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Climate Change and Human History in Ganga Plain during Late Pleistocene-Holocene

INDRA BIR SINGH

Geology Department, Lucknow University, Lucknow 226 007

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ABSTRACT

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The Ganga Plain exhibits a large variety of landforms produced essentially during last about 100 kyrs in response to base level, tectonic and climate change. Prominent changes in the monsoon rainfall in the Ganga Plain have been identified, namely, 45 kyrs BP, humid climate; 20-13 kyrs BP, low rainfall; 13-11.5 kyrs BP, high rainfall; 11.5-10.5 kyrs BP, low rainfall; 10.5-5.8 kyrs BP, high rainfall; 5.8-2.0 kyrs BP, low rainfall; and 2.0-0 kyrs BP, high rainfall. Palaeo-vegetation studies indicate that the Ganga Plain was a grassland, at least, since 45 kyrs BP, where C-4 type vegetation dominated. The lakes supported C-3 type vegetation and they show changes in the water budget in response to the changes in rainfall. There is evidence of occupation of Ganga Plain by humans, at least, since 45 kyrs. They occupied the high grounds close to the water bodies, mostly lakes and ponds. Initially human population was hunter-gatherer depending on rich fauna and wild vegetation. Frequent climate changes in latest Pleistocene-Early Holocene probably led to adaptation of agricultural practices by humans. Large-scale occupation of the Ganga Plain took place between 3.5-3.0 kyrs BP. Study of oxygen isotopes in teeth enamel show century-scale rainfall changes in the last 3.5 kyrs BP which show some correlation to the cultural changes in the Ganga Plain. Climate change and human history in the Ganga Plain is closely related and need to be studied by high-resolution investigations.

Key-words—Ganga Plain, Climate change, Human history, Late Pleistocene-Holocene, Palaeovegetation.

सारांश

अंतिम प्लीस्टोसीन-होलोसीन युग के दौरान गंगा के मैदान में जलवायु परिवर्तन तथा मानव इतिहास

इन्द्रबीर सिंह

गंगा के मैदान आधार स्तर, विवर्त्तनिक एवं जलवायु परिवर्तन के जवाब में पिछले लगभग 100 हजार वर्षों के दौरान आवश्यक रूप से निर्मित भू-आकृतियों के विविध प्रकार प्रदर्शित करते हैं। गंगा के मैदान में मानसून वर्षा में प्रमुख परिवर्तन पहचाने गए हैं, अर्थात् 45 हजार वर्ष ई.पू., आर्द्र जलवायु; 20-13 हजार वर्ष ई.पू., कम वर्षा; 13-11.5 हजार वर्ष ई.पू., अधिक वर्षा; 11.5-10.5 हजार वर्ष ई.पू., कम वर्षा; 10.5-5.8 हजार वर्ष ई.पू., अधिक वर्षा; 5.8-2.0 हजार वर्ष ई.पू., कम वर्षा; तथा 2.0-0 हजार वर्ष ई.पू., अधिक वर्षा। पुरावनस्पति अध्ययन संकेत करता है कि गंगा के मैदान कम से कम 45 हजार वर्ष ई.पू., से घास स्थल थे जहाँ पर सी-4 प्रकार की वनस्पति की प्रमुखता थी। झीलों ने सी-3 प्रकार की वनस्पति का समर्थन किया तथा वे वर्षा के परिवर्तन के जवाब में जलबजट में बदलाव प्रदर्शित करती हैं। मानव द्वारा कम से कम 45 हजार वर्षों से गंगा के मैदान में व्यवसाय के प्रमाण हैं वे जल स्रोतों अधिकतर झीलों व तालाबों के पास उच्च स्थलों पर रहे। प्रारम्भिक मानव जनसंख्या आखेटक संग्राहक रही जो कि प्रचुर प्राणीजात व जंगली वनस्पति

33rd Birbal Sahni Memorial Lecture delivered by Professor IB Singh on 14th November 2003 on the occassion of Founder's Day Function at Birbal Sahni Institute of Palaeobotany, Lucknow

पर निर्भर थी। नवीन प्लीसटोसीन प्रारम्भिक होलोसीन में बारंबार जलवायु परिवर्तन से मानव द्वारा कृषि पद्धति अनुकूलन को आगे बढ़ाया। गंगा के मैदान में बड़े पैमाने पर व्यवसाय 3.5-3.0 हजार वर्ष ई.पू., के मध्य हुआ। दंत वल्क में ऑक्सीजन समस्थानिकों का अध्ययन 3-5 हजार वर्ष ई.पू., के अंत में शताब्दी-पैमाने पर परिवर्तन प्रदर्शित करता है जो कि गंगा के मैदान में सांस्कृतिक परिवर्तन के सहसंबंधन को प्रदर्शित करता है। गंगा के मैदान में जलवायु परिवर्तन तथा मानव इतिहास का नजदीकी संबंध है तथा इसके उच्च विभेदन जाँच अध्ययन की आवश्यकता है।

संकेत-शब्दः- गंगा के मैदान, जलवायु परिवर्तन, मानव इतिहास, अंतिम प्लिस्टोसीन-होलोसीन, पुरावनस्पति।

INTRODUCTION

Studies in the history of the earth demonstrates that there have been changes in the climate, landforms and position of the continents which has strongly effected the distribution and evolution of life. Significant climate changes have taken place in Late Quaternary (Late Pleistocene-Holocene) effecting nature of vegetation, rainfall pattern and mammalian fauna. These changes also brought about important adaptations in humans in terms of migration, new adaptive strategies, occupation of new landscapes, and change from hunter-gatherer to agriculturist. It is generally surmised that climate changes strongly affected the human activity. Climate changes also brought about changes in the landforms, especially distribution of rivers and water bodies. The effect of climate change varied strongly from one area to the other. To obtain a more comprehensive analysis of palaeoclimate change, it is imperative to carry out systematic studies in different areas with varied landforms and vegetation.

The Ganga Plain occupies an unique location between Himalaya and Peninsular India with its own characteristic climate. However, studies in landform evolution and palaeoclimates in the Ganga Plain are rare; only in the last two decades some studies have been carried out. Moreover, Ganga Plain, at present, is one of the most densely populated regions of the world. The purpose of the present paper is to provide a review of landform evolution, palaeoclimate and palaeovegetation changes and evidences of palaeo-anthropogenic activity in Ganga Plain. Emphasis has been placed on understanding the history of human occupation in the Ganga Plain.

GANGA PLAIN

General Features

Indo-Gangetic plains are world's largest alluvial plains located between Himalaya and Peninsular India, where Ganga Plain makes its central part (Fig. 1). The Indo-Gangetic plains are foreland basin system of the Himalaya formed due to thrusting in the Himalaya in response to the collision of Asian and Indian plates (Seeber *et al.*, 1981; Lyon-Caen & Molnar, 1985; Singh, 1987, 1996). Initiation of Indo-Gangetic plains took place around Early Miocene (ca. 20 Ma BP). The sediments deposited during early history of these plains (Middle Miocene-Middle Pleistocene, 16.0-0.5 Ma BP) are exposed as Siwalik hills. The present-day near surface sediments of the Indo-Gangetic plains are of Holocene age; the older Late Quaternary sediments and Siwalik successions are burried under tens of metres of sediments (Singh, 1996, 1999).

The Ganga Plain is undergoing subsidence to accommodate new sediments coming from the Himalaya and some from the Peninsular Craton (in Marginal Alluvial Plain). The rate of subsidence and sedimentation is very high in the Peidmont zone, close to Himalaya and decreases near its southern margin, close to craton. The subsidence rates and accompanying sediment accumulation rates vary from few millimetres per 1000 yrs to several metres per 1000 yrs, mostly tens of centimetres per 1000 yrs.

The Ganga Plain extends from Aravalli hills in the west up to Rajmahal hills in the east, occupying an area of about 250,000 km. It is drained by a network of river channels, originating in the Himalayas; some in the alluvial plain and in Peninsular India. The Ganga River is the trunk river in which all other rivers meet. Beyond Farakka, it enters into Ganga delta plain where Ganga River branches off into a number of distributaries. Generally, the rivers of the Ganga Plain coming from the Himalaya flow south to southwest, but then swing in southeast direction. The rivers of the southern part of the Ganga Plain coming from the Peninsular Craton follow a northeast trend. Many streams originating in the alluvium meet the major river at different points. The rivers in the zone of axial drainage of the Ganga Plain follow E to ENE directions. The Ganga River is the trunk river into which all the rivers meet. The positioning and trends of the rivers are controlled by the active lineaments, some acting as gravity faults (Singh, 1996; Singh *et al.*, 1996; Agarwal *et al.*, 2002).

Climate

The Ganga Plain is located in the subtropical climate zone where rainfall pattern is essentially controlled by the southwest monsoon system. The southwest monsoon system becomes active in early June in Bengal, moves westward and by middle July extends over the entire Ganga Plain and continues until

October. There is a change in the amount of annual rainfall from east to west, from about 1600 mm in Bengal, 900 mm in middle part of Ganga Plain, and about 500 mm in western Uttar Pradesh and Haryana. There is also a north-south gradient in rainfall, especially in the middle and western parts of the Ganga Plain, from 1500 mm near Himalayan foothills to about 600 mm in the Bundelkhand region. It is important to note that about 80% of the rainfall occurs in the months of July to September by southwest monsoon. In the months of December-January some rainfall occurs due to westerly disturbances. This effect is more prominent in the western part of Ganga Plain. The annual seasonality in the Ganga Plain can be classified into three seasons:

1. *Warm rainy (monsoon) season.* It extends from July to October and is characterized by high rainfall due to SW monsoon system. Daily mean maximum temperature is about 30°C, the diurnal range (day and night) is usually 5-10°C.

2. *Cold dry season.* It extends from November to February and is characterized by low temperatures and low rainfall. Maximum temperature is 20-35°C; minimum temperature is 5-12°C in January. Diuranal range of temperature is 15-20°C. Some rainfall takes place due to western disturbances.

3. *Hot dry season.* It extends from March to June and is marked by high temperatures. Maximum temperature in May reach values of 40-46°C. The diurnal range of temperature is 15-25°C. NW dry winds dominate, there may be thunderstorms and dust storms.

Because of the specific SW monsoon controlled climate, the rivers and water bodies of the Ganga Plain receive most of their water budget during monsoon season. The rivers often get flooded, and also the water bodies (lakes and ponds) may cause flooding in their adjoining low-lying areas. In the rest of the seasons, humans depend for the water supply on the rivers, ponds, lakes and ground water resources which show decrease in water budget during dry seasons; and occasional winter rains from western disturbances.

Geomorphology

The Ganga Plain is a shallow asymmetrical depression with the gentle easterly slope; where the northern part exhibits a southward slope while the southern part shows a northerly slope (Singh, 1996). Traditionally two morphostratigraphic units are identified, namely the Older Alluvium (Bangar) and the Newer Alluvium (Khadar) (Oldham, 1917). The Bangar consists of higher interfluve areas, and the Khadar makes the deposits of major active rivers and their valleys. In another scheme of classification, the northern part of Ganga Plain close to the Himalaya is identified as Piedmont plain, consisting of Bhabar and Terai zones. The central part, betweem Piedmont plain and axial river (Yamuna River up to Allahabad, and Ganga River from Allahabad to Farakka) is described as Central Alluvial Plain. Area south of the axial river is described as Marginal Alluvial Plain, and has a slope towards north and northeast (Singh, 1996, 2002).

Regional geomorphic mapping helped in identification of several distinctive regional geomorphic surfaces which have been considered to have formed during Late Pleistocene-Holocene climate cycles (Fig. 2). These surfaces exhibit a distinct relative hierarchy. All these surfaces have deposits on them which are younger in age than the time of the formation

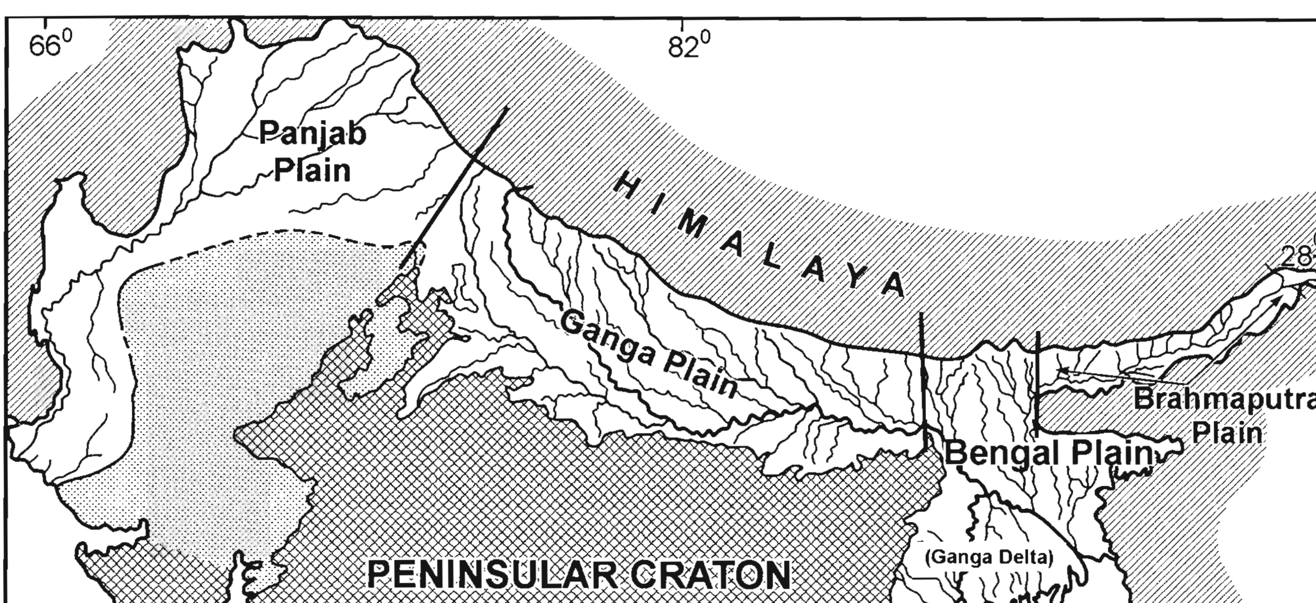

Fig. 1—Himalayan foreland basin system of Indo-Gangetic plains. The Ganga Plain occupies the central position.

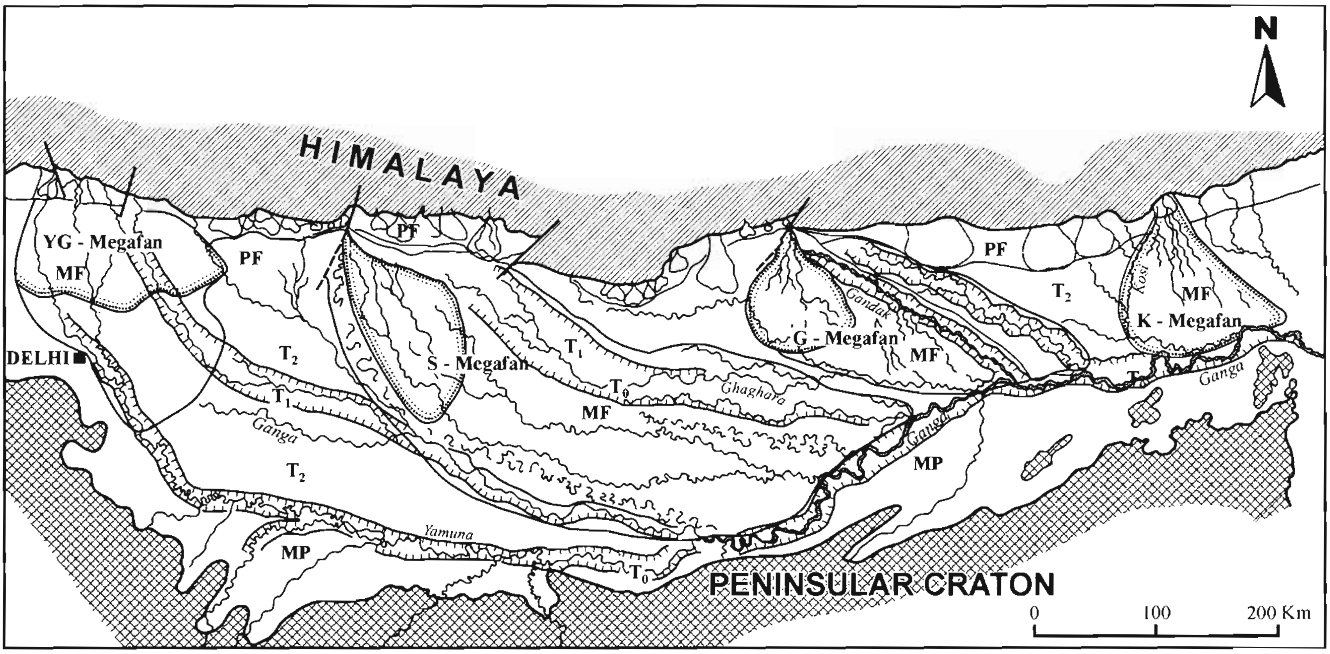

Fig. 2—Regional geomorphic surfaces of the Ganga Plain. T_2- Upland Terrace Surface, MP- Marginal Plain Upland Surface, MF- Megafan Surface (YG- Yamuna-Ganga Megafan, S- Sarda (Ghaghara) Megafan, G- Gandak Megafan, K- Kosi Megafan), T_1- River Valley Terrace Surface, PF- Piedmont Fan Surface, T_0- Active Flood Plain Surface (Modified after Singh, 1996).

of respective surfaces. So far it has been possible to date only the topmost deposits of these surfaces by luminescence methods (Srivastava *et al.*, 2003a). These geomorphic surfaces, their probable timing of formation and luminescence ages of the topmost deposits are as follows:

1. Upland Interfluve Surface (T_2) (probable timing of formation, 128-74 kyrs BP, OIS-5) (Luminescence age of upper part 51-7 kyrs BP).
2. Marginal Plain Upland Surface (MP) (probable timing of formation, 128-74 kyrs BP, OIS-5) (Luminescence age of upper part 76-32 kyrs BP).
3. Megafan Surface (MF) (probable timing of formation, 74-35 kyrs BP, OIS-4 and part of OIS-3) (Luminescence age of upper part 26-22 kyrs BP).
4. River Valley Terrace Surface (T_1) (probable timing of formation, 35-25 kyrs BP, part of OIS-3 and OIS-2) (Luminescence age of upper part 5-2 kyrs BP).
5. Piedmont Fan Surface (PF) (probable timing of formation, 25-10 kyrs BP, OIS-2) (Luminescence age of upper part 9-3 kyrs BP).
6. Active Flood Plain Surface (T_0) (probable timing of formation, 10 kyrs BP -present, OIS-1) (Luminescence age of upper part 0.5-0.2 kyrs BP).

[Oxygen Isotope Stage (OIS) = Marine Isotope Stage (MIS)]

An important inference of the above study is that near surface sediments of the Ganga Plain give ages between 1-7 kyrs BP, the sediments of older ages are seen only in cliff sections and deeper excavations. The Upland Interfluve Surface (T_2) and Marginal Plain Upland Surface (MP) are the most extensive surfaces occupying the vast areas of the Ganga Plain. The River Valley Terrace Surface (T_1) is well developed in the large rivers like Ganga, Ghaghara and make parts of the Khadar areas.

The interfluve surface exhibits abandoned channel belts, meander cutoffs, abandoned channel segments, minor incised active channels, ponds, lakes and aeolian ridges (bhur). The surface shows tens of kilometre scale undulations and areas of centripetal drainage with large number of water bodies of various dimensions (Srivastava, 1998; Sharma *et al.*, 2003). These features formed mostly during latest Pleistocene-Holocene (about last 20 kyrs BP) in response to changing climate (monsoon rainfall), base-level changes and intrabasinal tectonics; though it is difficult to assess the exact role of different parameters (Singh, 1996, 2001, 2002, 2004).

It has been argued that the Late Quaternary sedimentation in Ganga Plain has been mainly controlled by expanding and contracting fan systems (megafans and piedmont fans), which were responsible for formation of variety of drainage patterns (Singh & Ghosh, 1992; Singh, 1996). The present-day active and many abandoned channels of the Ganga Plain are relict of ancient anastomosing channel system.

Ganga Plain is a tectonically active basin where sedimentation pattern is strongly controlled by tectonic activity in the Himalaya and Ganga Plain. There are a number of evidences of neotectonic activity within the Ganga Plain (Singh *et al.*, 1996, 1999; Agarwal *et al.*, 2002; Parkash *et al.*, 2000). There is evidence of pulses of tectonic activity between 8-5 kyrs BP with an important tectonic event around 5 kyrs BP, which were responsible for shaping of some of the features in the Ganga Plain (Singh, 2001, 2002, 2004). The most important change was disruption of minor tributaries, and formation of a large number of ponds and lakes. Additionally, upwarped regions and areas of centripetal drainages were produced. Formation of few metre high mounds and large number of ponds and lakes was a significant change in the landform, which also controlled the pattern of human settlement. The high mounds, beyond the floods provided habitational sites; while lakes and adjoining wetlands were suitable agriculture sites. The landform changes in the Ganga Plain during last about 20 kyrs are depicted in Fig. 3.

The Ganga Plain at present exhibits rather diverse fluvial landforms. Important features are large and small river channels, natural levees, flood plains, alluvial ridges, ponds, lakes, wetlands, bhur (aeolian ridges), and low mounds.

The near-surface sediments of the Ganga Plain are only few thousand years old; the older sediments are buried under tens of metres of these young sediments. Large rivers have often exposed older sediments in cliff sections along their valley margins. Ravinous tracts and deep gulleys have also exposed older sediments. In Ganga River valley sediments upto 50 kyrs BP are exposed, while in the Yamuna River valley sediments upto 80 kyrs BP are exposed (Srivastava *et al.*, 2003a).

CLIMATE CHANGES IN LATE PLEISTOCENE-HOLOCENE

Based on the study of deep sea cores, ice cores, and general circulation models, it has been recognized that during Late Pleistocene-Holocene a number of climatic cycles of global significance are present which must have influenced the vegetation pattern on the land (Dansgaard *et al.*, 1993; Stuiver *et al.*, 1995). Two interglacials are identified separated by a glacial period, namely interglacial from 128-74 kyrs BP, glacial from 74-10 kyrs BP and interglacial from 10 kyrs BP-present. The interglacials were warm periods with increased rainfall, while glacials were cold periods with reduced rainfall. These major cycles contain millennium-scale climate oscillations of increased and reduced rainfalls respectively. The southwest monsoon system, hence the regional rainfall pattern varied through time (Prell & Kutzbach, 1987), and is superimposed on the glacial climate change often with some offset.

The last interstade (MIS 3) (60-30 kyrs BP) was comparable to present-day situation in terms of rainfall and temperature, with few periods of higher rainfall. The Last Glacial Maxima (LGM) (MIS 2) (30-10 kyrs BP) shows many prominent climate cycles. The time between 25-15 kyrs BP was of cold climate and low rainfall. Climate improved around 15 kyrs BP, but there was cooling and dry event of Younger Dryas between 11.5-10.5 kyrs BP. The Holocene (last 10 kyrs) is a time of higher temperature, high rainfall and short-scale century-scale fluctuations.

A number of studies on climate change in Indian region are available (Sirocko *et al.*, 1993; Kudrass *et al.*, 2001; Kale *et al.*, 2003). For the Indian subcontinent following modified climate changes can be considered. The time 25-13 kyrs BP was cooler and dry climate with low rainfall and minor climate fluctuations. The monsoon became strong around 13 kyrs BP and continued up to 5 kyrs BP, when rainfall was much more than today. Peak of the monsoon phase was 9-8 kyrs BP when monsoon was most strong. Between 5-3.5 kyrs BP monsoon weakened and rainfall was much reduced. After 3.5 kyrs BP monsoon improved; however, there were many millennium-scale fluctuations of strong and weak monsoon.

PALAEOENVIRONMENTS IN GANGA PLAIN

Palaeoenvironment reconstructions in the Ganga Plain have been attempted in last decade. Although only few studies are available, they have provided useful insight in the palaeomonsoon changes.

Mineralogical-geochemical and isotopic studies in the Kalpi area, Yamuna River valley have been carried out. The archaeological horizon of Kalpi section is dated 45 kyrs BP. The climate was more humid than today. The area supported a rich mammalian fauna like hippopotamus, elephant, turtles, crocodiles, equus, bovids, etc.

The interfluve areas (T_2-Surface) of the Ganga Plain shows a large number of water bodies. These water bodies (lakes and ponds) formed during latest Pleistocene-Holocene due to channel cutoff, avulsion and channel disruption. A large number of such lakes were formed in early Holocene (Agarwal *et al.*, 1992; Singh, 1996; Srivastava *et al.*, 2003b). Multi-proxy data from Sanai Tal, Rae Bareli has provided information on palaeoenvironments for last 15 kyrs BP (Sharma *et al.*, 2004a). This study allowed us to infer:

a. 20-13 kyrs BP- Low rainfall, formation of tributary network.

b. 13-11.5 kyrs BP- High rainfall, expansion of lake.

c. 11.5-10.5 kyrs BP- Reduced rainfall, reduction in vegetation of every type. It correspond to the Younger Dryas event.

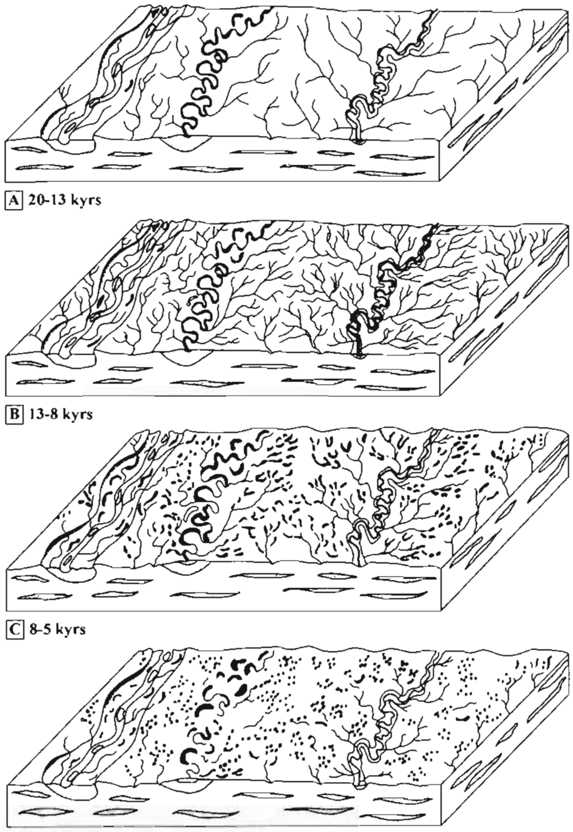

Fig. 3—Schematic representation of landform evolution of Ganga Plain during the last 20 kyrs. The upland interfluve areas exhibit significant changes in response to climate change and tectonics. There was a phase of channel enlargement during 13-8 kyrs BP. Tectonic events caused disruption of minor tributaries and formed number of water bodies (lakes) with adjacent highgrounds.

d. 10.5-5.8 kyrs BP- High rainfall, enlargement of lake, high aquatic plants.

e. 5.8-2.0 kyrs BP- Reduced rainfall, reduction in lake, high siltation rate.

f. 2.0-0 kyrs BP- Increased rainfall.

Study of oxygen isotopes in teeth enamel from archaeological sites in the Ganga Plain indicates high rainfall around 3.5-3.0 kyrs BP, and century-scale fluctuations during last 3.5 kyrs BP (Sharma *et al.*, 2004b). A schematic diagram showing changes in the palaeomonsoon of Ganga Plain is given in Fig. 4.

PALAEOVEGETATION IN GANGA PLAIN

The rich fauna of Kalpi section (45 kyrs BP) indicates that the area was essentially a grassland with small and large water bodies. The stable carbon isotopes of teeth enamel from Kalpi section also indicates a grassland with C-4 type vegetation. Moreover, carbon isotopes in several calcrete samples of Kalpi section indicates contribution of carbon essentially from C-4 type vegetation. Palynological study of Sanai Tal, Rae Bareli indicates that the area was essentially a grassland with dominance of C-4 type vegetation during last 15 kyrs (Fig. 5). There are evidences of some changes in vegetation in response to the changes in the rainfall pattern; however, the landscape always supported a grassland. Maceral studies of Sanai Tal samples show that plant debris consists of exclusively grasses, an indication of dominance of grasses in the catchment area of the lake.

Palynological studies of several lakes in the Ganga Plain (Misa Tal, Basaha lake) have indicated that the region was essentially a grassland during last about 10 kyrs (unpublished data).

It can be argued that throughout Late Pleistocene-Holocene, the Ganga Plain was essentially a grassland with few thickets. The grasses (Poaceae) of C-4 type dominated. It is quite likely that important changes in the composition of grasses during dry-wet climate cycles took place; but so far we have no information on such changes.

HUMAN HISTORY OF GANGA PLAIN

General Observations

It is generally discussed in the archaeological literature that during Palaeolithic time human occupation of the Ganga Plain did not take place, because, the stones, the prerequisite for making stone tools were not available. It is further emphasized that Ganga Plain did not witness early development of agriculture and village life, despite being a fertile, agriculture-suitable land. Reasons postulated were that Ganga Plain was a dense and tangled forest throughout Pleistocene and Early Holocene (Sharma, 1983; Kosambi, 1985; Misra, 2001; Agarwal & Kharakwal, 2002). Significant developments in the Ganga Plain took place only with the introduction of iron in the fourth millennium BP when enterprising farmers cleared the forest (Misra, 2001; Roy, 1983; Shinde, 2002).

Evidences of Human Occupation in Ganga Plain

It may be pointed out that there are scattered but significant records of human activity in the Ganga Plain since Early Palaeolithic which have been often overlooked. The known records of human activity in the Ganga Plain are:

(i) Early Palaeolithic artifacts from a cliff section of Yamuna River near Mau, Banda district (Lal, 1971).

(ii) Middle Palaeolithic artifacts in a conglomerate horizon of Yamuna valley in Kanpur Dehat district (unpublished information).

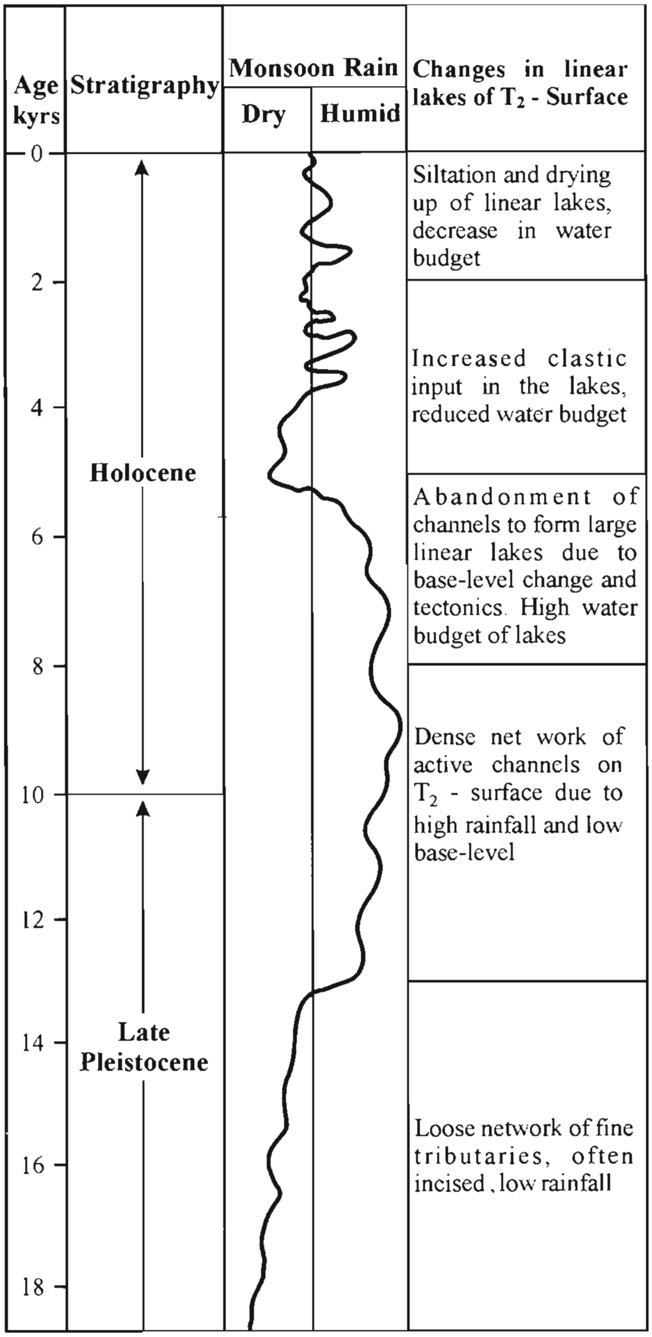

Fig. 4—Climate changes due to monsoon rainfall variation in Ganga Plain during latest Pleistocene-Holocene and corresponding changes in the Ganga Plain lakes.

(iii) Middle Palaeolithic artifacts (age 45 kyrs BP) from Kalpi, Jalaun district. This site is exceptionally rich in charred animal bones and many worked bone artifacts (Singh *et al.*, 1999; Tewari *et al.*, 2003a).

(iv) Epipalaeolithic artifacts in the Pratapgarh district (Sharma, 1975, 1980).

(v) Mesolithic settlement sites (10-8 kyrs BP) in Pratapgarh district, especially Sarai-Nahar-Rai and Damdama (Sharma, 1980).

(vi) Mesolithic artifacts of agate, flint etc. (10-8 kyrs BP) from a calcrete conglomerate horizon close to Yamuna River, Kanpur Dehat district.

(vii) Lahuradewa archaeological site in Sant Kabir Nagar district with human occupation since about 8 kyrs BP showing evidences of strong agricultural practices including domestication of rice (Tewari *et al.*, 2003b).

Large number of archaeological sites in Ganga Plain are dated between 3.0-2.5 kyrs BP (some going back in time to 3.5 kyrs BP) indicating large-scale inhabitation of Ganga Plain which continued later with distinctive cultural and pottery changes. This period led to urbanization of Ganga valley (Roy, 1983).

CHANGE FROM HUNTER-GATHERER TO AGRICULTURIST

One of the important aspects of the human evolution is change of hunter-gatherer community to the agriculture practices. This change was the result of a series of developments in the human behaviour, climate change and vegetation change over a long period of time. Short term intense climate change may motivate people to develop novel attitudes and concepts for better adaptation in changing conditions. To adapt to agriculture, keeping of animals and sedentary habit requirement of water is a must, and most of the early settlers (early agriculturist) preferred sites near lakes.

It has been argued that glacial-postglacial change (20-10 kyrs BP) triggered the beginning of agriculture. Between LGM (Last Glacial Maxima around 18 kyrs BP) and Early Holocene (10 kyrs BP) climate witnessed drastic changes and fluctuations, especially during Younger Dryas (11-10 kyrs BP). The climate deterioration during Younger Dryas played important role in the origin of agriculture in west Asia (Harris, 1998). The people in West Asia were pioneer in farming of wheat and this revolution (Neolithic revolution) spread to Europe and Asia (Childe, 1934).

The beginning of agriculture is now seen during change of climate from LGM to Early Holocene in two major centres, the Middle East and China (Yasuda, 2002a,b). However, it is likely that there were more centres and adaptations for agriculture began much earlier than considered today.

During Middle Palaeolithic time, a variety of subsistence modes developed and human adapted to food processing. In early agricultural activity, humans settled close to water bodies, where many wild varieties of edible cereals and fruits were available. Humans extensively used them after acquiring sedentary habit. Later, when natural supply of food was not sufficient, humans began cultivation of useful plants. Slash and burn cultivation must have been most common method of

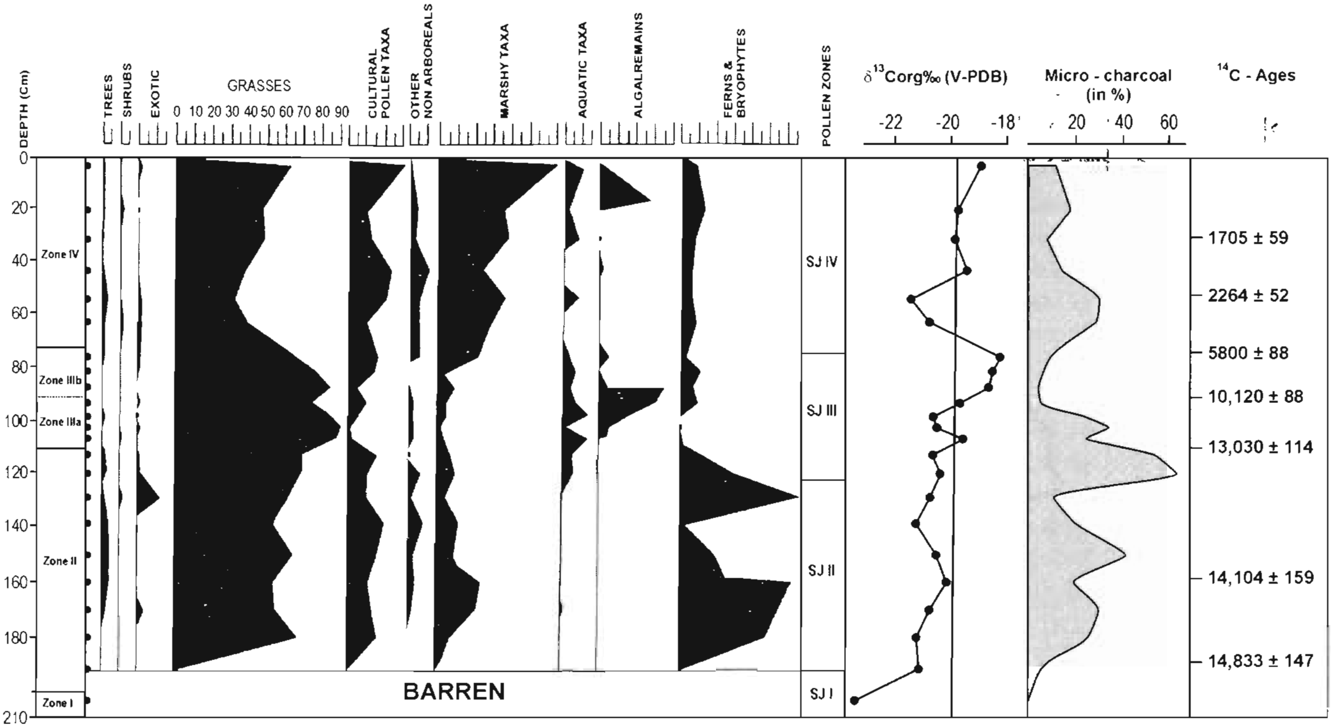

Fig. 5—Pollen diagram of Sanai Tal showing changes in the major plant groups. Grasses dominate throughout; trees are very subordinate. Variation in content of micro-charcoal is also given.

early agriculture. Burning would clear the fields for sowing and also produce ash to serve as fertilizer.

The humans living in the Ganga Plain must be extensively using a large variety of edible plant products available in plenty since Middle Palaeolithic. The climate changes, especially variation in monsoon rainfall during latest Pleistocene affected the water budget in small rivers and water bodies (lakes and ponds), and humans must have reacted to these changes adapting to new strategies.

Humans living on high grounds adjacent to shallow water bodies (ponds) must have used the wet-grounds adjoining the pond (water bodies) for early agriculture, where there was no need for ploughing or agriculture tools.

In the Ganga Plain, the agriculture probably emerged out of a complex background of climatic variation, shifting phytogeographic (vegetation) zones, monsoon pattern change, and river system evolution during latest Pleistocene-Early Holocene.

Cerelia pollens and culture pollen taxa, e.g., Chenopodiaceae are present in Sanai Tal deposits since 15 kyrs BP. Moreover, all the samples of this succession have yielded micro-charcoal. This data strongly indicates slash and burn cultivation in the area since 15 kyrs BP. Recently, cultigen rice has been recovered from Lahuradewa archaeological site dated around 8500 yrs. These preliminary results strongly suggest a possibility that change from hunter-gatherer to agriculturist in Ganga Plain took in Ganga Plain in latest Pleistocene. Systematic studies in Ganga Plain are needed to document the precise beginning of agriculture practices.

LATE HOLOCENE ARCHAEOLOGICAL HISTORY OF MIDDLE GANGA PLAIN

Most of the archaeological sites in Middle Ganga Plain, especially in the Lucknow region go back in time to about 3500 yrs BP. These sites have produced a well-documented record of succession of pottery which has helped in constructing the human settlement history of this region. In the Middle Ganga Plain earliest pottery type is *Black and Red Ware*, rather coarse and thick which may be even older than 3500 yrs BP.

A generalized archaeological history of Middle Ganga Plain for the last about 3500 yrs is given in the following

a. Red Ware dominated Early Period (3500-3000 yrs BP). The pottery is mostly red wares, wheel thrown and kiln burnt. Main pottery shapes are bowls, vessels, dishes, perforated and footed vessels, water vessels. Other associated pottery are plain Grey Ware and Black-Slipped Ware. In the western Ganga Plain Ochre-Coloured Pottery (OCP) characterize this time period and sometimes associated with copper hoards. People lived mostly in huts. Copper objects and rare iron objects are also known. There is evidence for agriculture, domestication of animals, hunting-gathering and meat-eating habits.

b. Pre-Northern Black Painted Ware (3000-2700 yrs BP). It is dominated by the pottery type of Painted Grey Ware (PGW), and plain and painted Black and Red Ware. The pottery is made of fine-grained and well-levigated clay, wheel thrown and well baked. Main shapes include dish, bowl and lota. PGW is painted in black colour with designs. The Black and Red Ware bear white or cream paintings. Terracotta toys are found. The PGW pottery is found mostly in the western Ganga Plain. Iron and copper objects also occur. The culture was village culture with agricultural cum pastoral subsistence. Horse along with buffalo, pig and sheeps were domesticated animals.

c. Early Historical period or Northern Black Painted Ware (NBPW) (2700-2000 yrs BP). It represents the period of urbanization and significant cultural changes including long distance trade, introduction of coins, writings, extensive use of iron. Ancient literature provides information about several capitals of large kingdoms. Buddhism and Jainism evolved in Ganga Plain and spread to other areas. A large variety of objects made of copper and iron are known. Northern Black Painted Ware (NBPW) was main pottery along with several other types of wares. The NBPW is a very fine quality pottery manufactured mainly in the Ganga Plain. Inumerable types of artifacts made up of stone, metals, terracotta are known. Last phase of the PGW (Painted Grey Ware) overlaps with the earlier phase of NBPW. Other associated wares were Black-Slipped Ware, Black and Red Ware and Red Ware. This was a period of intense agricultural activity which was supported by favourable rainfall and good fertile soil.

d. Kushan Period (2000-1700 yrs BP). It was the time when NBPW disappeared and Red Ware dominated as a pottery made in varied shapes and with stamped motifs on the outer surface. The pottery includes bowl with in-turned rim, lid-cum-bowl, sprinkler, spouted vessels. This period is marked by construction of large, well-planned structures of brick, and construction of large water storage tanks. Magnificent art pieces are known. The period was very prosperous.

e. Gupta Period or Post-Kushan or Classical Period (1700-1400 yrs BP). It is characterized by ornamental baked bricks, terracotta figurines, sculptures and temple forms. The characteristic pottery is Red Ware with prominent designs, stamped forms and relief. The main vessels are jar, vase, surahi, shallow and deep bowl, lid and handi. Population pressure led to irregular patterns in construction, robbing of bricks from older structures. Prominent brick temples were constructed, long distance trade was common.

f. Post Gupta Period or Post Classical Period (1400-1200 yrs BP). It is characterized by inferior quality of Red Ware with incised and embossed decorations, made in various shapes and sizes. The houses were built of mud bricks, baked bricks; the quality of construction of religious places was much superior. The seals are mostly of Buddhist creed. Terracotta figurines decrease in number.

g. Early Medieval Period or Rajput Period (1200-800 yrs BP). Although there is no specific aspect of pottery of this period, the earlier type of pottery continued in this time.

It can be summarized that in the Ganga Plain human were living at least since 45 kyrs BP (Middle Palaeolithic culture) and must have been attracted by rich fauna for hunting, sufficient water, and a variety of plant food. During Palaeolithic to Neolithic time humans preferred to live on the raised natural levees of abandoned channels, mostly which were large linear bodies. During later times (Historical period) humans spread in different landscapes of the Ganga Plain; many occupied levees and cliffs located along the larger rivers.

TOOTH ENAMEL IN PALAEOMONSOON RECONSTRUCTION

To understand the role of climate change on the human settlement, migration and evolution of culture, it is desirable

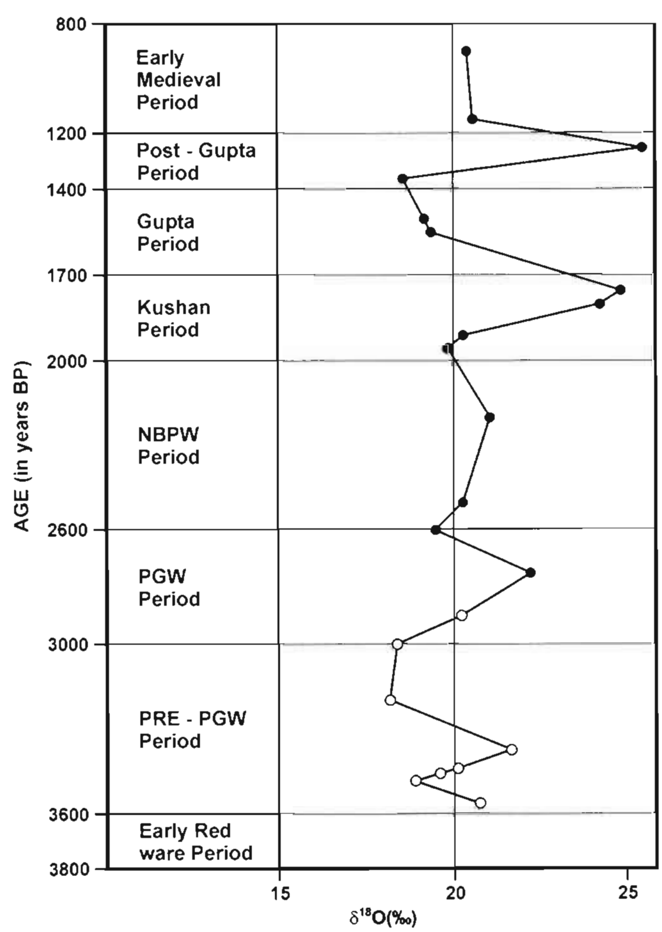

Fig. 6—Variation in the average enamel $\delta^{18}O$ values of herbivore teeth from Dadupur and Kalli Pachchhim archaeological sites near Lucknow. There are marked fluctuations due to changes in palaeomonsoon. Each cultural phase begins with a humid phase and ends with a dry phase.

to have precise and high resolution information of climate change. In the context of Ganga Plain, changes in the amount and pattern of rainfall, in response to changes in monsoon activity, would have effect on human history. Lately, oxygen isotopic composition in tooth enamel has been considered to be excellent proxy for determining the changes in rainfall.

Palaeo-rainfall can be reconstructed by anlaysing oxygen isotopic composition of mammalian hard tissues. Tooth enamel is considered to retain pristine oxygen isotope signatures helpful in calculating the composition of water and food consumed by the animals (Fricke *et al.*, 1998; Kohn *et al.*, 1998). Oxygen isotopic composition of phosphate in tooth enamel of herbovore mammals is useful in determining the composition of water consumed by the mammals, which is usually the local meteoric water (Fricke & O'Neil, 1996). Generally analysis of a single herbivore mammal, using late erupting M_3 molar is recommended.

In a pioneering effort to resonstruct the palaeomonsoon pattern for last about 4000 years in the Ganga Plain, phosphorites of the herbivore teeth enamel has been analyzed from three archaeological sites, namely Charda in Bahraich district, Dadupur and Kalli Pachchhim in Lucknow District. Analyses of M_3- molars of *Bos indicus* was used for palaeo-monsoon reconstruction (Sharma *et al.*, 2004b). The individual tooth show prominent monsoon seasonality, where teeth from Bahraich with higher rainfall show lighter isotopes, while teeth from Lucknow with lower rainfall show heavier isotope values. Moreover, bulk oxygen isotopic composition of M_3 from different cultural periods indicate rainfall changes through time. Conditions were humid around 3600 yrs BP, with a trend towards dry conditions until 2800 yrs BP. From 2500 to 1500 yrs BP there is increasing humidity, followed by a dry phase around 1300 yrs BP (Sharma *et al.*, 2004b).

A larger set of analyses of teeth enamel of herbivore animals utilizing different molars is available. This data set can not provide precise palaeomonsoon calculations; however, it can certainly provide general trend in rainfall pattern. This data set is plotted for Dadupur-Kalli Pachchhim archaeological sites (Lucknow) (Fig. 6). An important aspect of this study is that there are century-scale fluctuations in the isotopic values throughout the time span of 3600-800 yrs BP. The time periods of about 3500 yrs BP, 3200-3000 yrs BP and 1600-1500 yrs BP were particularly humid. Time periods around 3400 yrs BP, 2700 yrs BP, 1800 yrs BP and 1400 yrs BP were particularly dry. The dry spells may have decade long periods of droughts. A significant observation is that, with the beginning of each cultural period the climate is comparatively more humid and becomes relatively dry towards the end of the cultural horizon.

It shows that development and decline and different cultures in historic time were, at least, partly influenced by the climate changes, particularly the rainfall. These inferences are based on only limited samples. However, such studies have high potential to investigate the role of rainfall changes in cultural evolution of humans.

CONCLUDING REMARKS

The Late Quaternary succession of the Ganga Plain shows signatures of changing tectonic activity and climate which caused important changes in the landforms. The Ganga Plain developed high areas in the form of natural levee, terraces, alluvial ridges, aeolian (Bhur) ridges and mounds interspersed with low-lying areas of river channels, lakes and wetlands. The high areas were ideal for human settlements; while adjacent water bodies provided water, food to fulfill the human requirement. The Ganga Plain was a grassland at least since last 45 kyrs BP, and humans inhabited it due to availability of rich fauna and vegetation. Large-scale occupation of Ganga Plain took place between 3.5-2.5 kyrs BP on raised grounds close to the water bodies. The changing climate in latest Pleistocene and Holocene and availability of large variety of edible vegetation in Ganga Plain was conducive for agricultural activity. It is probable that agricultural activity was initiated in the Ganga Plain during latest Pleistocene (20-10 kyrs BP). Study of oxygen isotopes in teeth enamel suggests that century-scale rainfall variation played important role in cultural evolution of hunmans in last about 3.5 kyrs BP. High resolution studies in palaeoclimate and palaeovegetation can be helpful in understanding the human history of the Ganga Plain.

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