River systems in the Gangetic plains and their comparison with the Siwaliks: A review

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The Indo-Gangetic plains are drained by several fan and interfan rivers fringing the margin of the outer Himalaya. These fan and interfan river systems are distinctly different from each other in terms of hydrology and sediment transport and generate typical alluvial architecture below the plains. The Siwalik sequences stretching all along the Himalaya from Potwar Plateau in the west to the Tista valley in the east are considered as the most obvious ancient analogue for the Gangetic plains. This paper reviews the geomorphic setting, fluvial processes and sedimentation pattern in the Gangetic plains and draws parallels with the Siwalik Group.

THE Indo-Gangetic plains constitute the extensive alluvial plain of the Ganga, Indus and Brahmaputra rivers and their tributaries, and separate the Himalayan ranges from Peninsular India. These plains are the world's largest areas of Quaternary alluvial sediments derived from the largest orogen, i.e. Himalaya. The east-west trending Gangetic plains are a part of the active Himalayan foreland basin and are drained by a number of N–S trending river systems (Figure 1). These river systems are categorized into three distinct categories namely, mountain-fed, foothills-fed and plains-fed river systems[1]. These differ significantly in morphological, hydrological and sediment transport characteristics. The mountain-fed rivers are generally multi-channel, braided systems, characterized by many times higher discharge and sediment load in comparison to the single-channel, sinuous foothills-fed and plains-fed river systems (Table 1). The mountain-fed rivers such as the Ganga, Gandak and the Kosi transfer a great quantity of sediments from their source areas of high relief, and consequently form large depositional areas (fans) in the plains. The foothills-fed (e.g. Baghmati, Rapti) and plains-fed (e.g. Burhi Gandak, Gomti) rivers derive their sediments from the foothills and from within the plains, and a large proportion of this material is re-deposited in the plains after local reworking. The interfan areas, therefore, are dominated by overbank sediments and are represented by mud-dominated intervals in the Quaternary alluvial sequence of the Indo-Gangetic plains.

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Advances in the understanding of the small-scale geomorphic features have produced important progress in the environmental interpretation of fluvial sedimentation; nonetheless it is large architectural features that often provide a better understanding of the style of sedimentary formations. The present understanding of the sedimentary geometry of most ancient fluvial basin fills is still largely based on uncertain extrapolation from small-scale studies of present-day morphology and short-period behaviour. Studies on Siwalik outcrops in India[2–6], Nepal[7] and Pakistan[8–14] have essentially been focused to determine the types of rivers (in terms of size, discharge, and behaviour) that formed these sediment accumulations. But there are still major uncertainties about the large-scale changes of river regime involved in building the architecture and what these might mean in terms of the geomorphological patterns visible in present-day alluvial environments.

This paper is focused on the Ganga plains, i.e. the plains drained by the Ganga river and its tributaries. Geomorphologically, the Ganga plains consist of several fan and interfan areas, viz. Yamuna–Ganga megafan, Sarda fan[15], Gandak megafan[16] and Kosi megafan[17–21]. Fans (cones) are geomorphic features, triangular in plan with their apex at the gorge mouth, convex in form and characterized by steep gradient (20 cm/km) and interfan area (intercones) are reversed in plan, tapering from Himalaya, slightly concave at the edges and with a gradient of 10 cm/km and less[22]. The megafans are large size fans in humid environments of about 100–200 km width and 100–150 km length[15].

Based on subsurface features, the Ganga basin is limited to the west by the Aravalli–Delhi ridge and to the east by the Monghyr–Saharsa ridge. Several transverse faults criss-cross the basin and a major structural high, the Faizabad ridge divides the basin into the West Ganga plain (WGP) and the East Ganga Plain (EGP)[23–25]. The Gangetic plains are neotectonically active as evidenced by recent seismic activities (1833, 1906, 1934, 1987) in the region as well as the possibility of large earthquakes in the near future[26]. The seismic activity is related to subsurface transverse faults[25,27–30] as well as longitudinal faults in the Himalaya. Active tectonics in the EGP is also indicated by the high uplift rate (1.5 cm/yr) along MFT, based on the analysis of deformation of terraces along Baghmati river system[31]. The present models on

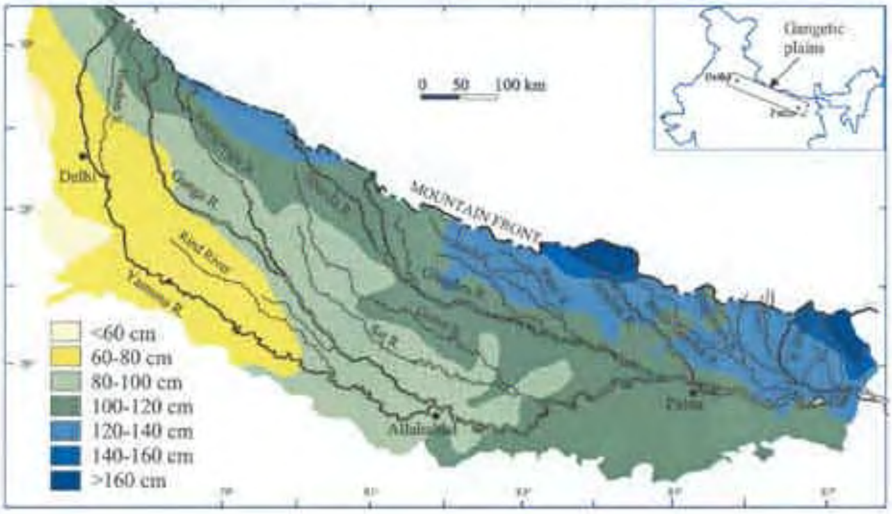

Figure 1. River systems and climatic variability across the Gangetic plains (modified after Singh[74]; the colours represent the average rainfall in the region.

Table 1. Hydrological characteristics of the rivers of Gangetic plains

River	River type	Total basin area (10^3 km^2)	Average annual discharge (cumecs)	Average sediment load (mt/yr)	Discharge per unit area (cumecs/km^2) × 10^{-3}	Sediment yield (10^3 t/yr/km^2)	Source (ref. no.)
Ganga* (Hardwar)	Mt	95	757	14	8	0.15	75
Ganga* (Kannauj)	Mt	240	1252	15	5	0.06	75
Yamuna	Mt	366	2949	125	8	0.34	75
Ramganga	Mt	32	482	10	15	0.31	75
Gomti	Pl	30	235	6	8	0.20	75
Rapti	Ft	20	–	15.6	–	0.78	44
Ghaghra	Mt	127	2993	125	24	0.98	75
Gandak	Mt	43	1555	82	36	1.91	1
Burhi Gandak	Pl	10	273	15	27	1.50	1
Baghmati	Ft	8	189	7	23	0.87	76
Kamla-Balan	Mx	3	68	8	23	2.67	1
Kosi	Mt	95	1792	193	19	2.03	77
Ganga$ (Farakka)	Mt	648	14555	729	22	1.125	75

*Ganga river data at upstream stations, indicating the characteristics of WGP.
$Ganga river data at India/Bangladesh border, the data indicating the cumulative hydrological characteristics of WGP as well EGP.
Mt, Mountain-fed; Ft, Foothills-fed, Pl, Plains-fed; Mx, Mixed-fed.

Himalayan seismotectonics predict westward decrease in crustal shortening and uplift rate along HFT[32,33], based on the higher crustal shortening rate and average Holocene upliftment rate in Nepal (≅ 20 mm/a and 15 mm/a respectively[32,34]) and lower rates in Dehradun (11.9 ± 3.1 mm/a and 6.9 ± 1.8 mm/a respectively 10–12 mm/yr[32,33]). These longitudinal and transverse faults along with basement configuration of the Gangetic plains have long been considered to influence the fluvial processes and sedimentation[15,20,35–39].

The Gangetic plains are also characterized by significant variation in the climatic parameters. The normal annual rainfall in the Gangetic plains varies from 60 cm to more than 160 cm[1] (Figure 1). In general, the West Ganga Plains (WGP) receive less rainfall (from 60–140 cm) in comparison with the East Ganga Plain (EGP) (90 – > 160 cm). Further, the northern part of plains area receives higher rainfall than the southern part. The temperature in Gangetic plains varies from 5°–25°C in winter to 20° – > 40°C during summer[1].

Fluvial processes and sedimentation in the Ganga plains

The East-west trending Gangetic plains are marked by geomorphological diversity manifested in terms of the morphological, hydrological and sediment transport characteristics of the rivers draining them. Most rivers display braided as well as meandering morphologies (e.g. Ganga, Kosi, Yamuna) and some of them show a systematic downstream change from braided to meandering (e.g. Kosi, Baghmati, Rapti) possibly due to downstream decrease in discharge and sediment supply[40]. Other rivers are either braided (e.g. Gandak, Brahmaputra) or meandering (e.g. Burhi Gandak, Gomti) throughout. It may also be noted from Table 1 that the rivers in the eastern part of the Gangetic plains, viz. Gandak, Burhi Gandak, Baghmati and Kosi, are characterized by higher discharge per unit area as well as high sediment yield in comparison to the rivers of western part of the Gangetic plains, viz. Ramganga, Rapti, Gomti and Yamuna.

Most of the rivers draining the fan areas are known for their rapid and frequent avulsions albeit with varying frequencies. The Kosi river has recorded a total westward migration of about 110 km in the last 200 years[17,18,20], the Sarda river has undergone frequent shifting and river capturing during the last 80 years[41], and the Gandak has migrated about 80 km eastward during the last 5000 years[16]. Most of these estimates are based on historical and archaeological records and no strong dating control is available. Hydrological and sediment transport data of these rivers indicate that these rivers are characterized by very high peak annual discharges and the discharges rise much before the monsoon arrives, clearly reflecting the snow melt contribution from the large and mountainous catchments[42].

Studies on the sedimentation record and facies distribution of megafan deposits reveal a dominance of sandy facies in the plains with a very narrow zone of gravel restricted to the reaches close to mountain front (10–20 km downstream of mountain front). Most workers have recognized distinct zonal distribution of facies, e.g. moving from upstream to downstream; four zones are recognized in Kosi megafan deposits[19], namely zone 1 (gravelly-sandy, braided, 20 km), zone 2 (sandy, braided, 95 km), zone 3 (fine sand/mud, straight, 40 km) and zone 4 (fine sand/mud, meandering, 160 km). In a more recent work, four zones have been recognized in the Ganga megafan from upstream to downstream namely, gravelly braided zone, sandy braid plain, anastomosing channel plain and meandering channel zone[43]. The 3D architecture of megafan deposits consists of multi-storied sandsheets (generally gravel in upper reaches), interbedded with overbank muddy layers (Figure 2). In Gandak

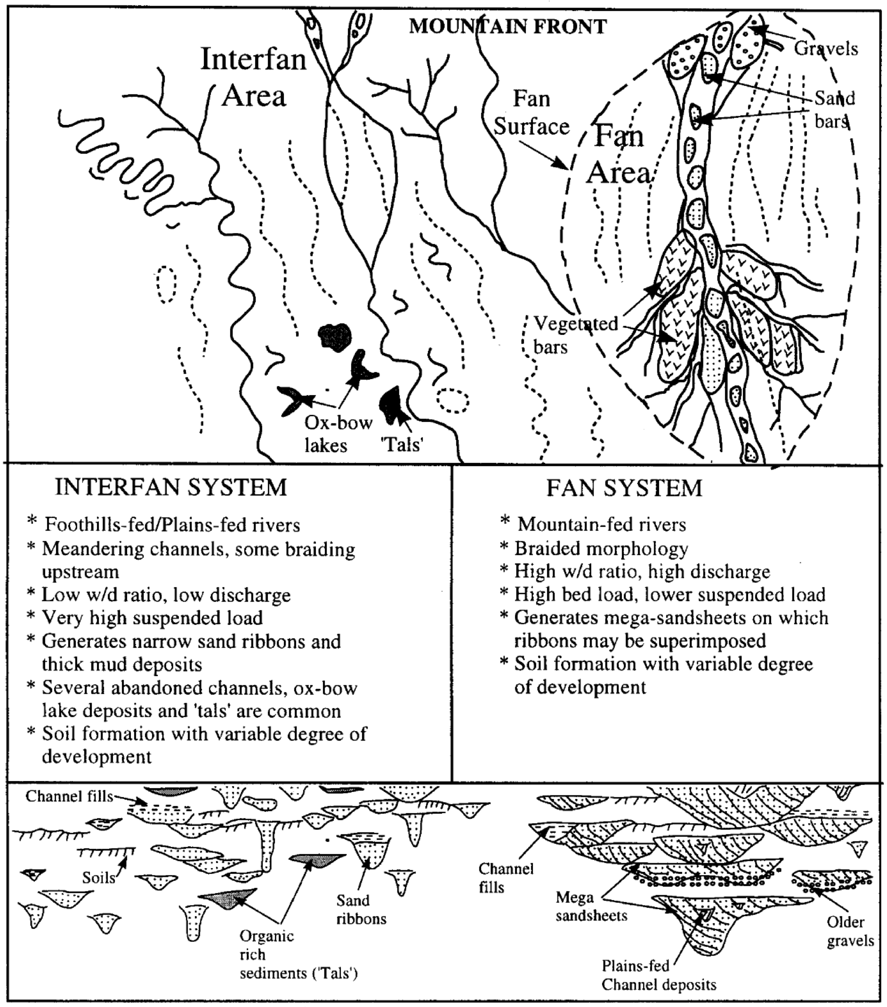

Figure 2. Fan–interfan sedimentation and a conceptual model of the alluvial architecture evolving below the Gangetic plains.

megafan, 65 km long and 120–130 m deep 3D architecture shows occurrence of sand as matrix and clays as lenses embedded in it[44]. It was interpreted as the deposition due to laterally migrating channel in both directions and overbank environment is being preserved as clay deposits[44]. The thickness and facies distribution varies from upstream to downstream. The sand sheets are typically 8–10 m thick and 16–20 m in case of multistoried bodies[21]. In general, a progressive decrease from upstream to downstream in (a) particle size, (b) thickness of beds, and (c) scale of cross-bedded sets has been reported in the surficial deposits[45]. In downstream reaches, variation in the characteristics of sand from pink arkosic sand to grey micaceous sand at around 270 m depth were interpreted as the change dominance of river systems from peninsular rivers to Himalayan rivers[46].

Contrary to the megafan deposits, which have received wide attention, the interfan areas are less understood. In general, the interfan areas are considered to be inactive regions with subdued fluvial activity, in which mud accumulates through overbank sedimentation. However, the available studies from the Gangetic plains indicate that rivers draining the interfan areas are characterized by rapid, frequent channel movements[36,41,44,47,48], with high sediment load[42,44] and rapid sedimentation on the floodplain[49]. Geomorphological mapping using satellite images have allowed reconstruction of palaeochannels of several interfan rivers namely Rapti, Little Gandak (both in UP plains), Burhi Gandak, Baghmati, Kamla-Balan (all in Bihar plains). All these studies show that these rivers are prone to avulsion in response to tectonics and/or local sedimentological readjustments. Our recent detailed studies on the Baghmati river system in north Bihar plains have revealed 8 major avulsions and several minor avulsions in a period of 230 years (1770–2000)[36]. Similar avulsion histories have also been reported from Sharda–Gandak interfan area[41,44] drained by the Rapti, Burhi Rapti, Kamwa, Ami and Little Gandak rivers.

The information available on the stratigraphy of the interfan area is very limited. Shallow alluvial architectural studies in the Gandak–Kosi interfan[50] showed that the top 2–3 m of the interfan area predominantly consist of muddy sequences, with narrow sandbodies defining former channel positions and very minor sandy layers defining crevasses (Figure 2). More detailed studies in the Baghmati river plains in north Bihar were carried out on the basis of subsurface records available from exposed sections and deep boreholes[51]. Borehole records in the midstream reaches of the Baghmati river down to about 300 m showed a 30–50 m thick mud rich unit including very thin sand layer (2–4 m) characterizing distal floodplain environment. In Sharda–Gandak interfan area, the top 10–20 m of sediments are characterized by muddy sequences with a basal coarse sand horizon[44]. The coarse sand layer at ~ 30–35 m depth was interpreted as a possible marker of the Rapti palaeochannel with high-energy fluvial regime. The Gomti river draining the UP plains is an example of a plains-fed river originating in the alluvium and is characterized by fine-grained muddy sediments throughout its course[52]. Based on mineralogical criteria, it was interpreted that the local redistribution of sediments is the main geomorphic work done by the river and most sections reflect little transportation and rapid sedimentation[52].

We now focus our attention on geomorphic variability and its manifestation in the sedimentation pattern across the Ganga plain. Although different fan areas and interfan areas in the Gangetic plains show similar characteristics, there exists a distinct differentiation between West Ganga plain and East Ganga plain in terms of river morphology and fluvial processes[53]. Besides the differences between the rivers draining the fan and interfan areas, the rivers of the western and eastern Gangetic plains are also distinctive in many ways. For example, the rivers in the West Ganga plains (WGP), e.g. Ganga, Yamuna, Ramganga, Gomti, are characterized by deep, stable and incised (of the order of 20–25 m, e.g. the Ganga river at Kanpur and the Yamuna river at Kalpi) channels. But the rivers in the East Ganga plains (EGP), e.g. Gandak, Burhi Gandak, Baghmati, Kamla-Balan, and Kosi rivers, are marked by shallow aggrading channels, frequent flooding and rapid channel migration. The incision and development of regional surfaces in the Gangetic plains have been related with mean sea level change during Pleistocene–Holocene period[54–56]. However, this correlation is based on unsubstantiated chronology and scientifically unsound concept. Recent studies on inland response of fluvial system to sea level changes indicate that such effects are limited to a distance of at most 300 km[57,58], although relief and climate change effects can extend up to about 1000 km up dip from coeval shoreline[57]. Therefore, sea-level influences in the Gangetic plains in the Kanpur region (about 1200 km inland from the present day coast), suggested by earlier workers[54–56,59], are highly unlikely. Changes in hydrological regimes induced by climate change coupled with neotectonics may be more likely reasons for such incision[60], analogous to the response of the western Indian rivers of Gujarat region to intensification of the SW monsoon between ~ 12 and 4.5 ka (ref. 61). However, more chronometric data and palaeoclimatic records from Gangetic plains are needed to confirm these speculations. On the other hand, the rivers of the EGP are shallow and no incision is reported, implying net aggradation of channels. The channels are also characterized by high frequency of avulsions and extensive overbank flooding[17,18,36,42,62]. Further, the available hydrological data for the different rivers of Gangetic plains indicate that the WGP rivers are marked by low sediment supply and high unit stream power (40–43 w/m^2) whereas the rivers of the EGP have low unit stream power (6–20 w/m^2) and high sediment yield[63] (5–10 times higher than WGP rivers, see Table 1). High sediment supply in the EGP is also reflected in the high sedimentation rate in the EGP in comparison to the WGP. A few radiocarbon dates from the floodplains for < 2 m of sequence provide evidence of rapid accumulation at the rate of 0.7–1.5 mm/yr measured over 10^3 years[49], whereas, the WGP are characterized by sedimentation rates of 0.2–0.05 mm/yr over a period of 10^4 years[44,64,65]. On the basis of this sharp difference in sediment supply, it is suggested that the WGP and EGP have responded differently to increase in humidity and SW monsoon intensification and this seems to be related to hydrological and sediment transport characteristics of the rivers. It has been pointed out that discharge-sediment relationship is an important factor controlling the aggradation/degradation in a river[58]. It is likely that high sediment load of the EGP rivers and resulting aggradation are manifestations of higher rainfall in the region[1] (Figure 1) and higher compression rate[31,32] and hence higher uplift in the source area[31]. However, more chronological data and hydrological data of rivers are needed to affirm these speculations.

Comparison with Siwaliks

The Siwalik Group, with a thickness of more than 5000 m of clastic sediments, was deposited in an east–west elongated basin parallel to the strike of the Himalaya. Early work on the Siwalik Group involving palaeogeographic reconstruction[3] showed that most of the Siwalik rivers flowed in a direction transverse to Himalayan strike, deposited the megafan sequences and joined a main river flowing in the easterly direction and ultimately draining the Bay of Bengal. It is not just the comparable location of the Siwaliks and the Gangetic plains which is striking but there are gross similarities reported in terms of alluvial architecture, fluvial processes, sedimentation rates and depositional environments. Based on the available literature, a summary of important Siwalik sequences and their interpreted depositional environment at different localities is presented in Table 2.

Alluvial architectural studies on exposed Siwalik sections have been carried out on a variety of scales with varying details. Detailed information on Lower and Middle Siwaliks from different parts of the Potwar Plateau in Pakistan are available where kilometer scale thick sections are exposed. Major sandstone bodies are 10s of meters thick and are continuous along strike for many kilometers[9,11,13]. These sandstone bodies are underlain by a major erosion surface, and are, in general, capped by a palaeosol. The major sandstone bodies are separated by around 100 m thick mudstone-dominated palaeosol-bounded sequences containing minor sandstone bodies (one to few meters thick) with lateral extent from several tens of meters to less than a kilometer[9]. These sequences have been interpreted as overbank deposits formed by filling of local low-lying area through small channels and crevasses followed by progressive shifting through avulsion[66]. This depositional environment is analogous to the modern interfan areas in the Gangetic plains namely, the Rapti river system[44] and the Baghmati river system[36]. All these sand bodies appear to be channel deposits, and their stacking in the sequence indicates reoccupation of channels as is frequently observed in the parts of the Gangetic plains[36,48,51].

In the Jammu area, three major lithofacies associations and several minor lithofacies have been reported from Lower Siwalik[67]. The major lithofacies includes sand-dominant association, sandy mud-dominant association and silty heterolithic associations. The first two major facies associations were interpreted to be stratigraphically related and were interpreted as channel and overbank deposits[67]. The silty heterolithic association was interpreted as upland interfluve deposit, related to sheet flow along the slopes. It has been suggested, that such large scale sheet flow processes are also operating in the modern Gangetic plains[59]. In our opinion, these thick muddy sequences represent interfan areas either with continued accumulation of floodplain sediments[51] followed by pedogenic alterations but absence of well-developed soil horizons (e.g. north Bihar plains[68]), or very thick muddy units with palaeosol horizons and calcretized units (e.g. Kalpi section, Yamuna plains[53,69]).

The Dhokpathan Formation of the Middle Siwalik in the Potwar Plateau shows two contemporaneous, interfingering fluvial systems, namely the blue-grey system and the Buff system[8]. The Blue-grey system, characterized by widespread sand sheets with low sand/mud ratio, was deposited by larger braided system while the Buff system characterized by shoe-string sand bodies was attributed to frequent avulsion in a 10–20 km wide floodplain. The difference in Blue-grey and Buff systems was explained on the basis of difference in source area analogous to mountain-fed rivers in fan areas and foothill-fed/plains-fed river systems in interfan areas. The Middle Siwaliks in the Garhwal Himalaya (Mohand area) shows the multistoried sandstone complex displaying frequent erosional surfaces and fining up in grain size from erosional surfaces to mudstone. It was interpreted as the deposit of a shallow braided river characterized by frequent avulsions and channel reoccupation[5]. Further, on the basis of swinging in palaeochannel direction form SE to NW, it was concluded that the sedimentation occurred in an alluvial fan setting, which was compared with Kosi megafan in north Bihar plains[5]. In the Nepal Himalaya, the Middle Siwaliks are characterized by thick, coarse to very coarse-stratified sandstone beds interbedded with pebbly sandstone and gray mudstones interpreted to have been deposited by sandy meandering/deep sandy braided river system[7].

Variations in alluvial architecture of the Siwaliks in terms of mean grain size and sand body proportion have

Table 2. 20 ma^{-1} Ma old fluvial system as interpreted from Siwalik sediments

	Formation*	Major events[7,78,79]	Potwar plateau[9,11,13,14]	Jammu & Kashmir Himalaya[67,80,81]	Panjab Himalaya[4,79,82]	Garhwal and Kumaun Himalaya[2,5]	Nepal Himalaya[7]	Sikkim Himalaya[83]
Upper Siwalik	Boulder Cong. Pinjor (2.5–<2.5)	Himalayan uplift 0.9 ma Movement on MBT (1.6 ma)		Channel sediments overtopped by floodplain sediments	Gravelly braided river in alluvial fan setting		Debris flow dominated braided systems Gravelly braided	
	Tatrot (5–2.5 ma)	Himalayan uplift (4–2 ma)		Broad alluvial plain, low sinuosity river	Braided or anastomosed channel	Braided river	Anastomosed Shallow sandy braided	Braided river; coalescing alluvial fan setting; medium grained sand; Fining towards downstream; similar to Tista river sediments
Middle Siwalik	Dhokpathan (7.9-5.1)	Fully established monsoon (7.0 ma) Reactivation of MCT in NW Himalaya and Nepal (8–6 ma)	Two river systems: Blue-grey system – large braided rivers; channel spreading laterally over 25 km; frequent avulsions; Buff system, ≤ 3 km wide; aggraded by avulsions on 10–20 km wide floodplains			Braided channel; shallow alluvial fan setting; low sinuosity; frequent avulsion and reoccupation	Deep sandy braided; Sandy meandering	
	Nagri (10.1–7.9)	Tectonic upheaval (11–7.5 ma) Initiation of monsoon (10.5 ma)	Larger braided river; higher sediment load, coarser sediment, higher discharge, larger channel than Chinji time		Meandering entrenched in some locations	Transition (?)	Meandering channel; flood flow dominated fine-grained	
Lower Siwalik	Chinji (13.1–10.1)		Braided river, 2 km wide; No rapid channel incision; Less strength of bank material, Megafan setting	Meandering, highly sinuous river	Meandering	Rivers – network of rivers rising from N, sedimentation in series of gigantic overlapping alluvial fan setting, meandering river	Fine grained meandering	

*Age in Ma based on magnetic reversal stratigraphy[11,70,71].

been recorded at (a) 10's of meter scale, (b) 100 m scale and (c) km scale and have been related to intra- and extra-basinal controls[10,12,13]. Small scale variations of the order of 10 m were linked to intrabasinal controls such as flooding and small scale avulsions. Medium scale variations of the order of 100 m were related to local changes in the position of large sediment fans triggered by autocyclic processes and/or mountain-front tectonism[12,13], similar to the swinging of present day Kosi fan. In the Chinji village, the time span between the reoccupancy of channel was recorded as 200,000 years for Chinji Formation and 60,000 years for Nagri Formation[10]. Comparing with the modern megafan systems, e.g. the Kosi with avulsion frequency of tens of years, the channel occupancy time period will be a few thousands years (on the basis of equations after Bridge and Mackey[70]). However, longer reoccupation time in Siwalik deposits suggests that the channels were less avulsive than the present-day Kosi megafan system[10].

Large (kilometer) scale variations manifested in increase in sand/mud ratio, sediment accumulation rate, and reconstructed hydrological parameters from Chinji to Nagri formation were explained by extrabasinal controls on the fluvial system. The role of sea level change was ruled out by the most workers[10,12,13] as the shoreline was ≅ 1000 km away from deposition site during Miocene[71]. Although most workers have considered the climatic effects to be minimal, at least one study in the eastern part of the Potwar Plateau[13] has argued that possible glaciation during Nagri time may have caused increased sediment load and discharge, manifested in higher sedimentation rate, and greater proportion and thicker sandstone bodies. On the other hand, the interglacial period was characterized by decrease in sediment load and discharge, which was reflected in low sedimentation rates and thinner sandstone bodies[13]. Uplift of tectonic front has been cited as the main extrabasinal control of change in depositional environment, which caused an increase in sediment accumulation rate, sediment flux and grain size[12]. It was suggested that deposition in Chinji Formation represents deposition by the smaller rivers on the fan surface or the interfan rivers[10] such as the present-day fan–interfan setting in north Bihar plains. Reconstructed palaeohydrological data[11] also suggest that the rivers of Chinji formation and Nagri Formation were equivalent to the present-day interfan river systems and megafan river systems respectively (Table 3). The increase in discharge and channel size during Nagri time may have been due to river piracy and restructuring of the drainage network, related to neotectonic activity in the upstream region[12]. The minor sand bodies were formed by small river channels and the major sand bodies were formed as the deposits of the largest, generally braided channel belts.

Further work in the Chinji area has highlighted the role of palaeogeomorphology and fluvial processes in large-scale variations in alluvial architecture[14]. The major

Table 3. Reconstructed hydrological and morphological parameters for Siwaliks and their comparison with the Gangetic rivers

	Rivers	Bankfull discharge (cumecs)	Channel sinuosity	Channel width (m)	Channel mean depth (m)	w/d ratio	Mean channel slope (cm/km)	Source (ref. no.)
Siwalik rivers systems								
	Chinji	700–800	1.1–1.12	320–710	4.1–4.4	68–162	5.6–11	11
	Nagri	1800–3500 (9000–32000)*	1.08–1.19	320–1050	5.8–8.7	36–205	5.6–11	11
	Dhokpathan	700–800	1.10–1.16	270–340	4.2–5.1	53–80	5.6–11	11
Fan rivers (Ganga plains)								
	Ganga (u/s)	5800	–	400	4.0	100	30	84
	Ganga (d/s)	32000		2012	15.0	134	16	84
	Yamuna	3300	–	244	3.5	70	30	84
	Ghaghra	7000	–	827	6.0	138	30	84
	Gandak (u/s)	12500	1.9	1083	8.2	133		1
	Gandak (d/s)	5250	1.0	757	6.5	117	–	1
	Kosi (u/s)	5750		631	8.1	78	11	1
	Kosi (d/s)	11338	–	610	5.2	117	11	77
Interfan rivers (Ganga plains)								
	Rapti	2500	–	240	4.7	51	19	84
	Burhi Gandak (u/s)	2050	1.2	191	6.3	30		1
	Burhi Gandak (d/s)	950	2.9	203	6.9	29	–	1
	Baghmati (u/s)	600	1.0	440	3	110	53	76
	Baghmati (d/s)	900	2.4	150	10	15	11	76
	Kamla-Balan (u/s)	400	1.0	115	3.8	30		1
	Kamla-Balan (d/s)	300	2.4	112	5.7	20	–	1

*For some large channels.

and minor sand bodies in the Chinji Formation were interpreted as the deposits of ~ 25 km wide main channel belt complex consisting of a major channel and several smaller rivers. In Chinji time when sedimentation rate was low[72], this channel belt complex was constrained by low valley walls, where the main channel belt was incised and smaller channels used to move freely through avulsion. An analogous situation exists in the present day WGP, where the main channels are incised, smaller interfan rivers move freely and sedimentation rates are lower. However, the scenario changed during Nagri time, which recorded high sedimentation rate[72] (and hence higher sediment load[14]) causing channel aggradation. In contrast to Chinji time, there was no constraint on the lateral movement by avulsion of the channel belt during Nagri time. This free movement of channel belt caused erosion of finer grained sediments and transferred downstream thereby resulting in higher sand/mud ratio in the deposits[14]. This situation may be compared with the EGP where the trunk river such as the Kosi swings freely and causes lateral development of thick sand body[21]. The interfan rivers in the EGP, as noted earlier, have shallow, aggrading channels and floodplain sedimentation rates are higher than in the WGP.

In general, the sedimentation rates in Siwalik were variable, e.g. 0.12 mm/yr in Lower Siwalik[72], 0.3 mm/yr in Middle Siwalik[72] and 0.67 mm/yr in upper Siwalik[73] measured over time periods of the order of 10^5–10^6 years. Applying a decompaction scaling of about 125% on the thicknesses involved, these rates are comparable to the rates computed for the EGP (0.7–1.5 mm/yr measured over 10^3 years[49]). On the other hand, the WGP has recorded a much lower sedimentation rate (0.2–0.05 mm[44,64,65]) which once again points to the geomorphological variability across the plains. Further, even though most of the workers have compared the alluvial fan setting in Siwalik times with the Kosi megafan, the present-day EGP rivers may be even more dynamic in comparison to the calculated avulsion rate of old rivers.

Concluding remarks

Fluvial landforms and alluvial sediments in the Indo-Gangetic plains are important Quaternary continental records, which hold potential for the examination of tectonic, climatic and lithological controls over their formation. This vast pile of alluvial sediments was produced and deposited in response to Himalayan orogenesis and are a most obvious modern analogue for the sequences of the Siwalik Group. Further studies on detailed stratigraphy, geochemistry and chronology of exposed sections as well as shallow and deep boreholes are necessary to understand the long-term controls on alluvial sedimentation in the extensive Gangetic plains.

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