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GEOLOGY

Stable Isotopes Evidence for Holocene Paleoenvironmental Changes in Khor Abdullah Southern Iraq

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ABSTRACT

Stable isotopes have emerged as valuable tools in the geosciences, particularly for thermometry and research on climate change. The essential comprehend depositional environments and paleoclimate interpretations. This understanding hinges on gathering insights from various lithological units and their depositional architecture. Sedimentary units are vital for analyzing changes in sea levels and sediment supply over time. However, studies involving stable isotopes in this region are limited, highlighting the necessity for this research. In this study, sub-bottom marine core in Khor Abdullah, specifically the Grand Faw Port were analyzed from a depth of 40 meters in the northwest Arabian Gulf region of southern Iraq. Ten bulk representative sediment samples were examined using a Mass Spectrometer, specifically an Iso-Analytical device, to calculate stable isotopes, including $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, and $\delta^{2}H$ (in ‰) for each sample. The z-values in the study area ranged between 121.37 and 60.41, the study employed (Z) values to determine whether the environments were marine, fresh, or mixed. The oxygen isotope $\delta^{18}O$ values ranged from 23.15 to 5.36‰, while $\delta^{13}C$ values ranged from -26.63 to -19.86‰. The analysis identified warm periods associated with marine transgression and cold periods tied to marine regression. Additionally, a positive relationship was found between Total Organic Carbon (TOC%) and the isotopes $\delta^{13}C$ and $\delta^{18}O$. This relationship is influenced by climatic factors such as variations in humid-dry and cold-warm conditions, which affect peat composition. Furthermore, changes in the proportions of calcium carbonate were also found to play a significant role in these dynamics.

Keywords: Stable isotope; Khor Abdullah; climate changes; TOC%; paleo-environment; Marine transgression and regression.

Evidencia de isótopos estables para cambios paleoambientales del Holoceno en Khor Abdullah, sur de Irak

RESUMEN

Los isótopos estables se han consolidado como herramientas valiosas en las geociencias, especialmente para la termometría y la investigación del cambio climático. Son esenciales para comprender los ambientes de depósito y realizar interpretaciones paleoclimáticas. Este entendimiento depende de la obtención de información de diversas unidades litológicas y su arquitectura deposicional. Las unidades sedimentarias son fundamentales para el análisis de los cambios en el nivel del mar y el suministro de sedimentos a lo largo del tiempo. Sin embargo, los estudios que involucran isótopos estables en esta región son limitados, lo que resalta la necesidad de esta investigación. En este estudio, se analizaron núcleos marinos subyacentes en Khor Abdullah, específicamente en el puerto de Grand Faw, a partir de una profundidad de 40 metros en la región noroeste del Golfo Arábigo en el sur de Irak. Se examinaron diez muestras representativas a granel de sedimentos utilizando un espectrómetro de masas, específicamente un dispositivo Iso-Analytical, para calcular isótopos estables, incluidos $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$ y $\delta^{2}H$ (en ‰) para cada muestra. Los valores de Z en el área de estudio oscilaron entre 121.37 y 60.41; el estudio empleó los valores de Z para determinar si los ambientes eran marinos, de agua dulce o mixtos. Los valores del isótopo de oxígeno δ18O variaron de 23.15 a 5.36‰, mientras que los valores de $\delta^{13}C$ oscilaron entre -26.63 y -19.86‰. El análisis identificó períodos cálidos asociados con transgresiones marinas y períodos fríos vinculados a regresiones marinas. Además, se encontró una relación positiva entre el Carbono Orgánico Total (TOC%) y los isótopos $\delta^{13}C$ y $\delta^{18}O$. Esta relación está influida por factores climáticos como las variaciones entre condiciones húmedo-secas y frío-cálidas, que afectan la composición de la turba. Asimismo, se determinó que los cambios en las proporciones de carbonato de calcio también desempeñan un papel significativo en estas dinámicas.

Palabras clave: isótopos estables; Khor Abdullah; cambios climáticos; TOC%; paleoambiente; transgresión y regresión marina.

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1. Introduction

Stable isotopes have become a valuable tool in the field of geosciences, particularly for thermometry, enabling the reconstruction of temperature history in both surface and subsurface environments. In carbonate rocks and sediments, $\delta^{18}O$ and $\delta^{13}C$ analyses are commonly employed to measure the proportions and assess the results (Reis et al, 2019). Stable isotope studies in the Arabian Gulf region may be few, especially in the northwestern Gulf. The northwestern Arabian Gulf, situated at the confluence of arid continental and marine influences, represents such a critical area, where nuanced shifts in precipitation, temperature, and sea level have profoundly shaped its geomorphology, ecosystems, and human history (Parker et al., 2006; Darling, 2011). Taha and Abdullah (2019) in their study, the paleoenvironments, temperature, and depth were determined by examining the stable isotopes (O^{18}/O^{16} and C^{13}/C^{12}) in carbonate rock layers (Mushrif formation) in southern Iraq. Al-Humaidan et al, (2023) confirmed that there were paleo-climatic changes as a result of marine transgression and regression, which led to changes in the paleoenvironments with the presence of Ancient River courses. The paleoenvironments were reconstructed by sedimentary analyses and geophysical surveys in the northwestern Arabian Gulf region. Gradual increase in the value of δO^{18} caused climatic changes that refer to weak dryness. On the other hand, differences of $\delta C1^{3}$ values as a result of changes in the value of discharge of underground waters to the Parishan lake in southern Iran (Noorollahi et al, 2011). The sedimentary composition of the northwestern section of the Persian/Arabian Gulf is characterized by instability and variability, which may be attributed to the numerous hydrological factors present in the area (Muttashar et al, 2024). The combination of total (TOC %) and ($CaCO_3$%) in sedimentary records develops the reconstructions of past environments. The TOC content is considered an indicator of historical biological productivity and the preservation of organic matter OM, which are often related to nutrient availability and oxygenation levels. These factors are sensitive to oceanographic and climatic conditions (Tyson, 1995; Tisdall. and Oades, 2006). Given the scarcity of studies on reconstructing ancient environments in the region using stable isotopes, we considered this type of study.

This paper aims to identify the paleoenvironments and paleoclimates of the Holocene period by utilizing stable isotopes. Also explains how to incorporate insights from stable isotopic signatures, TOC%, and CaCO3% found in the Holocene sedimentary record in the study area. This comprehensive analysis will enable us to reconstruct the region's paleoenvironmental evolution, providing valuable insights into understanding current and future climatic scenarios in this crucial area.

2. Study area

Khor Abdullah plays a vital role in Iraq's marine ecosystem and economy. Its strategic position makes it crucial for maritime research and shipping routes. It located northwest of the Arabian Gulf that extends between Warba and Bubiyan islands in Kuwait and the Al-Faw Peninsula in Iraq; it extends north to form Khor Al-Zubair, where the port of Umm Qasr is located as shown in Figure 1. The length of the Khor Abdullah canal is about 60 km, its width is 1-4 km, and with depth is 7-14 m. The Khor has a distinctive funnel shape at the entrance to the Arabian Gulf (Salman and Al-Moussawi, 1993). It is characterized by the presence of longitudinal sand barriers that extend longitudinally with the axis of the Khor, called the Shoals as. The coordinates of core 4 in Al Faw Port extend between (29°52' 25.068"N and 48°26' 49.412"E) to a depth of 40m below the bottom. The box contains core sediments, as illustrated in Figure 2.

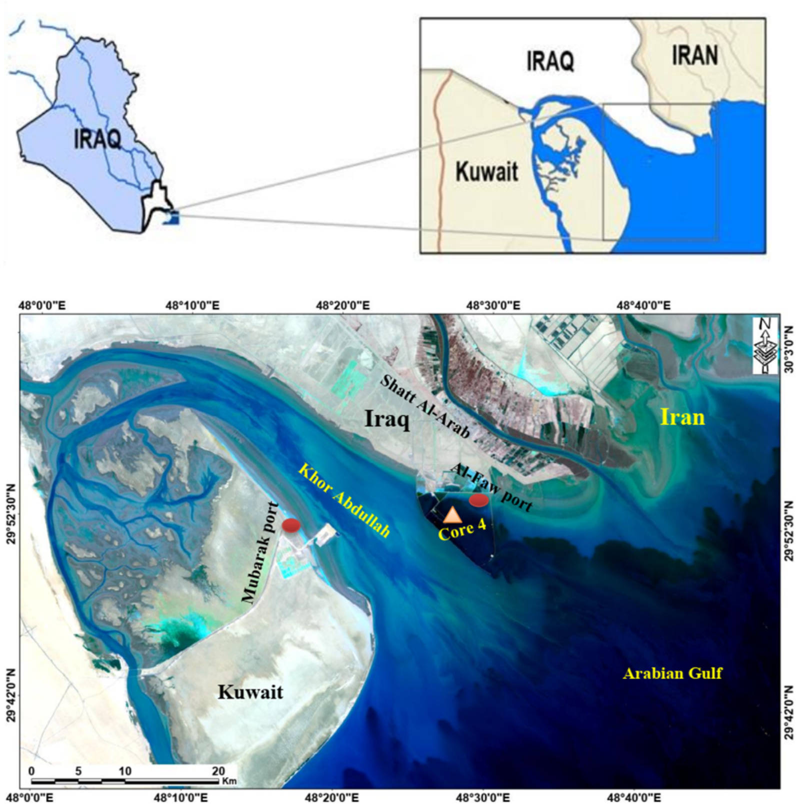

Figure 1. Study area explains the site of core at Al- Faw Port.

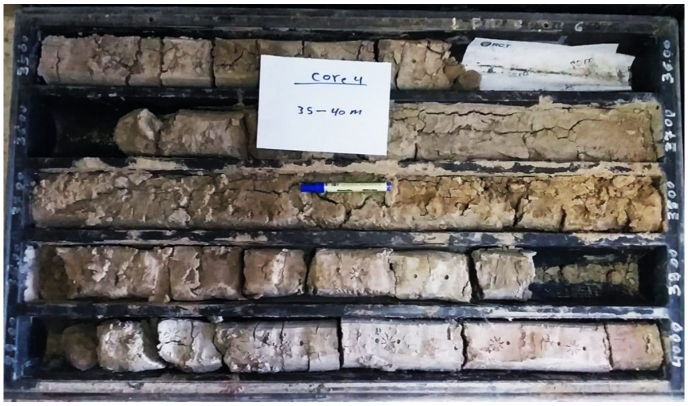

Figure 2. The box of the sediments core including 5 meters.

3. Geological setting of the study area

Iraq and the Arabian Gulf are among the most recent areas in the world characterized by continental collisions. During geological ages, tectonic development was linked to the Earth's movements, affecting the western plate (Al-Moussawi, 1993). Following these collisions and the influx of sediments from the northern and northeastern parts of Iraq, the coastal areas in the north and northwest of the Arabian Gulf experienced continuous subsidence as erosion and sedimentation processes continued to bury and build the sedimentary plain (Buday, 1980).

Al-Moussawi confirmed in 1993 that during the Pliocene era, the sea level reached more than 50 m above its current level, as the region was exposed to marine transgression, and the sea waters receded in the Arabian/ Persian Gulf during the Pleistocene (the period of the Würm glaciations). The second half of the Holocene is characterized by stable sea levels, during which rivers began to deposit sediment and create modern coastal features, such as estuaries and deltas. New land was formed, and coastlines continue to expand into the seas to this day (Roberts, 1999).

On the other hand, the thickness of the Quaternary sediments in Mesopotamia is about 120 m and is surrounded by Tertiary sediments (Bsho, 2004; Yacoub, 2011). During the Holocene period, the last 10,000-11,000 years, the climate was fluctuated, and thus its sediments presented various facies, reflecting different environments spread was characterized by being volatile and changing. Thus its sediments were characterized by various facies, so different environments spread in the Mesopotamian plain, such as fluvial, lake, estuarine, and aeolian environments (Yaqoub, 2011). Due to its location characteristics, the lower, the lower Mesopotamian basin likely experienced periodic phases of accumulation and erosion—often referred to as washing out—corresponding with the fluctuations in sea level that occurred during the Pleistocene (Aqrawi 1993).

4. Methodology and Materials

The following analyses were performed on the sediments in the core:

4.1 Stable Isotope Analysis

Ten representative samples of sediments from core 4 were analyzed. The stable isotopes of $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, and $\delta^{2}H$ were calculated for each sample by using a Mass Spectrometer. The stable isotopes of $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, and $\delta^{2}H$ were calculated for each sample using a mass spectrometer from Iso-Analytical Limited at Cornell University's Ecology and Evolutionary Biology Department USA. These data are the result of analyses performed on a Thermo Delta V isotope ratio mass spectrometer (IRMS) interfaced to a Temperature Conversion Elemental Analyzer (TC/EA). To ensure the accuracy and precision of the instrument an in-house standard is analyzed after every 8 samples. The standard deviation for the **internal standard Internal Benzoic Acid** for $\delta^{2}H$ was 2.84‰ and for **$\delta^{18}O$** was **0.45‰.** Corrections were performed using two-point normalization (regression) of four established standards (CH7 and EMA-P1 for hydrogen and CO-1 and CO-8 for oxygen.). Stable isotopes of $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, and $\delta^{2}H$ in‰ were calculated for each sample, the percentages of O%, C%, N%, and H% as shown in Tables 1 and 2.

4.2. Total organic carbon (TOC %).

Total organic carbon (TOC) is widely distributed over the Earth's surface, found in almost all aquatic and terrestrial environments (Schnitzer, 1978). Organic carbon accumulation in marine sediments is essential for controlling how organic matter breaks down (mineralization) and how materials circulate between the seabed and the ocean (Seiter et al, 2004). TOC analysis was conducted by the LOI (loss-on-ignition) method at the laboratory in the Marine Sciences Center (Nelson and Sommers, 1996).

4.3 Grain size analysis.

Grain size distribution provides the main insights into the sources of sediments and the intensity of their transport (Boggs, 2006). This distribution is closely associated with sedimentary processes and is affected with many factors, including the characteristics of the original rocks, as well as transport processes, weathering, erosion, and friction. By measuring the particle size distributions of sediments, researchers can analyze environmental reconstructions and sedimentation sequences (Lario et al., 2002). The results of the grain size analysis and total organic carbon, as reported by Al-Humaidan et al. (2023). The grain size analysis was conducted using the pipette method (Folk, 1974) on approximately 45 samples in the Sedimentology Laboratory at University of Basrah/ Marine Sciences Center.

4.4. The content Calcium Carbonate ($CaCO_3$%).

The calcium carbonate content in the sediments (a function of melting, dilution, and production) is widely used for stratigraphic correlation and the interpretation of paleo-oceanographic changes (Dunn et al., 1981; Gardner, 1982; Pisias and Prell, 1985).For understanding the processes that control on the preservation of $CaCO_3$, we needed an exact interpretation and explanation of the marine sediment record at depth (Milliman et al, 1999). Calcium carbonate content was measured according to Nelson (1982) at the Marine Chemistry Laboratory in the Marine Sciences Center.

5. Results

The importance of stable isotopes in environmental geological studies can be explained as follows:

5.1. Oxygen isotope $\delta^{18}O$ ($\delta^{18}O/\delta^{16}O$)

Oxygen-18 is a stable isotope of oxygen that occurs naturally. This isotope is classified as an environmental isotope. When analyzing oxygen isotopic ratios, they are commonly compared to two reference standards: VSMOW (Vienna Standard Mean Ocean Water) and VPDB (Vienna Pee Dee Belemnite). Oxygen measurements in water are typically reported about VSMOW (Vienna Standard Mean Ocean Water). In contrast, oxygen released from carbonate rocks or other geological records is reported to VPDB (Vienna Pee Dee Belemnite) (Brand et al., 2014). In the study area, the values of $\delta^{18}O$ relative to VSMOW ranged from 5.36‰ to 23.15‰, while the values of $\delta^{18}O$ relative to VPDB ranged from -24.79‰ to -7.53‰, as shown in Table 3. These changes are typically linked to alterations in the isotopic composition of precipitation (δp) or temperature. Such changes facilitate the retrieval of annual or seasonally specific signals.

5.2 Hydrogen isotope $\delta^{2}H$

Guire and Donnell (2007) pointed that the deuterium (^{2}H) and oxygen-18 ($\delta^{18}O$), the Stable isotopes of water, are used to evaluate the age, origin, and flow patterns of water within ecosystems. Evaporation and condensation are the major factors that influence the stable isotope composition of water. Researchers can explore the sources of water in streams and rivers, valuate ground water recharge, and examine various other hydrological processes by analyzing the variability in water isotopes (Cardenas et al., 2020). Table 1 presents the $\delta^{2}H$ values compared to VSMOW, ranging from -4.64‰ to -104.16‰.

5.3 Carbon isotope $\delta^{13}C$ ($^{13}C/^{12}C$)

The relationship between dissolved inorganic carbon DIC and the isotope composition of $\delta^{13}C$ is affected by several factors, including the equilibrium between dissolved CO_2 and atmospheric CO_2, as well as CO_2 produced through the degradation of organic matter and other sources. Consequently, the $\delta^{13}C$ isotope composition of DIC becomes a complex function of these processes (Anadon et al., 2002). Table 2 explains the $\delta^{13}C$ values, which ranged from -1.06 to -26.63‰.

5.4 Nitrogen isotope $\delta^{15}N$ (($^{15}N/^{14}N = \delta^{15}N$))

The nitrogen cycle plays a crucial role in marine biochemistry, as nitrogen availability can potentially limit biological productivity across large oceanic areas due to its status as a vital nutrient. Throughout geological history, the analysis of nitrogen isotopes in ancient marginal marine systems has provided valuable insights into nitrogen oxidation and redox conditions in the water column (Algeo et al., 2008; Tuite and Macko, 2013). According to Wei Wei et al. (2021), $\delta^{15}N$ isotopes have been widely used as indicators of depositional conditions in the study of paleoenvironments and ancient sediments. Research consistently shows a positive correlation between $\delta^{15}N$ values and paleosalinity, indicating that water-column salinity plays a crucial role in influencing the $\delta^{15}N$ signal. Marginal-marine and coastal areas are complex environments that significantly impact the production and preservation of nitrogen and organic carbon, making them vital to these processes (Hedges and Keil, 1995). In the study area, the results for the five analyzed samples ranged from 0.92 to 3.27‰, as shown in Table 2. Nitrogen isotope results were incomplete because nitrogen levels were at or below the detection limit.

Stable isotopes of $\delta^{13}C$, $\delta^{18}O$, $\delta^{15}N$, and $\delta^{2}H$ in‰ were calculated for each sample, the percentages of O%, C%, N%, and H% as shown in Tables 1 and 2.

To extract the value of (Z) we need to convert $\delta^{18}O$ vs. VSMOW to $\delta^{18}O_{VPDB}$ Equation (1) according to (Brand et al., 2014). The z values were obtained from equation (2) to determine the type of the environment, whether it is marine, fresh, or mixed (Epstein et al, 1953).

$$\delta^{18}O_{VPDB} = 0.97001 * \delta^{18}O_{VSMOW} - 29.99‰ \quad (1)$$

$$Z = 2.048(\delta^{13}C + 50) + 0.498(\delta^{18}O + 50) \quad (2)$$

If $Z > 120$ the environment is marine
If $Z < 120$ the environment is fresh

5.5 Sedimentary results

Particle size analysis results for sand, silt, and clay percentages by depth, along with total organic carbon and calcium carbonate percentages, are presented in Figure 3. Additionally, Figure 4 illustrates the lithology of the study area, along with a description of the core and sediment texture.

Table 1. Analytical results of $\delta^{18}O$, $\delta^{2}H$, O% and H% in Core 4.

NO.	Depth (m)	δ ¹⁸O vs. VSMOW(‰)	O%	δ²H vs. VSMOW (‰)	H%
1	1	20.15	18.59	-75.52	0.53
2	6	22.49	19.29	-79.41	0.44
3	10	19.24	20.04	-80.06	0.41
4	14	5.36	19.30	-104.16	1.85
5	19	19.86	13.29	-85.97	0.23
6	25	22.12	17.97	-83.89	0.28
7	28	23.15	11.14	-66.73	0.10
8	33	16.15	21.27	-89.54	1.25
9	37	22.49	13.40	-18.97	0.25
10	40	22.05	28.01	-4.67	0.77

***δ2H or $\delta^{18}O$ vs. VSMOW** = The corrected isotope delta value for ^{2}H and ^{18}O
*** VSMOW** =Vienna Standard Mean Ocean Water
*** VPDB** =Vienna Pee Dee Belemnite.

Table 2. Analytical results of $\delta^{13}C$, $\delta^{15}N$, C%, and N% in Core 4.

NO.	Depth (m)	δ ¹³C vs. VPDB (‰)	C%	δ ¹⁵Nvs. At. Air (‰)	N%
1	1	-4.97	5.96	3.27	0.08
2	6	-4.56	5.51	3.14	0.04
3	10	-4.89	5.77	-	-
4	14	-26.63	11.07	0.92	0.46
5	19	-1.79	4.37	-	-
6	25	-1.72	3.35	-	-
7	28	-1.06	3.06	-	-
8	33	-19.86	7.94	0.59	0.28
9	37	-1.95	3.41	-	-
10	40	-5.90	6.16	1.48	0.02

***$\delta^{13}C$ vs. VPDB (‰)** = The corrected isotope delta value for 13C is measured against a primary reference scale.

Table 3. δ ^{18}O vs. VSMOW, δ ^{18}O VPDB, and Z values.

NO.	Depth (m)	δ ^{18}O vs. VSMOW(‰)	δ^{18}O VPDB (‰)	Z	Environment	TOC%	$CaCO_3$
1	1	20.15	-10.44	111.92	Brackish - marine	1.544	18.43
2	6	22.49	-8.17	113.89	Brackish - marine	0.973	18.02
3	10	19.24	-11.32	111.64	Brackish - marine	1.84	15.91
4	14	5.36	-24.79	60.41	Fresh	4.4	3.42
5	19	19.86	-10.72	118.29	Brackish - marine	0.2	7.54
6	25	22.12	-8.53	119.52	Brackish - marine	0.64	10.05
7	28	23.15	-7.53	121.37	Marine	0.31	10.05
8	33	16.15	-14.32	79.49	Fresh	2.52	8.04
9	37	22.49	-8.17	119.23	Brackish - marine	1.32	10.89
10	40	22.05	-8.60	110.93	Brackish - marine	2.81	8.04

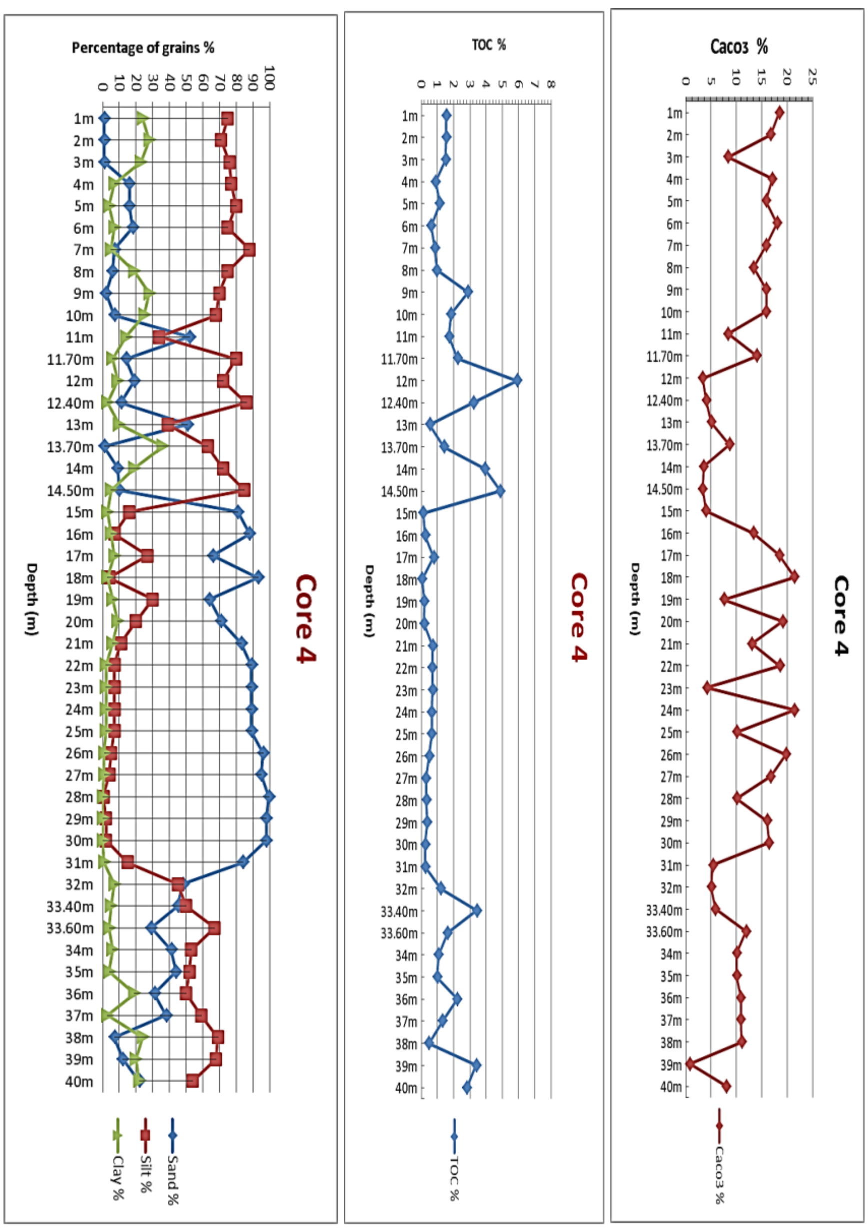

Figure 3. Graphs explain the percentages of the clay, silt, sand, TOC%, and CaCO3 % according to Al-Humaidan et al. (2023).

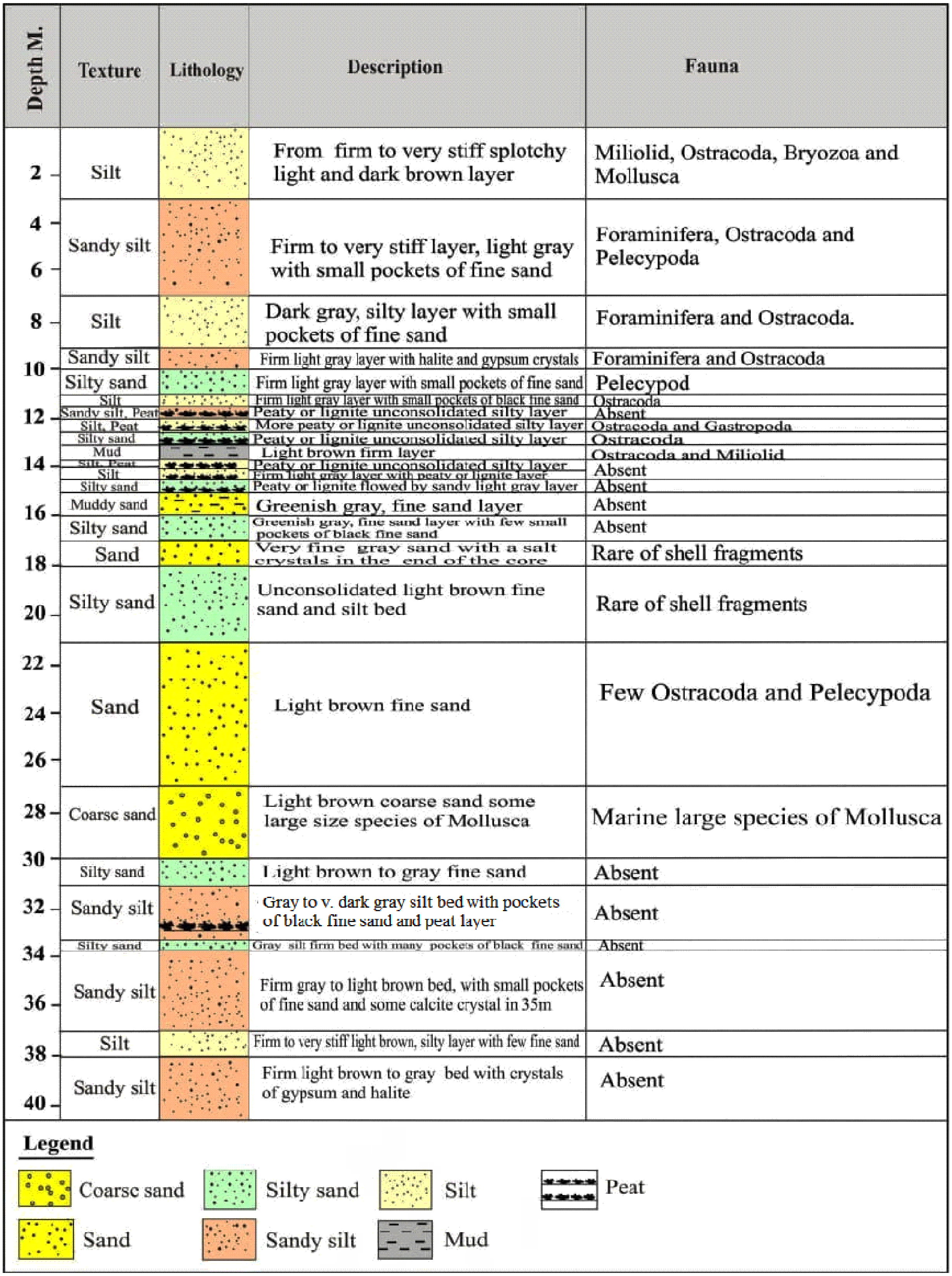

Figure 4. A stratigraphic section illustrating the sedimentary and lithological characteristics of core 4 with depths.

6. Discussion

Stable isotopes have become a valuable tool in geosciences, particularly for thermometry, enabling the reconstruction of temperature history in both surface and subsurface environments. In carbonate rocks and sediments, $\delta^{18}O$ and $\delta^{13}C$ analyses are commonly employed to measure the proportions and assess the results. However, it should be noted that these analyses often yield widely scattered results (Paul et al, 2013). The use of isotope geochemistry is growing in environmental studies as a means of collecting information on paleoenvironmental conditions. This includes investigating paleoclimate, paleohydrology, and the impact of photosynthetic activity on carbonate precipitation (Fritz and Fontes, 1986). The stable isotope results obtained for ($\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{2}H$) in Core 4 at several depths were variable, and this is evidence of climatic fluctuations and thus the change in depositional environments.

The $\delta^{18}O$ values ranged from –7.53 to –24.79‰. These variations likely reflect differences in temperature, source water changes, and rainfall patterns, as low values of $\delta^{18}O$ indicate freshwater Input environments (Marwick and Gagan, 2011)., and this is what was obtained in the study area was conducted at a depth of 28 m, where the highest value of **$\delta^{18}O$** was recorded (-7.53‰). In addition to this result, the value of Z was 121.37, which indicates marine transgression and an increase in temperature. This explains the melting of ice and the rise in sea level that began at a depth of 30 m. These results support the presence of some marine mollusks' species at these depths, as shown in Figure 7 (Al-Humaidan et al., 2023). This was confirmed by Dansgaard, (1964); and Cook, and Lauer, 1968 who indicated that during warmer periods, the isotopic composition of $\delta^{18}O$ tends to become more negative or 'lighter' (expressed as a more negative $\delta^{18}O$ value), suggesting a decrease in Earth's ice cover. Regionally, negative $\delta^{18}O$ signals (indicating higher $\delta^{16}O$ abundance) can indicate a rise in precipitation levels within a specific area.

The $\delta^{13}C$ VPDB results in the study area show that the depth value of 28 m is -1.06, which is the highest value, which indicates that the marine advance was at its peak and warmer periods, and this is confirmed by Nelson and Smith 1996 that shallow water conditions, the $\delta^{13}C$ tends to become enriched due to a higher concentration of bicarbonate compared to deeper water. The increases in $\delta^{13}C$ values are often observed alongside sea-level rise, whereas decreases in $\delta^{13}C$ are associated with sea-level fall. On the other hand, the values of the depth of 14 m and 33 m were the lowest, reaching ($\delta^{13}C$= -26.63 and -19.86‰), respectively, indicating lower sea levels, peat deposits, and marsh swamps, and thus a decrease in sea level.

According to Zeebe (2012), the increase in $\delta^{13}C$ values can also suggest a reduction in erosion from the terrestrial realm. Soil typically exhibits a more negative $\delta^{13}C$ value due to the presence of organic matter derived from plants, which is predominantly composed of C^{12} ions. When this soil is transported into the ocean, it introduces more C^{12} into the water, leading to an increase in $\delta^{13}C$ values. This is what we observe at depths of 14 m and 33 m, where the $\delta^{13}C$ values were (- 26.63 and -19.86‰), respectively, and they reflect the marsh environment rich in reed plants. Awadh (2014) noted that the ^{13}C values of the Euphrates deposits rich in organic N mention that the Organic matter is obtained from marine algae. Also, the ^{13}C and ^{15}N values in the Injana Formation indicate a partial mixture of marine algae with terrestrial-derived organic matter. While the Injana and Dibdibba formations have high C/N contents and low organic N values indicate higher terrestrial particulate or organic matter content.

In addition to isotope data, the TOC% provides further important information that supports the isotope results. These $\delta^{13}C$ results correspond well with the TOC findings, it is noted that there is a positive relationship between (TOC%) and the $\delta^{13}C$ isotope, as pointed out by (Tsiolakis et al, 2019), that the oxygen isotope $\delta^{13}O$ data shows a positive relationship with differences in (TOC %) and $\delta^{13}C$ records. During warmer periods, there is an increase in carbon isotope values, which highly align with the precession minima and summer insolation. Furthermore, positive relationship exists between the TOC% and $\delta^{18}O$, as shown in Figure 5. The isotope ratios found in sphagnum (A genus of algae that lives in peat layers) are influenced by the same climate factors (such as humid-dry and cold-warm conditions) that impact peat growth. This indicates that a positive correlation exists between the accumulation rate of peat and the $\delta^{13}C$ and $\delta^{18}O$ values (Túri et al, 2021).

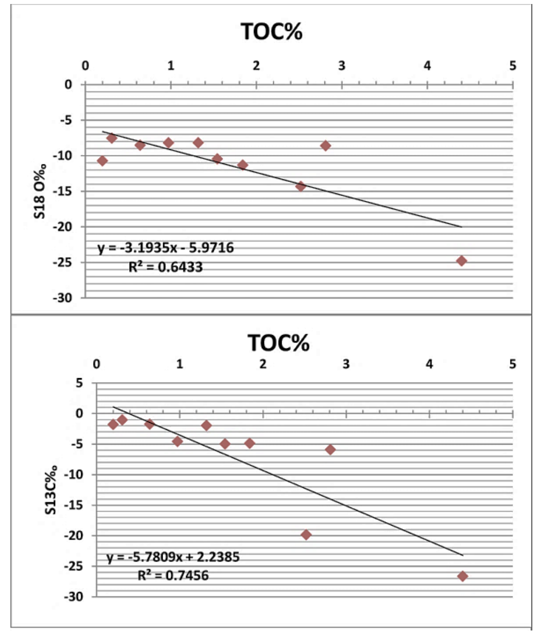

Figure 5. Positive relationship between TOC% and $\delta^{13}C$ and $\delta^{18}O$ due to changing in humid-dry and cold-warm conditions.

An illustrative chart has been created to show the relationship between depth, $\delta^{13}C$, and $\delta^{18}O$ as shown in Figure 6. This chart explains how environmental changes have occurred as a result of climate fluctuations, particularly during periods of sea transgression and regression. It is worth noting that the regression of the sea is found at depths of 14 m and 33 m. Puertas et al. (2010) identified four major phases of the Late Holocene in the SW Mediterranean region: an arid period, a high-humidity period, a dry and low-rainfall period, and a final high-humidity period that happened approximately 700 years ago. These phases were determined using analyses of $\delta^{18}O$, the Zr/Al ratio, the Rb/Al ratio, and the Sr/Al ratio. Additionally, higher (TOC) and $\delta^{13}C$ values in Holocene sediments may indicate seawater intrusion resulting from climate warming and rising sea levels. This supplied insights into the environmental transitions associated with warmer periods (Gao et al., 2024). Beyond geochemical proxies, faunal remains also support the previous results as Al-Humaidan et al. (2023) noted that the presence of large, dark-colored marine mollusc species, like *Cardilia* sp., *Crassostrea iridescens* and *Carditella pallida*, as illustrated in Figure 7. These aquatic species were recognized at depths of 28 to 30 m, in an area distinguished by coarse, unconsolidated sandy sediments, referencing a marine transgression.

The reason for the increase in **$\delta^{18}O$**, as Fontes et al (1996) pointed out, may be due to several factors, such as enrichment of rain inputs and decrease in relative humidity, in addition to the long period of residence of water bodies. Moreover, he pointed out that the decrease in **$\delta^{13}C$** leads to a decrease in the exchange of DIC (The total dissolved inorganic carbon) with CO_2 in the atmosphere and the oxidation of organic materials due to the growth of vegetation in watersheds. This is what was observed in the results of the study area, where $\delta^{13}C$ decreased at depths of 14m and 33m and recorded values of -26.63 and -19.86, at the same time TOC% increased at these depths to 4.4 and 2.52% respectively. Also, the results presented in Figure 6 show that the values of $\delta^{13}C$ and $\delta^{18}O$ increase during marine transgression, indicating the presence of salty seawater. In contrast, these values decrease during freshwater conditions and marine regression. This observation supports the findings of Klein et al. (1997), who noted a positive relationship between salinity and $\delta^{18}O$ in Standard Mean Ocean Water (SMOW) (‰).

Through the results obtained for the values of calcium carbonate in Core 4 between (0.48-21.44 percent), it was also noted that the proportions increased with fine grains and decreased with coarse grains, and the same is the case with TOC%. In sediment, Calcium carbonate content (being a function of dissolution, dilution and production) has been vastly utilized for interpreting paleo-oceanographic changes and stratigraphic correlation (Dunn et al., 1981; Gardner, 1982; Pisias and Prell, 1985).

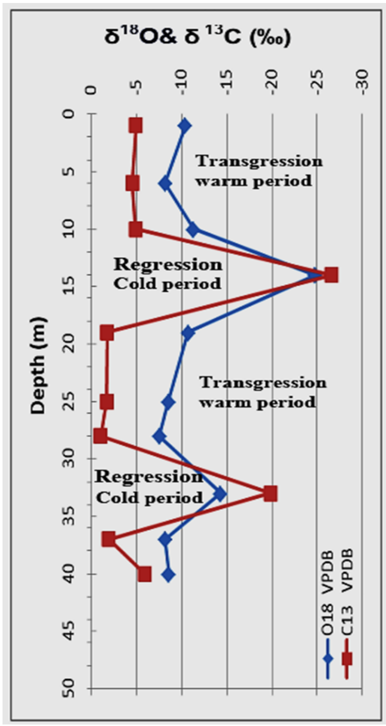

Figure 6. The graph between depth (m), $\delta^{13}C$, and $\delta^{18}O$ explains the marine transgression because of ice melting and regression periods in conjunction with periods of cold and warm in the study area in the Holocene epoch.

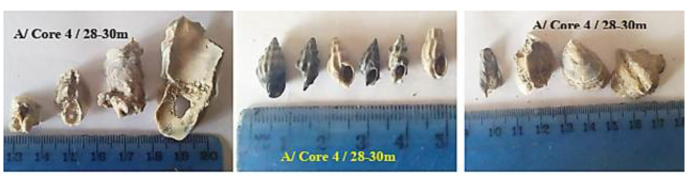

Figure 7. Large fauna at a depth of 28-30m in the fine-medium sand layer; These marine species are represented in Mollusca, such as *Crassostrea iridescens*, *Cardilia* sp., and *Carditella pallida* indicating marine transgression during the Holocene epoch (Al-Humaidan et al, 2023).

The difference in the values of $CaCO_3$ in the sediment is evidence of the difference in the environment and the water depth, as the high percentages indicate shallow water depths and high $CaCO_3$ productivity, while the deeper areas have a lower percentage of $CaCO_3$ due to rapid dissolution (Woosley, 2018). The average percentage of $CaCO_3$ in core 4 ranged (18.43 to 3.42%) as shown in Table 3.

These percentages are considered low, and this is confirmed by the few quantities and little diversity in the fauna present in the sediments, and that the sediments were deposited in shallow marine or fluvial-alluvial environments. Higher $CaCO_3$ percentages in the sediments may indicate warmer periods.

7. Conclusions

The Pleistocene-Holocene epoch witnessed significant climatic changes worldwide, including in the northwestern Arabian Gulf, which impacted sea levels. This study analyzes a 40-m stratigraphic column using ($\delta^{13}C$) and ($\delta^{18}O$) isotopes, revealing four phases of marine transgression/ regression and climate fluctuations. During warm periods, transgressions occurred at depths of 28-30 m and 10-0 m, indicated by higher $\delta^{18}O$ and $\delta^{13}C$ values, marine molluscs, and elevated $CaCO_3$% levels in sand layers represented marine environments. Cold periods of regression were found at depths of 14-18 m and 32-34 m, characterized by the presence of peat or lignite and higher TOC% values in silty clay layers, suggesting a marsh environment with decreased $\delta^{18}O$ and $\delta^{13}C$ values indicating freshwater input and vegetation cover.

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References

Algeo, T., Shen, Y., Zhang, T. & Nguyen, T. K. T. (2008). Association of 34S-depleted pyrite layers with negative carbonate δ13C excursions at the Permian-Triassic boundary: Evidence for upwelling of sulfidic deep-ocean water masses. *Geochemistry, Geophysics, Geosystems*, 9(4). https://doi.org/10.1029/2007GC001823.

Al-Humaidan, Z.A., Al-Jaberi, M. H., & Al-Mosawi, W. M. (2023). Assessment the Subbottom Sedimentary Situation for Khor Abdullah, NW Arabian Gulf Using Sedimentary Coring Analysis and Sub-Bottom Profile Technique. *Iraqi Geological Journal,* 56(2D), 150-166. https://doi.org/10.46717/igj.56.2D.12ms-2023-10-18

Al-Moussawi, S. N. (1993). The development of the Khor Al-Zubair region and its surroundings throughout modern geological history. *Iraqi Geological Journal*, 3(26). (In Arabic).

Anadón, P., Gliozzi, E., & Mazzini, I. Paleoenvironmental Reconstruction of Marginal Marine Environments From Combined Paleoecological and Geochemical Analyses on Ostracods. 227-247. https://doi.org/10.1029/131GM12

Aqrawi, A. A. M. (1993). Implication of sea level fluctuations sedimentation and neotectonic for the evolution of the marshland (Ahwar) of southern Mesopotamia. *Quaternary Proc 3,* 17-26. https://www.researchgate.net/publication/279563162_Implications_of_sea-

Awadh, S. M. (2014). Stable carbon and nitrogen isotopes and elemental composition and origin of organic matter from the Neogene Euphrates, Injana and Dibdibba formations in Iraq: discrimination between marine and terrestrial environments. *Geological Quarterly,* 58(4), 729–736. DOI: http://dx.doi.org/10.7306/gq.1174.

Boggs, S. J. (2006). *Principles of Sedimentology and Stratigraphy*. 4th edition, Prentice-Hall. https://www.kufunda.net/publicdocs/principles-of-sedimentology-and-stratigraphy-by-sam-jr-boggs.pdf

Brand, W. A., Coplen, T. B., Vogl, J., Rosner, M., & Prohaska, T. (2014). Assessment of international reference materials for isotope-ratio analysis (IUPAC Technical Report). *Pure and Applied Chemistry*, 86(3), 425–467. https://doi.org/10.1515/pac-2013-1023?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Bsho, D. Y. (2004). Hydrology investigations of the East Missan area. The General Commission for Groundwater of Iraq. Unpublished report (In Arabic).

Buday, T. (1980). *The Regional Geology of Iraq: Stratigraphy and paleogeography*. In: I. M. Kassab and S. Z. Jassim. (Eds.). Baghdad: Dar AlKutib Publishing House, Mosul, Iraq. 443P. https://www.scribd.com/document/405030728/REGIONAL-GEOLOGY-OF-IRAQ-BUDAY-1980-pdf

Cardenas, M., Rodolfo, R. S., Lapus, M. R., Cabria, H. B., Fullon, J., Gojunco, G. R., Breecker, D. O., Cantarero, D. M., Evaristo, J., Siringan, F. P. & Zhang, T. (2020). Submarine Groundwater and Vent Discharge in a Volcanic Area Associated With Coastal Acidification. *Geophysical Research Letters*, 47(1): e2019GL085730. https://doi.org/10.1029/2019GL085730

Cook G. A., & Lauer, C. M. (1968). Oxygen. In: Clifford, A.Hampel (Ed.). The Encyclopedia of the Chemical Elements. Reinhold Book Corporation, New York, pp. 499–512. LCCN 68-29938.

Dansgaard, W. (1964). Stable isotopes in precipitation. Tellus. 16 (4), 436–468. Bibcode: Tell...16.436D. https://doi.org/10.1111/j.2153-3490.1964.tb00181.x

Darling, W. G. (2011). The isotope hydrology of Quaternary climate change. *Journal of Human Evolution*, 60(4), 417-427. https://doi.org/10.1016/j.jhevol.2010.05.006

Dunn, D.A., Moore, & T.C., Keigwin, L.D. (1981). Atlantic-type carbonate stratigraphy in the late Miocene Pacific. *Nature,* 291, 225–227. https://doi.org/10.1038/291225a0

Epstein, S., Buchsbaum, R., Lowenstam, H. A. & Urey, H. (1953). Revised carbonate-water temperature scale. Bulletin of the Geological Society of America, 62, 417–26. https://doi.org/10.1130/0016-7606(1953)64[1315:RCITS]2.0.CO;2

Folk, R. L. (1974). *Petrology of sedimentary rocks*. Texas, USA: Hemphill's, Austin, 128-182. https://repositories.lib.utexas.edu/bitstreams/4537855d-d386-4794-bfbc-0f24715e64dc/download

Fontes, J., Gasse, F., & Gibert, E. (1996). Holocene environmental changes in Lake Bangong basin (Western Tibet). Part 1: Chronology and stable isotopes of carbonates of a Holocene lacustrine core. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 120(1-2), 25-47. https://doi.org/10.1016/0031-0182(95)00032-1

Fritz, P., & Fontes, J. C. (1986). *Handbook of Environmental Isotope Geochemistry, Vol. 2. Terrestrial Environments, B*. Elsevier Science Pub. Co. Inc., Amsterdam, 557 pp. https://inis.iaea.org/records/xz2zg-tf121

Gao, Q., Piotrowski, A. M., Li, Z., Loh, P. S., Han, C., Wang, Z., Yang, S., Guo, Z., Huang, D., & Chen, Y. (2024). Geochemical behavior of C, N, and S in sediments of Hangzhou Bay, Southeastern China: implications for the study of paleoclimate and sea-level changes. *Frontiers in Marine Science*, 11:1308739. https://doi.org/10.3389/fmars.2024.1308739

Gardner, J. V. (1982). *High-resolution carbonate and organic-carbon stratigraphies for the late Neogene and Quaternary from the western Caribbean and eastern equatorial Pacific*. In: Prell, W. L., Gardner, J. V., et al. (Eds.) Inuit Reports Deep Sea Drilling Projects Reports and Publications (DSDP), Washington (U.S. Govt. Printing Office) 68, pp. 347–364 http://deepseadrilling.org/68/volume/dsdp68_10.pdf

Guire, K. J., & Donnell, J. J. (2007). *Stable Isotope Tracers in Watershed Hydrology*. Blackwell Publishing Ltd. Book Editor(s): Robert Michener, Kate Lajtha ISBN: 9780470691854. https://doi.org/10.1002/9780470691854.ch11.

Hedges, J. I., & Keil, R. G. (1995). Sedimentary organic matter preservation: An assessment and speculative synthesis. *Marine Chemistry,* 49(2-3), 81-115. https://doi.org/10.1016/0304-4203(95)00008-F

Klein, R. T., Lohmann, K. C., & Kennedy, G. L. (1997). Elemental and isotopic proxies of paleotemperature and paleosalinity: Climate reconstruction of the marginal northeast Pacific ca. 80 ka. *Geology*, 25(4), 363-366. DOI: 10.1130/0091-7613(1997)025<0363:EAIPOP>2.3.CO

Lario, J., Spencer, C., Plater, A. J., Zazo, C., Goy, J. L., & Dabrio, C. J. (2002). Particle size characterisation of Holocene back-barrier sequences from North Atlantic coasts SW Spain and SE England. *Geomorphology*, 42(1–2), 25–42. https://doi.org/10.1016/S0169-555X(01)00071-X

Marwick, B., & Gagan, M. K (2011). Late Pleistocene monsoon variability in northwest Thailand: an oxygen isotope sequence from the bivalve Margaritanopsis laosensis excavated in Mae Hong Son province. *Quaternary Science Reviews*, 30(21–22), 3088-3098. https://doi.org/10.1016/j.quascirev.2011.07.007

Milliman, J. D., Troy, P. J., Balch, W. M., Adams, A. K., Li, Y. H., & Mackenzie, F. T. (1999). Biologically mediated dissolution of calcium carbonate above the chemical lysocline? Deep-Sea Research Part I. *Oceanographic Research Papers,* 46(10), 1653–1669. http://www.sciencedirect.com/science/article/pii/S0967063799000345

Muttashar, W.R., Al-Aesawi, Q. M., Al-Nasrawi, A. K., Almayahi, D. S., & Jones, B. G. (2024). Coastline instability evaluation: multitemporal bathymetric mapping and sediment characteristics. *Environmental Earth Sciences,* 83(1), 43. https://doi.org/10.1007/s12665-023-11375-3

Nelson, D. W., & Sommers, L. E. (1996). Methods of Soil Analysis. Part3. Chemical Methods. *Soil Science Society of America, Book Series no. 5,* 961-1010. https://doi.org/10.2136/sssabookser5.3.c34

Noorollahi, D., Lashkari, H., Amirzade, M., Azizi, G., & Sharafi, S. (2011). Climatic and Environmental Reconstruction Based on Stable Isotopes of Parishan Lake (Iran). *Journal of Rangeland Science,* 1(3), 203. https://www.researchgate.net/publication/337973513_Climatic_and_Environmental_Reconstruction_Based_on_Stable_Isotopes_of_Parishan_Lake_Iran

Parker, A. G., Goudie, A. S., Stokes, S., White, K., Hodson, M. J., Manning, M., & Kennet, D. (2006). A Record of Holocene Climate Change from Lake Geochemical Analyses in Southeastern Arabia. *Quaternary Research,* 66(3), 465-476. https://doi.org/10.1016/j.yqres.2006.07.001

Paul B. N., David, C. C., Gilles, B. E. C., Bethany, L., Ehlmann, J. R., Michalski, R. M., Steven, W. R., & Brad, S. (2013). Geochemistry of Carbonates on Mars: Implications for Climate History and Nature of Aqueous Environments. *Space Science Reviews,* 174, 301–328. https://doi.org/10.1007/s11214-012-9940-y

Pisias, N. G & Prell, W. L. (1985). High-resolution carbonate records from the hydraulic pistoncored section of Site 572. In: Mayer, L., Theyer, F., et al. (Eds.) Init. Repts., DSDP, 85, Washington (U.S. Govt. Printing Office), 711-722. https://doi.org/10.2973/dsdp.proc.85.119.1985

Puertas, C. M., Espejo, F. J., Ruiz, F. M., Moreno, V. N., Gámiz, M. R., Maria, M. P., & Garcés, B. V. (2010). Late Holocene climate variability in the southwestern Mediterranean region: An integrated marine and terrestrial geochemical approach. *Climate of the Past*, 6, 807–816. https://doi.org/10.5194/cp-6-807-

Reis, A., Erhardt, A. M., McGlue, M. M., & Waite, L. (2019). Evaluating the effects of diagenesis on the δ13C and δ18O compositions of carbonates in a mud-rich depositional environment: A case study from the Midland Basin, USA. Chemical Geology, 524, 196-212. https://doi.org/10.1016/j.chemgeo.2019.06.021

Roberts, N. (1999). The Holocene: An Environmental History by Neil Roberts. Malden, and Blackwell. *The Geographical Bulletin*, 41(2), Article 9. https://digitalcommons.kennesaw.edu/thegeographicalbulletin/vol41/iss2/9

Salman, H. H., & Al-Moussawi, S. N. (1993). *Hydrology of the Arabian Gulf, a hydrometrological view*. The Arabian Gulf, selected scientific studies, edited by Salman Daoud Salman et al., p. 20. In Arabic.

Seiter, K., Hensen, C., Schröter, J., & Zabel, M. (2004). Organic carbon content in surface sediments—Defining regional provinces. Deep Sea Research Part I: Oceanographic Research Papers, 51(12), 2001-2026. https://doi.org/10.1016/j.dsr.2004.06.014

Schnitzer, M. (1978). Chapter 1 Humic Substances: Chemistry and Reactions. *Developments in Soil Science,* 8(C), 1–64. http://www.sciencedirect.com/science/article/pii/S0166248108700163.

Taha, M. T., & Abdullah, E. J. (2019). Reconstruction of Paleo depth and Paleo temperature from C- O stable isotope records of Mishrif Formation, southern Iraq. *Iraqi Journal of Science,* 60(8), 1730-1742. https://doi.org/10.24996/ijs.2019.60.8.10

Tisdall, J. M. & Oades, J. M. (2006). Organic matter and water stable aggregates in soils. *Journal of Soil Science,* 33, 141-163. https://doi.org/10.1111/j.1365-2389.1982.tb01755.x?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Tsiolakis, E., Monopoli, T. S., Kontakiotis, G., Antonarakou, A., Sprovieri, M., Geraga, M., Ferentinos, G., Theodorou, G., & Zissimos, A. (2019). Integrated paleohydrology reconstruction and Pliocene climate variability in Cyprus Island (eastern Mediterranean). *IOP Conference Series Earth and Environmental Science,* 362(1), 01. https://doi.org/10.1088/1755-1315/362/1/012103?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Tuite, M. L. & Macko, S. A. (2013). Basinward nitrogen limitation demonstrates role of terrestrial nitrogen and redox control of ^{15}N in Late Devonian black shale. *Geology,* 41(10), 1079-1082. https://doi.org/10.1130/G34549.1

Túri, M., Hubay, K., Molnár, M., Braun, M., László, E., Futó, I., & Palcsu, L. (2021). Holocene paleoclimate inferred from stable isotope (δ^{18}O and δ13C) values in Sphagnum cellulose, Mohos peat bog, Romania. *Journal of Paleolimnology*, 66, 229–248. https://doi.org/10.1007/s10933-021-00202-z

Tyson, R. V. (1995). *Sedimentary Organic Matter: Organic Facies and Palynofacies*. Chapman & Hall. Springer Dordrecht. eBook ISBN: 978-94-011-0739-6. https://doi.org/10.1007/978-94-011-0739-6

Wei, W., Lu, Y., Ma, Y., Zhang, J., Song, H., Chen, L., Liu, H., & Zhang, S. (2021). Nitrogen isotopes as paleoenvironmental proxies in marginal-marine shales, Bohai Bay Basin, NE China. *Sedimentary Geology*, 421, 105963. https://doi.org/10.1016/j.sedgeo.2021.105963

Woosley, R. J. (2018). Carbonate Compensation Depth. In: White, W.M. (Eds.). *Encyclopedia of Geochemistry*. Encyclopedia of Earth Sciences Series. Springer, Cham. https://doi.org/10.1007/978-3-319-39312-4_85.

Yacoub, S. Y. (2011). Stratigraphy of the Mesopotamian Plain. *Iraqi Bulletin of Geology and Mining,* Special Issue, No. 4, 47-82, 7-32. https://ibgm-iq.org/ibgm/index.php/ibgm/issue/view/19

Zeebe, R. E. (2012). History of seawater carbonates chemistry, atmospheric CO_2, and ocean acidification. *Annual Review of Earth and Planetary Sciences,* 40, 141-165. https://doi.org/10.1146/annurev-earth-042711-105521