

## Possible factors that control calcite dissolution in the western tropical Indian Ocean

The oceans act as a major controlling device of atmospheric  $\text{CO}_2$  through the chemistry of the oceans and preservation of calcium carbonate in deep-sea sediments<sup>1</sup>. Carbon dioxide dissolved in sea water is present as  $\text{CO}_2$  gas,  $\text{H}_2\text{CO}_3$ ,  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ . All these species together constitute the Dissolved Inorganic Carbon (DIC)<sup>2</sup> which controls the sea water pH, which in turn controls preservation/dissolution of  $\text{CaCO}_3$ . Precipitation of carbonate carbon results in an increase in ocean  $\text{pCO}_2$ , and with it an increase in atmospheric  $\text{CO}_2$  concentration. Conversely, dissolution of  $\text{CaCO}_3$  results in a decrease in  $\text{pCO}_2$  (and atmospheric  $\text{CO}_2$ ) decrease<sup>3</sup>.

Therefore, in order to understand the past atmospheric  $\text{CO}_2$  fluctuations, it is necessary to know the dissolution and preservation patterns of calcium carbonate in the world oceans<sup>4</sup>. Two processes result in the dissolution of calcite after it reaches the seafloor. First, the degree of saturation state of  $\text{CO}_3^{2-}$  concentration of the overlying bottom waters<sup>5</sup>, and second, due to sedimentary organic matter respiration and resulting acidification of pore waters<sup>6,7</sup>.

Applying three palaeocarbonate ion proxies – planktonic foraminifera size index, shell weight and calcite crystallinity – to a set of core top samples, it has been documented that calcite dissolution commences from 2250 m onwards and intensifies at around 3900 m water depth in the western tropical Indian Ocean<sup>8</sup>. The present communication is aimed to address whether the dissolution of carbonate in the western tropical Indian Ocean is caused due to saturation state of the overlying bottom waters or due to acidification of pore waters driven by organic matter remineralization.

Six core top sediment samples used in this study were obtained during the cruises of *ORV Sagar Kanya* (SK 199C; Figure 1). All samples were oven-dried at  $50^\circ\text{C}$ ; a portion of the sample was weighed and disaggregated by soaking in distilled water and then wet-sieved through a  $>63\ \mu\text{m}$  sieve. A portion of the coarse fraction ( $>63\ \mu\text{m}$ ) was cleaned and sonicated. We have resorted here to the shell weight method<sup>9</sup>. The  $>63\ \mu\text{m}$  material was then dried and passed

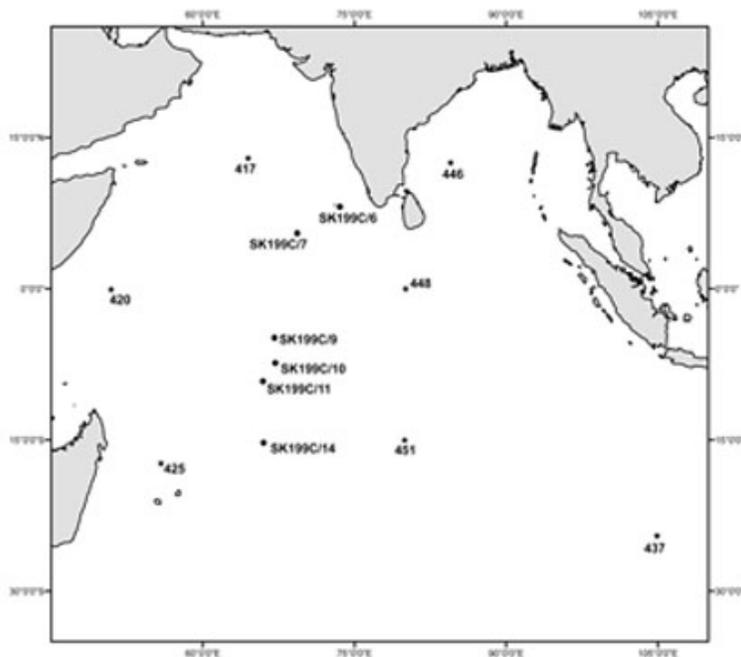
through sieves in order to isolate 350–420  $\mu\text{m}$  size fractions. Fifty shells of *Pulleniatina obliquiloculata* were picked and weighed on a microbalance ( $1\sigma$  precision:  $\pm 2\ \mu\text{g}$ ,  $n = 10$ ). Carbonate ion concentrations,  $[\text{CO}_3^{2-}]$  of water bathing the core tops were computed from GEOSECS stations in the western Indian Ocean (nos 417, 420 and 425) and eastern Indian Ocean (nos 446, 448, 451 and 437) following the procedure adopted by Taro Takahashi (pers. commun.). The pressure-normalized  $\text{CO}_3^{2-}$  concentration was calculated as follows:  $\text{CO}_3^{2-*} = \text{CO}_3^{2-} + 20(4 - h)$ ; where  $h$  is the depth (in km)<sup>10</sup>.

A linear decrease in shell weight was observed in the pressure-normalized carbonate ion ( $\text{CO}_3^{2-*}$ ) range from 90 to 125  $\mu\text{mol kg}^{-1}$  in the tropical region of the world oceans<sup>11</sup>, with a weight loss of  $0.30 \pm 0.05\ \mu\text{g}\ \mu\text{mol}^{-1}\ \text{kg}^{-1}$ . Bottom water  $\text{CO}_3^{2-*}$  concentration bathing the core tops in the present study is in the range 88–113  $\mu\text{mol kg}^{-1}$ , lying in the shell weight decrease zone documented by Broecker

and Clark<sup>11</sup> (Table 1). At a  $\text{CO}_3^{2-*}$  concentration of 97  $\mu\text{mol kg}^{-1}$ , a large variability in shell weight was noticed, which has been attributed to surface water  $\text{CO}_3^{2-}$  ion concentrations<sup>8</sup>. We find that in the present study, foraminifera shell weights show marginally higher values than those in the eastern Indian Ocean<sup>11</sup>.

As mentioned earlier, calcite dissolution in sediments above lysocline depths could take place in acidified pore waters. The core top foraminifera are also initially exposed to the benthic fluff layer at the sediment–water interface<sup>12</sup>. Therefore, this interface is perhaps a better description of the initial exposure environment in foraminifera from the core tops. Therefore, we use the term  $\Delta\text{CO}_3^{2-}$  interface instead of  $\Delta\text{CO}_3^{2-}$  pore-water.

To understand whether the dissolution taking place at Site SK199C/7 is due to this corrosive benthic fluff layer, we calculated the  $\Delta\text{CO}_3^{2-}$  interface –  $\Delta\text{CO}_3^{2-}$  bottom water gradient. We used the relationship from the core-top data of Broecker and Clark<sup>11</sup> for *P. obliquiloculata* shell weight and



**Figure 1.** Map showing core top locations in the tropical Indian Ocean along with GEOSECS stations used in the calculation of  $\text{CO}_3^{2-}$  concentrations. Solid circles indicate core top locations and stars indicate GEOSECS stations with numbers.

**Table 1.** Shell weights ( $\mu\text{g}$ ) of foraminifera species *Pulleniatina obliquiloculata*.  $\text{CO}_3^-$  ( $\mu\text{mol}/\text{kg}$ ) calculated using the program developed by Takahashi; pressure-normalized carbonate ion concentration,  $[\text{CO}_3^{*}]$  calculated from Broecker and Clark<sup>10</sup>,  $\text{CO}_3^{*} = \text{CO}_3^- + 20(4 - h)$ ; where  $h$  is the depth (in km);  $\Delta\text{CO}_3^-$  values calculated as  $\text{CO}_3^{*} - \text{CO}_3^-$

Station	Depth (m)	Latitude	Longitude	Shell weight			
				<i>P. obliquiloculata</i>	$\text{CO}_3^-$	$\text{CO}_3^{*}$	$\Delta\text{CO}_3^-$
SK199C/6	2250	8.13°N	73.56°E	33.17	77.59	112.59	35
SK199C/10	3305	7.36°S	67.17°E	29.11	83.61	97.51	13.9
SK199C/9	3320	4.86°S	67.09°E	32.05	83.70	97.29	13.6
SK199C/14	3368	15.27°S	66.01°E	35.1	83.97	96.61	12.64
SK199C/11	3373	9.17°S	65.95°E	31.63	83.99	96.54	12.54
SK199C/7	3944	5.51°N	69.34°E	26	87.25	88.37	1.12

bottom water  $\Delta\text{CO}_3^-$ , from the Indian Ocean as given below.

$\Delta\text{CO}_3^- = [P. obliquiloculata \text{ shell weight } (\mu\text{g}) - 24.53] / 0.2759$ .

Using the above relation and shell weights of *P. obliquiloculata*, we calculated  $\Delta\text{CO}_3^-$  interface. The gradient ( $\Delta\text{CO}_3^-$  interface –  $\Delta\text{CO}_3^-$  bottom water) was then calculated using,  $\Delta\text{CO}_3^-$  bottom water values (Table 1).

Thus, we obtain a value of  $+4.2 \mu\text{M}$  at 3900 m water depth. de Villiers<sup>12</sup> determined the  $\Delta\text{CO}_3^-$  interface to be within  $\pm 10 \mu\text{M}$  of bottom water. Shell weight measurements from both *Globigerinoides sacculifer* and *Globigerinoides ruber* suggest that there exists no significant gradient in  $\Delta\text{CO}_3^-$  across the sediment–bottom water interface below a depth of 1000 m in the Indian Ocean. Our value of  $+4.2 \mu\text{M}$  falls within the range of  $\pm 10 \mu\text{M}$ , suggesting that dissolution of carbonate around 3900 m water depth is due to undersaturation in  $\text{CO}_3^-$  concentration of bottom waters.

Calcium carbonate dissolution starts around 2250 m and intensifies at 3900 m in the tropical Indian Ocean<sup>8</sup>. We needed to study whether this intense dissolution occurring at 3900 m is a result of undersaturation of overlying bottom waters with respect to carbonate ion. This is important in order to know the calcite satu-

ration depth in the western tropical Indian Ocean, which is necessary to understand the oceanic response to the currently increasing  $\text{CO}_2$  levels. We used the relationship between *P. obliquiloculata* shell weight and bottom water  $\Delta\text{CO}_3^-$  from the core top data of Broecker and Clark<sup>11</sup> and data from the present study. We calculated  $\Delta\text{CO}_3^-$  interface –  $\Delta\text{CO}_3^-$  bottom water to be  $+4.2 \mu\text{M}$ , which is within  $\pm 10 \mu\text{M}$  of bottom water, the value derived by de Villiers<sup>12</sup>. This suggests that there is no gradient in  $\Delta\text{CO}_3^-$  across the sediment–bottom water interface at a depth of 3900 m. Therefore, we conclude that the intense dissolution along this transect in the western tropical Indian Ocean is due to bottom water  $\text{CO}_3^-$  undersaturation.

- Berger, W. H., *Geol. Soc. Am. Bull.*, 1974, **18**, 1385–1402.
- Riley, J. P. and Chester, R., *Introduction to Marine Chemistry*, Academic Press, London, 1971, p. 465.
- Broecker, W. S. and Peng, T.-H., *Global Biogeochem. Cycles*, 1987, **1**, 15–29.
- Naidu, P. D. and Malmgren, B. A., *Mar. Geol.*, 1999, **161**, 49–62.
- Berger, W. H., *J. Foraminiferal Res.*, 1973, **3**, 187–195.
- Emerson, S. and Bender, M., *J. Mar. Res.*, 1981, **39**, 139–162.

- Archer, D. and Maier-Reimer, E., *Nature*, 1994, **367**, 260–263.
- Naik, S. S. and Naidu, P. D., *Geochem. Geophys. Geosyst.*, 2007, **8**, Q08009.
- Lohmann, G. P., *Paleoceanography*, 1995, **10**, 445–447.
- Broecker, W. S. and Clark, E., *Paleoceanography*, 1999, **14**, 596–604.
- Broecker, W. S. and Clark, E., *Paleoceanography*, 2001, **16**, 531–534.
- de Villiers, S., *Deep-Sea Res. I*, 2005, **52**, 671–680.

ACKNOWLEDGEMENTS. We thank Dr S. Chaturvedi for sharing SK samples. This is National Institute of Oceanography contribution no. 4366.

Received 5 November 2007; revised accepted 2 April 2008

S. S. NAIK<sup>1</sup>  
P. DIVAKAR NAIDU<sup>2,\*</sup>

<sup>1</sup>National Centre for Antarctic and Ocean Research, Goa 403 804 India

<sup>2</sup>National Institute of Oceanography, Goa 403 004, India

\*For correspondence.  
e-mail: divakar@nio.org

## *Corallodiscus* Batalin (Gesneriaceae): A new generic record for Eastern Ghats, Orissa

The floristics of southern Orissa, often considered incomplete, was sporadically approached by Mooney, Gamble, Haines and subsequent workers. Hence, it provides an ideal background for further exploration and discovery of taxonomic novelties. We collected an interesting specimen belonging to family Gesneriaceae

from Similipadar Hills (19°41'12.53"N, 83°4'28.97"E) in the Karlapat range, Kalahandi District, part of the Eastern Ghats, Orissa. Critical analysis and scrutiny of the floristic work done by several researchers<sup>1–8</sup> helped us to identify this specimen as *Corallodiscus lanuginosus* (Wallich ex R.Br.) B. L. Burt. *C. lanugin-*

*nosus* is a highly variable taxon and has been reported to grow in moist rock crevices at 600–3600 m amsl from northeast India to China. Recent discovery of this species from the Western Ghats<sup>8</sup> and the Eastern Ghats (Prasad, RRL (B), col. no. 10217), extends its distribution to peninsular India. However, contrary to the