Sedimentological and mineralogical characteristics of khors sediments, Lake Nasser, Egypt

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Abstract

Thirty-two surface sediment samples were collected from eight major khors (El-Ramla, Kalabsha, Wadi-Abyad, El-Allaqi, Singari, Korosko, Tushka and Or) along Lake Nasser to study the sedimentological and mineralogical characteristics of the northern, middle and southern khors sediments. The observed lateral variations in grain size characteristics and its parameters are attributed mainly to the characteristics and the nature of source rocks surrounding the studied khors. Sand fractions (63 – 125 µm) were separated from the studied sediments. The heavy minerals content reflects a deficiency in pyroxenes and an enrichment of epidotes and amphiboles. This may confirm the effect of local contribution of these minerals from the surrounding country rocks. The insignificant lateral and seasonal variations in the calculated hydraulic fractionation indices, induced by the predominance of a provenance factor rather than a hydraulic fractionation factor. The observed variations in the transportation indices values, attributed mainly to the effect of local source from the surroundings of the studied khors. The clay minerals are mainly represented by kaolinite, smectite and traceable amounts of illite. The formation of clay minerals in the studied khors sediments is due to the weathering of the local country rocks.

Keywords: Lake Nasser, khors sediments, heavy minerals, clay minerals

1. Introduction

The number of major khors in Lake Nasser is about eighty-five, of which forty-eight located on the eastern bank and thirty seven on the western bank. Some sandy bottom khors as El-Ramla, Kalabsha, El-Allaqi and Tushka are relatively wider and shallower, than others, steep, rocky bottom, deep and narrow like khors Singari and Korosko (Figure 1).

The rock exposures in the catchment's area of the various studied khors are represented by different sedimentary rocks (Nubia Sandstone and shales) and sand sheets accumulated by the action of the wind, and basement rocks (Aswan granites, gneisses, schists, syanites, diorites, epidiorites and aegirine trachyte), basaltic sheets and dykes are also exposed (El-Ramly, 1973) (Figure 2). Although several studies have been carried out on Lake Nasser sediments (Philip *et al*., 1977; Hassan *et al*., 1977; El Dardir, 1992; Khalifa *et al*., 1994 and Gindy and El Dardir, 2008 & 2009), few studies were conducted on the khors sediments (El Dardir *et al*., 1988 and Ahmed *et al*., 1993). El Dardir *et al*. (1988) concluded that the heavy mineral assemblage of the heavy fraction in some of the studied southern khors sediments is that of sandstones of Nubia facies. Ahmed *et al*. (1993) concluded that the variations in grain size parameters and heavy minerals content of some northern khors sediments confirm the important role of local contribution from the surrounding country rocks. The clay minerals distribution attributed to a detrital origin. Also, they stated that the behaviour of elements are controlled by the relative abundance of the clay minerals, and by the source rocks. The objective of this study is intended to discuss the sedimentological and mineralogical characteristics of the major northern, middle and southern khors sediments along Lake Nasser. Khors samples were collected from the surface bottom sediments in Lake Nasser during the different seasons.

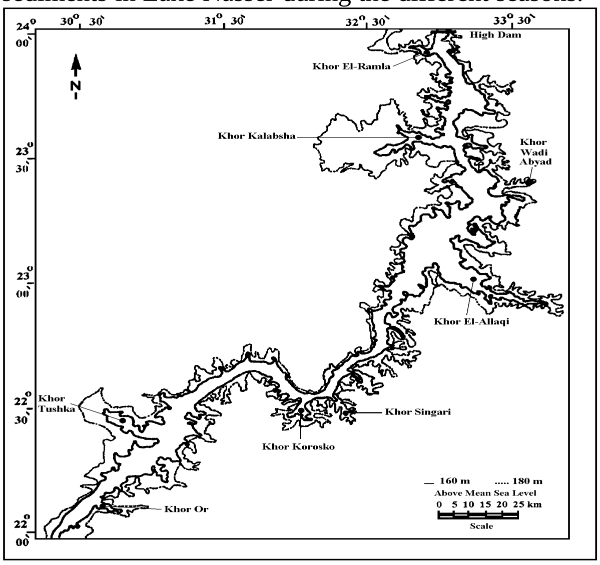

Figure 1: Location of khors sampling sites along Lake Nasser.

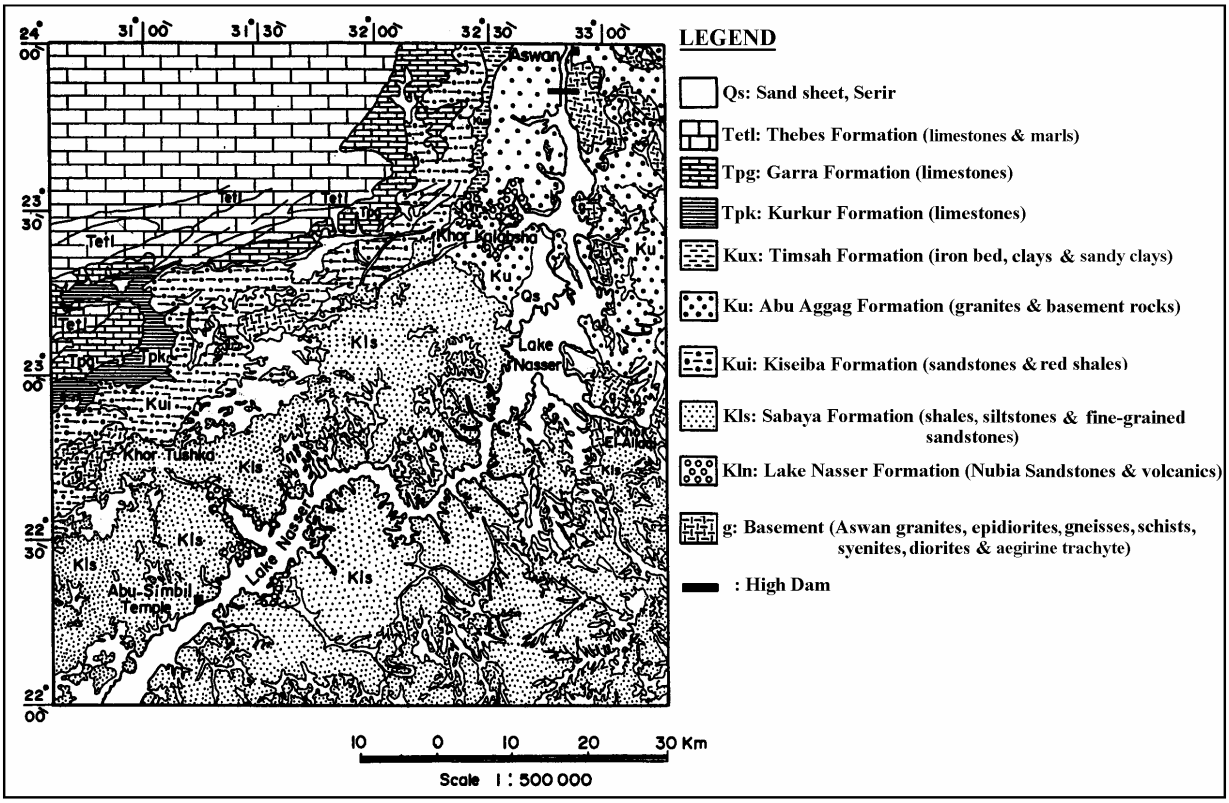

Figure 2: Geological map of Lake Nasser after CONOCO & EGPC (1987).

2. Materials and methods

Thirty-two surface bottom sediment samples were collected using Peterson grab sampler from eight major khors along Lake Nasser (300 km length) namely; (from north to south); El-Ramla, Kalabsha, Wadi-Abyad, El-Allaqi, Singari, Korosko, Tushka and Or (lying 10, 55, 70, 110, 175, 180, 245 and 280 km south of the High Dam, respectively) (Figure 1). The grain size distribution of studied sediments was determined by sieving technique for sand fraction (Folk, 1974). The pipette technique of Carver (1971) was carried out to estimate the fractions of silt and clay. The grain size parameters were calculated according to Folk and Ward's (1957) equations:

$$M_Z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

$$SK_I = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

$$K_G^{\backslash} = \frac{K_G}{1 + K_G}$$

Heavy minerals were separated from the very fine sand fraction (63 - 125 μm) of thirty-two samples using bromoform (sp. gr. 2.85). A systematic identification of mineral grains was carried out following the method given by Milner (1962) and Mange and Maurer (1992). To examine the influence of hydraulic fractionation by the shape, density and stability indices, the heavy mineral ratios (E/PHT, O/NO and ZTR/PH) of Flores and Schideler (1978) were calculated on the average heavy mineral content of the studied samples. To consider the effect of transportation of the heavy minerals in the studied samples related to its quantity in the original source (I_1, I_2 & I_3) were calculated following Gewaifel *et al.* (1981) as follows:

$$I_1 = \frac{\text{Average of heavy minerals in sediments}}{\text{Total average of White, Blue Nile and Atbara River}}$$

$$I_2 = \frac{\text{Average of pyroxenes in sediments}}{\text{Average of Blue Nile and Atbara River}}$$

$$I_3 = \frac{\text{Average of epidotes in sediments}}{\text{Average of White Nile}}$$

The clay fraction (< 2μm) of eleven representing the studied sediment samples were investigated using X-ray diffraction (XRD) technique to identify the clay minerals. Of these, seven samples were taken from khors (El-Ramla, Wadi-Abyad, El-Allaqi, Singari, Korosko, Tushka and Or) during winter, 2010, and four samples were taken from Khor Kalabsha during the different seasons to study the seasonal variations. The studied samples were scanned between 4 and 30° 2θ with speed rate 1° 2θ/minute. According to the X-ray powder diffraction table of Chen (1977), the clay minerals were identified. The relative frequency of the identified clay minerals were calculated according to the method of Griffin (1971).

3. Results and discussion

3.1. Grain size

The grain size analysis revealed that the sand fraction is the most abundant in the studied sediments (80 - 99%). The clay fraction constitutes lesser than 5%, while the silt fraction ranges from 0.8 - 18%. These fractions showed high range of variability among the investigated khors (Table 1).

3.1.1. Grain size parameters

The mean grain size diameters (M_Z) values of the studied sediments ranging between 1.13 ϕ (medium sand) and 3.42 ϕ (very fine sand) with an average value of 1.98 ϕ (medium sand); inclusive graphic standard deviation (σ_I) values ranging from 0.65 ϕ (moderately well sorted) to 2.29 ϕ (very poorly sorted) with an average value of 1.45 ϕ (poorly sorted); inclusive graphic skewness (SK_I) values range between -0.21 (negatively skewed) and 0.63 (very positively skewed) with an average value of 0.17 (positively skewed); and the graphic kurtosis ($K_G^\backslash$) values in the studied samples range from 0.41 (platykurtic) to 0.73 (very leptokurtic) with an average value of 0.54 (leptokurtic) (Table 2).

The low M_Z values in the analyzed samples from the northern khors (Khor El-Ramla) to the southern khors (Khor Or and Khor Tushka) (Table 2), reflects variable conditions of the surrounding country rocks (El Dardir, 1992). The inclusive graphic skewness (SK_I) is a measure of symmetry of grain size distribution. The analyzed khors samples have SK_I values vary between -0.21 (negatively skewed) at Khor Or and 0.63 (very positively skewed) at Khor El-Allaqi with an average value of 0.17 (positively skewed). The highest value was recorded at Khor El-Allaqi (sample No. 4) and the lowest one was obtained from Khor Singari (sample No. 5) (Table 2). No regular trend of variation of SK_I among the studied khors could be observed. The graphic kurtosis (K_G) measures the peakdness of the grain size distribution. It is a sensitive and valuable test of the normality of distribution. The studied samples have ($K_G^\backslash$) values rang between 0.41 (platykurtic) at Khor Tushka (sample No. 7) and 0.73 (very leptokurtic) at Khor El-Ramla (sample No. 1) with an average value of 0.54 (leptokurtic) (Table 2). The graphic kurtosis ($K_G^\backslash$) values shows a slight increase from south to north. To sum up, the characteristics of grain size and its parameters vary widely from one khor to another. These variations are attributed mainly to the characteristics and the nature of source rocks surrounding the studied khors. El-Ramly (1973) stated that the igneous and metamorphic rocks form the backbone of the eastern side of Lake Nasser, while Nubia Sandstone form the backbone of the western side (Figure 2). In fact, the hydrodynamics of the studied khors differ from one khor to another at least during the sampling time. While currents are strong in Khors Kalabsha, El-Allaqi, Korosko and Tushka, static hydrodynamic conditions prevail in Khors El-Ramla, Wadi-Abyad, Singari and Or (field observations).

Table 1: Percentages of sand, silt and clay of the analyzed khors sediments of Lake Nasser during the study.

Location	Km/H.D*	Sample No.	Sand (%)				Silt (%)				Clay (%)			
			sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.
Khor El-Ramla	10	1	82.3	84.0	85.5	84.5	12.7	13.6	13.5	12.8	5.0	2.4	1.0	2.7
Khor Kalabsha	55	2	91.5	92.5	91.0	93.0	7.2	6.6	7.4	5.0	1.3	0.9	1.6	2.0
Khor Wadi-Abyad	70	3	80.0	81.0	81.3	83.0	18.0	15.3	15.6	15.5	2.0	3.7	3.1	1.5
Khor El-Allaqi	110	4	92.3	92.2	91.8	93.5	6.0	5.9	6.5	5.5	1.7	1.9	1.7	1.0
Khor Singari	175	5	94.5	94.8	95.0	95.8	5.0	4.0	4.4	3.4	0.5	1.2	0.6	0.8
Khor Korosko	180	6	96.0	96.6	96.2	96.5	3.0	3.0	3.4	3.0	1.0	0.4	0.4	0.5
Khor Tushka	245	7	97.0	97.2	97.5	97.4	2.8	2.7	1.6	2.2	0.2	0.1	0.9	0.4
Khor Or	280	8	98.8	99.0	98.8	99.0	1.1	0.8	1.0	0.9	0.1	0.2	0.2	0.1
Average			91.5	92.2	92.1	92.9	7.0	6.5	6.7	6.0	1.5	1.3	1.2	1.1
			92.2				6.5				1.3			

(sp.: spring, 2009 su.: summer, 2009 au.: autumn, 2009 w.: winter, 2010)

*Km/H.D: Distance from High Dam (Km).

Table 2: Grain size parameters of the analyzed khors sediments of Lake Nasser calculated according to Folk equations.

Location	Sample No.	Grain size parameters																			
		Mz (ϕ)				σ_I(ϕ)				SK_I				K_G				$K_G^\backslash$			
		sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.
Khor El-Ramla	1	3.42	2.63	3.00	3.23	1.49	1.71	1.25	1.36	0.21	-0.01	0.17	0.04	2.71	1.17	1.81	2.46	0.73	0.54	0.64	0.71
Khor Kalabsha	2	1.80	2.17	1.43	1.47	1.86	1.64	1.98	1.76	0.18	-0.04	0.31	0.11	1.50	1.41	1.15	1.02	0.60	0.58	0.53	0.50
Khor Wadi-Abyad	3	2.43	3.13	2.50	2.43	2.29	1.96	2.12	1.88	0.29	0.06	0.10	0.08	1.26	1.81	1.16	1.46	0.56	0.64	0.54	0.59
Khor El-Allaqi	4	1.68	1.65	1.33	1.48	1.80	1.98	1.71	1.49	0.01	0.07	0.54	0.63	0.79	1.26	1.59	1.19	0.44	0.56	0.61	0.54
Khor Singari	5	2.50	1.67	2.10	2.43	0.97	1.55	1.04	0.81	0.03	0.03	-0.01	0.09	1.16	0.95	1.33	1.01	0.54	0.49	0.57	0.50
Khor Korosko	6	1.37	1.47	1.73	1.93	1.40	1.19	1.03	0.86	0.11	0.43	0.36	0.26	1.04	0.93	1.23	1.23	0.51	0.48	0.55	0.55
Khor Tushka	7	1.22	1.13	1.82	1.92	1.45	1.58	1.36	0.84	0.29	0.23	-0.20	0.21	0.80	0.71	0.93	1.23	0.44	0.41	0.48	0.55
Khor Or	8	1.53	1.35	1.42	1.93	1.29	1.03	1.22	0.65	-0.21	0.47	0.41	0.22	1.20	0.83	0.76	1.09	0.54	0.45	0.43	0.52
Average		1.99	1.90	1.92	2.10	1.57	1.58	1.46	1.21	0.11	0.15	0.21	0.20	1.31	1.13	1.24	1.34	0.54	0.52	0.54	0.56
		1.98				1.45				0.17				1.25				0.54			

(sp.: spring, 2009 su.: summer, 2009 au.: autumn, 2009 w.: winter, 2010)

3.2. Heavy minerals

Heavy minerals investigation of the studied khors sediments in Lake Nasser revealed the presence of opaque minerals (57.94%) and non-opaque minerals (42.06%). The non-opaque minerals include epidotes (17.66%), amphiboles (9.04%), zircon (6.09%), tourmaline (3.08%), pyroxenes (2.83%), mica (1.83%), garnet (0.46%), staurolite (0.45%), rutile (0.38%), spinel (0.19%) and apatite (0.05%) (Table 3).

3.2.1. Heavy minerals content

3.2.1.1. Opaque minerals (iron oxides)

Opaque minerals are the most predominant constituents in the heavy minerals content of all the investigated khors samples in Lake Nasser. They occur as subangular to subrounded grains, and are mainly represented by iron oxides (Figures 3-10). The relatively high frequency of opaques in the studied khors sediments progressively increase from the northern khors (Khor El-Ramla) (47.79 - 48.11%) to the southern khors (Khor Or)(65.29 - 65.70%) (Table 3). The progressive increase of the amounts of opaques from north to south as well as away from the main channel of Lake Nasser, suggests that these sediments were probably derived from the weathering of the Nubia Sandstone which widely distributed around the studied khors.

3.2.1.2. Epidotes: $Ca_2(Al, Fe)_3Si_3O_{12}(OH)$

Epidotes are the most frequent non-opaque heavy minerals found in the studied khors samples. The epidote grains are rounded, subrounded, elongated, as well as prismatic. They vary in colour from colourless to pale green. Most grains are characterized by strong birefringence and highly interference colours. Opaque inclusions are mostly noticed within the epidote grains (Figures 3 – 10). The obtained results explain that the frequency of epidotes in the studied sediments tends to increase from the southern khors (Khor Tushka) (15.15 - 15.30%) to the northern ones (Khor El-Ramla) (20.23 - 20.29%) (Table 3). This may suggest that epidotes were derived mainly from the weathering of the crystalline basement rocks, which located at the northern studied khors (Figure 2).

3.2.1.3. Amphiboles: $(Na, Ca, Mg, Fe, Al)_{7-8}(Al, Si)_8O_{22}(OH)_2$

Amphiboles are the second most abundant non-opaque heavy minerals in the studied khors samples. The identified amphibole grains are dominantly represented by green hornblende. The grains are generally broken prismatic, and show weak pleochroism (Figures 3, 5, 6, 7, 8 & 10). The relatively higher frequency of amphiboles recorded at the middle khor sediments (Khor Korosko and Khor Singari) (10.15 - 10.72%, 10.32 - 10.58%, respectively) and at the northern khors (Khor El-Ramla) (10.03 - 10.34%) (Table 3), may be attributed mainly to the local contribution from the weathering of the Nubia Sandstone and basement rocks, which widely distributed around the northern and middle khors (Figure 2).

3.2.1.4. Zircon: $ZrSi0_4$ and tourmaline: $Na(Fe, Mg, Al, Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$

Zircon and tourmaline are the third and fourth most abundant non-opaque heavy minerals in the investigated khors samples. Zircon grains are mostly colourless, rounded, as well as prismatic. They are characterized by very high relief, parallel extinction and strong birefringence (Figures 4, 5, 7 & 9). Tourmaline occurs as broken prismatic green grains characterized by moderate relief and strong pleochroism from green to bluish green (Figures 4 & 8). The frequency of zircon and tourmaline tend to increase from the southern khors to the most northern ones (Table 3); this suggest the local contribution from the Nubia Sandstone rich in zircon, tourmaline and rutile surrounding the khors (Ahmed *et al*., 1993).

3.2.1.5. Pyroxenes: $(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$

Pyroxenes are recorded in all the investigated khors samples and are mainly represented by pale green augite. The augite grains are elongate and subangular to subrounded. They are usually weakly pleochroic, whereas some of them show no pleochroism (Figures 3, 5, 6, 7, 8 & 10). The relative abundance of pyroxenes in the studied samples tend to increase from the southern khors (Khor Or) (2.18 – 2.30%) to the northern ones (Khor El-Ramla) (3.40 – 3.54%) (Table 3). The relative enrichment of pyroxenes at the northern khors sediments, may be attributed to the local contribution from the weathering of some volcanic basaltic islands, which exposed at the northern sector of Lake Nasser.

3.2.1.6. Mica: $K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$

Mica is represented by biotite brown to dark brown, greenish yellow to dark green colour. It occurs as irregular and angular flakes. The highest percentage recorded at the middle khors (Khor Singari and Khor Korosko) (2.49 - 2.66% and 2.25 - 2.40%, respectively), whereas the lowest value occurred at Khor Kalabsha (0.53 - 0.63%) (Table 3). The crystalline basement rocks, exposed at the northern and middle sectors of Lake Nasser have contributed to the increase of mica content at the studied northern khor sediments (Khor Singari and Khor Korosko).

3.2.1.7. Other minerals

Other minerals occurring in minor amounts (<1%) include 5 minerals garnet: $(Ca, Fe, Mg)_3(Al, Fe)_2Si_3O_{12}$(average = 0.46%), staurolite: $Fe_2Al_9Si_4O_{20}(O, OH)_2$ (average = 0.45%), rutile: TiO_2 (average = 0.38%), spinel: $MgAl_2O_4$ (average = 0.19%) and apatite: $Ca_5(PO_4)_3(F, Cl, OH)$ (average = 0.05%) (Table 3 and Figures 4,6,8 & 9).

Heavy minerals content is useful in determining the provenance of source area, tracing the sediment transport paths, indicating the action of particular hydraulic regimes and concentrating processes, locating the potential economic deposits and elucidating the diagenetic processes (Mange and Maurer, 1992). In fact, Lake Nasser acts at present as a store for the mineral constituents derived from the weathering of the Ethiopian plateau under tropic to subtropic climate (Gindy, 2001). Khalifa *et al*. (1994) attributed the main source of Lake Nubia sediments to Atbara River and Blue Nile with minor contribution from the White Nile, whereas the sediments of Lake Nasser were affected by local contribution from the Nubia Sandstone. Osman (1996) attributed the enrichment of banks sediments along the River Nile basin in the area (Aswan – Naga Hammadi) with pyroxene and amphibole to the derivation of these sediments from the basaltic rocks which covering the Ethiopian plateau, as well as some contribution from the basement rocks. Gindy (2001) and Gindy & El Dardir (2008) concluded that the sediments in the main channel of Lake Nasser reflected an enrichment of pyroxenes and a deficiency in epidotes and amphiboles relative to the normal Nile sediments. They attributed the main source of such sediments to the Nile contribution, as well as some local contribution from the volcanic basaltic islands, the crystalline basement rocks and from the Nubia Sandstone widely distributed in the country rocks surrounding the lake. The present study revealed that the heavy minerals content of the khors sediments reflects a relative deficiency in pyroxenes and enrichment of epidotes and amphiboles, may be attributed to the local contribution from the weathering of Nubia Sandstone, as well as the crystalline basement rocks which widely distributed around the studied khors (Figure 2). In contrast, the heavy minerals content of Lake Nasser (main channel) sediments reflected an enrichment of pyroxenes and a deficiency in epidotes and amphiboles indicating the important role of the Nile contribution to the main channel sediments in Lake Nasser, as well as some local contributions from the country rocks surrounding the lake (Gindy, 2001 & Gindy and El Dardir, 2008). Therefore, the present study of khors sediments agrees with the findings of Ahmed *et al*. (1993), where they concluded that the heavy minerals investigation of the northern khors sediments reflected a deficiency in pyroxenes and an enrichment of epidotes and amphiboles. Also, such study disagrees with the findings of Gindy (2001) and Gindy and El Dardir (2008), where they stated that the heavy minerals content of Lake Nasser (main channel) sediments reflected an enrichment of pyroxenes and a deficiency of epidotes and amphiboles.

3.2.2. Hydraulic fractionation indices

No significant variations in the calculated hydraulic fractionation indices by shape (E/PHT), density (O/NO) and chemical decomposition (ZTR/PH) using the equations of Flores and Schideler (1978) between the studied khors sediments in Lake Nasser, could be recorded. So, the differences in their amounts may indicate that shape, density and chemical decomposition are not related to a hydraulic fractionation factor in the studied khors, but may be induced by a provenance factor.

3.2.3. Transportation indices

To discuss the effect of transportation on the distribution of the heavy minerals, the transportation indices (I_1, I_2 and I_3) of Gewaifel *et al*. (1981) were calculated. The indices of transportation of opaques and epidotes are relatively high (average = 2.48 and 1.71, respectively). On the other hand, the transportation indices of amphiboles and pyroxenes are relatively very low (average = 0.33 and 0.06, respectively). Therefore, such variations in the transportation indices values are attributed mainly to the effect of local source from the surroundings of the studied khors.

3.3. Clay minerals

X-ray diffraction analysis of the clay fraction (<2μm) of khors sediments has revealed that kaolinite and smectite are the main clay minerals. Illite occurred in traceable amounts and recorded only at the southern khors. The frequency of the recorded clay minerals varied from one khor to another (Table 4 and Figure 11).

3.3.1. Kaolinite: $AI_2Si_2O_2(OH)_4$

Kaolinite is present as a dominant clay mineral in the studied samples. It ranged between 32.53% (Khor Or, sample No. 11) and 87.69% (Khor Kalabsha, sample No.5) with an average value of 69.89% (Table 4 and Figure 11). The highest frequency of kaolinite is recorded at the northern khors (particularly at Khor Kalabsha), as compared with the lowest frequency which recorded at the most southern khors (Khor Or). This increase attributed mainly to the local contribution from the kaolin - rich sediments, which occur and mined at Kalabsha area (41 km south of the High Dam).

Table 3: Relative abundance of heavy minerals in the 63 – 125 µm size fraction of the studied khors sediments in Lake Nasser during the study.

Location	Sample No.	Opaques				Epidotes				Amphiboles				Zircon				Tourmaline				Pyroxenes			
		sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.
Khor El-Ramla	1	47.94	48.11	48.00	47.79	21.15	21.18	21.30	21.26	10.34	10.23	10.03	10.07	7.63	7.54	7.65	7.74	6.00	6.15	6.13	6.29	3.54	3.45	3.40	3.43
Khor Kalabsha	2	52.09	52.22	52.36	52.20	20.23	20.25	20.29	20.27	8.13	8.20	8.30	8.20	8.49	8.61	8.31	8.33	6.10	5.85	5.78	6.00	3.38	3.35	3.35	3.40
Khor Wadi-Abyad	3	55.37	55.90	55.82	55.71	19.17	18.92	18.77	18.89	9.65	9.77	9.85	9.80	6.29	6.20	6.15	6.23	2.66	2.50	2.78	2.69	3.30	3.27	3.25	3.32
Khor El-Allaqi	4	57.59	58.16	58.39	57.69	18.12	18.00	18.10	18.33	7.98	7.85	7.74	7.93	6.93	6.75	6.65	6.74	3.16	3.10	3.00	3.07	2.59	2.65	2.55	2.63
Khor Singari	5	58.83	59.05	59.30	59.13	16.64	16.57	16.50	16.53	10.32	10.58	10.50	10.40	5.15	4.97	5.03	5.18	1.83	1.80	1.75	1.85	2.68	2.60	2.59	2.63
Khor Korosko	6	60.90	60.36	60.59	60.04	15.08	15.05	15.85	15.73	10.50	10.72	10.15	10.63	5.00	5.30	5.12	5.25	1.53	1.60	1.55	1.55	2.64	2.62	2.55	2.50
Khor Tushka	7	64.20	64.80	64.45	64.74	15.30	15.23	15.15	15.20	7.77	7.55	7.90	7.86	4.95	4.80	4.90	4.65	1.73	1.70	1.70	1.68	2.44	2.49	2.47	2.45
Khor Or	8	65.68	65.29	65.70	65.50	15.15	15.94	15.53	15.56	7.61	7.46	7.42	7.76	4.69	4.55	4.65	4.53	1.80	1.75	1.73	1.69	2.30	2.27	2.27	2.18
Average		57.83	57.99	58.08	57.85	17.61	17.64	17.69	17.72	9.04	9.05	8.99	9.08	6.14	6.09	6.06	6.08	3.10	3.06	3.05	3.10	2.86	2.84	2.80	2.82
		57.94				17.66				9.04				6.09				3.08				2.83			

Table 3: Continue.

Location	Sample No.	Mica				Garnet				Staurolite				Rutile				Spinel				Apatite			
		sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.	sp.	su.	au.	w.
Khor El-Ramla	1	2.03	2.05	2.1	2.09	0.23	0.24	0.25	0.24	0.4	0.35	0.39	0.39	0.4	0.4	0.43	0.4	0.34	0.3	0.32	0.3	-	-	-	-
Khor Kalabsha	2	0.53	0.55	0.63	0.6	0.36	0.35	0.33	0.35	0.24	0.2	0.23	0.25	0.3	0.29	0.29	0.28	0.15	0.13	0.13	0.12	-	-	-	-
Khor Wadi-Abyad	3	1.52	1.5	1.48	1.5	0.46	0.45	0.43	0.4	0.92	0.87	0.85	0.85	0.46	0.45	0.43	0.42	0.2	0.17	0.19	0.19	-	-	-	-
Khor El-Allaqi	4	2.03	2	2.07	2.05	0.58	0.55	0.54	0.59	0.21	0.2	0.2	0.22	0.39	0.38	0.38	0.35	0.19	0.16	0,18	0.18	0.23	0.2	0.2	0.22
Khor Singari	5	2.66	2.58	2.55	2.49	0.69	0.7	0.66	0.66	0.45	0.43	0.4	0.42	0.43	0.44	0.4	0.41	0.2	0.18	0.2	0.18	0.12	0.1	0.12	0.12
Khor Korosko	6	2.34	2.39	2.25	2.4	0.63	0.65	0.65	0.62	0.69	0.65	0.65	0.63	0.45	0.43	0.42	0.42	0.21	0.2	0.2	0.2	0.03	0.03	0.02	0.03
Khor Tushka	7	1.98	1.85	1.88	1.8	0.5	0.48	0.46	0.52	0.53	0.55	0.54	0.55	0.37	0.35	0.33	0.33	0.17	0.15	0.17	0.17	0.06	0.05	0.05	0.05
Khor Or	8	1.62	1.65	1.64	1.7	0.3	0.28	0.27	0.27	0.3	0.3	0.27	0.3	0.35	0.34	0.36	0.33	0,15	0.13	0.12	0.14	0.05	0.04	0.04	0.04
Average		1.84	1.82	1.82	1.83	0.47	0.46	0.45	0.46	0.46	0.44	0.44	0.45	0.39	0.38	0.38	0.37	0.2	0.18	0.19	0.18	0.06	0.05	0.05	0.06
		1.83				0.46				0.45				0.38				0.19				0.05			

(sp.: spring, 2009 su.: summer, 2009 au.: autumn, 2009 w.: winter, 2010)
- : Not recorded.

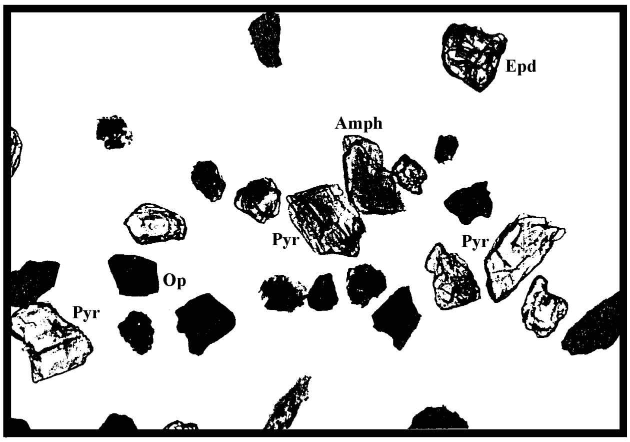

Figure 3: Photomicrograph shows epidote (Epd), amphibole (Amph), pyroxene (Pyr) and opaque minerals (Op).

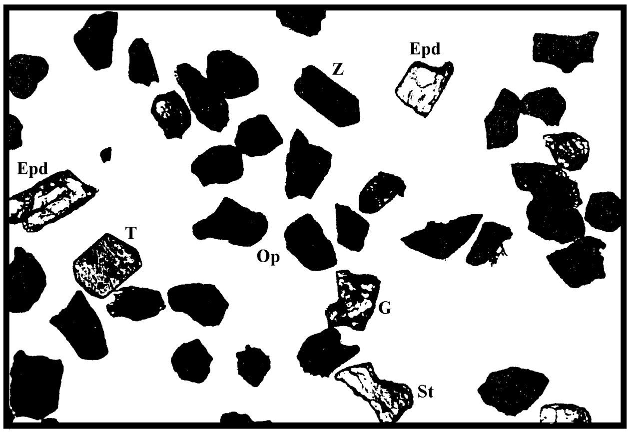

Figure 4: Photomicrograph shows prismatic epidote (Epd), zircon (Z), tourmaline (T), garnet (G), staurolite (St) and opaque minerals (Op).

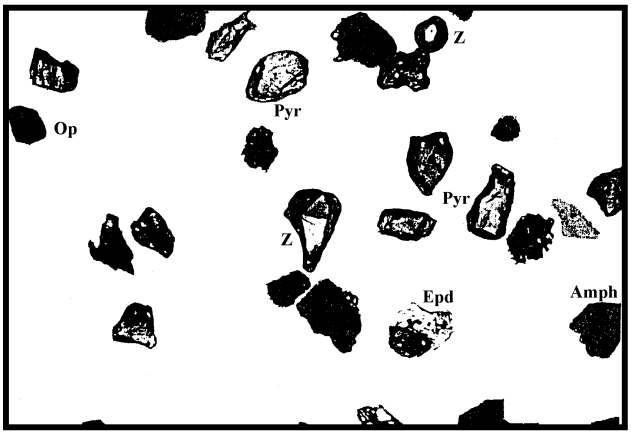

Figure 5: Photomicrograph shows epidote (Epd), amphibole (Amph), pyroxene (Pyr), well rounded zircon (Z) and opaque minerals (Op).

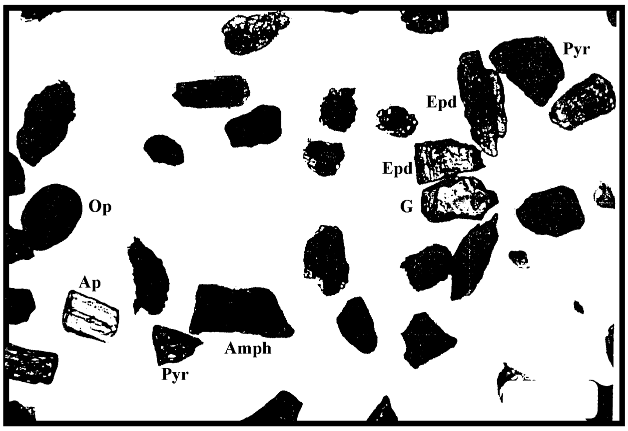

Figure 6: Photomicrograph shows pink garnet (G) with epidote (Epd), amphibole (Amph), pyroxene (Pyr), colourless apatite (Ap) and opaque minerals (Op).

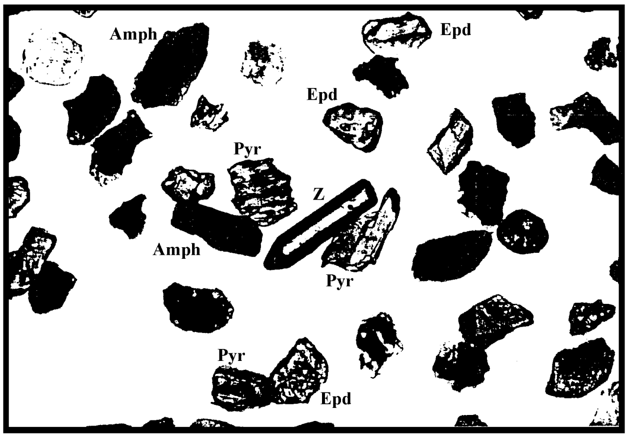

Figure 7: Photomicrograph shows prismatic zircon (Z) with epidote (Epd), amphibole (Amph) and pyroxene (Pyr).

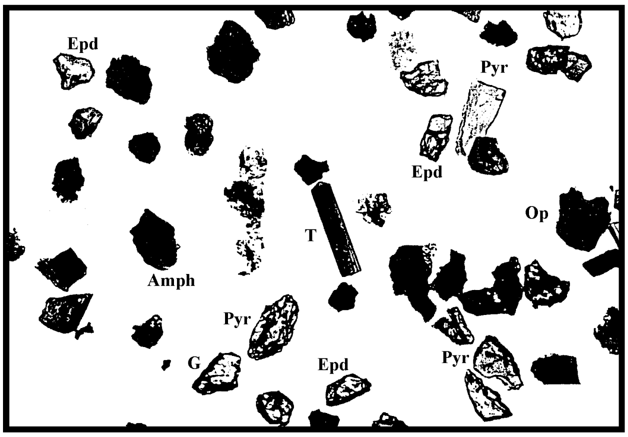

Figure 8: Photomicrograph shows prismatic tourmaline (T) with epidote (Epd), amphibole (Amph), pyroxene (Pyr), garnet (G) and opaque minerals (Op).

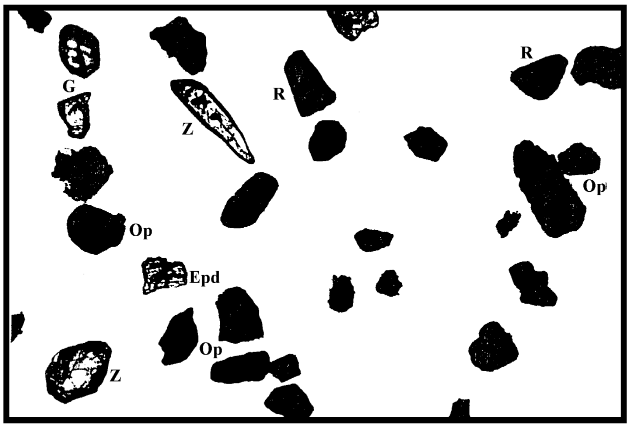

Figure 9: Photomicrograph shows brownish red rutile (R) with its characteristic very high relief with zorcon (Z), garnet (G), epidote (Epd) and opaque minerals (Op).

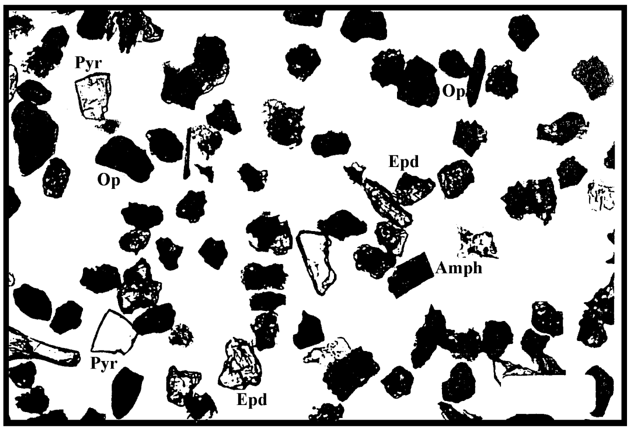

Figure 10: Photomicrograph shows epidote (Epd), amphibole (Amph), pyroxene (Pyr) and opaque minerals (Op).

Table 4: Percentages of the identified clay minerals in the khors sediments of Lake Nasser.

Location	Sample No.	Clay minerals		
		Kaolinite (%)	Smectite (%)	Illite (%)
Khor El-Ramla	1	71.74	28.26	--
Khor Kalabsha (sp.)	2	87.21	12.79	--
Khor Kalabsha (su.)	3	84.85	15.15	--
Khor Kalabsha (au.)	4	85.08	14.92	--
Khor Kalabsha (w.)	5	87.69	12.31	--
Khor Wadi-Abyad	6	80.36	19.64	--
Khor El-Allaqi	7	76.92	23.08	--
Khor Singari	8	72.34	27.66	--
Khor Korosko	9	56.72	43.28	--
Khor Tushka	10	33.33	50.00	16.67
Khor Or	11	32.53	55.42	12.05
Average		69.89	27.50	2.61

-- : Not recorded.

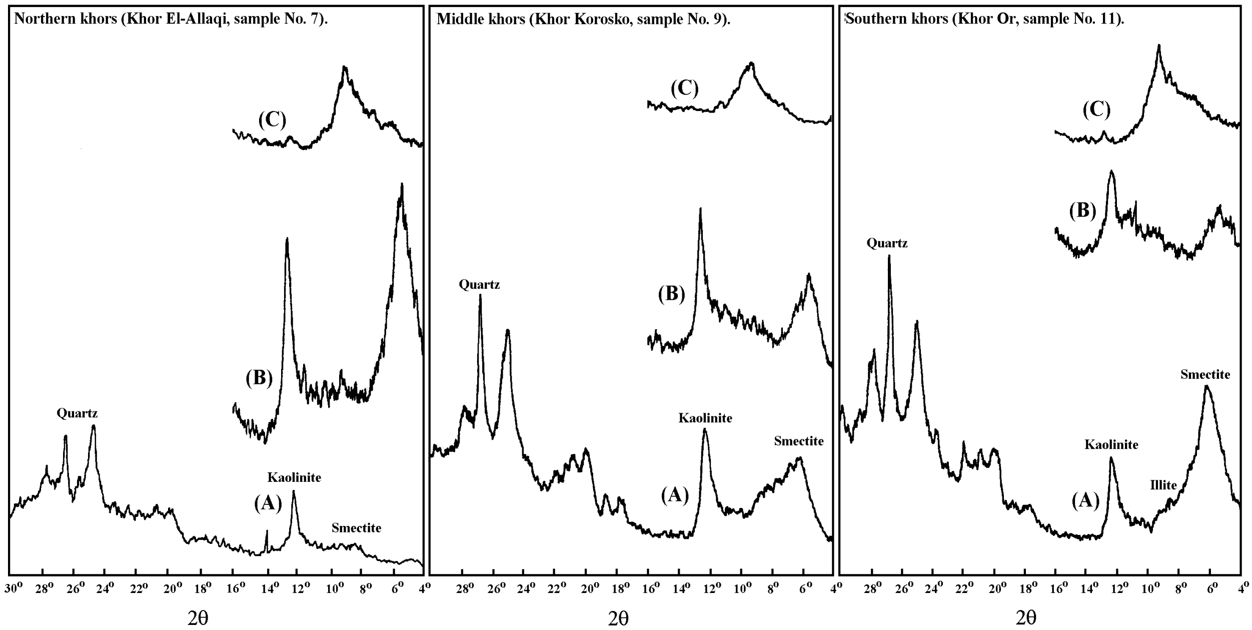

Figure 11: X-ray diffractogram patterns of clay fraction of the studied northern, middle and southern khors. (A) Air dried sample. (B) Sample treated with ethylene glycol. (C) Sample heated to 550 °C.

3.3.2. Smectite: $(Na, Ca)_{0.33}(Al, Mg)_2Si_4O_{10}(OH)_2.nH_2O$

Smectite represents the second abundant clay mineral in the studied samples. It ranged between 12.31% (Khor Kalabsha, sample No.5) and 55.42% (Khor Or, sample No. 11) with an average value of 27.50% (Table 4 and Figure 11). The relatively higher frequency of smectite was recorded at the most extreme southern khors in the lake and may be attributed to the local contribution from the Nubia Sandstone that widely distributed around the studied khors (Figure 2).

3.3.3. Illite: (K, H_3O) $(Al, Mg, Fe)_2(Al, Si)_4O_{10}[(OH)_2, H_2O]$

Illite occurred in low values (12.05 – 16.67%) and is completely absent in the northern and middle khors samples, where kaolinite shows high content. From this relation, it is clear that illite has been formed at the expense of kaolinite (Table 4 and Figure 11).

There are numerous opinions dealing with the origin of the clay minerals. Clay minerals are chiefly detrital on origin, reflect mainly the character of source area, and are only slightly modified by their depositional environments (Weaver, 1967). Kaolinite, illite and montmorillonite are considered as detrital particles transported from source area and were deposited with little, if any, diagenetic changes (Pryor and Glass, 1961). Keller (1970) classified the clay minerals genetically as either neoformed or transported. Also, he showed that the clay minerals, which were produced by weathering and alteration of silicates, are the most important types of the neoformed clay minerals. Hendriks (1985) reported that kaolinite and illite are of detrital origin, whereas smectite and mixed layer smectite – chlorite and chlorite are neoformations of an alkaline, ion – enriched marine environment. The highest frequency of kaolinite in the studied khor sediment samples at the northern khors (Khor Kalabsha), a result which may be attributed mainly to the local contribution from the kaolin - rich sediments located at 41 km south of the High Dam. The relatively higher frequency of smectite at the southern khors (Khor Or), may be attributed to the local contribution from the Nubia Sandstone which widely distributed around the studied khors.. The occurrence of illite in low values and is completely absent at the northern and middle khors, may confirm that illite has been formed at the expense of kaolinite.

4. Conclusions

Sedimentological and mineralogical characteristics of khors sediments along Lake Nasser revealed that the differences in the grain size characteristics and its parameters, may be attributed to the characteristics and the nature of source rocks surrounding the studied khors. Heavy minerals investigation of the studied khors sediments reflected an enrichment of epidotes and amphiboles and a deficiency in pyroxenes. This confirms the important role of local contribution from the surroundings of the studied khors.. The insignificant variations in the calculated hydraulic fractionation indices among the studied khors sediments may be induced by a provenance factor. Moreover, the observed variations in the transportation indices values are attributed mainly to the local source from the surroundings of the studied khors. X-ray diffraction analysis of the clay fraction of the studied khors sediments showed that kaolinite and smectite are the main clay minerals encountered in all the studied samples. Illite occurs in traceable amounts.. The highest frequency of kaolinite was recorded at the northern khors (Khor Kalabsha), may be attributed to the local contribution from the kaolin-rich sediments at Kalabsha area (41 km south of the High Dam). The relatively higher frequency of smectite at the most extreme southern khors (Khor Or), may be attributed mainly to the local contribution from the Nubia Sandstone which widely distributed around the studied khors. Illite occurs in low values and is completely absent, where kaolinite shows high content. This confirms that illite has been formed at the expense of kaolinite. It can be concluded that the distribution of heavy and clay minerals are related mainly to the local contribution from the country rocks surrounding the studied khors sediments in Lake Nasser.

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الخصائص الترسيبية والمعدنية لرواسب الأخوار ببحيرة ناصر – مصر

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إهتمت الدراسة الحالية بإلقاء مزيد من الضوء على الخصائص الترسيبية والمعدنية للرواسب الحديثة فى بعض أخوار بحيرة ناصر. يتضمن البحث عدد 32 عينة ممثلة لرسوبيات 8 أخوار رئيسية بطول البحيرة (300 كيلومتر) مرتبة من الشمال إلى الجنوب كالآتى: خور الرملة - خور كلابشة - خور وادى أبيض - خور العلاقى – خور سنجارى - خور كروسكو – خور توشكا - خور عور. وقد تم جمعها خلال أربعة مواسم مختلفة. أوضحت نتائج التحليل الميكانيكى أن التغيرات فى الخصائص والمعاملات الحجمية لرسوبيات الأخوار قد تكون إرتبطت أساساً بطبيعة صخور المصدر(country rocks). هذا وقد أوضحت نتائج الفحص الميكروسكوبى التعرف على مجموعة المعادن الثقيلة (heavy minerals) مثل الإبيدوت ، الأمفيبول ، الزركون ، التورمالين ، البيروكسين ، الميكا ، الجارنت ، الإشتروليت ، الروتيل ، الإسبنل والأباتيت مرتبة حسب وفرتها. هذا وقد عكس محتوى المعادن الثقيلة لرسوبيات الأخوار المدروسة إرتفاع نسبى لكل من الإبيدوت والأمفيبول ونقص نسبى فى البيروكسين مما يدل على التأثر الواضح لهذه المعادن بصخور المصدر المحيطة بالأخوار (surrounding country rocks). هذا وقد حسبت معاملات التكسير الهيدروليكية (hydraulic fractionation indices) المحتملة. أوضحت الدراسة أن التغيرات التى ليس لها مغزى فى حسابات المعاملات الهيدروليكية يعتقد أنها ترجع إلى عامل المصدر (provenance factor). أيضاً تم حساب معاملات النقل (transportation indices) لمناقشة تأثير عامل النقل على توزيع المعادن الثقيلة. فكان معامل النقل لكل من المعادن المعتمة والإبيدوت عالياً نسبياً. ومن الناحية الأخرى فإن معاملات النقل لكل من الأمفيبول والبيروكسين كانت منخفضة جداً نسبياً ويختلف كثيراً عن قيمته فى صخور المصدر. وتعزى مثل هذه التغيرات فى قيم معاملات النقل أساساً إلى التأثر بصخور المصدر المحيطة بالأخوار. أيضاً أوضحت نتائج التحليل المعدنى لمعادن الطين (clay minerals) وجود وفرة نسبية لمعدنى الكاؤلينيت والسمكتيت (kaolinite and smectite) وكميات ضئيلة من معدن الإليت (Illite). وقد ناقش الباحث أصل هذه المعادن الطينية والتى يعتقد أنها ترجع إلى تجوية الصخور المحيطة.