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Biogenic Sedimentary Structures Produced by *Architectonica laevigata* (Gastropod: Architectonicidae), Mandvi Intertidal Zone, Gulf of Kachchh, Western India

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Abstract

Biogenic structures of *Architectonica laevigata* (Gastropod: Architectonicidae) were studied along the lagoon of the Modwa spit area, Mandvi, Gulf of Kachchh. The traces are bilobed in cross-section, forming complex meandering trails, while their burrows are closely packed small holes about 1-2 mm in diameter. The traces are produced during low tides and are concentrated in specific areas within the intertidal zone, and also show substrate preference. These traces and burrows are intimately associated with each other, which reflect their behaviour modification to avoid steep thermal gradients and desiccation stress during low tide conditions in the lagoon and intertidal area. Similar traces are comparable with the ichnogenera *Gyrochorte* and *Scolicia,* which are abundant from Precambrian times to recent. Such traces, if preserved, serve as a good indicator for paleo-environmental conditions.

Key Words: Biogenic structures, Gastropod, Architectonicidae, traces, burrows, Gulf of Kachchh.

Introduction

The intertidal zone is considered to be a "stressed" area (Vermiji, 1978), and those organisms dwelling in this zone are considered to be "stress tolerant species" (s*ensu stricto* Vermeij, 1978). The organisms often undergo intense environmental and physiological stress, leading to behavioural switching (Faulkes, 2005) and behaviour modification. The stress factors include the thermal gradient and desiccation, along with competition. The behaviour of any organism is reflected in the biogenic sedimentary structures produced by them within the sediment or on surface. Biogenic sedimentary structures are the dominant features of modern as well as ancient soft-sediment intertidal environments (Patel and Desai, 2009). In the ancient rock record, morphological patterns preserved in the form of traces, burrows, and borings are good indicators of the behavioural strategy adopted by organisms during changing conditions (Desai, 2003). Biogenic structures made by intertidal gastropods are particularly interesting as they give insights into the behaviour of stress-tolerant species that are adapted to behavioural switching. Some of these structures are rarely preserved as they are made at the sediment-water interface and are commonly destroyed by erosion.

The soft-sediment intertidal zone of the Mandvi area, Western India (Fig. 1) registers varied behavioural activities and their resultant traces produced by the gastropod *Architectonica laevigata* Lamarck, 1816 (Architectonicidae). *A. laevigata* is a common intertidal gastropod of the Gulf of Kachchh (Hornell, 1909; Gopalkrishnan, 1970), having broad and conical shells that vary in size from minute to 50 mm or larger, with a varying umbilicus width. The protoconch of the Architectonicidae grows upside down, with the

umbilicus facing upwards and hence appearing to be coiled sinistrally, although the animal is organized dextrally (Bieler, 1993).

A. Laevigata shows a great variety of behavioural adaptation at the sediment-water interface, which includes substrate-specific locomotion, dwelling and feeding activities (Desai, 2003). Two basic interrelated behavioral activities are studied, namely burrowing and locomotion. Both activities are commonly observed in modern environments and are governed by stress acting in the intertidal zone during tidal fluctuations. Like other intertidal organisms, *A. Laevigata* takes refuge in and makes locomotion excursions into the surficial sediments during low tide.

Area of Investigation

The Mandvi area (Fig. 1a) has a semi-diurnal tide-affected coastline situated at the southernmost tip of the Kachchh Peninsula. The intertidal zone here has a soft substrate with sediments ranging from medium sand to fine silt along with different proportions of clay and mud. Geomorphologically, there is a dominance of ridge-and-runnel systems (RRS) in the area (Patel *et al.,* 2001). The western part of the study area is dominated by RRS, giving way to a tidal flat environment towards the east. It also comprises two small intertidal lagoons, one situated at Rawal Pir and the other at Modwa. The present study was carried out in the Modwa spit lagoon, which is shallow and elongated in nature and connected to the open sea towards the southeast. During low tide, it partially drains, leaving about 50% of the lagoonal area exposed. The remaining 50% of the lagoon area is comprised of thick algal mats. The sediments are fine-grained, with a peat layer 5-7 cm below the sediment-water interface. This zone is also inhabited by other benthic organisms such as crustaceans, polychaetes, bivalves and nemertea along with the abundant gastropod *Architectonica laevigata.*

Observed Habitat of *Architectonica*

Architectonica is found in a soft substrate of fine sand in the aerobic environment, 1-2 mm below the sediment-water interface (Fig.1b). It communicates with the external environment through a pair of highly active siphons by which it performs all vital physiological activities. It extends a siphon from the aperture upward towards the sediment-water interface, which creates a definite pattern on the surface. Miller (1974) suggested that gastropods living in sandy substrates have diverse locomotion modes and possess a long foot, often moving in a discontinuous way with the foot totally or partially buried.

The gastropod communities comprise about 500-600 individuals per m^2 area. The life position of each individual inside the burrow is with its long axis parallel to the bedding and its aperture nearly vertical. It was observed that the animal excavates a tunnel by its slender foot in an oblique manner, thus the opening is located on the surface slightly away from the shell and linked to the former by a tiny inclined tunnel 5-8 mm in length. Field observations during various tides on the Modwa spit suggest that the gastropods do not leave the burrow during high tides, unless they are eroded and relocated elsewhere by stronger tides. However, during receding tides they do come to the surface and move about, thus constructing locomotion traces. Several trails with blunt, burrowed ends were observed in the intertidal zone just after the area became exposed during low tide. These traces were abundant (up to 25 individuals per m^2) and of varied lengths, often crossing each other. However, according to the density of individual gastropods, less than 0.05% actually produces traces. The production of traces thus seems to be the exception rather than the rule.

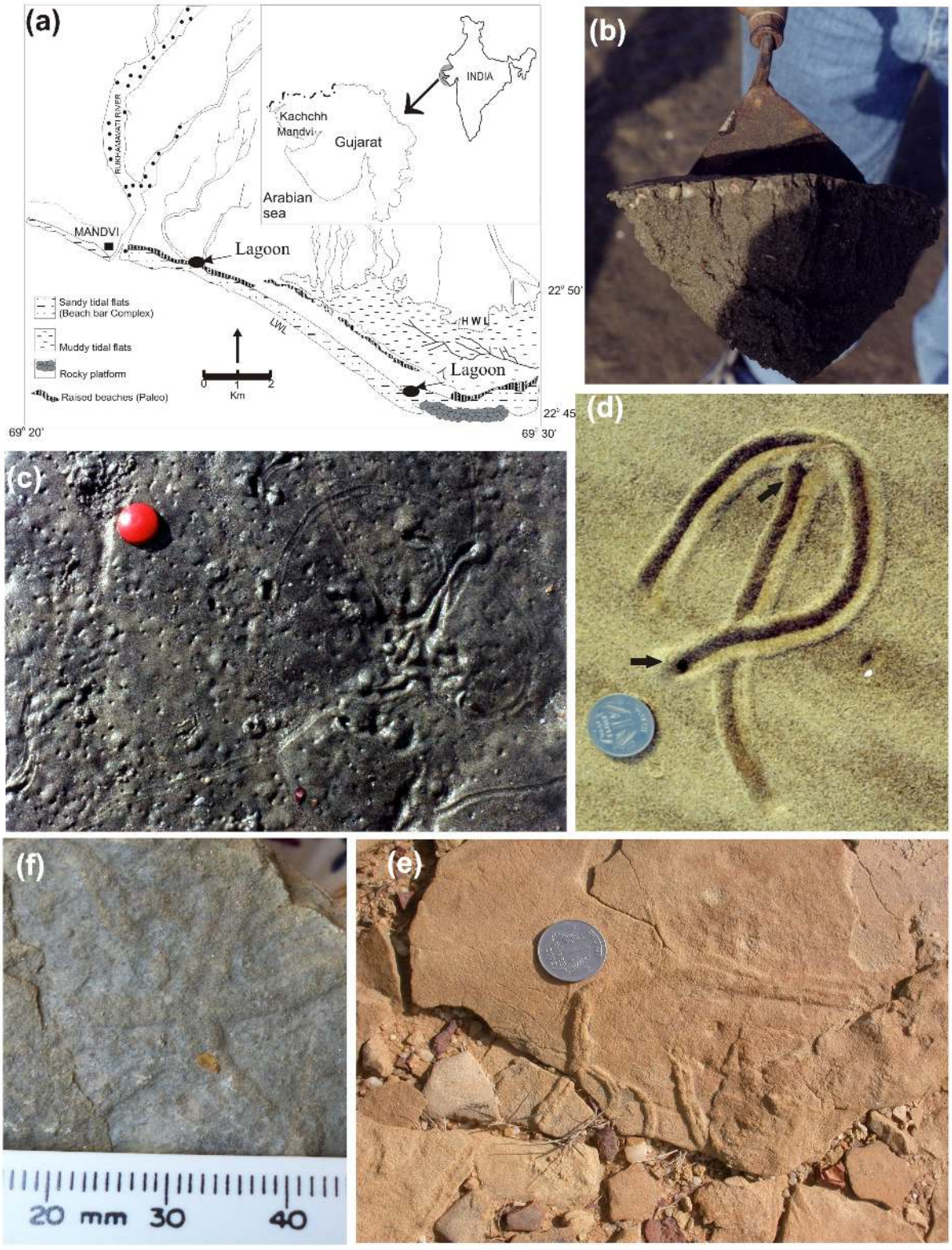
(a)
INDIA
Kachchh
Mandvi
Gujarat
Arabian sea
RUKMAVATI RIVER
MANDVI
Lagoon
Sandy tidal flats (Beach bar Complex)
Muddy tidal flats
Rocky platform
Raised beaches (Paleo)
0 1 2 Km
HWL
LWL
Lagoon
22° 50'
22° 45'
69° 20'
69° 30'
(b)
(c)
(d)
(f)
20 mm 30 40
(e)

Fig. 1: (a) Location map of the Mandvi intertidal zone; (b) *Architectonica laevigata* in life position; (c) Burrows of *A. Laevigata.* Red cap is 15 mm in diameter; (d) V-shaped locomotion trace of gastropod during low tide. Arrow indicates raised rim of temporary burrows. Coin is 24 mm in diameter; (e) Trace fossil Gyrochorte from the Jurassic (Jhuran Formation) of the Jara Dome in Kachchh. Coin is 24 mm in diameter; (f) trace fossil, cf *Archaeonassa*- a bilobed trace from the early Cambrian Nigalidhar section of Himalayas.

Morphology of Trails and Burrows

Trails:

These gastropods produce generally smooth, bilobed trails (Fig. 1d), with a prominent V-shaped morphology in cross-section. As they move about on the sediment-water interface, loose sediments along the lateral margins of the trail collapse outward after their passage. The resultant morphology of the trails is shallow (<1 cm), narrow and bilobed without any transverse ridges. They show rims of about 3-4 mm thick, with a total width of about 16-18 mm, the latter remaining constant throughout the trail. The trails show a low order of meandering and are often found criss-crossing each other. The end of each trail is marked with a semi-circular, rimmed depression. The substrate preferred for locomotion is slightly firm, medium-grained sediments. The depressions in the end of the trail are morphologically different from the burrows. These depressions may or may not be connected to the actual burrows. The orientation also differs significantly. In case of depression, the axis of orientation is coinsides with the trail and is at very small angle with respect to substrate.

Burrows:

Cylindrical, unlined burrows, with circular cross section, showing surficial expression as closely packed small holes of about 1-2 mm diameter are often seen all along the lagoon of the Modwa spit area (Fig. 1c). Each hole is associated with a near-vertical, cylindrically shaped, straight burrow of nearly 1-3 mm in length. The end of the burrow coincides with the aperture of the shell of *Architectonica laevigata*.

Locally, the gastropods also make temporary inclined burrows close to the surface at the end of the trail, as discussed earlier. The surficial expression of the burrows is in the form of elevated semicircular mounds about 1-2 mm high. The substrate preferred for burrowing is loose, fine-grained sediments.

Discussions

The present study describes modern *Architectonica laevigata* traces formed in a lagoon/intertidal setup. From a paleo-ecological point of view, the narrow, V-shaped meandering trail, if preserved, would be classified as *Repichnia* (locomotion traces). However, if the burrows were to be preserved, it would resemble small *Skolithos*.

The surfacial trace made by *Architectonica laevigata* in the lagoon of the Mandvi area, if preserved in the rock record, may be identical to the ichnogenera *Gyrochorte* or *Archaeonassa* (Fig. 1e, f). *Gyrochorte* is a common and abundant trace fossil of Mesozoic deposits in Kachchh (Patel *et al.,* 2008). These traces, which show a low order of meandering and cross-over structures, are frequently observed in the Jurassic Jara Dome

(Desai *et al.,* 2008) and can also be interpreted to have formed in an intertidal environment. Similarly the ichnogenus *Psammichnites*, a gastropod locomotion trace, is significant in Precambrian deposits of the Himalayas (Tal Group, Mussoorie area). *Psammichnites*, a Palaeozoic trace is also similar to the present form, but is interpreted to be constructed by hydraulically operated push-and-pull action of Gastropod (Seilacher, 2007). Fenton and Fenton (1937) also described similar bilobed trails, Ichnogenus *Archaeonassa* and their associated burrows from the recent sand and compared them with Cambrian occurrences of similar forms from British Columbia. Badve and Bhonsle (1987) studied similar burrowing habits of *Umbonium* in intertidal zones. However, in the case of *Umbonium* the burrows are inclined, whereas *Architectonica* burrows are nearly vertical.

Several studies have shown that the locomotion of intertidal dwelling gastropods is related to rhythmic tidal fluctuations, whereby these gastropods are adapted to rhythmic zonal migration synchronised with the tides (Naylor, 1987; Chelazzi *et al.,* 1987).

Architectonica is considered to be among the fastest burrowing gastropods, although its shell morphology does not reveal any burrowing behaviour (Savazzi, 1994). Two distinct types of activites were studied here, namely burrowing and locomotion. In the former activity, the nature of the burrows is in the form of short siphon tubes, suggesting that the gastropod is a suspension feeder. The close association of these gastropods suggests that they are non-aggressive and non-competitive, but still opportunistic.

Studies have suggested that in intertidal areas with extensive tidal oscillations, organisms are active during one phase and inactive during the other phase of tidal activity (Naylor, 1987). In the present study, burrowing/feeding activity is interpreted to be related to high tide, thus enabling the gastropods to suspension feed. During low tide the intense thermal gradient and desiccation might instigate the gastropods to undertake excursions, during which meandering locomotion traces are produced. The burrow at the end of the trace is interpreted to be a temporary resting burrow made in order to avoid the thermal gradient.

Conclusions

Architectonica, the fastest burrowing gastropod, inhabits intertidal stress zones. Their activities are governed by tidal fluctuations.

1) During high tides, burrows are stabilized and the animal does not come out of its burrow, being a suspension feeder.
2) The dense burrow systems indicate non-aggressive, non-competitive behaviour.
3) During low tides, the gastropods leave the burrow and undertake short random excursions.
4) Due to extreme exposure and to avoid desiccation, they make inclined temporary shelters at the end of the traces, which have raised rims.

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