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RESEARCH ARTICLE

Study of Ocean Acidification from Benthic Foraminifera in South Andaman India

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Abstract

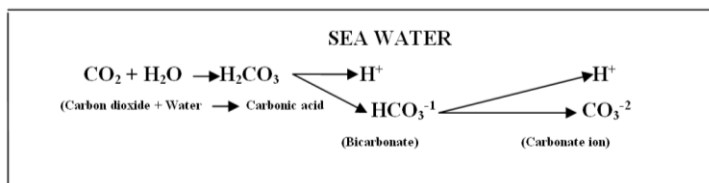
Ocean acidification is phenomenon where atmospheric CO₂ dissolves into the ocean, it forms carbonic acid (H₂CO₃). Some of carbonic acid dissociates in ocean waters, producing hydrogen ions (H⁺) and reduce of Carbonate ion concentration. As the number of hydrogen ions increases, the pH of the ocean water decreases, and the water becomes more acidic. To validate the relationship between shell mass changes and Mg/Ca changes of the foraminifera species *Calcarina spengleri* (Gmelin 1791), *Peneroplis planatus* (Fichtel and Moll 1921) and *Spiroloculina angulata* (Cushman 1917) selected from symbiotic barren and symbiont bearing foraminifera from the reef and deep water environments an innovative approach of measuring of shell weights with Mg/Ca analysis to study the impact of ocean acidification. Six bivariate plots between the diameter and weight of the foraminifers collected from shallow depth and deep water were carried out from the foraminiferal species respectively.

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Introduction

In recent years, ocean acidification has gained more interests from scientific communities and has increased serious concerns about its effects on marine organisms and ecosystem. When atmospheric CO₂ dissolves into the ocean, it forms carbonic acid (H₂CO₃). Some of carbonic acid dissociates in ocean waters, producing hydrogen ions (H⁺) and reduce of Carbonate ion concentration. As the number of hydrogen ions increases, the pH of the ocean water decreases, and the water becomes more acidic. Increasing of ocean acidification could alter biogeochemical cycle, disrupt physiological process of marine organism and damage marine ecosystem. Carbonic acid separate in ocean waters, producing hydrogen ions (H⁺) and reject of Carbonate ion concentration. As the number of hydrogen ions increases, the pH of the ocean water gradually decreases, and the Ocean water becomes more acidified in nature. Increasing of ocean acidification could alter biogeochemical cycle, disrupt physiological process of marine organism and damage marine ecosystem.

A reduction in the number of carbonate ions available will make difficult and/or require marine calcifying organism to use more energy to form biogenic carbonate (CaCO₃). Approximately 90% of inorganic carbonate ions and 9% of bicarbonate ions only 1% is dissolved CO₂. An increase in carbon dioxide in the atmosphere leads to an increase in carbon dioxide in the ocean. Subsequently, the pH and carbonate ion of surface deep sea water is lowered. This increase in carbon dioxide lowers the pH of the surface ocean.



Response of pelagic calcifiers to ocean acidification

Plankton (drifting organisms found in the water column) such as coccolithophores, foraminifera (calcite secreting) and pteropods (aragonite secreting) account for approximately three quarters of the global

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marine calcium carbonate production (Schubert *et al.*, 2006). As a result they are also responsible for almost all of the export of calcium carbonate to the deep sea, although their respective contributions can vary over regional and temporal scales (Fabry *et al.*, 2008). The response of planktonic calcifying organisms to ocean acidification will depend on a large number of factors such as the type of calcium carbonate secreted (calcite, aragonite or amorphous), the impacts of other environmental factors (e.g. temperature, nutrients), the life stage of the organisms and their calcifying mechanism (Kleypas *et al.*, 2006).

Coccolithophores

The phytoplanktonic are one of the most abundant marine primary producers found in the oceans. However to date, the response of only 4 of the approximately 250-500 coccolithophores species have been studied (Young *et al.*, 2005; Doney *et al.*, 2009b). While most studies have reported reduced calcification (25-66%) at elevated pCO₂ levels (Riebesell *et al.*, 2000; Zondervan *et al.*, 2001, 2002; Sciandra *et al.*, 2003; Delille *et al.*, 2005; Engel *et al.*, 2005), others have shown a doubling in calcification rates (Iglesias-Rodríguez *et al.*, 2002), or no significant change (Langer *et al.*, 2006). Increases in pCO₂ levels have also been demonstrated to directly affect the cell physiology through an alteration of the net growth rate and elemental ratios of uptake and production (Engel *et al.*, 2005). Initial studies have further suggested that increased pCO₂ coupled with under-saturating light intensities (Zondervan *et al.*, 2002), nitrogen limitation (Sciandra *et al.*, 2003) or trace metal (zinc, iron) limitation can reduce calcification rates or organic carbon production (Schulz *et al.*, 2004).

Pteropods

They are planktonic snails and an important component of polar and subpolar ecosystems (Bathmann *et al.*, 1991; Pane *et al.*, 2004). Data for *Clio pyramidata* (species of pteropod) indicates that when the saturation state reaches levels projected for the Southern Ocean surface waters by 2100 ($\Omega_{arag} < 1.0$) net dissolution will occur (Orr *et al.*, 2005; Fabry *et al.*, 2008; Figure 2.2). A recent study has shown that decreases in shell weights are already occurring in the Southern Ocean (Roberts *et al.*, 2008).

Impact of Ocean Acidification in Southern Ocean Chemistry

Marine life is adapted to a range of ambient CO₂ and pH conditions, from the high concentrations found in vent systems, to the fluctuating levels experienced in the intertidal zone. The adaptive responses of the organisms exposed to ambient levels will partially

define the extent to which they will react to the progressively lower pH levels in the future. The lowering of pH (Caldeira and Wickett, 2003) has a significant threat to Southern Ocean ecosystem by decrease of shell weight in calcium carbonate in pteropods (Roberts *et al.* 2008) and foraminifera (Moy *et al.* 2009). The small, amoeba-like, eukaryotic are abundant in the oceans. Laboratory experiments have shown that foraminifera shell mass decreases as carbonate ion concentrations decrease (Spero *et al.*, 1993; Bijma *et al.*, 1999, 2002). A reduction in the shell weights of foraminifera over the last two decades has already been measured in the Southern Ocean (Moy *et al.*, 2009). As with coccolithophores, environmental conditions such as temperature and food supply will strongly affect calcification (Fabry *et al.*, 2008). Great Barrier Reef have also shown decline in calcification in recent years (Cooper *et al.* 2008). The shell weights of both planktonic and benthic foraminifers reduce with decreasing [CO₂⁻³] or pH (Bijma *et al.*, 1999; Bijma *et al.*, 2002; Dissard *et al.*, 2010; Lombard *et al.*, 2010). Calcification (measured as increments of shell weight and diameter) of *Marginopora*, a large, dinoflagellate symbiont-bearing benthic foraminifer, is reduced as pH becomes lower (Kuroyanagi *et al.*, 2009). This reduction in calcification forced by increased pCO₂ has also been observed in the geological past. Barker and Elderfield (2002) reported a decrease in the shell weight of planktonic foraminifera over the last deglaciation. Here we reports results of culture experiments performed to assess the effects of ongoing ocean acidification on the calcification of symbiont-bearing reef foraminifers using a high precision pCO₂ control system. Living clone individuals of three foraminiferal species (*Baculogypsina sphaerulata*, *Calcarina gaudichaudii* and *Amphisorus hemprichii*) were subjected to sea water at five pCO₂ levels from 260 to 970 μ atm.

Biological activity in the oceans takes place primarily in the surface layer through which the sunlight penetrates the photic zone. This layer is also the area which experiences the highest alterations in carbon chemistry and ocean acidification. Surface dwelling organisms can therefore be directly exposed to rapid alterations in carbonate chemistry. In shelf seas, because they are well mixed in winter, benthic organisms are also exposed to pH variations and will experience the increased levels of atmospheric CO₂ very quickly (ICES, 2008). In the open ocean, the natural pH range, and the likely subsequent change, is a function of depth, with the greatest range in the surface layers.

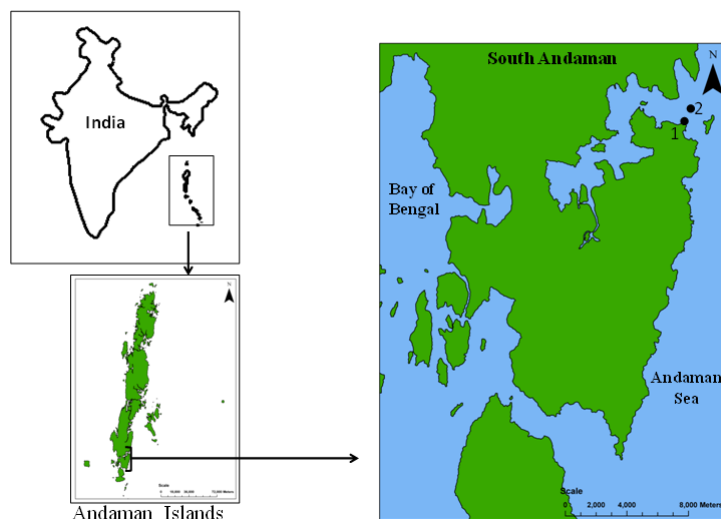
The Mg/Ca Ratio and Evolution

There are two central query of organic evolution that relate to bio mineralization in the ocean. One is, when organisms first evolved skeletons, did their skeletons tend to be of mineralogies favoured by ambient seawater? The second is, after particular types of organisms have evolved skeletons, have changes in seawater chemistry induced them to evolve new skeletal mineralogies? I will first take up the second question. We can consider two ways in which seawater chemistry has apparently influenced the evolution of skeletal mineralogy of animals. In the first, evident for anatomically simple animals, evolution has produced bio mineralization that is compatible with seawater chemistry. In the second, involving anatomically more advanced animals, evolution appears to have resisted the influence of seawater chemistry so as to favour relatively rapid calcification.

The cheilostome bryozoans have experienced evolutionary changes in their mineralogy since the Cretaceous that appear to have been dictated by the dramatic rise in the Mg/Ca ratio of seawater. Today all of their species produce aragonite, high-Mg calcite, or both, meaning that their skeletal mineralogy is compatible with modern seawater. Calcite was their predominant mineralogy during the Cretaceous, and it can be assumed this was low-Mg calcite because, as already noted, all extant organisms yet studied that today produce high-Mg calcite have produced low-Mg calcite in artificial Cretaceous seawater. Thus, the inferred secular increase in the Mg content of cheilostomes' skeletons was presumably phenotypic rather than being genetically governed. On the other hand, the cheilostomes' production of aragonite as the Mg/Ca ratio of seawater rose far into the aragonite domain during the Cretaceous is clearly an evolutionary phenomenon, having arisen polyphyletically, but not simultaneously in those lineages in which it appeared.⁹¹ Mollusks are anatomically more advanced than bryozoans, and they appear to have evolved in ways that have mitigated effects of changing seawater chemistry that would have tended to slow their rate of shell growth. The previously mentioned experiments of Lorens and Bender suggest that extant mollusks are at their physiological limit for excluding Mg from their pallial fluid. Similarly, Checa et al. found that scallops and oysters calcified in unconventional ways when grown in seawaters with higher Mg/Ca ratios than mollusks have ever experienced in nature. of crystal growth of low-Mg calcite is higher than that of high-Mg calcite, natural selection may normally have favoured the exclusion of Mg from calcite for all calcitic taxa whose bio calcification is not strongly controlled by ambient seawater chemistry, and mollusks have obviously had

sufficient control over their mineralogy to exclude Mg. It appears that, as the concentration of Mg in seawater has risen since Cretaceous time, mollusks have evolved in concert in order to exclude it. Thus, up to the present time in the modern aragonite sea, mollusks have been able to secrete low-Mg calcite in large regions of their shells. It appears that the experiments of (Lorens and Bender 1976, 1977 and Checa et al. 1987) have quite simply outrun the influence of seawater chemistry on molluscan evolution. The ocean are rapid relative to rates of input and removal of Mg^{2+} and Ca^{2+} , the Mg/Ca ratio has been remarkably uniform throughout the ocean at any given time in Earth's history. There is evidence, however, that this ratio has oscillated markedly since the beginning of the Cambrian Period, when skeletonised animals first became taxonomically diverse and abundant. Part of the evidence for this oscillation comes from calculations based on the observation that when oceanic crust forms along mid ocean ridges and via the eruption of deep-sea flood basalts, seawater circulates through the newly formed crust and changes its chemical composition before returning to the ocean.

STUDY AREA



St.1- shallow water (4mts), St.2 deep water (56mts)

Materials and Methods

To study the Ocean acidification by weight hypothesis from benthic foraminifers they are *Calcarina Spengleri*, *Peneroplis planatus* and *Spiroloculina angulata* the sediment samples were collected from two different depth shallow (4 mts) and deep (56 mts). The sediments Samples were collected through Van veen grab sampler subsequently treated with Rose Bengal dye to distinguish living and deceased species. Specimens

were collected by hand after sieving and drying of the sediment samples, and preserved in paleontological slides. Using Stereoscopic Binocular Microscope (Nikon – SMZ1500) microscope, species were identified and taken photographs. FEI Quanta 200 Environmental Scanning Electron Microscope (ESEM) with Energy-Dispersive X-ray Spectroscopy (EDS) system was used to study the variety of anomalous ultra features and chemical characteristic of foraminiferal species. In this system The EDS is attached with SEM that enables to analysis the elemental composition and also the ultra structure of the foraminiferal samples. Shell weight was measured to the nearest 0.1 µg using Sartorius Electronic Weigh Balance (ranging from 0.0001gram to 220grams).

For that specimens were rinsed in deionised water and air dried on paleontological slides. Then the species were mounted on aluminium SEM stubs using double-sided adhesive tabs. In this study the characteristic of an element with atomic structure is identified uniquely from one another in the form in the form of EDS spectrum along with ultra structures of the same species. After scrutinize the foraminiferal species through light microscope, species comes under the order Miliolida, and Rotaliida.

Measuring of shell weight – size with Mg/Ca analysis of benthic foraminifera to study the effects of ocean acidification

Large, algal symbiont-bearing benthic foraminifers, which are important primary and carbonate producers

in coral reefs, produce high-Mg calcite shells, whose solubility can exceed that of aragonite produced by corals, making them the “first responder” in coral reefs to the decreasing carbonate saturation state of seawater (K.Fujita *et al.*, 2011).

To validate the relationship between shell mass changes and Mg/Ca changes of the foraminifera species *Calcarina spengleri* (Gmelin 1791), *Peneroplis planatus* (Fichtel and Moll 1921) and *Spiroloculina angulata* (Cushman 1917) selected from symbiotic barren and symbiont bearing foraminifera from the reef and deep water environments an innovative approach of measuring of shell weights with Mg/Ca analysis to study the impact of ocean acidification were carried out.

Shell diameter and shell weight measurement

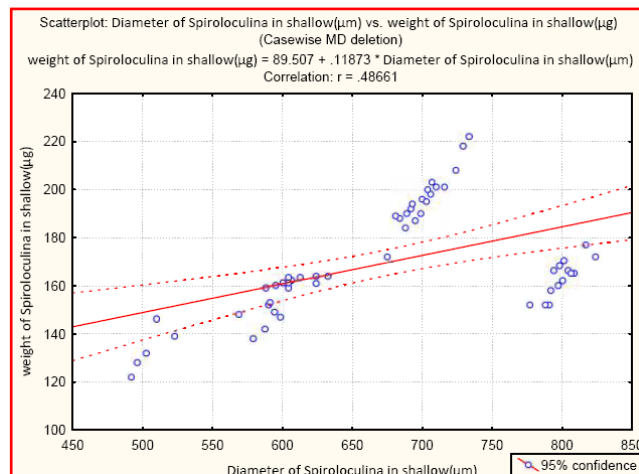
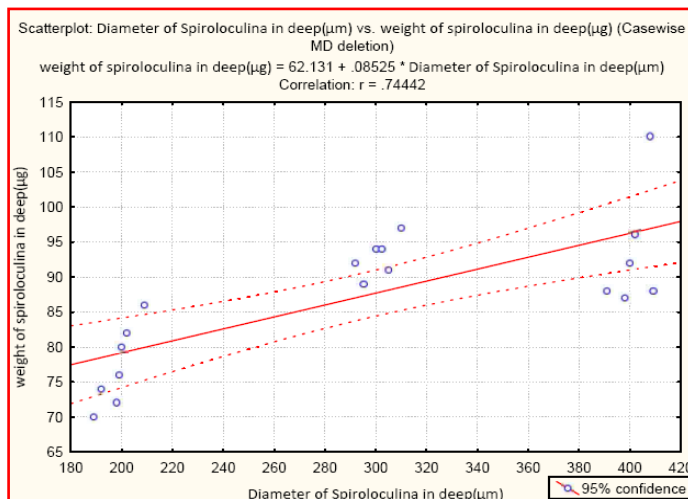
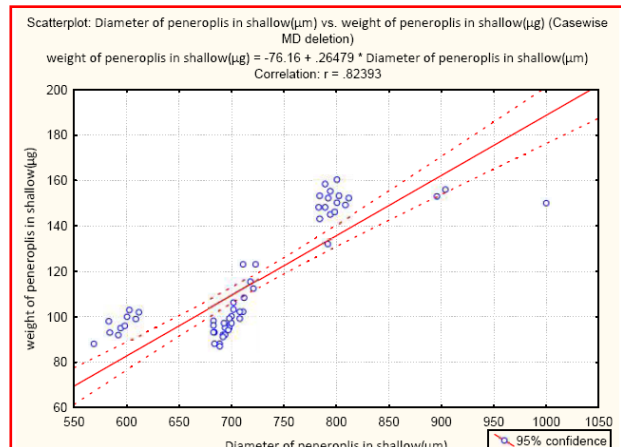
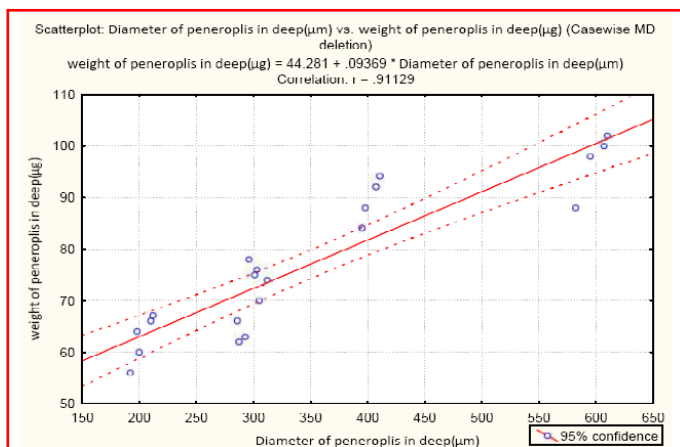
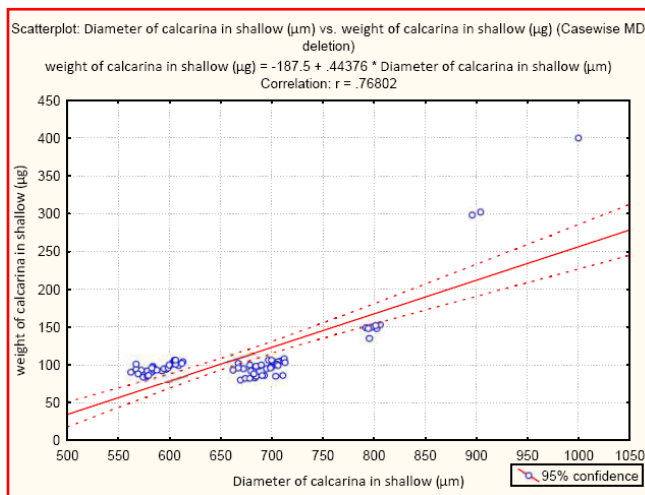
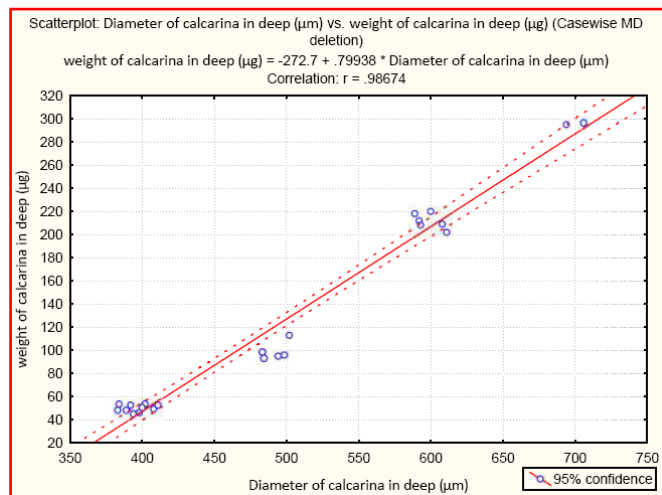
The shell diameter (the average of the maximum diameter from the final chamber and that crossing the first at the centre of the test and perpendicular to it) was measured to the nearest 0.001 mm on microscope using image analysis software . Shell weight was measured to the nearest 0.1 µg using Sartorius Electronic Weigh Balance (ranging from 0.0001gram to 220grams).

Results and Discussion

Measurements of diameters and weights of shells of *calcarina spengleri*, *peneroplis planatus* and *spiroloculina angulata* collected from shallow and deep water.

Species	Total number of foraminifera	Diameter	Weight	Environment
<i>Calcarina spengleri</i> -	1600	600µm to 1000µm	80µg to 400µg	Shallow water <4m
	600	400µm to 700µm	50µg to 290µg	deep water ~ 56 mts depth
<i>Peneroplis planatus</i>	1480	600µm to 1000µm	100µg to 153µg	Shallow water <4m
	530	200µm to 600µm	60µg to 105µg	deep water ~ 56 mts depth
<i>Spiroloculina angulata</i>	1140	500µm to 800µm	122µg to 196µg	Shallow water <4m
	320	200µm to 400µm	70µg to 90µg	deep water ~ 56 mts depth

Six bivariate plots between the diameter and weight of the foraminifera collected from shallow depth and deep water were carried out. Regression correlation coefficient 'r' value for of the foraminifera in shallow and deep water benthic show s set of values as 0.76802: 0.98674 ; 0.82393 : 0.91129 ; 0.48661: 0.74442.



Conclusion

In all cases range of 'r' values of shallow water foraminifera are comparatively lower than the 'r' values of foraminifera in deep water. This is because that shrinkage due to substitution of calcite with much smaller magnesium ions. Shrinkage of foraminifers' shells is more in shallow depth than shells in deep. Assuming that ocean acidification has decreased the calcification rates of the benthic foraminifera in shallow water resulting in lower shell weights, whereas the deep foraminifera are having higher shell weight comparatively. Based on the study it seems that shell weights of foraminifera in shallow water are lower than the deep water foraminifera owing to the replacement of larger Ca ions by smaller Mg ions (weight hypothesis).

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