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Late Holocene Charophytes and Gastropod Opercula from East Al Qurnah, Southern Iraq

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Abstract

Charophytes are indispensable tools in reconstructing Late Holocene environments due to their robust fossil record and ecological sensitivity. Therefore, their remains in sediments provide high-resolution archives for revealing paleoenvironmental conditions, especially in areas like southern Iraq, which has experienced significant environmental diversity due to Holocene sea-level fluctuations during the Holocene period. The 19 collected samples were subjected to grain size analysis to determine the type of sediments in the study area, and to micropaleontological investigations, which were the main purpose of the study—to detect charophyte species and thus reconstruct the paleoenvironments during the Late Holocene period in southern Iraq. The grain size analysis of the sediments showed that silt deposits dominated, encompassing both sandy silt and mud deposits. The study of charophytes revealed the presence of eleven species of gyrogonites and oospores belonging to five charophyte genera. The species of charophytes, along with the presence of gastropod opercula found at certain depths of the sample sites, contributed significantly to the identification of three facies: Facies 1, characterized by a freshwater environment; Facies 2, reflecting an oligohaline environment—both facies were present at all three study sites; and Facies 3, with its mesohaline environment, which was unique to the first site. Analysis of sediment types and sorting suggested that the appropriate depositional environment for these facies is a fluvial/backswamp setting. The presence of charophyte species further corroborated the existence of this sedimentary environment.

Keywords: Charophytes; Gyrogonites; Gastropda opercula;Late Holocene; Backswamp environment; Southern Iraq

1. Introduction

Southern Iraq experienced significant sea-level changes during the Quaternary, which were spatially variable due to glacio-hydro-isostatic effects, especially in the Late Pleistocene and Early Holocene (Lambeck and Chappell, 2001; Sissakian et al., 2020). These changes resulted in marine transgressions that flooded parts of the Mesopotamian Plain, followed by relative sea-level stabilization and sedimentary changes in the Late Holocene (Lambeck and Chappell, 2001; Kennett and Kennett, 2006).

Numerous studies have documented the marine impact in southern Iraq by analyzing the remains of faunal shells found in sediments. A study of recent marine deposits near Basrah revealed faunal assemblages dominated by small gastropods and lamellibranchs, confirming the marine origin of these sediments (Hudson et al., 1957). Additionally, a study by Plaziat and Younis (2005) found a mixture of marine, brackish water, and freshwater shells in some sediment layers-especially in marshes and polder-lake bottoms. A study of benthic foraminifera (Issa, 2010) and ostracoda (Issa, 2016) in sediments of northern Basra demonstrated the influence of sea-level change on southern Iraq during the Holocene. These investigations have provided valuable insights into both past and present environmental conditions in the region.

Paleoenvironmental studies in southern Iraq have explored the impact of sea-level fluctuations during the Holocene. Various types of biological remains have been examined, but there has been little focus on studying charophyte fossils. The presence of charophytes alongside other faunal shells has been noted in studies such as Al Sheikhly (2001), where they were found with ostracods and gastropod opercula. In Issa's study (2016), charophytes were used in conjunction with ostracod species to determine the biofacies of Late Holocene sediments in southern Iraq. Charophytes can be a valuable tool in geological and paleoenvironmental research, offering direct evidence for reconstructing the ecological and climatic conditions of ancient continental environments (Schneider et al., 2015; Demirci et al., 2023).

Interestingly, the fossilized remains of charophytes were found alongside gastropod opercula in the same sediments, enhancing their significance (Granados et al., 2021; Demirci et al., 2023). This discovery is particularly valuable in floodplain and riverine systems, as it provides important evidence for reconstructing Late Holocene paleoenvironmental conditions (Demirci et al., 2023). This unique assemblage sets the sediments of the Mesopotamian Plain apart, making them especially suitable for studying the Late Holocene sediments of southern Iraq.

Therefore, the current study aimed to identify the types of gyrogonites and oospores of charophytes preserved in the sediments of southern Iraq as a primary tool for paleoenvironmental inference. This was achieved by determining their environmental tolerances and habitat preferences, then defining the palaeoenvironments that existed at that time and assessing the extent to which these environments were affected by fluctuating conditions during the Late Holocene period. These interpretations were further supported by the presence of gastropod opercula accompanying the charophyte remains.

2. Materials and Methods

2.1. Location of the Study Area

The study area is located between the latitudes of 31°01′N and 31°02′N, and the longitudes of 47°25′30″E and 47°27′30″E. This specific region represents the eastern part of the Al-Qurnah District, situated north of the Basrah Governorate in southern Iraq, and lies in close proximity to the Tigris River (Fig. 1).

2.2. Sample Collection

Excavation activities were carried out in July 2019 at three sites using a Poclain excavator. Before sampling, the top layer of sediments at each depth was carefully removed to prevent any potential mixing of sediments that may have occurred during excavation. Samples were then collected from each location at different depths, ranging from 0.10 to 2.35 m.

2.3. Study Methods

Initially, sediment samples were subjected to wet sieving using a 63 μm mesh sieve, and subsequently dried at ambient temperature. For the analysis of the finer fraction, the pipette method was employed for particles measuring less than 0.0625 mm, following the procedures established by Folk (1980). The distribution of grain sizes was evaluated, and the relative proportions of each category—namely sand, silt, and clay fractions—were illustrated on a Folk ternary diagram (1980) to depict sediment distribution across the three locations.

In the micropaleontological investigation, a portion of the collected samples was washed through a 0.063 mm sieve to eliminate silt and clay particles. The microflora, which included gyrogonites and oospores from charophytes, along with the microfauna, represented by gastropod opercula, were carefully selected and affixed onto slides. Identification to the species level was accomplished using a binocular stereoscopic microscope. Photomicrographic documentation was carried out using a BEL microscope paired with a Sony Cyber-shot 1080 digital camera.

The identification of charophyte assemblages, including gyrogonites and oospores, was conducted by reviewing various literature sources. These sources included works by Wang and Chou (2006), Hutorowicz (2008), Shukla et al. (2012), Issa (2016), Casanova and Karol (2023), and Demirci et al. (2023). In contrast, the classification of gastropod opercula was based on studies by Checa and Jiménez-Jiménez (1998) and Glöer and Naser (2008).

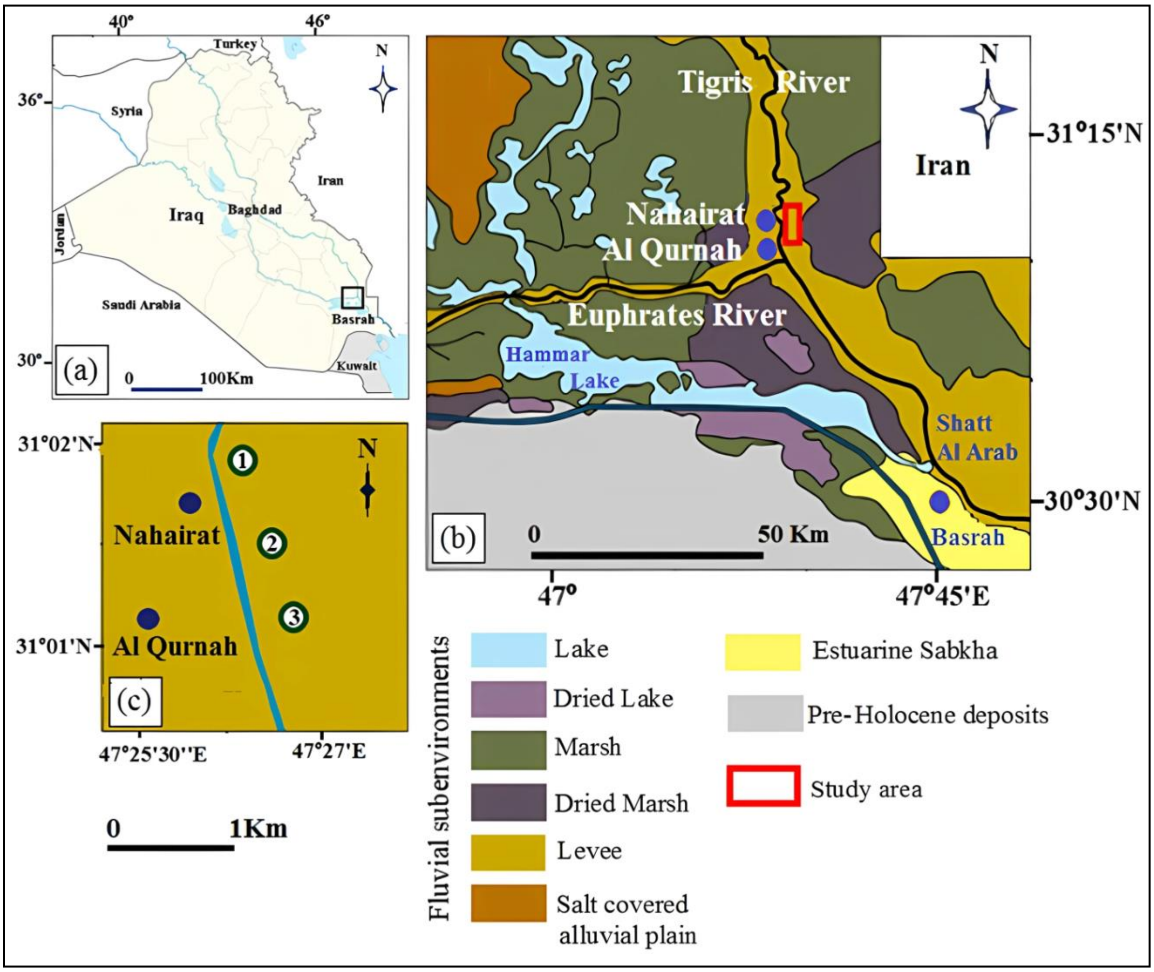

Fig.1. a) A map of Iraq;b) Location map of the study area(Modified afterMilli and Forti,2019);c) Sampling sites

3. Results

3.1. The Composition and Characteristics of Sediments

After analyzing the grain size, sediment classification was conducted by illustrating the ratios of sand, silt, and clay using a triangular diagram proposed by Folk (1980), as shown in Fig. 2 and Table 1. The analysis reveals that 63% of the total samples fall into the silt category, 26% are classified as sandy silt, and the remaining 11% are categorized as mud. Therefore, it can be inferred that the sediments in the study area are primarily composed of silt.

Based on the statistical grain size parameters outlined in Table 1, the sediments in the study area are classified as fine to very fine silt. The sediment deposits exhibit characteristics of being poorly to very poorly sorted.

Sediment sorting serves as a diagnostic tool that reveals the energy conditions, sediment transport dynamics, and depositional environments of the study area (Passega, 1972; Owens et al., 2005). The predominance of fine silt typically indicates deposition in low-energy environments such as floodplains and slow-moving river reaches (Owens et al., 2005). Poorly sorted fine silt sediments are characteristic indicators of a backswamp depositional environment, where low-energy water conditions are typical (Chen et al., 2020). The existence of a backswamp environment has been documented in the sediments of northern Basrah from the Late Holocene period (Issa, 2016).

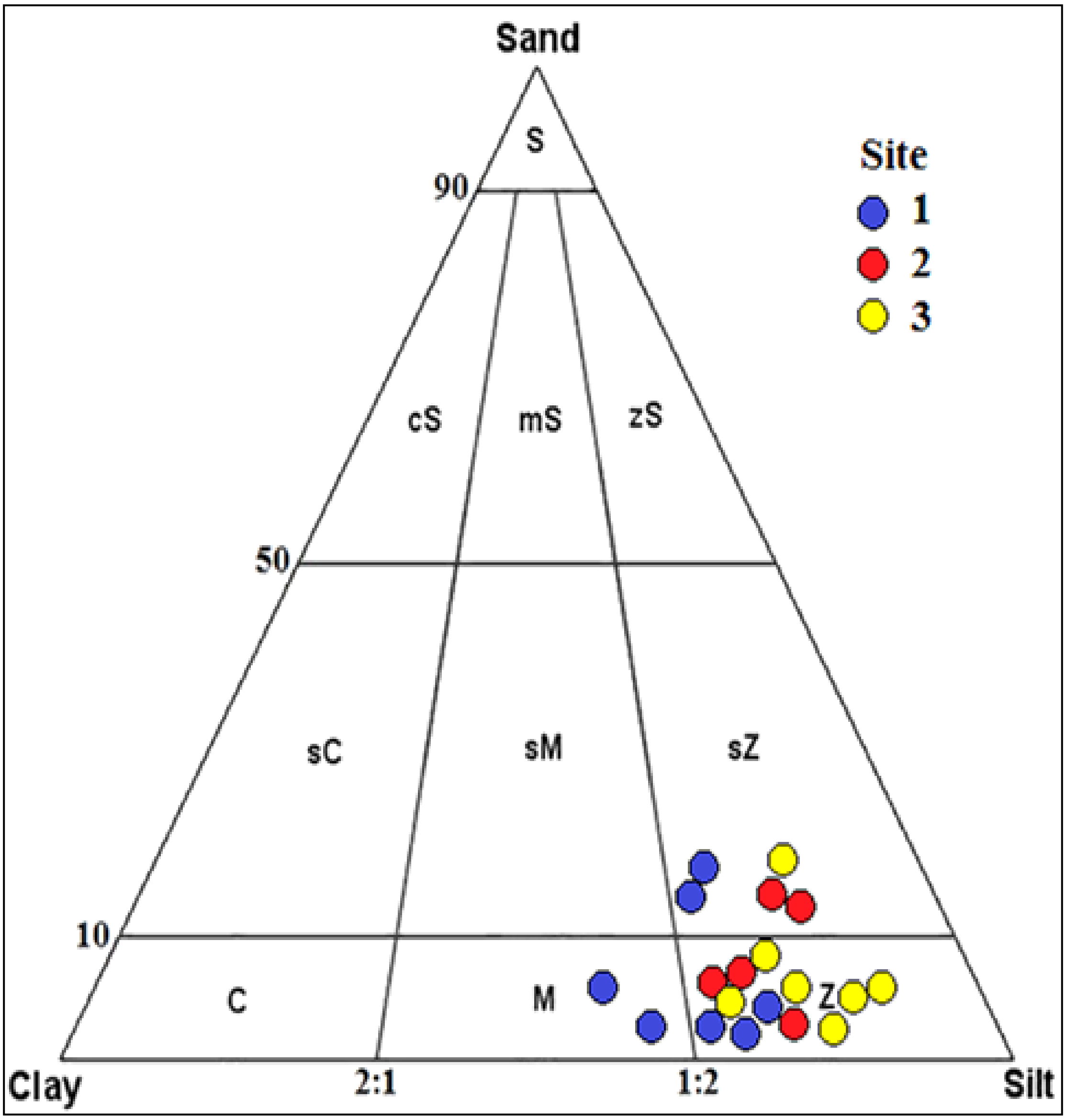

Fig.2 Triangular diagram representing the proportion of clay, silt and sand to identify the sediment texture

Table 1. Percentage distribution of sediment grain size of the three sites sediments, with their characteristics of mean and sorting

Site Number	Sample Number	Depth (m)	Sand %	Silt %	Clay %	Sediment texture	Mean M_Z	Sorting σI
	1	0.10-0.35	14	62	24	Sandy silt	6.28	2.09
	2	0.45-0.65	17	57	26	Sandy silt	6.77	2.25
	3	0.80-1.10	1	70	29	Silt	5.12	1.70
1	4	1.20-1.40	3	65	32	Silt	6.61	2.19
	5	1.70-1.90	5	71	24	Silt	7.20	2.38
	6	1.95-2.05	2	60	38	Mud	6.09	2.01
	7	2.10-2.35	6	54	40	Mud	7.51	2.5
	1	0.15-0.40	12	70	18	Sandy silt	7.14	2.37
	2	0.50-0.70	15	66	19	Sandy silt	6.73	2.24
2	3	0.80-0.95	7	67	26	Silt	6.83	2.27
	4	1.00-1.15	6	63	31	Silt	6.42	2.07
	5	1.20-1.5	4	74	23	Silt	7.54	2.43
	1	0.10-0.20	5	65	30	Silt	6.62	2.13
	2	0.30-0.40	9	70	21	Silt	7.13	2.30
	3	0.50-0.75	6	76	18	Silt	7.74	2.4
3	4	0.90-1.00	19	65	16	Sandy silt	6.61	1.71
	5	1.15-1.30	7	81	12	Silt	7.8	1.9
	6	1.40-1.50	6	81	13	Silt	7.6	1.85
	7	160-1.75	3	80	17	Silt	7.7	1.87

3.2. Micropaleontological Analyses

3.2.1.Charophytes species

Charophytes are the most common bioreminant component observed throughout of the study area at various depths, with gyrogonites of charophytes being the most abundant. Additionally, some species are present in the form of oospores, as illustrated in Plt.1 and detailed in Table 2. The identified species of Charophytes include: *Chara contraria* A. Braun ex Kützing, 1845, *Chara globularis* Thuiller, 1799, *Chara globularis* var. *globularis* Thuillier 1799, *Chara globularis aspera* (Detharding ex Willdenow) R.D.Wood, 1962, *Chara hispida* (Linnaeus, 1753), *Chara tomentosa* Linnaeus 1753, *Chara vulgaris* Linnaeus 1753, *Lamprothamnium papulosum* (K.Wallroth) J.Groves, 1916, *Lychnothamnus barbatus* (Meyen) Leonhardi 1863, *Nitellopsis obtusa* (Desv.) J.Groves, 1919, *Nitella hyalina* (DC.) C.Agardh, 1824. The presence and appereance of these species mark the first recorded instance of their existence in Iraq, particularly in the southern area.Only three species; *Chara globularis aspera* (Detharding ex Willdenow) R.D.Wood 1962 and *Chara hispida* Linnaeus, 1753, and *Nitellopsis obtusa* (Desv.) J.Groves, 1919 were previously documented in Late Holocene sediments of southern Iraq (Issa, 2016). Minor quantities of thalli encrustations were also identified which found with gyrogonites in the sediments, as demonstrated in Plt.2.

3.2.2.Gastropod opercula species

Among the distinctive remnants found within the sediments of the study area are the opercula of gastropods, whose shells are absent. Upon thorough identification, it was determined that all opercula belong to a single genus, *Bithynia,* as illustrated in Plt. 2 and Table 2. Comparison of these opercula with contemporary *Bithynia* species found in sediments of southern Iraq revealed notable differences, including greater thickness compared to recent specimens found in areas north of Basrah. Careful classification confirmed that the species is *Bithynia hareerensis* (Glöer and Naser, 2008). Furthermore, the opercula are ancient, dating back to the Late Holocene. This suggests that *Bithynia hareerensis* (Glöer and Naser, 2008) is not merely the modern species recorded in 2008 by Glöer and Naser, but rather a species that first appeared during the Late Holocene and continues to persist today.

3.2.3. Facies of the microflora and microfauna

Following the assessment of the charophyte and gastropod opercula species present at the three locations, as illustrated in Plt. 1 and Plt. 2, and detailed in Table 2 and 3, it was observed that there were commonalities in the assemblages of particular charophyte species at designated depths across all three sites, along with the consistent occurrence of *Bithynia hareerensis* opercula. Consequently, the assemblages at these sites were categorized into three distinct facies, as depicted in Fig. 3, arranged from bottom to top:

3.2.3.1. Facies 3

This facies is typically found at a depth of 2.10 m within the mud sediments of Station 1, with thicknesses reaching 0.25 m, as shown in Fig. 3. It is characterized by the presence of charophyte species, including gyrogonites of *Chara globularis aspera*, *Lamprothamnium papulosum*, and oospores of *Nitella hyalina*. *Lamprothamnium papulosum* was the predominant species, while the other species appeared in very small numbers.

The assemblage of charophytes species, along with variations in their individual density, can offer valuable information regarding the paleoenvironment of this facies deposits.This environment is characterized as brackish, where saline marine waters marginally intermingle with freshwater from rivers. The presence of *Lamprothamnium papulosum* serves as a clear indicator of this unique environmental settingconsidering the preferred environment which *Lamprothamnium papulosum* thrives in it that brackish water with fluctuating salinity (Avant, 2004), where ecosystems this species found in there characterized by significant periods of saline conditions (Beilby, 2015). *Lamprothamnium papulosum* has been recorded from oligohaline to polyhaline environments, indicating adaptability to mesohaline conditions (Kashta et al., 2025).

This interpretation is reinforced by the presence of the companion species *Chara globularis aspera* and *Nitella hyalina*. It is known that the former species thrives in brackish to slightly saline environments (Kotta et al., 2021), while the latter prefers freshwater, although it can also be found in saline conditions (Langangen et al., 2002). Notably, *Nitella hyalina* was found in the form of oospores, which further supports the possibility of a mixing of freshwater and saltwater. This process can expose the oospores, leaving them without their gyrogonites (Stragauskaitė et al., 2021). Therefore, the mesohaline environment is considered the ideal setting for this facies.

3.2.3.2. Facies 2

This facies consists of silt deposits in all three locations (Fig. 3). The thickness of this zone varies, with the maximum thickness recorded at 0.85 m at Site 1, followed by 0.5 m at Site 2, and a thickness of 0.35 m at Site 3.

The charophytes species assemblages in this facies were observed to comprise three groups, distinguished according to their abundance: The first group of species is highly abundant and dominantinthe facies represented; gyrogonites of *Chara hispida*, *Chara tomentosa* and oospores of *Nitellahyalina*. The second group included more species than the previous group, including; oospore of *Chara contraria* and gyrogonites of*Chara globularis aspera*, *Chara globularis* var. *globularis* and

Chara globularis. While the third group, the least diverse in term of species and abundance, included gyrogonite of *Chara vulgaris* and *Lychnothamnus barbatus*.

When previewing the three groups of species, it is noted that the dominant species thrive in oligohaline conditions. Although they can be found in freshwater, the majority of the environments they inhabit have water salinity limits within the oligohaline range (Langangen et al., 2002; Palma-Silva et al., 2004; Henricson et al., 2006; Borja et al., 2023). Therefore, the ideal environment for this facies is oligohaline.

As for the other species in the second and third groups, their presence reinforces the oligohaline nature of the facies environment. Species in these groups are known to inhabit both freshwater and brackish water environments, including oligohaline (low salinity) brackish waters (Wood, 1962; Urbaniak and Combik, 2017; Borja et al., 2023), except for two species—*Chara contraria* and *Lychnothamnus barbatus*—which thrive in freshwater (Wang and Chou, 2006; Diba et al., 2013). This demonstrates the influence of river water in this facies. The appearance of *Bithynia hareerensis* opercula here also confirms the influence of river water (Glöer and Naser, 2008).

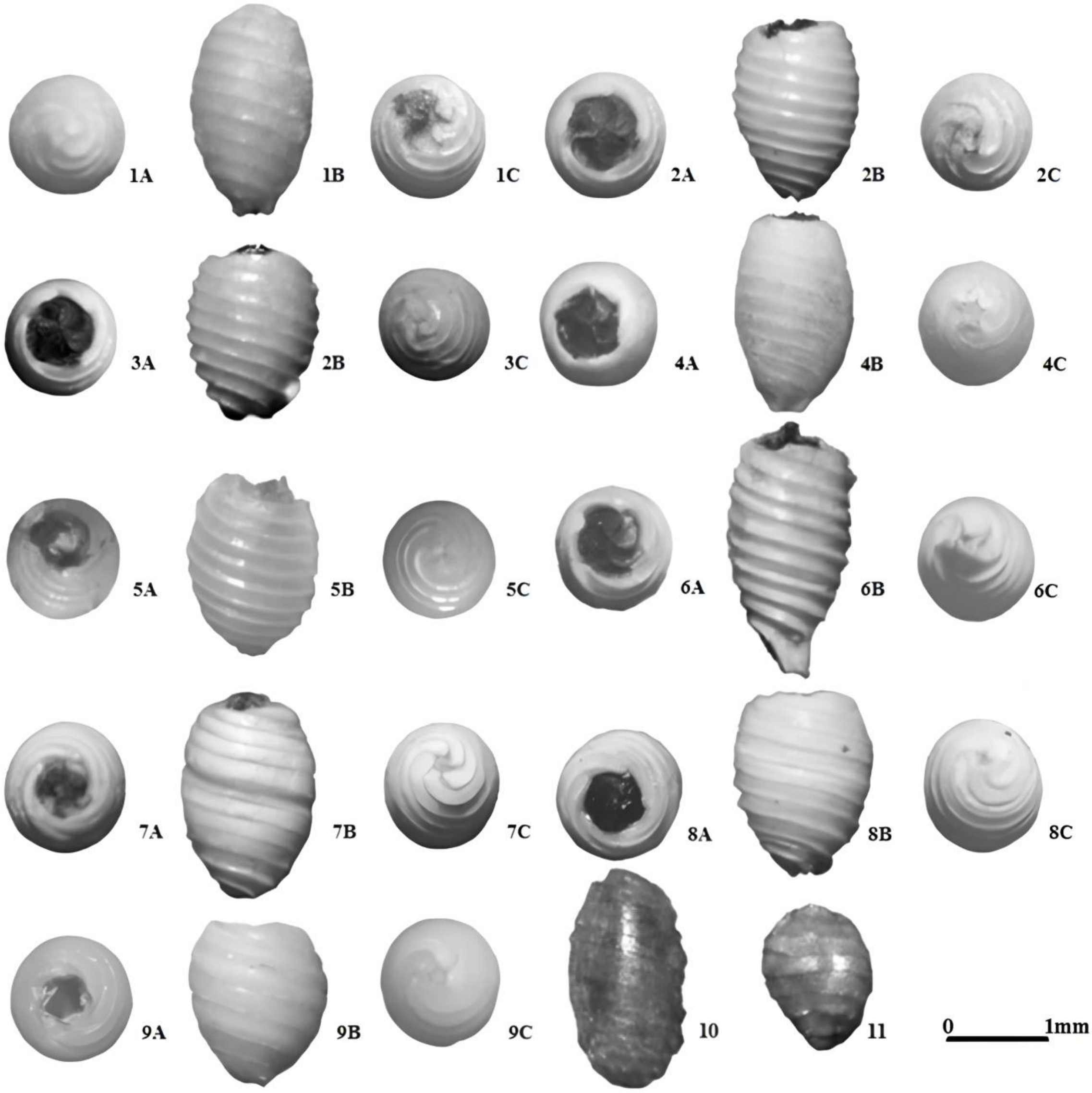

Plate 1. The charophytes species gyrogonites. 1A-C. *Chara globularis*: A. apical view, B. lateral view, C. basal view. 2A-C. *Chara globularis* var. *globularis*: A. apical view (apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 3A-C.*Chara globularis aspera*: A. apical view (apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view.

4A-C.*Chara hispida*: A. apical view (apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 5A-C.*Chara tomentosa*: A. apical view(apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 6A-C.*Chara vulgaris*: A. apical view(apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 7A-C.*Lamprothamnium papulosum*: A. apical view (apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 8A-C.*Lychnothamnus barbatus*: A. apical view(apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. 9A-C.*Nitellopsis obtusa*: A. apical view (apex of the oospore visible inside the calcified gyrogonite), B. lateral view, C. basal view. The charophytes species oospores.11. *Chara contraria*. 12. *Nitella hyalina.*

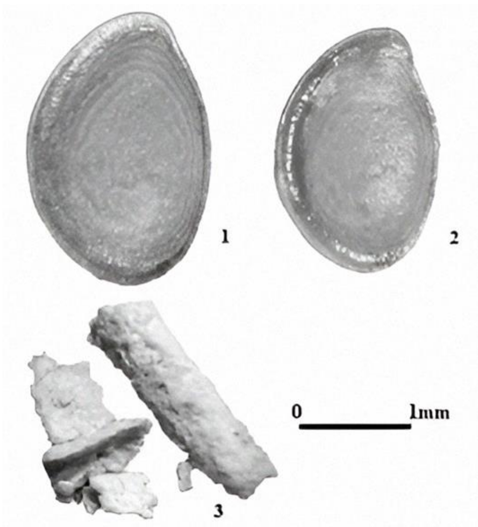

Plate 2.1and 2. *Bithynia hareerensis*. 3. Thalli encrustations of charophyte

3.2.3.3. Facies 1

The thickest facies was observed at Site 3, measuring 1.2 m. Silt deposits were the most commonwith a small amount of sandy silt. At Sites 1 and 2, the percentages of silt and sandy silt deposits weresimilar, with facies thicknesses of 1 and 0.8 m, respectively (Fig. 3).

The predominance of charophytes in theassemblage was evident, with species such asgyrogonites of *Lychnothamnus barbatus*, *Nitellopsis obtusa* and oospore of *Chara contraria*, in addition to the thalli encrustations. This was followed by the appearance of species gyrogonites represented by *Chara vulgaris* and *Chara tomentosa*. Howeverthe gyrogonites species such as*Chara globularis*, *Chara globularis* var. *globularis* and *Chara globularis aspera* were less abundant in the charophytes assemblage.

It is noted that the dominant species clearly indicate that the environment of this facies is freshwater, based on the preferred habitat of the species (O'Connor, 2015; Rey-Boissezon and Joye, 2015; Larkin et al., 2018). What sets this facies apart is the combination of the three dominant species and their roughly equal abundances. The presence of *Lychnothamnus barbatus*, *Nitellopsis obtusa*, and *Chara contraria* together serves as a reliable ecological indicator of a freshwater backswamp environment within a fluvial system (Nurashov et al., 2023). Therefore, the paleoenvironment of this facies is unquestionably a backswamp.

The remaining charophytes, which included *Chara vulgaris*, *Chara tomentosa*, *Chara globularis*, *Chara globularis var. globularis*, and *Chara globularis aspera*, accompanied the main group. Their presence and diversity are indicative of the strong influence of freshwater on this facies. These *Chara* species and varieties commonly occur together in freshwater habitats, and their presence also indicates relatively good water quality (Henwood, 2014; Bellino and Baldantoni, 2023). A significant environmental indicator that strongly suggests the influence of rivers in this facies is the noticeable prevalence of *Bithynia hareerensis* opercula, which is recognized for its riverine habitat (Glöer and Naser, 2008).

Table 2. Distribution and abundance of the charophytes species and *Bithynia hareerensis* opercula in the samples from the three sites

Site Number	Sample Number	*Chara contraria*	*Chara globularis*	*Chara globularis* var. *globularis*	*Chara globularis aspera*	*Chara hispida*	*Chara tomentosa*	*Chara vulgaris*	*Lamprothamnium papulosum*	*Lychnothamnus barbatus*	*Nitellopsis obtusa*	*Nitella hyalina*	*Bithynia hareerensis* opercula
		Charophyte species											
1	1	11-50	> 100	51-100	> 100		11-50	51-100		> 100	51-100		> 100
	2	11-50	11-50	51-100	> 100		11-50	> 100		> 100	> 100		> 100
	3	11-50	11-50	11-50	51-100	0-10	11-50	51-100		51-100	51-100	0-10	51-100
	4	0-10	0-10	0-10	0-10	> 100	> 100	0-10		0-10	0-10	11-50	11-50
	5	0-10			51-100	> 100	11-50	0-10		0-10		11-50	
	6		0-10	0-10	51-100	51-100	0-10		11-50			51-100	0-10
	7				11-50				> 100			0-10	
2	1	51-100	51-100	11-50	51-100		11-50	51-100		51-100	51-100		> 100
	2	11-50	11-50	51-100	> 100	0-10	11-50	51-100		> 100	51-100		51-100
	3	51-100	11-50	11-50	51-100			51-100		51-100	51-100		> 100
	4	0-10	0-10	0-10	51-100	> 100	> 100	0-10		0-10		> 100	0-10
	5		0-10		0-10	> 100	11-50	0-10	0-10		0-10	51-100	0-10
3	1	51-100	> 100	51-100	51-100		51-100	51-100		> 100	51-100		> 100
	2	11-50	11-50	51-100	> 100	0-10	11-50	51-100		> 100	51-100		> 100
	3	51-100	11-50	11-50	> 100		51-100	51-100		51-100	> 100		51-100
	4	51-100	0-10	51-100	51-100	0-10	11-50	> 100		51-100	51-100	0-10	51-100
	5	0-10	0-10	11-50	0-10	0-10	11-50	51-100			0-10		11-50
	6	0-10	0-10	0-10	51-100	51-100	51-100	0-10		0-10	0-10	51-100	0-10
	7	0-10	0-10	0-10	0-10	> 100	51-100	0-10	0-10	0-10		> 100	

Number of charophytes gyrogonites per sample: ● 0-10 ● 11-50 ● 51-100 ● > 100

Number of charophytes oospores per sample: ○ 0-10 ○ 11-50 ○ 51-100 ○ > 100

Number of *Bithynia hareerensis* opercula per sample: ○ 0-10 ○ 11-50 ○ 51-100 ○ > 100

Table 3. Facies summary–table illustrates facies names, thickness, sediment type, occurrence station, dominant taxa and diagnostic environment

Facies	Thickness (m)	Sediment Type	Occurrence Station	Dominant Taxa	Diagnostic Environment
Facies 1	0.8-1.2	Silt - Sandy silt	1,2,3	Charophytes species *Lychnothamnus barbatus* *Nitellopsis obtusa* *Chara contraria* *Chara vulgaris* *Chara tomentosa* Gastropod opercula species *Bithynia hareerensis*	Freshwater Backswamp
Facies 2	0.35-0.85	Silt	1,2,3	Charophytes species *Chara hispida* *Chara tomentosa* *Nitellahyalina* *Chara contraria* *Chara globularis aspera* *Chara globularis* var. *globularis* *Chara globularis* Gastropod opercula species *Bithynia hareerensis*	Oligohaline
Facies 3	0.25	Mud	1	Charophytes species *Chara globularisaspera* *Lamprothamnium papulosum* *Nitella hyalina*	Mesohalin

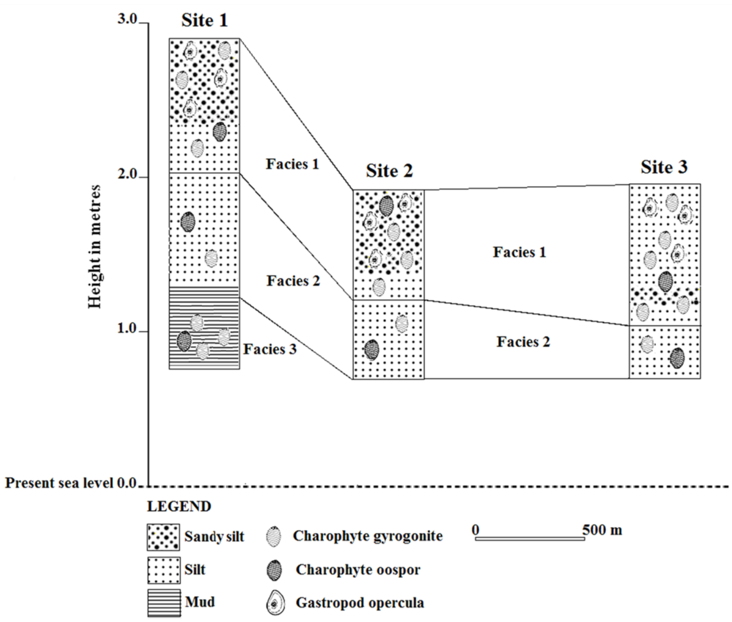

Fig. 3. Distribution of facies in the study area

4. Discussion

Charophytes are crucial paleoenvironmental proxies in Late Holocene studies. They offer well-preserved morphological remains that provide insights into past freshwater conditions, climate variability, and ecosystem changes. Consequently, reconstructions of paleoenvironments often rely on them (Détriché et al., 2009; Palacios-Fest, 2010; Apolinarska et al., 2011; Schneider et al., 2015; Ilijanić et al., 2025), particularly in freshwater and brackish systems during the Late Holocene and beyond (Schneider et al., 2015).

The ecological preferences of charophytes make them reliable indicators of past lake and wetland environments. An analysis of charophyte remains from Lake Afourgagh in Morocco has contributed to reconstructing water level fluctuations in the lake (Détriché et al., 2009; Détriché et al., 2013). In reconstructing paleoclimatic variation, a study of charophytes, along with the participation of microinvertebrates, successfully reconstructed the transition from the Medieval Climatic Anomaly to the Little Ice Age at an archaeological site in northern Texas, United States (Palacios-Fest, 2010). Regarding sedimentation dynamics and paleoclimatic implications, charophytes in sediments were able to reconstruct Middle to Late Holocene sedimentation patterns and paleoclimatic conditions in Lake Ulaan, southern Mongolia (Mischke et al., 2020). In tracking the timing and rates of climate change, charophytes are a powerful tool, as demonstrated by various studies conducted in the southwestern United States and the Alps (Palacios-Fest, 2010).

Charophytes are effective biostratigraphic tools, as they establish clearly defined biozones derived from their fossil records. This capability facilitates accurate dating and correlation of continental sedimentary sequences, while also connecting terrestrial and marine stratigraphic records through comprehensive methodologies (Musacchio, 2000; Pérez-Cano et al., 2022; Pérez-Cano et al., 2023). During the Early Cretaceous period, charophytes successfully defined biozones in Europe and Eurasia based on assemblages classified according to the occurrence of index species and their respective stratigraphic ranges (Pérez-Cano et al., 2022).

Charophytes are sensitive to environmental changes such as salinity, making them effective indicators of past ecological conditions in lakes, rivers, and wetlands (Demirci et al., 2023). The study of charophytes has also significantly contributed to detecting environmental transitions in aquatic systems. Charophyte assemblages in southern Iberia, around the Strait of Gibraltar, have documented transitions in lake and wetland environments, such as shifts from marine embayments to coastal lagoons, and eventually to freshwater wetlands during the Middle to Late Holocene. These changes reflect sea-level fluctuations and sedimentation dynamics (May et al., 2021).

Charophyte species have specific ecological requirements, especially regarding salinity, allowing to infer past salinity levels in non-marine water bodies by identifying fossil charophyte assemblages (Schneider et al., 2015). This was demonstrated when studying the remains of charophytes from the Midhnab Member of the Khuff Formation, found in lacustrine limestone deposits in Saudi Arabia, proving that the ancient environments were freshwater (Berthelin et al., 2006). Additionally, studying relict lake deposits—including charophytes—in the Arabian deserts (areas in Saudi Arabia and Oman) to reconstruct past climates and hydrological conditions during the Late Holocene and earlier periods has indicated episodes of more humid conditions with freshwater availability, contrasting with the current arid climate of the Arabian Peninsula (Rosenberg, 2011).

While charophytes have been noted in Iraqi studie, such as the study by Al-Sheikhly (2001), which mentioned their presence in terms of quantity rather than specific species, it was concluded that their presence alongside ostracods indicated a freshwater environment. Another study by Issa (2016) classified charophyte species and defined their environmental context, considering them a group that contributes to environmental diversity in southern Iraq. However, charophytes have not yet been the primary focus of any investigation. Further research would likely expand knowledge of their diversity and distribution in Iraq, especially in marshland and fluvial systems where they serve as valuable paleoenvironmental indicators.

Eleven species of charophytes were identified in Late Holocene sediments from southern Iraq, playing a key role in reconstructing paleoenvironments and clarifying the scenario of water salinity variation and its regional impact. Through this analysis, three basic environments were identified, represented by facies: Facies 1 – freshwater, Facies 2 – oligohaline, and Facies 3 – mesohaline environments.

The latter facies represented a distinctive environment within the study area, as it was exclusively identified at Site 1, specifically at its deepest point, where the primary charophytes were gyrogonites of *Lamprothamnium papulosum*. Paleoecological studies indicate that the presence of *Lamprothamnium papulosum* in sediment layers can act as an indicator of environmental conditions, including water salinity and historical hydrological events (Soulié-Märsche, 1994). What sets *Lamprothamnium papulosum* apart is its ability to thrive in brackish water environments. This species is typically found in shallow, sheltered bays and coastal lagoons, which are characterized by fluctuating salinity levels. It generally prefers salinity ranges of approximately 8 to 28 ppt and is not found in freshwater ecosystems, thus being recognized as a characteristic charophyte of brackish water.

What is particularly notable is the restricted diversity of charophytes in this facies, as only two species were found alongside*Lamprothamnium papulosum*: *Chara globularis aspera* and *Nitella hyalina*. This limited assemblage serves as evidence of specific environmental conditions, where charophyte diversity is often reduced in coastal marine-influenced environments, favoring a few salinity-tolerant species (Lin et al., 2022; Bellino and Baldantoni, 2023).

From the above, it can be concluded that seawater influence must have affected the region, and this influence is attributed to a single key factor: sea-level fluctuation during the Late Holocene, which facilitated the mixing of seawater with riverine input in the study area (Issa, 2010; Issa, 2016). This hydrological interaction led to the establishment of a mesohaline environment, represented by Facies 3.

As the influence of sea level fluctuations diminished and the impact of river water increased in the study area, the diversity of charophytes began to rise (Meurer et al., 2020), reaching a total of nine species. However, the prevalence of *Chara hispida*, *Chara tomentosa* and *Nitella hyalina* emerged as significant environmental indicators of the conditions in the region during that period. This abundance played a crucial role in defining the characteristics of facies 2, which marked the transition to oligohaline conditions in accordance with the habitat preferences of these species (Langangen et al. 2002; Palma-Silva et al., 2004; Henricson et al., 2006; Borja et al., 2023).The occurrence of *Bithynia hareerensis* opercula in Facies 2 reinforces the idea that the influence of marine waters decreases as river flow in the area rises.This is evident in the opercula habitat of *Bithynia hareerensis*, which exists in a riverine setting (Glöer and Naser 2008).

As the influence of sea-level fluctuations diminished and the impact of river water increased in the study area, the diversity of charophytes began to rise (Meurer et al., 2020), reaching a total of nine species. However, the prevalence of *Chara hispida*, *Chara tomentosa*, and *Nitella hyalina* emerged as significant environmental indicators of the conditions in the region during that period. This abundance played a crucial role in defining the characteristics of Facies 2, which marked the transition to oligohaline conditions, in accordance with the habitat preferences of these species (Langangen et al., 2002; Palma-Silva et al., 2004; Henricson et al., 2006; Borja et al., 2023). The occurrence of *Bithynia hareerensis* opercula in Facies 2 reinforces the idea that the influence of marine waters decreases as river flow increases in the area. This is evident from the habitat of *Bithynia hareerensis*, which is known to inhabit riverine environments, particularly in southern Mesopotamia, such as the Garmat Ali River near Basrah (Glöer and Naser, 2008).

Facies 3 indicates the stability of environmental conditions after the completion of sea-level fluctuation events. One of the conclusive pieces of evidence for this is the presence of well-preserved charophyte remains, which serve as bioindicators of long-lasting, calm, and clear aquatic habitats with stable chemical and physical conditions that support their growth and fossilization (Schneider et al., 2015). Also, the presence of well-preserved encrusted stems and gyrogonites of charophytes, as in Facies 3, indicates a more stable aquatic environment, such as a backswamp with sufficient depth and duration to allow for the completion of the charophyte life cycle (Issa, 2016). Evidence supporting this observation lies in the presence of charophytes and gastropod opercula preserved together, which is indicative of freshwater paleoenvironmental conditions where these organisms lived together (Hooker et al., 1995). Additionally, gastropod opercula are valuable for reconstructing hydrological stability during the Late Holocene, particularly in floodplains and riparian zones (von Suchodoletz et al., 2020). This fact has been confirmed in the study area.

According to Ghafor (2022) and Ghafor and Najaflo (2022), a salinity gradient is observed in the environment, ranging from mesohaline to oligohaline. In the current study, the environment transitions from the third facies, which was characterized by a mesohaline environment and was only identified at the deepest point of the first site, to an oligohaline environment in the second facies, observed at three sites, and finally to the first facies, where a freshwater environment was recognized at all three sites as well. This transition is attributed to marine water intrusion into riverine areas, creating a salinity gradient from mesohaline through oligohaline to freshwater conditions. This process shapes distinct ecological zones characterized by specific biological communities adapted to the salinity regime and its fluctuations (Klier et al., 2018). This provides clear and explicit evidence that the study area was affected by sea-level changes during the Late Holocene.

5. Conclusions

- Three distinct categories of sediments were identified in the research area. The most common type was silt, followed by sandy silt, whereas mud sediments were found to be the least abundant. The statistical parameters of grain size for the sediments in the study area have shown that the silt sediments were fine to very fine. The sorting characteristics of the deposits are poorly to very poorly sorted, indicating that the depositional environment is a backswamp with low-energy water conditions.
- This study is the first in Iraq to classify gyrogonites and oospores of charophytes. The classification revealed the presence of eight species of charophytes, whose appearance was recorded for the first time in Iraq, especially in the southern region. Six species were identified in the form of gyrogonites: *Chara globularis, Chara globularis var. globularis, Chara tomentosa, Chara vulgaris, Lamprothamnium papulosum,* and *Lychnothamnus barbatus*. The remaining two species, *Chara contraria* and *Nitella hyalina*, were present in the form of oospores.
- The gastropod species identified from the opercula in the study area is *Bithynia hareerensis*. This demonstrates that Bithynia *hareerensis* is not a recent species that appeared in southern Iraq, but rather existed during the Late Holocene period, following the end of sea-level fluctuations and the environmental stability that the study area experienced thereafter.
- Based on the classifications of charophytes, three distinct facies were identified, characterized by varying levels of water salinity: Facies 1 represents a freshwater environment, Facies 2 an oligohaline environment, and Facies 3 a mesohaline environment. The transition of salinity from mesohaline to oligohaline and ultimately to freshwater conditions is attributed to the influx of marine water into the study area, influenced by fluctuations in sea level during the Late Holocene. Given the environmental stability demonstrated in Facies 3, this study establishes that the environment has remained stable from the Late Holocene to the present.

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