6. Ostracods, Charophytes, and Pollen: Late Miocene paleoenvironments of the Baynunah Formation

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Abstract

Ostracods, charophytes and pollen were retrieved from sediments of the Baynunah Formation. Autoecological characteristics of the ostracods and the charophytes, together with detailed observations on the taphonomy of ostracod valves, provide a reconstruction of the depositional environments of the Baynunah freshwater system. These microfossil assemblages indicate the presence of a large floodplain with a slow-flowing river with high suspended sediment load, as well as a system of shallow, possibly isolated, water bodies with clear waters and submerged meadows of macroalgae. The water bodies were characterized by fluctuating salinities that could be linked to phases of evaporation-desiccation and regeneration of the freshwater environment, i.e. alternation of humid and dry periods. The landscape reconstructed through the pollen analyses indicate the presence of open woodland to grassland vegetation, with halophytes growing close to the water bodies.

Keywords: Ostracods, Charophytes, Pollen, Taphonomy, Arabian Peninsula, Palaeoecology

Running head: Palaeoenvironments of the Baynunah Formation

Introduction

The Al Gharbia region of Abu Dhabi Emirate preserves the only known outcrops of late Miocene terrestrial fossiliferous deposits from the entire Arabian Peninsula, the Baynunah Formation. Whybrow (1989) characterized the Baynunah Formation as comprised of fine to medium-grained quarzitic sands, silts, gypsum and conglomerates (see also Schuster, Chapter 3, this volume). Over 30 years of paleontological survey work has resulted in a significant assemblage of large and small vertebrates from these sediments (Hill *et al.*, 1999; Bibi *et al.*, 2013; Bibi, Chapter 2, this volume). The Baynunah fossil fauna is estimated to have an age between 8 and 6 Ma (Whybrow & Hill 1999; Bibi *et al.* 2013).

Almost all fossil bone remains come from lower parts of the Baynunah Formation, especially from beds characterized by higher-energy fluvial deposits. In contrast, the upper part of the Baynunah Formation comprises a sequence of silts and clays alternating with carbonates, and in which vertebrate remains are rare or absent. These cemented carbonates are resistant to erosion and, where exposed, preserve several vertebrate trackway sites (Bibi et al. 2012, 2013; Kraatz, Chapter 17 this volume). These carbonates also contain mollusk and ostracod shells and molds that have never been studied in detail.

The aim of the present research paper is to reconstruct the depositional environment of the upper part of the Baynunah Formation through analyses of micropalaeontological remains, in particular those of ostracod and charophyte communities and on palynological analyses. This contributes to our knowledge of fossil non-marine ostracods and charophytes of the Arabian region, with ten taxa reported here for the first time from the Miocene of the United Arab Emirates and six ostracod taxa new to the fauna of the entire Arabian Peninsula.

In general, knowledge of Neogene to Recent ostracods from the Arabian Peninsula is poor. Although ostracods are nearly ubiquitous in freshwater to hypersaline aquatic habitats, from, studies on the extant ostracod fauna of the area are scarce (Karanovic 2012). Dumont et al. (1986) discussed the taxonomy and distribution of extant fresh water ostracods in South Yemen. Mazzini & Sardella (2004) and Mohammed et al. (2014) found a total of 15 species of fresh water ostracods from the Quaternary and Recent of Socotra Island (Yemen). The only significant study of ostracods from the U.A.E. is the analysis of Recent Abu Dhabi near-shore and lagoonal ostracods by Bate (1971). Bate recognized eight different assemblages: near-shore shelf, back reef, tidal delta, lagoon channels, lagoon terrace (outer, central and inner lagoon), lagoon channel and tidal pool. In his study, the only ostracod not considered to be exclusively marine is the species *Cyprideis torosa*. Also from the U.A.E., Stewart et al. (2011) described ostracods from a lagoonal terrace facies in a mid-Holocene deposit at Musaffah, while Preston et al. (2015) described a *Cyprideis torosa* dominated assemblage from the Holocene Wahalah palaeolake.

Whybrow and Clements (1999) reported *Cyprideis* sp. from the Baynunah Formation, without providing further detail. A preliminary study on selected carbonate samples from the Baynunah Formation led to the recognition of five ostracod taxa: *Cyprideis* cf. *torosa, Heterocypris salina, Vestalenula cylindrica, Candona* sp. and *Prolimnocythere* sp. (Mazzini et al. 2013), of which four were first records for the late Miocene of the Arabian Peninsula.

Charophytes are submerged macroalgae with a well-developed complex thallus and morphology, and that can be found in fresh and brackish water bodies, but not in areas of high salinity (Soulié-Märsche 2008). In the process of sexual reproduction, charophytes produce oospores and calcareous gyrogonites that are amenable to fossilization. In the Baynunah Formation, Algae gen. et sp. indet. was previously reported by Whybrow & Clements (1999). In the Miocene of Iraq, abundant *Chara* sp. remains occur together with ostracods in the Zahra and Dibdibba Formations (Al Naqib 1967; Jassim et al.1984). In Saudi Arabia, charophyte gyrogonites have been reported from the Miocene (Burdigalian) of Al Dabtiyah (Whybrow et al.1987), and abundant gyrogonites of *Chara* sp. have been recorded from the

Mio-Pliocene Hofuf Formation (Powers et al.1963). Several studies have recorded living charophytes in Oman and Saudi Arabia, showing the crucial role that small or ephemeral water bodies play in preserving their biodiversity (Koja & Hussain 1990; Hussain et al. 2003).

Palynological data for this region are scarce. Whybrow and McClure (1980) reported a high proportion of grass pollen together with *Alchornea*, *Celtis*, Myrtaceae and palms from ?Middle Miocene samples from Saudi Arabia (and possibly Oman, their 'Site 2'), indicating a tropical deciduous broadleaf woodland. Whybrow & Clements (1999) reported Leguminosae (?*Acacia* sp.) from the Baynunah Formation.

The Arabian Peninsula today lies in an arid zone at the boundary between the Palaearctic and the Afrotropical zoogeographical regions (Martens et al. 2008). Palaeogeographical reconstructions of the Gulf area in the late Miocene indicate a lowland and freshwater marsh lake (the Mesopotamian Basin), limited to the northeast by the Zagros mountain belt and to the southwest by the Arabian highlands (Popov et al. 2004). The Baynunah Formation represents one of the few remnants of that freshwater palaeoenvironment, and the study of its micropalaeontological content can shed new light on Arabian palaeoenvironments and on faunal biogeographic relationships.

Materials and methods

Sampling focused mainly on silty clay and clay layers, these being the most suitable lithologies for micropalaeontological analyses and for ostracod preservation (Horne & Siveter 2016). Carbonate layers of the upper Baynunah Formation were also sampled as almost all of these had evidence of shell fragments, ostracods and charophytes visible in the field. Clay layers were sampled for both ostracods and pollen. Additionally, matrix associated with AUH 495, unionid shells collected from Jebel Barakah in 1994, was also sampled (O-JB1 495). Each sample had an average weight of 250 g and was carefully screened with a hand lens. A total of 46 samples from 9 different sites were processed (Tables 6.1-6.2), with just 16 samples devoid of microfossils. Samples were disaggregated in diluted (5% v/v) hydrogen peroxide. A second treatment with a surfactant for 24h was necessary for some samples. All samples were wet sieved through 65 and 125-micron meshes and oven dried at <50°C.

Ostracod valves and carapaces as well as charophytes were identified and picked from each sample. All specimens are housed at the Micropalaeontology Laboratory at the Istituto di Geologia Ambientale e Geoingegneria del Consiglio Nazionale delle Ricerche (IGAG CNR). Taxonomic identification of ostracods is based on Meisch (2000), Fuhrmann (2012) and Karanovic (2012). Dissolution and preservation of the valves were assessed following Danielopol et al. (1987).

For pollen analyses, 20 clay samples from the Hamra and Ras al Qa'ia sites were treated using hydrofluoric and hydrochloric acid to remove any inorganic constituents (Erdtman 1969). The application of heavy liquid ($ZnCl_2$) with a density of 2 g/cm^3 was used to increase the recoverability of palynomorphs. All samples are housed at the micropalaeontological laboratory at the Department of Geology and Palaeontology, Comenius University in Bratislava.

Results

We identified ten ostracod taxa from the Baynunah Formation: *Heterocypris salina* (Brady, 1868), *Vestalenula cylindrica* (Straub, 1952), *Cyprideis* gr. *torosa*, *Prolimnocythere* sp. A, *Prolimnocythere* sp. B, *Limnocythere* sp., Limnocytheridae indet., *Candona* sp. juv., *Sarscypridopsis* sp., and *Herpetocypris* sp. (Table 6.1, Figs 6.1, 6.2). The un-noded form of *Cyprideis* gr. *torosa* occurs in all samples and is frequently the dominant species. At Jebel Barakah and Bida' Al Mutawi'a, *Prolimnocythere* sp. B is the dominant species. *Sarscypridopsis* sp. dominates at Al Mirfa.

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Baynunah Formation ostracods are generally not very well preserved, mainly as a result of diagenetic processes that resulted in bio-chemical dissolution of their calcitic valves (Fig. 6.3). In some cases, the calcitic shells are entirely dissolved and only the internal molds are preserved (Fig. 6.3A), hindering taxonomic determination below genus level. In other cases, the valves are preserved but their surfaces are corroded (Figs. 6.3B-D) as a result of chemical processes during diagenesis (Danielopol et al. 1986). Biologically and chemically corroded valves become biomechanically weakened and fracture more easily, which explains the high frequency of fragmentary shells.

Charophyte remains have been found at four sites (Table 9,1). At Jebel Barakah and Al Mirfa, only broken gyrogonites of *Chara* sp. occur, whereas at Bida' Al Mutawi'a and Mleisa well preserved gyrogonites and thallus remains of *Chara* sp. are accompanied by gyrogonites of *Lamprothamnium* sp. (Fig. 6.5).

Pollen grains were found in only two of 20 samples. At Hamra, only Chenopodiaceae pollen grains were found whereas at Ras al Qal'a, *Pinus*, Asteraceae (*Centaurea* sp., *Ambrosia* sp.), Sapotaceae (*Argania* type), Rutaceae and Chenopodiaceae were identified (Fig. 6.4).

Discussion

The ostracod assemblages

Heterocypris salina (Fig. 6.1 A-B) is today generally found in small, shallow and slightly salty coastal and inland water bodies, where it often occurs with other halophilic ostracods, though it is also present in pure freshwater habitats (Meisch 2000). This species prefers a salinity ≤6‰ but can survive conditions up to 20‰ (Meisch 2000). Ganning (1971) found that the species prefers habitats that are high in nutrients (eutrophic) and low temperature, and noted that no individuals survived longer than three days at 30 °C.

Living *C. torosa* is typically found in brackish environments such as coastal lagoons, saline lakes, deltas and estuaries. When occurring in un-noded forms, it indicates that the salinity of the water must have been > 5‰ (Frenzel et al. 2012). Bate (1971) recorded *Cyprideis* sp. from the Abu Dhabi Lagoon, emphasizing that the species is not conspecific with the European *C. torosa* and that it is adapted to a hyperhaline rather than a brackish to marine environment. Bate's figures (pls. 1–3) are small and insufficient to provide confident taxonomic identification. Today, *C. torosa* is recognized as occuring along the Iranian coastal area of the Gulf (Wouters 2017). In the Baynunah, the occurrence of *C.* gr. *torosa* (Figs. 6.1C-H) together with the dominance of *H. salina* point to a permanent and still to slowly flowing saline water body that could reach a salinity of > 5-6‰.

Sarscypridopsis sp. (Figs 6.2A-B) belongs to a cosmopolitan genus that prefers open water bodies (Karanovic 2012) and brackish waters. A species similar to the one recovered in the Baynunah Formation has been found in the late Miocene of the Tabriz Basin in Iran (*Sarsicypridopsis* sp., Reichenbacher et al. 2011, fig. 7 j-l). The occurrence of *Vestalenula cylindrica* could indicate lower salinities and/or input from underground waters. *Vestalenula cylindrica* (Fig. 6.2C) has been recovered in sediments indicative of freshwater and brackish mesohaline environments, interstitial and spring habitats connected with fluvial, marshy and underground waters (Gross 2004).

The Limnocytheridae (*Prolimnocythere* spp., *Limnocythere* sp. A and Limnocytheridae indet.), although abundant, are not well preserved (Figs 6.2D-G). *Prolimnocythere* Karmishina 1970, is a fossil genus usually taken to be indicative of freshwater to brackish environments, with slow currents (Schornikov 2007). The genus *Limnocythere* is today non-marine and cosmopolitan in distribution. A study of *Limnocythere* species in African lakes has shown that they can inhabit a wide range of biotic and abiotic variables, reaching extremely high densities in soda lakes (Mengistou 2016).

Candona sp. (Fig. 6.2H) occurs in a single sample from Ras Al Qal'a, and only as juvenile forms. Although their transport cannot be excluded, their occurrence confirms the freshwater to slightly saline character of the water bodies. *Herpetocypris* sp. specimens are very fragmentary. Today, this genus generally occurs in shallow waters with abundant aquatic vegetation.

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Taphonomic observations

Taphonomy is an important source of non-taxonomic palaeolimnological data (Bergue et al. 2015). Degrees of carapace articulation, dissolution and preservation are particularly informative in ostracod assemblages (Cohen 1987). After deposition, ostracod valves may undergo dissolution, mechanical breakage or diagenesis. Usually, decay and predation by other organisms or ostracods after death cause disarticulation. In environments with rapid burial rates, the carapace can be rapidly filled with sediment and can subsequently be closed up by superincumbent loading; in other cases, such as quiet environments subject to rapid desiccation, the carapace will remain closed as a strategy to survive desiccation (Fig. 6.3A). In agitated environments, and those starved of sediment, the opposite will occur, and the carapaces will disarticulate easily into two valves. Disarticulated valves might be more easily destroyed than carapaces. In most of the studied samples, only carapaces were found, implying that the depositional environment was characterized by rapid burial rates and/or rapid desiccation.

In general, the ostracod carapaces recovered from the Baynunah Formation are complete, but they are not well preserved. In many cases, the valves — made of low-Mg calcite — are preserved, but their surface is eroded. The different degrees of preservation/dissolution of the ostracod shells can be linked to different taphonomic processes or effects. In waters undersaturated in calcite or low in pH (slightly acidic, pH ≤6.5), ostracod valves made of low-Mg calcite can undergo partial (Fig. 6.4B-D) or even complete dissolution both during peri-mortem and burial as a result of diagenetic processes. Ostracod valves deposited in environments with high sedimentation rates usually display few micro-boring holes and the degree of dissolution of the calcareous shell is less than for valves deposited in environments with low rates of sedimentation (Danielopol et al., 2002). Sometimes, a network of thin filamentous traces can be seen on the surface of many valves (Figs. 6.4E-F). This network is produced by 'microborers', organisms such as *Chytridiales* fungi or Actinobacteria, that bore into the chitinous layer and dissolve the calcitic valve (Danielopol et al. 1986). In a calm environment, low sedimentation rate can induce extensive biological or physico-chemical degradation, thus the percentage of valves with traces of microborings can be inversely correlated to the sedimentation rate (Namiotko et al., 2014). The ostracods recovered from the Baynunah Formation sites display a variable degree of dissolution. At Jebel Barakah, Bida' Al Mutawi'a, Al Mirfa and Mleisa, most of the specimens exhibit opaque, sometimes chalky, valves, with abraded edges and enlarged pores. Microborings were only found on specimens recovered from Kihal (Figs. 6.3E-F), occurring in 191 of 209 carapaces recovered. All these indications point to relatively quiet environments characterized by low sedimentation rates or rapid desiccation events.

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Paleoenvironments

The absence of marine ostracods and foraminifera, both common in Abu Dhabi lagoons today (Bate 1971; Murray 2014), excludes the possibility of a tidal environment or any direct connection with the sea in the upper part of the Baynunah Formation.

The studied samples can be differentiated into two groups. The first corresponds to sites where *C.* gr. *torosa* is the dominant species and sometimes the sole constituent of the ostracod assemblage. In modern environments, *C. torosa* prefers lagoons more than estuarine tidal flats and salt marshes, and thrives in oligo- to polyhaline waters, with muddy and sandy-mud sedimentation, avoiding active current waters (Cabral et al. 2017). This species tolerates low oxygen content, can be found at a water depth of up to 20m (Scharf et al. 2017) and is commonly found in waters that are Cl-SO_4 dominated and with an alkalinity/Ca ratio of <1 (Holmes & De Deckker 2017). If present, accompanying ostracod taxa such as *Prolimnocythere* sp. A, *Herpetocypris* sp., *Candona* sp. juv. and *H. salina* indicate lower salinities and the occurrence of aquatic vegetation. This points to the existence of water bodies characterized by a slow current, muddy substrate and fluctuating salinities. It could represent a large, slow-flowing water body where the salinity of the water was linked to the leaching of carbonates or evaporites, or salt concentration through evaporation. Fluctuating salinities might also be the result of alternating humid-arid periods, such as rainfall seasonality. At Hamra and Ras al Qal'a, the presence of Chenopodiaceae pollen grains (Fig. 6.4E) potentially confirms this latter scenario. Moreover, at Ras al Qal'a the occurrence of Sapotaceae (*Argania* type, Fig. 6.4C) indicates a semiarid climate and Asteraceae (*Centaurea* sp. and *Ambrosia* sp., Fig. 6.4D) and Rutaceae (Fig. 6.4B) pollen point to the presence of open woodland to grassland vegetation types.

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The second group corresponds to sites where *C.* gr. *torosa* is less abundant (Table 6.1) and the dominance of Limnocytheridae and *H. salina* are indicative of slightly saline to freshwater environments. Furthermore, *V. cylindrica* could indicate the presence of groundwater input that was fresh to low salinity. Charophytes also occur at all sites in this second group (Table 6.1). The occurrence of *Lamprothamnium* sp. and *Chara* sp. indicate periods of low salinity. In fact, the production of gyrogonites implies that growth conditions must have been suitable for the complete ripening and calcification of fructifications. Sexual reproduction is the necessary condition for the formation of gyrogonites, and several environmental factors affect their production. In deep and perennial water bodies, charophytes reproduce vegetatively, whereas in shallow waters, sexual reproduction is more common (Soulié-Märsche & Garcia 2015), and in some cases, the formation of gyrogonites can be forced by unsuitable environmental conditions such as threat of desiccation (Soulié-Märsche & Garcia 2015). Species of the genus *Lamprothamnium* form ripe oospores and gyrogonites (sexual reproduction) at salinities above ca. 20 ‰, while at lower salinities they reproduce vegetatively without producing gyrogonites and oospores (Soulié-Märsche 2008). The combination of Characeae and ostracod assemblages points to shallow and clear water bodies that periodically experienced increased salinity through evaporation, thus forcing the algae to reproduce sexually and finally desiccate. Both ostracods and charophytes are able to regenerate after considerable periods of desiccation, and their co-occurrence could indicate the onset of a humid episode, such as a rainy season. At two sites in this second group, Mleisa and Bida’ Al Mutawi’a, proboscidean and ungulate trackways are preserved (Bibi et al. 2012) suggesting a relationship between a rise in humidity and the activity of large vertebrates.

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Biochronology

The micropalaeontological remains also provide some information on the age of the Baynunah Formation. *Heterocypris salina* first appears during late Miocene (Meisch 2000) and *Vestalenula cylindrica* during the middle to late Miocene (Ligios et al. 2009). *Cyprideis* is first known from late Oligocene to early Miocene deposits (Gliozzi et al. 2017) and the genus becomes widely distributed in Tethyan and Paratethyan palaeoenvironments within a short time (Danielopol et al. 1990). *Cyprideis* gr. *torosa* is first recorded from the early part of the late Miocene (Tortonian, Gliozzi et al. 2017). Moreover, the oldest known "microborer" patterns on freshwater ostracods are 11 Ma in age (Danielopol et al. 1986). The ostracods therefore provide a maximum age of late Miocene for the Baynunah Formation, in general agreement with the vertebrate fossil evidence. The ostracods further confirm the late Miocene age of the upper parts of the Formation, from which vertebrate trackways have been described (Bibi et al., 2011; Kraatz et al., this volume).

Conclusions

Freshwater ostracods, charophytes, and pollen were recovered from the late Miocene sediments of the Baynunah Formation. No less than 10 ostracod species were identified, though the limited literature on Neogene to Recent freshwater ostracods from the Arabian Peninsula hindered more precise taxonomic identifications (the subject of a future study).

Palaeoenvironmental reconstructions indicate the presence of both permanent and ephemeral water bodies that experienced fluctuations in salinity probably driven by climatic shifts. The ostracods indicate the presence of a complex floodplain environment characterized by a slow-flowing muddy river and a system of shallow water bodies with clear waters and submerged meadows of macroalgae. Pollen remains indicate that the river was flowing through a grassland, while salt-tolerant plants such as *Salicornia* and *Atriplex* were growing close to the water bodies. The Baynunah environment was probably part of a much larger fluvial system that covered the low-lying Mesopotamian Basin during late Miocene (Popov et al. 2004). Varying taxonomic abundances of ostracods in conjunction with the presence or absence of charophytes provide strong indications for fluctuating salinity levels in the carbonates of the upper Baynunah. This was likely the result of seasonal changes in precipitation resulting in cycles of humid inundation then desiccation through evaporation. All in all, the micropaleontological remains indicate humid climatic episodes, perhaps linked to the Zeit Wet Phase (Griffin 1999), itself linked to the onset of the Asian/African monsoon at about 8 Ma (Böhme 2004).

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Figure captions

Figure 6.1. Freshwater ostracods from the Baynunah Formation: *Heterocypris salina*: A) external lateral view, broken carapace, from Mleisa locality MLS 2 (sample O-MLS2 10-20); B) external lateral view, RV, from Jebel Barakah locality JBR 1 (sample O-JB1 10-32). *Cyprideis* gr. *torosa*: C) internal view, female LV, from locality JBR 1 (sample O-JB1 10-34); D) carapace, dorsal view, from locality MLS 2 (sample O-MLS2 10-20); E) external lateral view, female LV, from locality JBR 1 (sample O-JB1 10-32); F) external lateral view, female RV, from locality JBR 1 (sample O-JB1 10-34); G) external lateral view, male LV, from Al Mirfa locality MIM 1 (sample O-MIR1); H) external lateral view, male RV, from locality MIM 1 (sample O-MIR1). Scale bars = 200 µm. Legend: RV, right valve; LV, left valve. For sample numbers refer to Table 9-1.

Figure 6.2. Freshwater ostracods from the Baynunah Formation: *Sarscypridopsis* sp. from Al Mirfa locality MIM 1 (sample O-MIR1): A) external lateral view, LV; B) internal view, RV. Scale bar = 500 µm. *Vestalenula cylindrica* from Mleisa locality MLS 1 (sample O-MLS1): C) right external view, carapace. Scale bar = 100 µm. *Limnocythere* sp. A: D) external lateral view, RV, from Shuwaihat locality SHU 4 (sample O-SHU1); Scale bar = 200 µm. *Prolimnocythere* sp. A: E) external lateral view, LV, from Bida' Al Mutawi'a locality BIM 4 (sample O-BIM1). *Prolimnocythere* sp. B: F) external lateral view, RV, from locality MLS 1 (sample O-MLS1). Limnocytheridae indet.: G) external lateral view, RV, from locality MIM 1 (sample O-MIR1); Scale bars = 100 µm. *Candona* sp. *juv.*: H) external lateral view, LV, from Jebel Barakah locality JBR 1 (sample O-JB1 495). Scale bar = 200 µm. Legend: RV, right valve; LV, left valve. For sample numbers refer to Table 6.1.

Figure 6.3. Examples of ostracod valve preservation. A) Partially dissolved carapaces of ostracods in carbonate sediment (sample O-JB1 10-33 from locality JBR 1). Scale bar = 200 µm. B) External lateral view, female RV, partially dissolved valve of *Cyprideis* gr. *torosa* (sample O-BIM1 from locality BIM 4). Scale bar = 200 µm. C) Detail of enlarged pore exits on the external surface of the *Prolimnocythere* sp. valve (sample O-BIM1 from locality BIM 4) illustrated in D. Scale bar = 10 µm. D) External lateral view, LV, partially dissolved valve of *Prolimnocythere* sp. (sample O-BIM1 from locality BIM 4). Scale bar = 100 µm. E) Detail of thin filamentous traces on the external surface of the *Cyprideis* gr. *torosa* valve (sample O-KHL4b from locality KIH 2) illustrated in F. Scale bar = 50 µm. F) External lateral view, LV, valve with microborings of *Cyprideis* gr. *torosa* (sample KHL4b from locality KIH 2) Scale bar = 200 µm.

Figure 6.4. Pollen grains from Ras al Qal'a and Hamra. Scale bars= 10 µm. A) *Pinus* from sample O-RAQ5 from locality RAQ 2. B) Rutaceae from sample O-HAM5 from HMR 5. C) Sapotaceae (*Argania* type) from sample O-HAM5 from HMR 5. D) *Ambrosia* sp. from sample O-HAM5 from HMR 5. E) Chenopodiacae from sample O-RAQ5 from RAQ 2.

Figure 6.5. Charophyte remains from the Bida' Al Mutawi'a trackway site (locality BIM 4, sample O-BIM1): A) Gyrogonite of *Lamprothamnium* sp, lateral view. Scale bar = 400 µm. B) Gyrogonite of *Chara* sp., lateral view. Scale bar = 300 µm. C) Gyrogonite of *Chara* sp., basal view. Scale bar = 200 µm. D) Gyrogonite of *Chara* sp., apical view. Scale bar = 200 µm. E) Corticate thallus fragment of *Chara* sp.. Scale bar = 300 µm.

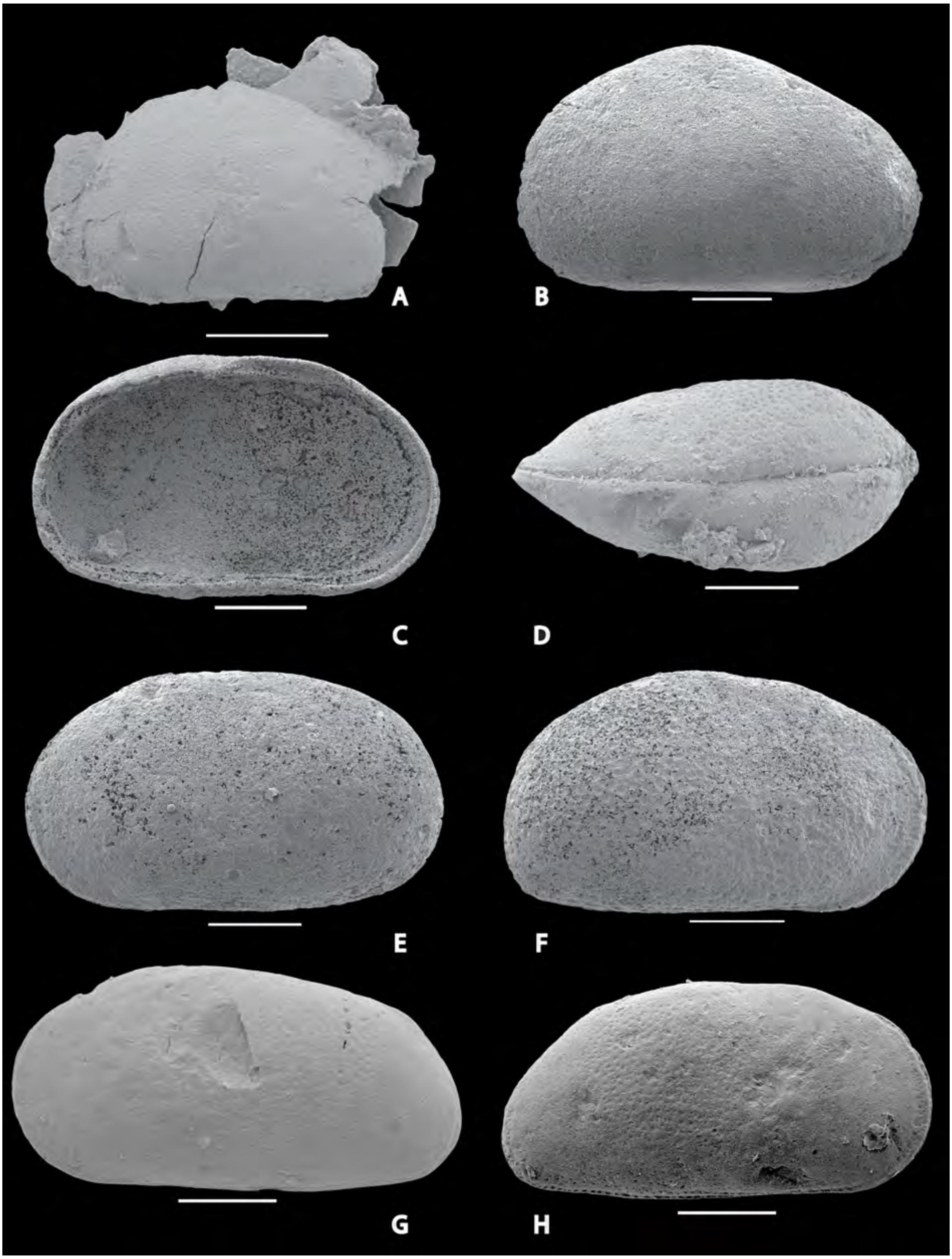
Table 6.1 List of samples from the Baynunah Formation. Multiple samples from the same stratigraphic section share a single GPS reading and are listed in stratigraphic order (from lowest to highest).

Locality	lat N	long E	Sample	Lithology
Mleisa				
MLS 1	23° 56' 52.8"	53° 03' 39.6"	O-MLS0	Silty clays
			O-MLS1	Carbonatic silt
			O-MLS2	Silty clays
			O-MLS3	Carbonatic silt
			O-MLS4	Sandy clay
			O-MLS5	Carbonatic silt
MLS 2	23º 56’ 50.6”	53º 08’ 24.0”	O-MLS2 10-20	Carbonatic silt
Ras al Qal'a				
RAQ 2	24° 09' 00.7"	52°58' 59.1"	O-RAQ1	Oolitic sandstone
			O-RAQ2	Carbonatic silt
			O-RAQ3	Carbonatic silt
Kihal				
KIH 2	24°07' 00.4"	53°01' 14.5"	O-KHL1	Carbonatic silt
			O-KHL2	Carbonatic silt
			O-KHL3	Carbonatic silt
	24° 07' 05.5"	53° 01' 16.0"	O-KHL4	Carbonatic silt
			O-KHL4a	Carbonatic silt
			O-KHL4b	Carbonatic silt
			O-KHL5	Silty clay
Hamra				
HMR 5	24° 06' 11.0"	52° 31' 41.7"	O-HAM1	Clay layer 1
			O-HAM2	Clay layer 2
			O-HAM3	Clay layer 3
			O-HAM4	Clay layer 4
			O-HAM5	Clay layer 5
			O-HAM6	Clay layer 6
			O-HAM7	Clay layer 7
			O-HAM8	Clay layer 8
			O-HAM9	Clay layer 9
			O-HAM10	Clay layer 10
			O-HAM11a	Carbonatic silt layer 1
			O-HAM11b	Clay layer 11
			O-HAM12	Carbonatic silt layer 2
			O-HAM13	Carbonatic silt layer 3
			O-HAM14	Carbonatic silt layer 4
			O-HAM15	Carbonatic silt layer 5
Bida' Al Mutawi'a				

BIM 4	23° 46' 07.2"	52° 33' 12.6"	O-BIM1	Carbonatic silt
Sir Bani Yas				
SBY 1	24° 21' 24.2"	52° 35' 20.1"	O-SBY2	Carbonatic silt
			O-SBY1	Carbonatic silt
			O-SBY0	Carbonatic silt
Shuwaihat				
SHU 4	24° 06' 42.2"	52°26' 14.0"	O-SHU1	Carbonatic silt
SHU 2	24° 06' 55.9"	52° 25' 53.3"	O-SHU2	Clay layer 1
SHU 2	24° 06' 56.5"	52° 25' 53.2"	O-SHU3	Clay layer 2
SHU 2	24° 06' 55.1"	52° 25' 55.5"	O-SHU-T 1	Carbonatic silt
Mirfa				
MIM 1	24° 05' 09.2"	53° 25' 58.9"	O-MIR1	Carbonatic silt
Jebel Barakah				
JBR 1	24º 00' 31.1"	52º 19' 50.9"	O-JB 10-33	Carbonatic silt
	24° 00' 31.3"	52° 19' 51.0"	O-JB 10-32	Carbonatic silt
	24º 00' 31.7"	52º 19' 51.1"	O-JB 10-34	Carbonatic silt
	unknown	unknown	O-JB1 495	Carbonatic silt

Table 6.2. Occurrences of ostracod taxa, charophytes and pollen grains at Baynunah Formation sites. The dominant ostracod taxon at each site is indicated in bold.

Site	*Cyprideis* gr. *torosa.*	*Vestalenula cylindrica.*	*Prolimnocythere* sp. A	*Prolimnocythere* sp. B	*Limnocythere* sp. A	*Heterocypris salina.*	*Candona* sp. juveniles	*Herpetocypris* sp.	*Sarscypridopsis* sp.	Charophytes	Pollen.
Jebel Barakah	X			**X**	X				X	X	
Bida' Al Mutawi'a	X			**X**						X	
Al Mirfa	X			X					**X**	X	
Mleisa	X	X	X			**X**				X	
Hamra	**X**			X		X					X
Ras al Qal'a	**X**					X	X				X
Kihal	**X**							X			
Sir Bani Yas	**X**										
Shuwaihat	**X**		X								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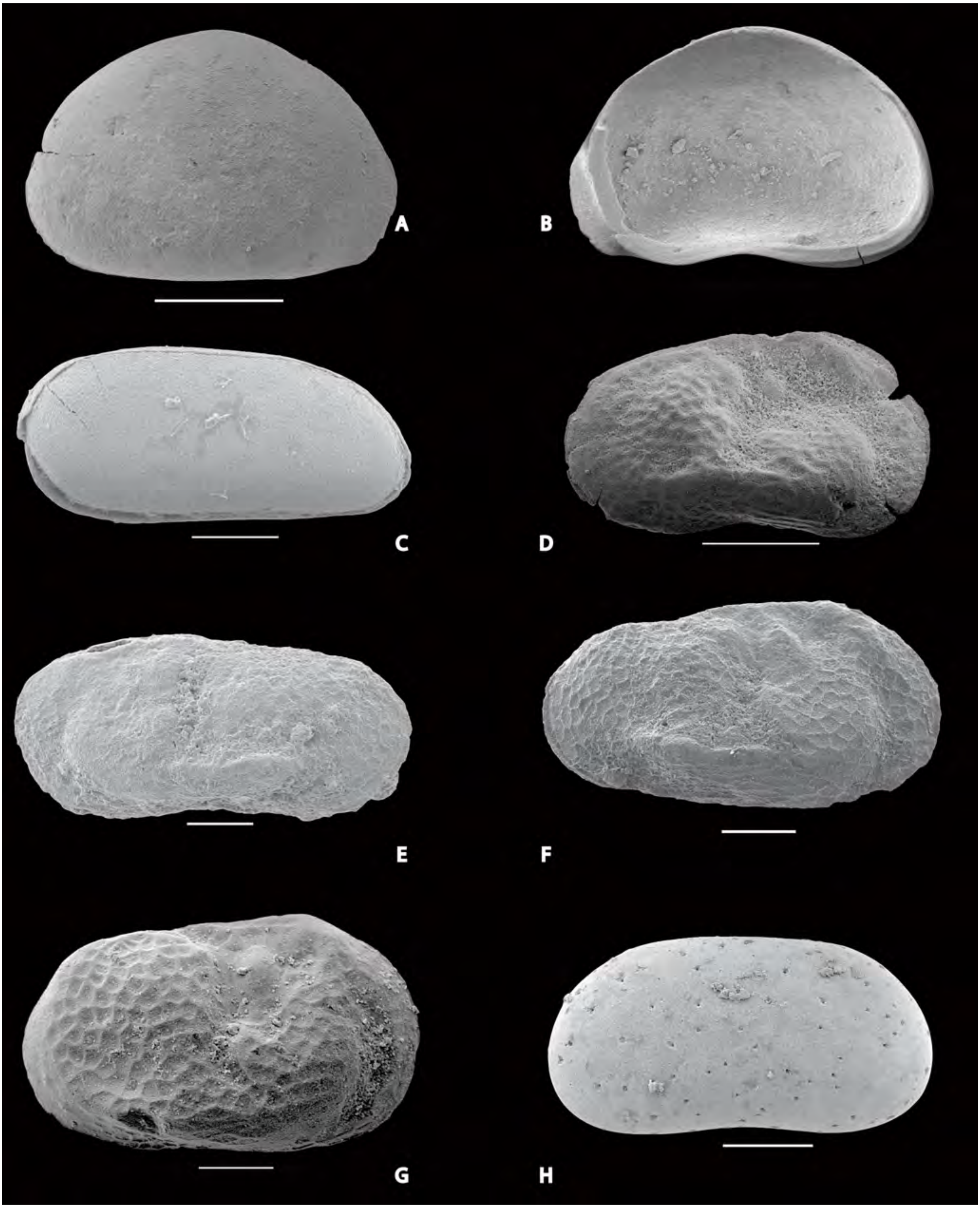
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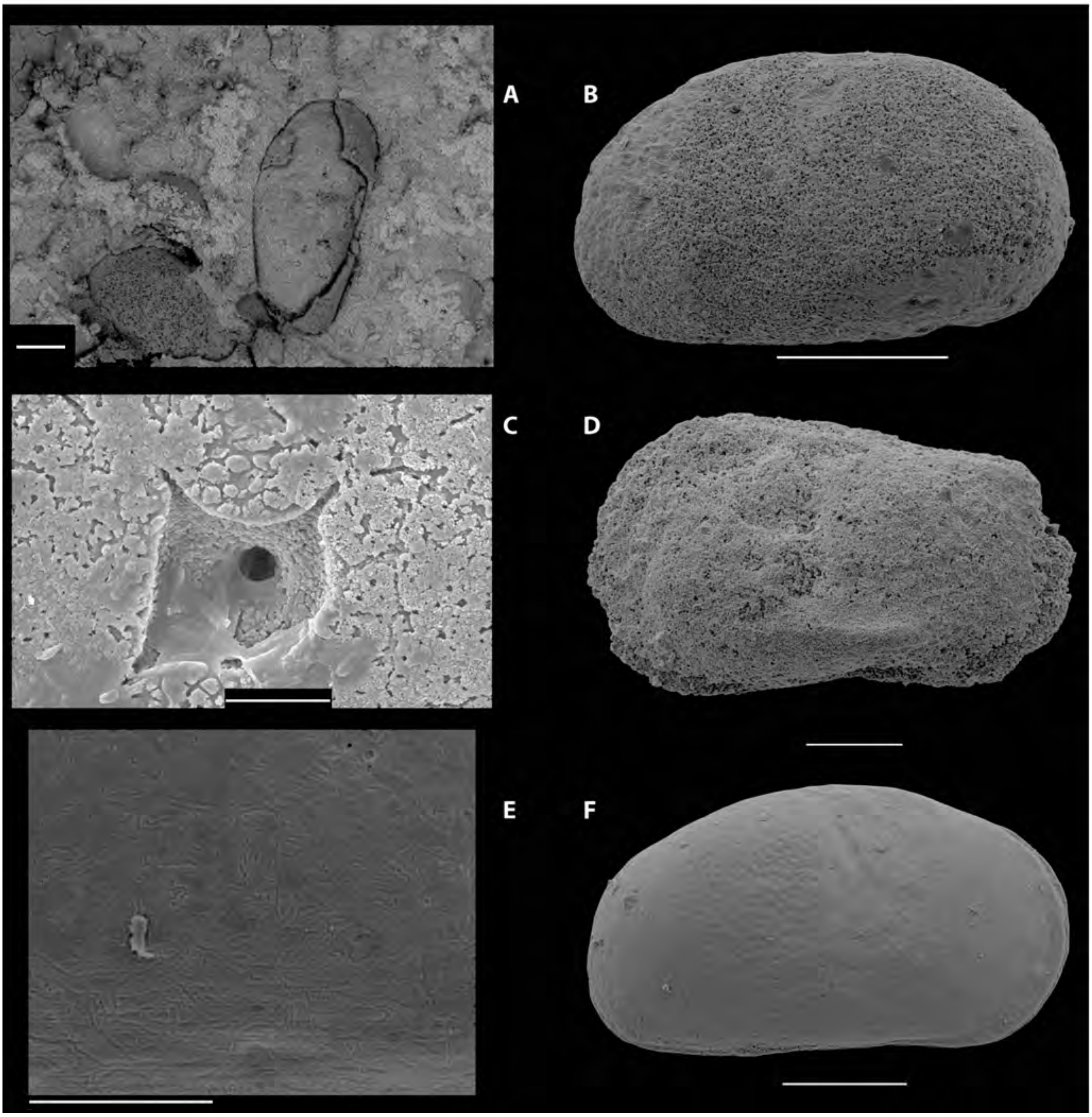
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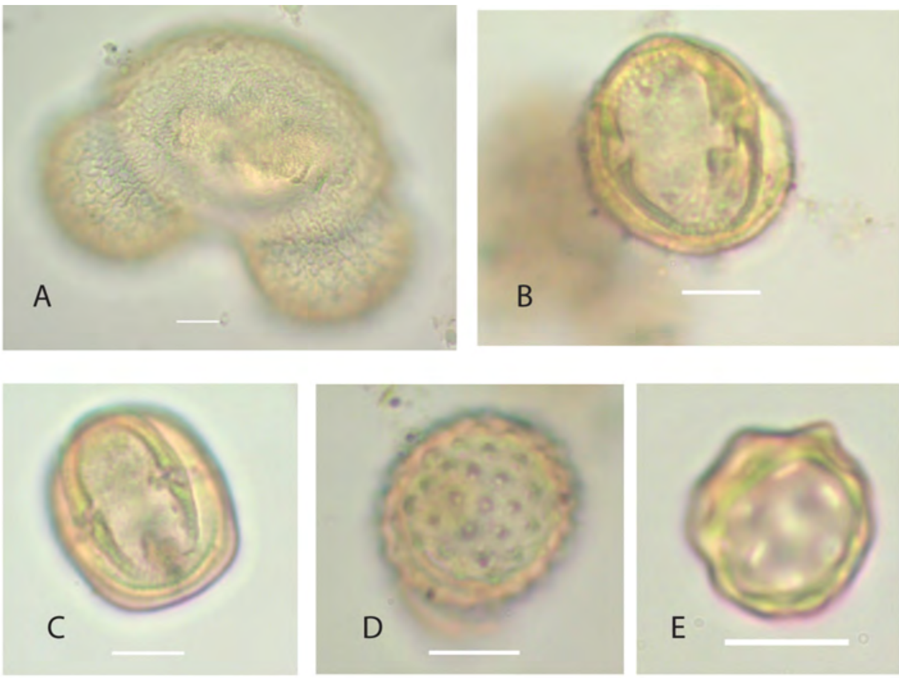
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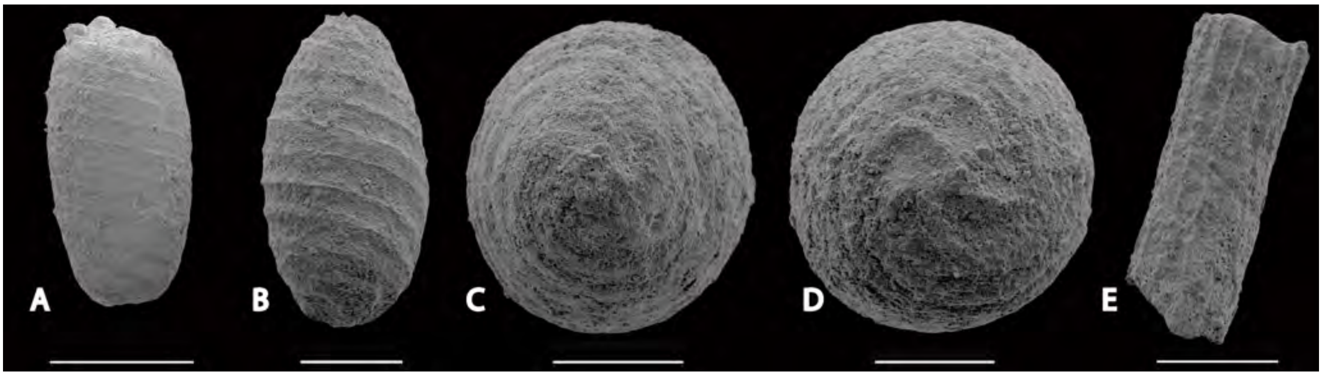
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