CHAPTER VI

Paleoenvironment and Paleoclimate during Late Quaternary - A Summary
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Evaluating past oceanographic and climate changes through the analyses of deep-ocean sediments necessarily involves the use of proxy indicators. Proxy indicators by virtue of their physical, biological and or chemical origins are indirectly related to paleoceanographic and climatic variables such as sea surface temperature, wind speed, nutrient content, precipitation, global ice volume. No proxy currently in use can claim a unique direct association with a single climate variable; all have the potential to be influenced by processes other than climatic changes or oceanographic variable of direct interest. Some of the more common processes that complicate the interpretation of proxy variables include regeneration of biological material in the intermediate and deep waters, post depositional diagenesis, erosion and redeposition. In addition, some proxies are influenced by a number of climatic and or oceanographic variables making it difficult to isolate the effect of any single variable. Each of them is physically, chemically, biologically or isotopically linked to the variable of interest but impacted differently by unrelated processes such as diagenesis, dissolution etc.

The paleoceanographic and paleoclimate data obtained from the Arabian Sea particularly in the eastern Arabian Sea is rather sparse. The proxy records from the Arabian Sea sediments have provided useful information regarding monsoon induced upwelling, which has close relation with the climate prevailed in Asia during that period. Moreover, the understanding of productivity has a close linkage to pCO₂ levels of the atmosphere during glacial interglacial time scales (Broecker, 1982; Broecker and Denton, 1989; Sigman and Boyle, 2000). The traditional proxy for paleoproductivity is organic carbon which has been successfully used in many of the oceanic regions by various researchers (e.g. Rixen et al., 2000; Kawahata et al., 1998; Ganeshram et al., 1999). But still there are certain uncertainties and controversies regarding Corg accumulation and its linkage to monsoon and surface productivity particularly in the eastern Arabian Sea.

In order to understand the paleoenvironmental and paleoclimatic changes in the southeastern Arabian Sea during the late Quaternary period, the present study was taken up. The data generated in the present work would serve as an archive and add to the existing data on the southwest coast of India. To achieve the objectives, three
sediment cores from the continental slope region off Cochin in the southeastern Arabian Sea were studied in detail. The core samples studied have provided information on sediment texture, sedimentation rates, organic carbon, calcium carbonate, clay minerals, and major and trace element compositions, which in turn are employed to infer the paleoenvironment and paleoclimatic changes.

The terrigenous material supply to the Arabian Sea is mostly influenced by the monsoon intensity and hinterland geology. The radiocarbon ages recorded for the sediment layers were up to 19500 years BP. Based on the radiocarbon ages, sedimentation rates were computed to understand temporal variations, depositional conditions and the paleomonsoon intensity in the region. The sedimentation rates varied from 4-27 cm/ka for the dated entire sedimentary column of the core. The higher sedimentation rate was recorded during the mid Holocene and the low sedimentation rate for the last 2 ka. Sedimentation rates generally decrease with increasing water depths as a result of reduced influence of the terrestrial input. The higher sedimentation rates were reported in the northeastern Arabian Sea, and reduced sedimentation rates in the southern Arabian Sea. The large-size rivers, when compared to small-size rivers in the south, that drain in the northern region through volcanic rocks may be the prime cause for high sedimentation, apart from the detritus from Indus river. Further, volcanic rocks that carpet the northern hinterland are more susceptible for physical and chemical weathering than the granitic gneisses and charnockites that occur in the catchment regions of southern rivers. The varied sedimentation rates reported for the eastern Arabian Sea by various workers can be attributed to the different dating techniques employed. For example, AMS C-14 dating technique provides more accurate results for the late Quaternary sediments than any other technique.

Texturally, all the three sediment cores exhibit varied grain-size particles and sandy mud to muddy texture. The core located in the upper slope region has recorded up to 60% of sand during the early Holocene. In general, sand content is higher in the shallow water core than in the cores of the deeper water, which exhibit silty clays and clayey silts. At the core site in the upper slope, gradual increase of silt with gradual decrease of clay was recorded. In the deeper slope region, the increased amount of clay compared to silt content was recorded. The currents although play a significant role in transport of fine sediments along and across the shore, which have influenced
the deposition of silts and clays, the role of sea level in the sediment distribution on the sea floor is not ruled out. Sea level variations may have influenced both the sediment texture and rates of deposition. As the sea level was -120 m during the LGM, the exposed continental shelf was wider and subsequently the river discharges are much far away from the present coastline. This might be the main reason for the coarse sand fraction at the core site in the upper slope region. Further, the enhanced hydrolysis on land due to intense monsoonal precipitation tends to enrich the coarse fraction of the sediments on the sea floor.

Organic matter reflects paleoproductivity and sediment dispersal and deposition. The organic carbon was higher in the cores of the deeper region than in the sediments of the upper slope. The oxidation and preservation of organic carbon has been widely debated and has been extensively employed as a paleoproductivity index. In general, increased sedimentation rate enhances organic carbon preservation in sediments. It is suggested that locations of organic carbon maxima on continental slopes are not controlled by the bottom water oxygen levels, but by a combination of factors viz., the sediment texture, dilution of organic matter by other sediment components and the settling fluxes of organic carbon. CaCO$_3$ content varied from 11-57 % in the upper slope region whereas it varied from 6-26 % in the deep water region. CaCO$_3$ has also been extensively employed as a proxy for productivity. It has been debated whether dissolution or dilution by terrigenous material influences the CaCO$_3$ content in the oceans. The CaCO$_3$ records in the Arabian Sea are mostly influenced by terrigenous dilution, caused by variations in the terrigenous lithogenic flux during the summer monsoon seasons. The similar dilution of CaCO$_3$ in the southeastern Arabian Sea is caused by the terrigenous lithogenic flux derived from the southwestern part of India and exposed continental shelf during the LGM.

Clay mineral studies indicate that smectite, illite, kaolinite and chlorite are the dominant clay minerals in the southeastern Arabian Sea. The temporal distributions reveal that smectite is dominant throughout the dated ages of the sedimentary layers. The clay mineral ratios are varied during early-middle-late Holocene and last glacial period. The study shows that K/C ratio is lower from middle Holocene to present and higher during the early Holocene in the upper slope region. K/I ratios are slightly higher from the middle to late Holocene period in both upper slope and deeper slope regions. Most of the previous studies, except Thamban et al. (2002), have recorded
higher smectite content in the southeastern Arabian Sea. Abundance of smectite in the present study area suggests its derivation from the erosion of basic volcanic rocks of central India under semi-arid climate, and transported southward in the shelf and slope regions by strong monsoonal currents. Kaolinite and illite reflect their derivation from the Precambrian crystalline rocks associated with the hinterland. It is suggested that sediment derived from the southwestern India is constantly supplying kaolinite and illite to the continental slope. Further, deposition by gravitational currents is also an important mechanism in the dispersal and deposition of clay minerals in the continental margin region.

The climate variations during the late Quaternary might have also influenced the clay mineral distribution in the southeastern Arabian Sea. The variations of sea level during glacial/interglacial periods might have induced changes in clay mineral composition. The clay mineral ratios, K/C and K/I, serve as indicators for continental humidity, which indicate the distinct events of monsoon intensification. The characteristic high rainfall and high temperature in southwestern region of India would have led to strong hydrological of illite. The last glacial period as recorded in the cores is characterized by significant contribution of weathered products, indicating relatively arid conditions prevailed on the hinterland. Kaolinite content and ratios of K/C and K/I, proxies of continued humidity, indicate distinct events of monsoon intensification.

The temporal variations documented in clay minerals in the present study show that kaolinite, chlorite and illite levels show an oscillating trend. Smectite levels are constant through out, kaolinite and chlorite levels are high since 6 ka BP, while illite is higher than both kaolinite and chlorite during 19.5 – 6.8 ka BP. High ratios of kaolinite/chlorite from 19.5–6.3 ka BP suggest the prevalence of humid conditions. Low K/C ratios since Mid-Holocene to the present indicate reduced monsoonal activity and consequently low weathering rates. Chlorite forms under arid conditions and high chlorite/illite ratio from 6.3 ka BP to the Present provide evidence for the extent of aridity. Generally, illite and chlorite form under dry/arid conditions and kaolinite under humid conditions. The gradual decrease in illite and increase in kaolinite from 17.4 ka BP suggest that the climate has gradually turned to warm humid conditions since then in this region. Based on clay mineral proxies, Gingele et al. (2004) have inferred more humid conditions between 11 and 6 ka BP and the onset
of more arid conditions around 5.5 ka BP, which reached a maximum at 3.6 ka BP. It appears that these arid conditions are responsible for the low sediment supply in the last 3 ka in the southwestern margin of India.

Clay mineral abundances and ratios express the intensity of weathering and hydrolysis on the adjacent landmass. The temporal distribution of clay minerals is controlled by the monsoon intensity, hydrolysis, sea level changes and climate of the region. High ratio values of clay minerals, particularly K/C and K/I suggest strong humid conditions since last glacial period. Monsoon intensity, southerly coastal currents and humid climate played a major role in the clay mineral distribution and abundance. The study strengthens the idea of employing the clay minerals as proxies to decipher paleomonsoon, paleoclimate and paleoenvironmental conditions during the Late Quaternary.

Abundances of major elements Al, Fe and Ti in cores AAS 38-4 and 38-5 are employed to investigate the changes in supply and source of detrital material to the eastern Arabian sea during the last glacial and the Holocene. The terrigenous records of cores reveal that the most significant, well-resolved environmental variations are evidenced during the early Holocene, associated with abrupt oscillations in the terrigenous signals.

The Al concentrations in sediments reflect the provenance and dilution effects. The low values of Al (~10 %) in sediments of the cores under present investigation is an intriguing factor because the hinterland consists of laterites and ultramafic rocks which are enriched in Al content. The low Al values in the eastern Arabian Sea sediments could be a dilution with lithic components that are low in Al content.

The Ti content in the core samples indicates a slightly higher content during the last glacial period than in the Holocene. Higher concentrations of Al and Ti coincide with the low CaCO₃ values during the last glacial period suggest greater terrigenous dilution during LGM. It has been suggested earlier by many that the CaCO₃ records from the Arabian Sea are mostly influenced by terrigenous dilution, caused by variations in the terrigenous lithogenic flux derived from the Arabian and Somalian Peninsulas during the summer monsoon season (Murray and Prell, 1992). The similar dilution of CaCO₃ in the southeastern Arabian Sea is caused by the terrigenous lithogenic flux derived from the southwestern part of India, when the sea level was low and during the LGM.
Trace elements of marine sediments provide important information on paleoproductivity, past oceanographic and climatic changes. Because these changes cannot be determined directly, geochemical proxies of climatic variations and paleoenvironmental conditions have been developed intensively during the last two decades. A large number of geochemical proxies, including major and trace elements, have been used to reconstruct the history of the productivity record. Sr/Al and Ba/Al ratios show an abrupt decrease during the early Holocene (8-10 ka BP), thereby indicating a sharp decrease in productivity during this period. This time interval coincides with the early Holocene humid interval, a period of intensified southwest monsoon in the Arabian Sea. A possible explanation for the observed sharp change during the early Holocene could be increased monsoonal precipitation on coastal regions, resulting in large amounts of fresh water flux to the core sites, and as a consequence upwelling-induced surface productivity would have weakened/ceased.

The use of Ba or Ba/Al ratios as a paleopxy has been extensively documented. Enrichment of productivity-related elements - Ba, V, Sr, P - during interglacial times has been recorded in the present study.

The major and trace elements are employed to infer paleoclimate and paleoproductivity in the southeastern Arabian Sea. All the major element abundances show distinct variation between the Holocene and the last glacial period. Si, Ti, Al and Fe are distinctly lower during the Holocene than in the last glacial period. Trace elements - V, Co, Ni and Ba - are distinctly low during mid- and late Holocene. Trace elements/Al ratios suggest that there are distinct temporal variations in all the three cores. The variation in the input of terrigenous material to the Arabian Sea relates to monsoonal activities. Al concentrations in sediments reflected the provenance and dilution effects. High Al and Ti values coincide with the low CaCO₃ values during the last glacial period, which suggests greater terrigenous dilution. The elemental/Al ratios show low surface productivity during the LGM. An abrupt decrease of Sr/Al and Ba/Al ratios during the early Holocene indicate sharp decrease in productivity. Ba/Al ratio as a paleopxy has been signified in this study too. Productivity related elements have been enriched during interglacial times. Most of the productivity indicated elements are lowered during the Holocene than in the last glacial period.