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Taphonomic Signatures on Some Intertidal Molluscan Shells from Tarut Bay (Arabian Gulf, Saudi Arabia)

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Abstract.- The present contribution documented a molluscan assemblage (bivalves and gastropods) collected from the intertidal water of Tarut Bay, east coast of Saudi Arabia and assessed the degree of post-mortal alteration of the shell material. In this assemblage, bivalve shells were totally dominated by disarticulated valves and had significant taphonomic alteration in their shells. Four principal taphonomic attributes were analysed: encrustation, bioerosion, fragmentation and abrasion. Three types of encrusters were recorded on shells of the present study: balanoids, polychaetes and bivalves (*Spondylus* and oysters). Amongst, balanoid barnacles represented the most common encrusters that were recorded in both gastropod and bivalve shells. It was observed that each encruster attached on the host as a single epibiont and no share with other epibionts on the same host. Bioerosion traces in shells were predominately those of clionid sponges and gastropods. They were represented by the ichnogenera *Entobia* and *Oichnus*. The presence of drill holes assigned to the ichnospecies *Oichnus simplex* Bromley, 1981 were made by muricid gastropods which are common in the study area. Fragmentation was mainly resulted from biological processes (bird predation) on the brittle-shelled bivalve species *Vepricardium asiaticum*. Many of bivalves were observed abraded, lacking-sheen, and showed evidence of corrosion.

Key words: Taphonomy, mollusca shells, Tarut Bay.

INTRODUCTION

Taphonomy of marine skeletal organisms involves biological, chemical and mechanical processes that lead to abrasion, bioerosion, disarticulation, dissolution, encrustation, fragmentation, precipitation, orientation, and sorting (Nielsen, 2004). These taphonomic signatures may indicate that the processes happened in a certain time sequence controlled by life habits and environmental conditions (Barkati and Asif, 1984; Meldahl and Flessa, 1990; Viana and Richter, 1998). The taphonomic condition of shells varied with environment. Shell beds, lags, or concentrations can be a common feature of shelf and coastal areas, and considerable research has been devoted to understanding their formation through taphonomic analysis (Brett, 2003).

Shells from the surface of the inner flats were better preserved than shells from the tidal channel (Flessa *et al.*, 1993). Santos and Mayoral (2008) indicated that in intertidal and shallow sublittoral environments, the hard substrates, including skeletons of living and dead organisms as well as rock clasts, may be colonised by a diverse array of endobionts (borers) and grazers, in addition to suspension feeding epibionts (encrusters)

The Arabian Gulf is a semi-enclosed sea, 850 km long and 250 km wide, connected to the Indian Ocean via the Strait of Hormuz. It is a shallow sea with an average depth of only 35 m. According to Zwarts *et al.* (1991), the Arabian Gulf is characterized by existence of extensive intertidal areas. They stated that the large intertidal areas in Arabian Gulf of Saudi Arabia are found around the former island of Tarut and NW of the former island of Abu Ali. However, the gulf waters have very slow currents and limited tidal range. The tide is found to contribute little to the flow, the wind generates strong currents along the coasts of Saudi Arabia and the United Arab Emirates (Azam *et al.*, 2006). The coastal current of Saudi Arabian appears to be enhanced by freshwater input from the iraqian Shatt Al Arab waterway. Molluscs are common on the sandy beach, and bivalves and gastropods in

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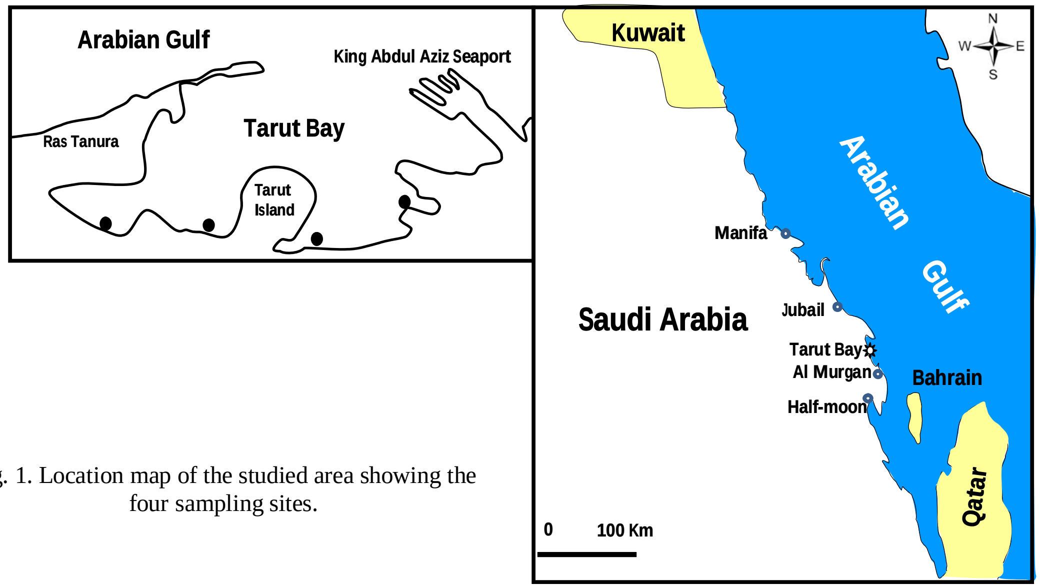

Fig. 1. Location map of the studied area showing the four sampling sites.

particular are well represented in the Arabian Gulf coast of Saudi Arabia.

The aim of the present study is to document the molluscan shells (bivalves and gastropods) of an intertidal sandy beach of Tarut Bay, Saudi Arabia, and to describe the taphonomic signatures of this assemblage.

MATERIALS AND METHODS

Study area

Tarut Bay (Latitude: 26° 37' 41 N, Longitude: 50° 5' 35 E) (Fig. 1) is the most important bay on the Gulf coast of Saudi Arabia for wintering and passage shorebirds. Additionally, the bay is the largest shrimp nursery in the country (Al-Sulami *et al.*, 2002). Newton (1995) stated that, Tarut bay is a large, shallow, sandy (and in places muddy) bay, with one of the richest and most diverse intertidal habitats in the Arabian Gulf.

Tarut Bay is characterized by mangrove area that provide a habitat for many bird species as they are very important breeding, feeding and nursery grounds for several types of birds and aquatic animals such as fish, shellfish, prawns, and crabs etc. Without healthy mangroves, populations of these animals would decline and eventually be lost from the region (Khan and Kumar, 2009). In addition, Tarut Bay is the single most important site for passage and wintering water-birds on the Saudi sector of the Arabian Gulf coast (Newton, 1995).

In the past decades, Tarut Bay was characterized by dense mangroves (Alyahya *et al.*, 2011). During the past 30 years, a considerable decline in mangrove due to the change in mangrove habitats within Tarut Bay. This change was resulting from human activity on the mangrove distribution in this area.

Sampling

The present study is based primarily on material collected from four sites within Tarut Bay, Arabian Gulf of Saudi Arabia (Fig. 1). More than 230 specimens of molluscs (bivalves and gastropods) had been collected at low tide from the intertidal zone.

In the laboratory, shell samples were cleaned, sorted, identified and measured. When necessary, the dead shells were carefully washed and brushed to remove the sediments of the interior of the valves. All shell samples were examined for taphonomic signatures (abrasion, fragmentation, bioerosion and encrustation); 91% of the studied samples showed significant signs of taphonomic features.

Sampling was undertaken in April 2013. All specimens are housed in the collections of

Department of Zoology, College of Science, King Saud University. All shells were originally composed of aragonite.

Fauna

A total of 28 species of mollusks (21 bivalves and 7 gastropods) were assigned for Tarut Bay area. Nearly all of these species belong to Indo-Pacific molluscan species.

Bivalvia

Diplodonta ravayensis; *Lima sowerbyi*; *Tellina radiata*; *Anodontia edentula*; *Amiantis umbonella*; *Anadara ferruginea*; *Chama reflexa* Reeve, 1846; *Dosinia alta*; *Dosinia tumida*; *Spondylus groschi ; Paphia (Protapes) gallus*; *Paphia (Protapes) rhamphodes*; *Paphia (Protapes) cor*; *Paphia undulata*; *Acrosterigma impolitum*; *Acrosterigma maculosum*; *Vasticardium assimile*; *Acrosterigma vertebratum*; *Chlamys (Chlamys) reticulata*; *Cardium (Orthocardium) porulosum*; *Vepricardium asiaticum*.

Gastropoda

Bulla ampulla; *Pseudominolia climacota*; *Hexaplax kuesterianus*; *Cymatium (Ranularia) boschi*; *Trochus maculates; Cerithidea cingulata*; *Spondylus gloriandus*

RESULTS AND DISCUSSION

Disarticulation

Bivalved shells may serve as sensitive indicators of rapid, episodic sediment accumulation (Allen, 1992). The rate at which organisms skeletons disintegrate after the death is a function of their delicacy, environmental energy, temperature, oxygen level and residence time on the seafloor (Brett, 2003). Degree of articulation is a good indicator of relative exposure time, or energy of the depositional environment.

In the studied area, all analyzed bivalve shells were disarticulated. The very delicate spines on the spondylid bivalve *Spondylus gloriandus* are present, again suggesting limited amounts of post-mortem exposure on the seafloor as well as limited transport. No size sorting is recognized and shells are more commonly oriented concave-up than concave-down. The shells occur with others that are oriented obliquely and vertically. These facts indicate transport of short duration in a moderately-energetic setting (Boucot *et al*., 1958; Seeling and Bengtson, 1999). This state falls within Model II of Johnson's framework (1960): *i.e*. extreme of ‘Within habitat time-averaged’ field of Kidwell and Bosence (1991) (Fig. 2). In this case, valves are rarely found in their life position and appear as parautochthonous associations (transported slightly in the vicinity of their habitats (Seeling and Bengtson, 1999).

Encrustation

Encrusters on Cenozoic shells are very common but published studies of them are surprisingly few (*e.g.* Taylor and Wilson, 2003; Kidwell, 2013). Taphonomically important encrusters whose hard-parts include bryozoans, serpulid worms, foraminifera, corals and barnacles (Parsons and Brett, 1991; Perry, 2000; McKinney, 1996, El-Hedeny, 2005,2007a,b).

In the studied area, encrustation represents 48% of the studied specimens (Fig. 2-1 to 2-7). Three types of encrusters were recorded on shells of the present study: balanoid barnacles, polychaetes and bivalves (*Spondylus* and oysters)

The most common encruster (52%) in the studied area is the balanoid barnacles genus *Balanus*. Balanoid barnacles are recorded at nearly similar morphological sizes and same directions (Fig. 2-1). They are usually found in all modern shallow marine environments, occupying shorelines of the continent (El Sorogy *et al*., 2003).

They are well developed as aggregates on the external surface of *Vasticardium assimile* (Fig. 2-1). Their position of attachment may indicate the direction of flow of food-bearing water. It is supposed that balanoid barnacles are able to orientate to water movement in order to allow for efficient food collection over a wide range of conditions (El-Hedeny, 2007a). Diverse ontogenic balanoid encrusters are also recognized by their early ontogenetic shell on the internal surface of the bivalve *Amiantis umbonella* (Fig. 2-3). In addition, there are some gastropods species encrusted with balanoid barnacle (Fig. 2-5, 2-7).

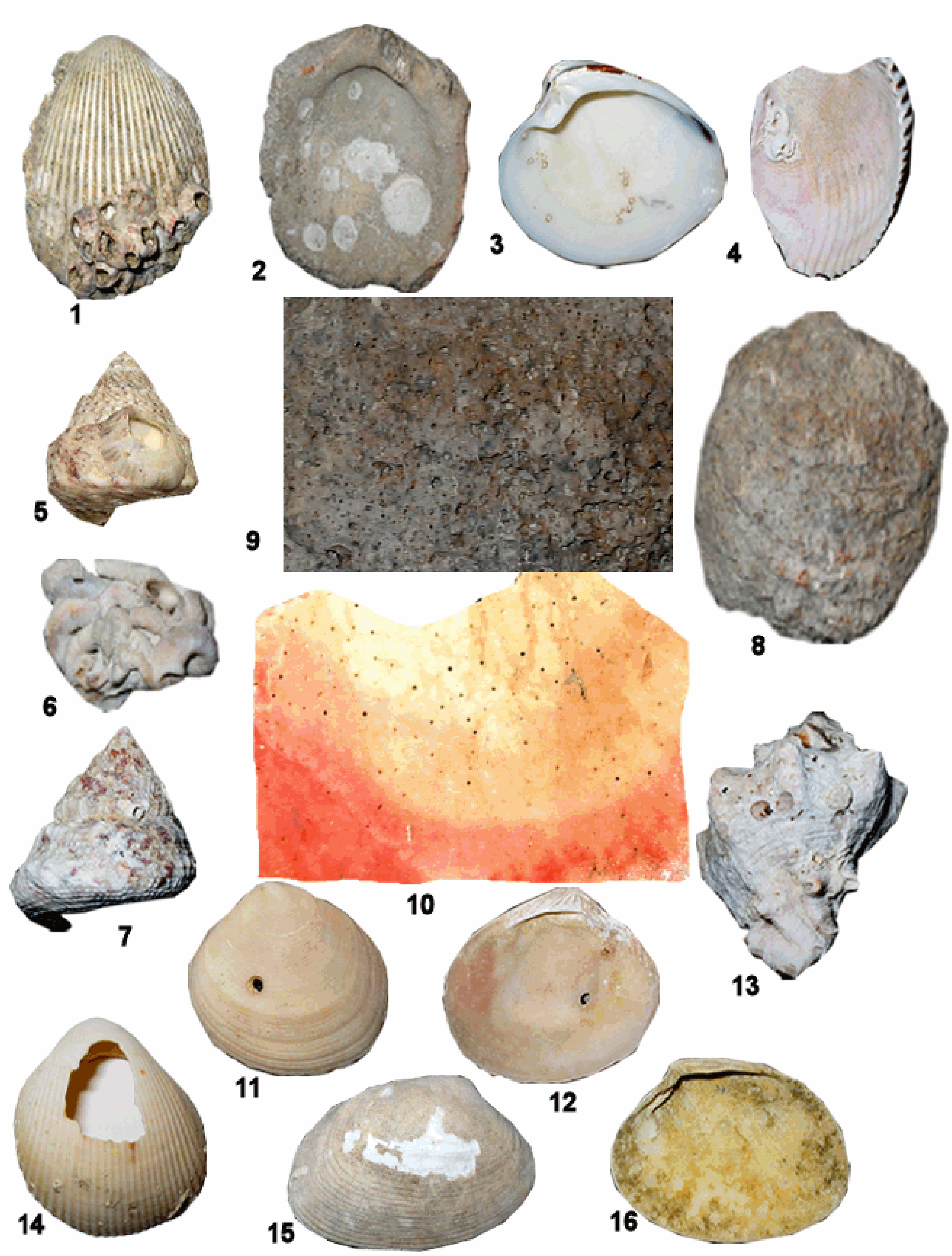

Fig. 2. Disarticulated bivalve and gastropod shells from Tarut Bay, Arabian Gulf. 1, balanoid barnacles encrusted on the external surface of *Vasticardium assimile*, with similar sizes and directions; 2, bivalves encrusted on the internal surface of *Chama reflexa*; 3; balanoid encrusters on the internal surface of the bivalve *Amiantis umbonella*; 4, sepulid worms aggregates on the internal surface of some bivalve shells; 5, Gastropod shell encrusted with balanoid barnacle; 6, dense clusters of serpulid worms; 7, balanoid barnacles encrusting a gastropod shell; 8, the ichnogenus *Entobia* on external surface of *Chama reflexa*; 9, close up of Figure 8 showing the dense rounded and closely spaced to connected chambers; 10, The ichnogenus *Entobia* on the internal surface of *Chlamys (Chlamys) reticulate*; 11, Boring of *Oichnus paraboloides* (external surface of bivalve shell); 12, Internal surface of bivalve shell showing a complete penetration of *Oichnus paraboloides;* 13, *Oichnus simplex* penetrating a gastropod shell; 14, fragmentation caused by bird pickings; 15, loss of surfaces features (growth lines) caused by abrasion; 16, lack of luster on the inner surface of bivalve shell.

The second type of encrusters (38%) is the serpulid worms. They may be present judging from tube morphology, are moderately common on some bivalve shells. They sometimes appear as dense clusters (Fig. 2-6) and in some cases develop as small aggregates on the internal surface of some bivalve shells (Fig. 2-4).

Diverse ontogenic stages of bivalves (*Spondylus* and oysters) are well developed on the internal surface of *Chama reflexa* (Fig. 2-2).

Bioerosion

Biological erosion is an important process in both modern and ancient marine environments (*e.g.* Gibert *et al*., 2007; Fang *et al*., 2013). Because of its shallowness and the high evaporation rates in the hot summer season, the Arabian Gulf is one of the saltiest seas (Bashitialshaaer *et al*., 2011; Dawoud and Al-Mulla, 2012). Fang *et al*. (2013) suggested that bioerosion rates increase under ocean warming. In the present study, borings are present in many specimens ascribed to either predators or endobionts (sponges). The majority of borings were small, rounded and closely spaced to connected chambers (Fig. 2-8 to 2-10). Depth of penetration did not exceed three millimeters and apertures were always less than one millimeter in diameter. These bioerosion traces were identified as *Entobia* Bronn, 1837. It is a product of borings by the siliceous clionid sponges (Bromley and D'Alessandro, 1984). They are strongly developed on external surface of *Chama reflexa* (Fig. 2-8, 2-9) and on the internal surface of *Chlamys (Chlamys) reticulata* (Fig. 2-10).

The second type of bioerosion is represented by small borings, perpendicular to the shell surface, produced by carnivorous gastropods and cephalopods. These bioerosion traces was identified as *Oichnus*, Bromley, 1981 and they were known from the Palaeozoic to Recent. For whole specimens it is recorded the presence of predatory drillholes and identified them as either *Oichnus paraboloides* or *O. simplex*.

Oichnus paraboloides Bromley, 1981 (Figs. 2-11, 2-12) is present with only one complete, finely preserved specimen. The hole is circular, with paraboloid shape, 1.5-2.3 mm in diameter. It was most probably produced by a naticid gastropod. On the other hand, *Oichnus simplex* (Fig. 2-13) consist of smooth, vertical, circular to subcircular holes with axes oriented perpendicular to the host, piercing throughout the shell, diameters range from 2.5-3.1 mm.

The process of predatory bioerosion has been studied in detail for naticid and muricid gastropods (Ziegelmeier, 1954; Carriker, 1981). Muricids typically hunt and drill prey epifaunally, whereas naticids usually drill infaunal prey within the substrate, although exceptions are known (Guerrero and Reyment, 1988; Savazzi and Reyment, 1989; Grey 2001; Dietl, 2003).

Fragmentation

Shell fragments are important components of many Recent and fossil marine benthic ecosystems (Zuschin *et al*., 2003). Shell fragments are very common in modern death assemblages (Tauber, 1942; Hollmann, 1968; Pilkey *et al*., 1969; Yamaguchi, 1977; Vermeij, 1979, 1982; Staff and Powell, 1990; Cadée, 1968, 1994; Zuschin and Hohenegger, 1998). In general, fragmentation is associated with high-energy environments such as beaches and tidal channels (Parsons and Brett, 1991), although Best and Kidwell (2000) observed high levels of fragmentation in all environments, even those with low energy. Fragmentation is potentially derived from a range of both physical and biological processes (Zuschin *et al*., 2003).

Regarding the physical processes, the gulf waters have very slow currents and limited tidal range. Consequently, shell fragmentation of the studied area by this process represents the minimal amount.

On the other hand, shell holes, caused by bird pickings (Fig. 2-14) were observed in many specimens (n=22) of the studied shells. Previously, MacArthur and Wilson (1967) have noted the importance of bird attack in fragmentation processes.

Predators (biological factor) are enhanced fragmentation and should take into account in taphonomic studies and depend mainly on shell strength (Zuschin *et al*. 2003).

Abrasion

Abrasion is another important taphonomic process, being probably associated with shell damages (Kotzian and Simões, 2006). Shell abrasion is often associated with physical transport, but it also can occur when the predator uses its radula and/or shell to abrade the shelled prey (Glaub *et al*., 2007).

In the study shells, abrasion is seen in the loss of surfaces features such as growth lines (Fig. 2-15), by a mottling of the shell surface and a lack of luster on the inner surface (Fig. 2-16). The processes of abrasion often leave shells with a glassy appearance (Driscoll and Weltin, 1973). These features may be due to acidification in the Arabian Gulf (Uddin *et al*., 2012). They stated that the Arabian Gulf waters are becoming increasingly acidic with time. Ocean acidification is an extremely concerning issue primarily because of its effects on marine organisms. A significant consequence of increasing atmospheric CO_2 is the acidification of the world's oceans (Pearson and Palmer, 2000). Ocean acidification is caused by dissolved carbon dioxide, increasing in line with rising concentration of atmospheric CO_2.

CONCLUSIONS

Tarut Bay beach contains molluscan shells that are affected by several taphonomic processes. The specimens are unique in that they comprise encruster and bioeroder traces. Abrasion and fragmentation are also recorded. The shell accumulation is totally dominated by disarticulated valves. Fragmentation is mainly caused by bird predation and no effect of mechanical fragmentation. The natural energy gradient in the study area is not sufficient to cause the mechanical fragmentation of shell material. Encrustation was the predominant in molluscan shells of Tarut Bay, represented by balanoids, polychaete tubes and some ontogenically diverse bivalve shells. Balanoid barnacles represent the most common encrusters, and are probably the most abundant encruster in the terms of area occupied and skeletal biomass. Bioerosion traces in shells are predominately those of clionid sponges and gastropods. The ichnospecies *Entobia* is mostly common on the exterior surfaces of the host (*Spondylus*) and on the interior of a number of *Chlamys* as well. Two types of gastropod drill holes are recognized: *Oichnus simplex* probably produced by muricids, and *O. paraboloides*, probably produced by naticids, based on the morphology of the drill holes. Muricids are well represented in the shell assemblage of the study area.

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