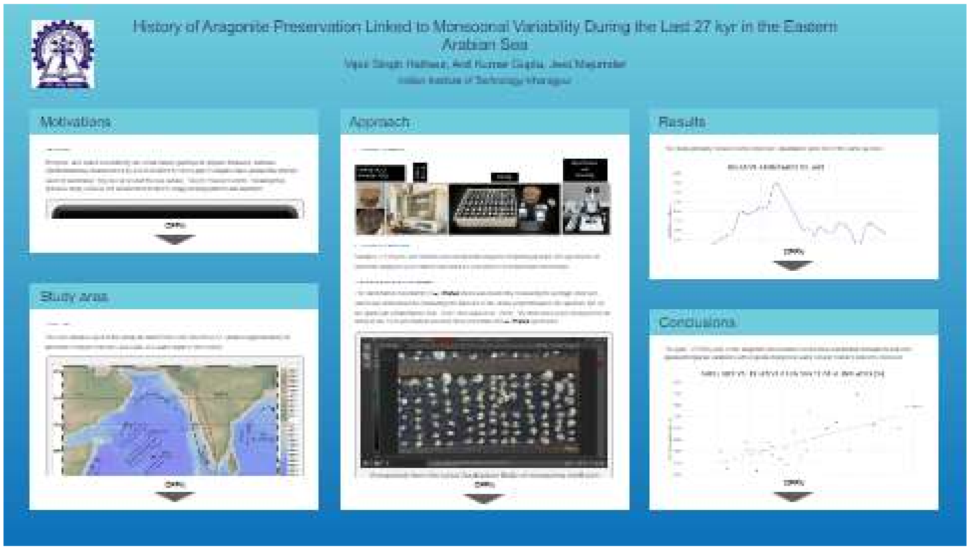
History of Aragonite Preservation Linked to Monsoonal Variability During the Last 27 kyr in the Eastern Arabian Sea



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PRESENTED AT:

AGU23 WIDE. OPEN. SCIENCE.

MOTIVATIONS

Pteropods?

Pteropod, also called sea butterfly, are small marine gastropods (phylum Mollusca, subclass Opisthobranchia) characterized by a foot modified to form a pair of winglike flaps (parapodia) that are used for swimming. They live at or near the sea surface. They're "mucus feeders," meaning they spread a sticky mucous net around their bodies to snag passing particles and plankton.

Images of live pteropod species

As ocean acidification progresses, the survival of pteropods and other creatures that form shells and skeletons—coral, oysters, starfish—becomes even more uncertain.

Food of Pteropods: Diatoms, Zooplanktons, Copepods.

Importance of Pteropods

Pteropods are nicknamed the potato chips of the sea, because they are essential food for everything from juvenile fish to herring, mackerel, rays, seabirds, and whales. Like cutting a link in a chain, the loss or decline of pteropods and similar organisms can disrupt the entire food chain.

Why I used pteropods to link aragonite preservation?

Pteropods, which are planktic gastropods with delicate aragonitic shells, have long been considered canaries in the coal mine for assessing the impacts of ocean acidification due to their sensitivity to changes in ocean chemistry.

Pteropod shells are excellent recorders of climate change, as carbonate ion concentration and temperature in the upper water column have dominant influences on pteropod shell carbon and oxygen isotopic composition.

[VIDEO] https://www.youtube.com/embed/6H_VDhXiFk4?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Importance of species used.

The species named *Heliconoides inflatus* is found in tropical and subtropical waters all around the world.

Shallow calcification depths for *H. inflatus* (75 m), therefore a good potential proxy carrier for past variations in surface ocean properties.

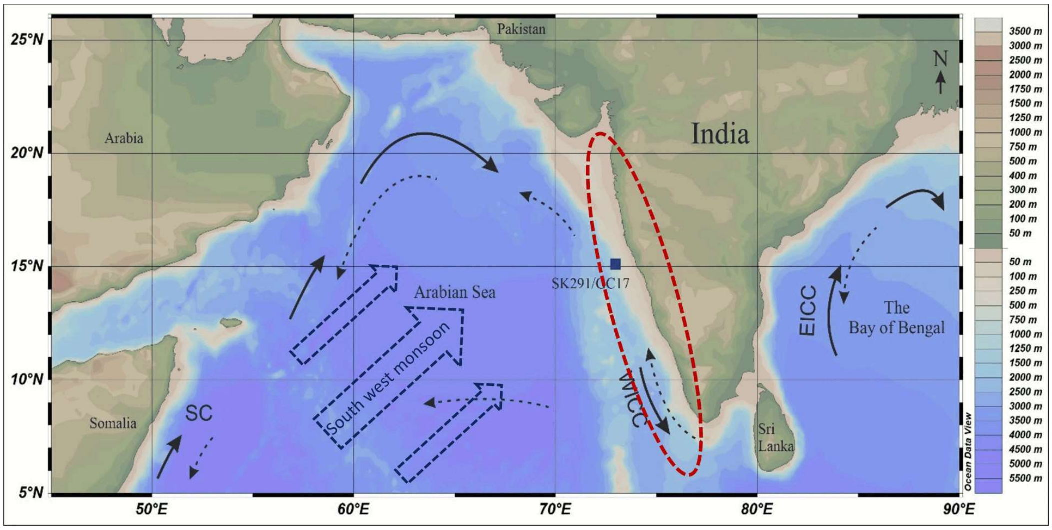
H. inflatus is well adapted to upwelling water masses according to Thiede et al. (1992).

Wall-Palmer et al. (2012, 2013) discovered that the LDX of *H. inflatus* in sediment displayed a substantial association with the Vostok atmospheric CO_2 concentrations. As a result, it is possible to more precisely reconstruct historical conditions from the fossil record by using the parameters controlling the abundance of these microfossils.

STUDY AREA

Study Site

The core samples used in this study are taken from Core SK291/GC17, situated approximately 95 kilometres offshore from the Goa coast, in a water depth of 182 meters.



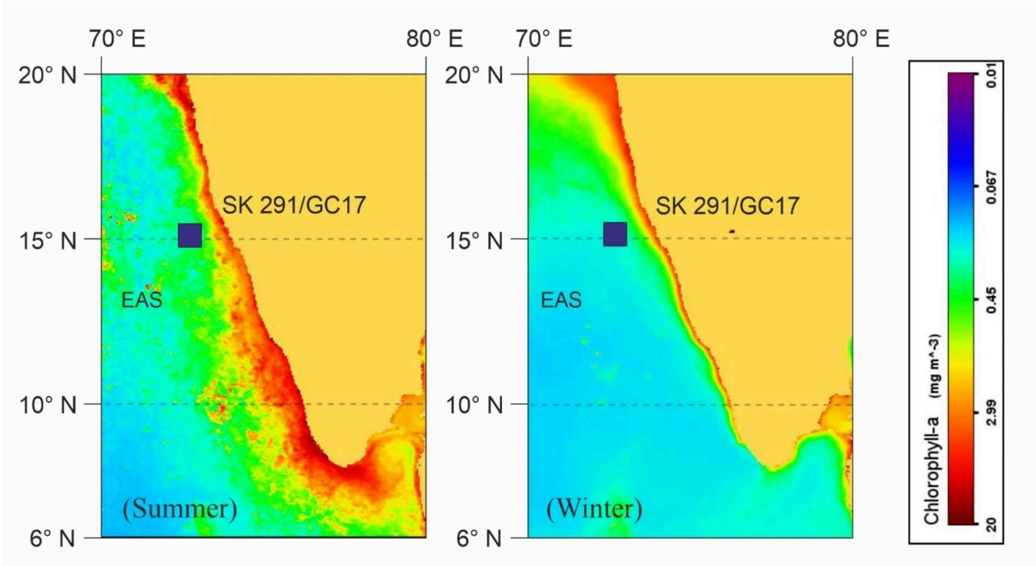
Map showing the location of the Core SK291/GC17.

What's special about the site and study?

<u>The site is located close to the upper boundary Arabian Sea Oxygen Minimum Zone with significant upwelling, therefore the data produced by the proxies will reveal monsoonal variability over a wide period.</u>

This study addresses millennial-scale variations in aragonite/carbonate preservation and how they relate to the past local environment.

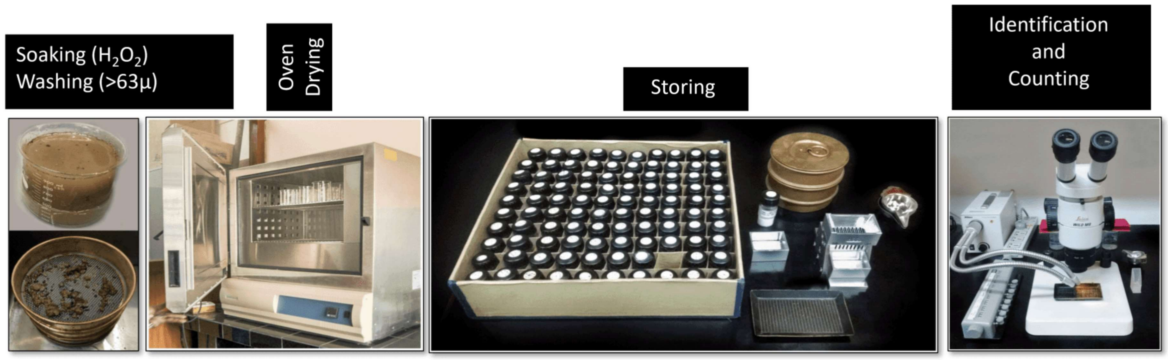
The monsoon winds in the eastern Arabian Sea (EAS) have a significant impact on the biological and hydrographic conditions of the water column. During the Indian summer monsoon (ISM) or southwest monsoon (SWM) season, moderate upwelling-induced primary productivity occurs, while weak upwelling is observed during the winter or northeast monsoon (NEM) due to reversing winds. The EAS receives additional nutrients from river runoff during the summer monsoon, particularly from the Western Ghats in India, which further enhances productivity.



Chlorophyll-a concentration in Indian Summer and Winter monsoon

APPROACH

1. Sample Processing

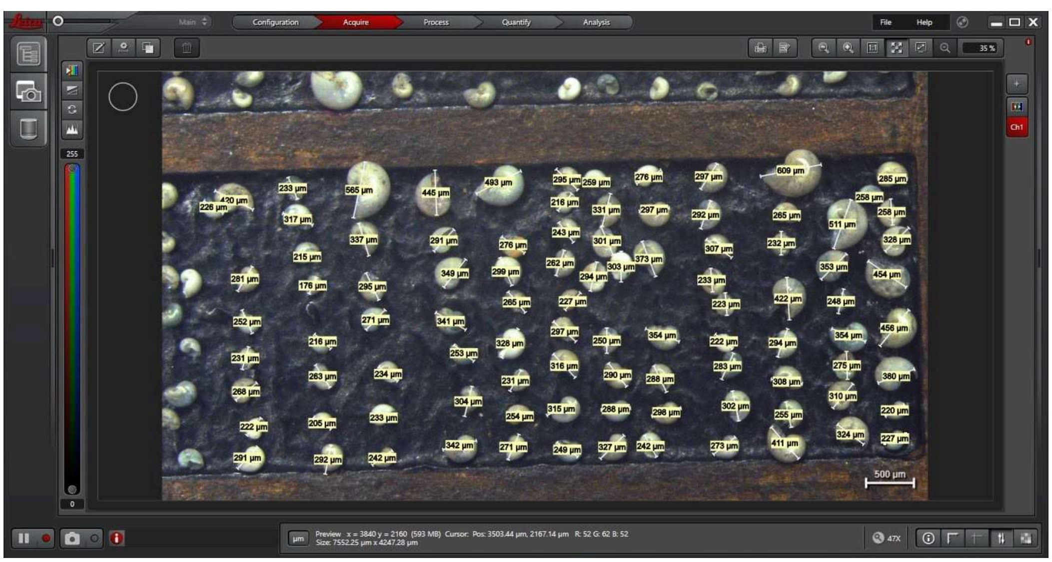


2. Picking of Pteropods

Samples (>125 µm) size fraction were divided into aliquots comprising at least 300 specimens on which the analyses were carried out under a Leica stereo zoom binocular microscope.

3. Average shell size of *H. inflatus*

The calcification/ dissolution of *H. inflatus* shells was studied by measuring the average shell size, which was determined by measuring the diameter of the shells perpendicular to the aperture line on the spiral side (Wall-Palmer et al., 2013; Sreevidya et al., 2019). The shell sizes were measured for all shells in the >125 µm fraction selected from more than 200 *H. inflatus* specimens.



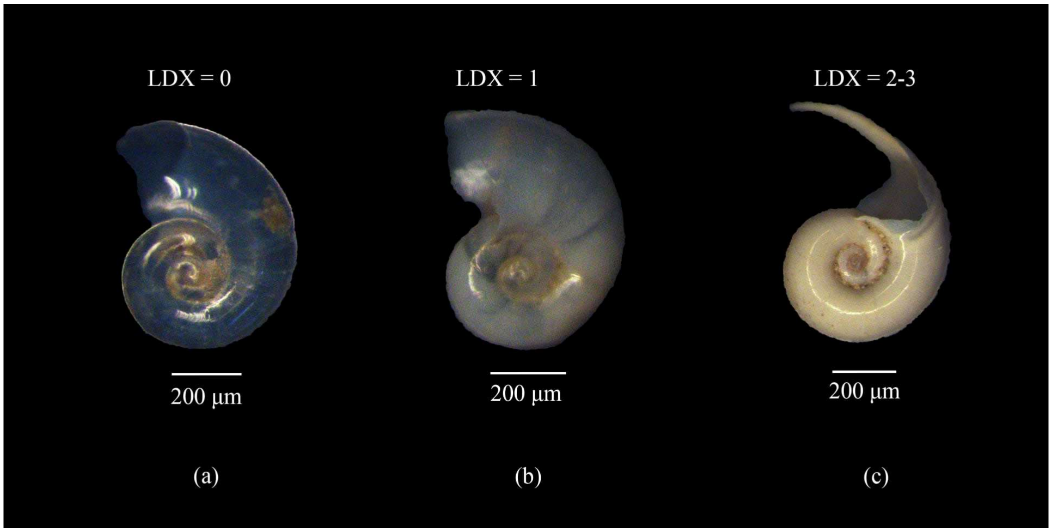
A snapshot from the Leica Application Suite of measuring shell size

4. The *Limacina* Dissolution Index (LDX)

The damage in pteropod shells is estimated using aragonite dissolution proxy.

- The *Limacina* Dissolution Index (LDX), was developed by Gerhardt et al. (2000) and published as a scale used to determine the extent of calcification in pteropod shells.

- It involves qualitative analysis of the surface of Heliconoides inflatus shells on a scale of zero to five, with zero indicating a transparent, lustrous, and well-preserved shell, and five indicating an opaque-white, lustreless, and perforated shell.



Different stages of *Limacina* Dissolution Index

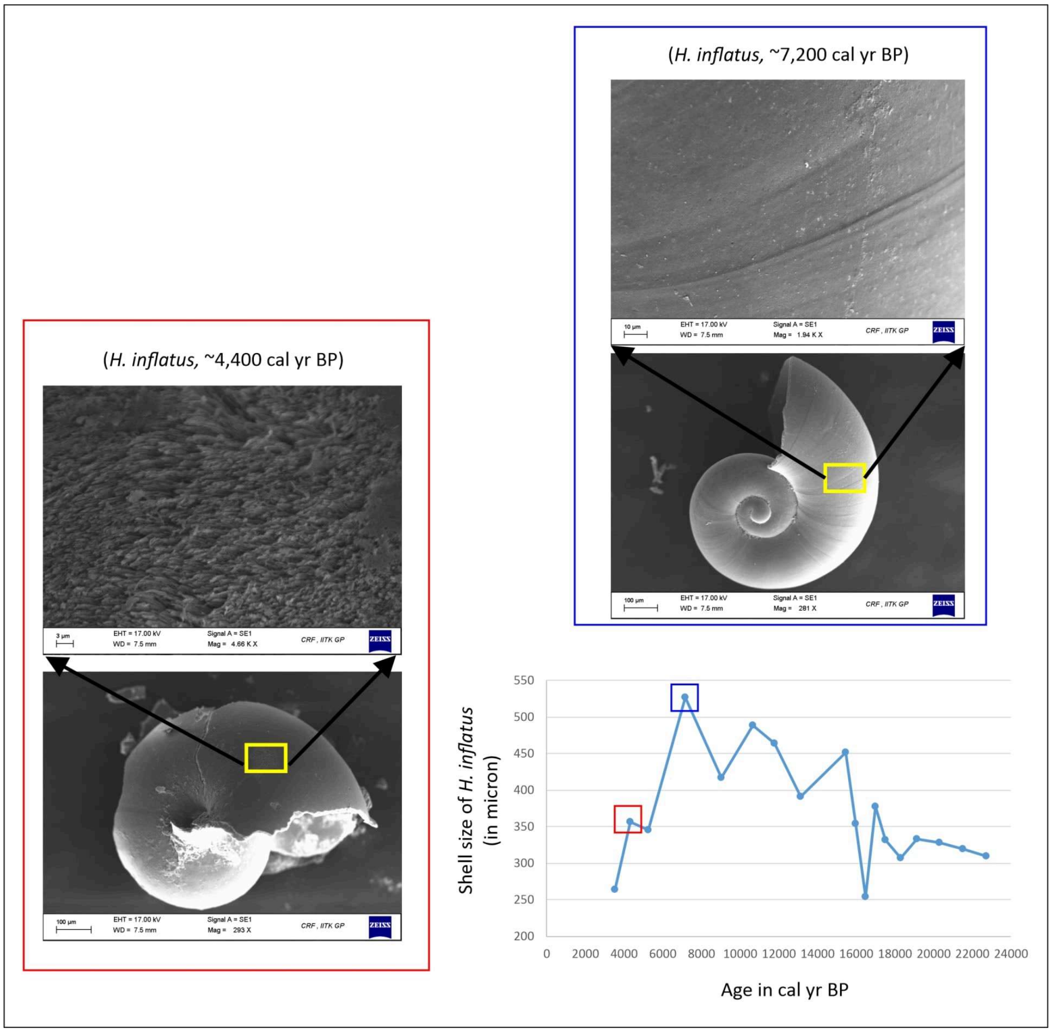
- Using light microscopy, at least ten shells (up to thirty shells) of adult *H. inflatus* with a size of 300 µm or larger were allocated a value from this scale for each sample, and the mean was calculated to determine the LDX value (Gerhardt and Henrich, 2001).
- Pteropod shells were examined under the stereo zoom microscope to apply the *Limacina* dissolution index (LDX). The LDX value for each sample was then calculated according to the following equation (Gerhardt et al. 2000; Gerhardt and Henrich 2001):

$$LDX = \frac{\sum n_P \times P}{\sum n_P}$$

- Where n_P is equal to the number of tests per preservation stage P (0–5) with the sum of nP being at least 10.

5. Dissolution on the shell surface was further evaluated using a scanning electron microscope (SEM)

To improve faunal identification and study the morphological characteristics of dissolution in pteropod shells, a series of specimens were analyzed in a Scanning Electron Microscope (SEM) (Model No. JEOL JSM-6490) at the Department of Geology and Geophysics, Indian Institute of Technology Kharagpur.



Two different stages of Dissolution deciphered under the SEM

A total of 6 pteropod species under 5 genera were identified from 24 core sediment samples.

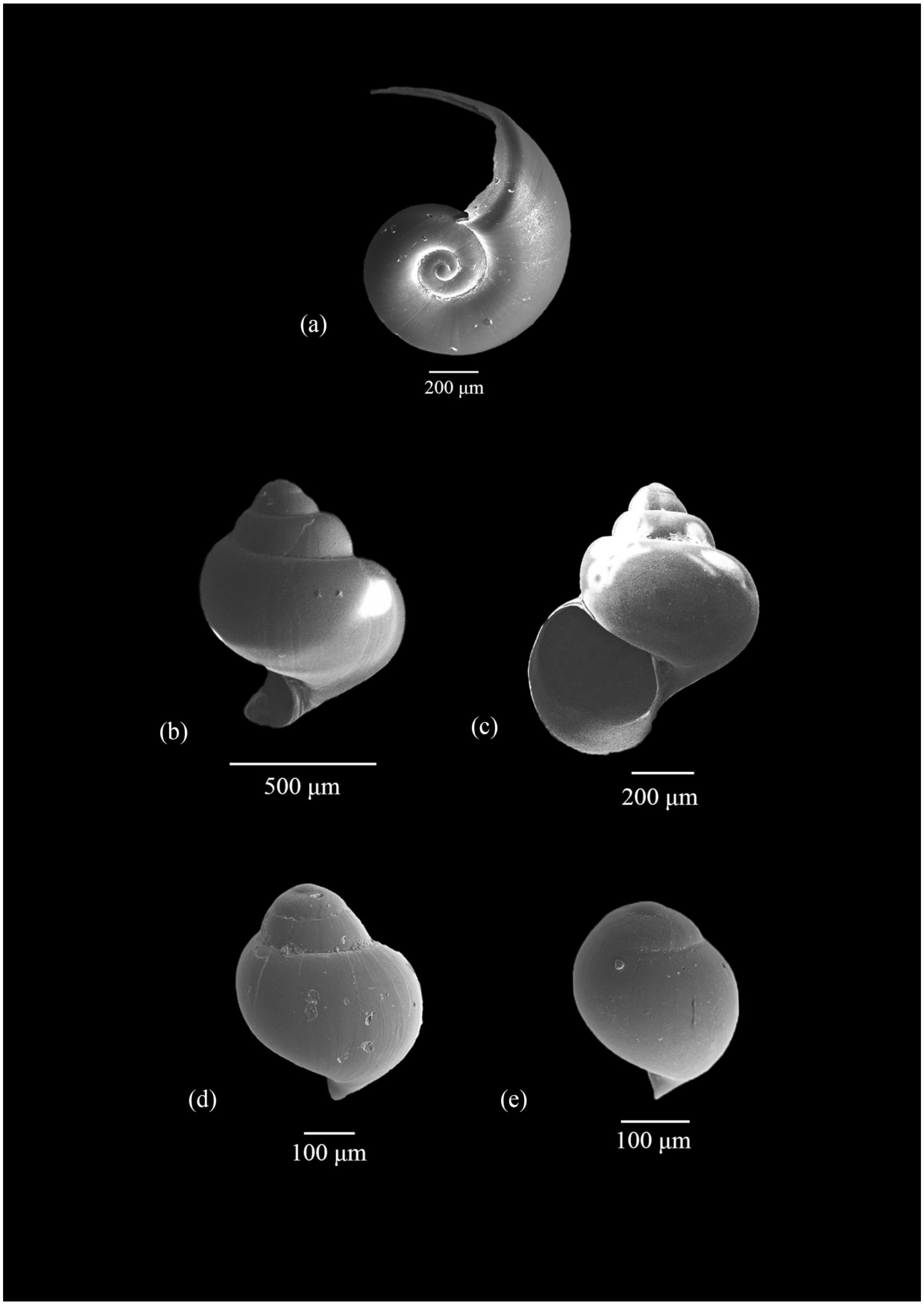


Plate 2. (a) Adult shell of *Heliconoides inflatus,* apical view, (b-c) adult shells of *Limacina trochiformis*, and (d-e) juvenile shells of *Limacina trochiformis*.

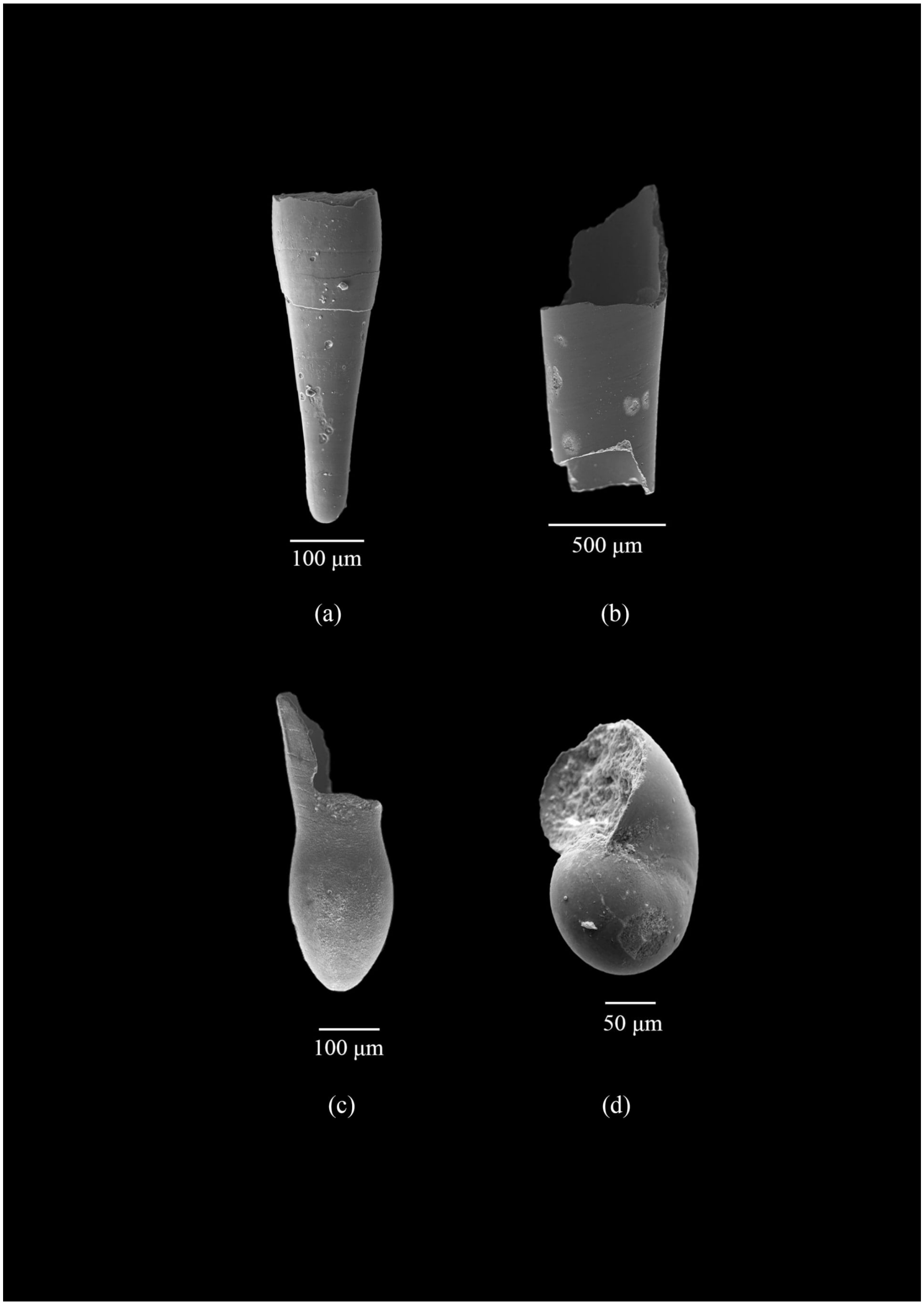
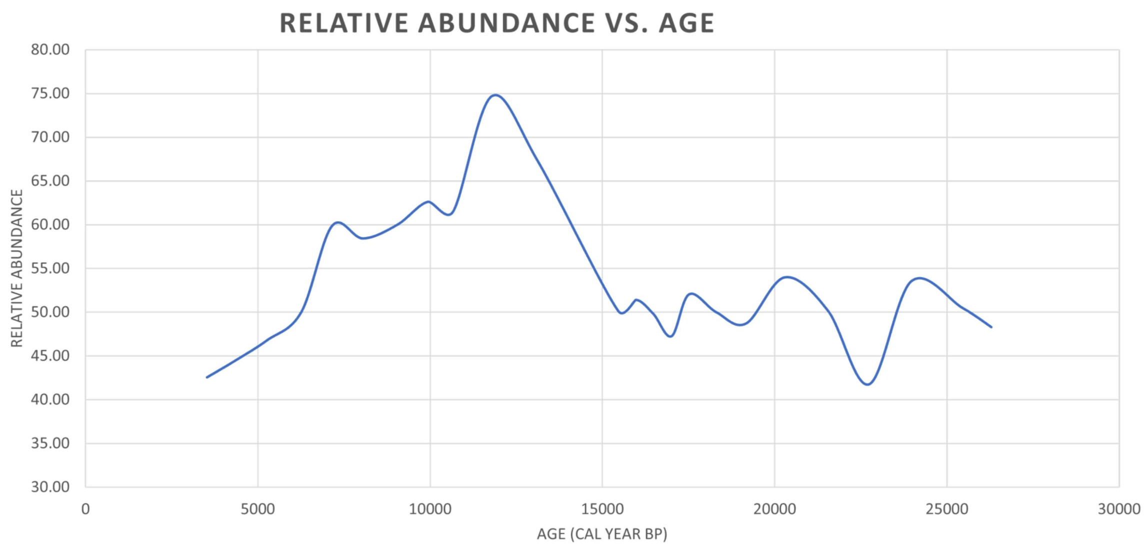


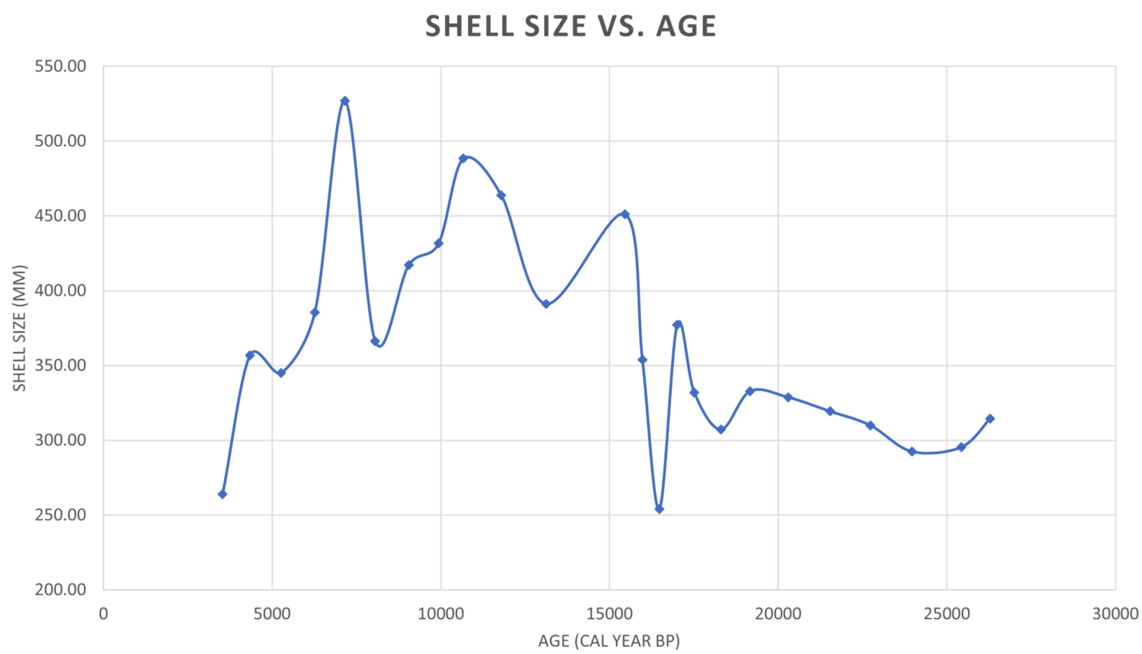
Plate 3. (a) *Creseis virgula constricta* (adult shell), (b) *Creseis acicula* (fragment of adult shell), (c) *Telodiacria quadridentata* (protoconch), and (d) *Gleba cordata* (larval shell).

RESULTS

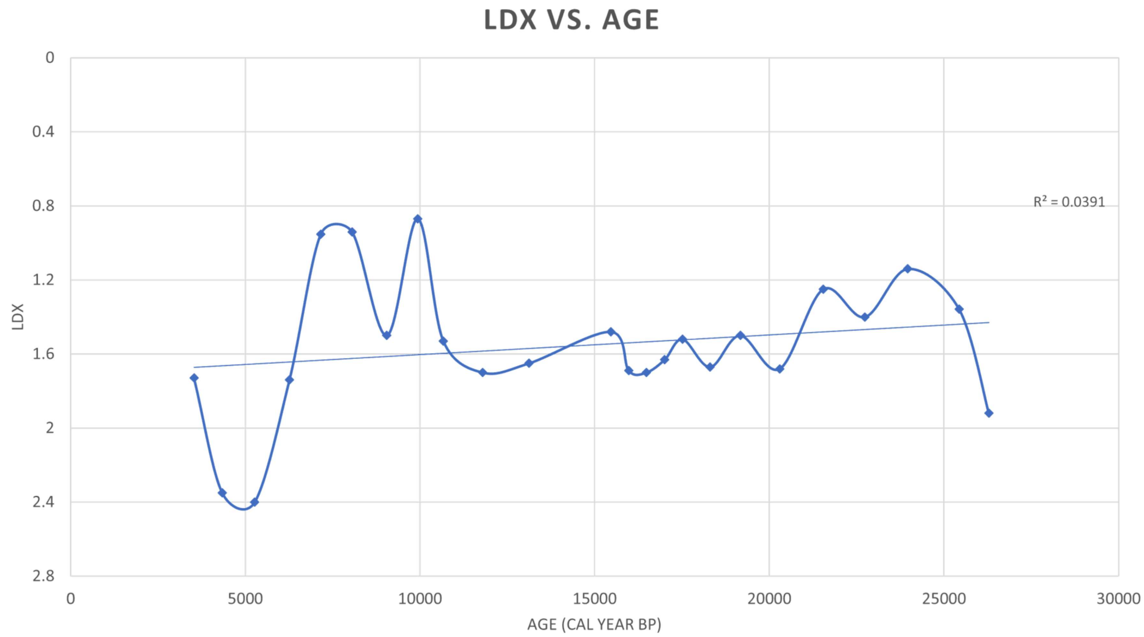
The study primarily focuses on the shell size, abundance and LDX of the same species.



The relative abundance of *H. inflatus* is significantly higher with an average value of 53.16%. There is a progressive increase to maximum abundance at 11,792 cal yr BP after 16,478 cal yr BP. Further, there is an overall decreasing trend up to 3,529 cal yr BP.



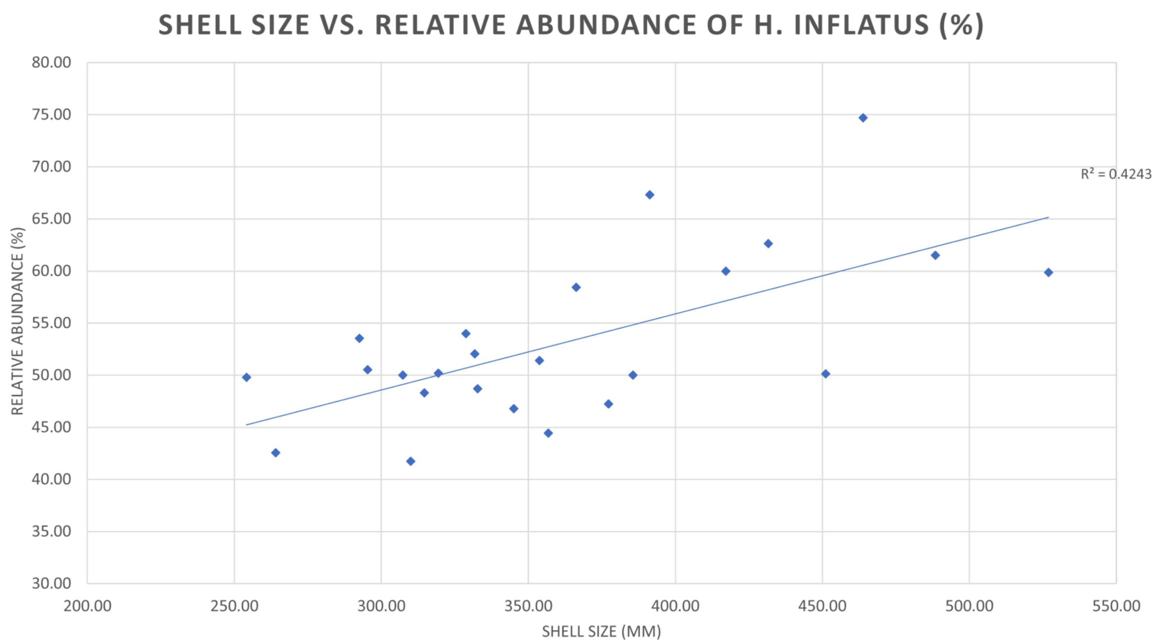
The trend of shell size is generally increasing from 26,282 cal yr BP up to 3,529 cal yr BP. The average shell size is 363 µm. There is an overall increase in shell size from 26,282 to 17,005 cal yr BP. Then there is an abrupt decrease in shell size to its lowest value at 16,478 cal yr BP (254µm). Following this, there is a periodic trend of increasing and decreasing sizes, which ends at 264 µm at 3,529 cal yr BP with the highest average shell size (526.90 µm) at 7,157 cal yr BP.



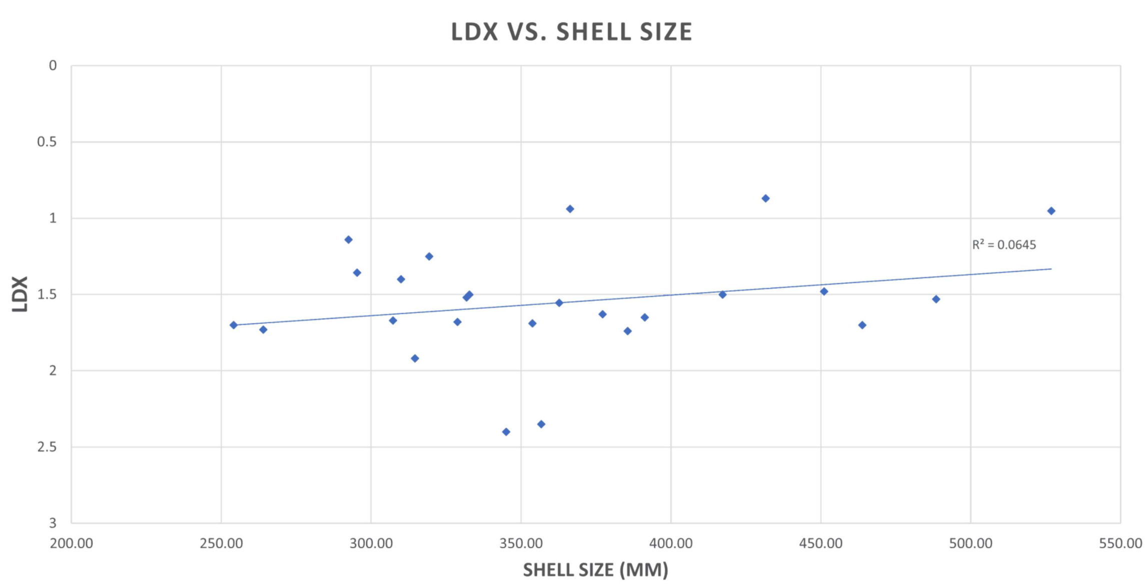
LDX also has a slight negative trend with age. The values of LDX range from 0.87 to 2.35 at the highest with the average value of 1.554. Starting from the LDX value of 1.92 at 26,282 cal yr BP, there is a decreasing trend up to 23,964 cal yr BP. After this, there is an overall slightly increasing- decreasing trend up to 10,668 cal yr BP. Hereafter, the LDX values fluctuate from their lowest to highest and end at the average value (1.554) at 3,529 cal yr BP.

CONCLUSIONS

The past ~27,000 years of the aragonite preservation record show substantial fluctuations linked to glacial-interglacial variations with regional changes in water column features linked to monsoon.



A good positive correlation (R = 0.65) between the shell size and the relative abundance of H. inflatus. This means that as shell size increases, the relative abundance tends to increase slightly, but the relationship is not very strong due to other environmental factors.



No clear correlation between shell size and LDX with R = 0.25. The values for LDX do not appear to follow any discernible pattern as the shell size increases or decreases.

However, we can observe a general trend where the smaller shells tend to have lower LDX values, while larger shell sizes tend to have higher LDX values. This suggests that there may be a correlation between shell size and the degree of shell dissolution caused by ocean acidification, with larger shells being more vulnerable to dissolution than smaller shells.

Take home messages for these proxies

1. The results indicate that the seasonal reversal of monsoon winds, productivity, and seawater carbonate chemistry were the primary factors influencing pteropod preservation in this area.
2. During the phases of higher productivity(during SWM), the shell size increased due to the greater availability of food.
3. Previous research conducted in the northern Indian Ocean has associated the poor preservation or absence of pteropods during warm intervals with a strong SWM, an extended OMZ, and a shallow Aragonite Compensation Depth (ACD). The SWM-induced upwelling and high biological productivity increase local CO2 production, resulting in aragonite undersaturation and intensified pteropod shell dissolution by enhancing carbon oxidation in the intermediate water column and sediments. As the core location is situated above the ACD/Aragonite Lysocline Depth and OMZ, there is an inverse relationship between pteropod abundance and dissolution.
4. There were fewer pteropods recorded during MIS 2 compared to MIS 1. The regional pteropod record also displayed similar variations. Some evidence suggests that the NEM may have intensified, which led to high surface productivity conditions due to intensified winter monsoon. As a result, the reduced preservation of pteropods during MIS 2 is thought to be caused by increased productivity induced by the NEM, which is distinct from the SWM.
5. The data suggests that the smaller shell size and higher LDX during 6,000 cal yr BP are due to some local disturbances in the area. The larger shell size and relatively higher LDX values during the peak of LGM and onset of deglaciation point towards the long-time exposure of shells to the sediment-water interface and preferential dissolution of smaller shells, possibly due to the low sedimentation rate.

According to Elderfield curve (2002), I believe the proxies I have used are in the optimism phase!!!

AUTHOR INFORMATION

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ABSTRACT

Heliconoides inflatus shell size, and its abundance and dissolution were analysed encompassing an age range from ~27,000 to 3,500 calibrated year before the Present (cal yr BP) from Core SK291/GC17, off the coast of Goa, eastern Arabian Sea (EAS). A total of 6 pteropod species belonging to 5 genera were identified from 24 core sediment samples. *Heliconoides inflatus*, earlier widely known as *Limacina inflata*, has a helical aragonite microstructure which is more susceptible to dissolution than the other pteropod species. Furthermore, the shell size of this species is correlated with surface productivity, whereas, its abundance is a proxy for upwelling induced productivity. During ~27,000-16,000 cal yr BP, low relative abundance and shell size of *H. inflatus*, suggest overall low productivity due to weak Indian Summer Monsoon (ISM) in the EAS. It was followed by higher abundance and bigger shell size of *H. inflatus* during ~15,000-7,000 cal yr BP, indicating increased productivity driven by strong ISM winds in the EAS. During ~7,000-3,500 cal yr BP, the low abundance and shell size of *H. inflatus* indicate a weak phase of ISM coinciding with the 4.2 ka dry event. The Limacina Dissolution Index (LDX) of *H. inflatus* is a proxy to understand variation in aragonite preservation. Moderately low dissolution of aragonite is evident during ~27,000-7,000 cal yr BP. Due to a rise in the sea level, Core SK291/GC17 fell below the upper horizon of the Oxygen Minimum Zone (OMZ) after ~7,000 cal yr BP. Poor preservation of aragonite can be seen during ~6,000-3,500 cal yr BP, which might have occurred due to intensification of the corrosive OMZ. There is a good correlation between the relative abundance and shell size of *H. inflatus*. So, during phases of higher productivity, the shell size of *H. inflatus* increased due to greater availability of food. This study suggests that total pteropod populations as well as relative abundances of certain pteropod species could be used as proxy to understand ocean chemistry and productivity in the past.