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Invited review

Climatic control of sediment transport from the Himalayas to the proximal NE Bengal Fan during the last glacial-interglacial cycle

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ABSTRACT

Clay mineralogy, siliciclastic grain-size, major elements, $^{87}Sr/^{86}Sr$, and εNd analyses of deep-sea sediments cored in the north-eastern Bay of Bengal are used to reconstruct evolution of detrital sources and sediment transport to the proximal part of the Bengal deep-sea fan during the last climatic cycle. εNd values (−13.3 to −9.7) and $^{87}Sr/^{86}Sr$ ratios (0.721–0.733) indicate a mixture of sediments originating from the Ganges-Brahmaputra rivers and the Indo-Burman ranges. Interglacial Marine Isotopic Stages (MIS) 5 and 1 are associated with a higher contribution of sediments from the Ganges-Brahmaputra river system than is the case for glacial MIS 6, 4, 3, and 2. Siliciclastic grain-size combined with Si/Al and Si/Fe ratios indicate coarser glacial sediments with numerous turbidite layers. Glacial turbidite layers display similar clay mineralogical compositions to hemipelagic sediments. Only few of turbidite layers (MIS 6, 4, and 2) are slightly unradiogenic (εNd −13.3), suggesting a higher contribution of Ganges-Brahmaputra river sediments. Independently of changes in the sedimentary sources, the smectite/(illite + chlorite) ratio of cores located on the NE Bengal Fan indicates higher inputs of primary minerals (illite and chlorite) from the highlands of the river basins (relief) during glacial MIS 6, 4, 3, and 2 and an increased contribution of pedogenic minerals (smectite and kaolinite) during interglacial MIS 5 and 1. Maximum smectite/(illite + chlorite) ratios during the warm sub-stages of MIS 5 suggest an intensification of summer monsoon rainfall associated with higher rates of physical erosion of the Indo-Gangetic flood-plain and/or dominant summer hydrological conditions transporting a higher proportion of sediments deriving from the Ganges-Brahmaputra rivers to the NE Bengal Fan. In addition, a higher production of smectite in soils of the Indo-Gangetic flood-plain during periods of intensification of monsoon rainfall cannot be excluded.

1. Introduction

The Ganges-Brahmaputra river system is characterized by one of the highest sediment discharge (~1 × 10^9 t yr^{-1}) and physical denudation rates (~760–930 mm km^{-2} yr^{-1}) in the world (Milliman and Meade, 1983; Milliman and Syvitski, 1992; Summerfield and Hulton, 1994; Galy and France-Lanord, 2001), mainly controlled by tectonic activity, glacier scouring and Indian monsoon rainfall. The Indian monsoon results from differential land-sea heating and induces seasonal variations in precipitation and runoff, as well as a seasonal reversal in wind direction (Webster, 1987). 95% of the annual Ganges-Brahmaputra river sediments are transferred during the summer monsoon rainfall (Singh et al., 2007). Today, about 30% of the sediments exported from the Himalayas are delivered to the lower abandoned delta plain and/or the Bengal Fan (including the Swatch of No Ground, Goodbred and Kuehl, 1999, 2000; Rogers, 2012). Due to large freshwater influx during the wet summer monsoon, a plume of sea

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surface salinity reduction (~7‰) can be observed up to 15°N of latitude in the Bay of Bengal (Levitius et al., 1994). This large river basin is very reactive to monsoon rainfall and sediments from the Ganges-Brahmaputra river system and the Bengal Fan: as a result it constitutes an ideal area to establish the link between erosion and climate. Up to now, sediments transported from the Ganges-Brahmaputra river system has been intensively studied (e.g. Galy et al., 1999; Galy and France-Lanord, 1999; Singh et al., 2008; Garzanti et al., 2011a,b; Lupker et al., 2013) while sediments deposited on the Bengal Fan remain relatively poorly documented.

The Bengal deep-sea fan, which is the largest submarine fan in the world (3000 km N-S and 1400 km E-W, Curray et al., 2003), is mainly fed in the north by the Ganges-Brahmaputra river system (Curray and Moore, 1971; Curray et al., 2003) and, to a lesser extent, by rivers from the Indo-Burman ranges (Arakan coastal rivers estimated at around 130 × 10^6 t yr^{-1}, Stoll et al., 2007), the Irrawaddy river (260–350 × 10^6 t yr^{-1}, Ramaswamy et al., 2004; Rao et al., 2005) in the east and by several Indian rivers (Mahanadi: 60 × 10^6 t yr^{-1}, Godavari: 160 × 10^6 t yr^{-1}, Krishna: 16 × 10^6 t yr^{-1}, Ahmad et al., 2009; Tripathy et al., 2011) in the west. Several N-S valleys have been observed on the surface of the fan, but today only one is connected to the main submarine canyon: ''the Swatch of No Ground'' (Emmel and Curray, 1984) (Fig. 1). It has been estimated for the Holocene that about one third of the total load of the Ganges-Brahmaputra river system accumulates on the shelf, and that the bulk of the remaining sediments rapidly passes through the Bengal shelf (Kuehl et al., 1989, 1997; Goodbred and Kuehl, 1999) and is transferred to the deep-sea fan by turbidity currents via the Swatch of No Ground. Fine sediments from the Ganges-Brahmaputra river system and other rivers are also then transported by surface and intermediate currents that reverse seasonally in the northern Bay of Bengal during the summer- and winter Indian monsoon (Chauhan and Vogelsang, 2006).

The role of Himalayan orogeny and global climate on the long term evolution of the erosion has been intensively investigated through the Neogene (e.g. France-Lanord et al., 1993; Derry and France-Lanord, 1996; France-Lanord and Derry, 1997; Galy et al., 1999; Clift et al., 2002, 2008; Clift, 2006). However, the variability of physical erosion, the flux and the type of sediments exported to the deep-sea fan by the Ganges-Brahmaputra river system during the Quaternary remain poorly documented. At such a time scale, changes in the strength of the Indian monsoon rainfall and in sea-level are driven by mechanisms with different periodicities and which represent important processes driving physical erosion and chemical weathering of the Himalayas, river discharge, turbidity transport and sediment supply to the Bengal Fan. However, the climatic control on this complex sedimentary system during the late Quaternary also remains poorly constrained. Much of the sediments derived from erosion of the Himalayas and Indo-Burman ranges are well preserved, especially in the proximal part of the Bengal Fan, providing an opportunity to examine how clastic sediments are transported to the Bengal Fan by paleo-environmental changes (Derry and France-Lanord, 1996; Colin et al., 1999; Lupker et al., 2013). Previous studies have established that today, in the northern part of the Bay of Bengal, only the western part of the Bengal Fan is still active (presence of a single active valley), whereas the eastern part is mainly composed of abandoned channels (Emmel and Curray, 1984; Curray et al., 2003). The Bengal Fan displayed active growth during the Holocene, with the rapid development of the main western channel-levee system, which presumably started about 12,800 years ago (Weber et al., 1997). This active valley is the main transfer route of Himalayan material to the Bengal Fan at least during the Holocene (Kuehl et al., 1989; Weber et al., 1997; Lupker et al., 2013).

The active channel has shifted during the Quaternary, and the coexistence of several active channels during specific periods cannot be excluded. These changes can be related to variations in the morphology of the rivers feeding the Bay of Bengal (Curray et al., 2003). Curray et al. (2003) suggested that the eastern part of the Bengal Fan was fed by an active valley (named E4 channel by Curray et al., 2003) until 125 kyr BP. However, the north-eastern Bay of Bengal, is characterized by mixed and complex sources with a change between the last glacial maximum (LGM) and the Holocene (Colin et al., 1999). These variations have been attributed to a modification of the dominant surface circulation pattern induced by changes in the relative intensity of the summer and winter monsoons. During glacial periods, an increase of the terrigenous input has been observed and is attributed to an intensification of physical erosion on the Himalayas and/or an increase in the export of sediments to the proximal Bengal Fan during sea-level low stand (Colin et al., 2006). In addition, it has been suggested that variations in the ocean current patterns through time control sediment provenances in the distal eastern Bay of Bengal and in the Andaman Sea (Ahmad et al., 2005; Awasthi et al., 2014). Higher contributions of sediments from the Himalayan system are observed during periods of strengthening of the summer Indian monsoon, whereas during the LGM, due to a southward shift of the locus of the SW monsoon rainfall belt to Myanmar, there was an increase in sediment supply derived from the Indo-Burman Ranges (Ahmad et al., 2005; Awasthi et al., 2014).

In this study, high-resolution investigations of the clay mineralogy, grain-size and major elements, combined with Sr and Nd isotopic compositions, have been conducted on two deep-sea gravity cores located in the proximal Bay of Bengal for the last glacial-interglacial cycle (last 182 kyr) in order to reconstruct the temporal variability of sediment export to the proximal north-eastern Bengal Fan and its potential links to climatic changes (Indian monsoon and/or sea-level changes). Previous studies have shown that Sr and Nd isotopic compositions in deep-sea sediments of the Bay of Bengal are particularly useful for distinguishing between the main sedimentary sources feeding the Bengal Fan (Bouquillon et al., 1990; France-Lanord et al., 1993; Fagel et al., 1994, 1997; Colin et al., 1999, 2006; Galy and France-Lanord, 2001; Gourlan et al., 2010). Mineralogy of the clay size-fraction has been used to establish the state of chemical weathering of the detrital material (Fagel et al., 1994, 1997; Colin et al., 1999, 2006; Lupker et al., 2013) and when combined with Sr and Nd isotopic compositions, allows us to constrain sedimentary sources under strong erosion within river basins (Colin et al., 2010). Siliciclastic grain-size, combined with major elements, useful for constraining in order to constrain sediment transport dynamics to the Bengal Fan.

2. Material and methods

2.1. Sediments

Core MD12-3412 (Location: 17°10′94″N; 89°28′92″E. Length: 32.2 m) was collected at a water depth of 2368 m on the north-eastern part of the Bay of Bengal during the MD191/MONOPOL expedition of the French R/V Marion Dufresne II in 2012. Core MD77-180 (Location: 18°28′N, 89°51′E. Water depth: 1986 m) was collected during the OSIRIS III expedition of the French R/V Marion Dufresne I in 1977 (Fig. 1). These cores were retrieved near the continental slope, in the upper part of the Bengal deep-sea fan (Emmel and Curray, 1984; Curray et al., 2003) (Fig. 1). The lithology of these cores is mainly characterized by intercalated layers of clay and silt and the sediment accumulation record is a combination of relatively continuous hemipelagic deposition and episodic sediment gravity-flow deposition mainly observed during glacial periods. 240 samples were taken on the top part of core MD12-3412