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SEDIMENTOLOGICAL AND MINERALOGICAL STUDY OF RECENT SEDIMENTS IN KHOR AL-ZUBAIR SOUTHERN IRAQ

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ABSTRACT

This study investigates the sedimentological and mineralogical properties of recent deposits in the Khor Al-Zubair region, southern Iraq, with the aim of interpreting depositional environments and identifying the prevailing geological conditions sedimentary system. Core samples were collected from three stations (St1, St2, St3) at depth of 3 meters, subdivided into surface, middle, and bottom layers, this is, yielding 27 samples for grain-size analysis and 6 for X-ray diffraction (XRD) mineralogical analysis.

Grain-size results show a dominance of fine-grained sediments, with silt content of 47-92%, clay 7-52%, and low sand fractions 1-18%. Most samples classify as very fine sandy clay or clayey silt with minor. Median grain sizes range from 4.9-5.8ϕ, with positive skewness

indicating deposition dominated by suspended load. Sorting values are weak to moderate, reflecting limited energy variation in a low-energy environment.

Mineralogical analysis highlights the predominance of non-clay minerals, especially quartz, indicating a clear continental source. Carbonate minerals, mainly calcite with minor dolomite and gypsum, this suggests chemical precipitation and early diagenetic processes in a transitional coastal setting. suggest chemical precipitation and early diagenetic processes in a transitional coastal setting. Weak or absent clay mineral reflections in some samples are attributed to fine grain sizes or semi-amorphous components such as smectite.

High similarity in sedimentological and mineralogical properties across stations confirms lateral continuity and environmental uniformity. The study concludes that recent sediments were deposited in a low-energy estuarine–deltaic environment dominated by suspended-load deposition and weak current activity, providing key insights into the evolution of coastal environments in southern Iraq.

Keywords: KhorAl-Zubair, Sedimentology, Mineralogy analyses, Holocene Sediments, Depositional environment.

1. INTRODUCTION

Khor Al-Zubair, Southern Iraq encompasses some of the most prominent coastal wetland flats, characterized by abundant sedimentary and geomorphic features. Variations of their original character and channel pattern comes by a combination of tectonic, sedimentary and hydraulic effects. The interaction has produced a number of identifiable geomorphological features such as the sand spits and islands which support strong evidence for the dynamic process of fluvial sedimentary in this area. A few islands (e.g., Island (Hajam) were originated by old meanders of the main stream and related to dissimilar flow energies, this also ascribes to an enduring tectonic activity along with current depositional and morphological details in terms of morphology situation and depositional environment (Al-Mosawi *et al*., 2022).

Investigations in recent times have revealed that Khor Al-Zubair experiences extreme differential-tide dominance and high asymmetry which characterizes a costal system with varying sedimentary regime. It is affected by the tides (carrying an inflow from the Arabian Gulf, in addition to freshwater from Shatt Al-Arab). The long period of exchange then led to a wide spectrum of soil sediments from gravely deposits to claysone, siltsy ones (Shareef *et al*., 2015).

Concerning Quaternaries of southern Iraq, Al-Kaaby and Albadran (2020) provided informations for Northern Arabian Gulf region on sedimentological as well mineralogical properties Basra-and Khor AlZubair, Their results showed that the sediments are composed of sandy clay and sandy silt, in addition to few heavy minerals such as rutile, zircon and tourmaline as well as light ones like calcite and dolomite, Our findings highlight the complication in sediment sources, both continental and marine (pierini,2025). These results might be useful to compare with the young deposits examined in the study region and could provide a sound reference.

Mineralogical investigations have shown that the sediments of Khor Al-Zubair are enriched in clay minerals such as illite, kaolinite, and chlorite, in addition to quartz, calcite, and feldspar. Evaporite minerals including halite and gypsum are also present, reflecting the influence of evaporation and elevated salinity on sediment formation (Aldaood and Albadran, 2019).

Sissakian *et al*., (2021) conducted a comprehensive geomorphological and structural study of the Khor Al-Zubair area within the framework of the southern Mesopotamian plain. Their work analyzed stratigraphic successions, sedimentary units, and tectonic processes that contributed to shaping the regional landforms. The results indicated that Khor Al-Zubair represents a coastal depression formed by recent accumulations and continuous fluctuations in sea level.

Dakheel (2022) studied hydrodynamic of Khor Al-Zubair channel using 3D shallow water model. The results of this work showed that the semidiurnal tidal currents have a much influence on flow directions, and the deposition and transport of fine-grained sediment in estuary Attenuated by Yield stress sediment.

Additionally, Al-Fartousi *et al*., (2017) provided a numerical-model to estimate suspended sediment transport in Khor Al-Zubair channel, using field data for current velocity and direction. They concluded that tide-related processes and anthropogenic modifications largely shape sediment dynamics, which might be the cause of such recent morphological change within the channel.

A review of previous studies indicates that research has evolved from initial descriptive fieldwork to advanced analytical approaches and precise numerical modeling. Collectively, these studies highlight Khor Al-Zubair as a dynamic environment influenced by tidal forces, hydrodynamic processes, and human activity. Nevertheless, there remains a need for integrated investigations that combine sedimentological and mineralogical analyses within a chronological framework to elucidate the evolution of depositional environments through recent geological time.

The present study focuses on three selected stations within Khor Al-Zubair, located in the northwestern Arabian Gulf. Its objective is to conduct a geological analysis to characterize and interpret the sedimentological and mineralogical properties of Khor Al-Zubair deposits, with the objective of reconstructing depositional environments and elucidating the characteristics of the prevailing sedimentary system.

2. Fundamentals of Smart Materials

Study Area Location

Kamel *et al.*, (2024) reported that the study area, represented by the Khor Al-Zubair channel in southern Iraq, is situated within the southern part of Basra Governorate. Its precise coordinates fall within a geographic zone extending between longitude (29″ and 23″) and latitude (58″), in the northwestern Arabian Gulf. This area is distinguished as an important maritime navigation route, functioning as an estuarine system that integrates both marine and continental waters.The study area extends between latitudes (30°24′N and 30°29′N), and longitudes (47°83′E and 47°86′E), thereby defining its geographic range within the Khor Al-Zubair region (Fig.1).

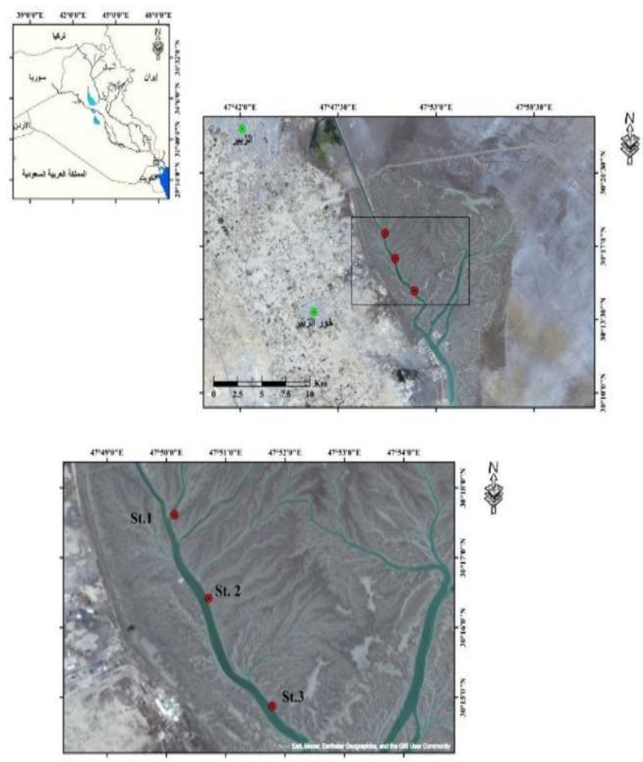


Figure1. Location of the study station

Geological Setting of the Study Area

Tectonically, the Khor Al-Zubair area lies within the Mesopotamian Plain, which forms part of the Zagros Foreland Basin. This basin exhibits continuous responses to compressional stresses resulting from the collision between the Arabian and Iranian plates, leading to folding, faulting, and the development of subsurface fractures (Sissakian *et al.*, 2021).

According to a comprehensive review of the geological framework of the Mesopotamian Basin, the region has experienced continuous subsidence from the Upper Miocene to the present day (Sissakina and Alnsari, 2021). Studies in Khor Al-Zubair indicate the presence of minor subsurface faults and localized uplifts that have influenced channel curvature and the inclination of its bed (Albadran and Khaleefah, 2022).

Geomorphologically, Khor Al-Zubair is considered one of the most distinctive areas in southern Iraq due to its diversity. The region is characterized by numerous branching tidal channels forming a complex dendritic network, which is a typical feature of coastal-deltaic environments in areas of low gradient (Albadran *et al*., 2009).

Methodology

Sediment samples were collected from three stations along the Khor Al-Zubair channel in southern Iraq, using cores that reached a depth of three meters at each station.

The methodology applied in this study involved the following:

Field Work

Sediment samples were collected from three stations along the Khor Al-Zubair channel in southern Iraq, using cores that reached a depth of (3 meters) at each station (St1, St2, St3). Each meter of the core was subdivided into three sections-surface, middle, and bottom-yielding nine samples per station. In total, (27) samples were obtained from all stations combined. Table (1) presents the geographic coordinates of the study stations.

Table (1) Geographic Coordinates of the Study Stations Using GPS

Station	Area name	Latitude	Longitude
S1	Khor Al-Zubair	N 30°29'36.05´´	E 47°83'56.16´´
S2	Khor Al-Zubair	N 30°27'37.10´´	E 47°84'52.12´´
S3	Khor Al-Zubair	N 30°24'79.54´´	E 47°86'30.82´´

Laboratory Work

Grain-Size Analysis

Grain-size analysis was conducted on (27) sediment samples collected from three stations (St1, St2, St3), each representing a (3meter) core subdivided into three levels (surface, middle, and bottom), yielding nine samples per station. The primary objective was to separate the sand fraction from the silt and clay fractions using the wet sieving method with a (63µm) sieve. The retained sand fraction was collected, dried in an electric oven at (50°C), and subsequently analyzed (salemi et al., 2010).

Following the methodology of Folk (1974), granulometric analysis of the silt and clay fractions was performed using the pipette method. The suspension was placed in a graduated glass cylinder, to which a dispersing agent (sodium hexametaphosphate) was added at a concentration of (20 mg per 1000 ml) to prevent flocculation and ensure proper dispersion of clay particles. The cylinder was shaken to achieve homogeneity, and aliquots were withdrawn at specific time intervals using a pipette, as outlined by Folk (1974).

The results of grain-size analysis for silt and clay were processed to construct cumulative curves illustrating the percentage distribution of sand, silt, and clay. Sediment textures were classified using the Folk (1974) triangular diagram, while statistical grain-size parameters were calculated according to Folk and Ward (1957).

Mineralogical Analysis

Six sedimentary samples were selected for mineralogical analysis using X-Ray Diffraction (XRD). These samples were collected from three stations within the study area, with two samples taken from each station: one from above the second meter and another from below the third meter depth at the first station, and similarly for the other stations. The aim was to identify and compare mineralogical variations among the study sites.

The samples were prepared by grinding them into a fine, homogeneous powder and sieving them through a (75 µm). The analysis was conducted using an X-Ray Diffraction instrument to determine both the qualitative mineral composition and the relative quantitative proportions of the sedimentary components. Diffraction patterns were recorded within an appropriate 2θ range and compared with standard mineral spectra to accurately identify mineral phases, following the methodology of Biscaye (1965).

3. RESULTS

The results presented in (Table 2) and (Figure 2) illustrate the textural and granulometric analysis of the sediment samples (St1, St2, St3). A clear dominance of silt is observed across all depths, ranging between (51-88%). Sand content varied between (1-13%), while clay ranged from (11-47%). This distribution reflects a depositional character dominated by the texture classified as Very Slightly Sandy Clayey Silt.

At Station 1 The first depth (1meter) shows a vertical textural gradation from top to bottom. A slight increase in sand content is noted in the upper part, indicating deposition under relatively higher-energy conditions. Moving downward, sand content decreases gradually while silt increases, reflecting a reduction in depositional energy. In contrast, the deeper layers (2-3meter) exhibit clear textural homogeneity and stability in granulometric proportions, suggesting long-term depositional stability. Collectively, these characteristics indicate that sediments at Station 1 were deposited in a calm, low-energy environment.

At Station 2 The textural analysis results reveal a clear dominance of fine-grained sediments, represented mainly by silt and clay, with only minor contributions from sand. Sand content ranged between (1-18%), silt between (47-92%), and clay between (7-52%). This textural distribution reflects a fine-grained depositional character dominated by silty clay and slightly clayey silt, a pattern commonly associated with coastal and estuarine environments. At a depth of 1 m, noticeable textural variation is observed across the three levels. In the upper part, slightly clayey silt dominates, accompanied by a significant reduction in sand content, indicating deposition in a calm environment where suspended load is the primary contributor. In the middle part, clay content increases markedly (52%), shifting the texture to Silty Clay, which reflects a substantial decrease in depositional energy. In the lower part, sand content rises relatively (18%), suggesting the influence of higher-energy conditions for a temporary period, such as tidal activity or limited current flow. At a depth of (2meter), the sediments exhibit relative textural homogeneity, with the texture classified as Slightly to Very Slightly Sandy Clayey Silt. This is accompanied by a clear reduction in sand content and a relative increase in clay (30-42%). Such homogeneity indicates relatively stable depositional conditions, with suspended-load sedimentation processes prevailing.

At a depth of (3 meter), the highest proportion of silt was recorded (92%), accompanied by a sharp decrease in clay (7%) and sand (1%). Accordingly, the prevailing texture is classified as Very Slightly Sandy Slightly Clayey Silt. This level reflects deposition in a very calm, low-energy environment, far removed from sources of coarse sediments, where the relative stability of the water column allowed the settling of fine silt. The dominance of silt and clay, the limited variation in sand content, and the vertical textural gradation collectively indicate that the sediments of Station 2 were deposited within a quiet estuarine creek environment, specifically within the Khor Al-Zubair system, with only minor influences from tidal currents. The localized variations in sand and clay proportions represent short-term responses to hydrodynamic or tidal fluctuations during certain seasons, without altering the overall low-energy depositional character of the environment.

At Station 3 The granulometric analysis results show a clear dominance of silt and clay across all studied depths. Silt content ranged between (58–80%), while clay varied between (18-41%). Sand content was very low, ranging only between (1-2%). Most of the sediments were classified as Very Slightly Sandy Clayey Silt, with limited occurrences of Very Slightly Sandy Slightly Clayey Silt at certain levels. At a depth of 1 m, a vertical textural gradation was recorded, represented by a gradual increase in silt content from top to bottom (65-74%), accompanied by a decrease in clay proportions. This indicates a slight stabilization of depositional energy toward the lower part, with fine suspended-load sedimentation continuing.

At a depth of 2 m, relative changes in clay and silt proportions were observed. Clay content increased in the middle level (41%) and then decreased markedly in the lower level (18%), shifting the texture to Slightly Clayey Silt. This variation reflects a short-term response to hydrodynamic fluctuations, manifested in differences in tidal current intensity or periods of water stagnation.

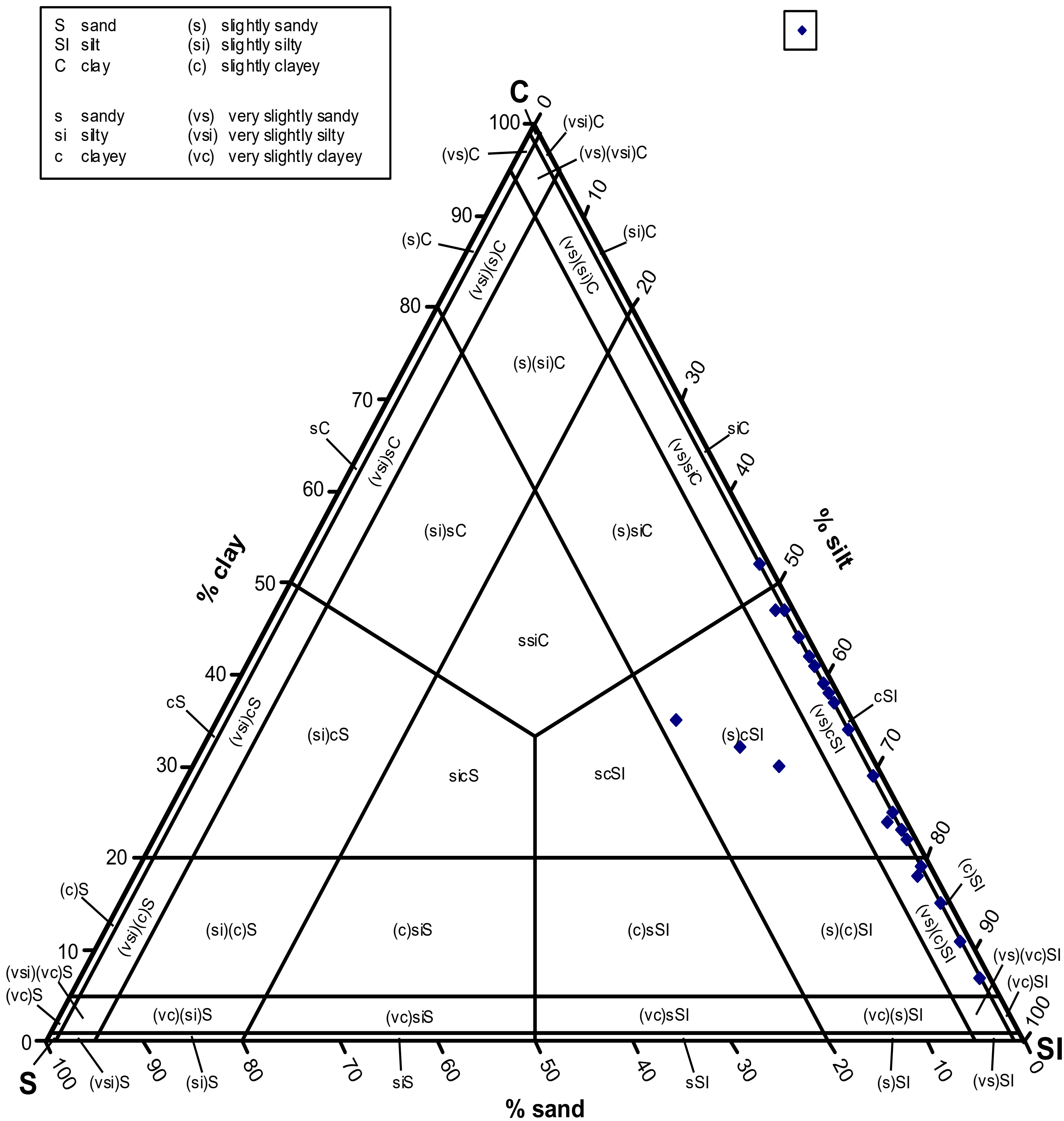
At a depth of 3 m, the sediments exhibit clear textural homogeneity, with silt content stabilizing between (76-77%) and sand proportions remaining constant. This uniformity indicates long-term stability in depositional conditions, with the absence of high-energy environments.

The overall textural characteristics of the three stations demonstrate that deposition occurred within a low-energy estuarine creek environment, specifically within the Khor Al-Zubair system. The dominance of fine suspended-load sedimentation processes is evident, with weak tidal currents controlling sediment distribution. Furthermore, the high proportions of silt and clay suggest deposition in inner or marginal areas of the creek, far from sources of sandy sediments.

Table (2): Percentages of Sand, Silt, and Clay

NO.	depth (m)	Levels	% Sand	% Silt	% Clay	Particle Size Distribution Classification Folk (1974)
st1	1	Top	13.0	55.0	32.0	Slightly Sandy Clayey Silt
		Mid	1.0	74.0	25.0	Very Slightly Sandy Clayey Silt
		Bot	1.0	84.0	15.0	Very Slightly Sandy Slightly Clayey Silt
	2	Top	1.0	60.0	39.0	Very Slightly Sandy Clayey Silt
		Mid	2.0	51.0	47.0	Very Slightly Sandy Clayey Silt
		Bot	1.0	88.0	11.0	Very Slightly Sandy Slightly Clayey Silt
	3	Top	1.0	55.0	44.0	Very Slightly Sandy Clayey Silt
		Mid	1.0	52.0	47.0	Very Slightly Sandy Clayey Silt
		Bot	1.0	62.0	37.0	Very Slightly Sandy Clayey Silt
St2	1	Top	1.0	80.0	19.0	Very Slightly Sandy Slightly Clayey Silt
		Mid	1.0	47.0	52.0	Very Slightly Sandy Silty Clay
		Bot	18.0	47.0	35.0	Slightly Sandy Clayey Silt
	2	Top	10.0	60.0	30.0	Slightly Sandy Clayey Silt
		Mid	1.0	57.0	42.0	Very Slightly Sandy Clayey Silt
		Bot	1.0	58.0	41.0	Very Slightly Sandy Clayey Silt
	3	Top	1.0	60.0	39.0	Very Slightly Sandy Clayey Silt
		Mid	1.0	92.0	7.0	Very Slightly Sandy Slightly Clayey Silt
		Bot	1.0	92.0	7.0	Very Slightly Sandy Slightly Clayey Silt
St3	1	Top	1.0	65.0	34.0	Very Slightly Sandy Clayey Silt
		Mid	1.0	70.0	29.0	Very Slightly Sandy Clayey Silt
		Bot	2.0	74.0	24.0	Very Slightly Sandy Clayey Silt
	2	Top	1.0	61.0	38.0	Very Slightly Sandy Clayey Silt
		Mid	1.0	58.0	41.0	Very Slightly Sandy Clayey Silt
		Bot	2.0	80.0	18.0	Very Slightly Sandy Slightly Clayey Silt
	3	Top	1.0	77.0	22.0	Very Slightly Sandy Clayey Silt
		Mid	1.0	76.0	23.0	Very Slightly Sandy Clayey Silt
		Bot	1.0	76.0	23.0	Very Slightly Sandy Clayey Silt

Figure (2) illustrates the classification of sediments according to the Folk (1974) triangular diagram



Grain Size Statistical Parameters

The results of the grain-size analysis at Station 1, as shown in (Table 3), indicate a predominance of coarse to medium silt fractions. The mean grain size (Mean Size) values ranged between (4.9ϕ) and (5.8ϕ), suggesting deposition under low- to moderate-energy conditions, which are characteristic of semi-enclosed transitional coastal environments.

All samples exhibit positive skewness values, reflecting the dominance of fine particles within the grain-size distribution. This pattern indicates relatively calm depositional conditions that favor the settling of fine suspended material, with only limited influence from stronger currents. Such characteristics are consistent with the nature of estuarine environments subject to tidal effects.

Kurtosis values ranged between (0.5 and 0.7), Grain-size analysis indicates moderately to relatively platykurtic distributions, reflecting fluctuations in transport dynamics, overlapping sediment sources, and variable hydrodynamic energy. Sorting values (1.8–2.5) classify the sediments as poorly to moderately sorted, consistent with unstable depositional conditions near river mouths and estuarine creeks. Median and mean grain-size values show close agreement, confirming statistical reliability and relative homogeneity across depositional levels. At Station 2, limited variation with depth suggests continuity of depositional processes with minor hydrodynamic influence. Mean grain-size values (5.03–5.6 ϕ) indicate dominance of medium to coarse silt, typical of low- to moderate-energy semi-enclosed coastal settings. Positive skewness (0.62–0.84) reflects enrichment in fine particles under calm conditions, while kurtosis (0.48–0.70) further supports variable energy regimes influenced by tidal processes, ranging between (3.9ϕ and 4.3ϕ). This convergence highlights a relative homogeneity in grain-size distribution across sedimentary levels and reinforces the reliability of the statistical results.

The grain-size analysis results at Station 3 reveal limited variation in statistical properties with depth and across sedimentary levels, indicating only minor changes in depositional conditions (Al-Daraji et al., 2025).

Mean grain-size values ranged between (5.2ϕ and 5.6ϕ), showing the predominance of coarse to medium silt. This grain-size range reflects deposition in a low- to moderate-energy environment. The similarity of values across different levels suggests relative continuity in sediment supply.

Skewness values varied considerably, ranging between (0.13 and 0.8). The prevailing positive skewness indicates dominance of fine particles within the grain-size distribution. However, relatively lower skewness values at certain levels-particularly at 3 m depth-suggest a near-symmetrical distribution, pointing to short episodes of higher hydrodynamic activity compared to other levels.

Kurtosis values ranged between (0.47 and 0.75), indicating that the grain-size distribution is moderately to relatively platykurtic. This reflects fluctuations in transport and depositional conditions, as well as variations in hydrodynamic energy.

Sorting values ranged between (2.1 and 2.5), classifying the sediments as poorly to moderately sorted. This indicates instability in depositional conditions, where repeated changes in current velocity led to the deposition of grains of varying sizes within the same layer. Median values showed relative variation, ranging between (3.8ϕ and 5.6ϕ). This reflects limited differences in the dominance of fine-grained fractions across sedimentary levels, highlighting the variable influence of transport and depositional processes within the same station. Overall, the "Grain-size analysis across the three stations indicates deposition in a low-energy transitional coastal environment influenced by tidal processes and spatial variations in current intensity. The strong similarity among stations reflects a unified environmental framework, while minor differences highlight local variations in depositional conditions and sediment supply. These findings are consistent with previous conclusions regarding the sedimentary dynamics of the Khor Al-Zubair area (Shareef et al., 2015 and Al-Daraji et al.,2024).

Table (3) Volumetric parameters of the sediments in the study area

NO.	depth (m)	Levels	Mean Size	Skewness	Kurtosis	Sorting	Median
st1	1	Top	5.4	0.65	0.64	2.4	4.1
		Mid	5.3	0.77	0.7	2.4	3.9
		Bot	4.9	0.71	0.66	2	3.9
	2	Top	5.5	0.69	0.55	2.4	4.1
		Mid	5.8	0.65	0.52	2.2	4.5
		Bot	5.3	0.79	0.57	2	4
	3	Top	5.5	0.79	0.51	2.3	3.9
		Mid	5.5	0.78	0.5	2.4	3.9
		Bot	5.4	0.77	0.51	2.1	4
St2	1	Top	5.2	0.71	0.7	2.2	4
		Mid	5.6	0.62	0.48	2.5	4.3
		Bot	5.4	0.72	0.59	2.4	4
	2	Top	5.2	0.75	0.64	2.4	3.9
		Mid	5.5	0.74	0.61	2.3	4
		Bot	5.6	0.84	0.53	2.4	3.9
	3	Top	5.5	0.79	0.61	2.4	3.9
		Mid	5.03	0.72	0.62	1.8	4
		Bot	5.3	0.66	0.6	2	4.2
St3	1	Top	5.2	0.76	0.54	2.2	3.9
		Mid	5.4	0.78	0.64	2.3	3.9
		Bot	5.4	0.74	0.67	2.3	4
	2	Top	5.6	0.78	0.57	2.4	4
		Mid	5.4	0.76	0.47	2.5	3.8
		Bot	5.3	0.8	0.62	2.2	3.9
	3	Top	5.2	0.56	0.75	2.2	4.4
		Mid	5.6	0.13	0.69	2.1	5.6
		Bot	5.3	0.43	0.69	2.1	4.8

Mineralogical Analysis

Station 1 at 2 meter depth-Top, The X-Ray Diffraction (XRD) pattern of the studied sample from Station1, shown in (Figure 3), reveals that the mineralogical composition of the sediments is dominated by quartz, the most abundant and distinct mineral in the sample. Quartz recorded high-intensity diffraction peaks at (2θ≈ 26.6°), corresponding to a d-spacing of (3.34 Å), in addition to weaker peaks at (2θ≈ 20.8°) and (36.5°), with d-spacing values of (4.26 Å) and (2.46 Å), respectively. This indicates the abundance of silicate grains of continental origin within the sediments. Calcite was also identified with notable intensity, diagnosed by its main peak at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with secondary peaks. This reflects the role of chemical and biological processes in enriching the sediments with carbonates, likely associated with shallow marine or semi-marine depositional environments, This is consistent with what was concluded(Abo-Turab *et al.*,2025).

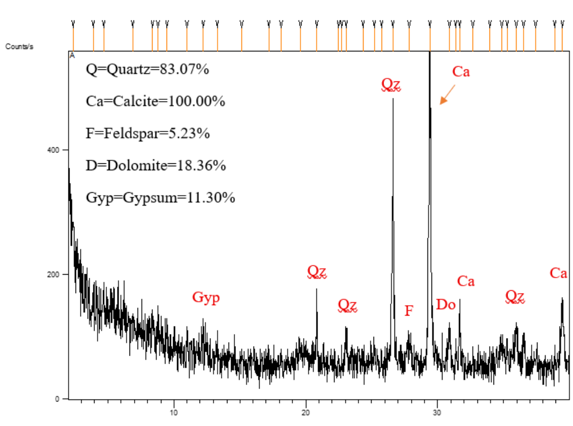


Figure (3): X-Ray Diffraction Pattern of Station 1 (at 2 m depth, upper level)

Station 1 at 3 meter depth-Bottom ,The X-Ray Diffraction (XRD) pattern of the sediments at Station 1, shown in Figure (4), indicates that the mineralogical composition is dominated by non-clay minerals. Quartz is the prevailing mineral, appearing with several distinct diffraction peaks, most notably the main peak at (2θ ≈ 26.6°), corresponding to a d-spacing of (3.34 Å). Additional secondary peaks were observed at lower angles, such as (2θ ≈ 20.8°) and (36.5°), with d-spacing values of (4.26 Å) and (2.46 Å), respectively. These results highlight the dominance of silicate components of continental origin in the sediments. Calcite was also detected with relatively high intensity, particularly at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with secondary peaks. This indicates a significant presence of carbonate material at this depth. Feldspar was identified with relatively weak intensity, with peaks near (2θ ≈ 27–28°), corresponding to d-spacing values between (3.30-3.18 Å), reflecting a limited contribution from igneous or metamorphic source rocks. Dolomite was recognized with low-intensity peaks at (2θ ≈ 31°), corresponding to a d-spacing of (2.89 Å), suggesting minor secondary dolomitization processes or the presence of a mixed carbonate source within the sediments.

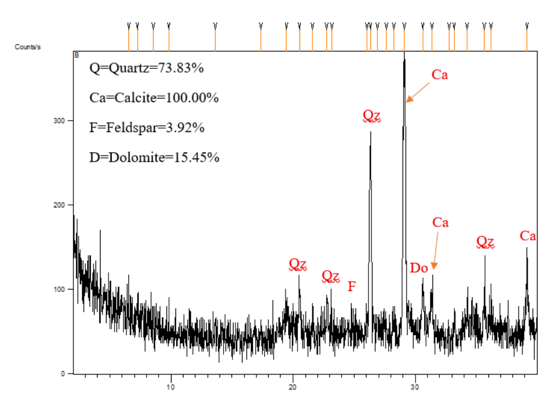


Figure (4): X-Ray Diffraction Pattern of Station 1 (at 3 m depth, lower level)

Station 2 at 2 m depth-Top, The X-Ray Diffraction (XRD) pattern of the sediments at Station 2, shown in Figure (5), indicates that the mineralogical composition is primarily dominated by non-clay minerals. Quartz is the prevailing mineral, with its main high-intensity peak appearing at (2θ ≈ 26.6˚), corresponding to a d-spacing of (3.34 Å). Additional secondary peaks were observed at lower angles, such as (2θ ≈ 20.8° and 36.5°), with d-spacing values of (4.26 Å) and (2.46 Å), respectively. These peaks confirm the abundance of silicate components of continental origin. Calcite was also identified with relatively high intensity, particularly at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with additional secondary peaks. This reflects a significant presence of carbonate material at this depth. In contrast, dolomite was detected with relatively weak intensity, with peaks at (2θ ≈ 31°), corresponding to a d-spacing of (2.89 Å), suggesting limited secondary dolomitization processes after deposition. Overall, the mineral assemblage reflects a clear dominance of silicate and carbonate minerals, with a secondary presence of dolomite. This composition indicates a coastal–transitional depositional environment influenced by fluctuating chemical and hydrodynamic conditions within the study area.

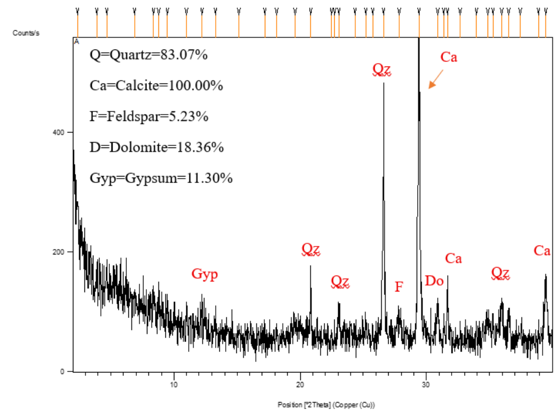


Figure (5): X-Ray Diffraction Pattern of Station 2 (at 2 m depth, upper level)

Station 2 at 3 m depth-Bottom, The X-Ray Diffraction (XRD) pattern of the sediments, shown in Figure (6), demonstrates the dominance of non-clay minerals in the mineralogical composition. Quartz is the prevailing mineral, with its main high-intensity peak appearing at (2θ ≈ 26.6°), corresponding to a d-spacing of (3.34 Å). Additional secondary peaks of lower intensity were also observed, confirming the dominance of silicate components of continental origin. Calcite was identified with relatively strong intensity, particularly at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with secondary peaks. This indicates a notable presence of carbonate material at this depth. Dolomite was also detected with relatively weak intensity, with its main peak at (2θ ≈ 31°), corresponding to a d-spacing of (2.89 Å), suggesting limited secondary dolomitization processes after deposition. Overall, this mineral assemblage reflects a clear dominance of silicate and carbonate minerals, with a minor contribution from dolomite. Such composition points to a coastal–transitional depositional environment influenced by fluctuating chemical and hydrodynamic conditions in the study area.

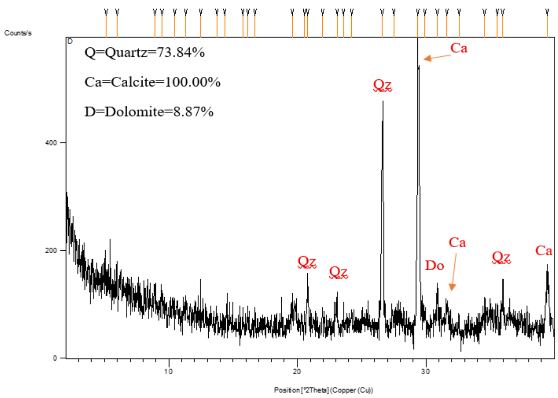
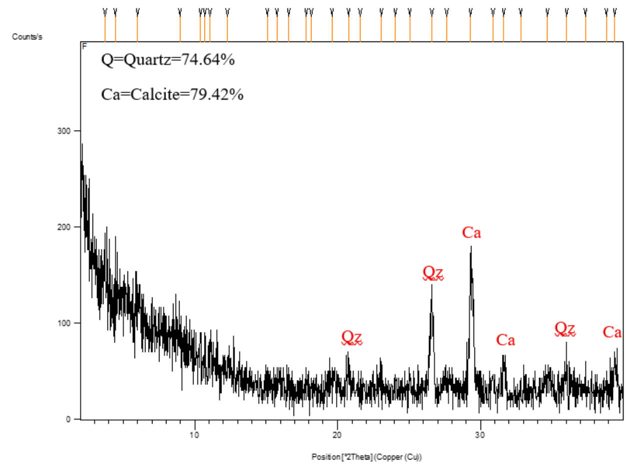


Figure (6): X-Ray Diffraction Pattern of Station 2 (at 3 m depth, lower level)

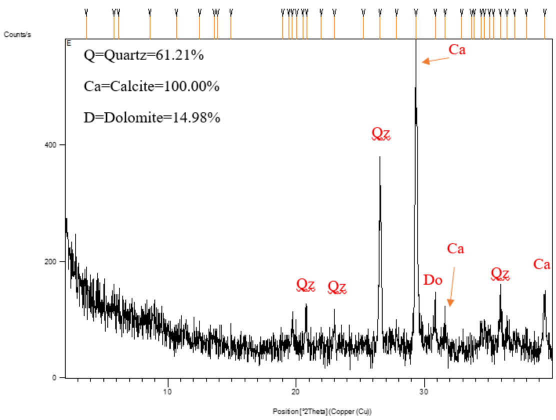
Station 3 at 2 m depth-Top, The X-Ray Diffraction (XRD) pattern of the sediments, shown in Figure (7), demonstrates the dominance of non-clay minerals in the mineralogical composition. Quartz is the prevailing mineral, with its main high-intensity peak recorded at (2θ ≈ 26.6°), corresponding to a d-spacing of (3.34 Å). Additional secondary peaks of lower intensity were also observed, confirming the dominance of silicate components of continental origin. Calcite was identified with clear intensity, particularly at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with other secondary peaks. This indicates a significant presence of carbonate material at this depth. Dolomite was also detected with relatively weak intensity, with its main peak at (2θ ≈ 31°), corresponding to a d-spacing of (2.89 Å), suggesting limited secondary dolomitization processes after deposition. Overall, the mineral assemblage reflects a clear dominance of silicate and carbonate minerals, with a minor contribution from dolomite. This composition points to a coastal–transitional depositional environment influenced by fluctuating chemical and hydrodynamic conditions in the study area.

Figure (7): X-Ray Diffraction Pattern of Station 3 (at 2 m depth, upper level)



Station 3 at 3 m depth-Bottom , The X-Ray Diffraction (XRD) pattern of the studied sample, shown in Figure (8), indicates that the mineralogical composition of these sediments is dominated by non-clay minerals. Quartz is the most abundant mineral, with its main high-intensity peak appearing at (2θ ≈ 26.6°), corresponding to a d-spacing of (3.34 Å). Additional secondary peaks of lower intensity were observed at higher angles, reflecting the dominance of silicate components of continental origin and their strong resistance to weathering and transport processes. Calcite was also identified with relatively clear intensity, particularly its distinctive peak at (2θ ≈ 29.4°), corresponding to a d-spacing of (3.03 Å), along with other secondary peaks. This indicates the presence of carbonate material in the sample, likely linked to carbonate deposition or the influence of limestone sources in the depositional environment. On the other hand, clay mineral peaks were either absent or very weak, accompanied by a relative increase in background intensity at lower angles. This suggests the presence of amorphous materials or extremely fine particles that did not produce distinct crystalline peaks in the diffraction pattern, This is consistent with what was concluded(Al-Badran and Al-Kaabi,2016).

Figure (8): X-Ray Diffraction Pattern of Station



3 (at 3 m depth, lower level)

3 DISCUSSION

The sedimentological and mineralogical analyses of the deposits in the Khor Al-Zubair area reveal that the prevailing depositional system is characterized by a clear dominance of fine-grained particles, with a high degree of uniformity in both textural and mineralogical properties across the studied stations. This pattern indicates that sedimentation processes in the area were not associated with high-energy conditions but rather occurred predominantly in relatively calm environments dominated by suspended deposition, a distinctive feature of modern coastal-estuarine settings.

Grain-size statistical parameters, particularly the mean and median values, fall within the range of medium to coarse silt, reflecting a transitional environment influenced by both fluvial input and limited coastal processes. This trend toward finer grain-size distribution is typically linked to the reduced efficiency of water currents in reworking sediments and removing fine materials. Recent studies have shown that such grain-size distributions are common in low-energy coastal environments, where relatively stagnant conditions allow fine sediments to accumulate over extended periods (Gao *et al*., 2021; Mishra *et al*., 2024).

The predominance of poor to moderate sorting observed in most sedimentary horizons does not indicate severe depositional disturbance but rather reflects periodic fluctuations in depositional energy. These fluctuations are likely driven by continuous variations in tidal current intensity, which deposit different grain sizes within the same sedimentary horizon without achieving effective sorting. Recent studies have highlighted that this depositional behavior represents a natural response in estuarine environments influenced by the interaction of fluvial discharge and tidal currents (Perera *et al*., 2023).

Bivariate relationships among statistical parameters further support this interpretation, demonstrating that sediment behavior is governed by similar transport and depositional mechanisms across the study area. This suggests relative stability in sediment supply sources, with only minor local influences reflecting slight variations in current strength or proximity to secondary water channels. Such depositional patterns are typical of khor (tidal inlet) environments, where hydrodynamic conditions vary spatially without causing major changes in the overall environmental framework.

Mineralogically, X-ray diffraction results reveal a clear dominance of non-clay minerals, with quartz being the most abundant. This indicates a continental origin of the sediments and their high resistance to weathering and transport processes. It also suggests continuous sediment input into the Khor Al-Zubair area from adjacent fluvial systems, followed by redistribution in a low-energy environment, consistent with recent sedimentological studies of transitional coastal settings (Gao *et al*., 2021; Boggs, 2012).

The presence of calcite in variable proportions reflects a carbonate contribution, either from biological activity in the adjacent shallow marine environment or from the re-deposition of calcareous materials. The secondary occurrence of dolomite suggests limited post-depositional transformation (secondary dolomitization), without significantly altering the overall sedimentary character. The occurrence of gypsum in certain horizons is interpreted as a reflection of localized chemical conditions, resulting from relatively elevated salinity and increased evaporation rates. Such conditions are recurrent in semi-enclosed coastal environments, as documented in recent studies of modern khor systems (Mishra *et al*., 2024).

4. CONCLUSION

The sedimentological study indicates that the sediments in the Khor Al-Zubair area are dominated by fine-grained particles, represented mainly by silt and clay, with a lower proportion of sand. This distribution is reflected in the sedimentary classification, which falls within fine silty-clay textures.

Grain-size analysis results Displaysss that the mean grain size is concentrated within the silt range, with positive skewness values recorded at all stations. This reflects the dominance of fine particles and indicates relatively calm depositional conditions associated with low-energy environments.

Minor vertical variations in sedimentary texture were observed at certain depths, while overall homogeneity was noted across most levels.

This suggests that changes in depositional conditions were temporary and limited, without causing interruptions or shifts in the general sedimentary pattern of the area.

X-Ray Diffraction (XRD) results revealed the dominance of non-clay minerals in the sediments, particularly quartz, which reflects sediment supply of continental origin with high resistance to weathering and transport. Calcite, dolomite, and gypsum were also identified, indicating the influence of chemical and diagenetic processes, consistent with the environmental characteristics of semi-enclosed coastal systems.

The strong similarity in sedimentological and mineralogical properties among the three stations (St1, St2, St3) confirms the unity of the prevailing depositional system during the studied periods. These fine-grained sediments represent a laterally extensive sedimentary unit, supporting the interpretation that Khor Al-Zubair deposits are recent coastal sediments formed within a tidal estuarine environment of low energy. They provide an important sedimentary record for understanding the evolution of the coastal environment in southern Iraq.

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