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Potentiality of Physical Upgrading for Valuable Heavy Minerals from Sermatai Area, Egypt

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Abstract

In this work we are concerned with the potentiality of using mineral processing for raising the grade of the valuable heavy minerals (VHMs) from the Quaternary stream sediments of Wadi and Delta Sermatai located on the southern coast of the Red Sea, Egypt. A rigorous understanding of the chemical and mineralogical characteristics of the studied samples is a prerequisite for the selection and development of the physical processing used in order to produce a high-grade concentrate. For this purpose, the grain size distribution analysis, heavy liquid separation tests as well as XRF, and SEM analysis are performed. The magnetite, ilmenite, garnet, zircon, rutile, apatite, sphene, pyrolusite, celestine, and heavy green silicates are the valuable heavy minerals recorded in the studied samples; but their quantity varies between Wadi and Delta. The upgrading experiments are performed via a shaking table in conjunction with the low and high-intensity magnetic separator in order to obtain the high-grade concentrates from the valuable heavy minerals, and after applying the optimum separation conditions, the total heavy mineral (THM) assay increase from 8.32% to 46.04% for Wadi Sermatai, while for Delta Sermatai increase from 8.37% to 50.13% into 8.89% and 9.59%, respectively, by mass yield. The THM recovery values reach 66.84% for Wadi Sermatai and 67.23% for Delta Sermatai. After the results of the chemical analysis of the concentrates, it is proved that the Sermatai area is considered as a potential source for some economic elements such as Fe, Ti, Zn, Zr, Cr, V, and Sr.

1. Introduction

The Sermatai area is located in the extremely southern part of the Eastern Desert of Egypt nears the Sudan Borders. It is bounded by the latitudes of 22° 00` and 22° 25` N, and the longitudes of 36° 20` and 36° 45` E (Figure 1). It is located between the Abu Ramad city in the north and the Halaieb city in the south, covering an area of about 180 km². The Quaternary deposits in the studied area are represented by the gravels, sabkha, and wadi deposits. The alluvial wadi deposits are well-distributed in the large parts of the studied area along the Red Sea shoreline. It exposed mainly in Wadi Sermatai, Wadi Hibru, and many other wadis in the studied area.

Generally, the stream sediments are formed by the erosion and transport of soil, rock debris, and other materials within the catchment basin [1-3]. Heavy minerals (HMs) such as rutile, zircon, ilmenite, magnetite, sillimanite, monazite, chromite, tourmaline, garnet, and staurolite can be present within the stream sediments, and some of these HMs have a greater economic value than the others due to their importance in various industrial products such as pigments (ilmenite, rutile, and leucoxene), ceramics (zircon) or for the recovery of high-value components such as rare earth oxides (monazite). Other heavy minerals; of lower value; such as garnet and magnetite can also be

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recovered for the commercial applications [4-6]. Exploitation of HMs from the stream sediments has been carried out for the first time effectively since the 1950s [7]. Nowadays, processing of HMs from the stream sediments has become a profitable business in many countries such as Australia, China, Indonesia, and India [8-11], and for this reason, the Nuclear Materials Authority is working hard in order to explore and exploit the Egypt's resources of VHMs.

The physical upgrading for the stream sediments are important and necessary processes that must be carried out in order to raise the grade of minerals of economic value and to get rid of, as far as possible, the useless associated minerals. Normally, the physical upgrading for stream sediments does not require any comminution processes, reducing the processing costs, and saving energy [12]. Most of the physical upgrading processes begin with a gravity concentration in order to separate HMs from the associated gangue, and are mainly composed of quartz and feldspar [5, 8-10, 13-22]. After gravity concentration, the obtained HMs can be separated by the magnetic, electrostatic; or flotation separation techniques, depending on the mineralogical content and the properties of each mineral being separated [23-30]. Therefore, it is essential to decide on the physical upgrading processes that can recover the most VHMs at a fast and efficient processing rate.

In this research work, we aimed to study the potentiality of mineral processing in order to recover and concentrate the VHMs from the Quaternary stream sediments of Wadi and Delta Sermatai located on the southern coast of the Red Sea, Egypt. In order to achieve the recovery and concentration of VHM, this work dealt with the grain size distribution analysis, heavy liquid separation tests as well as mineralogical and chemical analysis were performed. As a result of the aforementioned analysis, the gravity separation was chosen as a first step for concentration, and then the magnetic separation was followed at different magnetic field intensities in order to obtain the concentrates of different economic minerals.

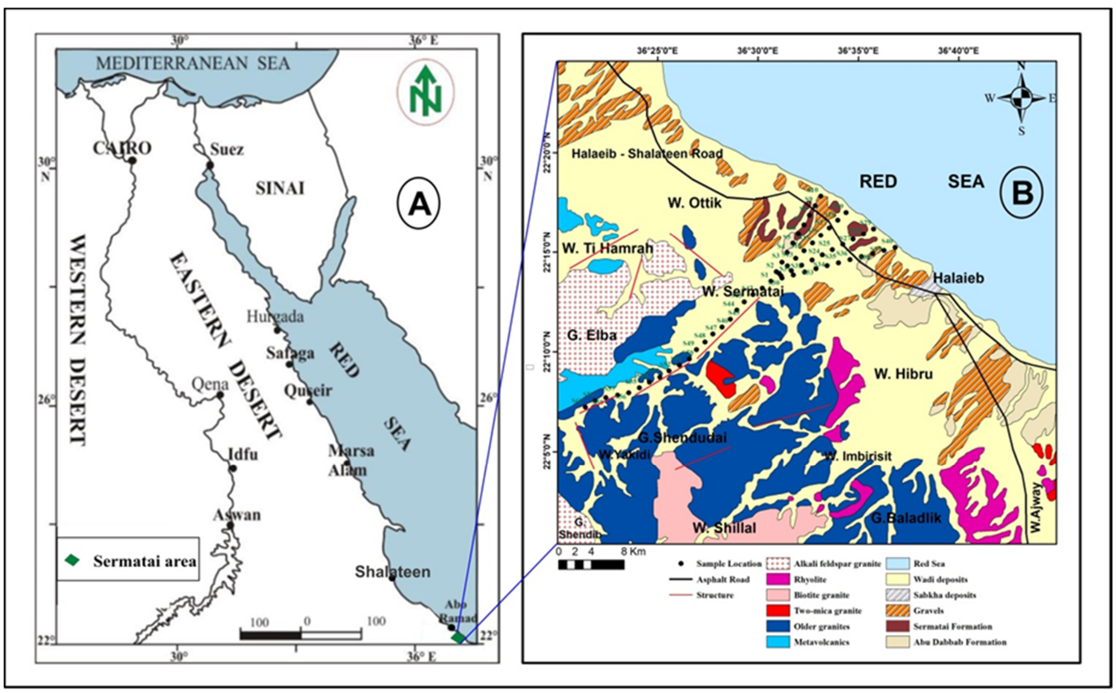

Figure 1. (A) A general location map of Sermatai area. (B) Geological map showing sample location for Sermatai area, southeast of the Eastern Desert, Egypt. [31, 32]

2. Sampling and Methodology

The studied area covers about 84 km^2, which includes the Sermatai Wadi and Delta. The Sermatai Delta covers about 34 km^2 and was studied by taking 40 samples represented in 4 radial profiles. As for Sermatai Wadi, it covers 50 km^2 and was studied by taking 20 sampling points. All samples were taken by applying an auger sampler to a depth of about 1 m with a weight ranging from 10 kg to 15 kg for each sample and the distance between each sample and the next one was about 2 km.

Initially, the total weight of each sample was determined and divided into the representative portions using the John's riffle splitter; one of these representative portions of each sample was kept as a reference sample while other the representative parts were used in the various experiments such as the grain size distribution analyses, apparent density measurements, slimes and organics determinations, and heavy mineral separation.

The grain size distribution analyses were performed for a representative sample weighing about 250 g by sieving through a sieve series of 2, 1, 0.5, 0.25, 0.125, and 0.063 mm (ASTM codes) representing gravel, very coarse sand (V.C. sand), coarse sand (C. sand), medium sand (M. sand), fine sand (F. sand), very fine sand (V.F. sand), and mud sizes respectively.

The apparent density values shed light on the presence of HM concentrations in the raw sand or not [33, 34]. Therefore, the apparent density measurements were performed for each sampling point by weighing the representative sample, pouring it into a graduated cylinder, and compacting it well by pressing to simulate the field deposit. The sample weight was divided by its volume in order to obtain the apparent density value.

Another representative portion was used to calculate the percentage of the samples' content of slime and organic matter, starting by treating with hydrogen peroxide (30%) to get rid of the organic matter, and then washing it with water for several times to get rid of the slime and salts. Thereafter, the deslimed fractions were subjected to heavy liquid separation using bromoform ($CHBr_3$) with a specific gravity of 2.89 for estimating the total heavy minerals (THMs) content in each sample. The grain size distribution analyses for THMs were done in order to determine the size distribution of these target minerals. Identification of VHMs that was obtained from bromoform separation was performed using optical microscopy and a scanning electron microscope (SEM) supplied with a Philips XL 30 energy-dispersive spectrometer (EDS) unit.

The potentiality of upgrading VHMs was initially implemented by preparing two technological samples weighing about 20 kg to 25 kg per sample, one representing the Delta samples, and the other representing the Wadi samples. The physical upgrading processes were first conducted via gravity concentrator using the Wilfley Shaking Table No. 13. The magnetic separation of the concentrate that was obtained as the shaking table product was carried out using a Carpco dry high intensity magnetic separator (DHIMS).

The major and trace element analyses for both the feed samples and concentrated products were performed via wavelength dispersive X-ray fluorescence (XRF) spectrometry using Axios advanced, Sequential WD_XRF Spectrometer [35]. For the XRF measurements, the representative samples were ground up into powder (less than 75µm) within an agate mortar and the total loss on ignition (L.O.I.) was determined after heating for 2 h at 1000 °C. The detection limit for the elements measured using the XRF technique was estimated at 20 ppm for the major elements and 2 ppm for the measured trace elements.

3. Results and discussions

3.1. Mineralogical characterization results

The grain size distribution analyses for the Wadi and Delta Sermatai samples were presented in details at Tables 1 and 3. The samples show a high degree of homogeneity: indeed, the sandy fraction, with about 89.63% and 81.4 % of the total percentages in weight of Delta and Wadi Sermatai, respectively, on average, was most present, while the others, the gravelly and silty-clayey fractions, showed lower percentages in weight.

The cumulative percent passing curves show the distribution percentages of different size fractions for the representative samples of Wadi and Delta Sermatai (Figure 2). From these curves, the effective diameter values of D_{80} are 0.37mm and 0.67 mm for Delta and Wadi Sermatai respectively.

The apparent density values for the Sermatai Delta samples are ranging from 1.57 g/cm^3 to 2.24 g/cm^3, with an average of about 1.85 g/cm^3. As for the values of the Wadi samples, they ranged from 1.66 g/cm^3 to 2.17 g/cm^3 with an average of about 1.83 g/cm^3 and this indicates displaying of HMs in the studied samples, but in medium concentrations. The apparent density values are listed in details at Tables 1 and 3.

Table 1. Detailed results of apparent density measurements, slime, and organics content, heavy and gangue light mineral content, and grain size distribution analyses for Sermatai Delta samples.

Profile No.	Sample No.	Apparent density g/cm^3	Slimes and Organics %	Heavy minerals %	Gangue light silicate minerals %	Grain size distribution analyses %						
						Pebble +2 (mm)	V.C. sand -2+1	C. sand -1+0.5	M. sand -0.5+0.25	F. sand -0.25+0.125	V.F .sand -0.125+0.063	Silt -0.063
1	S1	1.93	5.83	**6.57**	87.60	12.04	11.38	22.66	26.09	15.88	8.52	3.43
	S2	1.88	3.58	6.34	90.07	12.03	10.97	20.34	26.66	19.27	8.79	1.94
	S3	1.78	7.10	9.29	83.61	6.47	2.05	3.56	17.67	41.51	20.49	8.25
	S4	1.78	3.47	11.12	85.41	0.00	2.37	6.85	28.9	38.38	20.25	3.24
	S5	1.73	2.23	20.05	77.72	0.00	0.03	0.01	14.79	76.08	8.40	0.7
	S6	1.76	5.85	5.61	88.54	7.32	9.58	19.69	29.82	23.39	7.60	2.61
	S7	1.85	4.31	3.33	92.36	8.19	10.45	14.47	25.96	30.8	8.31	1.82
	S8	1.81	4.99	6.60	88.41	4.83	5.78	10.52	27.44	33.26	14.14	4.02
	S9	1.91	5.17	5.69	89.14	10.88	11.62	23.64	20.17	18.26	12.77	2.66
	S10	1.82	14.21	7.41	78.38	0.00	4	14.73	27.54	26.12	20.96	6.65
	P1 Rep.	2.16	8.36	7.20	84.44	7.07	6.78	13.72	25.1	30.52	13.77	3.04
	Average	1.86	5.92	8.11	85.97	6.26	6.82	13.65	24.56	32.13	13.09	3.49
2	S11	1.90	3.90	5.54	90.56	13.63	16.5	27.35	21.68	11.00	6.95	2.89
	S12	1.92	3.31	8.33	88.36	7.7	8.15	19.16	30.04	20.51	11.30	3.14
	S13	1.79	7.50	10.93	81.57	0.11	6.55	11.79	16.26	23.99	27.63	13.65
	S14	1.83	7.04	9.34	83.62	0.14	7.99	20.21	26.01	20.78	17.24	7.64
	S15	1.86	8.80	10.83	80.37	0.00	9.12	15.89	19.08	24.16	25.06	6.7
	S16	1.84	10. 0	9.79	80.21	0.00	8.37	18.19	19.48	25.14	24.10	4.73
	S17	1.68	2.83	7.08	90.09	0.44	1.22	9.39	34.34	36.65	15.33	2.62
	S18	1.74	3.54	7.55	88.91	0.33	3.63	21.25	30.76	27.4	12.58	4.05
	S19	1.76	3.98	7.21	88.81	0.18	6.6	35.02	37.48	13.68	5.14	1.89
	S20	1.89	5.92	10.10	83.98	6.94	11.14	15.11	19.17	20.83	20.65	6.17
	P2 Rep.	1.88	6.49	10.07	83.44	4.51	7.44	18.2	24.81	22.19	18.08	4.76
	Average	1.83	5.76	8.80	85.44	3.09	7.88	19.23	25.37	22.39	16.73	5.29
3	S21	1.78	3.75	10.43	85.81	0.15	13.16	16.51	19.2	21.05	22.19	7.73
	S22	1.88	5.61	8.66	85.73	0.08	10.57	25.73	23.51	18.64	14.42	7.05
	S23	1.88	7.31	8.25	84.44	0.00	8.69	22.09	28.34	20.3	13.3	7.27
	S24	1.93	12.06	8.30	79.64	4.25	7.64	19.42	24.37	23.3	15.39	5.62
	S25	1.92	12.54	7.89	79.56	9.42	7.17	14.27	22	23.61	14.78	8.74
	S26	1.77	1.75	3.97	94.29	2.96	6.61	24.16	40.49	21.02	4.06	0.69
	S27	1.93	3.69	5.31	91.00	12.07	14.61	25.45	23.02	12.92	7.55	4.38
	S28	1.80	2.62	9.05	88.33	3.63	6.69	11.74	26.58	34.29	14.49	2.57
	S29	1.60	16.93	3.99	79.08	4.84	5.75	6.3	30.93	36.42	8.32	7.44

Table 1. Continues of Table 1.

	S30	1.96	4.77	7.26	87.97	11.82	12.46	18.81	20.03	16.39	13.71	6.79
	P3 Rep.	1.57	6.60	8.00	85.40	4.37	9.28	19.08	26.28	22.46	13.14	5.4
	Average	1.82	7.06	7.37	85.57	4.87	9.33	18.51	25.89	22.76	12.85	5.79
4	S31	1.83	13.10	9.14	77.75	0.00	7.45	15.67	21.62	25.78	19.84	9.64
	S32	2.24	5.85	7.74	86.41	0.00	7.90	20.99	35.39	21.12	10.75	3.85
	S33	1.91	6.83	7.47	85.70	12.14	11.24	14.65	21.91	20.49	12.61	6.97
	S34	1.94	11.68	7.20	81.11	8.61	10.67	12.37	21.23	23.81	15.51	7.80
	S35	1.94	6.24	5.49	88.27	6.13	13.23	19.67	23.87	19.83	12.25	5.03
	S36	1.88	10.23	9.03	80.74	1.44	8.55	13.76	23.70	29.25	18.65	4.64
	S37	1.86	10.99	9.17	79.84	0.00	7.73	13.28	20.60	26.49	21.41	10.51
	S38	1.93	12.18	7.59	80.23	7.79	10.32	13.94	20.50	23.49	16.74	7.23
	S39	1.79	4.63	9.41	85.96	9.62	3.95	4.92	30.66	30.08	13.90	6.87
	S40	1.83	13.53	6.83	79.64	10.15	15.95	12.30	13.52	21.79	17.78	8.51
	P4 Rep.	1.88	9.45	8.06	82.49	3.27	9.68	15.36	24.48	24.16	13.54	9.51
	Average	1.91	9.52	7.92	82.56	5.38	9.70	14.26	23.41	24.21	15.72	7.32
	S (1-40)	1.79	6.21	8.37	85.42	4.68	8.29	17.16	25.08	24.04	15.06	5.69

Table 2. Detailed results of HMs distribution analyses; and magnetic separation fractionation for Sermatai Delta samples.

Profile No.	Sample No.	Heavy mineral size distribution analyses %							Magnetic separation of heavy mineral contents			
		+2 mm	-2 +1	-1 +0.5	-0.5 +0.25	-0.25 +0.125	-0.125 +0.063	-0.063 Mm	Magnetite %	Mag. @1 amp. %	Mag. @3 amp. %	Non-mag.@ 3 amp. %
1	S1	0	0.28	7.5	21.22	34.51	30.69	5.8	14.64	38.51	41.58	5.27
	S2	0	0	6.32	19.26	36.18	32.5	5.74	17.21	40.4	35.7	6.69
	S3	0	0.28	1.14	5.2	32.73	48.16	12.49	8.5	42.79	40.59	8.12
	S4	0	0.28	1.19	5.96	29.63	55.87	7.06	8.1	45.67	36.19	10.04
	S5	0	0	0.13	1.64	85.84	12.07	0.33	3.43	36.96	52.37	7.25
	S6	0	0	1.89	6.7	38.14	47.6	5.68	9.9	41.34	37.85	10.92
	S7	0	0	4.81	10.37	40.74	39.26	4.81	5.56	33.7	50.37	10.37
	S8	0	0	3.51	10.95	34.59	39.05	11.89	8.2	35.93	46.04	9.84
	S9	0	0	7.38	12.52	25.43	44.66	10.01	7.86	37.15	46.21	8.79
	S10	0	0	2.48	12.97	32.14	42.21	10.21	12.52	37.83	40.61	9.04
	P1 Rep.	0	0	3.45	10.23	41.43	37.36	7.52	9.05	40.4	43.37	7.19
	Average	0	0.08	3.62	10.64	39.21	39.04	7.41	9.54	39.15	42.81	8.5
2	S11	0	0	13.03	23.7	29.2	27.94	6.12	17.22	40.75	35.55	6.48
	S12	0	0	3.93	15.61	34.09	36.35	10.01	15.54	33.13	43.14	8.19
	S13	0	0	3.36	7.97	22.95	47.66	18.06	14.72	32.1	40.16	13.02
	S14	0	0	5.83	15.4	28.69	30.02	20.06	16.85	32.37	40.13	10.66
	S15	0	0	5.22	9.43	26.47	39.88	19	15.01	40.09	32.65	12.24
	S16	0	0	5.95	10.13	25.99	43.32	14.61	12.5	38.39	35.36	13.76

Table 2. Continues of Table 2.

	S17	0	0	2.19	12.12	35.84	43.99	5.85	9.57	46.16	34.6	9.67
	S18	0	0	4.69	12.12	32.39	40.8	10	11.4	33.75	44.17	10.68
	S19	0	0	6.26	36.32	32.49	20.35	4.58	15.7	36.49	36.93	10.88
	S20	0	0	4.73	10.53	25.25	45.16	14.33	14.55	36.31	38.58	10.56
	P2 Rep.	0	0	5.98	13.89	27.61	40.49	12.04	9.09	37.78	38.92	14.21
	S21	0	0	13.03	23.7	29.2	27.94	6.12	12.54	47.98	28.55	10.94
	S22	0	0	3.93	15.61	34.09	36.35	10.01	10.69	36.21	41.72	11.38
	S23	0	0	3.36	7.97	22.95	47.66	18.06	11.44	36.41	42.82	9.33
	S24	0	0	5.83	15.4	28.69	30.02	20.06	8.56	39.11	42.82	9.51
	S25	0	0	5.22	9.43	26.47	39.88	19	12.21	40.33	38.16	9.31
3	S26	0	0	5.95	10.13	25.99	43.32	14.61	10.44	30.13	51.68	7.74
	S27	0	0	2.19	12.12	35.84	43.99	5.85	11.63	30.97	46.88	10.53
	S28	0	0	4.69	12.12	32.39	40.8	10	10.46	45.3	38.56	5.67
	S29	0	0	6.26	36.32	32.49	20.35	4.58	3.02	41.3	45.01	10.67
	S30	0	0	4.73	10.53	25.25	45.16	14.33	15.39	45.35	29.49	9.77
	P3 Rep.	0	0	5.98	13.89	27.61	40.49	12.04	10.26	41.26	38.01	10.47
	Average	0	0	5.56	15.2	29.18	37.81	12.24	10.6	39.49	40.34	9.57
	S31	0	0	5.06	11.31	28.01	44.94	10.68	10.85	43.70	36.76	8.69
	S32	0	0	5.02	20.87	35.60	31.92	6.58	11.16	38.22	43.18	7.44
	S33	0	0	5.02	13.87	31.27	39.81	10.03	9.65	37.53	44.25	8.57
	S34	0	0	3.68	10.65	31.76	42.98	10.93	10.74	40.87	41.16	7.22
	S35	0	0	2.15	15.21	30.41	38.25	13.98	8.74	32.52	50.15	8.59
4	S36	0	0	3.31	9.49	31.25	47.43	8.53	9.06	44.80	38.34	7.80
	S37	0	0	2.79	7.97	26.77	50.12	12.35	9.54	36.06	45.51	8.89
	S38	0	0	4.21	9.38	27.96	50.66	7.80	9.28	36.57	45.94	8.22
	S39	0	0	1.15	11.15	37.89	44.20	5.61	10.20	47.37	36.24	6.18
	S40	0	0	2.57	3.95	18.84	54.50	20.13	7.88	43.93	37.44	10.75
	P4 Rep.	0	0	4.18	12.27	29.73	42.78	11.04	9.64	42.97	38.62	8.77
	Average	0	0	3.56	11.46	29.95	44.33	10.70	9.70	40.41	41.60	8.28
	S (1-40)	0	0	4.76	12.76	30.72	38.58	13.18	11.65	41.26	34.76	12.33

Table 3. Detailed results of apparent density measurements, slime and organics content, heavy and gangue light mineral content, and grain size distribution analyses; for Wadi Sermatai samples.

Sample No.	Apparent density g/cm^3	Slimes and Organics %	HMs contents %	Gangue light silicate mineral contents %	Grain size distribution analyses %						
					Pebble +2(mm)	V. C. sand -2+1	C. sand -1+0.5	M. sand -0.5+0.25	F. sand -0.25+0.125	V. F. sand -0.125+0.063	Silt -0.063
S41	1.78	4.84	9.23	85.93	3.73	5.22	15.44	24.27	25.86	18.36	7.11
S42	1.83	4.32	6.73	88.95	8.05	9.99	22.88	23.81	11.27	4.75	3.22
S43	1.94	4.44	6.76	88.80	11.87	15.82	24.11	25.15	13.77	6.49	2.80
S44	1.87	5.27	5.93	88.80	13.26	17.63	25.86	23.45	12.50	5.33	1.97
S45	1.98	3.11	4.64	92.25	23.92	23.15	24.04	14.90	8.43	4.05	1.51
S46	1.77	4.02	6.15	89.83	15.52	17.64	27.09	21.79	10.15	4.45	3.36
S47	1.87	10.77	8.30	80.93	8.49	8.43	19.10	25.13	18.07	11.72	9.07
S48	1.77	7.51	9.15	83.34	8.57	6.76	19.35	25.23	19.08	13.64	7.37
S49	1.84	4.34	5.88	89.78	21.69	17.17	24.24	17.94	9.13	4.48	5.35
S50	1.82	4.39	5.40	90.21	23.07	17.08	23.13	19.40	11.04	4.29	2.00
S51	1.76	3.54	6.65	89.81	16.77	17.08	25.74	24.23	9.97	3.98	2.23
S52	1.79	2.21	3.37	94.42	26.18	27.96	26.00	14.28	3.87	1.09	0.62
S53	1.66	4.67	11.46	83.87	0.52	3.40	17.88	35.38	24.65	13.03	5.15
S54	1.82	3.29	8.33	88.38	9.73	11.63	24.31	26.13	15.85	6.76	5.59
S55	1.77	5.17	9.49	85.34	0.46	17.28	31.89	24.81	14.14	7.85	3.57
S56	2.17	3.39	6.38	90.23	28.31	19.59	21.46	16.16	8.09	4.32	2.08
S57	1.83	4.40	10.87	84.73	9.04	14.69	22.21	22.75	16.55	10.11	4.65
S58	1.81	4.48	8.98	86.54	16.17	11.75	16.03	25.76	19.82	7.55	2.92
S59	1.81	3.47	9.66	86.87	14.30	11.09	19.38	26.91	18.21	7.52	2.58
S60	1.78	6.32	12.02	81.66	10.01	8.07	16.86	23.82	24.12	15.37	1.76
S Rep.	1.82	4.34	8.32	87.34	14.62	13.73	21.89	22.94	14.75	8.09	3.98
Average	1.83	4.68	7.79	87.53	13.54	14.06	22.33	23.06	14.73	7.77	3.76

Table 4. Detailed results of HM distribution analyses; and magnetic separation fractionation for Wadi Sermatai samples.

Sample No.	Heavy mineral size distribution analyses %							Magnetic separation of heavy mineral contents			
	+2 mm	-2 +1	-1 +0.5	-0.5 +0.25	-0.25 +0.125	-0.125 +0.063	-0.063 Mm	Magnetite %	Mag. @ 1A %	Mag. @3A %	Non-mag. @ 3A %
S41	0	0	3.59	12.26	30.76	42.47	10.93	14.85	47.16	31.04	6.95
S42	0	0	9.64	25.71	33.84	25.33	5.48	18.67	46.92	29.38	5.02
S43	0	0	9.42	20.60	34.70	26.69	8.59	17.60	50.38	26.44	5.59
S44	0	0	12.10	23.62	34.31	24.32	5.64	19.84	40.14	35.33	4.69
S45	0	0	16.62	25.00	29.79	20.96	7.63	20.69	42.43	32.68	4.20
S46	0	0	13.11	24.97	30.82	24.13	6.97	17.18	43.16	33.66	6.01
S47	0	0	6.36	18.32	31.57	33.08	10.67	14.39	40.37	38.74	6.49
S48	0	0	5.22	15.67	28.99	36.56	13.55	12.81	41.24	37.76	8.19
S49	0	0	15.62	22.42	26.45	25.19	10.33	12.91	40.00	40.00	7.09
S50	0	0	16.57	25.14	31.10	22.35	4.84	17.81	43.23	36.18	2.78
S51	0	0	13.45	27.74	33.69	19.29	5.83	17.68	41.34	37.16	3.82
S52	0	0	19.51	34.32	28.77	10.25	7.16	11.40	46.45	38.85	3.31
S53	0	0	3.47	16.65	35.51	33.53	10.84	15.65	40.42	35.64	8.30
S54	0	0	7.55	21.06	31.27	16.46	23.66	18.25	42.16	31.03	8.57
S55	0	0	13.52	23.60	30.30	24.95	7.62	17.48	42.06	29.46	10.99
S56	0	0	14.12	23.85	30.27	19.57	12.19	18.61	37.12	36.80	7.47
S57	0	0	8.89	18.83	32.48	28.24	11.56	20.47	34.27	36.32	8.95
S58	0	0	6.04	17.22	39.03	25.65	12.07	17.97	41.05	34.42	6.57
S59	0	0	6.21	19.73	38.04	21.64	14.38	18.62	44.82	29.19	7.36
S60	0	0	3.67	13.32	30.79	40.03	12.20	16.16	38.88	31.75	13.21
S Rep.	0	0	9.09	20.37	32.25	28.49	9.80	16.14	30.65	40.17	13.03
Average	0	0	10.18	21.45	32.13	26.15	10.09	16.91	41.63	34.38	7.08

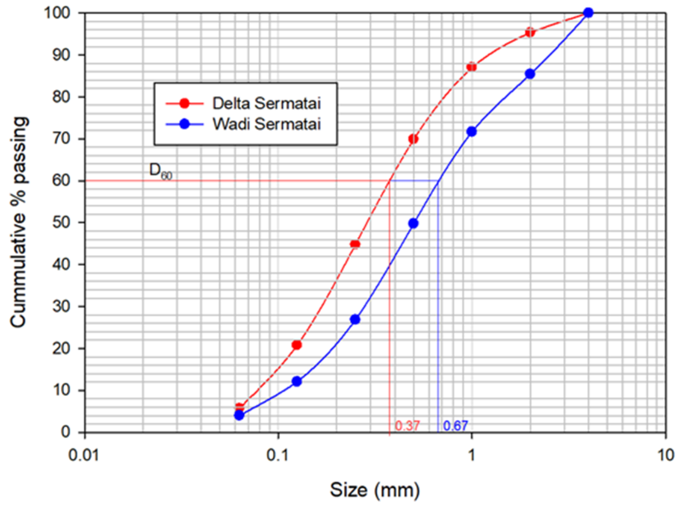

Figure 2. Grain size distribution analyses of Wadi and Delta Sermatai original samples.

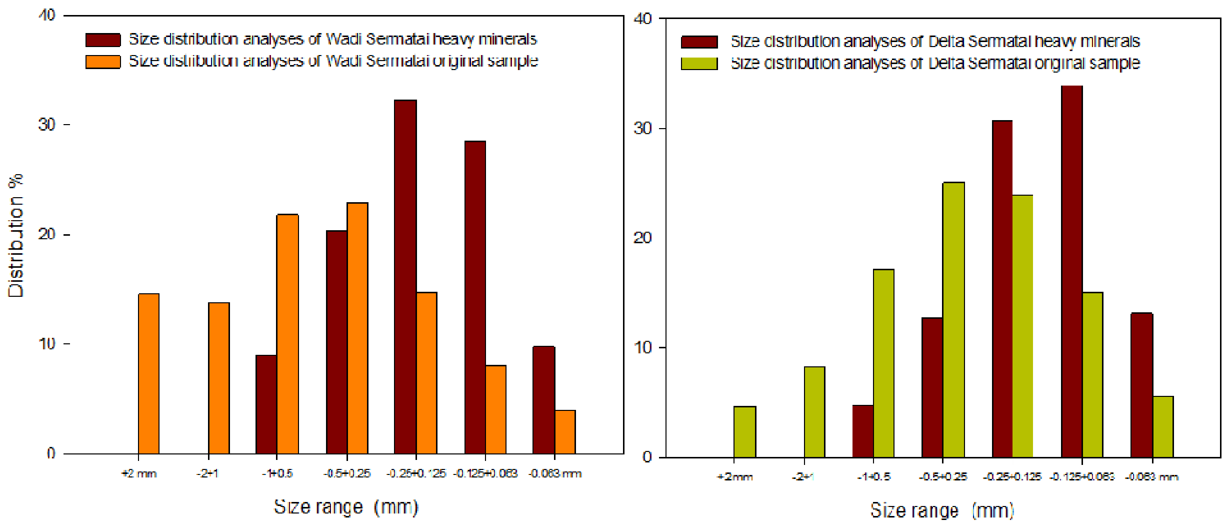

Figure 3. Histogram showing grain size distribution analyses for Wadi and Delta Sermatai original samples in comparison with their heavy mineral distribution analyses.

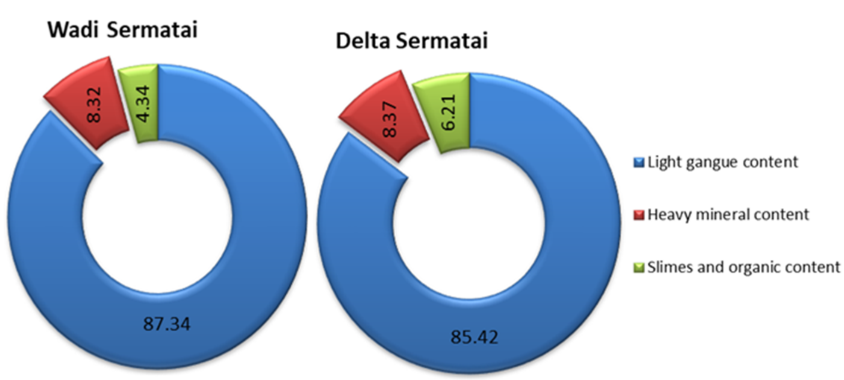

Figure4. Pie-charts showing and comparing percentages of heavy and light mineral content as well as slimes and organics for Wadi and Delta Sermatai original samples.

The slimes and organic matter content values were presented in details for each sample of the Wadi and Delta at Tables 1and 3, where the values ranged between 1.75% and 16.93% mass for the Delta Sermatai with an average of 6.99% mass, while the Wadi values ranged between

2.21% and 10.77% mass with an average of 4.68%.

The HM content of each Sermatai sample was estimated by separating about 100 g of the representative sample using bromoform ($CHBr_3$, with specific gravity of 2.89), in which the ratio of the heavy minerals to the light minerals was calculated after separation, acetone washing and drying; the results obtained were presented in details at Tables 1 and 3.The light gangue minerals of the Delta and Wadi Sermatai samples represented high values, as the average values of the delta were 85.42% mass, while the Wadi average reached 87.34% mass. As for the values of the heavy mineral content, they ranged between 3.33% and 20.05% mass with an average of 8.37% mass for the Delta samples and for the Wadi samples, it ranged between 3.37% and 12.02% mass with an average of 8.32% mass.

The microscopic examination of the light gangue minerals of all samples confirmed that they contained abundant amounts of quartz, feldspars, and micas. This seems very plausible science it comes from the rocks surrounding the area; while the microscopic examination of the heavy minerals with the aid of SEM that provided with EDS confirmed the presence of a large group of VHM as magnetite (Figs. 5a and 5b), garnet (Figure 5c), ilmenite (Figure 5d), khatyrkite (Figure 6a), sphene (Figs. 6b and 6c), xenotime (Figure 6d), pyrolusite (Figs. 7a and 7b), apatite (Figure 8a), zircon (Figure 8b), celestine (Figure 8c), and rutile (Figure 8d).

The grain size distribution analysis of THM was carried out, and it was resulted that 86.82% of the heavy minerals in the delta samples and 90.2% of the heavy minerals in the Wadi Sermatai samples were present in the sandy size. The heavy mineral distribution analyses were listed in details at Tables 2 and 4 and also graphically represented in histogram at (Figure 3).

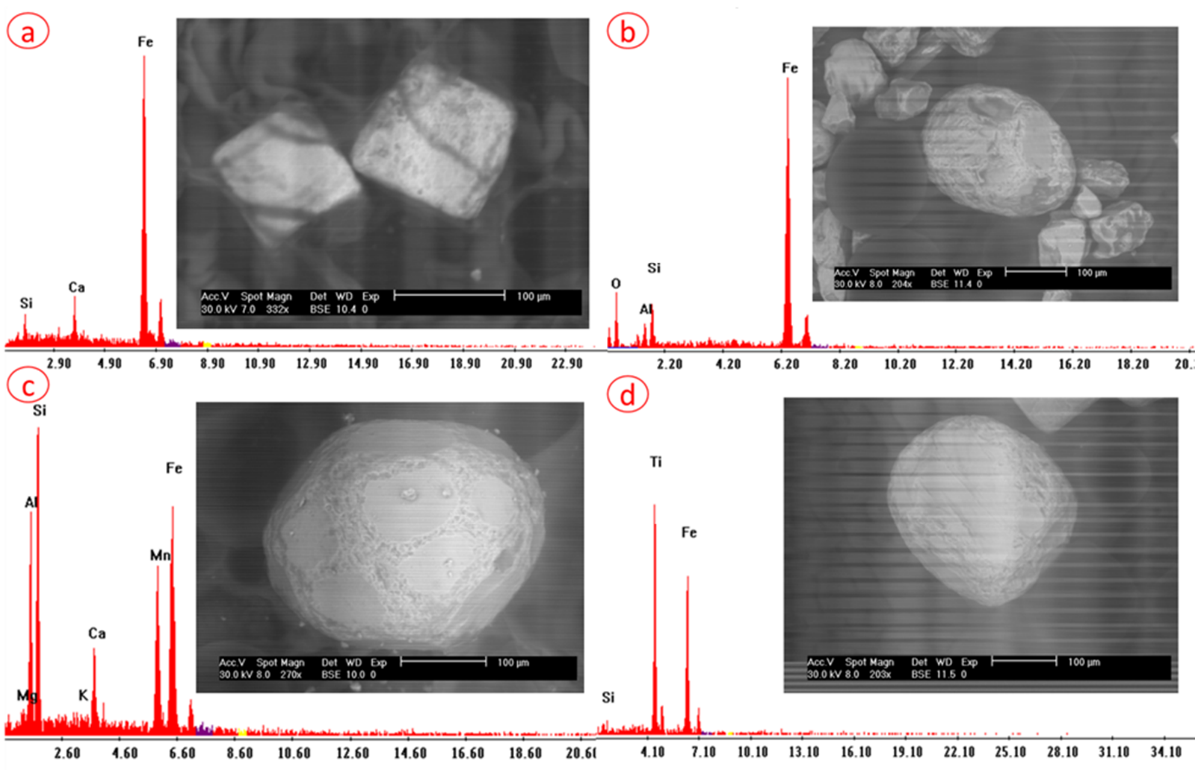

Figure 5. Back-scattered electron (BSE) images and corresponding EDS spectra for a. and b. magnetite, c. garnet, and d. ilmenite.

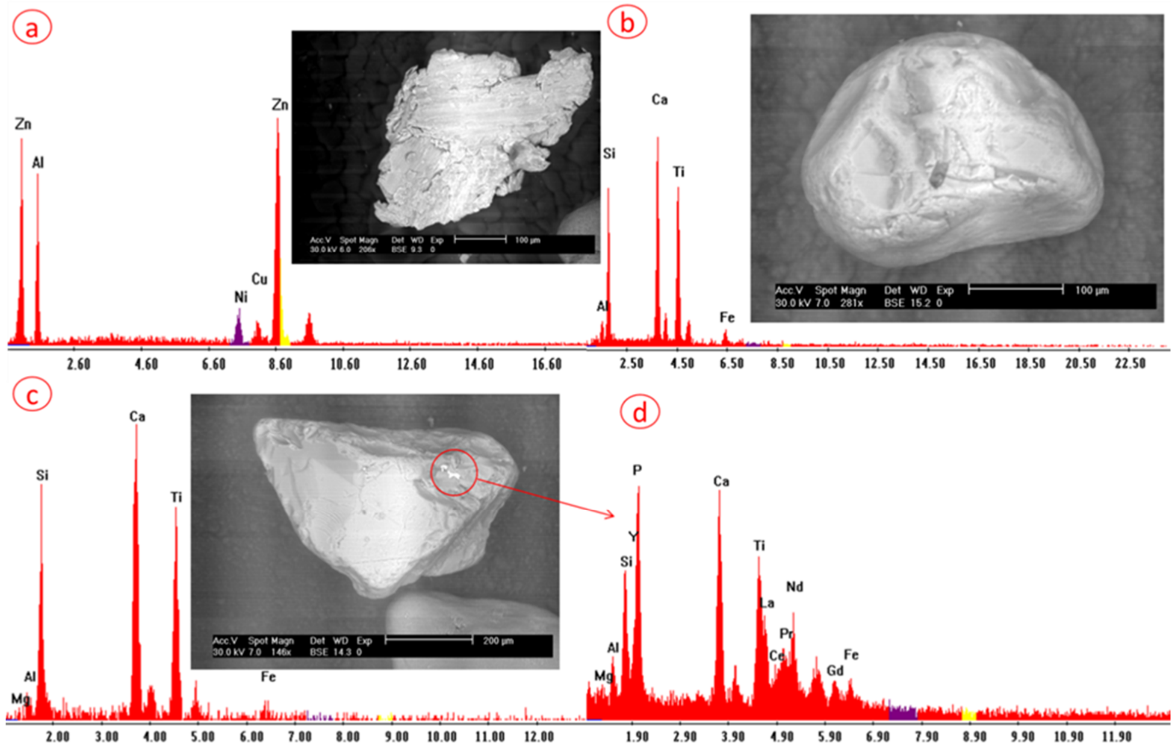

Figure 6. Back-scattered electron (BSE) images and corresponding EDS spectra for a. khatyrkite, b and c. sphene, and d. xenotime inclusion.

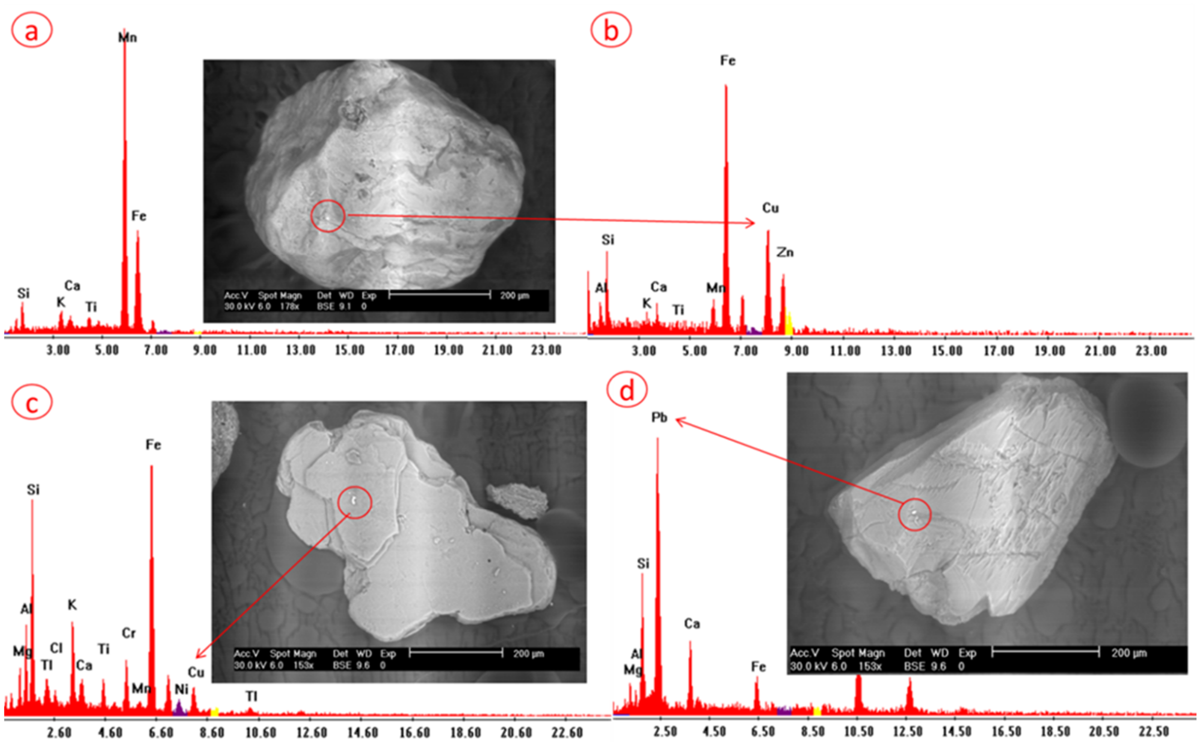

Figure 7. Back-scattered electron (BSE) images and corresponding EDS spectra for a. pyrolusite, b. base metal inclusion on pyrolusite surface, c. base metal inclusions on mica surface, and d. base metal inclusion on heavy silicate mineral.

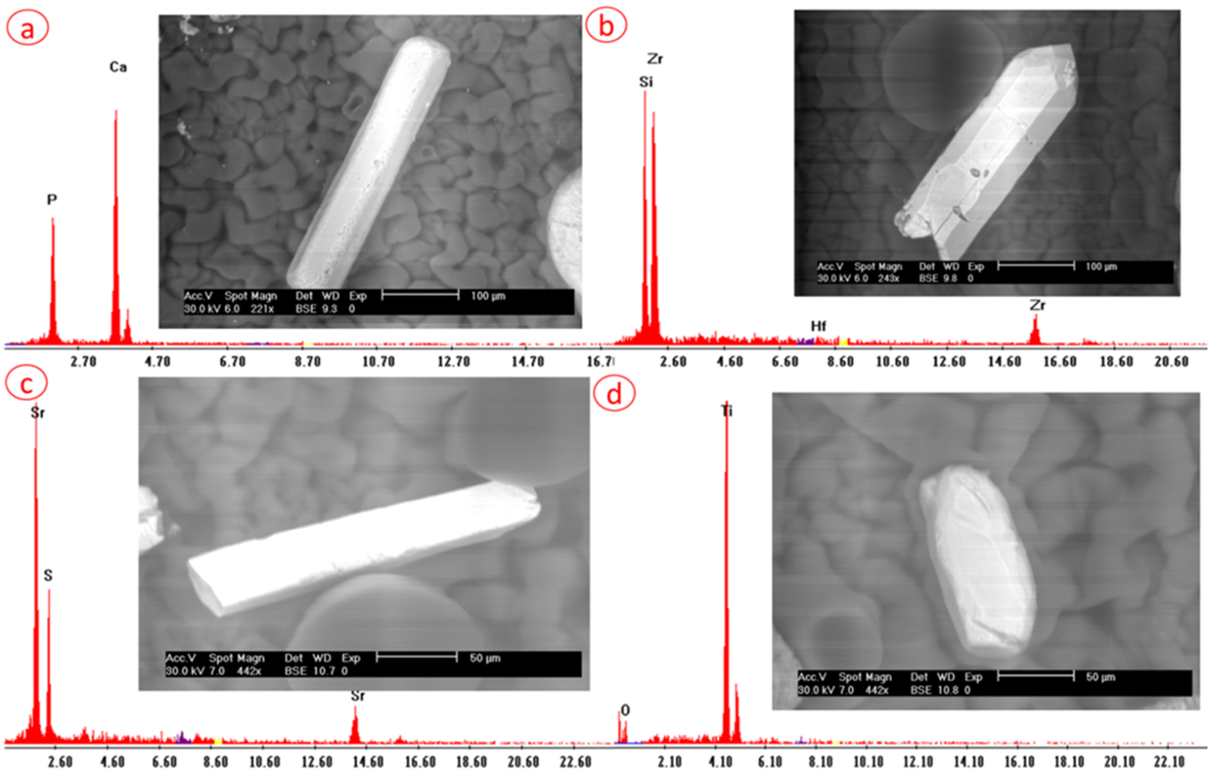

Figure 8. Back-scattered electron (BSE) images and corresponding EDS spectra for a. apatite, b. zircon, c. celestine, and d. rutile.

3.2. Physical upgrading results

The physical upgrading of VHM from the stream sediments of Wadi and Delta Sermatai began with gravity concentration processes a via shaking table in order to eliminate low-density gangue silicate minerals such as quartz and feldspar, which were present in large proportions and produced heavy mineral concentrates. The magnetic separation processes were carried out as a second step on the concentrates obtained from the gravity concentrators in order to separate the magnetic heavy minerals from the paramagnetic heavy minerals and also from the diamagnetic heavy minerals.

3.2.1. Shaking table concentration

Wilfely Shaking Table No. 13 was used as a tool for raising the THM grade of the Wadi and Delta Sermatai samples by going through two rounds of scavenging concentration stages that performed after a rougher step to recover the remaining heavy minerals in tails that were not recovered during the initial roughing stage.

The operation conditions for the roughing and scavenging concentration stages using the shaking table as the feed rate, water flow rate, stroke length, and inclination angle were optimized and listed at (Figure 9). It is quite clear that the scavenging stages have greater values of the operation conditions than the roughing stage, and this comes as a result of the increase in the proportion of the light gangue minerals and the decrease in the heavy minerals during the scavenging stages compared to the roughing stages.

After completion of each gravity concentration stage (rougher and scavenger), a representative sample weighting about 100 g of each one of the gravity concentration products (concentrate and tail) was subjected to a heavy-liquid separation test using bromoform for determination of the THM assay and material balance.

The assay and material balance of the wet gravity concentration processes for the Wadi and Delta Sermatai samples were presented in (Figure 9). The results obtained revealed that the scavenging was a very important and effective stage science it raised THM recovery value from 35.7% after the rougher stage to 66.84% after two rounds of the scavenging stages for the Wadi Sermatai technological sample, while for the Delta Sermatai sample, the scavenging stage raised the THM recovery value from 27.77% after rougher to 67.23 %.

The material balance also revealed that the THM assay was raised from 8.32% to 46.04% for the Wadi Sermatai sample and from 8.37% to 50.13% for the Delta Sermatai sample after the rougher and scavenger concentration stages in 8.89% and 9.59% by mass yield for the Wadi and Delta Sermatai samples respectively. The enrichment ratio of the Wadi and Delta Sermatai samples were 5.53% and 6%, respectively; this means that the Wadi and Delta Sermatai concentrates have 5.53 and 6 times, respectively, the THM concentration of the feed.

The final concentrates of the studied samples obtained after the wet gravity concentration operations were collected, dried, weighed, and analyzed elementally using XRF spectrometry, and compared with the XRF analyses of the feed samples and presented in Table 5 in addition to the calculated elemental enrichment ratio (ER). The elemental enrichment ratio was calculated by dividing the grade of the concentrate by the grade of the feed (c/f) and its value refer to how many times the concentrate has element concentration relative to the feed.

From the results of Table 5, the enrichment ratio values of the major elements such as SiO_2, Al_2O_3, K_2O, and SO_3 indicate that their grades were reduced in the concentrate than in the feed, and this indicates a reduction in the percentages of the gangue minerals that have low specific gravity such as quartz and feldspar as a result of the wet gravity separation processes via the shaking table. To the contrary, the enrichment ratio values for the elements such as Ti, Fe, Mn, Ni, Zn, Pb, Zr, Cr, Y, and Nb, and this in addition to some rare earth elements such as Nd, Sm, Sc, and La indicate a doubling of their grade in the concentrate than in the feed sample, and this is related to a doubling of the ratios of their minerals such as ilmenite, magnetite, rutile, sphene, zircon, garnet, and xenotime in the concentrate as a result of the high value of its specific gravity during wet gravity separation processes.

3.2.2. Magnetic separation

The Carpco high intensity magnetic separator (HIMS) Model MLH (13) III-5" was used to fractionate the heavy mineral concentrate obtained from the gravity concentration processes into the ferromagnetic, paramagnetic, and diamagnetic minerals in the studied samples, and obtained a clean concentrate from these fractions. The magnetic separation processes were achieved at the pre-optimized factors of a medium air gap of 1.5 cm, magnetic field current at 1 and 3 amperes, magnetic roll speed of 30 rpm, and optimum feed rate of 39.2 g/min.

Four magnetic fractions were resulted from the magnetic separation processes via HIMS; ferromagnetic mineral fraction, paramagnetic mineral fraction that separated at 1 ampere, paramagnetic mineral fraction that separated at 3 amperes, and finally, the diamagnetic mineral fraction that separated at 3 amperes. The ferromagnetic fraction percentages were 11.53% and 14.49% mass for the Wadi and Delta Sermatai samples, respectively, while the paramagnetic fraction at 1 ampere reached 38.21% and 25.93% mass for the Wadi and Delta samples respectively. As for the results of separating the paramagnetic fraction at 3 amperes, they were 11.69% and 31.24% mass for the Wadi and Delta samples, respectively. Finally, the diamagnetic fraction had the percentages of 38.56% and 9.45% mass for the Wadi and Delta Sermatai samples, respectively (Figure 9).

Table 5. XRF elemental analyses demonstrating feed grade, concentrate grade, and enrichment ratio (ER) for Delta and Wadi Sermatai samples.

Sample	Delta Sermatai			Wadi Sermatai		
	Feed grade (f)	Conc. grade (c)	ER (c/f)	Feed grade (f)	Conc. grade (c)	ER (c/f)
Major elemental oxide in wt.%						
SiO_2	67.32	40.57	0.60	67.96	52.57	0.77
TiO_2	0.56	5.95	10.63	0.56	2.62	4.68
Al_2O_3	14.15	10.76	0.76	13.85	13.11	0.95
$Fe_2O_3^{Total}$	4.13	27.75	6.72	4.56	16.34	3.58
MnO	0.095	0.63	6.63	0.097	0.32	3.30
MgO	1.77	2.98	1.68	1.62	3.23	1.99
CaO	3.04	6.22	2.05	2.34	4.53	1.94
Na_2O	4.06	2.14	0.53	4.71	3.60	0.76
SO_3	0.23	0.01	0.043	0.02	0.02	1.00
K_2O	2.23	0.76	0.34	2.64	1.23	0.47
P_2O_5	0.21	0.29	1.38	0.25	0.44	1.76
L.O.I.	2.03	0.98		1.21	1.61	
Trace elements in ppm						
V	37.2	659.3	17.72	33.8	340.4	10.07
Ni	16.4	54.1	3.30	14.7	39.4	2.68
Zn	51.6	240.0	4.65	67.5	190.5	2.82
Cu	6.8	15.3	2.25	7.3	15.0	2.05
Pb	6.3	28.7	4.56	8.9	16.8	1.89
Sr	230.6	388.4	1.68	203.6	320.8	1.58
Rb	41.8	15.1	0.36	48.9	36.8	0.73
Zr	206.4	1244.2	6.03	239.8	1244.2	5.19
Hf	7.0	62.5	8.93	9.40	26.5	2.82
Cr	36.5	944.6	25.88	22.5	156.7	6.96
Ga	15.2	24.4	1.61	19.2	26.0	1.35
Mo	0.5	1.6	3.20	0.40	2.80	7.00
Co	6.2	29.3	4.73	4.40	32.6	7.41
Ag	0.3	0.9	3.00	0.3	0.4	1.33
Nb	12.2	124.1	10.17	21.0	87.1	4.15
Ta	4.0	1.0	0.25	2.90	10.8	3.72
Y	20.0	108.0	5.40	29.2	82.3	2.82
Sc	7.5	50.4	6.72	8.8	43.3	4.92
La	19.3	104.5	5.41	19.4	97.5	5.03
Ce	45.4	291.5	6.42	20.2	211.6	10.48
Nd	7.1	115.9	16.32	1.90	95.1	50.05
Sm	-	14.7	14.70	-	18.4	18.4
U	0.7	3.1	4.43	1.20	0.30	0.25
Th	6.5	28.0	4.31	8.50	19.0	2.24

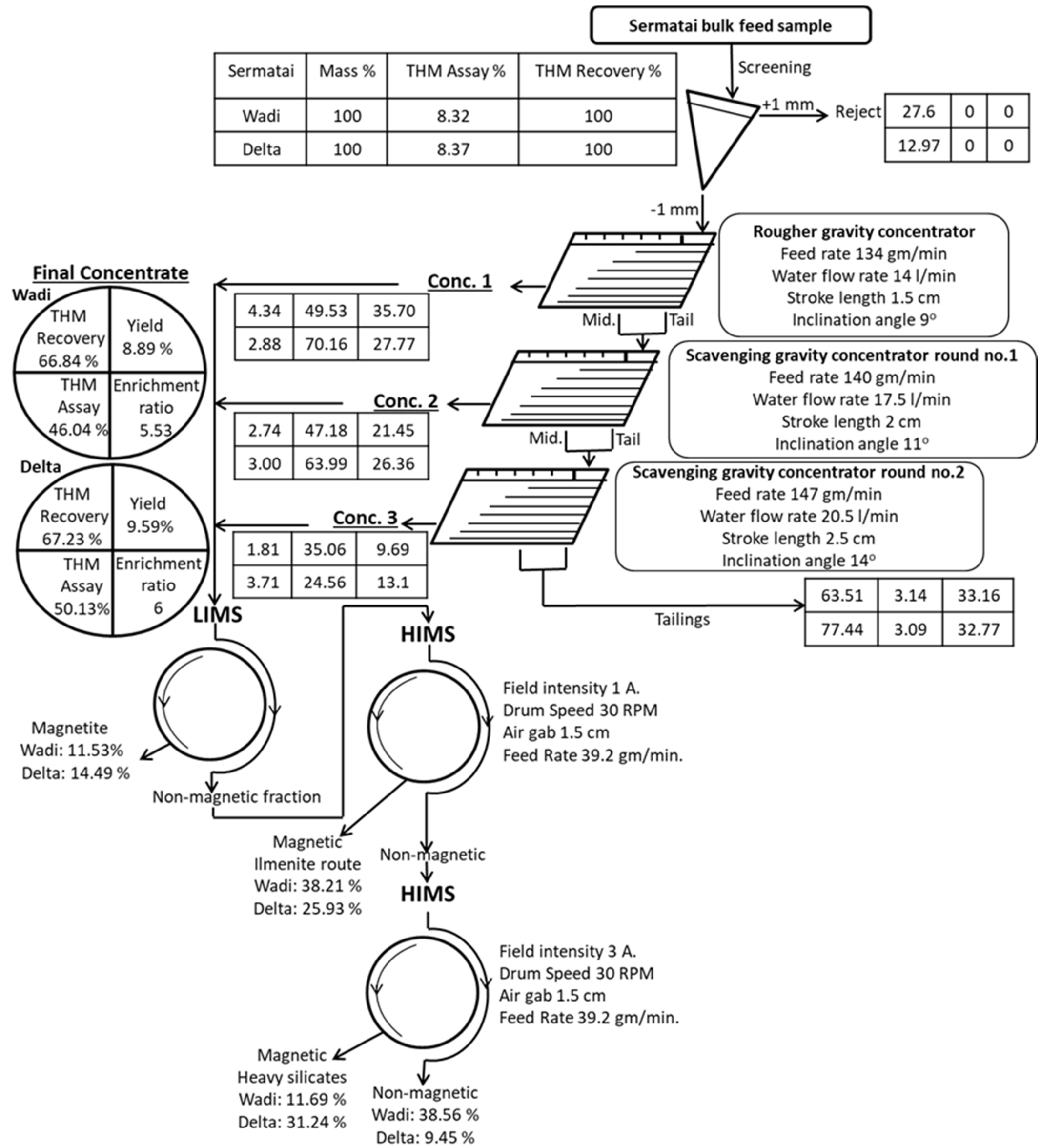

Figure 9. Flowsheet with material balance for recovery of THM from Wadi and Delta Sermatai feed sample under optimum conditions.

4. Conclusions

About 60 sampling points were studied during this work in order to cover the stream sediments of the Sermatai area (Wadi and Delta), which has an area of about 84 Km^2. The present work included two main parts: the mineralogical characterization and the potentiality of physical upgrading for VHM. The results of mineralogical characterization and evaluation included that the THM assay of the Wadi and Delta Sermatai samples was 8.32% and 8.37%, respectively, which were magnetite, ilmenite, garnet, khatyrkite, sphene, pyrolusite, apatite, zircon, celestine, and rutile, where these minerals were found in the sandy size. The light gangue minerals of the Delta and Wadi Sermatai samples represented the high values of 85.42% and 87.34% mass, respectively, while the slimes and organic matter contents were the least present, amounting to 6.21% and 4.34% mass for Delta and Wadi Sermatai, respectively.

The physical upgrading tests for the Wadi and Delta Sermatai technological samples proved their potentiality for raising the grade of VHM via a shaking table in conjunction with a dry high-intensity magnetic separator. From the assay and material balance results, the scavenging concentration stages proved to be effective through the wet gravity concentration processes science they raised the THM recovery values from 35.7% after the rougher stage to 66.84% after two rounds of the scavenging stages for the Wadi Sermatai sample, while for the Delta Sermatai sample, the scavenging stage raised the THM recovery value from 27.77% after rougher to 67.23%. The material balance also revealed that the THM assay was raised from 8.32% to 46.04% for the Wadi Sermatai sample and from 8.37% to 50.13% for the Delta Sermatai sample after the rougher and scavenger concentration stages in 8.89% and 9.59% by mass yield for the Wadi and Delta Sermatai samples, respectively.

Accordingly, the Sermatai area represents one of the sites where the economic concentrations of heavy minerals can be obtained through the physical upgrading techniques that have proven their effectiveness.

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پتانسیل افزایش عیار با روش‌های فیزیکی برای مواد معدنی سنگین با ارزش از منطقه **Sermatai**، مصر

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چکیده:

در این کار ما به پتانسیل استفاده از فرآوری مواد معدنی برای افزایش عیار مواد معدنی سنگین (VHMs) از جریان‌های رسوبی چهارتایی در مناطق وادی (صحرایی) و دلتا (مصب رود) سرماتای واقع در سواحل جنوبی دریای سرخ، مصر می پردازیم. درک دقیق ویژگی‌های شیمیایی و کانی‌شناسی نمونه‌های مورد مطالعه، پیش نیازی برای انتخاب و توسعه پردازش فیزیکی مورد استفاده به منظور تولید کنسانتره با عیار بالا است. برای این منظور، تجزیه و تحلیل توزیع اندازه دانه، آزمایش‌های جداسازی مایع سنگین و همچنین آنالیز XRF و SEM انجام می‌شود. مگنتیت، ایلمنیت، گارنت، زیرکون، روتیل، آپاتیت، اسفن، پیرولوزیت، سلستین و سیلیکات‌های سبز سنگین از کانی‌های سنگین با ارزش ثبت‌شده در نمونه‌های مورد مطالعه هستند. اما مقدار آنها بین مناطق صحرایی و دلتای رود متفاوت است. آزمایشات ارتقاء از طریق یک میز همراه با جداکننده مغناطیسی با شدت پایین و با شدت بالا به منظور به دست آوردن کنسانتره با عیار بالا از مواد معدنی سنگین انجام می‌شود و پس از اعمال شرایط جداسازی بهینه، کانی کل سنگین (THM) سنجش از ۸/۳۲ ٪ به ۰۴۶/۰۴ ٪ برای Wadi Sermatai افزایش یافت، در حالی که برای Delta Sermatai از ۸/۳۷ ٪ به ۵۰/۱۳ ٪ به ترتیب با عملکرد جرمی به ۸/۸۹ ٪ و ۹/۵۹ ٪ افزایش یافت. مقادیر بازیابی THM برای Wadi Sermatai به ۶۶/۸۴ ٪ و برای Delta Sermatai به ۶۷/۲۳ ٪ می رسد. پس از نتایج آنالیز شیمیایی کنسانتره ها، ثابت می‌شود که منطقه سرماتای به عنوان منبع بالقوه برخی از عناصر اقتصادی مانند Fe، Ti، Zn، Zr، Cr، V و Sr در نظر گرفته می‌شود.

کلمات کلیدی: سرماتای، سواحل جنوبی دریای سرخ، مواد معدنی سنگین با ارزش، غلظت ثقلی، جداسازی مغناطیسی