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Geochemical Investigation of Quaternary Sabkha Sediments in the Sirte Basin, North Central Libya

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Abstract

In this study, the depositional environment, paleoweathering, paleoclimate, maturity, and paleoproductivity of the sediments of Sabkhat Wadi Matratin, As Sabkha Al Kabirah, Sabkhat Al Uwayjah, Sabkhat Ghuzayil, Sabkhat Zaqqut, Hatiyat Al Muhayriqah, Hatiyat Muraq, Hatiyat Jabbanah, and Qarat Suhub were appraised based on the major oxide concentrations. The results showed that the studied sediments were deposited in a suboxidized marine environment with noteworthy terrestrial input. The arid conditions prevailed during the deposition. It's possible that the sediments have been somewhat weathered or are extremely fresh. The immaturity of the sediments is a defining feature. There was variation in the paleoproductivity from low to high.
Keywords: Geochemistry, Sabkha Sediments, Depositional Environment, Paleoweathering, Paleoclimate, Maturity, Paleoproductivity, Sirte Basin, Libya.

1. Introduction

Sabkha, also known as a salt marsh, is divided into two types: (1) Coastal sabkha; and (2) Inland sabkha. The inland sabkha is situated farther from the coast and receives its water and salt supply from groundwater, rainfall, or old trapped brines rather than direct tidal flooding. In contrast, the coastal sabkha is a salt flat close to the shoreline that is occasionally flooded by seawater (e.g., Banat *et al.,* 2005; König, 2012; Chenchouni, 2017; Rajendran *et al.,* 2021). Previously, the sabkha sediments in Libya were studied in terms of mineralogy, sedimentology and geochemistry (e.g., Abdel Galil and El-Fergany, 2011; Musa, 2016; Shaltami *et al.,* 2017; Mohammed *et al.,* 2021, 2022; Masoud and Khameiss, 2024). This study intends to assess the geochemistry of sabkha sediments in the Sirte Basin, north-central Libya. The depositional environment, paleoclimate, maturity and paleoproductivity were determined utilizing major oxide data. The sediments of nine sabkhas (Sabkhat Wadi Matratin, As Sabkha Al Kabirah, Sabkhat Al Uwayjah, Sabkhat Ghuzayil, Sabkhat Zaqqut, Hatiyat Al Muhayriqah, Hatiyat Muraq, Hatiyat Jabbanah, and Qarat Suhub, Fig. 1) were evaluated. There are two coastal sabkhas (Sabkhat Wadi Matratin and Sabkhat Al Uwayjah), while the other sabkhas (As Sabkha Al Kabirah, Sabkhat Ghuzayil, Sabkhat Zaqqut, Hatiyat Al Muhayriqah, Hatiyat Muraq, Hatiyat Jabbanah, and Qarat Suhub) are of the inland type. The age of the studied sediments ranges from Pleistocene to Holocene (Njoma, 1980; Innocenti and Pertusati, 1984; Domaci, 1985; Jurak, 1985; Kodym, 1985).

2. Methodology

The chemical data provided by Njoma (1980), Innocenti and Pertusati (1984), Domaci (1985), Jurak (1985), and Kodym (1985) were utilized by the authors. The chemical data were obtained using X-ray fluorescence (XRF). A total of seventeen samples were assessed in this study (Fig. 1). The studied samples are clastics and evaporites. Notably, the elemental concentrations reported by Njoma (1980), Domaci (1985), Jurak (1985), and Kodym (1985) were used to determine the major oxide concentration in the sediments of Sabkhat Al Uwayjah, Sabkhat Ghuzayil, Sabkhat Zaqqut, Hatiyat Al Muhayriqah, Hatiyat Muraq, Hatiyat Jabbanah, and Qarat Suhub. To calculate the values of FeO*, CaO in the silicate fraction (CaO*), chemical index of alteration (CIA), weathering indices (α_{Mg} and α_{Ca}), and index of compositional variability (ICV), the equations shown in Table 1 were used.

3. Results and Discussion

The major oxide concentration varies noticeably due to the various types of the studied sediments (the values of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, SO_3, and Cl range from 1.07 to 50.96%, 0.02 to 0.48%, 0.14 to 7.65%, 0.07 to 3.96%, 0.06 to 3.56%, 0.01 to 0.06%, 0.63 to 12.32%, 0.89 to 38.49%, 0.49 to 38.72, 0.15 to 12.42%, 0.01 to 0.2%, 1.4 to 51.02%, and 0.46 to 57.29%, respectively, Table 2).

3.1. Depositional Environment

A number of parameters, including MgO, Fe_2O_3, SiO_2/Al_2O_3, Fe/Al, Ca/(Ca+Fe) and Al/(Al+Fe), can be used to define the depositional environment (Lyons and Severmann, 2006; Ratcliffe *et al.,* 2007; Liu *et al.,* 2015; He *et al.,* 2019; Khan *et al.,* 2023). The deposition of the studied sediments in a marine environment is clearly illustrated in Figs. 2-5. Moreover, it is also evident that there was terrestrial input during deposition, as demonstrated in Fig. 5. In addition, the Fe/Al ratio (0.3-0.92) indicates that suboxic conditions were the prevailing paleo-oxygenation setting.

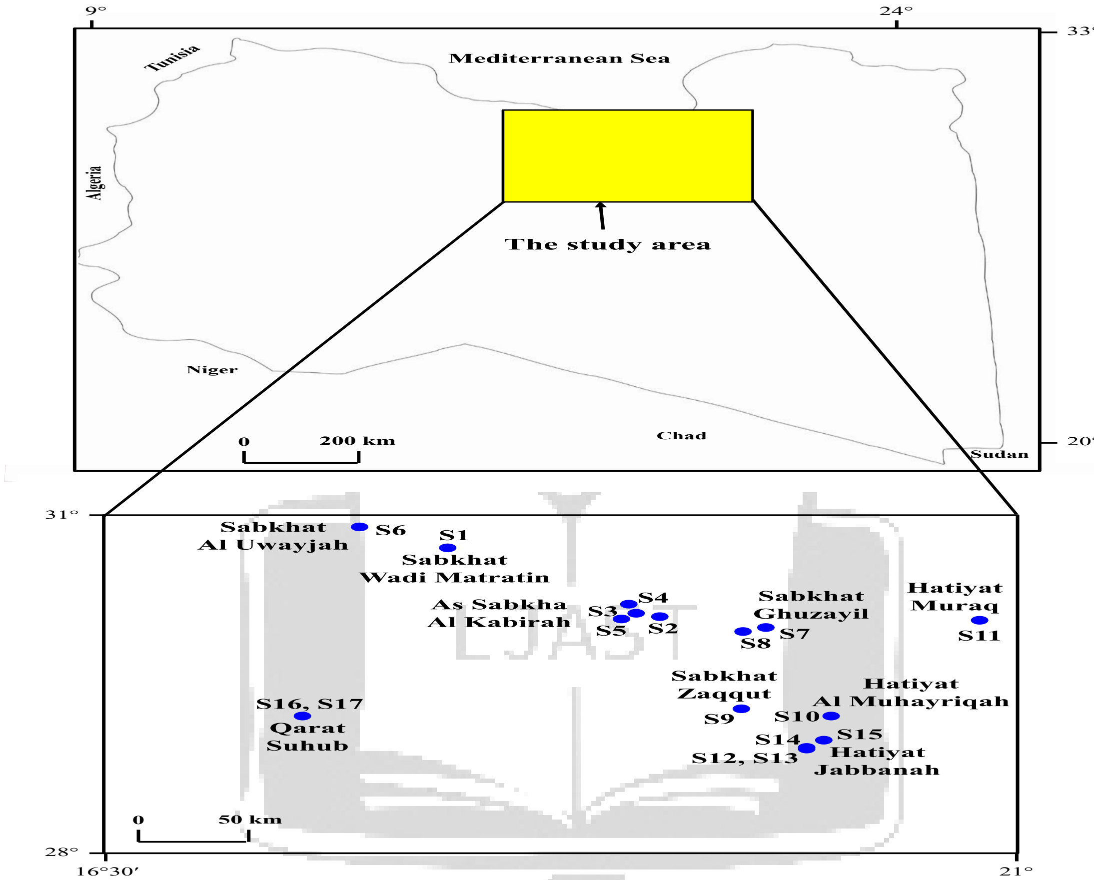

Fig. 1: Location map of the studied sabkhas (modified after Njoma, 1980; Innocenti and Pertusati, 1984; Domaci, 1985; Jurak, 1985; Kodym, 1985).

Table 1: Equations utilized to calculate the parameters

Parameters	Equation	Reference
FeO	$FeO = 0.8998*Fe_2O_3$	
CaO*	If $Na_2O>CaO-P_2O_5$, then $CaO* = CaO-P_2O_5$, while if $Na_2O<CaO-P_2O_5$, then $CaO* = Na_2O$	McLennan *et al.* (1993)
Chemical index of alteration	$CIA = (Al_2O_3/(Al_2O_3+CaO^*+Na_2O+K_2O))100$	Nesbitt and Young (1982)
Weathering indices	$\alpha_{Mg} = (Al/Mg)_{sample}/(Al/Mg)_{upper\ continental\ crust}$ $\alpha_{Ca} = (Ti/Ca)_{sample}/(Ti/Ca)_{upper\ continental\ crust}$	Gaillardet *et al.* (1999)
Index of compositional variability	$ICV = (Fe_2O_3+K_2O+Na_2O+CaO*+MgO+MnO+TiO_2)/Al_2O_3$	Cox *et al.* (1995)

Table 2: Chemical analysis data (concentration in wt%) of the studied sabkha sediments (after Njoma, 1980; Innocenti and Pertusati, 1984; Domaci, 1985; Jurak, 1985; Kodym, 1985)

Area	Lithology	Sample No. in the sheets	Sample No. in this work	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO*	MnO	MgO
Sabkhat Wadi Matratin	Sandstone	21	S1	50.96	0.44	6.56	2.59	2.33	0.06	5.83
As Sabkha Al Kabirah	Siltstone	32	S2	14.02	0.10	2.66	0.66	0.59	0.01	1.84
	Silt	33	S3	30.20	0.48	7.65	3.96	3.56	0.05	5.49
	Salt	34	S4	2.61	0.02	0.34	0.13	0.12	0.01	0.63
	Sand	35	S5	5.32	0.03	0.45	0.20	0.18	0.02	1.09
Sabkhat Al Uwayjah	Evaporite	2	S6	1.07	-	0.14	0.07	0.06	-	0.86
Sabkhat Ghuzayil	Evaporite	51	S7	7.56	0.12	1.13	0.54	0.49	0.01	1.82
	Evaporite	52	S8	14.00	0.18	2.42	0.84	0.76	0.02	2.42
Sabkhat Zaqqut	Evaporite	54	S9	10.93	0.13	1.62	0.60	0.54	0.02	1.35
Hatiyat Al Muhayriqah	Evaporite	55	S10	5.85	0.26	1.16	0.81	0.73	0.01	1.18
Hatiyat Muraq	Evaporite	56	S11	47.77	0.10	1.07	0.24	0.22	0.01	1.25
Hatiyat Jabbanah	Halite	30	S12	1.63	0.08	0.23	0.09	0.08	0.00	3.72
	Gypsum	31	S13	3.17	0.08	0.60	0.28	0.25	0.01	0.73
	Evaporite	32	S14	25.70	0.30	2.72	1.03	0.93	0.03	5.05
	Evaporite	34	S15	9.97	0.03	0.72	0.26	0.23	0.01	12.32
Qarat Suhub	Evaporite	54	S16	9.03	0.13	1.86	0.87	0.78	0.02	2.03
	Evaporite	55	S17	31.28	0.38	4.89	2.42	2.18	0.05	5.28

3.2. Paleoweathering

Three parameters—CIA, α_{Mg}, and α_{Ca}—were used to assess the paleoweathering of the studied sediments. Low chemical weathering or extremely fresh sediments are indicated by the CIA values (0.29-61.89%, Fig. 6). The values of α_{Mg}, and α_{Ca} (0.01-0.17 and 0.001-0.12, respectively) support this assumption.

3.3. Paleoclimate and Maturity

Libya's climate changed during the Holocene from a largely arid Pleistocene to a humid period in the Early to Middle Holocene, characterized by Saharan lakes and marshes, and then gradually returned to desert conditions in the Late Holocene. Conditions throughout the Pleistocene were more arid, but not hyper-arid, especially before the Last Glacial Maximum. This aridity gradually increased until the Holocene Wet Period started about 9.4 ka BP. Arid periods, such the 8.2 ka aridity event, caused the vegetation to dwindle during the Holocene's more humid phase, which was followed by the Late Holocene when arid conditions returned. The prevalence of arid climate during the deposition of the studied sabkha sediments is clear in Figs. 7 and 8. Furthermore, it is evident from the ICV values (1.98-358.83) that the studied sediments are immature.

Table 2: Continued

Area	Lithology	Sample No. in the sheets	Sample No. in this work	CaO	Na_2O	K_2O	P_2O_5	SO_3	Cl
Sabkhat Wadi Matratin	Sandstone	21	S1	15.31	1.28	1.48	0.09	3.62	-
As Sabkha Al Kabirah	Siltstone	32	S2	18.83	10.21	0.55	0.02	28.80	9.58
	Silt	33	S3	19.95	3.80	1.67	0.14	13.80	-
	Salt	34	S4	23.66	6.86	0.15	0.01	41.18	5.09
	Sand	35	S5	23.12	9.35	0.29	0.01	32.74	7.39
Sabkhat Al Uwayjah	Evaporite	2	S6	2.09	-	0.37	-	1.40	57.29
Sabkhat Ghuzayil	Evaporite	51	S7	36.04	0.49	0.23	0.01	47.71	0.46
	Evaporite	52	S8	9.65	26.00	0.69	0.01	15.79	28.36
Sabkhat Zaqqut	Evaporite	54	S9	36.65	0.58	0.34	0.01	34.25	0.90
Hatiyat Al Muhayriqah	Evaporite	55	S10	7.85	36.88	0.27	0.08	5.84	43.02
Hatiyat Muraq	Evaporite	56	S11	20.23	0.92	0.36	0.02	22.50	0.70
Hatiyat Jabbanah	Halite	30	S12	0.89	38.72	1.20	0.01	6.24	49.87
	Gypsum	31	S13	38.49	0.77	0.16	0.01	51.02	2.44
	Evaporite	32	S14	13.65	11.53	0.67	0.06	15.92	12.56
	Evaporite	34	S15	4.69	9.86	12.42	0.12	6.35	40.23
Qarat Suhub	Evaporite	54	S16	5.76	37.16	0.42	0.11	3.90	42.93
	Evaporite	55	S17	19.23	6.27	1.11	0.20	17.18	7.40

3.4. Paleoproductivity

To evaluate the paleoproductivity of the studied sediments, the P/Al and P/Ti ratios were employed. These parameters imply that the paleoproductivity fluctuated from low to high levels (Fig. 9). It should be noted that the paleoproductivity of the Sabkhat Al Uwayjah sediments has not been evaluated because P is not analyzed in these sediments.

4. Conclusions

This study yielded five conclusions:

(1) Significant terrestrial input was present in the suboxidized marine environment where the studied sediments was deposited.

(2) The predominant conditions during deposition were arid.

(3) The sediments may be very fresh or have undergone some weathering.

(4) Immaturity is a characteristic of the sediments.

(5) The paleoproductivity differed significantly.

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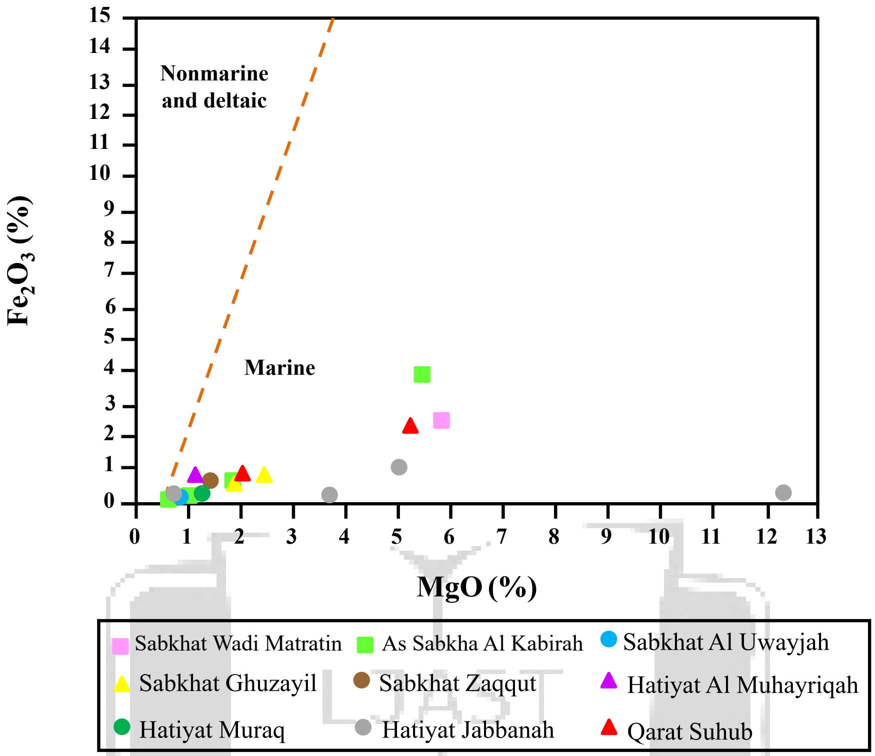

Fig. 2: Binary plot of MgO vs. Fe_2O_3 showing the depositional environment of the studied sabkha sediments (fields after Ratcliffe *et al.*, 2007).

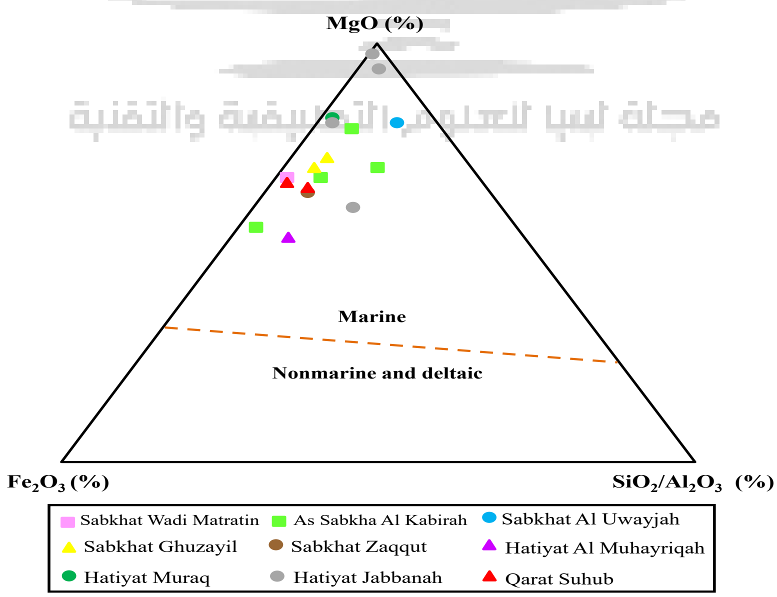

Fig. 3: Ternary plot of MgO-Fe_2O_3-SiO_2/Al_2O_3 showing the depositional environment of the studied sabkha sediments (fields after Ratcliffe *et al.*, 2007).

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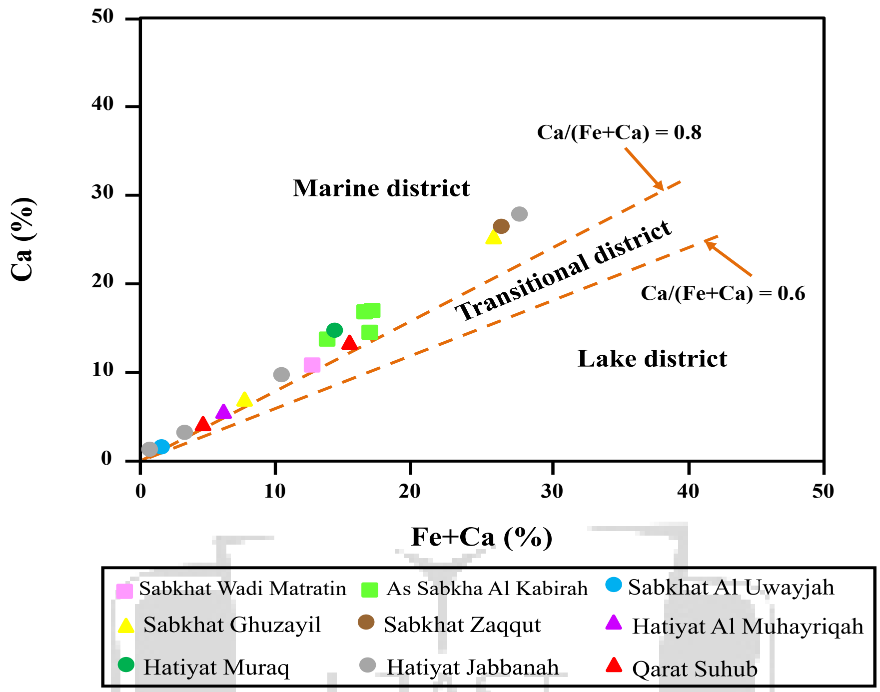

Fig. 4: Binary plot of Fe+Ca vs. Ca showing the depositional environment of the studied sabkha sediments (fields after He *et al.*, 2019).

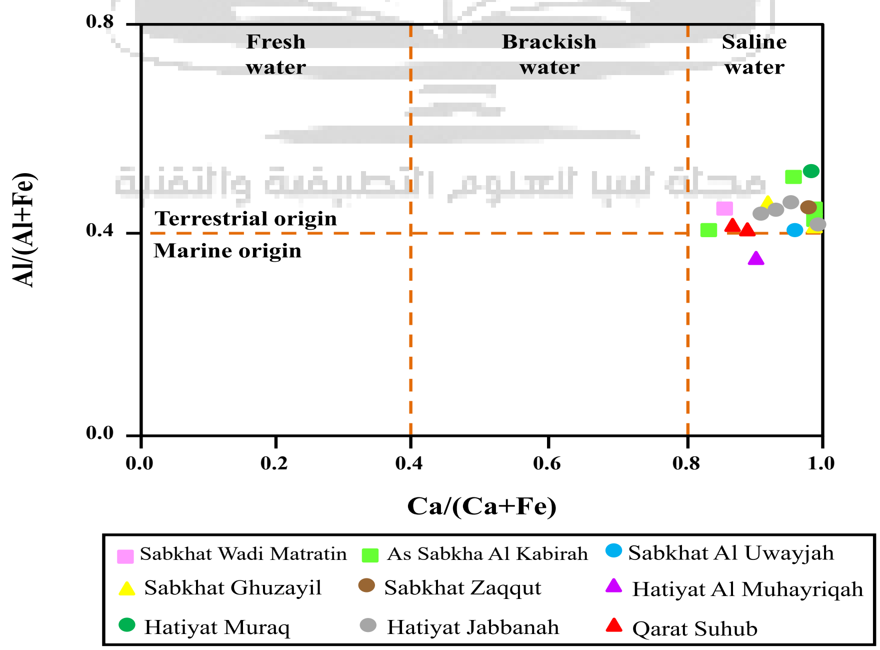

Fig. 5: Binary plot of Ca/(Ca+Fe) vs. Al/(Al+Fe) showing the depositional environment of the studied sabkha sediments (fields after Liu *et al.*, 2015; Khan *et al.*, 2023).

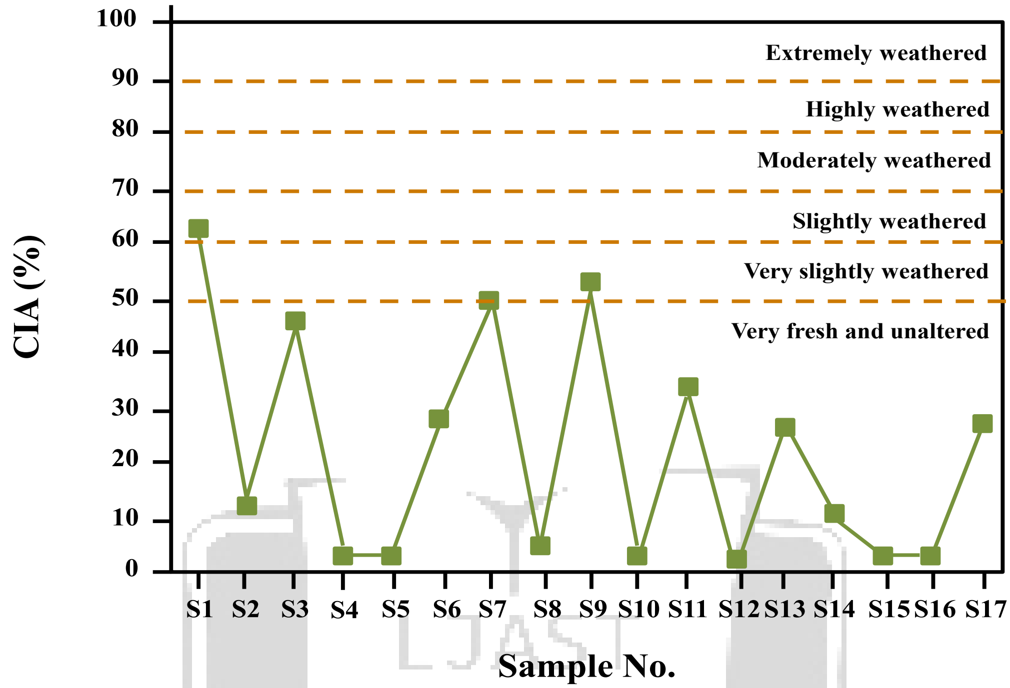

Fig. 6: Binary plot showing the paleoweathering effect on the studied samples based on the CIA values (fields after Nesbitt and Young, 1982).

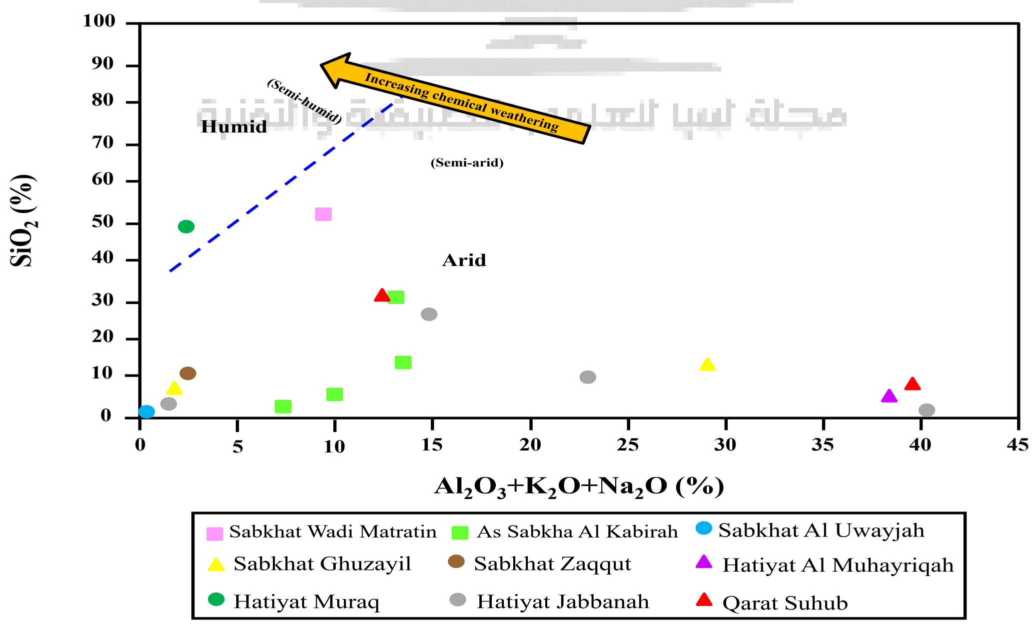

Fig. 7: Binary plot of $Al_2O_3+K_2O+Na_2O$ vs. SiO_2 showing the paleoclimate conditions during deposition of the studied sediments (fields after Suttner and Dutta, 1986).

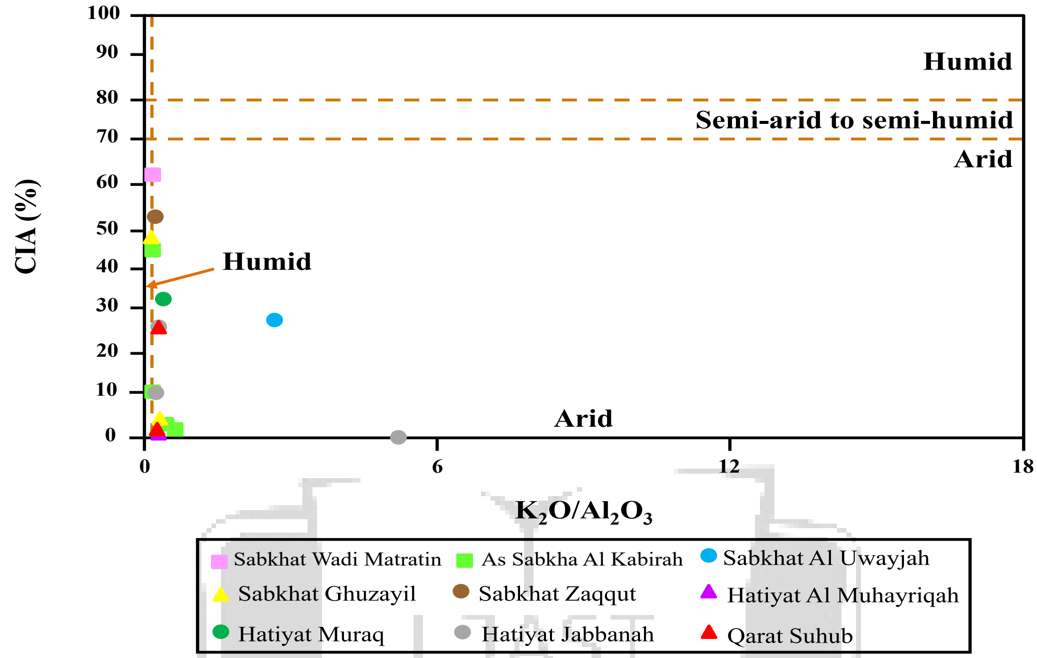

Fig. 8: Binary plot of K_2O/ Al_2O_3 vs. CIA showing the paleoclimate conditions during deposition of the studied sediments (fields after Nesbitt and Young, 1982; Roy and Roser, 2013).

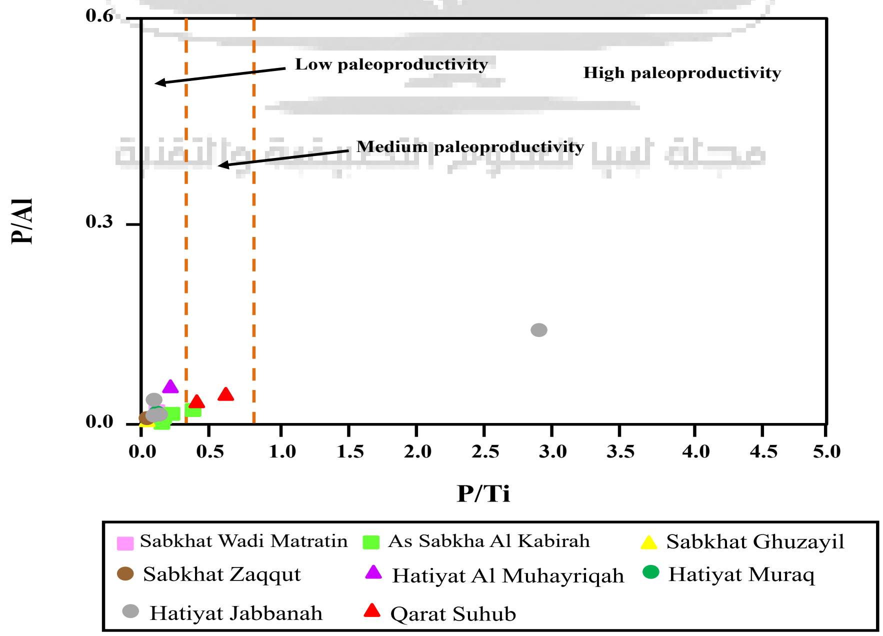

Fig. 9: Binary plot of P/Ti vs. P/Al showing the paleoproductivity level during deposition of the studied sediments (fields after Yang *et al.,* 2022).

References

1. Abdel Galil, M. and El-Fergany, E. (2011): Sedimentological significance and brine chemistry of recent coastal sabkha, northwest Libya. Journal of King Abdulaziz University: Marine Sciences; 22(2): 135-158.
2. Banat, K.M., Howari, F.M. and Kadi, K.A. (2005): Water chemical characteristics of the Red Sea coastal Sabkhas and associate evaporite and carbonate minerals. Journal of Coastal Research; 21(5):1068-1081.
3. Chenchouni, H. (2017): Edaphic factors controlling the distribution of inland halophytes in an ephemeral salt lake "Sabkha ecosystem" at North African semi-arid lands. Science of the Total Environment; 575: 660-671.
4. Cox, R., Low, D.R. and Cullers, R.L. (1995): The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States. Geochimica et Cosmochimica Acta; 59: 2919-2940.
5. Domaci, L. (1985): Geological Map of Libya, 1:250000, Sheet: Bir Zaltan, NH 34-14, Explanatory Booklet. Industrial Research Centre (IRC), Tripoli, Libya; 89p.
6. Gaillardet, J., Dupré, B. and Allègre, C.J. (1999): Geochemistry of large river suspended sediments: silicate weathering or recycling tracer? Geochimica et Cosmochimica Acta; 63(23-24): 4037-4051.
7. He, C., Ji, L., Su, A., Wu, Y., Zhang, M., Zhou, S., Li, J., Hao, L. and Ma, Y. (2019): Source-rock evaluation and depositional environment of black shales in the Triassic Yanchang Formation, southern Ordos Basin, north-central China. Journal of Petroleum Science and Engineering; 173: 899-911.
8. Innocenti, F. and Pertusati, P. (1984): Geological Map of Libya, 1:250000, Sheet: Al Aqaylah, NH 34-5, Explanatory Booklet. Industrial Research Centre (IRC), Tripoli, Libya; 105p.
9. Jurak, L. (1985): Geological Map of Libya, 1:250000, Sheet: Wadi Bu Ash Shaykh, NH 33-12, Explanatory Booklet. Industrial Research Centre (IRC), Tripoli, Libya; 113p.
10. Khan, D., Zijun, L., Qiu, L., Kuiyuan, L., Yongqiang, Y., Cong, N., Bin, L., Li, X. and Habulashenmu, Y. (2023): Mineralogical and geochemical characterization of lacustrine calcareous shale in Dongying Depression, Bohai Bay Basin: Implications for paleosalinity, paleoclimate, and paleoredox conditions. Geochemistry; 83(3): 125978.

11. König, P. (2012): Plant life in the Umm as Samim, Oman – A case study in a major inland sabkha. Journal of Arid Environments; 85: 122-127.
12. Kodym, O. (1985): Geological Map of Libya, 1:250000. Sheet: Sabkhat Ghuzayil, NH 34-10, Explanatory Booklet. Industrial Research Centre (IRC), Tripoli, Libya; 104p.
13. Liu, Z.H., Zhuang, X.G., Teng, G.E., Xie, X.M., Yin, L.M., Bian, L.Z., Feng, Q. and Algeo, T. (2015): The Lower Cambrian Niutitang Formation at Yangtiao (Guizhou, SW China): Organic matter enrichment, source rock potential, and hydrothermal influences. Journal of Petroleum Geology; 38: 411-432.
14. Lyons, T.W. and Severmann, S. (2006): A critical look at iron paleoredox proxies: New insights from modern euxinic marine basins. Geochimica et Cosmochimica Acta; 70(23): 5698-5722.
15. Masoud, M. and Khameiss, B. (2024): Mineral composition of coastal landforms in Wadi Al-Suwani at Al-Bardia region, east of Tobruk city, Libya. Scientific Journal for the Faculty of Science-Sirte University; 4(2): 15-32.
16. McLennan, S.M., Hemming, S., McDaniel, D.K. and Hanson, G.N. (1993): Geochemical approaches to sedimentation, provenance, and tectonics. In Johnson, M.J. and Basu, A. (eds), Processes Controlling the Composition of Clastic Sediments: Geological Society of America, Special Paper; 284: 21-40.
17. Mohammed, A.A., Anan, T.I. and Gheith, A.M. (2021): Distribution and significances of the major oxides in recent coastal sabkha sediments of the Al-Dafna Plateau, northeast Tobruk, Libya. Scientific Journal for the Faculty of Science-Sirte University; 1(2): 12-19.
18. Mohammed, A.A., Anan, T.I. and Gheith, A.M. (2022): Mode of formation of the coastal sabkha sediments in the coastal plain of Al-Dafna Plateau. Scientific Journal for the Faculty of Science-Sirte University; 2(2): 33-37.
19. Musa, M.M. (2016): Mineralogy and geochemistry of the Sabkha Sediments along the Mediterranean Coast from Surman to Ras Jdeir, Jifarah plain, NW Libya. Unpublished MSc Thesis, Benghazi University, Libya.
20. Nesbitt, H.W. and Young, G.M. (1982): Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature; 299: 715-717.

21. Njoma, B. (1980): Geological Map of Libya, 1:250000. Sheet: An Nuwfaliyah, NH 33-8, Explanatory Booklet. Industrial Research Centre (IRC), Tripoli, Libya; 87p.
22. Rajendran, S., Al-Kuwari, H.A., Sadooni, F.N., Nasir, S. and Govil, H. (2021): Remote sensing of inland Sabkha and a study of the salinity and temporal stability for sustainable development: A case study from the west coast of Qatar. Science of the Total Environment; 782: 146932.
23. Ratcliffe, K.T., Morton, A.C., Ritcey, D.H. and Evenchick, C.A. (2007): Whole-rock geochemistry and heavy mineral analysis as petroleum exploration tools in the Bowser and Sustut basins, British Columbia, Canada. Bulletin of Canadian Petroleum Geology; 55(4): 320-336.
24. Roy, D.K. and Roser, B.P. (2013): Climatic control on the composition of Carboniferous–Permian Gondwana sediments, Khalaspir Basin, Bangladesh. Gondwana Research; 23(3): 1163-1171.
25. Shaltami, O.R., Errishi, H. and Fares, F.F. (2017): Environmental geochemistry of the surface sediments of Sabkhat Daryana, NE Libya. Science and its applications; 5(1): 30-35.
26. Suttner, L.J. and Dutta, P.K. (1986): Alluvial sandstone composition and paleoclimate. Framework mineralogy. Journal of Sedimentary Petrology; 56: 326-345.
27. Yang, M., Zuo, Y., Fu, X., Qiu, L., Li, W., Zhang, J., Zheng, Z. and Zhang, J. (2022): Paleoenvironment of the Lower Ordovician Meitan Formation in the Sichuan Basin and adjacent areas, China. Minerals; 12(1): 75.