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Monsoon-influenced variation in productivity and lithogenic sediment flux since 110 ka in the offshore Mahanadi Basin, northern Bay of Bengal

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ABSTRACT

The Indian monsoon drives seasonal changes in precipitation and weathering across India as well as circulation and productivity in the northern Indian Ocean. Variation in paleo-monsoon intensity and its effect on productivity and lithogenic fluxes is poorly constrained in the Bay of Bengal. In this paper, we present analysis of a sediment record from the offshore Mahanadi Basin recovered during the Indian National Gas Hydrate Program Expedition 01 (Site NGHP-01-19B). We reconstruct variation in biogenic and lithogenic components during the last 110 kyr using measurements of total organic carbon (TOC), total nitrogen (TN), TOC/TN, $CaCO_3$, biogenic silica (BSi), δ^{13}TOC, δ^{15}TN, bulk mineralogy from X-ray diffraction, bulk and lithogenic grain size distribution, magnetic susceptibility, bulk density, and Ca, Br, and Zr/Rb from x-ray fluorescence (XRF). The mass-accumulation rate (MAR) of $CaCO_3$, a function of marine productivity, drastically increased between 70 and 10 ka and is correlated to previously-documented elevated Asian dust fluxes and increased Bay of Bengal salinity during a weakened southwest monsoon. Decreased freshwater input over this period likely diminished stratification, allowing for increased mixing and nutrient availability, thus enhancing productivity despite weaker southwest monsoon winds. The MAR of lithogenic material is highest during the Holocene suggesting that sediment supply driven by monsoon intensity is a stronger control on margin sedimentation than sea level at the Mahanadi Basin. Over the entire record, magnetic susceptibility and XRF Zr/Rb are strongly correlated with $CaCO_3$, suggesting higher primary mineral input under a weakened southwest monsoon. TOC/TN and δ^{13}TOC also increase under glacial conditions, suggesting higher relative input of terrestrial C4 organic matter. These results highlight the Mahanadi Basin as a supply-dominated margin where terrigenous sedimentation is strongly influenced by monsoon intensity, and that productivity is limited by variation in monsoon-driven stratification on glacial-interglacial timescales rather than a direct response to monsoon winds.

1. Introduction

The northern Indian Ocean and peninsular India are influenced by monsoon-driven environmental variability occurring on orbital and suborbital timescales (e.g. Clemens and Prell, 1990; Kutzbach, 1981; Overpeck et al., 1996; Prell and Kutzbach, 1987; Sirocko et al., 1993). The modern Asian monsoon system varies in strength and precipitation across the region, and can be generally subdivided into the Indian, East Asian, and western North Pacific monsoons (Wang et al., 2001; Wang and Ho, 2002). The Indian monsoon system is a seasonal reversal in prevailing winds as a response to the migration of the intertropical convergence zone (ITCZ) driven by insolation of the Indian subcontinent and Tibetan Plateau (Chao, 2000; Chao and Chen, 2001; Gadgil, 2003). The summer monsoon, or southwest (SW) monsoon, occurs during the northward migration of the ITCZ and the resultant southwesterly winds result in wet, higher precipitation conditions over the Indian region. The winter monsoon, or northeast (NE) monsoon, occurs during the southward migration of the ITCZ and the resultant northeasterly winds produce drier conditions over the Indian region. The monsoon is influenced externally by teleconnections with

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northern high latitudes (e.g. Gupta et al., 2003; Schulz et al., 1998; Sirocko et al., 1996; Wang et al., 2001), Pacific Ocean (e.g. Krishnamurthy and Goswami, 2000; Kumar et al., 1999; Mehta and Lau, 1997), and Southern Hemisphere climate (Clemens and Oglesby, 1992; An et al., 2011). Uplift of the Tibetan Plateau during the Late Cenozoic intensified the Asian monsoon and influenced global climate (Molnar et al., 1993; Raymo and Ruddiman, 1992; Ruddiman and Kutzbach, 1989; Zachos et al., 2001). The specific timing of uplift-driven intensification remains unresolved, but ranges between 24 and 2.6 Ma (e.g. Clift et al., 2004; Clift, 2006; Nie et al., 2008; An et al., 2001).

The Asian monsoon influences 11 of the 20 rivers with the highest sediment discharge to the oceans (Milliman and Meade, 1983), and also acts a driver of marine productivity (e.g. Brink et al., 1998; Brock et al., 1991; Curry et al., 1992; Liu et al., 2002), thus making the monsoon a major factor in terrigenous and marine biogenic sedimentation in the northern Indian Ocean and western Pacific Ocean. Past changes in the monsoon, on time scales ranging from decadal to Myr, have been investigated through a wide array of paleoenvironmental and paleoceanographic proxies applied to records including marine sediments (e.g. Clift et al., 2008; Emeis et al., 1995; Oppo and Sun, 2005; Prell et al., 1980; Weber et al., 1997), loess and paleosol deposits (e.g. An et al., 1991; Ding et al., 2001; Guo et al., 2004; Kukla et al., 1988; Maher and Thompson, 1995; Quade and Cerling, 1995), speleothems (e.g. Burns et al., 2002; Dykoski et al., 2005; Fleitmann et al., 2007; Wang et al., 2001, 2008; Zhao et al., 2010), ice cores (e.g. Thompson et al., 2000), lake sediments (e.g. Enzel et al., 1999; Morrill et al., 2006; Wei and Gasse, 1999; Xiao et al., 1995), tree rings (e.g. Feng et al., 1999; Hughes et al., 1994), and corals (e.g. Charles et al., 2003; Tudhope et al., 1996). Like the modern monsoon system, regional variation in the monsoon system can be reflected in paleomonsoon records (Wang et al., 2003). Many unresolved questions remain in the understanding the past and continued evolution of the monsoon (see Wang et al., 2005 for a review of these issues and proxy methods), particularly involving uncertainties in the timing of the monsoon (e.g. Caley et al., 2011; Clemens and Prell, 1990, 2007; Clemens et al., 2008, 2010; Kutzbach, 1981; Ruddiman, 2006).

As an archive for paleo-monsoon records, the northern Indian Ocean, the Bay of Bengal is relatively under-sampled compared to the Arabian Sea. In the Arabian Sea, the strength of the monsoon has been shown to influence terrigenous sediment flux (e.g. Caley et al., 2011; Clemens and Prell, 1990, 1991; Clift and Gaedicke, 2002; deMenocal et al., 1991; Kumar et al., 2005), sea surface temperature (SST) and salinity (SSS) (e.g. Anand et al., 2008; Govil and Naidu, 2010; Prell et al., 1980) and productivity (e.g. Altabet et al., 2002; Gupta et al., 2011; Hermelin and Shimmield, 1995; Kroon et al., 1991; Reichart et al., 1998; Schulz et al., 1998; Ziegler et al., 2010). Fewer records exist in the Bay of Bengal; however, the influence of the monsoon in the Bay of Bengal has been observed using terrigenous flux proxies (e.g. Burton and Vance, 2000; Colin et al., 1998; Weber et al., 1997), organic geochemical proxies (e.g. Fontugne and Duplessy, 1986; Ponton et al., 2012), and proxies of SST and salinity (e.g. Cullen, 1981; Prell et al., 1980; Govil and Naidu, 2011; Rashid et al., 2011; Schulenberg, 2011) that indicate monsoon-influenced changes in surface ocean conditions and terrestrial weathering on glacial-interglacial and suborbital timescales. The research presented here using a sediment core recovered during the Indian National Gas Hydrate Program Expedition 1 (NGHP01) provides an opportunity to investigate variability in lithogenic and biogenic sedimentary constituents in the western Bay of Bengal, as potential effects of monsoon-induced changes in erosion/weathering and biological productivity.

2. Geologic and oceanographic setting

2.1. Tectonic setting and terrigenous inputs

The Mahandi Basin is a sedimentary basin on the eastern margin of India formed during the Jurassic rifting of Gondwanaland (Rao et al., 1997; Sastri et al., 1981; Subrahmanyam et al., 2008). The basin extends both onshore and offshore, and the post-rifting evolution of the basin has involved multiple marine transgressions and regressions (Fuloria, 1993). The Mahanadi River drains the Precambrian Eastern Ghat province (Rickers et al., 2001) including one of the richest mineral belts on the Indian subcontinent, resulting in higher concentrations of trace metals in suspended river sediments compared to other rivers in peninsular India (Chakrapani and Subramanian, 1990a). Kaolinite, chlorite, quartz, dolomite, and minor montmorillonite and illite are characteristic suspended sediments discharged by the Mahanadi River to the Bay of Bengal (Chakrapani and Subramanian, 1990a; Subramanian, 1980). The Mahanadi River discharges approximately 15 × 10^6 metric tons of sediment to the Bay of Bengal each year, dominated by the coarse silt-size fraction (Chakrapani and Subramanian, 1990b). The monsoon is the primary control of present-day sediment discharge in the Mahanadi Basin with 90% of the annual sediment delivery to the Bay of Bengal occurring between July and September during the summer monsoon (Chakrapani and Subramanian, 1990b).

2.2. Physical oceanography and biological productivity

Surface ocean circulation in the Bay of Bengal is driven primarily by the Indian monsoon, and consists of seasonally-reversing gyres (Potrema et al., 1991; Schott and McCreary, 2001; Schott et al., 2009; Shetye et al., 1993; Varkey et al., 1996). These circulation patterns result in a seasonal reversal of the East India Coastal Current (EICC) along the western boundary of the Bay of Bengal: northward during the SW monsoon and spring inter-monsoon, and southward during the NE monsoon and fall inter-monsoon (Shankar et al., 1996). During the SW monsoon, Ekman-driven coastal upwelling occurs along the eastern peninsular Indian margin, although this upwelling is limited to within 40 km of the coast due stratification from enhanced freshwater input (Shetye et al., 1991). These major circulation patterns initiate mesoscale eddy currents in all seasons (e.g. Babu et al., 1991, 2003; Nuncio and Prasanna Kumar, 2012; Prassana Kumar et al., 2004 Shetye et al., 1993). These seasonal variations also generate Kelvin waves along the east coast of India, which in turn instigate propagation of Rossby waves (Potrema et al., 1991; Yu et al., 1991) that can also initiate the incursion of the Southwest Monsoon Current into the Bay of Bengal east of Sri Lanka (Vinayachandran et al., 1999) during the summer monsoon. Intermediate water masses in the Bay of Bengal are sourced from primarily Indonesian Intermediate Water, Antarctic Intermediate Water and Red Sea Intermediate Water (You, 1998; Sengupta et al., 2013). Below 1500 m, deep waters are derived from beyond the northern Indian Ocean (Mantyla and Reid, 1995), but primarily composed of Indian Ocean Deep Water (Varkey et al., 1996; Sengupta et al., 2013). Sediments in the Bay of Bengal are a source of nutrients and a sink of oxygen for bottom water (Broecker et al., 1980).

Seasonal variation in precipitation results in a large, seasonally-shifting salinity gradient in the surface waters of the Bay of Bengal. Annual average salinities in the mixed layer range from 27 to 35‰ decreasing from the northern reaches of the bay to 5° N (Antonov et al., 2010; Talley, 2013; Varkey et al., 1996). This salinity gradient becomes more extreme during the summer monsoon due to increased precipitation, ranging from 21 to 35‰.