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FACIES ARCHITECTURE OF THE GANDAK MEGAFAN, GANGA PLAIN, INDIA

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ABSTRACT

Gandak Megafan is an important geomorphic feature of Ganga Plain, located at the border of Uttar Pradesh and Bihar states. It is a skewed megafan, drained by a number of rivers like Rohini, Chhoti Gandak, Jharahi, Daha, Gandaki, Dabra, Mahi, Great Gandak, Baya, Dhanauti, Balan and Burhi Gandak from west to east. The fan surface exhibits abundance of water bodies, representing meander scars, abandoned channels, ox-bow lakes, ponds and low-lying areas where fine-grained sediments are deposited. The active river systems of Gandak Megafan exhibit shallow to moderate entrenchment. Consequently, channel born sediments are restricted within their valleys and cannot be moved on the high surfaces even during peak discharge. In the cliff sections exposed on the river banks five major litho facies namely, Mottled Silt, Mottled Silty Sand, Shelly Clayey Silt, Variegated Sandy Clayey Silt, and Alternating Silt and Clay are identified, which have poor development of bedding structures and formed under low energy conditions. Seven facies identified in channel deposits of Gandak Megafan rivers are planar cross-bedding, trough cross-bedding, ripple bedding, climbing ripple lamination, low-angle planar cross-bedding, laminated mud, and rooted sand. Subsurface succession indicates at least three-fan depositional events separated by a thick mud unit. The subsurface data indicates that during initial stage of fan sedimentation the rivers were capable of carrying the coarser material for a longer distance. Gradually, the discharge of rivers decreased because of drier climate causing recession of fan building. Finally, the active rivers became somewhat entrenched in the fan surface and active fan deposition ceased. During present inactive phase, deposition of muddy sediments is taking place on interchannel areas, while sand deposition is restricted to few channels.

Key Words: Ganga Plain, Megafan, Channel deposits, Interchannel deposits, Facies.

INTRODUCTION

Alluvial fans are the most important fluvial landforms, developed close to the mountain chain in response to the high sediment supply. In foreland basin setting, formation and changes in the alluvial fan system is mainly controlled by the tectonic and climate change in the orogen. Thus, study of alluvial fans of a foreland basin may help in understanding the changes in the orogen, which may control the supply of the sediment.

Ganga Plain exhibits a narrow belt of piedmont fans close to the Himalayan orogen and several large megafans, which cover a large part of the Ganga Plain (Singh, 1996). It has been argued that the Late Quaternary sedimentation in Ganga Plain has been mainly controlled by the expanding and contracting fan systems (piedmont fans and Megafans) (Singh and Ghosh, 1992; Singh, 1996).

Geddes (1960) emphasized that the northern part of Ganga Plain consists of cones and inter-cones areas. He observed that large rivers, emerging on to the Ganga Plain from the Himalayas were forming cones. Wells and Dorr (1987), Singh and Ghosh (1992), Mohindra *et al.* (1992) and Shukla *et al.* (2001) have preferred to use the term "Megafan" for these cones.

Remotely sensed data have helped in identification of Megafans as distinctive geomorphic surfaces in north-central part of the Ganga Plain consisting of Kosi, Gandak, Sharda (Ghaghara) and Yamuna-Ganga megafans from east to west (Singh and Ghosh, 1992; Singh, 1996). These megafans were formed by snow-fed Himalayan rivers during Late Pleistocene under increased sediment supply and water budget.

Gole and Chitale (1966), Wells and Dorr (1987) and Singh *et al.* (1993) have described the Kosi Megafan for its channel shifting, sedimentation and facies analysis. Shukla *et al.* (2001) have described the sedimentation processes and evolution of Ganga Megafan. The Gandak Megafan is constructed by the activity of Gandak river system. Mohindra *et al.* (1992) and Mohindra and Parkash (1994) have studied the interchannel areas of Gandak Megafan (between Rapti and Great Gandak Rivers) for its pedology, clay minerology and historical geomorphology. Sinha and Friend (1994), Sinha (1995, 1996) and Jain and Sinha (2004) studied the river systems and sedimentology of Quaternary alluvial deposits and fluvial dynamics of the Gandak-Kosi interfan.

However, so far no systemic study of the geomorphology, sedimentation processes and deposits of Gandak Megafan are available. The megafan deposits are essentially concealed in the subsurface and only little information on the subsurface stratigraphy is available; no absolute ages of these deposits have been determined. The present paper describes the geomorphic features and near surface deposits of the Gandak Megafan. An attempt has been made to provide a generalized evolutionary model of the fan, using the available information.

STUDY AREA

Gandak Megafan is a prominent feature at the border of Uttar Pradesh and Bihar states between 83°23' E to 86°41' E longitude and 25°15' N to 27°27' N latitude (fig. 1). It covers the Gorakhpur, Maharajganj, Kushinagar and Deoria districts of Uttar Pradesh and Begusarai, Khagaria, Muzaffarpur, Samastipur, Vaishali, Saran, Siwan, Gopalganj, East Champaran and West Champaran districts of Bihar.

The Gandak megafan is a skewed Megafan, bounded in the west by Rohini and Rapti rivers and in the east by Burhi Gandak River. The Ghaghara and Ganga rivers to the south and Siwalik Hills in the north make its boundaries with the marginal alluvial plain and Nepal respectively. The fan surface is drained by a number of independent major rivers like Chhoti Gandak, Great Gandak and Burhi Gandak (Singh, 1998).

GEOMORPHOLOGY OF GANDAK MEGAFAN

Gandak megafan is 350 km long and 60 to 190 km wide in different parts. It is skewed in SE direction occupying an area of about 32,000 km^2, two times the area of the Kosi Megafan. The central part of the fan is 2 to 10 m higher than its margins. Apex, the highest point of the fan surface is located near Tribeni (120 m), where Great Gandak, leaves the mountain and debouches on to the plain. Great Gandak, also known as Narayani in Nepal is the main river of Gandak Megafan. At Tribeni, the Great Gandak River is formed by the confluence of Sonaha, Panchnad and Narayani rivers.

Great Gandak River spreads out beyond its gorges in the vicinity of Tribeni making 2 to 5 km wide valley, depositing gravel and sand in the area. The grain size of the channel sediments of river decreases in the downstream direction (from Tribeni to Hajipur) because of decreasing slope and energy of the flow.

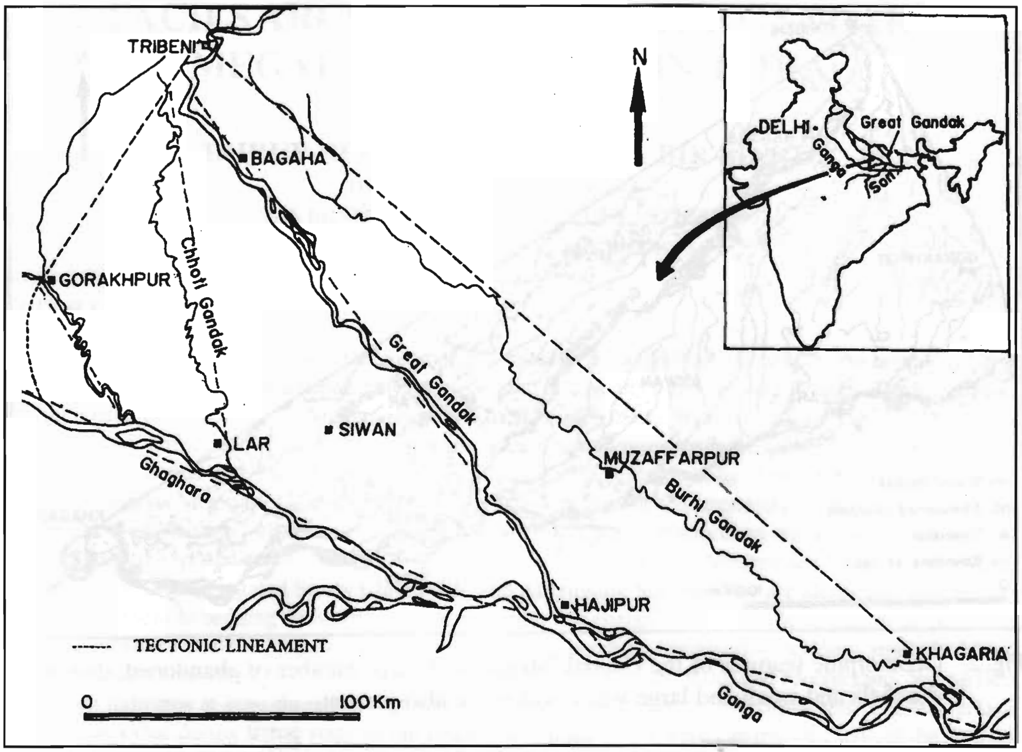

Fig.1. Location map of Gandak Megafan. The outline of the megafan is defined by tectonic lineaments. Main rivers of the megafan and its southern boundary are emphasized.

Gandak Megafan is drained by a number of small and large rivers, namely Rohini, Chhoti Gandak, Jharahi, Daha, Gandaki, Dabra, Mahi, Great Gandak, Baya, Dhanauti, Balan and Burhi Gandak from west to east. Many of these streams are arranged in a radial pattern (fig. 2). These streams either join each other or meet the Ghaghara or the Ganga River (the lower fan boundary streams).

The streams of the Gandak megafan can be classified into two types, those originating on the fan surface and those originating outside the fan surface. Those originating outside the fan surface begin in the Himalaya and are snow-fed. They are perennial, braided streams with high sediment water discharge. These river channels exhibit huge sand flat, sand bars, braid bars and islands during low discharge periods. The rivers originating on the fan surface are meandering in nature and are mostly ground water fed. Some of the rivers are part of the abandoned channels of ephemeral nature, carrying water only during rainy season. The rivers originating on the fan surface have low sediment discharge.

The rivers of Gandak Megafan are entrenched showing variable degree of incision along their courses. These rivers rarely overtop their banks and therefore unable to modify the surface of the fan further. The distribution of channel born sediments is restricted within their valleys, while the broad interchannel areas remain almost unaffected by active river systems.

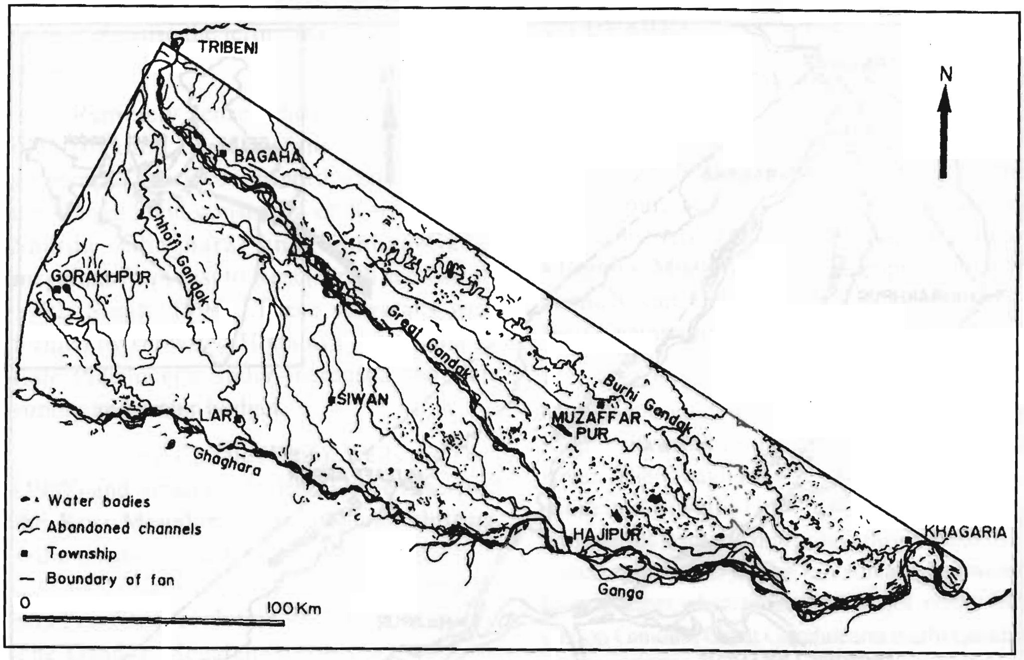

Fig. 2. Geomorphic features of the Gandak Megafan. A large number of abandoned, disrupted channels and small and large water bodies are also present.

It has been argued that Ganga Plain is tectonically active and the drainage has been essentially controlled by the active lineaments. In the piedmont zone conjugate system of strike slip faults (lineaments) trending NW-SE and NNE-SSW control the rivers, NW-SE lineaments is most prominent becoming WNW-ESE and WE in the southern part of the Central Ganga Plain (Singh and Rastogi, 1973; Singh, 1996; Singh *et al.*, 1996). Mohindra and Parkash (1994) proposed several faults in the Gandak Megafan, namely, Rohini, Rapti, Gandak, Ghaghara and Ganga faults. Great Gandak and Rohini rivers in the Piedmont zone show NNE-SSW orientation. Rapti, Great Gandak and Burhi Gandak rivers are aligned in NW-SE direction. The Chhoti Gandak flows from north to south. Ghaghara and Ganga Rivers are oriented in WNW-ESE to W-E. The orientation and alignment of rivers in a preferred direction on Gandak Megafan are controlled by tectonic lineaments and they also demarcate the boundary of the fan and have direct control on the shape and size of the fan (fig. 1).

Gandak megafan is a relict feature (Singh, 1996) or landscape fossil (Mukerji, 1990) where large amount of sediment-water is moved through few incised channel areas. At present, the large interchannel areas are modified mainly by sheet flow and activity of minor gullies during monsoon rains when sediment-water movement and active deposition takes place.

A geomorphic map of the Gandak Megafan has been constructed using satellite data and SOI topographical maps (fig. 2). It exhibits abundance of meander scars of anastomosing river system of the past. In the southern part many lakes, ponds and abandoned channels are visible which may carry water during monsoon season. It is reasonable to assume that abandoned channel system of the megafan belongs to the time when Gandak Megafan was active.

Based on the spot heights (from SOI topographical sheets), geomorphic features present on the surface (fig. 2) and breaks in slopes of the surface, the Gandak Megafan is divided into proximal, middle and distal parts (fig. 3). Table 1 gives the slope gradient, mean grain size of the channel sediment, channel width and length of three important rivers of Gandak Megafan in different parts of the fan. The proximal part of the Megafan has more slope gradient than the middle and distal parts. A short description of different segments of Gandak Megafan is as follows:

PROXIMAL FAN

This part is close to apex and covers an area of about 1500 km^2, about 5 % of the fan area. The lower boundary is undulatery in such a way that radius of fan increases from western to eastern margin. Chhoti Gandak in this part shows a narrow and shallow channel, which remains dry for most of the months during a year. Great Gandak exhibits broad channel and 5-10 km wide valley. Burhi Gandak is characterized by narrow and shallow channel.

Slope gradient in inter-channel area is gentler near eastern and western margins and steeper in the central part. This region exhibits swampy area and dense mixed forests. The irregular swampy areas of terai remain filled with water for most of the months in a year and are birthplaces of many meandering alluvial plain rivers.

MIDDLE FAN

It makes the middle part of the fan with an area of about 12,000 km^2, about 38 % of the fan area. The radius of fan increases from western to eastern margin.

Chhoti Gandak flows essentially in southward direction and shows a relief (height of river banks) of 0.5 to 3 m. Great Gandak splits mostly into two channels; separated by braid bars, sand flats, mid channel bars and islands. This river is marginally entrenched in its older channel deposits showing a relief of 1-2.5 m.

Table 1: Characteristic features of important rivers of the Gandak Megafan. Segment wise characteristics are given.

PARAMETERS	RIVER	PROXIMAL FAN	MIDDLE FAN	DISTAL FAN
River length (km)	Chhoti Gandak	30	100	69.22
	Great Gandak	40	140	88.58
	Burhi Gandak	20	140	238.91
Slope gradient (Cm/km)	Chhoti Gandak	28.80	28.80	20.00
	Great Gandak	60.00	42.80	15.80
	Burhi Gandak	69.00	12.00	8.60
Mean size $M_Z(\phi)$	Chhoti Gandak	2.13	2.61	2.62
	Great Gandak	1.88	2.43	3.10
	Burhi Gandak	2.03	2.44	2.94
Sinuosity of river	Chhoti Gandak	1.7	2.11	2.33
	Great Gandak	1.3	1.12	1.13
	Burhi Gandak	1.53	2.01	1.63

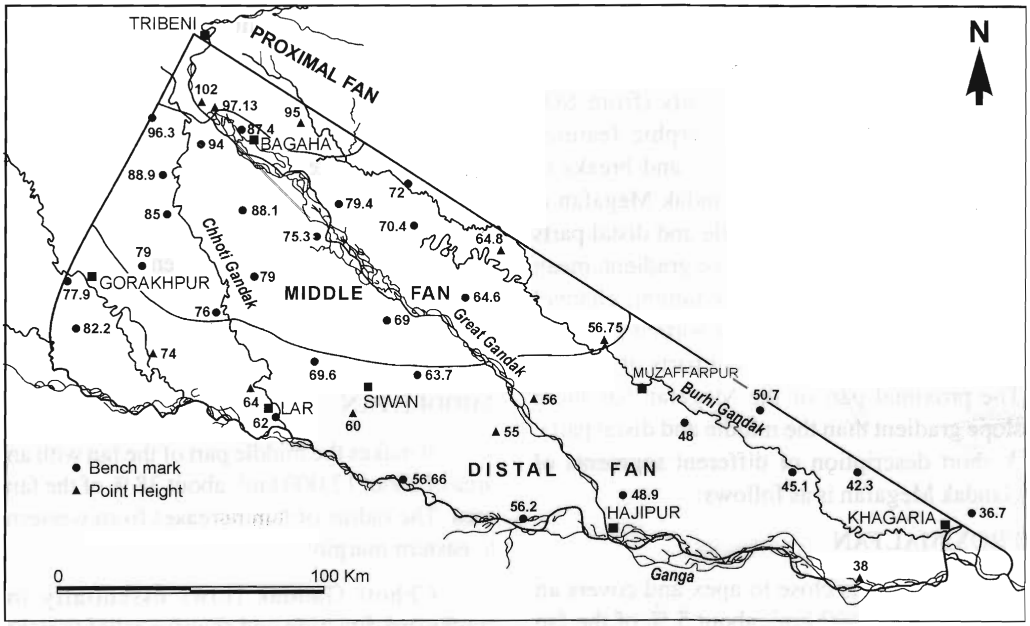

Fig. 3. Gandak Megafan showing three distinct fan segments. A number of spot heights of the megafan surfaces are given.

Burhi Gandak is moderately entrenched and shows natural levees with a relief of 2 to 5 m.

Interchannel areas form the major portion of fan surface with maximum elevation in western margin (near Bagaha, 90.5 m) and minimum in eastern margin (near Muzaffarpur, 56 m). This part exhibits many abandoned channels, abandoned meanders, meander scars, and ox-bow lakes.

DISTAL FAN

The area located between middle part and southern boundary of the fan makes the distal fan. Radius of the fan increases from western to eastern margin in such a way that it is highly skewed in southeast direction. The area of distal fan is 19,000 km^2, about 59 % of the total fan area.

Chhoti Gandak is entrenched and shows relief up to 7 m at some places. Great Gandak is entrenched, showing relief up to 5 m. Usually single channel is present in Great Gandak and if there are two channels, they are separated not by islands as in the middle fan but by braid bars, which are unstable and temporary in nature. Burhi Gandak is entrenched showing 2 to 5 m relief and development of symmetrical terraces at many places, and shows prominent point bar and natural levee deposits.

Interchannel area of distal fan has maximum elevation in western part (between Gorakhpur and Lar, 75 m) and minimum in eastern part (near Khagaria, 36 m). Abundance of ponds, lakes and waterlogged low-lying areas are important features of distal fan. Chillua Tal, Ramgarh Tal, Likhia Tal, Poh Tal are important tals (ponds) in the western part. The Rambhar Tal, Kusehar Tal, Chakahwa Tal, Jatwur Tal, Ropan Chhapra Tal and Nikahary Tal are important tals and lakes in the central part. Baraila Tal and Kabar Tal and many unnamed tals and lakes are present in the eastern part. Shahpur Patori, Fatehpur, Motipur, Musapur and many places are characterized by waterlogged low-lying areas and are filled with water for many months in a year.

These main rivers of Gandak Megafan exhibit changes in their characteristics, namely channel width, valley width and entrenchment (relief) in different segments (Table 2) of the fan.

FACIES ARCHITECTURE

Channel and interchannel areas are important types of depositional domain and make distinctive facies of near surface Gandak Megafan deposit. In the channel areas, gravel, sand and silty sand are deposited showing prominent developments of inorganic sedimentary structures, where as in the interchannel areas fine-grained muddy sediments are deposited rarely showing any primary inorganic sedimentary structures.

INTERCHANNEL AREAS

Rivers are entrenched making raised interchannel areas, situated 5-10 m above the present day river level and are usually not inundated by flood overtopping of major rivers. Even the rivers, which are, shallow and are not entrenched spread their water only up to 1-3 km from its channel. Hence, the deposition on large interchannel areas is independent of active river channels. Parts of the interchannel areas are water logged by accumulation of rainwater during monsoon season. Sediment transfer on the surface takes place mainly by sheet flow. The rate of sedimentation is slow, giving enough time for bioturbation by plant and animal activity. Repeated wetting and drying also destroy the primary bedding. To document the facies changes, litho-logs were prepared at widely separated localities, A (near Mehsi, 20 km NE of Muzaffarpur), B (Khagaria), C (Doharighat, 50 km west of Lar), and D (Banakta Misir, 15 km north of Lar). Five facies are identified in the deposits of interchannel areas (fig. 4).

(i) Mottled Silt

It is yellow to brown colored well sorted silt with low clay fraction (up to 4 %). It makes 40 cm to 1.5 m thick laterally extensive units. Sometimes, it contains calcareous nodules of irregular shape. Physical structures are absent due to intense mottling. Few sediment filled burrows are present. The mottled silt facies is a result of deposition by sheet flow during

Table 2: Channel width, valley width and relief of the important river of the Gandak Megafan.

Parameters	River	Proximal fan	Middle fan	Distal fan
Channel width (m)	Chhoti Gandak	25-75	75-150	100-200
	Great Gandak	500-1500	300-800	500-1000
	Burhi Gandak	75-150	100-200	100-200
Valley width (km)	Chhoti Gandak	0.10-0.20	0.20-0.40	0.25-0.50
	Great Gandak	10.0	10.0-20.0	5.0-10.0
	Burhi Gandak	0.2-0.3	0.20-0.50	0.5-1.5
Relief (m)	Chhoti Gandak	0.1-0.4	0.5-3.0	3.0-7.0
	Great Gandak	1.0-1.5	0.5-1.5	2.0-5.0
	Burhi Gandak	0.5-1.0	2.0-4.0	3.0-7.0

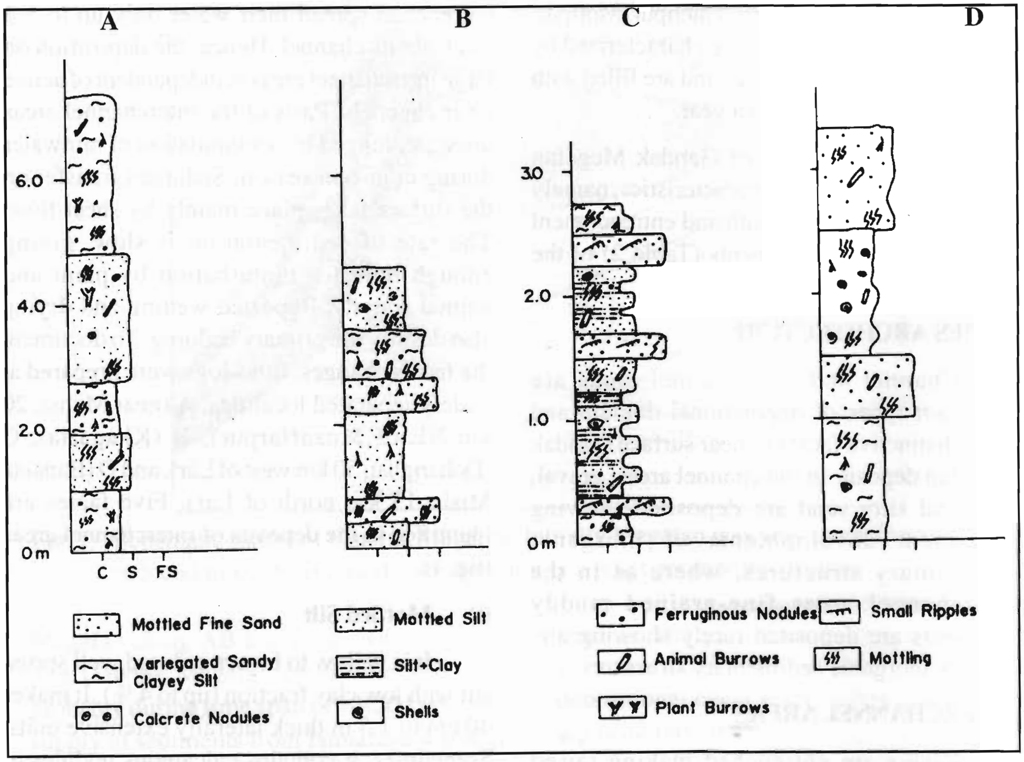

Fig. 4. Sedimentological characteristics of the interchannel deposits of the Gandak Megafan. A-Muzaffarpur, B-Khagaria, C-Doharighat, D-Lar

monsoon season. During rainy season, run-off produces sheet flow and moves the fine-grained sediments. Kumar *et al.* (1995) suggested that sheet flow is most important process for the reworking of fine-grained sediments on the upland terrace (interchannel) surface.

(ii) Mottled Silty Sand

It makes yellow to buff colored lensoid units in which grain size decreases upward. This facies occurs frequently in the interchannel areas as 1 to 3 m thick horizons. Mottling causes obliteration of physical structures, but when degree of mottling is low, some faint laminations can be observed. Bioturbation is common in form of passively filled burrows. This facies is considered to be deposited in small channels and gulleys (Singh, 1996; Singh *et al*, 1999).

(iii) Shelly Clayey Silt

It is brown to dark yellow in color and is highly mottled by plant and animal activities. The most prominent feature is the presence of gastropod and bivalve shells. The thickness ranges from 20 cm to 2 m. Percentage of clay in this facies is high. This facies represents deposition in low energy conditions from suspension in lake environment. Singh (1996) and Singh *et al.* (1999) have described this facies from central Ganga Plain and assigned them to be the deposited in lakes and ponds.

(iv) Variegated Sandy Clayey Silt

It is reddish yellow, grayish black to dirty yellow in color, making 1 to 2 m thick units. Sediments are moderately sorted. It shows development of ferruginous nodules and clay coated grains. Due to high degree of mottling physical structures are obscured. This facies is considered to be deposited in lower flat surfaces where wanning sheet flows during heavy rains are main agent for deposition (Singh, 1996; Singh *et al.*, 1999). Ferruginous nodules develop due to moisture retained in low-lying areas.

(v) Alternating Silt and Clay

This lithofacies shows alternate bands of silt and clay, which make laterally persistent units. Bands of silt and clay are similar in thickness but at places the silty bands are thicker and show discordances. The clayey bands often contain millimeter thin sand lenses. The unit shows prominent ferruginisation. The thickness of individual bands varies from 10 to 20 cm. This facies is completely mottled due to intense plant and animal activity. This facies represents deposits of linear ponds or lakes produced due to abandonment of the channels. The clayey bands are product of deposition during low energy events and the silty sediments represent deposits of relatively higher energy conditions during monsoon.

CHANNEL AREA

Channel areas are regions of sand deposition and have been studied by trenching the braid bars, lateral bars and point bars of the Great Gandak, Ghaghara, Chhoti Gandak, and Burhi Gandak rivers. Seven facies are identified in channel bar deposits (fig. 5).

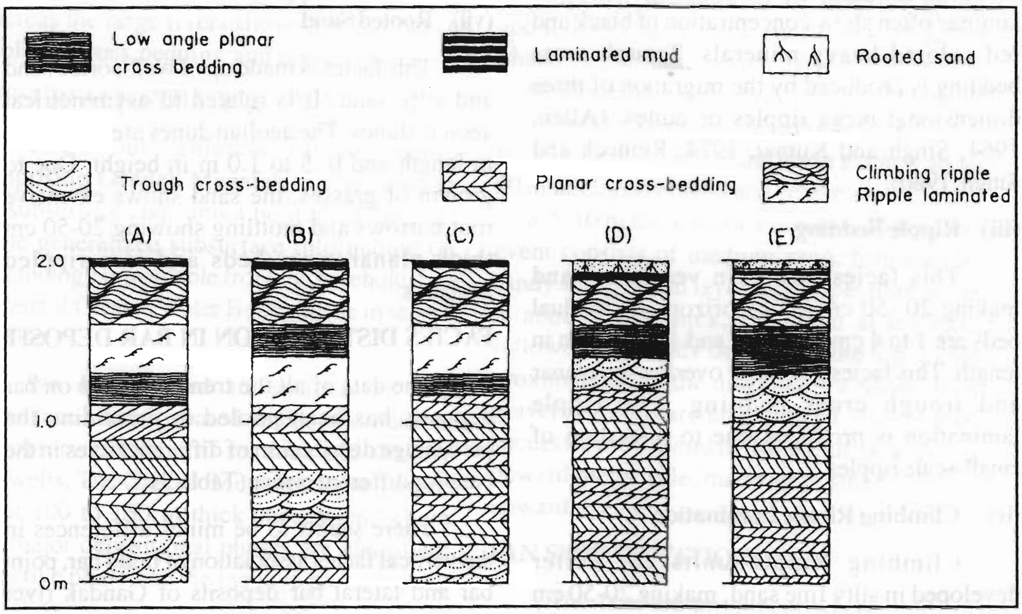

Fig. 5. Sedimentological and lithofacies characteristics of the river channel deposits in Gandak Megafan. A, B – Chhoti Gandak point bar, C – Burhi Gandak point bar, D–Great Gandak braid bar, E – Ghaghara lateral bar.

(i) Planar Cross-Bedding

This is very common facies of the channel bar deposits, 20 cm to 1 m in thickness and laterally persistent for several meters. The planar cross bedding mostly occurs in cosets where the thickness of individual set varies from 10 - 20 cm. The foreset laminae are inclined at an angle of 15°-25°. The thickness of individual planar cross bed is more in braid bar and lateral bar deposits than in the point bar deposits. The planar cross bedding is formed by migration of large bed forms namely the two-dimensional mega ripples and dunes (Allen, 1970; Reineck and Singh, 1980).

(ii) Trough Cross-Bedding

This unit is characterized by 40 cm-1.5 m thick lenticular horizons laterally traceable for several meters. It shows trough cross bedding in cosets, where the thickness of individual bed ranges from 10 to 20 cm. Width of the trough varies from 50 cm to 1.0 m. The individual foreset laminae often show concentration of black and red colored heavy minerals. Trough cross bedding is produced by the migration of three dimensional mega ripples or dunes. (Allen, 1964; Singh and Kumar, 1974; Reineck and Singh, 1980).

(iii) Ripple Bedding

This facies occurs in very fine sand making 20 -50 cm thick horizons. Individual beds are 1 to 4 cm in height and 10 to 25 cm in length. This facies generally overlies the planar and trough cross bedding. The ripple lamination is produced due to migration of small-scale ripples.

(iv) Climbing Ripple Lamination

Climbing Ripple units are better developed in silty fine sand, making 20-50 cm thick horizons. The angle of climb varies from 20° -50°. The height of individual ripple bed ranges from 2 to 4 cm and length from 5 to 15 cm. Climbing ripple lamination is produced by the migration of small ripples when much sediment is available from suspension. This facies is developed near top of the bar sequences. Jopling and Walker (1968) studied climbing ripple lamination and described that increase in suspension, increases the angle of climb.

(v) Low Angle Planar Cross-Bedding

This occurs as 10 to 30 cm thick units where 2 mm to 1 cm thin laminae run laterally for 1 to 2 m and intersect the adjacent set of laminae at low angle. The dip of inclined laminae is usually 8-12°. This facies is deposited in waning flows on top of the bar.

(vi) Laminated Mud

This mostly occurs as 5 to 20 cm thick lenses of silty mud associated with climbing ripple facies. It contains faecal pellets and shows fibrous root mottling. This facies occurs at the top of bar sequences.

(vii) Rooted Sand

This facies is made up of well-sorted sand and silty sand. It is related to asymmetrical aeolian dunes. The aeolian dunes are 1.5 to 4 m in length and 0 .5 to 1.0 m in height. Due to growth of grasses, the sand shows extensive root burrows and mottling showing 20-50 cm thick planar cross beds and rare rippled horizons.

FACIES DISTRIBUTION IN BAR DEPOSIT

The data of all the trenches made on bar deposits has been pooled to determine the percentage distribution of different facies in the bars for different rivers (Table 3).

There seems to be minor differences in the vertical facies association of braid bar, point bar and lateral bar deposits of Gandak river system. Two facies associations are most common in all the bar types. Facies association 1- Planar cross bedding - Trough cross bedding - Low angle planar cross bedding - Ripple

Table 3: Distribution of lithofacies in the channel deposits of Gandak Megafan rivers.

CHANNEL FACIES	CHHOTI GANDAK (%)	GREAT GANDAK (%)	GHAGHARA (%)P	BURHI GANDAK (%)
Planar Cross Bedding	40	63	65	47
Trough Cross Bedding	16	10	18	12
Climbing Ripple Lamination	17	14	7	18
Ripple Bedding	21	-	-	18
Low angle Cross Bedding	5	6	4	4
Laminated Mud	1	1	1	1
Rooted Sand	-	6	5	-

bedding - Climbing ripple lamination - Laminated mud and Rooted sand. Facies association 2- Trough cross bedding - Planar cross bedding - Low angle planar cross bedding - Ripple bedding - Climbing ripple lamination and laminated mud.

Smaller rivers shows dominance of trough cross bedding and climbing ripple lamination, whereas the large rivers shows predominance of planar cross bedding and rooted sand.

SUBSURFACE STRATIGRAPHY

Enormous amount of sediments comprising Gandak Megafan is concealed in the subsurface and cannot be studied directly. Some generalized subsurface information on the lithology is available from the borehole data of Central Ground Water Board, made in search of water.

We have tried to synthesize the subsurface lithology based on this information, and observation in cliff sections and shallow dug wells. The Gandak Megafan deposit make about 100 to 150 m thick succession, where two major depositional phases are identified: the active phase and the inactive phase (fig.6).

At present Gandak Megafan is in inactive phase, however slow aggradation is taking place. The aggradation is as channel deposits and interfluve deposits. In the channel deposits three broad facies are identified, namely sandy gravel, cross-bedded sand and ripple laminated fine sand. The interfluve deposit is represented by mottled mud. Topmost 10-15 m of the subsurface succession is made up of channel deposit alternating with interfluve deposits formed during inactive phase.

Below the deposit of inactive phase about 100-150 m thick succession of active phase is present, which is represented by dominance of sandy sediments. In general three major events are identified within the top 80 m of the succession, the lower event is about 50 m thick gravel sand and coarse sand, capped by a 5-10 m thick muddy deposit. The second event consists of medium sand, followed by sandy silt and mud layer. The upper third event is about 20 m thick, fine sand at the base followed by muddy deposits at the top. In the proximal part of the megafan few meter thick gravel horizons are encountered. The overall succession of Gandak Megafan is a fining upward megacycle, made up of smaller fining upward cycles.

FAN SEDIMENTATION

The fans are prominent where uplift of mountain provides a continuous supply of fresh debris from steep drainage basins (Beaty, 1970; Kochel, 1990) and develop at the base of a mountain front on a wide alluvial plains and in

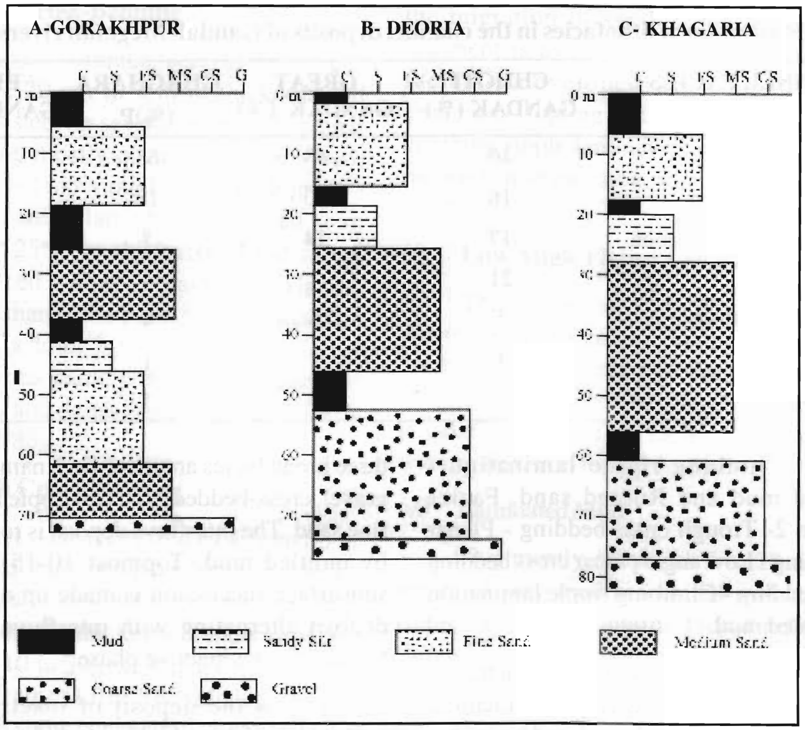

Fig. 6. Schematic lithology of different segments of Gandak Megafan deposits. Deoria is located 40 km north of Lar. In all the three successions three fan events are identified, each capped by a mud layer. The lithologs represent generalized successions of several boreholes of each area respectively.

intermontane basins (Saito, 1984) where an emerging stream deposits a sediment body whose sloping surface forms a segment of a cone (Blissenback, 1954 and Bull, 1972, 1977). Models of alluvial fans can incorporate channel avulsion, but they cannot as yet account for channel migration (Parker, 2000). Paola (1988) has adopted the basin filling models for the evolution of fan. Heller and Paola (1992) and Paola *et al.* (1992) discuss factors effecting the deposition of conglomerates and grain size changes in the alluvial basin close to an orogen front.

Continent is a patchwork of zones of tectonic uplift and subsidence. Uplift creates the potential energy difference, which ultimately drives erosion and thus sediment production, in upland areas. In an alluvial fan system where sediment supply is high and a network of channel is formed, sediment is deposited, wherever flow of the river loses the capacity to carry it. Continuous deposition in one channel aggrades the river bed, causing another channel to become hydrologically more active. This mechanism of activation and abandonment of river channels, deposits and fill the available space, creating a fan like morphology.

In long term sediment deposition tends to be strongly biased towards zones of tectonic subsidence. So, new accommodation space is continuously being created for continued sedimentation. Thus zones of tectonic subsidence not only create the zones of sediment accumulation, but also help to limit the aerial spreading of such zones by consuming the sediment so buried. The implication of the perfect balance between the creation of accommodation space by subsidence and its filling by sediment deposition is that fan no longer progrades.

A declining base level, sediment supply or increasing water supply can promote channel incision into the fan. The changes in grain size of fan deposits reflect changes in such factors as sediment supply, water budget and thus climate change.

The Gandak Megafan provides a good example of fan building due to high sediment supply in the past, where accommodation space is provided by subsidence. The fan had a network of anastomosing channels controlling the sediment distribution. In the distal part fine-grained sediments were deposited. Changes in water budget, base level and intrabasinal tectonics caused incision of major drainages and abandonment of other channels, which ultimately ceased the megafan building activities.

DISCUSSION

As already mentioned earlier, there is scanty information on the subsurface stratigraphy of Gandak Megafan and no dates of megafan deposits are available. Thus, it is difficult to construct a depositional model for Gandak Megafan.

The regional geomorphology of the Ganga Plain has been explained by climate cycles of Late Pleistocene-Holocene (128 kyrs-Present), where deposition of Megafan is considered during marine isotope stages (MIS = OIS) 3 and 4 (74-35 kyrs) (Singh, 1996; Srivastava *et al.*, 2003). The top most fan deposits in Ganga Megafan, exposed in cliff sections give ages of 26-22 kyrs BP. The Ganga River probably incised in the megafan deposit around 20 kyrs. The Ganga Megafan deposits are overlain by piedmont fan deposits, aeolian sand deposit and interfluve (doab) deposits of Holocene age. The sediment of Ganga Megafan deposits are coarser grained then the sediments of present day Ganga River. Gohain *et al.* (1990), Singh *et al.* (1993) have made systematic study of Kosi Megafan and proposed a depositional model based on surface and subsurface data. In the subsurface of Kosi Megafan coarse grain sandy sediments dominate. On the top about 10 meters thick muddy sediments are present with intercalation of thin fine sand bodies.

The subsurface sediments of the Ganga River Valley have channel sand deposits, which are coarser grained than the present day Ganga River sand (Singh *et al.*, 1990). In the subsurface of Ganga delta region coarse-grained channel sands are present. The coarse grained sediments of Ganga Megafan, Ganga River Valley and Ganga delta region appeared to be broadly contemporary belonging to Late Pleistocene. It seams likely that deposition of megafans took place during marine isotope stages 4 and 3 (74-35 kyrs) and partly in marine isotope stage (MIS) 2 (35-10 kyrs). During this time span (74-20 kyrs), there are number of climate cycles of strong and weak monsoon (Prell and Kutzbach, 1987). In this time period there is no evidence of any major tectonic event in Himalaya. Change in rainfall essentially controlled the supply of sediments from Himalaya and building of the megafans. Intrabasinal tectonics of Ganga Plain and eustatic base level change induced down cutting and filling of the river channels influencing the deposition on the megafans. Gupta (1997) argued that formation of megafan in the Ganga Plain is controlled by tectonic activity in the Himalaya causing river divergent, reduction in number of outlets and increased sediment load in to the basin.

We propose following model for the Gandak Megafan (fig. 7). Figure 8 represents the schematic cross section of the Gandak

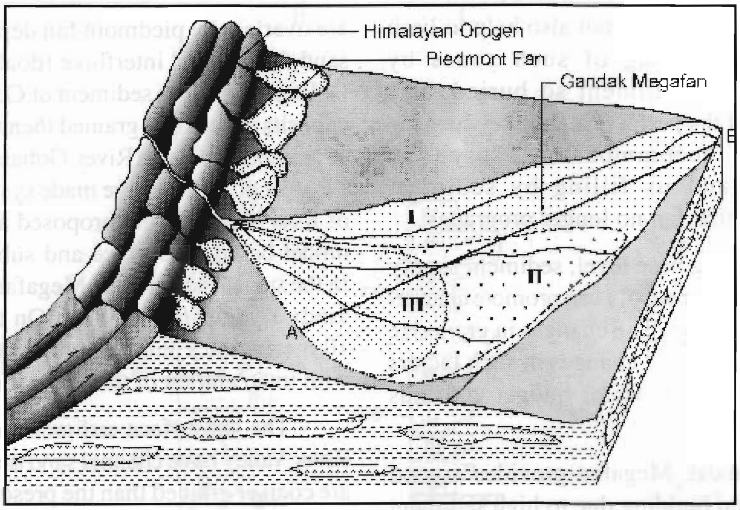

Fig. 7. Schematic model of Gandak Megafan. Initially Megafan was very large (I) and gradually reduced to stages II and III. At present it is a relict geomorphic feature.

Megafan along AB line as shown in figure 7. The Gandak Megafan deposition took place probably during time span of 74-20 kyrs, when supply of sediments from Himalaya was high. In the initial phase very coarse-grained sediments were brought and deposited essentially by anastomosing system of braided streams. The second sandy depositional event is somewhat fine grained. The third depositional event is more fine grained & the top is muddy in nature.

These sandy depositional events separated by mud deposits may be related to the humid-dry climate cycles of marine isotope

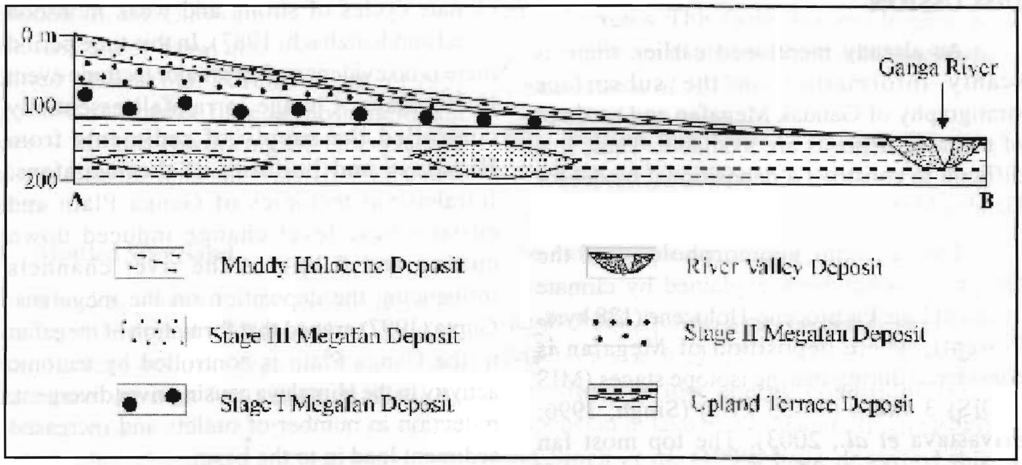

Fig. 8. Schematic section across the Gandak Megafan. A-B points are demarcated on figure 7. Deposits of stages I and II are in the subsurface. Top of the deposits of stage III and Holocene cover are seen on the megafan surface.

stages 3-4. After the deposition of sandy megafan succession probably the main channel became incised in the megafan surface.

The incision of channel also led to abandonment of many channel segments of anastomosing network. In the distal part of the fan, the channel segments were converted to large water bodies. The incision of channel may be related to the lower base level during LGM and Early Holocene, and tectonic event. A tectonic event during 8-5 kyrs produced slightly undulatery topography and changed many small tributaries to lakes (Singh 2001, 2002). During Holocene the deposition of several meters thick muddy sediments has taken place.

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