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Mineralogical Investigation of Economic Minerals Content in Wadi Arar, Northern Border Region, Kingdom of Saudi Arabia

Mohamed Ismail Moustafa[1]*, Mohammed Ismael Abu Shariah[1] and Mohamed Saad Aljuhani[2]

[1]College of Engineering, Northern Border University, Northern Border Region, Arar 91431, P.O. Box 1321, Kingdom of Saudi Arabia;
ismail2251962@yahoo.com, mohdshariah@yahoo.com
[2]Department of Mining Engineering, Engineering King Abdulaziz University, Jeddah 21589, P.O. Box 80200, Kingdom of Saudi Arabia;
msjuhani@yahoo.com

Abstract

Objectives: Mineralogical Investigation was conducted in Wadi Arar to detect economic minerals in Arar city at Northern Border Region (NBR), Kingdom of Saudi Arabia (KSA). **Methods/Analysis:** A study area is located between latitudes 30o 59.735′ N and 30o 55.187′ N, Longitudes 41o 02.027′ E and 40o 59.896′ E, and it is length was 7.5 km approximately. Twenty samples was collected across 7 profiles perpendicular or diagonal along the Wadi Arar, from the top of surficial layer and their averages depth ranged between 40-70 cm. Several experimental methods carried out for each sample including: drying, screening, splitting, sieving, microscopic investigation, magnetic fractionation, wet gravity, and X-Ray Diffraction (XRD). **Findings**: Most of economic heavy minerals included ferromagnetic grains (most probably) such as magnetite, Ilmenite, and traces of rutile and zircon. In addition, some of other heavy minerals were also recorded including pyroxenes (mainly augite), magnesite and dolomite. **Novelty/Improvement:** This study is the first to investigate the economic value of Wadi Arar. The results provided valuable recommendations for further work that can help researchers and agencies (government or private) to better understand the value of mineralogical Investigation in the region.

Keywords: Half-size Shaking Table, Economic Minerals, Magnetite, Magnetic Separator, Mechanical Shaker, Wadi Arar

1. Introduction

The identification for most of accessory mineral components of crystalline hard rock's (igneous and metamorphic) or sedimentary rocks in a definite region can be recognized by studying the contents of the majority of economic minerals of the detrital deposits of streams or valleys located in the regions of these rocks; especially when such rocks are the upstreams for them. The Arabic term "Wadi" is always dedicated to dry streams and hence the expression "Wadi deposits" is sometimes used instead of "stream sediments"[1]. The Wadi deposits are due to the physical and chemical weathering and diverse transport

**Author for correspondence*

processes which affected such crystalline hard rocks. In fact, most of the economic minerals in such rocks in the familiar situation are scarce. Thus, the determination of all types and contents of their associated economic minerals through the study of thin sections taken from small weights of samples of these rocks may be difficult. Then, the study of Wadi sediments to investigate and identify their contents of economic minerals will successfully help in determining the nature of the mineral resources of the source rocks region. Especially regions of little investigation studies.

Wadi Arar starts by small Sha'ibs from about 125 km towards Arar' city and meets many Wadis and Sha'ibs; then it continues in the direction to the Iraqi border[2,3]. The area which contains Wadi Arar is located between Latitudes 31° 00′N - 30° 45′ N, and Longitudes 40° 30′ E and 41°05′ E and is characterized by a rocky layer of limestone and sandstone with a few of dolomites and silt, which called Aruma formation of the Cretaceous Era[2,3].

In[4] stated that a few studies are dealt with most Wadis and Sha'ibs in KSA, mainly concerned with geological mapping at various scales and stratigraphic classification in addition to description of the component rock varieties. Also, there are no enough studies available to show the soil type and soil properties of Wadi Arar. Careful survey of relevant literature indicates that nothing has been published on economics of stream deposits in Saudi Arabia except for construction materials[1].

In the present work the mineralogical composition of some collected samples representing almost the most top surficial meter of the deposits of Wadi Arar will be investigated and then the economic value of the Wadi will be concerned.

2. Methodology

2.1 Sampling

The studied area of Wadi Arar (Figure 1 and 2) is

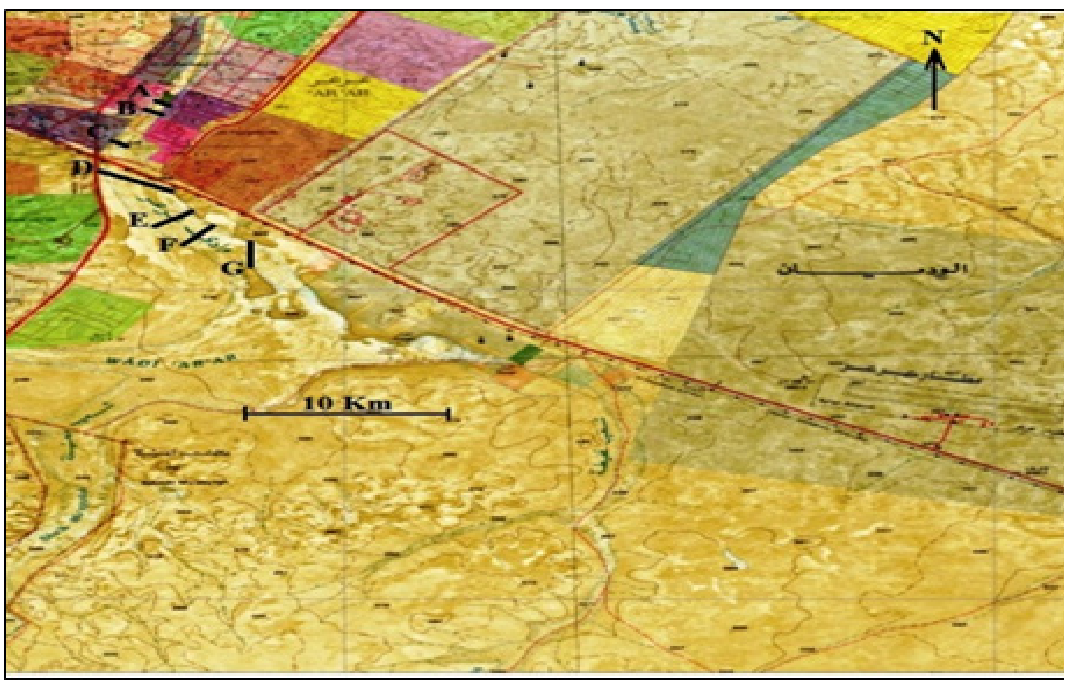

Figure 1. Map shows samples location across the Wadi Arar.

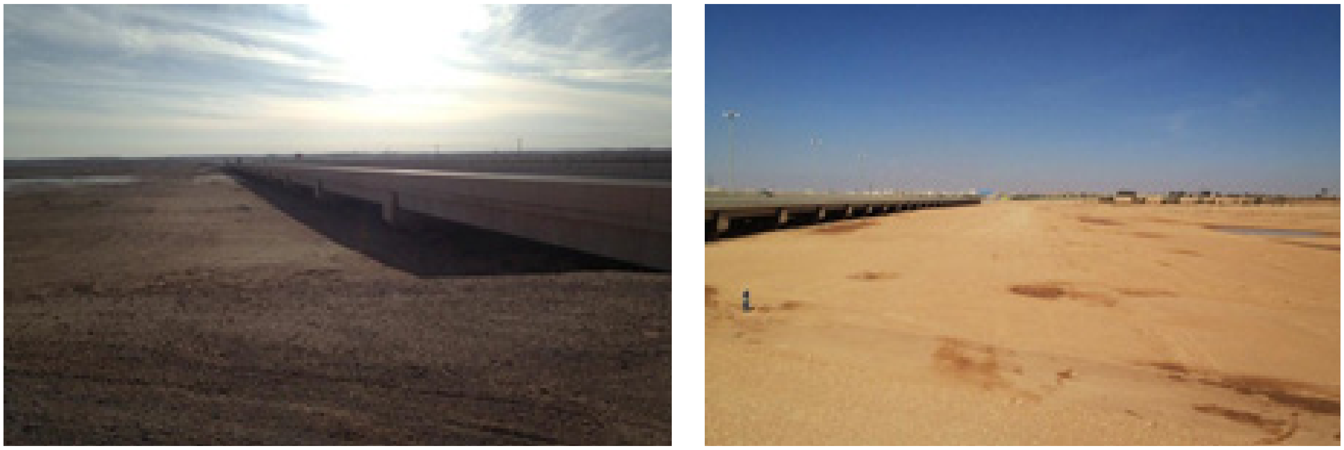

Figure 2. Images show study area view.

located between latitudes 30° 59.735′ and 30° 55.187′ and Longitudes 41° 02.027′ and 40° 59.896′ with an approximate length of 7.5 km. Twenty samples were taken from the most top surficial meter of the deposits of Wadi Arar. Their averages depths ranged between 30-60 cm while their weights ranged between 3.280 kg to 5.416 kg. These samples were located across 7 profiles perpendicular or diagonal on the path direction of the Wadi. Except of the first profile (A), each of the other six profiles (B,C,D,E,F and G) includes three samples (two on the two sides of the Wadi and the third located at the middle of the distance between them). The first profile includes only two samples one at each side. The width of the located profiles of the studied samples of the Wadi ranges between 100 m at profile A and 1500 m at profile D. The location map shows 20-samples that taken from 7-profiles across Wadi Arar as shown in Figure 1.

2.2 Techniques

Several techniques and instruments were used in the mineralogical investigation and identification of the collected samples from Wadi Arar as following; drying, screening, splitting, sieving, microscopic investigation, magnetic fractionation, wet gravity, and X-Ray Diffraction (XRD).

Oven used for samples drying at 110° C for two hours. Screening using a size aperture screen of 5 cm to remove trash and/or large sediment grains. Jones riffle splitter to obtain representative samples of relatively small weights. Each sample was splitted; about 1/4 the original sample weight.

Mechanical shaker and a set of standard sieves, have size apertures of 50mm, 3mm, 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.063mm, and 0.045mm; at a definite adjustment of operating conditions to study the size distribution of the collected samples. Each individual representative sample was subjected to sieving where 9 fractions of different size classes were obtained; in addition to the obtained size class (+50 mm) of step no. 2 :+ 50 mm, - 50 mm + 3 mm, - 3 mm + 2 mm, - 2mm +1 mm, - 1mm + 0.5mm, - 0.5 mm + 0.25 mm, - 0.25mm + 0.125 mm, - 0.125 mm + 0.063 mm, - 0.063 mm + 0.045 mm, and - 0.045 mm.

Heavy liquid separation technique using Bromoform (density of 2.89 gm/cm^3), separating funnels, glass funnels, fast filtration papers, glass rods, holders and acetone for washing. Binocular microscope for investigating the mineral composition of the various samples and also counting the detected economic and heavy mineral grains.

Some of economic opaque minerals were detected only in the two sized fractions -250+125 μ and -125+63 μ. Then, each of these two obtained size class fractions, corresponding to a definite collected original sample, was mixed to produce a definite composite sample. For each of the obtained 20 composite samples, a small representative sample; ranges in weight between 21.2 and 31.7 grams was taken and subjected to the heavy liquid separation technique.

A definite representative number of grains; ranges between 500 and 1000, for each individual heavy fraction were detected and counted. The grain size of the mineral grains must be considered during the microscopic counting. The weight percent of each mineral in every fraction is calculated usingequation[5]:

$$Q = \frac{pnd.\ 100}{P\ (\sum nd)}$$

where

P: weight of the subfraction.

n: number of grains for a given mineral.

d: specific gravity for the same mineral.

p: weight of the quartered sample.

Outotec laboratory high intensity induced roll magnetic separator, Model: MIH (13) 111-5 PHYSEP-INC USA; for differentiation of the different heavy minerals into magnetic and non-magnetic mineral fractions. The separator was adjusted at definite parameters of operating conditions; air gab of 2 mm, feeding rate of 10 kg/hr, rotor speed of 120 r.p.m., a definite splitter adjustment between the two obtained magnetic and non–magnetic fractions and ampere (A) values of 0.05, and 2 amperes.

Magnetic separation used to ensure the ability of the various heavy and economic minerals in the obtained heavy liquid fractions to the magnetic differentiation, a magnetic fractionation was carried out for a composite sample obtained by mixing all of the obtained individual heavy liquid fractions using the high-intensity induced roll magnetic separator at two successive current ampere values where three fractions were obtained: the magnetic fraction at 0.05 A; it contains the majority of the ferromagnetic mineral grains, the magnetic fraction at 2A; it contains most of the paramagnetic minerals, and finally the non-magnetic fraction which contains most of the non-magnetic minerals.

The laboratory shaking table to investigate the wet gravity concentration of the various economic and heavy minerals in a definite tabled concentrate. The following parameters represents the optimum adjustment of operating conditions:

Feeding rate = 20 kg/hour.

Feeding pulp density = 15-20%.

Deck side slope = 8-12mm/meter.

Stroke length = 16 mm.

Stroke frequency = 300 r.p.m.

Wet gravity concentration used for both two size classes of -250+125 and-125+63 microns for the twenty investigated samples ; samples from A1 up to A20, were subjected to a process of wet–gravity concentration using the laboratory shaking table. Two final fractions were obtained: the tabled concentrate fraction contains most of the economic minerals in addition to some of the relatively finer heavy mineral grains and the tailing fraction which contains the majority of heavy and light gangue minerals.

XRD technique; Philips X-ray generator (PW 3710/31) with automatic sample changer (PW 1775; 21 position) using scintillation counter, Cu-target tube and Ni filter at 40 kV and 30 mA was used. This instrument is connected with computer system using X 40 diffraction program and ASTM cards for mineral identification.

3. Results

The obtained 9 grain size class fractions were weighed and their original weight percentages were calculated. Also, the weight percentages of gravel, sand, and silt clay size components were calculated (Table 1). It was detected

Table 1. The grain size distribution and the various grain size components of the different studied samples across Wadi Arar

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
A1	+50	0.00	2.37	43.70	53.93
	+3	43.88			
	+2	10.05			
	+1	8.30			
	+0.50	14.03			
	+0.25	10.70			
	+0.125	8.31			
	+0.063	2.36			
	+0.045	1.25			
	-0.045	1.12			
	Total	100.00			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
A2	+50	8.22	0.29	30.98	68.73
	+3	48.29			
	+2	12.22			
	+1	10.13			
	+0.50	12.59			
	+0.25	5.42			
	+0.125	2.13			
	+0.063	0.75			
	+0.045	0.27			
	-0.045	0.02			
	Total	100.00			
A3	+50	0.00	0.35	26.05	73.60
	+3	60.13			
	+2	13.47			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+1	8.15			
	+0.50	9.79			
	+0.25	5.64			
	+0.125	2.00			
	+0.063	0.47			
	+0.045	0.27			
	-0.045	0.08			
	Total	100.00			
A4	+50	8.59	0.37	32.60	67.03
	+3	47.56			
	+2	10.88			
	+1	8.69			
	+0.50	12.38			
	+0.25	7.20			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.125	3.30			
	+0.063	1.03			
	+0.045	0.35			
	-0.045	0.02			
	Total	100.00			
A5	+50	0.00	0.23	34.00	65.77
	+3	53.86			
	+2	11.91			
	+1	8.49			
	+0.50	14.88			
	+0.25	7.17			
	+0.125	2.65			
	+0.063	0.81			
	+0.045	0.18			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	-0.045	0.05			
	Total	100.00			
A6	+50	0.00	2.66	56.70	40.64
	+3	31.62			
	+2	9.02			
	+1	8.12			
	+0.50	9.08			
	+0.25	11.75			
	+0.125	21.45			
	+0.063	6.30			
	+0.045	2.12			
	-0.045	0.54			
	Total	100.00			
A7	+50	0.00	0.52	49.13	50.35

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+3	39.80			
	+2	10.55			
	+1	7.52			
	+0.50	13.50			
	+0.25	17.17			
	+0.125	9.61			
	+0.063	1.33			
	+0.045	0.44			
	-0.045	0.08			
	Total	100.00			
A8	+50	0.00	0.55	64.96	34.49
	+3	26.71			
	+2	7.78			
	+1	5.25			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.50	14.01			
	+0.25	30.67			
	+0.125	12.40			
	+0.063	2.63			
	+0.045	0.39			
	-0.045	0.16			
	Total	100.00			
A9	+50	0.00	0.99	34.95	64.06
	+3	53.70			
	+2	10.36			
	+1	6.69			
	+0.50	10.24			
	+0.25	8.31			
	+0.125	7.32			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.063	2.39			
	+0.045	0.72			
	-0.045	0.27			
	Total	100.00			
A10	+50	0.00	0.91	58.61	40.48
	+3	30.00			
	+2	10.48			
	+1	9.04			
	+0.50	14.37			
	+0.25	14.33			
	+0.125	15.04			
	+0.063	15.04			
	+0.045	0.71			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	-0.045	0.20			
	Total	100.00			
A11	+50	0.00	1.91	53.10	44.99
	+3	34.95			
	+2	10.04			
	+1	7.57			
	+0.50	11.54			
	+0.25	10.50			
	+0.125	17.32			
	+0.063	6.17			
	+0.045	1.28			
	-0.045	0.63			
	Total	100.00			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
A12	+50	0.00	4.02	56.61	39.37
	+3	29.33			
	+2	10.04			
	+1	8.12			
	+0.50	11.53			
	+0.25	11.43			
	+0.125	14.90			
	+0.063	10.63			
	+0.045	3.67			
	-0.045	0.35			
	Total	100.00			
A13	+50	0.00	1.00	43.51	55.49
	+3	43.80			
	+2	11.69			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+1	8.76			
	+0.50	13.94			
	+0.25	8.64			
	+0.125	9.19			
	+0.063	2.98			
	+0.045	0.93			
	-0.045	0.07			
	Total	100.00			
A14	+50	0.00	1.98	88.22	9.80
	+3	5.95			
	+2	3.85			
	+1	4.66			
	+0.50	14.27			
	+0.25	23.33			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.125	31.06			
	+0.063	14.90			
	+0.045	1.48			
	-0.045	0.50			
	Total	100.00			
A15	+50	0.00	2.91	54.77	42.32
	+3	32.02			
	+2	10.30			
	+1	8.46			
	+0.50	11.54			
	+0.25	10.14			
	+0.125	17.20			
	+0.063	7.43			
	+0.045	1.91			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	-0.045	1.00			
	Total	100.00			
A16	+50	0.00			
	+3	23.11			
	+2	7.77			
	+1	8.54	2.29	66.83	30.88
	+0.50	12.29			
	+0.25	13.53			
	+0.125	24.37			
	+0.063	8.10			
	+0.045	1.94			
	-0.045	0.35			
	Total	100.00			
A17	+50	0.00	1.62	50.55	47.83

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+3	35.83			
	+2	12.00			
	+1	9.40			
	+0.50	14.34			
	+0.25	10.19			
	+0.125	11.45			
	+0.063	5.17			
	+0.045	1.23			
	-0.045	0.39			
	Total	100.00			
A18	+50	0.00	1.01	44.96	54.03
	+3	42.91			
	+2	11.12			
	+1	8.10			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.50	14.74			
	+0.25	11.74			
	+0.125	7.65			
	+0.063	2.73			
	+0.045	0.69			
	-0.045	0.32			
	Total	100.00			
A19	+50	0.00	0.66	40.57	58.77
	+3	49.13			
	+2	9.64			
	+1	8.66			
	+0.50	13.80			
	+0.25	9.00			
	+0.125	7.41			

Table 1 Continued

wt %	Grain Size Classes (mm)	Samples	Various Grain Size Contents, wt %		
			Silt & Clay	Sand	Gravel
	+0.063	1.7			
	+0.045	0.61			
	-0.045	0.05			
	Total	100.00			
A20	+50	0.00	1.24	45.71	53.05
	+3	43.00			
	+2	10.05			
	+1	7.48			
	+0.50	12.75			
	+0.25	12.33			
	+0.125	9.91			
	+0.063	3.24			
	+0.045	0.83			
	-0.045	0.41			
	Total	100.00			

that in the investigated samples the gravel sized fractions ranges between 9.8 and 73.6 wt. %, the sand sized fractions ranges between 26.05 and 88.22 wt. % while the silt and clay sized fractions ranges between 0.29 and 4.02 wt. %.

Miltonstated that "The soil grains distribution trends are approximately similar. Sand grains are extremely the main content of sediment soil in Wadi Arar[6]. The average contents of sand, fine grains and gravels are 54%, 30% and 16% respectively".

It was noticed that there are a clear individual negative correlation between gravel fraction wt% and both of fine sand fraction wt%, very fine sand fraction wt% and to somewhat silt & clay fraction wt% (Figure 3). The reason may be related to the prevailing sedimentation conditions of Wadi Arar stream and also the weakness of the stream along its path when partially filled with water. McClure supposed that a period of rainfall, considerably greater in magnitude than any of the Pleistocene would seem necessary to have carved out the main through-flowing wad is of the Arabian Peninsula[7]. Anton introduced circularity into the argument by supposing that a semi-arid climate probably can explain the required erosion and necessary transportational competence[8]. Elsewhere, he then supposed that coarse formations indicate former existence of a semi-arid environment. In such regimes, it would be the occasional flash flood with great competence for debris transport that was involved. In envisaged a different prevailing climate, arguing for a tropical, hyper-humid

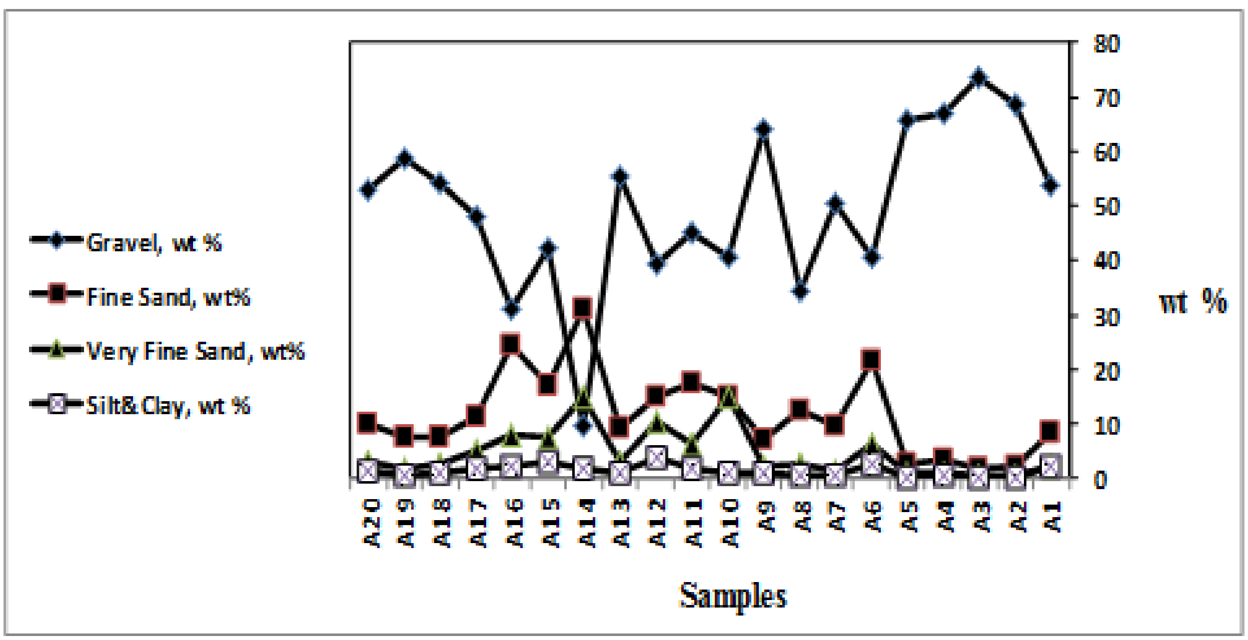

Figure 3. The distinct positive relation between the calculated gravel size class wt% and both of fine sand, very fine sand and silt & clay size class wt% for most of investigated collected samples.

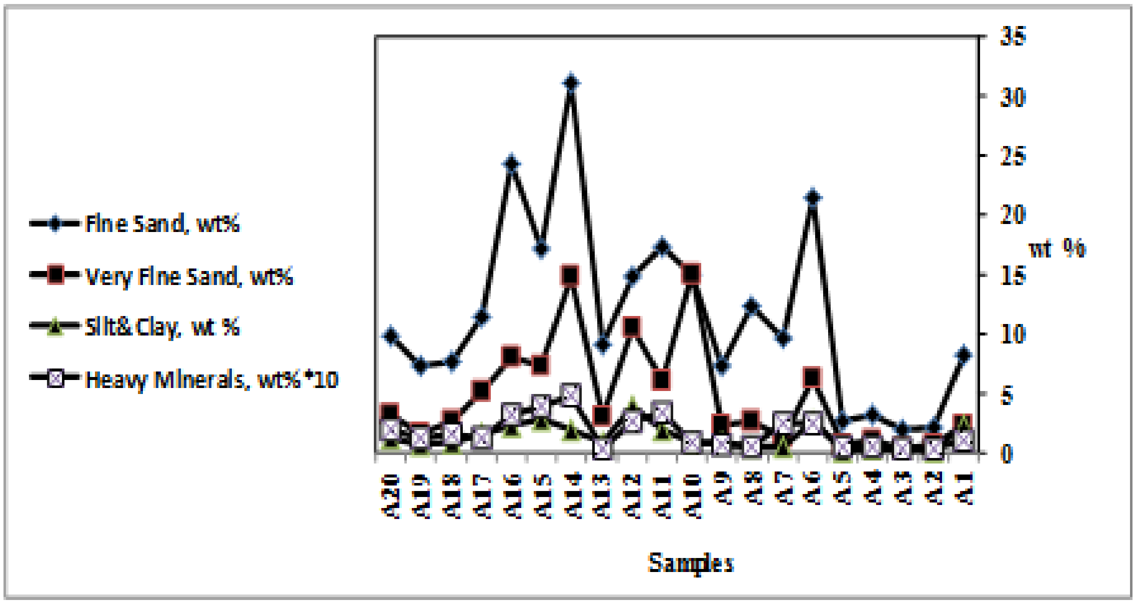

Figure 4. The distinct positive relation between the calculated individual heavy.

regime during the transition from late Pliocene to early Pleistocene[9].

On the other hand, the positive correlation between both of the fine sand fraction wt% and the very fine sand fraction wt% is highly obvious. Due to the relatively lower contents of the calculated individual heavy mineral fractions wt% the correlation between heavy minerals wt% and these two corresponding size classes wt% for the studied 20 samples are not clear. Multiplying each value of heavy mineral wt% in 10 and detecting the relation between such two sand size classes' wt% and the enlarged obtained heavy liquid wt% gives up the expected relation between the relatively finer grain sizes and the associated contained heavy minerals (Figure 4). Most of previous studies ensure that heavy minerals are highly concentrated in the relatively finer grain size classes[10,11].

The results of the obtained heavy mineral fractions are shown in Table 2. The investigation of these fractions under the microscope reflects that the investigated grains can be categorized into two major groups:

a. Opaque black grains with distinct metallic luster. A considerable number of these grains are iron black with chain structure which is characteristic for ferromagnetic grains of high magnetic susceptibilities. The majority of these grains have relatively finer grain sizes they are angular to subangular with minor of subrounded and spherical shapes. Many of the grains have cubic octahedrons crystals. The XRD pattern of some picked individual ferromagnetic grains is given in Figure 5A, the pattern shows the normal magnetite lines in accordance with the ASTM Card No. 19-629. Only the main line of hematite was obtained but in very weak intensity; may be due to the martitization of

Table 2. The obtained heavy mineral contents of the various studied samples due to the using of heavy minerals separation technique by Bromoform

Samples	Composite sample of the two mixed grain size classes, + 0.125& + 0.063 mm wt%	Bromoform heavy frac-tion, wt %	Original heavy minerals content, wt %	Mineralogical composition, wt %	
				Opaques, wt %	Translucent to trans-parent grains, wt %
A1	10.67	1.05	0.11	78.80	21.20
A2	2.88	1.36	0.04	69.10	30.90
A3	2.47	1.33	0.03	84.70	15.30
A4	4.33	1.42	0.06	85.50	14.50
A5	3.46	1.63	0.06	83.50	16.50
A6	27.75	0.95	0.26	74.60	25.40
A7	10.94	2.31	0.25	83.60	16.40
A8	3.02	1.49	0.05	85.00	15.00
A9	9.71	0.82	0.08	75.00	25.00
A10	20.87	0.41	0.09	72.80	27.20

Table 2 Continued

Samples	Composite sample of the two mixed grain size classes, + 0.125& + 0.063 mm wt%	Bromoform heavy frac-tion, wt %	Original heavy minerals content, wt %	Mineralogical composition, wt %	
				Opaques, wt %	Translucent to trans-parent grains, wt %
A11	23.49	1.46	0.34	75.80	24.20
A12	25.53	1.05	0.27	79.60	20.40
A13	12.17	0.34	0.04	81.00	19.00
A14	45.96	1.05	0.48	71.30	28.70
A15	24.63	1.59	0.39	71.10	28.90
A16	32.47	1.00	0.33	81.50	18.50
A17	16.62	0.78	0.13	75.60	24.40
A18	10.38	1.58	0.16	77.50	22.50
A19	9.11	1.31	0.12	79.50	20.50
A20	13.15	1.52	0.20	77.80	22.20

some magnetite grains. Some of these grains are locked with various parts of pyroxene or carbonate minerals. However, magnetite still represents the major component; more than 85 %, of such locked grains. Some minor magnetite grains are well rounded and highly spherical with pitted surfaces like the majority of magnetite grains.

b. Another kind of the opaque black grains seems to be having a core of translucent dark green, pale grain or pale brown with highly pitted surfaces. The majority of the individual opaque grains is subangular to subrounded and is spherical rather than elongated. Some Ilmenite grains were detected; theyare angular to subangular dull grey with bluish tints. The XRD pattern of Ilmenite grains is given in Figure 5B the pattern shows the normal Ilmenite lines in accordance with the ASTM Card No. 3-0781. All of these opaque grains have weight % ranges between 69.1% and 85.5% of the counted grains.

c. The other group of investigated grains is translucent to transparent coloured and colourless grains. The majority of grains are translucent with dark green, light green and light brown colours; they are composed of pyroxene mineral varieties; mainly augite.

Translucent to transparent red, brown and yellow rutile grains with elongated shapes were detected; the grains are mainly present in the fine grained sand sizes. The XRD pattern of some picked rutile grains is given in Figure 5C the pattern shows the normal rutile lines in accordance with the ASTM Card No. 4-0551. Most of detected zircon grains are colorless tetragonal and elongated particles; highly concentrated in the very fine sand sized grains. The XRD pattern of some picked zircon grains is given in Figure 5D, the pattern shows the normal zircon lines in accordance with the ASTM Card No. 6-0266. All of these translucent to transparent grains have weight % ranges between 14.5% and 30.9% of the counted grains; see Table 2. In these percentage values, augite is considered the essential mineral component while both of magnesite, dolomite, rutile and zircon are considered subordinate mineral components.

In the calculations a value of 4.5 as specific gravity of the opaque mineral grains was chosed due to the presence of some gangue heavy minerals; up to 10-15%, as staining on the surfaces of opaque grains or locked with them. On the other hand, an average value of 3.20 as specific gravity for the translucent detected minerals which lies between 3 and 3.6.

The investigation of the obtained magnetic and non-magnetic fractions reflects the following; the weight % of the obtained highly ferromagnetic fraction equals 41% of the magnetically treated composite sample. At 2 A most of pyroxeneand Ilmenite mineral grains in addition to some of magnetic rutile grains are contained in the obtained magnetic fraction. The weight % of the obtained paramagnetic minerals fraction equals 43.4% of the magnetically treated composite sample. The non–magnetic varieties at 2A include most of the other detected minerals including magnesite, dolomite, rutile, zircon and some quartz grains. Its weight % equals 15.6% of the magnetically treated composite sample.

Virtually, in the process of wet gravity concentration to obtain the majority of economic minerals within the tabled concentrate with a recovery ranging between 90-95%, some of the gangue silicates must be cutted and taken within the tabled concentrate. In fact, there are small

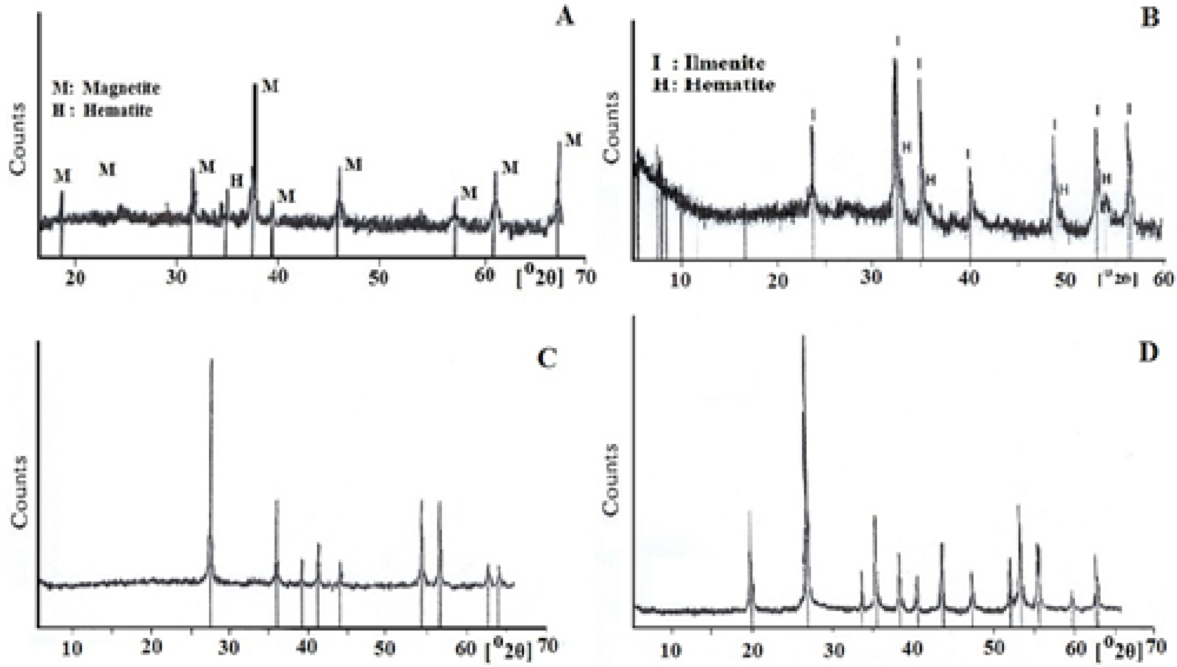

Figure 5. X-ray diffractograms of magnetite grains (A), ilmenite grains (B), rutile grains (C), and zircon grains (D).

differences in specific gravities between some of detected economic minerals, especially magnetite, and some of the associated gangue minerals (sp. gr. ranges between 3-3.6). However, to obtain the economic minerals in recovery values more than 90%, the tabled concentrate must contaminated with some of the relatively lighter gangue minerals. The obtained tabled concentrate; containing most of economic minerals (especially magnetite), was dried and weighed.

The obtained tabled concentrate weighs 81.5 grams. The contained gangue minerals in the table concentrate is about 10%. For such tabled concentrate a circuit of wet low intensity magnetic separation can be suggested to obtain the essential ferromagnetic mineral component in a definite magnetic fraction. The mineability to concentrate and separate Ilmenite requires more detailed study to investigate average grade and quality of the mineral.

4. Discussion: Importance of the Study

In this study, several economic minerals associated with sediments of Wadi Arar detectable; such as: magnetite, titanium minerals (Ilmenite and rutile) and zircon. Generally, these economic minerals can be contributed in industrial sectors essentially to achieve Kingdom of Saudi Arabia's vision 2030 (KAS's vision 2030) successfully.

The mineralogical investigation of surficial sediments reflects the occurrence of some important economic minerals as iron and titanium. Magnetite is a major in iron ore and steelmaking industry. It can be used as a dense medium in mineral separation processes.

Titanium minerals (Ilmenite and rutile); both Ilmenite and rutile are used for the production of titanium. The advantages of titanium metal over the others are high strength in relation to its density, resistance to corrosion, ability to retain its properties from 300°F to 1000°F. Titanium metal is used in military aircraft and in missiles. It is particularly outstanding in its resistance to sea water. Because of its excellent corrosion resistance it is used as a material of construction for industrial application when high corrosion resistance, higher operating temperature and production purity are required. Titanium forms extremely hard metallic compounds with carbon, silicon, nitrogen and boron. These are used as tips for cutting tools and in abrasive stones and wheels. Titanium dioxide is used as a opacifier in porcelain enamels on steel sheet for refrigerators, sanitary ware, etc. Ceramic titanates are used in electric industry. Both Ilmenite and rutile are now extensively used in the paint industry as well as in the rubber, plastic, paper, textile and ceramic industries[12,14].

Ilmenite is mainly used for the manufacture of titanium dioxide white pigment which is the whitest of all white pigments known today. Such pigment is more stable than all others, being entirely unaffected by acids or alkalis that dissolve and destroy other whites. It has good ability to maintain its visual appearance for a considerable period of time. It is stable up to 1800° C. Rutile is mainly used in the manufacture of arc-welding electrodes, for the production of titanium dioxide electrodes and as coating materials ill tile in ship-building and other structural steel for which there is a growing demand[14].

They stated that "The three principal zircon based industries are refractories, foundries and ceramics[15]. For many years the foundry market dominated the use of zircon sand where it was used in molds and shall cores. Zircon flour also becomes important to the foundry market. In addition, zircon sand was important to the glass industry where it was used in making refractory bricks for furnace living. Owing to its chemical inertness, good heat conductivity, high specific gravity, low expansion, good resistance to abrasion, high melting point and not showing any shrinkage on being heated up to l,750° C, zircon is an outstanding refractory mineral. Another traditional usage is in the ceramic industry, where finely milled material is applied to glazes and its high refractive index utilized to good effect for pacification purposes".

Zircon sands bonded into bricks are also used as refractory bricks in glass and aluminum industries where it has special properties *pf* resistance to spalling and wetting by glass and aluminum[15]. Approximately 95% of zirconium is consumed in the form of zircon, zirconium dioxide, or other zirconium compounds. About 40% is used chiefly for facings on foundiy moulds; about *25%* in fused cast and bonded refractories; 10% in abrasives; and about *25%* in ceramics, alloy metals, and chemicals. Zirconium offers excellent corrosion resistance and, consequently, is widely used in chemical process equipment, reactor vessels, and aerospace engineering. In particular, in the nuclear industry zirconium in the form of zircaloy has yet to find a competitor as a cladding and structural material in water-cooled, pressurised, and boiling water type nuclear reactors[13].

The Kingdom of Saudi Arabia's vision 2030 can be able to reduce the dependent on oil income through other sector such as mining and minerals exploration, to share the country's growth and development through KSA's vision 2030. This study shows that it is both possible and essential to strengthen the contribution of minerals exploration in the Northern Border region to expand national economy through investment, exports, employment associated, creative new working plans, increase foreigner exchange, new quality and quantity products (minerals & goods) with mining sector for KSA's vision 2030 achievement to sustainable development and growth.

5. Conclusions

Wadi Arar is one of several main wadies in the Northern Border Region at the Kingdom of Saudi Arabia. The mineralogical investigation of surficial sediments reflects the occurrence of some important economic minerals as iron and titanium. The occurrence of magnetite and Ilmenite economic minerals in definite grain size classes of the friable surficial sediments particularly fine and very fine sand sizes facilitate and simply the used flow sheet for concentrating and separating such economic minerals. Also, the overall costs of extracting these minerals will be diminished. The recorded economic minerals are considered the first attempt to investigate the economic value of Wadi Arar. This study shows that it is both possible and essential to strengthen the contribution of minerals exploration in the Northern Border region to expand national economy through investment, exports, employment associated with mining sector for KSA's vision 2030 achievement to sustainable development. The results provided valuable recommendations for additional plans to determine possibilities of rare minerals occurrence in the area that can contribute in KAS's 2030 vision.

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7. References

1. Al-Safarjalani AM. Placer gold deposits in the Hofuf Formation, the Eastern Province of Saudi Arabia. King Faisal University, Faculty of Agriculture, Department of Soil and Water, Saudi Arabia. Research Project; 2004. p. 1–101.
2. The Ministry of Municipal and Rural Affairs. Public administration to coordinate projects. Deputy Ministry for Urban Planning, Kingdom of Saudi Arabia; 2012.
3. Al-Khattabi AF, Dini SM, Wallace CA, Banakhar AS, Al-Kaff MH, Al-Zahrani AM. Geological map of the Arar Quadrangle Sheet 30, Saudi Geological Survey, Kingdom of Saudi Arabia; 2010.
4. Soliman MAM, Alsubhi MB. Geological and structural studies on Jabal Daf-Jabal Abu Bakr Area, Wadi Fatima. Master Thesis in Applied Geology. Faculty of Earth Sciences - Structural Geology and Remote Sensing. Kingdom of Saudi Arabia; 2012.
5. Strakhov NM, Bushinskii GI, Pustovalov LV. MetodyIzocheniya Ocadochnykh Porod, Tom I" (Methods of Studying Sedimentary Rocks) [M]. Moskva; 1957. p. 611.
6. Milton DI. Geology of the Arabian Peninsula: Kuwait. Professional Paper, 560-F. USGS Numbered Series; 1967. p. 1–7.
7. McClure HA, Khali AAR, AI-Sayari SS, Zöetl JG. Quaternary period in Saudi Arabia. Springer-Verlag, New York; 1978. p. 252–63. https://doi.org/10.1007/978-3-7091-8494-3_11.
8. Anton D. Aspects of geomorphological evolution: Paleosols and dunes in Saudi Arabia. Quaternary Period in Saudi Arabia. Springer-Verlag, New York; 1984. 2:275–94.
9. Hoetzl H, Zöetl JG. Middle and Early Pleistocene. Quaternary Period in Saudi Arabia. Springer-Verlag, New York; 1984. 2:333–49.
10. Alghamdi M, Hegazy A. Physical properties of soil sediment in Wadi Arar, Kingdom of Saudi Arabia, International Journal of Civil Engineering. 2013; 2(5):1–8.
11. Moustafa MI, Hegab OA, El Agami NL. Remarks on the physical, mineralogical features and amenability of separation of rare accessory minerals from the black sands of

the northern coast of Egypt, Egyptian Mineralogist; 2000. 12:29–49.

12. Padmanabhan NPH, Sreenivas T, Kao NK. Processing of ores of titanium, zirconium, hafnium, niobium, tantalum, molybdenum, rhenium and tungsten: international trends and the Indian scene, High Temperature Materials and Processes. 1990; 9(2-4):217–47. https://doi.org/10.1515/HTMP.1990.9.2-4.217.
13. Moustafa MI. Investigations of some physical properties of zircon and rutile to prepare high purity mineral concentrates from black sand deposits, Rosetta, Egypt. M.Sc. Thesis, Faculty of Science University Egypt; 1995.
14. Sinha RK. Industrial minerals. IBH Publishing Co & New Delhi Oxford; 1982.
15. Bashir VS. Zircon sand and its application in ceramic industry, Saket Industrial Digest. 1996; 2(6):23–28.