Variaions in terrigenous sediment discharge in a sediment core from southeastern Arabian Sea during the last 140 ka

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The bulk concentration (wt%) and mass accumulation rates (MAR; g/cm²/ka) of terrigenous source representing elements such as Al, Ti, K and Zr in a sediment core (SK-129/CR-05) from southeastern Arabian Sea, record considerable variations in riverine sediment discharge over the last 140 ka. The mean Al concentration (4.51 ± 0.47%) and its MAR (0.105 g/cm²/ka) are higher during the glacial period and lower (3.61 ± 0.58%; 0.084 g/cm²/ka) in the interglacial period. This suggests an increased terrigenous sediment discharge (TSD) of ~25% corresponding with chemical weathering (K/Al ratio) during glacial times than in the interglacials. The last ~ 5 ka received lowest and uniform TSD (mean Al concentration ~2.36 ± 0.06%; Al MAR, 0.075 g/cm²/ka; K/Al ratio, 0.23 ± 0.003) may be due to weak monsoon and stabilized sea level. Marine Isotope Stage (MIS) – 1 and 4 recorded the lowest and highest TSD respectively. Interestingly, during MIS–5, interstadials (5.1, 5.3 and 5.5) were associated with relatively larger TDS, suggesting humid conditions and intense precipitation. On the contrary, stadials (5.2 and 5.4) were characterized by relatively smaller TDS, indicative of low precipitation and arid condition in the Indian subcontinent.

Keywords: Arabian Sea, marine environment, marine isotope stage, mass accumulation rate, terrigenous sediment discharge.

TERRIGENOUS sedimentation in the marine environment is mainly through fluvial or eolian pathways, which provides information about conditions on the continent and mechanisms of transport from continent to marine environment. The type and amount of terrigenous material depend on climatic conditions on the continent. About 95% of terrigenous material in the ocean reaches by the rivers and is deposited on continental margins.1 The elements and their transport pathways in the Arabian Sea suggest a number of sources, viz. detrital input from Somalia, aeolian from Arabia, detrital riverine input from Indus, Tapti and Narmada rivers and weathering of Deccan trap, gneissic rocks, latites and submarine weathering of Carlsberg Ridge.2–7 The lithogenic input in the western Arabian Sea is largely eolian and is fluvial in the southeastern Arabian Sea8, with a meager aeolian fraction.9,10 Existing palaeoceanographic studies in the southeastern Arabian Sea are confined to productivity variation, clay mineralogy and hydrography changes11–18, and variations of terrigenous input through geochemistry is not well recorded. In the present study, bulk concentration of terrigenous source elements (Al, Ti, K and Zr) and their mass accumulation rates (MAR; g/cm²/ka) are investigated in order to understand the variations of riverine sediment discharge in the southeastern Arabian Sea during the last 140 ka.

During the 129th cruise of ORV Sagar Kanya (Figure 1), a 5.52 m long gravity sediment core (SK-129/CR-05) was raised from southeastern Arabian Sea (9°21′N: 71°59′E; water depth 2300 m). The sediment core was sub-sampled at 2 cm interval, dried and powdered in an agate mortar. Globigerinoides ruber, a planktonic foraminifera with a size range of 250–350 μm was used for oxygen isotope study and determination of calcium carbonate procedure has been published earlier.19 For the chemical analyses of major and trace elements, the sediment was treated with a
mixture of HNO₃, HClO₄ and HF in a PTFE vial using a microwave. After digestion, the solutions were evaporated to near dryness under infrared lamp on a hot plate in a draft chamber. The residue was brought into a clear solution with 2 M HNO₃ and final volume was made. These samples were analysed for Al, Ti, Fe, Na, K, Mg, Ba, Sr, Co, Cr, Li, Ni, Sc, V, Y, Zn and Zr with a Thermo Jarrel Ash IRIS-AP on a inductively coupled plasma-atomic emission spectrometry (ICP-AES). An international reference standard material (JB-2) supplied by Geological Survey of Japan was used to check the accuracy, which was better than ± 5 for the elements analysed. Dry bulk density was calculated using the equation of Curry and Lohmann. MAR were estimated by the individual element concentration, linear sedimentation rate (LSR) and dry bulk density. Element excess has been calculated following the equation: Eleexcess = Eletotal − (Tisample × Ele/Alhub) [19].

The age model for the present sediment core is based on the oxygen isotope record of G. ruber [19]. This core covers a time span of 140 ka from late isotope stage 6 to the Present. The age model was derived by identifying globally recognizable isotopic events in the δ¹⁸O records following Prell et al., and by assigning ages according to Martinson et al. [23]. Linear interpolation between the oxygen isotope stage boundaries reveals variations in sedimentation rates between 3.67 and 5.20 cm/ka (average of 4.14 cm/ka) [20], with highest sedimentation (5.2 cm/ka) during Marine Isotope Stage (MIS)-4 and lowest (3.6 cm/ka) during MIS-3. During MIS-5, sedimentation rates varied from 0.8 to 7 cm/ka. Occurrence of high abundance of glass shards at 308 cm depth interval corresponds to Youngest Toba Tuff (YTT) of ~74 ka from northern Sumatra [24]. Matches well with the δ¹⁸O chronology and confirms the interpolation of timescale derived from δ¹⁸O stage boundaries are reasonable.

The carbonate content in the core varies between 30 and 66%, with highest values (50 to 66%) during Holocene and a short pulse of high carbonate content (66%) during the early MIS-5 (Figure 2). The carbonate content during the last 5 ka is uniformly high (65%). Carbonate content during MIS-1, -3 and -5 is higher and during MIS-2, -4 and -6 is lower; this suggests increased productivity during interglacials than in the glacials. Similarly, other productivity proxies such as biogenic opal and biogenic Ba showed increased productivity during major interglacials [19].

Aluminum shows a perfect positive correlation with Ti (r = 0.99, n = 140), suggesting sole supply from terrigenous source. Similarly, Al also shows a strong positive correlation with Li (r = 0.97), Zr (r = 0.96), K (r = 0.93), Sc (r = 0.93), Na (r = 0.90), Cr (r = 0.89), Mg (r = 0.85), V (r = 0.85) and Fe (r = 0.70), indicating their supply from a common source. The positive but comparatively poor correlation coefficient between Al and Fe (r = 0.70) compared to other terrigenous source elements could be due to the presence of excess Fe (~25%) (structurally unsupported) throughout the core. This excess Fe might have been supplied from the weathering of laterites from the hinterland, which in turn have been utilized in the formation of authigenic phases, such as verdine and glucony facies in the shelf and pyrite, as observed in the present sediment core. Calcium carbonate, Sr and Ba exhibit positive correlation among themselves, suggesting a biogenic source and act as a diluent to the detrital elements.

Clay mineralogy, seafloor sediment distribution and sediment trap data suggest that lithogenic fraction in the eastern Arabian Sea is largely fluvial in origin. MAR of Al, K, Ti and Zr (g/cm²/ka) are indicative of terri-

Table 1. Mean Al (%) concentration, Al mass accumulation rate (g/cm²/ka) and K/Al ratio during different marine isotope stages (MIS) in a sediment core (SK-129(CR-05)) from southeastern Arabian Sea.

<table>
<thead>
<tr>
<th>Period (ka)</th>
<th>Al (%)</th>
<th>Al MAR (g/cm²/ka)</th>
<th>K/Al ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last 5 ka</td>
<td>2.36 ± 0.06 (06)</td>
<td>0.075</td>
<td>0.23 ± 0.003</td>
</tr>
<tr>
<td>0–12 (MIS-1)</td>
<td>2.78 ± 0.54 (14)</td>
<td>0.085</td>
<td>0.24 ± 0.015</td>
</tr>
<tr>
<td>12–24 (MIS-2)</td>
<td>4.37 ± 0.21 (12)</td>
<td>0.096</td>
<td>0.27 ± 0.004</td>
</tr>
<tr>
<td>24–59 (MIS-3)</td>
<td>4.03 ± 0.33 (32)</td>
<td>0.087</td>
<td>0.27 ± 0.012</td>
</tr>
<tr>
<td>59–75 (MIS-4)</td>
<td>4.80 ± 0.48 (21)</td>
<td>0.136</td>
<td>0.30 ± 0.025</td>
</tr>
<tr>
<td>75–129 (MIS-5)</td>
<td>3.53 ± 0.45 (49)</td>
<td>0.099</td>
<td>0.28 ± 0.021</td>
</tr>
<tr>
<td>129–141 (MIS-6)</td>
<td>4.32 ± 0.43 (12)</td>
<td>0.123</td>
<td>0.27 ± 0.009</td>
</tr>
<tr>
<td>Mean glacial</td>
<td>4.51 ± 0.47 (45)</td>
<td>0.105</td>
<td>0.28 ± 0.030</td>
</tr>
<tr>
<td>Mean interglacial</td>
<td>3.61 ± 0.58 (95)</td>
<td>0.084</td>
<td>0.26 ± 0.021</td>
</tr>
</tbody>
</table>

Total number of sediment samples analysed during each isotope stage is given in brackets.
The high terrigenous flux suggests intensive hydrolysis resulting in enhanced erosion due to increased precipitation. In MIS-5, interstadials (5.1, 5.3 and 5.5) received reduced sediment discharge compared to stadials (5.2 and 5.4). A similar observation in the Niger Fan of Atlantic Ocean was attributed to the precessional variations, particularly 19 to 23 ka frequency band. The higher sediment discharge during interstadials suggests intense precipitation and humid condition. On the other hand, low sediment discharge during stadials is indicative of low precipitation and arid condition in the subcontinent. The low MAR (Figure 3c) between 110 and 120 ka (MIS-5d) could have resulted due to low sediment accumulation rate and lack of oxygen isotope data points (Figure 2b). MAR generally follow the LSR and this low MAR is not accompanied by corresponding elemental concentration (Figure 2a, b). Therefore, we suspect that the low MAR during MIS-5d could be an artifact and may not be related to climatic changes.
associated with potash feldspar. The K/Al ratio, which represents illite, is used as a proxy for chemical weathering. The K/Al ratio in the present sediment core varies from 0.22 to 0.39 (Figure 3) and suggests high chemical weathering intensity (0.28) during glacial than during interglacials (0.26). The last 5 ka has recorded low and constant K/Al ratio (0.23 ± 0.003%), suggesting low chemical weathering due to weak monsoon. The highest K/Al ratio (0.39) at ~74 ka could be due to presence of YTT, where glass shards from the ash layer have high Al and low K content compared to the associated sediments.


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