Archaeo-mineralogical Characterization of ancient copper and Turquoise mining in south Sinai, Egypt

by Mohamed M. Megahed

Fig.1 - Shows a map of Sinai Peninsula

The study aims to investigate the source zones for copper in south Sinai, Egypt during the pharaonic ages, to determine the extent of a manufacturing centre and its position and to know the systems of metallurgical works, fire places and furnaces. The study had two main aspects: 1)it has been done a serious survey to investigate the mines of the south Sinai, during which several different mining features were randomly chosen for excavations such as open cisterns, plates and galleries, collected every small things and fine details of the mining technology used at these sites; 2) careful investigations by a serial of different analytical techniques for Ore and slag samples from the selected mines have been applied; the obtained information can be married up and exploited to determine exactly the main activity for each site.

Sinai Peninsula or simply Sinai (/ˈsaɪnaɪ/; Arabic: سيناء Sīnā'; Egyptian Arabic: سينا Sīna, is a peninsula in Egypt, the only part of the country located in Asia. It is situated between the Mediterranean Sea to the north and the Red Sea to the south; it is triangular in shape, with northern shore lying on the southern Mediterranean Sea and southwest and southeast shores on Gulf of Suez and Gulf of Aqaba of the Red Sea. It is a land bridge between Asia and Africa. Sinai has a land area of about 60,000 km2 (23,000 sq mi) and a population of approximately 1,400,000 people. Administratively, Sinai Peninsula is divided into two governorates: the South Sinai Governorate and the North Sinai Governorate (Fig. 1). Three other governorates span the Suez Canal, crossing into African Egypt: Suez Governorate on the southern end of the Suez Canal, Ismailia Governorate in the center, and Port Said Governorate in the north [www.sinaiwikipedia].

Transition from the Neolithic to Chalcolithic periods occurred in more than one geographic area, as archaeo-metal lurgical evidence suggests that copper smelting was discovered independently in many different parts of the world. In ancient ages two regions with occurrences of copper deposits are known in Egypt: central southern part of Sinai Peninsula and the eastern desert. Sinai was the site of extensive copper exploitation in pharaonic times. The copper occurrences are classified as strati form deposits, copper occur in the form of secondary minerals, predominantly malachite (rarely azurite and chrysocolla) impregnating Paleozoic clastic sediments. In some localities, copper minerals are mixed with manganese oxides, copper contents in the ore vary from 3 to 18% [Gerald F., Vladimir H., and Antonin P., 1995]. The mining of copper had been carried out for long time on the surface, there are also known previously horizontal cavities, galleries which follow the ore mineralization some 40-50 meters into the rock.

The copper ore mined at several localities in Sinai which include Wadi Al-Maghara, Wadi Kharag, Wadi Al-Nasib, Serabit Al Khadem, Regeita, Samara, Abu El Nimran and others. The indications about copper mining in Serabit El-Khadim are less clear, as the ancient working indications in that area have not taken the enough intention of research and study, although the copper ore is found in the divinity of the temple of Serabit El-Khadim [Gardiner A., Peet T., & Cerny J., 1955].

Turquoise also was mined in ancient times at the same areas; a lot of archaeological researches were carried out to prove and investigated the sites of turquoise mining in south Sinai. This was confirmed by a peculiar appearance, which strangely enough has not been observed by any earlier travellers.

A lot of papers have been written by travellers, scholars and researchers about ancient mines of copper and turquoise in south Sinai area, Egypt [Petrie W. M. F., 1906, Gardiner A., Peet T., & Cerny J., 1955, El Shazly S. M., 1959, Charles B., and Dominique V., 1997, Rothenberg B., 1987, Paul T. N., & Ian S., 2000, Beit-Arieh, I., 1987], but all of these papers had a shortage, there was integrated between the mines of copper and the mines of turquoise in these papers,

especially in Wadi Al- Maghara, Wadi Al-Nasib, Wadi Kharag and Serabit Al-Khadim, they couldn't determine exactly the activity of each site.
This study aims to clear this point and determine exactly the mines of copper and turquoise, the study also aims to know the nature and correlation of many of mining features, the relation of the mining shifts to the underground gallery systems and the function of plates, to have a better understanding of the formation of the mining region's post and present topography, especially of the relation between the different mining features and the landscape features which often appeared to be extremely odd, to investigate the source zones for copper in south Sinai, Egypt during the pharaonic ages, to investigate the positions and ground plan situations of single manufacturing objects (earth houses, a house with stone socle, stone house, metallurgical works, fire places, furnaces, etc., to determine the extent of a manufacturing Centre and its position and to know the systems of metallurgical works, fire places, furnaces, etc.
To achieve that the study had two main aspects: first, a serious survey to investigate of the mines of south Sinai was a cured; several different mining features were randomly chosen for excavation such as open cisterns, plates and galleries, collected every small things and fine details of the mining technology used at these sites.
Secondly: Careful investigations by a serial of different analytical techniques for Ore and slag samples from the selected mines have been applied; the obtained information can be married up and exploited to determine exactly the main activity for each site.

HISTORICAL AND MINERALOGICAL STUDY

Sinai was called Mafkat or "country of turquoise" by the ancient Egyptians From the time of the First Dynasty or before, the Egyptians mined turquoise in Sinai at two locations, now called by their Egyptian Arabic names Wadi Magharah and Serabit El-Khadim. The mines were worked intermittently and on a seasonal basis for thousands of years. Modern attempts to exploit the deposits have been unprofitable. These may be the first historically attested mines.
Archaeologists have found that the very earliest known settlers in the Sinai-they arrived about 8,000 years ago-were miners. Drawn by the region's abundant copper and turquoise deposits, these groups slowly worked their way southward, hopping from one deposit to the next. By 3500 BC, the great turquoise veins of Serabit El-Khadem had been discovered. At the same time, the kingdoms of Egypt became united under its first pharaohs, and these great rulers soon turned their eye eastward. By about 3000 BC the Egyptians had become masters of the Sinai mines, and at Serabit El-Khadem they set up a large and systematic operation. For the next two thousand years, great quantities of turquoise were carved from Serabit El-Khadem, carried down the Wadi Matalla to the garrisoned port at El-Markha (just south of Abu Zenima), and set aboard boats bound for Egypt. For the Egyptians, the brilliant blue-green stone served myriad purposes: scarabs were carved from it, and the bright mineral enamels of powdered turquoise were used to color everything from fine statuettes to bricks.
Richard Lepsius, in the 33rd of his famous letters written during his antiquities hunting mission in 1845 on behalf of his Majesty Fredrick William 1V of Prussia, made the following, often quoted statement concerning the Egyptian mining temple at Serabit El-Khadim in south Sinai. The divinity, who was mostly revered here in the middle and new kingdom was Hathor, with the designation, also found in Wadi Maghara (Mistress of Mafkat) i.e.(the copper country), for Mafkat signified (copper) in the Hieroglyphical, as well as in Coptic language.
The meaning of Mafkat (= copper) as viable evidence for pharaonic copper mining was entirely within (the spirit of the time) of early nineteenth century, although even then slag samples from slag-hills at Serabit could have been analyzed.
In 1984 the historian J. Muhly used the meaning of Mafkat (now revised as turquoise) as the principal evidence for his astonishing conclusion that, in contrast to the evidence

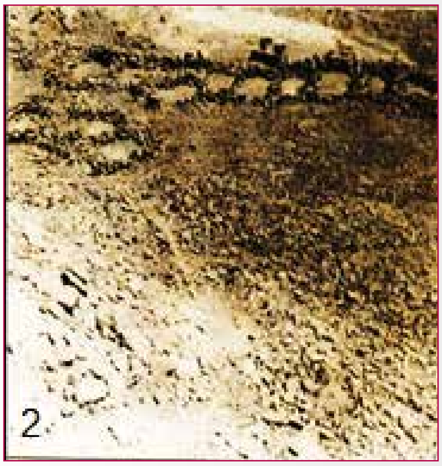


Fig. 2 - Shows the ancient smelters houses in wadi Maghara.

Fig. 3 - Shows a stair on the eastern mountain, leads to ancient smelters houses in wadi Maghara.

Fig. 4 - Shows a casting mold in wadi Maghara.

Fig. 5 - Shows a general view of Wadi Nasib.

Fig. 6 - Shows copper deposits in the rocks in Wadi Nasib.

from the wadi Arabah no ancient copper mines have yet been identified in the south Sinai. Nor have any copper smelting sites been found in the area [Muhly J., 1984].
Flinders Petrie,s pioneering work in Sinai was mainly concerned with excavations at the mining temple of Serabit El-Khadim and the turquoise mining camps of Maghara, but on the pages of his Sinai report, especially in the chapters contributed by C.T. Currelly, there are numerous references to substantial remains of ancient copper mining and smelting in various parts of the south Sinai [Petrie W. M. F., 1906].
El Shazly of the Geological survey of Egypt, published in 1959 a report on the copper deposits of Sinai, several ancient copper mines have been reported in Sinai, which included Gebel Um Rinna, Serabit El-Khadim and Maghara [El Shazly S. M., 1959].
The copper ore mined in Sinai in the ancient time was largely malachite associated with a little azurite and chrysocolla. El Shazly also reported copper mineralization at several localities in Sinai which include Serabit, Regeita, Samara, Abu El Nimran and others.
Wadi Maghara considers the first and important area in south Sinai, which the ancient mineralogy missions sent to it. Beside Turquoise, there are no doubt copper was also obtained here. This was confirmed by a peculiar appearance, which strangely enough has not been observed by any earlier travellers.
There are debris of ancient smelters houses, which date back to the old kingdom (2780- 2230 BC), and the middle kingdom (2134-1778 BC), also a huge quantities from copper slag, destroyed pots and casting molds which returned back to old and middle kingdom were found in the region (Figs.2- 4).

In the region of Bir Nasib, in the vicinity of the well of Nasib are large slags heaps and ruins of several smelting furnaces. Rothenberg noticed small adits during his visiting's to Wadi El-Nasib area, these small adits visible in the sandstone cliffs surrounding the smelting area show green lumps consisting of malachite, paratacamite and quartz.
The whole district extending as far as Um Bogma and Gebel Um Rinna is rich in copper mineralization.
The mines of the ore are situated about one and a half hours to the north-west in Gebel Um Rinna, here in several horizontal sandstone layers, have been squeezed wedge-shaped masses of earthy copper oxide of unusual dimensions. The old inhabitants drove shafts and labyrinth-like cavities in many directions, leaving pillars of rock untouched to prevent the whole from caving in judging by the dimensions of these workings the quantity of ore extracted must have been very large even now immense masses of cupriferous rock are still to be seen [Rothenberg B., 1987].
Another mine, where caverns of about 80 feet had been emptied, seemed to have been destroyed because of depletion; the ore contained 18% of pure copper of high quality. These ores could be reduced without any additional flux; Rothenberg obtained 18% pure copper and an equal quantity of iron slag (Figs.5, 6).
On the hill above the other mine, we can see a small, 8 feet long obelisk of sandstone, on its side, facing the ground, it showed beautifully worked hieroglyphs.
According to the Egyptian tradition, these mine working were commemorated by royal hieroglyphic inscriptions and proto-sinaitic inscriptions of the middle kingdom. Some Nabataean inscriptions near the workings indicate that mining occurred here also in later periods. On the opposite side of the valley, about 200m., south of the slag heap, and right next to the ancient copper mines, a large hieroglyphic inscription of the Ramesside period, and a smaller inscription probably of the Middle Kingdom were discovered by Rothenberg. The Ramesses 11 inscription is of particular interest because it shows, on either side of the royal cartouche, two figures who are named as the (Royal Butler Neferronpe and the Captain of the Host, paenlevi) high ranking members of the Egyptian hierarchy, and clearly the joint leaders of an expedition to the Pharaonic mines and smelters of Bir Nasib [Rothenberg B., 1987].
To the northern west of Wadi Nasib located one of the oldest and important copper mine in south Sinai, it is Wadi Kharag mine. This mine is a very rough and irregular excavated adit, about 100 m., long, 10 m., wide and 2 m., high. It still shows in the region some fragments from smelting pots, slags, copper mineralization besides manganese and iron ores. The latter had apparently been left untouched by the ancient miners as they were only interested in the copper ore.
Here too, an Egyptian engraving was found (Fig. 7). It is a crude drawing of a shrine in which the Egyptian god Ptah (who is frequently associated with workmen, sits on a chair, holding what appears to be a sceptre.
Further up on the hill, right above the copper mine, a stela of Sesostris 1(1971-1928 BC) of the 12th Dynasty, was discovered by Rothenberg expedition [Rothenberg B., 1987].
About 150 m., further on, there was a typical Egyptian miners camp, similar to the camps of Maghara. It consisted of a long row of semi-detached rooms, constructed in a semicircle against a cliff. Engraved on this rock was a monumental hieroglyphic inscription of the 5th Dynasty (Fig. 8), which reads: the king of upper and Lower Egypt, Sahure, who lives forever- Thoth, Lord of Terror, who smites the Land of the Setjet {Asia}.

Evidently site of Wadi Kharag was a centre of old and middle kingdom copper mining and is, in fact, the earliest Pharaonic copper mining camp so for discovered in Sinai.
Although the copper ore is found in the divinity of the temple of Serabit El-Khadim, the indications about copper mining in this area are less clear [Gardiner A., Peet T., & Cerny J., 1955].
In 1987 Beit Arich [Beit-Arieh, I., 1987], discovered same opened casting molds, made of nubian sandstone and a base of below in the region of Serabit El-Khadim.
To the East and west of the temple at Serabit El-Khadim are to be seen the Mines which were carved in sandstone, there are in the neighbor-hood and we can fallow the old paths which lead to them [Charles B., and Dominique V., 1997], (Figs.9, 10).
Amang the cultural achievements related to Sinai is the earliest alphabetic script invented the so-called proto-Synatic or proto-Synatic inscriptions. These were found carved on the rocks at Maghara, Serabit El Khadem and Wadi Nasib. Scholars date them to the New Kingdom or perhaps even as early as the Middle Kingdom. The script was used by the miners during their work and habitation there. Some scholars state that this script was derived from hieroglyphics, and that it was the basis from which the Phoenicians invented their alphabet, which, in turn, is the mother of the modern western alphabet. Hopefully, archeologists will eventually shed some light on the steps that originally led to the formation of the script, its place in time, and other details [Saad El-Din M., Makhtar G., 1998].

METALLURGICAL STUDY

Egyptians probably drew their first supplies of copper as native metal and step by step from the abundant malachite stones found in south Sinai region and in the hills near Red Sea in the eastern desert.
Malachite was probably the first metallic ore smelted on an important scale. To smelt copper from malachite requires a temperature of at least 1083Oc and a reducing atmosphere. At one time archaeologists suggested that Neolithic man could have accidentally satisfied these metallurgical conditions when he used malachite stones to surround his camp fires [Konrad J. A., 1999].
The earliest known method of copper smelting in pottery kilns was pieced together based on bowl-shaped depressions in the earth of south Sinai area. Clay sides of these depressions were discolored by heat mixed with sand that filled and surrounded these depressions were bits of greenish copper slag, which contained small prills or blobs of metallic copper. Nearby sandstone blocks could be fitted together to form a furnace with a total depth of 80cm and width of 45cm. charcoal fuel made from desert a acacia trees and carbon dated at 3500 BC., was also found at the site. An iron oxide flux was probably gathered from nearby cliffs. Tests on this slag showed that furnace temperatures reached 1180-1350 Oc., these temperatures would have required some form of forced draft, possibly pumped into the furnace with draft, possibly pupped into the furnace with a goatskin bag and a clay tubes (Fig.11).
Along Wadi Kharag area we can see copper smelting slag, fragments of copper casting crucibles and furnace fragments accompanied by Egyptian sherds, it is a clear evidence of copper smelting in situ.
In the early 19th century, Ruppell noted a large slag heap at Bir Nasib, immediately next to the ancient well which is still up till now in the region (Fig.12).
Petrie 1906, surveyed this slag heap and his calculations of about 100,000 tons of slag, was recently confirmed by

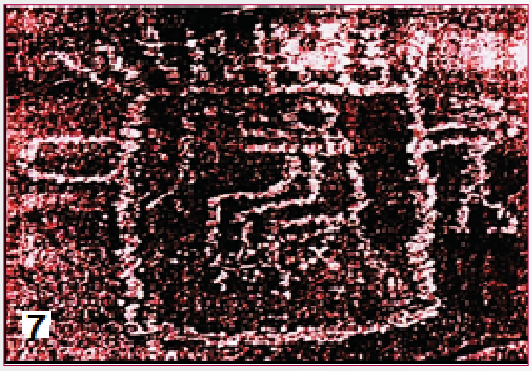


Fig. 7 - Shows ancient inscription represents the God Path sitting on a chair, Wadi Kharag area.

Fig. 8 - Shows a hierographic inscription from the 5th Dynasty, old kingdom, Wadi Kharag area.


Fig. 9 - Shows the temple of Hathor, Serabit El-Khadim.

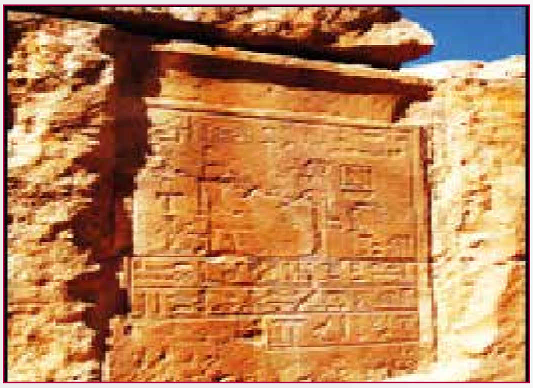


Fig. 10 - Shows a hieroglyphic tablet of the reigning Pharaoh above a mine in the region of Serabit El-Khadim.

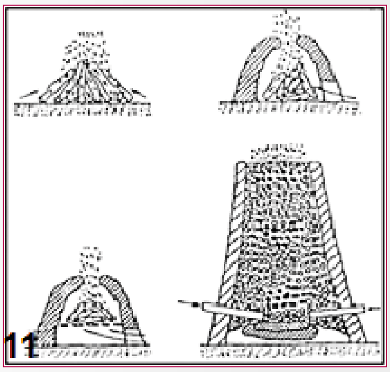


Fig. 11 - Shows the development of ancient smelting furnaces [Nofal A. A., Waly M. A., 1995].

Fig. 12 - Shows a huge hill of slag in Wadi Nasib.

Bachmann, who calculated the quantity of metallic copper produced at Bir Nasib as about 5000 tons- a huge quantity of copper for ancient times [Petrie W. M. F., 1906].

Bachmann also established that the Egyptian smelting slag at Bir Nasib is manganese rich of fayalite type, as which be expected considering the close relation between manganese deposits and copper mineralization typical of this area.

Rothenberg trial trenches in Bir Nasib area provided definitive stratigraphic and ceramic evidence for a new kingdom date for the site's top layers and it seems reasonable to assume that the lower layers belong to earlier periods of the pharaonic copper industries at Bir Nasib. These are probably related to the hieroglyphic and proto-Sinaitic rock engravings of the middle kingdom found on the hills surrounding the valley of Bir Nasib [Rothenberg B., 1987].

MATERIALS AND METHODS

A serial of different analytical techniques for ore and slag samples from the selected mines have been applied; the obtained information can be married up and exploited to determine exactly the main activity for each site.

Stereo microscopy (Nikon SMZ 800N) was used to obtain a rapid and representation characterization of the microstructure. The application of this technique is followed by XRF analysis to know the elemental distributions. For these investigation a Sky ray instrument (EDX-Pocket-111, Devices S/N: 760073) was used. Also X-Ray diffraction analysis was carried out for same samples were taken from the selected sites, by using a Philips X-Ray, Diffract meter type: pw1840 with Cu k& Radiation, to identify the compounds of these samples.

RESULTS

Precious results were obtained from this study, which can be summarized in the following sub paragraphs.

Stero Microscope

Stereo microscopy (Nikon SMZ 800N) was used to obtain a rapid and representation characterization of the microstructure. The samples were crass sectioned, embedded in epoxy resins in and polished with Sic paper of mesh 600-4000 (grain size 30-5 um).

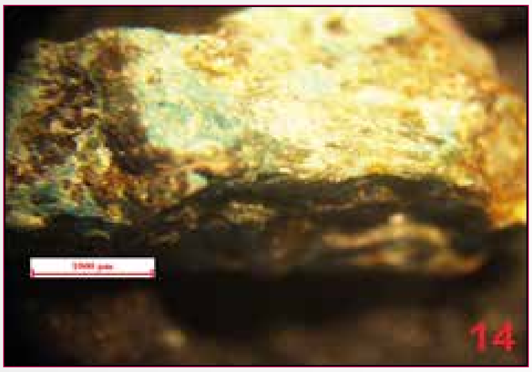
The surface morphology and mineralogical investigations for the selected samples have been observed by using this microscope, the obtained investigation results are shown in (Figs.13- 22).

X-Ray Fluorescence Analysis

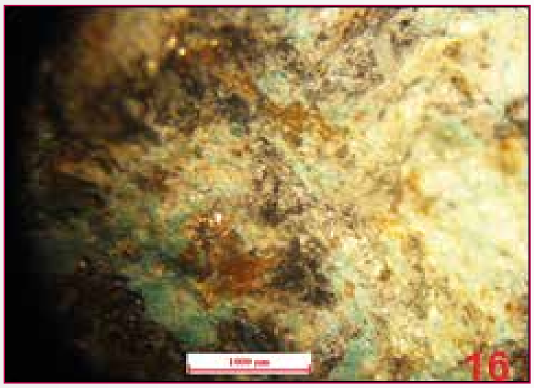
Eight samples from the selected sites were analyzed by this technique to determine its composition, by using: a Sky ray instrument (EDX-Pocket-111, Devices S/N: 760073). XRF analysis results are shown in (Table 1).

Elements % / *Samples*	Cu	Fe	Cl	P	Mn	Zn	Mg	Sr	Zr	Si	K	S	Ti	Ni	Al	Ca
Maghara Ore	5.07	10.90	0.00	0.08	0.11	0.00	13.85	0.00	0.00	15.52	0.00	6.74	0.10	1.32	3.31	1.31
	0.03	0.06	0.00	0.00	0.01	0.00	1.07	0.00	0.00	0.15	0.00	0.05	0.00	0.02	0.19	0.01
Maghara Slag	0.02	0.06	0.00	0.00	56.20	0.73	0.00	0.25	0.01	1.00	0.40	0.00	0.08	0.00	0.00	0.58
	0.01	0.03	0.00	0.01	0.15	0.01	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Kharag Ore	24.74	7.87	2.64	0.00	0.13	0.01	0.00	0.00	0.00	19.47	0.08	0.00	0.09	2.78	2.10	0.26
	0.08	0.05	0.03	0.00	0.06	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.03	0.25	0.00
Kharag slag	0.28	5.97	0.00	0.00	26.68	0.05	0.00	0.07	0.02	3.78	0.14	13.13	6.91	0.00	1.08	0.54
	0.01	0.10	0.00	0.00	0.10	0.00	0.00	0.01	0.00	0.11	0.01	0.09	0.02	0.00	0.25	0.01
Nasib Ore	8.48	12.62	0.00	0.00	0.18	0.01	12.37	0.00	0.00	17.85	0.02	0.68	0.07	1.75	2.12	0.25
	0.04	0.06	0.00	0.00	0.01	0.00	1.06	0.00	0.00	0.15	0.00	0.02	0.00	0.02	0.16	0.00
Nasib slag	0.41	6.22	2.55	0.00	46.85	0.34	0.00	0.23	0.01	2.98	0.27	0.00	0.43	0.00	0.00	0.68
	0.03	0.12	0.03	0.00	0.29	0.02	0.00	0.00	0.00	0.15	0.01	0.00	0.01	0.00	0.00	0.01
Serabit Ore	0.72	9.93	0.00	0.22	9.12	0.03	0.00	0.10	0.04	20.85	1.15	0.00	0.39	0.00	5.80	5.88
	0.01	0.06	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.14	0.01	0.00	0.00	0.00	0.17	0.01
Serabit Slag	0.00	9.13	1.84	0.24	0.17	0.01	0.00	0.06	0.05	25.16	1.15	0.00	1.49	0.00	8.82	3.71
	0.00	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.14	0.01	0.00	0.00	0.00	0.17	0.01

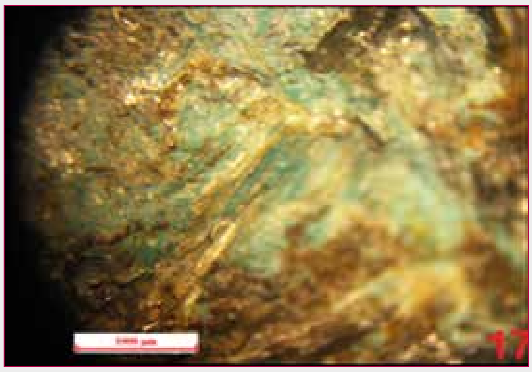
Tab. 1 - Shows XRF analysis results for ore and slag samples from south Sinai region.



Figs.13, 14 - Show the green-blue spots in a predominant brown surface of ore sample from Wadi Al-Maghara.

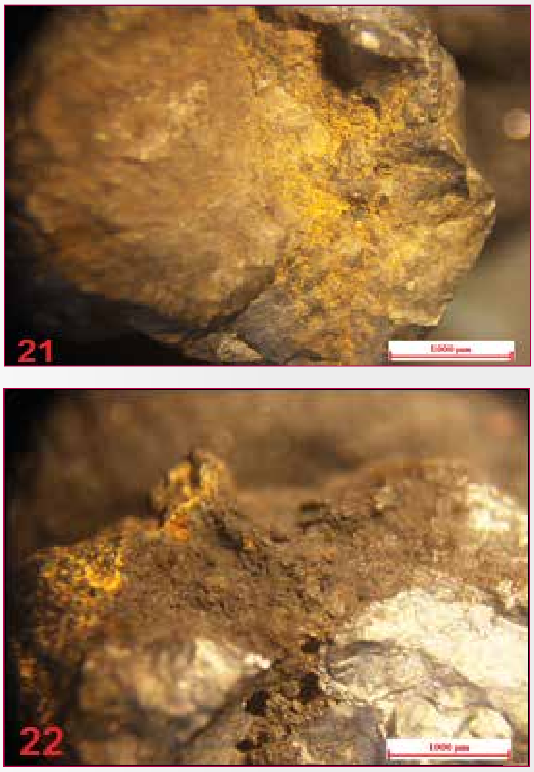


Figs.15, 16 - Show the green-blue spots in a predominant brown surface of an ore sample from Wadi Kharag.



Figs.17, 18 - Show the green-blue spots in a predominant brown surface of ore sample from Wadi Al-Nasib.

Figs. 19, 20 - Show the green-blue spots in a predominant brown surface of ore samples from Serabit El-Khadem.



Figs. 21, 22 - Show the different colours and composition of a slag sample from Wadi Al-Nasib.

DISCUSSIONS

Detailed investigations and analysis that were done in this paper led to various considerations which can be summarized in the next points.

Stereo Microscope

The surface morphology of the samples has been first observed by using this microscope showed that there are green-blue spots in a predominant brown surface. These green-blue deposits represent the ore of copper in the rock samples which were taken from the selected areas in south Sinai, also we can notice that the density of these deposits colours were differ from sample to another as shown in (Figs. 13-20).

Also stereo microscope examinations of the cross section of the ore samples revealed a heterogenous structure of the composition, the difference in composition clearly visible in the images.

We can see the green/blue colors of copper ores, especially Malachite and Azurite, behind this layer, there is a layer of Cuprous Oxide which appears in red/brown and orange purities behind them, these compounds are contacted with the Silica, Iron Oxides and others. The analysis results by XRF and XRD (tables 1, 2) confirmed this detected.

Investigation for the slag sample, which was taken from Wadi El-Nasib area, allowed us to see different colours for the surface of the sample consists of yellow/ brown and back, this indicates a bout the difference in composition, as shown in Figures (21-22).

X-Ray Diffraction Analysis (XRD)

X-Ray diffraction analysis was carried out for five samples (four ore samples and one slag sample) were taken from the selected sites, by using a Philips X-Ray, Diffract meter type: pw1840 with Cu k& Radiation. The obtained diffraction scan given in (Figs.23-27), and the identified compounds represented in (Table 2).

XRF Analysis

XRF analysis results in (table 1), show the changes in composition of the elements in the rock of the four sites (ore samples). It can be clearly seen for the two samples from Wadi El-Nasib and Wadi kharag that the copper content increases in the rock (8.48 for Wadi El-Nasib and 24.74 for Wadi kharag), but it decreases in the rock of Wadi El-Maghara and

Samples	Compounds		
Major		Minor	Traces
Maghara Ore	Lime (CaO)	Piustite (FeO) Kaolinite($Al_2Si_2O_5(OH)_4$ Tin Oxide (SnO_2) Quartz (SiO_2)	Tephroite (Mn_2SiO_4) Copper Zinc(CuZn)
Kharag Ore	Atacamite($Cu_2(OH)_3Cl$)	Iron (Fe) Aragonite ($CaCO_3$) Andradite ($3CaO.Fe_2O_3.3SiO_2$) Nentokite (CuCl) Copper Zinc Tin Sulfide (Cu_2ZnSnS_4)	Chalcocite Cu_2S Tin Oxide SnO_2
Al Nasib Ore	Copper (Cu) Cuprite (Cu_2O)	Tephroite (Mn_2SiO_4)	Piustite (FeO) Calcite ($CaCO_3$) Atacamite($Cu_2(OH)_3Cl$) Deweylite ($4MgO_3.SiO_2.6H_2O$) Silver Cyanate (AgOCN)
Serabit Al-KhademOre	Lime (CaO) Paratacamite($Cu_2(OH)_3Cl$)	Piustite (FeO) Tephroite (Mn_2SiO_4)	-------------
Al Nasib Slag	Orthoclase ($KAlSi_3O_8$)	Quartz (SiO_2) Silicon Oxide (SiO_2) Calcite ($CaCO_3$)	Aluminum Oxide (Al_2O_3) Tephroite (Mn_2SiO_4) Andradite ($3CaO.Fe_2O_3.3SiO_2$)

Tab. 2 - Shows XRD analysis results of ore and slag samples from the selected areas.

Serabit El-Khadem (5.07 for Wadi El-Maghara and 0.72 for Serabit El-Khadem), whereas the amount of Mg increases in the rock of Wadi El- Maghara (13.85) and Wadi El-Nasib (12.37), the content of S increases in the rock of Wadi El-Maghara (6.74). The higher amount of Al in the samples of Wadi El-Maghara (3.31) and Serabit El-Khadem (5.80) can be clearly seen, whereas the amount of Al decreases in the Rock of Wadi Kharag (2.10) and the Rock of Wadi El-Nasib (2.12), also the element of P was existence in the ore sample (0.22) and the slag sample (0.24) of El- Maghara.
The high concentration of Fe in the ore samples of Wadi El-Maghara (10.90), Wadi El-Nasib (12.62), Serabit El-Khadim (9.93) and Wadi Kharag (7.87) is obviously seen (Figs.13-20).
The amount of Ca was found in the ore and slag samples of Serabit El-Khadem (5.88), (3.71) and it was existence in a small amount in the ore of Al- Maghara (1.31), these results are confirmed and supported by XRD analysis results.
XRF analysis revealed that there are many elements are found in ore samples of Serabit El-Khadem and Wadi El-Maghara such as Cu, P, Fe and Al. Also the analysis show a higher copper content in the samples of Wadi Kharag, Wadi El-Nasib and Wadi El-Maghara, but it is existence in very small amount as purities in Serabit El-Khadem ore sample (0.72).
These results indicate that the main elements of the chemical composition of turquoise are found obviously in Serabit El-Khadem and El- Maghara more than in Wadi El-Nasib and Wadi Kharag. In contrast the copper is found more clearly in Wadi Kharag, Wadi El-Nasib and also in Wadi El-Maghara.
Turquoise ($Cu\ Al_6\ (PO_4)_4(OH)_8 \cdot 4H_2O$) is a semi- precious stone, it is a secondary mineral occurring in the potassic alteration zone of hydrothermal porphyry copper deposits, turquoise is formed by the action of meteoric waters, usually in arid regions, on aluminous igneous or sedimentary rocks (as vein filling in volcanic rocks) and phosphatic sediments [www.mindat.org/min-4060.html]. It has many colours such as sky-blue, bluish green, apple green or greenish grey and the hardness is 5-6. To mine the turquoise, the Egyptians would hollow out large galleries in the mountains, carving at the entrance to each a representation of the reigning pharaoh a symbol of the authority of the Egyptian state over the mine and its yield. Although many of the region's pharaonic reliefs were destroyed by a British attempt to re-open the mines in the mid-nineteenth century, the excellent bas relief of Pharaoh Sekhemkhet on the east face of Gebel Maghara survives. Also at Serabit Al-Khadem are the ruins of a temple dedicated to Hathor, containing a large number of bas-reliefs and carved steals [www.geographia.com/egypt/sinai/serabit.htm].

XR Diffraction Analysis

X-ray analysis showed the nature and the composition of ore and slag samples as it shown in (Figs.23- 27 and Table 2). The data obtained declared that Al-Maghara ore, forms mainly of Lime (Ca O), minor of Piustite (FeO), Kaolinite ($Al_2\ Si_2\ O_5\ (OH)_4$, Tin Oxide (SnO_2), Quartz (SiO_2) and traces of Tephroite (Mn_2SiO_4) and Copper Zinc(CuZn). Kharag ore forms mainly of Atacamite($Cu_2(OH)_3Cl$), minor of Iron (Fe), Aragonite ($CaCO_3$), Andradite ($3CaO.Fe_2O_3.3SiO_2$), Nentokite (CuCl), Copper Zinc Tin Sulfide (Cu2ZnSnS4), and traces of Chalcocite Cu_2S and Tin Oxide SnO_2. Al-Nasib ore forms

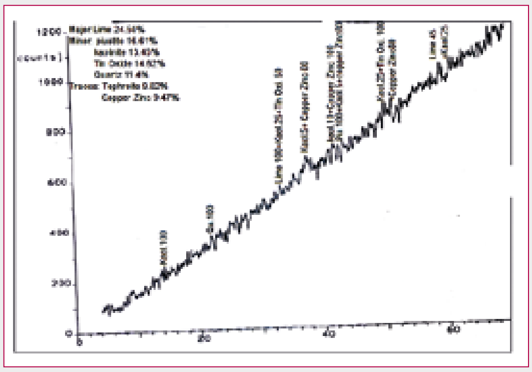


Fig. 23 - Shows XRD scan for ore sample from Wadi Al-Maghra.

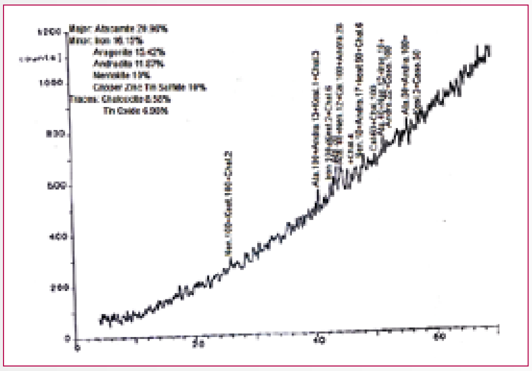


Fig. 24 - Shows XRD scan for ore sample from Wadi Kharag.

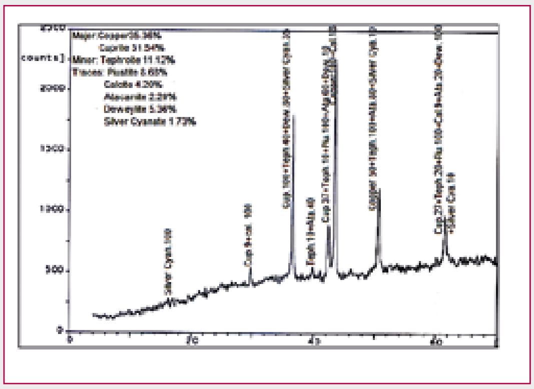


Fig.25 - Shows XRD scan for ore sample from Wadi Al-Nasib.

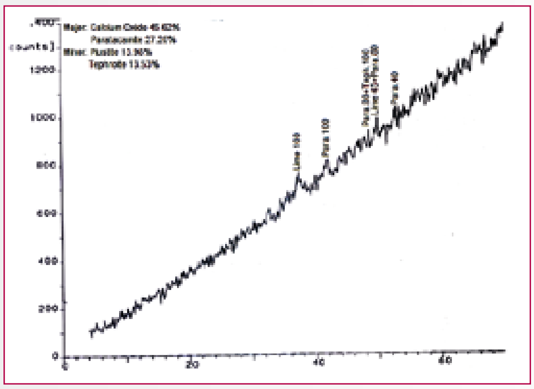


Fig. 26 - Shows XRD scan for ore sample from Serabit Al-Khadem area.

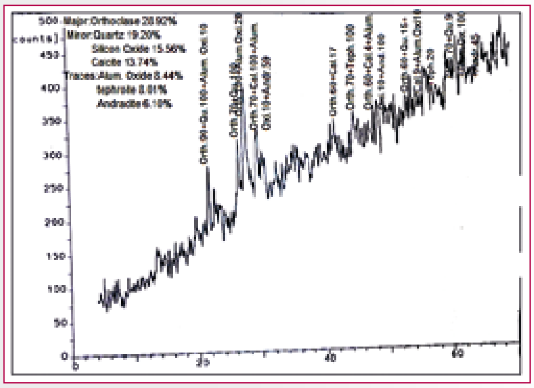


Fig. 27 - Shows XRD scan for slag sample from Wadi Al-Nasib.

mainly of Copper (Cu), Cuprite (Cu_2O), minor of Tephroite ($Mn2SiO_4$), and traces of Piustite (FeO), Calcite ($CaCO_3$), Atacamite($Cu_2(OH)^3Cl$), Deweylite ($4MgO_3.SiO_2.6H_2O$), Silver Cyanate (AgOCN). Serabit Al-Khadem ore forms mainly of Lime (CaO), Paratacamite($Cu_2(OH_{)3}Cl$), minor of Piustite (FeO) and Tephroite (Mn_2SiO_4).

The presence of copper as a major element in the rock of Wadi El-Nasib indicates that the rock of this area was rich with the deposits of copper more than others, this result confirms the results of Stereo microscope investigations and XRF analysis, and also it confirms the previous studies which were occurred by the pioneers scientists and researchers.

Cuprite was found as a major element in the rock of Wadi El-Nasib, it is the most widely occurring alteration mineral of copper. Cuprite is formed as a result of reaction between copper deposits that present in rock and oxygen.

The presence of Lime (CaO) as a major element in the rock of Wadi El-Maghara and Serabit El-Khadem, also the presence of Calcite ($CaCO_3$) as a minor compound in the rock and slag of Wadi El-Nasib confirmed Stereo microscope investigations and XRF analysis results (Figs.13-22 &Table 1).

The existence of Piustite (FeO), Kaolinite($Al_2Si_2O_5(OH)_4$ and Quartz (SiO_2), as minor compounds in the rock of Wadi El-Maghara and Serabit El-Khadem helped in formation of turquoise in those two areas, these compounds include the main elements, which composed turquoise.

From XRD analysis results we can say the indications about the existence of the main compounds of turquoise composition such as P_2O_5, Al_2O_3, Fe2O$_3$ and CuO are found obviously in the rock of Serabit El-Khadem and El- Maghara, but the indications about copper mining in Serabit El-Khadim are less clear. In contrast the copper is found more clearly in Wadi Kharag, Wadi El-Nasib and less in wadi El-Maghara. These results confirm XRF analysis (Table 1).

Metallurgy investigations

In the early 19th century, Ruppell noted a large slag heap at Bir Nasib, immediately next to the ancient well which is still up till now in the region. Petrie 1906 [Petrie W. M. F., 1906], surveyed this slag heap and his calculations of about 100,000 tons of slag, was recently confirmed by Bachmann, who calculated the quantity of metallic copper produced at Bir El-Nasib as about 5000 tons- a huge quantity of copper for ancient times.

Bachmann also established that the Egyptian smelting slag at Bir El-Nasib is manganese rich of fayalite type, as which be expected considering the close relation between manganese deposits and copper mineralization typical of this area [Rothenberg B., 1987].

In 1967 Rothenberg investigated this slag; it was turned out to be natural nodules of Hematite and manganese, common in the Nubian sandstone horizon of Sinai and Arabah [Rothenberg B., 1970, Rothenberg B., 1972]. Rothenberg surveys 1978, in Bir Nasib cleared several trial trenches at different parts of the slag heap, utilizing some of the large pits dug previously by treasure hunting Bedouin [Rothenberg B., 1987]. He found a scarab and glass bead in the top layer of the slag dating according to Schulman to the new kingdom, also there was locally manufactured pottery of typical Egyptian shapes, although a recent investigation of slags from Bir El-Nasib in south Sinai show the production of unfluxed copper in pre-dynastic times and the use of iron ore fluxes by some unspecified times during the old kingdom.

Rothenberg trial trenches in Bir El-Nasib area provided definitive stratigraphic and ceramic evidence for a new kingdom date for the site's top layers and it seems reasonable to assume that the lower layers belong to earlier periods of the pharaonic copper industries at Bir El-Nasib. These are probably related to the hieroglyphic and proto-Sinaitic rock engravings of the middle kingdom found on the hills surrounding the valley of Bir El-Nasib.

My investigations and researches in that area confirmed Rothenberg results, I found big amounts of ancient metallurgy tools spired on the surface of the region everywhere, such as different kinds of pottery, fragments of glass and slags, debris of pottery vessels in different shapes and styles, also a lot of proto-Sinaitic inscriptions engraved on the rock surfaces.

Also I noticed a lot of holes in situ (hole in the ground with the depth of 70-80 cm), whereas the first smelting processes of copper were occurred. After that copper smelting developed from the initial use of small (hole in the ground) or bowl furnaces to advanced, technologically sophisticated shaft furnaces.

A long Wadi Kharag area we can see copper smelting slag, fragments of copper casting crucibles and furnace fragments accompanied by Egyptian sherds, it is a clear evidence of copper smelting in situ.

Stereo microscope investigations (Figs 21, 22) show the different colours and composition of the slag sample from Wadi El-Nasib.

XRF analysis results of the slag samples (table 1), show that copper content in the slag of Wadi El-Maghara site has decreased to (0.02) in comparison to the slag of Wadi El-Nasib (0.41), and to (0.28 for the slag of Wadi Kharag, but the analysis didn't indicate any trace of copper content in the slag of Serabit El-Khadem (0.00). While Mn concentration increased in the slag samples of Wadi El-Maghara to 56.20, in the slag of Wadi Al-Nasib to (46.85) and in the slag of Wadi Kharag to (26.68), but it decreased in the slag sample of El- Serabit to (0.17). Fe dramatically increased in the slag of Serabit El-Khadim to (9.13), in the slag of Wadi El-Nasib to (6.22) and in the slag of Wadi Kharag to (5.97). Also the element of P was existenced in the slag sample of Wadi El-Maghara to (0.24).

The amount of Ca was found in the ore and slag samples of Serabit El-Khadem (5.88), (3.71), and it was existence in a small amount in the ore of El- Maghara (1.31), these results are confirmed and supported by XRD analysis results.

X-ray analysis results of Wadi Al-Nasib slag sample declared that it forms mainly of Orthoclase (KAlSi3O8), minor of Quartz (SiO2), Silicon Oxide (SiO2), Calcite (CaCO3), and traces of Aluminum Oxide (Al2O3), Tephroite (Mn2SiO4) and Andradite (3CaO.Fe2O3.3SiO2) (Fig. 27& table 2).

John F. Merkel occurred an experimental simulations and reconstruction of ancient copper smelting generated new data against which to evaluate the archaeo-metallurgical evidence. He proved that during over 2000 years from the chalcolithic period through the late bronze age, copper smelting developed from the initial use of small (hole in the ground) or bowl furnaces to advanced, technologically sophisticated shaft furnaces capable of operating with large slag weights up to 25kg, the best preserved examples of new kingdom copper smelting furnaces with slag tapping capabilities are at Timna [John F. M., 1995, John F. M., 1990]. Also Rothenberg and others studied the ancient Mining and Metallurgy activities in Timna, they studied each step in the ancient production of copper, from mining to final casting, is present at Timna [Rothenberg B., 1983, Rothenberg B., 1985, Rothenberg B., 1990, Rothenberg B., 1995, Lupu A., and Rothenberg B., 1970, Bachmann, H. G., 1978, Craddock P. T., 1980, Craddock P. T., 1988].

CONCLUSION

The study proved that the cisterns were in fact mining shafts and also the gallery openings in the sandstone walls of valleys were true mining quarries dispersed surrounding the main area of mining in Serabit El-khdim and Wadi El-Nasib.
The investigations carried out on same Ore and Slag samples from the selected four sites in south Sinai, have shown that the combination of Stereo microscope, XRF and XRD analysis is well suitable for the characterization of Ore and Slag samples.
Results of investigations of sites in south Sinai cleared the difference between the sites of turquoise and the sites of copper.
The investigations and analysis obtained results declared that, the indications about the existence of turquoise deposits in the rocks of Serabit El- Khadem and Wadi El-Maghara are clearer; but the indications about copper mining in Serabit El-Khadim are less clear. In contrast the copper is found more clearly in Wadi Kharag, wadi El -Nasib and less in wadi El-Maghara.
From the previous results we can deduced that Serabit El-Khadem was the main area to get turquoise during the middle and new kingdom, but Wadi El-Maghara was the oldest area to have Turquaise and copper in ancient ages. The others two areas Wadi Kharag, Wadi El-Nasib were rich mines to have the copper.
After all of these studies we can deduce that Wadi El- Nasib area was used as a Centre of copper smelting and it was the largest in the old world.

ABSTRACT

Egyptians probably drew their first supplies of copper as native metal and step by step from the abundant malachite stones found in south Sinai region and in the hills near Red Sea in the eastern desert.
There was integrated between the mines of copper and the mines of turquoise in the literature studies of south Sinai, especially in wadi El-Maghara, Wadi El-Nasib, Wadi Kharag and serabit El-Khadim, so this study tries to clear this point and determine exactly the mines of copper and the mines of turquoise. The study aims to investigate the source zones for copper in south Sinai, Egypt during the pharaonic ages, to determine the extent of a manufacturing centre and its position and to know the systems of metallurgical works, fire places, furnaces, etc.
To achieve that the study had two main aspects: first, a serious survey to investigate of the mines of south Sinai was a cured; several different mining features were randomly chosen for excavation such as open cisterns, plates and galleries, collected every small things and fine details of the mining technology used at these sites.
Secondly: Careful investigations by a serial of different analytical techniques for Ore and slag samples from the selected mines have been applied; the obtained information can be married up and exploited to determine exactly the main activity for each site.

KEYWORDS

SOUTH SINAI; COPPER ORE; TURQUOISE; SLAG; ANALYSIS; STEREO MICROSCOPE; XRF; XRD

AUTHOR

MOHAMED M. MEGAHED
mmm03@fayoum.edu.eg
FACULTY OF ARCHAEOLOGY, FAYOUM UNIVERSITY, EGYPT

REFERENCES

Bachmann, H. G. (1978) *The phase composition of slags from Timna site 39*, archaeo-metallurgy, IAMS Mongraph no. 1, pp. 21-23.
Beit-Arieh, I. (1987) *Canaanites and Egyptians at Serabit El Khadim*, In Rainly, A., Ed., Egypt, Israel, Sinai, Tel Aviv, p. 59.
Charles B. & Dominique V. (1997) The Middle Kingdom Temple of Hathor at Serabit el-Khadim, in *The temple in Ancient Egypt, New discoveries and recent research* (S. Quirke eds.), British museum, U.K., p. 82-89.
Craddock P. T. (1980) *The composition of copper produced at the ancient smelting camps in the Wadi Timna*, Israel, British museum Occasional paper no. 20, pp.165-175.
Craddock P. T. (1988) The composition of Metal artifacts from site T200 and from adjacent sites in the Wadi Timna andArabah, In *The Egyptian Mining temple at Timna* (B. Rothenberg ed.,) London, Institute for Archaeo- Metallurgical studies, Institute of Archaeology, pp. 169-181.
El Shazly S. M. (1959) *Recent Investigations of Egyptian Copper Deposits*, Symp., Appl., Geology in the Near East, Ankara 1955, Unesco, Cairo.
Gardiner A., Peet T. & Cerny J. (1955) *The Inscriptions of Sinai*, Vol. 2, London, P.39.
Gerald F., Vladimir H. & Antonin P. (1995) Application of Geophysics in the research of ancient mining in Egypt, In *Proceedings of the first international conference on Ancient Egyptian Mining &Metallurgy and Conservation of Metallic Artifacts*, 10-12 April, Cairo, Egypt, p. 35.
John F. M. (1990) Experimental reconstruction of bronze age copper smelting based on archaeological evidence From Timna, In *The ancient metallurgy of copper* (B. Rothenberg ed.), IAMS, London, pp. 78-122.
John F. M. (1995) Simulation experiments on Egyptian new kingdom copper smelting, In *Proceedings of the first international conference on Ancient Egyptian Mining& Metallurgy and Conservation of Metallic Artifacts,* Cairo, Egypt, 10-12 April, pp.79-87.
Konrad J. A. (1999) *Copper, its trade, Manufacture, Use and Environmental Status*, International Copper Association, LTD, USA, p.1.
Lupu A. & Rothenberg B. (1970) The extractive Metallurgy of the early iron age copper industry, In *The Arabh, Israel*, Archaeologia Austriaca, Heft 47, pp.91-130.
Muhly J. (1984) *Bibliotheca Orientalis XLI*, p. 290.
Nofal A. A. & Waly M. A. (1995) Foundry Technology of Ancient Egypt, In *The 1st Conference on Ancient Egyptian*, Cairo, Pp. 175 – 181.
Paul T. N., & Ian S. (2000) *Ancient Egyptian Materials and technology*, Cambridge University Press, p. 152.
Petrie W. M. F. (1906) *Researches in Sinai*, London.
Rothenberg B. (1970) *An Archaeological Survey of South Sinai*, first season, P.E.Q.102, p. 4-29.
Rothenberg B. (1972), *Sinai Explorations 1967-1972*, Yearbk. Mus., Haaretz, Tel Aviv, p. 31-42.
Rothenberg B (1983) Exploration and Archaeo-metallurgy, In *The Arabah valley*, Bulletin of the Metals museum, Vol. 8, pp.1-16.
Rothenberg B. (1985) Copper smelting furnaces, In *Arabah, Israel: The Archaeological Evidence*, British Museum Occasional paper no. 48, pp.123-150.
Rothenberg B. (1987) *Pharaonic copper Mines in south Sinai*, IAMS, London, no. 10/11, pp.1-7.
Rothenberg B., (1990) Copper smelting furnaces, tuyeres, slags, iongot- mouds and ingots, In *The ancient Metallurgy of copper* (B. Rothenberg ed.,) London: IAMS, pp.1-72.
Rothenberg B. (1995) Archaeo-metallurgical survey methodology, In *Proceedings of the 1st international conference on ancient Egyptian Mining, Metallurgy and Conservation of Metallic Artifacts*, Cairo, Egypt, 10-12 April, pp. 59-77.
Saad El-Din M., Makhtar G. (1998) *Sinai, The Site & The History*, New York University Press, p. 40.

https:// www.sinaiwikipedia
https://www.mindat.org/min-4060.html
http://www.geographia.com/egypt/sinai/serabit.htm

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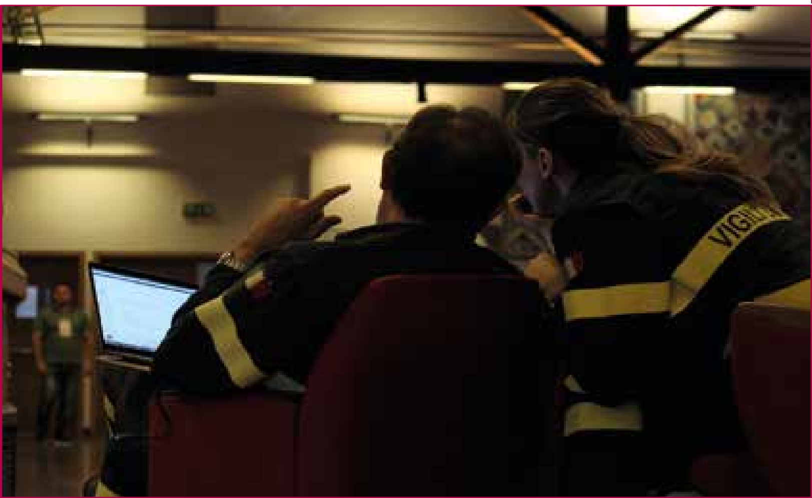

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