CHAPTER-1

INTRODUCTION AND BACKGROUND INFORMATION

The expansion and contraction of deserts and their relationship to changes in climate including the albedo and atmospheric circulation patterns have long been investigated. Conventionally the dry land expansion has been associated with high-latitude glacial epochs and the contraction episodes with more humid phases. A synchronous response of different desert systems to climate changes has been assumed (Lancaster, 1981, 1990). However, more recent studies based on luminescence dating technique suggest that the local and regional factors significantly modulated the geomorphic response of the dry land. In Indian context, it is now widely accepted that the Himalaya and Tibetan plateau exert significant influence on the regional and global climate (Kutzbach et al, 1989; Ruddiman and Kutzbach, 1989; Molnar et al., 1993). On a regional scale, Himalayan glaciers along with the Tibetan plateau influence the southwest monsoon in the region. For example, a reversal of monsoon pattern has been attributed to the build up of ice cover over Himalaya and Tibet during Last Glacial Maximum (LGM). The coupled heating and cooling of the Himalayas and the southern Indian Ocean regulate the strength of the SW monsoon (Duplessy, 1982). It has been suggested that during the Late Pleistocene, unstable climate in the Himalayas had induced synchronous century scale changes in sea surface salinity of the Bay of Bengal (Chauhan, 2003) In Central India, extensive loess deposits are attributed to the southward propagation of cold front during the glacial time (Willam and Clark, 1984). Similarly, the advancement and retreat of the Himalayan glaciers should have a profound effect in the expansion and contraction of Thar Desert margins (Pant, 1993). Recent evidences suggest that dune accretion peaked in the southern desert margin during the LGM (Juyal et al., 2003). In view of this, the stratigraphic sequences in the desert margins (fluvial and aeolian) are important in order to discern the ambient climatic condition during their deposition. One of the advantages of studying these sequences in the desert margin is their amplified geomorphic response to even a minor climatic perturbation.

Similarly, the proglacial deposits such as moraines and lakes in the Higher Himalaya respond too readily to a slight increase or decrease in temperature. For examples, with an increase in temperature of 0.65^0C in the temperate region, there would be a corresponding retreat of around 100 m in the valley glacier and vice-versa. Since proglacial lakes are genetically related to the proximity of the valley glaciers, they respond in accordance with the glacier advancement and retreat. Mapping the distribution of proglacial features and comparing them with their modern counterparts helps in reconstructing the periods of extreme temperature depression during the glacial episodes (Bradely, 1999). In the Higher Central Himalaya modern peroglacial environment exists in areas that are located above ~4000 m and geomorphic evidences suggest that in the past such areas descended to lower altitude at ~3000 m. This signifies lowering in the temperature/precipitation conditions in the past.

Conventionally an inference towards the glacial advancement and retreats in the proglacial areas is based largely on the record of moraines, particularly the lateral moraines. However, a detailed climatic reconstruction based on moraine is limited by (i) poor preservation and fragmentary nature of the deposit and (ii) problem of dating due to lack of suitable dating material. This further limits the usages of moraine as a palaeoclimatic index. Compared to this the lacustrine sediments preserve a continuous record of climate change in the sensitive proglacial environment (Dahl and Nesje, 1996).

Desert Margin

The North Central Gujarat enclosed between 22^0 - 25^0 N and $72^0 - 73.5^0$ E forms the

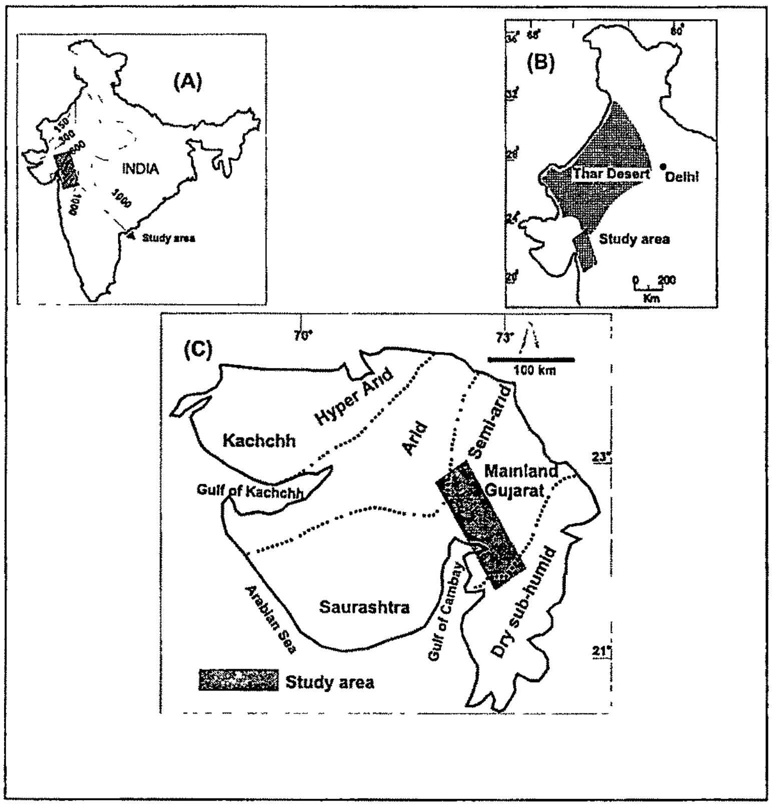

Figure-1.1. Study area (A) Isohytes (mm) showing decreasing trend towards northwest. (B) Location of Thar Desert with respect to the study area. (C) Broad Climatic zones of Gujarat.

southern margin of Thar Desert. Rann of Kachchh and Arabian Sea flank it in the west and the Aravalli Mountains constitute the eastern boundary (Fig.1.1). Majority of the rivers have their catchment in the Aravalli upland and drain through the vast alluvial plains before debouching into the Ranns of Kachchh and Gulf of Cambay. These rivers, from north to south, are the Banas, Rupen, Sabarmati, Mahi, Orsang and the Narmada (Fig. 1.2). Regional stratigraphy based on sub-surface data shows nearly 300 m thick Quaternary sediments resting on Tertiary basement (Biswas, 1987; Maurya et al., 1995; Tandon, et al , 1997). Zeuner (1950) recognized the palaeoclimatic significance of the exposed Quaternary deposits in the Sabarmati, Mahi and Narmada basins, and postulated that the climate fluctuated between wet and dry during the Pleistocene.

The Sabarmati River originates in the southwestern spurs of the Aravalli hills in Mewar region and meets the Gulf of Cambay (Fig. 1 2 and 1.3). Over this distance it passes through three geomorphic zones, viz. the rocky upland, the middle alluvial plains and the lower estuarine zone (Tandon et al., 1997, Fig.1.2). Zeuner (1950) investigated the Sabarmati basin and suggested that the repeated dry and wet climate facilitated the sedimentation in the basin, which shifted its course gradually to the east during the Quaternary. Based on lineament and drainage studies, Sareen et al. (1993) have shown that while the regional drainage in the Gujarat alluvial plain follows the NE-SW regional slope the Sabarmati River follows a N-S to NNE-SSW trend (Fig. 1 4). On the basis of sedimentological and geomorphological studies, Sridhar et al. (1994) suggested that the Quaternary sediments in the Sabarmati basin are unrelated to the present day river.

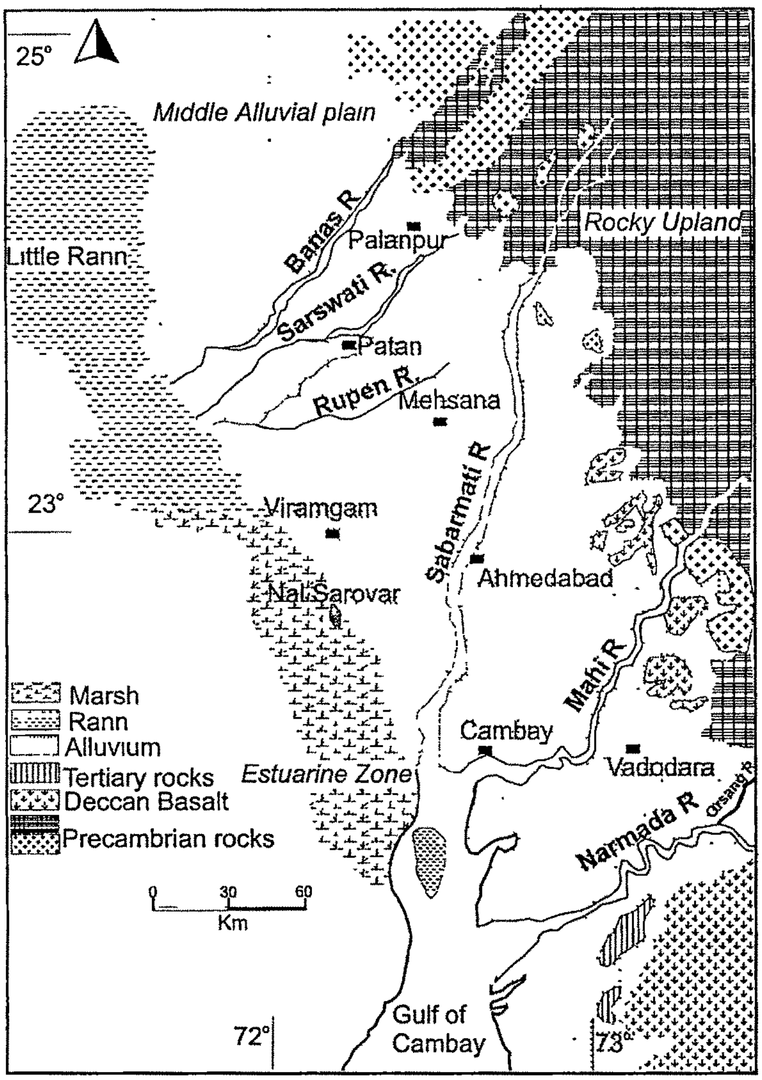

Figure-1.2. Geomorphology of the southern margin of Thar Desert. Major rivers originate from Aravalli upland region and drain through the vast alluvial plain before meeting the Rann and the Gulf of Cambay. Three broad geomorphological features are the Upland areas, the middle alluvial plain and the estuarine zone (after Merh and Chamyal, 1997).

The Mahi River is the third largest river in Gujarat. It originates from 556 m elevation in Malwa region of Madhya Pradesh and flows about 180 km in Gujarat before emptying into the Gulf of Cambay (Fig. 1.2 and 1.3). The Mahi River basin presents near identical geomorphic zonation like the Sabarmati basin. The three broad geomorphic zones can be divided into the upper rocky terrain, the middle alluvial plain and the lower estuarine zone

(Fig 1.2). Present day Mahi River flows along the eastern flank of the Cambay graben. Varying thickness (10-40m) of Quaternary sediments exposed along its course indicate that sedimentation in the Mahi basin was strongly influenced by tectonics, climate and sea level changes (Pant and Chamyal, 1990; Rachna Raj et al., 1998,1999; Juyal et al., 2000; Chamyal et al. 2003). Agrawal et al. (1996) based on remote sensing data, indicated presence of a palaeo-delta of Mahi River towards the west from its present course and suggested that it had an extensive (5-10 km wide) flood plain (Fig. 1 4). The palaeo delta was structurally controlled by NE-SW trending Precambrian lineaments.

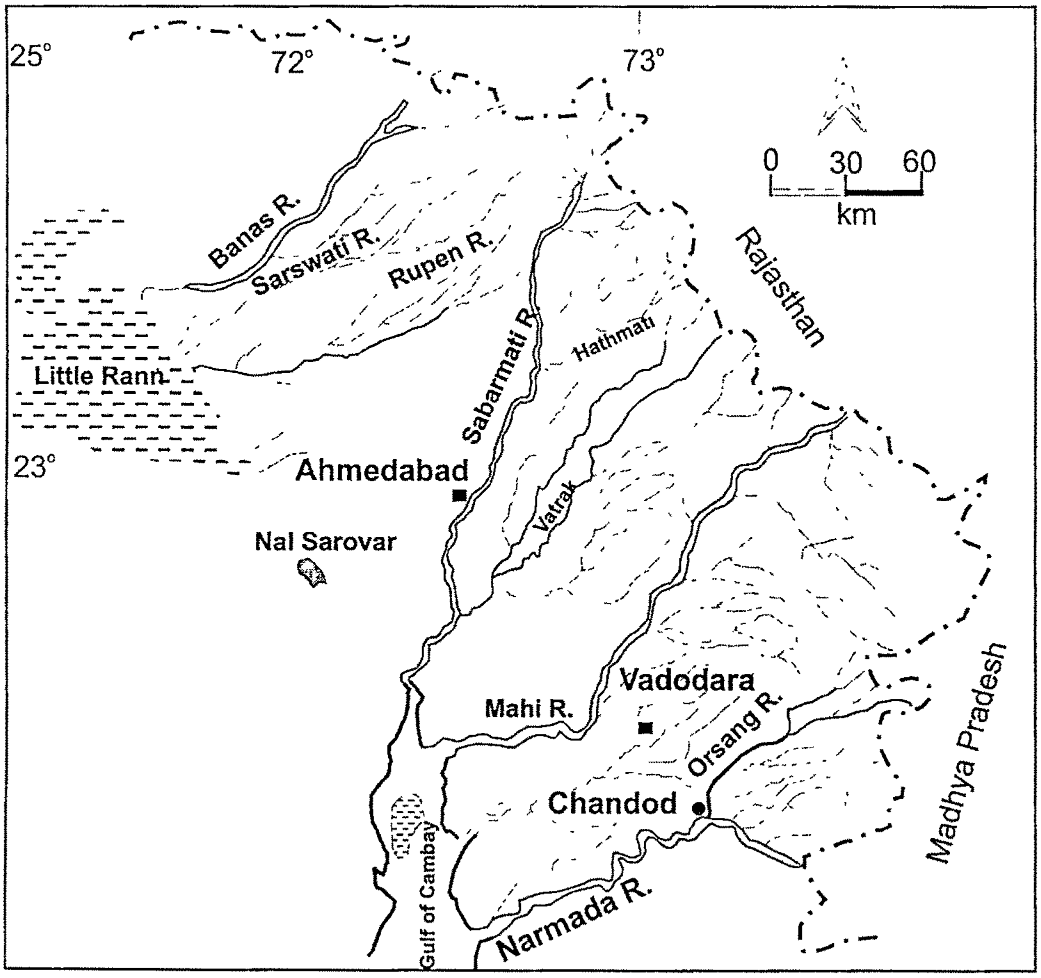

Figure- 1 3 Drainage map of the study area

The Orsang River emerges from the SE margin of the Aravalli ranges at

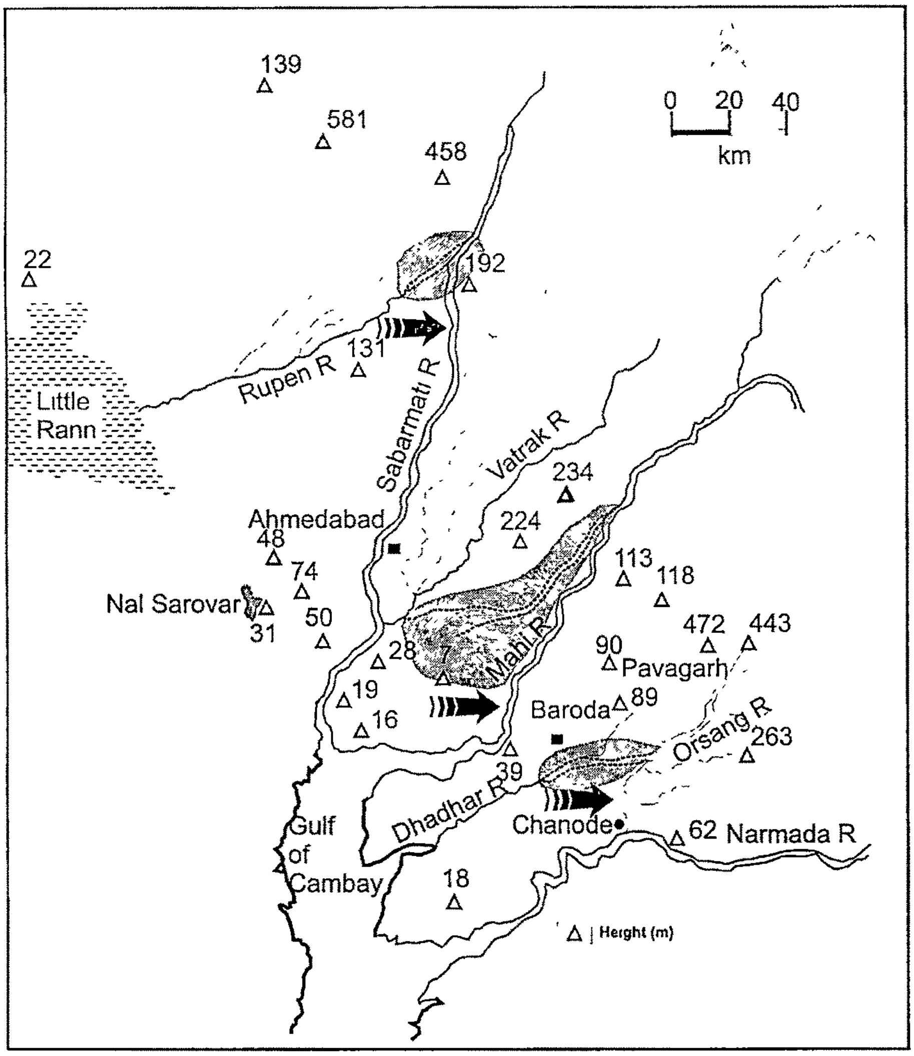

Figure-1.4 Map showing palaeo courses of Sabarmati, Mahi and Orsang rivers (dotted and shaded area) suggesting SW flow (in accordance with regional slope). Present course is towards SE suggesting anticlockwise swing marked by thick arrows (after Agrawal et al. 1996 and Merh and Chamyal, 1997).

Nurpur in Madhya Pradesh, and after flowing for about 20 km in the alluvial plain in Gujarat it meets the Narmada River at Chandod (Fig.1.2 and 1.3). In such a short distance the river has incised 20-40 m thick Quaternary sequences exposing multiple cycles of fluvial sedimentation that is invariably capped by the aeolian sand sheets. Similar to Sabarmati and Mahi Rivers, Orsang River also deviates from the regional SW slope in the alluvial plain and flows towards SE (Fig. 1.4). It has been suggested that the Orsang River has captured the E-W flowing Heran and Ucch Rivers (Maurya et al., 2000).

Geomorphology and tectonic setting

The alluvial plain beginning at the foothills of the eastern Aravalli corridor extends WSW up to the Gulf of Cambay and Rann of Kuchchh (Fig. 1.2) Both, the alluvial plain and the lower estuarine zone have preserved extensive records of the Quaternary sediments. Overall, the slope of alluvial plain has a distinct bias towards west-southwest (Sareen et al., 1993). Except for the rivers like Banas, Saraswati and Rupen the other major rivers viz. the Sabarmati, Orsang deviate from the regional slope with preferential flows towards SE (Fig. 1.4). In the alluvial plain these rivers have deeply incised channels reaching a depth of ~40 m. Following this banks become less steep and river channel progressively widens towards the lower estuarine zone (Figs. 1 2 and 1.3). Subsurface data indicate that the presence of pre-existing step faults parallel to the Eastern Cambay Basin Margin Fault (ECBMF) acted as the depocenter for Late Pleistocene sedimentation (Maurya et al., 1995). A plot of subsurface lithology between Mehsana (NW) and Ankleshwar (S-SE) shows presence of horst and graben structures. Sabarmati and Mahi Rivers lie in a horst segment in which 200-300 m thick Quaternary sediments rest over the Tertiary basement (Fig. 1.5A and B). Sediments were derived from the eastern upland made up of the Precambrian rocks and the Deccan volcanics. Partial Present day Sabarmati River flows parallel to the faults related to the Cambay graben (Fig.1.5A). It has been suggested that the Sabarmati River used to flow towards SW and was draining into the Rupen River, which is also considered as palaeo-course of the Sabarmati River (Sridhar et al., 1994)

Numerous NNE-SSW trending fractures have developed consequent to the formation of Cambay graben, which are responsible for the present day N-S course of the Sabarmati River. Sareen et al. (1993) suggested an age of <300 ka for the emergence of the modern

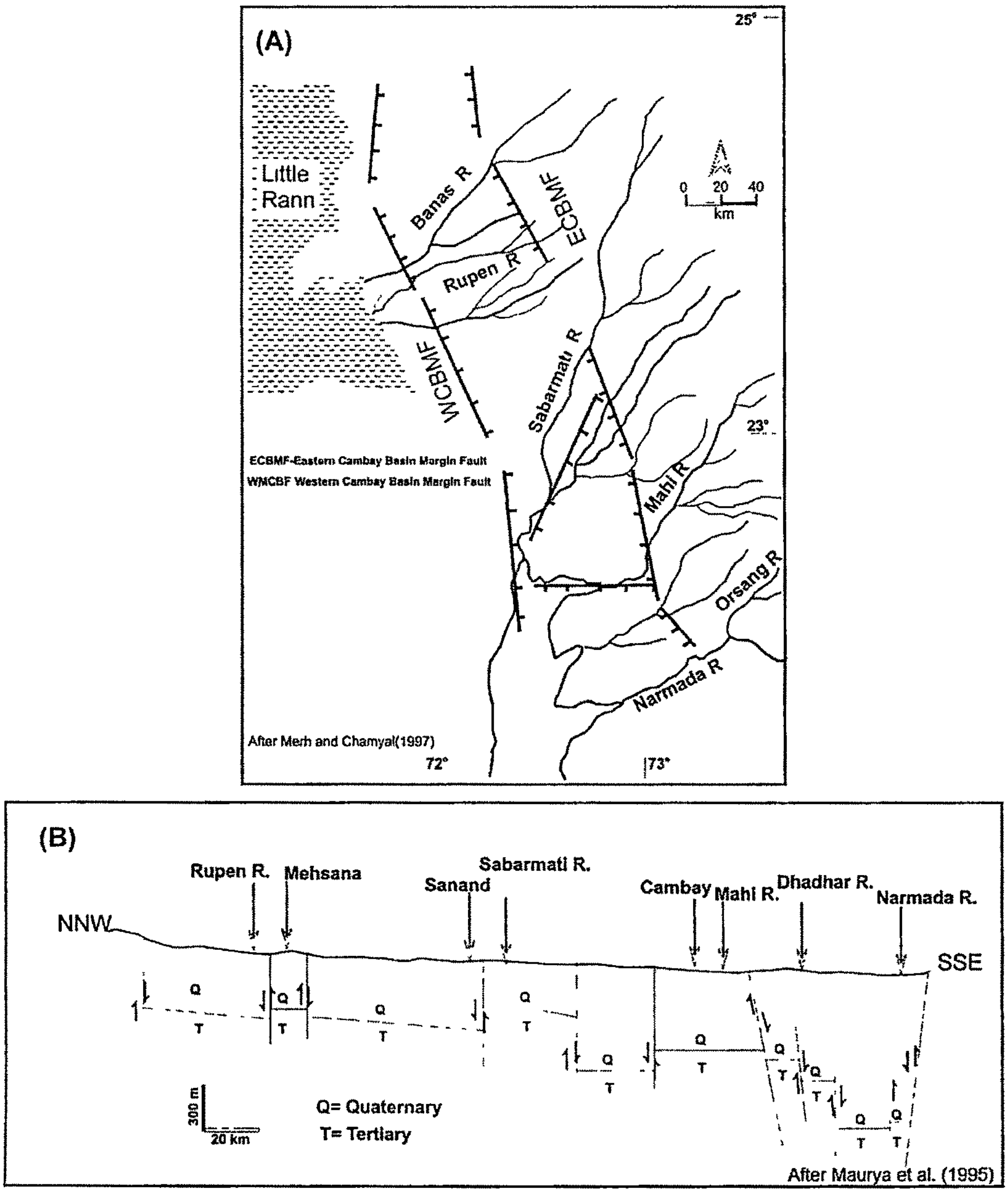

Figure-1.5. (A) Drainage pattern in the Cambay graben (B) Basement topography of Quaternary sediments (after Maurya et al. 1995 and Merh and Chamyal, 1997).

river that has captured the course of Vatrak (Maurya et al., 2000). According to Sridhar et al. (1994) it is undoubtedly the most recent and active river, which had the power to incise the Quaternary sediments Tandon et al (1997) based on luminescence dating suggested that fluvial sedimentation in the Sabarmati River basin continued at least up to 39 ka and the N-S adjustment of the Sabarmati River could have occurred around this time

Similarly in the structurally controlled Mahi River basin, the chronology of the exposed Quaternary sediments indicate that deposition commenced around the Last Interglacial (125 ka) and continued till 30 ka (Juyal et al., 2000). This was the period when the river was flowing due southwest from its present course as suggested by Agrawal et al. (1996). It is likely that the present course would have been occupied after at least 30 ka when it captured the course of Mini, Mesri and Goma rivers (Maurya et al., 2000). Several NNW-SSE trending fractures that developed parallel to the ECBMF have strongly influenced the drainage pattern of the river. It has been found that whenever the river approaches a lineament it deviates from its NE-SW path and takes a NNE-SSW course (Merh and Chamyal, 1997)

Not much data exists on the Orsang River basin. Sant and Karanth (1993) suggested that the regional tectonics in the Lower Narmada basin has shortened the basin areas of westerly flowing tributaries of Narmada and Mahi Rivers during the Pliocene and Pleistocene. They suggested successive stages of the landform development in the lower Narmada basin and opined that the present day topography (elevated surfaces and low-lying areas) in the region is due to the release of stresses during early Pleistocene. According to their study, Orsang was an independent river. Evidence towards this comes from the study of Maurya et al (2000) indicating that the Orsang River had captured the course of E-W flowing Heran River due to tectonic activity along Cambay basin fault that caused the river to flow along or parallel to basin axis.

Climate

Three broad climatic zones from south to north can be found. They are the dry sub-humid Orsang basin (mean annual rainfall ~1000 mm), followed by semi-arid Mahi and Sabarmati basins (mean annual rainfall ~750 mm) and towards its north is the arid Banas basin (mean annual rainfall <750 mm) The Sabarmati and Mahi Rivers flow through a semi-arid region whereas the Orsang River in the dry sub-humid region (Fig.1.1).

Stratigraphy

A generalized stratigraphy of the exposed Quaternary sequences in the river basins of Sabarmati, Mahi and Orsang begins with mottled fractured clay. Which is over lain by gravel horizons, at times occurring as channel deposits. This is succeeded by silty sand, showing evidences of pedogenesis and effect of groundwater fluctuations. This is overlain by massive gravel horizon that is followed by two or three pedogenised silty sand horizons. One such horizon, which is red in color, has been referred as the red bed or red soil by earlier workers and used as a stratigraphic marker in the region (Pant and Chamyal, 1990; Khadkikar et al., 1996; Tandon et al., 1997; Maurya et al., 2000). The pedogenised horizon is overlain by fluvial silty sand, at times graded with distinct fining upward sequences. Towards the upper part this unit becomes fluvio-aeolian in character. Finally the aeolian sand sheet marks the termination of Quaternary sedimentation in the region. The detailed description of the studied sections is presented in chapter-3.

Zeuner (1950) was the first to provide a detailed description of the exposed Quaternary sequences in the Sabarmati River basin. According to him the mottled clay is the oldest exposed deposit overlain by cemented gravel that in turn is capped by red soil developed on riverine silt. This silt is over lain by fluvio-aeolian deposit and the wind blown sand demarcates the termination of Quaternary sedimentation. Following this Merh and Chamyal (1997) and Tandon et al. (1997) elaborated upon the sequence stratigraphy.

Merh and Chamyal (1997)		Tandon et al. (1997)	
Formation	Lithology	Formation	Lithology
Mahudi	Dunal Sands Aeolian silt	Sabarmati	Fine to medium sand
Saroli	Grave-III Coarse Sand Mud	Akhaj	Fine sand
Hirpura	Rubified silt	Mehsana	Medium –Fine Sand Fine sand, Caliche Silty clay
Lakroda	Mud, Gravel-II Mud Grave-I Bluish clay	Waghpur	Red sand (pedogenised and rhizoconcertionary), Cemented gritty sand stone, interbedded with red sand

The four fold stratigraphic sub-division is based on the exposed cliff sections along the Sabarmati River. As seen above there is overall agreement in terms of the number of formations identified, however, the lithologic details of the formations do not match. The rubified silt of Merh and Chamyal (1997) is equivalent to the red pedogenised sand (Waghpur formation of Tandon et al., 1997) The present study is however, confined to the last fluvial phase in the region overlying the red soil.

In the alluvial plain two broad surfaces are recognized (Maurya et al. 1998, 2000). The older surface S_1 and the younger surface S_2. S_1 surface is made up of Late Pleistocene fluvial sediments that are invariably capped by the aeolian sediments. In Sabarmati, Mahi and Orsang basins this surface has been extensively gullied Compared to this, the S_2 surface which occupy incised river valleys are dominantly fluvial in the inland locations such as Mahudi in the Sabarmati basin and become fluvio-marine in areas proximal to the estuarine environment e.g. Sultanpur and Kothiyakhad in the Mahi basin. This surface does not have aeolian sand cover (Fig 1.6). Merh and Chamyal (1997) have reconstructed the Quaternary alluvial stratigraphy in the Mahi River basin. According to them the sequence rests on basal marine clay and the three formations recognized are shown in the table below.

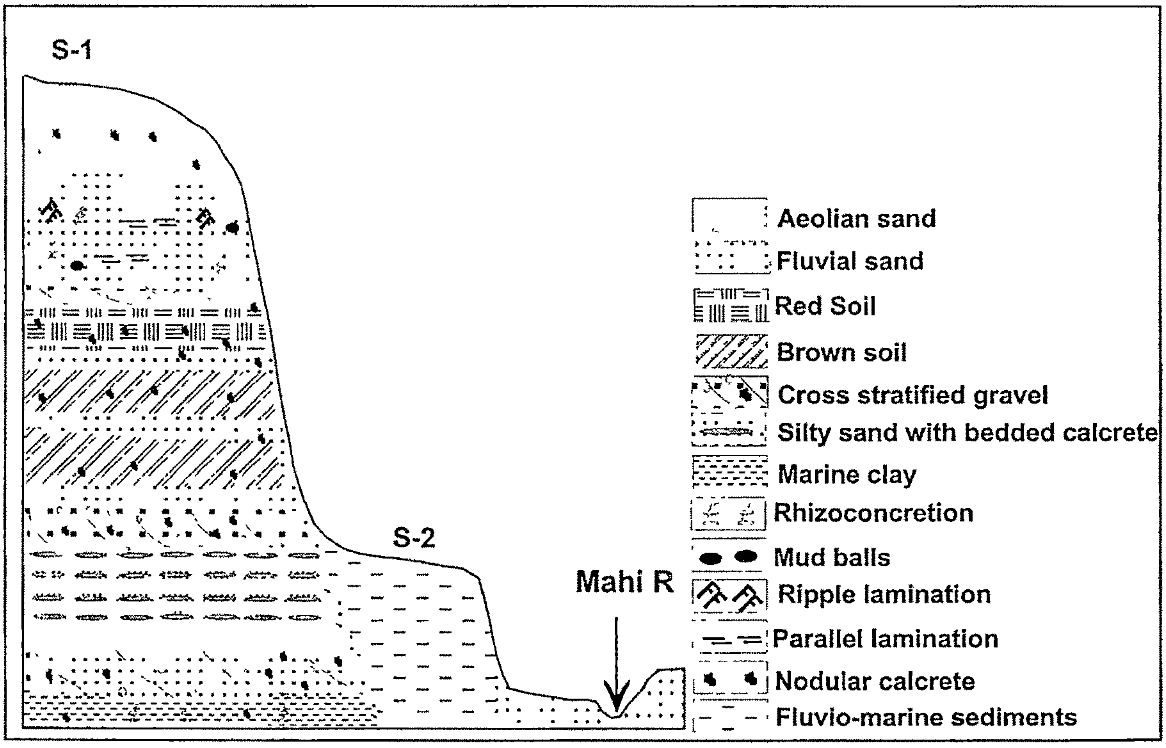

Figure 1.6. Generalized Quaternary stratigraphy in the Mahi basin along with the older S_1 and younger S_2 surfaces. Similar surfaces occur in the Sabarmati and Orsang basins as well.

These formations are better developed at Rayka, which is considered as the type locality in the Mahi basin. The sequence commences with the deposition of marine clay containing both benthic and planktonic foraminifera (Rachna et al., 1998). This clay horizon is known to extend to a depth of 25 m below the present sea level (Murthy, 1975). In the exposed sections thickness of the horizon varies between 0.5 to 3 m and shows evidences of post-depositional pedogenesis. This is overlain by planar cross-bedded gravel (Gravel-I) with a sharp erosional contact. Gravel-I is overlain by a sandy silt layer with a mud capping, and is overlain by trough cross bedded gravel (Gravel-II) that is followed in turn by thick sandy silt with intercalated three palaeosol horizons The lower two palaeosols are grey in color where as the upper one is red in colour (red soil). Immediately above the red palaeosol lies the aeolian sand marking the termination of the sequence (Juyal et al., 2000)

Formation	Lithology
Singrot	Aeolian sand Fluvial sequence
Shihora	Red silty sand (red soil) Brown silty sand Alternating silt and sand with calcrete layers
Rayka	Cross stratified gravel Pedogenised fractured mud (vertisol) Stratified silts and calcrete bands (marly) Planar to epsilon cross stratified gravel Basal marine clay

Stratigraphic evidence of fossil dunes has long been used to understand the episodes of expansion and contraction of deserts. It is now extensively documented that the world's deserts experienced large amplitude changes with respect to the spatial extent of aeolian activity. These extremes have been linked to the Last Glacial Epoch and the Holocene optima based on the changes in the aridity. Several studies have underscored the importance of stratigraphical sequences in the desert margins, as in these regions minor perturbation in the climate affects the aeolian activities on a spatially amplified scale.

Hemispherically synchronous expansion and contraction of deserts and a peak in dune accretion in Africa, Australia and Asia around the Last Glacial Maximum (LGM) has been suggested since long (Williams, 1975; Sarenthein, 1978). However, contrasting evidence for the Late Quaternary contraction of southern African deserts and expansion of their northern counterparts also exists (Lancaster, 1981; Shaw and Cook, 1986; Partridge, 1997). Quantification of the timing and duration of the expansion and contraction of deserts have an important bearing on the magnitude of albedo change through time. These have a direct impact on changes in the past atmospheric circulation patterns. With the availability of direct dating of dune sand using luminescence dating (Singhvi et al., 1982), such questions can now be addressed quantitatively.

In general, aeolian activity in the sub-tropical deserts has been associated with arid phases. Major controlling factors in aeolian deposition are the wind vector (the relative drift potential), the sediment supply, basin geomorphology, and vegetation cover (Tchakerian, 1994; Kocurek and Lancaster, 1999). For establishing aridity across hemispheres and in desert expansion/aeolian accretion episodes, a large chronometric database on dune accretion activity is needed. In this regard, desert margins (by virtue of their unique geomorphological locations) are important. In such regions, minor shifts in the environmental parameters such as temperature, precipitation or wind can induce amplified changes in the processes controlling aeolian dynamism.

In the Thar Desert, Goudie et al. (1973) suggested that the present day aeolian activity occurs in regions with <250 mm annual rainfall. According to them, the presence of fossil dunes in the areas with present day annual rainfall exceeding 1000 mm indicates a spatial shift in overall monsoon gradient during the past. Current researches show that the strength of the monsoon wind and availability of wind erodable sediments are important determinants for the aeolian activities in the present day Thar Desert, although the rainfall gradient from east to west partly mimics the spatial pattern of sand mobilization (Kar, 1993). Over the geological time scale, fluctuations in the strength of monsoon winds in the region (as well as rainfall) controlled the spatial extent of the dune building activity Based on this premise, "dune shifts" of ~100 km in the Sahara, ~1200km in southern Africa, ~350 km in the Thar Desert and > 800 km in the loess-desert boundary in China have been inferred (Goudie et al., 1973, Yan and Petit-Maire, 1994; Partridge, 1997).

Lancaster (1990) modeled the effects of climate change on dune mobility and aeolian sedimentation in deserts. According to him in periods of high rainfall dunes are stabilized by vegetation, and the dune fields are dormant The model suggested that with an increase in sand supply during dry periods, conditions favourable for sediment deflation by winds were created. Dune accretion on the other hand, requires optimum vegetation/moisture or a reduction in wind speed to facilitate sand deposition (Fig. 1.7).

Evidence of spatially variable moisture regimes during the Last Glacial Maximum, exists. For example, the southwest American deserts experienced an increase in effective moisture, high lake levels, and woodland expansions (Benson et al., 1990). On the other hand in India, evidence from the oceans and Thar Desert suggests that the SW monsoon was weaker at this time (Bryson and Swain, 1981; Chawla et al., 1992; Duplessy, 1982; Enzel et al., 1999) and that the geomorphic processes in the Thar Desert were nearly dormant (Kar et al , 2001). Thar Desert is located at the end of the Sahara-Arabian desert tract and at northwestern limit of the SW monsoon. The sand moving winds in the Thar desert are linked to the SW monsoon system such that they exceed the threshold for sand movement only for two summer months preceding the onset of monsoon, (Chawla ét al., 1992; Kar et al., 1998; Wasson et al , 1983).

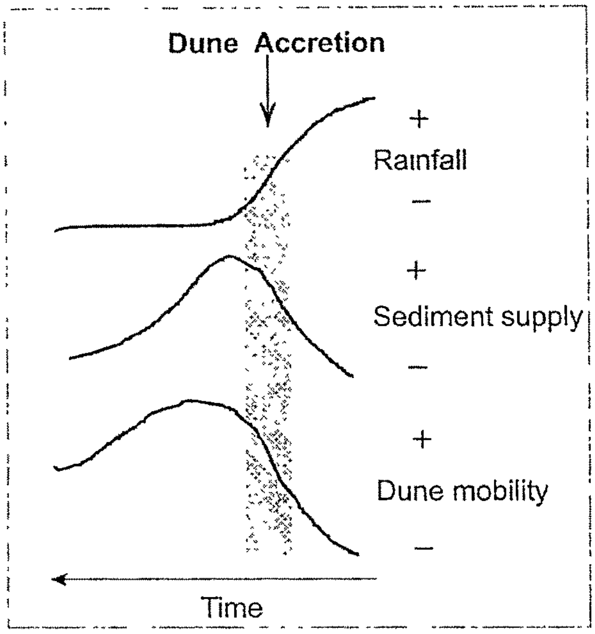

Figure-1 7. A relationship between rainfall, sediment supply and dune mobility is shown (plus and minus symbols are for high and low). The figure depicts an optimization of the above parameter for dune accretion (after Lancaster, 1990).

In the north Central Gujarat the mean annual precipitation varies from ~550 mm (north) to ~>1000 mm (south) indicating a northward decreasing precipitation gradient of ~2 mm/km (Fig. 1.8). The period from May to September has a large number of windy days (~72%, average speed 38 km/hr) with winds blowing from the west-southwest coinciding with the southwest monsoon period. The trends of dunes in the region also follow this direction (Allchin and Goudie, 1971). The narrow pediment plain along the Aravalli foothills in the east is usually covered by deflation lags and at times has a thin veneer of fluvial sediments. In areas where the wind blows through narrow wind gaps, obstacle dunes are seen. The random distribution and absence of any discernible direction of the fossil dunes in the region suggest their genesis from local aeolian reworking of older alluvium (Singh, 1977; Wasson et al , 1983).

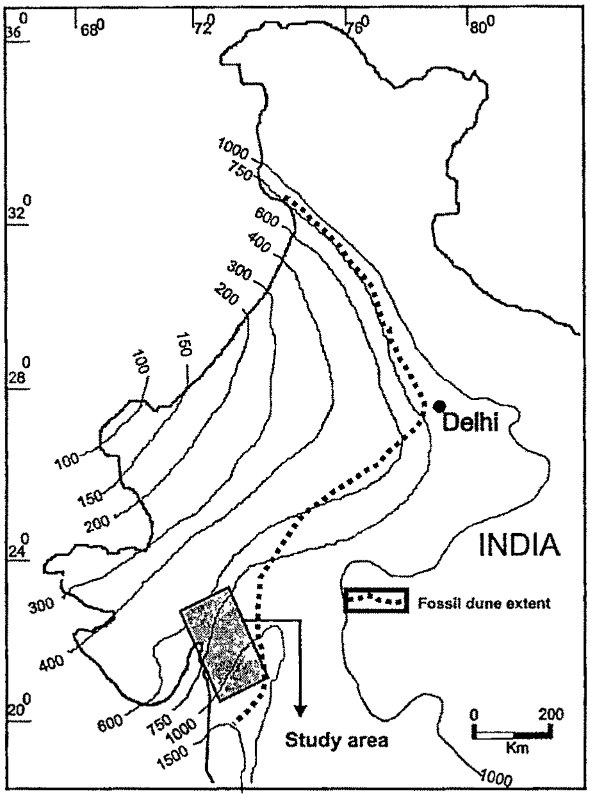

Figure-1.8. Map showing the distribution of rainfall (mm) in the western India. Former extent of desert is shown with dotted line (after Chawla et al., 1992).

Central Himalaya

Expansion and contraction of continental ice sheets have modulated the global climate during the Quaternary. At regional scale the mountain glaciers had profound effect on the terrestrial climate especially the Himalaya and Tibetan plateau have influenced the southwest monsoon in the region (Ruddiman and Kutzbach, 1989; Molnar et al., 1993). Indirect evidences of Quaternary glaciation in the Himalaya comes from a pollen zone of the Plio-Pleistocene basin fill of Kashmir (Karewa Group) indicating prevalence of a cold and dry climate estimated to date between 0.7 – 0.6 Ma (Agrawal et al., 1989). Burbank and Johnson (1982) on the basis of magnetostratigraphy and fission track dating of the Karewa succession, suggested that the terminal phase of the uplift in Kashmir occurred about 0.3 – 0.4. This coincides with the loess accretion in the valley suggesting prevalence of glacial climate (Pant, 1993).

Since moraines are the direct manifestation of glaciation, based on field mapping and relative chronology, it has been suggested that at least three glacial advances can be identified in the Himalaya pertaining to the Quaternary advancement (Derbyshire et al., 1991, Holmes and Street-Perrot, 1989). It has further been observed that Quaternary glaciation in the Himalayas during Last Glacial cycle were not synchronous through out the region. In some areas glaciers reached their maximum at Last Glacial Maximum (LGM) where as in other parts they were extensive between 60-39 ka. The latter has been attributed to increase summer monsoon precipitation where as the former indicates regional cooling (Benn and Owen, 1998). In Central Himalaya, evidence from Gangotri glacier suggests that maximum extent of ice occurred approximately 63 ka ago. The main valley glaciers began to retreat between about 20 to 16 ka and the present position was reached around 5 ka (Sharma and Owen, 1996). Schafer et al. (2002) have suggested that moraine corresponding to the less arid MIS-4 has been dated to 68 ka (using ^{10}Be and ^{26}Al exposure age technique) in central Tibet and the advancement dated to LGM were less extensive. According to them no extensive ice covered the Central Tibet since >170 ka. Schafer et al. (2002) contradicts the idea that substantial glaciation in Tibetan plateau influenced the regional to hemisphere-wide climate change (Emies et al. 1995; Sarkar et al. 1990).

The Himalaya stretches over 2000 km east west (from Burma to Afghanistan) and over 1000 km north south (from the desert of Central China to the Indo-Gangetic Plain) having average elevation of 6000 m and has a profound effect on the climate of this subcontinent (Benn and Owen, 1998; Owen et al., 2002). For example, a reversal of monsoon pattern has been attributed to the build up of ice cover over the Himalaya and the Tibetan plateau during LGM, which increased land-sea thermal contrast (Duplessy, 1982). The salinity gradient in the Indian Ocean was much steeper (Duplessy, 1982) which reflects drastic reduction of fresh water input from Himalayan rivers (William and Clark, 1984). This in turn may have exposed vast tracts of sparsely vegetated alluvium leading to its deflation by northeast winds. Extensive loess deposits in most of north and central India are the direct manifestation of glacial climate (William and Clark, 1984; Pant, 1993). The other land manifestations of climate change are the expansion and contraction of Thar Desert margins (Wasson et al , 1983; Singhvi and Kar, 1992). The strong winter monsoon may have had an amplifying effect on the katabatic or gravity winds (Pant, 1993), which were responsible for the increased amount of quartz, dust plumes and large flux of Asian pollen into the Arabian Sea (Kolla and Biscay, 1977; Prell and Van Campo, 1986; Sirocko and Lange, 1991; Rea, 1994).

Evidences of late Quaternary climate from Higher Central Himalaya (Fig. 1.9) are virtually non- existent. Studies carried out in the Bhimtal-Naukuchiatal lake basin (Lesser Himalaya) suggest prevalence of arid and humid climate during the upper Pleistocene (Kotlia et al., 1997). Similarly the relict lake deposits from eastern Kumaun Himalaya indicate occurrence of three temperate humid and at least two well-defined arid episodes between 36 ka and 10 ka (Kotlia et al., 2000).

The Higher Central Himalaya is a narrow corridor between the Great Himalyan Range and the Indo-Tibetan water divide. Trans Himadri Fault (THF) demarcates the boundary between the Central Crystallines in the south and the Tethyan sedimentary rocks in the north (Fig. 1.9). This region has a unique record of glaciation that is constrained by its structural configuration. Past glacier advances were limited by the THF and at places rivers were blocked behind the tectonically uplifted ridges giving rise to lakes. A cartoon depicting the formation of proglacial lake in the study area is shown in figure 1 10.

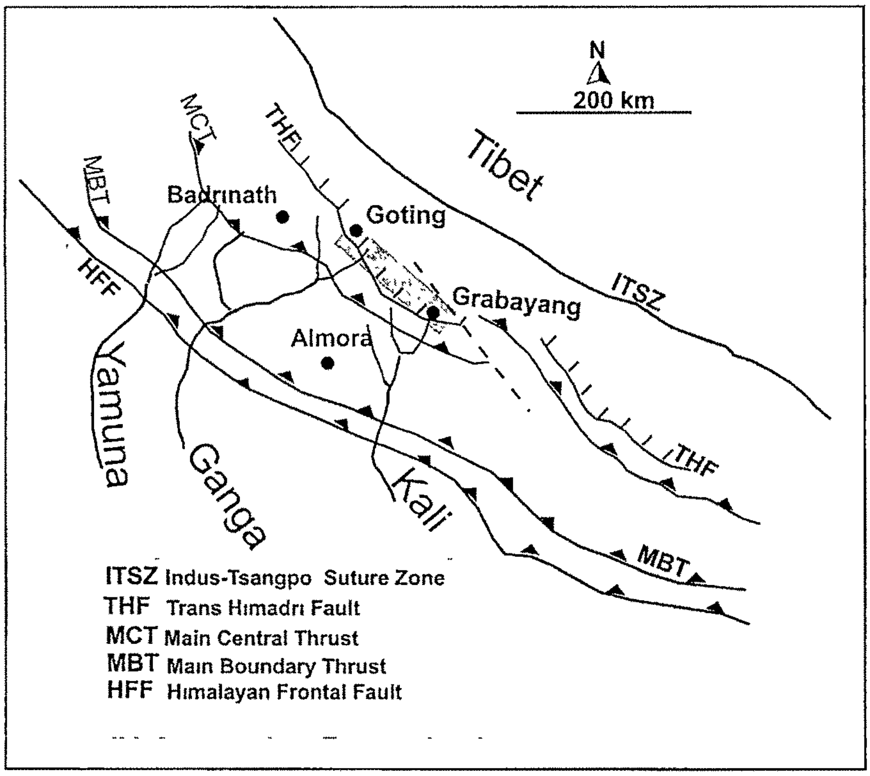

Figure-1.9. Map showing the study area along with the major structural boundaries. Garbayang and Goting basins lies north of THF (after Valdiya, 1993).

In the present study detailed investigations were carried out in three basins, viz. the Gori Ganga, the Dahuli Ganga and the Alaknanda which revealed preservation of three glacial advancements. These advancements are well differentiated on the basis of relative dating techniques and lithological contrasts. The oldest termed as stage-I was most extensive invariably reaching up to an elevation of around 3000 m. Following this the other two were of lesser magnitude (Pant and Juyal, in preparation). However, in absence of direct dating, chronology of the similar advancements that are dated to 63 ka (Sharma and Owen, 1996) in the region is extrapolated to assign ages to these stages. Thus glacial stage-I was assigned ~60 ka age (MIS-4), stage-II (MIS-2) and the youngest stage-III a neoglacial period.

Although the reconstruction based on the sedimentological manifestation of valley glaciation (lateral moraines) helped in putting the down valley limit to the Quaternary glaciation in the Central Himalaya, however, the evidences were not sufficient/adequate enough to bring out the finer structures of climate change during past 60 ka. This prompted for more continuous and detailed archive of climate change in the region.

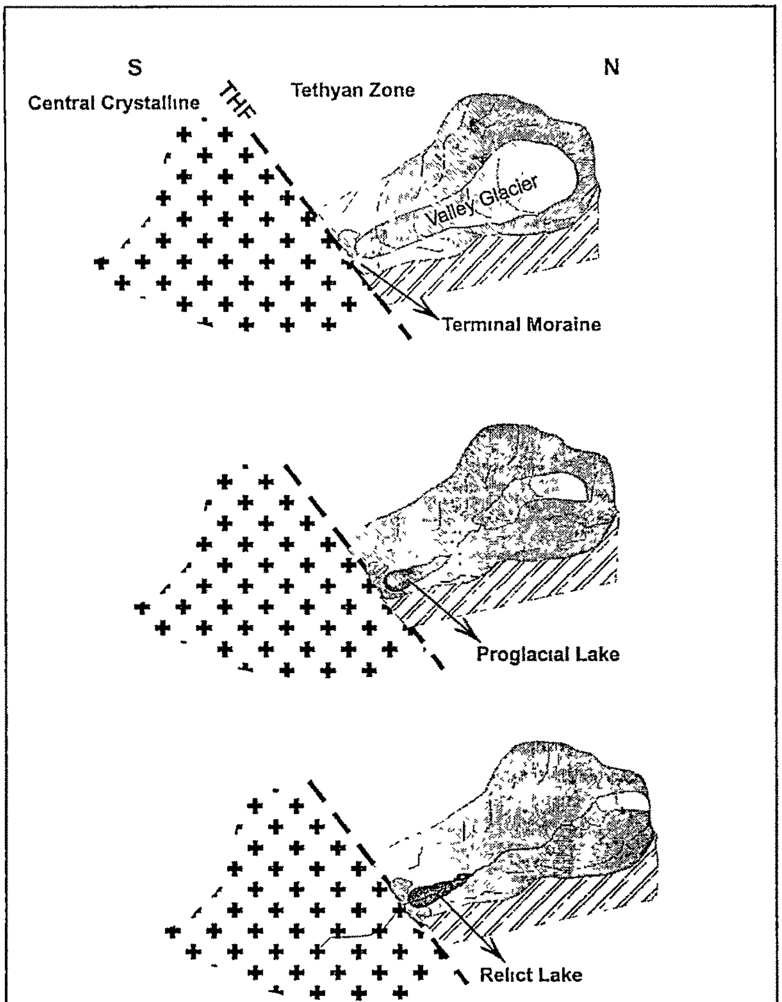

Figure1.10. Schematic represenation of proglacial lake formation. (A) Valley glacier blocked against the THF (B) Terminal moraines of retreating glacier form a barrier in which lacustrine sedimentation commenced (C) Increasing meltwater discharge during the climatic optima breached the barrier exposing the lacustrine sediments.

The relict lake sediments that are associated with the retreat of the stage-I glaciation in the region were mapped. These have preserved near continuous record of sedimentation since their ınception These lakes lasted for considerable lengths of time and later drained out leaving a relict lake sedimentary record that preserved records of contemporary climate and seismicity.

Study area and climate

Two basıns vız. the Goting (30°49'30"N; 79°49'E) and Garbayang (30°5'30"N; 80°50'20"E) that are investigated in the present study are located in the higher Central Himalaya of Chamoli and Pithoragarh districts of Uttaranchal (Fig. 1.9). Garbayang basin lies in a transitional zone between dry steppe (Tibetan plateau) and the sub-humid (Himalayan) climate zone. The SW monsoon is the dominant source of precipitation. Moisture laden SW winds enter into the basin through the narrow valleys in Garbayang during June-September which account for 80% of the total precipitation, and part of it falls as snow over the glaciers (Hasnain, 1999). During November to February, the westerly disturbances (winter monsoon) contribute the remaining 20% of the precipitation. The precipitation regime in the Himalaya controls the spatial extent of the glaciers. Goting basin lies north of the Nanda Devi massif that acts as a geomorphic barrier for the southwest monsoon. The decreasing gradient in moisture from Nanda Devi Massif (south) and Goting basin (north) is manifested in the scanty valley glaciers and increasing aridity. While the equilibrium line altitude (ELA) of the glaciers to the south of the massif varies between 4500 – 4700 m, ELA for most of the glaciers to its north are located around or above 5000 m altitude (Pant, 1999).

Scope of the present thesis

Based on the earlier studies, as discussed above it can be suggested that

(i) except for few chronometric data from the Sabarmati (Tandon et al., 1997; Srivastava et al., 2001), and Mahi basins (Juyal et al., 2000), the chronology of fluvial aggradation rely on indirect age estimates.

(ii) dry lands are known for abrupt climatic changes in the past. Except for few studies from the core Thar Desert, little is known from the desert margin 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 (Khadkikar et al., 1999).

(iv) present day rivers are slope deviatory and have deeply incised the Quaternary alluvium. 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 (Chawla et al.,1992; Thomas et al., 1999; and Kar et al., 2001). However, barring few preliminary data on the chronology of fossil dunes in the southern margin of Thar desert (Tandon et al., 1997; Juyal et al., 2000; and Srivastava et al., 2001) no detailed study on the chronology of dune accretion exists.

(vi) similarly, except for few selected studies such as by Sharma and Owen (1996) on Quaternary glaciation and Kotlia et al. (1997 and 2000), on the relict lake sediments, not much information exist 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