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Prospectivity of Economic Heavy Minerals from El Manzala Lake Bottom Sediments, North Nile Delta, Egypt

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ABSTRACT

El Manzala Lake is considered as the biggest coastal saline lake in Egypt. The lake receives fluvial, ground-water and marine sea water. It also receives huge amounts of drainage water from five main drains namely; Bahr El Bakar, Ramsis, Hadous, El Tawil, El Serw and Faraskour and receives little amounts of fresh water from Souffra, Ratma and Inaniya canals. The bottom sediments of El Manzala Lake are mainly composed of two fractions of different grain size; the first consists mainly of sand and found exclusively in the northern part of the lake, and the second is mainly made up of silt and clay, and predominant in the southern part. The mineralogical investigation that was carried on these sediments led to the identification of considerable number of minerals that are concentered in the northern part (up to 2.7%), they are of economic importance and were classified into two categories namely opaque and non-opaque minerals. The most important opaque minerals are ilmenite, magnetite, leucoxene, chromite and pyrite. The most abundant opaque mineral in both of northern and southern part of the lake is ilmenite and followed by magnetite. While the non-opaque minerals are represented by rutile, zircon, monazite and garnet with few concentrations of titanite, apatite and gahnite. The most abundant non-opaque mineral in the northern and southern part of the lake is rutile. The variation in their shapes and habits indicates that they were inhered from different sources. The distribution and abundance of the recorded economic heavy minerals are controlled by the grain size of the sediments and the depth of water in the lake, where the majority of the identified minerals are concentrated in the fine sand-sized fraction in the northern part. The potential source of economic heavy minerals is the northern part of the lake are extended from the shore of Mediterranean Sea from the north to the drains of Bahr El Bakar and Faraskour in the east and west respectively.

Keywords: saline lake, ground-water, marine sea water, drainage, sediments, mineralogical

1. Introduction

Black sand is a mixture of light minerals and number of highly resistant economic heavy minerals that exist in the fine sand size, and found as part of placer sediments. The Egyptian black sand has special importance as the Nile River and its tributaries concentrate their load minerals of different sources along its course from the central and eastern parts of Africa in the south to the Mediterranean Sea in the north (El Kammar *et al*., 2010). These loads of heavy minerals reflect composition of the parent rocks that they were derived from.

These sediments occur along the Mediterranean Sea coast in a zone extending from Abu Qir in the west to El Arish in the east. They occur in two forms, beach deposits and coastal sand dunes. Sands with grades suitable for exploitation occur in the beach of Rosetta, Damietta and north Sinai at Rommana and El Arish (Dabbour, 1994). Also the coastal sand dunes of El Burullus – Baltim and El Arish are relatively enriched in economic minerals (Barakat, 2004). These economic metals-rich heavy minerals include ilmenite, magnetite, garnet, zircon, rutile and monazite (El Kammar el al., 2010).

El Manzala Lake is considered as the biggest coastal saline lake in Egypt. It is located at the northeastern quadrant of the Nile Delta, to the south of the Mediterranean Sea, to the west of Suez

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Canal, to the southeast of Damietta province, and to northeast Dakahlia province. It is an important and valuable resource area for fish and wildlife. The economic importance of El Manzala Lake comes from the high production level of fishes as its average production during period from 1993 to 2013 is 45.9% of the total production of northern Nile Delta lakes (GAFRD, 2012). It is considered as one of the most important wetlands in Egypt for the water birds and listed as an Important Bird Area (IBA) (Bird Life International, 2007).

Abu Khatita et al. (2016) recognized that the high amount of separated heavy minerals (reaches up to 10.5%), were recorded from the bottom sediments of El Manzala Lake along the Mediterranean coast, and located close to El-Boghaz outlet and gradually decreases southwards. The economic heavy minerals comprise magnetite, ilmenite, monazite, zircon, garnet, epidote, hornblende and leucoxene.

El Manzala Lake receives huge amounts of drainage water containing several types of waste, including domestic, industrial, and agricultural, from four main drains namely Faraskour and El Serw from the west, Bahr El Bakar from the east, Hadous, Ramsis and El Tawil from the south, in addition to several pumping stations. Drainage waters mainly enter the lake from the southern and eastern sides as well as from the northern inlet that connect it to the Mediterranean Sea (Farahat, 2019). Fresh water from the River Nile enters the lake through Soufra, Ratma and Inaniya from the west (Fig. 1).

Generally, El Manzala Lake is suffering from several problems, which vary between land reclamation and exposed to high amount of drainage water which reaches up to about 7500 million cubic meters of untreated domestic, industrial, and agricultural drainage water. The southern side of the lagoon exposed to huge amounts of drainage water via several drains (Shetaia, 2017). This caused the elevation of modern rate of sediment accumulation in the northeastern Nile-delta, as determined by particle reactive chronometric tracers (1.2 cm/year), is somewhat higher than the mean rate of accumulation during the past 7500 years (Benningers et al., 1998).

Nowadays, the Egyptian government pays a special attention to the black sand projects and constructs huge projects in El Burullus, Baltim, Dammitta, and Ghelion areas to separate each economic heavy mineral with high grade of purity to the local and international markets. Although there are many environmental studies were carried on both water and sediments of El Manzala Lake, publications on its economic heavy minerals are infrequent and insufficient. In this study the mineralogical investigation and the potentiality of the existing economic heavy minerals take place on the sediments of the first meter from the bottom sediments of El Manzala Lake, to show the distribution of these minerals and evaluate their economic output.

2. The study area

El Manzala Lake is bounded by longitudes 31° 45′ and 32° 50 ′ E, and latitudes 31° 00′N and 31° 35′N (Fig. 1). The length of El Manzala Lake is 35 km from northwest to southeast and its width is about 30 km. Like the other delta lagoons, El Manzala Lake is shallow, its depth is ranging from 0.7 to 1.5 m and has more than 1000 islands (EEAA, 2013) which cause shrinking the area of open water from 700 km^2 to less than 500 km^2 (Ahmed *et al*., 2009; Ayache *et al*., 2009). These islands divide the lake into several regions (30 basins) with different depth and water quality, known to the local fishermen as Bohours. Each of them has more or less distinctive ecological characters (Rashed and Abdel-Azeem, 2010). Many sand bars (up to 2 km wide, and 1–2 m high) separate El Manzala Lake from the Mediterranean Sea except where they have been artificially cut.

El Manzala Lake receives both of fluvial, ground-water and marine sea water (Reinhardt *et al*., 2001), where the straits of El-Gamil, Ashtoum Al-Gamil, Al-Baghdadi, El-Deiba and recently Al-Burg connect the northeast corner of El Manzala Lake with the Mediterranean Sea. Great amounts of wastewater drain into the lake from its western and southern coasts. The most important drainage ditches are: Bahr El-Baqar, Bahr Hadous, Ramsis, Al-Sirw, and Faraskur drains. The northwestern part of the lake is connected to Damietta estuary by the three canals El-Ratama, El-Souffara and Innaniya. These canals were constructed mainly to freshen the north-western part of the lake by Nile water during the flood season (Rashed and Abdel-Azeem, 2010).

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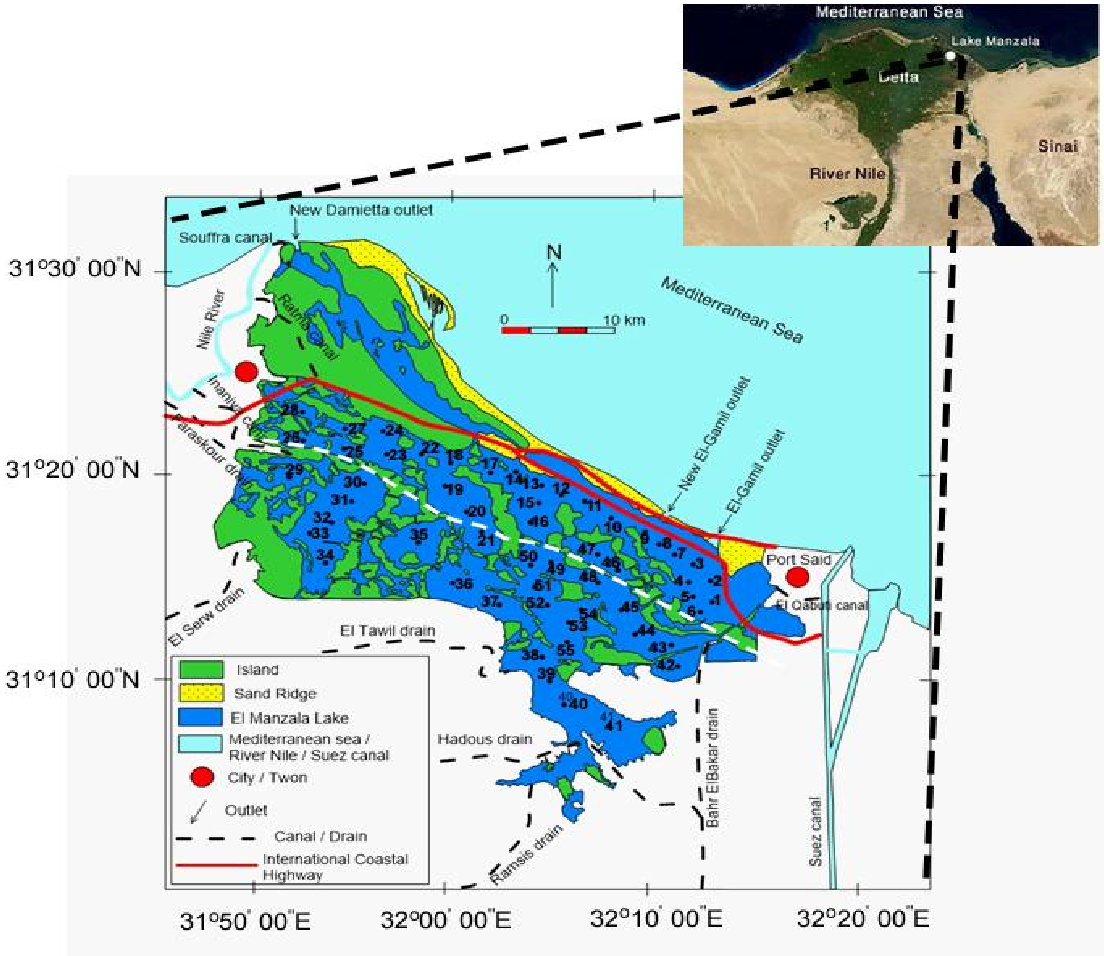

Fig. 1: Land sat image and location map of El Manzala Lake showing locations of collected samples (after Shetaia, 2017).

3. Sampling, Separation and Analytical Methods

This study focuses on some economic heavy minerals, namely; magnetite, ilmenite, rutile, leucoxene, zircon, monazite, and garnet. A total of 55 representative samples were collected on systematic grid patterns from the first meter of El Manzala Lake bottom sediments. The average weight of each sample is about 10 kg. The collected samples were dried and quartered using John's Splitter and an automatic rotary splitter to obtain representative samples (about 60-80gm) for different mineralogical treatments. Each sample was sieved to obtain three fractions; (>800µm, 800µm-63µm and< 63µm). The obtained size fraction is weighted and subjected to decantation method to remove silt and clay particles. Quantitative mineralogical analyses for the collected samples were carried out by heavy liquid separation using bromoform and methylene iodide solutions (sp. gr. 2.86 g/cm^3 and 3.3 g/cm^3 respectively), and magnetic fractionation using a Frantz Isodynamic Magnetic Separator (Model L-1). The characterized condition of Frantz Isodynamic Magnetic Separator are side slope of 5°, forward slope of 20° and step of currents 0.2, 0.5, 1.0, 1.5 magnetic and 1.5 non-magnetic current amperes. Each individual mineral was picked under the binocular stereo-microscope. A Philips SEM model XL30 equipped with an energy dispersive X-ray (EDX) unit SEM-EDX was used to study the separated grains and give a semi-quantitative chemical composition of the investigated minerals. The analytical work was done in the laboratories of the Nuclear Material Authority of Egypt.

The sediments of El Manzala Lake are mainly composed of two fractions of different grain size; the first consists mainly of sand fraction located in the northern part of the lake (Fig. 2 a, b) which characterized by high concentrations of economic and strategic heavy minerals. The second type is represented by silt and clay fractions and located in the southern part of the lake (Fig. 2c) which can

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be used as fertilizer for the desert land. Figure (2d) shows the process of building of large basins to receive the dredging sediments from the basin of El Manzala Lake.

Fig. 2. Photomicrographs show: a, b) Sand-sized fraction, c) Clay-sized fraction and d) basins to receive dredging sediments.

4. Results and Discussion

4.1. Heavy mineral composition of the bottom sediments

The recorded heavy minerals separated from the bottom sediments in both northern and southern parts of El Manzala Lake are of economic importance, and there is a marked enrichment in some of them, such as ilmenite, magnetite and leucoxene (Tables 1&2). According to their optical properties, the investigated minerals are classified into two main categories namely; opaque and non-opaque minerals. The following is a brief discussion on the obtained mineralogical data.

First: Opaque Heavy Minerals

The concentrations of opaque heavy minerals in the studied bottom samples are given in Tables 1&2. The most important of them are ilmenite, magnetite and leucoxene.

Table 1: The abundance of opaque, non-opaque, green silicates and clay in the bottom sediments of northern part of El Manzala Lake.

Sample.No.	Opaque minerals			Non- opaque minerals				Total Economic Minerals%	Green Silicates%	Total Heavy Minerals %	Clay Content %
	Magnetite%	Ilmenite%	Leucoxene%	Rutile.%	Garnet.%	Zircon.%	Monazite.%				
1	0.21	0.863	0.03	0.11	0.09	0.12	0.007	1.43	2.07	3.5	12.43
2	0.33	1.072	0.1	0.09	0.04	0.11	0.008	1.75	2.15	3.9	10.51
3	0.31	1.072	0.13	0.07	0.07	0.06	0.008	1.72	2.12	3.84	10.21
4	0.28	0.51	0.16	0.09	0.08	0.08	0.01	1.21	2.29	3.5	10.64
5	0.25	0.55	0.15	0.04	0.07	0.06	0.01	1.13	2.17	3.3	10.97
6	0.28	0.8	0.11	0.08	0.06	0.05	0.09	1.47	2.73	4.2	11.48
7	0.24	0.76	0.11	0.06	0.05	0.05	0.09	1.36	2.94	4.3	9.34
8	0.23	1.46	0.13	0.1	0.07	0.08	0.1	2.17	3.33	5.5	7.18
9	0.28	1.794	0.17	0.18	0.09	0.1	0.106	2.72	4.38	7.1	4.26
10	0.26	0.47	0.11	0.08	0.07	0.08	0.09	1.16	3.14	4.3	9.59
11	0.25	0.56	0.09	0.07	0.06	0.07	0.08	1.18	2.92	4.1	10.73
12	0.21	1.03	0.08	0.06	0.05	0.07	0.07	1.57	2.63	4.2	10.91
13	0.33	1.02	0.08	0.05	0.05	0.06	0.08	1.67	2.43	4.1	11.11
14	0.27	1.13	0.07	0.06	0.05	0.05	0.07	1.7	2.25	3.95	11.32
15	0.26	1	0.06	0.05	0.04	0.06	0.07	1.54	2.31	3.85	14.73
16	0.24	0.96	0.05	0.06	0.04	0.06	0.06	1.47	2.28	3.75	15.96
17	0.21	0.69	0.04	0.05	0.03	0.05	0.06	1.13	1.97	3.1	12.75
18	0.2	0.97	0.04	0.06	0.04	0.05	0.05	1.41	1.99	3.4	12.98
19	0.19	0.985	0.05	0.05	0.04	0.03	0.055	1.4	1.9	3.3	18.27
20	0.19	0.95	0.03	0.04	0.05	0.03	0.05	1.34	1.86	3.2	23.52
21	0.18	0.91	0.04	0.03	0.06	0.03	0.05	1.3	1.8	3.1	25.32
22	0.17	0.88	0.04	0.03	0.05	0.02	0.04	1.23	2.17	3.4	12.83
23	0.19	0.85	0.05	0.04	0.04	0.03	0.05	1.25	2.25	3.5	12.96
24	0.18	0.87	0.04	0.04	0.04	0.03	0.04	1.24	2.26	3.5	13.27
25	0.18	0.62	0.04	0.03	0.03	0.02	0.04	0.96	1.34	2.3	14.82
26	0.16	0.46	0.03	0.03	0.04	0.02	0.04	0.78	1.02	1.8	15.51
27	0.17	0.3	0.05	0.04	0.05	0.04	0.06	0.71	1.46	2.17	13.48
28	0.16	0.31	0.05	0.04	0.04	0.04	0.06	0.7	1.51	2.21	13.87
46	0.16	0.68	0.08	0.07	0.02	0.02	0.09	1.12	2.45	3.57	23.19
47	0.12	0.71	0.07	0.06	0.03	0.02	0.08	1.09	2.41	3.5	22.94
Min.	**0.12**	**0.3**	**0.03**	**0.03**	**0.02**	**0.02**	**0.007**	**0.7**	**1.02**	**1.8**	**4.26**
Max.	**0.33**	**1.794**	**0.17**	**0.18**	**0.09**	**0.12**	**0.106**	**2.72**	**4.38**	**7.1**	**25.32**
Av.	**0.22**	**0.84**	**0.08**	**0.062**	**0.051**	**0.053**	**0.057**	**1.36**	**2.28**	**3.65**	**13.57**

Table 2: The abundance of opaque, non-opaque, green silicates and clay in the bottom sediments of the southern part of El Manzala Lake.

Sample.No.	Opaque minerals			Non- opaque minerals				Total Economic Minerals%	Green Silicates%	Total Heavy Minerals %	Clay Content%
	Magnetite%	Ilmenite%	Leucoxene%	Rutile.%	Garnet.%	Zircon.%	Monazite.%				
29	0.1	0.24	0.03	0.02	0.02	0.03	0.01	0.45	0.55	1	35.26
30	0.16	0.15	0.04	0.02	0.04	0.03	0.05	0.49	1.23	1.72	38.21
31	0.15	0.14	0.03	0.02	0.03	0.03	0.04	0.44	1.21	1.65	39.45
32	0.14	0.26	0.03	0.02	0.03	0.03	0.04	0.55	1.05	1.6	45.42
33	0.11	0.13	0.01	0.01	0.02	0.03	0.01	0.32	0.68	1	50.56
34	0.06	0.1	0.007	0.007	0.008	0.01	0.008	0.2	0.6	0.8	78.52
35	0.07	0.1	0.006	0.008	0.009	0.01	0.007	0.21	0.99	1.2	53.43
36	0.07	0.099	0.005	0.006	0.006	0.01	0.004	0.2	0.73	0.93	86.69
37	0.07	0.092	0.005	0.005	0.005	0.009	0.004	0.19	0.71	0.9	87.98
38	0.05	0.085	0.004	0.005	0.005	0.008	0.003	0.16	0.54	0.7	92.29
39	0.058	0.099	0.003	0.004	0.004	0.008	0.004	0.18	0.52	0.7	91.45
40	0.03	0.072	0.002	0.003	0.003	0.007	0.003	0.12	0.38	0.5	90.57
41	0.013	0.07	0.001	0.001	0.001	0.003	0.001	0.09	0.21	0.3	93.56
42	0.11	0.13	0.02	0.01	0.03	0.04	0.01	0.35	0.77	1.12	86.15
43	0.086	0.1	0.008	0.007	0.01	0.02	0.009	0.24	0.89	1.13	75.94
44	0.02	0.041	0.006	0.005	0.009	0.01	0.009	0.1	1.03	1.13	74.16
45	0.054	0.12	0.01	0.009	0.03	0.08	0.037	0.34	0.94	1.28	70.23
48	0.11	0.64	0.05	0.06	0.04	0.01	0.07	0.98	1.82	2.8	38.61
49	0.1	0.68	0.03	0.05	0.04	0.01	0.06	0.97	1.93	2.9	39.18
50	0.1	0.725	0.03	0.06	0.03	0.01	0.005	0.96	1.94	2.9	39.47
51	0.09	0.726	0.02	0.05	0.03	0.009	0.005	0.93	1.47	2.4	51.72
52	0.09	0.749	0.02	0.04	0.03	0.008	0.003	0.94	1.36	2.3	57.28
53	0.08	0.752	0.02	0.04	0.03	0.008	0.03	0.96	1.04	2	59.96
54	0.07	0.449	0.01	0.03	0.02	0.007	0.004	0.59	1.31	1.9	58.89
55	0.05	0.25	0.01	0.03	0.01	0.05	0.03	0.43	1.37	1.8	65.79
Min	**0.01**	**0.04**	**0.001**	**0.001**	**0.001**	**0.003**	**0.001**	**0.09**	**0.21**	**0.30**	**35.26**
Max	**0.16**	**0.75**	**0.05**	**0.06**	**0.04**	**0.08**	**0.07**	**0.98**	**1.94**	**2.90**	**93.56**
Av.	**0.08**	**0.28**	**0.02**	**0.021**	**0.020**	**0.019**	**0.018**	**0.46**	**1.01**	**1.47**	**64.03**

I. Magnetite Fe_3O_4

Magnetite is predominant and recorded as massive angular to sub-angular crystals accumulation (Fig. 3a) and the octahedron crystals of magnetite are less frequent. The EDX microanalysis (Fig. 3b) shows the composition of magnetite with Fe (73.7%), and O (26.3%).

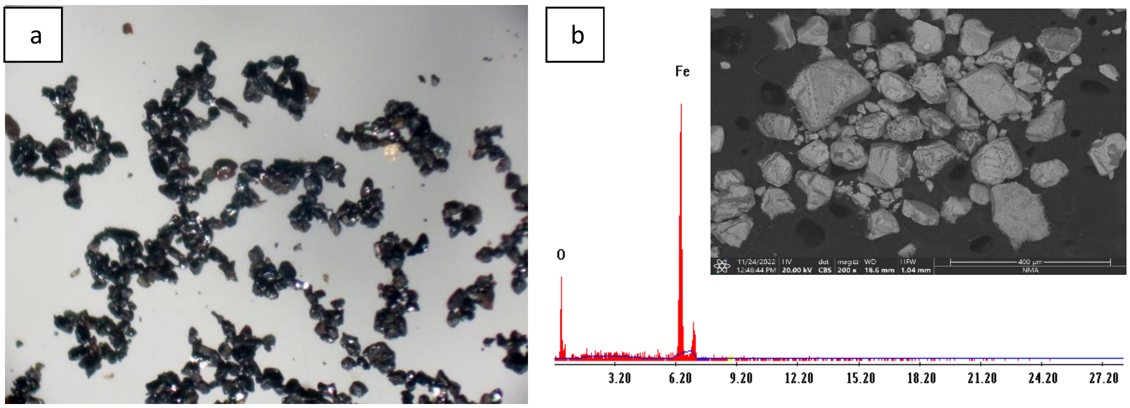

Fig. 3: a) Photomicrograph of granular, angular to sub-angular magnetite, 15x. b) EDX pattern and BSE of magnetite mineral.

II. Ilmenite $FeTiO_3$

Ilmenite occurs as homogeneous, black with metallic luster. Ilmenite exists as irregular grains with sharp edges (Fig. 4a) and as rounded and oval grains (Fig. 4b), indicating that it is inherited from different sources. Some grains are oval with smooth and pitted surface due to dissolution during transportation. The EDX microanalysis data show the composition of normal-ilmenite (Fig. 4c) with Ti (ranges from 66.4 to 88.5%), and Fe (ranges from 11.5 to 31%). Ferri-ilmenite is less frequent in the investigated samples.

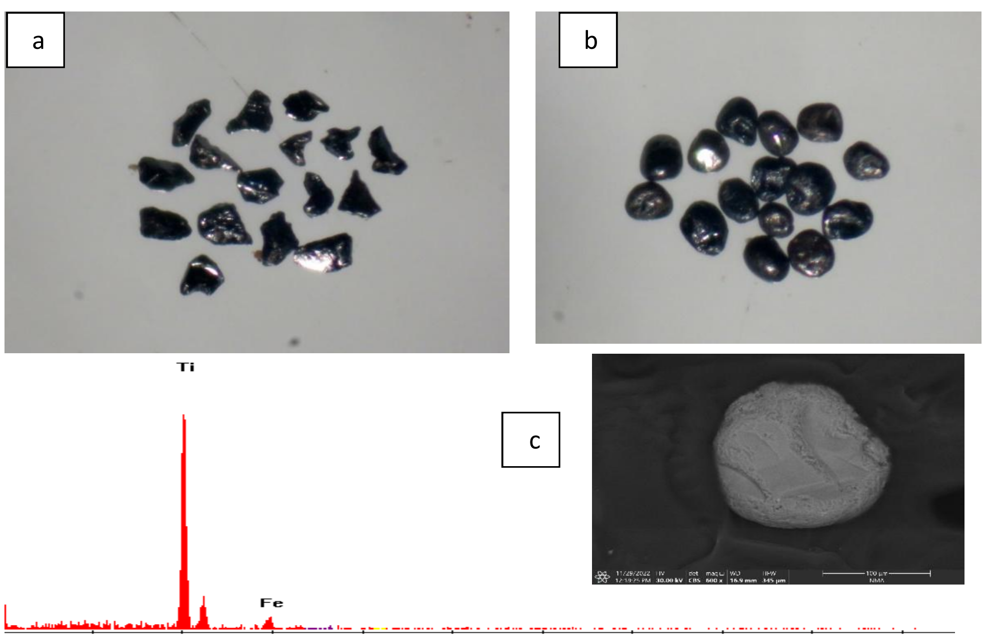

Fig. 4: a) Irregular ilmenite grains with sharp edges, 25x, b) rounded and oval ilmenite grains, 30x, and c) EDX pattern and BSE of ilmenite mineral.

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III. Leucoxene

The leucoxene commonly occurs as rounded grains, opaque in transmitted light. A rough pitted surface is characteristic of most grains. The color of leucoxene grains from the Egyptian black sands vary from dark brown to black representing the remaining of ilmenite, to brown and yellowish white (Fig. 5a). The color depends mainly on the degree of alteration (Mohamed, 1987, Mohamed, 1998 and Elsner, 2010). Ibrahim (1995) stated that, as the iron content decreases, the grain color becomes lighter brownish yellow, yellow, yellowish white and light creamy colors. The EDX microanalysis data show the composition of leucoxene (Fig. 5b) with Ti (66.5%), Fe (30.88%) with traces of Mn and Si.

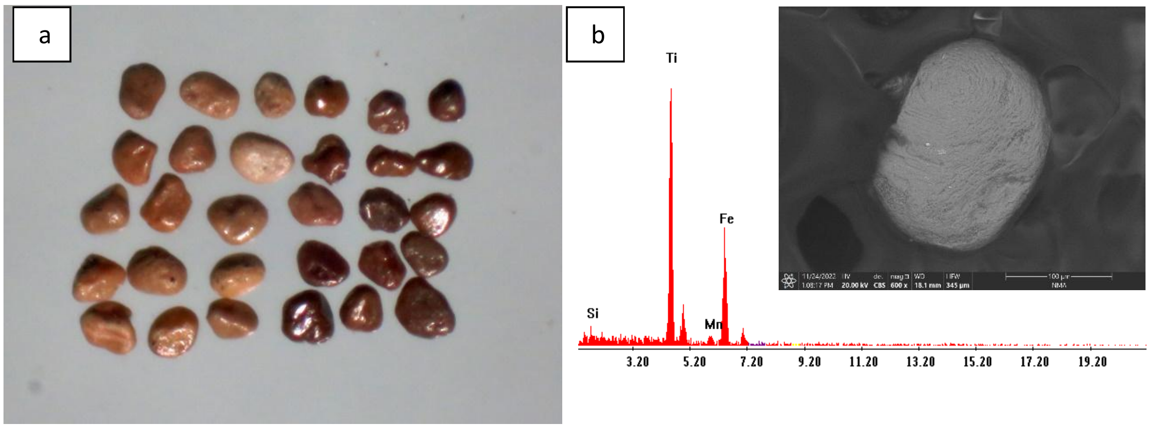
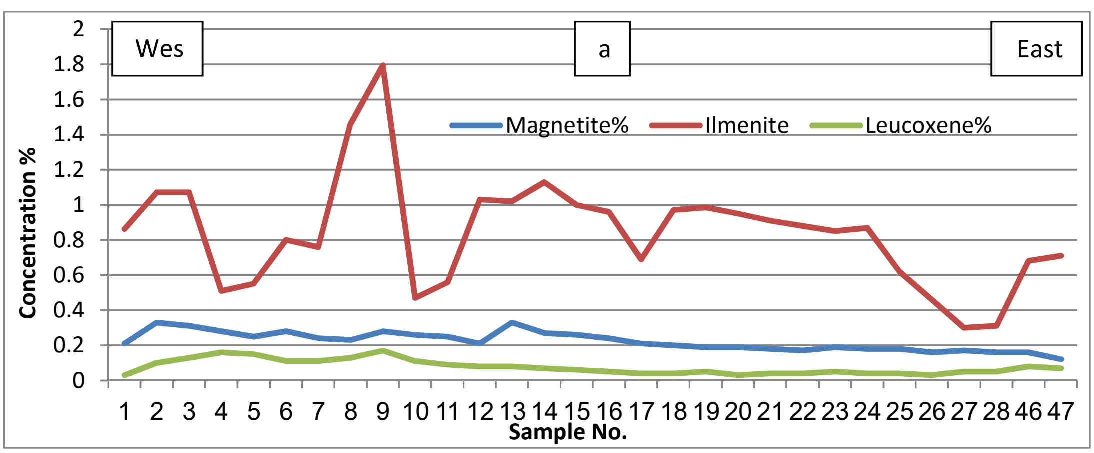


Fig. 5: a) dark brown, brown to light brown and white leucoxene 30x. b) EDX pattern and BSE of leucoxene mineral.

Figure (6) summarizes the abundance of opaque minerals in both of northern (Fig. 6a) and southern part (Fig. 6b) of the lake, where ilmenite is the most abundant mineral in the two parts, followed by magnetite, while leucoxene is the least abundant mineral. In the Northern part of the Lake, the content of ilmenite in the sediments ranges from 0.3 to 1.79% with an average of 0.84%, magnetite ranges between 0.12 and 0.33% with an average of 0.22%, and leucoxene ranges from 0.03 to 0.17% with an average of 0.08%.

In the southern part of the lake ilmenite content ranges from 0.04 to 0.75% with an average of 0.28%, magnetite ranges from 0.01 to 0.16% with an average of 0.08%, and leucoxene ranges from 0.001 to 0.5% with an average of 0.02%.



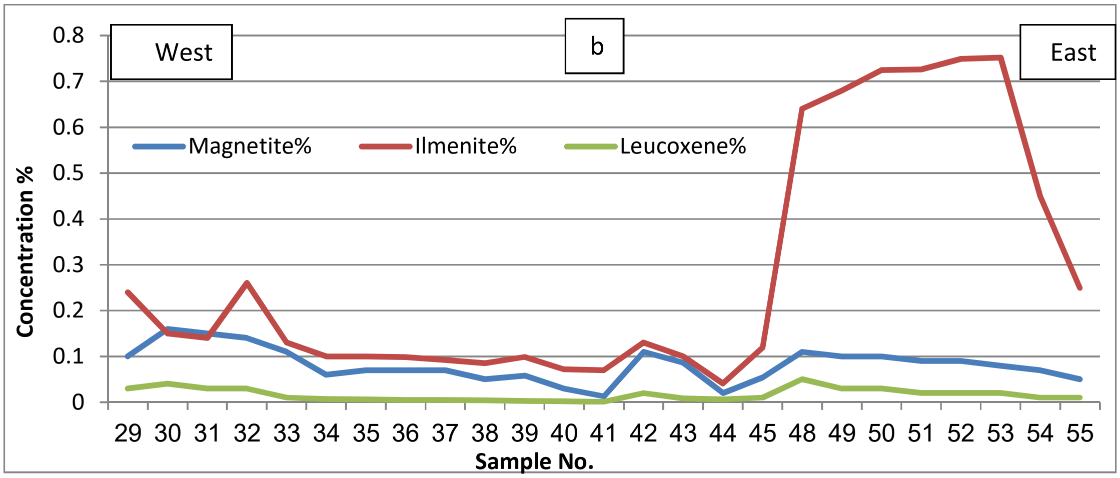


Fig. 6: The distribution of opaque minerals in (a) the northern part, (b) southern part of the lake.

Second: Non-opaque Heavy Minerals

The non-opaque heavy minerals are used to estimate the provenance that they were derived from (Zack *et al*., 2004). In case of El Manzala Lake, due to the effect of inheritance from different sources, transportation, weathering and diagenesis, some modifications may be shown in their composition and structure. The frequencies of these minerals are listed in Tables (1&2).

I. Zircon ($ZrSiO_4$)

Is one of the most physically and chemically stable accessory minerals. In the present study, zircon shows a distinct heterogeneity with respect to size, color, habit and composition (Fig. 7a, b&c). This heterogeneity can be attributed to the provenance from which zircon was derived (Phllander, et al., 1999). The crystal habits of zircon vary from prismatic tetragonal, bi-pyramidal crystals to euhedral prismatic crystals reflecting a magmatic origin. Some zircon grains are colorless prismatic (Fig. 7a), red prismatic (Fig. 7b) and colorless rounded (Fig. 7c). It is concentrated in both non-magnetic and magnetic fractions at 1.5A. The non-magnetic zircon grains are colorless with high transparency. On the other hand, the magnetic zircon grains attain brown and reddish brown colors. The variation in the color of zircon may be attributed to the density of fine inclusions as well as to their iron content. The EDX microanalysis data of zircon (Fig. 7 d, e &f) show that the Zr content ranges from 51 to 57%, Si (ranges from 43 to 48%), Hf (ranges from 4.7 to 5.9) and Fe content ranges from 1.1 to 2.91% (in magnetic type).

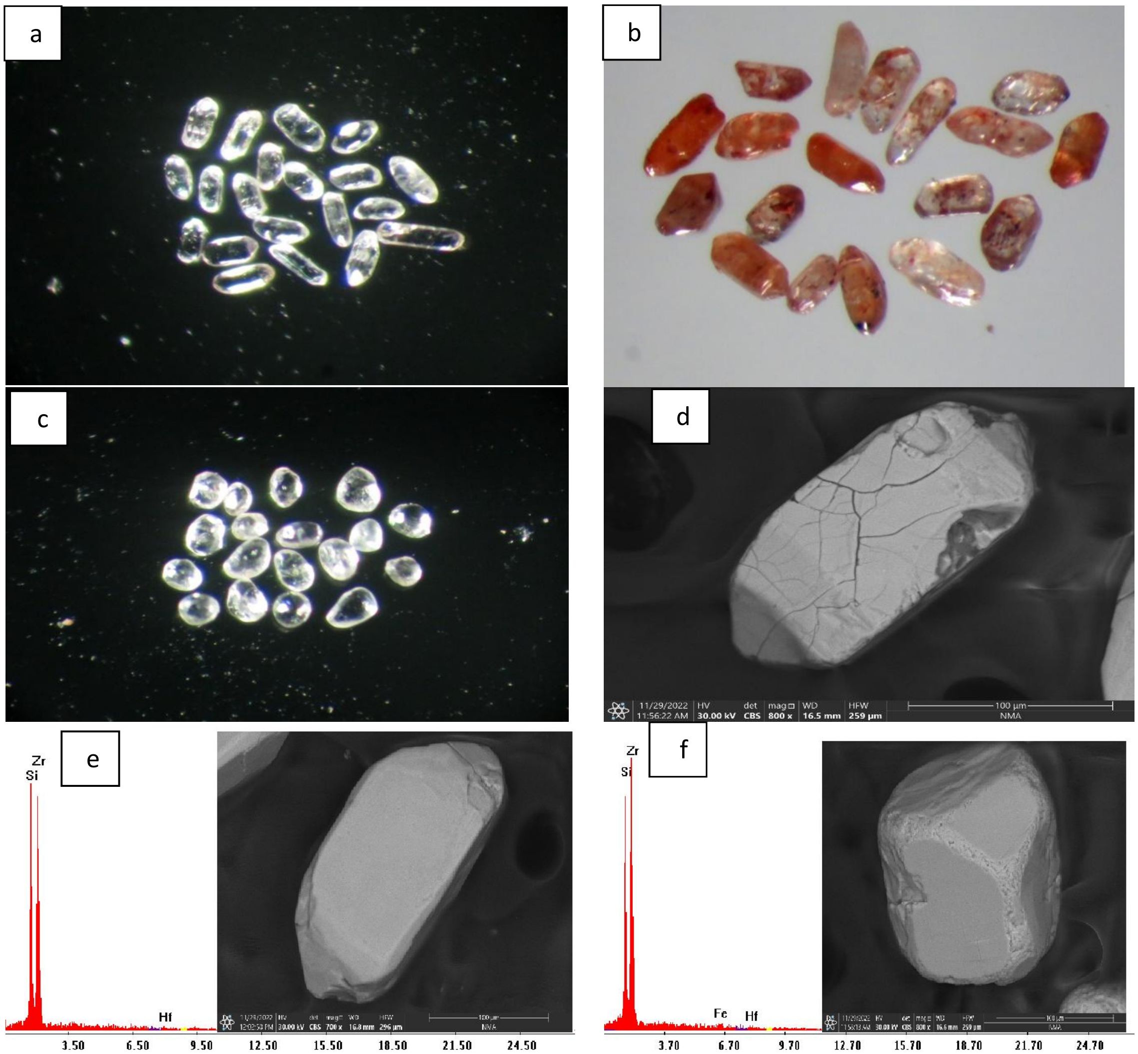


Fig. 7: Photomicrographs show: a) colorless prismatic zircon, 30x, b) red prismatic zircon, 40x, c) colorless rounded zircon, 30x, and d, e & f) EDX pattern and BSE of zircon mineral.

II. Garnet $Fe_3 Al_2 (SiO_4)_3$

Garnet grains are angular to subangular, irregular to rounded. The encountered garnets are commonly light rose to light red in color (Fig. 8a). The EDX microanalysis (Fig. 8b) shows that garnet is mostly of almandine composition in which Si content is 40%, Al is 22.6%, Fe is 27.6%, Mg is 8.25%, and Ca is 1.5%.

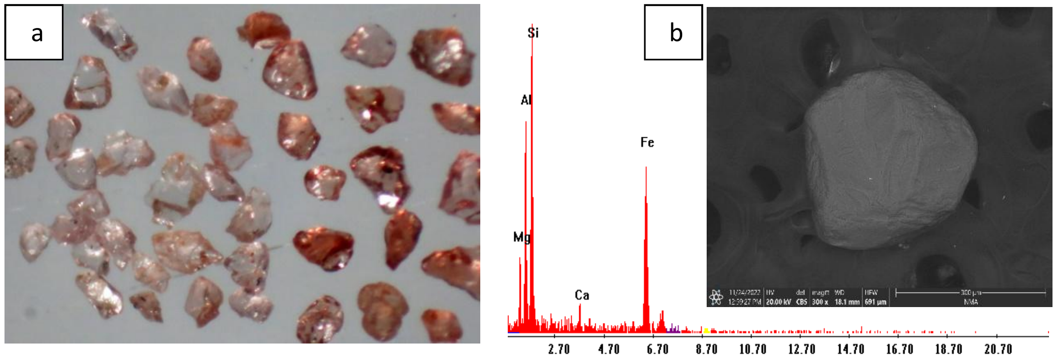


Fig. 8: Photomicrographs show: a) angular light rose to dark rose garnet, 30x, & b) EDX pattern and BSE of almandine garnet.

III. Rutile (TiO_2)

Rutile has a wide range of magnetic susceptibilities. It is concentrated in the low magnetic fields as it is essentially composed of TiO_2 with little iron. It occurs as red to black rod-like shape (Fig. 9a), Red and black, rounded, discoidal and oval (Fig. 9b). The EDX microanalysis data (Fig. 9c) show the composition of rutile with Ti (up is to 94.4%), and Fe (3.3%).

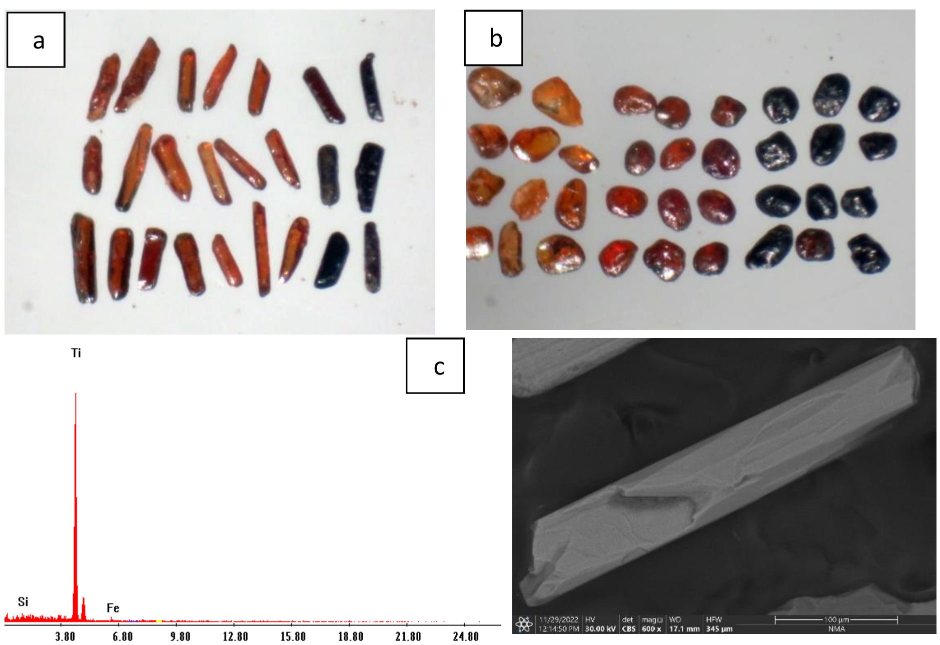


Fig. 9: Photomicrographs show: a) red to black road like shape rutile, 30x, b) Red and black rounded, discoidal and oval rutile, 30x, & c) EDX pattern and BSE of rutile mineral.

IV. Monazite (Ce, La, Nd, Th) PO_4

Monazite is confined to the fine and very fine sand-sized fraction. Monazite grains display different levels of roundness. They expose different colors and shapes ranging from colorless rounded, lemon yellow and red monazite (Fig. 10a). Moustafa, (2009) reported that the Egyptian beach monazite is colorless to pinkish in color, and mostly derived from highly differentiated granite. Moreover; El-Kammar, et al. (1992) believed that the monazite of the Egyptian black sand is almost exclusively supplied by the White Nile. The EDX microanalysis data (Fig. 10b) show that the investigated monazite is mainly of Ce-monazite type with Ce content up to 30%, Th content is up to

8% (highly radioactive monazite containing more than 6% Th and have reddish color), P content is up to 25.5%, Ca content up to 1.4%, La content is up to 16.7%, Pr is up to 5.01%, Sm is up to 1.58%, and Gd is up to 1.86%. The BSE image shows the pitted surface of monazite indicates that they were dissolved under the control of the alkaline sea water.

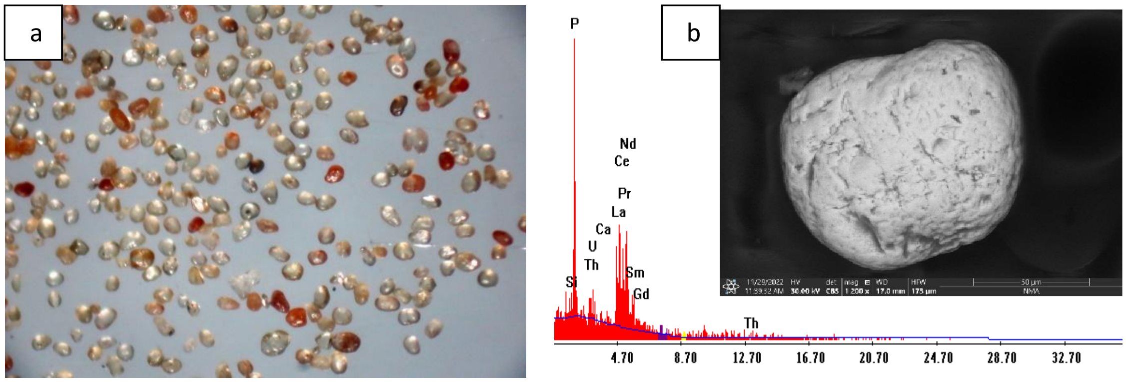


Fig. 10: Photomicrographs show: a) colorless rounded, lemon yellow, red monazite, different colors and shapes of monazite grains, 15x, & b) EDX pattern and BSE of monazite mineral.

V. Titanite (Ca Ti Si O_5)

Titanite is less common in the studied sediments. Its color varies from yellowish to brownish yellow with vitreous luster (Fig. 11a). Titanite mineral grains have subhedral to anhedral habits with imperfect cleavage. Titanite was separated at magnetic field strength 1.0A and less common in 0.5A. The EXD microanalysis data (Fig. 11b) show the composition of the investigated titanite in which Ti is 36%, Ca is 30.35% and Si is 28.08% with minor amounts of Mg, Al and Fe.

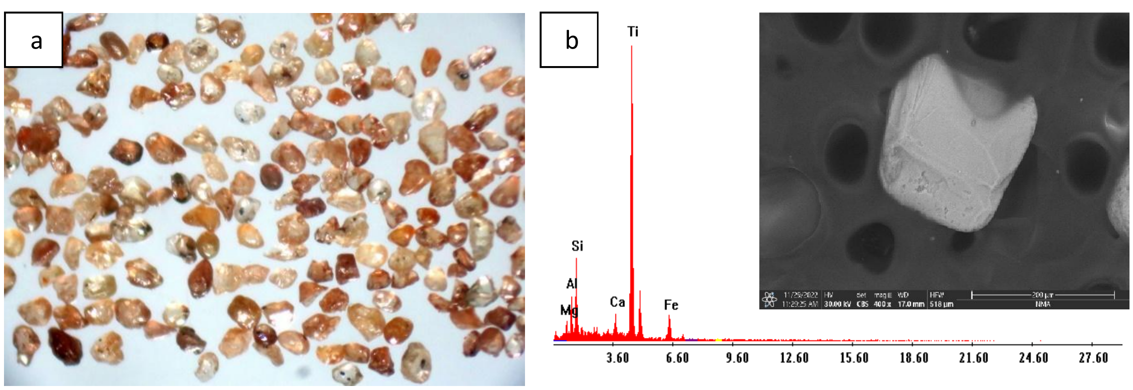


Fig. 11: Photomicrographs show: a) yellowish to brownish yellow titanite, 15x, & b)EDX pattern and BSE of titanite mineral.

The distribution of the non-opaque heavy minerals in the northern and southern part of El Manzala Lake is shown in figure (12). In the northern part (Fig. 12a) rutile is the most abundant mineral where its concentration ranges from 0.03 to 0.18% with an average of 0.62%. Monazite ranges from 0.007 to 0.106% with an average of 0.057%, zircon ranges from 0.02 to 0.12% with an average of 0.053%. The least common mineral is garnet; it ranges from 0.02 to 0.09% with an average of 0.05%.

The most abundant mineral in the southern part of the lake (Fig. 12b) is rutile too. It ranges from 0.01 to 0.06% with an average of 0.021%. In contrary garnet is the second abundant mineral; it ranges from 0.001 to 0.04% with an average of 0.02%, zircon ranges from 0.003 to 0.08% with an average of 0.019%. The least abundant mineral is monazite; it ranges from 0.001 to 0.07% with an average of 0.018%.

The comparison between the average content of the opaque and non-opaque economic heavy minerals in both northern and southern part of El Manzala bottom sediments is shown in figure (13).

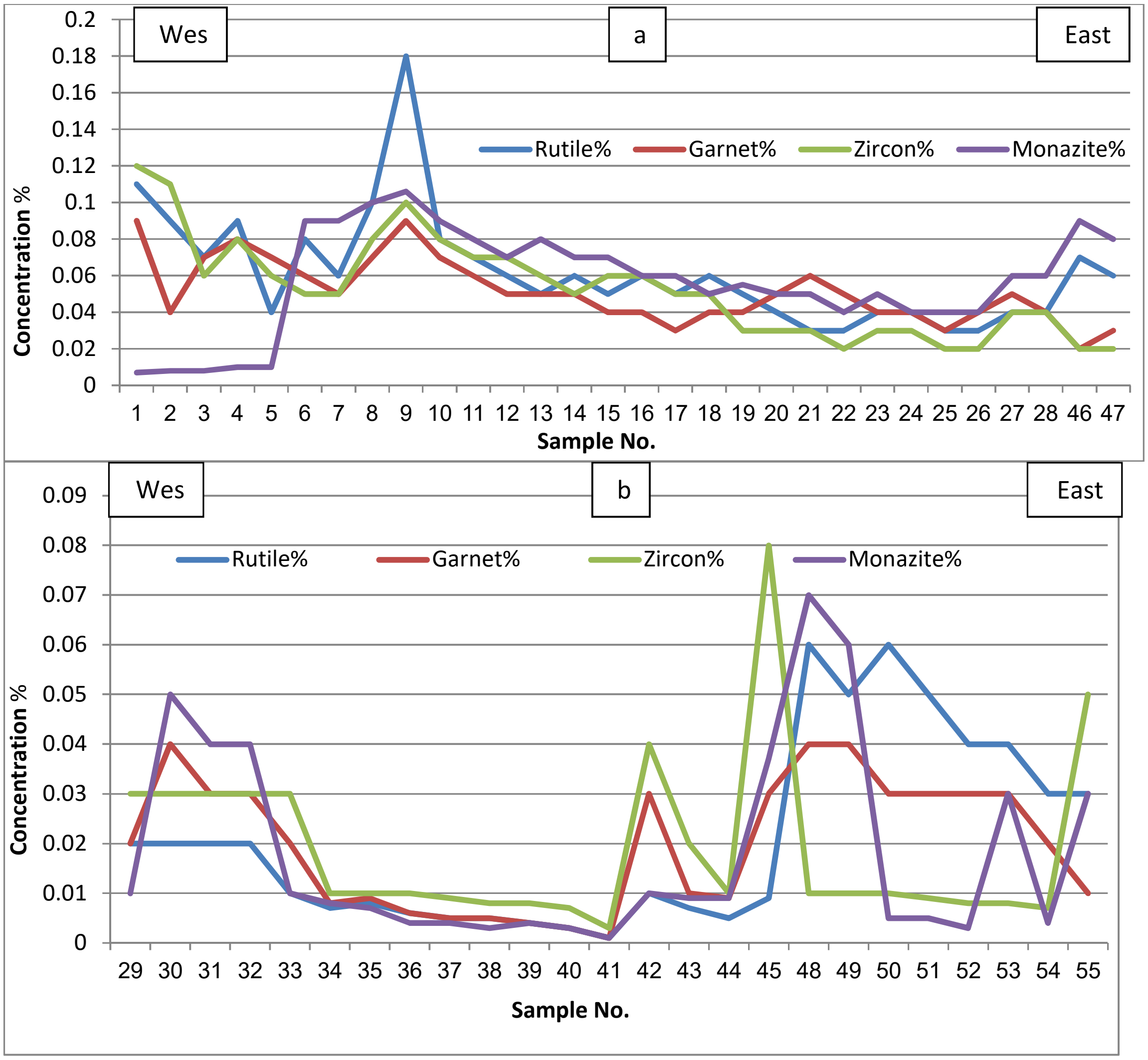


Fig. 12: The distribution of non-opaque minerals in (a) the northern part, (b) southern part of the lake.

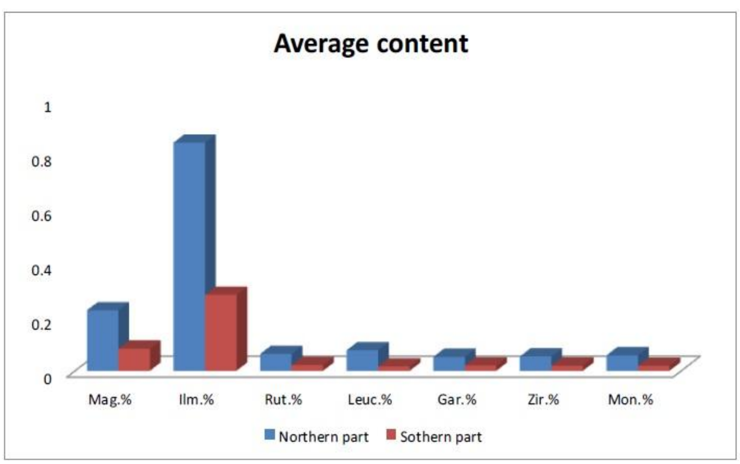


Fig. 13: Average content of opaque and non-opaque minerals in the northern and southern part of El Manzala bottom sediments.

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Third: Accessory Minerals

I. Chromite ($FeCr_2O_4$)

Chromite is the main ore of chromium that has many industrial uses. It is characterized by its high resistivity to heat. Chromite usually occur as well formed octahedron crystals vary in color from black to brownish black with metallic luster. It is concentrated during isodynamic separation process at 0.2A and 0.5A fractions (Fig. 14).

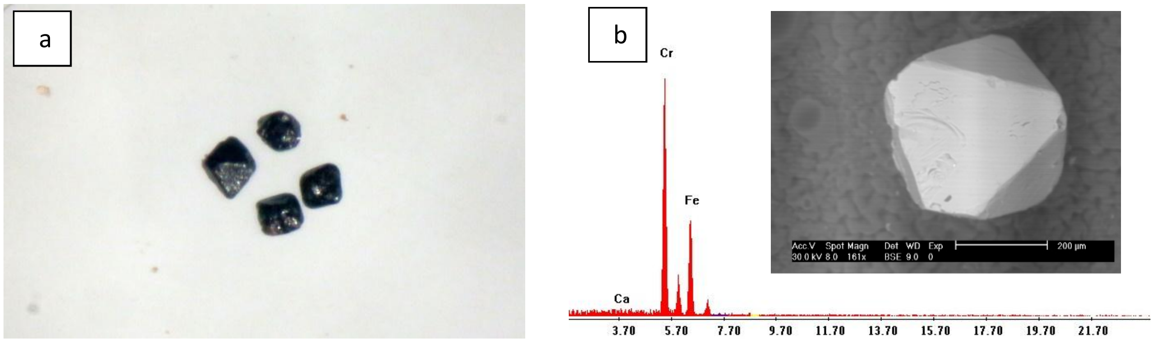

Fig.14: (a) Photomicrograph of chromite, 30x., & b) EDX pattern and BSE of chromite mineral.

II. Pyrite (FeS_2)

Pyrite framboidal pyrite is frequent in the investigated sediments (Fig. 15a&b). Under anoxic environments, which are typical of deeper strata, the hydrogen sulphide (H_2S) needed for the formation of iron sulphides is produced by biogenic reduction of sulphate, either by degradation of organic matter or by methane oxidation (Garming *et al*., 2005). Typical conditions are maintained at the bottom sediments of Manzala. The EDX microanalysis data (Fig. 15c) shows that pyrite is composed of S (ranging from 56.42 to 57.6%), Fe (ranges from 39.19 to 41.67%) with few amounts of Si (up to 3%).

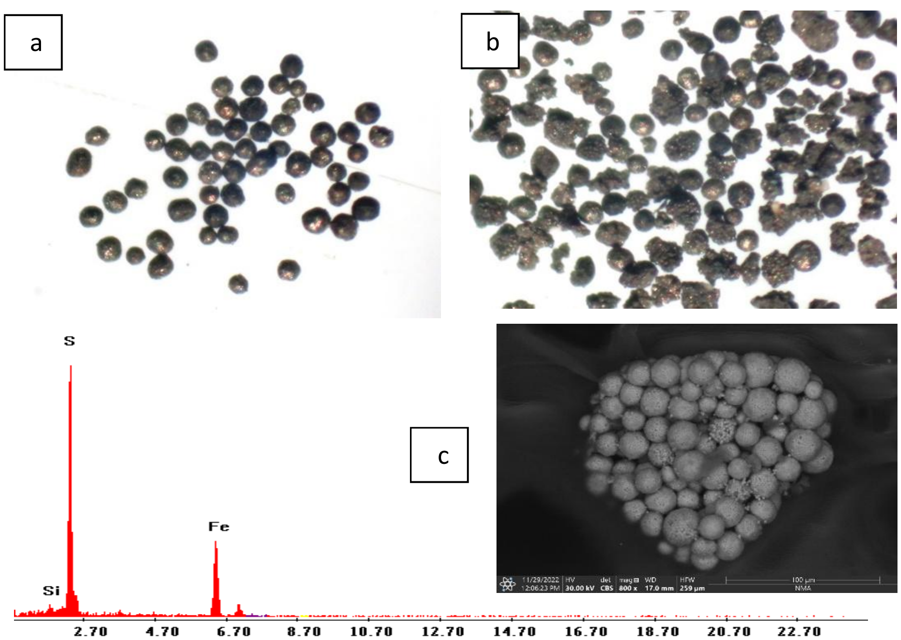

Fig. 15: Photomicrographs show: a&b) well-rounded Golden yellow pyrite, 30x, & c) EDX pattern and BSE of pyrite mineral.

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III. Gahnite ($ZnAl_2O_4$)

Gahnite is a rare mineral belongs to spinel group. Its color varies from blue, green and yellow (Fig. 16a). Gahnite mineral is recorded in investigated sediments in few amounts in the form of subhedral angular grains. The EDX microanalysis (Fig. 16b) shows the composition of gahnite in which Al ranges from 48.6 to 59.35%, Zn ranges from 35.73 to 37.13%, and Fe ranges from 5 to 11.5%.

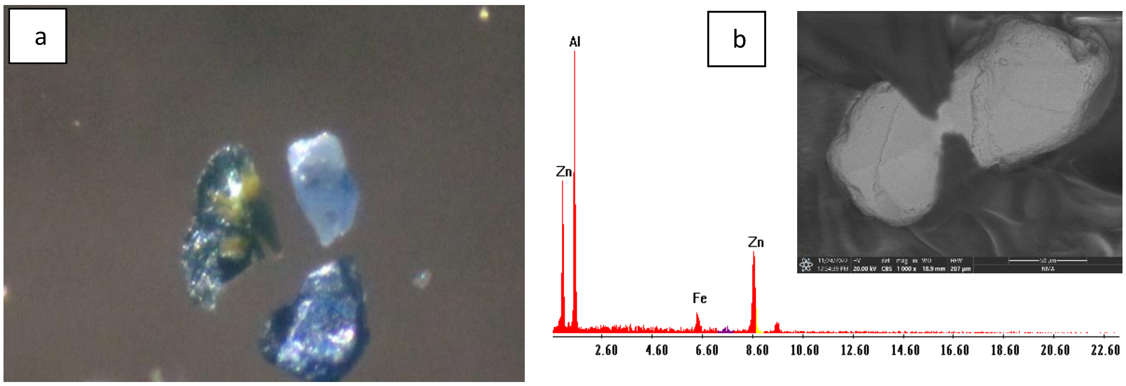

Fig. 16: a) Photomicrograph of gahnite, 45x. & b) EDX pattern and BSE of gahnite mineral.

Fourth: Green Silicates

The recorded green silicates are mixture of amphiboles and pyroxenes of different types, their distribution varies from place to place and concentrated in the northern part of the lake, where they range from 1.02 to 4.38% with an average of 2.28%, on the other hand their content in the southern part ranges from 0.12 and 1.94% with an average of 1.01% (Tables 1&2).

2) Heavy minerals content and grain size

Shetaia (2017) clarified that, the grain size analysis of the bottom sediments of EL Manzala Lake exhibits three categories; loam, clay loam, and clay, and the spatial distribution for different facies showed the majority of lagoon covered by clay loam. The obtained data indicated that, the samples that lie in the northern part of the lagoon contain high percentage of sand fraction relative to the other grain sizes. Loam covers the areas that lie at front of New El-Gamil outlet along with the northwestern part of lagoon. In contrast, clay facies cover a considerable part of southeastern part of lagoon while clay loam covering the majority of lagoon.

Clay fractions in El Manzala Lake tend to accumulate in relatively deep waters (redeposited in deeper waters at the center of the lake) compared to the coarse silt that accumulated in relatively shallow water. Fine fractions are trapped at and near regions occupied by drain inflow. Areas facing drain effluent were characterized by homogenous suspension as rolling is the predominant mode of transportation (Farahat, 2019). This could be controlled by inland sources and probably related to settling conditions of particles and local sedimentological processes (El Kammar *et al.,* 2010).

These results conform well with the present study, the data obtained from applying decantation method on the investigated samples show that the percentage of clay-sized fraction ranges from 4.26 to 25.32% with an average of 13.57% in the northern part (Table.1), while it ranges from 35.26 to 93.56% with an average of 63.03% in the southern part (Table. 2). These data clarify that the sand-sized fraction (Fig. 19a&b) is predominant in the northern part near New El Gamail outlet facing the Mediterranean Sea (Fig. 17a) while the clay sized fraction is present exclusively in the southern part of the lake to the south of Bahr El Bakar, and Faraskour drain (Fig. 17b).

The dashed white line in figure (1) represents the promising location for the prospecting of economic heavy minerals (northern part) according to the results obtained from the present study.

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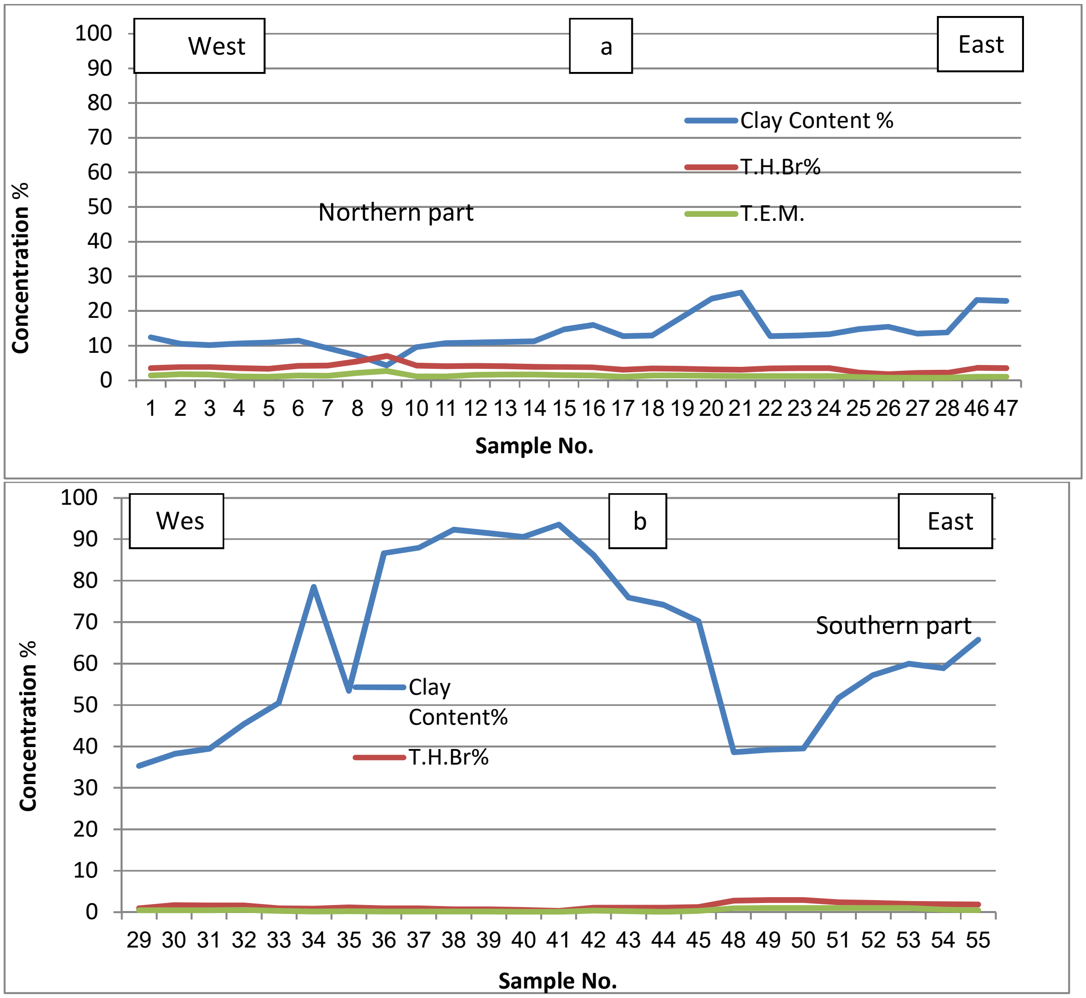

Fig. 17: Relation between clay content, total economic minerals and total heavy mineral in a) northern part, b) southern part of EL Manzala Lake.

4. Conclusions

El Manzala Lake is considered as the biggest coastal saline lake in Egypt. It is located at the northeastern quadrant of the Nile Delta, and to the south of the Mediterranean Sea. The sediments of El Manzala Lake are mainly composed of two fractions of different grain size; the first consists mainly of mud and clay which can be used as fertilizer for the desert land. The second type is represented by sand fraction which characterized by high concentrations of economic and strategic heavy minerals.

The mineralogical investigation led to identification of considerable number of minerals which are of economic importance, and are classified into two categories namely opaque and non-opaque minerals. The most important opaque minerals are ilmenite, magnetite and leucoxene. Their grains vary in shape and habits indicating that they were inhered from different sources and distances, the pitted surface of ilmenite indicates the dissolution during transportation. The euhedrality of magnetite may suggest that it is derived from granitic rocks. The different colors of leucoxene reflect different degrees of alteration.

The non-opaque minerals are represented by rutile, zircon, monazite and garnet with few concentrations of titanite. The crystal habits of zircon vary from prismatic tetragonal, bi-pyramidal to euhedral prismatic reflecting a magmatic origin. Rutile grains display different colors ranging from yellow to black according to their iron content. Monazite is confined to the fine and very fine sand-sized fraction and is mainly of Ce-type. Granites, pegmatites and sandstones are the main sources of the ultrastable zircon, monazite and rutile minerals. The presence of garnet is indicative of metamorphic origin. In addition to them chromite, pyrite gahnite minerals are recorded as accessory minerals.

The concentrations of the recorded minerals vary from place to place where the highest potential occurs close to the northern part of the lake. Ilmenite is the most abundant opaque mineral in both northern and southern part of the lake followed by magnetite. It is worthy to mention that the distribution and abundance of the recorded heavy minerals are controlled by grain size where the majority of identified heavy minerals are concentrated in the fine sand-sized fraction and increase towards the northern part of the lake (loam).

The northern part of the lake is characterized by the predominance of ilmenite >Magnetite> Leucoxene >rutile>Monazite>zircon, while garnet is the least abundant mineral. In contrast, the distribution of the recorded economic minerals in southern part is slightly different, where their abundance is as follows: Ilmenite> Magnetite> rutile> garnet> zircon > monazite >Leucoxene.

According to the previous data the Northern part of the lake is considered as potential source of economic heavy minerals. It extends from the shore of Mediterranean Sea from the north to the drains of Bahr El Bakar and Faraskour in the east and west respectively.

5. Recommendations

The authors strongly recommend the dredging of the bottom sediments of Manzala Lake in the northern part which is considered as potential source for economic heavy minerals and also to dig for more depth in the southern part to avoid the clay that cover the sandy sediments in order to evaluate the economic outcome from the recorded heavy minerals.

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