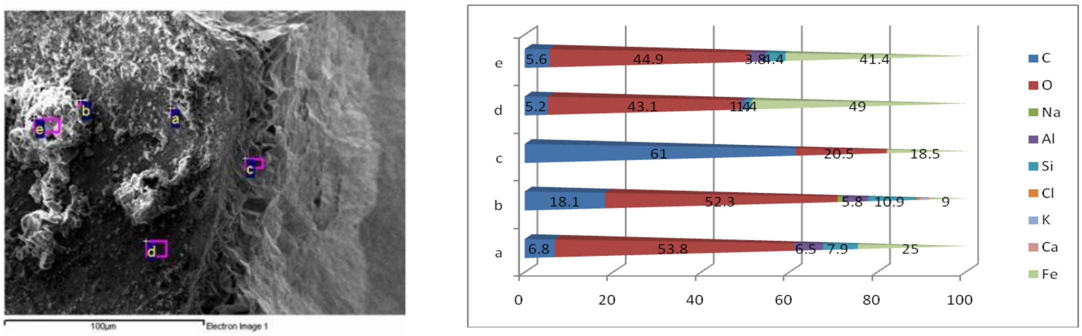



Figure **17:** The investigated micro-areas and the EDS analysis values for each spectrum

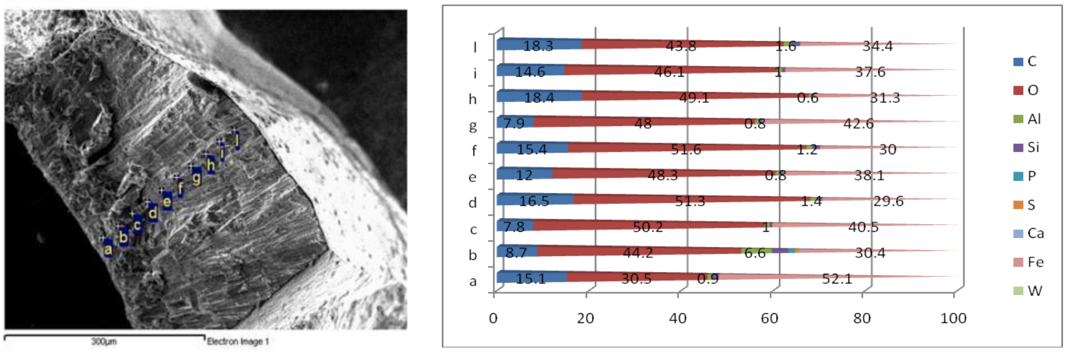



**Figure 18:** The investigated micro-areas and the EDS analysis values for each spectrum

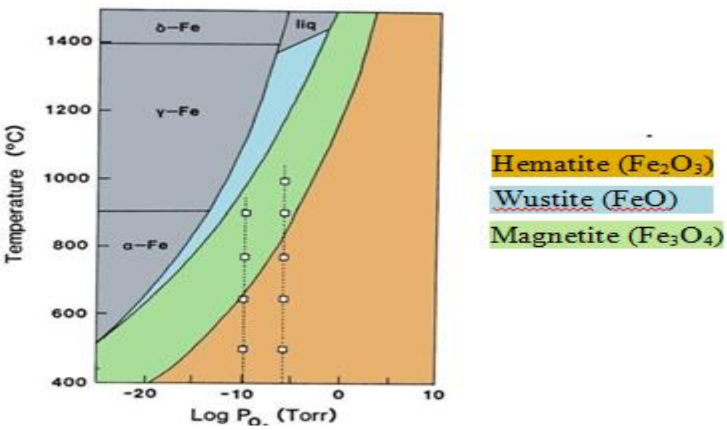



**Figure 19:** Iron Oxide (Fe-O) phase diagram as a function of temperature and pressure

From the EDS determinations the possibility appears reliable that the composition of the whole sample was a stable and stoichiometric iron compound. To have a confirmation of this, the Xray diffraction method was applied and the results indicate the existence of a single phase $Fe_2O_3$, hematite.

By considering the reported diagram of the system three Fe-O phases as existence as a function of temperature and pressure, it is possible to derive information about the condition of stability of the mineral (Fig. 19).

## 8. Sample 4

The sample represents a fragment of a hematite vein interbedded between the local ferruginous sandstone rocks exposed about 500 m northeast of the site along the Wadi Al Mataha. The sample was collected as a possible source of iron ore used by the Nabatean (Fig. 20).

The sample shows the domination of iron oxides with the presentation of Si, Mg, Mn and Al. The rich iron content of the sample with close mineralogical similarities to some slag samples and the close geographical location of the sample may suggest a suitable source for the iron within the Petra area. Other areas were not sampled at this stage of the research.

**Figure 20.** Sandstone bearing rich hematite veins exposed at the vicinity of the site. Naturally detached small fragments from the sample body allowed us to analyze the upper and the inner parts of the surface (Figs. 21 & 22) the results are summarized in Figure 23.

**Figure 21.** Digital photo Sample 4

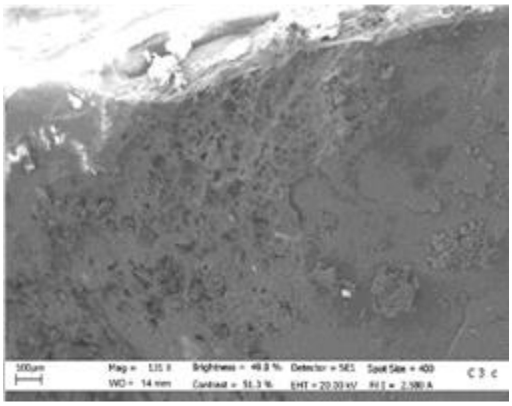


**Figure 22.** Enlargement of one fragment of sample 4

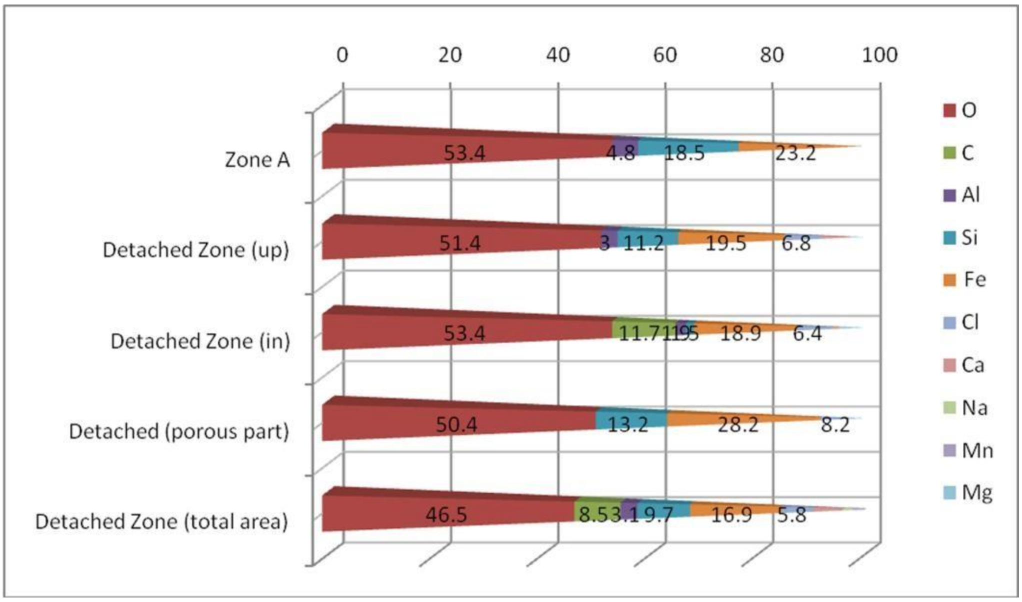



**Figure 23.** EDS Analyses of Various Fragments of Sample 4

## 9. Sample 5

Possible copper ore is found in abundance on the surface of the location sediments and has been differentiated for its completely inhomogeneous nature (Fig. 24a). Only spot analysis can be indicative for the nature of the compositing material. From the spectra it is possible to note the strong presence of copper and only from spot "9" small amount of Sn was revealed (microphoto in Fig. 24b).

Even in this case, the visualization of the dispersion of the main elements (Fig 25) can provide a preliminary overview of micro-areas to be investigated at higher magnification for the individuation of elements as fingerprints of the whole sample. The EDS results exhibit a predominance of copper, but without a constant behavior as some parts of the sample might have been weathered. X-ray diffraction indicates the presence of quartz, cuprite and tenorite (Fig. 26).

By utilizing the correlation diagrams for the experimental results for comparing those with the common minerals containing the oxidation forms of Si, Ca, Al, it is possible to add some other elements of comparison for a more precise identification of the material's composition (Fig. 27).

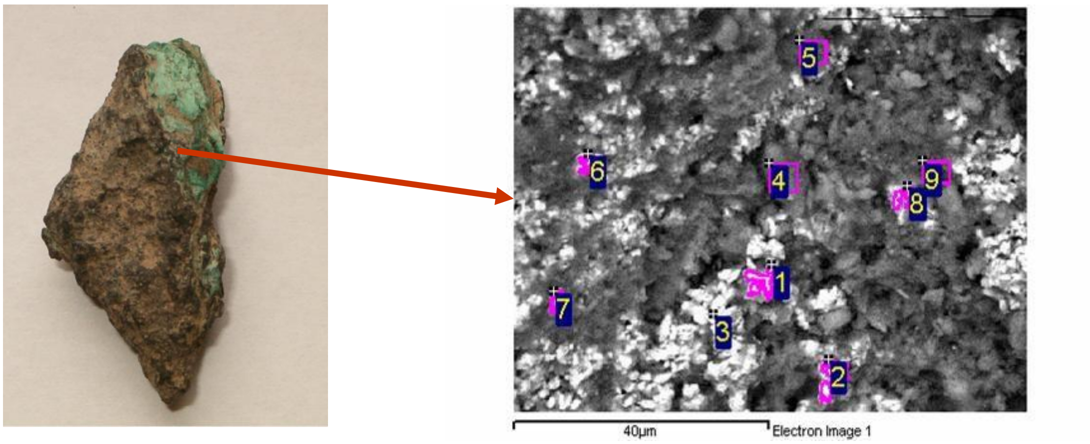
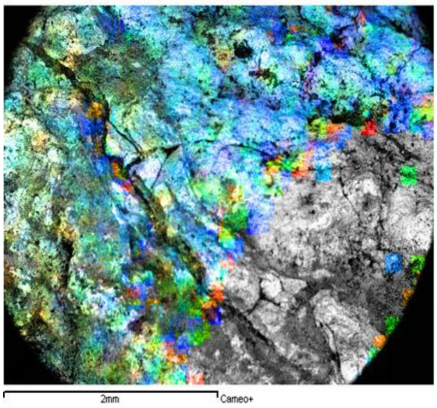



**Figure 24.** a Sample 5 and b- the enlarged micro-areas



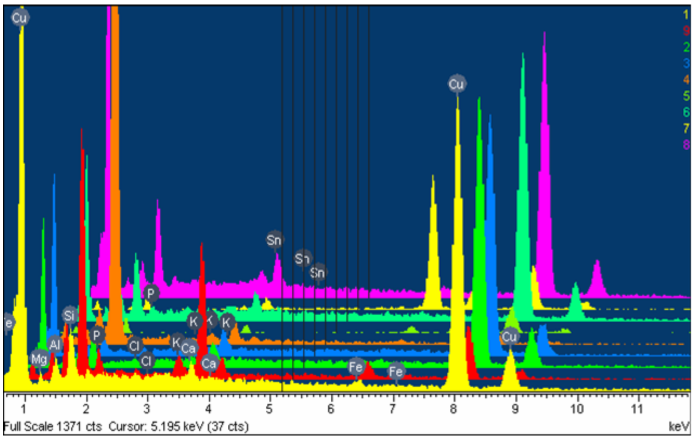
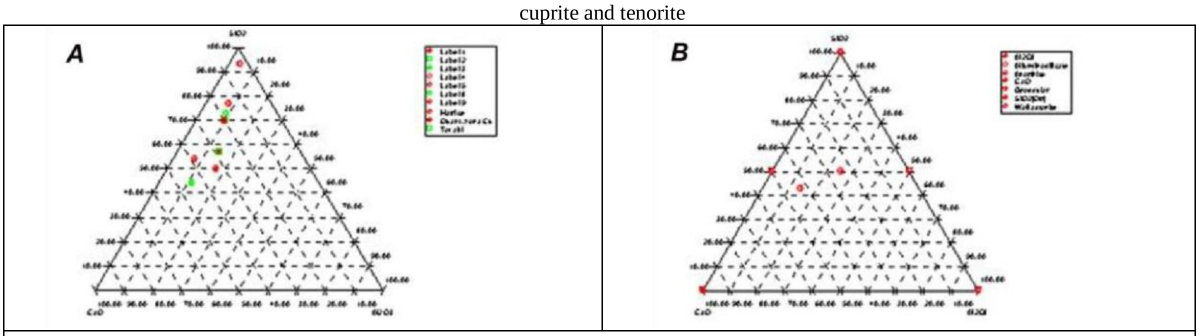




**Fig 25**. Distribution : Fe (blue) **Figure 26:** X-ray diffraction spectrum of Sample 5 Cu (sky) Ca (red) showing the presence of quartz, cuprite and tenorite




***Common minerals in this System include:***

*Quartz $SiO_2$ [Qtz], Corundum $Al_2O_3$, Aluminosilicate $Al_2SiO_5$, Wollastonite $CaSiO_3$ [Wo], Anorthite $CaAl_2Si_2O_8$ [An], Grossular Garnet $Ca_3Al_2Si_3O_{12}$ [Gr]*

**Figure 27. A** - Correlation diagram for experimental data $SiO_2 – CaO – Al_2O_3$ and **B** - Three component system diagram $SiO_2 – CaO – Al_2O_3$ [24].

## 10. Sample 6

The archaeological sample is from a nail found at the Nabatean Winged Lion temple in Petra's central area. The nail is about 5.5 cm long and completely corroded, it had a square section and was made from iron (Fig. 28). In the SEM microphotos, different states of iron degradation are represented. From its shape, it appears as a nail, and to verify this EDS analyses were carried out on the head, shaft and tip of the object (Fig. 28).

The sample shows a good presentation of Fe, O and Si (Fig. 29). This could be the result of weathering. The high percentages of O and Si elements with the presence of Mg show a close compositional similarity with that of the analyzed ferruginous sandstone. Therefore, a local source for some of the iron artifacts can be suggested at this stage of research.

This Nabatean coin was found on an erosional section southwest of the Winged Lion temple in the central area of Petra. The coin is likely to be made of Bronze (Fig. 30). The piece is of green color on some areas because of copper corrosion (Figs. 31 & 32). The coin is completely covered by corrosion products and it is not possible to associate a real composition to the metallic alloy however, it was possible to observe zones on the sample, (Figs. 31, 32).

Only with superficial enrichments of the elements, separation of phase was achieved, but for the massive presence of Cu, Pb and Sn it is possible to realize the nature of the material as bronze as shown in the qualitative spectra of sample (Fig. 33).

The sample reveals a macrostructure with homogeneous crystals which the EDS analysis indicates as quartz crystals (Fig.32). The X-Ray diffraction revealed quartz, cuprite, and a mineral with aluminum silicate Al2SiO5 (Kyanite) (Fig. 33).

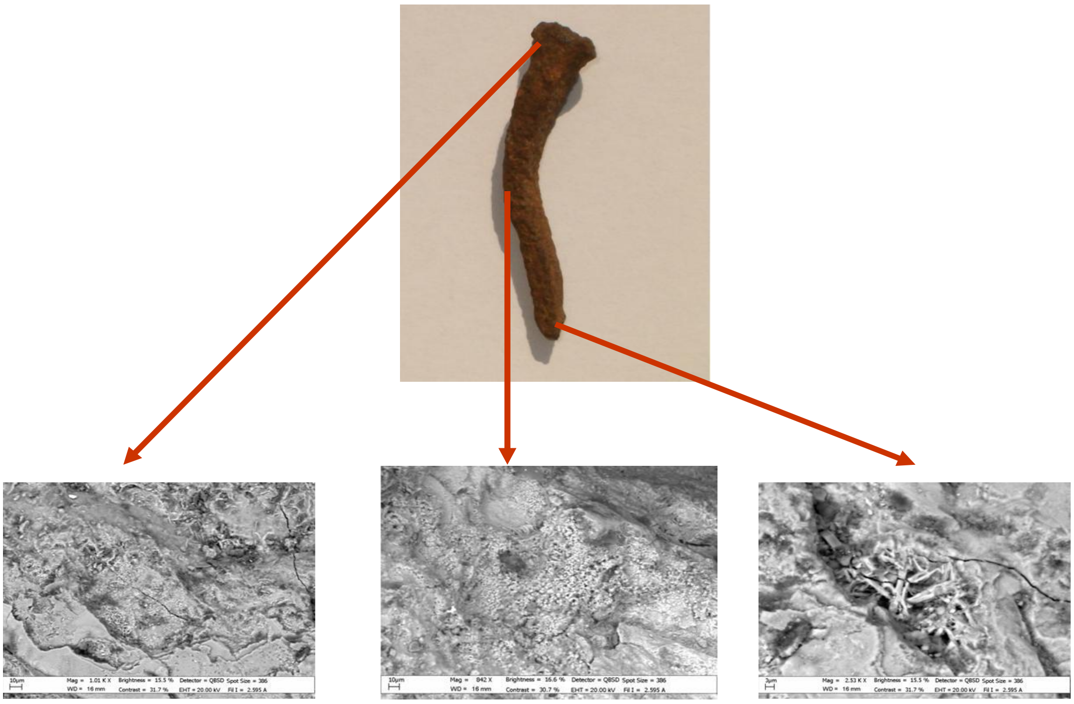


**Figure 28.** digital image and the SEM enlargements of the head, body and tip of sample 6

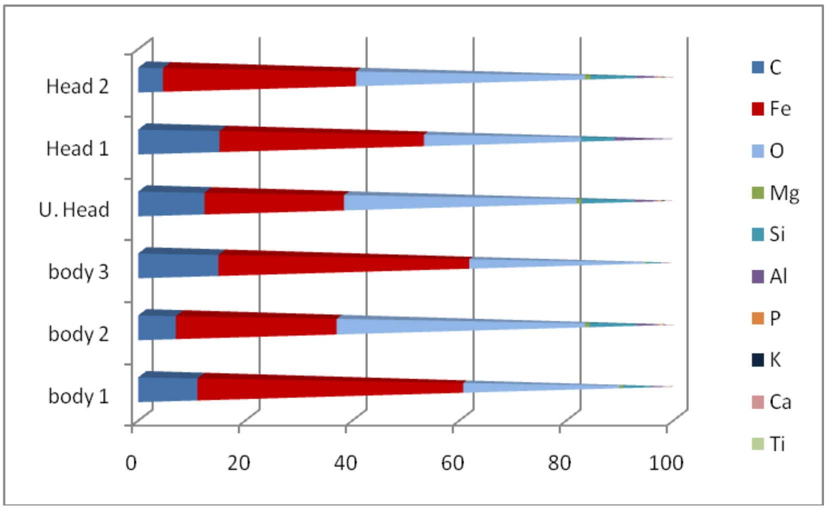



**Figure 29** . EDS analysis values for each spectrum of the head, body and tip of sample 6 **Sample 7**

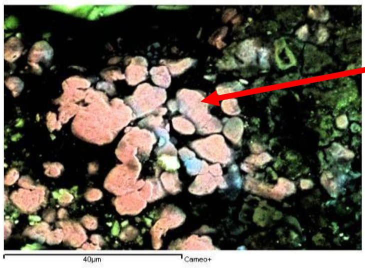


**Fig 30.**X ray -mapping of copper, red

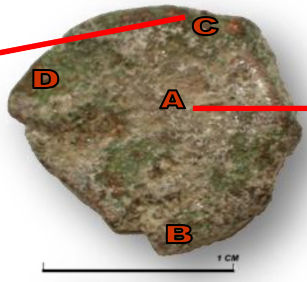



**Fig 31.** Ancient Nabatean coin

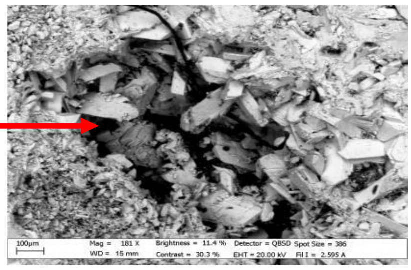


**Fig 32.** Pb crystals

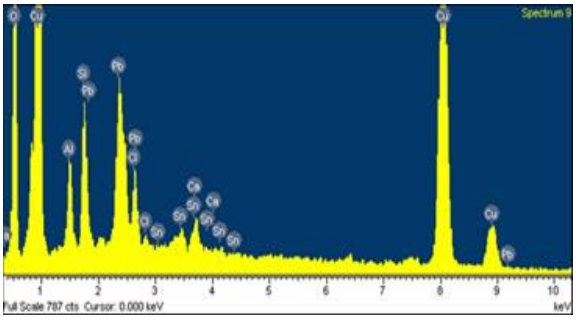



**Figure 33:** X-Ray diffraction spectra of Sample 7 shows strong presence of Cu, Pb and Sn, From the data summarized in Table 10, the attempt to determine the original composition of brass from the determination of the single element average concentration was performed, unfortunately, the advanced degradation state of the item allows only to point out a big amount of Pb in the alloy (Fig. 34)

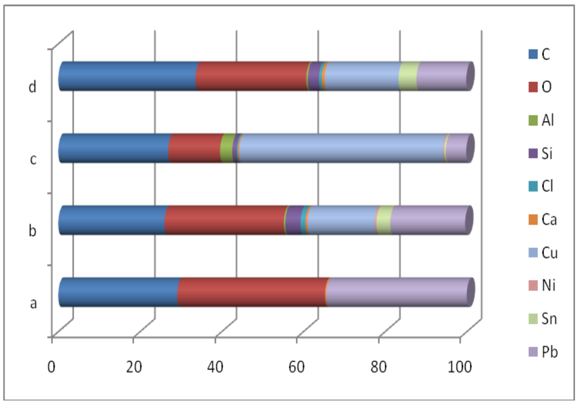



**Figure 34:** EDS analysis in areas of the dimension of 1 μm of sample 7 showing high Pb value

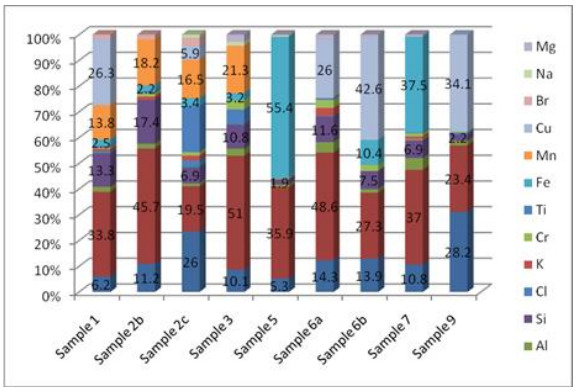



**Figure 35.** Summery of the chemical composition of the different analyzed samples

## 11. Discussion

Based on the observation and the analysis results of the investigated site and samples, the following conclusions may be drawn from the present study:

This preliminary approach to the study of the Petra's metallic findings can establish a useful background of knowledge for further investigations in different disciplines encouraging research to understand ancient metallurgy in Jordan. The analyses of the collected slag samples from this location in Petra suggest that the samples were derived from *in situ* smelting of iron and copper ores. This is the first evidence of Nabatean smelting in Jordan. Each sample yielded specific results not only about its nature, but also about its formation history. Some composition values with their constancy in the samples seem to adhere to a well-defined compound presence, but the punctual and zonal investigations suggest inhomogeneity and dishomogeneity of the sample matrix. This also found to be true due to either different processing stages or different preservation conditions of the samples.

Probably the analysis of more and well stratified samples combined with the other actual evidences, can give a more integral image of the Nabatean metallurgical process. At this stage, the results obtained demonstrate the validity of the methodology applied, by considering each sample not in its unity but in all the small parts and each of them containing specific information. The significant presence of the Mg, Fe, Cu and K (Fig. 35) in most of the analyzed slag samples which match with the collected potential raw material samples from the local sandstone outcrop (exposed about 500 m northeast of the site along the Wadi Al Mataha) might indicate the use of the local material by the Nabatean to manufacture their metal objects.

These analyzed raw material samples-though they are indicative-they are still too limited and not covering all the potential metallurgical aspect of the geographic area of the Petra area, and do not allow a general treatment of the matter especially with respect to the copper source. Therefore, copper ore needs to be further researched and more samples need to be collected from expected potential sources in-site and off-site.

This study needs to be proceeded with an archaeological excavation in the coming future to conform the nature of metalworking on the site and more samples needed to be analyzed to further our understanding of the Nabatean metal technology.

Finally, considering all the results obtained, an analytical lecture of the results can propose a reliable answer of the question previously proposed on the source of metal, and to contribute to the understanding of the Nabatean culture and related social and technological behavior.

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