Quaternary sediments of Indo-Gangetic, Brahmaputra and adjoining inland basins and the problem of demarcation of Pleistocene-Holocene Boundary

S.K. Kar, Surendra Prasad & Gopendra Kumar

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The Quaternary sediments deposited in the Indo-Gangetic, Brahmaputra and adjoining smaller inland basins and *Duns* formed after the Middle Pleistocene Himalayan Orogenic Movement (HOM-4), are fluvial-fluviolacustrine and or lacustrine in nature. A synthesis of the available data in the Brahmaputra Basin and its comparison with that of the Indo-Gangetic Basin and *Duns* suggests two cycles of sedimentation, separated by a period of erosion and non-deposition and continuous in inland basins, such as Bhimtal-Naukuchia Tal, Hawalbagh in Kumaun region in Uttar Pradesh and Loktak Lake in Manipur. The sediments of the first cycle which terminated in late Upper Pleistocene are, in general, oxidised and referred as the Older Alluvium, while that of the second assigned to Holocene, are unoxidised grey in colour and constitute the Newer Alluvium.

Key-words — Palaeoenvironment, Indo-Gangetic Basin, Brahmaputra Basin, Himalayan Orogenic Movement, Quaternary (India).

S.K. Kar & Surendra Prasad, Geological Survey of India, Lucknow 226 024, India.
Gopendra Kumar, 48 Pandariba, Old Kanpur Road, Lucknow 226 004, India.

सारांश

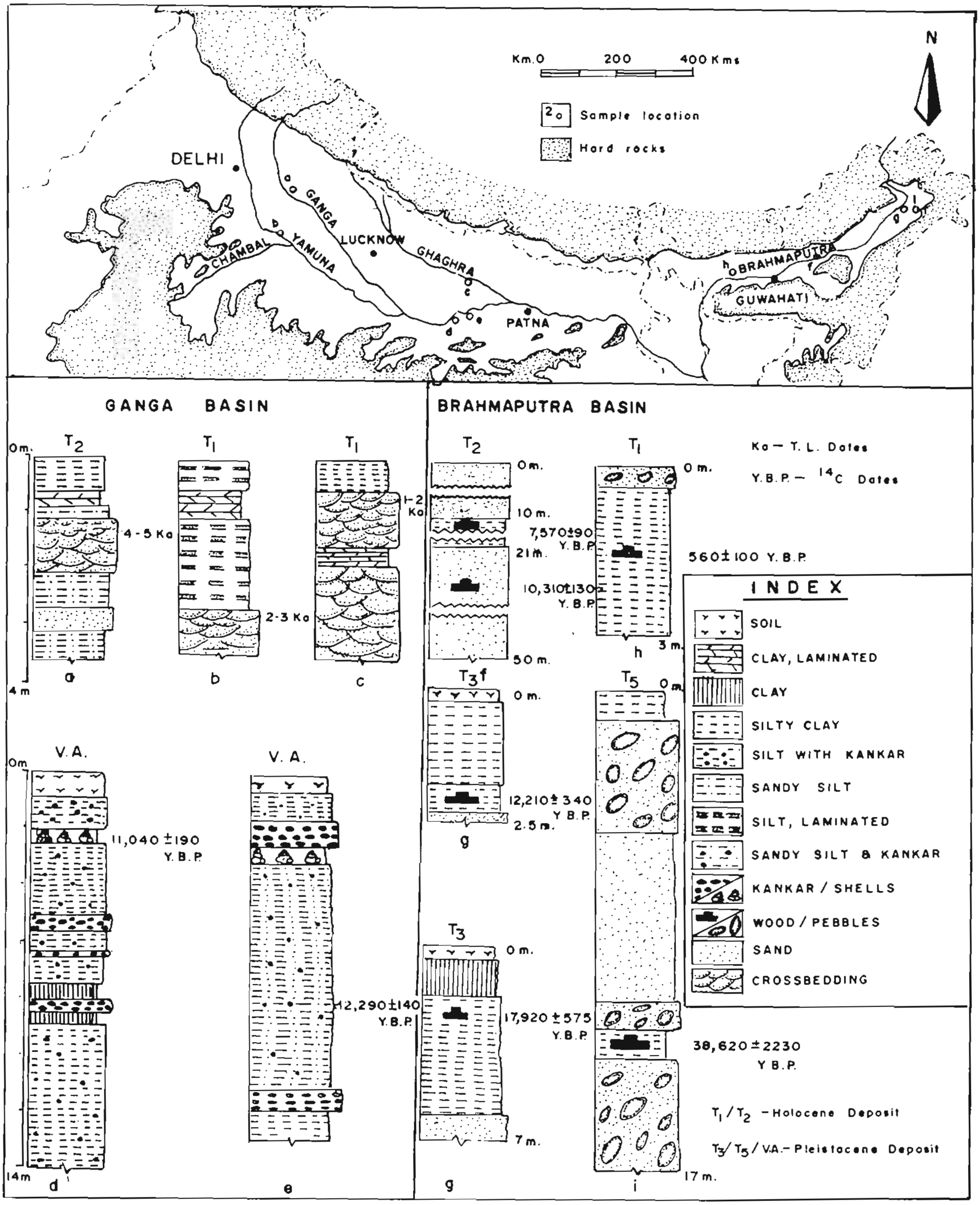
इंडो-गंगा, ब्रह्मपुत्र एवं आस-पास की अंत:स्थली द्रोणीयों के क्वाटरनरी युगीन अवसाद तथा प्लिस्टोसीन-होलोसीन सीमा के सीमांकन की समस्या

एस. के. कर, सुरेन्द्र प्रसाद एवं गोपेन्द्र कुमार

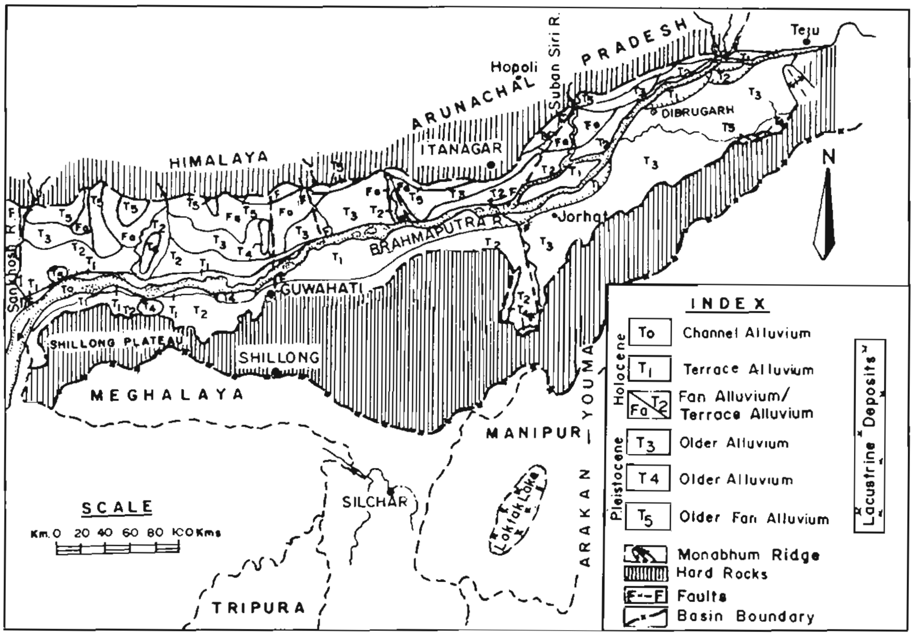
इंडो-गंगा, ब्रह्मपुत्र एवं आस-पास की छोटी अंत:स्थली द्रोणीयों तथा दून में निक्षेपित क्वाटरनरी अवसाद जो मध्य प्लिस्टोसीन हिमालय पर्वतन प्रक्रिया के पश्चात् बने हैं, नदीय, नदीय-सरोवरी अथवा सरोवरी परिस्थितियों की देन हैं। ब्रह्मपुत्र द्रोणी पर उपलब्ध आँकड़ों के विश्लेषण तथा दून एवं इंडो-गंगा द्रोणी से इसकी तुलना से पता चला है कि ये अवसाद दो चक्रों में निक्षेपित हुए हैं। ये अवसाद एक दूसरे से अपरदन, अनिक्षेपण तथा अविच्छिन्न अंत:स्थली द्रोणीयों जैसे उत्तर-प्रदेश में कुमायुं क्षेत्र में भीमताल - नौकुचियाताल तथा मणिपुर में लोकताक झील, के कारण अलग है। अनंतिम उपरि प्लिस्टोसीन कालीन पहले चक्र के अवसाद सामान्यत: ऑक्सीकृत हैं तथा इन्हें प्राचीनतर जलोढ़ के नाम से जाना जाता है जबकि होलोसीन कालीन दूसरे चक्र के अवसाद भूरे रंग के अनाक्सीकृत है तथा नवीनतर जलोढ़ कहलाते हैं।

IN the Indian subcontinent, the Quaternary fluvial, fluvio-lacustrine and lacustrine sedimentation has broadly been related to three cycles of sedimentation (Kumar *et al.*, 1996a). These three cycles correspond to supersequences XIII (upper part), XIV and XV of Shanker *et al.* (1996). The first cycle of sedimentation formed part of the ongoing Late Neogene sedimentation in the Siwalik Basin or the Foredeep that continued into Lower Pleistocene. It terminated with last phase of Himalayan Orogeny (HOM-4) during early Middle Pleistocene. The second cycle initiated in Middle Pleistocene in basins formed after HOM-4, viz., the Indo-Gangetic, Brahmaputra, *Duns* (valleys) in sub-Himalaya and inland basins in Lesser Himalaya and Arakan Youma mountains and terminated in late Upper Pleistocene. It continued in some smaller inland basins/lakes. The third cycle of sedimentation commenced on the advent of Holocene and is still continuing. The sediments of the first cycle formed part of the Kimin Formation or the Upper Siwalik Group. In the northern part of the basin these sediments were involved in HOM-4 and gave rise to folded were and uplifted sub-Himalayan ranges. In the southern part these constitute the Banda Group in the Bundelkhand Plain (Kumar *et al.*, 1996 a,1996 b) and the Dihing Formation forming the Mana Bhum Ridge and Arakan-Youma mountains (Krishnan, 1968) in the Brahmaputra Plain.

The sediments related to second and third cycles, generally described as the Quaternary deposits, formed extensive Indo-Gangetic and Brahmaputra Plains, between the Himalaya in the north, the Vindhyan ranges, Shillong Plateau and Arakan Youma mountains in the south (Text-figure 1). These Quaternary sediments were classified as the Older Alluvium and Newer Alluvium by Medlicott (1865) and as Pleistocene river terraces and alluvium in Brahmaputra Plain by Maclaren (1904). Wadia (1939)



Text-figure 1— Map showing location of Indo-Gangetic and Brahmaputra plains.



Text-figure 2—Map showing distribution of Late Pleistocene-Holocene sediments in Brahamputra Basin, Assam and Loktak Lake, Manipur.

classified these sediments as the Older Alluvium (the *Bhangar*) and Newer Alluvium (the *Khadar*) in the Indo-Gangetic Plain. This classification was accepted by Pascoe (1964) and most of the other workers.

The data generated during the last three decades in the Indo-Gangetic Plain, Uttar Pradesh and Bihar were synthesised by Kumar *et al.* (1996a, 1996b) and Sinha *et al.* (1995), respectively. The present paper synthesises the published data on the Brahmaputra Basin and adjoining inland basins (Anon, 1974 in Balasundaram, 1977; Goswami *et al.*, 1984; Kar, 1981 a, 1981b, 1990, 1991; Kar & Ramesh, 1984; Goswami & Kar, 1978, 1979; Khan, 1977; Goswami & Ramesh, 1979; Bhatnagar *et al.*, 1990; Satyanarayana & Kar, 1987; Sinha & Sinha, 1984; Buragohain *et al.*, 1995; Sinha *et al.*, 1995; Sinha, 1996) and traverses taken by one of us (SKK). The information is compared with that on the Indo-Gangetic Basin to establish lithostratigraphy for regional correlations with special reference to the Pleistocene-Holocene Boundary. The radiometric carbon dating and TL dating of samples were carried out at the Birbal Sahni Institute of Palaeobotany, Lucknow and Physical Research Laboratory, Ahmedabad, respectively.

PLATE 1

1, 2. Red silt-clay and light brown sand (T_5 Unit) unconformably overlying Tertiary Sandstone (Tipam Sandstone), Silchar, Assam.

3,4. Closeup view of the bouldery member (T_5 Unit) Jayrampur, Tirap District, Arunachal Pradesh.

5. Brown Silty-clay and sand sequence of T_4 Unit, Mirza, Kamrup District, Assam.

6&7. Occurrence of sand dykes in silty clay member of T_2 Unit indicating neotectonic activity in the area, Soalkuchi, Kamrup District, Assam.

8. Grey-sand, clay and pebbly sand sequence of T_2 Unit Chhayagaon, Kamrup District, Assam.

9. Orange brown clay (T_4 Unit) exposed on the bank of river Brahmaputra; Mirza, Kamrup District, Assam.

10. Exposed bank section of sandy clay and sand sequences of T_1 Unit, Saikhowaghat, district Tinsukia, Assam.

11. Grey sand and silt-clay sequence of T_2 Unit, Kamrup District, Assam.

12. Yellowish orange silty clay of T_3 Unit being mined for brick kiln purposes, Dibrugarh, Assam.

13. Contact of grey sandy silt (T_1 Unit) overlying the grey silty clay of T_2 Unit Soalkuchi, Kamrup District, Assam.

14. Contact relation between grey, silty clay of T_2 Unit and orange brown silty clay of T_4 Unit, Palasbari, Kamrup District Assam.

15. Contact relationship between grey silty clay of T_2 Unit and yellowish orange silty clay of T_3 Unit, Tinsukia, Assam.

16. Disconformable relationship between grey, calcareous silt of Newer Alluvium (Bhat Alluvium) and reddish brown silty clay of Varanasi Alluvium (Older Alluvium), East of Kasia, Uttar Pradesh.

17. Reddish brown silty clay with calcretes of Varanasi Alluvium (Older Alluvium), Auraiya, Uttar Pradesh.

18. Spatial distribution of T_1 and T_2 Unit Soalkuchi, Kamrup District, Assam.

19. Photo showing disposition of T_1 and T_2 Terraces of Rapti River, Gorakhpur, Uttar Pradesh.

20. Stabilised channel bar (T_0 Unit) of Brahmaputra River north of Palasbari, Palasbari District, Assam showing collection of sand samples.

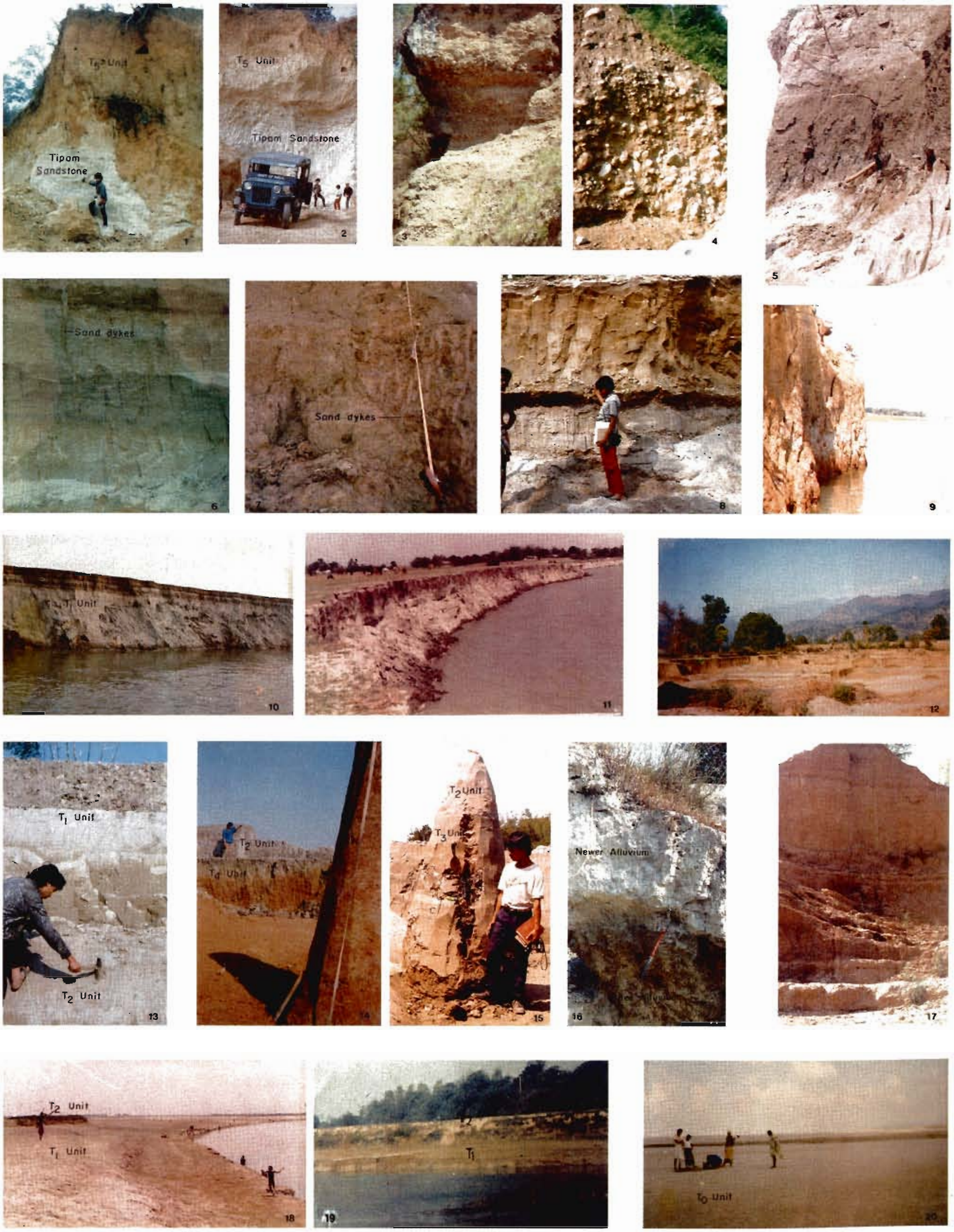
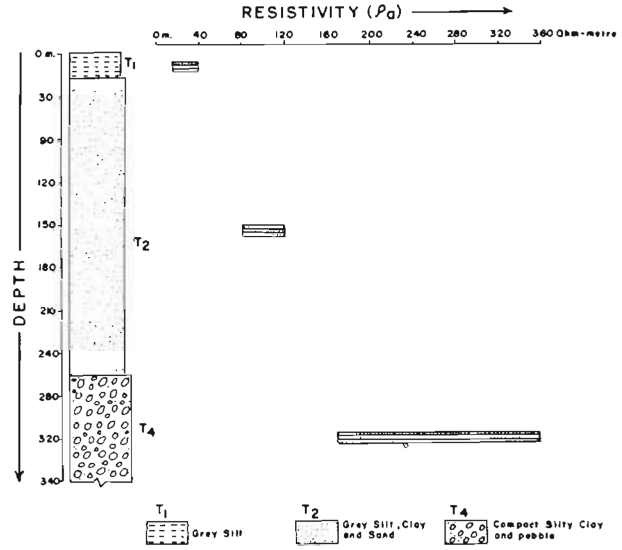

T_5 Unit
Tipam Sandstone
1
T_5 Unit
Tipam Sandstone
2
3
4
5
Sand dykes
6
Sand dykes
7
8
9
10
11
12
T_1 Unit
T_2 Unit
13
T_2 Unit
14
T_2 Unit
T_3 Unit
15
Newer Alluvium
16
17
T_2 Unit
T_1 Unit
18
T_1
19
T_0 Unit
20

PLATE 1

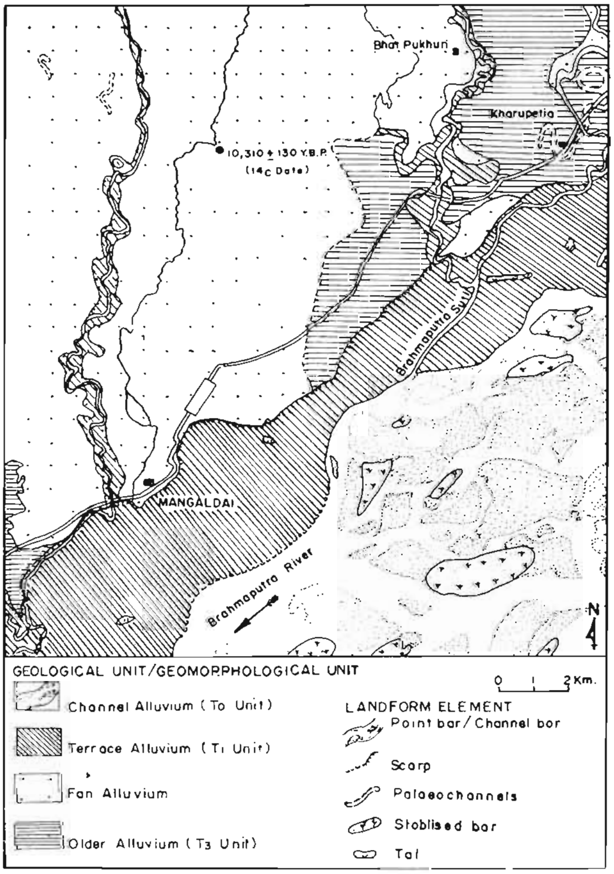
BRAHMAPUTRA BASIN

The Brahmaputra Plain in Assam, covering an area of about 56,000 sq km evolved during Middle Pleistocene period by alluviation of the depression formed between the sub-Himalaya and the Precambrian massif of the Shillong Plateau and the uplifted Arakan Youma Mountains due to post-Siwalik Himalayan Orogenic Movement. Its development is linked with phases of uplift, glaciation (?) and erosion of the Himalaya, and basement tectonics affecting the Shillong massif and the basin of deposition (Balasundaram, 1977).

The Quaternary sediments have been classified into Older Alluvium and Newer Alluvium (Table 1), the former forming high level terraces of either side of the valley and the latter superimposed over the Older Alluvium close to hill-fronts as fans and within narrow flood plain of the present rivers defined by their palaeobanks as low level terraces (Text-figures 2, 3). The Older Alluvium sediments show varying degree of oxidation and have higher resistivity due to their being semi-consolidated as compared to Newer Alluvium which is unoxidised (Text-figure 4).



Text-figure 4—Correlation diagram of resistivity vis-a-vis Quaternary sediments (data source- Rao, 1989)



Text-figure 3—Geological and geomorphological map of Mangaldai area, Darrang District, Assam (after Satyanarayan & Kar 1987).

Table 1—Generalised lithostratigraphy of the Quaternary deposits of Brahmaputra Basin

AGE	LITHOSTRATIGRAPHY	
		Channel Alluvium (T_0)
Holocene	Newer Alluvium	Terrace Alluvium (T_1)
		Terrace Alluvium (T_2)
		Alluvial Fan (Fa)
	Disconformity	
? Middle to		Older Terrace Alluvium (T_3)
Upper Pleistocene	Older Alluvium	Older Terrace Alluvium (T_4)
		Older Terrace Alluvium (T_5)
	Unconformity	
Upper Pliocene to Lower Pleistocene	Kimin (Upper Siwalik) and Dihing Formation	

Older Alluvium

It is a valley-fill deposit comprising three cycles of alluviation each separated by a period of non-deposition and erosion giving rise to three high level terraces (T_5-T_3) about 6-40 metres above the present level of the river. The sediments of the first cycle has widest and highest distribution on either sides of the Brahmaputra Valley and the subsequent cycles successively occupy narrower and lower levels (Text-figure 5). The sediments rest unconformably over the folded Siwalik Supergroup or over the Dihing

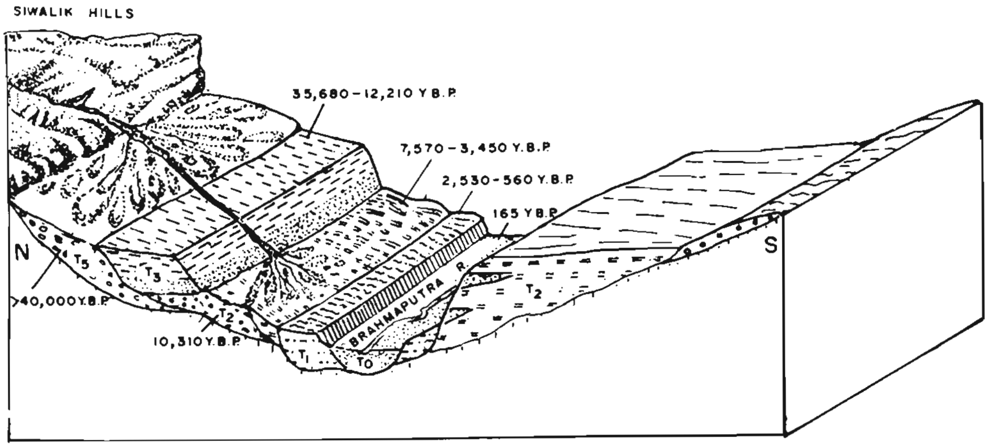
Table 2 — Radiometric (^{14}C) ages of Quaternary sediments from the Brahmaputra Valley and adjoining inland basins/lakes (samples dated by the Birbal Sahni Institute of Palaeobotany, Lucknow. BS refers to their Lab. Reg. No.)

GEOLOGICAL FORMATION		DATING MATERIAL	DEPTH OF SAMPLE (bgl) IN m	AGE (^{14}C HALF LIFE 5568 YR) IN YR BP	REMARKS
A. Newer Alluvium					
T_0	i.	Wood	1.0	100 ± 95	BS 627
	ii.	Wood	1.0	160 ± 90	BS 570
	iii.	Wood	1.2	165 ± 80	—
T_1	i.	Wood	1.6	560 ± 100	BS 572
	ii.	Wood	2.0	1,060 ± 120	BS 5626
	iii.	Wood	3.0	1,570 ± 90	BS 748
	iv.	Wood	2.0	1,780 ± 90	BS 750
	v.	Wood	4.5	2,530 ± 130	BS 747
T_2	i.	Wood	2.0	3,450 ± 110	BS 313
	ii.	Wood	2.5	7,570 ± 120	
Fan (Fa)	i. Mangaldai	Wood	25.0	10,310 ± 130	
B. Older Alluvium					
T_3	i.	Peat	1.5	17,920 ± 575	
Backswamp		Peat	1.4	12,210 ± 340	
T_4		Wood	2.5	34,680 ± 2960	
T_5	i.	Wood	1.75	35,680 ± 1810	BS 571
	ii.	Wood	12.5	38,020 ± 2230	BS 573
	iii.	Wood	2.2	40,000	BS 712
	iv.	Carbonised wood	34.3	> 40,000	BS 783
C. Fluvio-lacustrine, Loktak Lake, Manipur					
	i. 760 RL	Wood	2.0	1,780 ± 100	BS 147
	ii. 800 RL	Peat	5.3	11,470 ± 190	BS 145
	iii. 800 RL	Peat	10.0	25,465 ± 660	
	iv. 820 RL	Peat	2.5	32,560 ± 1170	
D. Hapoli Formation					
	Ziro Valley	Peat		40,000	
	Tale Valley	Carbonised wood		25,400 ± 750	BS 248

Formation, older Tertiaries (Pl. 1, figs 1, 2) and Precambrian basement rocks.

There is no data to construe the lower age limit for the sediments. The sedimentation in the basin probably initiated sometime during Middle Pleistocene and continued till late Upper Pleistocene, as indicated by the presence of peat in T_3 dating around 18,000 BP.

Older Terrace Alluvium (T_5) — This forms the highest terrace of the Quaternary landscape and abuts against the dissected mountain front of the Sub-Himalaya and is exposed almost continuously



Text-figure 5—Disposition of Late Quaternary sediments-across Brahmaputra River, Assam (model after clark & Williams 1986).

along the northern boundary of the Brahmaputra Plain (Maclaren, 1904), about 20-40 m above the river level. It also occurs in discontinuous linear zones on southern part of the basin. Deposited as superimposing mega-fans (the Chapar/Kuklong Formation—Poddar *et al.* in Balasundaram, 1977), it has a proximal end comprising semi-consolidated, poorly sorted melange of boulder, pebble, gravel, sand and silt with well developed soil profile. The pervasive pedogenic transformation imparts it blood red, brick red to ochre yellow colouration due to ubiquitous oxidation. Its distal end has characteristic laterised top. The reddish brown silty clay (2-4 m thick) is underlain by thick boulder bed (Pl. 1, figs 3, 4). Together with T_4 and T_3 units, it has been referred as Older Alluvium by Medlicott (1865). In Upper Assam, a carbonised wood associated with this unit indicates an age 38,020±2230 BP (Text- figure 1, i; Table 2).

Older Terrace Alluvium (T_4) — This unit has very limited distribution in the entire Brahmaputra Plain and occurs in detached and isolated outcrops (about one km wide) 15 m above the river level but 15-20 m below terrace T_5. It also occurs as a hummock in T3 terrace. A typical section at Parbatipur in Upper Assam exposes about 3 m of orange brown silty clay at top followed below by pebble-boulder sequence more than 20 m thick (Pl. 1, figs 9, 5, 14). It is well exposed around Palasbari, Kamrup District, and referred as "RED BANK" (Coulson, 1942). Its equivalent unit in Bangladesh Plain is referred as Barind (Horgan & McIntire, 1954). It corresponds to Sorbhog Formation in Manas Basin, Lower Brahmaputra Valley (Poddar *et al.* in Balasundaram, 1977). The radiometric ^{14}C date of 34,680 ± 2960 BP of entrapped wood comes from Khowai Valley, Tripura (Anon, 1968).

Older Terrace Alluvium (T_3) — This is the most extensively developed unit of the Older Alluvium. On the north bank of the Brahmaputra River it is exposed almost continuously in narrow belt from near Pasighat (Khan, 1977) to Sankosh River in the west, while on the south bank it is extensively developed forming wide plain between Namsai and Ledo and continues up to west of Jorhat. Its surficial extensions further in west have not been recorded/ mapped possibly due to subsidence of the area along NNW-SSE trending cross-fault along Dhansiri River, a south bank tributary of the Brahmaputra River (Text-figure 2). In a section at Tinsukia, the top 1.5 m, is composed of silty clay followed below by fine to medium sand more than 3 m thick (Text figure 1g). The soil development is reached up to ultisolic level. The typical colour is yellowish orange (Pl. 1, figs 12,15). At places, a black plastic clay or silty clay horizon, about 3.6 m thick, is encountered about 1-2 m below top, which in the basal part contains peat, carbonised wood and leaf-impressions. From near Tinsukia, a carbonised wood has been dated to 17,920 ± 575 BP. The T_3 surface hosts a number of back swamps which enclose peat beds dating 12,210 ± 340 BP (Table 2).

Newer Alluvium

This is the third and the youngest cycle of ongoing Quaternary sedimentation which initiated on the advent of Holocene. It is subdivided into three subcycles which, in ascending order, are represented by the Alluvial fan deposits, Terrace Alluvium (T_2-T_1) and Channel Alluvium (T_0). The alluvial fan deposits are superimposed over the Older Terrace Alluvium (T_3), while the latter two representing the flood plain deposits, are confined to present day channel courses and deposited over cut and eroded Terrace Alluvium (T_3) (Pl. 1, fig.15; Text-figure 2).

Alluvial fans — These mark the initiation of the Newer Alluvial cycle and are developed mainly along the northern hill front forming piedmont zone. In this zone the rivers draining the Himalaya and the Mishmi Hills debouch in the plain dumping their load in the form of alluvial fans of varying dimensions. Such fans are extensively seen upstream of the trijunction of the Brahmaputra, Dibong and Lohit rivers, and at other places, such as, Mangaldai (Text-

Table 3—Generalised Quaternary, lithostratigraphy of the Indo-Gangetic Basin and foredeep

AGE	LITHOSTRATIGRAPHY
Holocene	Channel alluvium and colovial fan deposits Terrace Alluvium Alluvial Fan deposits
	---- Disconformity ----
	Palaeo-aeolian deposits
	----Disconformity----
Middle to Upper Pleistocene	Varanasi Alluvium
	---- Unconformity ----
Upper Pliocene to Lower Pleistocene	Upper Siwalik and Banda Groups

figure 3). These fans are essentially made up of unoxidised sediments containing angular to subangular boulders in apical part and gradually grading to coarse sand at the distal end. The entrapped wood is dated 10,310 ± 130 BP. Similar fans of smaller dimensions are also developed along the northern margins of the Tertiary Hills in the southern part of the plain.

Terrace Alluvium — It is essentially a deposit of the present Brahmaputra drainage system which has been deposited as low-level terraces within the flood-plains of the rivers defined by palaeobanks. The sedimentation and development of the Terrace Alluvium is not uniform and continuous throughout the course of the Brahmaputra River. It appears to have been controlled by neotectonic block movements along N-S or NNW-SSE trending cross-faults such as Dhubri Fault (Gee, 1934), Manas, Dhansiri-Kopili faults, etc. The flood-plain is narrow with no or insignificant sediments if Terrace Alluvium (T_1) in uplifted blocks, such as between Guwahati and west of Goalpara. The development of about 60 km wide flood-plain with Terrace Alluvium (T_2) west of Dhansiri (south bank) River, may be due to down faulting of area to its west.

The sedimentation of the Terrace Alluvium has taken place in two phases, one forming the Terrace-T_2, about 3-4 m below T_3-surface. While the other, Terrace-T_1 is 1-3 m below it (T_2). The T_2 terrace comprises grey silty-clay and pebbly sandstone (Pl. 1, figs 8,11). Peat and wood associated with it at Hazo give ^{14}C age of 7,570 ± 120 BP. In the wide terrace, north of Palasbari in Soalkuchi (Hazo) area numerous sand dykes are seen (Pl. 1, figs 6, 7) which may be related to pre-historic earthquake in the area (Kar, 1990).

The Terrace T_1 (Pl. 1, figs 13, 18) is extensively developed downstream of Jorhat. It is continuously seen along the right bank of the Brahmaputra River up to Sankosh River. Its development along the left bank is restricted up to a few km. upstream of Guwahati and again downstream of Goalpara. The surface is replete with abundant channel features such as cut-off meanders, levees, backswamps in the form of numerous open water/marshy lands. It is composed dominantly of grey sand overlain by silt (Pl. 1, figs 10, 13). The ^{14}C dates of the wood fragments associated with some of the silty clay deposits in backswamp area and with sand in the terrace range between 2,530 ± 130 and 560 ± 100 BP (Table 2).

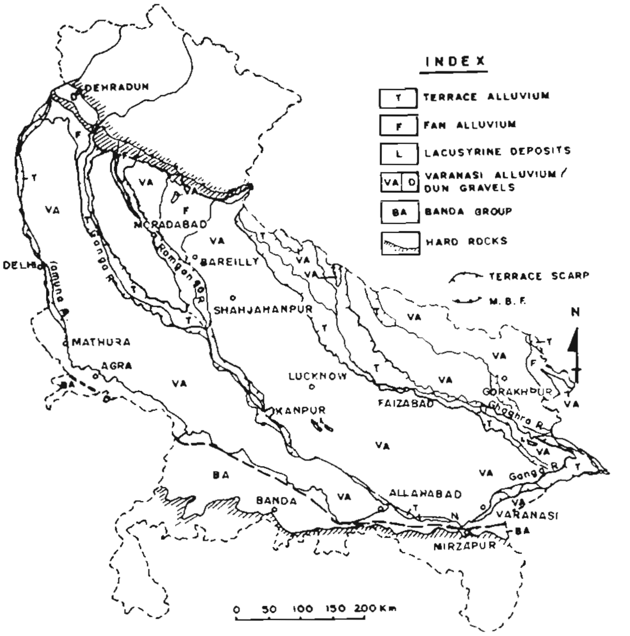
Channel Alluvium (T_0) — The present day active channel, defined by banks of the rivers, and its associated depositional elements like point-bar, channel-bar, meander-scrolls, etc. are grouped under T_0. These are dominantly sandy in nature. In one such established channel bar (Pl. 1, fig. 20) the decomposed vegetal matter gives ^{14}C dates 160 ± 90 and 100 ± 95 BP.

INDO-GANGETIC BASIN

It is one of the largest basins in the world of Quaternary fluviatile deposits. It extends from Indus Basin in the west to Ganga Basin in the east merging with Brahmaputra Basin in the Bengal Plain. Of these basins, the area covered by the Ganga drainage system lies between the sub-Himalayan ranges in north and the Vindhyan and the Chotanagpur plateau in south while that covered by the Indus lies between sub-Himalaya and the Aravalli ranges. The Delhi-Haridwar ridge forms the dividing line.

Lithostratigraphically, the sediments have broadly been classified as Older Alluvium and Newer Alluvium (Wadia, 1939), the former has been named variously in different section (Kumar *et al.*, 1996a, 1996b; Thussu, 1995; Saini & Anand, 1996; Saini & Mujtaba, 1996; Das Gupta, 1996; Roy *et al.*, 1987; Garg & Singh, 1991, 1992, 1993; Sinha *et al.*, 1995, 1996). The classification given by Kumar *et al.*, (1996a) is followed here with some modifications (Table 3).

In the modified classification, the Older Alluvium (Wadia, 1939) has been subdivided into Banda Group and Varanasi Alluvium. The former, coeval with the Upper Siwalik Group, was deposited in the Siwalik Basin or foredeep, and hence, does not form part of the sedimentation in the Indo-Gangetic Basin (Kumar, 1996b). The Varanasi Alluvium is most extensively developed and studied in the Gangetic Plain of Uttar Pradesh (Text-figures 6, 7). It rests unconformably over the Banda Group with development of a *kankar* conglomerate containing vertebrate fossils at base and continues eastwards to Bihar and plains of Bengal where it merges with the Older Alluvium of the Brahmaputra Basin. In the west, it continues into plains of Haryana and Punjab and further west in Pakistan.

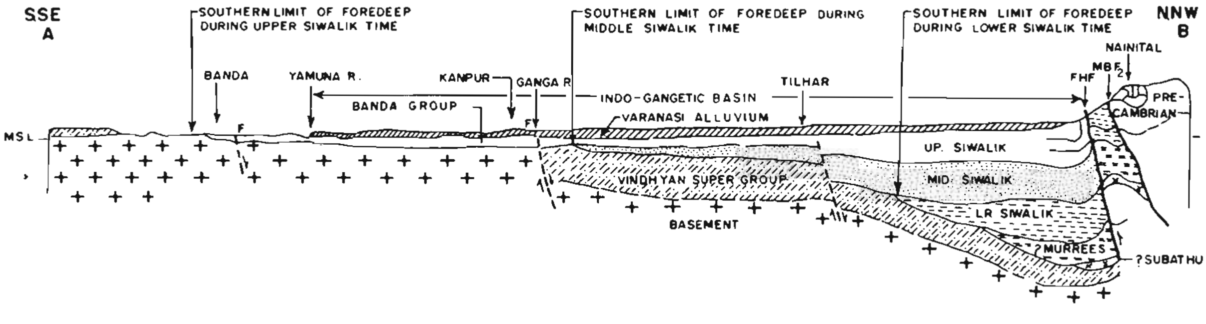


Text-figure 6—Quaternary geological map of Ganga Basin, Uttar Pradesh.

The Varanasi Alluvium comprises large coalescing mega-gans of material brought down from Himalaya and show considerable facies variation from rudaceous in apical part close to sub-Himalaya in north to an alternation of fine sand and lacustrine loamy silty clay at distal end in south. In Bihar plain, different facies have been named differently as distinct formations such as Ganauli, Hazipur, Maguraha, Volcanic Ash Bed, Thakurganj, Khutauna, Sonpur Formations, etc. by Sinha *et al*. (1995), which is untenable in the light of studies in Uttar Pradesh. It is significant that the Varanasi Alluvium also unconformably overlies the horizon yielding Lower Pleistocene vertebrate fossils equivalent to Upper Siwalik (Verma, 1997). An ash bed has also been recorded at the base of the rudaceous facies at Garjia in the Kosi Valley in Nainital District, Uttar Pradesh (Shukla & Kar, 1997). In Bengal plain, the Older Alluvium is represented by the Lalgarh Formation of which the Lower Lalgarh may correspond to the Banda/Upper Siwalik Group and the Upper Lalgarh, containing reworked laterite, vertebrate fossils and Palaeolithic tools of Middle to Upper Pleistocene age (Vaidyanathan & Ghosh, 1993), may be equivalent of the Varanasi Alluvium The sediments, in general, show varying degree of oxidation from dark reddish to yellowish-brown (Pl.1, fig. 17) with development of *kanker* (caliche) beds at 4-5 levels, each representing short break in sedimentation due to fluctuations in climate from warm humid to semi-arid or arid at different intervals. The other evidence for such breaks is the presence of a *kanker* conglomerate, about 30 cm thick, noticed in river bluff section at Kanar near Malihabad, Uttar Pradesh (Nigam, 1994).

The sedimentation of the Varanasi Alluvium terminated in Late Upper Pleistocene due to onset of cool climate related to last glaciation. The glaciation brought about withdrawal of drainage and development of residual lakes over the Varanasi Alluvial plain. These lakes were the sites for the deposition of grey lacustrine clays enclosing rich fauna comprising fresh water molluscs, ostracods, and charophytes which give ^{14}C date of 11,040 ± 190 BP, about 2 m below ground level (Joshi & Bhartiya, 1991). The palaeo-aeolian deposits were also formed in eastern Uttar Pradesh which have been referred as *Bhur* deposits (Dwivedi *et al.*, 1991, 1997; Khan *et al.*, 1991, 1992) and which give TL date of 10 Ka in western Uttar Pradesh (Table 4).

The Newer Alluvium of Wadia (1939) has been divided into three formations — the Alluvial Fan, Terrace Alluvium and the Channel Alluvium in ascending order. In addition, there are lacustrine deposits exposed in dried up or active lakes over the Varanasi Alluvial plain. The Newer Alluvium, as a



Text-figure 7—Generalised geological section showing configuration of foredeep and Indo-Gangetic Basin.

rule, is unoxidised. The Alluvial Fan deposits formed as a result of rejuvenation of the drainage system on return of warm humid climate on the advent of Holocene. These are superimposed over the Older Alluvium (Pl.1, fig. 16) along debouching points of the rivers close to sub-Himalaya. The evolution and development of the present drainage system is controlled by basement configuration and cross faults (Khan *et al.*, 1996; Prasad *et al.*, 1996).

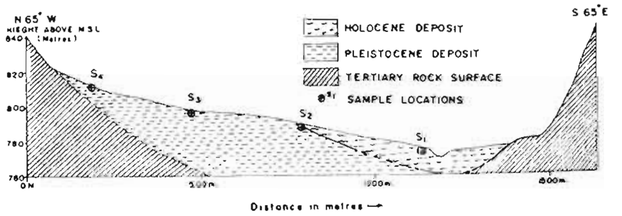
The flow direction of the rivers of the Indo-Gangetic Plain is controlled by the Delhi-Haridwar Ridge resulting in easterly flow of rivers of the Ganga System and westerly of the Indus System. The development of terraces, T_2 and T_1 (Pl.1, fig. 19) is discontinuous and controlled by neotectonic adjustments along cross-faults (Khan *et al.*, 1996) in area lying to the west of Monghyr Ridge (Sastri *et al.*, 1971) and not by fluctuations in the sea level. The effect of sea level changes may have controlled the development of the terraces in area to the east of the ridge. The TL ages of 4000-5000 BP and 3000-1000 BP are obtained from terrace T_2 and T_1, respectively (Table 4). In the Bengal delta, the corresponding ^{14}C date is 4,810±120 BP (Vaidyanathan & Ghosh, 1992).

The Channel Alluvium (T_0) is confined within the active flood plain of the rivers defined by banks. It occurs as point-bar, lateral bar, channel bar, etc.

The lacustrine deposits which correspond to the Newer Alluvium are seen in many palaeodrainage lines represented by cut-off meander-loops (ox-bow lakes) on the Varanasi Alluvial plain. It comprises grey clays with marl beds which have given ^{14}C age of 8,300 BP (Rajagopalan, 1992).

INLAND AND DUN (VALLEY) BASINS

A large number of small isolated inland and *Duns* basins developed contemporaneously with the formation of the Indo-Gangetic and Brahmaputra Basins during Himalayan Orogeny-4 both in the



Text-figure 8—Diagrammatic cross-section across Loktak Lake, Manipur.

Table 4—Radiometric (^{14}c) and TL ages of Quaternary sediments from the Indo-Gangetic Plain, Uttar Pradesh (samples dated at PRL, Ahmedabad)

GEOLOGICAL FORMATION	LOCATION	MATERIAL	DEPTH OF SAMPLE bgl IN m	AGE ^{14}C IN BP; TL IN Ka
A. Newer Alluvium				
T1	Ghaghra River near Dohrighat	Sand	1.0	1-2 Ka
T1	Yamuna River near Etawah	Sand	3.0	2-3 Ka
T2	Ganga River near Sareli (Badaun)	Sand	1.4	4-5 Ka
B. Palaeo-aeolian deposit				
	Mound near Shekhupur (Badaun)	Light brown sand	8.0	10 Ka
C. Older Alluvium				
Varanasi Alluvium	i. Sukhdevghat (Muzaffar Nagar)	Calcrete	15.0	12,740 ± 850 770 BP
	ii. Zamania (Varanasi)	Calcrete	10.0	12,290 ± 140 BP

Arakan Youma and the Himalaya. Here sedimentation coeval with the Varanasi Alluvium/Older Alluvium and Newer Alluvium took place. Some of these basins (lakes) are active where fluviolacustrine sedimentation is still continuing.

Basins in the Arakan Youma Mountain

One of the inland basins located in the Imphal Valley is the Loktak Lake (Pl. 2, figs 1, 2) that has been studied in detail (Kar, 1981; Ray & Sar, 1969; Sarkar & Chandra, 1980; Shukla & Mahapatra, 1986; Shukla, 1987). Earlier, Oldham (1883) had considered the entire Imphal Valley to have been formed due to erosion of the crest of an anticline in the Disang Formation. Of the Quaternary sediments, only 206.60 m have been studied (54.20 m of surface exposures and 152.40 m from a core of a drill-hole in the periphery of the present level of the lake; Text-figure 8). The drilling did not touch the basement rock (Ray & Sar, 1969). However, in an exposed section along the peripheral margin, Tureloo Valley, a lignite bed containing Pliocene-Pleistocene flora has been recorded (Bhattacharya, 1973).

The Loktak Lake sediments comprise unconsolidated boulder beds interbedded with grey to black clay with peat as seen exposed along the margin of lake. The boulder bed contains rounded to surrounded boulders and pebbles of siltstone and shale set in sandy matrix derived from the Disang Formation. The matrix in the boulder bed exhibits variable degree of oxidation from brown to yellow at the highest exposed level at 820 m, gradually reducing to greyish yellow mottled at 800 m to unoxidised at 760 m (lake level). The clay sediments increase in thickness towards the centre, and on exposure, forms hard and lumpy blocks (Pl. 2, fig. 3, 4). The C^{14} ages obtained from the peat are 32,560 ± 1170 BP at highest level of 820 m, 25,465± 660 BP at 810 m, 11,470 ± 190 BP at 800 m and 1,780± 100 BP at 760 m lake level. Palynological analysis of these samples at depth 15 to 20 m indicated a heterogeneous assemblage of ferns (Pteridaceae and Polypodiaceae), conifers (Pinaceae), monocotyledons and dicotyledons. The monocotyledons are represented largely by wild grass-pollen along with those of cultivated type. The dicotyledons are dominated by pollen belonging to the member of Anacardiaceae, Asteraceae, Euphorbiaceae and Rubiaceae. This assemblage indicates a Late Quaternary age (Sarkar & Chanda, 1980).

Basins in the Himalayan domain

A large number of intermontane basins, *Duns* (Valley) in the sub-Himalaya and inland basins in Lesser Himalaya are recorded. The *Duns* were formed after the folding and uplift of the Siwalik Supergroup during HOM-4 where sedimentation commenced in the Middle Pleistocene and is still continuing. One such *Dun*, is the Dehradun Valley in northwest Himalaya, Uttar Pradesh where the Quaternary valley fill— the Dun Gravels, have been classified as the Shyampur Formation and the Newer Alluvium, the former is considered coeval with the Varanasi Alluvium and the latter corresponds to Alluvial Fan deposits (Nambiar & Rai, 1994). Similar valley fills have also been recorded from western Nepal (Corvinus, 1995).

In the Lesser Himalayan domain, a large number of basins or lakes have been recorded. In eastern Himalaya, these are located in Ziro and Tale Valleys. In Ziro Valley, the fill constituting the Hapoli Formation (Shanker *et al.*, 1989), is exposed in three levels. The peat associated with the middle level gives ^{14}C age of 40,000 BP (Anon, 1978) while in Tale Valley the carbonised wood dates 25,400 ± 750 BP (personal communication by G.C. Vaz, GSI to SKK).

In Uttar Pradesh, a large number of desiccated and active lakes occur in Kumaun Lesser Himalaya. These include Nainital, Naukuchia Tal, Bhimtal, Sat Tal, Hawalbagh, etc. The Lake sediments exposed between Bhimtal and Naukuchia Tal have been studied by Kotlia (1995). In an exposed 52 m thick sequence, the fluvio-lacustrine deposits comprise 'conglomerate-mudstone-claystone with unconsolidated sandstone.' The conglomerate consists of angular clasts of mafic Bhowali Volcanic embedded in silt to gravel size matrix. It occurs at several levels each indicating, possibly, palaeo-landslides. The mudstones, silty in nature, show well defined laminations and are greyish to bluish in colour. Silty claystones are dark brown to reddish coloured and enclose several pieces of charcoal. The 'sandstone' layers are greyish to light brown and the one occurring about 10.5 m above the base has yielded Upper Pleistocene micromammalian assemblage of Soricidae and Muridae families. The radiocarbon dates of mudstone from 19.6 and 33 m above the base give ages 40,000 and 32,320± 2270 BP (Kotlia, 1995). Similar data is also available from Hawalbagh area in Kosi Valley, where the lake formed around 44,000 BP and lasted till 2,000 BP (Valdiya *et al.*, 1996).

DISCUSSIONS

A comparative study of the data available from the Brahmaputra Basin, Indo-Gangetic Basin and *Duns* indicates that sedimentation post-dates Siwalik/ Dihing Group in basins formed due to early Middle Pleistocene HOM-4, and appears to be more or less simultaneous. The sediments have been classified into Older Alluvium and Newer Alluvium, the former showing varying degree of oxidation, while the latter, are unoxidised. The only difference being the absence of *Kanker* (caliche) in the Older Alluvium of the Brahmaputra Basin which in the Indo-Gangetic Basin is found at 4-5 levels each representing a break of short duration in sedimentation related to changes in climate from warm humid to arid or semi-arid. Though, there is no development of the *Kanker* in the Brahmaputra Basin, these short breaks in

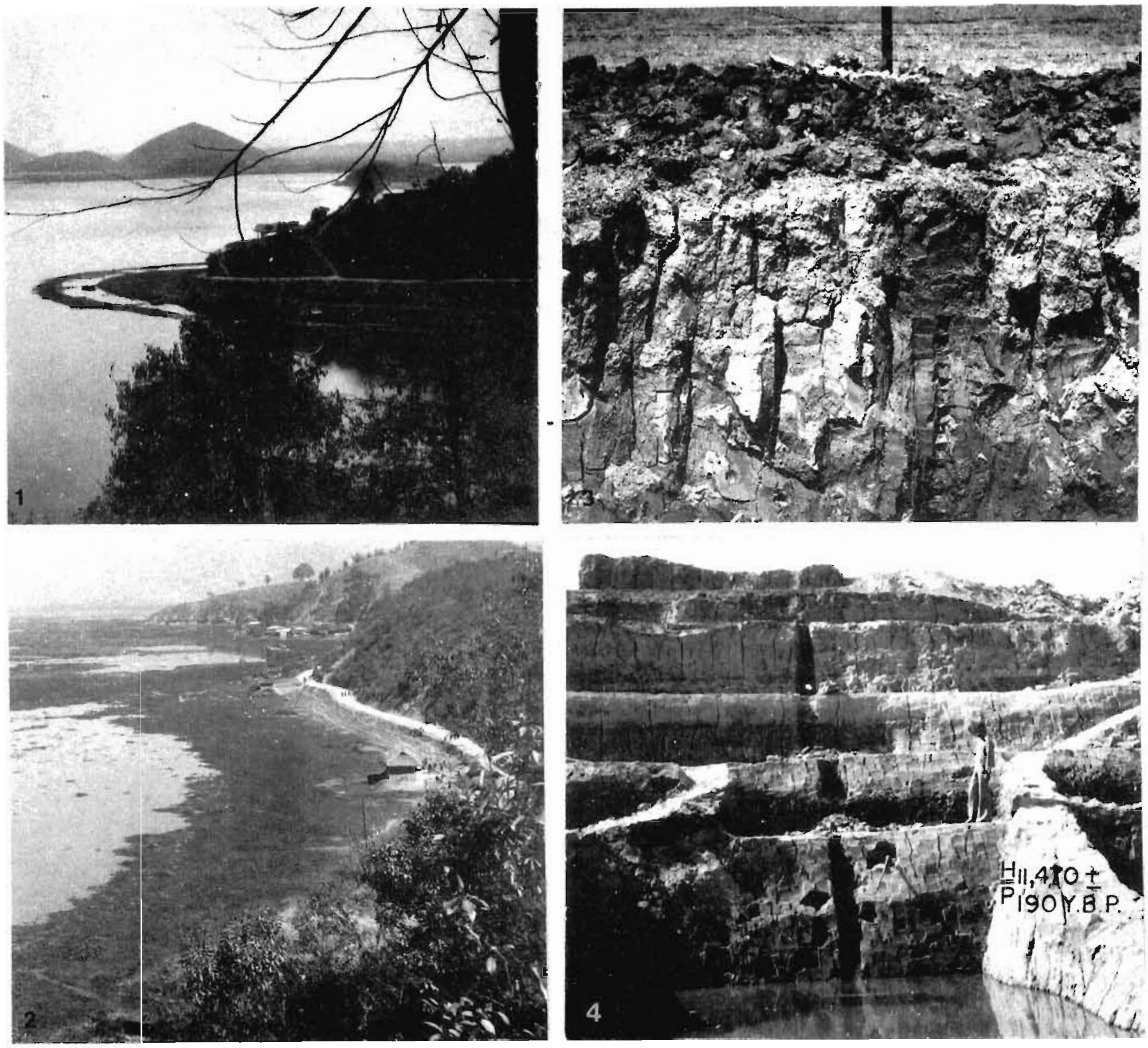


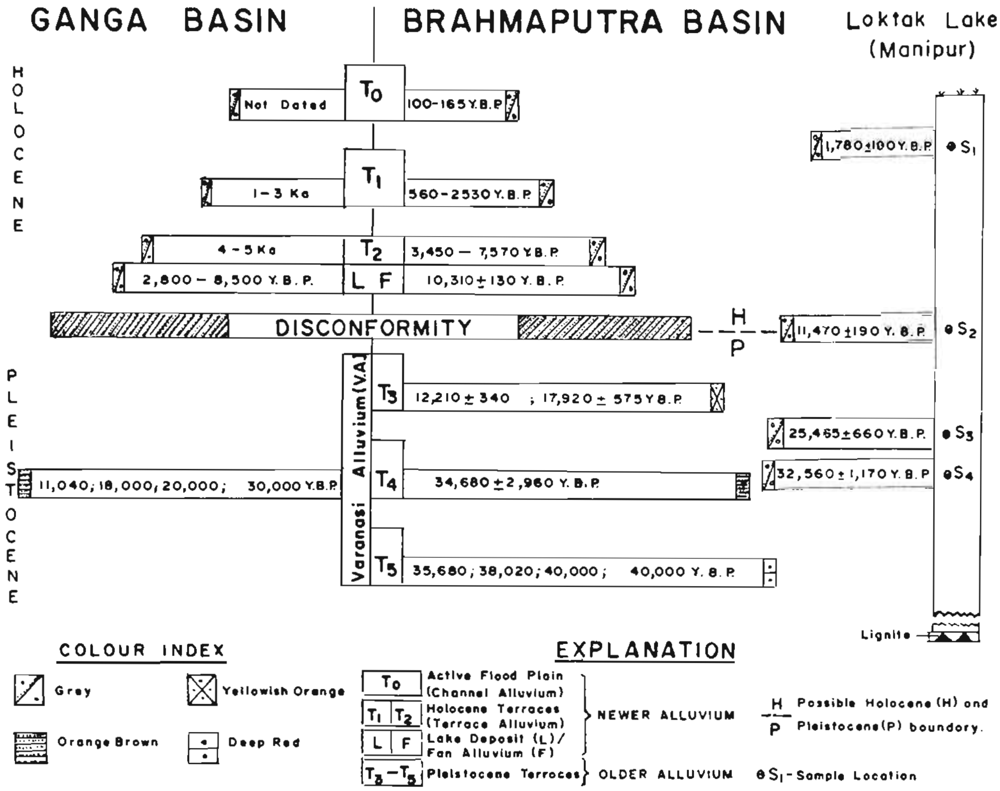
PLATE 2

1. View of Loktak Lake, Manipur.
2. Bog and peat accumulation around the Loktak Lake, Manipur.
3. Section exposing sticky black clay/peat deposit of Loktak Lake, Manipur.
4. Loktak Lake deposit showing possible Pleistocene-Holocene (H/P) interface.

sedimentation resulted in deposition of Older Alluvium in three sub-cycles, each separated by a period of erosion leaving wide benches (terraces) on either side of the Brahmaputra Valley. There is no data to indicate the lower age limit for initiation of sedimentation in the Brahmaputra Basin which in the Indo-Gangetic Basin commenced during Middle Pleistocene.

There appears to be an appreciable break in between sedimentation of the Older Alluvium and the Newer Alluvium in all the basins as the sediments of the latter are unoxidised. This break in sedimentation may be related to global cooling due to last glaciation towards the end of Upper Pleistocene resulting in cessation of fluvial sedimentation. The effects of this change in climate are also reflected in lowering of the sea level and impounding of water over T_3 terrace and Varanasi Alluvial plain.

With the return of warm humid climate on advent of the Holocene, the drainage rejuvenated



Text-figure 9 —^{14}C/T.L. records and possible Pleistocene-Holocene Boundary.

leading to deposition of younger alluvial fans of varying dimensions over the Older Alluvium and subsequently defining of courses of the present drainage system and their flood plains confined to palaeo-banks on either sides and deposition of Terrace Alluvium. The radiometric ages of 10,310± 130 BP from Alluvial fan and 7,570 to 3,450 BP (Text-figure 9) from terraces of the Mangaldai area, Assam are indicative of time of initiation of sedimentation of the Newer Alluvium and deposition of the Terrace Alluvium. This warming of climate is also reflected in a marine transgression around 14,500 BP along the West Coast of India (Nigam *et al.*, 1992). It is interesting that the data from eastern coastal region of China also suggest a transgression around 10,000 BP as it overlies a peat deposit dated 11,520±690, 11,510±570 and 10,800±140 BP, occurring at different depths (Song-Ling & Yun-Shan, 1985). The palaeomagnetic studies in this area also indicated an age of 12,350 BP (Morner, 1977). The palynological studies on sediments of the Tsokar Lake, Laddakh have indicated amelioration of climate 10,000 BP wherein a decline in steppe vegetation and increase of junipers has been recorded (Bhattacharya, 1989).

In inland Loktak Lake/Basin and other basins in Lesser Himalaya, there appears to be continuous sedimentation beginning sometime in Late Pleistocene (earlier than 40,000 BP) and continued into Holocene. The field observations in the Loktak Lake deposits show a gradual change in degree of oxidation from yellowish brown in Older sediments, dating around 32,560 BP, to unoxidised sediments giving an age around 1,780 BP. The sediments giving an age around 11,470 BP (Pl. 2, fig. 4) show mottled appearance of grey and yellow, hue and lie in between. This possibly indicates an interface between Pleistocene and Holocene.

PLEISTOCENE-HOLOCENE BOUNDARY

The demarcation of an epoch boundary requires a record of continuous sedimentation. The separation of the Pleistocene sediments (Older Alluvium) from the Holocene (Newer Alluvium) is primarily based on degree of oxidation. The oxidised sediments, in general, are assigned to Pleistocene while the unoxidised to Holocene. However, sediments of Older Alluvium, which were not exposed to atmosphere, do not show oxidation. Since the studies in the fluvial Indo-Gangetic and Brahmaputra Basins show an unconformable or disconformable relationship between the two, these areas are not suitable for demarcation of the boundary.

The studies from inland basins show almost continuous fluvio-lacustrine sedimentation from Late Pleistocene (around 40,000 BP) to Holocene (around 2,000 BP), and are therefore, ideally suited for demarcation of the boundary. The marked climatic changes at the Pleistocene/Holocene Boundary, from warm-humid to cooler related to last glaciation in Late Pleistocene and reversed to present warm-humid climate, may have their reflections not only in characters of sediments and rate of sedimentation but also in flora and fauna. The detailed studies on these aspects are lacking. In addition, studies on chemostratigraphy and magnetostratigraphy may also help in regional and global correlations for demarcation of the boundary.

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