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Textural Analysis and Clay Mineralogy of Sabkha Sediments in Wadi El-Sahal and Wadi El-Suwani, Tobruk City, Libya

Mohamed Masoud[1], Mohammed Abas[1] and Fathi Ajweedah[2]

[1]*Department of Natural Resources University of Tobruk, Tobruk-Libya.*

[2]*Department of Environmental Sciences University of Tobruk, Tobruk-Libya.*

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A B S T R A C T

This study compares sediment characteristics of Wadi Elsahal and Wadi Al-Suwani sabkhas. This study sheds light on the grain size analysis and clay minerals, using the carbonate-sand-mud separation method, the sand-silt-clay method, and X-ray diffraction (XRD) to determine the proportions of clay minerals. In the intertidal zone, Wadi El-Suwani has a higher carbonate content (54.66%) than Wadi Elsahal (46.16%) and a slightly lower sand content (32.16% vs. 37%). The mud content is similar with Wadi El-Sahal slightly higher at 16.83%. In the supratidal zone, Wadi Elsahal shows higher carbonate (51.66%) and clay (29%), while Wadi El-Suwani has more sand (15%) and mud (47%). Both sabkhas show similar silt content (~69%). Clay mineral analysis from Wadi Elsahal reveals kaolinite ranging between 51–63% and illite from 37–49%. These differences reflect variations in depositional energy, with Wadi Elsahal indicating a stable carbonate-rich environment, while Wadi El-Suwani suggests more episodic energy events like wind or floods. Based on sediment and mineral composition, Wadi Elsahal represents a stable intertidal sabkha dominated by biogenic carbonates and fine sediments, while Wadi Al-Suwani reflects a dynamic supratidal sabkha environment influenced by variable energy and sediment supply. This study provides valuable insights into the sedimentary and mineralogical differences between Wadi ElSahal and Wadi El-Suwani sabkhas, contributing to a deeper understanding of coastal depositional processes in eastern Libya. The findings are significant for identifying stable versus dynamic sabkha environments, offering useful implications for sedimentology, geomorphological mapping, and environmental planning in arid coastal regions. There is a lack of detailed comparative studies focusing on the sediment and clay mineral characteristics of adjacent sabkha environments in eastern Libya especially between Wadi Elsahal and Wadi ElSuwani. This study aims to analyze and compare grain size and clay minerals in both sabkhas identify the dominant depositional processes and evaluate the environmental stability of each sabkha zone.

Introduction

The term sabkha refers to both coastal and inland salt flats, these features are common geomorphological elements along the Mediterranean coastline of Libya. Sabkha sediments are modestly developed at specific Wadi outlets, such as El-Sahal and Toburag, where both intertidal and supratidal sabkhas have been identified

Corresponding author: E-mail: Elwrfally2017@gmail.com

and sampled along the coastal zone of Tobruk city. Generally, sabkhas are influenced by flash flooding events, either due to tidal influx or seasonal rainfall in the main Wadis. During high tides, tidal pools are partially inundated with seawater on a daily and seasonal basis, leading to the formation of intertidal and supratidal sabkhas. The spatial distribution and presence of evaporite deposits in these environments are primarily governed by the prevailing climatic conditions during their deposition. Kinsman (1969). Wadis El-Sahal Toburag are home to the intertidal sabkha sediments, which are primarily formed of calcareous mud with a small amount of calcareous sandy mud. The composition of the supratidal sabkha deposits varies from calcareous mud and mixed siliciclastic-carbonate in Wadi Toburag, where clay silt class predominates, to pure carbonate Wadi El-Sahal. (Masoud et al., 2020). In Wadi El-Suwani at Al-Bardia Region, both intertidal and supratidal sabkhas contain high quantities of quartz, according to the mineralogical analysis, with smaller amounts of calcite, dolomite, albite, microcline, and hematite (Masoud and Khameiss, 2024). Additionally supporting the impact of terrestrial input and possible riverine inflow into the depositional environment is the occurrence of detrital minerals such as quartz and kaolinite in the Al Faidiyah Formation. According to these observations, the mineralogical composition and depositional properties of these formations are influenced by environmental conditions Masoud and Khameiss (2025). According to Weaver (1958), the diagenetic processes slightly alter the detrital clay minerals, which identify the parent rocks. Silicate minerals often undergo weathering and alteration to form new minerals, whereas transported clay minerals are the consequence of pre-existing clay minerals weathering and altering (Keller, 1970). Clay minerals are found in sediments and are associated with the source materials, the deposition environment, and the burial diagenesis (Millot, 1970). A sabkha is a flat, saline-enriched region subject to occasional flooding and dominated by carbonate or sulfate minerals. Periodic inundation, such as tidal or seasonal water input, followed by evaporation drives the accumulation of evaporites. They occur as intertidal or supratidal flats in arid zones and are often associated with poorly developed vegetation (El-Omla & Aboulela, 2012). There is a lack of detailed comparative studies focusing on the sediment and clay mineral characteristics of adjacent sabkha environments in eastern Libya especially between Wadi ElSahal and Wadi El Suwani This study aims to analyze and compare grain size and clay minerals in both sabkhas identify the dominant depositional processes and evaluate the environmental stability of each sabkha zone.

1 Materials and Methods

1.1 Field work

The study area is located between two geographical sites. The first is Wadi El Sahal, located within Tobruk City about 15 kilometers to the east at latitude 32°08′08″ N and longitude 23°49′48″ E. The second is Wadi El-Suwani situated in the Al Bardia region, approximately 140 kilometers east of Tobruk and close to the Libyan-Egyptian border, about 20 kilometers away, at latitude 31°45′07″ N and longitude 25°05′12″ E. Fig (1). Twelve samples were collected from two sabkhas, with six samples taken from each sabkha. Each sabkha was divided into an intertidal sabkha and a supratidal sabkha Fig (2).

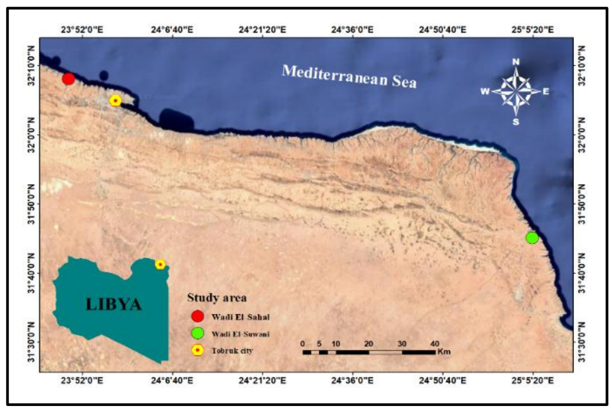

Figure. 1. Illustrates the study area which includes two sabkhas, one located to the west of Tobruk City and the other to the east.

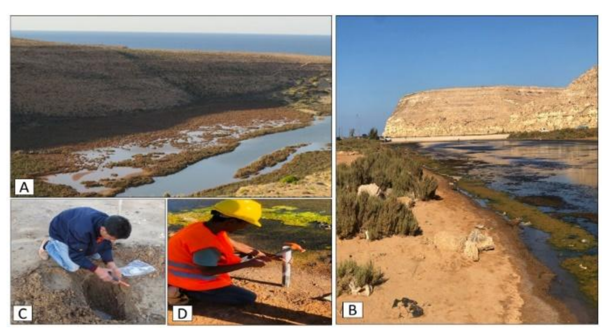

Figure. 2. A. Represents the Wadi El-Sahal sabkha. B. Shows the Wadi El-Suwani sabkha. Image C Illustrates the process of direct sample collection using the trench method where samples are placed in plastic bags. D. Shows the placement of the core sampler in the Wadi El-Suwani sabkha to preserve the samples inside the cores

1.2 Methods

Carbonate-sand-mud content

Twelve sabkha samples were examined to assess their carbonate, sand, and mud contents. Following grinding, all samples were soaked in distilled water to eliminate any soluble salts before being weighed. After drying, the samples were once more weighed. To eliminate the carbonates, samples were then gently heated to 60ºC for 30 minutes, and after that diluted HCl (10%) was progressively added. After the samples' effervescence stopped, they were cooled, cleaned by decanting them with distilled water to remove the acid, dried, weighed, and their carbonate content was determined. In order to eliminate the organic matter, H2O2 (6%) was additionally added to the samples (Carver, 1971; Tucker, 1988). Samples were carefully cleaned by decantation using distilled water, dried, and weighed once the action had ceased. The number of organic materials was then ascertained. A 0.063 mm wet sieve was used to separate the sand fraction from the residue, which was then dried and weighed. The mud fractions are collected in beakers after passing through a 0.063 mm sieve with water.

1.2.1 Sand - Silt - clay content:

The pipette method was used to analyses 12 mud samples (Folk, 1968). This technique relies on the fact that particles settle through a water column at size-dependent velocities in a diluted suspension. Samples need to be evenly distributed before applying this technique. Using a manual stirrer, the mud fractions that passed through the 0.063 mm filter were combined with distilled water and a dispersant (sodium hexameta phosphate solution) in a 1000 ml measuring cylinder. The following depth and time are followed when a pipette is gradually put into the fluid (Folk, 1968).

1.2.2 Clay mineralogy

The separated mud fractions were placed into a 1000 ml cylinder following the removal of salts, carbonates, organic materials, and the sand fraction. Following thorough dispersion, the clay fraction wall that remained was collected after 3 hours and 27 minutes from a depth of 5 cm and placed on sanitized glass slides (Carver, 1971). For each sample, three orientated slides were made separately, and the remaining clay was allowed to dry at ambient temperature. The first slide was inspected as an air-dried sample, the second was heated to 550˚ for two hours, and the third was treated with ethylene glycol in an oven set at 60˚ for roughly four hours (Hardy and Tucker, 1988), then cooled gradually before being analyzed as the hot specimen. Crystalline mineral phases found in the hydration products were identified at the Metallurgy Institute of Minerals using an X-ray diffractometer type PW3710 with Cu Kα radiation.

2 Result and Discussion

2.1 Carbonate-sand-mud Analysis

The results obtained are given in Table (1), and Figs (3) provide a graphic representation of how these components vary in depth.

Table. 1: The coastal Sabkha sediments' carbonate, sand, and mud components were estimated.

S. No.	Depth cm	Sabkha			Carbonate %	Sand %	Mud %
1	0-5	Wadi El-sahal	Intertidal	Core	48	42	10
2	5-9				40.5	34	25.5
3	9-15				50	35	15
Average					46.16	37	16.83
4	0-8		Supratidal	Trench	55	2	43
5	8-14				53	2	45
6	14-22				47	2.5	50.5
Average					51.66	2.16	46.16
7	0-6	Wadi El-Suwani	Intertidal	Core	55	33	12
8	6-9				51	35	14
9	9-17				58	28.5	13.5
Average					54.66	32.16	13.16
10	0-12		Supratidal	Trench	41	5	54
11	12-26				60	4	36
12	26-30				45.5	3.5	51
Average					48.83	4.16	47

Based on the analytical results presented for the sediments of Wadi El-Sahal and Wadi El-Suwani sabkhas, a comparative assessment reveals distinct differences in their carbonate, sand, and mud content across both intertidal and supratidal zones. In the intertidal zone, Wadi El-Suwani shows a higher average carbonate content (54.66%) compared to Wadi El-Sahal (46.16%). This indicates that the El-Suwani intertidal environment is more enriched in carbonate materials, which may reflect higher biological productivity or sedimentation from carbonate sources. The sand content is also slightly lower in Wadi El-Suwani (32.16%) compared to Wadi El-Sahal (37%), while the mud content is relatively similar with Wadi El-Sahal having a slightly higher value (16.83%) than Wadi El-Suwani (13.16%). In the supratidal zone, a more pronounced contrast is observed. Wadi El-Suwani again shows a higher average mud content (47%) compared to Wadi El-Sahal (46.16%) but significantly lower carbonate content (48.83%) compared to Wadi El-Sahal (51.66%). Additionally, sand content in Wadi El-Suwani remains minimal (4.16%) compared to Wadi El-Sahal (2.16%), although both sabkhas exhibit very low sand proportions in the supratidal environment. Based on these compositional characteristics, Wadi El-Sahal sabkha can be classified as a carbonate-rich intertidal sabkha with moderate mud accumulation and low sand content, indicating moderate depositional energy and biogenic inputs. In contrast, Wadi El-Suwani sabkha, particularly in its supratidal zone is characterized by high mud and moderate carbonate accumulation, suggesting a lower energy setting with limited wave action and stronger influence of evaporation and fine sediment trapping, classifying it as a muddy supratidal sabkha with increasing carbonate influence toward the intertidal area (Alsharhan & Kendall, 2003). There is a noticeable similarity in sand content among the samples collected from the cores in both sabkhas. In the intertidal zone of Wadi El-sahal the sand percentages from the core samples are 42%, 34%, and 35%, with an average of 37%. Similarly in Wadi El-Suwani intertidal zone, the sand percentages are 33%, 35%, and 28.5%, with an average of 32.16%. This close range in values indicates a consistent sedimentological environment in both locations, with comparable depositional energy and grain size distribution during the formation of the intertidal sediments. The similarity in sand percentages between the cores suggests that both sabkhas have experienced similar hydrodynamic conditions influencing the sorting and deposition of sand-sized particles in their intertidal zones, despite variations in carbonate and mud content (Woodroffe, 2002; Scholle & Ulmer-Scholle, 2003).

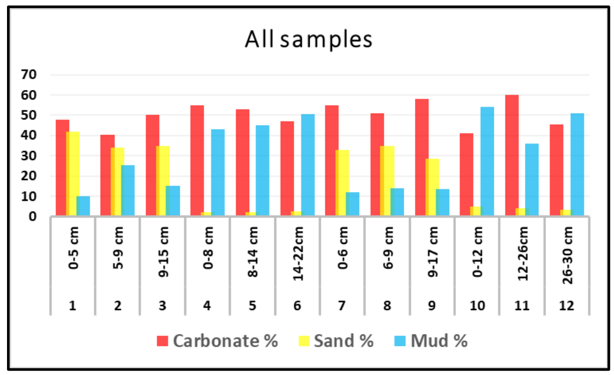

Figure. 3. Vertical distribution of carbonate - sand - mud content with depth in the intertidal and Supratidal sabkha sediments of Wadi El-Sahal and Wadi El-Suwani.

2.2 Sand -silt - clay composition Analysis

The following is a description of the texture classes found in the analyzed Sabkha samples: Table (2) and represented graphically in bar graphs shown in Figs (4)

Table 2. Data of sand - silt - clay composition determined in the sabkha sediments

S. No.	Depth cm	Sabkha			Sand %	Silt %	Clay %
1	0-5	Wadi El-Sahal	Intertidal	Core	5	67	28
2	5-9				1	70	29
3	9-15				3	73	24
Average					3	70	27
4	0-8		Supratidal	Trench	2	60	38
5	8-14				2	68	30
6	14-22				1	80	19
Average					1.66	69.33	29
7	0-6	Wadi El-Suwani	Intertidal	Core	4	70	26
8	6-9				6	72	22

9	9-17				8	67	23
Average					6	69.66	23.66
10	0-12		Supratidal	Trench	7	73	20
11	12-26				22	62	16
12	26-30				16	74	10
Average					15	69.66	15.33

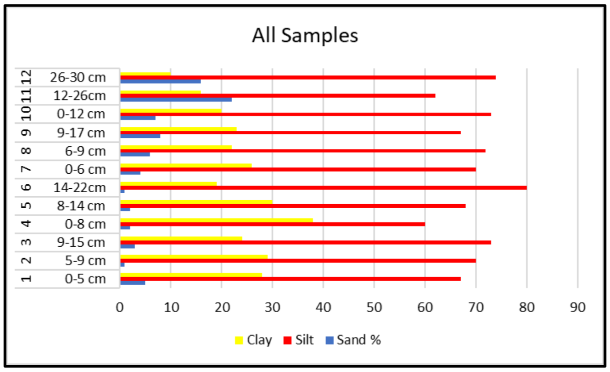

Figure. 4. Vertical distribution of Sand -silt - clay content with depth in the intertidal and Supratidal sabkha sediments of Wadi El-Sahal and Wadi El-Suwani.

The sediment profiles of Wadi El-Sahal and Wadi El-Suwani sabkhas demonstrate important differences in sand silt and clay distribution across the intertidal and supratidal zones. In the intertidal zone, Wadi El-Sahal exhibits a very low sand content averaging only 3% while silt and clay reach 70% and 27%, respectively indicating, a dominance of fine-grained sediments influenced by low-energy depositional environments (Zahran & Abou El-Anwar 2019)

Wadi El-Suwani intertidal zone shows slightly higher sand content with an average of 6 percent while silt and clay are nearly similar to those in Wadi El-Sahal with values of 69.66 percent and 23.66 % respectively suggesting similar depositional settings with slightly stronger energy conditions capable of transporting small amounts of sand (Mansour et al 2023.)In the supratidal zone Wadi El-Sahal maintains low sand content at 1.66 percent with silt at 69.33 percent and clay at 29 percent reflecting a predominantly muddy and stable sabkha surface where wind and evaporation processes dominate over water movement (Salem and Omar 2018).Wadi El-Suwani supratidal zone differs significantly with an average sand content of 15 percent silt at 69.66 percent and clay decreasing to 15.33 percent indicating a higher influence of episodic energy events possibly wind-driven or occasional flooding that brings in coarser materials (Shahin et al 2022).

The similarity in silt content between both sabkhas in all zones suggests consistent fine sediment input, likely from atmospheric dust or evaporitic deposition. The significant difference lies in sand content especially in the supratidal zone where Wadi El-Suwani receives greater sand accumulation than Wadi El-Sahal possibly due to local geomorphological differences or sediment supply (Ali and Al-Hashimi 2020). The generally low sand percentages in both sabkhas, especially in the intertidal zone, are attributed to the sabkha environment's low-energy conditions, which prevent the transportation and deposition of coarser materials like sand. These coastal plains are dominated by wind and evaporation rather than strong currents or wave action, thus favoring the accumulation of silt and clay (Abu Khadra et al 2021).

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2.3 Pipette analysis of sabkha mud samples

Data in percentage are summarized in Table (3) and are illustrated graphically in bar graphs diagram shown in Fig. (5).

Table 3. Results of pipette analysis in percentages for different mud fractions.

S. No.	Depth cm	Sabkha			C. Silt 5 Ø	M. Silt Ø 6	F. Silt 7 Ø	V. F. Silt 8 Ø	Clay 9 Ø
1	0-5	Wadi El-Sahal	Intertidal	Core	15	20	18	13	34
2	5-9				19	27	14	7	33
3	9-15				14	30	22	10	24
Average					16	25.66	18	10	30.33
4	0-8		Supratidal	Trench	15	10	12	13	50
5	8-14				10	2	6	14	68
6	14-22				17	10	1	20	52
Average					14	7.33	6.33	15.66	56.66
7	0-6	Wadi El-Suwani	Intertidal	**Core**	30	9	25	3	33
8	6-9				43	19	2	8	28
9	9-17				41	21	5	6	27
Average					38	16.33	10.66	5.66	29.33
10	0-12		Supratidal	Trench	20	2	23	13	42
11	12-26				4	12	3	25	56
12	26-30				60	5	10	2	23
Average					28	6.33	12	13.33	40.33

It is observed that in Wadi Al-Sahl the samples collected from the cores were dominated by silty sand and clay, while the samples collected from the trench contained coarse silt, and the highest percentage 56% was clay in contrast in Wadi El-Suwani the coarse silt and clay were the most abundant components in all the samples whether collected from the cores or the trench Overall, the increased silt content in intertidal sabkhas is the result of a balance between sediment supply, moderate hydrodynamic activity, periodic inundation, and biogenic surface stabilization. These factors work synergistically to favor the deposition and preservation of silt within the intertidal zone (Qassas et al., 2024). These areas often receive sediment inputs through aeolian transport and episodic fluvial flows. During rare rainfall events or flash floods, suspended fine sediments are transported from inland regions toward the sabkhas. Additionally, wind-blown dust contributes to the steady deposition of clay-sized particles (Khalaf & Al-Ruwaih, 1996). Also, the strong evaporative regime in arid zones causes groundwater to rise via capillary action, bringing dissolved salts to the surface. This evaporation-driven mechanism promotes the precipitation of evaporite minerals such as gypsum and halite, which can trap and stabilize fine sediments, thereby enhancing the mud content in the sabkha surface (Barth & Böer, 2002).

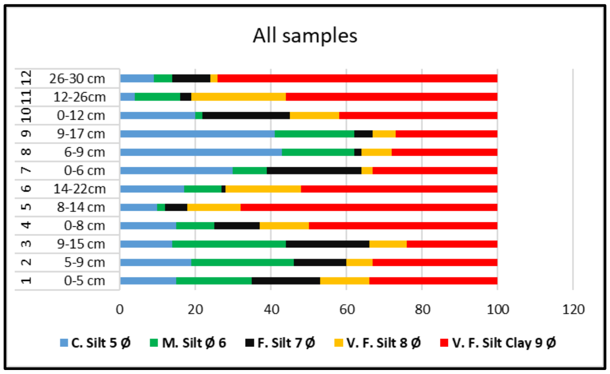

Figure. 5. Percentages of silt and clay fractions in intertidal and Supratidal sabkha sediments of Wadi El-Sahal and Wadi El-Suwani.

2.4 XRD of clay minerals in sabkha deposits

Table (4) provides a summary of the results, and Figure (6) provides a bar graph that graphically represents them. Their patterns of X-ray diffraction are displayed in Figures (7) Kaolinite and illite make up the majority of the clay minerals found in the investigated Sabkahs deposits.

Table 4.: Relative percentages of clay minerals determined in sabkha deposits.

S. No	Depth (cm)	Sabkha		Kaolinite %	Illite %
1	0-5	W. El-Sahal	Intertid	51	49
7	0-6	Wadi El-Suwani		63	37

Two sediment samples were collected from different sabkha environments to analyze the clay mineral composition, focusing on kaolinite and illite. The first sample was taken from the intertidal zone of Wadi El-Sahal at a depth of zero to five centimeters. The results showed that the typical peaks of kaolinite mineral with d-spacing of 7.03Aº (001) were seen in all analysed samples. The range of its content is 51–63%. The illite mineral, on the other hand, was distinguished by its distinctive peak of 10 Å, which ranges from 37 to 49%. A strong leaching environment is necessary for the creation of kaolinite, which is generally formed by the weathering and soil formation of all rocks. In marsh environments, such circumstances are typically found, and kaolinite is a typical mineral of continental weathering (Millot, 1970). Transportation often has no effect on kaolinite, so its composition and quantity remain unchanged when it enters the basin of deposition (Perrin, 1971). According to Carroll (1971), illite may be the direct result of chemical weathering in alkaline, semi-arid, and arid soils.

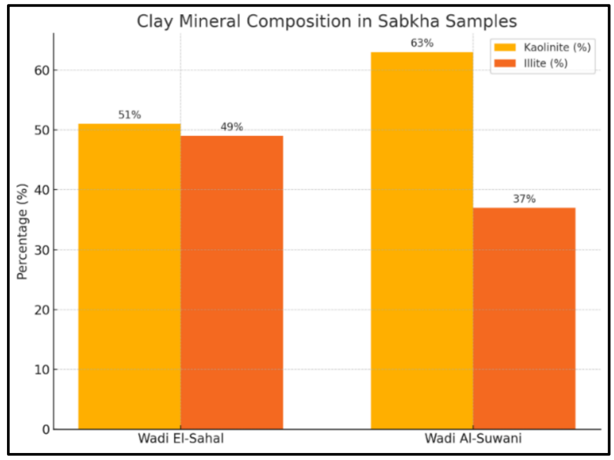

Figure. 6. Histograms showing the relative percentages of clay minerals in the intertidal sabkha.

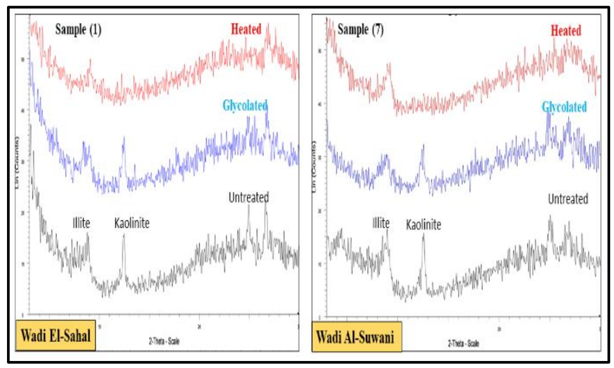

Figure. 7. X-ray diffraction pattern showing the clay minerals identified Wadi El-Sahal and Wadi El-Suwani.

3 Conclusions

This study aimed to explore and compare the sedimentological and mineralogical features of sabkha environments in Wadi El-Sahal and Wadi Al-Suwani, both located along the coastal zone of Tobruk, eastern Libya. Through the analysis of grain size distribution, carbonate content, and clay mineral composition, clear differences were identified between the two sabkhas, shaped by their distinct geomorphological settings and depositional dynamics.

The intertidal sediments in both areas were largely composed of silt and clay, indicating low-energy conditions. However, Wadi El-Sahal showed a higher proportion of clay and finer silt fractions, suggesting a relatively more stable and calmer depositional environment, likely dominated by gradual sedimentation and limited disturbance. In contrast, Wadi El-Suwani presented higher carbonate content and a noticeable increase in coarser silt particles, hinting at more active sediment input, possibly related to intermittent wind or flood events.

In the supratidal zones, the contrast became more pronounced. Wadi Wadi El-Sahal maintained its fine-grained character, with high clay content and minimal sand, reflecting a surface shaped by evaporation and low-energy accumulation. On the other hand, Wadi El-Suwani displayed a higher sand fraction and lower clay content, pointing to periodic influences of stronger energy processes that may carry and deposit coarser materials.

The pipette analysis provided further support for these observations, with Wadi El-Sahal samples being richer in very fine and fine silt, while Wadi El-Suwani had a greater share of medium to coarse silt. Mineralogical analysis confirmed that kaolinite and illite are the dominant clay minerals in both sabkhas, with Wadi El-Suwani exhibiting slightly higher kaolinite content, possibly reflecting enhanced continental weathering input.

In summary, Wadi El-Sahal can be described as a stable sabkha environment where fine particles and carbonate materials settle gradually under calm conditions. In contrast, Wadi El-Suwani reflects a more dynamic setting, influenced by fluctuating energy levels and a broader range of sediment inputs. These differences underscore the importance of local geomorphology and climatic influences in shaping the nature of coastal sabkhas in arid regions.

4 Recommendations

Based on the sedimentological and mineralogical findings of this study, the following recommendations are proposed:

It is recommended to extend the mineralogical analysis to include additional clay minerals such as smectite and chlorite, especially in the supratidal zones where sediment input may vary seasonally. This would offer a more complete picture of the diagenetic processes affecting sabkha environments in eastern Libya.

Future studies should integrate geochemical indicators (e.g., salinity, trace elements, organic carbon content) to better understand the interaction between sediment composition and environmental factors such as evaporation and groundwater rise.

Employing satellite imagery and GIS-based tools in future research can assist in mapping sabkha expansion, sediment distribution, and identifying changes over time without relying solely on field sampling

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