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Geochemical and Mineralogical Characters of the Coastal Plain Sediments of the Arabian Gulf, Kuwait

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Abstract

The present study deals with detailed geochemical and mineralogical studies of the coastal plain sediments formed along the shoreline of the Arabian Gulf area, Kuwait. These deposits are mainly fluviomarine and beach sands.

The coastal plain deposits of the central Kuwait shoreline zone were found to consist of average medium-grained sand. The sand composed, on average of about 90% sand, and about 10% or less is mud, and has a unimodal distribution with a mode of medium sand (1-2 ф). The sediments consists mainly quartz, Feldspar, clay minerals with carbonate minerals (detritus calcite and dolomite) and rock fragments (chart). The mineralogy of the clay fractions of the sediments is dominated by illite, palygorskite, mixed layer illite-montmorillonite with minor amounts of chlorite and Kaolinite. Heavy minerals are concentrated in the very fine sand fraction and are dominated by opaque minerals, and non opaque minerals which represented by amphiboles, pyroxenes, epidotes, dolomite, zircon, tourmaline, rutile, garnet and other which represented by Staurolite, Kyanite, Andalusite and Sillimenite as a trace amounts. The chemical analysis for the detrital amphibole grains from sandstone of coastal plain sediments shows the following features; the grains which have (Na + K) <0.50 its composition ranges from actino hornblende to magnesio hornblende, but the grains which have (Na + K) >0.50 its composition have wide variation and on the (Na + K) -Al_{IV} diagram can be characterized two association: Association 1 which characterized by low amount of Al_{IV} and low amount of (Na + K), by comparing the chemical composition of this association and the chemical composition of amphibole grains from older basement rock, can, these association may be derived from metamorphic source rocks and association 2 which characterized by high amount of Al_{IV} and low amount of (Na + K), which may be derived from volcanic source rocks.

Keywords: Coastal area; Heavy minerals; fluviomarine sediments; clay minerals; Chemical Composition; Electro probe micro analyzer (EPMA)

Introduction

The state of Kuwait is located in the northern corner of the Arabian Gulf, between Longitudes 46°30′ and 48°30′ East and Latitudes 28°30′ and 30°08′ north. The Arabian Gulf is a marginal sea measuring some 1,000 km in length and 200-300 km in width covering an area of approximately 226,000 km^2 .the entire basin lies upon the continental shelf whose margin and slope occur in the Gulf of Oman. At the head of the Gulf is the Tigris- Euphrates delta which extends for about 100 km seaward from the river mouth, covering most of the northern half of the Kuwait offshore area [1]. The Gulf is flanked by the low lying Arabian coast on the west and mountainous Iranian coast on the east [2]. The Arabian Gulf is a large shallow marginal sea trending NW-SE, and separated from the Arabian Sea of the Indian Ocean by the Straits of Hormuz. It is bordered by the Arabian Peninsula in the south and west, by Iraq in the north and Iran on the east. The floor of the Arabian Gulf basin is asymmetric, sloping gently on the Arabian side and steeply on the Iranian flank. Consequently, its axis, which has an average depth of about 35m, lies closer to the Iranian coast. The floor of the Arabian Gulf basin slopes gradually from the shallow deltic northern part to deeper waters in the south, where it reaches more than 100m at the Straits of Hormuz [3]. Extensive intertidal flats occur in the northwestern part of the Arabian Gulf, fronting the estuarine plain of Shatt-al-Arab and along the coast of Kuwait. The intertidal – flat area of Kuwait can be divided into two main provinces, namely: Kuwait Bay province at the north and the southern Kuwait coastal area province. Kuwait Bay province is a shallow tide-dominated sheltered environment, with very flat bottom topography. It has an extensive intertidal flat, covered mainly by muddy sediments [4]. The southern coastal province, extending from Ras al Ard to the southern border of Kuwait, the intertidal zone is narrow and is covered mainly by sand deposits. The present studied area lies in the southern province. The Quaternary history of the area was affected mainly by climatic changes and weathering. These are all clear from the exposure of the Pleistocene and Holocene coastal ridges that composed of calcareous sandstone [5]. The marine area of Kuwait, in the north-western corner of the Arabian Gulf was almost completely exposed about 10,000 yr BP [6]. A review of the Holocene geological history of the Tigris-Euphrates-Karun delta [1] and the structural evolution of the Arabian Gulf [7], revealed that the northern half of the area offshore from Kuwait is an integral part of the ancient delta which is presently submerged in the northern part of the Gulf. Several studies have examined the sediment logical aspects of the coastal area of Kuwait and the northern Gulf [3,8-13]. Hilmy et al. [8] investigated the mineralogy and fabrics of the opaque mineral grains in Kuwait beach sediments and discusses their possible sources. Emery [14] investigated the marine geology of the entire Gulf and discussed its water characteristics. Sugden [15] reviewed certain aspects of Arabian Gulf sedimentation with particular emphasis on shallow water along the Saudi Arabian shore. Khalaf [4] studied the sediment logical characteristics of the recent intertidal flat sediments of Kuwait. This study attempts to use the geochemical and XRF analysis of major and trace elements forming the recent sediments of coastal plain deposits of Kuwait to gain a better understanding of their sources,

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transportation and deposition. Three main sources are suggested for the intertidal sediments of Kuwait according to [16].

- Shatt-al-Arab fluviatile deposits,
- Aeolian dust fallout, and
- Direct chemical and biogenic precipitation from the Gulf water.

Sampling and Analytical procedures

Thirty samples were collected from the sediments of shoreline coastal plain area at five locations (Shuwaikh - Ras Al-Ard – Al Beda –Fahaheel and Mina Abdulla) which lie between the shuwaikh area in north to Mina Abdulla area in south (Figure 1). Samples were taken from the top 5cm of the sediments. Each of the samples was split into two parts; one part was air dried and used for grains size analysis using standard sieve and sedimentation technique [17].

The second portion of each sample was used light and heavy mineral separation and microscopic identification. The fractions are spilled on a separation funnel full of a specific gravity of 2.86 bromoform. The heavy minerals were collected on the filter paper and washed by Ethyl Alcohol and dried. While the lighter ones were collected on another filter paper and washed by Ethyl Alcohol. The heavy fractions were subjected to magnetic separation which separates the heavy fraction into: magnetic minerals and non-magnetic minerals. The magnetic minerals fraction includes magnetite and ilmenite. In general, the average percentage of non-magnetic minerals increases with decreases of size fraction (0.125-0.0625 mm fraction) whereas the magnetic fraction of magnetite and ilmenite minerals is highly concentrated in the size 0.250-0.125 mm size fraction. To carry out the identification of clay mineralogy seven samples were collected from the muddy intertidal sediments at five locations. The clay size fraction 4-2μm was separated by means of sedimentation method. A suction-onto-ceramic disc method [18] was used for the preparation of oriented clay samples for X-ray diffraction analysis. The analysis was carried out on a powder diffract meter using nickel-filter Cu-K radiation. The identification of clay minerals involved the standard pre-treatments of glyceration and heating at 550°C. The semi-quantitative estimates of the relative amounts of clay minerals were calculated by the method suggested by [19].

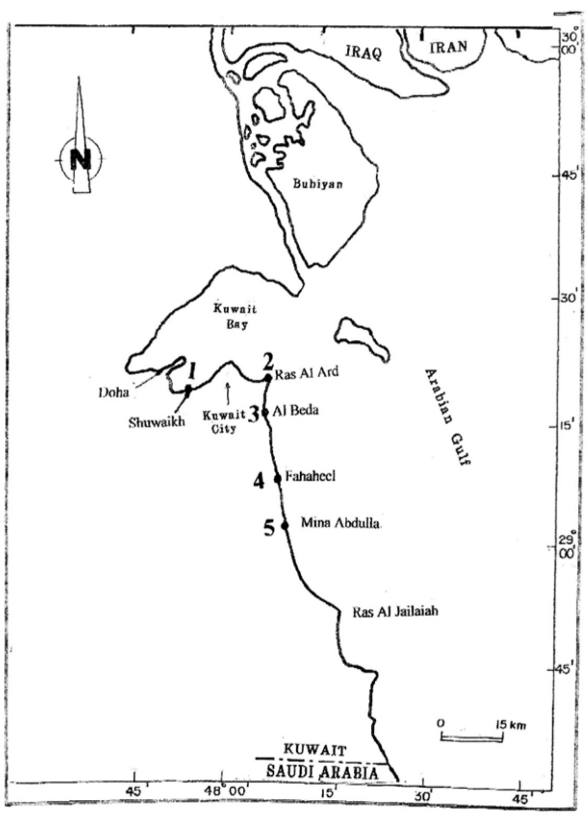

Figure 1: Coastal area and sampling localities are shown by numbering points.

Results

Textural classes

Grain-size distribution:

General feature: The statistical parameters of grain size distribution are summarized in Table 1. The statistical grain-size parameters were computed by moment method. The distribution is generally uni-modal with a mode of medium sand sized (1-2ϕ). From Table 1, it can be noted that the mean (M_Z) and the median (M_d) diameters are nearly identical in each samples. The average difference between M_Z and M_d ranges from - 0.07 to 0.91 ϕ and 0.42 ϕ .These sediments range in grains size from coarse sand to fine sand , moderately sorted to poorly sorted, and Strongly coarse skewed to strongly fine skewed. It is considered that the grain-size distribution of sandstones is strongly affected not only by the abundance of coarse-sized grains but also that of fine grains from silt to clay-sized. This feature may be responsible for the difference between the data noticed by naked eye in the field and the data obtained by grain size analysis technique.

Sandstone petrography

Light minerals:

Main constitutes: Sandstone from the coastal plain deposits mainly consists of Carbonates, quartz, feldspars, rock fragments, with matrix, cement and heavy minerals. The argillaceous matrix smaller than 30μm ranges 4.4 to 8.7 %. The cement composed of silica or carbonate ranges 5.1 to 8.5 %.

- **Carbonates:** The frequency ranges of carbonate grains in the fine sand ranges from 40.3% to 44.5% of the total light minerals. Carbonate grains are mainly represented by detrital calcite and biogenic grains. The detrital calcite was found to be in the form of sub-rounded to round. The micritic calcite grains are thought to be produced as a result of mechanical breakdown of the micritic envelopes of recent shell fragments [2].
- **Quartz:** The framework of the sandstone is made up of quartz grains and its frequency ranges from 22.0% to 39.6% of the total mineral composition. Quartz change from course to very fine-grained in size and the majority is medium grained. The roundness of quartz grains range from sub-angular to sub-round and the most abundant is sub-rounded. Based on the type of extinction and singularity of the quartz grains, and according to the empirical classification of quartz given by Folk [20], three distinct varieties were observed as follows:

1. Mono quartz with straight extinction,
2. Mono quartz with various degrees of wavy extinction,

Location	Sample No.	Median (M_d)	Mean (M_z)	Sorting (σ_I)	Skewness (Sk_I)	M_z - M_d
I-Shuwaikh (SH)	1	0.60	0.85	1.18	-0.24	0.72
	2	2.00	1.93	1.34	0.43	-0.07
	3	0.20	0.63	1.54	-0.44	0.43
	4	1.89	1.97	1.55	0.19	0.08
	5	1.70	1.73	1.39	0.03	0.03
	6	2.08	2.99	1.80	0.87	0.91
Average		1.41	1.68	1.47	0.14	0.35
II- Ras Al Ard (RA)	7	2.30	1.73	1.86	-0.27	-0.60
	8	0.30	0.60	1.70	0.27	0.30
	9	2.00	2.03	1.43	0.19	0.03
	10	1.80	1.88	0.42	0.09	0.08
	11	1.30	1.51	0.27	0.17	0.21
	12	1.89	1.97	1.55	-0.29	0.08
Average		1.60	1.62	1.21	0.03	0.02
III- Al Beda (AB)	13	1.30	1.00	1.34	-0.30	0.61
	14	1.16	2.57	1.68	-0.03	0.41
	15	1.50	1.58	0.43	-0.07	0.08
	16	2.00	2.77	1.53	0.76	0.77
	17	2.01	2.54	1.99	-0.07	0.53
	18	1.80	1.83	1.21	0.41	0.03
Average		1.63	2.05	1.36	0.12	0.41
IV- Fahaheel (FA)	19	1.70	2.07	1.63	0.19	0.37
	20	2.33	2.23	0.28	-0.07	-0.10
	21	1.98	1.96	0.41	0.09	-0.02
	22	2.40	2.37	1.29	-0.11	0.03
	23	1.71	1.98	1.88	-0.90	0.27
	24	1.93	1.55	1.14	0.09	-0.01
Average		2.01	2.03	1.11	-0.12	0.09
V-Mina Abdulla (MA)	25	1.84	2.61	1.58	0.59	0.77
	26	1.70	1.60	0.41	0.06	-0.10
	27	1.52	1.88	0.35	-0.07	0.36
	28	2.30	1.97	1.63	-0.29	-0.33
	29	2.43	2.16	0.75	-0.52	-0.27
	30	1.76	2.12	1.58	0.07	0.36
Average		1.93	2.06	1.09	-0.03	0.13

M_d -median
M_z - mean size
σ_I - graphic standard deviation
Sk_I - Skewness

Table 1: Statistic parameters of grain size distribution of coastal plain sediments.

3. Poly quartz composed of interlocked aggregates (two or more) of sub individual quartz crystals with different orientation and have straight to slightly undulate extinction. The poly quartz grains may contain either strained or unstrained quartz crystals or both.

- **Feldspars:** Feldspars are the third dominant detrital mineral. The maximum percentage of feldspar grains may reach up to 18.1% of the total framework. The distinction between small untwined K-feldspar grains and quartz grains is not easy under microscope. Therefore, K-feldspar grains detected by chemical staining method involved a reaction which produces a colored precipitate on a specific mineral surface [21].

As a result, K-feldspar (orthoclase and micro cline) grains were easily recognized. The roundness of feldspars grains range from sub-rounded to round. Many of the grains, especially of plagioclase, show dirty surface by alteration to kaolinite and calcareous matters. The frequency percentage of feldspars may reach up to 15.5%.

- **Rock fragments:** Rock fragments are not common constituents, and range from 5.1% to 8.3% of the total framework of sandstone samples. Fragments of chart and gypsum, calcite grains were found in a small amount of light minerals. Fragments of sedimentary rocks such as sandstone and shale, muscovite and chlorite are also included.

Heavy minerals: Heavy minerals generally constitute a small part of the sand fractions and range from 8.3% to 13.9% averaging about 11.1%. Heavy minerals are treated as opaques and non-opaques.

- **Opaque heavy minerals:** This group is the dominant constituent of the heavy minerals recorded represented mainly by iron oxides of hematite, ilmenite, magnetite, pyrite and spinel. They constitute about 22.8% of the heavy minerals fraction.

- **Non-opaque minerals:** The non-opaques are the most useful in genetic interpretations, so they are recalculated to the total 100%; excluding micas and altered minerals and the opaque minerals.

It is evident from Table 2 that amphibole, pyoxenes and epidotes constitute averaging 62% of the non-opaque heavy minerals.

- **Amphiboles:** Amphiboles are the most frequent heavy mineral group with percentages ranging from 18.7% to 30.8%. Hornblende is the most abundant mineral in this group. Amphibole grains are sub-rounded to round. Some of grains show dirty surface by weathering.

- **Pyroxenes:** These are the second most abundant mineral group and are found in most samples examined. It ranging between

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Sample No.	Dolomite	Opaque	Non Opaque	Non Opaque							
				Amphibole	Pyroxene	Epidote	Zircon	Tourmaline	Rutile	Garnet	Mica	Others
Shuwaikh												
SH-1	8.2	14.6	76.8	21.5	12.0	9.3	5.4	4.0	1.6	8.8	3.1	2.5
SH-4	10.0	13.8	76.2	28.9	15.1	10.8	6.1	2.2	0.9	9.3	2.2	2.2
SH-6	13.1	10.5	76.4	19.0	18.7	4.6	8.2	3.5	-	3.9	1.5	1.3
Ras Al Ard												
RA-7	12.9	11.6	75.5	18.7	11.1	11.4	5.9	0.9	1.1	6.8	4.2	2.4
RA-9	10.6	18.4	71.0	21.0	17.9	8.0	7.4	1.8	1.5	10.1	3.1	1.1
RA-12	6.9	14.9	78.2	22.2	21.3	6.5	3.8	2.9	0.5	7.7	1.9	1.9
Al Beda												
AB-14	15.2	21.1	63.7	21.6	13.8	5.1	3.3	2.3	0.8	5.1	3.9	2.0
AB-16	11.4	17.7	70.9	25.2	16.2	10.2	4.9	2.5	-	9.2	2.0	2.3
AB-18	15.6	18.9	65.5	22.5	15.4	11.2	1.5	1.3	-	4.0	3.5	2.0
Fahaheel												
FA-20	9.9	21.5	68.6	25.3	24.5	6.9	1.8	1.1	0.7	8.7	5.0	0.9
FA-22	13.5	15.6	70.9	22.4	20.1	8.2	4.4	2.3	0.5	11.5	2.7	1.1
FA-25	13.9	22.8	63.3	30.8	25.0	8.9	2.0	0.9	-	5.0	4.4	2.3
Mina Abdulla												
MA-24	14.9	19.9	65.2	18.9	23.1	12.1	5.5	3.1	0.5	6.2	5.7	1.6
MA-25	8.1	16.4	75.5	19.6	24.9	9.6	3.5	1.8	0.1	4.3	4.9	1.3
Average	11.7	17.0	71.3	22.7	18.5	8.8	4.6	2.2	0.9	7.2	3.4	1.8

Others = Staurolite, Kyanite, Andalusite and Sillimenite

Table 2: Frequency percentages of heavy minerals in the coastal plain sediments.

11.1% and reaches up to 25% Pyroxenes are represented by both monoclinic (augite and diopside) and rhombic (hyperthene and enstatite) types. Augite is the most common and includes two varieties; the greenish yellow and the brownish violet. Pyroxene grains usually occur as euhedral to subhedral prismatic crystals with smooth sub-rounded to round terminations.

- **Epidotes:** Occur in all samples studied and represented essentially by pistachite: zoisite and clinozoisite are less common. Pistachite is the main constituents of this group. Epidotes usually found in appreciable amounts, with average relative frequencies of 4.6% to 12.1%. They are represented mainly bythe subhedral greenish pistachite variety, with a few colorless, angular to subangularzoisite grains.
- **Zircon:** Zircon is also present in considerable amounts, averaging about 4.6% of the heavy fraction. It occurs mostly in colorless and rounded to sub-rounded grains. Some grains contain minute inclusions of opaques. It is a radioactive bearing element and has some admixture of Fe, Ca, Ti and Ni. Zircon grains are almost prismatic in shape, with sub-rounded terminations.
- **Tourmaline:** Tourmalines were only positively identified in all of the analyzed samples with maximum frequency percentages of 4.0%. It recorded in two varieties, brown and blue. The brown variety is the most abundant.Tourmaline grains are mostly sub-rounded.
- **Rutile:** Rutiles are represented by subhedral prismatic grains. Two varieties of rutile have been recognized; foxy red and yellow.
- **Garnet:** Garnet is recorded in most abundant in all samples and its average frequency percentage is about range 7.2%.Two varieties of garnets have been encountered; colorless, reddish brown and pinkish grains.
- **Dolomite:** Dolomite occurs in considerable amounts in the heavy fraction of the studied sediments. It is commonly present as irregular to sub-rounded grains with varying degrees of roundness. Rhombohedral dolomite was also recorded with black cores, which indicates entrapment of mud particles during the early digenetic stages of these grains. Its average frequency percentage is from 6.9% to 15.6%.
- **Mica:** Mica represented by muscovite, chlorite, and biotite. Both muscovite and chlorite occur abundantly, biotite was less frequency. Grains form about 3.4% of the heavy minerals and occur as irregular flaky grains and slightly rounded.
- **Others:** All the transparent heavy minerals which occur in trace quantities in the sediments were included under the heading “other”. These include: Staurolite, Kyanite, andalusite and sillimenite.

Chemical Composition of Amphibole

The amphiboles are such a variable group that an accurate determination of their compositional range in sediment requires the analysis of a large number of grains. Even so, electron microprobe studies of detrital amphibole can be fruitful. Mange-Rajetsky and Oberhanshi [22] demonstrated a stratigraphic trend in amphibole compositions in the Molasse of Savoy (France) which they related to progressive metamorphism of the developing Alpine source area. Morton [23] distinguished two amphibole populations in the early palaeogene sediments of the south-west Rockall plateau (NE Atlantic) on the basis of variations in Si, Mg/(Mg + Fe) and (Na + K). Twenty five amphibole grains from coastal plain deposits of the studies area were analyzed by EPMA. The amount of each element was calculated on the basis of numbers of ions of 23 Oxygen Table 3. The chemical composition data were plotted on the classification diagram by Leake [24] to differentiate the variety of the amphiboles from sandstone of coastal plain deposits. The basis which used in this classification are the variation in Si, Mg/ (Mg + Fe) and (Na + K). On this basis, there are two groups of amphibole grains, one which have (Na + K) less than 0.50 and other which have (Na + K) more than or equal to 0.50. Also from the chemical composition of amphibole grains from studied samples, the grains which have (Na + K) less than 0.50, its composition

Sample No.	SH-2	SH-2	SH-2	SH-2	SH-2	SH-2	RA-11	RA-11	RA-11	RA-11
Point No.	1	2	3	4	5	6	1	2	3	4
SiO_2	47.5	50.87	40.68	43.12	44.07	44.61	43.48	45.00	42.42	44.23
TiO_2	0.11	0	1.53	3.25	3.32	1.4	1.79	2.34	1.77	1.37
Al_2O_3	5.33	3.46	14.23	12.24	11.09	7.8	8.71	11.00	9.57	9.26
Cr_2O_3	-	-	-	-	-	-	-	-	-	-
FeO	24.59	22.9	11.11	12.08	11.36	24.86	25.23	13.46	25.79	23.52
MnO	0.51	-	-	0.11	0.1	0.54	0.29	0.2	0.53	1.11
MgO	19.51	21.18	13.86	13.47	13.93	6.23	5.79	12.69	4.49	6.38
CaO	0.68	0.68	12.61	11.35	11.87	10.52	10.22	11.26	10.74	10.66
Na_2O	0.07	-	3.75	2.37	2.09	1.8	1.94	1.7	1.6	0.99
K_2O	0.01	-	1.2	0.55	0.73	0.95	0.95	0.64	1.15	1.13
Total	**98.31**	**99.09**	**98.97**	**98.54**	**98.56**	**98.71**	**98.4**	**98.29**	**98.06**	**98.65**
A	2.587	2.651	2.608	2.627	2.635	2.484	2.471	2.620	2.445	2.498
OX.No.	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000
Si	7.027	7.344	5.972	6.283	6.403	6.874	6.736	6.574	6.641	6.777
Ti	0.012	0.000	0.169	0.356	0.363	0.162	0.209	0.257	0.208	0.158
Al	0.929	0.589	2.462	2.102	1.899	1.416	1.590	1.894	1.766	1.672
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	3.042	2.765	1.364	1.472	1.380	3.203	3.269	1.645	3.376	3.014
Mn	0.064	0.000	0.000	0.014	0.012	0.070	0.038	0.025	0.070	0.144
Mg	4.302	4.558	3.033	2.925	3.017	1.431	1.337	2.763	1.048	1.457
Ca	0.108	0.105	1.983	1.772	1.848	1.737	1.696	1.763	1.801	1.750
Na	0.020	0.000	1.067	0.670	0.589	0.538	0.583	0.482	0.485	0.294
K	0.002	0.000	0.225	0.102	0.135	0.187	0.188	0.119	0.230	0.221
Al(4+)	0.973	0.656	2.028	1.717	1.597	1.126	1.264	1.426	1.359	1.223
Al(6+)	-0.043	-0.067	0.434	0.385	0.302	0.290	0.326	0.469	0.406	0.449
Mg/Mg+Fe	0.586	0.622	0.690	0.665	0.686	0.309	0.290	0.627	0.237	0.326
Na+K	0.022	0.000	1.292	0.772	0.724	0.724	0.770	0.601	0.715	0.515

Sample No.	RA-11	RA-11	AB-15	AB-15	AB-15	AB-15	AB-15	AB-15	FA-22	FA-22
Point No.	5	6	1	2	3	4	5	6	1	2
SiO_2	43.9	43.56	41.16	40.92	42.49	43.12	42.2	43.09	42.18	43.23
TiO_2	2.01	1.41	1.51	1.99	0.9	1.66	1.62	1.48	1.69	1.71
Al_2O_3	8.59	10.44	11.01	10.56	10.82	10.11	10.36	10.32	10.64	9.78
Cr_2O_3	-	-	-	-	-	-	-	-	-	-
FeO	23.27	20.36	22.06	27.56	23.6	23.84	24.7	19.91	24.16	24.34
MnO	0.48	0.54	0.55	0.66	0.65	0.74	0.87	0.47	0.69	0.7
MgO	6.75	8.26	7.30	3.48	6.3	5.8	5.32	9.23	5.27	5.79
CaO	10.63	10.69	11.39	10.39	11.08	11.2	10.92	11.6	11.01	10.56
Na_2O	1.74	1.48	1.57	1.52	1.19	1.16	1.33	1.34	1.45	1.26
K_2O	1.08	1.26	1.47	1.26	1.22	1.04	1.19	1.04	1.1	0.89
Total	**98.45**	**98.00**	**98.02**	**98.34**	**98.25**	**98.67**	**98.51**	**98.48**	**98.19**	**98.26**
A	2.492	2.516	2.472	2.425	2.479	2.490	2.467	2.527	2.468	2.480
OX.No.	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000
Si	6.745	6.627	6.374	6.459	6.561	6.629	6.548	6.527	6.544	6.673
Ti	0.232	0.161	0.176	0.236	0.105	0.192	0.189	0.169	0.197	0.198
Al	1.555	1.872	2.010	1.965	1.969	1.832	1.895	1.842	1.945	1.779
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	2.990	2.590	2.857	3.638	3.048	3.065	3.205	2.522	3.134	3.142
Mn	0.062	0.070	0.072	0.088	0.085	0.096	0.114	0.060	0.091	0.092
Mg	1.545	1.873	1.685	0.819	1.450	1.329	1.230	2.084	1.219	1.332
Ca	1.750	1.742	1.890	1.757	1.833	1.845	1.815	1.883	1.830	1.746
Na	0.518	0.437	0.471	0.465	0.356	0.346	0.400	0.394	0.436	0.377
K	0.212	0.245	0.290	0.254	0.240	0.204	0.236	0.201	0.218	0.175
Al(4+)	1.255	1.373	1.626	1.541	1.439	1.371	1.452	1.473	1.456	1.327
Al(6+)	0.300	0.499	0.384	0.424	0.531	0.461	0.443	0.369	0.489	0.452
Mg/Mg+Fe	0.341	0.420	0.371	0.184	0.322	0.302	0.277	0.452	0.280	0.298
Na+K	0.730	0.681	0.762	0.719	0.597	0.550	0.636	0.594	0.654	0.552

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Sample No.	FA-22	FA-22	FA-22	FA-22	MA-27	MA-27	MA-27	MA-27	MA-27	MA-27
Point No.	3	4	5	6	1	2	3	4	5	6
SiO_2	40.5	41.45	39.83	42.06	37.72	38.15	43.5	46.49	41.73	40.92
TiO_2	1.48	0.66	0.47	0.77	0.92	0.92	0.61	0.99	1.46	2.03
Al_2O_3	10.84	15.33	16.6	13.48	21.37	21.03	13.3	7.13	10.95	11.36
Cr_2O_3	-	-	-	-	-	-	-	-	-	-
FeO	26.5	11.37	13.06	16.2	18.13	18.00	14.53	17.65	22.36	24.36
MnO	0.72	0.35	0.21	0.46	0.45	0.47	0.44	0.36	0.62	0.71
MgO	4.6	13.16	11.56	10.18	5.39	5.04	11.02	12.86	6.84	4.87
CaO	10.83	11.8	12.63	10.07	9.7	9.29	10.88	10.52	10.88	10.64
Na_2O	1.56	3.79	3.94	4.89	5.51	5.44	4.42	1.3	1.54	1.7
K_2O	1.32	0.15	0.11	0.21	0.29	0.31	0.25	0.3	1.32	1.27
Total	**98.35**	**98.06**	**98.41**	**98.32**	**99.48**	**98.65**	**98.95**	**97.60**	**97.7**	**97.86**
A	2.430	2.610	2.587	2.561	2.565	2.551	2.604	2.564	2.470	2.448
OX.No.	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000	23.000
Si	6.381	6.079	5.893	6.286	5.630	5.726	6.394	6.942	6.466	6.400
Ti	0.175	0.073	0.052	0.087	0.103	0.104	0.067	0.111	0.170	0.239
Al	2.013	2.650	2.894	2.375	3.759	3.720	2.304	1.255	2.000	2.094
Cr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	3.492	1.395	1.616	2.025	2.263	2.259	1.786	2.204	2.898	3.186
Mn	0.096	0.043	0.026	0.058	0.057	0.060	0.055	0.046	0.081	0.094
Mg	1.080	2.877	2.549	2.268	1.199	1.127	2.414	2.862	1.580	1.135
Ca	1.828	1.854	2.002	1.613	1.551	1.494	1.713	1.683	1.806	1.783
Na	0.477	1.078	1.130	1.417	1.594	1.583	1.260	0.376	0.463	0.515
K	0.265	0.028	0.021	0.040	0.055	0.059	0.047	0.057	0.261	0.253
Al(4+)	1.619	1.921	2.107	1.714	2.370	2.274	1.606	1.058	1.534	1.600
Al(6+)	0.394	0.729	0.787	0.661	1.389	1.445	0.698	0.197	0.466	0.493
Mg/Mg+Fe	0.236	0.674	0.612	0.528	0.346	0.333	0.575	0.565	0.353	0.263
Na+K	0.742	1.106	1.151	1.457	1.650	1.642	1.306	0.434	0.724	0.769

Table 3: Chemical composition of Amphiboles grains included in some sediments of Coastal plain deposits of Arabian Gulf, Kuwait.

ranges from actino-hornblende to magnesio-hornblende, the majority lies in the area of actino hornblende. The grains which have (Na + K) more than 0.50, its composition have wide variation from edenite, ferroedenite hornblende, paragasite hornblende, ferroenparagsite hornblende, paragasite to ferroanparagasite, but the majority lies in the area of variable paragasite Figure 2. On the (Na + K)-Al_{IV} diagram the chemical composition of the studied samples, can be divided into, two associations: Association A characterized by low amount of (Na + K) and low amount of Al_{IV} and association B characterized by high amount of Al_{IV} and low amount of (Na + K) (Figures 3 and 4). Figure 5 show photo-micrograph of amphibole grains in thin sections prepared for EPMA analysis from the studied samples.

Mineralogical Features of Argillaceous Matrix

Clay minerals are little distributed in the coastal plain sandstone deposits. These minerals which have been identified by means of thin section observations and X-ray diffraction pattern consists of large amounts of illite which is predominates in most samples, with a relative frequency ranging from 33% to 46% and averaging 39%. The basal X-ray reflection of illite is represented by a broad peak in the region between 10.0 A^0 and 10.3 A^0, which is sharpened and shifted to 10 A^0 after heating at 550^{0}C for one hour. This indicates that illite in the studied samples contains traces of expandable layer [25]. Palygorskite was found to represent the second most common clay mineral in the majority of the analyzed samples. Its percentages range from 25% to 34% with an average of about 29.9% of the clay mineral content. Palygorskite was identified on the basis of its main basal reflection at 10.5 A^0 and 6.4 A^0, which do not expand by glyceration, but collapse upon heat treatment. Illite-montmorillonite mixed layer mineral was identified in all the samples analyzed but the frequency was lower than the first and second minerals ranging between 19% - 26% and averaging 22%. Illite - montmorillonite is characterized by broad basal X-ray reflection at the 14 A^0- 18 A^0 regions in the glycerated samples, which is replaced by a sharp peak at 10 A^0 on heating at 550^{0}C for one hour. Samples were found to be relatively deficient in kaolinite and chlorite. The relative percentage of each mineral never exceeded 8% of the clay mineral, with an average of about 4.6% Table 4.

Discussion and Conclusions

Khalaf et al. [16,26] divided the intertidal area of Kuwait into two main environments;

1. The northern intertidal flat (Kuwait Bay and northern area), which is close to Shatt-al-Arab estuary and is considered as a sheltered low energy environment. This Northern Province is characterized by very extensive tidal mud flats and
2. The southern coastal area (south of Kuwait Bay), which is relatively far from Shatt-al-Arab estuary and is considered as an open-sea, high energy environment. The southern province on the other hand consists of a narrow sandy tidal flat in the north, which becomes boarder southward, and is characterized by the presence of coastal terraces.

The studied sediments and the Tigris-Euphrates Recent sediments [27] show some resemblance in their heavy mineral suite. It is evident, therefore, that the wind-borne sediments carried into the study area during dust storms are the primary contributor of dolomite. On the other hand, the classic heavy minerals are thought to have originated from the surface deposits of the areas lying to the north and to the west of Kuwaiti offshore zone and to have been transported to the study area as wind-borne and river-borne sediments [2]. The contribution

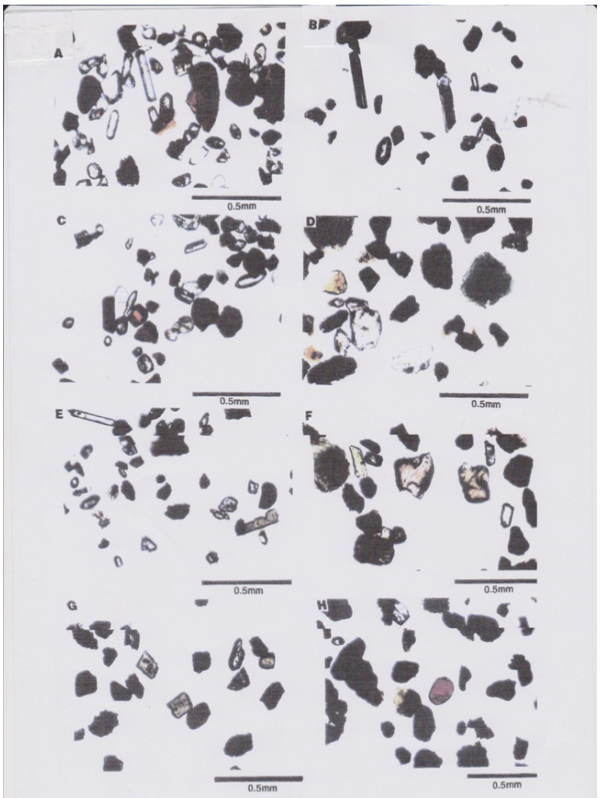

Figure 2: Photo-micrographs of heavy minerals in thin sections prepared for counting from the coastal plain sediments.

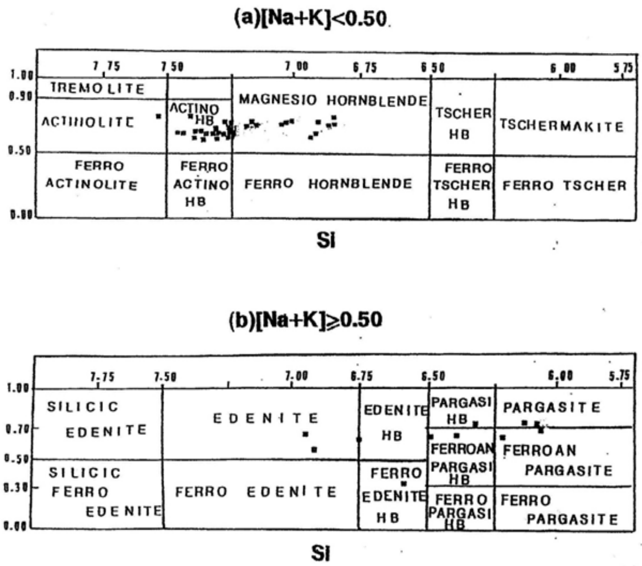

Figure 3: Showing the chemical composition of the amphiboles grains from the coastal plain sediments.

of dust fallout to the sediments of the Arabian Gulf has been reported in a number of previous studies. Sugden [15] estimated that one third of all Arabian Gulf sediments isaeolian in origin. Pilkey and Noble [28] and Kukal and Saadallah [29] reported that the wind-transported sediments are a major contributor to the detrital sediments in the northern parts of the Gulf. Emery [14] and Khalaf et al. [16] stated that Arabian Gulf dust fallout is composed mainly of calcareous silt, rich, in dolomite. On the other hand, the greater part of the Tigris-Euphrates suspended material is deposited in Iraq and only about 10% of the material that passes Bagdad city can reach the Arabian Gulf. These statements strongly suggest that the dust and dust storms, which are commonly derived from the prevailing NW winds which pass over southern Iraq and Kuwait, are far more important than the Tigris-Euphrates River system as a source of detrital sediments in the study area. Comparison between the composition of the marine bottom

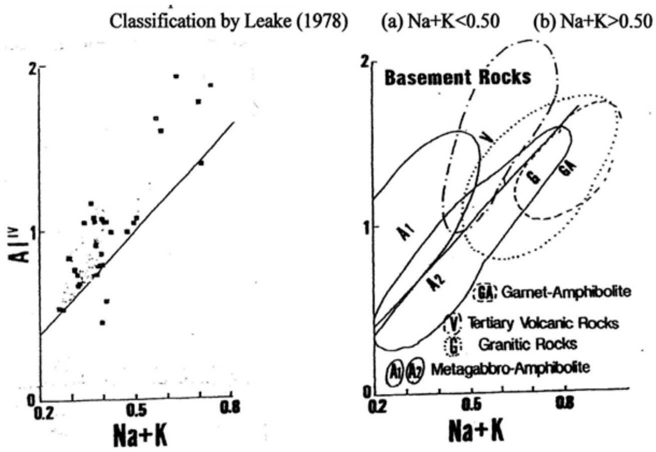

Figure 4: Na+ K-Al^{IV} diagram of detrital amphiboles in the coastal plain sediments. The right figure is of the basement rocks & volcanic rocks.

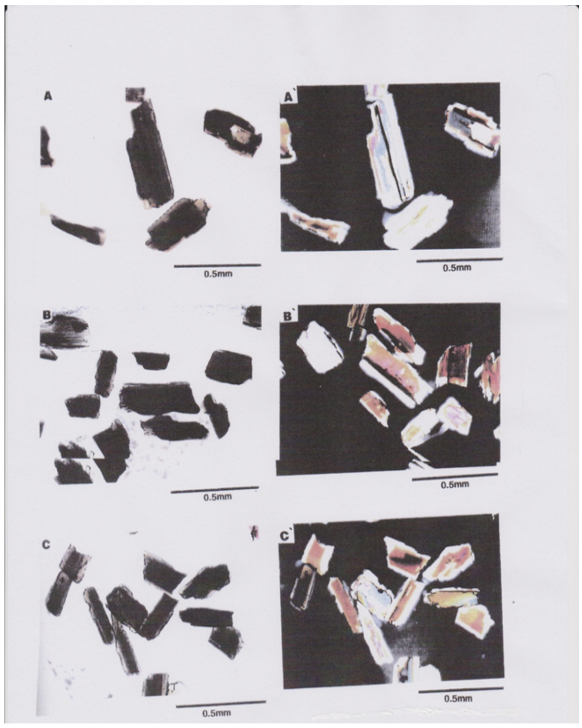

Figure 5: Photo-micrographs of amphibole grains in thin sections prepared for EPMA analysis from the coastal plain sediments. (A-F) under plane polarized light and (A'-F') under cross section.

sediments of Kuwait Bay and that of the fallout from dust storms over Kuwait territory indicates the presence of considerable quantities of Aeolian material in Kuwait Bay sediments. Kukal and Saadallah [29] have indicated the occurrence of Aeolian admixtures in the sediments of the northern Arabian Gulf, near Shatt Al-Arab. Grain size and mineralogical investigations of the intertidal sands indicate that these sands are derived from the coastal deposits. Grain size parameters of the intertidal sands reflect the variation in the energy level along the coastline of Kuwait. High energy waves along the southern coast are responsible for the good sorting of the intertidal sand. The textural and mineralogical investigations of coastal sediments suggested that they are partly derived from inland deposits such as ridges and beach rocks, also Aeolian processes form another potential source [30]. The Recent intertidal muddy sediments of Kuwait consist mainly of carbonates and terrigenous mineral grains. Terrigenous material is quartz, feldspar and clays with high-Mg calcite. The abundance of high- Mg calcite in the sediments of studied area could be attributed to suitability of this area for chemical and biochemical precipitation of these carbonates minerals. On the other hand, the proximity of the northern area to Shatt-al-Arab estuary and, therefore, fresh water and terrigenous matter supply, could be responsible for the low productivity of high -Mg calcite [16]. With regard to the transparent heavy minerals, it can be noticed that the studied samples heavy minerals are similar to the Recent Tigris-Euphrates sediments [27] in the abundance of hornblende, pyroxene and dolomite and are more related to the dust fallout and recent surface deposits of Kuwait because of the similarity in the abundance of dolomite. On the other hand, they are similar to the Tigris-Euphrates recent sediments as far as the unstable heavy minerals are concerned (amphiboles and pyroxenes) (Table 5). The chemical property of detrital grains of amphibole included in the sediments of studied samples can give information for source rock by comparing the chemical composition of amphibole grains of the coastal plain sediments and the chemical composition of amphibole grains from some older basement rocks around Kuwait. Where there is no available data about chemical composition of amphibole grains for the basement rocks of these deposits, so we try comparing the chemical composition of amphibole grains of coastal sediments with some data of chemical composition of amphibole grains from igneous and metamorphic rocks analyzed by [31]. From the chemical composition of amphibole grains from the coastal plain deposits, the grains which have (Na + K) <0.50 its composition ranges from actino hornblende to magnesio hornblende, but the grains which have (Na + K) >0.50 its composition have wide variation and on the (Na + K)- Al_{IV} diagram can be characterized two association: Association 1 which characterized by low amount of Al_{IV} and low amount of (Na + K), by comparing the chemical composition of this association and the chemical composition of amphibole grains from older basement rock, can be say, these association may be derived from metamorphic source rocks and association 2 which characterized by high amount of Al_{IV} and low amount of (Na + K), may be derived from volcanic source rocks. Al-Bakri et al. [2] mentioned the main potential sources of the recent marine sediments of Kuwait are dust fallout originated from southern Iraq and river-borne sediments from the Shatt-al-Arab River. Shatt-al-Arab estuary which its sediments contained assemblage derived from the disintegration of metamorphic and basic igneous rocks [32], so the chemical composition of amphibole grains of coastal deposits of Kuwait supporting its sources from sediments of Shatt-al-Arab river which derived from basic igneous rocks and metamorphic rocks. The clay minerals of the marine sediments of Kuwait are chiefly composed of illite, palygorskite, illite-montmorillonite mixed layer while kaolinite

Sample No.	Illite %	Palygorskite %	Illite-Montmorillonite %	Chlorite %	Kaolinite %
Shuwaikh					
SH-2	33	29	24	6	8
SH-5	36	30	26	3	5
Ras Al Ard					
RA-8	35	33	23	2	7
RA-11	40	30	22	3	6
Al Beda					
AB-16	38	34	20	4	4
Fahaheel					
FA-25	45	28	20	3	4
Mina Abdulla					
MA-30	46	25	19	3	7
Average	39	29.9	22	3.3	5.9

Table 4: Clay mineralogy of 4-2 μm fractions of Coastal plain sediments of Arab Gulf, Kuwait.

Heavy minerals	Present study (0.125-0.063mm)	Dust Fallout Khalaf et al. (1980) (Average C.S+V.S.C)	Surface Deposits of Kuwait Khalaf et al. 1980 (Average C.S+V.S.C)	Euphrates &Tigris (Ali 1976) (0.25-0.06mm)
Opaque	18.2	20.8	25.9	9.6
Amphibole	22.7	17.1	12.3	11.0
Pyroxene	18.5	17.3	12.4	17.3
Epidote	8.8	4.5	5.8	18.8
Zircon	4.6	1.2	2.5	2.6
Tourmaline	2.2	0.7	0.6	1.8
Rutile	0.9	-	-	-
Garnet	7.2	2.5	3.7	6.5
Dolomite	11.7	28.0	31.8	2.8
Mica	3.4	7.1	4.1	16.0
Other	1.8	1.4	1.9	13.4

Table 5: Average relative frequency percentages of heavy minerals in studied area, dust fallout ,surface deposits and Euphrates and Tigris basins.

and chlorite are found in small amounts. It seems that many factors are influencing the distribution of the clay minerals in the study area. The heterogeneous nature of the clay minerals is indication of a primary detrital origin for the clay fraction constituents. Suspended sediments of Shatt-al-Arab and its submerged Pleistocene estuarine deposits are important sources of illite, the illite-montmorillonite mixed layer, and chlorites [28,33]. The absence of palygorskite in the suspended sediments of the Shatt-al-Arab and its occurrence in the dust fallout sediments [16] suggests that this mineral has been developed as a diagenetic mineral. Palygorskite can result from the reaction of hypersaline water with other detrital clay minerals in the sabkhatized flood plain of the lower Mesopotamian plain in southern Iraq [34,35]. Therefore, it is suggested that the palygorskite is most probably derived from the ancient Mesopotamian flood plain and carried into the region of study by dust storms. Another source of palygorskite is the submerged ancient estuarine sediments of the Shatt-al-Arab [36]. Based on the results of this study and a number of previous studies. Kalaf et al. [16,26], Al-Bakri et al. [2]. Source rock of the recent intertidal sediments of Kuwait are derived from the following source:

1. The fluviatile deposits discharged in the northern part of the Arabian Gulf by Shatt-al Arab estuary
2. Aeolian dust fallout. Previous studies mentioned, direct chemical and biological precipitation from the gulf water also plays an important role as a source of these deposits.

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