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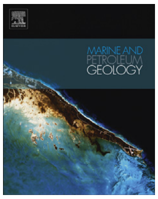

Long-timescale variation in bulk and clay mineral composition of Indian continental margin sediments in the Bay of Bengal, Arabian Sea, and Andaman Sea

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ABSTRACT

This study documents X-ray diffraction results from bulk powders and oriented clay-size aggregates using samples from sites drilled and cored during the Indian National Gas Hydrate Expedition 01 (NGHP01). These sites are located in the Krishna–Godavari Basin, Mahanadi Basin, and Andaman accretionary wedge of the Bay of Bengal, and the Kerala-Konkan Basin of the Arabian Sea. Calcite is more abundant at the pelagic sites of the Andaman Sea and Kerala-Konkan Basin, which is consistent with previous studies of biological productivity and dilution by lithogenous influx. Hemipelagic sediments in the Krishna–Godavari Basin and Mahanadi Basin are comprised primarily of smectite-rich and illite-rich clay mineral assemblages, respectively. We attribute those contrasts to differences in detrital sources between the Deccan basalts (smectite sources) and Precambrian rocks of the Eastern Ghats Belt; those sources remained consistent over the entire history of sedimentation (0–9 Ma). Higher quartz content in the Mahanadi Basin and higher feldspar content at the Krishna–Godavari Basin reinforce these interpretations of detrital provenance. Smectite is the most abundant clay mineral in the Andaman Sea sediments likely due to weathering of volcanic sources along the Sunda Arc. Strata from the Kerala-Konkan Basin show a shift at 23 Ma from a smectite–kaolinite clay mineral assemblage to an increasingly illite-rich assemblage. We also see steady decreases in kaolinite and increases in chlorite and quartz over the 30-Myr record, which indicates increasing influences of material derived from physical weathering. The higher abundance of fully hydrated smectite in the Krishna–Godavari Basin may play a minor role in gas hydrate formation by sustaining higher permeabilities at any given value of mudstone porosity or void ratio.

1. Introduction

Sedimentary environments of the northern Indian Ocean are influenced by dynamic tectonic and climatic conditions that link the uplift of the Tibetan Plateau and Himalayas and development of the Indian monsoon (e.g., Clift et al., 2008; Curray, 1994; Molnar et al., 1993). Himalayan uplift and monsoon variation result in changes in provenance and weathering that are reflected as stratigraphic variation in mineralogy in marine records over tectonic and orbital timescales (e.g., Brass and Raman, 1990; Debrabant et al., 1993; Krissek and Clemens, 1991; Liu et al., 2003). Sedimentary basins along the Indian margin are host to accumulations of gas hydrate (Collett et al., 2008; Jaiswal et al., 2012; Lee and Collett, 2009; Mazumdar et al., 2014; Ramana et al., 2009; Rees et al., 2011). These basins also record the effects of past monsoon variation (Ponton et al., 2012; Phillips et al., 2014; Rashid et al., 2011; Tripathy et al., 2011).

Bulk and clay mineral abundances in marine sediments are useful indicators of detrital provenance and dispersal patterns (e.g., Forsberg et al., 1999; Moros et al., 2004; Underwood and Pickering, 1996; Yuste et al., 2004), as well as paleoclimatic conditions in the source areas (e.g., Singer, 1984; Thiry, 2000). Smectite-group

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minerals (e.g. montmorillonite, nontronite, saponite) can be detrital or authigenic in origin; they are widely regarded as chemical weathering products of volcanic rocks and pedogenesis in arid-to-semiarid climates, whereas kaolinite is a product of intense leaching in humid tropical soils (Biscaye, 1965; Chamley, 1989, 2001). In this paper, we refer to smectite-group minerals simply as smectite. Chlorite and illite are formed via mechanical weathering of plutonic, metamorphic, and sedimentary rocks in continental areas (Chamley, 1989).

The occurrence of marine gas hydrate on continental margins is controlled primarily by pressure, temperature, and methane saturation conditions and additional factors associated with host sediments such as ionic strength of pore water (Sloan and Koh, 2008). Methane saturation within marine sediments is influenced by a variety of factors including the rate of methanogenesis (a function of organic carbon quantity and quality), the rate of advection of methane or higher order hydrocarbons, and porosity and permeability (both lithologic and fracture related). Higher values of porosity in hemipelagic mud deposits, which are influenced by mineralogy, grain-size distribution, microfabric, and compaction, may enhance gas hydrate accumulation by sustaining pathways for fluid migration (e.g., Clennell et al., 1999; Lorenson, 2000; Xu and Ruppel, 1999). The relationship between mineralogy and enhanced gas hydrate accumulation in marine sediments is primarily related to elevated quartz and feldspar abundance in intervals of coarser grain size and moderate to high porosity (e.g. Bahr et al., 2008; Expedition 311 Scientists, 2006) or other related authigenic mineralization, which may help sustain porosity with depth (Rose et al., 2014).

Laboratory and modeling studies indicate that smectite-group clays, specifically montmorillonite, promote the formation of methane hydrate (Cha et al., 1988; Ouar et al., 1992; Park and Sposito, 2003; Riestenberg et al., 2003). The mineral surface of hydrated clay minerals, especially 2:1 layer swelling clays, have been shown to provide reaction surfaces for geochemical reactions (Sposito et al., 1999). Smectite surfaces can thermodynamically promote the formation of structure I methane hydrate by the ordered absorption of water molecules (Cha et al., 1988; Park and Sposito, 2003). This promotion effect has been shown to significantly reduce the pressure required for methane hydrate formation, but this effect can be negated by the presence of dissolved silica (Riestenberg et al., 2003).

Sites drilled during Indian National Gas Hydrate Program Expedition 01 (NGHP01) provide an opportunity to document mineralogical changes over sediment depths of 180–690 m below seafloor (mbsf) and on kyr-to-Myr timescales. The cores were recovered from previously un-drilled regions of the east and west margins of peninsular India, as well as the Andaman accretionary wedge (Fig. 1), at water depths ranging from 895 to 2663 m (Table 1), all within the modern gas hydrate stability zone. NGHP01 presented an opportunity to examine how depositional history and sediment composition have influenced gas hydrate distribution on the Indian continental margins. In this paper we describe variations in bulk mineralogy (relative abundances of total clay minerals, quartz, feldspar, calcite) and clay mineralogy (relative abundances of illite, smectite, chlorite, kaolinite) in sediment cores recovered during NGHP01. We measured sediment samples recovered from the offshore Krishna-Godavari (Holes NGHP-01-03B, NGHP-01-05C, NGHP-01-07BD, NGHP-01-10BD, NGHP-01-14A, NGHP-01-15A, NGHP-01-16A, NGHP-01-20AB) and Mahanadi Basin (Holes NGHP-01-18A, NGHP-01-19A), the Andaman Sea (Hole NGHP-01-17A), and the Kerala-Konkan Basin (Hole NGHP-01-01A). These records allow for interpretations of sediment provenance through time across a broad swath of Indian Ocean environments, as well as the fundamental relation between mineral content and gas hydrate occurrence.

2. Previous studies

The global-scale distribution of clay minerals and quartz in seafloor sediments has been long-established as an indicator of latitudinal climate zonation (Biscaye, 1965; Griffin et al., 1968; Leinen et al., 1986; Petschick et al., 1996; Rateev et al., 1969; Windom, 1975, 1976). Dispersal of fine-grained suspended sediment is affected by prevailing winds, surface currents, bottom currents, and density currents, so there are many exceptions to the simple latitudinal zonation, including the northern Indian Ocean (Thiry, 2000). Across the northern Indian Ocean, surface sediments can be classified into distinct clay-mineral provinces (Venkatarathnam and Biscaye, 1973; Goldberg and Griffin, 1970; Kolla et al., 1976, 1981a,b; Kolla and Rao, 1990). On Indian peninsular margins in the Bay of Bengal and Arabian Sea, smectite is generally the dominant clay mineral, introduced as a chemical weathering product of the Deccan basalts (Bhattacharyya et al., 1993, 2006) and via pedogenesis on the Indo-Gangetic Plain (Fagel et al., 1994; Pal et al., 2012; Srivastava et al., 1998). Illite- and chlorite-rich sediments are common on the Bengal Fan and Indus Fan, due to mechanical weathering in the Himalayan region and transport via the Ganges-Brahmaputra and Indus Rivers (Chakrapani et al., 1995; Kolla and Rao, 1990; Venkatarathnam and Biscaye, 1973).

On the eastern Indian margin near the Krishna–Godavari Basin, smectite is the dominant mineral in surface sediments, but smectite content decreases to the north at the expense of illite and chlorite from Ganges–Brahmaputra sources (Wijayananda and Cronan, 1994; Raman et al., 1995; Rao, 1991; Rao et al., 1988). The Krishna and Godavari Rivers drain the Deccan Basalts in their upper reaches, providing a source of smectite from weathered volcanic rocks with further alteration to these clays as these rivers pass through the Precambrian Eastern Ghats (Rao, 1991; Rao et al., 1988).

On the western Indian shelf north of Goa, smectite is the dominant clay mineral in sediments derived from the Deccan basalts (drainage of the Tapti and Narmada Rivers), and a smectite-kaolinite assemblage with minor illite and chlorite is dominant in sediments south of Goa derived from the gneissic provenance of the Western Ghats (Rao and Rao, 1995). The western Indian continental slope has elevated illite and chlorite content relative to the shelf due to along-slope transport from the Indus fan (Rao and Rao, 1995). The lower slope off the southwest tip of India contains high illite and chlorite abundance due to additional input waters from the Bay of Bengal (Chauhan and Gujar, 1996). Overall, the western Indian margin surface sediments represent mixing between Indus, Deccan Trap basalt, and peninsular gneissic rock sources, shown by clay mineralogy and Sr–Nd isotopic signatures (Kessarkar et al., 2003).

Clay mineral assemblages at the distal Bengal Fan and Central Indian Basin show long-timescale fluctuations of relative illite and smectite abundance attributed to changes in relative input from Himalayan and peninsular Indian sediment sources and/or changes in chemical weathering intensity in the Indo-Gangetic Plain (Aoki et al., 1991; Bouquillon et al., 1990; Brass and Raman, 1990; Derry and France-Lanord, 1996; Fagel et al., 1994; France-Lanord et al., 1993). Turbidity currents bearing Himalayan-derived illite can reach as far as the Central Indian Basin (Rao and Nath, 1988). With increasing southward distance from the Bengal Fan, illite and chlorite contents decrease and smectite and kaolinite contents increase (Debrabant et al., 1993). Similarly, the Indus Fan contains turbidites bearing Indus-derived illite and chlorite and pelagic intervals bearing smectite (Debrabant et al., 1991).

Variations in clay mineral assemblages in Quaternary sediment records have been used as proxies of the Indian monsoon intensity on orbital timescales in which a higher flux of chemical weathering