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Carbon and nitrogen elemental and stable isotopic compositions of surficial sediments from the Pakistan margin of the Arabian Sea

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ABSTRACT

The factors controlling sedimentary organic matter distributions are the subject of ongoing debate. We report here the carbon and nitrogen contents and stable isotopic compositions for surface sediments and downcore profiles from sites ranging in water depth from 140 to 3200 m, located across the Indus margin of the Arabian Sea. The sites spanned the intense midwater oxygen minimum zone (OMZ) and showed dramatic differences in bottom-water redox conditions, benthic communities, and degrees of bioturbation. Five primary stations were studied, at 140, 300, 940, 1200 and 1850 m water depth, with sampling in March–May (''intermonsoon'') and August–October (''late-to-postmonsoon'') 2003. High-resolution sampling was also conducted across the upper (140–275 m) and lower OMZ (600–1200 m) boundaries. The sampling strategy was selected to help clarify the roles of oxygen availability and other potential environmental factors in determining sediment organic matter content and composition, the extent of organic matter cycling within the sediments under contrasting depositional conditions, and the fate of organic matter deposited during the southwest monsoon. As previously noted on this and other OMZ margins, there was a roughly inverse spatial relationship between bottom-water oxygen and sedimentary organic matter concentrations. However, variability in organic carbon content within the OMZ that was unrelated to oxygen, and the fact that maximal organic carbon contents occurred under relatively oxidizing conditions towards the lower OMZ boundary, rather than at the OMZ core, indicate that factors other than oxygen contribute significantly as controls on carbon distributions. Despite a 3-fold range in organic carbon content, carbon-to-nitrogen ratios showed no systematic trends across the OMZ, with values reflecting uniform (predominantly marine) organic matter inputs. Nitrogen isotopic signatures ($\delta^{15}N$ values) in the range of 6.5–8.5‰ also did not show clear cross-OMZ trends, and are attributed to a ^{14}N-depleted nitrate pool created by pelagic denitrification. There was little downcore change in organic matter content at any site, suggesting either that organic matter decay occurs largely in the water column, or that decay within the sediments (at oxygenated sites) is masked by bioturbation. Seasonal variability in organic matter content and composition was restricted to the most surficial sediments, and changes were ephemeral, suggesting rapid turnover of organic matter deposited during the southwest monsoon, on timescales of weeks. Stable C isotopic compositions trended towards more negative values in surficial sediments at hypoxic sites within the OMZ core. This is attributed to a chemosynthetic bacterial imprint.

1. Introduction

Cycling and burial of organic matter (OM) in continental margin sediments is important to the global cycles of C, N and other bioelements and to ocean productivity and climate (e.g., Berner, 1982; Walsh, 1991). The intense mid-water OMZ of the Arabian Sea was discovered early in the 20th century and, soon after, spatial correspondence was observed with a belt of sediments on the continental slope that were rich in OM and largely devoid of benthic fauna (Sewell, 1934a, b), and represent the largest expanse of hypoxic sediments on Earth (Helly and Levin, 2004). The correlation between water-column O_2 depletion and sediment OM enrichment became some of the earliest evidence used to support a claim that O_2 availability is the main determinant of organic C burial in marine sediments (e.g., Demaison and Moore, 1980; and references therein). More recently, this has been questioned, and the controls on sedimentary OM content in the Arabian Sea have been much debated (Pedersen et al., 1992; Paropkari et al, 1992; Calvert et al., 1995). Here and in other settings, factors including OM supply and quality, organic–mineral interactions, the abundance and activities of benthic organisms, and physical factors such as winnowing and hydrodynamic sorting, have also been suggested to contribute (Hedges and Keil, 1995; and references therein). However, the

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mechanisms, interactions and relative importance of these controlling processes remain the subjects of ongoing research and debate.

We report here the carbon and nitrogen contents and stable isotopic compositions of sediments recovered from sites spanning the OMZ on the Pakistan margin of the Arabian Sea. Sediments ranged from homogenous, fully bioturbated deposits above and below the OMZ to clearly laminated deposits at the OMZ core. A first objective of this high-resolution sampling programme (across the margin and down-core) was to permit detailed assessments of the relationship between sediment OM content and bottom-water oxygen concentration and the degree of sedimentary OM cycling under contrasting depositional conditions. Repeat sampling, before and after the southwest monsoon, was carried out to determine the impact and fate of monsoon-driven OM deposition. The collected data also form an essential underpinning to more detailed studies described in other articles in this volume. The objectives of these studies were to characterize OM source and quality and to quantify benthic processes and fluxes, and to assess how these, and the size and function of benthic faunal communities relate to redox conditions and sedimentary OM content, and how they contribute to observed cross-margin OM distributions.

2. Methods

Studies were carried out across the Pakistan margin of the Arabian Sea in the area immediately north of the Indus River Canyon (Fig. 1) over two pairs of cruises on RRS *Charles Darwin* (CD) in 2003. The first pair of cruises took place in the spring intermonsoon season (CD 145, March 12–April 9; and CD 146, April 12–May 29), and the second pair during the late- and immediate post-southwest-monsoon season (CD 150, August 22–September 15; and CD 151, September 17–October 20). Studies were focused on five primary stations (Fig. 1) in a depth range that spanned the mid-water oxygen minimum zone (OMZ, ca. 100–1300 m), as defined by bottom-water dissolved O_2 concentrations (Fig. 2) and sediment characteristics; at 140 m ("seasonally hypoxic"), 300 m ("OMZ core"), 940 and 1200 m ("lower OMZ transition") and 1850 m ("below OMZ"). These definitions are based on a combination of dissolved oxygen (DO) concentrations (from water-column profiles obtained with a Seabird DO sensor attached to a CTD; see Brand and Griffiths, 2009, for sensor and calibration details) and sediment properties, as distinguished by abundance of macrofauna and extent of visible lamination in X-radiographs (Cowie and Levin, 2009). The stations all fell on a single cross-margin transect (Fig. 1), with the exception of the 940-m station, which was located slightly to the southeast. Cores from these sites were collected in both seasons, on all cruises. Sediments also were collected at secondary stations across the lower OMZ transition (between 700 and 1100 m), across the upper OMZ boundary (140–275 m depth), and at 3200 m (the NAST site of the German BIGSET program; Pfannküche and Lochte, 2000). Cores from these sites were collected only on a subset of the cruises. Notably, the presence of some benthic infauna at all depths, and in both seasons (Hughes et al., 2009; Levin et al., 2009), indicates non-zero DO concentrations at the benthic interface even at the core of the OMZ (consistent with estimates derived from DO data obtained with CTD profiling). Average locations and general hydrographic properties at the five primary stations are listed in Table 1. Details of the secondary sites are provided in Table 3 and elsewhere in the volume (Levin et al., 2009).

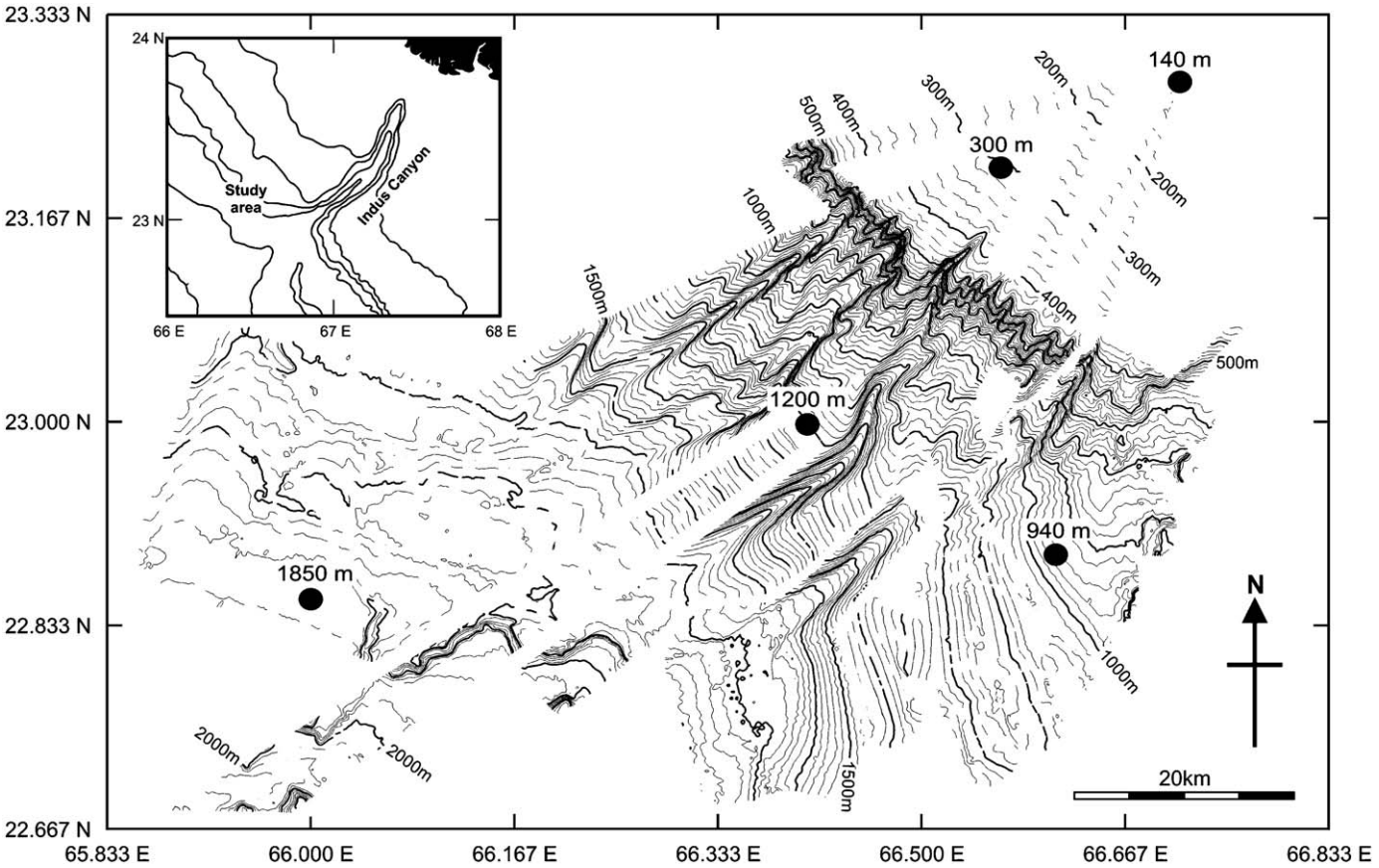

Fig. 1. Site map showing wider study area (inset), bathymetry and primary station locations off the Indus margin of the NE Arabian Sea (Pakistan). Courtesy of Gareth Knight, Liz Rourke and Brian Bett (National Oceanography Centre, Southampton, UK).