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Mineralogical characteristics of surface sediment in Sulaibikhat Bay, Kuwait

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ABSTRACT

Surface sediment samples were collected from 35 locations in Sulaibikhat Bay, Kuwait. Grain sizes, total organic carbon (TOC), carbonate and mineralogical data were determined. The geographical distribution of these parameters, and their relationships with each other are described. Grain-size analysis showed a high positive correlation between clay minerals and organic matter (measured as TOC), but a high negative correlation between clay minerals and carbonate content (measured as CaCO3). Grain-size analysis also showed that the southeastern part of the Bay, which contains muddy sediments with a predominant silt fraction, also has the highest clay content. The calcium carbonate in the sediments, particularly in the western part of the Bay, is composed of sand-sized biogenic calcareous fragments of aragonite. There appears to be a positive relationship between coarse-grained sediments and the biogenic content of bottom sediments in the Bay. This study shows that there is an abundance of carbonate, clay minerals, feldspar, pyrite, gypsum and muscovite in different particular parts of the Bay. An abundance of pyrite close to the Ghazali outfall with low oxidation-reduction potential (ORP) values (48.0-188 mV) may be associated with the presence of hydrogen sulphide and pyrite in the sediments suggest the possibility that reducing conditions prevail because of sulphate reduction associated with the decomposition of organic matter. The high correlation of pyrite with TOC supports the view that the presence of pyrite is an indicator of the presence of sewage waste under anaerobic conditions.

Keywords: Grain sizes; sediment; aragonite; pyrite.

INTRODUCTION

Urbanization and industrial expansion have put remarkable ecological stress on the Kuwaiti environment. There are serious concerns, not only for the integrity and productivity of the coastal ecosystem, but also for the safety of potable water produced by coastal desalination plants (Khan, *et al.,* 1999; Alshemmari, 2009; Alshemmari, *et al.,* 2010). The Kuwaiti marine environment is exposed to a range of polluting discharges, including industrial and municipal wastewaters, desalination and power plant effluents, and urban runoff (Al-Muzaini, 2002). Also considered municipal sewage to be an important source of pollution in Kuwait's marine environment. The whole Sulaibikhat Bay coastline is completely urbanized with major recreational and other developments: Entertainment City, Doha, Sulaibikat Sport Club, Doha West's desalination plants, water outfalls, Ghazali sewage discharge, the Hospital Area Complex, Kuwait University (KU) and the Kuwait Institute for Scientific Research (KISR). The area in front of the Ghazali outfall is dominated by anoxic sediments (Al-Sarawi, *et al.,* 2002).

Kim, *et al.* (2007) found a relationship between low TOC content and large particle size and (thus) small surface area. They pointed out that clay minerals such as illite, chlorite and kaolinite were not present in coarse sediments in the samples they investigated. However, they indicated that clay minerals such as illite were present in the fine sediments. Feldspar abundance in Kuwait Bay has been studied by Al-Ghadban & El-Sammak (2005) who, in their semi-quantitative mineralogical analysis, showed that feldspars make up almost 30% of the total minerals in suspended sediment in eastern Kuwait Bay.

This study shows the abundance of carbonate, clay minerals, feldspar, pyrite, gypsum and muscovite in different particular parts of the Bay and understands their correlations with other environmental factors.

METHODOLOGY

Sulaibikhat Bay is a small embayment situated to the southeastern side of the Kuwait Bay. It is located at the longitude and latitude of 47° 51‘E and 29° 21‘N respectively, covering about 45 km^2. The southern part (the Sulaibikhat Bay area) of Kuwait Bay has undergone considerable development over the years. There is Shuwaikh port in the eastern area. The whole southern coastal area of Kuwait Bay is almost completely urbanized, being occupied by Kuwait City, Sulaibikhat and Doha (Figure 1).

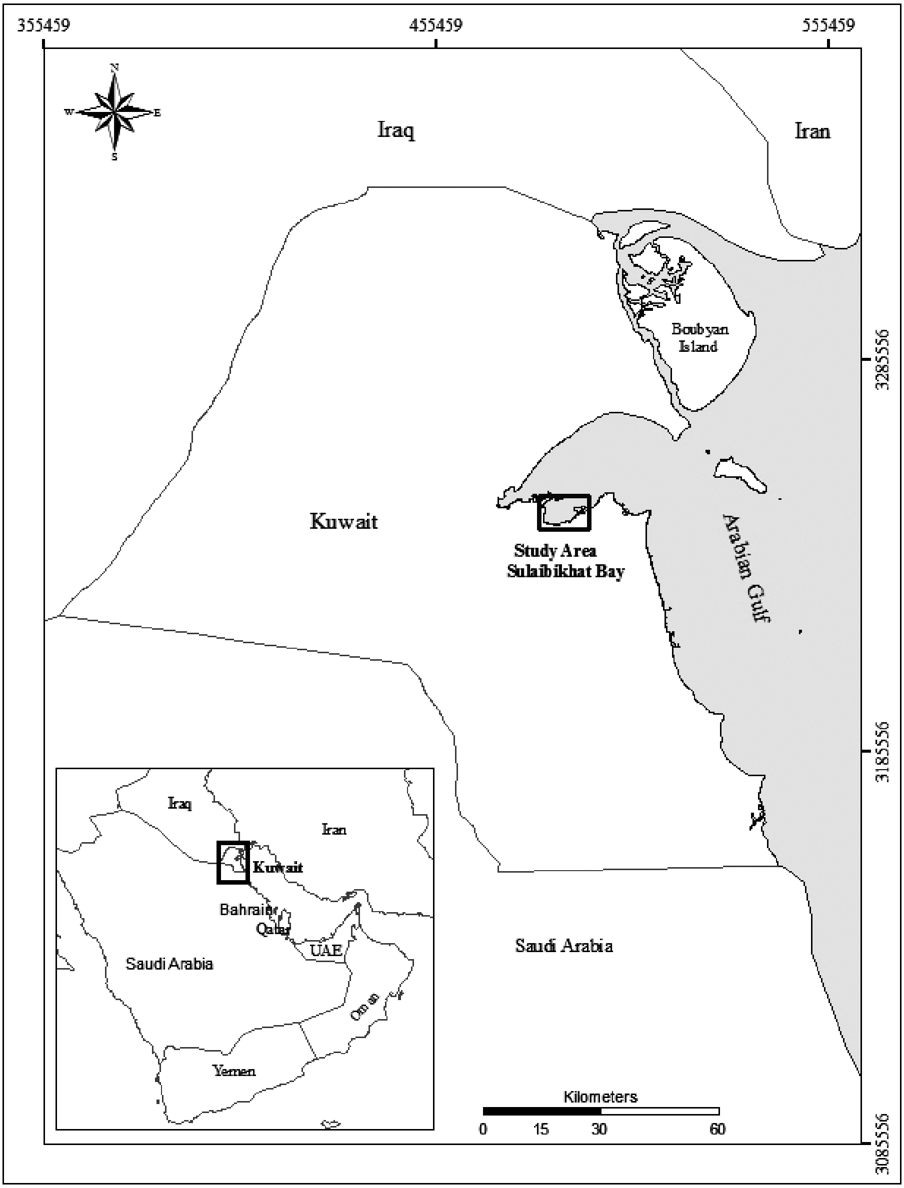

Fig. 1. Location map of Kuwait showing Sulaibikhat Bay.

The Sulaibikhat Bay area receives different types of effluents in different locations in the Bay. Thirteen potential discharge points have been distinguished around Sulaibikhat Bay. Thermal effluents are received from the Doha East and Doha West Power and Desalination Plants in its western part. The area also receives raw sewage effluents from the municipal sewage pumping station which discharges into the southern part of Sulaibikhat Bay. These developments have significantly contributed to Kuwait's coastal area pollution, with Sulaibikhat Bay being described as one of the most vulnerable coastal areas to be affected (Al-Bakri, 1996; Al-Ghadban, *et al.,* 2002). The Bay has also undergone substantial filling and dredging activity for the Free Trade Area project of the eastern part of Sulaibikhat Bay.

The bathymetry of the Bay in the west and southwest are areas of deposition, whereas the central part is subjected to scouring actions which maintain a relatively deep tidal channel. The greatest water depth (5.5 m) was recorded in the centre of the Bay (Alshemmari, 2009).

Surface sediment samples were collected from 35 stations, covering the offshore and onshore areas of Sulaibikhat Bay (figure 2).

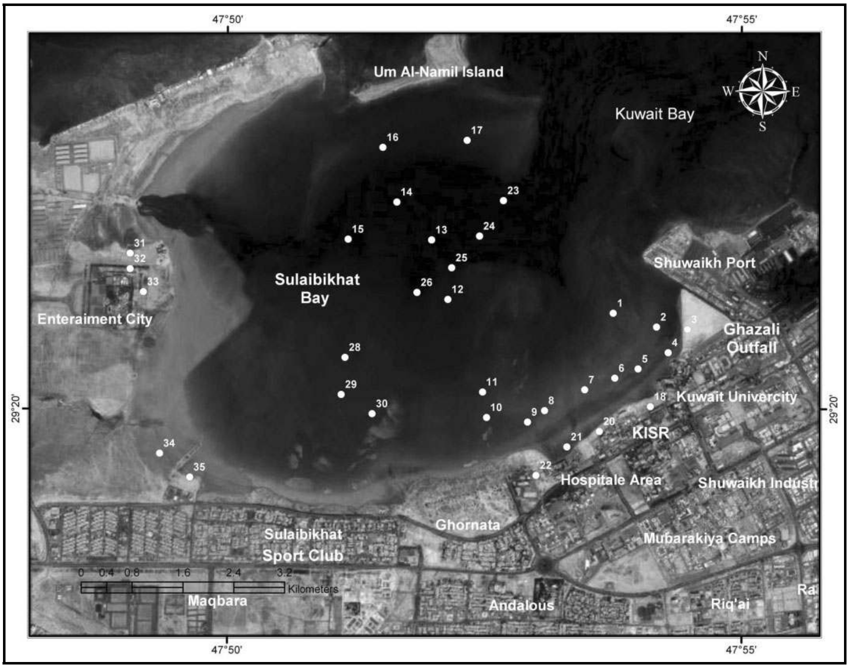

Fig. 2. Location of sampling site in Sulaibikhat Bay.

Sediment samples were collected using a Van Veen grab sampler operated from aboard a small boat. On collection, the upper 5 cm of each sediment sample was transferred, using an acid-rinsed plastic scoop, to a cleaned polythene box. The surface sediment samples (˜0.3g dry) were digested in Teflon reaction vessels for total trace metals extraction according to the modified MOOPAM, (1999) (The Regional Organization for the Protection of the Marine Environment (ROPME)). The grain size, TOC and carbonate content were determined and presented by Alshemmari, *et al.* (2010). Sub-samples were dried, crushed and homogenized in preparation for mineralogical, TOC and carbonate analysis and stored in an air-tight plastic bag, labeled with the station number. These were kept in a desiccator for any future analysis. Sampling methodology and analysis were described in detail by Alshemmari, *et al.* (2010). In this study, aliquots of bulk dried sediment from the surface sediment sites were subjected to mineralogical analysis using whole-sediment X-ray diffraction (XRD). The dried sediment samples were manually crushed, using an agate pestle and mortar, until a fine powder similar in consistency to flour was produced. The samples were then presented for analysis as randomly oriented samples within backfilled aluminium sample holders. X-ray diffraction analysis was performed using an X'Pert Pro diffractometer (PANalytical B.V.) fitted with an X'Celerator and a secondary monochromator. Each sample was scanned from 3 to 70°, 2θ at a time for about 54 min. which represents just over 1.24°/min. Radiation was Cu K-alpha, with a wavelength of 1.54059 Å. The diffractometer system was analyzed at the School of Chemical Engineering and Advanced Materials, Newcastle University-UK. Following analysis, the dominant clay and non-clay minerals were identified manually by matching the peaks recorded in diffractograms to specific crystalline phases on the basis of their characteristic X-ray diffraction patterns. The clay mineral fraction was not separated for additional characterization because of time constraints (clay minerals are difficult to identify in bulk samples, so a different sample preparation technique is required for clay mineral analysis).

A simple semi-quantitative approach was developed in order to study the relative abundances of the major minerals and the variations of those abundances (Figure 3). As quartz is present in all samples, and the quartz 3.34 Å peak was a prominent feature of all of the diffractograms, this peak was used as a reference against which the ratios of the major XRD peaks of all other minerals were determined (i.e., the ratios of the major peak for an individual mineral to the 3.34 Å quartz peak). The most intensive peak for each mineral was chosen to quantify individual mineral abundance. The data represent, in semi-quantitative form, the ratio of the abundance of each mineral to that of quartz; these data were determined at each sample station. This methodology can be considered to be semi-quantitative only, especially for clay minerals whose mineralogy is naturally variable and whose diffractograms are particularly susceptible to orientation effects. The spatial distributions of the mineralogical data for the 34 surface sediment samples from Sulaibikhat Bay were mapped using Surfer Software (version 8.01).

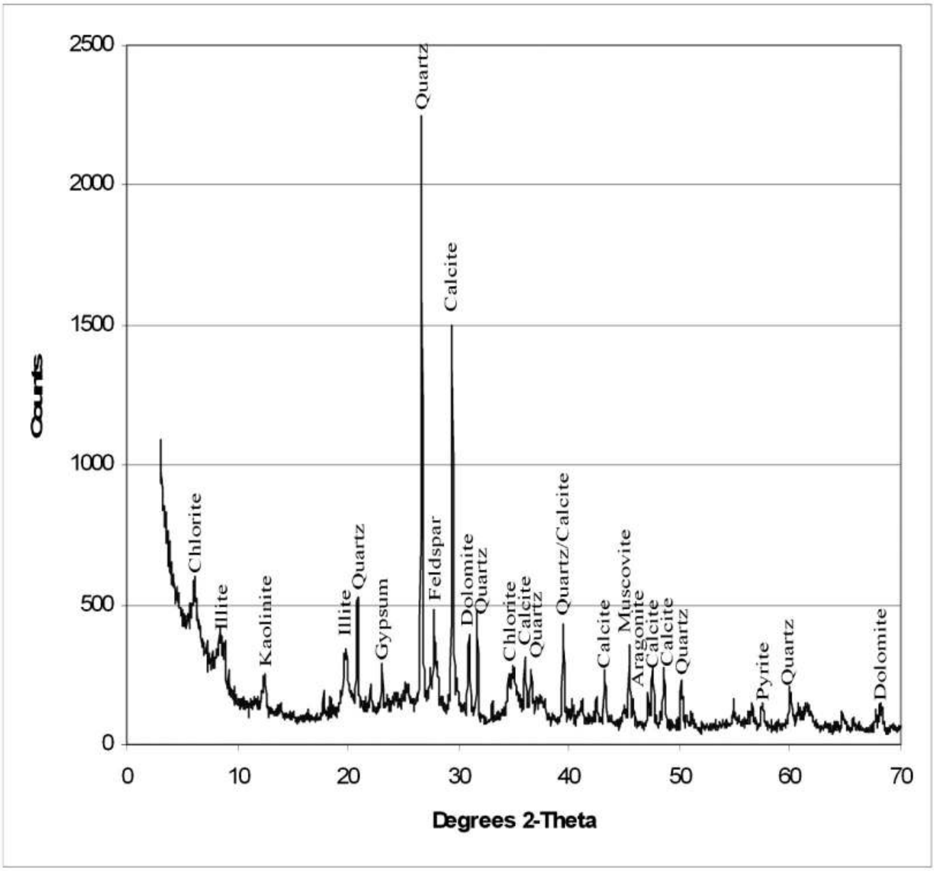

Fig. 3. X-Ray diffractogram showing distribution of minerals with relative abundance of quartz in the study area.

XRD is a useful tool for both qualitative and quantitative analysis of the abundances of minerals in sediments. The intensity of diffraction peaks on a diffractogram is related to the number of the equivalent diffraction planes present in the sample, if a number of other factors are held strictly constant (Hardy & Tucker, 1988). In theory, it is therefore possible to determine the quantity of a particular mineral species present, by means of the intensity of the diffraction peak. However, because a number of sediment characteristics cannot be held constant between replicate analyses (e.g., particle size, chemical composition, crystal imperfection, crystal orientation and the presence of amorphous substances), or because these are not clearly known, the analysis is more accurately characterized as being semi-quantitative, rather than quantitative (Jackson & Barak, 2005).

A rapid semi-quantitative analysis of the quantities of individual minerals present may be made by direct comparison of peak intensities of minerals identified on a diffractogram. As the peak intensities of the diffractions of particular minerals in a mixed sample are proportional to their concentrations, they can be used to make rough estimates of the relative proportions of the minerals in the mixed sample. Semi-quantitative analysis makes the mineral identification of individual minerals in sediment samples much more valuable (Hardy & Tucker, 1988). Unfortunately, the intensity of a mineral diffraction peaks cannot be directly used as correct measure of abundance because of the different diffracting abilities of minerals of different crystal systems. However, semi-quantitative comparisons of mineral abundances can be made between samples by considering the ratios of various diffraction peaks (Hardy & Tucker, 1988). This approach was used in this study. Mineralogical results for the surface sediment samples from Sulaibikhat Bay were spatially mapped using Surfer Software (version 8.01).

RESULTS

Results of the mineralogical analysis are presented in Table 1, in semi-quantitative form, showing abundance of each mineral relative to that of quartz. The mineralogical analyses indicate that quartz and calcite are the predominant minerals. Other minerals include carbonate minerals, feldspars and clay minerals. Carbonate minerals are represented by calcite, dolomite and aragonite, with average abundances relative to quartz of 1.02, 0.16 and 0.08, respectively. Alkali feldspars show an average relative abundance of 0.11 within a range of 0.05-0.20, and plagioclase feldspars show an average relative abundance of 0.17 within a range of 0.04-1.18. The maxima were at stations where very fine sediments of clayey silt were dominant.

Table 1. Mineralogy of surface sediments from Sulaibikhat Bay. Results represent the ratio of the largest peak for a given mineral to the largest intensity peak of quartz.

Station	Calcite	Dolomite	Aragonite	Chlorite	Illite	Kaolinite	Alkali Feldspar	Plagicoclase Feldspar	Pyrite	Gypsum	Muscovite	Quartz
SS01	0.65	0.14	0.05	0.13	0.10	0.19	0.07	0.08	0.17	0.07	0.16	1.00
SS02	1.04	0.16	0.08	0.11	0.11	0.25	0.10	0.06	0.35	0.15	0.16	1.00
SS03	1.28	0.17	0.06	0.15	0.13	0.15	0.17	0.08	0.09	0.14	0.13	1.00
SS04	0.85	0.16	0.04	0.16	0.12	0.21	0.08	0.47	0.07	0.11	0.15	1.00
SS05	0.19	0.18	0.04	0.13	0.11	0.05	0.10	0.05	0.07	0.13	0.09	1.00
SS06	1.27	0.15	0.05	0.14	0.10	0.22	0.15	0.11	0.08	0.15	0.16	1.00
SS07	1.33	0.16	0.05	0.13	0.09	0.08	0.13	0.23	0.04	0.15	0.15	1.00
SS08	1.23	0.11	0.06	0.11	0.10	0.10	0.10	0.14	0.05	0.14	0.10	1.00
SS09	1.03	0.13	0.05	0.13	0.08	0.07	0.09	0.11	0.04	0.12	0.09	1.00

Cont. Table 1. Mineralogy of surface sediments from Sulaibikhat Bay. Results represent the ratio of the largest peak for a given mineral to the largest intensity peak of quartz.

Station	Calcite	Dolomite	Aragonite	Chlorite	Illite	Kaolinite	Alkali Feldspar	Plagicoclase Feldspar	Pyrite	Gypsum	Muscovite	Quartz
SS10	1.52	0.15	0.09	0.15	0.11	0.17	0.15	0.14	0.06	0.17	0.15	1.00
SS11	1.30	0.21	0.06	0.14	0.09	0.08	0.12	0.13	0.05	0.12	0.14	1.00
SS12	0.74	0.20	0.09	0.07	0.05	0.06	0.14	0.06	0.14	0.07	0.11	1.00
SS13	0.90	0.19	0.07	0.10	0.07	0.07	0.11	0.06	0.08	0.11	0.09	1.00
SS14	1.45	0.13	0.07	0.16	0.12	0.20	0.16	0.17	0.04	0.17	0.14	1.00
SS15	1.19	0.11	0.06	0.14	0.11	0.07	0.13	0.10	0.04	0.13	0.12	1.00
SS16	1.07	0.11	0.06	0.10	0.06	0.07	0.11	0.13	0.06	0.10	0.11	1.00
SS17	1.12	0.17	0.09	0.12	0.08	0.11	0.15	0.25	0.09	0.18	0.10	1.00
SS18	1.14	0.18	0.06	0.14	0.10	0.09	0.07	0.09	0.08	0.13	0.07	1.00
SS19	1.33	0.13	0.07	0.13	0.09	0.28	0.11	0.15	0.09	0.16	0.17	1.00
SS20	0.98	0.16	0.07	0.12	0.06	0.07	0.05	0.08	0.05	0.13	0.07	1.00
SS21	1.54	0.17	0.05	0.14	0.09	0.09	0.14	0.06	0.09	0.20	0.11	1.00
SS22	1.49	0.16	0.06	0.15	0.10	0.07	0.13	0.07	0.10	0.15	0.13	1.00
SS23	0.81	0.09	0.13	0.08	0.05	0.20	0.13	0.04	0.22	0.11	0.06	1.00
SS24	1.45	0.16	0.07	0.14	0.12	0.13	0.20	0.09	0.07	0.19	0.10	1.00
SS25	na	na	na	na	na	na	na	na	na	na	na	na
SS26	1.08	0.24	0.06	0.09	0.05	0.09	0.09	0.15	0.12	0.06	0.18	1.00
SS27	0.62	0.11	0.09	0.10	0.04	0.10	0.09	0.64	0.08	0.09	0.11	1.00
SS28	0.82	0.71	0.13	0.09	0.04	0.07	0.13	1.18	0.05	0.07	0.14	1.00
SS29	1.22	0.17	0.10	0.12	0.07	0.10	0.09	0.26	0.07	0.07	0.17	1.00
SS30	0.65	0.13	0.05	0.12	0.10	0.18	0.05	0.08	0.18	0.07	0.16	1.00
SS31	0.51	0.05	0.16	0.06	0.06	0.05	0.12	0.24	0.09	0.06	0.06	1.00
SS32	0.66	0.12	0.05	0.13	0.10	0.18	0.06	0.07	0.16	0.07	0.16	1.00
SS33	0.83	0.08	0.32	0.12	0.05	0.11	0.07	0.06	0.13	0.11	0.26	1.00
SS34	0.65	0.06	0.00	0.06	0.04	0.08	0.06	0.05	0.07	0.06	0.08	1.00
SS35	0.70	0.06	0.07	0.09	0.04	0.06	0.08	0.08	0.06	0.08	0.11	1.00
Average	1.02	0.16	0.08	0.12	0.08	0.12	0.11	0.17	0.10	0.12	0.13	1.00
STDEV	0.33	0.11	0.05	0.03	0.03	0.06	0.04	0.22	0.06	0.04	0.04	0.00
Max	1.54	0.71	0.32	0.16	0.13	0.28	0.20	1.18	0.35	0.20	0.26	1.00
Min	0.19	0.05	0.00	0.06	0.04	0.05	0.05	0.04	0.04	0.06	0.06	1.00

(na: not analyzed because average grain size > 1mm; very coarse sand)

Three clay minerals were present: chlorite, illite and kaolinite, which showed average relative abundances of 0.12, 0.08 and 0.12, respectively. Pyrite, gypsum and muscovite showed average relative abundances of 0.10, 0.12 and 0.13, respectively. The range for muscovite was 0.06-0.26 and the maximum for pyrite, 0.35, was from station 2, close to the Ghazali sewage discharge (Figure

4). The maximum for gypsum was at station 21 on the upper tidal flat. Three carbonate minerals were identified: calcite, dolomite and aragonite. As seen in Figure 4, calcite exhibits its greatest abundance relative to quartz in the southeast and north of Sulaibikhat Bay and its relative abundance falls modestly towards the centre of the Bay. The lowest calcite to quartz ratios occur in the western margins and adjacent to the Ghazali outfall. Dolomite abundance relative to quartz is at its highest in a limited area in the southwest centre of Sulaibikhat Bay. Relative abundances of dolomite were much lower in the remainder of the Bay. The distribution of aragonite is shown in Figure 4. The highest abundance relative to quartz is near the western shoreline, and its abundance falls quite sharply towards the east. The sediments in the west of Sulaibikhat Bay are characterized by silty sand. The relative abundance of chlorite is illustrated in Figure 4. The highest abundance relative to quartz is seen at the Shuwaikh Port coast, in the southeast of Sulaibikhat Bay and also in the northwest. Chlorite abundance falls gradually towards the centre of the Bay. The relative abundance of illite has parallels with that of chlorite (although it differs from kaolinite), as seen in Figure 4. It has greatest relative abundance at the Shuwaikh Port coast in the southeast of Sulaibikhat Bay and in the northwest. The central part of the Bay has lower relative abundances of illite and the lowest relative abundances are close to the Sulaibikhat Sports Club. The relative abundances of kaolinite to quartz are shown in Figure 4. The highest relative abundance of kaolinite is at the coast at Shuwaikh Port (in the southeast of the Bay) and in the northeast. The abundance falls gradually towards the centre of the Bay and is lowest in the west. Feldspars comprise a large mineral group, which is illustrated here in terms of alkali feldspars and plagioclase feldspars. The abundance of alkali feldspars is illustrated in Figure 4. The highest abundance relative to quartz is in the north central part of Sulaibikhat Bay and it falls towards the southwest.

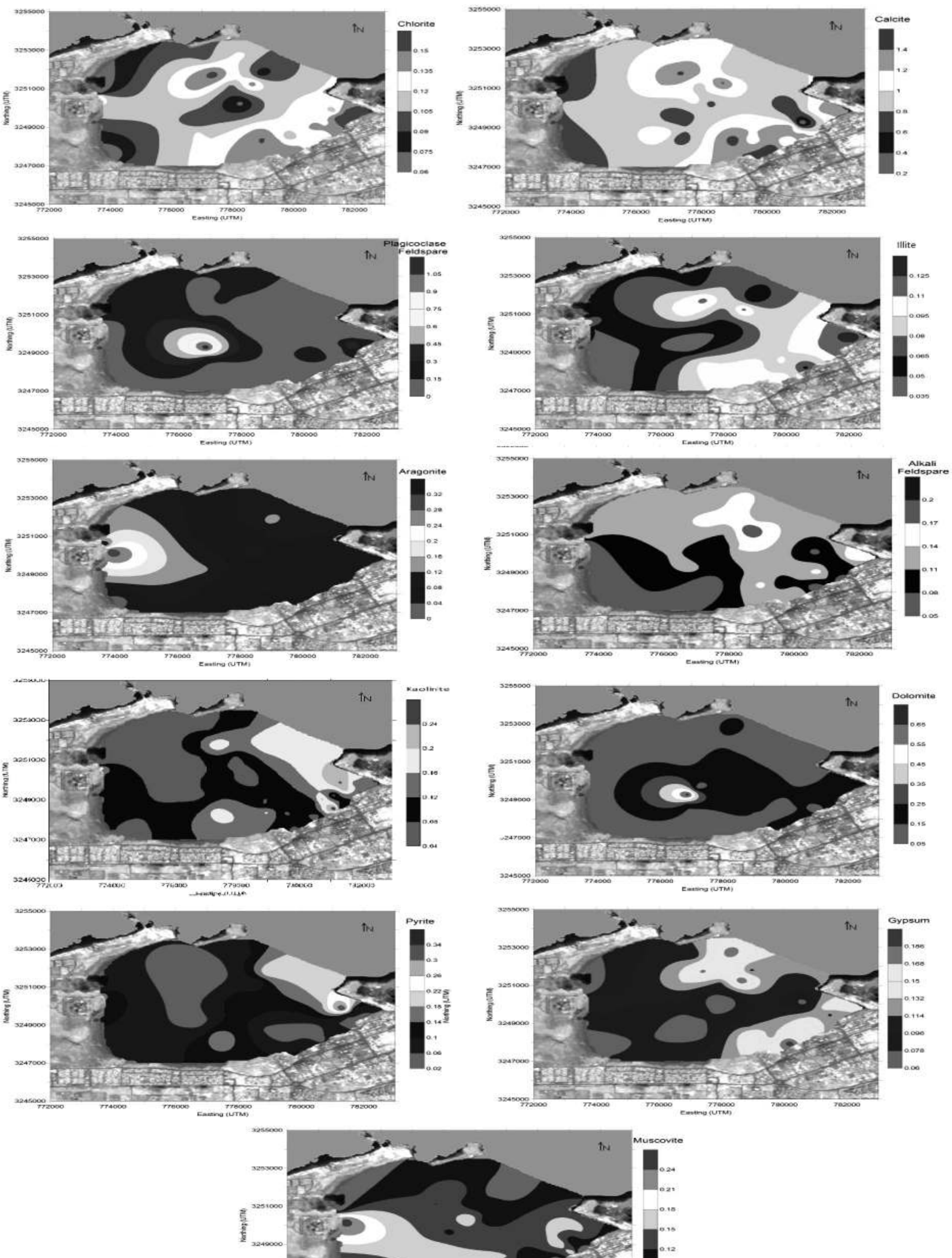

Fig. 4. Geographical distribution of minerals in the study area.

As seen in Figure 4, the greatest abundance of plagioclase feldspar relative to quartz is in a limited area in the southwest centre of Sulaibikhat Bay. Much of the remainder of the Bay area, including the coastline extending over Doha village, Entertainment City, Sulaibikhat Sports Club, and Sulaibikhat City has a low ratio of plagioclase to quartz. As seen in Figure 4, the highest relative abundances exhibited by pyrite are in a restricted area adjacent to the Ghazali outfall. The relative abundance of pyrite drops sharply towards the south coast of Sulaibikhat Bay and also towards the west. Gypsum is a common mineral in saline sedimentary environments. It is a sulphate that can form by precipitation from highly saline waters. The distribution of gypsum in Sulaibikhat Bay is illustrated in Figure 4. The highest abundance of gypsum relative to quartz is in the southeast, adjacent to the drainage outfall. Most of the rest of the Bay has much lower gypsum abundance. However gypsum abundance increases in the north, adjacent to the margin of Kuwait Bay. Muscovite is a common rock-forming silicate mineral found in igneous, metamorphic and detrital sedimentary rocks. Its highest abundance relative to quartz is seen at the coast in the west of the Bay near Entertainment City, as seen in Figure 4. Relative abundances are moderate over much of the central and southwestern areas of the Bay. The lowest abundances occur to the north, where Sulaibikhat Bay merges with Kuwait Bay.

For grain size parameters, clay was inversely correlated with sand, carbonate, aragonite, gypsum and pyrite. Silt was negatively correlated with sand, carbonate, and aragonite, and positively correlated with TOC, calcite, dolomite, chlorite illite, alkali feldspar and gypsum. Sand was inversely correlated with clay, silt, TOC, calcite, dolomite, chlorite, illite and gypsum, and positively correlated with carbonate and aragonite. The inter correlations of the grain size data with other parameters presented (minerals, TOC and carbonate) demonstrate the importance of grain size in controlling mineralogy. TOC was positively correlated with silt, clay minerals, pyrite and gypsum, and inversely correlated with sand and calcium carbonate. Carbonate was negatively correlated with clay, silt, TOC, clay minerals and gypsum, and positively correlated with sand and aragonite. Carbonate minerals (calcite, dolomite and aragonite) showed inter correlations with each other, and also showed high correlations with grain size (sand, silt and clay). Calcite ratio showed a positive correlation with silt, chlorite, illite, alkali feldspar and gypsum, and an inverse correlation with sand. Al-Ghadban & El-Sammak (2005), in their study of the mineralogy of suspended sediment in Kuwait Bay, believed that calcite was sourced from agitation of the sea bed or by direct precipitation of inorganic carbonate. Dolomite showed a positive correlation with chlorite, illite and silt, and a negative correlation with sand. Aragonite was inversely correlated with clay, silt and illite, and positively correlated with sand, carbonate and muscovite. This suggests that the carbonate of the east and north study area is of biogenic origin because of abundance and its positive correlation with aragonite only. Also, it confirms the work of Dames & Moore, (1983), who described sediments in the east and north of Sulaibikhat Bay as mostly of biogenic origin in the form of calcareous fragments cemented by aragonite. It is clear that the distribution of aragonite reflects availability of shell debris and other biogenic material. A positive relationship seems to exist between the coarse grain size and the biogenic content of bottom sediments in the Bay confirming this relationship found in Arabian Gulf by Al-Ghadban, *et al.* (1998); Khalaf & Al-Hashash, (1983); Al-Bakri, *et al.* (1984) and Al-Dousari & Al-Awadhi, (2012). They also found dolomite to be abundant in airborne dust and in recent surficial deposits in Kuwait.

DISCUSSION

In this study, the presence of clay minerals (chlorite, illite and kaolinite) correlated positively with both silt particle size and TOC Table 2. Thus, finer particle sizes tend to be associated with higher concentrations of organic matter. This study also identified negative correlations between clay minerals and both sand particle size and the presence of carbonate. This is consistent with clay mineral abundances observed in this study of Sulaibikhat Bay. Keil, et al. (1994) and Kim, *et al.* (2007) reported that fine particles showed a significant positive correlation with organic content and clay mineral content. They attributed this to the fine grain size of clay minerals (and hence large surface area) and the formation of a monolayer of organic matter sorbed to the clay mineral surfaces. This might also be the case in Sulaibikhat Bay. Kaolinite abundance in Kuwait Bay has been studied by Al-Ghadban & El-Sammak, (2005) who, in their semi-quantitative mineralogical analysis, show that kaolinite percentages reach up to 5% of the total minerals in Kuwait Bay suspended sediment. Alkali feldspar showed a positive correlation with silt, calcite, illite and gypsum, whereas plagioclase feldspar did not show any correlations. Pyrite correlated positively with TOC and kaolinite, but show no more correlations. The correlation of pyrite with TOC supports the above discussion reflecting the presence of pyrite as an indicator of the occurrence of sewage waste under anaerobic condition (UNESCO/WHO/UNEP, 1996). Gypsum ratios were positively correlated with silt, TOC, calcite, chlorite, illite and alkali feldspar, but inversely correlated with sand and carbonate. Muscovite was positively correlated with aragonite, chlorite and kaolinite, and did not show any other correlations. In this study, low ORP values (48.0-188 mV) were recorded in the southeast of Sulaibikhat. These may be associated with the presence of hydrogen sulphide and pyrite in the sediments and suggest the possibility that reducing conditions prevail because of sulphate reduction associated with the decomposition of organic matter. Scholz & Neumann, (2007) found that TOC contents decreased with depth in pyrite-rich sediments, indicating that organic matter had been progressively metabolized by micro organisms. In addition, they found that the release of CO2 into pore water during metabolism was accompanied by a pH decrease from 7.7 to 6.8. Their findings are consistent with those of this study of Sulaibikhat Bay described by Alshemmari, *et al.* (2010) where, in the core closest to the Ghazali sewage discharge, the TOC decreases with depth from 8.80% to 4.20% were accompanied by the lowest pH recorded in the Bay. This suggests that low pH might be useful as an indicator of active decomposition of organic matter.

The southeastern part of Sulaibikhat Bay contains fine-grained muddy sediments with the highest TOC values (6.02%) recorded in this study. In contrast, the sand size fractions are dominant in the northwestern seaward part of the Bay, where it contains aragonite with the highest calcium carbonate concentrations recorded in this study. Similar findings were reported by Rubio, *et al.* (2000) from the Ria de Vigo coastal embayment in Galicia in northwestern Spain, where fine sediments are relatively rich in organic matter and are the most heavily polluted sediments, particularly in the inner part of the Ria de Vigo embayment. Another similarity with Sulaibikhat Bay reported by Rubio, *et al.* (2000) was that carbonate-rich sediments, dominantly sands containing biogenic deposits of aragonite produced by benthic organisms, were concentrated in the outer part of the Ria de Vigo embayment, and that their dominance decreases rapidly landward. The grain size relationships of with TOC and carbonate content identified in Sulaibikhat Bay are also consistent with other studies that show significant inter-correlation of sediment grain size with TOC and CaCO3 (Keil, *et al.,* 1994; Mayer, 1994; Kim, *et al.*,2006).

Table 2. Correlation coefficient matrix (r) for grain size, mineral contents, TOC and carbonate in surface sediment of sulaibikhat Bay (n35, n = 34 for all mineral except grain size, dolomite and plagioclase feldspar, for which n = 33).

	%Clay	**%Silt**	**%Sand**	**% TOC**	**%CaCO$_3$**	**Calcite**	**Dolomite**	**Aragonite**	**Chlorite**	**Illite**	**Kaolinite**	**Alkali**	**Plagioclase**	**Pyrite**	**Gypsum**	**Muscovite**
%Clay	1	0.12	-0.489(**)	0.20	-0.486(**)	-0.20	0.20	-0.30(*)	0.25	0.26	0.07	-0.14	0.12	-0.09	-0.06	-0.12
%Silt		1.00	-0.926(**)	0.386(*)	-0.516(**)	0.578(**)	0.463(**)	-0.603(**)	0.443(**)	0.471(**)	0.06	0.30(*)	-0.21	-0.17	0.504(**)	-0.03
%Sand			1.00	-0.415(*)	0.639(**)	-0.432(*)	-0.483(**)	0.645(**)	-0.485(**)	-0.514(**)	-0.08	-0.21	0.14	0.19	-0.419(*)	0.07
%TOC				1.00	-0.799(**)	0.19	0.14	-0.20	0.411(*)	0.567(**)	0.443(**)	0.11	-0.22	0.396(*)	0.382(*)	0.16
%CaCO$_3$					1.00	-0.18	-0.17	0.352(*)	-0.547(**)	-0.554(**)	-0.390(*)	0.09	0.06	-0.11	-0.340(*)	-0.25
Calcite						1.00	0.34(*)	-0.13	0.569(**)	0.426(*)	0.19	0.570(**)	-0.07	-0.25	0.713(**)	0.17
Dolomite							1.00	-0.31(*)	0.371(*)	0.32*	-0.03	0.23	-0.04	0.01	0.25	0.13
Aragonite								1.00	-0.21	-0.366(*)	-0.06	0.01	0.01	0.17	-0.11	0.379(*)
Chlorite									1.00	0.822(**)	0.355(*)	0.25	0.05	-0.21	0.645(**)	0.32(*)
Illite										1.00	0.455(**)	0.34(*)	-0.10	0.03	0.590(**)	0.13
Kaolinite											1.00	0.06	0.05	0.506(**)	0.25	0.411(*)
Alkali Feldspar												1.00	-0.04	-0.19	.604(**)	-0.11
Plagioclase													1.00	-0.24	-0.09	0.04
Pyrite														1.00	-0.14	0.22
Gypsum															1.00	-0.05

(n35, n = 34 for all mineral except grain size, dolomite and plagioclase feldspar, for which n = 33).

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

CONCLUSION

Grain-size analysis data shows a high positive correlation between clay minerals and organic matter (measured as TOC), but a high negative correlation between clay minerals and carbonate content (measured as CaCO3). Grain-size analysis data also shows that the southeastern part of the Bay, which contains muddy sediments with a predominant silt fraction, also has the highest clay content. It appears that calcium carbonate in the sediments, particularly in the western part of the Bay, is composed of sand-sized biogenic calcareous fragments of aragonite. There appears to be a positive relationship between coarse-grained sediments and the biogenic content of bottom sediments in the Bay. The present study shows that there is an abundance of carbonate, clay minerals, feldspar, pyrite, gypsum and muscovite in different particular parts of the Bay. An abundance of pyrite close to the Ghazali outfall reflects the presence of sewage waste under anaerobic conditions.

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الخصائص المعدنية للرواسب السطحية في خليج الصليبيخات في الكويت

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مركز أبحاث البيئة والعلوم الحياتية- معهد الكويت للأبحاث العلمية- الكويت

خلاصة

تم جمع عينات الرواسب السطحية من 35 موقعا في خليج الصليبيخات في الكويت وذلك لتحديد أحجام حبيبات الرواسب السطحية، والكربون العضوي الكلي (TOC)، والكربونات والمعادن. كما تم وصف التوزيع الجغرافي لهذه المعايير، و تحديد العلاقة فيما بينها. أظهر تحليل حجم الحبيبات وجود علاقة إيجابية بين ارتفاع المعادن الطينية والمواد العضوية (تقاس على أنها TOC)، في حين أظهر التحليل وجود علاقة سلبية بين ارتفاع المعادن الطينية ومحتوى الكربونات (تقاس على أنها كربونات الكالسيوم $CaCO_3$). وأظهرت تحاليل حجم حبيبات الرواسب في الجزء الجنوبي الشرقي من خليج الصليبيخات المشتمل على رواسب طينية تسودها الطمي، أيضا أعلى محتوى من الطين. بينما تتكون رواسب كربونات الكالسيوم في الجزء الغربي من الخليج من الرمال والشظايا الجيرية الإحيائية من أراجونيت. واتضح أن هناك علاقة إيجابية بين الرواسب من الحبيبات الخشنة والمكونات الإحيائية في رواسب القاع في الخليج. وتشير هذه الدراسة أن هناك وفرة من الكربونات، المعادن الطينية، ومعادن الفلدسبار والبايرايت والجبس والماسكوفايت في أجزاء متباينة من الخليج. كما أن وفرة البايرايت بالقرب من مصبات الغزالي والمتزامن مع انخفاض قيم الأكسدة والاختزال (ORP) (من 188 حتى 48.0 فولت) والمرتبطة بوجود كبريتيد الهيدروجين والبايرايت في الرواسب تشير إلى إمكانية أن تتحول البيئة إلي حالة الأختزالية بسبب اختزال الكبريتات نتيجة لتأثرها بتحلل المادة العضوية. العلاقة الطردية بين البايرايت و TOC يدعم وجهة النظر القائلة بأن وجود البايرايت هو مؤشر على وجود مخلفات الصرف الصحي تحت الظروف اللاهوائية.

كلمات البحث: أحجام الحبيبات؛ الرواسب؛ أراجونيت؛ البايرايت.

حوليات الآداب والعلوم الاجتماعية

ANNALS OF THE ARTS AND SOCIAL SCIENCES

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- تصدر عن مجلس النشر العلمي بجامعة الكويت.
- صدر العدد الأول سنة ١٩٨٠م.
- تنشر الموضوعات التي تدخل في مجالات اهتمام الأقسام العلمية لكليتي الآداب والعلوم الاجتماعية.
- تنشر الابحاث والدراسات باللغتين العربية والإنجليزية شريطة أن لا يقل حجم البحث عن ٥٠ صفحة وأن لا يزيد عن ٢٠٠ صفحة مطبوعة من ثلاث نسخ.
- لا يقتصر النشر في الحوليات على أعضاء هيئة التدريس لكليتي الآداب والعلوم الاجتماعية فحسب ، بل يشمل ما يعادل هذه التخصصات في الجامعات والمعاهد الاخرى داخل الكويت وخارجها.
- تمنح المجلة الباحث خمسين نسخة من بحثه المنشور كإهداء.

رئيس هيئة التحرير

د. فاطمة إبراهيم آل خليفة

ثمن الرسالة للأفراد

(٥٠٠ فلس)

نوع الاشتراك	الكويت	الدول العربية	الدول الأجنبية
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جامعة الكويت ـ تأسس عام ١٩٩٤م

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سلسلة الإصدارات

سلسلة علمية محكمة

تُعنى موضوعاتها بمنطقة الخليج والجزيرة العربية، وتهدف إلى إبراز خصوصيتها، ورصد قضايا التنمية بأبعادها الحضارية الشاملة في ضوء المتغيرات الجارية.

قواعد النشر

أولاً : أن يكون البحث أو (الدراسة) معنية بشؤون منطقة الخليج والجزيرة العربية في المجالات الآتية: السياسة، الاقتصاد، الجغرافيا، التاريخ، علم النفس، الاجتماع، الأنثروبولوجيا التربية، اللغة العربية وآدابها، الثقافة، البيئة، القانون، الإعلام ، التراث (الآثار والحضارة والفنون) .

ثانيـــاً: أن تمثل الدراسة إضافة جديدة إلى حقل التخصص.

ثالثـــاً: لم يسبق تقديمها أو جزء منها للنشر إلى جهة أُخرى.

رابعـــاً: ألا يقل عدد صفحات البحث أو (الدراسة) عن ١٠٠ صفحة.

خامساً: يقدم المركز مكافأة مالية رمزية عن كل دراسة.

الاشتراكات

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الأفراد	٤ د.ك	٤ د.ك	١٤ دولاراً
المؤسسات	٢٥ د.ك	٢٥ د.ك	٦٨ دولاراً

المراسلات

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