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Oxygen isotopic evidence for decrease in calcification rate of *Porites* coral from the Lakshadweep Island

Syed Masood Ahmad*, Sadia Farnaaz, Netramani Sagar, Waseem Raza, Kompally Venkatesham

CSIR – National Geophysical Research Institute, Paleoclimate Lab, Uppal Road, Hyderabad 500 007, India

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ABSTRACT

Reef-building corals are under tremendous physiological stress due to the changing climate and industrial pollution. Several studies have documented rapidly declining coral cover and reduced coral diversity in Indo-Pacific regions. The main threats to coral reefs are caused by increasing sea surface temperature (SST) and ocean acidification. However land-based sources of pollution in coastal regions can also contribute in rapid decline of coral cover. We report here a significant decrease in calcification rate (~10–15%) in a scleractinian coral (*Porites lutea*) collected from a Lakshadweep (Kavaratti) island in the southeast Arabian Sea. Our observation is mainly based on high-resolution oxygen isotopic record and X-radiography of coral. To investigate seasonal changes, a monthly-scale SST record was developed by using oxygen isotopes. The observed reduction in the calcification rate of *Porites* coral from 1989 to 2003 A.D. is attributed to climate change and anthropogenic activity in the vicinity of coral growth. This decrease in calcification rate is consistent with the decline in growth rate of genus *Porites* from the Great Barrier Reef (GBR). Such a reduction in calcification of *Porites lutea* appears to have been caused by the temperature stress, ocean acidification and local environmental pollution. However it is difficult to assign any one particular reason for the observed change.

1. Introduction

Scleractinian (stony) corals are formed exclusively in marine environments in tropical regions. The skeletons of scleractinian corals (e.g. genus *Porites*) provide an unaltered record of the chemical and physical conditions that existed in the surrounding seawater at the time of their formation. Living scleractinian corals provide an excellent archive of paleoclimatic records covering the past few decades to several hundreds of years (Carriquiry et al., 1994; Dunbar et al., 1994; Mcculloch et al., 1994; Cole et al., 2000; Charles et al., 2003). As the growth-rate in these corals is generally high (~1–2 cm/y) they preserve records of past climate, oceanographic and monsoonal changes on weekly to monthly time resolution. Corals therefore provide an exceptional time window for paleoclimatologists to look into many phenomena of ecological, geochemical, climatic, and paleontological interest.

Stable carbon and oxygen isotopes ($\delta^{18}O$ and $\delta^{13}C$) in coral bands are extensively used for tracing past SST, paleomonsoonal, and paleoceanographic changes (Carriquiry et al., 1994; Dunbar et al., 1994; Mcculloch et al., 1994; Charles et al., 1997, 2003; Cole et al., 2000; Gagan et al., 2000; Damassa et al., 2006). Both these isotopic tracers depend on several parameters such as temperature, salinity, cloud cover, river discharge, upwelling, ocean circulation, and metabolic processes (Erez, 1978; Swart et al., 1996; Gagan et al., 2000; Zinke et al., 2004; Grottoli and Eakin, 2007). The skeletal $\delta^{18}O$ is used in decoding relative temperature and salinity variations (Epstein et al., 1953; Weber and Woodhead, 1972; Chakraborty and Ramesh, 1993; Charles et al., 1997; Kim and O'Neil, 1997), whereas $\delta^{13}C$ is mainly used in reconstructing nutrients levels in seawater and metabolic processes in corals (Erez, 1978; Gagan et al., 2000). The skeletal $\delta^{18}O$ values in scleractinian corals of Lakshadweep islands provide valuable paleoclimatic information on extremely high-resolution time-scale because of their high growth rate (~2 cm/y) (Chakraborty and Ramesh, 1993). High growth rate of corals from these islands enables subannual sampling at weekly to monthly resolution. Generally skeletal $\delta^{18}O$ change in seasonal bands of *Porites* varies from 0.19 to 0.23‰/°C (Fairbanks and Dodge, 1979; Chakraborty and Ramesh, 1993, 1997; Cole et al., 1993; Quinn et al., 1993; Cobb et al., 2003; Linsley et al., 2008). In a given coral species, most variability in $\delta^{18}O$ results from sea surface

* Corresponding author.
E-mail addresses: masoodahmads@ngri.res.in, smasoodahmad@rediffmail.com (S.M. Ahmad).

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temperature (SST) and seawater salinity (SSS) (Fairbanks and Dodge, 1979; Cole et al., 1993; Cobb et al., 2003; Linsley et al., 2008; Rixen et al., 2011). However in regions where salinity is relatively constant year-round, the $\delta^{18}O$ signatures primarily record SST changes (Ahmad et al., 2011). Several studies have demonstrated that the $\delta^{18}O$ gradient in Indian Ocean corals are linked to central Pacific SST changes on a variety of time scales (Charles et al., 1997, 2003; Cole et al., 2000; Damassa et al., 2006). Coral record from the southwest Madagascar has shown ENSO and Indian Ocean Dipole (IOD) variability for the last two centuries (Zinke et al., 2004). A significant warming of ~1.3 C° has been reported in the western Indian Ocean since the early 1800 AD (Cole et al., 2000).

In contrast to oxygen isotopes, $\delta^{13}C$ values in coral skeletons are predominantly influenced by the metabolic processes such as the photosynthesis and respiration in the coral polyp (Erez, 1978; Grottoli and Eakin, 2007). Photosynthesis is a light driven metabolic reaction that causes isotope fractionation. The bulk of the photosynthetically fixed carbon is translocated from the zooxanthellae to the coral host (Swart et al., 1996; Grottoli and Eakin, 2007). Therefore, as the rate of photosynthesis increases the skeletal $\delta^{13}C$ increases and vice-versa. In addition to the metabolic processes, skeletal $\delta^{13}C$ is also influenced by ingestion of zooplankton (heterotrophy), dissolved inorganic carbon (DIC) of seawater; coral's spawning events etc. (Erez, 1978; Swart et al., 1996; Gagan et al., 2000; Grottoli and Eakin, 2007). Sometimes centennial-scale decreasing $\delta^{13}C$ trends in scleractinian corals are also linked to anthropogenic changes in atmospheric carbon dioxide (^{13}C Suess Effect) (Dassié et al., 2013 and references therein).

The Lakshadweep Archipelago in the southeast Arabian Sea consists of several small islands between 10 and 12°N and 72–74°E. Kavaratti Island is located about 345 km southwest of the Malabar coast of Indian Peninsula, between Agatti and Andrott islands (Fig. 1). This island is relatively small (around 6 km in length and 1 km in breadth) with a large lagoon. The average annual rainfall in and around Kavaratti island is 3500 mm, mostly during the southwest (SW) monsoon (June–September). Coral reefs around the Lakshadweep islands are considered to be among the most biologically diverse ecosystems (Anu et al., 2007). Isotopic and trace elemental records from scleractinian corals of these islands are very limited (Chakraborty and Ramesh, 1993, 1997; Naqvi et al., 1996; Ahmad et al., 2011). Large changes in physical environment and chemical composition of surface waters around these islands are known to occur in response to SW monsoon forcing, Indian Ocean Dipole and El Nino (Chakraborty and Ramesh, 1993; Ahmad et al., 2011). Lowering in SST during June to September is linked with the SW monsoon-induced upwelling (vertical mixing) which brings colder water to the surface. The monsoon-induced seasonal changes are recorded in isotopic signatures of banded scleractinian corals of these islands (Chakraborty and Ramesh, 1993, 1997; Ahmad et al., 2011).

Several studies have demonstrated that an increase in atmospheric carbon dioxide can significantly reduce coral calcification rate due to a decrease in carbonate ion concentration (Kleypas and Langdon, 2006; Hoegh-guldberg et al., 2007). Massive coral colonies of *Porites* coral from the Great Barrier Reef (GBR) have shown a marked reduction in the linear extension rate and skeletal density during the last few decades (De'ath et al., 2009). This reduction in calcification is consistent with changes in oceanic pH and carbonate ion concentrations (Kleypas and Langdon, 2006). De'ath et al. (2012) have shown a major decline in coral cover of GBR during the last 27 y. The observed decrease in growth and calcification rates of *Porites* coral could also be attributed to the temperature stress. Recently the main causes for this coral mortality in GBR have been assigned to tropical cyclones, coral predation by crown-of-thorns starfish (COTS) and coral bleaching. In contrast, northern part of the GBR showed no overall decline in coral cover. Despite

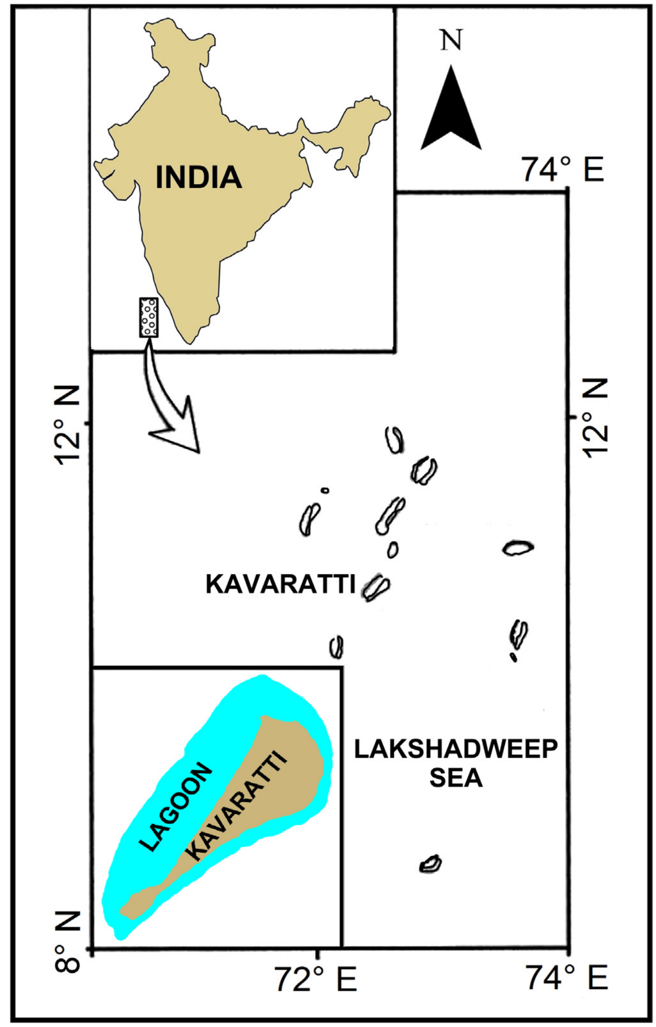

Fig. 1. Location map of Kavaratti Island.

the known links between coral mortality with elevated temperature and ocean acidification, the response to rapid increase in anthropogenic induced climatic changes on various species of scleractinian corals is still debated.

This paper provides first direct evidence of a marked reduction in calcification rate of reef-building corals growing in the Lakshadweep islands. More specifically, this study aims to study effects of climate and anthropogenic changes on scleractinian corals from these islands.

2. Methodology

A coral sample was obtained by underwater drilling of a live *Porites* boulder during low tide in November, 2003. Drilling was carried out at a water-depth of ~1 m from inside the lagoonal area of Kavaratti Island. A 0.7 cm thick slice was then made from the drilled coral core along the growth axis, cleaned with distilled water in an ultrasonic water bath, and subjected to X-radiography. Visual examination of the coral X-radiograph indicates alternating high and low density bands (Fig. 2). The chronology was established by designating the minimum $\delta^{18}O$ value in a given year to April–May and maximum $\delta^{18}O$ to July–August. The age of the growth bands (high density and low density bands) was established by assigning the sample collection time as the first year (2003 in this case). SST in this region is lowest during July–August due to monsoon-induced