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Research Paper

First report of the bivalve *Placuna placenta* (Linnaeus, 1758) from the Late Miocene–Early Pliocene strata of the Minab region and Qeshm Island, Persian Gulf, Southern Iran: Palaeoecology, systematic and taphonomy

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Abstract
The Late Miocene–Early Pliocene bivalve *Placuna placenta* (Linnaeus 1758) is reported for the first time from southern Iran. The shells of this species are extremely thin and fragile, and mostly disarticulated in our material, affected by compression, bioerosion, encrustation, and abrasion. In the Qeshm Island, midlate Miocene samples from Rahgostar were collected from marly deposits of the Guri Member of the Mishan Formation, Zagros basin. In the Minab region, samples from Bandzark were collected from MiocenePliocene sandstones of the Tiab Anticline in the Makran Basin. The studied species and their taphonomic features revealed tidal/intertidal shallow marine environment with high productivity, high rate of sedimentation, and rapid burial processes in low energy and high environmental stress, caused by strongly reduced salinity. Specimens of both assemblages affected by reworking processes, are represented by the following ichnospecies: *Maeandropolydora sulcans*, *Oichnus simplex*, and *Trypanites weisei*.
Keywords: *Placuna placenta*, Placunidae, Taphonomy, Paleoecology, Qeshm Island, Iran.

Introduction

The genus *Placuna* (Lightfoot 1786) is a commonly occurring bivalve in the Indian subcontinents and is represented by three species reported from both the eastern and western coasts (Das et al. 2019), among these, the translucent, flat oyster *Placuna placenta* (Linnaeus 1758), commonly known as Windowpane coastal regions of India, China, and Philippines (Yonge 1977; Murty et al. 1979; Pota and Patel 1988; Ingole and Clemente 2006).

These flat bivalves are suspension feeders and can survive within the wide range of temperature, salinity, and dissolved oxygen conditions (Pota and Patel 1988). They inhabit sandy-muddy substrates, ranging from intertidal to subtidal environments (Pota and Patel 1988). All this general

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environmental information suggests that this species is an ecologically tolerant bivalve. Morphologically, the shells are inequivalved, sub-circular, extremely compressed, and translucent to opaque. Like other epifaunal and semi-infaunal bivalves, they are monomyarian and non-siphonate. The posterior muscle scar is placed centrally. The postero-venter appears to possess a gape, although no byssal notch is present (Purchon 2013). In comparison, although there is plenty of information on their shell morphology, their autecology, motility, and tiering concerning to the sediment-water interface is poorly known.

This paper deals with palaeoecology, occurrence and palaeogeographic importance of the upper Miocene bivalve *Placuna placenta* (Linnaeus 1758) from the upper part of the Mishan Formation at Rahgostar outcrop in Qeshm Island, Persian Gulf, (Fig. 1a) and the Mio–Pliocene Sandstone of Tiab Anticline at Bandzark outcrop in the Minab region, Makran basin, southern Iran (Fig. 1b).

Geological Setting

The oil-bearing Zagros basin is northwest-southeast-trending from northern Iraq to southeast Iran and has been interpreted as the active zone of the Arabia–Eurasia collision belt (Stöcklin 1968; Alavi 2004; Allen et al. 2006). During the Miocene and Pliocene, the biogeographic boundaries between the Indo-Pacific and Mediterranean remained stable (Harzhauser et al. 2002), and subsequently, the Zagros and Makran basins were connected to open marine environments. Qeshm Island is considered a part of the Southern Zagros, based on tectonic and sedimentological evidence, such as the similarity of folding of the large anticlines of the island, and the coordination along them, in corresponding with the Zagros anticlines (Pilgrim 1908; Amri Kazemi 2004; Hassani et al. 2014).

The tectonic reconstructions suggested that subduction in the Makran Subduction Zone (MSZ) was initiated in the Late Cretaceous (e.g., Berberian et al. 1982; McCall and Kidd 1982; McCall 2002). The sedimentary hanging wall of the main décollement is folded and imbricated in the modern accretionary prism (e.g., White and Louden 1982; Ellouz-Zimmermann et al. 2007b; Grando and McClay 2007) and the accretionary wedge likely developed in the offshore region since the Early–Middle Miocene to Recent (Mokhtari et al. 2019).

The Makran Basin extends from the Oman Sea coasts in the south to the Jazmurian depression in the north. Its western limit is the Minab Fault which separates the Makran and Zagros basins. There are no formal lithostratigraphic divisions in the Makran Basin; thus, the Makran successions are informally divided into different units (Ghaedi et al. 2016). Ghaedi et al. (2016) adopted 14 lithological subdivisions of the Makran Miocene successions and their main properties from Peterson and Rudzinskas (1982).

1) Tiab sandstone (Red to brawn sandstone, fissile mudstone, and rubbly beach limestone), 2) Kheku sandstone (thinly bedded siltstone and sandstone with mudstone, limestone, and minor pebble conglomerate), 3) Gushi marl (gypsiferous and calcareous, with interbedded siltstone and sandstone), 4) Tahtun unit (polymictic, matrix-supported conglomerate with minor sandstone), 5) Sabz unit (gypsiferous shale and silty-shale, with minor sandstone and limestone-thinly bedded, rhythmic sequence of shale/mudstone and sandstone, with minor lenses of limestone), 6) Darkhunish shale (grey shale with minor siltstone and sandstone), 7) Dar Pahn unit (sandstone and shale, with minor mudstone and conglomerate), 8) Band-e-Chaker unit (thickly bedded sandstone, with interbedded siltstone and shale) 9) Jagin Shale (with sandstone, siltstone, conglomerate, and shell beds; buff to red sandstone and conglomerate, with shell beds; Sandstone and conglomerate, with minor shale and shell beds), 10) Shahr-e-Pum unit (rhythmically bedded sandstone, with minor shale; thinly bedded sandstone and shale; rhythmically bedded sandstone, with minor shale), 11) Ab-Shahr unit (rhythmically and thinly bedded sandstone and minor shale), 12) Dehirdan unit (calcarous shale, with sandstone, minor siltstone, and limestone), 13) Angohran unit (rhythmic, thinly bedded sandstone and shale, with minor siltstone and conglomerate), 14) Vaziri unit (shale and sandstone, with shell beds, limestone, and conglomerate. Reefal, coral-algal limestone and reef talus (Fig. 2).

The first studied locality is in Qeshm Island (Rahgostar outcrop), which is situated near the road leading to Direstan village, between 26° 46' 19" N, and 55° 57' 13" E (Fig. 1a). The next locality is in the Minab region (Bandzark outcrop), in the middle of Bandzark city, between 27° 3' 51.10" N, and 56° 58' 49.01" E (Fig. 1b). In Qeshm Island, the bivalve *Placuna placenta* (Linnaeus 1758) is collected from the lower marl interbedded strata at the uppermost part of the Mishan Formation. This marl is loose grey, fossiliferous, overlaid by two shelly limestone beds, interbedded with marl horizon macroinvertebrate fauna. The Agha Jari Formation with dark red-brownish sandstone rests at the topmost of the studied horizons (Fig. 3). In the Minab region, the samples were collected from the Tiab sandstones, where strata are sculptured by the wind and those layers bearing clusters of *P. placenta* (Linnaeus 1758) more prominent (Fig. 4c). The Tiab Sandstone (Fig. 1b) crops out only in a small area close to the present coast on the join between the Minab and Taherui quadrangles, where it forms the middle subdivision of the Makran Unit within the Tiab Anticline. A total thickness of 478 m was recorded in a measured section reported by McCall (2002). The base of the succession is never seen but it is conformable beneath the Minab Conglomerate (Fig. 4e). Red and brown calcarenite and very fine-grained calcareous sandstone of dune facies are associated with brown to light grey rubbly limestone (beach rock) and greenish grey soft fossiliferous calcareous mudstone. A rich planktonic foraminiferal microfauna suggests that the base is in the *Globorotalia humerosa* zone of the Late Miocene and that the succession extends into the earliest Pliocene time. The unit is thus a facies variant of the Kheku Sandstone. Macrofossil debris is abundant, and reworked from shallow marine and estuarine sources. A beach or offshore bar environment is indicated, with some deltaic representation (McCall 2002). In the study location of the Rahgostar outcrop, the Agha Jari sandstone overlaid the upper part of the Mishan Formation marls that contains macrofossils such as crabs, gastropods and bivalves, ichnofossils, annelids of the genus *Ditrupa*, algae and foraminifera. In Qeshm Island these equivalent units consist of bryozoans, echinoids, corals, gastropods, pectinid and oyster bivalves, crustaceans such as crabs and balanoids, and their fragments. Among microfossils foraminifers, ostracods, and fish teeth, were noted, all with highly preserved structures.

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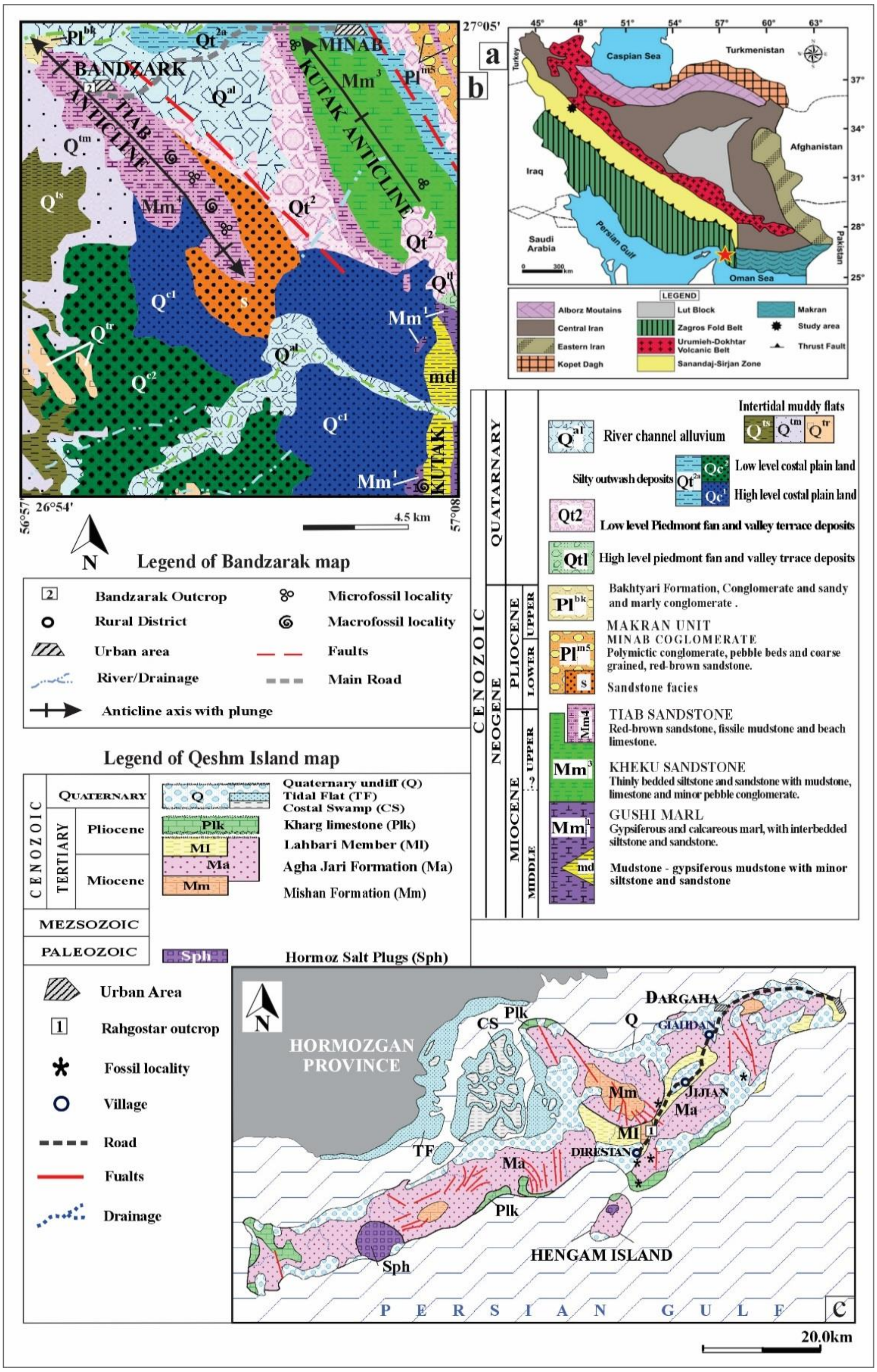

Fig 1- **(a) Tectono-sedimentary map of Iran** (modified from Stöcklin 1968)**; (b) Geological map of the studied area in the Minab region, Makran Basin, southern Iran** (Modified after Peterson and Rudzinskas 1982; McCall 1985; Fakhari 1995)**. (c) Geological map of the studied area in Qeshm Island, Persian Gulf** (after Huber 1975).

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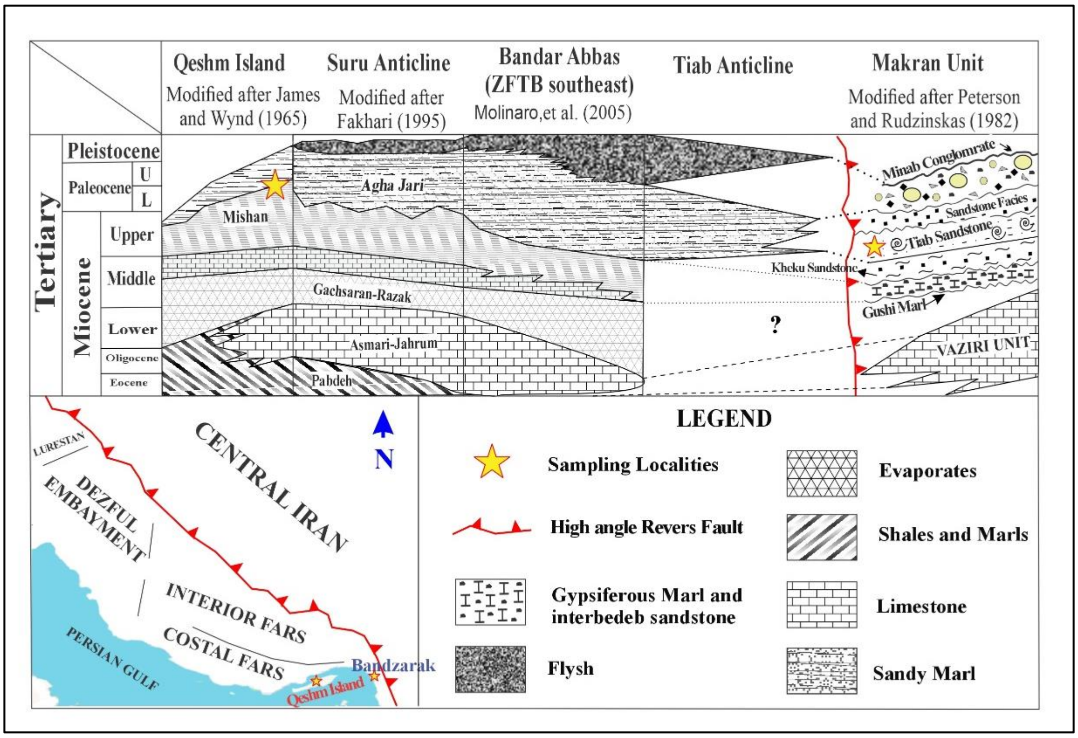

Fig 2- Mio-Pliocene stratigraphy chart of Hormozgan Province (Modified after James and Wynd 1965; Shearman et al. 1976; Fakhari 1995; Molinaro et al. 2005; Vega et al. 2012; Gholamalian et al. 2023)

Material & Methods

The bivalve *Placuna placenta* (Linnaeus 1758) was collected in fossiliferous marl of the upper part of the Mishan Formation marl unit in the Rahgostar outcrop (Fig. 3), but it is less common than in the Bandzark outcrop, where *P. placenta* occurs in clusters and was the only macrofossil in the outcrop. Most of the shells remain articulated. In total, 48 specimens were collected 24 samples from the Rahgostar outcrop, and 24 samples from the Bandzark outcrop. The shells of *P. placenta* were cleaned using a mild detergent. They are encrusted by bryozoans and young bivalves and show traces of bioerosion. Many of them are disarticulated, fragmented compressed, and broken. Five well-preserved specimens, 11 moderately preserved, and eight poorly-preserved specimens were collected in the Rahgostar assemblage. In turn, the Bandzark assemblage delivered 14 well-preserved specimens, seven moderately preserved, and three poorly preserved specimens. Almost all specimens collected from the Bandzark assemblage are articulated, and almost all of them are well preserved. Measurements were done with the help of a pair of calipers, Due to the very thin shells and their fragility, almost all of the commissures of our specimens are slightly broken. Measurements of all specimens (right or left valves) include Length (L): maximum shell length measured parallel to the hinge axis; Height (H): maximum shell height perpendicular to length; of both valves are tabulated (Tables 1 and 2). Because almost all specimens of the Rahgostar outcrop are disarticulated, we cannot measure their width (W), and the maximum thickness of both (articulated) valves was measured only for the specimens of the Bandzark outcrop. Photos of encrusting bryozoans were taken with the help of the Motic DM-143-FBLED-A5 Digital Binocular Stereo Microscope, with 5.0 Megapixels resolution, at the University of Isfahan. The studied material is stored at the Geology Department, Faculty of Sciences, University of Isfahan under the EUIC museum acronym.

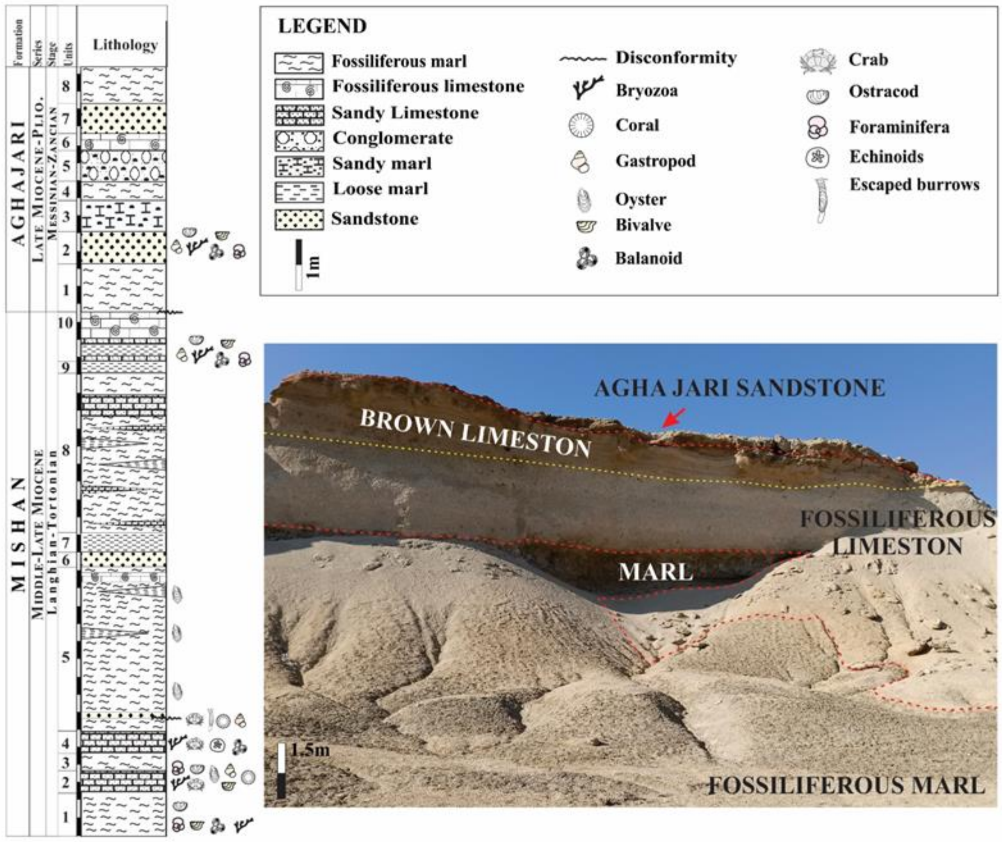

Fig 3- Rahgostar outcrop in Qeshm Island, with almost 20 m strata at the top of the Mishan Formation; and stratigraphic column of the studied areas in the Qeshm Island and Minab region, based on geological maps and fieldwork, is illustrated almost all of the strata of the Mishan and Agha Jari formations, which have outcropped in both studied areas.

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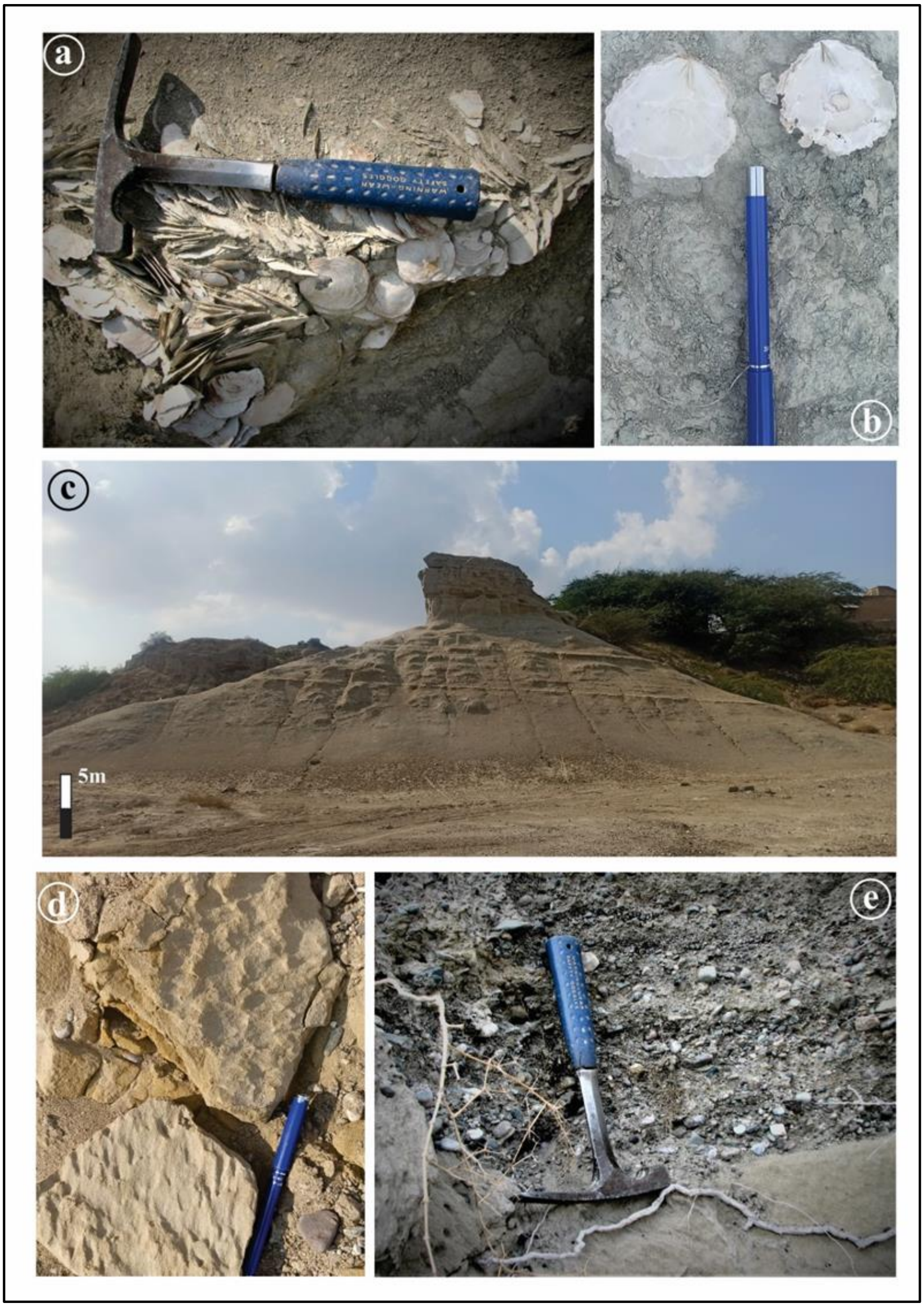

Fig 4- Field photos of the outcrop in Bandzark section, Minab region, Makran Basin, southern Iran. a: A cluster of *P. placenta* (Linnaeus 1758)**; b: Two disarticulated shells, with damaged outlines and edge chipping, the specimen in right side showing borings; c: The section of the Bandzark outcrop is almost 25m fine marly sandstone bearing *P. placenta* clusters; d: Ripple marks of the Tiab Sandstone; e: The boundary of the Tiab Sandstone and Minab Conglomerate.**

Taphonomy, Ecology and Palaeoecology

The shells of *P. placenta* (Linnaeus 1758) are the only skeletal macrofossils found during the study in the Bandzark sandstone. the monospecific nature of the fauna indicates high environmental stress, caused by strongly reduced salinity (Fürsich and Oschmann 1993; El Sabbagh 2016). Yonge (1977), described extant *P. placenta* from Singapore, indicating its wide distribution including the Gulf of Aden

India, the Malay Peninsula, the southern coasts of China, and the northern coasts of Borneo to the Philippines. The species *P. placenta* occurs from mid-tide levels to depths of up to 20 m but always on the same type of bottom, often associated with a mangrove, but never a coral coast.

Table 1- Measurements of *P. placenta* (Linnaeus 1758) valves from the Mio–Pliocene of the Bandzark outcrop (BPL), Tiab Anticline, Minab region, Hormozgan province, southern Iran.

Specimen number	Valve type	Length (mm)	Height (mm)	H/L	W (mm)
BPL-1	Articulate	66	63	0.95	4
BPL-2	Left	broken	43	-	-
BPL-3	Left	50	47	0.94	-
BPL-4	Articulate	70	64	0.91	0.5
BPL-5	"	92	90	0.98	2
BPL-6	"	86	80	0.93	1.5
BPL-7	"	75	75	1	1.5
BPL-8	"	54	48	0.88	1
BPL-9	Left	44	40	0.9	-
BPL-10	Right	broken	broken	-	-
BPL-11	Articulate	64	broken	-	2
BPL-12	"	47	47	1	1.5
BPL-13	Right	59	57	0.96	-
BPL-14	Right	49	48	0.98	-
BPL-15	Left	59	60	1.01	-
BPL-16	Right	60	59	0.98	-
BPL-17	Left	47	47	1	-
BPL-18	Articulate	55	47	0.85	1
BPL-19	Right	60	62	1.03	-
BPL-20	Left	63	62	0.98	-
BPL-21	Right	54	59	1.09	-
BPL-22	Right	60	64	1.06	-
BPL-23	Articulate	55	50	0.9	1
BPL-24	Articulate	51	53	1.04	1

Also, mentioned important note about *P. placenta*: 1- No difference for this animal lies on which valve and, the cause of this is sometimes acorn of barnacles attached to the surface of right valve (which means the calculating of the right and left valves for taphonomic conclusions is meaningless); 2- It cannot move like *Pecten* and escape from predation (which means the lack of predatory boring like the ichnogenus *Oichnus* Bromley 1981, refers to the absence of predators maybe cause of not a suitable environment for predatory); 3- The larger shells, which attain diameters of up to 15 cm, are probably little disturbed by water movements, although they may maintain position on the shore by expelling water 'forward' between the valves and moving with hinge foremost (Yonge 1936). 4- The final thickness of the shells is about 1 mm; 5- Old shells losing their transparency become sub-opaque, white and, somewhat friable, suggestive of dull white mica which has lost its transparency through weathering (Hornell 1909b; Yonge 1977).

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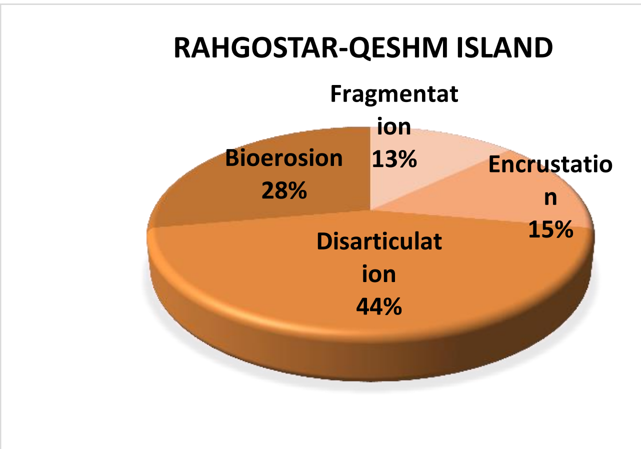
Table 2- Measurements of *P. placenta* (Linnaeus 1758) valves from the Middle Miocene of the Rahgostar outcrop (Q-PL), Qeshm Island, Persian Gulf, southern Iran.

Specimen number	Valve type	Length (mm)	Height (mm)	H/L	W (mm)
Q-PL-1	Right	46	44	0.95	-
Q-PL-2	Left	47	45	0.96	
Q-PL-3	Left	66	68	1.03	-
Q-PL-4	Left	54	56	1.03	-
Q-PL-5	Right	64	62	0.97	-
Q-PL-6	Right	64	67	1.04	-
Q-PL-7	Right	broken	68	-	-
Q-PL-8	Left	48	44	0.91	-
Q-PL-9	Right	broken	broken	-	-
Q-PL-10	Right	69	67	0.97	-
Q-PL-11	Right	54	50	0.92	-
Q-PL-12	Right	48	45	0.94	-
Q-PL-13	Right	50	43	0.86	-
Q-PL-14	Left	57	57	1	-
Q-PL-15	Right	46	43	0.93	-
Q-PL-16	Right	broken	broken	-	-
Q-PL-17	Right	broken	broken	-	-
Q-PL-18	Left	broken	broken	-	-
Q-PL-19	Right	49	44	0.9	-
Q-PL-20	Right	40	38	0.95	-
Q-PL-21	Left	broken	broken	-	-
Q-PL-22	Left	broken	49	-	-
Q-PL-23	Right	broken	broken	-	-
Q-PL-24	Right	45	45	1	

Laxmilatha (2015) observed that *P. placenta* is found on muddy or sandy substrata from shallow water up to 100 m depth. It hides under muddy surfaces as a deliberate effort to be inconspicuous to predators (Young 1979). The animal is a filter feeder and feeds on phytoplankton, zooplankton and, organic detritus (Behera 2017).

Specimens from the Rahgostar assemblage show more taphonomic alteration than those from Bandzark: 87.5%, of specimens from the Rahgostar show traces of bioerosion and encrustation, while 95.83% of specimens from Bandzark show such traces.

In the Rahgostar assemblage disarticulation amounts to 44%, fragmentation to 13%, bioerosion to 28% and, encrustation to 15% of specimen, respectively. The percentage of disarticulation and fragmentation of the samples in the Bandzark assemblage are 28, 6, 40 and, 26%, respectively (Fig. 5).



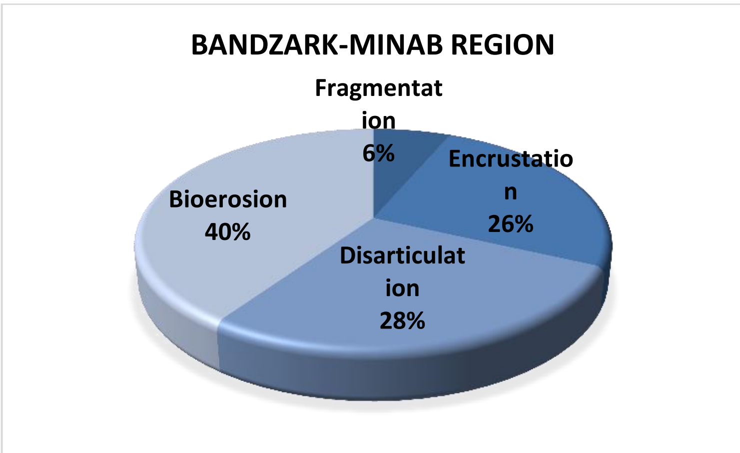


Fig 5- Relative abundance (in %) of bioeroded, encrusted, disarticulated and, fragmented specimens of *P. placenta* (Linnaeus 1758)**.**

El-Hedeny (2007) mentioned that the processes of encrustation and bioerosion are positively correlated with primary productivity and negatively with the sedimentation rate and energy.

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Similarly, disarticulation as a taphonomic feature is positively correlated with the rate of sedimentation. In other words, more articulated shells suggest their rapid burial and, fragmentation suggest high water energy and a stormy environment after the death and before burial processes, and it is negatively correlated with the processes of encrustation and bioerosion.

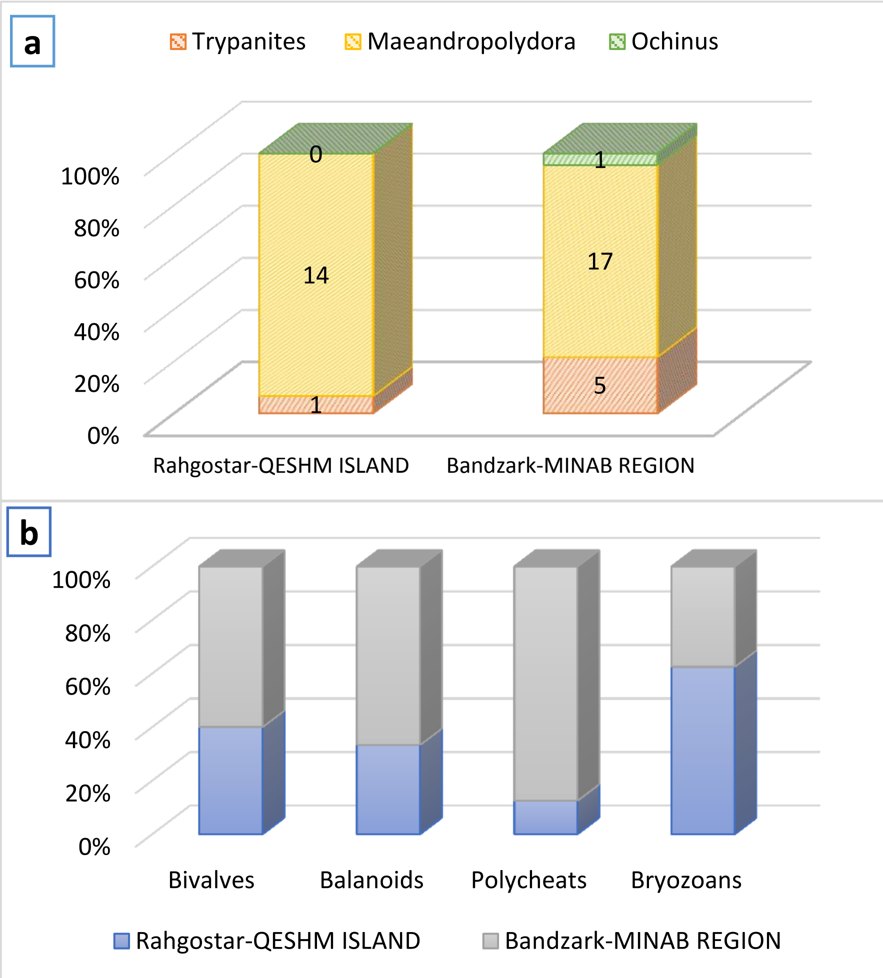

Fig 6- (a) The most common ichnogenera of borers (in % and exact number of samples) recorded in the studied areas; and (b) Relative abundance (in % and exact number of specimens) of encrusters of *P. placenta* (Linnaeus 1758)**.**

Only three ichnospecies of *P. placenta* shells produced by bioeroders are observed in this study, namely, *Maeandropolydora sulcans* Voigt 1977, *Oichnus simplex* Bromley, 1981 and *Trypanites weisei* Mägdefrau 1932.

The most common domichnia is *Maeandropolydora* Voigt 1977 (see Fig. 6a), represented by long, sinuous to contorted galleries with two or more apertures (see Pl. 4, Fig. 6 and Pl. 7, Fig. 5), known from Cretaceous to Pleistocene (Bromley and D'Alessandro 1983; Zitt and Mikulas 1994). *Oichnus simplex* Bromley, 1981 is the only ichnospecies (Praedichnia) in the Bandzark assemblage represented by circular/subcircular boring (Pl. 6, Fig. 2) made by gastropods, octopods or unknown predators (Bromley 1981; Nielsen and Nielsen 2001). Predation marks occur on live hosts (Pickerill et al. 2002).

Another domichnia of this study is *Trypanites weisei* Mägdefrau 1932, a flattened U-shaped chamber with figure-of-eight entrance (Pl. 3, Fig. 8 and Pl. 7, Fig. 6). The ichnogenus *Trypanites* is characteristic of estuaries (Gingras et al. 2012) and rocky shorelines of shallow-marine siliciclastic systems (Gibert et al. 2012), and carbonate platforms in subtidal and intertidal environments (Knaust et al. 2012; Naimi et al. 2021). It is known from the Cambrian to Recent and ascribed to sipunculid/polychaete annelid (Taylor and Wilson 2003).

The ichnogenus *Trypanites* Mägdefrau 1932 was found only on one specimen from the Rahgostar assemblage and on five specimens from the Bandzark assemblage, which may show the percentage of matching environments where the studied specimens lived or recorded, with the environments mentioned above, is weak (Fig. 6a).

Encrusters are balanoids, sheet-like Cheilostomata bryozoans, calcareous tubes of polychaetes and, attached juvenile valves of undefined bivalves (Fig. 6b).

Balanoid barnacles usually occur in all modern shallow marine environments, occupying shorelines (El Sorogy et al. 2003). Bryozoans most commonly encrust hard substrates at shallow water depths (e.g., El Sabbagh 2008; Salahi et al. 2018).

Hard substrates in the modern oceans are often heavily encrusted by polychaetes. They are common in all marine settings, ranging from the intertidal down to hadal depths (e.g., Hill 2013; Ippolitov et al. 2014; Mandor et al. 2022). Serpulids typically occur in the intertidal marine environments (El-Sorogy et al. 2003).

In the study case encrusters show that except bryozoans, the percentage of all other encrusters is more common in the Bandzark assemblage than in the Rahgostar one. Especially, the difference is in number of polychaetes (only one in Rahgostar's, while 7 samples in Bandzark's).

The high percentage of bryozoans refers to the low rate of sedimentation of the environment in the Rahgostar area in comparison to the Bandzark area.

Systematic Paleontology

The systematics of Cheilostomata bryozoans is based on Bassler (1953), and Zágoršek (2010); and the systematics of *P. placenta* is based on Yonge (1977) as well as Bieler et al. (2010). The bivalve *P. placenta* and encrusting them Cheilostomata bryozoans are the only sclerobionts recognized in the study area.

Phylum **Mollusca** LINNAEUS, 1758
Class **Bivalvia** LINNAEUS, 1758
Subclass **Autobranchia** GROBBEN, 1894
Superorder **Ostreiformii** FERUSSAC, 1822
Order **Pectinida** GRAY, 1854
Suborder **Anomiidina** GRAY, 1854
Superfamily: **Anomioidea** RAFINESQUE, 1815
Family: **Placunidae** YONGE, 1977
Genus: ***Placuna*** LIGHTFOOT, 1786
(Fig. 7)

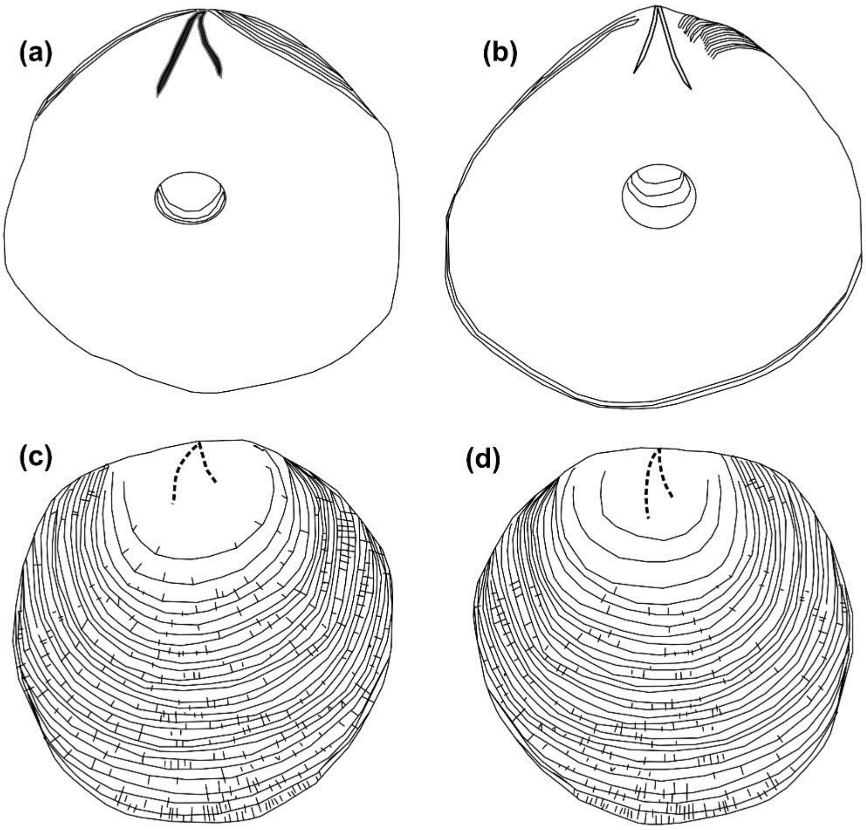

Fig 1- ***Placuna placenta*** (Linnaeus 1758) **(no scale); (a) Left valve, interior surface, showing primary ligament with scars of adductor and anterior pedal retractor; (b) right valve, interior surface, exhibiting unequal V-shape crurae and adductor muscle scar; (c) left valve, the lamellate exterior surface, the ventral region shows fine growth lines; (d) right valve, the outer surface, the dorsal region shows a shadow sign of crurae.**

Placuna is monomyarian, with low umbones, V-shaped crurae, and pallial line, often obscured. Valves circular to sub-circular and laterally compressed. All the characters seen in our specimens are common with the species observed from the Indian subcontinent by Das et al. (2019), from Singapore by Yonge (1977), and from Indonesia by Abida et al. (2023).

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Placuna placenta (Linnaeus 1758)
(Pl. 1-8)

Description: Shell thin, very flat, roughly circular or subcircular in shape, inequivalent, periostracum absent. Inner surface smooth, outer surface lamellate, growth lines present. Transparent when juvenile, turning opaque with age. Lacking radial lines on the external surface. Crurae below the umbones, unequal in size, adductor muscle scar slightly anterior of the midline. Pallial line obscure and non-sinuated. The specimen examined has a damaged or broken outline (Das et al. 2019).

Distribution: Today it extends from the Gulf of Aden to Taiwan in the east (Matsukuma 1987; Huber 1975; Das et al. 2019).

Material: 24 disarticulated specimens, 8 specimens are left valves and 16 specimens are right valves, Rahgostar outcrop, near Direstan road, Qeshm Island, Persian Gulf, southern Iran; and 24 specimens, (11 samples are articulated, 6 shells are left valve and 7 shells are right valve, collected from the Bandzark outcrop, in the middle of Bandzark city, Minab region, Hormozgan province, southern Iran.

Remarks: the preserved shells from both outcrops show all characteristic features of this species.

Occurrence: MiddleLate Miocene of Guri Member of Mishan Formation, Zagros Basin of Qeshm Island, Persian Gulf, southern Iran. MioPliocene of the Tiab Sandstone of Makran Basin, Minab region, southern Iran. Recently, living Indo-Pacific species.

Phylum **Bryozoa** Ehrenberg, 1831
Class **Gymnolaemata** Allman, 1896
Order **Cheilostomata** Busk, 1852
Suborder **Ascophora** Levinsen, 1909
Infraorder **Umbonulomorpha** Gordon, 1989
Superfamily **Schizoporelloidea** Jullien, 1883
Family **Crepidacanthidae** Levinsen 1909
Genus ***Crepidacantha*** Levinsen, 1909
Cribellopora* aff. *hluchovensis Zágoršek, 2010
Pl. 3, Figs. 3-4

Diagnosis: See Zágoršek (2010).

Material: one encrusting colony, indwelling into the internal surface of the right valve of *Placuna placenta* (Linnaeus 1758), collected at the Rahgostar outcrop, near Direstan road, Qeshm Island, Persian Gulf, southern Iran

Remarks: the preserved colony shows almost all characteristic features of this species eroded.

Occurrence: MiddleLate Miocene of the Guri Member of the Mishan Formation, Zagros Basin of Qeshm Island, Persian Gulf, southern Iran; and/or Langhian, Miocene (see Zágoršek 2010).

Conclusion

The Bandzark strata, which are an outcrop of the Tiab Sandstone, show muddy/sandy substrata of tidal/intertidal shallow marine environments with low productivity, high rate of sedimentation, and low energy. The lack or low rate of presence of low-energy bioeroders and encrusters like *Entobia* (the product of boring sponges), in the Bandzark assemblage probably shows the high rate of sedimentation. In both studied outcrops, the low diversity of fauna and the absence of encrusters of warm and low energy environments, like corals and sponges may indicate high rate of suspended sediments in wavy environments. The clusters of *P. placenta* in Bandzark originated due to a high rate of productivity in warm waters of the Paratethys seaway, *P. placenta* as the only macrofossil of Bandzark indicates high environmental stress, caused by strongly reduced salinity. Articulated specimens in the Bandzark outcrop are associated with rapid burial processes after death, and, disarticulated specimens in Rahgostar are negatively correlated with the rate of sedimentation. Balanoids which are the most common encrusters at Bandzark, are positively correlated with the high-water energy. The traces of bioerosion belong to three ichnospecies, *Maeandropolydora sulcans* Voigt 1977, *Oichnus simplex* Bromley 1981 and *Trypanites weisei* Mägdefrau 1932. The most common ichnofossils is domichnia *Maeandropolydora* present in all the investigated shells. The strata of the Rahgostar outcrop which are part of the marly deposits of the Mishan Formation, originated within a lagoon and carbonate ramp or shelf, close to open marine environments.

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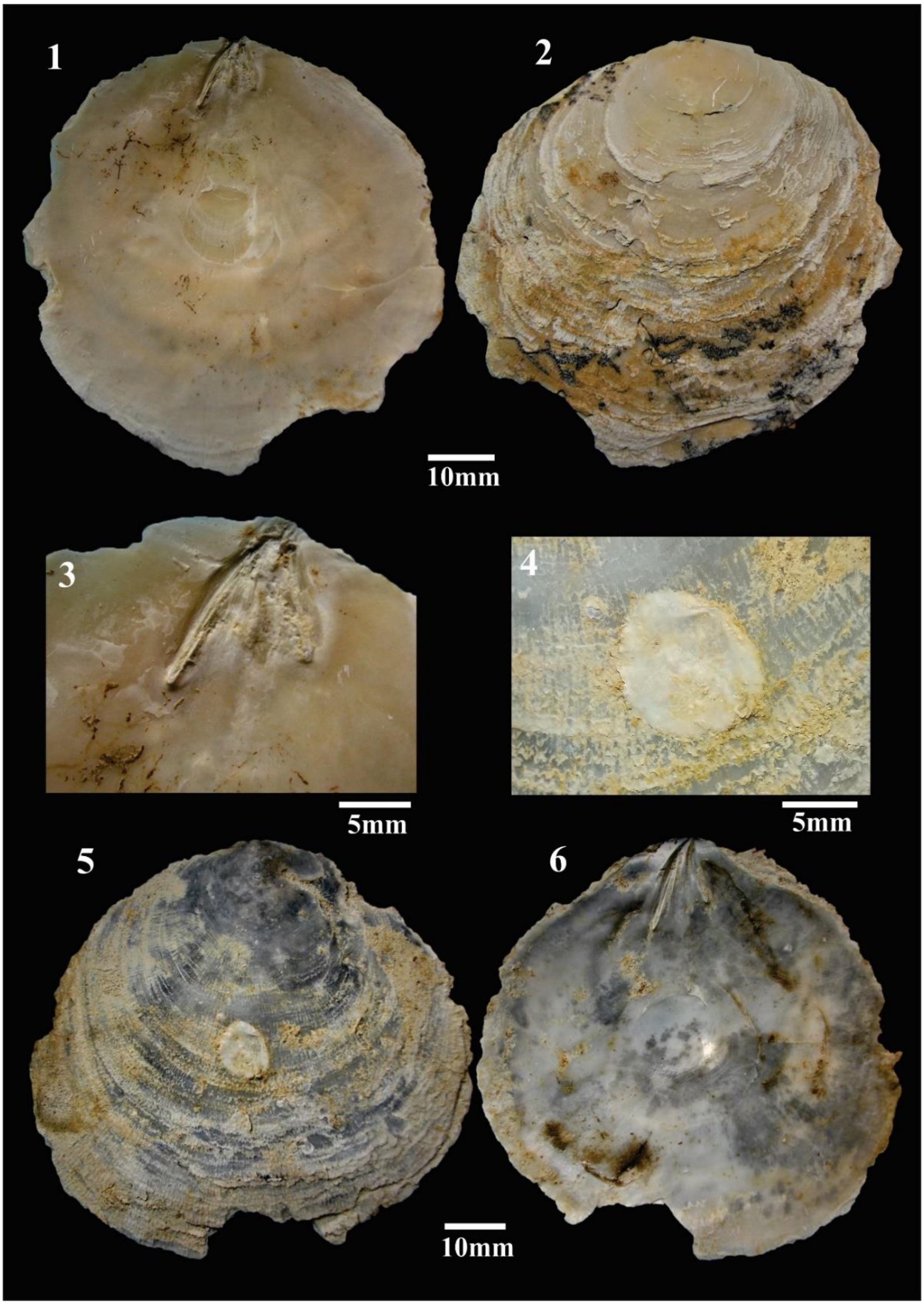
PLATE 1

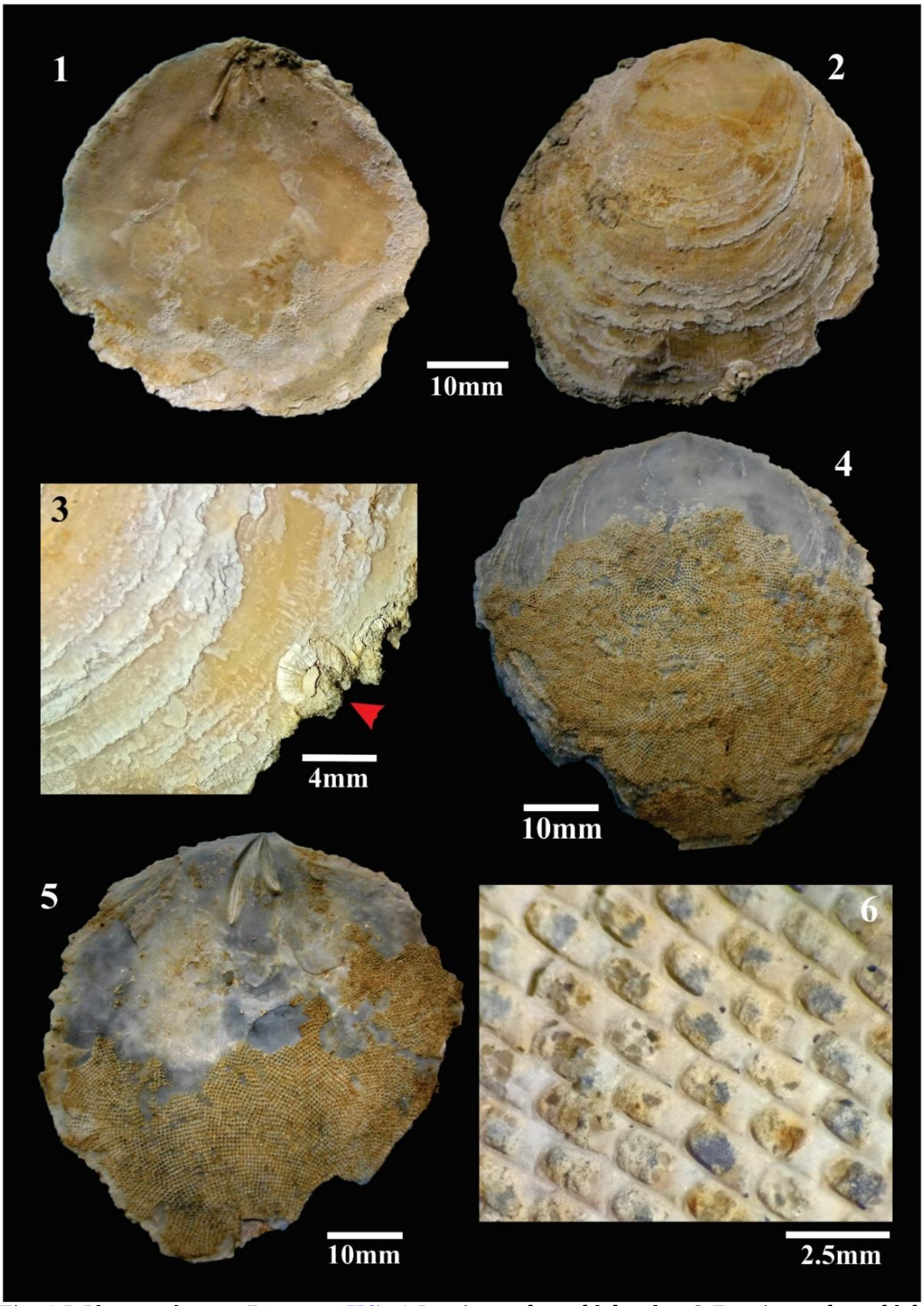


Figs 1-3 *Placuna placenta* (Linnaeus 1758)**; 1-2 Interior and exterior surface of the left valve, 3 Close-up of fig. 1, showing ligamental area (Q-PL-14).**

Figs 4-6 *Placuna placenta* (Linnaeus 1758)**; 4 Close-up of fig. 5, showing the fixed juvenile bivalve; 5 External view of the left valve bear a fixed valve of a juvenile bivalve, which cannot be maybe a juvenile member of family Placunidae, because they used to hide under muddy surface; 6 Interior surface of left valve, not affected by taphonomic implications (Q-PL-3).**

https://doi.org/10.22108/jssr.2024.142783.1297

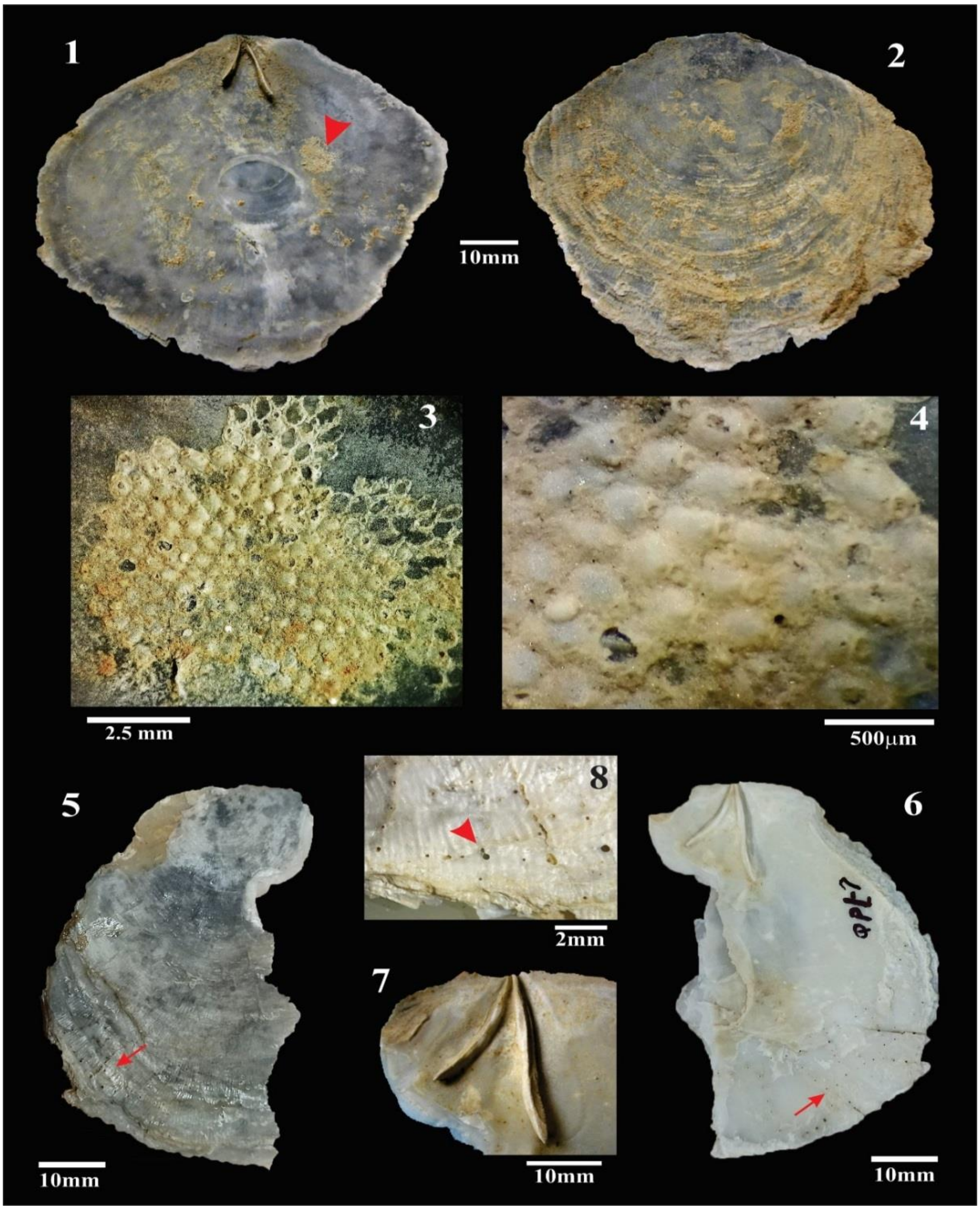
PLATE 2



Figs 1-5 *Placuna placenta* (Linnaeus 1758)**; 1 Interior surface of left valve; 2 Exterior surface of left valve, display a balanoid fused to the ventral margin; 3 Close-up of fig. 2, showing a fused balanoid that partly broken and a ruined shell of another balanoid (Q-PL-2); 4 Exterior surface of the left valve, that most part of it covered by a sheet-like colony of a cheilostomat Bryozoan; 5 Interior surface of the left valve, covered by an encrusting colony of Bryozoans(Q-PL-4).**
Fig 6 *Biflustra* d'Orbigny, 1852; Close-up of fig. 4, showing genus *Biflustra* d'Orbigny, 1852, an encrusting colony of order Cheilostomata (Q-PL-4).

https://doi.org/10.22108/jssr.2024.142783.1297

PLATE 3



Figs 1-2 *Placuna placenta* (Linnaeus 1758)**; 1 Interior surface of right valve, red arrow head points right at an encrusting colony of cheilostomat bryozoans; 2 Exterior surface of right valve (Q-PL-5).**

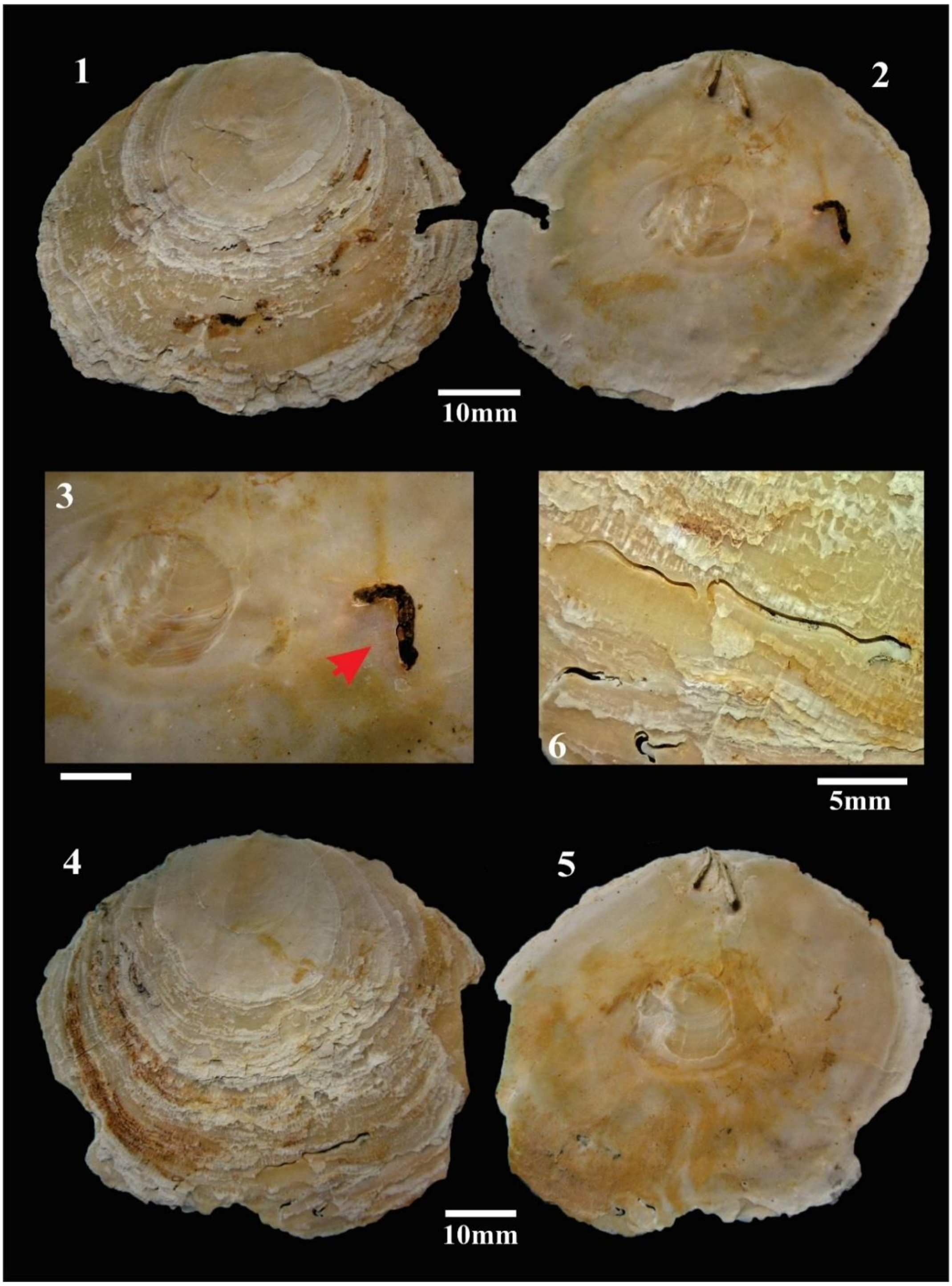
Figs 3-4 *Cribellopora* aff. *hluchovensis* Zágoršek, 2010; Close-up of fig. 1, display the species *Cribellopora* aff. *hluchovensis* Zágoršek, 2010, an encrusting colony of cheilostomat bryozoans, covered interior surface of the valve, and is slightly eroded (Q-PL-5).

Figs 5-7 *Placuna placenta* (Linnaeus, 1758); 5 Exterior surface of right valve of an ill preserved sample, red arrow is showing performed ventral margin by polychaete worms, the producers of ichnogenus *Trypanites* Mägdefrau, 1932; 6 Interior surface of right valve, red arrow shows near outline of the valve is performed; 7 Close-up of fig. 6, exhibiting V-shape crurae of the right valve (Q-PL-7).

Fig 8 *Trypanites weisei* Mägdefrau, 1932; Close-up of fig. 5, showing ventral margin of the valve is perforated by of ichnospecies *Trypanites weisei* Mägdefrau, 1932, note red arrowhead pointing right at the figure-of-eight entrance (Q-PL-7).

https://doi.org/10.22108/jssr.2024.142783.1297

PLATE 4



Figs 1-3 *Placuna placenta* (Linnaeus 1758)**; 1 Exterior view of the right valve, with a little compression and edge chipping; 2 Interior view of the right valve, bear a remain of a tube of a polychaeta; 3 Close-up of fig 2, showing bear a remain of a tube of a polychaeta (red arrowhead), near the scar of adductor muscle (Q-PL-19); 4 Exterior view of the right valve of a moderately preserved sample; 5 Interior view of the right valve shows a damaged outline; 6 Close-up of fig 4, display ichnogenus *Maeandropolydora* Voigt 1965 and growth line of the valve (Q-PL-16).**

(All specimens of Plates I to IV were collected from the Rahgostar outcrop, Qeshm Island, Persian Gulf, Southern of Iran)

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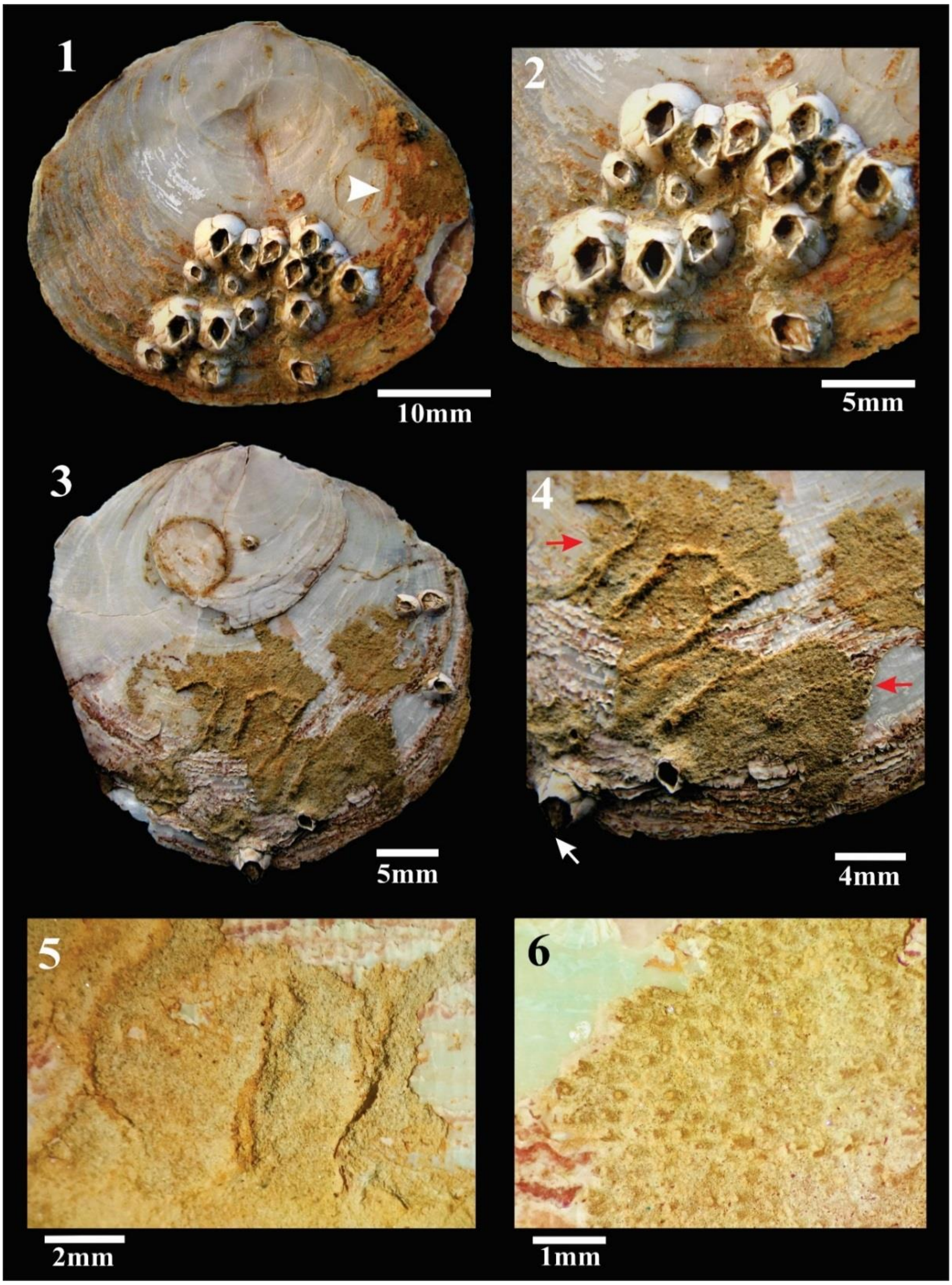
PLATE 5



Figs 1-6 *Placuna placenta* (Linnaeus 1758)**; 1 Exterior view of an undefined valve of an articulated sample, with a fixed pack of balanoid cluster and a piece of an undefined colony of encrusting bryozoans (white arrowhead); 2 Close-up of fig. 1, that gives a better look of balanoid cluster (BPL-23); 3 Exterior surface of the left valve; 4 Close-up of fig 3, showing a fused balanoid to the ventral outline (white arrow) and several pieces of undefined colonies of sheet-like bryozoans (red arrows); 5 Close-up of fig. 4, showing several calcareous tubes of polychaete worms, dwelling on the surface of the valve and covered by encrusting bryozoans; 6 Close-up of fig 4, that gives a better look of encrusting bryozoan covered by mud (BPL-9).**

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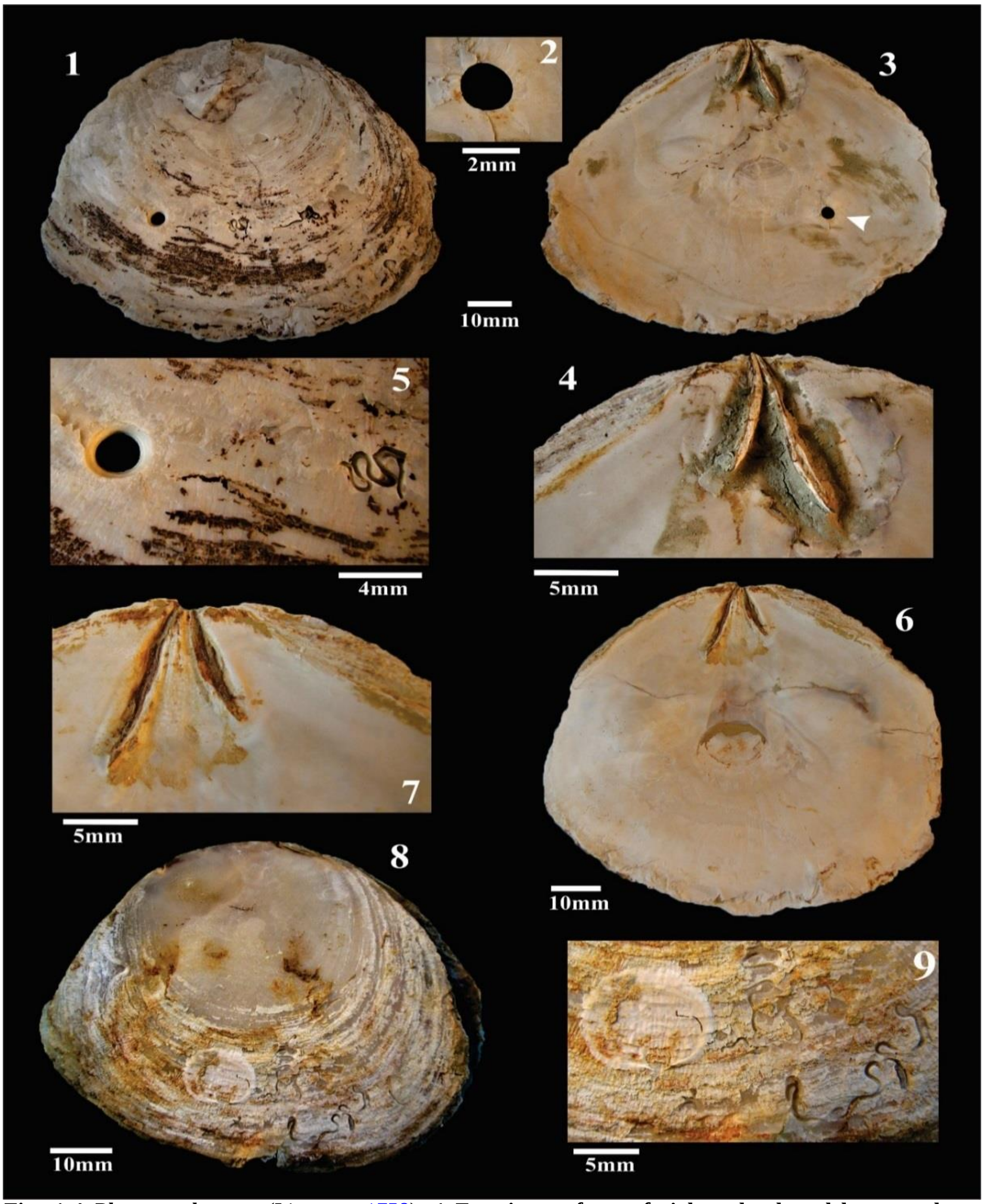
PLATE 6



Figs 1-4 *Placuna placenta* (Linnaeus 1758)**; 1 Exterior surfaces of right valve bored by a predator around the muscular adductor, and produce ichnospecies *Oichnus simplex* Bromley 1981; 2 Close-up of fig. 3, display a drill hole on interior surface of the valve, which is ichnospecies *Oichnus simplex* Bromley 1981; 3 Interior surfaces of the right valve shows the praedichnia *Oichnus simplex* Bromley, 1981 (white arrow head), close to the scar of muscular adductor; 4 Close-up of fig 3, exhibiting V-shape crurae of the right valve (BPL-6).**

Fig 5 *Maeandropolydora sulcans* Voigt 1965 and *Oichnus simplex* Bromley 1981; two bioerosion features, which are dwelling on exterior surface of the right valve (BPL-6).

Figs. 6-7 *Placuna placenta* (Linnaeus 1758)**; 6 Interior surfaces of the left valve; 7 Close-up of fig. 6, showing ligamental area of the left valve (BPL-6).**

Figs. 8-9 *Placuna placenta* (Linnaeus 1758)**; 8 Exterior surfaces of an undefined valve of an articulated sample; which is bearing ichnospecie *Maeandropolydora sulcans* Voigt 1965 and an undefined small bivalve; 9 Close-up of fig. 8, gives more close vision of the surface of the valve, showing an undefined juvenile bivalve is perforated by activity of polychaete worms (BPL-5).**

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PLATE 7

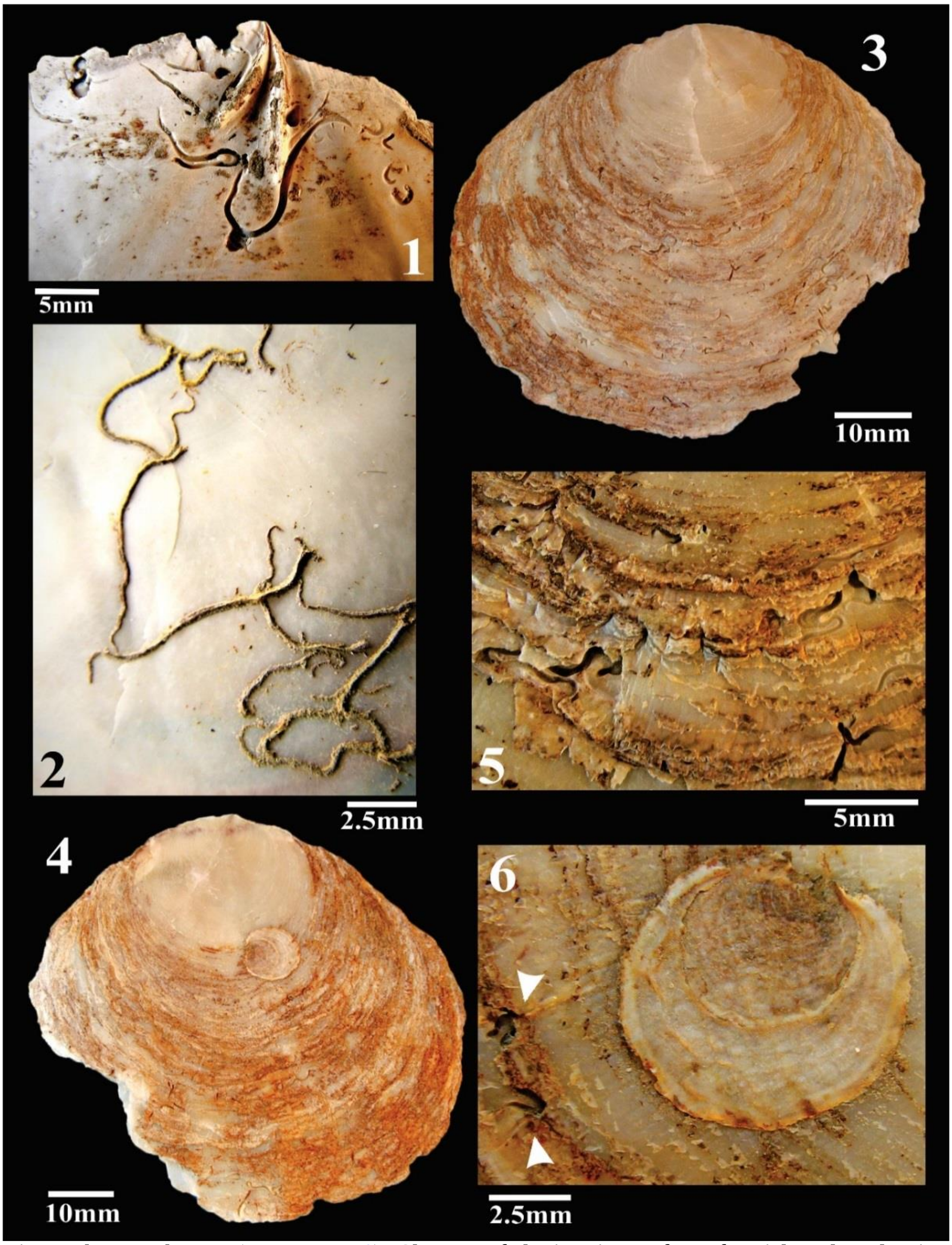

Fig. 1 *Placuna placenta* (Linnaeus 1758)**; Close up of the interior surface of a right valve, showing ichnospecie *Maeandropolydora sulcans* Voigt, 1965 around the ligamental area (BPL-L1).**

Fig. 2 Close up of the interior surface of the left valve of a broken shell, showing the results of polychaetae activities (BPL-2).

Figs. 3-6 *Placuna placenta* (Linnaeus 1758)**; 3 Exterior surfaces of right and left valves of an articulated specimen, both surfaces bear ichnogenus *Maeandropolydora* Voigt 1965 and abrasion in ventral margins of both valves; 4 Close-up of fig. 3, showing ichnogenus *Maeandropolydora* Voigt, 1965; 5 Close-up of fig. 4, showing a fixed valve of a juvenile bivalve shell (or maybe another stages of the bivalve *Placuna*), and two U-shaped galleries of ichnospecies *Trypanites weisei* Mägdefrau 1932, see white arrow heads (BPL-1).**

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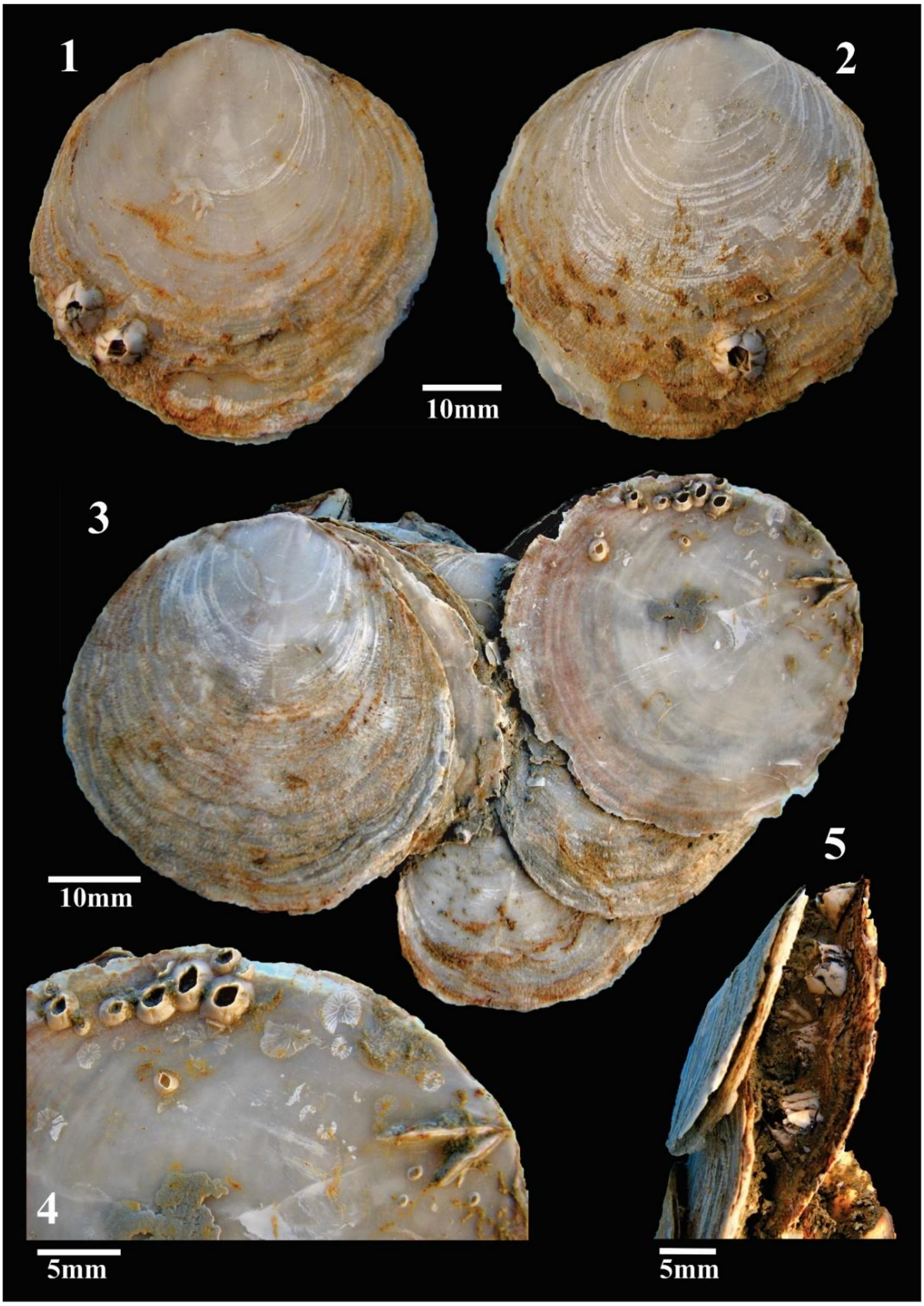
PLATE 8



Figs 1-5 *Placuna placenta* (Linnaeus 1758)**; 1-2 Exterior surfaces of right and left valves of an articulated specimen, both surfaces bear balanoids barnacles (BPL-24); 3 a pack of fused shells, display articulated and disarticulated valves accumulation; 4 Close-up of fig. 3 showing interior view of the right valve of a disarticulated sample with fused cluster of balanoids (BPL-C1); 5 Laterally view of a pack of Placunidae and balanoid barnacles fused to the exterior of an articulated shell (BPL-C2).**

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