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Mineralogical and Geochemical Studies on Manganese Deposits at Abu Ghusun Area, South Eastern Desert, Egypt

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Abstract

The Abu Ghusun manganese deposit is subjected to mineralogical and geochemical studies in order to elucidate its petrogenesis. Manganese occurs as sheets, lenses, encrustation and fracture filling within clastic sediments of the Abu Ghusun Formation of Oligocene age. The mineralogical, and geochemical data confirmed by microscopic investigations, X-ray diffraction (XRD), infrared absorption spectrometry (IR), differential thermal analyses (DTA), thermo gravimetric (TG), environmental scanning electron microscope (ESEM) and chemical analyses of major and trace elements. The results showed that Abu Ghusun manganese deposits include two different ore types: 1- massive ore and 2-manganiferous sandstone ore. The main mineralogical composition of manganese ore types are pyrolusite, psilomelane, rhodochrosite and hematite. The gangue minerals are quartz, feldspar, rock fragments, apatite and calcite. The geochemistry of Abu Ghusunmanganiferous sandstone and massive ore types indicated that they are rich in Cr (60, 58 ppm), Zn (132, 200ppm), Ba (12050, 1414 ppm), Sr (3400, 353 ppm) and V (156, 196 ppm) respectively. The discrimination diagrams based on major and trace elements also indicated that Abu Ghusun manganese deposit is a hydrothermal origin. The manganiferous sand stone (40.9% MnO_2) and the massive ore types (48.1 % MnO_2) lie in the field of high grade B..

1. Introduction

Abu Ghusun manganese area lies at the intersection of 35° 12' E longitude and 24° 26' N latitude. It can be easily reached through Mersa Alam-Abu Ghusun asphaltic road 1 km further west direction from Abu Ghusun village (Fig. 1).

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Manganese ore deposits occur in a great diversity of host rocks such as carbonate, siliciclastic, volcanic and metamorphic rocks and range in ages throughout geologic history.

Marine manganese oxide deposits are classified based on their mineralogy, composition and tectonic settings as hydrogenous, diagenetic and hydrothermal deposits (Hein et al., 1997).

Hydrogenous manganese deposits are those slowly precipitated from seawater (Ingram, et al., 1990) and composed of amorphous iron and are poor in manganese oxide. The Mn/Fe ratio is ~1 and Ni and Cu are represented by high concentrations (>3000 ppm).

Diagenetic manganese deposits occur as nodules and are precipitated from hydrothermal solutions or pore waters within altered sediments (Klinkhammer et al., 1982 and Manheim et al., 1988).

Hydrothermal manganese oxide deposits are directly precipitated from low-temperature hydrothermal solutions in continental environments or sedimentary exhalative manganese mineralization deposited in marine environments (Ingram et al.; 1990, Nicholson; 1992a and Hein et al.; 1997). These deposits are generally of laminated and strata bound forms.

Diagenetic and hydrothermal deposits are characterized by high Mn/Fe ratios (Hein et al., 1994 and 1996). Although there are some similarities between these two deposit types, they are mostly distinguished with their morphologic, tectonic and growth rates (Kuhn et al., 1998).

Egyptian Manganese ores are located in two major localities beside other several small occurrences. The economic deposits of manganese are Um Bogma in Central Western Sinai and Elba in South Eastern Desert. The reserve of these ores in Um Bogma is about 1.7 million tons (Fahim et al., 2013). Small occurrences occur in mialik, Kalahin (G. Duwi), Wadi Abu Tarief and Wadi Abu Shar.

The present work deals with the geolgoy, mineralogy, and geochemistry of the different ore types and to throw some light on the origin of the ore and the paragenesis of its minerals.

2. Geology of manganese ores

The manganese deposits are enclosed within clastic sediments of the Abu Ghusun Formation of Oligocene age. These clastic sediments consist, at the base of, gypsiferousclaystones (60 cm thick) followed by two isolated conglomeratic sandstone beds (48 and 14 cm thick). Manganese deposits occur as irregular sheets, encrustation and fracture filling or rounded to stretched lenses varying from 15 cm up to 100 cm in diameter, occupying the same stratigraphic level of the Abu Ghusun Formation (Fig. 2). These lenticular bodies are connected or disconnected. The exposed manganese beds are represented by three main layers dipping (43°/NE) and alternating with clastic sediments of the host rocks (Fig.3). The true thickness of these beds are (40 cm, 14 cm and 40 cm) arranged respectively from bottom to top. Structurally, the area was affected by minor faults striking (120°) with short distance displacement

3. Materials and analytical methods

A great number of samples of manganese ore and surrounding host rock were collected from the manganese mine and subjected to detailed petrographical, mineralogical, and geochemical investigations. Polished sections were prepared and investigated using a reflected light microscope. Samples powders were analyzed for their mineralogical composition using X-ray powder diffraction (XRD) technique using (PW 3710 Based) diffract meter type with Cu-K radiation (λ=1.78 Å). Infrared absorption analyses (IR) of manganese ore powdered samples were run using Perkin-Elmer 683 infrared spectrophotometer at the Central Laboratories of Tanta University.

Differentional thermal analyses (DTA)of manganese ore powdered samples were done using Shimadzu DTA-50 H and TGA-50 H with α-Al_2O_3 as a reference material at the Central Laboratories of Natural Resources of Egyptian Authority. Morphology and chemistry of manganese minerals were investigated by ESEM-attached with EDX, Philips XL 30 ESMA. Chemical analyses of selected samples were performed. XRD, SEM and the chemical analyses were performed at the Laboratory of Nuclear Materials Authority, Qatameia, Cairo. Major oxides and trace elements of selected samples were performed using different wet chemical analytical techniques, at the Laboratory authority, Qatameia, Cairo.

4. Results

4.1. Microscopic Examination

The manganese deposits in this study are classified into two types depending on the field observation, color variation, petrography and XRD technique (Table 1).

1. M**assive ore type** is fine-grained with dull black appearance. It consists mainly of pyrolusite (60 in vol.%), psilomelane (30 in vol.%), associated with small of hematite . Gangue minerals are represented by epigenetic quartz veinlets (8 in vol.%), apatite (2 in vol %) and calcite(<1 in vol %) within the interstitial spaces of the ore minerals (Fig. 4A).

2. Manganiferous sandstone ore-type is medium to coarse grained, it consists mainly of pyrolusite (25 in vol. %), psilomelane (15 in vol. %), rhodochrosite (5 in vol. %) and rare hematite. Detritus grains include syngenetic quartz (35 in vol. %), feldspar (12 in vol. %), rock fragments (6 in vol. %), and rare calcite and apatite (Fig. 4B).

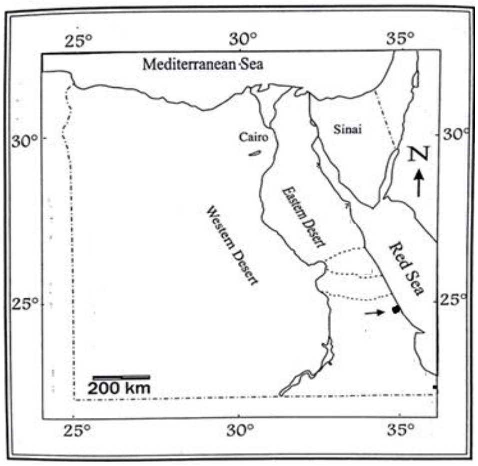


Fig.1: Map showing the location ofAbu Ghusun manganese ore.

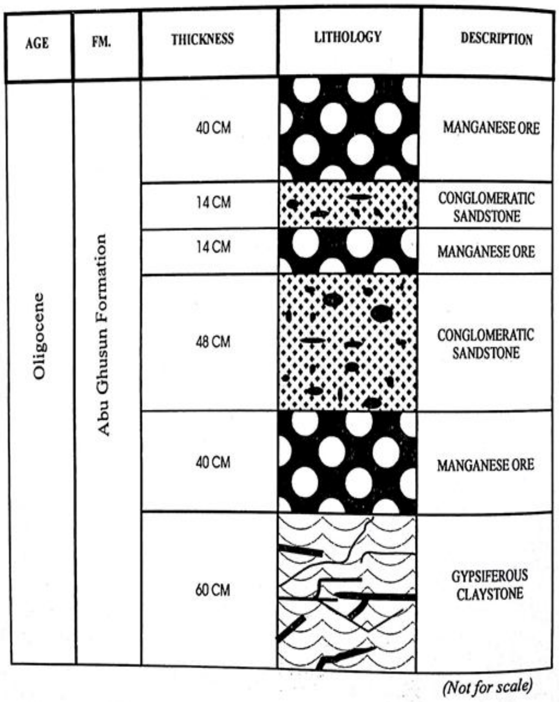


Fig. 2: Composite litho-straigraphic section at the outcrop of Abu Ghusun manganese mine.

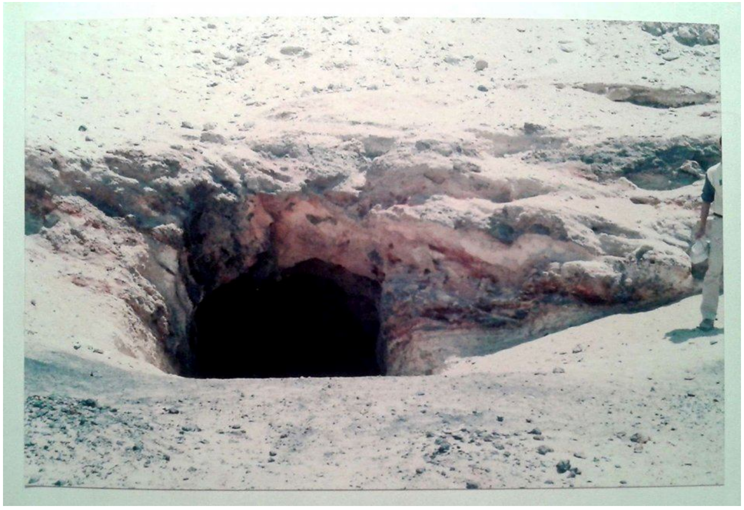


Fig. 3: Panoramic view of Abu Ghusun manganese mine

Table.1: The ore minerals, gangue minerals and the main textures in the different manganiferous ore types of Abu Ghusun deposits.

Ore type/ Percentage	Essential >or equal 10%		Minor <10%-1%		Rare Less than 1 %		Main Texture
	Ore mineral	Gangue Mineral	Ore minerals	Gangue Minerals	Ore minerals	Gangue Minerals	
Massive ore type	Pyrolusite Psilomelane	-------	Hematite	Quartz Apatite	---------	Calcite	1-Open space filling 2-Vein replacement 3-Deformation
Manganiferous s ore type	Pyrolusite Psilomelane	Quartz plagioclase	Rhodo-chrosite	Perthite Microcline Rock fragments	Hematite	Calcite Apatite	1-Open space filling 2-Rim replacement 3-Colloform 4-Deformation

Petrographic investigations of Abu Ghusun manganese ores indicated that manganese minerals occur mainly as pyrolusite, psilomelane while rhodochrosite and hematite occur as minor constituents. Quartz, feldspars, rock fragments, apatite and calcite are the essential gangue minerals.

Pyrolusite occurs as white to light brown massive or fine grained-aggregates associated with the gangue minerals in massive ore type or coats the detritus grainsinmanganiferous sandstone ore type. Psilomelaneoccurs as darker very fine aggregates associated with pyrolusite. Rhodochrosite and hematite are recorded by XRD in most of the studied manganiferous sandstone ore type.

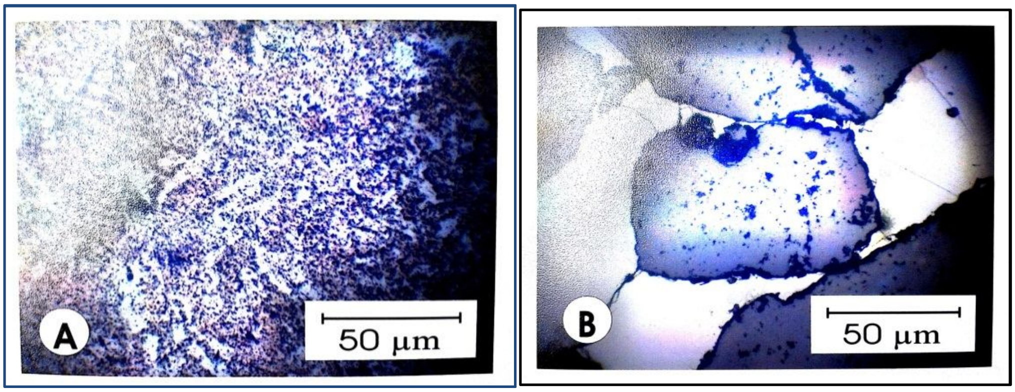


Fig. 4: Photomicrographs showing:

(A): Massive ore type (R.L). (B): Manganiferous sandstone ore type(R.L.)

Quartz is the main gangue mineral in the studied manganese ore, occurs as epigenetic veinlets or small grains filling the interstitial space between manganese minerals. Syngenetic quartz occurs as detrital grains enveloped within manganese matrix in manganese sandstone ore type. Quartz grains are colorless to yellowish grey, frequently moderate to poorly sort with angular to sub-rounded edges (Fig.5A).

Feldspars are recorded in all studied samples of mangaiferous ore type. They are represented by plagioclase, microcline and perthite. Rock fragments are common in manganiferous ore type with different dimentions up to 2 mm in diameter (Fig. 5B).Apatite is common in massive ore type and rare in manganiferous sandstone ore type. It is found as prismatic or needle-shaped crystals scattered within the ore minerals. Calcite occurs as rare constituent recorded by using XRD technique in few samples belong to manganiferous sandstone ore type. The microscopic investigation of Abu Ghusun manganese deposits indicated that the main textures are represented by open-space filling, replacement, colloform and deformation textures (Figs.5C- F).

4.2. Mineralogical Studies

X-ray diffraction analysis (XRD) indicated the presence of several manganese and gangue minerals in the manganese ores from Abu Ghusun deposits (Table 2). Manganese minerals are dominated by a mixtures of Mn oxides, hydroxide and carbonate minerals.

Mn oxide minerals are represented by pyrolusite (MnO_2) which was identified by its characteristic peaks at d=3.14 Ǻ, 2.41 Ǻ, 1.63 Ǻ, 2.13 Ǻ, 1.56 Ǻ, 1.98 Ǻ and 1.43Ǻ.

Mn hydroxide minerals occur as psilomelane which was detected at d=2.41 Ǻ and 1.56 Ǻ. Mn carbonate minerals occur as rhodochrosite ($MnCO_3$), detected at d= 3.29 Ǻ, 4.24 Ǻ, and 2.82 Ǻ. In all samples, the Fe-bearing minerals occur as hematite , detected at d= 2.7 Ǻ, 1.69 Ǻ, 1.84 Ǻ, 1.45 Ǻ and 2.20 Ǻ. Gangue minerals presented by Quartz, feldspar and calcite were identified in the XRD pattern of the studied samples. (Figs. 6 and 7).

Infrared (IR) data of different manganese ore types of Abu Ghusun deposits are shown in Table 3. The investigation of IR spectra shows that pyrolusite and psilomelane are the dominant manganese minerals associated with minor hematite. Quartz and calcite are the main gangue minerals.

IR spectra of the studied samples (Fig. 8) revealed the presence of the following bands: 3422-3400 cm^{-1} due to O-H stretching vibration. 2400-2350, 1741-1731, 1615 and 1480 cm^{-1}, which are attributed to CO_3^{2-} anion, 705-686 cm^{-1}, which is attributed to C-O bond. 1120 and 1100-1000 cm^{-1}, which are attributed to Si-O bond.876, 783 and 411-380 cm^{-1}, which are attributed to Mn-O stretching or lattice vibration. 596-575, 350-318 and 221 cm^{-1} that are attributed to Fe-O stretching or lattice vibration.

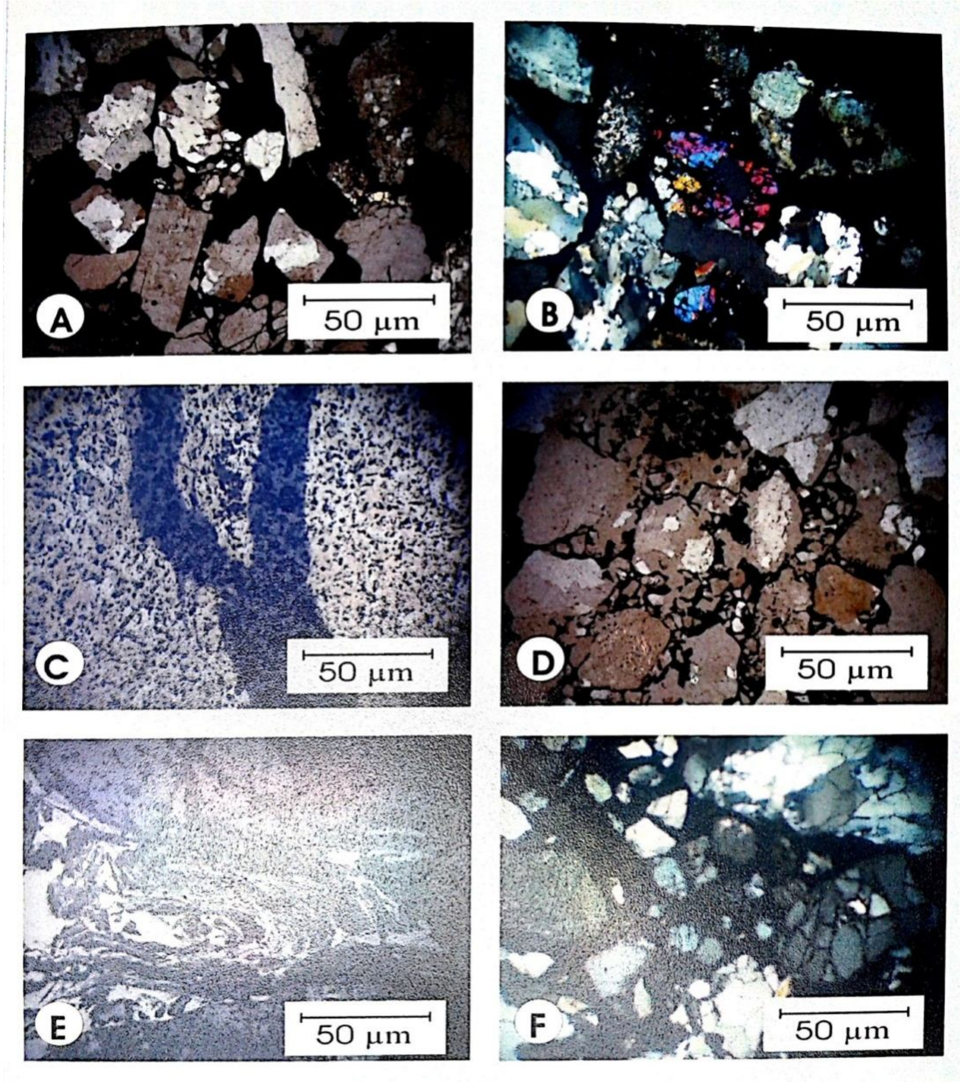


Fig. 5: Photomicrographs showing:

(A) Poorly sorted quartz grains with angular to subangular edges (P.L.).
(B) Rock fragments and epidote grains swim within the manganese matrix (C.N.)
(C) Quartz veinlets cut pyrolusite and psilomelane giving riseve in replacement texture (R.L.)
(D) Manganese minerals corrode the hosted quartz grains forming rim replacement texture (C.N.).
(E) Pyrolusite shows concavo-convex surfaces forming colloform texture (R.L.)
(F) Highly deformed grains forming deformation texture (C.N.).

Table 4 shows the relation between the absorbed frequencies of the incident infrared waves (ν) and the refractive indices (n) for the studied samples.

In manganiferous sandstone ore type: the refractive index in sample No. 38 is equal to 2.3 while in sample No. 39 is equal to 4.23 at the same frequency (221 cm^{-1}). The higher concentration of ferric ion (Fe^{+2}) in sample No.39, causes decrease in the infrared velocity and increase the refractive index.

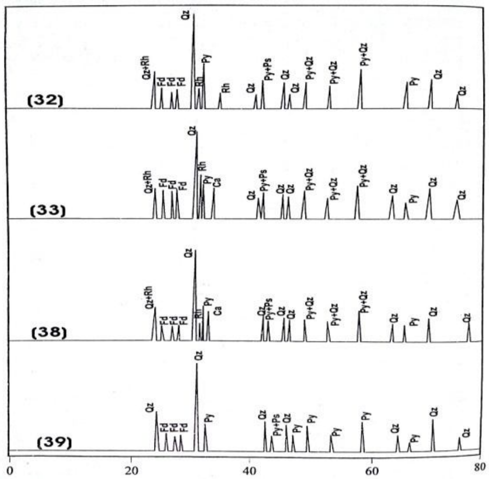


Fig. 6: X-ray charts for manganiferous sandstone ore type of Abu Ghusun deposits.

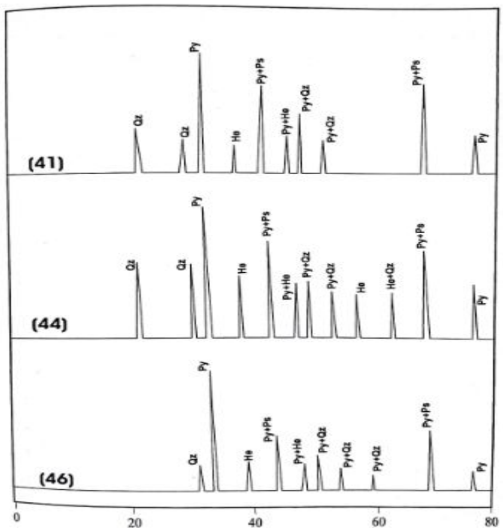


Fig. 7: X-ray charts for massivetype of Abu Ghusun deposits.

Massive ore type: the refractive index in sample No. 41 is equal to 1.11 while in sample No. 46 is equal to 1.67 at the same frequency (411 cm^{-1}), this is due the higher concentration of manganese ion in sample No. 46. However , the refractive index in sample No. 41 is equal to 31.25 and in sample No. 46 has the same value at the same frequency (575 cm^{-1}). It means that the concentration of Si^{+4} ions in sample No 41 is equal to the concentration of Si^{+4} ions in sample No. 46.The differential thermal analysis (DTA) and the rmogravimetric analysis (TG) were carried out for four samples selected from Abu Ghusun manganese ore types (Figs. 9 & 10). The employed temperature was ranging between 0-1050 °C (Table 5).

Table 5and Fig.9reflected that all the studied samples show slight upward and downward peaks in the temperature range of (95-155 °C) indicating the continuous loss of moisture and absorbed water. The other changes are due to decomposition and recrystallization of the minerals. Pyrolusite is detected in all samples by the presence of endothermic peaks at temperature range of 640-660 °C owing to bixbyite formation. Other endothermic peaks are situated at temperature range of 829-984 °C, it is an evidence for B-hausmannite formation. Psilomelane was detected in most of samples, showing endothermic peaks at temperature range of 323-343 °C due to dehydration and decomposition giving rise pyrolusite. Rhodochrosite was detected only in manganiferous sandstone ore type. It shows exothermic peaks at temperature range of 587-589 °C. Neumann (1977) stated that rhodochrosite has an exothermic peak at 585°C.

Gangue minerals are represented by calcite and quartz. Calcite was detected in most samples between 728-771 °C, whereas calcite mineral decomposed into CO2. Quartz was detected only in one sample (No.39) belongs to manganiferous sandstone ore type at temperature 469 °C. Table 6 and figure 10 show that theweight loss of manganese ores of Abu Ghusun deposits ranges from 7.78% to 13.47 with total average 10.67%. It is noticed that the average weight loss of the studied manganiferous sandstone ore type is less than that of massive ore type due to the presence of silicate minerals.

The interpretation of the thermo gravimetric curves (TG) indicates that there are two distinctive stages of weight loss in the different ore types: the first stage at 590 °C- 850 °C due to decomposition of pyrolusite to bixbyite. The second stage is over than 800 °C until 1050 °C, which is attributed to B-hausmannite formation.

Table 3: Infrared absorption bands for the different ore types in Abu Ghusun deposits

Manganiferous sandstone ore type				Massive ore type			
38		39		41		46	
Wave number	Intensity	Wave number	Intensity	Wave number	Intensity	Wave number	Intensity
3401	W,p	3422	W,p	3402	M,sp	3410	M,Sp
…….	…….	…	…..	2352	M,Sp	2400	M,Sp
……..	……	….	…….	1741	W, sp	1731	W,sp
1480	S,b	….	………	1615	W, sp	1615	W,sp
……..	….	1039	S,b	1118	M,b	1118	M,b
876	M, sp	783	M,sp	1001	W, sp	1000	W,b
705	W, sp	686	W, sp	705	M,sp	680	M,Sp
596	M, sp	580	W, sp	575	S,sp,	575	S,sp
410	W, sp	380	S.sp	411	M,Sp	400	M,Sp
318	S, sp	…….	…….	336	W,Sp	350	W,sp
221	W, sp	221	W, sp	221	W,Sp	….	…….

S=strong, M=medium, W=weak, sp=sharp, b=broad.

Table 4: Relation between the absorbed frequencies of the incident infrared waves (v) and the refractive indices (n)

Manganiferous sandstone ore type				Massive ore type			
38		39		41		46	
Wave Number (ν)	Refractive index (n)	wave Number (ν)	Refractive index (n)	Wave Number (ν)	Refractive index (n)	Wave Number (ν)	Refractive index (n)
221	2.3	221	4.23	221	1.55	350	0.53
318	1.33	380	2.13	336	0.45	411	1.67
410	0.16	463	8.1	411	1.11	575	31.25
596	1.18	528	6.93	575	31.25	703	2.81
705	0.63	580	6.14	705	3.13	1118	0.39

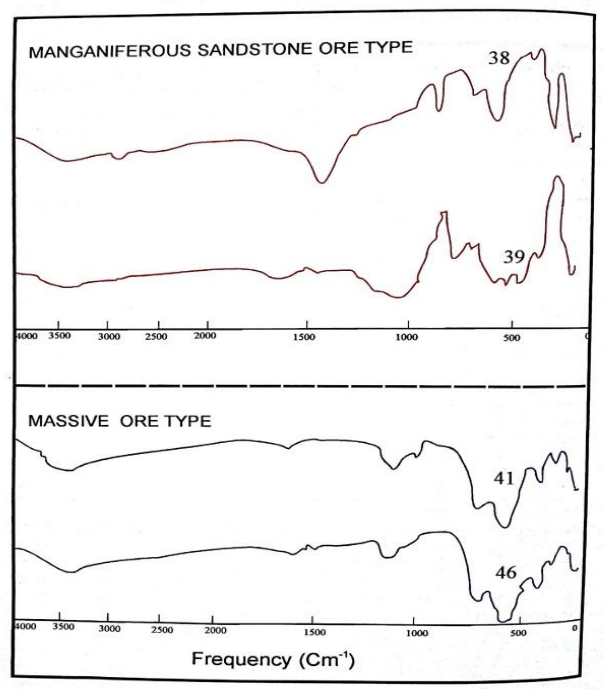
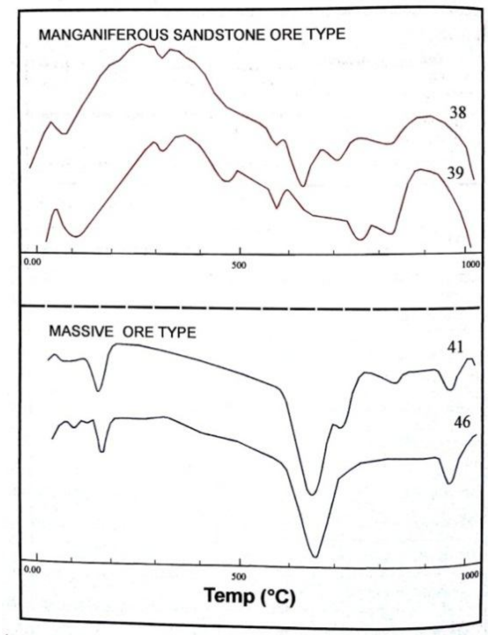


Fig. 8: Infrared absorption bands for the different manganese ore types of Abu Ghusun deposits.



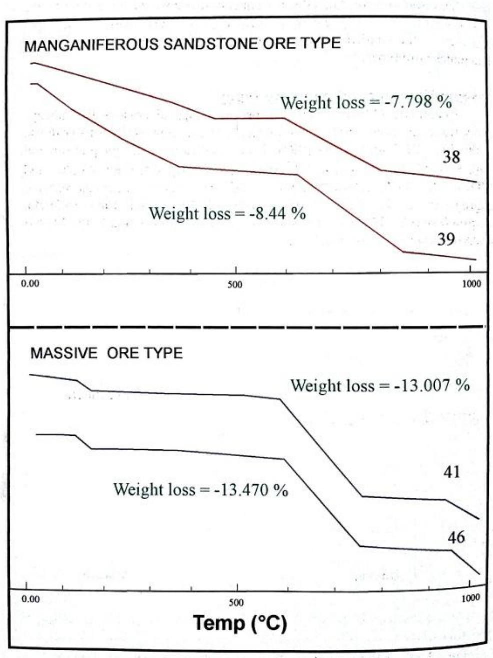


Fig. 9: Differential thermal analysis curves for the different manganese ore types of Abu Ghusun deposits.

Fig. 10: Thermo gravimetric analysis curves for the different manganese ore types of Abu Ghusun deposits

Table 5: The temperature degrees of manganese and associated minerals during thermal reactions detected in DTA in Abu Ghusun deposits

Ore Type	Manganiferous sandstone ore type				Massive ore type			
SampleNo	38		39		41		46	
Heat Effect	Endo	Exo	Endo	Exo	Endo	Exo	Endo	Exo
Moisture	96.72		102.99		153.41		152.59	
Pyrolusite	642.9		660		656.33		653.88	
β-hausmanite	833.42		829.37		983.25		979.13	
Psilomelane	323.83		326.17				342.54	
Rhodochrosite		587.3		589				
Calcite	728.71		771.65		732.68			
Quartz			469.9					

Table 6: The total weight loss due to heating up to 1050 °C for different manganese ore types in Abu Ghusun deposits

Ore type	Sample No.	Wt. loss due to moisture (°C)		First Stage (°C)	Second stage (°C)	Total Wt. %
Manganiferous Sandstone Ore type	38	20-450		610-800	800-1000	7.798
	39	20-350		630-850	850-1050	8.443
Massive Ore type	41	20-110	110-150	590-760	930-1050	13.007
	46	50-120	120-150	600-750	950-1050	13.470

Environmental Scanning Electron Microscope (ESEM) observation

Environmental Scanning electron Microscopy observations (Figs.7, 8 and 9.) of the studied samples indicate that pyrolusite occurs as prismatic-shaped crystals with traverse cracks.EDX data reflect typical composition of pyrolusite with MnO (81.5%). Quartz occurs as irregular grains with SiO_2 (65.7%). Apatite occurs as globular grains with CaO (43.3%) and P_2O_5 (39%). Psilomelane ($Ba(Mn^{+2}, Mn^{+4})_9O_{18}. 2H_2O$) occurs as massive aggregates, with MnO (75.14%) and BaO (5.39%). Plagioclase ($CaAlSi_2O_8$) with SiO_2 (44%), Al_2O_3 (25.8 %) and CaO (20.6%).

Paragenesis

Mineralogical and petrographical investigations of manganese ore types from Abu Ghusun area suggest the nature and the order of each mineral to each other. In massive ore type, it is clear that the pyrolusite and psilomelane were formed firstly and directly from hot aqueous solution. On the other hand, in manganiferous sandstone ore type, it is noticed that quartz, feldspars and rock fragments are coated by manganese cement, indicating that these gangue minerals were deposited firstly and cemented later by primary manganese minerals. Rhodochrosite and hematite were seemed to be formed in latest stages due to diagenetic processes as a result of phsico-chemical change in the depositional environment. Stanton (1972), stated that rhodochrosite is always formed in moderately low (Eh) environments with presence of carbonate ions (CO_3^{2-}). On other hand, hematite can be formed under moderate oxidation potential (Eh) that is sufficient for crystallization of this mineral. According to Lahiri (1971), rhodochrosite and hematite have a syngenetic nature.

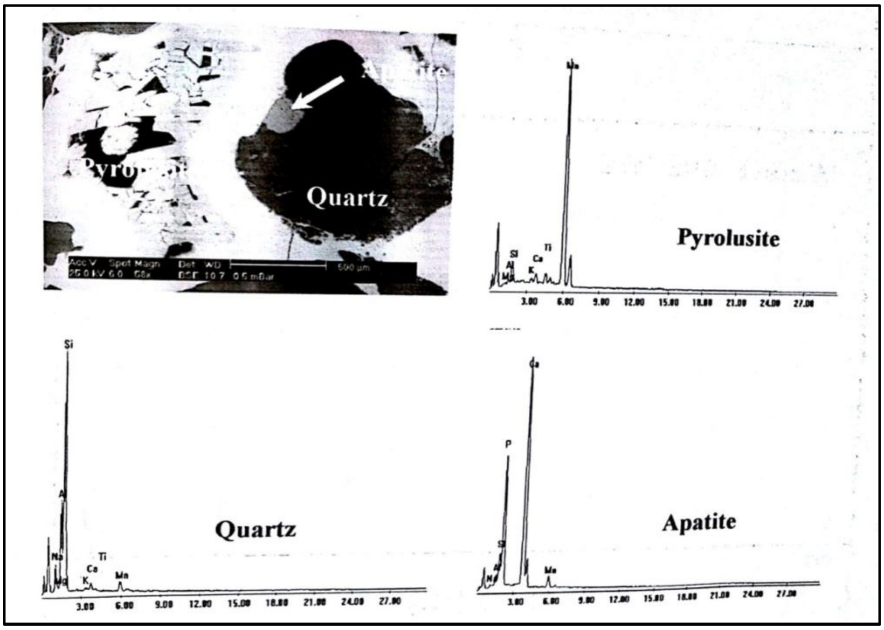


Fig. 11: EDX spot analyses and close up-view showing pyrolusite (bright), quartz (black) and apatite (dark grey)

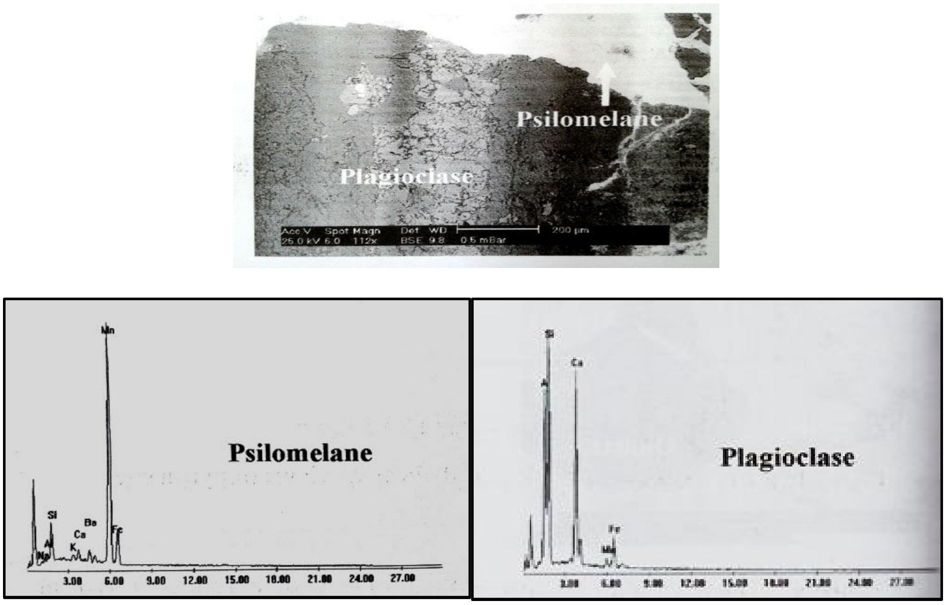


Fig.12: EDX spot analyses and close up-view showing psilomelane (bright) and plagioclase (grey).

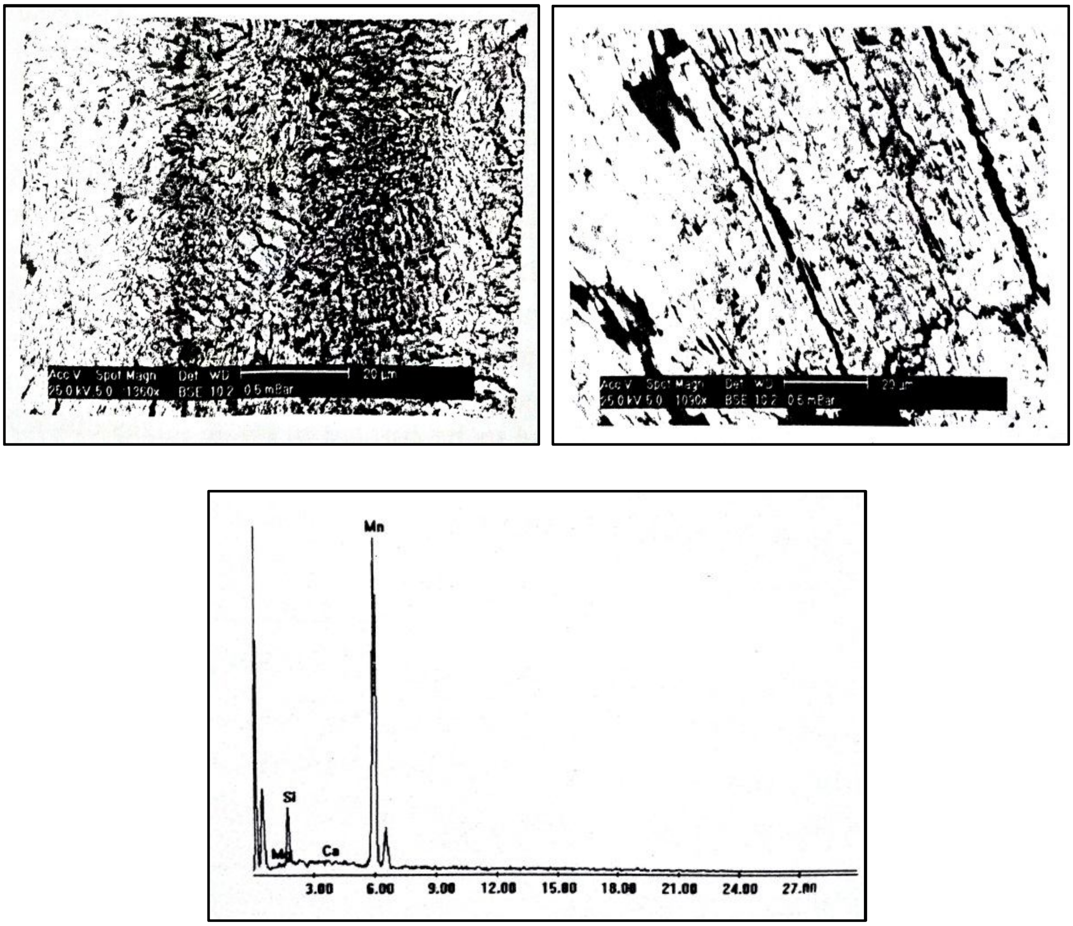


Fig.13: EDX spot analsis and close up-views of pyrolusite

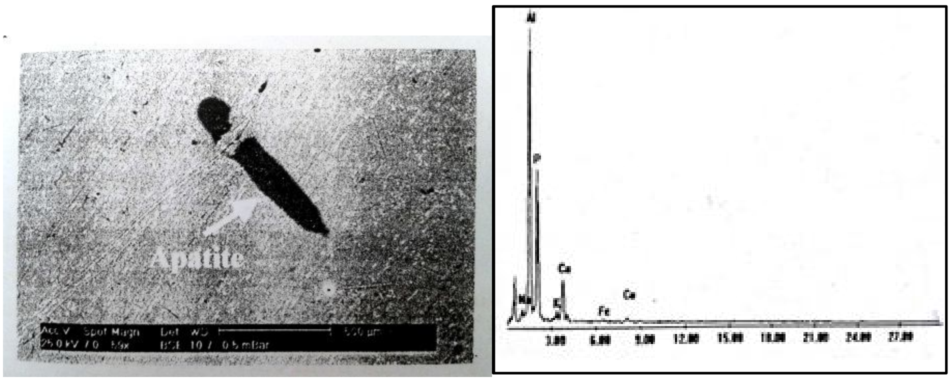


Fig. 14: EDX spot analysis and close up-view of apatite.

4.3. Geochemistry of manganese ore

Major and trace element contents of ten selected samples of Abu Ghusun manganese ore types are shown in Table 7. The manganiferous sandstone ore type is rich in SiO_2(av. 20.68%), MnO (av. 41.95%), CaO (11.2%) and Na_2O (2.61%) and poor in TiO_2(o.o), Al_2O_3 (av. 4.92 %), FeO (av.1.29%), MgO (av. 5.52%), K_2O (av. 0.64%) and P_2O_5 (av. 0.41%), due to the presence of psilomelane and pyrolusite as well as quartz, plagioclase, calcite and rock fragments. The massive ore type is rich in MnO(av.44.66%), MgO(av. 19.94%) and CaO(av.8.32) and poor in SiO_2(0.62%), TiO_2(av.0.09), Al_2O_3(av.5.06%), FeO(av.3.77%), Na_2O(av. 1.51), K_2O(av.0.32%) and P_2O_5(av.0.22%) due to the presence of pyrolusite and psilomelane as well as quartz and apatite.

Mn/Fe ratios in hydrothermal deposits are higher than 10 or lower than 0.1, but in hydrogenic deposits, it is about 1 (Rona, 1978). Higher amounts of Mn/Fe ratio or lower amounts of it is indicator of intense differentiation and segregation of these two elements in sedimentary environments and therefore is indicator of hydrothermal deposits. The Mn/Fe ratios for Abu Ghusun massive ore change in a wide interval (6.3 to 75.59). Such range indicates that the mineralization is not hydrogenetic but could be a hydrothermal type. The amounts of Mn/Fe ratio in Abu Ghusunmanganiferous sandstone ore range from (19.78 to 45.7), with an average is 31.8 similar to Mn/Fe ratio (26.89) in hydrothermal deposits at Baby Bare at the Northeast Pacific Ocean (Rona, 1978).

The manganiferous sandstone ore type is rich in Cr (66ppm), Co (av.61ppm), Zn(av.132ppm), Zr(257ppm), Ba(12050ppm), Sr(av. 3400ppm) and V(av.157ppm) and poor in Cu(av.27ppm), Ni(av.35ppm), Rb(av. 18ppm), Pb(13ppm) and Ga(av.0.5ppm), whereas the massive ore type is rich in Cr (av.58ppm), Cu(av. 45ppm), Zn (av.200ppm), Ba(av.1414ppm), Pb(av.49ppm), Sr (av.353ppm) and V(av.196ppm) and poor in Co(av.11ppm, Ni(av.19ppm), Zr(av.33ppm), Rb(av.3ppm) and Ga (av.3ppm).

Table 8 shows the comparison of some trace elements (total averages) between Abu Ghusun manganese ore with some stratiform-type manganese deposits in Egypt (Abu Shaar El Qeblimanaganese ore and Um Bogma manganese ore).

It is noticed that Abu Ghusun Manganese ore is characterized by higher contents of Cr, Zr, Ba and Sr and lower contents of Ni, Cu and Zn than that the other local stratiform manganese deposits. On the other hand, Co, Pb and V contents show some variation.

High cobalt concentrations are indicative of marine environment as pointed out in the discrimination diagram between supergene and hydrothermal deposits of Nicholson(1990). In this respect, all Abu Ghusun samples plotted in the hydrothermal field (Fig. 15°A).Plotting the data of the present study on the (Al-Mn-Fe) ternary diagram of Bonatti et al.,(1972), reveal that the studied manganese deposits fall in the field of manganese nodules (Fig. 15 B). Such deposits are characteristic for relatively hydrothermal origin.

(Co+Ni+Cu)*10, Fe_2O_3 and MnO(wt.%) Discrimination diagram was used to discriminate between hydrogenous and hydrothermal manganese deposits (Sugisaki et al., 1987). The plotting of the studied Manganese ore samples of Abu Ghusun are shown in figure 15C. In this respect all samples are plotted in hydrothermal field. Creater et al. (1982) used the (Cu+Ni+Co)* 10, Fe and Mn (wt.%) triangle diagram to distinguish between hydrogeneous and hydrothermal deposits. Plotting the data of Abu Ghusun manganese samples in this diagram reveal that all samples fall in hydrothermal field (Fig. 15 D).

Toth (1980) used the Co/zn ratio to differentiate between hydrothermal and hydrogenous type deposits where the Co/Zn ratio of 0.15 is indicative of hydrothermal type deposit and a ratio of 2.5 indicates hydrogenous type deposits. The Co/Zn ratios of both Abu Ghusun massive and magnaiferous ores, range between 0.04 to 0.09 with an average 0.06 and from 0.06 to 1.50 with an average 0.5 respectively, more or less around the Co/Zn ratio for hydrothermal manganese deposits given by Toth (1980).

According to Dorokhin et al. (1969) and based on the total manganese content in both manganiferous sandstone and massive ore types of Abu Ghusun deposits (41.95% and 44.66% MnO2 respectively) lie in the field of high grade B(40-50%MnO).

Table 7: Chemical analyses for manganese ore types in Abu Ghusun deposits

OreType	Manganiferous sandstone ore type					Massive ore type						
Sample	**32**	**33**	**39**	**40**	**average**	**41**	**42**	**43**	**44**	**45**	**46**	**average**
Major oxides (wt%)												
SiO_2	31.57	3.71	12.26	35.2	20.68	1.7	0.59	0.7	0.22	0.29	0.27	0.62
TiO_2	0	0	0	0	0	0	0.02	0.5	0.02	0.03	0	0.09
Al_2O_3	6.02	02.35	1.12	10.2	4.92	3.57	6.43	3.78	8.88	3.88	3.87	5.06
Fe_2O_3	0.24	0.24	0.3	0.24	0.25	0.12	0.84	0.72	1.32	0.6	0.61	0.7
FeO	1.22	1.22	1.52	1.22	1.29	0.6	5.59	3.66	6.72	3.05	3	3.77
FeO*	1.44	1.44	1.79	1.44	1.52	0.71	6.3	4.31	7.91	3.59	3.6	4.4
MnO	29.6	56.1	57.9	24.2	41.95	45.9	42.96	41.14	42.77	48.12	47.1	44.66
MgO	6.1	7.06	3.03	6	5.52	19.14	21	22.11	16.4	20	21	19.94
CaO	11.2	11.2	9.8	9.8	10.5	8.3	8.4	8.5	8.42	8.4	8	8.32
Na_2O	3.06	2.29	2.63	2.49	2.61	1.8	0.98	1	2.2	1.35	1.75	1.51
K_2O	0.57	0.57	0.52	0.92	0.64	0.16	0.33	0.22	0.38	0.38	0.45	0.32
P_2O_5	0.4	0.22	0.7	0.33	0.41	0.25	0.2	0.2	0.06	0.32	0.3	0.22
L.O.I	7.4	9.4	8.2	8.4	8.35	13.79	12	12.2	8.53	13	12.5	12.2
Mn/Fe	24.11	45.7	37.81	19.76	31.8	75.59	9.02	11.13	6.3	15.64	15.58	11.53
Total	97.38	94.36	97.98	99	97.15	95.35	99.34	94.73	95.92	99.42	98.85	97.44
Trace elements (ppm)												
Cr	64	80	60	63	66	58	52	50	80	62	46	58
Co	11	10	214	10	61	9	8	8	25	9	8	11
Ni	43	41	19	38	35	20	19	14	17	31	13	19
Cu	33	27	17	33	27	51	51	48	30	46	46	45
Zn	93	158	142	136	132	166	212	181	253	202	188	200
Zr	279	260	158	333	257	26	38	30	45	34	27	33
Rb	16	22	12	24	18	3	6	4	6	0	3	3
Ba	1340	13093	22918	10852	12050	750	1663	1307	3581	599	588	1414
Pb	15	0	10	29	13	36	49	44	107	26	33	49
Sr	2870	2623	4702	3406	3400	273	431	319	532	258	308	353
Ga	2	0	0	0	0.5	0	0	5	5	4	5	3
V	96	109	329	97	157	180	173	196	268	189	173	196
Co/Zn	0.12	0.06	1.50	0.07	0.46	0.05	0.04	0.04	0.09	0.04	0.04	0.06

Table 8: comparison between trace elements of Abu Ghusun manganese ore with some of local stratiform-type manganese deposits

ore / element	Abu Ghusun manganese		Abu Shaar El Qebli Area (Abdel Motelib, 1996)	Um Bogma area (Saad et al. 1994)
	Manganiferous sandstone ore	Massive ore		
Cr	66.75	58	n.d.	n.d
Co	61.25	11.17	237	8
Ni	35.25	22.17	95	187
Cu	27.5	45.33	83	511
Zn	132.25	200.33	496	2504
Zr	257.5	33.33	n.d	n.d
Rb	18.5	3.66	n.d	n.d
Ba	12050.75	1414.66	941	638
Pb	13.5	49.17	4	1734
Sr	3400.25	353.5	100	106
Ga	0.5	3.17	n.d	n.d
V	157.75	196.5	308	n.d

5. Conclusions

Based on the geological, mineralogical and geochemical data , the following genetic consideration for Abu Ghusun manganese deposits can be summarized as follows:

1- The Abu Ghusun manganese deposits are generally enclosed within the clastic sediments of Abu Ghusun Formation of Oligocene age in the form of sheets, lenses, encrustation and filling the fractures.
2- The small tonnage and limited extent of the manganese deposits are characteristic for the hydrothermal nature.
3- The presences of colloform texture and amorphous materials as well as lack of any sedimentary texture such as oolitic and pisolitic textures support hydrothermal origin.
4- The Mn/Fe ratio ranges from 6.3 to 75.59, typical to hydrothermal origin.
5- The excessively low concentration of TiO_2 with an average (0.045%) in the studied manganese ores confirms their hydrothermal origin.
6- The deposits are rich in Ba, Sr, V and Zn and mainly depleted in Co, Cu and Ni contents that emphasis the hydrothermal origin of these deposits.
7- The Oligocene Manganese ore is well known in the world: the Oligocene Mn ore of Chiatura region in the former USSR (Bolton and Frakes, 1985) and Groote Eylandt occurrence in Australia (Pracejus, 1989) display some similarity to Abu Ghusun manganese deposits.

Thus, the above mentioned criteria indicate that the present ore was resulted from hydrothermal activity, which may be related to Tertiary volcanic activities that were corresponding to the starting of Red Sea rifting (most probably of Oligocene age). However some local occurrences bear some clues such as irregular stratified and lensoidal geometries that indicate a deposition as reworked detritus of manganese-rich sandstones by fluvial processes.

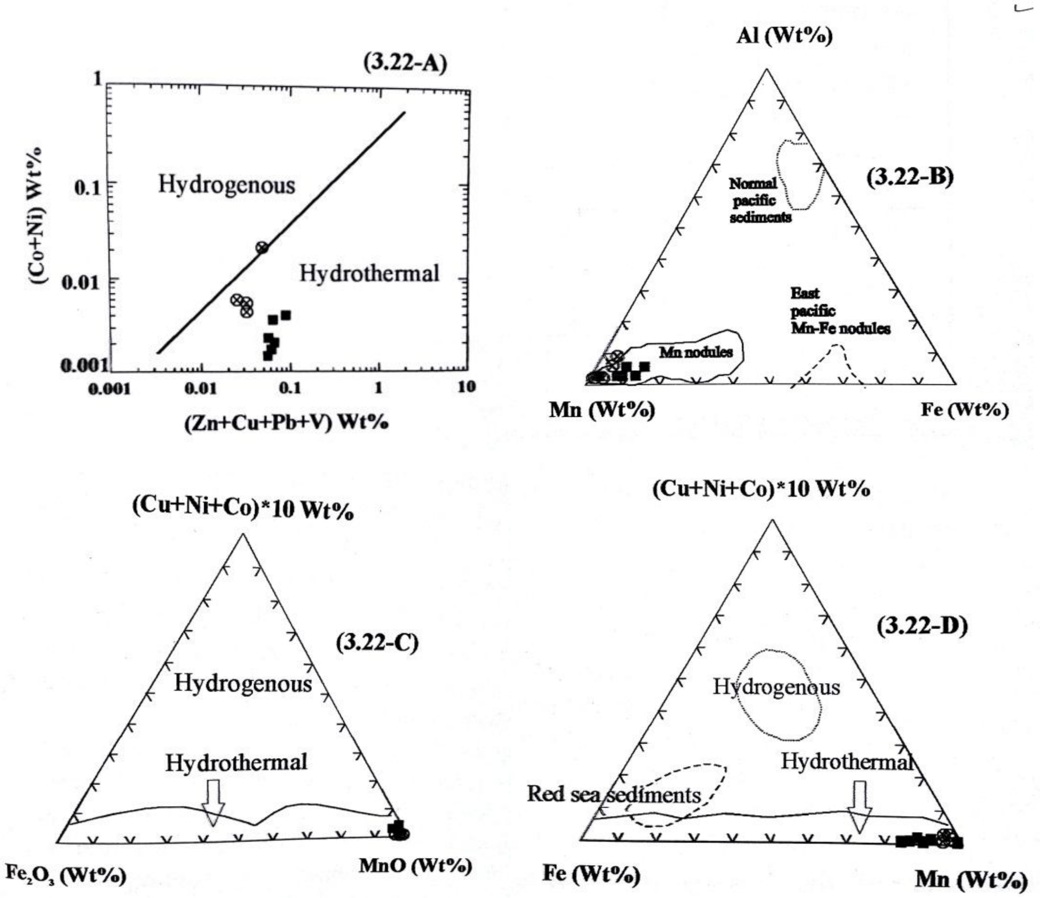


Fig. 15: A)(CO+NiO versus (As+Cu+Pb+V+Zn) in Wt% after Nicholson (1990)
B) (Al-Mn-Fe) triangle diagram after Bonatti et al. (1972).
C) (Cu+Ni+CO)-Fe_2O_3-MnO triangle diageam after Sugisaki et al. (1987).
D) (Cu+Ni+CO)-Fe-Mn triangle diagram after Cretar et al. (1982).

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