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Features of Intertidal Bioerosion and Bioconstruction on Limestone Coasts of Langkawi Islands, Malaysia

(Ciri Antara Pasang Surut Biohakisan dan Biopembinaan di Pantai Batu Kapur, Pulau Langkawi, Malaysia)

MIKLÓS KÁZMÉR*, MOHD SHAFEEA LEMAN, KAMAL ROSLAN MOHAMED, CHE AZIZ ALI & DANKO TABOROŠI

ABSTRACT

The purpose of this paper was to provide a practical guide assisting field workers in identification and interpretation of frequently occurring bioerosional textures created in limestone by intertidal organisms along the coasts of Langkawi Islands, Malaysia. The discussion follows the textural succession from the supratidal down to the lower intertidal zone. Traces left by lichens, boring sponges, molluscs (littorinid snails, the chiton Acanthopleura*, the bivalve* Lithophaga*) and the echinoid* Echinometra *are illustrated. Products of bioconstructing organisms, specifically oysters and barnacle are also described. Ecological tolerance of each group is given.*

Keywords: Barnacle; bioconstruction; bioerosion; echinoid; Holocene; intertidal; mollusc; Langkawi; Malaysia

ABSTRAK

Tujuan penulisan ini adalah untuk menyediakan panduan praktikal untuk membantu pekerja lapangan dalam pengenalan dan tafsiran tentang kekerapan berlakunya kejadian biohakisan tekstur dalam batu kapur oleh organisma pasang surut di sepanjang Pantai Pulau Langkawi, Malaysia. Perbincangan ini mengikut tekstur turutan daripada suprapasang surut sehingga ke zon rendah pasang surut. Jejak yang ditinggalkan oleh liken, span gerek, moluska (siput litorinid, chiton Acanthopleura*, bivalve* Lithophaga*) dan ekinoid* Echinometra *ditunjukkan. Produk organisma biopembinaan, khususnya tiram dan teritip, juga dinyatakan. Toleransi ekologi untuk setiap kumpulan turut diberikan.*

Kata kunci: Biohakisan; biopembinaan; ekinoid; Holesen; Langkawi; Malaysia; moluska; pasang surut; teritip

INTRODUCTION

Rocky limestone coasts are widespread in tropical and temperate regions and exhibit a range of idiosyncratic morphologies. Marine notches are particularly well developed in limestone coasts and are widely used to understand relative sea level change (Moses 2013; Pirazzoli 1996). Bioerosion is a major factor in the production of these notches (Kelletat 2005).

A seminal paper on marine notches of Langkawi was written by Hodgkin (1970), which inspired subsequent research and is still frequently cited today. He cursorily described bioerosion features and attributed them to a zonal system.

Here we provide a selection of examples of bioerosion observed at meso-scale along the limestone coasts of Langkawi Islands, Malaysia. The purpose of this paper was to provide a practical guide assisting field workers in identification and interpretation of bioerosional textures created in limestone substrates by various intertidal benthic organisms.

The following discussion describes the field occurrence of bioerosion agents and the erosion features they produce, as observed between the supratidal and the lower intertidal zone. This paper aimed to provide geologists and geomorphologists with an easy-to-use field manual that could assist them in identification of the most frequent bioerosional features. To the best of our knowledge, this will be the first systematic report on bioerosional traces in Langkawi. It is part of a joint research project dedicated to identification of Holocene coastal uplift and subsidence in the Langkawi Islands by using marine bioerosional features.

REGIONAL GEOLOGICAL SETTING

Langkawi archipelago is made up of 99 islands located 25 km off the western shore of northern Peninsular Malaysia (Figure 1). The geology of this archipelago is made up of four sedimentary rock formations namely the Machinchang, Setul, Singa and Chuping formations, spanning from Early Cambrian to Middle Permian age and Late Triassic granitic intrusives (Jones 1981; Lee 2009; Mohd Shafeea et al. 2007).

The Ordovician-Early Devonian Setul and Permian Chuping formations are both made of crystalline limestone. The Setul Formation covers most of the eastern coast of Langkawi's main island, Pulau Tuba and the eastern part of Pulau Dayang Bunting. The Chuping Formation dominates the western part of Pulau Dayang Bunting and many small islands within the Kuah Strait. Details on geology of the Setul Formation have been described by Jones (1981) and Che Aziz Ali et al. (2003) while details on geology of the Chuping Formation can be obtained from Jones (1981) and Mohd Shafeea (2003).

As a result of prolonged preferential weathering on these limestone formations, the eastern part of Langkawi archipelago shows typical island karst topography, consisting of dissected ridges and isolated hills and islands with steep to nearly vertical slope (Mohd Shafeea et al. 2007). Much of the shoreline is often delimited by cliffs and these often have notches at water level (Hodgkin 1970).

METHODS

Geomorphological observations were made by the naked eye, helped by a hand magnifier and a water-resistant digital camera. Observations were recorded in a water-resistant field notebook. Locations of field observation were recorded by a Garmin GPS unit. These are listed in Table 1 and mapped in Figure 1.

RESULTS

BIOERODERS

Bioerosion is the destruction and removal of lithic substrate by direct biological action (Neumann 1966). The most common bioerosional agents are microbial organisms and macrobioeroders.

Several microorganisms, mostly cyanobacteria, but also bacteria, algae and marine fungi are known to attack limestone substrates and produce identifiable scars (Glaub et al. 2007). Various traces created by microbes are on microscopic scale thus beyond the scope of this paper. At any rate, microscopic bioerosional features can only be noted in places where they are not immediately overprinted by eroding activities of larger organisms. In tropical regions, microbial effects on coastal rocks are most evident in the form of ubiquitous 'phytokarst' - highly irregular and extraordinarily jagged type of karren that develops in eogenetic limestones attacked by boring cyanobacteria (Jones 1989; Taboroši & Kázmér 2013).

Rock-boring microorganisms are food to a variety of larger grazing organisms such as littorinid snails, limpets,

TABLE 1. Geographical coordinates of locations in Langkawi Islands, Malaysia

Figure	Island	bedrock	Latitude	Longitude
2	Pulau Langgun	O	N 06° 26' 42.7"	E 99° 53' 01.4"
3	Pulau Langgun	O	N 06° 26' 42.7"	E 99° 53' 01.4"
4	Pulau Dayang Bunting	P	N 06° 14' 04.4"	E 99° 47' 00.0"
5	Pulau Langgun	O	N 06° 26' 42.7"	E 99° 53' 01.4"
6	Pulau Langgun	O	N 06° 26' 42.7"	E 99° 53' 01.4"
9	Pulau Langgun	O	N 06° 26' 42.7"	E 99° 53' 01.4"
10	Pulau Dayang Bunting	P	N 06° 26' 42.7"	E 99° 53' 01.4"
11	Pulau Dayang Bunting	P	N 06° 26' 42.7"	E 99° 53' 01.4"
12	Pulau Jerkom Besar	P	N 06° 15' 25.9"	E 99° 46' 20.1"
13	Pulau Bumbon Kecil	O	N 06° 17' 49.7"	E 99° 51' 35.6"
14	Pulau Jerkom Besar	P	N 06° 15' 25.9"	E 99° 46' 20.1"
15	Kuala Kilim	O	N 06° 25' 38.4"	E 99° 52' 15.3"
16	Pulau Jerkom Besar	P	N 06° 15' 25.9"	E 99° 46' 20.1"
17	Pulau Jerkom Besar	P	N 06° 15' 25.9"	E 99° 46' 20.1"
18	Kuala Kilim	O	N 06° 25' 36.8"	E 99° 52' 14.7"

O – Ordovician-Early Devonian Setul Limestone
P – Middle Permian Chuping Formation (grey crystalline limestone and saccharoidal marble)

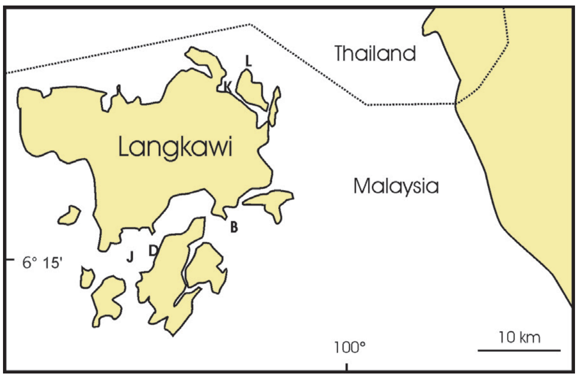

FIGURE 1. Locations of photographed sites at Langkawi Islands. **B** – Bumbon Kecil, **D** – Dayang Bunting, **J** – Jerkom Besar, **K** – Kilim mouth, **L** – Langgun (see Table 1)

chitons and echinoids (Bromley 1992). These wear down the rock surface while grazing on these epilithic organisms (Fórnos et al. 2006). Various molluscs (chitons and limpets especially) bear mineralized teeth on their radulae and echinoids on their jaws; their grazing of the microbial biofilm removes a thin layer of the rock, ultimately leading to erosional forms typical of each group.

Boring organisms (mostly bivalves) apply a combination of chemical and physical methods to create a cavity in a rock and do so mostly for protection from predators. They create boreholes that completely and permanently houses the occupant.

LICHENS

Lichens - a symbiotic association of algae and fungi-live only in the supratidal zone. While excreting oxalic and other acids at the rock surface (Adamo & Violante 2000; Chen et al. 2000), they etch tiny, shallow holes. When alive, salt-tolerant lichens act bioprotectively; after death, features of bioerosion become visible (Carter & Viles 2005) (Figures 2 & 3).

SPRAY

All rock surfaces within the intertidal and supratidal zone are affected by sea spray (Figures 4 & 5). It appears that sea spray can produce a variety of dissolution features, which can overprint traces of bioerosion. Although morphologies created by sea spray are not bioerosional features *per se*, we mention them here because they are often encountered by field workers and may develop in conjuction with microbial activity. It is important to recognize them and avoid confusion with bioerosional features produced by macroinvertebrates.

Wave splash and sea spray produces pools in pits and indentations in coastal rocks. These pools experience highly variable water chemistries due to evaporation and addition of wave splash and rainwater in different proportions, as well as drastic changes in temperatures due to solar heating and

FIGURE 2. Lichens (white spots) in the supratidal zone. Coin is 24 mm in diamater. Pulau Langgun

FIGURE 3. Frequent holes of millimetre diameter etched by lichens in the supratidal zone. Scale in inches and centimetres. Pulau Langgun

FIGURE 4. Intricate karren, a dissolution feature in the wave spray zone, above high tide level. Pulau Dayang Bunting. Scale in inches and centimetres

FIGURE 5. Dissolution features in the spray zone (cockled surface of Moses, 2003). Scale in inches and centimetres. Pulau Langgun

cooling by seawater. That may lead to significant corrosion (Moses 2003; Taboroši & Kázmér 2013). Furthermore, cyanobacteria, other microbes and fungi tend to be the only organisms adapted to life in these chemically and thermally extreme environments and their bioerosional activity contributes to the overall geomorphic shaping.

LITTORINID SNAILS

Littorinid snails (Figure 6) and similar gastropods inhabit rocky shorelines and specialize in scraping biofilms and turf algae off exposed surfaces. Some of them appear to be capable of scratching the rock with their radulas and consuming endolithic organisms as well. Though they do not leave bioerosional traces visible to the naked eye, they do contribute to the overall bioerosional process and lowering of the bedrock surface (Taboroši & Kázmér 2013).

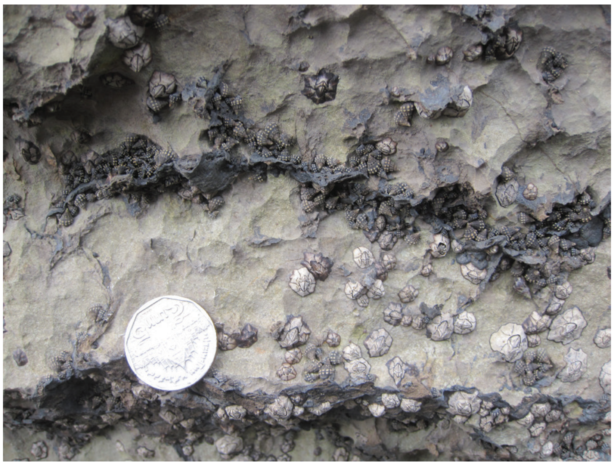

FIGURE 6. Littorinid snails grouping and hiding on highly eroded lower supratidal rock. *Chthamalus* barnacles are attached to rock surface. Coin is 24 mm in diameter. Pulau Langgun

Littorinid snails are tolerant to desiccation and wide variations of salinity and are also able to take up oxygen from both water and air (Henry et al. 1993). Having these capabilities they are eminently adapted to live in the uppermost intertidal and especially in the lower supratidal zone. Their distribution partly overlaps with the upper zone of limpets.

LIMPETS

Limpets (Figures 7 & 8) are gastropods with a conical, uncoiled shell and a broad foot. They are known for the way they tightly cling to rock and are ubiquitous in intertidal and lower supratidal zones. Their distribution partly overlaps with the lower zone of littorinid snails. They possess radula with silica-containing teeth used to scrape algae off and from within rock substrate. Limpet activity on rock surfaces produces rasping marks and homing scars that often correspond exactly to the size and shape of an individual's shell. Limpets tend to dominate various intertidal environments, especially in the upper intertidal zone (Andrews & Williams 2000). Sea spray allows them to occupy the lowermost supratidal as well.

FIGURE 7. Limpets hiding in shadow and underwater during low tide. Food is provided by green biofilm covering the eroded surface of Pleistocene limestone for these grazing molluscs. Saurashtra Peninsula, Diu, India

FIGURE 8. Limpets grazing on biofilm covering the eroded surface of Pleistocene limestone. Note irregular pitting and furrows produced by these grazing animals. Saurashtra Peninsula, Diu, India

While frequently observed in various tropical and temperate coasts (Kázmér & Taboroši 2012), we did not observe these animals in the few locations visited in Langkawi during a week-long visit in June 2013. Neither did Hodgkin (1970) mention any. Whether human food gathering or a natural factor caused their absence, is not clear. Probably this is temporary and populations will be restored. However, they are most probably there in Langkawi and locally contribute to bioerosion. Images are added taken in another location to facilitate identification.

CHITON

Chitons (Figures 9 & 10) are some of the most obvious bioeroders of the intertidal zone; their eight-plated shell and a colourful margin of soft tissue make them conspicuous in many sites. They are armed with a radula of extremely hard magnetite-capped teeth that allow them to easily remove layers of calcium carbonate and other substrates while grazing on biofilms (Rasmussen & Frankenberg 1990). Their rasp marks are usually meandering or straight sets of parallel grooves engraved into substrate (Figure 9). They also produce pronounced homing scars – larger pits that accommodate an individual animal's body size and represent its long term residence (Figure 10).

Chitons tend to concentrate in the middle and upper intertidal, making excursions both slightly above and below (Donn & Boardman 1988; Harper & Williams 2001).

FIGURE 9. Chiton grazing traces. Green epilithic algae have been rasped by the radula together with the uppermost layer of rock inhabited by endolithic algae. Scale in millimetres. Pulau Langgun

FIGURE 10. Chiton (Acanthopleura sp.) hiding in a cavity during low tide. This mollusc is probably a major bioeroder in the Langkawi Islands. Lithophaga borehole in upper left corner. Pulau Dayang Bunting. Pen is 1 cm in diameter

LITHOPHAGA

Boring bivalves are powerful bioeroders. They are sessile organisms that physically and chemically bore into rocks as means of protection from predators. They enlarge bored voids as they grow and gradually reduce the overall volume of host rock from within.

Best known rock-boring bivalves belong to *Lithophaga* (Figures 11 & 12) and related genera, which create deep club-shaped cavities that accommodate the shell and increase in diameter as the organism grows. The boreholes

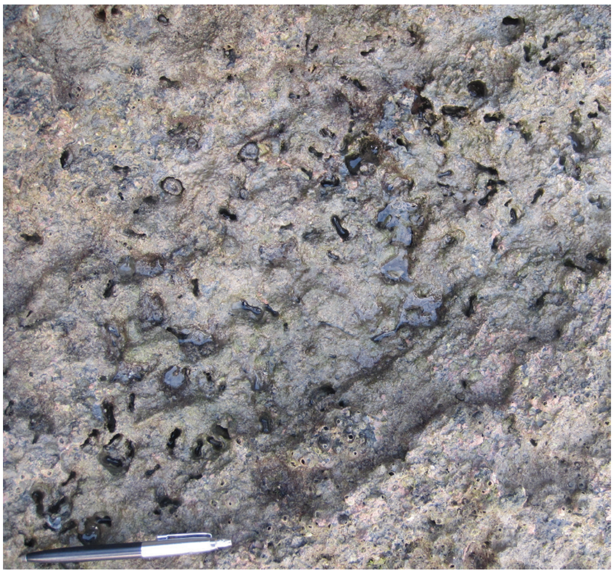

FIGURE 11. Living *Lithophaga* boring bivalves. The animals are hidden in their bored and etched cavities within the rock. Soft parts are visible through dumbbell-shaped openings corresponding to the animal's double siphon morphology. Lower intertidal. Pen is 13 cm long. Pulau Dayang Bunting

FIGURE 12. Eroded *Lithophaga* boreholes. Oval outline: cross-section close to aperture. Rounded outlines: cross-section distal to aperture. The eroded borings are ca 1.5 cm in diameter. Pulau Jerkom Besar

have dumbbell-shaped openings at the rock surface, the shape corresponding to the organism's inhalant and exhalant siphons. Once the top layers of the rock have been eroded, the original dumbbell form is lost and the borehole assumes a more circular shape. With further erosion, only the deepest ends of boreholes become visible as semi-globular pits before they are completely destroyed.

Rock-boring bivalves are restricted to shallow marine environments, found intertidally and subtidally down to about 10 m (Bromley & Asgaard 1993).

ECHINOIDS

Echinoids (Figure 13) feed on algae and are capable of rasping bedrock with their rapidly growing calcite teeth, rooted in the five jaws of their chewing organ, known as Aristotle's lantern. Some genera, particularly *Echinometra*, are especially effective bioeroders. In addition to rasping the rock surfaces as part of the grazing process, they excavate individual hiding holes during their lifetime. Rock-boring echinoderms are known to live subtidally. The upper limit of their distribution is controlled by desiccation. They can also live in the lower intertidal zone beneath ledges or in tidal pools, where permanent water cover is ensured (Asgaard & Bromley 2008).

FIGURE 13. Heavily eroded, circular to oval boreholes of the echinoid *Echinometra*. Diameters ca. 5-6 cm. Pulau Bumbon Kecil

SPONGES

Certain sponges, notably *Cliona* spp. (Figure 14) are known to penetrate calcareous substrates (rock and shells) and produce interconnected networks of voids, whose overall morphology is reminiscent of the sponge's own anatomy (Ekdale et al. 1984). Both mechanical and chemical methods are applied in excavating the cavities (Zundelevich et al. 2007). While the sponge is alive, brightly colored sponge tissue can be seen emerging from the openings in the rock surface or is observed thoroughly covering the rock surface (and concealing the openings). After the death of the sponge colony, numerous small apertures become visible in the rock surface. Following erosion of the surface layer, a complex internal network becomes exposed. Boring sponges live in the subtidal zone, as they cannot tolerate any desiccation.

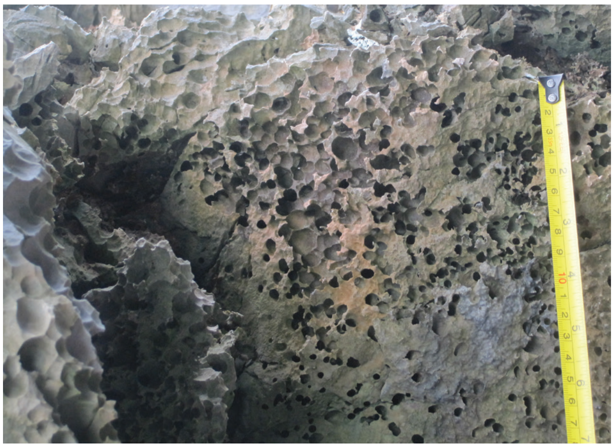

FIGURE 14. Cavity network, etched and excavated by a boring sponge. Small-diameter boreholes are the typical surface expression of endolithic activity by a boring sponge. Surface erosion exposed the interior chambers that hosted the bulk of the animal's body. Scale in inches and centimetres. Pulau Jerkom Besar

BIOCONSTRUCTORS

Bioconstruction is the production of sedimentary structures by living organisms (Naylor et al. 2002; Spencer & Viles 2002). Coral and algal reefs are among the best known bioconstructions, but there are many other organisms that create biosedimentary structures, particularly in the intertidal zone. We mention here two examples of solitary skeleton-building and encrusting organisms; oysters and barnacles. Both seem to be particularly abundant along the shores of Langkawi Island.

OYSTERS

Oysters (Figures 15 & 16), capable of cementing themselves to hard substrates, can form wave-resistant crusts of considerable thickness. They can be dominant in the middle part of the intertidal zone, forming a crust 0.5-1.0 m in vertical extent. Distribution is delimited upwards by their (in) tolerance to desiccation and downwards by the presence of seastars that predate on newly settled juveniles (Shumway 1996). Oysters can form a horizontal ledge (*corniche* of Pirazzoli 1996: 44), up to 1 m wide (Taboroši & Kázmér 2013, Figure 2.9h).

BARNACLES

The common name 'barnacle' (Figures 6, 17 & 18) hides a very rich taxonomical diversity. Many barnacles live in the upper intertidal zone and in the surf-sprayed lower supratidal zone. *Balanus* is considered a good sea-level indicator, living above mean sea level, but extending

FIGURE 15. Living oyster encrusting a small ridge of rock. Kuala Kilim. Coin is 28 mm in diameter

FIGURE 18. Living barnacles (*Tetraclita* sp.) in the lower intertidal. Kuala Kilim. Scale in inches

FIGURE 16. Intertidal oyster ledges. Living oysters on surface, dead shells below. Vertical extent of the protruding ledge is about 0.5 m, horizontal extent 0.7 m. Seastack north of Pulau Jerkom Besar

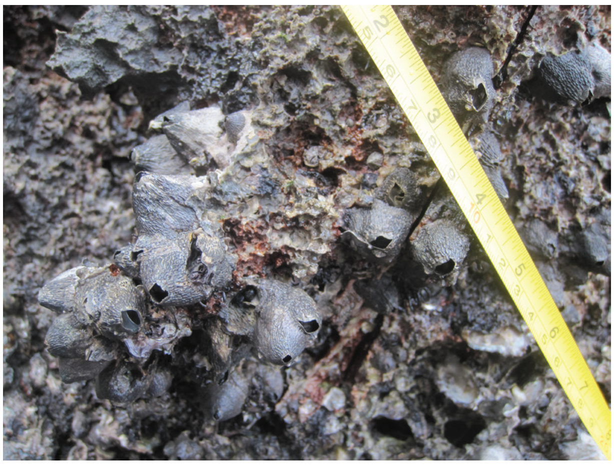

FIGURE 17. Living barnacles (*Tetraclita* sp.) in the lower intertidal. Scale in inches. Pulau Jerkom Besar

upwards into the supratidal zone dependent on wave action. *Chthamalus* (Figure 6) is a poor indicator: it is difficult to establish a good zone (Laborel & Laborel-Deguen 1994). *Tetraclita*'s zonal habits are unknown as yet.

Barnacles tend to settle in close proximity to each other, forming dense communities. Overgrowth of each other is possible. Their conical form and long-lasting calcite shell enables preservation even on rocky surfaces exposed to strong wave action. Although barnacle crusts are not particularly thick, they constitute an easily identifiable bioconstructional feature.

CONCLUSION

Bioeroding and bioconstructing organisms are common, although frequently overlooked features of the coastal zone. The appearance of their markings in rocks (or lack thereof) depends on the environmental needs and sensitivity of the particular organism, as well as interaction with other organisms and competition for food and space. This paper is intended to facilitate their recognition, based on both the organism and its traces.

Bioerosion is a collective process, in which many organisms destroy rocks by different means, in different ways and for various reasons. In the intertidal zone, where bioerosion seem to be the most effective, the traces of various organisms concur, modify and overprint each other (Taboroši & Kázmér 2013).

The intricate relationship among the microbial film on rock surfaces, bioerosion and bioconstruction and their environmental relationship have been discussed in a multitude of papers (for a thorough review see Spencer & Viles 2002). For the purpose of understanding intertidal geomorphological processes, especially marine notch formation, the zonation of marine bioeroders and bioconstructors relative to sea level is important. As this zonation is displayed by different organisms at different places, it is of utmost importance to identify the organisms and the traces they are responsible for.

SUMMARY

Intertidal bioeroding and bioconstructing activity and associated physical processes are widespread along the coasts of Langkawi Islands, Malaysia. Lichens, littorinid snails, limpets, chitons, boring bivalves, boring echinoids and boring sponges (in this order between the supratidal and the lower intertidal zone) act on the limestone bedrocks, leaving permanent marks recognizable for long time after the disappearance of the original organisms that created them.

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Miklós Kázmér
Department of Palaeontology, Eötvös University
Pázmány sétány 1/c, H-1117 Budapest
Hungary

Mohd Shafeea Leman & Kamal Roslan Mohamed
Geology Program, Faculty of Science and Technology
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor Darul Ehsan
Malaysia

Che Aziz Ali
Institute for Environment and Development (LESTARI)
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor Darul Ehsan
Malaysia

Danko Taboroši
Island Research & Education Initiative
Pohnpei, FM 96491
Federated States of Micronesia

*Corresponding author; email: mkazmer@gmail.com

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