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QUATERNARY ALLUVIATION OF THE GANGA PLAIN

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ABSTRACT

The Quaternary alluviation of Ganga plain started during the deposition of Boulder Conglomerate mapped earlier as Upper Siwalik Boulder Bed and continued until today. The entire sedimentation took place in three distinct phases marked by prominent geological events. The oldest Quaternary deposits ushered during Late Pliocene time marked by OLDUVAI magnetic event (1.88-1.72ma). This period witnessed the maximum influx of sediments possibly due to the final phase of Himalayan Orogenic Movements resulting into thick Quaternary piles(1-1.5 km). The next phase of sedimentation, generally referred as Varanasi Alluvium, witnessed volcanic activity, Matuyama magnetic reversal and fluctuating climatic conditions. This phase witnessed three major sedimentation cycles. The resultant thickness of this unit is of the order of 250-300m. The sedimentation continued until the end of Pleistocene time or the Last Glacial Maxima (14,000 yr B.P). The Pleistocene-Holocene transition in Ganga plain is represented by aeolian and lacustrine sediments indicating a drier/cool phase. The early Holocene shows resurgence of sediments supply resulting into development of huge fan deposits. The present day drainage network with large scale terrace alluviation continued from mid Holocene to present day. The thickness of the sediments is drastically reduced to 10-20 metres. This indicates stabilisation of foreland basin. However, minor sectorial neotectonic adjustment is still continuing.

Key words : Quaternary Alluviation, Ganga Plain.

INTRODUCTION

The Gangetic Plain covering an area of about 0.4×10^6 km^2 is an unique Quaternary feature of India, which has attracted the attention of historians, geographers, archaeologist, earth scientists and host of others from time immorial to understand and unravel the mystery of its development. The Quaternary period is of great significance as it has witnessed evolution of the alluvial plains, neotectonic movements, glacial pulsations, sea level changes and desertification during time domain of last 1.8 million years of earth's history. The geological processes operating during the Quaternary period have shaped the landscape, landform and surface geomorphic features over the globe, as we see now.

In India the Quaternary deposits can essentially be classified into two major domain/basin of deposition (i) the Indo-Gangetic basin and (ii) the Peninsular basins. The Indo-Gangetic basin with an area of 850,000 Km^2 lies between 67^0 and 96^0 E latitudes and 22^o and 30^o N longitudes comprising major basins of Indus (including parts of Pakistan), Ganga and Brahmaputra. The Peninsular basins comprise subbasins of Narmada, Mahanadi, Godavari, Krishna, Wardha and Mahi rivers.

The vast spread of the Gangetic Plain restricted between Peninsular Shield in the south and Himalaya in the north, came into existence at the close of Plio-Pleistocene time both due to the pulses of Himalayan Orogenic and epeirogenic movements and also climatic changes (Kumar *et al.*, 1996). The resultant negative relief- the foreland basin, known as Indo-Gangetic Trough, was later filled with Quaternary sediments, forms the part of Ganga Plain.

The present paper deals with the lithostratigraphic sequence of the Quaternary pile, its chronological order and tectonic imprints resulting into the alluviation of Ganga Plain and its contemporary and correlatable development in other basins of India.

GEOMORPHIC SETTING

The Indo Gangetic plain having the lofty Himalaya in the north, the vast alluvial plain in the middle and peninsular ridges/plateau in the south can broadly be classified into three river basins viz. Indus basin, Ganga basin and Brahmaputra basin. The average elevation of Indo-Gangetic plain varies from 280m in Punjab Plain to 60m above msl in Lower Ganga Plain. The Ganga Plain is marked by two prominent physiographic highs (ridges) namely Delhi-Haridwar Ridge (DHR) in the west and Monghyr-Saharsa Ridge (MSR) in the east. The Punjab Plain lies to the west of Delhi-Haridwar ridge. The Ganga basin and its sub basins have evolved with distinct morphological characters reflecting Quaternary geodynamics.

The Ganga basin is named after the trunk channel Ganga, which drains the central alluvial plain. The total length of the Ganga from its source at Gangotri in Uttarkashi district in Uttaranchal State to its outfall into the Bay of Bengal, in West Bengal is 2525 km. Its major tributaries that drain the northern and southern provenance are Yamuna, Ghaghra, Gandak, Kosi, Son,etc. The total area of the Ganga Basin is 861.4 km^2, 40% of which falls between DHR and MSR.

REGIONAL GEOLOGY

Rocks of Proterozoic to Quaternary sequence are exposed in the area. The northern part under the Himalayan domain exposes the well-documented rocks of Proterozoic to Neogene. On the south are exposed the Peninsular shield comprising the rocks of Bundelkhand Granitic Complex (BGC), Vindhyan Supergroup, Bijawar and Chotanagpur Gneissic Complex, Gondwana and Deccan Trap (fig. 1). The central alluvial fills are represented by thick pile of Quaternary sediments.

The Upper Siwalik Group along the northern margin and its coeval Banda Group adjacent to peninsular shield in the south represent the oldest Quaternary sequence (Kumar *et al.*, 1996). The Upper Siwalik Group comprising Tatrot, Pinjor and Upper Boulder Conglomerate (UBC) ranges in age from the Late Pliocene to Early Pleistocene. The central alluvial plain exposes Middle to Late Pleistocene sediments namely Varanasi Alluvium (Older Alluvium) and Holocene sediments (Newer Alluvium).

The Quaternary sediments lie directly over the Proterozoic basement in the southern part and over Siwalik in the north (fig.2). However, in the intermontane valleys within the Himalayan domain the Quaternary sediment lies over the various pre-Quaternary rocks. The thickness of the Quaternary sediments vary from less than 100m in the south to over 1000m near the Himalayan margin indicating a northward sloping of the basement rock (Fuloria,1969; Sastri *et al.*, 1971; Rao,1973; Srinivasan and Khar,1996; Pathak *et al.*, 1978).

TECTONIC GRAIN OF THE GANGA PLAIN

The studies indicate that the Ganga Basin is tectonically bounded by Delhi-Haridwar Ridge in the west, Monghyr-Saharsa Ridge in the east and Foot Hill Fault (FHF) in the north (Fuloria, 1996). The Delhi-Hardwar Ridge acts like principal water divide between the Ganga drainage basin in the east and Indus drainage basin on the west.

The available aeromagnetic and gravity data indicates that the Ganga Basin is characterised by uneven horst and graben topography which has been subdivided from west to east into seven tectonic units, namely (i) Delhi-Hardwar Ridge- north-easterly extension of Aravalli Range, (ii) West U.P. Shelf,

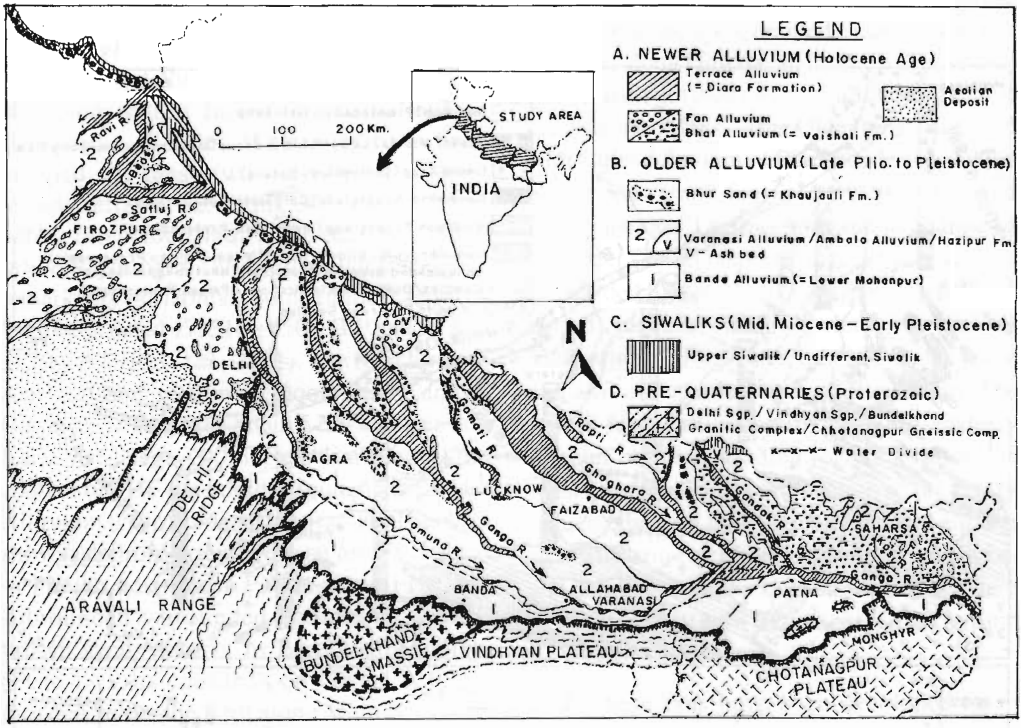


Fig.1. Distribution of Quaternary sediments in Ganga Plain.

(iii) Sarda Depression, (iv) Faizabad Ridge, (v) East U.P. Shelf, (vi) Gandak Depression and (vii) Monghyr-Saharsa Ridge- north-easterly extension of Chhotanagpur Plateau.

The Faizabad Ridge, a prominent subsurface promontory of Bundelkhand Granitic Complex separates the Ganga Plain into East U.P. Shelf and West UP Shelf. The East U. P. Shelf is bounded on the south along Allahabad-Mirzapur-Chakia area by the Vindhyan rocks. The West UP Shelf with prominent northeast trending Moradabad fault is bounded by the Aravalli-Delhi Belt in the southwest. The two prominent physiographic lows namely the Sarda and Gandak Depressions occupy the northern part of West U.P. Shelf and East U.P. Shelf respectively. The Sarda Depression striking roughly NNE-SSW direction is reported to have sediment cover of the order of 6000 m of Proterozoic (Vindhyan), Mesozoic, Palaeogene and Neogene ages (Fuloria,1996). The Gandak Depression is reported to have 1,500m thick pile of unconsolidated sediments above the Siwalik rocks. The eastern limit of the depression coincides with the northeastern extension of Vindhyan rocks and their contact with the Chota Nagpur granites (Monghyr-Saharsa Ridge). Mall *et al.* (1987) has indicated in detail the depth of basement in different sectors with some additional prominent sub surface features in Ballia, Gorakhpur, Ghazipur, Varanasi, Azamgarh and Sultanpur areas.

QUATERNARY MORPHOLOGY

The morphology of the Quaternary deposits is largely dependent on their mode of occurrence, genesis and distribution in space and time. In Ganga basin following Quaternary morphological units can be identified and

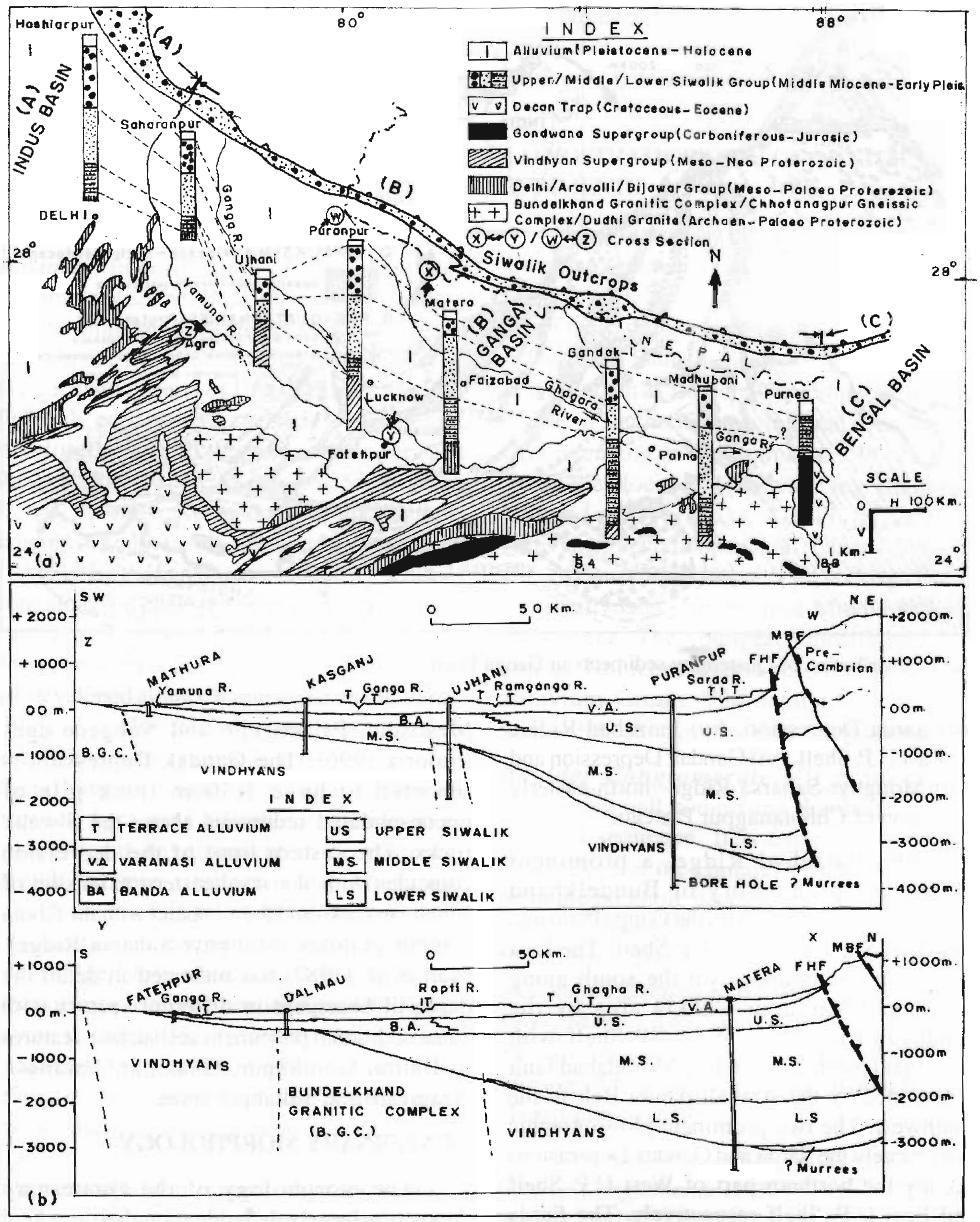


Fig.2. Subsurface geological profile based on borehole logs (a) Location of boreholes and pre-Quaternary outcrops (b) Subsurface cross sections (X-Y 8 W-Z), (Data source : Fuloria, 1969).

mapped on 1:50,000 scale.

High Level Terraces : The high level terraces of glacial and fluvioglacial origin have been observed within Intermontane valleys of Himalaya. Six tier of terraces have been mapped. Of these two older terraces show tectonic effects viz. tilting of beds, preferred pebble orientation, fault scarp etc. The comparatively younger fluvioglacial terraces are remarkably horizontal. Some of these terraces have been dated 17, 310 ±450 y B.P and 11,830 ±270 y B.P (Rai *et al.,* 2001). The river terraces near Kalagad section in Doon Valley and at Garjia show tilting of about 5-15° (Shukla and Kar, 1997; Negi, 2002). Near Haridwar at the contact of FHF the bouldry sequence of Older Alluvium is thrusted and the fractured pebbles show a definite orientation, so also its coeval in Punjab basin near Pinjor along FHF and subrounded to rounded boulder in reddish brown sandy matrix in Bhaghirithi valley. (Plate-1A). Its coeval Doon Gravel is found thrusted below the Krol along Main Boundary Fault (MBF) near Rishikesh.

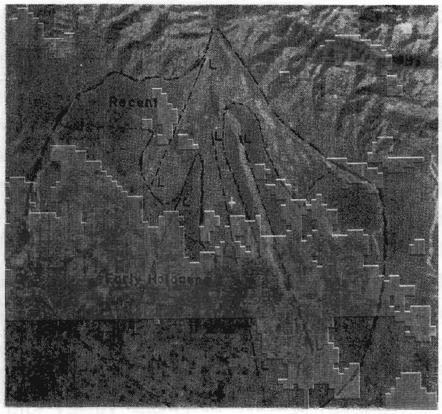
Sand Dunes : The Aeolian sand deposits in the form of dunes, barchans and sheet are well developed in the western part of Indo Gangetic plain in the states of Rajasthan, Haryana, and Punjab. However, in the Central Ganga Plain in parts of U.P and Bihar the aeolian sands are mapped as Bhur sand/sandy facies of older alluvial unit. The Bhur sand deposits of fluvioaeolian origin in Gorakhpur-Deoria-Motihary area are observed as 9-10m thick sequence of sandy ridges (Prasad *et al.,* 1997).

Alluvial Fan (Piedmont Zone) : The development of major fans along Sub-Himalayan foothills viz. Gola fan, Gandak megafan, Ganga megafan, Sarda megafan, Kosi fan etc are reported by many researchers (Gole and Chitale,1966; Dorr and Wells,1987; Mohindra and Parkash, 1992, Shukla *et al.,* 2001), Goodbred, 2003. The study of imagery and aerial photographs of these fans indicate their broad characters with diverging drainage pattern from the apex, braided channels, linearly disposed along Himalayan foothills. These fans can be distinguished and differentiated into two generations of fans — the Older fans associated with Older Alluvium of Pleistocene age and the Newer fans (mud fans and colluvial fans) of Holocene age. The morphogenetic change of the Older fans in response to tectonic impulses is recorded by derelict palaeochannels, *tals* and buried channels which are clearly seen along Maharajganj-Gorakhpur area in Gandak basin and also in Pathankot area of Ravi basin. The newer fans exhibit south to south-easterly orientation, high gradient partly overlap the older fans. The clast composition of these fans indicate marked lithological variation e.g. the characteristic calcareous nature of Gandak fan and dominantly arenaceous/argillaceous nature of Damra fan (Ravi), Ramnagar (Gola) fan and Kosi fans of Bihar.

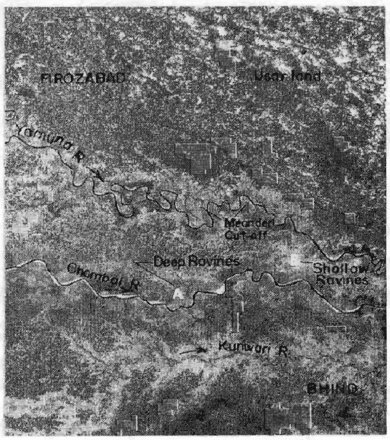
These fans have been developed in an episodic manner. Thus older fan is often marked by newer fans and their differentiation in the field becomes difficult. Most of these fans are of clast oriented gravels (colluvial fans) except Gandak and Ramnagar fans, which are characteristically argillaceous (silt-clay) in nature possibly formed as major mud flows (Prasad and Khan, in press).

The development of the fan marked along major cross faults/tear faults (transverse to the foothill faults) such as Yamuna Tear near Paonta Sahib, Ganga Tear near Haridwar Gola Tear (Plate-1B) near Haldwani, Sarda Tear near Tanakpur and Gandak Tear near Tribenighat (fig. 3) etc. in Ganga basin and Chenab Tear near Akhnur, Beas Tear near Pong, Sutlej Tear near Ropar, Ghhagghar Tear near Chandigarh in Punjab Plain (Prasad and Kar, 2004), indicates its tectonic origin possibly during the upliftment of Siwalik belt along Foot Hill Fault (FHF).

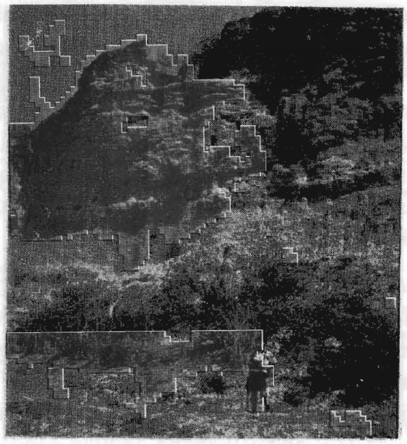
A-Fractured pebbels in the rudaceous facies of Older Alluvium indicating neotectonic affects. Loc.-Tehri, Uttaranchal.



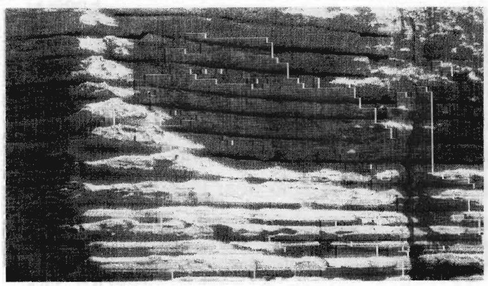
B-Alluvial Fan of Holocene age along Gola Tear, Uttaranchal (IRS imagery), L - L Lineaments.



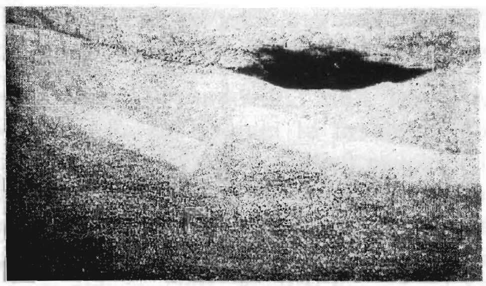
C- Ravinous tract along Chambal Valley, Agra-Bhind area (IRS imagery).



D- Reddish brown silt-clay with calcrete (Upper member of Varanasi Alluvium) Loc.-Dalmau.



E- Varve deposit in Himalaya, Kali Basin, Uttaranchal (Courtesy : R. Kumar)



F- Neotectonic activity in Varves, Tapovan, Uttaranchal (Courtesy : P.V.S. Rawat)

PLATE-1A

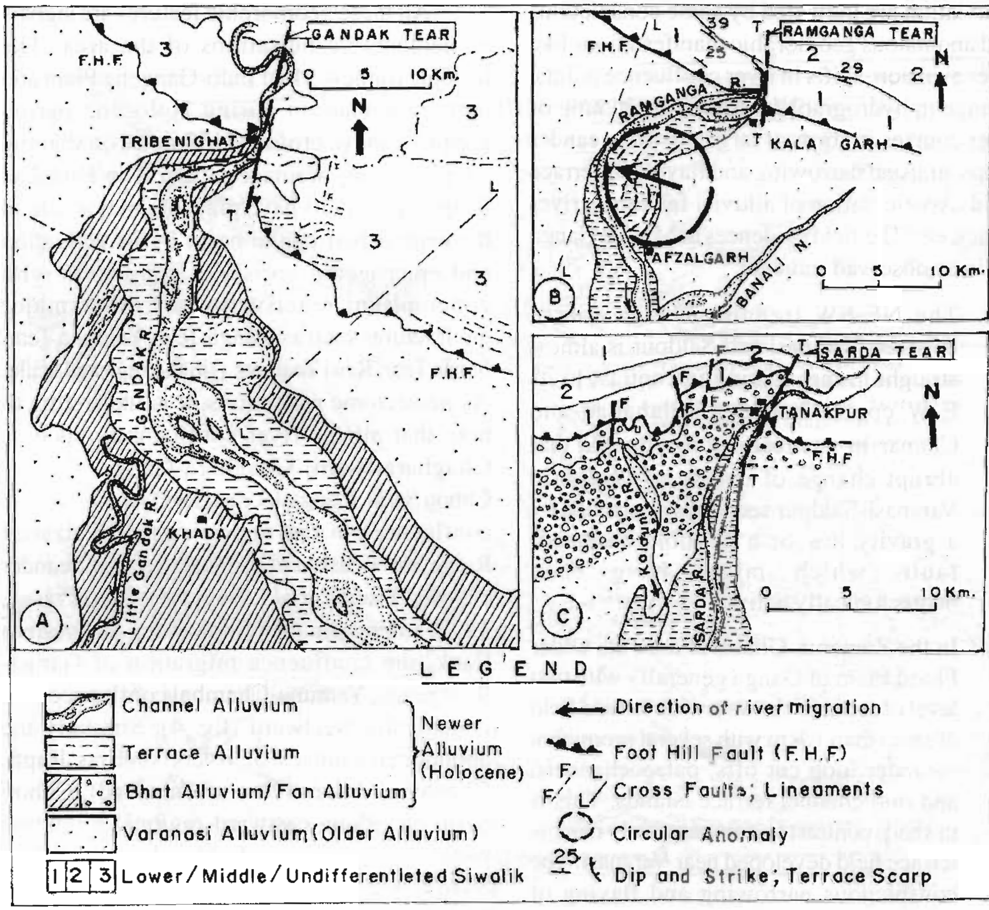


Fig.3. Effects of tear faults on Quaternary sediments.

***Alluvial Plain* :** The central part of the Ganga plain exhibits wide morphological features marked by large fertile tract, waterlogged/ marshy areas (10-20 km linear belt enclosing numerous *tals* and palaeochannels, to the north of Ganga river (between Unnao and Pratapgarh), usar lands and ravine formation along Yamuna, Chambal and Betwa rivers in the southern periphery (Plate-1C). This plain is represented by three broad levels of terraces. Of these, the oldest terrace known as Varanasi Plain is formed during Middle to Late Pleistocene time (Kumar *et al.,* 1996; Singh, 1996). The remnants of Pleistocene rivers can be seen as isolated small water bodies in the form of *tals,* swamps, *jhils,* and palaeochannels. The ^{14}C dating of these swampy sediments (Sanai lake) recorded age of 14,833 ± 147 to 1705 ± 59 yr BP (Sharma *et al.,* 2004). The present day drainage namely the Ganga and its tributaries has deposited Holocene sediments composed of two terraces as an inset within the vast older alluvial plain (Varanasi Plain). The younger sediments (Holocene deposits) are deposited by river metamorphosis.

***River Metamorphosis* :** The reflections of basement configuration on Quaternary alluviation are indicated by some conspicuous and anomalous geomorphic manifestations like river avulsion, shifts in river confluence points, change in hydrographic regime, shortening of river courses in form of large cut off meander loops, unusual narrowing and flaying of terrace fields, reorientation of alluvial fan lobes, river piracy, etc. The field evidences in Middle Ganga Plain as observed indicate:

(i) The NE-SW trending Ganga course between Varanasi and Saidpur is almost straight to meandering in contrast to its E-W course between Allahabad and Chunar in upstream. It is possible that abrupt change of course of Ganga in Varanasi-Saidpur section is controlled by a gravity low or a possible basement fault, which might have been neotectonically active.

(ii) In the Zamania-Ghazipur area the Older Flood Plain of Ganga generally with two level of terraces shows a wide terrace field of more than 10km with several prominent meander loop cut offs, palaeochannels, and mid channel terrace islands. This is in sharp contrast to comparatively narrow terrace field developed near Varanasi. The conspicuous narrowing and flaying of terrace fields in adjoining Ghazipur -Ballia area with several oxbow lakes (Suraha Tal, Kolia *Dah*, etc) may be due to base level neotectonic adjustments and flood plain reorganisations (Khan and Prasad, 1997).

(iii) The concentric gravity high zone near Muhammadabad-Buxar area controls the confluence point of Chhoti Sarju river with Ganga. The Chhoti Sarju which was originally flowing south-easterly, now takes a easterly trend near Chitbaragaon. Similarly the right bank tributary, the Karamnasa river has changed its N-S course near Chandauli which roughly runs parallel to the trend of high gravity axis (Prasad et al., 996).

All these geomorphic features are signals of neotectonic pulsations of the area. The tectonic framework of Indo-Gangetic Plain and their rejuvenation during Holocene period appears to have profound influence on shaping the present day drainage pattern. The 'Faizabad Ridge' appears to have played a major role in the central part of the basin by its activation and epierogenic uprise, in conjuction with concomitant reactivation of other major geofractures such as Ganga Tear, Yamuna Tear, Sarda Tear, Kosi Tear, etc., on the regional scale. As neotectonic reflections, it is interesting to note that all the river confluences (such as Ghaghara-Rapti, Ghaghara-Ganga, Ganga-Chhoti Sarju, Ganga-Gomati and Ganga-Yamuna confluence) in the region east of 'Faizabad Ridge' show eastward shifts with many meander cut offs (Prasad *et al.*, 1996; Khan and Prasad, 1997) whereas in the region along the western flank, the confluence migration of Ganga-Ramganga, Yamuna-Chambal confluence, etc. is generally westward (fig. 4). Similarly the abondoned courses of rivers such as Rapti, Ghaghara (downstream of Faizabad), Chhoti Sarju etc. show eastward regional migration pattern in their terrace field and rivers such as Sarda, Ganga, Ramganga, Yamuna and Ghaghara on the western flank of Faizabad Ridge show general westward shift trends. Delhi-Hardwar Ridge has undergone activation in Late Pleistocene- Holocene period due to epirogenic movements and development of Yamuna Tear lead to diversion and shifting of river Saraswati (extinct) / once flowing westward in Arabian sea and got defunct leaving many abandoned channels. The diversion lead to carving out the present day Yamuna course passing through Paonta Sahib-Delhi-Mathura-Agra and finally capturing the course of Chambal river downstream of Auraiya. Likewise, Beas Tear and Sutlej Tear in Punjab Plain also resulted westward channelisation of Bease and Sutlej courses respectively. Similarly the reactivation of

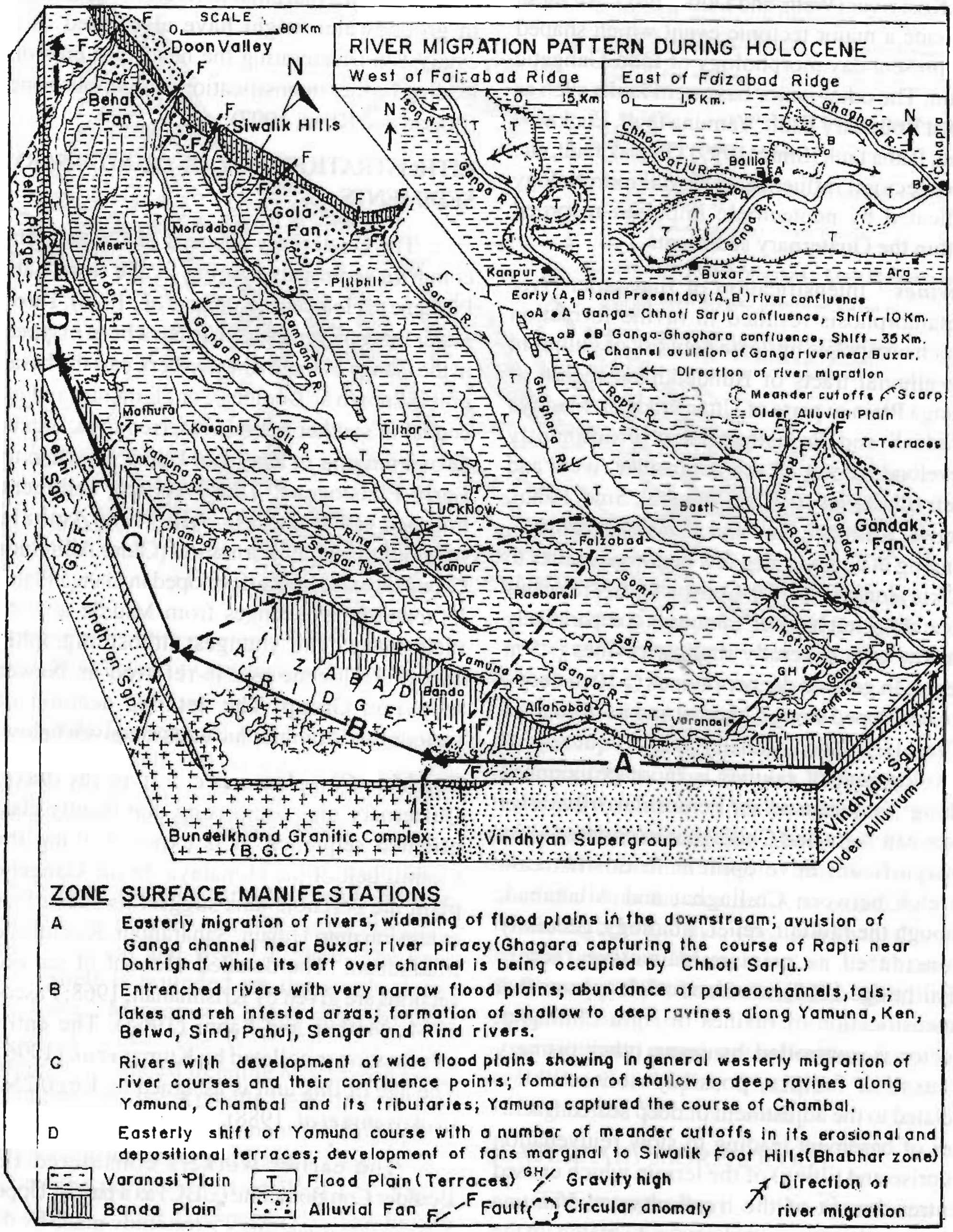


Fig.4. Regional subsurface basement configuration of Upper and Middle Ganga Plain and its surface manifestations.

Monghyr-Saharsa Ridge has frequently shifted the Kosi river (Wells and Dorr, 1987). All these indicate a major tectonic event which shaped the present day morphology of Indo-Gangetic Plain. The other major basement faults such as Great Boundary Fault, Yamuna fault, Lucknow fault, Patna fault (Sinha,1999),Gandak fault, etc. have sectoral influence on fluvial morphology indicated by neotectonic impulses recorded within the Quaternary sediments.

Ravines : Intensification of first order river metamorphosis resulted in ravine formation which comprises intricate network of gullies in the alluvial tracts of Bundelkhand region of Ganga Plain in parts of Uttar Pradesh, Madhya Pradesh and Rajasthan. It is prominently developed along all the peninsular rivers and their tributaries such as Chambal, Sind, Pahuj, Betwa, Kunwari, Ken and also along Yamuna, ranging in width from a few hundread metres to 12 km along the banks. Conspicuously ravinous zone along left bank of Yamuna is comparatively narrow with generally shallow ravines (<5 m deep). In general deeper ravines (>10 m deep) are developed along Chambal and its tributaries (Plate1C). The intensity and frequency of development of ravines is more pronounced along Yamuna and its Peninsular tributaries between Agra and Chillaghat in contrast to its insignificant development in downstream stretch between Chillaghat and Allahabad, though the rainfall, relief, lithology, generally considered as primary causative factors (Fairbridge,1968), are identical. It appears that intensification of ravines in Agra-Chillaghat sector is controlled by some other primary causative factors, possibly neotectonics, related to the adjustment of deep seated fractures of basement leading to slow rejuvenation (uprise and tilting) of the terrain which caused entrenchment of the trunk channel Yamuna along with its major tributaries to match up the base level of erosion. This rejuvenation process also triggered reorientation of groundwater profile with shallow water table ranging from 5-6 m in ravinous free zones to 20-35 m in the ravinous zones marginal to rivers. This change in groundwater might have also acted as a catalyst in accelerating the headward erosion leading further intensification of ravinous zone (Prasad and Khan, 1997).

LITHOSTRATIGRAPHY OF QUATERNARY SEDIMENTS

The Quaternary deposits of Ganga Plain comprise sediments ranging in age from Late Pliocene to Holocene (Kumar *et al.,* 1996). Three major lithostratigraphic units have been mapped in the Ganga Plain. In the northern part the basal unit is known as Boulder Conglomerate and its coeval in southern part is referred to as Banda Group ranging in age from Upper Pliocene to Early Pleistocene. The overlying sediment mapped as Varanasi Alluvium/Ambala Alluvium/Hazipur Formation (Older Alluvium Group) is extensively developed in Ganga Plain. Its tentative age ranges from Middle to Late Pleistocene. The youngest lithostratigraphic unit of Holocene age is referred as Newer Alluvium Group. The detailed account of various lithostratigraphic units are given below:

Boulder Conglomerate : It is the basal Quaternary unit comprising dominantly clast oriented sequence. It is exposed along the foothill belt of the Himalaya. In the Gangetic plain the borehole data suggest its subsurface extension upto Ujhani, Saharanpur, Raxaul and Madhubani. The detailed account of various sections are given by Krishnanan, 1968; Pascoe 1964; Mathur and Sahni (1964). The entire information is collated by Kumar *et al.* (1996). The age of this unit is assigned as 1.6±0.2Ma (Yokoyama *et al.,* 1988).

The earlier workers considered the Boulder Conglomerate (UBC) as a part of Upper Siwalik Group. However the study made by the authors in different river basins namely Manabhum anticline (Dihing pebble bed) of Upper Assam and UBC of Beas Basin, H.P.

Himalaya and Ramnagar of Kosi basin in Uttaranchal Himalaya suggest that this UBC unit is distinct from the two lower units, the Tatrot and Pinjor, in terms of lithological dissimilarities, unconformable relationship and mode of deposition. It appears that UBC is very unlikely a part of Siwalik sequence and is more akin to the younger Quaternary sequence. This unit has distinct entity in terms of lithoilogical character, provenance, mode of origin and post depositional/deformational structures. The Tatrot and Pinjor are essentially the fluviatile low energy arenaceous deposits. But the UBC is a product of high energy environment with unstable source area. Therefore, it is not out of place to suggest that UBC can be considered as the basal unit of Quaternary deposit in India. This hypothesis can also be corroborated with the worldwide magnetic records (Riser, 1999) wherein the Olduvai event marks the boundary of Pliocene- Pleistocene. The UBC are the deposits of Early Pleistocene time and Tatrot and Pinjor rocks were deposited during the Pliocene time (Pilgrim,1939; Colbert,1935). This reversal is dated 1.88-1.72 Ma. This major tectonic event is correlated with the Tibetian Plateau upliftment in the Indian subcontinent (Crowley and Gerald, 1991) and also marked the upheaval in the source rocks. This upheaval possibly produced the enormous volume of clasts which were deposited in the form of (UBC). The die down of tectonic forces is imprinted as broad warps like Manabhum anticline.

Banda Group : The Banda Group of sediments comprising thick variegated clays and red quartzofeldspathic non micaceous sand (*moorum*) of Peninsular provence resting unconformably over the Vindhyans/Bijawars/ B.G.C. are exposed in the southern part of the Ganga plain adjoining Peninsular shield. It has been divided into Variegated Clays and Chitrakoot Formation (Kumar *et al.,* 1996). The Variegated Clays with lateritic gravel horizons is concealed and encountered in the boreholes at depths ranging from 384-498 mbgl (Pathak *et al.,* 1978). The Chitrakoot Formation consists of reddish brownish to greyish silt-clay with calcrete and quartzofeldspathic non micaceous sand (*moorum*) consisting rounded to subrounded grains of abundant translucent quartz, feldspar, subangular to angular chalcedony, jasper and occasional pink and smoky quartz. The top soil adjoining its contact with Varanasi Alluvium in Bhind-Morena-Jalaun-Kalpi-Mirzapur-Chakia-Ara-Patna-Kiul sector (fig. 1) is deep grey to black and sticky which may be primarly due to impounding of seasonal monsoon water, which remains stagnant for about 3-4 months. The topmost silty layer is loessic in nature (Verma and Mehrotra,1991) and often contains gypsum incrustations associated with muddy sequence in parts of Jhansi and Banda districts (Srivastava,1970) in Uttar Pradesh and is also reported in Punjab Plain (Nagaur district, Rajasthan).

Amongst various vertebrate and invertebrate fossils reported (Dean, 1835; Lydekar,1882; Pilgrim,1904; Chakravarti, 1931; Prasad,1996; Verma,1996; Mishra, 2001 and Mukherjee,1949) from Kalpi, Daulatpur, Allahabad, Naini in Uttar Pradesh and Bhagalpur in Bihar the presence of *Stegodon insignis, Hexaprotodon sivalensis* and *Equus sivalensis* is of special significance due to their age correlatable with Upper Siwalik. Recently Singh *et al.* (1999) collected several fossil bone fragments near Kalpi including an elephent tusk (3.54m long) which gave an ^{14}C age of more than 40Ka. Mathur (2001) while carrying out detailed biostratigraphic studies of Quaternary section in parts of Ganga plain reported distinct invertebrate faunal assemblages viz. charophytes (*Lychnothamnus barbatus, Chara* sp. Cf. *C. surajpurica*), reworked Lameta Group microfossils (ostracode and Boraginaceae seeds), gastropods (*Caecilioides* sp) and ostracodes (*Candona* sp. cf.. *C. paionica, Zonocypris costata, Limnocy-*

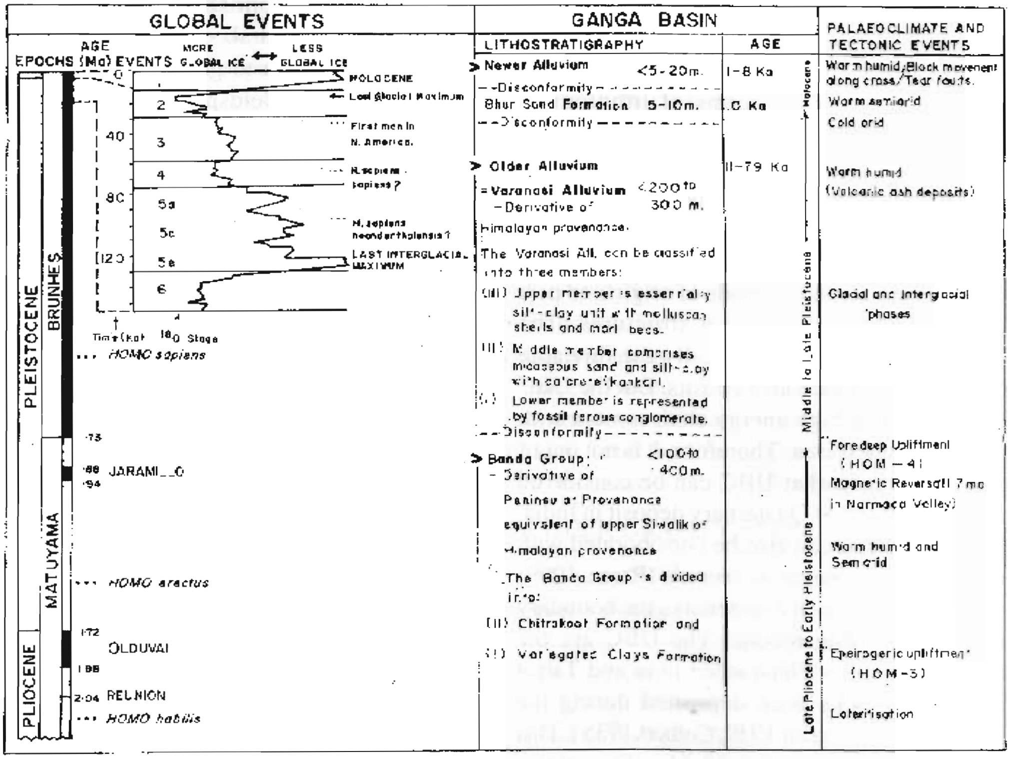


Fig. 5. Global events and their correlation in Ganga Basin.

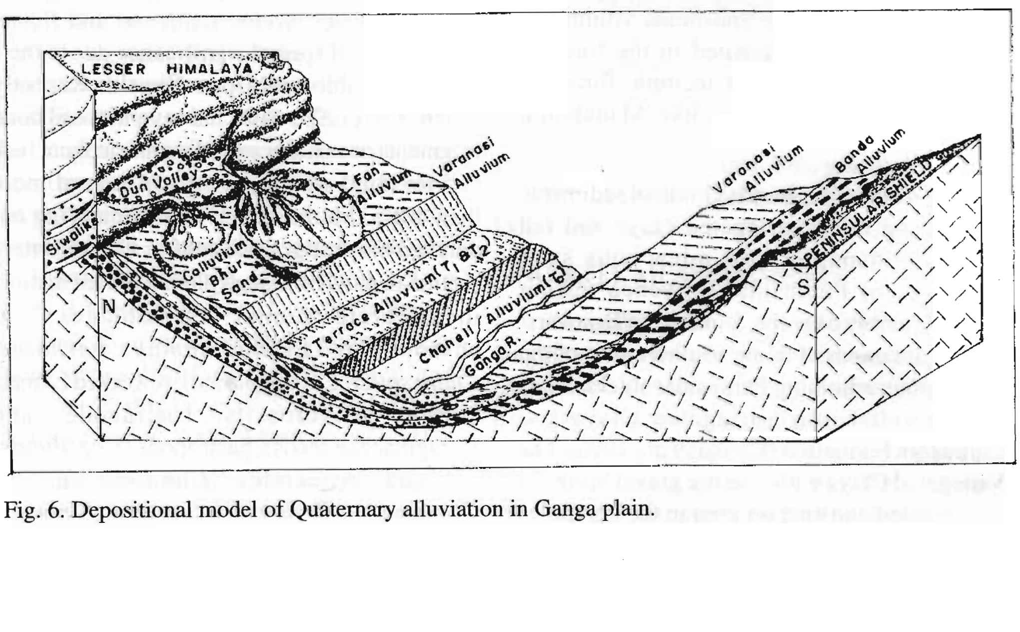


Fig. 6. Depositional model of Quaternary alluviation in Ganga plain.

there sp. cf. *L. blankenbergensis, Cypris decaryi, Cypris* sp. cf. *C.pubera*) within Chitrakoot Formation (= Baba Ghat Formation). The presence of a foraminifer, *Discorbis* sp. and an ostracode *Cyprideis* sp. indicate their tolerance for high salinity. XRD analysis of surficial soil samples indicates dominance of montmorillonite, quartz and illite minerals (Prasad and Khan, 1996). Kumar *et al.* (1996) considered Banda Group equivalent to Tatrot and Pinjor stage of Upper Siwalik Group on faunal affinity. However, the present authors have equated it in parts with the Boulder Conglomerate Formation (UBC). The lateral extent of this Formation can be traced from Pinahat in Chambal valley to Allahabad, south of Yamuna and Ganga confluence and further east of Karamnasa river in Bihar. The subsurface extension of Banda Group towards north can be extended upto Ujhani-Faizabad-Deoria and further east roughly parallel to Ghaghara river. The borehole data at Begusarai in Bihar indicate its thickness more than 450m (Basement not touched).

Older Alluvium Group : This is the most extensive Quaternary sediment mapped in the entire Indo-Gangetic Plain. In the central Ganga Plain it is named as Varanasi Alluvium/Hazipur Formation. Its equivalent formations in three domains are as given in Table-1.

Lthostratigraphically, Varanasi Alluvium is a polycyclic sequence comprising rudaceous facies, sandy facies and silt-clay facies. The thickness of this lithic pile is of the order of 250-300m as deduced from various borehole logs and geophysical surveys. Based on occurrence of three thick clay horizons this thick pile can further be subdivided into Basal, Middle and Upper members (fig. 5). Each member starts with rudaceous facies and ends with clayey facies. The lithofacies variations from basal to upper member possibly indicate transition from high-energy environment to low

Table1: Stratigraphic sequence of Ganga Plain

Age	Himalayan Domain		Central Ganga Plain	Marginal Ganga Plain
Holocene	Yamuna,Bhagirithi,Alaknanda, Ramganga,Kali Channel Alluvium(T_0) Yamuna,Bhagirithi,Alaknanda, Ramganga,Kali Terrace Alluvium (T_1,T_2 and T_3)	**Newer Alluvium**	Ganga/Yamuna/ Ghaghara/Gandak/ Kosi Channel Alluvium(T_0) Ganga/Yamuna/ Ghaghara/Gandak/ Kosi Terrace Alluvium(T_1 and T_2) Bhat Alluvium/Vaishali'Ramnagar Fm(Fan Alluvium)	Chambal,Betwa,Sor Channel Alluvium(T_0) Chambal,Betwa,Sor Terrace Alluvium(T_1)
Early Holocene to Late Pleistocene		Bhur sand (Fluvioaeolian deposit) /Lacustrine Deposit		
Middle to Late Pleistocene	**Doon Gravel** Shyampur Fm/Koti Marora Fm Bhaltiyana Fm	**Older Alluvium**	Varanasi/Madhubani/Hazipur Fm	Lalgarh/Mohanpur Fm
Early Pleistocene	? Boulder Conglomerate(UBC)			Banda Group Chitrakoot Fm
Pliocene	**Upper Siwalik** ----Basement--- Pinjor Tatrot		----Basement concealed--- Siwalik(?)	Variegated Clay Fm
Proterozoic			BGC/Vindhyans/Bijawars	

energy environ-ment. The rudaceous facies of Varanasi Basal Member is well exposed in Ganga plain and is mappbale unit as observed at Garjia in Kosi Valley, Chandighat near Haridwar in Uttaranchal and Chambal-Yamuna section in Madhya Pradesh and Uttar Pradesh. The Varanasi Middle Member is predominantly a sandy facies unit while the Varanasi Upper Member is essentially silty clay unit. The surface exposure of the Varanasi Alluvium in the Ganga plain along major rivers represents the upper silt-clay member (Plate-1D). Its lateral extension in Satluj, Ganga and Brahmaputra basin has been designated by various names [e.g. Ambala Older Alluvium in Haryana, Ludhiana Formation in Punjab, Damana/ Vaishnodevi Formation in J&K, Varanasi Older Alluvium in Uttar Pradesh, Shyampur Formation /Dun Gravel in Uttaranchal; Hazipur/ Madhubani/Gobardhana Formation in Bihar, Barind/Sijua/Ganauli/ Matiali Formation in West Bengal and Chapar/Kuklong/(T3,T4,T5 Unit) Formations in Assam]. Kumar *et al.* (1996) considered this formation as part of coalescing older megafans of sediments brought down from Himalayan provenance with considerable facies variation from rudeceous in apical part close to Siwalik Foothills to an alteration of fine sand and lacustrine silty clay at distal end in the south. It rests unconformably over Boulder Conglomerate of Upper Siwalik in the northen part and over Banda Group in southern part with maximum thickness not exceeding 300 m. Its basal part is represented by gravely sequence comprising clasts of quartzites, gneisses, limestone, clay pellets, red sandstones of Upper Siwalik, etc in red sandy matrix in the northern Siwalik foothill margin as observed near Ramnagar, Uttranchal and Jarwa section in Gonda district. This basal bouldery sequence has been observed overlying an ash bed (fig-6) near Garjia (Shukla and Kar,1997), Balmikinagar in Bihar (Prakash *et al.,* 1989) and Kosar (26°44'35":78°46'00") in Chambal valley (Srivastava and Upadhyaya,1990).This remarkable find throws a new light regarding the sedimentation process of the Varanasi Formation in the Ganga Plain. Similar occurrences of ash beds are reported from the Son and Narmada Valley (Acharya and Basu,1993).

The borehole data at Rae Bareily and Kanpur (Panki) indicate 275m thick Varanasi Alluvium (VA) sequence followed by Banda Group. This VA sequence is characteristically represented by three major cycles of deposition indicated by 3 distinct clay horizons, which are indicative of climatic fluctuations during their deposition. The VA basin boundry became shallower and shallower as we approach towards south and almost demarcated along Ganga-Yamuna-Chambal course.

The XRD analysis of the upper silt-clay member shows presence of quartz, muscovite, albite, illite and chlorite and small amount of microcline, amphibole, sepiolite and calcite. The presence of sepiolite suggests sedimentation in closed basin under warm arid climate. The analysis of feurrginous concretions (ferrcrete) of Older Alluvium in Part of Punjab Plain (Hoshiyarpur district) shows high concentration of trace elements (Li-67 ppm; Ni - 384 ppm; Cu - 63 ppm; Zn - 86 ppm; Sr - 170 ppm; Y - 48 ppm; La - 99 ppm; Ce - 830 ppm; Zr - 274 ppm; Nb - 173 ppm and Se - 6 ppm). The vertebrate fauna recorded from the calcareous shoals of Yamuna valley, Ganga bridge foundation at Phaphamau and at Prahladpur-Guraini section (Dean,1835; Pascoe,1964; Chakravarti,1932; Prasad,1996; Verma,1996; Mishra, 2001) from the Basal Varanasi Member contains *Seminopithecus* sp., *Elephus antiquus* (*namadicus*) Falc. and Cautl., *Bos namadicus* Falc., *Bubalus palaeindicus* Falc., *Equus* sp. Hippopotamus, molar teeth of *Gavialis* sp. and fragment of rib bone of tortoise (Chelina) and broken platron of *Trionyx* sp. Similar faunal assemblage of Middle Pleistocene age is also recorded from Surajkund Formation in the Narmada valley (Tiwari *et al,* 2001) and Kosar Formation in Chambal valley (Srivastava and Upadhyaya,1990)

The sedimentation of the Varanasi Alluvium terminated in the Late Upper Pleistocene due to onset of cool climate related to last glaciation around 14 Ka(LGM). The glaciation brought about withdrawl of drainage and development of residual lacustrine bodies in the form of palaeotals and palaeochannels over the Varanasi Plain. These lakes are the sites of deposition of grey lacustrine clays and marl deposits enclosing rich fauna comprising resh water molluscs, ostracodes, and charophytes which gives ^{14}C date of (4833 ± 147 to 1705 ± 59Yr B.P. (Sharma *et al.,* 2004), 11,040±190 Yr BP(Joshi and Bhartiya, 1991) and 8,300 Yr BP (Rajagopalan, 1992). The Bhur Sand Formation (palaeo Aeolian deposits) occurring as sandy mounds and ridges in eastern Uttar Pradesh and Bihar (Dwivedi *et al.*,1997) which has also been referred as sandy facies of Varanasi Alluvium in western part of Ganga Plain gives TL date of 10 Ka (Kumar *et al.*, 1996).

Newer Alluvium Group **:** The Newer Alluvium is essentially deposited by present day drainage network within the carved out basins of the Older Alluvium during Holocene time. It has limited aerial extent.

The Newer Alluvium Group has been classified into Fan Alluvium, Terrace Alluvium and Channel Alluvium in ascending order. The Fan Alluvium marks the initition of the Holocene cycle and is developed mainly along the northern mountain front forming piedmont zone. This fan deposit has been designated by various names e.g. Bhat Alluvium/Vaishali/ Motihari Formation in Gandak Basin, Ramnagar/ Gola/ Baheri in Ramganga Basin and Markanda/ Jagadhari Formation in Satluj basin. These fan deposits are essentially made up of unconsolidated gravely to bouldey sequence in apical parts and gradually grading to silt at distal end excepting in case of Bhat Alluvium/ Vaishali Formation, which is dominantly calcareous sandy silt and clay. The radio carbon dating of freshwater shells from the upper part (1-2 m bgl) of Vaishali Formation (Table-2) in

Table 2: Record of ^{14}C and TL age of Quaternary sediments of Indo-Gangetic Plain.

Geological Formation	Sample Location	Dating Material	Depth of Sample	Age
A. Newer Alluvium				
Channel Alluvium	Dohri Ghat	Ghaghara Point bar sand	1.0m	1-2Ka
	Etawah		3.0m	2-3Ka
Terrace Alluvium		Yamuna Point Bar sand		
Fan Alluvium				
	Baduan	Ganga terrace sand	1.4m	4-5Ka
	Muzaffapur-Samastipur	Shells in the silt of Vaishali Formation	1-2m	2415 Yr B.P
B. Palaeo Aeolian Deposits (Bhur sand)	Badaun	Sand	8m	10ka
C. Older Alluvium				
Varanasi Alluvuium	Zamania	Calcrete(*Kankar*)	10.0m	12,290±140 Yr BP
	Sukhdevghat	Calcrete(*Kankar*)	15.0m	12,740±650 Yr BP.
	Kalpi	Vertebrate fossil	10m	42000*
	Kalpi	Sand	10-15m	79,000±250*
				*Dates recorded by shri I.B.Singh(personal communication).

parts of Muzaffarpur and Samastipur area in Bihar have given ages of 2415 Yr. B.P to 1065 Yr. B.P (Sinha *et al.*, 1996).The presence of pottery pices, charcoal and bricks are reported from Laldhang and Markanda Fan(Saini and Mujtawa, 2002). Terrace Alluvium is developed within wide flood plain (Terraces) of the present day Ganga river and its tributaries. It comprises cyclic sequence of grey micaceous sand, silt and clay. Its thickness varies from few metres to about 20m and shows well developed sedimentary structures. The Channel Alluvium is confined within the active flood plain of the rivers and occur as point bar, channel bar and lateral bar sand and overbanksilt.

DISCUSSION

The Quaternary development in Indogangetic Basin is not an isolated event. Its deposits correlatable with those of other basins of India throw light on sedimentation processes in terms of time chronology. An attempt has been made to correlate the various Quaternary units, its stratigraphic position and alluviation process in relation to timeframe and tectonics.

The Quaternary deposits of Ganga Plain comprise Boulder Conglomerate/ Banda Group (Upper Pliocene to Lower Pleistocene-1.88 to 0.80 Ma), Varanasi Alluvium (Middle Pleistocene to Late Pleistocene-0.70 Ma to 0.14 ma) and Newer Alluvium of Holocene age (Fan Alluvium-10000 to 7000 yBP and Terrace Alluvium- 7000 to 3000 yrBP).

The deposition of Boulder Conglomerate probably took place during OLDUVAI events (1.88-1.72Ma) along the northern margin and its coeveal Banda Group adjacent to Peninsular shield on the south (fig. 6). After the deposition of Boulder Conglomerate there was a lull in sedimentation. This period of non deposition is represented by volacanic activity as observed in the ash beds near Garjia (Shukla and Kar, 1997) of Uttaranchal state and elsewhere in western Himalaya (Rao,1993).

The beginning of Middle Pleistocene sedimentation witnessed important geological events marked by volcanic activity as referred above, magnetic reversal and climatic changes followed by deposition of new sets of Quaternary sediments generally referred to as Varanasi Alluvium. These deposits saw a resurgent hydrodynamic condition resulting into huge supply of sediments in the form of mega fans in the Ganga Plain and continued till the end of Pleistocene time with varied pulses of sediment inflow. The constituent sediments are marked by alternate sand and clay facies. In general there are minimum three clay facies interspersed by coarse clastics. Its cumulative thickness varies from 250-350m near the Siwalik foothills to less than 300m along the central margin of the basin near Dalmau and decreases further southward. Varanasi Alluvium appears to be deposited in successive pulses of sediments each overlying the others and prograding southwards covering parts of the Banda Group of sediments.

The fossil record as discussed also indicates two characteristic group of faunal and floral assemblages. The divergent faunal/floral assemblage points towards culmination of Banda Group of species and arrival of new genera during Mid-Late Pleistocene time because of climatic change influenced by volcanic activity during the end phase of Banda Group of sediments. The faunal/floral assemblage of Banda Group possibly died down and new genera developed during Mid-Late Pleistocene time. The other examples of fossil content from Narmada Valley indicate the Narmada Homoerectus which was excavated alongwith typical Middle Pleistocene fauna like Stegodon namadicus and Susnamadicus in the gravel conglomerate layer in which it was found insitu just overlying the boundary of Goss Matuyama magnetic reversal. This reversal is dated at 0.76 Ma (Sonakia, 2002).

The basal bouldery unit of Varanasi Alluvium exhibits tectonic effects in the form of fractured pebbles(Plate-1), inclined beds and local thrusts. These neotectonic movements resulted a number of isolated tectonic basins in Himalayas later filled up by reddish clay deposits, varves (Plate1E,F) at places dated back to 50,000yBP. Many of these lakes like Loktak Lake of northeast India shows continuous sedimentations (Kar *et al.,* 1997). The oldest C14 dates of 32,560 yB.P. from upper part of the black clay sequence of Imphal basin is recorded. The last phase of VA sedimentation represented by fluvioglacial deposits in Himalayas dated 17310 ±450 y B.P and 11830 ±270 y B.P. Also in Brahmaputra Plain equivalent fluvial deposites dates 18-12ka.

The end phase of Varanasi Alluvium sedimentation is represented by fluvial, lacustrine and aeolian sedimentation and it is presumed that Ganga basin was completely filled up and a set of drainage line did flourish and continued upto early Holocene time. The Ganga Basin has also witnessed major tectonic events in the form of Tear faults along which the present day drainage system started to set in. The tectonic events possibly triggered bursting of the many Himalayan lakes during Early Holocene resulting the release of huge volume of muds deposits in the Ganga plain at the point of debouching along major rivers as mud fans like Gandak fan, Kosi fan, Ramnagar fan, etc. The present day river system during Middle to Late Holocene period carved out its own terraces in response to neotectonic adjustments in the Ganga Plain.

Although the basic tectonic framework of the basin has already been stabilised, yet many of the local cross faults get rejuvenated from time to time possibly in relation to plate movements. As a result, the earthquakes of major and minor intensity recorded in the last few hundread years in the Ganga Plain are indications of minor tectonic readjustments, suggesting continuance of the sedimentation process and tectonic adjustment in the Ganga basin up to the present time.

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