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CHAPTER-6

CONCLUSIONS

The present study demonstrates that fluvial and aeolian sediments in the region have recorded the southwest monsoon variability. The older event (MIS-5) was pronounced in basins away from the coastal region such as Sabarmati and Orsang. Though in Sabarmati basn, sequence below red soil has not been attempted in the present study, however, in Orsang basin, fluvial activity since MIS-5 is well preserved, suggesting fluvial response to the precipitation change. The alluvial plain of Mahi basin lies close to the Gulf of Cambay where evidence of Last Interglacial transgression is seen in the form of marine clay at Rayka (Rachna Raj et al., 1998; Juyal et al., 2000). Subsequent events corresponding to MIS-4 and 3 suggests that the fluvial regime has responded to the over all climatic pattern of the region during the Late Quaternary. The youngest event that represents MIS-3 has been wide spread in the basins of Sabarmati, Mahi and Orsang suggesting regional fluvial response to enhance precipitation during the last 100 ka.

This phase ended after around 30 ka, which is also the beginning of glacial maximum corresponding to MIS- 2 (Winograd et al., 1997), during which the climate was drier due to the weakened southwest monsoon (Duplessy, 1982). This led to the exposure of the fluvial sediments to sub-aerial weathering as indicated by the moderately developed soil towards the upper part of the sequence in Sabarmati basin and pedogenised silty sand in Mahi and Orsang basins. At places evidence for localized channel activities are seen between 30 to 20 ka. However, the dominant sedimentation was caused by enhanced wind activity (dune accretion) that was initiated around 32 ka in the study area and shows spatial variability between Orsang and Sabarmati basins.

In the southern most Orsang basin, dunes younger than 21 ka have not been found. In the Mahi basin dune accretion started well before the Last Glacial Maximum and continued till around 12 ka. where as in Sabarmati basin, the aeolian activity persisted until around 5 ka. This indicates a northward shift in parameters responsible for dune formation. An interesting observations was unlike the core of Thar Desert, southern margins experienced dune deposition despite a weak SW monsoon. Local factors, i.e. the availability of a large alluvial plain, proximity to the Arabian Sea with low sea level, facilitated a source-proximal aeolian deposition. A humid phase between 11-8 ka is seen. This accords with the strengthening of SW monsoon in the region. This was also the period during which the microlithic culture appeared in the region. Following the humid phase, dune deposition in the southern Mahi basin ceased, whereas in the northern Sabarmati basin it continued until around 5 ka. Since 5 ka, the southern margins have not experienced any major aeolian activity.

The organic carbon content also suggests that the region had scanty vegetation cover during the arid Glacial maximum (weak monsoon) and the vegetation improved gradually

with the onset of southwest monsoon after 18 ka. An optimum vegetation cover preventing dune mobility was established around 12 ka and continued uninterrupted till around 8 ka in both Mahi and Sabarmati basins. Following this, there appears to be a marginal decline in vegetation in the Sabarmati basin, however, the Mahi basin remained unaffected. A summary of the climatic variability (monsoonal) based on fluvial and aeolian sequences from Sabarmati, Mahı and Orsang basin is shown in figure 6.1 and figure 6.2 depicting the sequential evolution of the landform since Late Quaternary.

The incision of Quaternary alluvium appears to be modulated by the interplay of climate, tectonıcs and sea level changes. However, effect of sea level on incision was more pronounced in the narrow coastal region of Sabarmati basin and probably the lower alluvial plain of Mahi basin. Tectonism could have been the on going process as indicated by the structural configuration and geomorphic evidence preserved in the alluvial plain such as tilted terraces, badland topography and ingrown scroll plains. The process of incision would have accelerated with the availability of moisture as indicated by the incision of stabilized dunes dated at around 10-12 ka. This coincides with the period of establishment of southwest monsoon in the region.

Late Quaternary glaciation in Central Himalaya was structurally controlled which limited the extent of valley glaciers in the vicinity of THF. Damming caused by terminal moraines of the retreating valley glaciers gave rise to proglacial lakes in Garbayang and Goting basins after Marine Isotope Stage-4. A near continues record of climate change since LGM to the beginning of Holocene is well preserved in these basins. Last Glacial Maximum at Garbayang and Goting is dated to 18±3 ka. Sedimentological evidence in association with magnetic susceptibility and geochemical data from Goting lacustrine succession indicate period prior to 18±3 ka (LGM) was relatively warmer and stable with fewer oscillations.

During LGM low magnitude high frequency oscillations indicate prevalence of climatic instability. Extrapolating the data from Garbayang basin, it can be said that glacial climate prevailed in the region until around 13 ka. Period between 12 ka and 11 ka is identified as postglacial cooling corresponding to the Younger Dryas. Together with the LGM, the Younger Dryas cooling evidence suggest that the region was influenced by the North Atlantic climatic perturbation. The evidence obtained from the Higher Central Himalaya suggest that late Quaternary climate was linked to the Northern Hemisphere glaciation.

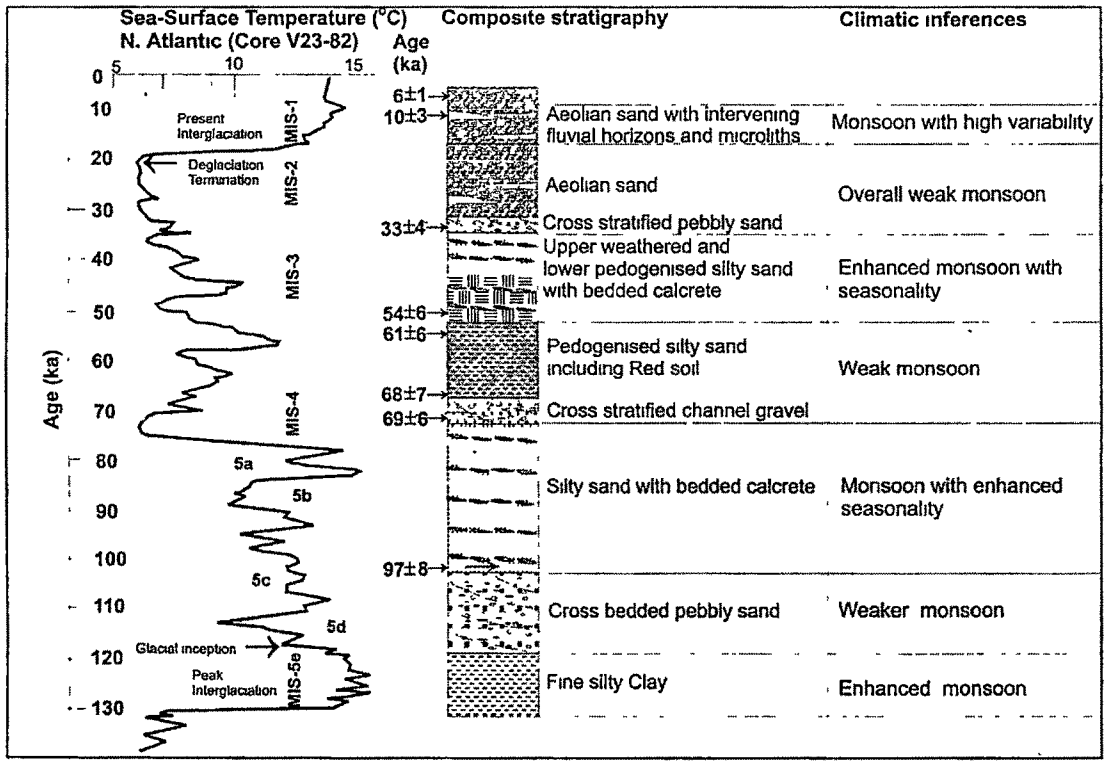

Figure-6.1. Palaeomonsoon reconstruction based on the BGSL chronology obtained on fluvial and aeolian sequences in Sabarmati, Mahi and Orsang basins during last 130 ka. A broad concordance is seen with the North Atlantic Sea surface temperature (Bradely, 1985). Similar pattern though less amplified is seen in the equatorial Indian ocean (Beaufort, 1996) and Guliya ice core (Shi et al., 2001).

The lacustrine environment in the region terminates with the beginning of Holocene that is represented by the deposition of a thick (5-10 m) outwash gravel dated to 11±1 ka suggesting sudden increase in meltwater discharge. Evidence similar to this are also obtained from the Bay of Bengal where a magnitude increase in sediment load was found between 11-7 ka. This has been attributed to the enhance discharge in the Ganga-Brahmputra system (Goodbred Jr. and Kuehl, 2000).

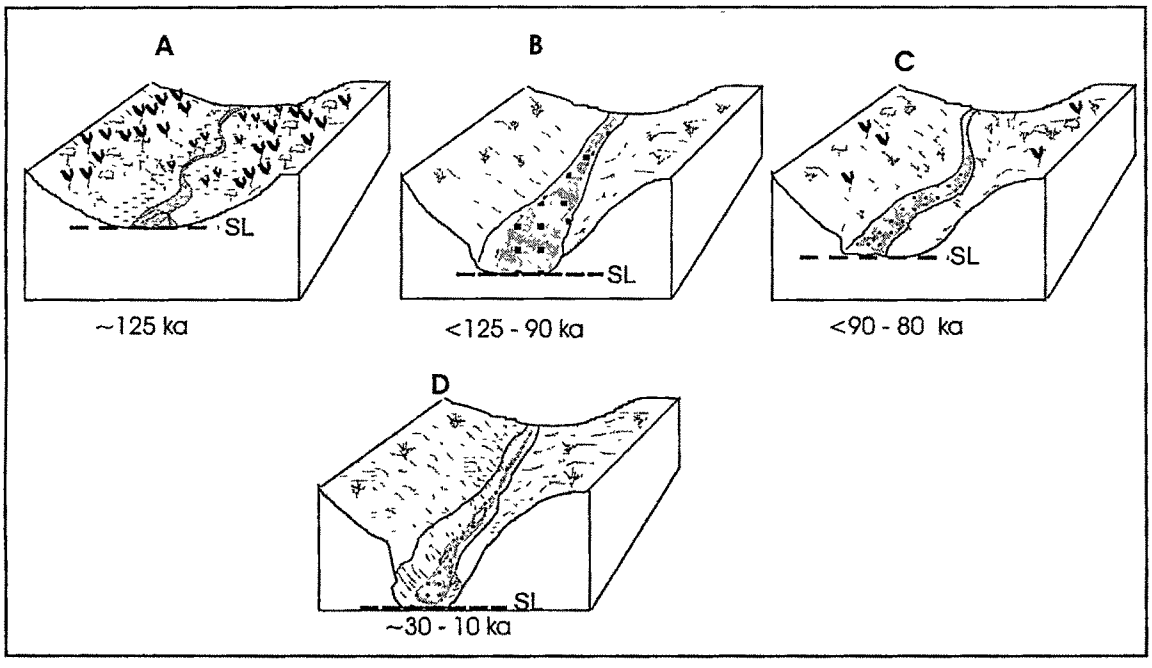

Figure-6.2 (A) Meandering river, cohesive river banks with wide flood plain and vegetated catchment, dominantly suspended load rivers.
(B) Braided fluvial regime, sparsely vegetated catchment, dominantly bed load rivers.
(C) Transitional meandering-braided river system with well defined thalweg and flood plains.
Fluvial system reverts back to condition (B) around 70-60 ka and rejuvenated during 50-30 ka {similar to situation (C)}.
(D) With the onset of arid climate, regional dune building activity began, this was also the period of the beginning of incision of the Quaternary alluvium.
(Sea level is suggestive)

IRSL chronology demonstrated that lake organic carbon in Garbayang and Goting basins suffered from variable amount of hard water effect leading stratigraphic inconsistency and overestimation of radiocarbon ages. This is important in view of the fact that many relict

lakes in the region are located in the limestone terrain. Thus this study caution using bulk organic carbon with out having an independent check on the radiocarbon ages from such areas.

Furthermore, the study also suggests that continued activity along THF facilitated the development of proglacial lakes around 60 ka. Direct dating of seismic evidence indicates that THF was active between 24 to 13 ka. This has implications towards crustal shortening along MCT indicating the process is ongoing and that the zone of plate convergence has not shifted southwards unlike the suggestions made in the evolutionary model (LeFort, 1975; Stocklin, 1980).

Though the evidence related to east west extension is limited, direct dating of the oldest outwash gravel terraces at Goting suggests that differential movement along east-west extension, post-date 11 ka. These evidence support the observations made by Hurtado Jr. et al. (2001) in Thakkola graben (Nepal Himalaya) that north-south and east-west extensions are inter linked in areas where north trending rift extend close to THF.

There appears to be a synchrony in climatic events between the desert margin and proglacial lacustrine environment of Higher Central Himalaya. Widespread occurrence of the longest glacial advancement in Higher Central Himalaya has been attributed to the less humid MIS-4. Evidence from mountain glaciation indicates that glacial advancement during MIS-4 was widespread and occurred both in northern and southern hemisphere (Bradely, 1999). Comparing this period with the desert margin, it shows presence of a weak hydrological regime during which fluvial system were dominantly braided in nature that led to the deposition of assorted bedload during episodic flood surges. Luminescence dating bracketed this period between 69 to 61 ka. Considering the near continuous sedimentation in Garbayang lake after the MIS-4, it is likely that the underlying sand bodies, well rounded

gravel horizons and thick mud layers below the upper lacustrine succession would correspond to the MIS-3 pluvial phase.

In the desert margin MIS-3 is dated between 54 to 33 ka during which the enhanced precipitation led to strengthening of the fluvial system. Rivers were persistent in their flow and banks were well defined, that led to the aggradations of over bank facies. Following this, gradual metamorphosis of fluvial system in the desert margin took place. Aeolian process dominated the sedimentation, however, there were events of episodic fluvial activity after 30 ka and around 20 ka the widespread aeolian activity sets in. The lacustrine deposits at Goting and Grabayang show peak glacial aridity around this period. Following this the lake record indicate fluctuating climate though remained largely glacial till around 13 ka. The chronology of the aeolian sequence in sub-humid Orsang basin indicates that after the peak glaciation, aeolian activity ceased there. However, it continued in the Mahi and Sabarmati basins suggesting prevalence of dry condition until around 12 to 10 ka. This period probably indicate the postglacial cooling identified as Younger Dryas in Garbayang. Around 10 ka evidence of sudden increase in meltwater discharge is seen in the form of outwash gravel dated to 10 ka at Goting. In the desert margin, geomorphic response of this event is seen in the form of landscape stability (in terms of aeolian sedimentation), emergence of microlithic culture and the deposition of fluvially reworked aeolian sands. Additionally, the incision of alluvium in the desert margin initiated after 20 ka and appears to have accelerated during the beginning of Holocene when the proglacial lakes breached with the deposition of outwash gravel suggesting beginning of warm condition.

Contemporary climatic events recorded in the desert margin and the Central Himalaya suggest linkages between these two extreme geomorphic and environmental settings. The major climatic events (stadials and interstadials) are broadly in agreement with the global

climatic record during last 100 ka suggesting the influence of Northern Hemisphere Glaciations. This would imply that the climate of Indian sub-continent responded to ice sheet dynamics. This seems logical considering the fact that glacial advancement during LGM in Himalaya and Tibet was less extensive. Similar evidence suggesting linkages between Northern Hemisphere Glaciations and Asian climate comes from the loess deposition in China, glaciations in the East Tibet during >100 ka, and strengthening of the northeast Indian monsoon. However, considering the proximity of the desert margin to the Himalayas, it is envisaged that the high mountains and Tibetan plateau would have amplified the climatic perturbations that originated in the northern latitude. The observations are important in view of the fact that Himalaya along with the Tibetan plateau was considered as pace maker for regional and global climate.

Future Studies

Present study demonstrates that regional and global climatic events are well recorded in the desert margin sediments. A broad climatic reconstruction has been made. However, there is still uncertainty about the nature of transition from wet period to the dry periods. Was it abrupt or gradational? This is important in view of the fact that evidence of abrupt climate change during the Holocene have been reported from the Thar desert (Enzel et al., 1999), North Africa (Petit-Maire and Guo, 1996) and Sahara (Claussen, et al., 1999). Such abrupt changes have been attributed to a feedback mechanism within the climate system of dry land that amplify and modify external forcing leading to abrupt climatic changes.

In view of this future studies would attempt at the major transional boundaries (environmental) in the sedimentary archives and extend the studies from humid southern desert margin to the core of the dry and arid Thar Desert. This would involve selecting

representative fluvial systems in each climatic zone. The same is partly done in the present study but confined to sub-humid south to the semi-arid north.

One of the interesting observation was the enhanced dune building activity which corresponds to the Last Glacial Maxium (LGM). This is at variance with the observations made in the Thar Desert where peak dune accretion postdates the LGM. Was that due to the geomorphological constrains as suggested in the present work or variability in the threshold limits of dune accretion (moisture, vegetation, sediment supply and wind) from relatively moist (southern margin) with that of the drier northern core region? In order to understand this, more sites with archeological control (like Akhaj) would be investigated in the region.

Evidence presented from the Himalayan region are limited to the last 20 ka. Also an inference regarding the timing of the longest glacial advancement is extrapolated from other basin. Present study has shown that in the higher Himalaya, the most extensive valley glacier terminates approximately at same altitude (~3000) and attributed to the MIS-4. Future study would involve direct dating of this crucial evidence from the region that was known to be the first global cooling event after the Last Interglacial.

Furthermore, Garbayang lacustrine succession covers at least the last 60 ka, we have sampled the last 20 ka. Therefore, a realistic comparison between the climate sensitive desert margin and the higher Himalaya would require a comprehensive investigation of Garbayang lacustrine succession in future.

Evidence of seismicity is another area, this would require an integrated study involving, geomorphological, structural, sedimentological and chronometric studies. The evidence presented in the thesis are important in terms of understanding the geodynamics of the region north of Main Central Thrust, which was considered seismically inactive.