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Mid-Holocene Indian Summer Monsoon variability off the Andaman Islands, Bay of Bengal

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ABSTRACT

A sediment core retrieved from the Andamans Forearc Basin (AFB) near Landfall Island, North Andaman, provides a record of sediment provenance and climate change during the mid to late Holocene. Radiocarbon ages ranging from 6078 to 1658 indicate that the core represents the interval from 6500 BP to the present. Grain size variation indicates a cyclic variation of wetter and drier conditions corresponding to changes in intensity of the Indian Summer Monsoon (ISM), which was at greatest intensity near 6400, 5300 and 3300–3000 BP. Geochemical parameters including abundance of $CaCO_3$, εNd and $\delta^{18}O$ in *Globigerinoides ruber* are consistent with a long-term trend from cooler, wetter conditions to the warmer, drier conditions at present. Chemical weathering intensity, which lags behind climate changes on land, shows a pulse of highly weathered sediment deposited at about 4000 BP. During the short-duration pulses of intense monsoon activity, sandy sediment was supplied from the Andaman Islands. The Irrawaddy, Salween, and Sittang rivers of Myanmar are the secondary sediment sources for the study area.

1. Introduction

The Indian monsoon is one of the most anticipated and studied weather phenomena of the Asian subcontinent. It has an immense socio-economic impact in India and all around South Asia because of its tremendous effects on agriculture, flora, and fauna. The Indian Summer Monsoon (ISM) supplies not only the large rivers of India such as the Ganga, Brahmaputra, and peninsular rivers, for example the Mahanadi, Godavari, Krishna, and the Cauvery, but also the large rivers in Myanmar, the Irrawaddy, Salween and Sittang. These rivers dump large quantities of sediment into the Bay of Bengal (BOB). Since the Pleistocene, the intensity of the ISM has fluctuated significantly (Fontugne and Duplessy, 1986). The fluctuations in the magnitude of the monsoon influence the formation and release of clays and detritus, temporally and spatially. These sediments hold the record of the mode of occurrence, tectonic settings, and the environment under which it has been deposited. BOB marine sediments are made up of the weathering products from continents (Windom, 1976), so changes, shifts, and weathering intensity in source areas are archived in these sediments.

Ocean sediments hold a variety of potential paleoclimate proxies in lithology such as carbonates, organic and detrital materials, and biogenic opals (Wei et al., 2003). To reconstruct the past climate, ocean, paleocirculation and continental weathering history, several proxies such as palynology (pollen and spores, phytoliths) (Braccoa et al., 2011), clay mineralogy (Das et al., 2013), micropaleontology (foraminifera) and stable isotopes of C and O (Chauhan, 2003; Nath et al., 2012), and εNd of seawater (Gourlan et al., 2008) are commonly used. For example, biogenically-related elements and magnetic properties of sediments have been useful in reconstructing paleoclimate shifts in the Bay of Bengal and the Andaman Sea (Colin et al., 1998). Geochemical proxies that have been used in the region include those sensitive to redox conditions, such as Mn, (Mangini et al., 1990; Dymond et al., 1992) and biogenic/nonbiogenic scavenged Ti and Al present in pelagic sediments (Goldberg and Arrhenius, 1958; Murray and Leinen, 1996; Klump et al., 2000). Fluctuations in the Na/Al, Mg/Al, Ca/Al ratios and chemical weathering intensity (CWI) values of the marine sediments are also often used to delineate wet and dry conditions in regions surrounding the ocean basins (Wei et al., 2003; Sun et al.,

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2009). Oxides such as CaO, MgO, and Na_2O are considered more soluble and mobile, while Al_2O_3, SiO_2, and TiO_2 are considered to be more insoluble and resistant (Mackereth, 1966; Engstrom and Wright, 1984). Sun et al. (2009) proposed chemical weathering intensity (CWI) an alternate to chemical index of alteration (CIA) to understand the intensity of weathering and apparently wet or dry conditions. CWI was calculated using the molecular proportion of the oxides following the equation: $\mathrm{CWI} = (\mathrm{CaO} + \mathrm{MgO} + \mathrm{Na_2O})/\mathrm{Al_2O_3} \times 100$. Generally, higher values of CWI indicate stronger weathering and presumably wetter conditions and a strong monsoon, while low CWI values reflects less intense weathering and drier conditions (Sun et al., 2009). For example, around the South China Sea (Wei et al., 2003) from 9000 to 6700 BP, lower values of Na/Al, Ca/Al, and Mg/Al ratios supported by low CWI values point towards weak monsoon conditions (Sun et al., 2009).

The radiogenic isotope ratios and composition of dissolved trace metals ($^{147}Sm/^{144}Nd$, Mn/Ca, Nd, Hf, Sm) in planktic foraminifera and in Mn-oxyhydroxide coatings on fish teeth are also well studied (e.g. Staudigel et al., 1985; Vance and Burton, 1999; Burton and Vance, 2000) as means of deciphering climate shifts. The residence times of Nd, Hf and Pb in seawater are shorter than the mixing time of the global ocean ($\leq$1000 years), making these isotopic systems suitable for identifying changes in erosion and past climate at large scale (e.g. Burton et al., 1997; Gourlan et al., 2008), but also at a time scale of several thousand years (Rutberg et al., 2000; Piotrowski et al., 2004, 2009; Stoll et al., 2007; Gourlan et al., 2010).

The Bay of Bengal (BOB) is a potential area for deciphering the paleoclimate changes in the Indian subcontinent (Chauhan and Suneethi, 2001), as it receives a very large freshwater influx and sediments (2000 million tons annually) from Himalayan and Indian peninsular rivers (Fig. 1) during the northeast and the southwest monsoons (Chauhan and Vogelsang, 2006). Sediment deposition in the BOB appears to be dominantly detrital in origin rather than biogenic or diagenetic. The detrital input relates directly to physical and chemical erosion of the surrounding terrains and is strongly dependent on the monsoon intensity, especially the southwest or summer monsoon (Sarin et al., 1979; Bhushan et al., 2007; Achyuthan et al., 2013). Several paleoclimatic studies have been carried out on marine sediment cores retrieved from the BOB (Chauhan and Vogelsang, 2006; Rashid et al., 2007, 2011; Gourlan et al., 2010 and references therein). However, to date no high-resolution data have been presented from the Andaman fore-arc basin.

Landfall Island lies in the Andaman forearc basin (AFB), an arcuate trough in the eastern Bay of Bengal, with the Sumatran Archipelago to the south–southeast and the Indo-Burmese ranges to the north–northeast. The Andaman-Nicobar group of islands constitutes a part of an island arc system formed by convergence of the Indian and Southeast Asian plates (Misra and Roy, 1984). The Andaman-Nicobar ridge is an imbricate stack of fault slices and folds consisting of flakes of seafloor ophiolites and the overlying sediments, capped thin beds of Quaternary sediments. Structural studies in Andaman fore-arc basin (AFB) revealed that movement along N–S normal and E–W strike-slip faults resulted in the development of a fore-arc basin in which Oligocene and Mio-Pliocene sediments were deposited (Misra and Roy, 1984; Pal et al., 2003). The fore-arc region, to the west of the West Andaman Fault (WAF) and the Sumatran fault system, immediately overlies the rupture zone (Ammon et al., 2005; Lay et al., 2005). Thick Neogene-Quaternary sedimentary deposits of terrestrial origin are present in the Andaman Islands fore-arc basin (Wang, 1999). In addition to the detrital sediments, volcanic rocks (andesite and dacite composed of plagioclase, orthopyroxene, clinopyroxene, olivine, titano-magnetite, hornblende, and minor quartz) occur on North Andaman Island and Landfall Island (Ray et al., 2011). In this paper we present a detailed study on the sediment texture, grain size, geochemical data, carbon and oxygen isotope on planktic foraminifera (*Globigerinoides ruber*) and Nd isotopic composition of a sediment core collected close to Landfall Island from a water column of 250 m (Fig. 1) to infer important paleoenvironmental shifts from the mid-late Holocene.

2. Materials and methods

A gravity sediment core nearly 124 cm in length was retrieved along with two short cores (nearly 80 cm in length) near Landfall Island at (13°47″15.05″N, 92°53″47.96″E) during the Sagar Nidhi cruise, organized by National Institute of Ocean Technology (NIOT), Chennai, and Institute of Ocean Management (IOM), Anna University, Chennai, in June 2008 (Fig. 1). All three sediment cores were collected within 15 m of each other and were examined for color using the Munsell colour chart, for texture, for sorting and for presence of heavy minerals and occurrence of sedimentary structures. Comparison of the three cores provided information about consistency of the sediment record over short distances. As all three sediment cores were similar; the longest sediment core was considered as representative. It was sub sampled at 2 cm intervals, and the subsamples were dried at 50 °C and preserved for analysis of sediment texture, Nd isotopic composition, geochemistry, stable isotopes of C and O (in *G. ruber*) and radiocarbon dating. Five organic-carbon rich sediment samples were radiocarbon dated by liquid scintillation counting following acid-base-acid pretreatment at the Department of Geosciences, University of Arizona, Tucson, USA (Table 1 and Fig. 2). A reservoir age correction of 400 years was applied, and the dates were calibrated using Calib 6.0 (Stuiver et al., 2010) following Stuiver and Reimer (1993). Sediment textural analysis was carried out on twenty three samples using the pipette method, following Krumbein and Pettijohn (1938). Organic matter (OM) content was analyzed following the protocols of Loring and Rantala (1992) (Fig. 3).

Table 1
^{14}C and reservoir calibrated ages analysed at selected depths of the marine sediment core.

S.no.	Lab ID	Depth (cm)	^{14}C age (years BP)	Reservoir calibrated age (years BP)
1.	A15142	14–16	2085 ± 120	1658
2.	A 15143	34–36	3360 + 280/−270	3179
3.	A 15144	68–70	4285 + 165/−160	4376
4.	A15145	86–88	5035 + 130/−125	5402
5.	A 15189	110–112	5680 ± 170	6078

Calcium carbonate ($CaCO_3$) percentage was determined by calculating the mass difference resulting from treatment the sediment samples with 10% HCl, following Carver (1971) (Fig. 3). Carbonate-free samples representing the entire length of the core were analyzed for major oxides and trace elements using the XEPOS XRF Spectrometer (powder method) at the Department of Geology, University of Pune, Pune. The instrument was calibrated using international reference samples such as GBW07108 (rock), GBW 03108 (limestone), NIST 1413 (sand, high alumina), and BCS 394 (bauxite). The major oxides data (Table 2) were then used in calculating the chemical weathering intensity (CWI) using the molecular proportion of the oxides following (Sun et al., 2009) (Fig. 3) and for calculating the correlation matrix presented in Table 3). For the stable C and O isotope analyses, planktic foraminifera *(G. ruber = G. ruber)* were handpicked from each of 31 samples, which covered the entire sediment core. For this purpose,