CHARACTERISTICS OF SOME HEAVY MINERALS FROM EGYPTIAN BLACK SANDS

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SUMMARY: The mineralogical characteristics and composition of zircon, amphiboles and pyroxenes which are common heavy minerals in Egyptian black sands have been determined. The minerals can be used for genetic and provenance studies. They indicate that the black sands were derived from the Nile sediments which were derived from the igneous and metamorphic complex along the upper reaches of the Nile.

Key Words: Black sands, Nile Sediments, Zircon, Amphiboles, Pyroxenes.

INTRODUCTION

Black sands occur along the Mediterranean coastal plain North of the Nile Delta, especially at the Nile outpourings near Rosetta and Damietta. The black sands of Rosetta were described by Higazy and Naguib (12), Rittman and Nakhla (23) and Nakhla (18). Two types of black sands are encountered: the concentrated ore, which is very dark in colour and contains from 70 to 90 per cent heavy minerals, and the diluted ore, which is lighter in colour and contains up to 40 per cent heavy constituents. The economic value of the black sands was studied by Higazy and Naguib (12), Kamel *et al.* (13), and El-Shazly *et al.* (9).

Field and mineralogical studies have shown that the black sands North of the Nile Delta were derived from the Nile sediments discharged into the Mediterranean. The heavy minerals were concentrated mainly through the sorting action of waves. The original source of the black sands is, however, a composite one.

The original source of a detrital sand grain is the igneous and/or metamorphic rock in which the grain was originally crystallized. The grain's immediate source is the rock or sediment from which the grain was most recently derived. In first cycle sands, the original and immediate sources are the same. In multicycle sands, the original an immediate sources are different; most multicycle sands have several different original source rocks. The several sources of typical multicycle sand may include eroded igneous and/or metamorphic rocks as well as recycled sediments and sedimentary rocks. Contributions from a variety of original source areas are mixed repeatedly in multicycle sands. Additions may come from new source areas, whereas subtractions may be made by a variety of processes.

Accessory heavy minerals in sands have been used in petrogenetic and provenance studies (20). Some authors have used the relationship between certain heavy minerals or the presence of a particular assemblage of heavy minerals to indicate the original sources of the sand. Others used the characteristics of particular heavy minerals as provenance indicators.

The assemblage of heavy minerals encountered in the black sands of Rosetta has led to the conclusion that such sands were mainly derived from the igneous and metamorphic complexes constituting the upper reaches of the Nile, although some additions from sedimentary deposits within the Nile basin might have occurred (12, 23). The present paper gives the characteristics of some heavy minerals that could be used as provenance indicators.

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SAMPLES AND TECHNIQUES

In the present study focus has been made on zircon, amphiboles and pyroxenes which constitute significant portions of the heavy minerals of the black sands North of the Nile Delta (6, 23). Samples of black sands were sieved and the fractions between 0.250-0.063 mm were separated. From these fractions, magnetic minerals were removed by a hand magnet. Zircon, amphiboles and pyroxenes were separated using a Frantz Isodynamic Separator (4, 17). The separated minerals were studied under the polarizing microscope and by X-ray powder diffraction. Portions of these separated minerals were further purified under the binocular and the purified samples were chemically analyzed.

RESULT AND DISCUSSION

Zircon

Zircon is among the most stable minerals commonly found in rocks. Zircon survives erosion during transportation and is much less altered than most other accessory minerals. Consequently, detrital zircons may be recycled many times, and multicycle sands may contain zircons from a variety of original source rocks. Zircon has, therefore, been used by some authors in provenance studies (8,9,14,21).

Different varieties of zircon are encountered in Egyptian black sands. Table 1 gives the distribution of different types of zircon in the black sands according to the classification used by El-Hinnawi (6) and El-Hinnawi *et al.* (8).

Table 1: Distribution of Different Classes of Zircons.

	Classification	Average %
I	Classification according to colour: Colourless	75.0
	Light-coloured (cream, yellow, etc)	20.0
	Dark-coloured (brown, red, dark grey, etc)	5.0
II	Classification according to inclusions: Without inclusions	5.0
	With inclusions	95.0
III	Classification according to zoning: Without zoning	97.0
	With zoning	3.0
IV	Classification according to shape: Euhedral (idiomorphic)	6.0
	Subhedral	44.0
	Anhedral	50.0

The length (1), breadth (b) and elongation (1/b) of euhedral zircon grains (doubly-terminated grains) have been used by several authors for classification and genetic purposes. El-Hinnawi (6) found that 84.4 per cent of zircons in the black sands of Rosetta have elongation between 2 and 4. Zaghloul and Kamel (24) found that 73 per cent of zircons have elongation between 1.5 and 2.5. On the other hand, El-Shazly *et al.* (10) pointed out that most zircons range in elongation between 1.5 and 2.0 . The differences between these results are mainly attributed to the fact that the different authors used different sizes of zircons (and grains of different shapes) in their measurements. El-Hinnawi (6) used one fraction (0.125-0.063 mm) and measured euhedral grains only. The other authors used different fractions and measured euhedral as well as subhedral (or broken) grains. The latter are shorter than euhedral grains (for the same size), and hence they have lower elongation.

In the present study, the length and breadth of zircon grains were measured under the microscope using a calibrated micrometer eyepiece. The following size fractions of zircon were used: 0.200-0.125 mm, 0.125-0.100 mm, 0.100-0.071 mm, and 0.071-0.063 mm. The grains were embedded in a mixture of sulphur and methylene iodide, with a refractive index of 1.79 in order to reduce the intensity of the relief of the grains (which have a refractive index of about 1.96), thereby reducing the error in the measurements (6,7).

Figure 1 illustrates the distribution of length, breadth and elongation of zircon grains and their variation with size. Both the length and breadth decrease with decrease in size. On the other hand, as the grain size decreases, the elongation of zircon increases. Coarse grains are generally stout and mostly with broken edges (and hence low elongation), while fine grains are more acicular with doubly-terminated edges (and hence the higher elongation). Figure 2 illustrates the relationship between length and breadth of zircon grains as exhibited by the reduced major axes (RMAs) which are lines fitted mathematically to scatter diagrams of length versus breadth (14,15). The figure shows that the angle of inclination of the RMAs decreases with decrease in the size of the zircon grains which means that the grains of zircon become more elongated with decrease in size. Another important relationship between length and breadth is the positive correlation between both. This has been considered as indication of the derivation of zircon from one source (8,15). In the present case, this indicates derivation from the igneous and metamorphic complex along the upper reaches of the Nile.

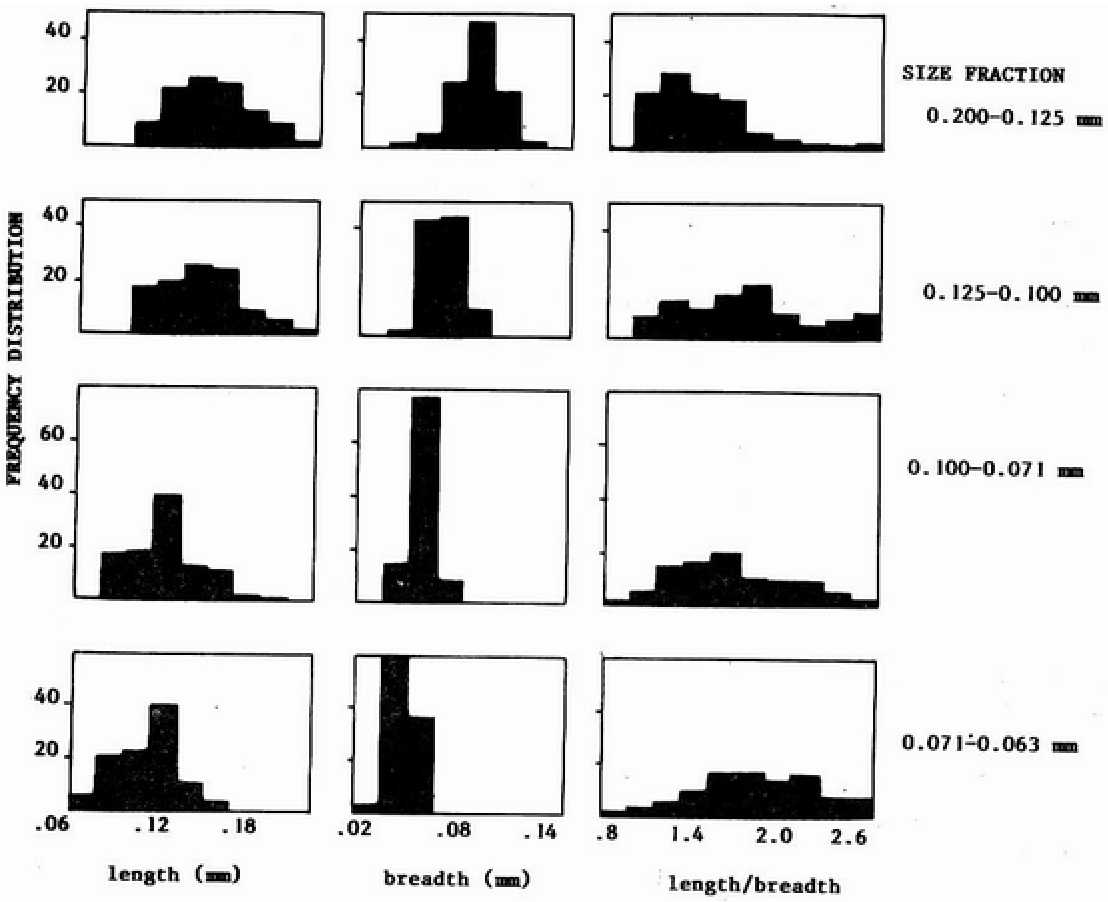

Figure 1: Distribution of length, breadth and elongation of zircons from Rosetta black sands.

The hafnium / Zirconium Ratio

The hafnium/zirconium ratio in zircons provides a further proof to the origin of zircon. Hafnium is known to substitute for zirconium in zircon; the Hf/Zr ratio varies generally from 0.01 to 0.05 (corresponding to a Hf weight percentage of 0.6 to 3.0) (2). Despite the similarities between Hf and Zr, slight segregation may occur during crystallization in igneous rocks. A positive correlation apparanetly exists between Hf content of zircons and the rock types in which they were formed (3). Numerous studies have reported an increase in Hf content from basic to acidic igneous rocks (11).

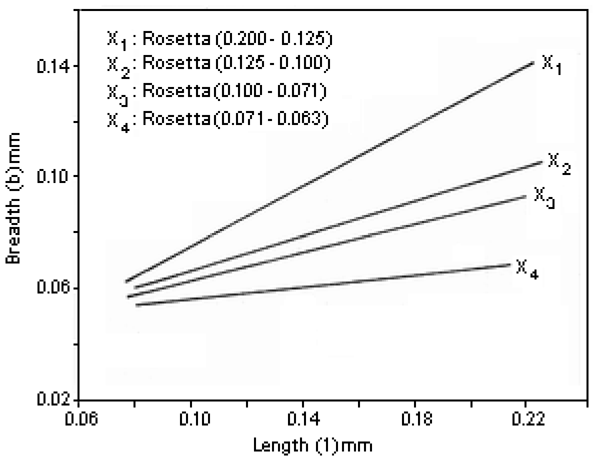

Figure 2: Relationship between length and breadth of zircons from Rosetta black sands. Lines are Reduced Major Axes (see text).

El-Hinnawi (1964) found that the Hf/Zr ratios in zircons from Rosetta black sands were 0.033 for the colourless zircons and 0.048 for coloured varieties. He concluded that zircons were mainly derived from acidic rocks (granites). Abdel Gawad (1), however, found a lower Hf/Zr ratio of 0.019 for colourless zircons and 0.022-0.035 for coloured varieties (the higher the ratio the higher the magnetic susceptibility of the zircon grains). Recently, Owen (19) pointed out that the concentration of hafnium in detrital zircons is a reliable indicator of petrogenesis. The frequency distribution of Hf is statistically similar for zircons in sands that were derived from the same source.

In the present work, 12 samples of zorcon were separated from concentrated and dilute black sands and from the Nile sediments collected from Rosetta and Damietta branches of the Nile Delta (the fraction between 0.063-0.125 mm was used). The zircons were repeatedly passed through a Frantz Isodynamic Separator at the same angle of inclination and current to separate zircon grains that have the same magnetic susceptibility. These samples consisted almost entirely of colourless zircons; coloured and zoned varieties were removed. This was carried out to eliminate the possibility of variation in composition of zircons due to variation in colour, zoning or magnetic susceptibility. The zircon samples were then analyzed by X-ray fluorescence to determine their hafnium content (the analyses were carried out at the university of Frankfurt by the first author). The results obtained showed that the hafnium content of the zircons was about 1.68 $\pm$ 0.10% by weight. This corresponds to a Hf/Zr ratio of 0.028 ($\pm$ 0.002). No significant difference in the Hf content was found in zircons from the Nile sediments and those from the black sands. This indicates that the black sands were derived from acetic rocks in the upper reaches of the Nile (the Hf/Zr ratio in acidic rocks is about 0.025; in basic rocks it is about 0.014) (11).

Amphiboles

Amphiboles are among the common heavy minerals encountered in the Rosetta black sands. The coarse heavy mineral fractions (0.250-0.125 mm) may contain up to 42% amphiboles, while the finer fractions (0.125-0.063 mm) contain up to 26 per cent. Microscopic examination of the amphibole grains revealed that the predominant types encountered are calcic amphiboles. Green hornblendes are the most common (more than 90%). These hornblendes are slightly pleochroic and exhibit moderate birefringence. Most grains are angular to subangular and several show saw-teeth marks and glassy rims. Many grains include opaque inclusions of different shapes and sizes. Less common are grains of oxyhornblende, with its characteristic brownish-yellow to reddish-brown pleochroism and high birefringence. Soda-amphiboles represented by glaucophane-riebeckite are uncommonly encountered. Riebeckite is differentiated from glaucophane by its blue-green colour, distinct pleochroism from pale-brown to dark blue and smaller extinction angle.

X-ray powder diffraction analyses of enriched amphibole samples carried out at the Institute of Metallurgy, Academy of Scientific Research and Technology, Cairo, showed the presence of the characteristic diffraction peaks of "hornblende". The peaks with d-spacings of 8.43, 3.38, 3.28, 3.09, 2.95, 2.71 and 2.56 were found in all samples analyzed, which confirms the results of the microscopic examination that revealed that revealed that the main amphiboles present in the black sands are hornblendes.

In order to determine the exact composition of amphiboles in the black sands, chemical analyses of three enriched samples (the purity of the samples was about 99%) were carried out. Table 2 gives the results of the analyses together with the calculated number of ions on the basis of 24 (0, OH). According to the classification of amphiboles recommended by the International Mineralogical Association Commission on New minerals and Mineral Names (16), the results show that the amphiboles encountered in the black sands are calcic ((Na+K) < 0.50;

Table 2: Chemicals Analyses of Amphiboles (Wt %).

Oxide	BS1	BS2	BS3
SiO_2	51.10	48.90	48.16
Al_2O_3	7.00	9.80	5.90
Fe_2O_3	2.12	2.30	4.95
FeO	6.60	8.70	8.95
MnO	0.09	0.19	0.20
MgO	17.99	15.43	14.01
CaO	12.00	11.93	12.80
Na_2O	0.68	0.99	1.35
K_2O	0.05	0.18	0.20
TiO_2	0.33	0.46	0.56
H_2O	1.98	2.00	2.10
Total	99.94	100.88	99.18

Number of ions on the basis of 24 (O, OH)						
Si	6.99	8.0	6.93	8.0	7.05	8.0
Al	1.01		1.07		0.95	
Al	0.12	4.89	0.57	4.89	0.07	4.86
Fe^{3+}	0.22		0.25		0.55	
Fe^{2+}	0.76		1.03		1.10	
Mg	3.67		3.26		3.06	
Mn	0.01		0.02		0.02	
Ti	0.03		0.05		0.06	
Na	0.18	1.95	0.27	2.11	0.38	2.43
Ca	1.76		1.81		2.01	
K	0.01		0.03		0.04	
OH	1.81	1.81	1.89	1.89	2.05	2.05

BS1: Rosetta BS2: Baltim BS3: Gamasa

Ti < 0.50). Figure 3 illustrates the relationship between the ionic rations of Mg/ (Mg+Fe^2) and Si. The three analyzed samples appear all in the field of magnesio-hornblende.

Hornblendes are generally formed under a wide range of pressure and temperature and are characteristic of a wide variety of intrusive and metamorphic rocks. The magnesium-rich hornblendes are generally characteristic of gabbros. Oxyhornblendes are characteristic of a wide variety of volcanic rocks varying from basalts to trachytes. Glaucophane-riebeckite amphiboles are, on the other hand, characteristic of greenschists and amphibolites. The amphiboles in the Rosetta black sands were, therefore, derived mainly from basic instrusive and volcanic rocks, with minor additions from metamorphic rocks.

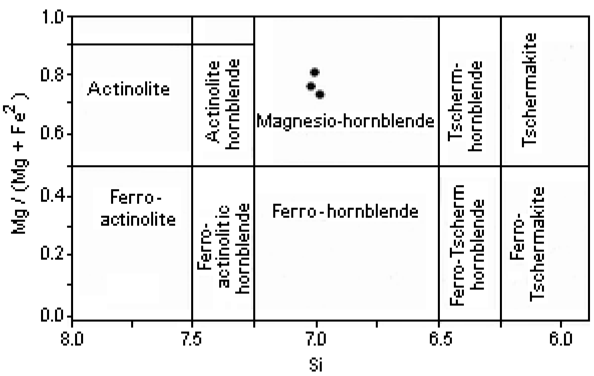

Figure 3: Classification of Amphiboles from Egyptian Black Sands, according to the diagram of calcic amphiboles by IMA (see text).

Pyroxenes

Pyroxenes are abundant in the heavy mineral fractions of the black sands and are more enriched in the coarse than in the fine fractions. The former contain an average of 20% pyroxenes, while the latter contain about 12%. Under the microscope the pyroxenes consist mainly of clinopyroxenes: pale greenish augite and some pigeonite. Few grains of colourless diopside are also present. Orthopyroxenes (mainly hypersthene) are found in subordinate amounts.

X-ray powder diffraction analyses of enriched pyroxene samples showed the characteristics diffraction patterns of augite. The main diffraction patterns of augite. The main diffraction lines encountered are: 3.31, 3.20, 2.99, 2.94, 2.87,2.56 and 2.51. Since these lines overlap with those of diopside, it was found necessary to analyze the pyroxene samples chemically to determine their exact composition. Table 3 gives the chemical composition of three enriched samples of pyroxenes (purity about 99%), together with the calculated number of ions on the basis of 6 oxygens (5). Figure 4 is a triangular representation of the Mg, Fe (Fe^2+Fe^3+Mn) and Ca atomic percentages. The analyzed pyroxene samples appear all in the field of augite.

Augites are typically present in basic igneous rocks. Those encountered in the black sands must had been derived from such rocks which are abundant in the upper reaches of the Nile. The fact that the augites are fresh (no alteration products have been detected by X-ray powder diffraction analysis or by microscopic examination) indicates that they were derived from fresh basic igneous rocks. The transportation route in the Nile sediments did not cause any marked alteration in the minerals.

Table 3: Chemicals Analyses of Pyroxenes (Wt %).

Oxide	BS1	BS2	BS3
SiO_2	50.00	49.26	51.10
Al_2O_3	2.39	3.12	2.41
Fe_2O_3	1.65	1.46	1.62
FeO	13.21	14.00	11.09
MnO	0.31	0.42	0.29
CaO	17.11	18.10	16.95
Na_2O	0.47	0.39	0.51
K_2O	0.09	0.08	0.09
TiO_2	1.40	1.13	1.31
H_2O	-	0.011	-
Total	100.08	100.16	99.98

Number of ions on the basis of 6 Oxygens						
Si	1.89	2.0	1.87	2.0	1.91	2.0
Al	0.11		0.13		0.09	
Al	-	2.01	0.01	2.01	0.02	2.02
Fe^{3+}	0.05		0.04		0.05	
Fe^{2+}	0.42		0.46		0.35	
Mn	0.01		0.01		0.01	
Mg	0.76		0.69		0.82	
Ca	0.69		0.74		0.68	
Na	0.03		0.03		0.04	
K	0.01		0.01		0.01	
Ti	0.04		0.03		0.04	
Mg	39.6		35.6		42.9	
Fe	24.5		26.3		21.5	
Ca	35.9		38.1		35.6	

BS1: Rosetta BS2: Baltim BS3: Gamasa

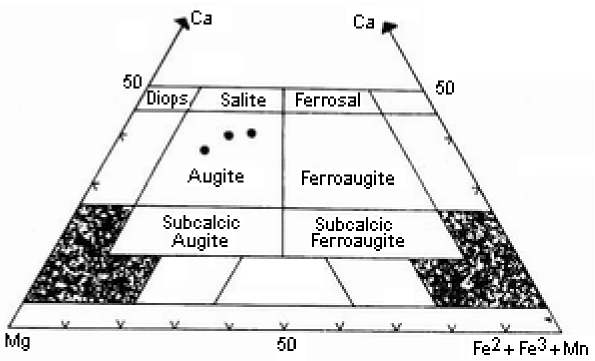

Figure 4: Classification of Pyroxenes from Egyptian Black Sands, as exhibited in the triangular diagram Ca-Mg-Fe atomic percentages.

REFERENCES

1. Abdel Gawad AM: X-ray Spectrographic Determination of Zirconium-Hafnium Ratio in Zirconium Minerals. Amer Mineral 51:464, 1966.

2. Ahrens LH, AJ Erlank: Hafnium. In: KH Wedepohl "Handbook of Geochemistry" Vol. II/5. Springer Verlag, Heidelberg, 1969.

3. Butler JR, AJ Thompson: Zirconium: Hafnium Ratio in Some Igneous Rocks. Geochim Cosmochim Acta 29:197, 1965.

4. Carver RE: Procedures in Sedimentary Petrology New York, Wiley-Interscience, 1971.

5. Deer WA, et al : Rock Forming Minerals. Vol 4, framework Silicates. London, Longmans, 1963.

6. El-Hinnawi E: Mineralogical and Geochemical Studies on Egyptian Black Sands. Beitr Mineral Petrol 9:519, 1964.

7. El-Hinnawi E: Methods in Chemical and Mineral Microscopy. Amsterdam, Elsevier Publ Co, 1966.

8. El-Hinnawi E, et al: Mineralogy and Chemistry of Nubian Sandstones from the Central Eastern Desert of Egypt. N Jb Miner Abh, 118:211, 1973.

9. El-Shazly EM, et al: Distribution of Beach Zircon along the Mediterranean Coast, Egypt. Egypt J Geol 25:113, 1981.

10. El-Shazly EM, et al: Physical Properties of Beach Zircon from the Mediterranean Coast, Egypt. Part 1. Egypt J Geol 25:95, 181.

11. Erlank AJ, et al: Hafnium. In: KH Wedepohl "Handbook of Geochemistry". Vol II/5, Springer Verlag, Heidelberg, 1978.

12. Higazy RA, AG Naguib : A Study of the Egyptian Monazitebearing Black Sands. Proc. 2nd United Nations Conf. Peaceful Uses Atomic Energy, Sess. E-9, P1486, 658, 1958.

13. Kamel OA, et al: Mineralogical Analysis and Evaluation of Black Sands at Eastern Part of East Side Nile Section, Abu Khashaba Area, Rosetta, Egypt. Ann Geol Surv Egypt 3:227, 1973.

14. Larsen LH, A Poldervaart: Measurement and Distribution of Zircons in Some Granitic Rocks of Magmatic Origin. Miner Mag 31:544, 1957.

15. Larsen LH, A Poldervaart: Petrogenic Study of Bold rock Batholith Near Bidwell Bar, California.Bull Geol Soc Amer 72:69, 1961.

16. Leake B: Nomenclature of Amphiboles. Miner Mag 42:533,1978.

17. Lewis DW: Pratical Sedimentology. Stroudsburg, Hutchinson Ross Publ Co, 1984.

18. Nakhla FM: Mineralogy of the Egyptian Black Sands and its Application. Egypt J Geol 2: 1, 1958.

19. Owen MR: Hafnium Content of Detrial Zircons, a New Tool for Provenance Study. J Sedim Petrol 57:824, 1987.

20. Pettijohn FJ, et al: Sand and Sandstones. Heidelberg, Springer Verlag, 1973.

21. Poldervaart A: Zircon in Rocks. I. Sedimentary Rocks. Amer J Sci 253: 433, 1955.

22. Poldervaart A: Zircon in Rocks. II. Igneous Rocks Amer J Sci 254:521, 1956.

23. Rittmann A, FM Nakhla: Contributions to the Study of Egyptian Black Sands. Egypt J Chem 1: 127, 1958.

24. Zaghloul ZM, E Kamel : Mineralogical and Petrographical Features of Zircon of the Black Sands of Rosetta. Bull Instit Desert Egypt 16:1, 1966.

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