Chapter 5

Fluvial sediments in diverse depositional settings: Applicability of Luminescence dating

This chapter deals with the various geomorphological archives studied for the feasibility of luminescence dating with respect to daylight exposure. It discusses the processes of sediment depositions in these archives and sampling strategies. Finally the results are presented; however, implications of these results with respect to paleoclimatic reconstruction and neo-tectonic studies are discussed in chapter 6 of the thesis.

Daylight exposure of sediment during the transportation leads to the resetting of geological luminescence. However, in case of fluvial sediments bleaching may be partial or heterogeneous due to the attenuation of daylight by water column (Fig. 1.2, chapter 1), depth of sediment transport and turbidity (Berger and Luternauer, 1987). In such case, luminescence ages could be overestimated from the real age. In the conventional Multiple Aliquot Additive Dose (MAAD) method, palaeodose estimation is based on a measurement of 35 – 40 aliquots with the assumption that all the aliquots have witnessed identical bleaching, thermal and radiation history. Fluvial sediments are transported under different environmental conditions (bed load, high turbidity flow, sheet wash, suspension load etc). Considering this, the above assumption may not be true for fluvial sediments.

In many cases large scatter in the dose verses luminescence output was attributed to heterogeneous bleaching at grain level (Clarke, 1996; Li, 1994). Recent development of Single Aliquot Regeneration (SAR) method (Murray and Wintle, 2000) and the Single grain method permits some estimate of heterogeneous bleaching. SAR methods provide opportunity to select the palaeodose corresponding to the minimum paleodose from a set of aliquots that is supposed to be the most bleached.

High topographic relief, glaciers and intense southwest monsoon imply high erosion and sediment fluxes to the Himalaya drainage systems that eventually contribute to high sediment flux into the Bay of Bengal (Goodbred and Kuehl, 2000). The present study was limited to the southern topographic front and the foothill region of Himalaya (the pediment plain) and aimed to understand the spatial and temporal variation in sedimentation. Broadly, two major processes that contribute sediment to the Himalayan rivers are, (i) the glacial outwash and (ii) monsoon induced sediment input (landslides and colluvium). These processes are dominant source of sediment, particularly during the summer monsoon, which contributes ~80% of the precipitation in the Himalayan region (Hasnain, 1999). Since majority of the sediments is transported during monsoon time this would imply poor-bleaching environment due to high-energy transport turbidity, enhanced and variable sunlight flux. Hence for reliable age estimation on such fluvial sediments, it was essential to ensure that geological luminescence was erased to a residual level prior to their burial. This aspects was examined for following sedimentary archives. From bleaching process point of view, these depositional environments imply variable intensity and duration of daylight. The archives used were–

1. Flash flood and incised terrace sediments (T_1).
2. Low energy slack water deposit.
3. High energy alluvial fan deposit
4. Tectonically uplifted fluvial terraces.

5.1 Flash flood deposits

5.1.1 Introduction

Ganga is a major river (>1000 km in length) in north India, drains through a vast alluvial plain before reaching the Bay of Bengal. Himalaya provide most of the Ganga plain sediments. Floods are common during the summer caused both by the monsoon and glacial melt. During this period, the upper catchments of the Ganga River viz. the Bhagirathi River and the Alaknanda River witness frequent landslides that at times lead to the temporary blockage (natural dam) of the rivers. Breaching of such dams cause flash floods that inundundate the lower valley and results in transportation of huge quantity of sediments. The peak of a flood event last for couple of hours to a day whereas its recessional phase can last for few days to a week. Majority of the sediment flux occurs during the peak flood condition and decreases rapidly with the time, thereafter.

Recent meteorological observations suggest that frequencies of flash flood incidences in Himalaya are increasing. Two schools of thought exist towards explaining this increase. The first school suggests that inherent fragility of the terrain is responsible for increase in flood frequencies. The second school suggests that large-scale deforestation during the last century made the higher Himalayan catchments vulnerable during the monsoon (Ives and Messerli, 1989). This debate so far has been inconclusive due to absence of long-term data on the past frequency of flash flood in Himalaya. Studies have shown that the Tethyan and higher Himalayan crystalline are areas of high erosion due to high topographic relief and widespread glacial activity. Compared to this, the lesser Himalaya is a zone of low relief and thickly forested (Valdiya, 1998).

In view of the controversies regarding the genesis of such events, an attempt was made to construct long term record of flash flood events in the Alaknanda basin. Towards this, the youngest incised terrace (T_1) located ~ 6 m above the present day Alaknanda River was studied.

5.1.2 1970's Alaknanda flood

In the upper Alaknanda valley a lake called the Gohna Tal (lake) was created on 22nd September 1893, when around 150-200 million cubic meters of dolomite, shale and quartzite boulders blocked the course of a river Birehi Ganga, a tributary of Alaknanda

River. Gohna Lake was 270 m high, 3 km wide at the base and around 600 m wide at the summit. On 20th July 1970 the southern mountain front (south of high Himalayan crystalline) witnessed unprecedented rain in Alaknanda basin. A majority of the tributary streams of the Alaknanda originates from this region. The width of the lake was to ~700 m and the water depth reduced to ~10 m. This reduction in the lake dimension was attributed to excessive silting during the preceding years (Pal, 1986). Excessive surface runoff during the cloud bursts paved way for slope instability in the tributary valleys of the Alaknanda. The landslide debris assisted in the formation of temporary dams on the tributary streams. Their sequential breaching led to flash flood in the lower Alaknanda valley (Pal, 1986; Weidinger, 1998). The break of Gohna Lake added to the fury of the flood (Weidinger, 1998). Thus, combined effect of the breaching of Gohna Lake and numerous temporary dams on the tributary streams of the Alaknanda River implied unprecedented sediment supply transport. The sediment aggraded in wide valleys along the Alaknanda River e.g. at the confluence of the Birehi Ganga River and the Alaknanda River, around Kaleshwar, Srinagar, Bagwan, Rishikesh (IDPL) and Haridwar (the upper Ganga canal). This peak flood event lasted for around 24 hours during which flood sediments traveled a distance of around 250 km (Birehi Ganga to Haridwar). The 1970's flood deposits can be seen even today in the entire stretch of Birehi to Haridwar (Weidinger, 1998). They are distinct in appearance in the sense that the sediment are dominated by 5-10 m thick grayish dolomite rich sand and pebbles, either abutting the river banks or resting unconformably on the youngest terrace (T_1). A reconstruction of duration of the recession phase based on eyewitness accounts indicates that the flood lasted for over a week.

5.1. 3 Field stratigraphy and sampling details

In view of ascertaining the extent of pre depositional bleaching during flash flood, samples for luminescence dating were collected as function of distance from the source of the flood. Further, in order to understand the bleaching as a function of grain size (mode of transport), both the peak flood sediments and that deposited during the recessional phase (flood plain) were collected. However, the later was found only at Kaleshwar. In addition to this, youngest terrace (T_1) at Srinagar was documented for sedimentology and stratigraphy to reconstruct the past flood history of the Alaknanda basin. This terrace was also sampled for luminescence dating in order to constrain different flood event. Below is the geomorphological and stratigraphic detail of the locations sampled for luminescence study (Fig.5.1 and 5.2).

(i) **Birehi-Alaknanda confluence**–A 6 m thick flash flood deposit of 1970 flood was located 100 m above the confluence (30^{O} 24'N and 79 ^{O} 23' E). The deposit comprises assorted boulders, pebbles and occasional sand lenses. Maximum boulder size was ~3 m along the long axis. Dolomite, quartzite and slate were the dominant lithology. An iron griddle of a bridge that was washed during the 1970 flood was found embedded in the sediment. Sample for luminescence study (MVW-9) was collected from sand lens that was located 1.5 m below the surface (Fig. 5.3)

(ii) **Kaleshwar**–A relatively wide valley around Kaleshwar (30^{O} 70'N and 79 ^{O} 15' E) was plugged with the flood sediments that are spread over a distance of 100 m from the present day river channel. In the exposed section thickness of the deposit varied from 2 – 6 m. From bottom upwards the sequence comprised a 4 m thick coarse pebbly angular sand with false bedding rest over the gravel. This is overlain by 20-50 cm thick impersistent channel gravel. About 30 cm thick laminated sandy-silt lay above this. Towards the top, 1.1 m thick massive silty clay marked the termination of flood sediment. Two samples (KL-1 and KL-2) were collected from the underlying coarse pebbly sand and one sample (KL-3) was collected from the silty horizon (Fig. 5.1)

(iii) **Srinagar**–Two localities on either side of the Alaknanda river were sampled for luminescence study (30^{O} 13'N and 78 ^{O} 46' E). On the left bank, ~ 2 m thick 1970 flood sediment was located above the youngest fluvial terrace T_1 around Keshav Rai temple. The terrace sediment was dominated by coarse to medium textured light grey sand with no discernable bedding and rested unconformably on the underlying surface T_1. Sample OTS-4 was collected from the 1970 flood sediment (Fig. 5.1 and 5.2).

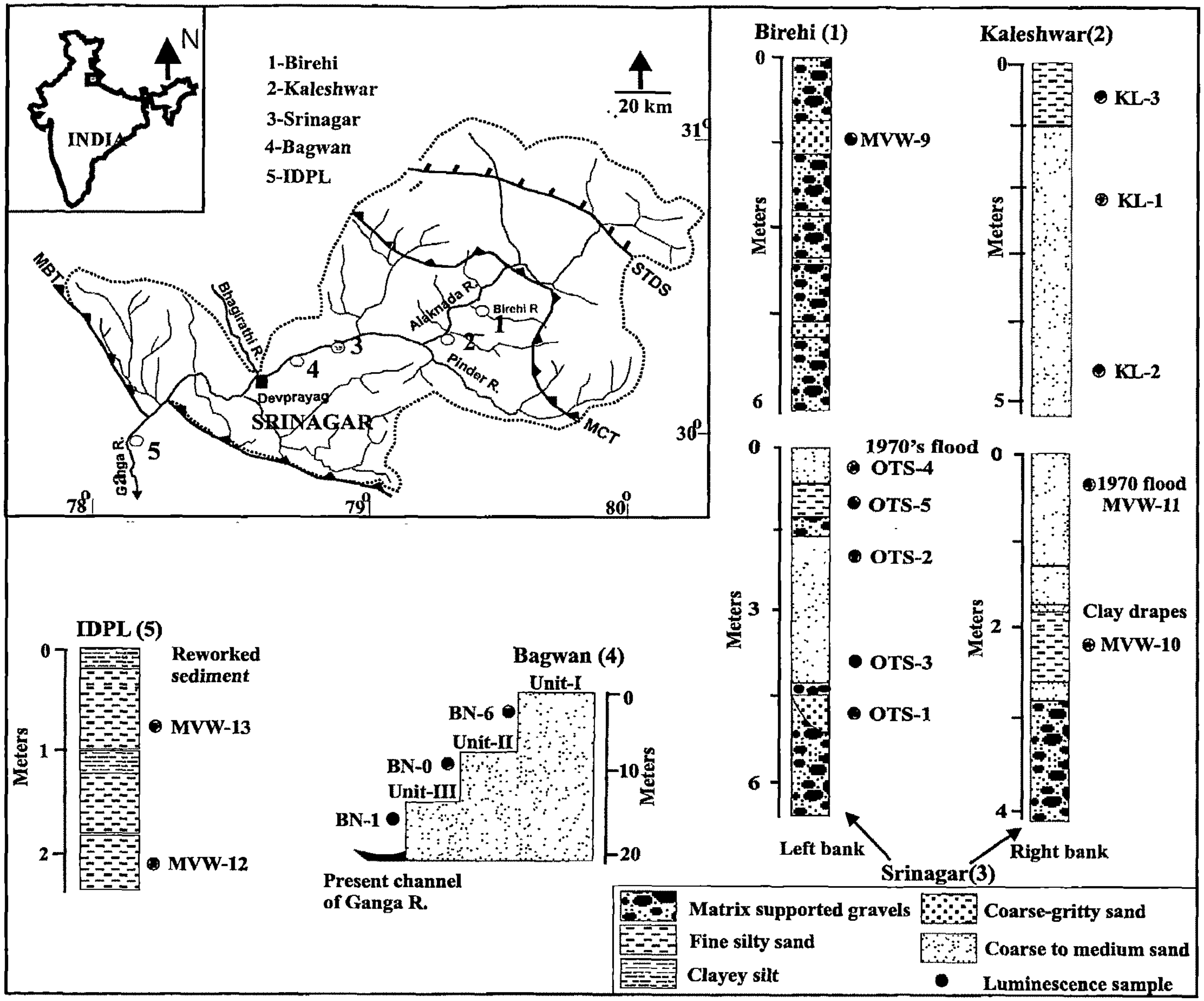

Fig. 5.1. The sample locations (indicated by numbers 1, 2, 3, 4 and 5 on area map) and stratigraphy of the 1970's flash flood deposit.

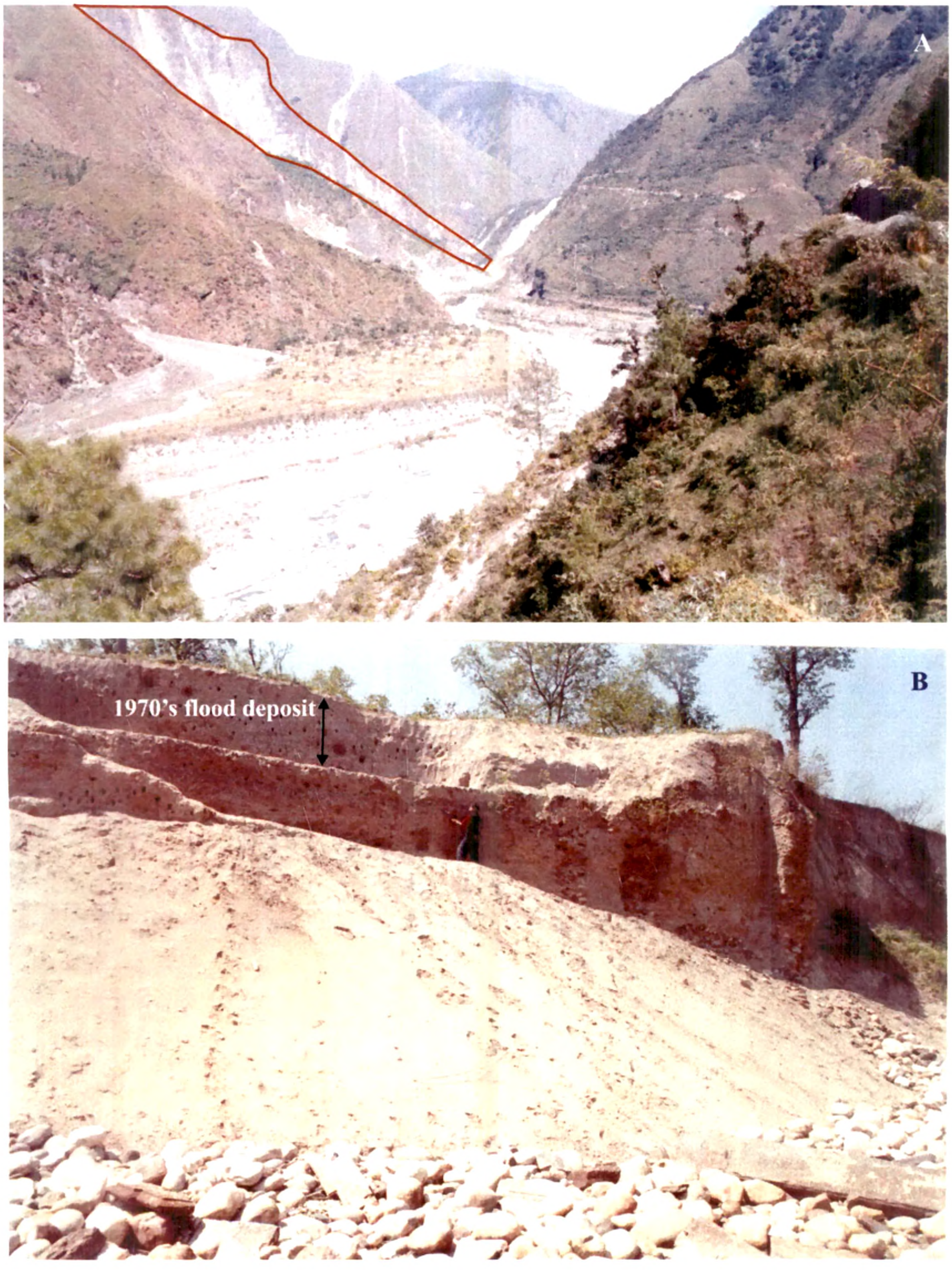

Figure 5.2. (A) The area shown by red line is the part of the mountain slipped during damming of the Birehi Ganga river on 22nd September, 1894. That dam was breached in the year of 1970 and thus created worst flash flood of the century. (B) The area at Srinagar where sediment of this flood was deposited as shown by arrows.

On the opposite flank of the Alaknanda River, a wide ~ 4 m thick scroll bar deposited during the 1970 flood was also excavated for sedimentological and luminescence studies. These sediments were deposited on a 160 cm thick channel gravel. From bottom upwards, 75 cm thick mottled, medium to fine sand with burrows was capped by clay drapes. This was overlain by a massive 40 cm thick coarse to medium gray sand. Coarse to medium gray laminated sand capped this. The sequence terminated with the deposition of 80 cm thick massive coarse to medium gray sand. Two samples one 30 cm below the upper most horizons (MVW-11) and another 18 cm below the 75 cm thick sand horizon (MVW-10) were collected (Fig. 5.1).

(iv) **Bagwan–** Three flood units probably representing flash flood pulses were identified close to a tributary stream meeting the Alaknanda river at Bagwan (30^{O} 13'N and 78^{O} 14' E). The oldest Unit-I lies approximately 20 m above the present flood plain and is dominated by massive, medium to coarse grey sand. A weaker flood Unit-II follows this, whereas the lowermost Unit-III lies close to the present day flood plain. Only this unit preserved well-developed laminae with occasional clay drapes. Plastic pieces at the lower part of Unit-III were found. Each unit was sampled for luminescence study. Sample BN-6 was collected from Unit-I, BN-0 from Unit-II and BN-1 from Unit-III (Fig. 5.1).

(v) **Industrial Development Pharmaceutical Limited (IDPL), Rishikesh–** This section lies on a wide undulating flood plain of the Ganga River ~ 5 km downstream of Rishikesh at IDPL (30^{O} 04'N and 78^{O} 16' E). The sequence (bottom unexposed) begins with a 70 cm thick brownish fine sandy-silt contained potsherd. This is overlain by a 20 cm thick dark brown weakly weathered clayey-silt. Following this, a 40 cm thick micaceous silty-sand was observed. Finally a 40 cm thick clayey-silt marks the termination of the sedimentation. Two samples one each from the bottom most horizon (MVW-12) and from the micaceous silty sand (MVW-13) were collected for luminescence dating (Fig. 5.1).

(vi) **Youngest Terrace (T_1):** A 625 cm thick fluvial sequence is exposed on the left bank of the Alaknanda River near Keshav Rai temple. From bottom upwards the sequence began with poorly sorted, gravelly boulders (195 cm thick). This is overlain by 390 cm thick pale yellow, well-sorted medium to fine sand. Towards the top of this horizon, swelling and pinching pebbles embedded in sandy matrix could be seen. This horizon was overlain by 40 cm thick silty-clay with occasional rounded to angular gravel. Additionally this horizon shows evidence of human activity that is preserved in the form of charred bones and dispersed charcoal specks. The 1970 flood sediments finally overlie this.

The sedimentary characteristic and textural attributes of the sediment suggests that except for the bottom most gravel, the overlying horizons were deposited as flood plain sediments during events of high floods in the Alaknanda River. For the luminescence study four samples (OTS-1, OTS-2, OTS-3 and OTS-5) were collected from this sequence (Fig. 5.1)

5.1.4 Results and Discussion

All the samples were analyzed using the SAR protocol of Murray and Wintle (2000). In order to evaluate the bleaching heterogeneity of the sediments both average and least 10% of the dose distribution in palaeodose were used (Table 5.1). In addition to this, grain size analyses was also carried out as a function of distance in order to see if there is any grain size dependency in bleaching (Fig. 5.3).

The paleodose distribution of the first sample (MVW-9) that was proximal to the source of the 1970 flood (Birehi-Alaknanda confluence) had a large scatter (relative standard deviation > 38%) as shown by wide paleodose distribution (Fig. 5.4). This sample was dominated by very coarse (>250 μm) sand (>91% by weight). The average palaeodose (mean of all aliquot) was 26 Gy whereas the least 10% palaeodose was 9 Gy. This implies that sediment transportation occurred under poor light condition or the floodwater turbidity attenuated the day light flux. Considering that the flood originated from the Birehi Ganga River (~15 km upstream) during the midnight, poor light condition appears to be the likely possibility of insufficient bleaching of sediment.

Further 50 km down stream from the Birehi Ganga-Alaknanda confluence, two samples were analyzed at Kaleshwar. Sample no. KL-1 was dominated by coarse sand (87%) yielded mean palaeodose 24 Gy whereas the least 10% was 9 Gy.

Table 5.1. Paleodose of Flash flood sediments from various locations and flood plain deposit from Srinagar terrace T_1 analyzed using SAR.

Sample No.	Location	Distance from origin of flood (km)	Paleodose (Gy)	
			Least 10%	Mean
MVW-9	Birehi	0	9 ± 2	26 ± 10
KL-1	Kaleshwar	50	9 ± 1	24 ± 13
KL-3	Kaleshwar	50	1 ± 0.3	3.3 ± 2.6
OTS-1	Srinagar	150	20 ± 1	31 ± 9
OTS-2	Srinagar	150	3.4 ± 0.5	5.7 ± 1.6
OTS-3	Srinagar	150	18 ± 0.5	27 ± 7
OTS-4	Srinagar	150	9 ± 3	27 ± 14
OTS-5	Srinagar	150	1.7 ± 0.1	2.3 ± 0.6
MVW-10	Srinagar	150	0.8 ± 0.2	2.7 ± 1.3
MVW-11	Srinagar	150	23 ± 4	32 ± 6
BN-0	Bagwan	200	5 ± 0.2	14 ± 8
BN-1	Bagwan	200	11 ± 3	29 ± 10
BN-6	Bagwan	200	18 ± 5	45 ± 15
MVW-12	IDPL	250	7 ± 1	15 ± 5
MVW-13	IDPL	250	8 ± 1	20 ± 7

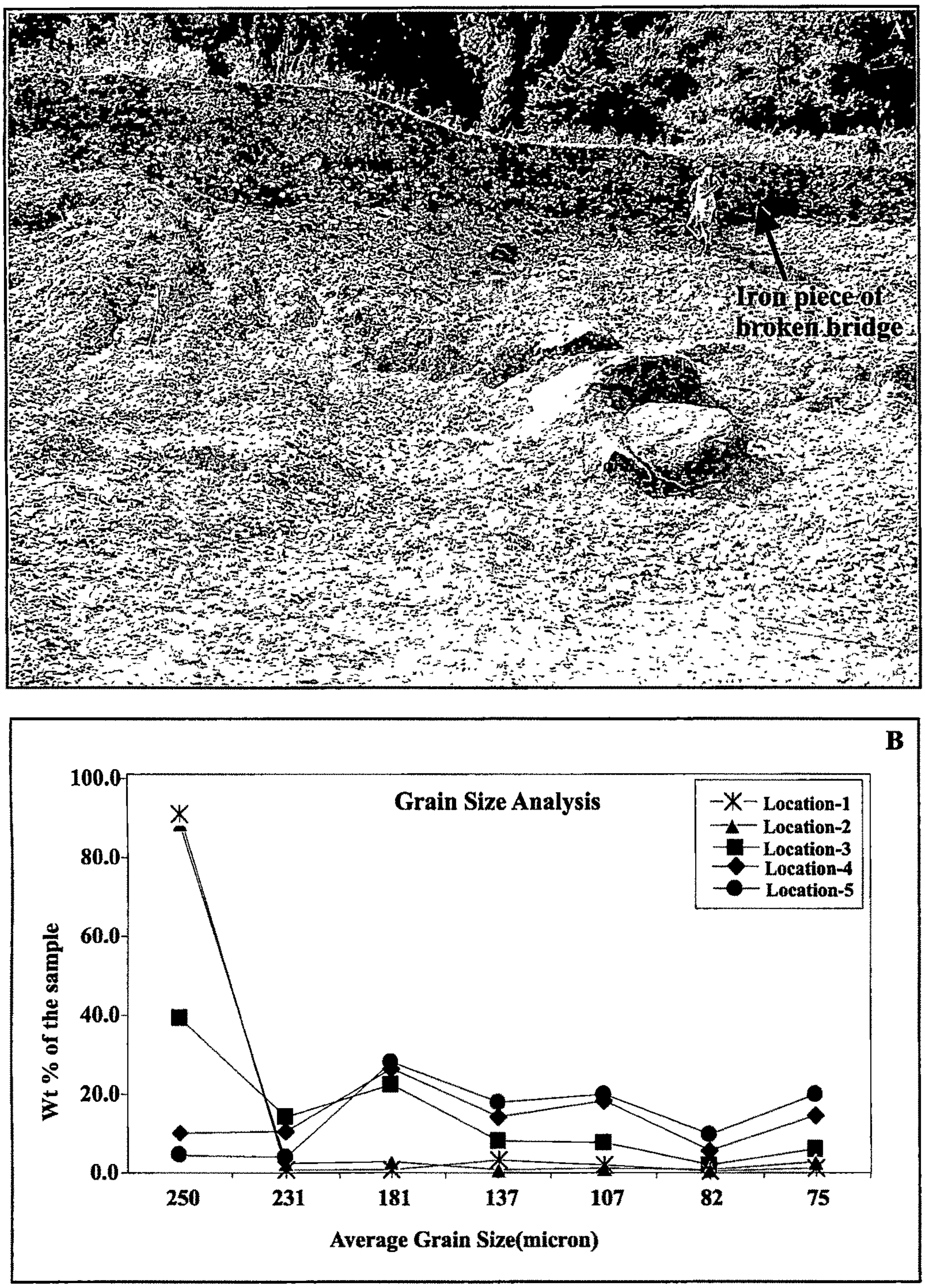

Fig. 5.3. (A) 1979's flood deposit at Birehi comprising matrix supported gravels. A piece of iron bridge was found buried in the sediment. (B) Variation in grain size of the 1970's flood sediment with respect to distance of transport. The coarse fraction of the sediment decreases with distance of travel.

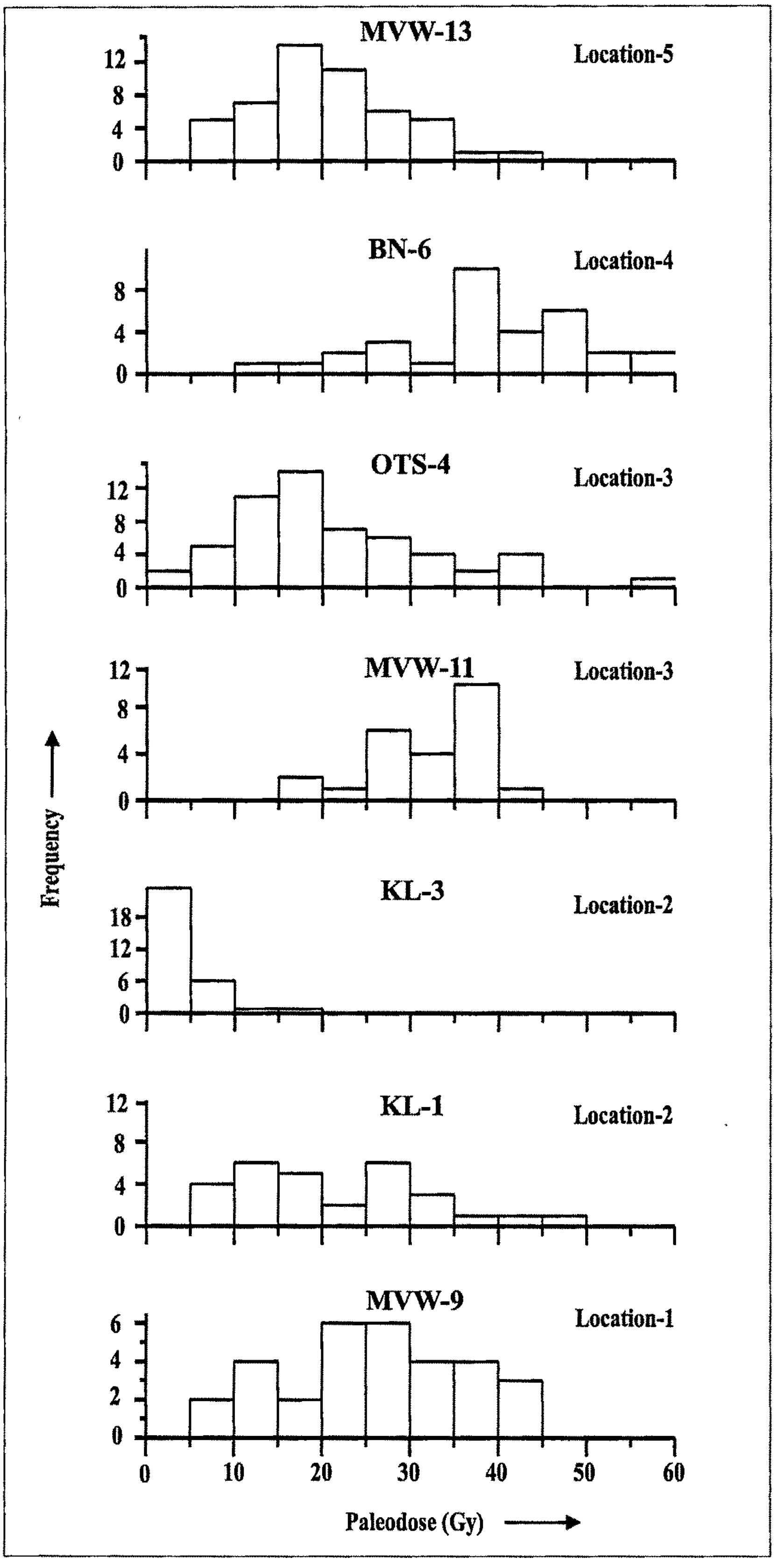

Fig. 5.4. Dose distribution of 1970's flood sediment

3) overlying the coarse sand was 3.3 Gy and the least 10% was 1 Gy. The lower palaeodose of KL-3 is attributed to the deposition during the recessional phase of flood. Thus, sediment prior to deposition remained in suspension hence facilitating pre-depositional bleaching. Further downstream at Srinagar, 150 km from the Birehi Ganga-Alaknanda confluence, four samples were analyzed from the left and the right flanks of Alaknanda River near Keshav Rai temple. Sample OTS-4 collected from the 1970 flood deposit whereas OTS-5 collected from the tope of Terrace T_1 was silty sand (flood plain deposition). The average palaeodose of OTS-4 was 27 Gy and the least 10% was 9 Gy. The average palaeodose of OTS-5 was 2.3 Gy and the least 10% was 1.7 Gy. Samples from stratigraphically equivalent sequence on the right flank indicated that the average palaeodose of the bottom flood plain sample (MVW-10) was 2.7 Gy and the least 10% was 0.8 Gy. The average palaeodose of the overlying 1970 flood sample (MVW-11) was 32 Gy and the least 10% was 23 Gy. These data indicate samples below the 1970 flood deposits (OTS-5 and MVW-10) were exposed to daylight flux before deposition, a reasonable assumption considering their deposition on flood plain environment.

Bagwan is located 200 km down stream from Birehi Ganga. A total of three samples from Unit-I (BN-6) and Unit-II (BN-0) and Unit-III (BN-1) were analyzed. BN-6 was deposited during the peak flood condition and BN-0 was deposited during the recessional phase of the flood. Compared to this, BN-1 was a recent flood event. The average palaeodose of 1970 peak flood sediment (BN-6) was 45 Gy and the least 10% was 18 Gy. For sample BN-0 the average palaeodose was 14 Gy and least 10% was 4.8 Gy. Whereas for recent flood deposit (BN-1) the average palaeodose was 29 Gy and least 10% was 11 Gy.

The farthest sampling site was near Rishikesh at IDPL about 250 km from Birehi Ganga. At this location two samples were analyzed from a 170 cm thick sequence. The lower MVW-12 was pre 1970 deposit whereas MVW-13 was deposited during the 1970's flood. The average palaeodose of MVW-12 was 15 Gy and the least 10% was 7 Gy. Compared to this the 1970 flood deposit (MVW-13) gave an average palaeodose of 20 Gy and the least 10% was 8 Gy.

The above study suggested that pre-depositional bleaching of sediments in high gradient Himalayan rivers during flash flood are inadequately bleached. There was no systematic increase in bleaching as a function of distance was observed. However, comparing the two extreme samples one collected at Birehi-Alakanada confluence and another at the farthest point (IDPL), a marginal decrease (~35%) in the palaeodose was observed. Considering that the 1970 flood occurred only 35 years ago, the palaeodose of the most bleached sample (MVW-13) at IDPL had significant unbleached component. The study thus indicate that in high energy fluvial environment like Himalaya, during flash flood event, even a distance of 250 km was inadequate for resetting the geological luminescence to a residual value. A part of this was possibly due to flood initiation during the night and it traveled that distance in an overcast sky condition.

It appears that bleaching of flash flood sediment is influenced by the grain size. This study indicates that sediment transported in suspension experienced relatively high bleaching (> 85%) compared to the high turbid coarse fraction. Thus beside the distance, the mode of transport is important. In the present case the flood plain sediment (KL-3) that was deposited 50 km from the origin had 80-90% reduction in palaeodose compared to its counter part that was deposited during peak flood event. This indicates high bleaching probability for sediments that are deposited on flood plain.

Compared to the 1970 flash flood samples, the terrace T_1 sediments (flood plain aggradation) show less variability between the average and least 10% palaeodose suggests bleaching was nearly homogeneous and total. In the terrace T_1, the difference between the average and the least 10% palaeodoses varied between 36 % (OTS-1) and 26% (OTS-5).

The study suggests that during the flood events, it is the mode of transportation besides the distance that decides the extent of predepositional bleaching of acquired luminescence. Suspended load has experience a higher and somewhat unattenuated daylight exposure compared to coarse-grained bed load sediment that only sees a highly attenuated daylight spectrum.

5.2 Low energy slack water deposit

5.2.1 Introduction

Low energy slack water deposits are fine-grained sand and silts that settle out of suspension in protected areas of reduced flow velocity during high magnitude floods.

Deposition occurs in areas like back-flooded tributaries, eddy zones or along the irregularities in the channel margin (Baker et al., 1988). These deposits occur at the mouth of east flowing Moti Chur river that meets the Ganga river at Raiwala. At the studied location, the river channel is about 200 m wide and 5 m deep giving rise to large width to depth ration of ~40 (Fig. 5.5). In view of this, the large magnitude floods in the Ganga river that exceed the channel capacity spill over the Moti Chur river. The flood sediments in such geomorphological situation get enough time to remain in suspension before settling. This ensures grading of different grain size. Since longer time is involved in slack water sedimentation, it can be assumed that pre-depositional bleaching of such sediment is adequate.

A typical slack water deposit corresponding to one flood event would constitute the bottom sand followed by silt and invariably capped by clay drape (Kale et al, 2000). In other words they can be called as the fining upward sequences similar to the over bank facies. The vertical stacking of such units would imply that each flood event was magnitude higher then the preceding one. Hydrologists use these records to reconstruct the paleo flood history of a river much beyond the historical record, which is limited to few decades or so. However, in order to reconstruct the spatial and temporal variability of palaeoflood events, it is important to obtain reliable age estimates on them. In the recent years some progress has been made using the luminescence dating technique that was limited to the western and central Indian rivers (Kale et al, 2000; 2003) and no study exists from the high energy fluvial system of Himalaya.

High topographic relief of this region implies poor preservation potential for slack water deposits. As a result, so far no classical slack water sequences have been reported. However, in the low energy environment caused by the sudden change in gradient (alluvial plain), enhances the chances for the preservation of slack water deposit increases. That is because during floods, the excess water either spill over on to the flood plain or enters into the a tributary stream that meets the major river. Such a location was identified near at Raiwala, here the Ganga River has wide flood plain and a tributary stream called Motichur meets it from the Siwalik hills.

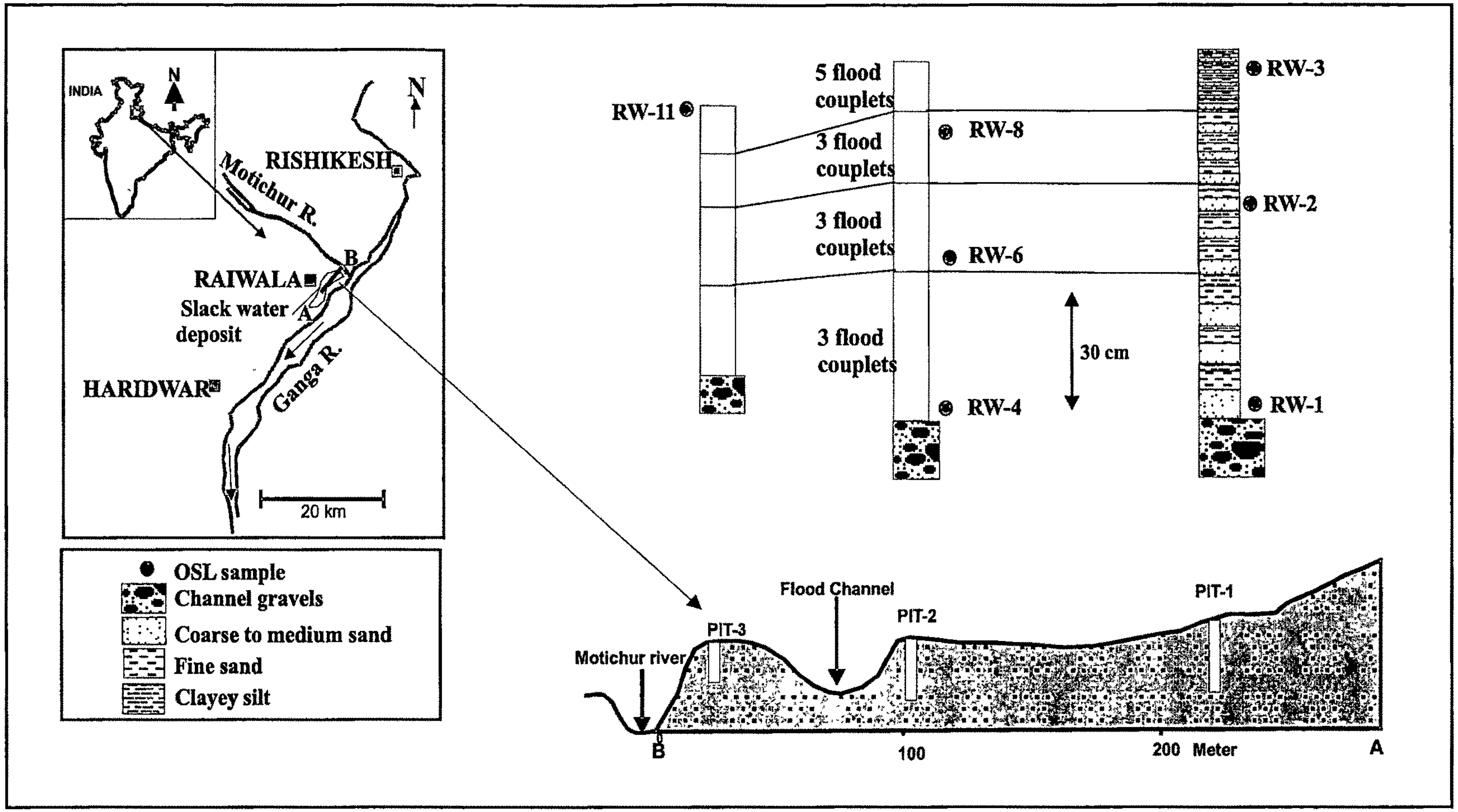

Fig. 5.5. Location and stratigraphy of the section studied for slack water deposits near the confluence of Ganga R. and Motichur stream. In total, 14 flood couplets were identified and correlated from three Pits-1,2 and 3 as shown in figure.

5.2.2 Field stratigraphy and sampling details

On the right bank of the Ganga river slack water deposits were located. These deposits occur in a tributary river Motichur that meets the Ganga at right angle (Fig. 5.5). Presently the Ganga river flows ~200 m east from the studied area. In order to reconstruct the palaeoflood stratigraphy, three pits at some interval (as shown in fig. 5.5) were excavated laterally. This was done to ascertain the lateral continuity of the flood deposits and a composite lithostratigraphy of the palaeoflood succession was made. The flood deposits were underlain by channel gravel. Each flood unit begins with medium to coarse sand followed by silty-sand and capped by clayey-silt. Together they constituted a single flood couplet. A total of 14 such flood couplets were identified suggesting each successive flood event was higher than the preceding one. The thickness of the flood sequences exposed in four-dug pit varied from 75 cm to 120 cm with individual flood couplet thickness ranged from 5 cm to 20 cm. Out of the 14 flood couplets the lower 5 couplets were thicker (15-20cm). For luminescence dating, 7 samples were collected from three pits numbered as P1 (sample RW-1, 2 and 3), P2 (sample RW-4, 6 and 8) and P3 (sample RW-11). P3 was the closest from the tributary channel (30 m), followed by P2 (100 m) and P1 (200 m). In order to estimate the extent of bleaching on modern fluvial sand, a surface sample (RW-12) was collected from the bank of the Motichur stream (Fig. 5.5)

5.2.3 Results and Discussion

Samples were analyzed using the multiple aliquot partial bleach regeneration and the SAR protocol. It was observed that the except for sample RW-1 and RW-2, all other palaeodoses obtained using the partial bleach technique were underestimated compared to the mean SAR palaeodoses. The paleodose using partial bleach for the sample RW-2 is unusually high that had been attributed to large scatter in the data. Barring few samples as shown in Table 5.2, the partial bleached palaeodose were close to the least 10% palaeodoses obtained using the SAR technique. However, the mean palaeodoses obtained by SAR were overestimated by a factor of ~2. Further compared to the mean palaeodoses the least 10% have shown stratigraphic consistency. Thus suggests that samples were heterogeneously bleached even in a low energy fluvial environment as suggested from a

Table 5.2. Paleodose using partial bleach method, mean paleodose and average of least 10% obtained through SAR in the slack water deposit at Raiwala, Haridwar.

Sample no. (Pit-no.)	Depth From Top (cm)	Paleodose De (Gy)		
		Partial Bleach	Mean	Least 10%
RW-3 (P1)	20	6.5 ± 1.8	9 ± 4	3 ± 1
RW-2 (P1)	95	26 ± 12	6.3 ± 2.6	2.7 ± 0.5
RW-1 (P1)	165	23 ± 7	19 ± 9	8.2 ± 1.6
RW-8 (P2)	0	2.8 ± 0.7	7.4 ± 2.6	3.5 ± 0.8
RW-6 (P2)	42	1.5 ± 0.6	5 ± 1	2.5 ± 0.3
RW-4 (P2)	118	20 ± 7	22 ± 8	11 ± 2
RW-11 (P4)	20	1.4 ± 0.7	6.5 ± 3	2.5 ± 0.4
RW-12 (0 age)	–	0.5 ± 0.8	3.5 ± 1.4	1.5 ± 0.3

wider dose distribution too (Fig. 5.6). In view of this, the stratigraphically consistent palaeodoses obtained using the least 10% were used for the age estimation.

5.3 High energy alluvial fan deposit

5.3.1 Introduction

Fluvial mega fans forms where river exist the topographic front of a mountain and migrate laterally in adjacent basin leading to the deposition of large fan shaped bodies (DeCelles and Cavazza, 1999). Mega fans are large geomorphic features (10^3 - 10^5 km^2, low gradient (0.1^0 – 0.01^0) with distinct lateral gradation in the sediment texture (DeCelles and Cavazza, 1999; Horton and DeCelles, 2001). Sedimentation began with the deposition of coarse boulders and pebbles at the fan apex (proximal end), and the finer sediments are carried towards the distal end farthest from the fan apex (Gabler et al., 1997). Process-wise, it can be suggested that fluvial mega fans are important in the dispersal and deposition of sediments in the tectonically active areas (Leier, et al., 2005).

Based on the global distribution of mega fans, Leier et al., (2005) inferred that these features are confined to 15^0 - 35^0 latitude on northern and southern hemisphere and are absent in tropical climate. This would imply that climate play important role even if the tectonic and geomorphological condition were favorable. Thus, their occurrences in sedimentary record can be used to reconstruct the past climatic condition (Leier, et al., 2005).

In the northwestern Ganga plain, mega alluvial and piedmont fans are distinctive geomorphic features. These large size, low relief sedimentary bodies are identified as Yamuna - Ganga Mega Fan (YG-MF), Sarda Mega Fan, Gandak Mega Fan and Kosi Mega Fan. Lateral extent of these features range from few tens to hundreds of kilometer. In order to create such a large body, it is essential that there should be enough sediment supply and stream power to transport sediment from mountain to the alluvial plain. Leier et al., (2005) examined 202 rivers using satellite imageries, topographic maps and digital elevation model suggested that fluvial mega fan development occurs where rivers discharge is modulated by seasonality. These authors suggest a minimum river discharge of ~$20m^3/s$ for the development of mega fan. In our case, the typical discharge of Ganga

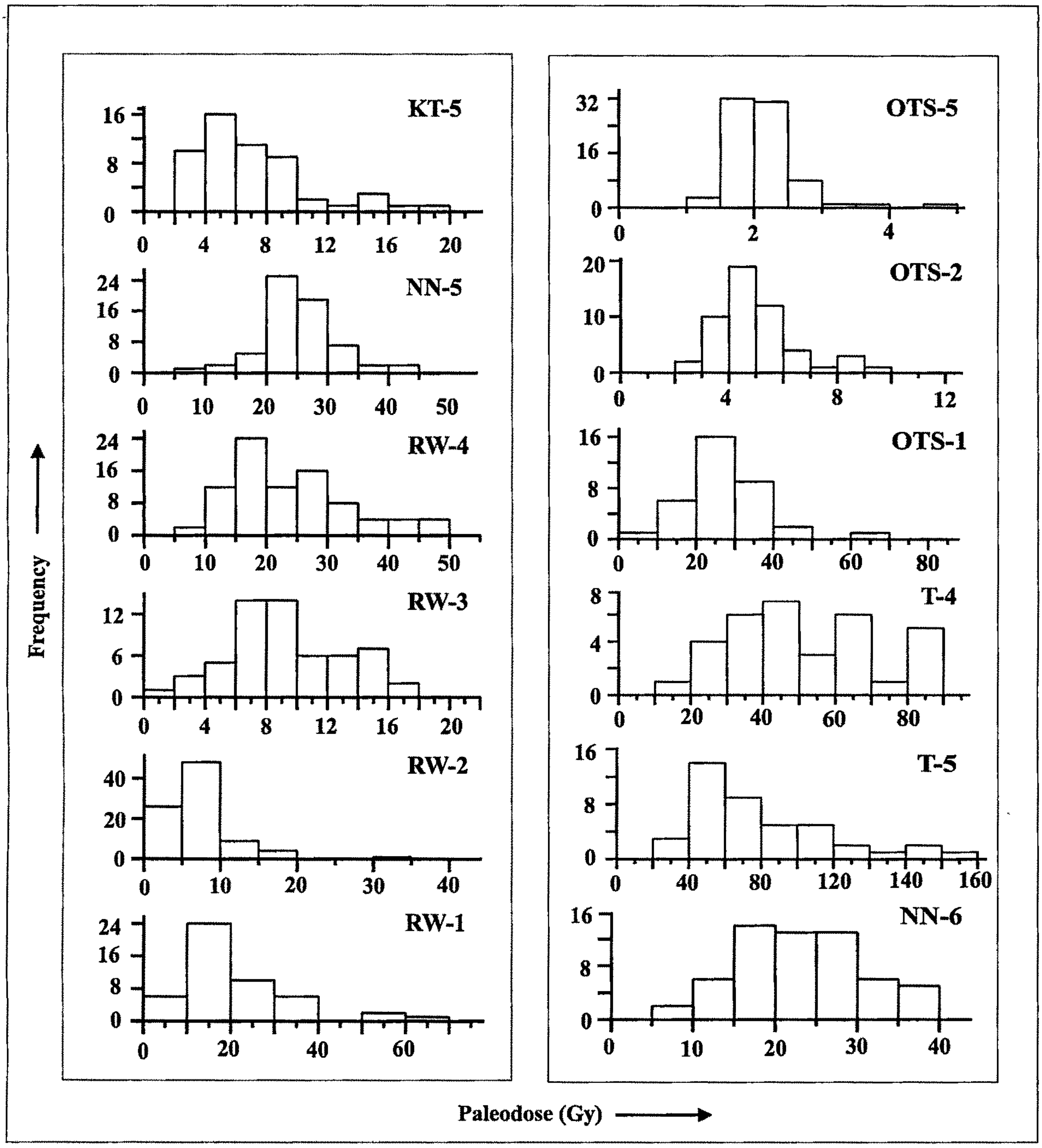

Fig. 5.6. Paleodose distribution of sediment samples from various locations in Himalaya

River is between 20-40 m^3/s during the monsoon (July-October) and for rest of the year it reduces to around less than 5 m^3/s rest of the year (Goodbred Jr., 2003). Thus, the terrain is conducive for the development of mega fans of course e.g. sediment supply, slope and accommodation space are prerequisite.

Usually piedmont alluvial fans are characteristic features of arid landscape, however, such features have been reported from the sub-humid Ganga basin (Shukla et al., 2001). Pediments are broad, gently sloping areas formed by fluvial erosion and usually covered with scattered detritus. Thickness of the detritus increases towards the down slope of the pediment where it is covered with compound alluvial fan deposits (Press and Siever, 1986). In the western Ganga plain, 25 – 30 km wide pediment alluvial fans covers the mega fan surface and occurs adjacent to the Siwalik mountain front (Fig. 5.7). Coalescing of smaller fans (3 – 20 km wide and 10 – 30 km long) has given rise to the piedmont fans and their proximity to the mountain front implies gravelly sediments (Shukla et al., 2001).

Singh (1996) suggested that megafan aggradation in Ganga plain occurred during the time of the initiation of humid climate preceded by an arid phase when huge amount of sediment from the Himalaya were transported into the Ganga plain. During arid periods, reduced vegetation cover facilitates sub aerial exposure of the sediment for weathering. With the initiation of humid condition this weathered material is transported and deposited in areas where the relief changes abruptly. Such areas are located at the mountain fronts. This could have been the case for the development of fans at the foothill of the Himalaya (Shukla et al., 2001). Recently, Goodbred Jr., (2003) has suggested the transitional climatic condition in the Ganga plain favored mega fan aggradation. Considering the above processes, fan sedimentation can be used as a surrogate climatic marker for arid-humid transition. Similalrly, the formation of the younger piedmont alluvial fans has been attributed to reduced sediment supply and subdued tectonic activity in the Himalaya during the latest Pleistocene-Holocene phase (Singh et al., 1997).

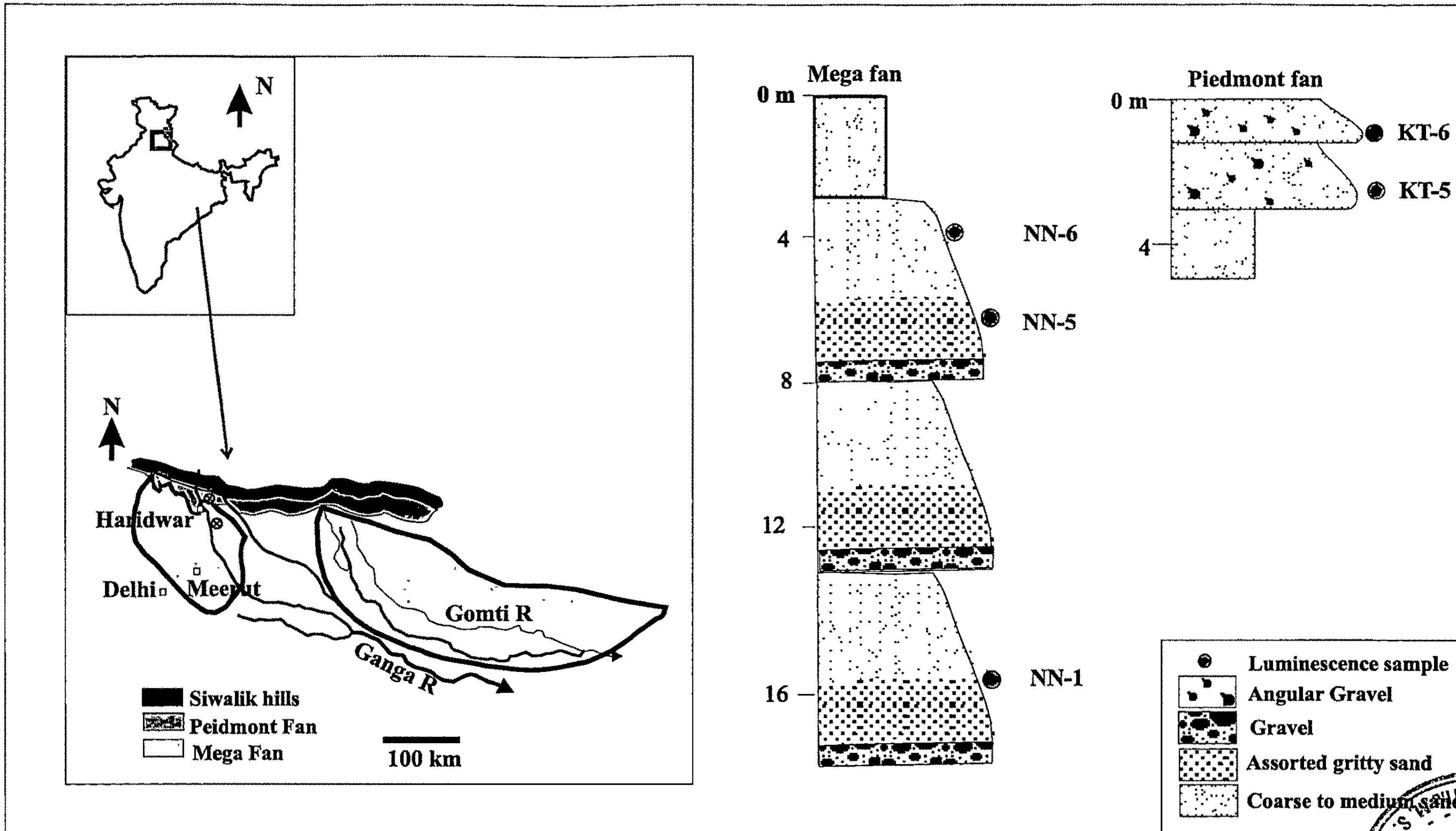

Fig. 5.7. Location and stratigraphy of the samples from Yamuna Ganga mega and piedmont fan. Three fining upward episodes of sedimentation in the mega fan were identified. (After Srivastava et al., 2003)

5.3.2 Study area and climate

The N-S trending, 150 km long and 100 km wide Ganga mega-fan is located in the western Ganga plain (Fig. 5.7). Due to the incision by the Ganga river, 15 – 20 m thick alluvial fan sediments are exposed and can be observed from the northern Siwalik foot hill (Haridwar) to the south of Delhi. Based on their geomorphological occurrences, the mega fan can be divided into two parts (i) the western upland interfluves area (Doab) and (ii) the eastern Ganga- Ramganga upland interfluves (Ruhelkhand bangar;) (Dasgupta, 1975). Innumerable, abandoned channels can be seen in satellite imagery on the fan surface that are truncates at the margins of the Ganga river valley. Present day Ganga river valley that runs N-S is 10-20 km wide and comprises two distinct geomorphic surfaces (i) the active flood plain (T_0) and an elevated river valley terrace (T_1). There is evidence to support that the Ganga River has laterally shifted within its valley in response to tectonics. This is manifested in the development of stepwise tilted T_1 surface (Singh, 1996).

Based on geomorphic and sedimentologic studies, Shukla et al., (2001) have divided the Ganga mega fan into four zones from the northern foothills to the south. These are the gravelly braided streams (Zone-I); sandy braid plain (Zone-II); anastomosing channel plain (Zone-III) and meandering channels with broad interfluves (Zone-IV).

5.3.3 Field stratigraphy and sampling details

Present study dealt with the luminescence characterization and chronology of the mega and pediment alluvial fan that were exposed at Nagal. Details of the sections investigated are given below.

(i) Mega fan sequence – The mega fan sequence studied was located near Nagal town, 30 km, SSE of Haridwar in the district of Uttaranchal (29°54'N, 78°12'E). Incision by the Ganga river has exposed a 18 m thick section on its left bank. According to Srivastava et al., (2003), the lower 15 m of the sequence three episodes of mega fan aggradation can be observed. Each episode began with the deposition of dispersed gravels at the base and terminates with the deposition of fining upward cross-bedded sand (Fig. 5.7). In the upper 3 m a marked change in nature of sedimentation was observed. Sediments in this part are dominantly clayey. The top 3 m is made up of fine muddy sediments, which are devoid of any physical structures. Shukla et al., (2001) on the basis of architectural element argued that the lower cross-bedded units are braided channel deposits and are directly related to fan sedimentation. Whereas, the top muddy unit is a result of sedimentation by sheet flows and gullies occurred after the fan surface was incised and abandoned by the active sedimentation of the major rivers. Therefore the lower 15 m of the sequence only marks the phase of active fan formation and rest 3 m is the result of surface modification of abandoned fan surface.

In order to understand the bleaching characteristic of fan sediments and chronology of mega fan aggradation, five samples collected from the exposed 18 m section (Fig. 5.7).

(ii) Piedmont fan sequence – Near Sabalgarh, piedmont alluvial fan has been incised by the Kotwali river and has exposed 5 m thick sediment succession (Fig. 5.7). Stratigraphy of the section begins with 2 m thick mottled clay at the base. This is overlain by 3 m thick matrix supported angular to sub angular gravel (~20 cm) with sharp erosional contact. Lithoclast analyses of the gravel suggest that they were transported from schistose provenance. The present day lithology of the gravels that are lying on the riverbed has source in the northern Siwalik mountain (Srivastava, et al. 2003). This implies that during the piedmont alluvial fan aggradation, significant amount of lesser Himalayan sediment were transported to the study area. For luminescence study one sample was collected from the mottled clay and two samples from the gravelly horizon (Fig. 5.7).

3.4. Results and discussion

In order to reconstruct the past climatic condition based on alluvial fan stratigraphy, it is important to constrain the events of fan aggradation. Few studies pertaining to the chronology of the alluvial fans in the Ganga plain were attempted by Srivastava et al., (2003). However, the ages were based on the MAAD technique, which could be somewhat overestimated, i.e. process wise for fan sedimentation, MAAD ages would imply average for poorly and well-bleached grains. Thus, there is a possibility that the earlier estimates could be the overestimate of the real age.

In view of this, the present study made an attempt to ascertain the extent of pre-depositional bleaching experienced by the fan sediments before estimating the depositional ages. Towards this, six samples from mega and piedmont alluvial fan were analyzed using MAAD and SAR techniques. MAAD technique was employed on all the eight samples. The results obtained indicate that the MAAD paleodoses are higher (16% - 88%) compared to mean SAR paleodoses (Table 5.3). This indicates that alluvial fan sediments have experienced heterogeneous bleaching during the transport. This was further indicated by the differences in palaeodoses computed using the mean and the least 10% (Table 5.3) of the paleodoses. Based on these results, it can be suggested that alluvial fan sediments suffer from variable bleaching condition during the transportation.

5.4 Incised fluvial terraces

5.4.1 Introduction

Collision of the Indian plate with that of Eurasia around 55 Ma ago led to the initiation of Himalayan orogeny. Continued compress following the collision was manifested sequential evolution of major boundary thrusts from north to south. The first one to form was the Main Central Thrust (MCT) followed by the Main Boundary Thrust (MBT) and the youngest one was the Main Frontal Thrust (MFT). It was suggested that with the evolution of these thrusts, sesimicity also progressed southward. Therefore, conventional modal of seismicity in Himalaya suggests that MFT is the most active domain (Gansser, 1964; Wesnousky et al., 1999; Senthil et al., 2001; Thakur et. al., 2004). However, recent evidences including the present work indicate that this may not be true and the older thrusts probably are still active (Wobus et al., 2005; Mukul, 2000; Mukul et al., 2005). Recent studies have shown presence of out of sequence thrusting in the Himalayan region, antiquity of these structures are still uncertain, but certainly they are younger than the MFT. In order to understand the seismicity in Himalaya, fluvial terrace sequences in North-Eastern Himalaya were investigated for sedimentological and chronometric studies. These sequences are developed in the Tista river basin near

Table 5.3. Paleodoses of the samples collected from mega fan and piedmont fan sections

Serial No.	Sample No.	Paleodose (Gy)		
		MAAD	SAR	
			Least 10%	Mean
1	NN-1	87 ± 5	18 ± 6	38 ± 11
2	NN-5	91 ± 2	15 ± 3	25 ± 6
3	NN-6	–	10 ± 2	25 ± 8
6	KT-5	13 ± 2	2.6 ± 0.3	7 ± 4
7	KT-6	7 ± 1	2.2 ± 0.8	6 ± 3

Kalimpong (27^{0} 4'N, 88^{0} 29' E). Several workers (Adams 1980; Burnett and Schumm 1983; Nakata, 1989; Schumm, 1986; Valdiya, 1998) have recognized that morphology of river terraces can be used as a surrogate for active tectonics. During the differential movement along the riverbed, rivers incise to acquire the ambient base level and forms terraces. The terraces are nothing but the ancient riverbeds. In a tectonically active river basin, the presence of a sequence of incised terraces indicates multiplicity of seismic events. Due to the differential movement, such terraces are usually unpaired in nature. Considering that the Global Positioning System (GPS) data that determine rate of convergence is limited to less than a decade, tectonically evolved fluvial landforms can provide supplement information on constant shortening over longer time scale (10^3 to 10^5 years). In view of this, fluvial terraces in the lower Tista valley were investigated for long-term reconstruction of palaeoseismic history of the region. This work was based on a detailed structural framework provided by Mukul (2000).

5.4.2 Geomorphology, tectonic setting and sample location

The study area is bounded by the MBT (north) and South Kalijhora Thrust (SKT) (south). Tista River originates in northern Sikkim (Trans Himalayan) and flows southward towards the foothill. It runs approximately N-S, parallel to the transport direction of the foreland thrusts (Fig. 5.8 and 5.9). The MBT is exposed in the Kalikhola section, south of the Kalijhora town (Acharya, 1994) and manifested by the juxtaposition of Gondwana rocks against the Lower Siwaliks. In the field, MBT appears as folded and crumpled zone. This is attributed to the activity associated with the SKT, 500 m south of the MBT (Mukul, 2000). Due to the activity along the SKT, the lower Siwalik rocks have been thrusted up and lie with a tectonic contact with the middle Siwaliks. Additional surface expression of SKT is seen along the east bank of the Tista River. These are the duplexes consisting of three horses developed on the hanging wall of the middle Siwalik sandstone. Further 1.5 km south of the SKT, Andheri Jhora thrust (AJT) was located. The Main Frontal Thrust (MFT) is located 30 km south of AJT. Five such terraces with distinct vertical offsets have been recognized on the west bank of the Tista River. These terraces developed on the hanging wall of AJT and are exposed on the western bank of the Tista river. The unpaired nature of the terraces (confined to the western bank), differentiated by distinct vertical offsets (20 – 5 m) and presence of duplexes underlying these terraces together indicate their formation due to episodic tectonic activity along the AJT and their associated imbricate faults (Mukul, 2000). Further south of AJT two raised surfaces were located ~1 km and ~21 km from the mountain front. These features are attributed to the presence of blind thrust (Fig. 5.9).

The physical characteristic of the terraces (poor sediment cover and incised Siwalik basement) is suggestive of degradational type strath terraces. This is a likely possibility considering the concentration of thrusts sheets in a narrow zone. In such tectonomorphic situations, the rivers occupied riverbeds for limited time due to episodic tectonic surges. In view of this, chronology of the fluvial terraces would in principle with providing estimate on the rate of incision from T_5 to T_0. Further, an estimation based on the luminescence ages can be utilized for calculating the rate of convergence much beyond the historical record.

However, before estimating the ages of different terraces, it is important to understand the bleaching history of the sediment. In tectonically active and monsoon dominated region like lower Tista valley, heterogeneous bleaching of fluvial sediment is a likely possibility.

5.4.3 Results and discussion

Considering the uncertainty associated with the bleaching of fluvial sediment; all the samples (4 from terraces and 2 from the raised surfaces) were investigated for the extent of predepositional bleaching. Further all the samples were analyzed using the conventional MAAD protocol. It was observed that except two samples, the MAAD paleodose averaging numerous grains (10^6) in 40-50 aliquots was significantly higher compared to the SAR average paleodose that is attributed to the large scatter in data due to heterogeneous bleaching. The dose distribution histograms of SAR palaeodose are shown in figure 5.6. The wide dose distribution of the samples indicates heterogeneous bleaching. In view of this, the least 10% paleodose of SAR was used for final age computation (Table 5.4).

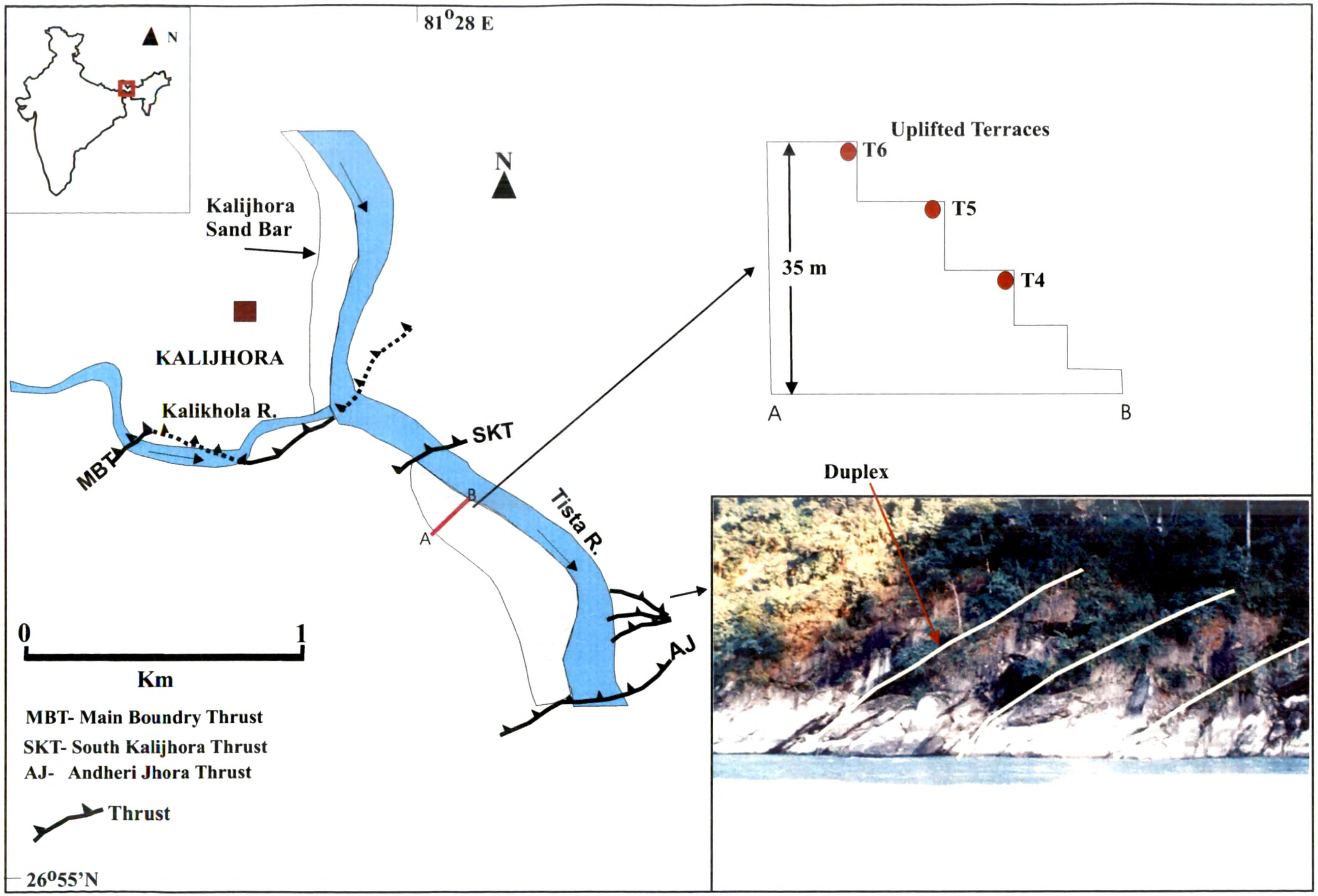

Fig. 5.8 a total of five terraces were identified in the section A-B as shown in the figure in the vicinity of South Kalijhora Thrust. These terraces were formed due to tectonic activity in the duplexes as shown (after Mukul, 2000)

Table 5.4. Paleodoses of terrace sediments obtained through MAAD and SAR analysis.

Serial No.	Sample No.	Paleodoses		
		MAAD	SAR	
			Least 10%	Average
1	T-6	184 ± 68	40 ± 2	80 ± 39
2	T-5	180 ± 39	22 ± 2	73 ± 31
3	T-4	68 ± 28	7 ± 0.4	43 ± 23
4	T-0	0.6 ± 1.3	0.2 ± 0.6	2.5 ± 2.2
5	PRLT-3	128 ± 43	77 ± 5	145 ± 48
6	PRLT-5	26 ± 2	28 ± 1	58 ± 24

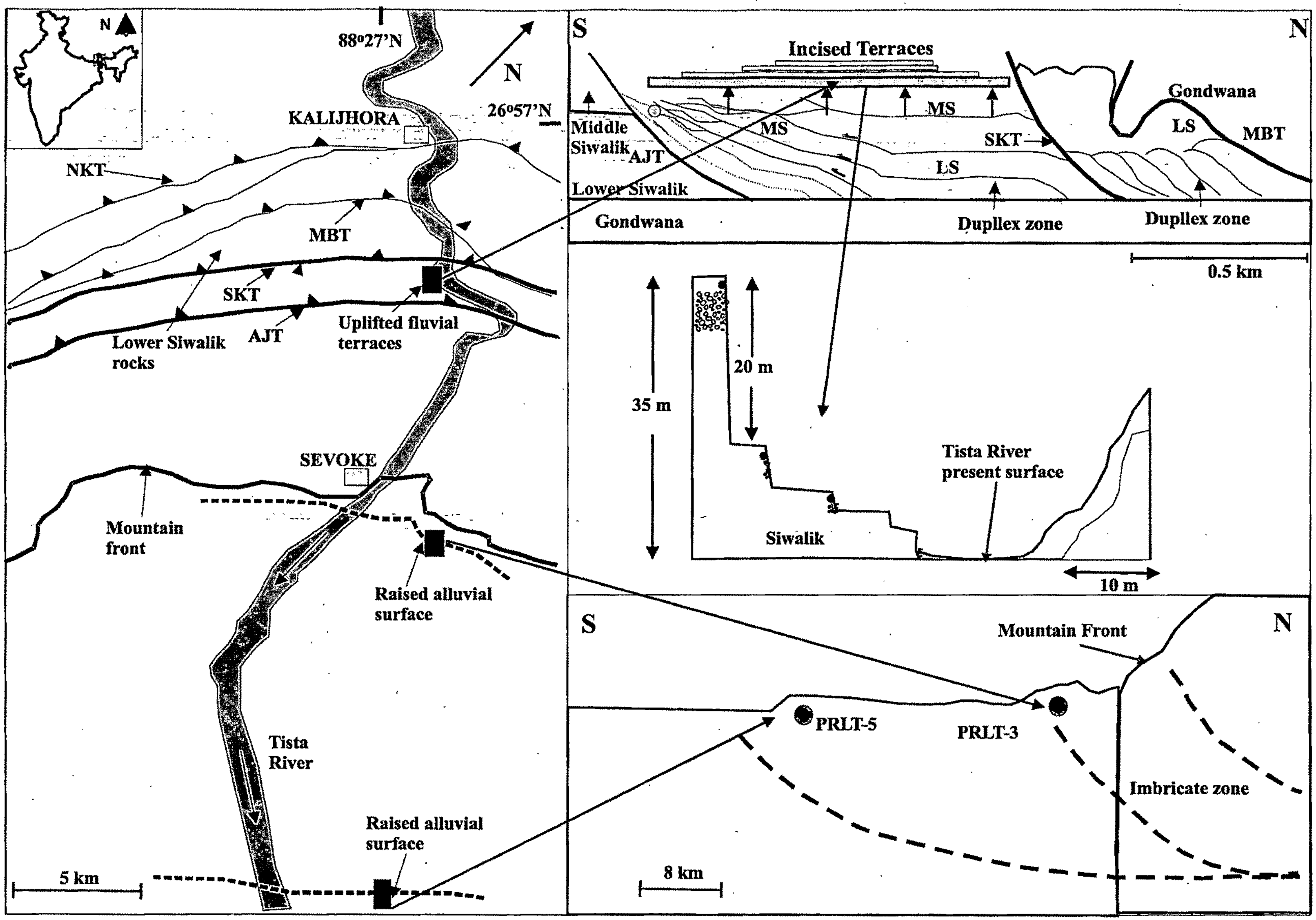

Fig. 5.9. Location and geological setting of the fluvial terraces identified in the vicinity of SKT and MBT. These terraces were formed due to tectonic uplift. Two raised surfaces (PRLT-3 and PRLT-5) were identified in the south of mountain front (After Mukul, 2000) (SKT=South Kalijhora Thrust, NKT=North Kalijhora Thrust, MBT=Main Boundary Thrust, LS=Lower Siwalik, MS=Middle Siwalik, AJT= Anjherijhora Thrust)

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