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A first look at factors affecting aragonite compensation depth in the eastern Arabian Sea

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ABSTRACT

Water column measurements suggest shoaling of aragonite saturation depths (ASD) throughout the world oceans, due to increase in greenhouse gas concentration. Past records of aragonite saturation state under different climatic conditions are required to assess the impact of climatic changes on shoaling/deepening of ASD. The preservation state of organisms having aragonite skeletons, is used to assess the past changes in aragonite saturation depths, with respect to the modern ASD. Here for the first time, we delineate and discuss the factors that affect the modern aragonite compensation depth (ACD) in the eastern Arabian Sea by using pteropod abundance in the surface sediments. A total of 78 spade core-top samples collected along seven latitudinal transects, covering the continental shelf, slope and abyssal region of the eastern Arabian Sea were used. Pteropods were picked from coarse fraction (≥63 μm). Based on the pteropod preservation, we report that in the eastern Arabian Sea, ACD lies at a water depth of ≤525 m, which matches with the chemically defined aragonite saturation depth. We further report that the ACD shoals from north to south. The zone of high pteropod abundance coincides with low $\%C_{org}$. The increase in pteropod abundance in the outer shelf region coincides with the drop in dissolved oxygen concentration. The deeper limit of pteropod abundance lies in the center of the oxygen minimum zone with higher $\%C_{org}$. Therefore, we suggest that the pteropod abundance in the eastern Arabian Sea is not always related with the lower dissolved oxygen, but is strongly influenced by $\%C_{org}$. This first report of the pteropod based aragonite compensation depth estimates from the eastern Arabian Sea will help in assessing future changes in ACD under the influence of anthropogenic green-house gas emissions.

1. Introduction

The oceans act as a sink for 20–40% of the anthropogenic carbon-dioxide emissions (DeVries, 2014). The marine organisms that secrete calcium carbonate, help in sequestering a large amount of this carbon dissolved in seawater. The marine organisms secrete both the aragonite and high-magnesium calcite in the modern ocean. Out of these two most common forms of biogenic carbonate, aragonite is metastable and is one-and-a-half times more soluble than calcite in seawater (Berner, 1976; Morse et al., 1980; Morse and Arvidson, 2002). Aragonite constitutes ~12% of the total calcium carbonate flux throughout the world oceans (Berner and Honjo, 1981) and as high as 22.5% of the total calcite flux in the Somali Basin (Singh and Conan, 2008). Pteropods, which are pelagic gastropods (Bé and Gilmer, 1977), secrete aragonite shells and thus are responsible for a large fraction of aragonite flux in the oceans (Hashimi and Nair, 1976; Berger, 1978; Almogi-Labin, 1984; Panchang et al., 2007; Singh and Conan, 2008). The efficiency of marine organisms to secrete calcium carbonate depends on seawater pH. Both the field and laboratory culture studies suggest that the anthropogenic green-house gas emission induced drop in seawater pH has adversely affected aragonite saturation depth (Sarma et al., 2002; Feely et al., 2012; Jiang et al., 2015) and thus pteropod preservation (Bednaršek et al., 2012, 2014). The presence or absence of pteropods in sediments has often been used to assess the aragonite compensation depth (ACD) (Berger, 1978). However, in regions with high organic carbon flux and low dissolved oxygen, seawater pH at the sediment-water inter-phase is also modulated by the decay of organic matter. Such decay of organic matter in oxygen poor environment decreases seawater pH and may affect pteropod based ACD estimates (Berger, 1978; Millero et al., 1998). Additionally, biologically mediated decomposition of organic matter within the sediments also releases metabolic CO_2 in the pore-water and lowers the pH, thus further dissolving carbonates above the chemical lysocline (Berger, 1978, Emerson and Bender, 1981; Milliman et al., 1999) and is responsible for shoaling of ACD in the continental slope region. Additionally, as the organic matter decay depends on the availability of oxygen, often a close link is observed between bottom water oxygen concentration and pteropod preservation (von Rad et al., 1995, 1999).

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The eastern Arabian Sea being the locale for very high productivity and perennial intermediate depth oxygen minimum zone (OMZ), is ideal to understand the relationship between ACD and OMZ. The shallow ACD (500 ± 200 m) in the northeastern Arabian Sea was attributed to the strong OMZ resulting in poor pteropod preservation (von Rod et al., 1999). A considerable deepening of the ACD to depths which fall well within the modern day oxygen minimum zone, has been inferred prior to the Holocene, especially during the deglaciations, from several cores collected from the northern Indian Ocean (Klöcker and Henrich, 2006; Klöcker et al., 2006; Singh et al., 2000; Sijinkumar et al., 2010, 2014; Naidu et al., 2014). The relationship between OMZ and ACD is, therefore, obscure. In the northern and eastern Pacific, although the low pteropod abundance was reported in surface sediments lying within the OMZ, the weak OMZ of central Sargasso Sea in the North Atlantic, does not affect the pteropod deposition in the sediments (Berger, 1978). Therefore, it is necessary to understand the factors that control pteropod distribution in regions affected by OMZ as temporal changes in aragonite preservation have been used to reconstruct past changes in OMZ, thermocline, carbonate saturation, water mass pathways and paleobathymetry (Herman and Rosenberg, 1969; Almogi-Labin, 1982; Haddad and Droxler, 1996; Reichart et al., 1998; Singh, 1998; Arz et al., 2001; Gerhardt and Henrich, 2001; Singh et al., 2001; Klöcker and Henrich, 2006; Klöcker et al., 2006; Naidu et al., 2014).

Plankton net studies suggest that pteropods are one of the dominant zooplankton in the eastern Arabian Sea (Goswami, 1985; Goswami and Padmawati, 1996). Modern pteropod distribution in sediments has been used by several workers to map the aragonite compensation depth (ACD) in the northeastern Arabian Sea (George et al., 1994; Reichart et al., 1998; Millero et al., 1998; Mintrop et al., 1999; von Rad et al., 1999; Ivanova, 2000; Klöcker and Henrich, 2006). The modern pteropod distribution in sediments has also been documented from both the eastern and western Arabian Sea and adjacent marginal seas (Herman and Rosenberg, 1969; Hashimi and Nair, 1976; Almogi-Labin, 1982, 1984; Almogi-Labin et al., 1986, 1988; Auras-Schudnagies et al., 1989; Singh et al., 1998, 2001, 2005). However, in the majority of such studies, surface pteropod distribution, was documented only from the shelf and upper slope region (up to ~200–300 m water depth) and thus ACD has not been documented from the eastern Arabian Sea. Therefore, it is pertinent to study the recent pteropod distribution in sediments from the eastern Arabian Sea to delineate ACD. The precise estimates of ACD will not only help to understand the relationship between ACD and OMZ, but also to assess any future shift in ACD in this region as a result of ocean acidification.

1.1. Regional setting

The eastern Arabian Sea is influenced by the monsoon winds, resulting in seasonally reversing coastal currents (Shankar et al., 2002). During summer monsoon season, strong winds induce coastal upwelling off the southern tip of India elevating nutrient concentrations and primary productivity (Wyrtki, 1971, 1973; Lévy et al., 2007). The high surface productivity and restricted ventilation (You and Tomczak, 1993) results in perennial intermediate depth oxygen minimum zone covering the upper slope region (varying in depth from ~150 m to 1200 m) of the entire eastern Arabian Sea (Naqvi et al., 2003). Although no major river drains in the southeastern Arabian Sea, as compared to the Indus, Narmada and Tapti rivers in the northeastern Arabian Sea, a large part of the precipitation in the Western Ghats is drained into this region (Chauhan et al., 2011). The associated terrigenous input is however restricted only to the inner shelf (Hashimi and Nair, 1976; Chauhan et al., 2011). A narrow hypoxic zone develops in the shallow shelf region during the summer monsoon season (Naqvi et al., 2003). During November to February, the atmospheric circulation reverses and the resultant winter monsoon current brings low salinity water from the Bay of Bengal, which reaches up to the central west coast of India (Shankar et al., 2002).

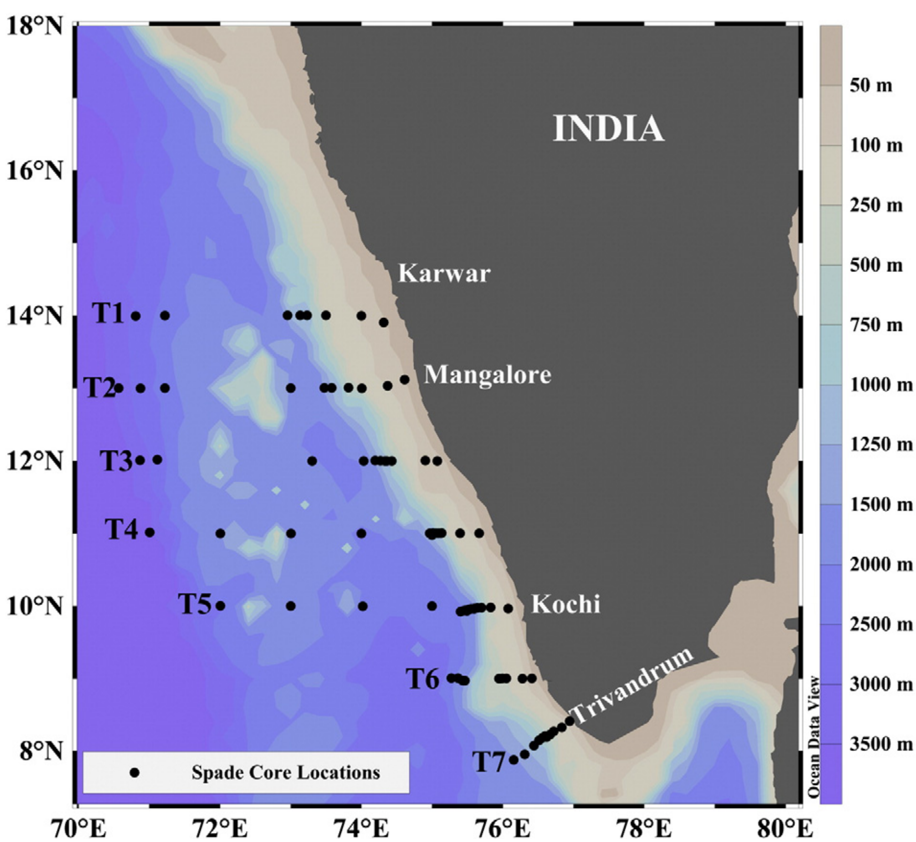

Fig. 1. All the spade core locations along seven transects (T1–T7). The bathymetry is shown in shaded contours and the scale is given on the right side of the figure.

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