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Original article

Bioerosion and encrustation of the rocky shore dwellers along the Arabian Gulf, Northeast Saudi Arabia

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ABSTRACT

The coastal area between Al-Khafji and Al-Jubail, Arabian Gulf, Saudi Arabia is characterized by natural and artificial rocky shores, which inhabited by intensive dwellers. The present work aimed to shed light on the taxonomy, distribution, and environmental factors affecting the abundance of the invertebrate borers and encrusters in the study area. A total of 614 specimens of bivalve, gastropod, coral, and lithified rocky shores were collected from 13 sites. Eighteen ichnospecies of 8 ichnogenera were identified and illustrated. These traces were produced by clionid sponges (31.75%), endolithic bivalves (26.19%), naticid gastropods (24.60%), polychaete annelids (15.08%), acrothoracican barnacles (1.85%), and vermitid gastropods (0.53). The rocky shore dwellers act as hard substrate for colonization by serpulids, barnacles, bryozoans, and other cemented invertebrates. Most of the thick invertebrates and lithified rocky grounds were bioeroded by endolithic bivalves, clionaid sponges, polychaete annelids, and acrothoracican barnacles, while the thin walled invertebrate dwellers were bioeroded by naticid gastropods and clionaid sponges. Barnacles, serpulid worms and some molluscs were intensively covered the rocky shore blocks and solid rubbish in intertidal area facing wave action to comb microscopic food from the water.

1. Introduction

Boring, rasping, drilling, and scraping activities were the most common bioerosion structures resulted by different organisms on hard substrates using mechanical and/or chemical processes (Buatois et al., 2002; Santos and Mayoral, 2008; Richiano et al., 2012). Lithified rocky shores and associated skeletons of the invertebrate dwellers can be used by several other organisms for shelter and/or food (Gibert et al., 2004; El-Sorogy, 2008; Demircan et al., 2023). Some invertebrates, such as bryozoans, serpulid worm tubes, balanids, corals, algae and ostreids use hard skeletons of the invertebrate rocky shore dwellers as substrates for colonization. Other organisms can destruct these substrates through bioerosion (Taylor and Wilson, 2002; Lopes, 2012). Therefore, bioerosion weak the substrates and can convert carbonate rocks into fine chips and consequently accelerates the mechanical destruction by waves and currents (Bromley, 1970; Lopes, 2012).

The bioerosion structures produced by macro- and microorganisms can be tunnels, chambers or holes, which represent the domichnia or praedichnia as ethological categories. Moreover, these structures may record rasping, scraping, and gnawing. Therefore, they can be ascribed to represent the paschichnia (Warme, 1975; Gibert et al., 2004; Verde, 2007; Lopes, 2012). The detection of the paleoecological and paleoenvironmental conditions prevailing in marine environments throughout the geological history were the application importance of studying of bioerosion (Bromley, 1970; Lopes, 2012). Works concerned with taphonomic signatures in the Aabian Gulf are very scarce (e.g. El-Gendy et al., 2015; El-Sorogy et al., 2018, 2020; Demircan et al., 2021). These articles dealt with the bioerosion and encrustation on the intertidal bivalves, gastropods, and corals. Although the coastal zone along the Arabian Gulf have been subjected to a lot of works up on environmental studies (e.g. El-Sorogy et al., 2016, 2019; Youssef et al., 2016; Al-Kahtany et al., 2015, 2018; Alharbi et al., 2017; Alharbi and El-Sorogy, 2019). Therefore, the objectives of the present work are: (i) to document the distribution of the invertebrate rocky shore dweller along the coastal area between Al-Jubail and Al-Khafji, (ii) to identify the bioeroders and encrusters affecting these rocky shore dwellers, and (iii) to analyze the bioerosive structures from an ethological standpoint.

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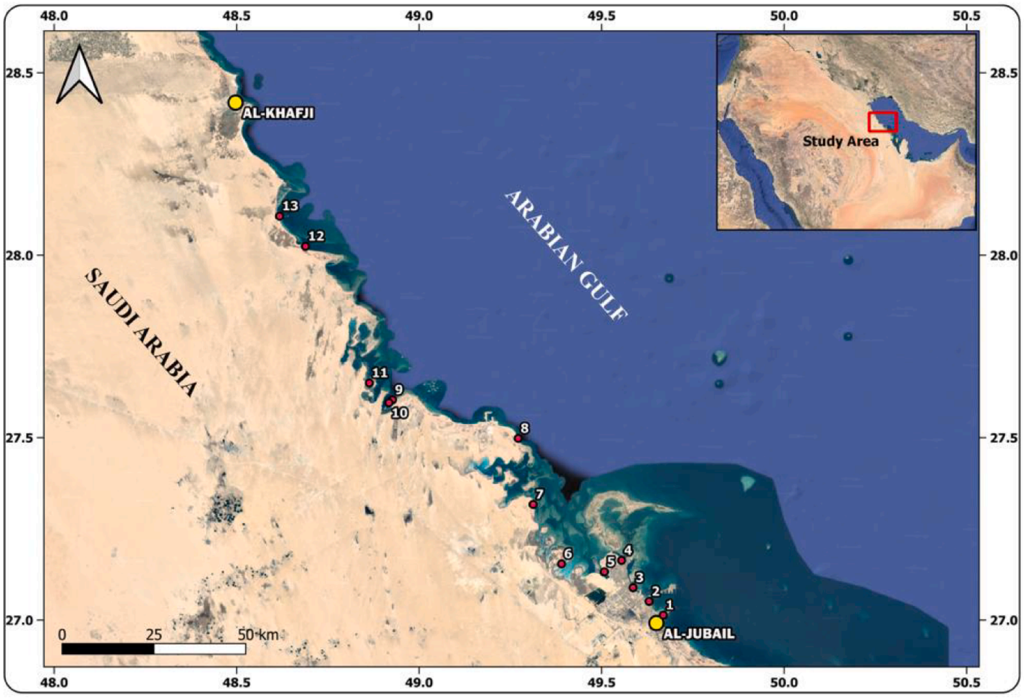

Fig. 1. Location map of the study area and sample stations.

2. Material and methods

The study area is located between Al-Jubail and Al-Khafji, along the Arabia Gulf coast, Saudi Arabia, between latitudes N27°0́084″ – N28°1́826″ and longitudes E49°4́000″ – E48°3́137″ (Fig. 1). The coastline is sandy-dominated shore, with artificial and natural rocky in parts. The sandy shores are characterized by fine to coarse, moderately sorted sand grains, with biogenic concentrations of gastropods, bivalves, foraminifers, and seagrass in parts. The natural and artificial rocky shores are inhabited with different invertebrate dwellers (Fig. 2). A total of 614 bivalves, gastropods, corals, and lithified rocky shore specimens were collected from 13 rocky shore sited in the area between Al-Jubail and Al-Khafji (Fig. 1). The 383 specimens which showed bioerosion and/or encrustation signatures were washed, examined and identified and differential distributions on the skeletal surfaces were evaluated. All examined specimens are housed in the Museum of the Department of Geology and Geophysics, College of Science, King Saud University, Saudi Arabia.

3. Results

3.1. Bioerosion

The recorded borings on the rocky shore dwellers were produced by endolithic bivalves (*Gastrochaenolites*), clionaid sponges (*Entobia*), polychaete annelids (*Caulostrepsis, Maeandropolydora,* and *Trypanites*), and naticid gastropods (*Oichnus*), acrothoracican barnacles (*Rogerella*), and vermitid gastropods (*Renichnus*). Table 1 illustrated the recorded ichnospecies and their trace makers, ethological category, numbers of the bioeroded seashells, and abundance throughout the studied 13 sites. The following is a summary of the identification, and description of these groups.

3.1.1. Clionaid sponge borings

Traces of clionaid sponges are ethologically classified as domichnia, and are represented by a series of small swollen chambers connected by thin canals to other chambers and multiple apertures, 0.5 and 2 mm in diameter (Wilson and Palmer, 1992). Such borings cause dramatic increase in rate of bioerosion and sediment production, as well as destroy countless carbonate hardgrounds. This group of traces includes the ichnogenus *Entobia* Bronn, 1837 (ichnofamily Entobiaidae Wisshak et al., 2019), which is strongly developed on external and internal surfaces of bivalve and gastropod shells, as well as some corals and hard grounds. In the study area, clionaid sponges accounted 31.75 % of total bioerosion traces, and represented by *Entobia geometrica* Bromley and D'Alessandro, 1984, *E. ovula* Bromley and D'Alessandro, 1984, and they are *E. cretacea* Portlock, 1843, and *Entobia* isp. (Table 1). Twenty-nine specimens of *Entobia geometrica* were recorded on the external and internal surfaces of *Plicatula*, *Glycymeris, Pinctada, Barbatia*, *Conus,* and some recorded on the lithified rocky shore grounds. *E. geometrica* shows networks of chambers interconnected by irregularly distributed cylindrical galleries (Fig. 3A-C, F-H). The chambers with circular apertures of different sizes, 2.5–3 mm in diameter for larger apertures, and 1–2 mm in diameter for the smaller ones (Demircan et al., 2021). Borings of *E. geometrica* are closely similar in morphology and size to borings made by *Cliona celata* Grant (Bromley and D'Alessandro, 1984).

Seventeen specimens of *E. cretacea* are developed on the external surfaces of *Protapes* (Fig. 3D, G). The boring is branched, resembling a well-developed camerate or string-of-beads form. *E. cretacea* differs from *E. geometrica* in that the apertures of the former were smaller, as well as its chambers were connected by single intercameral canals. Fourteen specimens of *E. ovula* have been observed on external surfaces of *Protapes* and *Fulvia* (Fig. 3D, G, 5I). Borings in four stages graduated from narrow and branched tunnels to curved rows of elongated, and oval chambers. *E. ovula* was previously recorded from the Early Eocene from India, among others (Gurav and Kulkarni, 2018). Sixty specimens of *Entobia* isp. were reported as networks of linear chambers, with

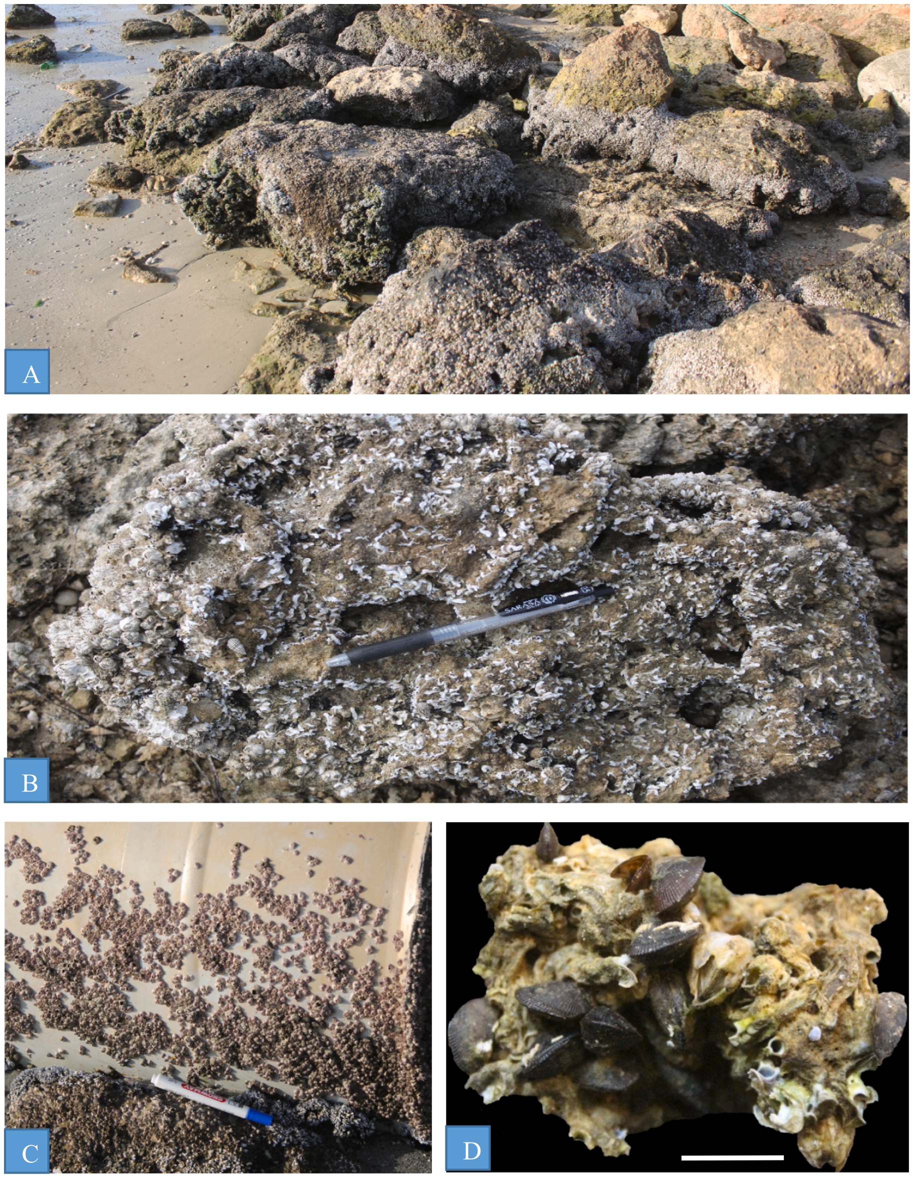

Fig. 2. Invertebrate dwellers from the Arabian Gulf coast. A. Rocky shore blocks covered by serpulid worm tubes and blaniids in intertidal area facing sea water, site 2; B. Rocky shore block covered by serpulid worm tubes, balanids and gastropods, site 5; C. Encrusting balanids up on a barrel thrown in the intertidal area, site 2; D. Fixed byssate bivalves (*Brachidontes*) on intensive serpulids, site 2.

apertures 0.3–1.5 mm in diameter on the surfaces of *Glycymeris*, *Conus,* and *Lopha* (Fig. 3H, I, 4A, 6E, 7A, C).

3.1.2. Endolithic bivalve borings

The borings of endolithic bivalves belong to *Gastrochaenolites* Leymerie, 1842, which is produced mostly by the lithophagids, gastrochaenids, and pholadids as a domichnion. In the study area, the bivalve tracemakers are preserved within the borings in some cases (Fig. 4). The borings are usually oriented perpendicular to the thick substrate of coral and bivalve skeletons, and hard rocky grounds. They are less than 1.0 cm to more than 10 cm deep and up to 5 cm wide. In some hard shore rocky grounds, *Gastrochaenolites* may intersect and subsequently be bored with clionaid sponges, encrusted and nested by a variety of organisms inside, such as serpulids and bryozoans. In the study area four ichnospecies belongs *Gastrochaenolites* (ichnofamily Gastrochaenolitidae Wisshak et al., 2019) were recorded and accounted 26.19 % of the total bioerosion traces. They include *G. lapidicus*, *G. torpedo*, *G. dijugus, G. ornatus* Kelly and Bromley, 1984, and *Gastrochaenolites* isp. (Table 1).

Twenty-four *Gastrochaenolites torpedo* were recorded on the external surfaces of *Protapes, Pinctada, Chama,* thick corals, hard-grounds (Fig. 4B, D, H). These borings are smooth with elongated chamber, 0.5–1.4 cm in diameter and up to 1.5 cm in depth. Presence of *G. torpedo* perpendicular to steep substrates might be to avoid sedimentary deposition (Bromley, 2004; Uchman et al., 2017; Demircan et al., 2021).

Twenty-two specimens of *Gastrochaenolites lapidicus* were recorded on the external surfaces of *Pictada, Acrosterigma,* thick corals, lithified hard grounds (Fig. 4C, F, 5 J, 6G). *G. lapidicus* is produced recently by the bivalves *Lithophaga* and *Hiatella* (Kelly and Bromely, 1984; Uchman et al., 2002). The borings are smooth, with circular to ovate chambers and circular or elliptical neck, 6–13 mm wide, and 7–20 mm long. Five specimens of *G. dijugus* are oriented normal to the shell surfaces of *Acrosterigma, Fulvia, and Glycymeris* (Fig. 6A-C). The borings are circular to subcircular in transverse section, 2.5–4 mm in diameter. *Gastrochaenolites ornatus* is recorded in site 2 (4 borings) in the form of ovoid to elongate chambers 10–35 mm in length and 5–12 mm in width, normal to the shell surface and ornamented with concentric lines. 44 specimens of *Gastrochaenolites* isp. occur as small, subcircular borings without distinct neck, 4–9 mm in diameter, and up to 7 mm deep on lithified

Table 1
The recorded ichnospecies and their trace makers, ethological category, numbers of the bioeroded seashells, and abundance throughout the studied sites.

Ichnotaxa	Tracemaker	Ethological category	Studied localities													Total bioeroded seashells
			1	2	3	4	5	6	7	8	9	10	11	12	13	
Gastrochaenolites torpedo	Endolithic bivalves	Domichnia		11	6		3		3					2		25
G. lapidicus	Endolithic bivalves	Domichnia		10	4		5		3					2	2	26
G. ornatus	Endolithic bivalves	Domichnia		4												4
G. dijugus	Endolithic bivalves	Domichnia					5									5
Gastrochaenolites isp.	Endolithic bivalves	Domichnia	2	8	6	4	4		5	5	2		2	4	2	44
Maeandropolydora sulcans	Polychaete annelids	Domichnia										7		2	2	11
Caulostrepsis taeniola	Polychaete annelids	Domichnia		6	2		8	2						2		20
Trypanites isp.	Polychaete annelids	Domichnia	2	9	4				4					7		26
Entobia geometrica	Clionid sponge	Domichnia	8	5	3			5						3	5	29
E. cretacea	Clionid sponge	Domichnia		6						4	2			2	3	17
E. ovula	Clionid sponge	Domichnia		6						3	2				3	14
Entobia isp.	Clionid sponge	Domichnia	3	4	5	3	2		6	5	5	5	2	10	10	60
Oichnus paraboloides	Carnivorous gastropods	Praedichnia	7	12		2					6	2		2		31
O. simplex	Carnivorous gastropods	Praedichnia		4	6			4	6			2				22
O. ovalis	Carnivorous gastropods	Praedichnia						6				8	1			15
Oichnus isp.	Carnivorous gastropods	Praedichnia		5	5		2		3	3	2			2	3	25
Rogerella isp.	Acorn barnacles	Praedichnia		7												7
Renichnus isp.	Vermetid gastropods	Praedichnia				2										2
Total	22	97	41	11	29	17	30	20	19	24		38	30	383		

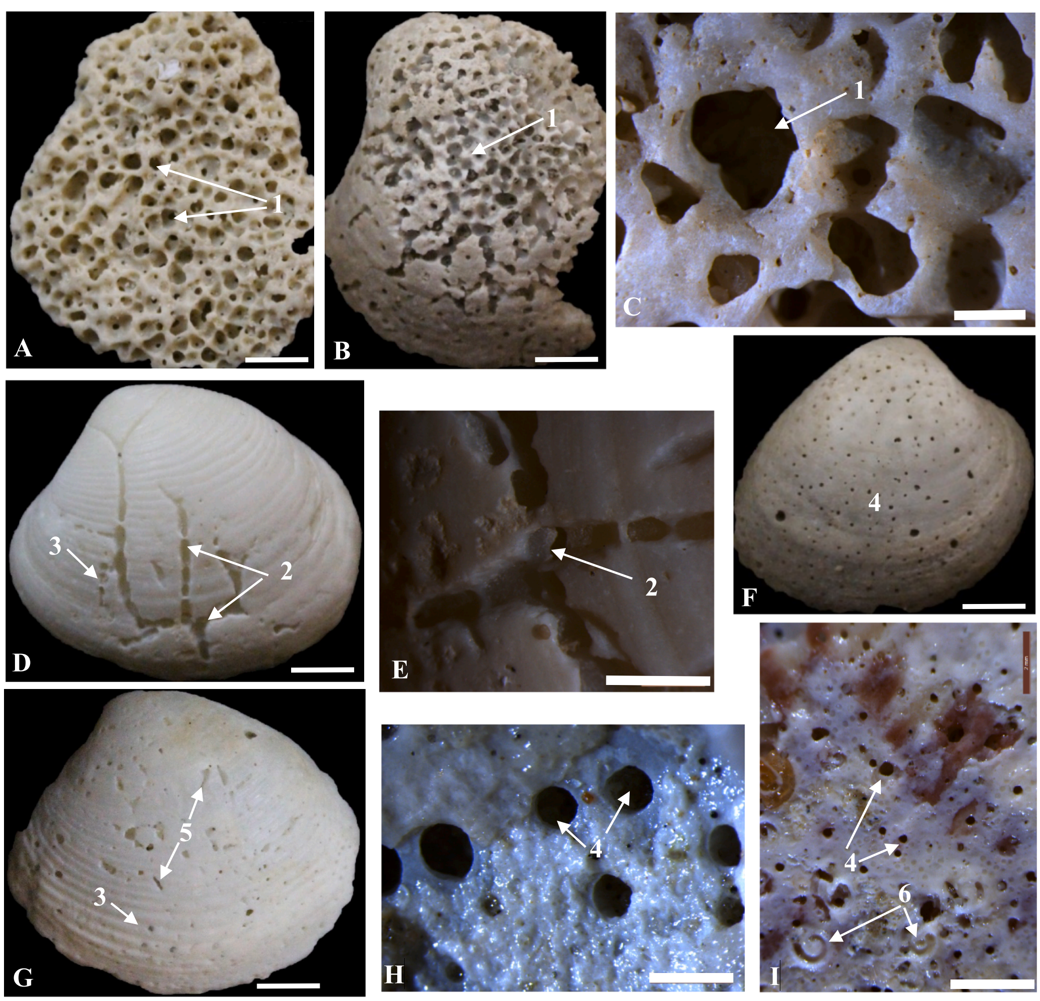

Fig. 3. Clionaid, polychaete, and vermetid borings. A-I. *Entobia geometrica* (1), sites 1, 2, 6, and 13; *Entobia cretacea* (2), site 2; *Entobia ovula* (3), sites 2 and10*; Entobia* isp (4), sites 2, 4, and 6; *Caulostrepsis taeniola* (5), site 10; *Renichnus* isp (6), site 4. Traces developed on the external and some internal surfaces of *Plicatula*, *Protapes*, *Fulvia,* and *Amiantis.* Scale bar = 10 mm, except of C, E, H, and I = 2 mm.

Fig. 4

Fig. 4. Bivalve, gastropod, clionaid, and polychaete borings. A-H. *Gastrochaenolites torpedo* (1), site 2; *G. lapidicus* (2), sites 2; *G. ornatus* (3), site 2; and *Oichnus* isp. (4), sites 2, 13; *Entobia* isp. (5), sites 2, 5, 13; *Trypanites* isp. (6), site 2. Traces developed on the external shell surfaces of *Protapes, Pinctada, Conus, Chama,* corals, and lithified rocky shore grounds. Some of the trace makers still present within the drill holes. Scale bar = 10 mm, except of G = 2 mm.

rocky grounds, and surfaces of *Conus, Plicatula, Chama, Pinctada, Lopha,* and *Barbatia* (Fig. 4A, D-F, 6G, 7C).

3.1.3. Naticid gastropod borings

Praedichnial borings of carnivore gastropods belong to the ichnogenus *Oichnus* Bromley, 1981 of the ichnofamily Oichnidae Wisshak et al., 2019. *Oichnus* accounts 24.60 % of the total bioerosion in the form of small circular to subcircular and oval borings normal to the external surfaces of the mollusc shells. Most of the traces penetrate the substrate while some ones terminate within the substrate as a shallow pit (Fig. 5D, F), indicating a failed drill attempt (Chattopadhyay and Dutta, 2013). *Oichnus paraboloides* Bromley, 1981, *O. simplex* Bromley, 1981, *Oichnus ovalis* Bromley, 1993, and *Oichnus* isp. were identified in the study area (Table 1).

Thirty-one borings of *O. paraboloides* were developed on the surfaces of *Callista, Barbatia, Lopha,* and *Tapes* shells (Fig. 5A-C). Borings are circular, paraboloid, normal to the surface in most cases, 1.4–2.8 mm in diameter. In thick shells, some borings terminate inside the shell. Twenty-two specimens of *O. simplex* were developed on the bivalve and gastropod shells (*Barbatia, Fulvia, Circe, Spondylus, Bulla,* and *Conus*), and serpulid worm tubes (Fig. 5D, E). Borings showed circular to subcircular shape, 1.7–2.4 mm in diameter, more or less perpendicular to the substrate. Fifteen specimens of *O. ovalis* developed on the gastropod *Conus* (Fig. 5G, H). They show oval shape, not fully penetrate the shell in most cases. Twenty-five traces of *Oichnus* isp. were found on shells of the bivalve *Barbatia* and the gastropod *Conus* (Fig. 4B, 5F, I). Borings are circular to slightly ovoid in shape, normal to the shell walls in most cases, 1.6–2.4 mm in diameter.

3.1.4. Polychaete annelid borings

Borings of polychaete annelids account 15.08 % of the total bioerosion traces and they are represented in the study area by *Caulostrepsis taeniola* Clarke, 1908, *Maeandropolydora sulcans* Voigt, 1965, and *Trypanites* isp. (Table 1). They belong to the ichnofamily Osteichnidae Hopner and Bertling, 2017. *C. taeniola* is a domichnion produced by spionid polychaetes traces (Bromley, 2004). Twenty specimens were recorded on the mollusc shell of *Acrosterigma, Fulvia, Glycymeris,* and *Conus* (Fig. 3G, 6E, F, I). *C. taeniola* consists of smooth a U-shape galleries and a central axial depression. Boring galleries range from straight to curved, 2–8 mm in length and 0.25–1.5 mm in width, with aperture 1 mm in diameter.

Eleven borings of *M. sulcans* are well-developed on the external surface of the gastropod *Conus* shell (Fig. 6D, H). They are shallow, long and sinuous borings, 0.2 mm in diameter, 10 mm long and 1–2.3 mm wide. Twenty-six *Trypanites* are normal to the substrates of *Plagiocardium, Glycymeris*, *Chama,* and *Acrosterigma,* thick coral and echinoid fragments, and limestone rocky grounds (Fig. 4C, D, F). They are narrow, cylindrical, and unbranched borings, 1.2–2.8 mm in diameter.

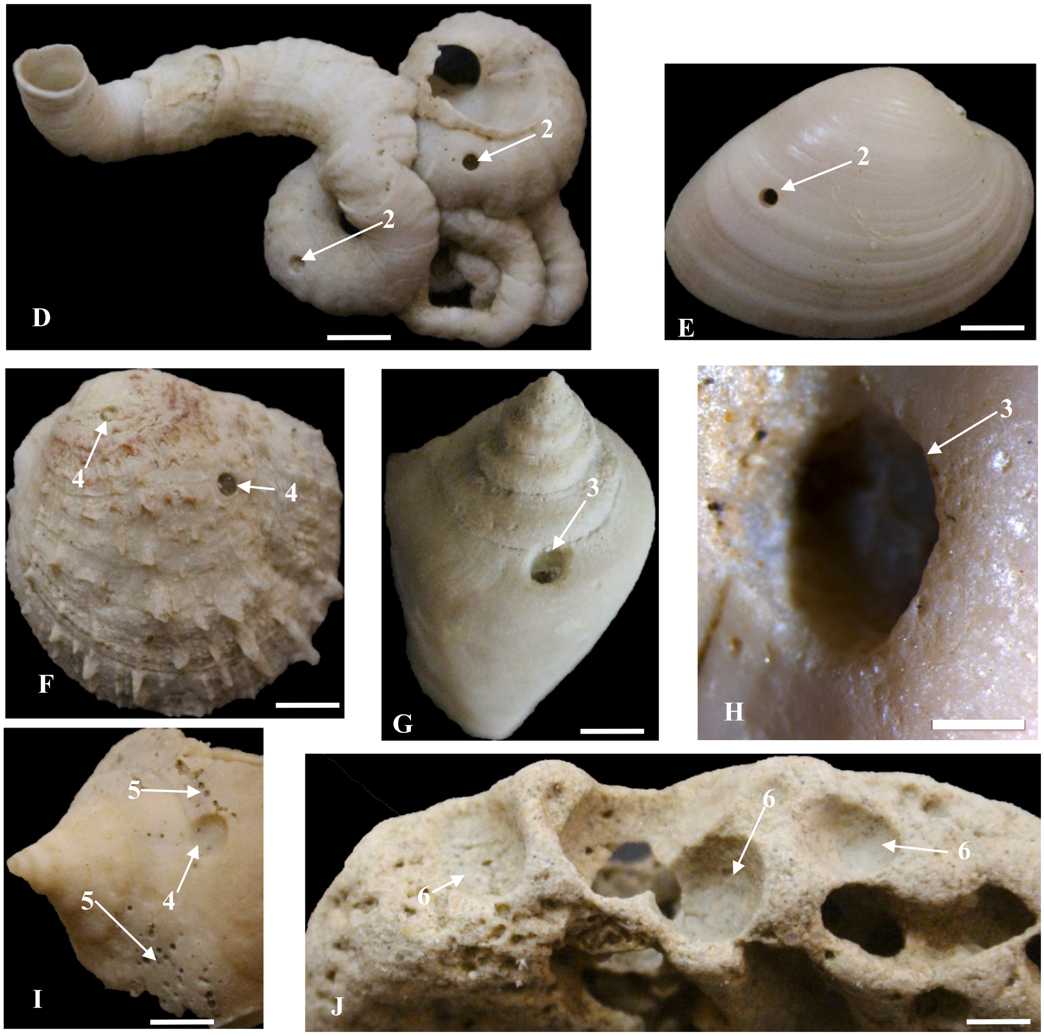

Fig. 5. Gastropod, clionaid, and bivalve borings. A-J. *Oichnus paraboloides* (1), site 2; *O. simplex* (2) sites 2, 6, and 7; *Oichnus ovalis* (3), site 10; *Oichnus* isp. (4), site 12; *Entobia ovula* (5), site 13, *Gastrochaenolites lapidicus* (6), site 2. Traces developed on the surfaces of *Callista, Spondylus, Barbatia, Conus* and serpulid worm tubes. Scale bar = 10 mm, except of C and H = 2 mm.

Ethologically, *Trypanites* is classified as a domichnion, which trace maker uses an acid to dissolve the carbonate substrates (Taylor and Wilson, 2003).

3.1.5. Acrothoracican barnacle borings

Borings of acrothoracican barnacles are represented by ichnogenus *Rogerella* de Saint-Seine, 1951 (ichnofamily Echinoidea Wisshak et al., 2019). Seven traces developed on the internal shell surfaces of the bivalves *Pinctada* and *Chama* (Table 1, Fig. 6E, G, J). *Rogerella* shows rounded to oval-like depressions with slit-shaped apertures, 0.5–1.0 mm in width, 0.7–2.2 mm in length and 1.2–2.1 mm in depth.

3.1.6. Vermetid gastropod borings

Borings of vermetid gastropods belong to ichnogenus *Renichnus* Mayoral, 1987 and are repeated by *Renichnus* isp. (Fig. 3I). Two traces developed on the internal surface of the bivalve *Amiantis*. *Renichnus* isp. is a shallow half-moon, kidney-shaped or annular depressions. Ethologically, *Renichnus* is classified as praedichnia (El-Sorogy et al. 2022).

3.2. Encrustations

The invertebrate rocky shore dwellers and the lithified hardgrounds act as hard substrates for settlement by other invertebrates, including serpulids, bryozoans, barnacles, and cemented bivalves (Figs. 2, 7). Serpulids are tube-dwelling polychaetes, circular to sub-circular in cross-sections, always cryptic in habit, and tend to heavily encrust overhangs and the sides of crevices in rocky grounds (Wilson and Palmer, 1992; El-Hedeny, 2005). The serpulids are the most common encrusters throughout the studied sites. These worm tubes encrust the external and internal surfaces of the molluscs *Acrosterigma, Donax, Chama, Glycymeris, Lunella*, *Bulla, Hexaplex, Conus,* as well as coral skeletons and lithified rocky ground (Fig. 2 A, B, D, 4E, 5D, 6C, E, 7D, F, G). Barnacles were the second abundant encrusters. In the studied sites, they are solitary or form aggregates on the lithified hard-grounds, external and internal surfaces of bivalves (*Acrosterigma, Amiantis, Glycymeris, Hexaplex, Circe*), and the gastropod *Conus* shells (Fig. 2A, C, 6F, H, 7B). Bryozoans are the least abundant in the study area, encrusting the internal smooth surface and the external surface of *Glycymeris, Pinctada* (Fig. 7E, F). Bryozoan colonies are sheet-like representatives of *Holloporella*, *Membranipora*, *Celleporaria*, and *Watersipora* spp. Many bivalves are attached to the lithified rocky shore hardgrounds, such as *Septifer* and *Modiolus* fixed by byssus. Moreover, many of small bivalves, such as *Plicatula*, *Brachidontes, Planaxis, Chama*, and *Pinctada* were cemented to other large and thick bivalve shells (Fig. 2D, 7A, C). However, the settlement of these encrusters on the internal surfaces of many mullusc shells indicates a postmortem colonization. On the other hand, the settlement up on the external surfaces implying mostly *syn*-vivo colonization (El-Sorogy et al., 2020).

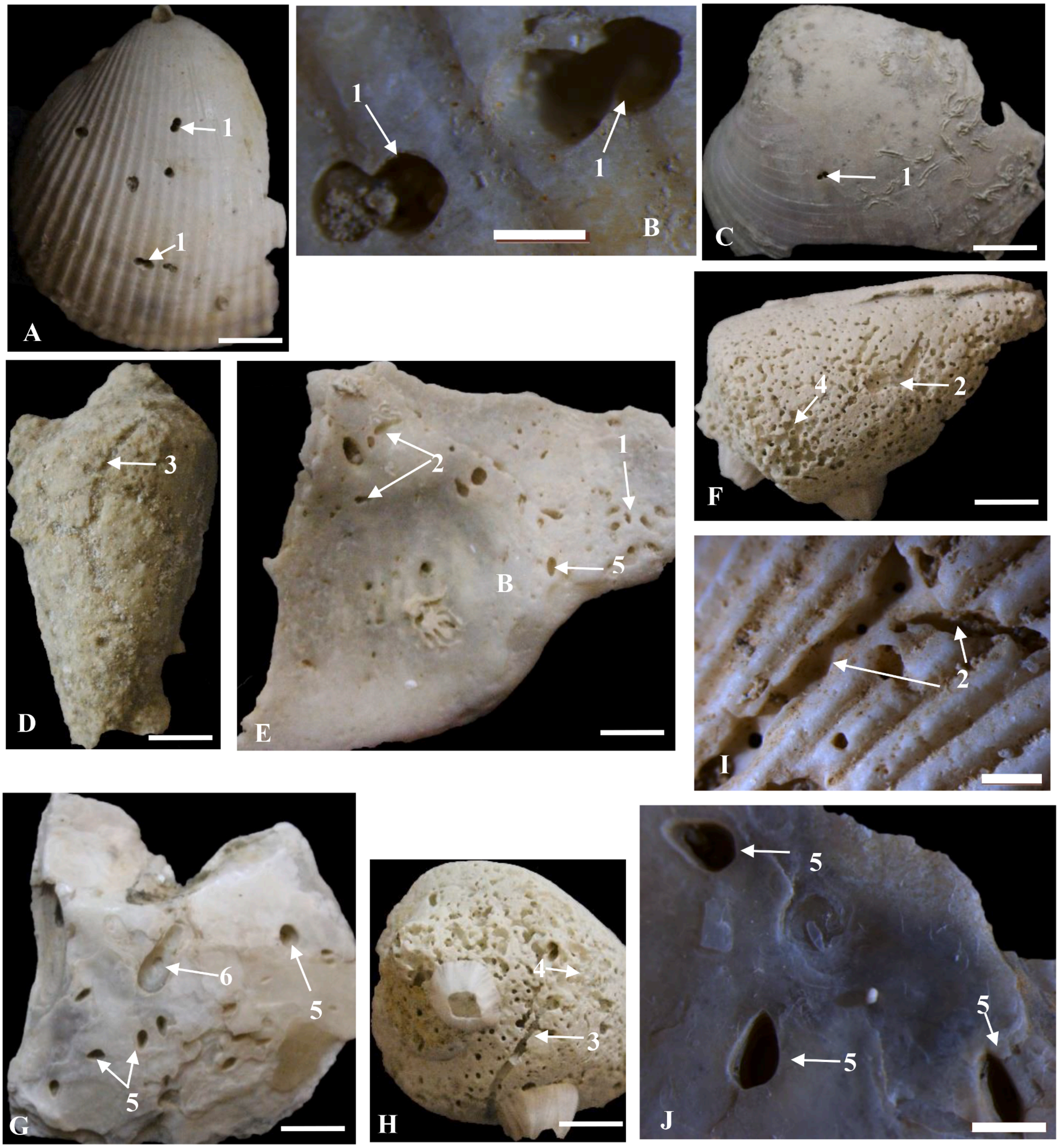

Fig. 6. Bivalve, polychaete, barnacle, and clionaid borings. A-J. *Gastrochaenolites dijugus* (1), site 5, *Caulostrepsis taeniola* (2), sites 10, 13; *Maeandropolydora sulcans* (3), sites 2, 10, 13; *Entobia geometrica* (4), site 12; *Rogerella* isp., site 5 (5); *Gastrochaenolites* isp. (6), site 5. Traces developed on the mollusc surfaces of *Acrosterigma, Fulvia, Glycymeris, Plagiocardium, Glycymeris, Chama, Pinctada* and *Conus*. Scale bar = 10 mm, except of B, I, and J = 2 mm.

4. Discussion

The lithified substrate of the rocky shores constitutes a high-energy, stable and well-oxygenated environments characterized by high productivity suitable for suspension feeders (Wilson and Palmer, 1992; El-Sorogy et al., 2019). Organisms inhabited rocky substrates are subjected to physical and biological stress factors. Physical factors, such as wave action, scouring and covering by sand, especially in the presence of sandy beaches, and exposure, to ultraviolet light, heat, desiccation, rain, runoff of fresh water from the land during low tides. The competition for space and food, predation, grazing, and scavenging are the biological factors. Cementation and infaunalization by boring or nestling are adaptations for dealing with the rigors of hard substrate life.

Degree of articulation and fragmentation is a good indicator of relative exposure time, or energy of the depositional environment (El-Sorogy, 2015). More than 95 % of the collected bivalves in the current study have been disarticulated. Articulation occurred at rocky shore areas, particularly in specimens that are physically stuck within the spaces between rock blocks and to species that have extremely thick ligaments or dentitions resistant to disarticulation. On the other hand, disarticulated valves occurred at areas with considerable water energy. In the study area, broken seashells might be found close to abrasion and bioerosion, which could lessen the density and thickness of the shells and so make breaking easier. In such an environment, predators and

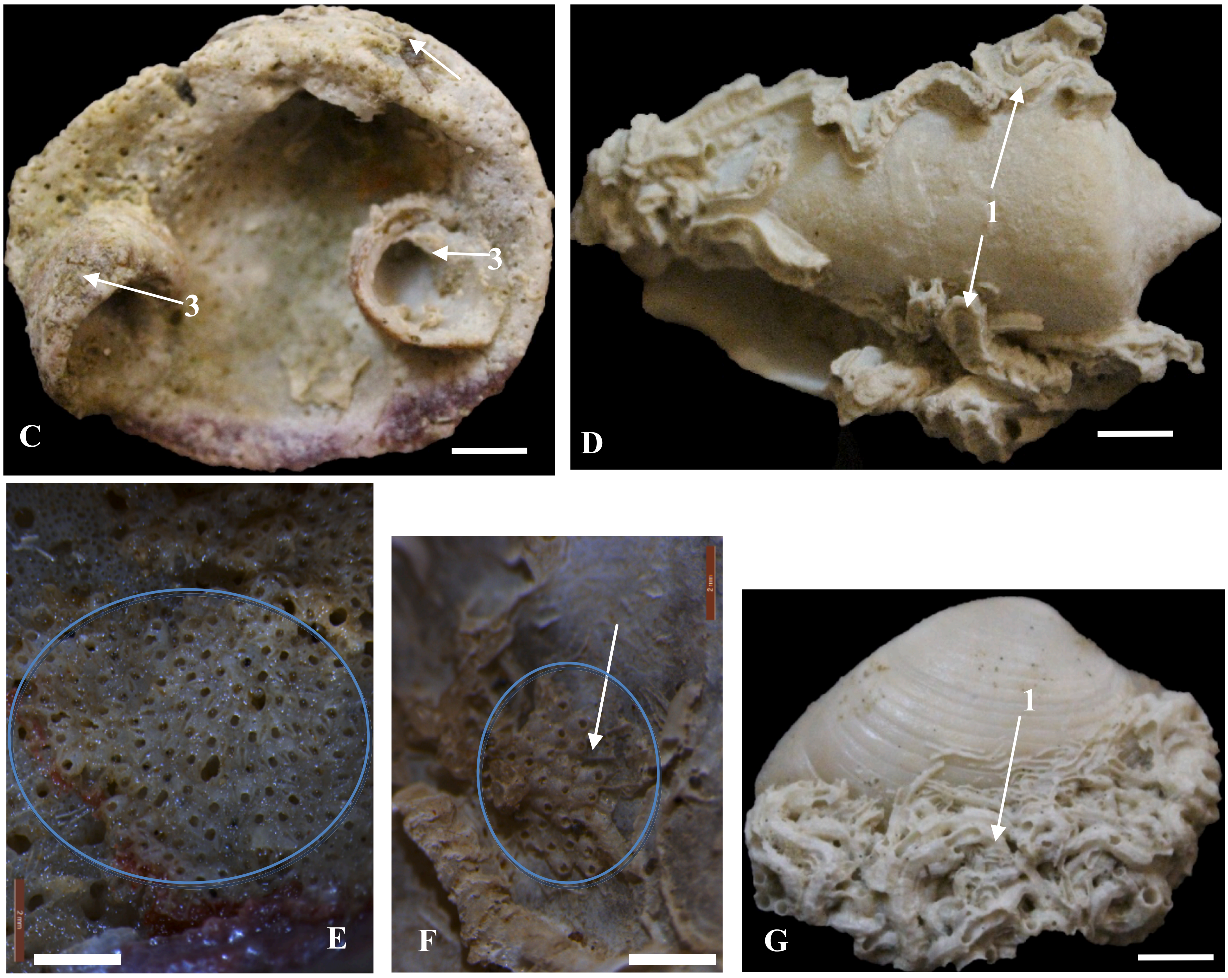

Fig. 7. Abundant encrusters from the Arabian Gulf coast. A-G. Encrustation of serpulids (1), sites 2, 4, and 12; cheilostomate bryozoans (blue circle), site 5 and 7; barnacles (2), site 3; and cemented bivalves (3), site 7. All encrusted up on hard skeletons of the invertebrate rocky shore dwellers. Scale bar = 10 mm, except of E and F = 2 mm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

other species are likely fragmentation agents as well.

383 of 614 specimens belong to bivalves, gastropods, corals, and lithified rocky shore were affected by different types of bioeroders. The total materials/bioeroded materials were 273/183 for gastropods, 211/144 for bivalves, 87/41 for corals, and lithified rocky shore specimens 43/15. The abundance of the reported bioerosion traces in the studied rocky shore were in the following order: clionaid sponge (31.75 %) > endolithic bivalve (26.19 %) > naticid gastropod (24.60 %) > polychaete annelid (15.08 %) > acrothoracican barnacle (1.85 %) > vermitid gastropod (0.53 %) traces. All bioerosion traces include dwelling traces (domichnia), except for the naticid gastropods which produce traces of predation (praedichnia) (Odumodu and Okon, 2016). Most of the rocky shore dwellers were bioeroded by clionid sponges. Some parts of shells, especially the external surfaces were intensively bioeroded with *Entobia geometrica* and *Entobia* isp. (Fig. 3A, B, 4A, 6F, H), indicating that boring occurred during their life-time (El-Sorogy, 2015). However, most shells showed a few scattered borings.

The rocky shore, mollusc shells, and coral skeletons were favorable substrates for the boring bivalves, polychaetes, and acrothoracican barnacles. They are bioeroded by representatives of the genera *Gastrochaenolites, Maeandropolydora*, *Trypanites, Caulostrepsis,* and *Rogerella*. Moreover, these substrates were colonized by many filter-feeding epifaunal serpulid, barnacles, bryozoans, and other small bivalves. *Oichnus,* on the other hand, preferred thinner shells. It was produced mostly during the lifetime of molluscs, and likely have caused their death (Bromley, 1981; Hauser et al., 2008). Some shells show more than one *Oichnus*, either as a shallow depression or a pit within the shell (Fig. 5D, F), which may be a record of unsuccessful attempts of predation (Hauser et al., 2008; El-Sorogy et al., 2021). In order to comb microscopic food from the water, barnacles, serpulid worms, and some molluscs, such as *Brachidontes* and *Planaxis*, intensively incrusted the rocky shore blocks and solid rubble in intertidal area facing wave action.

5. Conclusions

1. Eighteen ichnospecies produced by clionaid sponges, endolithic bivalves, naticid gastropods, polychaete annelids, acrothoracican barnacles and, vermetid gastropods were identified and illustrated in the coastal area between Al-Khafji and Al-Jubail, Arabian Gulf, Saudi Arabia. Traces of clionaid sponges, polychaete annelids, endolithic bivalves were ethologically classified as domichnia, while borings produced by carnivore gastropods are ethologically classified as praedichnia.

2. In a descending order of abundance, the identified traces include the following: *Entobia* (*E. geometrica, E. ovula E. cretacea,* and *Entobia* isp.), *Gastrochaenolites* (*G. lapidicus*, *G. torpedo*, *G. dijugus, G. ornatus*, and *Gastrochaenolites* isp.), *Oichnus* (*O. paraboloides, O. simplex, O. ovalis,* and *Oichnus* isp.), *Caulostrepsis taeniola*, *Maeandropolydora sulcans*, *Trypanites* isp., *Rogerella* isp., and *Renichnus* isp.
3. The larger and thicker rocky shore dwellers in intertidal area offered a favorable substrate for many filter-feeding epifaunal serpulids, barnacles, bryozoans, and other bivalves, which were favorable substrates for the boring bivalves, polychaetes, and acrothoracican barnacles. On the other hand, carnivore naticid gastropods preferred thinner shells of bivalves and gastropods.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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