

A deep sea community at the Kebrit brine pool in the Red Sea

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Abstract Approximately 25 deep sea brine pools occur along the mid axis of the Red Sea. These hypersaline, anoxic, and acidic environments have previously been reported to host diverse microbial communities. We visited the Kebrit brine pool in April 2013 and found macrofauna present just above the brine–seawater interface (~1465 m). In particular, inactive sulfur chimneys had associated epifauna of sea anemones, sabellid type polychaetes, and hydroids, and infauna consisting of capitellid polychaetes, gastropods of the genus *Laevipithus* (fam. Elachisinidae), and top snails of the family Cocculinidae. The deep Red Sea generally is regarded as extremely poor in benthos. We hypothesize that the periphery along the Kebrit holds increased biomass and biodiversity that are sustained by prokaryotes associated with the brine pool or co-occurring seeps.

Keywords DHAB · Inactive chimneys · Benthic fauna · Cnidarians · Molluscs · Polychaetes

Introduction

The Red Sea is a young ocean located on an extrusion zone where the African and Arabian tectonic plates pull apart, a process that started only 40 million years ago (Braile et al. 2006;

Coleman 1993). Along the mid axis of the Red Sea some 25 deep, sea brine pools occur (Bäcker and Schoell 1972; Degens and Ross 1969; Swallow and Crease 1965). These are topographic depressions consisting of hypersaline with acidic and anoxic water. There is also generally increased temperature compared to the seawater above. On the bottom of the brine pools lay metalliferous sediments (typically several meters thick) of potential high economic value (Anschutz et al. 1999; Hartmann et al. 1998). At the brine–seawater interfaces, the physical and chemical properties change rapidly over a few meters. How steep these interfaces are, and whether they are gradual or more stepwise differ among and, hence, typify the individual brine pools (Antunes et al. 2011).

Methanotrophic (methane oxidising), thiotrophic (sulfur oxidising), and carbon dioxide reducing prokaryotes are found in the brine pools and their interfaces (Antunes et al. 2011). The density gradients at the brine–seawater interface also act as particle traps for inorganic and organic material coming from above (Hartmann et al. 1998; Henneke and De Lange 1990; LaRock et al. 1979) that further fuel microbial production (Eder et al. 2002; Ryan et al. 1969; Scholten et al. 2000). RNA/DNA sequencing efforts from Eastern Mediterranean deep hypersaline anoxic basins (DHABs) also indicate the presence of specialized single celled eukaryotes in the brine pool water, especially fungi, ciliates, and stramenopiles (e.g., Edgcomb et al. 2009; Stock et al. 2012). Metazoans seem to be absent from the brine pool itself, though Danovaro et al. (2010) reported evidence of a metazoan that can complete its life cycle in a Mediterranean brine basin.

Deep sea brine pools are a special form of cold seeps (defined as an area of the ocean floor where hydrocarbon-rich fluid seepage occurs) and cold seeps are found worldwide in areas with tectonic activity. Cold seeps often have associated macrofauna along the rim where the dominating species tend to be bivalves belonging to the families Vesicomidae or Mytilidae, vestimentiferan tube worms, frenulates (Siboglinidae), and Cladorhizidae

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and Hymedesmiidae sponges (e.g., Cordes et al. 2007; Levin et al. 2003; Sibuet and Olu 1998). Many of these species are harbouring thiotrophic, methanotropic, or methylotrophic symbiotic bacteria (Dubilier et al. 2008; Duperron 2010; Fisher 1990) and are possibly relying on symbiont chemotrophy for their carbon nutrition. Batang et al. (2012) reported the presence of one shallow (10 m at 840–850 m depths) brine pool at the continental margin of the Red Sea, the Thuwal seep 20 km offshore the Saudi coastline, with associated macrofauna along its rim. However, except for the observations of Oliver et al. (in press) of one species of a bivalve occurring around the Valdivia brine pool, no such fauna is yet documented from any of the other mid axial deep sea brine pools in the Red Sea. We visited the Kebrit brine pool in April 2013 and report here on the presence of macrofauna both associated with inactive chimneys and occurring solitary along the rim just above the brine-seawater interface.

Material and methods

Study site

The Kebrit brine pool (24° 43' 21" N, 36° 16' 37" E, Fig. 1) was visited 15–19 April 2013 during Leg 4 of the 2013 King Abdullah University of Science and Technology (KAUST) Red Sea Expedition. The 1 by 2.5 km Kebrit Deep basin is one of the smallest mid axial brine pools in the Red Sea. Its maximum depth is 1549 m (Pautot et al. 1984; Scholten et al. 2000), and it is filled by an 84 m deep layer of brine holding large amounts of H₂S (125–374 μM; Hartmann et al. 1998), high CO₂ concentrations, small amounts of N₂, methane, and ethane (Bäcker and Schoell 1972; Faber et al. 1998). It is the high concentration of H₂S that has given it its name (*Kebrit* is the Arabic word for sulfur).

The brine seawater interface (around 1465 m) presents a steep gradient where our measurements (using a high range conductivity, temperature, and density (CTD) device) showed that salinity increased from 40.6 to 242, pH drops from 8.00 to 5.17, oxygen levels decreased to zero, and the temperature rose from 21.7 to 23.4 °C (Table 1). This is consistent with what previously has been reported (Bäcker and Schoell 1972; Eder et al. 1999; Hartmann et al. 1998).

Blum and Puchelt (1991) reported on the occurrence of porous massive sulfide fragments, some in the shape of smokers 1–1.5 m in height and 15–20 cm in diameter at Kebrit. They analysed some of these chimneys for chemical composition, but did not report anything on associated fauna.

Underwater observations and sampling

Underwater observations were conducted using the ROV Max Rover (DSSI, USA) system as described in Batang

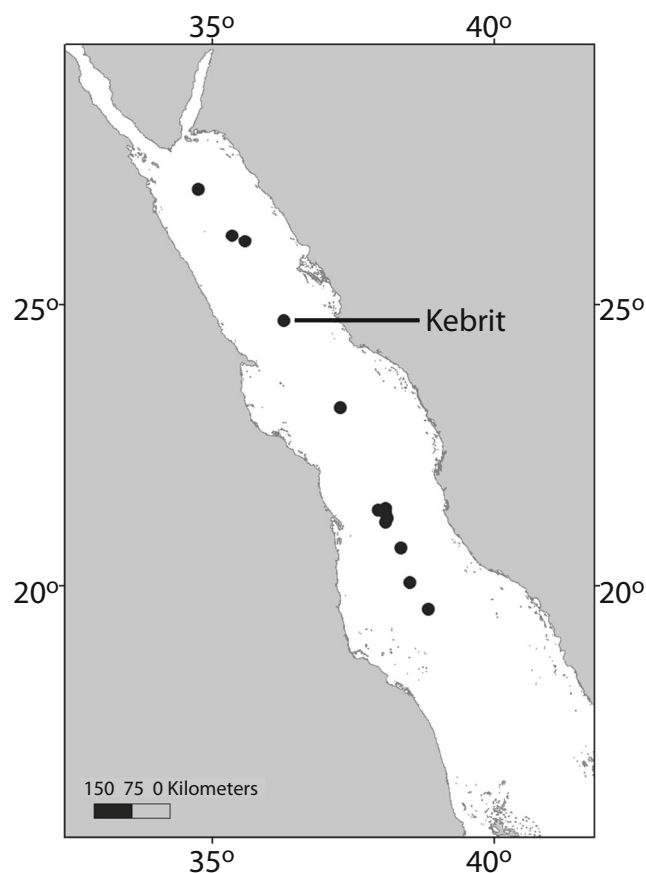


Fig. 1 Location of the Kebrit brine pool in the Red Sea

et al. (2012). Video records were made using the SEA MAX Wide Angle & Zoom Color TV universal underwater video camera recording while cruising along the rim of the brine. The ROV was navigated based on the display compass, the depth meter, and sonar with the Tracklink ultrashort baseline transponder system (Linkquest, USA). Two High-Definition Ocean ProHD Undersea cameras (1080×1920 image resolution, 30 frames per second) with pan and tilt (with wide angle and zoom features) were also used at sites of interest. Samples were collected using the ROV's robotic arm fitted with a fabric bag. The samples were then transferred to the surface in the bag and immediately inspected by eye before they were brought back to the laboratory for further analysis; frozen at –20 °C, preserved in ethanol or kept in filtered (GF/F, retaining particles down to 0.7 μm) sea water.

Collected fauna were tentatively identified under a microscope or dissecting microscope. Electron micrographs were taken on a FEI Quanta 200. Shells were examined following cleaning with dilute bleach and coating with 5 nm AuPd. Chimney pieces were cut in slices with a diamond saw and assessed uncoated.

Table 1 CTD data for a depth range of 1463–1469 m at the Kebrit brine pool indicating rapid and significant changes in salinity, dissolved oxygen, pH, and temperature

Depth (m)	Temperature (°C)	Salinity	Oxygen (mg L ⁻¹)	pH
1462.8	21.7	40.6	4.03	8.00
1463.2	21.7	40.6	4.07	8.00
1463.3	21.7	40.7	4.09	8.00
1463.6	21.8	60.3	3.57	7.62
1464.0	21.9	125.5	2.33	6.63
1464.3	21.9	163.7	1.81	6.08
1464.6	22.0	180.1	1.63	5.80
1464.8	22.1	194.6	1.46	5.61
1465.2	22.2	208.3	1.32	5.49
1465.6	22.3	219.0	1.18	5.39
1465.9	22.4	226.4	1.09	5.32
1466.3	22.5	230.9	1.02	5.26
1466.6	22.6	234.2	0.96	5.22
1466.9	22.7	236.8	0.91	5.19
1467.2	22.8	238.0	0.87	5.17
1467.3	22.8	237.7	0.83	5.17
1467.3	22.9	237.4	0.81	5.17
1467.4	22.9	237.3	0.78	5.16
1467.4	22.9	238.0	0.77	5.16
1467.5	23.0	238.0	0.75	5.16
1467.8	23.0	239.7	0.72	5.16
1468.2	23.1	241.1	0.71	5.16
1468.4	23.1	241.4	0.69	5.17
1468.4	23.2	240.8	0.68	5.17
1468.5	23.1	241.0	0.67	5.17
1468.8	23.2	242.0	0.65	5.17
1469.2	23.3	242.2	0.64	5.17

Molecular methods

Total genomic DNA was extracted from ethanol-preserved specimens using the DNA Easy Blood and Tissue Kit (Qiagen) following the manufacturer's protocol for animal tissue. DNA yield of the extractions was quantified on a Qubit 2.0 fluorometer (Invitrogen) and partial COI, 28S, 18S, and 16S sequences were generated by PCR using the primer pairs as described in Oliver et al. (in prep). The 25 µL PCR reactions included 5 µL 5X Phusion buffer, 0.5 µL 10 mM dNTPs, 1.25 µL each primer (10 µM), 1.25 µL 50 mM MgCl₂, 0.125 µL Phusion High-Fidelity DNA polymerase, and 1 µL DNA extract (~10 ng/µL).

Thermal cycling conditions were: 98 °C for 2 min, then 37 cycles of 98 °C for 30 s, 30–40 s at annealing temperature, and 72 °C for 1 min, followed by a final extension of 10 min at 72 °C. A negative (no template DNA) and positive control (template DNA known to amplify) were included in all PCRs. All PCR products were checked on a 1 % agarose gel

and cleaned with illustra ExoStar 1-Step (GE Healthcare) before being sequenced on an ABI 3730xl Capillary Sequencer (Applied Biosystems) using the respectively forward and backward PCR primer.

Results

In situ underwater observations

A distinct “shoreline” is present above the Kebrit brine–seawater interface. Two types of fish were seen; one unidentified flatfish was seen on several occasions dwelling on the rim, swimming slowly away when disturbed by the ROV (Fig. 2a). Some individuals of an ophidiform fish were also observed, at times swimming almost into the brine pool (Fig. 2b). Also, specimens of caridean shrimps were encountered (Fig. 2a).

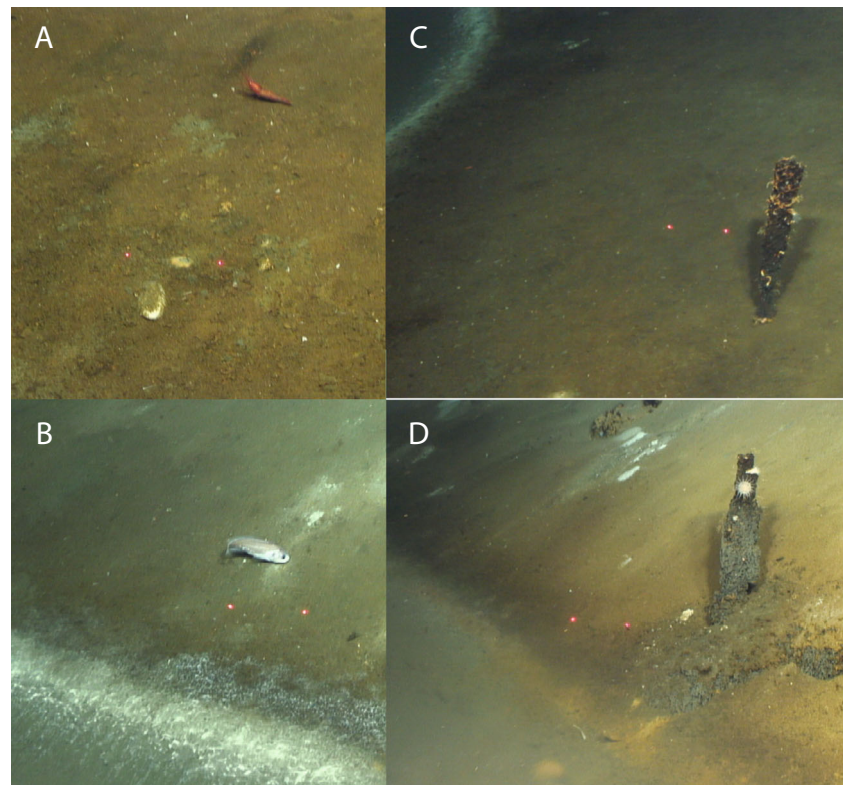
We observed a number of inactive chimneys at the Kebrit site. Many of the chimneys were located along the rim within a meter from the brine seawater interface, and one chimney was also popping out within the brine pool. A closer inspection of some of the chimneys revealed associated epifauna that included hydroids, sea anemones, and sabellid type polychaetes (Fig. 2c, d, Table 2).

Collected samples

Two chimneys were retrieved using the robotic arm of the ROV, and some sediment samples were also grabbed together with the chimneys. Remains (periostracum fragments) and one live individual of a solemyid clam (based on sequence data to be a *Solemya* sp.), along with one corbulid bivalve, and two gastropods (one of the family Marginellidae and one of the genus *Putzeysia* (fam. Calliotropidae)) followed with the sediment samples. The chimneys were of porous and layered structure (Fig. 3a–c), 17 and 28 cm long, around 4 cm wide, and 2–3 cm deep. When crushing part of the chimney, live animals and mollusc shells were frequently retrieved. Four ~2 cm high chimney fragments contained capitellid polychaetes ($N=5$), gastropods of the genus *Laeviphitus* (fam. Elachisinidae) ($N=21$), and top snails based on DNA sequence data found to be one species belonging to the family Cocculinidae ($N=17$), as well as tiny bivalves ($N=7$), which had settled in the empty gastropod and bivalve shells (Table 2). The shells were often highly corroded and covered with mineral deposits. Numerous reddish faecal pellets were also found inside the chimney pieces.

Partial COI, 28S, 18S, and 16S DNA sequences were retrieved for nine specimens (though it was not successful for all genes for all individuals; see Table 3 for details and accession numbers and best BLAST match). There was a lack of available sequences from closely related species, and any phylogenetic analysis beyond blasting was, therefore, not done.

Fig. 2 Fauna on the Kebrit rim 24° 43' 21" N, 36° 16' 37" E, ~1465 m depth. Images are captured from the ROV. The two red laser points are 10 cm apart. **a** A flatfish. **b** An ophidiform fish and a shrimp. **c** and **d** Inactive chimneys seen populated by sabellid type polychaetes, hydroids, and sea anemones. Chimney (**c**) was 17 cm long, around 4 cm wide, and 2 cm deep, chimney (**d**) was 28 cm long, 5.5 to 3.5 cm wide and 2–3 cm deep, thinnest at the bottom



Discussion

Since their initial discovery in the late 1970s, vent and seep macrofauna communities have been described from numerous places around the world (Baker et al. 2010). Yet, any reports from the mid axial brine pools in the Red Sea has so far been missing, with the only proof of benthic macrofaunal life being

the documentation of holes in the sediment close to the brine pools indicating burrowing polychaetes (Monin et al. 1982; Young and Ross 1974). However, Oliver et al. (in press) recently observed small bivalves associated with one of the brines. We did not bring equipment for quantitative sediment sampling. Our findings are, therefore, only qualitative, but despite that, provide a first glance into a novel, and to the Red Sea, a unique community.

The most conspicuous feature at the Kebrit rim was the inactive chimneys. Several species of macrofauna were associated with the chimneys; hydroids, sabellid type polychaetes, and sea anemones had settled outside and molluscs and capitellids were living inside. With their porous bubble structure and complex mineral composition, the interior of the chimneys probably provide an intricate habitat for microorganisms and a sheltered habitat for the metazoans where they can live inaccessible to predators such as fish.

The species found at Kebrit were typical for a reducing community (Baker et al. 2010; Sibuet and Olu 1998). All the solemyid remains collected together with the sediments suggest that the group is common in the Kebrit rim sediments. Solemyid bivalves are species with reduced and sometimes totally lacking digestive systems relying on thiotrophic microbial symbionts for their nutrition (Taylor and Glover 2010). Finding this bivalve in the Kebrit sediments is not surprising. The gastropod genus *Laeviphitus* that was found to be numerous inside the chimneys is also frequently reported as a member of vent and seep fauna (e.g. Galkin and Goroslavskaya

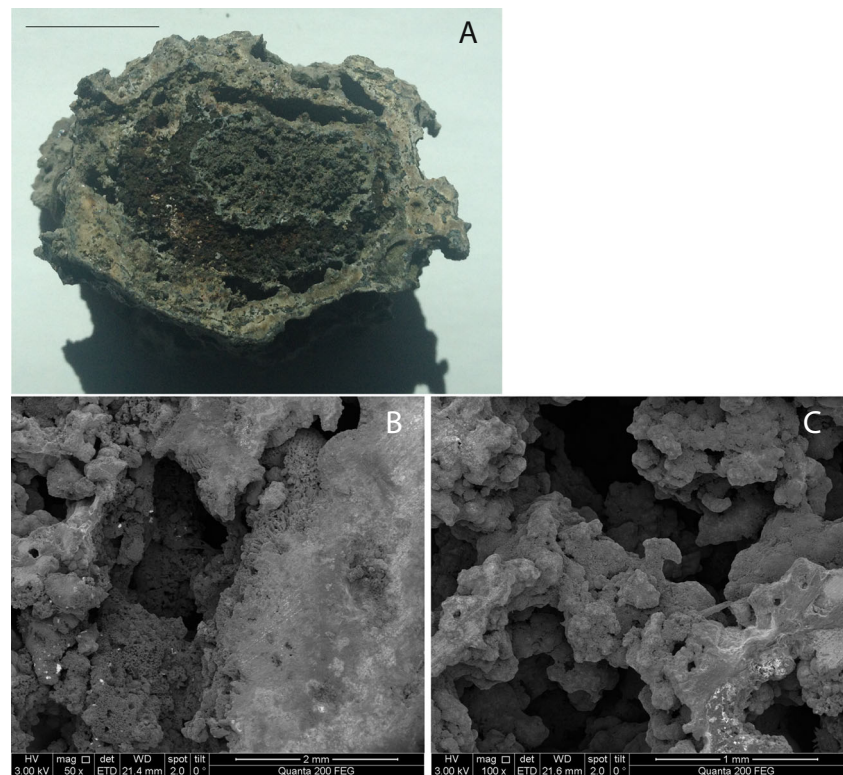
Table 2 Sampled fauna at the rim of the Kebrit brine

Species	Location	Number of individuals
Cnidaria		
Actiniaria indet.	CE	4
Hydroida indet.	CE	8
Bivalvia		
Bivalvia juv. indet.	CI	7
Corbulidae gen. et sp. nov	S	1
<i>Solemya</i> sp.	S	1
Gastropoda		
Cocculinidae indet.	CI	17 ^a
<i>Laeviphitus</i> sp.	CI	21 ^a
Marginellidae indet.	S	1
<i>Putzeysia</i> sp.	S	1
Polychaeta		
Capetellidae indet.	CI	5
Sabellidae indet.	CE	19

CE chimney exterior, CI chimney interior, S sediment

^a Number includes empty shells

Fig. 3 Cross sections of the chimneys **a** Photograph showing the layered structure. Variation of *blackish*, *lighter greyish* (more silica rich) and *red* (iron rich) areas. Scale bar is 1 cm **b** Representative photomicrographs from the cross section of the chimney (electron microscopy) showing the porous bubble structure



2010; Mullineaux et al. 2005; Ritt et al. 2010). Cocculiniform limpets that also were abundant inside the chimneys have likewise been reported from sulfide-rich, reducing environments such as whale bones and sunken drift-wood (Baco and Smith 2003; McLean 1992). Most vent/seep organisms are endemic to a narrow geographical area (Dover and Trask 2000; Sasaki et al. 2010). As this is the first report on this type

of fauna from the Red Sea, it is likely that many of the species found are new to science. Some of the species will be described elsewhere.

Cold seep communities in oligotrophic oceans rely to a large extent on chemosynthetic processes (either directly via symbioses or indirectly via heterotrophy) and are not fuelled by carbon sources of phytoplanktic origin (e.g., Carlier et al.

Table 3 Overview of individuals sequenced in this study and their associated accession numbers

Specimen (Number of individuals sequenced)	Location	Successful target	EMBL accession numbers	Best NCBI BLASTN match (species, accession number and (% identity))
Solemyid clam (1)	Sediment	18S	HG942544	<i>Solemya</i> sp., AM293666 (95 %)
		16S	HG942545	<i>Solemya velesiana</i> , KC984674 (87 %)
		COI	HG942539	<i>Solemya velesiana</i> , KC984744.1 (84 %)
Capitellid polychaete (2)	Chimney, interior	18S	HG942552	<i>Notomastus latericeus</i> , AY040697 (96 %)
		16S	HG942553	No match
		28S v1; 28S v2	HG942554; HG942555	<i>Dasybranchus</i> sp., AB771480.1 (88 %)
Cocculoid limpet (5)	Chimney, interior	18S	HG942546	<i>Cocculina messingi</i> , AF120508.1 (96 %)
		16S	HG942547	<i>Cocculina</i> sp., GQ160670.1 (90 %)
		28S	HG942548	<i>Cocculina</i> sp., AB282796.1 (91 %)
		COI	HG942540	<i>Cocculina</i> sp., AB238591 (88 %)
<i>Laeviphitus</i> sp. (1)	Chimney, interior	18S	HG942549	18S/16S/ 28S/ COI: None available for comparison.
		16S	HG942550	
		28S	HG942551	
		COI	HG942538	

2010). This is also to be expected for the Kebrit benthic community. Vent/seep gastropods typically feed by grazing on bacterial and detritus films though some also have bacteria symbionts (Dubilier et al. 2008; Sasaki et al. 2010). Capitellids are regarded as opportunistic deposit feeders that also would exploit brine-derived carbon via heterotrophy (Carlier et al. 2010; Tsutsumi et al. 2001). Symbiotic bacteria are not known for this group (Cuomo 1985; Felbeck et al. 1981). Sabellid type polychaetes, sea anemones, and hydroids could probably settle on any suitable hard substrate in the vicinity of the brine pools. Hence, it is unclear if the chimney epifauna took advantage of the chimneys only as a hard substrate to settle on, or if they depended on them for other reasons. But, given the extreme oligotrophic character of the deep Red Sea (Wishner 1980), it would be likely that the fauna relied on carbon derived directly or indirectly from the brine pools or associated seeps at the rim.

Shrimps and two species of fish were recorded by the brine pool. To what extent these motile animals were associated with the brine pools, as, e.g., shown for shrimps living near brines elsewhere (Copley and Young 2006), or just incidental visitors, await further studies. We were unable to collect any of the shrimps and fishes and can, therefore, not say anything about their feeding preferences.

No empty benthic mollusc shells were found with the sediments and most of the shells retrieved from the chimneys were damaged. The damage was probably caused partly by corrosion and partly because other gastropods had been grazing on them. Vent/seep molluscs commonly have thin shells as calcium carbonate is more energetically costly to produce in high pressure environments and also more easily corroded (Sasaki et al. 2010; Vermeij 1993). The calcium layer disappears before the periostracum (the organic coating around the shells) (Sasaki et al. 2010), and this could explain the high amounts of solemyid periostracum remains that were found. All the shells retrieved from within the chimneys were covered with mineral deposits that for some were not possible to remove with bleach in order to help identification. Mineral deposits are common on shell surfaces of vent/seep molluscs and are precipitated by bacterial activity (Warén and Bouchet 1989).

The Red Sea is a highly oligotrophic ocean and unique compared to other oceanic regions in that its water temperature remains higher than 21 °C all the way to the bottom (Wishner 1980). Such high bottom temperatures lead to faster mineralisation of organic material and a higher metabolic demand of deep sea organisms compared to other deep sea ecosystems. This likely is part of the explanation why the deep areas of Red Sea are extremely poor in benthos with only 0.05 g C/m² (Monin et al. 1982; Pfannkuche 1993). With that background, the Kebrit rim apparently is an ecosystem with increased biomass and biodiversity compared to the surroundings.

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