CHRONOLOGY OF DRYLAND SEDIMENTS IN WESTERN INDIA AND THEIR CORRELATION WITH THE CLIMATIC CHANGES IN CENTRAL HIMALAYA

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SUMMARY

The study is an attempt to reconstruct the Late Quaternary climate change from ecologically sensitive desert margin of western India (North Central Gujarat) and proglacial lake deposits in the Higher Central Himalaya. In the desert margin, three river basins viz. the Sabarmati, Mahi and Orsang were investigated for their fluvio-aeolian records. A detailed field stratigraphy supported by sedimentology and chronometric studies enabled in reconstructing the pattern of climate change during past 100 ka. Similarly, the relict lake sediments in the Garbayana and Goting basins of Higher Central Himalaya were studied for reconstructing palaeoclimatic and seismic events. The data thus generated on pattern of climate change during the Late Quaternary has been compared in order to see the linkages between the desert margin and the Higher Central Himalaya.

Based on the earlier studies it can be suggested that

(i) except for few chronometric data from the Sabarmati and Mahi basins, the chronology of fluvial aggradation was mainly based on indirect age estimates.

(ii) dry lands are known for abrupt climatic changes in the past. Except for few studies from the core of the Thar Desert, little is known from the desert margins about the nature of climatic transition.

(iii) fluvial aggradation in the region is intimately associated with the southwest monsoon; and only a tentative palaeo-monsoonal reconstruction is available.

(iv) present day rivers are slope deviatory and have deeply incised the Quaternary sequences. No estimate (time and factors responsible) exists.

(v) a detailed dune chronology along the east west transects of the Thar desert has been reported by various workers. However, barring few preliminary data on the chronology of fossil dunes in the southern margin of Thar desert no detailed study on the chronology of dune accretion exists.

(vi) similarly, except for few selected studies on Quaternary glaciation and on the relict lake sediments, not much information was avialabe on the Late Quaternary climate from the Central Himalaya.

In view of the above the present study aims at the following:

1. Ascertaining the timing and ambient environment during fluvial aggradation in the region with emphasis on the upper fluvial sequence.
2. Climate, chronology and spatial variability in parameters responsible for dune accretion.
3. Comparison of the climate record from desert margin sediments with that of the proglacial lakes in the Central Himalaya in order to ascertain the linkages if any.

In order to achieve the above objectives, following techniques are used.

1. Statigraphic and sedimentological studies.
2. Dating techniques involving luminescence and radiocarbon dating
3. Geochemical and magnetic studies for deciphering the past climatic changes.

It has been found that the chronology of the older fluvial record in the Orsang basin indicates fluvial response to the pluvial phases corresponding to Marine Isotopic Stage-5e (MIS-5e) and MIS-5a. Similar evidence was found in the Mahi basin. In addition to this a pluvial phase that has been dated to 50-30 ka (MIS-3) was widespread in the basins of Sabarmati, Mahi and Orsang. The evidence for MIS-3 being a wet period also comes from the fluvial record and stable isotope studies on pedogenic carbonates from the Thar suggesting normal monsoon-like conditions during MIS-3. Earlier studies have shown that pedogenesis and fluvial aggradation occurred between 59-39 ka in the Sabarmati basin and 54 and 30 ka in the Mahi basin. Out side the realm of Thar Desert, rich faunal assemblages, suggested a humid phase between 40-30 ka in the southern Ganga Plain.

Prior to the onset of aeolian deposition, the southern margin of Thar Desert experienced regional-scale fluvial sedimentation and the transition from fluvial to aeolian sedimentation was gradual. After around 30 ka, the fluvial regime started dwindling and aeolian deposition began. Of the two events of dune deposition mentioned above, Event-1, which agewise corresponds to the Last Glacial Maximum (LGM), was widespread in

the region. This evidence is at variance with Main land Thar Desert where the aeolian activity was subdued during LGM on account of its association with SW monsoon.

Presence of alluvium and a low sea level stand for most of the time interval under consideration indicates that in general, the dune accretion was not supply-limited. The controlling factors should have been the wind vector and the moisture/vegetation cover. This is in contrast to the core of Thar Desert where LGM ages are largely missing from aeolian records. Such dune deposition around the LGM in southern margin suggests that climate was critically balanced in respect of dune forming conditions such that both sand deflation and their subsequent stabilization occurred.

The present study, therefore, indicates that after the early Holocene (11-8ka) humid phase, conditions favourable for dune deposition progressively shifted northward in the Sabarmati basin. This implies that since the early Holocene humid phase in the Mahi basin, environmental conditions could not have exceeded the geomorphic threshold for dune deposition. This is despite evidence of abrupt climatic changes in this period (Enzel et al., 1999), recorded in Lunkaransar Lake in northern Thar. Although the change in solar insolation during the Holocene was gradual, changes in North African climate and vegetation were comparatively abrupt. Such an abrupt change in climate is typical of the dry land regions and suggests a feedback mechanism within the climate system, which amplify and modify external forcing, leading to abrupt climatic events.

Climate simulations in Sahara and Arabia suggest that during the mid-Holocene, vegetation change in these regions was abrupt compared to slowly varying orbital forcing. This was attributed to an internal feedback in the climate system. Vegetated land surfaces have lower albedo and hence absorb more solar radiation, which eventually lead to an increase in greenhouse effect. A similar scenario for the southern Thar margin can be suggested after 10 ka. With enhanced moisture associated with the re-establishment of SW monsoon around 12 ka, an internal feedback mechanism was established. Climate change after 8 ka, as seen in the Sabarmati basin, was unable to perturb the vegetation-induced moisture/precipitation cycles in the Mahi basin. Compared to this, the northern Sabarmati basin remained moisture-deficient until around 5 ka. Following this, a phase of landscape stability was achieved and it continues till today. On the other hand, episodic dune

building activity continued in the north central Thar around 4 ka, 2 ka and 0.6 ka suggesting a definite shrinkage of aeolian activity belt from 10 ka to 5 ka

In the Higher Central Himalaya, geomorphological configuration of Garbayang and Goting basins indicate that THF acted as a natural barrier against the advancing valley glaciers. This is evident by the presence of terminal moraines at Chhiyalek (Garbayang) and Khal Khuras (Goting). This event is placed at MIS-4. Since no subsequent moraine intercalation in lacustrine deposits is seen, it can reasonably be inferred that the lacustrine sedimentation in Garbayang commenced after the MIS-4.

The sedimentation pattern suggests a proglacial lacustrine environment. The upper lacustrine sequence indicates varve sedimentation around 20±3 ka. Between 20±3 ka to <13±2 ka, sedimentation was dominantly varve in character. This was succeeded by thicker laminae (~3 cm) along with rhythmic appearance of fine sandy-silt laminations suggesting enhanced discharge from the glaciers. The lake then reverted back to cooler condition after 13±3 ka during which fresh water supply reduced and anoxic conditions for the preservation of thick clay rich organic laminations prevailed. Coarse detrital flux, less carbonaceous matter and distinct calcareous laminae suggesting resumption of fresh water influx into the lake.

Between 12-11 ka, a marked abrupt drop in susceptibility, S-ratio and elemental concentration indicate that the lacustrine sediments did register the postglacial cooling. Coincidentally the timing corresponds to the Younger Dryas period associated with North Atlantic climatic perturbation. In continental sequences Younger Dryas events correspond to reduction in African and Asian monsoon strength. More recently, evidence of postglacial cooling in Southeast Africa is attributed to the onset of north winds associated with the Younger Dryas. Following this climate appears to have improved gradually and with full establishment of Holocene climate and catastrophic melting of valley glaciers resulted into the deposition of the topmost gravel dated to 10 ka. Evidence similar to this are also obtained from the Bay of Bengal where an increase in the magnitude of sediment load was found between 11-7 ka. This has been attributed to enhance discharge in the Ganga-Brahmputra system.

In the adjoining Goting basin, lacustrine succession shows an overall concordance in the variation of the elemental data with the susceptibility with subtle difference in terms

of absolute magnitude. Alumina levels range between 20.2 and 17.2 (wt. %) and TiO_2 values vary between 0.66 and 0.8 (wt %). Broadly two distinct domains of contrasting values are seen A consistent high values of Fe, Ti, Al and susceptibility are located between >24±2 ka and <18±3 ka. Following this a marked decrease is seen till 16 ka and beyond. In addition to this, sediments older than 18 ka show high amplitude and low frequency fluctuations, which is succeeded by high frequency oscillations of low amplitude after 18 ka.

In the recent past increasing evidence suggest that a link between Northern-Hemisphere glaciation and Indian monsoon system exists. It has been demonstrated that increase in grain size in the loess deposits of China are linked to the North Atlantic cooling caused by episodic surges of ice bergs (Heinrich events), thus suggesting a teleconnection between the two. Similarly, the climate change prior to 11 ka in tropical Africa was closely linked to the cold conditions in the Northern Hemisphere. Furthermore, inter hemispheric synchrony of abrupt postglacial warming has been suggested to be in phase with that of the Northern Hemishpere. Pattern and timing of the summer monsoon enhancements in western Chinese loess plateau show a correlation with that of the North Atlantic climatic record suggesting a teleconnection between tropical ocean air masses and North Atlantic climate system. Recent studies based on benthic foraminifera record from eastern equatorial Indian Ocean show that Indian monsoon varied dramatically since past 5.5 Ma. According to them, though not certain of the mechanism, however they documented a strong link between changes in the intensity of the Indian monsoon, biotic activity in the Indian Ocean and North Hemisphere glaciation. The above evidence are indicative of the fact that Northern Hemisphere glaciation significantly modulated the global climate during the late Quaternary. There are arguments for the Tibetan plateau uplift and growth of large continental ice sheets through positive feed back mechanism and synchrony in Northern Hemisphere glaciation and phase of uplift of the northern Tibet. However, the recent evidence from Tibet negates the albedo of the Asian continent as a critical parameter for regional to hemisphere-wide climate change. This is based on their study on glaciation in Tibet suggesting limited ice cover at least during >170 ka. In view of this, the climate instability recorded at Goting that lies close to southern fringe of the Tibetan plateau possibly relate to the Northern

Hemispheric glaciation. The role of Tibetan Plateau in adjusting the Asian and Northern-Hemispheric atmospheric circulation by latitudinal migration (north-south) of westerly jet during warm (interstadial) and cold (stadial) phases. Thus, it is likely that during the cold stadials, westerly jets would have penetrated beyond the Himalayan foot hills and probably reached the southern and western plains. This is evidenced by the dune building activity in the desert margin and loess deposition in the Central India.

Evidence of regional cooling and weak southwest monsoon has been suggested for less extensive valley glaciation during 22 to 16 ka in the Central Himalaya. The study also suggests absence of glacial moraine intercalation with lake deposits at Garbayang and Goting. Thus implying that valley glaciers remained much above the limit of penultimate glaciation (~60 ka) between 21 to 17 ka. Similar evidence have been reported from east and west Tibet indicating overall cold and dry conditions. However, the period was dominated by fine structure of low magnitude high frequency climatic instability in the lacustrine record. Such fluctuations during low summer insolation and global ice volume suggest millennial scale climatic controls, independent of orbital scale forcing. Due to large uncertainty associated with the IRSL ages, short term fluctuations remained unresolved at this stage of the study.

Limestone constitutes one of the major lithofacies in Himalaya, and some of the lakes are located predominant in limestone terrain. Unless checked and if possible corrected for hard water effect, uses of such ages for deducing palaeoclimatic inferences may be misleading. Though large uncertainty associated with IRSL chronology prevents corrections for the hard water reservoir effect, however, it does indicate that the bulk radiocarbon ages in some cases are >50% over estimated.

Evidence of seismicity suggests that the Higher Central Himalaya, flanking southern Tibet responded to neotectonic activity associated with north-south and east-west extension structures. Events such as gorge formation, truncation of lateral and end moraines and perched glacial valleys are associated with the seismicity related to north-south extension (THF). These features terminate against the rising footwall of THF implying continued upliftment pre dating these events. An indirect age estimate for continued activity along THF is provided by an OSL age of 63 ka on the oldest valley glaciation from Gangotri glacier. Based on the existence of morphologically similar

advancements in Gori Ganga and Kali river basins, assigned MIS-4 to this event. It is thus reasonable to suggest that reactivation of north-south extension in Central Himalaya pre date MIS-4 and its activity continued episodically as indicated by four distinct events that are bracketed between 24-17 ka and 14-13 ka respectively. Subsequent events relate to east-west extension structures, and a luminescence age on terrace T_1 indicates that the events postdate 11 ka (4.20). The most recent activity was in 1980 that caused ~3 m NE striking surface rupture in upper most outwash gravels at Garbayang. This was triggered by an earthquake which had an epicentre ~50 km south of the THF (along the MCT) that had also caused vertical as well as lateral movement in the region.

The present study demonstrates that the 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 at Sabarmati, 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. Subsequent events corresponding to MIS-4 and 3 suggest that the fluvial regime has responded to the overall 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, during which the climate was drier due to the weakened southwest monsoon. 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, whereas, the aeolian activity persisted until around 5 ka in the Sabarmati basin. This indicates a northward shift in parameters responsible for dune formation. An interesting observation unlike the core of Thar Desert, southern margins has 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 accord 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 incision of Quaternary sequences appears to be modulated by the interplay of climate, tectonics and sea level changes. However, effect of sea level on incision was more pronounced in the narrow coastal region of Sabarmati basin and probably in 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 MIS-4. A near continuous 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 evidences 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 suggests that late Quaternary climate was linked to the Northern Hemisphere glaciation.

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 an increase in sediment load was found between 11-7 ka. This has been attributed to the enhance discharge in the Ganga-Brahmputra system.

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 lime stone terrain. 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. 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 supports the observations made 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 synchronous 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. Comparing this period with the desert margin, it shows presence of a weak hydrological regime during which fluvial systems 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 indicates 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 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 suggests 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 observation is important in view of the fact that Himalaya along with the Tibetan plateau was considered as pace maker for regional and global climate.