Chapter-VI

SUMMARY AND CONCLUSIONS

The present study was aimed to address three important aspects of the northern Indian Ocean viz. the surface water circulation in the Arabian Sea, the pattern of surface sediment dispersion, and the palaeoclimatic reconstruction using sediment core samples of the Bay of Bengal.

As a part of ocean circulation studies (air-sea exchange of CO_2) in the Arabian Sea, several profiles of water column in the Arabian Sea were investigated for hydrographic parameters and radiocarbon content of the dissolved inorganic carbon (Broecker et al., 1985; Bhushan et al., 2000; Dutta, 2001). ^{14}C measurements were made in the water column of the Arabian Sea and the equatorial Indian Ocean to assess the temporal variations in bomb ^{14}C distribution and its inventory. In the present study, four GEOSECS stations were reoccupied (three in the Arabian Sea and one in the equatorial Indian Ocean) to discern the temporal variation in the water column inventories of bomb radiocarbon. It is observed that the sites investigated show increased penetration of bomb ^{14}C along with a decrease in its surface water activity. This indicates that during the last two decades since GEOSECS, vertical mixing has led to a deeper penetration of ^{14}C in the water column, while the surface activity has decreased probably due to an overall decrease in the atmospheric ^{14}C concentration.

The radiocarbon distribution in the water column in the top 1000 m is found to be modulated by the vertical mixing rates. Based on the available bomb ^{14}C inventories of the atmosphere and the water column, the air-sea exchanges of CO_2 were fitted in a box model (Oeshger et al., 1975, Broecker et al., 1980) to obtain the vertical mixing rate/upwelling rates. The upwelling rates derived by model simulation of bomb ^{14}C depth profile ranged from 3-9 m yr^{-1} (Bhushan et al., 2008). The western Arabian Sea areas experiencing high wind-induced upwelling have yielded higher upwelling rates (5-9 m yr^{-1}). However, the upwelling rate estimates of the GEOSECS stations were higher than obtained for the same location during this study after two decades. This is attributed to reduced ^{14}C gradient compared to that during the GEOSECS sampling expedition.

The spatial and temporal variability in the Bay of Bengal sedimentation pattern is governed by the physical erosion of the drainage areas of major rivers that contribute to the terrigenous flux predominantly influenced by the SWSM activity with a smaller supplementary contribution resulting from the effect of the NEWM. In addition to this continental source, an appreciable contribution results from the overhead biological productivity.

The geochemical indicators for detrital proxies show a decreasing trend from the coast to the open ocean regions, implying decreasing continental influence as a function of distance from the coast. This accords well with the observation made by earlier workers (e.g. Rao and Kessarkar, 2001; Rao et al., 2005). Similar trends are also noticed in C_{org} that can be attributed to a better preservation in the proximal areas (mainly due to enhanced sedimentation) rather than enhanced productivity.

The Sr and Nd isotopic composition of the Bay of Bengal sediments carry the imprint of the source areas (provenance) from where the materials have been derived. Though, the Bay of Bengal receives sediment from both Himalayan and peninsular rivers, it is however the G-B River system that has an overwhelming effect.

In the northern Bay of Bengal, the high $^{87}Sr/^{86}Sr$ (0.725–0.735) and low ε_{Nd} (-18 to -12) of the surface sediments indicate a strong G-B River system influence. However, samples from the western Bay of Bengal show mixed signatures of Sr and Nd isotopes mainly derived from the rivers draining the eastern continental margin of India, viz. the Mahanadi, Godavari, Krishna and Cauvery Rivers. The low radiogenic $^{87}Sr/^{86}Sr$ and high radiogenic ε_{Nd} in surface sediments from the Andaman Sea points signifies from the Irrawaddy River.

Two gravity cores collected from the central and southern Bay of Bengal were analysed for geochemical and isotopic proxies to reconstruct the climatic history during the last 50 kyr. Considering that the sediment flux is intimately associated with the tectonic and climatic variability (monsoon), the sedimentary archive in the Bay of Bengal provides a rare opportunity to reconstruct the past climatic (Gupta and Thomas, 2003) and tectonic activity (Metivier and Gaudemer, 1999).

In the central Bay of Bengal (core 4032), a discernable increase in the sedimentation rate around 40 kyr is observed. A prominent increase is also observed in the mass accumulation rate after 20 kyr (post LGM) i.e. between 18 kyr and 14 kyr implying sediment mobilization during the transitional climatic condition following the LGM (Goodbred Jr., 2003). In the southern Bay of Bengal (core 4040) a monotonous sedimentation rate is seen except between 17 kyr and 15 kyr, when a marginal increase is observed.

In the central Bay of Bengal, a general decrease in the ratios of detrital proxies since the last LGM to the present is indicative of source variation with a corresponding increase in productivity due to the intensification of the SW monsoon. This is attributed to the increase of biogenic component leading to relative decrease in the detrital component. The high ratio of biogenic proxies (Ba/Al, Sr/Al) between 50 kyr and 35 kyr suggests a monsoon induced enhanced productivity. After 35 kyr and till 18 kyr consistent low values of biogenic proxies are interpreted as a weakening of the monsoon acitvity.

However, after 15 kyr a stepwise increase in productivity indicates a gradual strengthening of the monsoon.

In the southern Bay of Bengal, the increasing trend in productivity proxies prior to 30 kyr indicates strengthened monsoon activity prior to 30 kyr. A declining trend observed after 30 kyr suggests a decrease in monsoon intensity. However, in the southern Bay of Bengal Ca/Al and Sr/Al ratios show an increase in productivity around 20 kyr (LGM) that can be attributed to an enhanced northeast wind driven productivity. After 20 kyr, Ba/Al suggests a stepwise strengthening of the productivity implying re–establishment and dominance of the southwest monsoon. It is worth mentioning here that a discernable low value around 8.5 kyr in all the three proxies indicate temporary weakening of the monsoon. This could as well correspond to a short lived cooling event dated to 8.2 kyr in the northern latitude (Alley et al., 1992, 1997).

The higher $^{87}Sr/^{86}Sr$ ratio (0.718-0.719) obtained in sediments of the southern Bay of Bengal is attributed to the Himalayan source sediments, whereas for the Irrawaddy sediments the $^{87}Sr/^{86}Sr$ ratio is ~0.713 and for that of the Arakan Coast it is 0.716 (Colin et al., 1999). The Irrawaddy River primarily drains into the Andaman Basin and during winters the sediment input from the Irrawaddy River to the Bay of Bengal is more prominent as the EICC moves southeastward (Shetye et al., 1996).

It has been observed that during periods of strengthened NEWM, the low $^{87}Sr/^{86}Sr$ contribution is from the Irrawaddy River, whereas during enhanced SWSM periods, the Himalayan source became dominant as indicated by the high $^{87}Sr/^{86}Sr$ ratio. This is further indicated by the Nd isotopic composition (ε_{Nd}) in the silicate fraction of the select sediment samples of the two cores. The high ε_{Nd} values recorded in the core from the central Bay of Bengal at 34 kyr, 20 kyr and 16 kyr, and in the southern Bay of Bengal core at around 20 kyr is interpreted as strengthened NEWM, during which more radiogenic ε_{Nd} was contributed by the Irrawaddy River system. In the absence of suspended sediment data from the Irrawaddy River, the above interpretation should be treated as a working hypothesis for future investigation.

Conclusions

The following inferences can be drawn from the present study:

1) The upwelling rates determined for the Arabian Sea and the Equatorial Indian Ocean stations ranged from 3-9 m yr^{-1} which is low when compared to the GEOSECS stations. High upwelling rates obtained correspond to the western region of the Arabian Sea, which is known for high wind induced upwelling. The atmospheric ^{14}C concentration has almost stabilized since about a decade leading to the reduced gradient of ^{14}C, which could be the reason for lower estimates of upwelling rates.

2) Lithogenic proxies in the surface sediments show a progressive decrease from the coast to the open ocean. This is attributed to the reduction in detrital sediment flux and an increase in the biogenic flux.

3) The observed decreasing trend in C_{org} from the coast to the open sea suggests a better preservation of C_{org} in coastal regions of the Bay of Bengal that is probably due to enhanced continental sediment flux.

4) Increased sediment flux in the Bay of Bengal occurred during the transitional climatic condition between the Last Glacial Maximum (LGM) and Holocene and this is attributed to the combination of low sea level, exposed coastal zone, and the strengthening of SWSM.

5) A general decrease in the ratios of detrital proxies since LGM to the present is due to increased productivity as a result of gradual strengthening of the SWSM.

6) The low $^{87}Sr/^{86}Sr$ ratios and enhanced ε_{Nd} values represent periods of weakened SWSM at the expense of a strengthened NEWM. It is due to an enhanced NEWM with the supply of low radiogenic $^{87}Sr/^{86}Sr$ from the Irrawaddy River (along the Arakan coast). In addition, the western fan of the Irrawaddy River along the Arakan Coast is suggested to be a likely contributor for high radiogenic ε_{Nd} during periods of enhanced NEWM.

7) Based on the Sr and the Nd isotopic variations, it is inferred that NEWM began to strengthened after 30 kyr and culminating at about 20 kyr. However after 20 kyr to 10 kyr a progressive strengthening of the SWSM is observed.

8) Three dominant periodicities of 2.4, 2.8 and 3.7 kyr noticed in the lithogenic and biogenic proxies are synchronous to the well known insolation cycles of 2.5, 2.77 and 3.95 kyr of solar origin. This indicates the influence of solar forcing in modulating the climate in the Bay of Bengal and parts of the northern Indian Ocean.