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NEOGENE/QUATERNARY BOUNDARY IN THE SIWALIK

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ABSTRACT

During the last decade the increased interest in the Neogene/Quaternary boundary problem has opened up more questions on the selection of basic criteria for the determination of the boundary. The co-ordinated efforts of research workers of the world are expected to reach a consensus soon on the choice of criteria. The modern multidisciplinary approach of palaeomagnetic, radiometric, bio-stratigraphic and palaeoclimatic studies has established geochronological framework in some key sections of the world.

The limitation in the choice of basic criteria in the Siwalik hinders any direct determination of the Neogene/Quarternary boundary in it. For extrapolating the boundary much emphasis has to be given on palaeomagnetic and palaeontologic correlations with world stratotypes. The results of palaeomagnetic polarity measurements recently obtained in the Siwalik indicate that a detailed palaeomagnetic column is possible to be established which would help in recognising the boundary when it is matched with the standard palaeomagnetic time-scale of the world and supported by micromammalian correlation and palaeoclimatic interpretation.

At the present state of our knowledge the determination of the boundary should better be based on the exact correlation of the Siwalik faunal zones with that of the European stratotype where the Neogene/Quaternary boundary is well defined and dated. As such the correlation of Pinjor zone of Upper Siwalik with the Lower and Middle Villafranchian, and the synchroneity of other events in Pinjor-Boulder conglomerate transition suggest that the boundary may tentatively be drawn in the upper part of Pinjor.

INTRODUCTION

In recent years the Neogene/Quaternary boundary problem has become one of the most interesting as well as debatable stratigraphic problems in the world. The selection of basic criteria for the determination of Neogene/ Quaternary boundary still being in a formative stage, the recognition of this boundary in many regions based on evidences of general climatic cooling, as deduced from fossils, from the nature of sediments, from the fluctuation of sea-level, etc. remains controversial. The prevailing choice of basic criteria are mainly—(1) first climatic deterioration or onset of glaciation ; (2) first appearance of certain group of mammals, e.g., *Elephas-Leptobos-Equus* (E-L-E) Group (of Tobien) and certain microtines and microtoid cricetines, as well as disappearance of *Hipparion;* ; (3) appearance of Man ; (4) appearance and extinction of certain planktonic foraminifers, nanno-fossils and radiolarians ; and (5) ratio of extinct/ living molluscan species. Recently Selli's conception of 'Pre-Glacial Pleistocene' in deep sea cores has added to the list of criteria.

Though the study is much advanced in Europe a consensus of opinion is yet to be reached on a clear cut definition of the lower boundary of Pleistocene, which will have wider applicability in basic principle and would overcome the difficulties arising out of lack of necessary evidences of criteria in certain areas. Very recently an integrated study of modern palaeomagnetism, radiometry, biostratigraphy, palaeoclimatology and tectonism has indicated a more accurate chronological differentiation in Plio-Pleistocene times.

A marked discrepancy has been noted in the chronology of some geological events in different latitudes of the two hemispheres. A combined data (Berggren & Van Couvering, 1974) indicate that climatic cooling with concomitant onset of glaciation commenced in the late Cenozoic at 2.5 to 3 m.y. ago in middle latitudes in both north and south hemispheres, whereas it started in Antarctic continent much earlier at 4 m. y. ago. Thus the boundary based on climatic consideration is apparently diachronus having restricted value for world wide correlation. For such distinct correlations palaeomagnetic polarity measurements play an increasingly important role. Palaeomagnetic time-scale has been established in several Plio-Pleistocene deposits of the world by a combined study of geomagnetic polarity measurements and radioactive age determinations. A colmun of paleomagnetic events erected in certain deposits without having the possibility of radio-active dating, may be correlated with the matching events of the well dated

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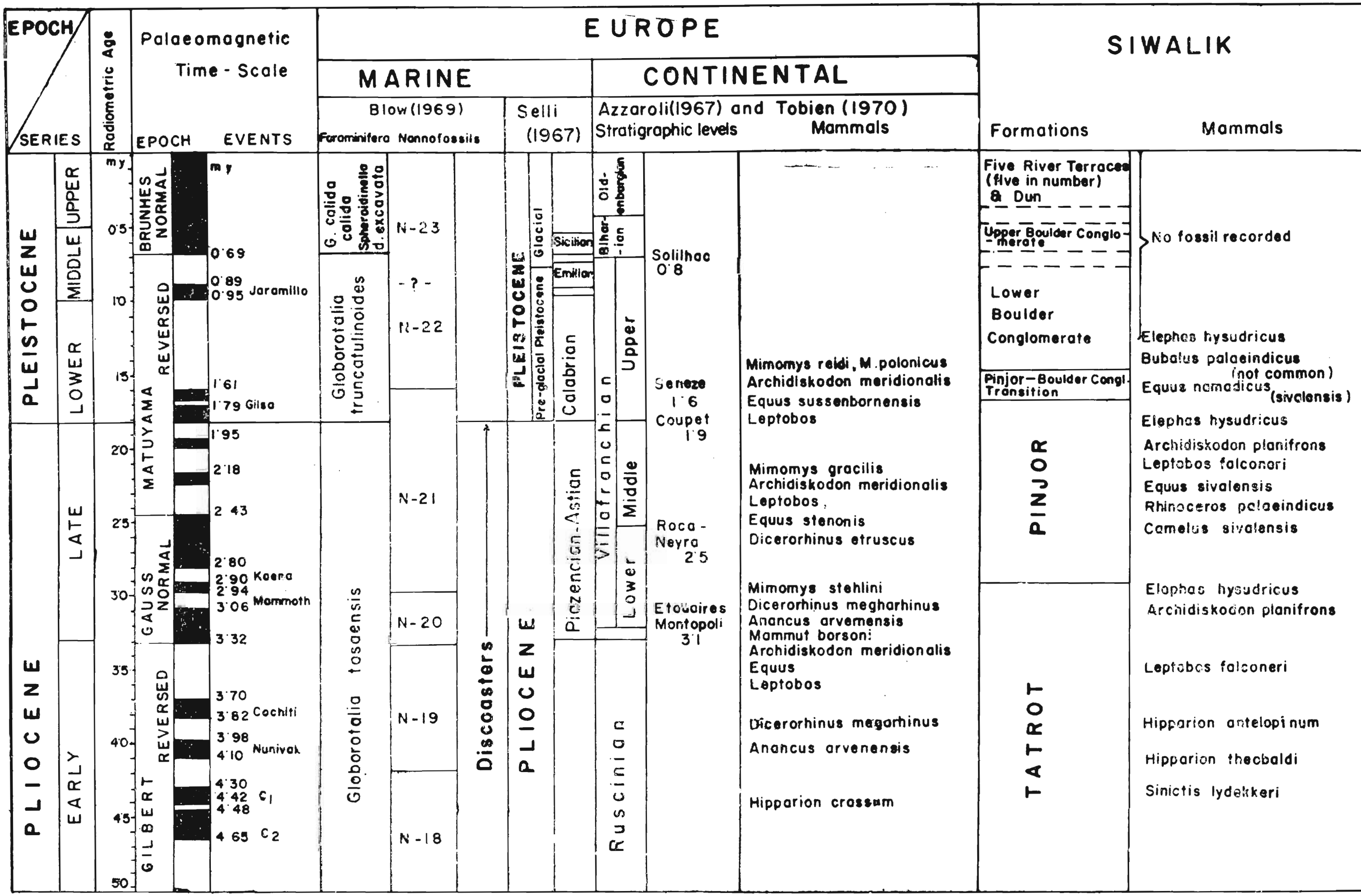
PLIO-PLEISTOCENE CORRELATION



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world standard column that may be supported by the changes in palaeontological and palaeoclimatic events. A geochronological framework would ultimately be established.

Our understanding, so far, of the Neogene/Quaternary boundary in the Siwalik is based largely on the interpretation of the mammalian distribution in the Upper Siwalik sequence. It is understood that primarily a stratigraphic boundary should indicate a prominent break in one or more of the geological events, namely, sedimentation, climatic condition, life, tectonic activity, geomorphic features, etc., the synchroneity of which is significant. A co-ordinated study in this direction has been undertaken in selected areas in the Siwalik with a view to establish the position of the Neogene/Quaternary boundary. The absence of any volcanic ash bed in the Siwalik precludes determination of absolute age of the deposits, while the lack of any marine intercalation prohibits correlation with Astian-Calabrian stratotype of Europe where the boundary is best recognised. Nevertheless the recent geomagnetic measurements point to the possibility of establishing a palaeomagnetic column in the Siwalik which can be matched with the standard column. Based on this the changes in the population of larger mammals as well as micro-mammals and also of palaeoclimatic changes as deduced from spore-pollen, micromammals, palaeosol character, etc. in the Upper Siwalik can be precisely correlated with those of the sub-divisions of type Villafranchian sequence (see chart).

RECOMMENDATIONS ON NEOGENE/ QUATERNARY BOUNDARY:

The following points of view on the definition of the boundary have been recommended by the INQUA Subcommission on Neogene/Quaternary Boundary:

(1) At the base of Astian and Piacenzian of Italian sequences corresponding to *Globorotalia tosaensis* Zone 21 of Blow's scheme (Banner and Blow, 1965), and to the base of Lower Villafranchian and their equivalents marking the beginning of Gauss Normal Epoch (3.3 to 3.5 m.y.);

(2) At the base of marine Calabrian of Italy corresponding to the base of *Globorotalia truncatulinoides* zone, coinciding with the base of Upper Villafranchian and with the beginning of Gilsa (formerly Olduvai) normal event of Matuyama Reversed Epoch (1.6 to 1.8 m.y.);

(3) At the base of Selli's Glacial Pleistocene coinciding with the base of Biharian, near the Matuyama/Brunhes Epoch boundary (0.69 to 0.7 m.y.). It corresponds with the maximum worldwide cooling marked by the appearance of *Globigerina calida calida* and *Spheroidinella dehisens excavata*, Zone 23 of Blow's scheme.

LATE NEOGENE CORRELATION

The Siwalik biochronology is based on the late Neogene mammalian correlation with the equivalents in the European stratotype sequence. As Siwalik exhibits a remarkable continuity in sedimentation right from Kamlial of early Middle Miocene to Pinjor of uppermost Pliocene, some of the key horizons precisely correlated with the well dated mammal horizons of Europe made it possible to establish the relative positions of other less prolific mammal horizons in the Siwalik. Dhok Pathan and Pinjor fauna are very precisely correlated with Pikermi-Samos-Salonica, and Lower-Middle Villafranchian fauna of Europe respectively. The Chinji, Nagri and Tatrot fauna though have directly been correlated with pre-Vallesian, Vallesian and Ruscinian respectively, it is strongly corroborated with the relative positions in respect of Dhok Pathan and Pinjor zones.

Hipparion fauna plays an important role in the correlation of Chinji and Nagri zones although controversy prevails regarding the first appearance of *Hipparion* in North America, Europe and Asia. The similarity of Chinji fauna with that of pre-Vallesian of Europe and Africa has been re-established by Gentry (1970) and Hussain (1971). Hussain emphasises that though *Hipparion* is reported to appear as early as in Chinji, the abundance of the genus at 300 m above the Chinji/Nagri boundary may in fact represent the first valid occurrence of *Hipparion* in the Siwalik. He puts the *Hipparion* datum in the Vallesian dated 12.5 m.y. The succeeding Dhok Pathan fauna demonstrates the differentiation of *Hipparion* into gracile and massive species which marks Turolian (10-6.5 m.y.) of Europe. The absence of *Hipparion* in the recent collection from the uppermost Chinji beds occurring near Ramnagar (Sastry & Dutta, 1977) and the presence of a large Primate fauna containing *Ramapithecus* (Dutta *et al* 1976) in this collection suggest a correlation with the Fort Ternan beds of Kenya which has been dated at 14 m.y. (Simons, 1972). Prasad (1970) has also assigned a Sarmatian age to Nagri zone of Haritalyangar.

Thus Pilgrim's contention that the Chinji has an inescapable Middle Miocene (i.e., pre-Vallesian) character holds good in the light of recent studies. He opines that the reported presence of *Hipparion* in Chinji is an instance of indigenous, parallel evolution, correlatable with the *Hipparion* fauna of North America.

Although *Hipparion* appeared in Europe and Africa in Upper Miocene it reached the peak of its development in Turolian. Similarly, *Hipparion* appeared in Upper Chinji with rare occurrence and also not very common in Nagri, but became most prolific with its proper environment in Dhok Pathan. Dhok Pathan fauna shows striking resemblance with that of the Pontian of Pikermi-Samos-Salonica as well as Turolian of Spain. The Samos fossil bed has been directly dated as 8.5 m.y. and Turolian is indirectly dated at 10 to 6 m.y. Turolian is tentatively equivalent to marine Tortonian correlatable with N16 zone of Blow's scheme.

Recent researches suggest that there are evidences of dessication of Mediterranian Sea marking completion of a sedimentary cycle at the end of Miocene. The age of the end-cycle has been estimated at 5 m.y. (Berggren and Van Couvering, 1974).

Thus placing Pontian in Upper Miocene, Van Couvering and Miller (1971) conclude that Matthew's proposition that appearance of *Hipparion* should mark the beginning of Pliocene in Eurasian land mammal biochronology stands invalid and abandoned.

That the Dhok Pathan fauna is exactly equivalent to Pontian of Pikermi has been strongly put forward by Pilgrim (1938) on the basis of similarities between Pontian *Tetralophodon longirostris* and *T. perimensis* of Dhok Pathan zone, and also Gomphotherium (Choerolophodon) appearing in Dhok Pathan and European Pontian.

The classification of Pliocene into early and late Pliocene by Bandy and Wilcoxin (1970), Bolli and Premoli-Silva (1973) and Berggren and Van Couvering (1974), (dated approximately between 5 m.y. and 1.8 m.y.) placed Ruscinian (Zanclian) and Piacenzian-Astian (Lower and Middle Villafranchian) into early and late Pliocene respectively (Berggren, 1974, fig. 11). Since the recommendation of the Subcommission on the Plio-Pleistocene boundary in early 60's, a considerable amount of data have accumulated which have drastically modified the earlier conceptions. Some of these points as put forward by Berggren (1974) are given below:

"1. Radiometric and palaeontologic information is in general agreement that the lower part if not all of the Villafranchian *s.s.* is of Pliocene age, and is equivalent, for the most part, the Astian/Piacenzian Stage.

2. Oxygen isotope (palaeotemperature) studies by Emiliani (Emiliani *et al.*, 1967) have revealed a general cooling trend across Pliocene/Pleistocene boundary in La Castella in Calabria, Southern Italy from an average summer surface-water temperature of 23-25°C in the Late Pliocene to about 15°C in the Calabrian".

The late Ruscinian and early Villafranchian fauna have common assemblages with only a few elements showing evolutionary replacements (Tobien, 1970). Similarly, Tatrot fauna has many common elements in Pinjor with primitive elephantids predominating over the just appeared advanced forms like *Elephas hysudricus* etc. The Pinjor fauna has strong resemblance with that of Et-Mo and also Roccaneyera Niveau corresponding to Lower and Middle Villafranchian, having at least one of the E-L-E group appearing in Lower Villafranchian of Europe. In Rumania, Southern Russia and some parts of Eastern Europe *Equus* appeared in Pliocene definitely earlier than *Elephas* and *Leptobos*. The first of the elephantids to reach Europe was *Mammuthus africanaus*. the presence of which in East Africa has been dated between 3.5 to 2.5 m.y., while the first record of *Equus* in East Africa is dated at 2.5 m.y. (Maglio, 1970). Maglio further points out that *Elephas* appeared in Lake Rudolf basin of Africa in Pliocene much earlier than *Equus*. Thus the earlier conceived first appearance of E-L-E Group to mark the beginning of Pleistocene does not hold good.

With the late Neogene correlation the Dhok Pathann and Pinjor zones could be decisively placed with Turolia and Lower-Middle Villafranchian respectively. The less diversified faunal zones of Chinji, Nagri and Tatrot may be correlated with Oeningian (pre-Vallesian) Vallesian and Ruscinian, respectively.

EXISTING VIEWS :

There exist several schools of thought regarding the position of Neogene/Quaternary boundary in the Siwalik, which are as follows :

(*a*) at the base of Tatrot—as drawn on the basis of palaeo-climatic and palaeontologic considerations suggested by Matthew (1929), Lewis (1937), DeTerra and Paterson (1939), Colbert (1951),

(*b*) between Tetrot and Pinjor—drawn mainly on palaeontological basis—put forward by Sahni and Khan (1964), Prasad (1970), etc.

(*c*) Pinjor as transitional passage between Pliocene and Pleistocene, suggested mainly on the basis of field data on stratigraphy and tectonicity, by Wadia (1943),

(*d*) between Pinjor and Lower Boulder Conglomerate zone on stratigraphic, sedimentational, tectonic, palaeoclimatic and palaeontologic considerations—persistently maintained by Pilgrim (1938—'44), Gill (1951) Balasundaram and Sastry (1972).

In the absence of any regional break between Dhok Pathan and Tatrot and considerable development of mammalian life in Tatrot as recently demonstrated by Sahni and Khan (1964) and later workers the first view stands invalid.

The second view has stressed too much on the appearance of *Elephas*, *Equus* and *Camelus*. But it has been sufficiently clear in the earlier chapter that this idea no longer stands strong. Also it is shown by Sahni and Khan (1964), Verma (1971) and others that even *Elephas hysudricus* appeared in Tatrot, and *Equus* is known from Tatrot since long.

However, during the last decade a major change has taken place on the method of approach to the problem and at the same time notable developments on the age and classification of Villafranchian type sequence, which is the world stratotype, offer ample scope for rethinking on the boundary problem in the Siwalik.

RECENT TRENDS

Lithological sequence and tectonic activity :

The non-interruption of the Siwalik sedimentation from Kamlial to Pinjor is now beyond question (Acharyya *et al* 1976) though there exist local disconformities which are penecontemporaneous. The frequent lateral and vertical facies variations throughout the Siwalik make it almost impossible to establish a regional lithostratigraphic classification from Kamlial to Pinjor. Kamlial to Pinjor is represented by alternations of sand-silt-clay and Boulder Conglomerate shows a marked change in lithology consisting of boulders, cobbles, pebbles with silty lenses.

The general nature of sand/silt/clay alternation suggests that the fluctuation in rate of sedimentation was more or less similar from Kamlial to Pinjor showing a decrease in the degree of compaction upwards. The geological map recently prepared by Dutta (1974) with the help of aerial photographs shows a unit of pebble bed/sandstone alternation in the upper part of Pinjor and is overlain by huge mass of cobbles and pebbles of Lower Boulder Conglomerate. This indicates a sudden increase in rate of sedimentation and energy of deposition. It is interesting to note that more or less similar mode of sedimentation persisted from Lower Boulder Conglomerate to Second river terrace.

The lithological succession and tectonic sequence established recently in Pinjor area by Sastry & Dutta (1977) are given below :

Formations		*Tectonic sequence*
Present Flood plain		
Extraordinary Flood Plain		
Fifth terrace		
Fourth terrace		
Third terrace		
Second terrace		
	Erosion	Basawlan Thrust; open upright folds
Dun		
First terrace		
	Erosion	Uplift
Upper Boulder Conglomerate (terrace ?)	Erosion	Lohgarh Thrust; reclined and decollement folds E-W Open refolding N-S Open asymmetric upright folds
Lower Boulder Conglomerate		
Pinjor-Boulder Conglomerate Transition (Pebble-sand alternation)		
Pinjor		
Tatrot ?		

Field evidences suggest that in the upper part of Pinjor the material supply suddenly became rapid due to one or more of the events, namely, rise in river gradient, continual tectonic activity, increased precipitation, etc. The tectonic activity intensified at the end of Lower Boulder Conglomerate by cross folding of Tatrot-Pinjor-Lower Boulder Conglomerate followed by a low-angle thrust (Lohgarh Thrust) accompanied by recline and decollement folding. Thus the beginning of the deposition of pebble/silty sand intercalation indicate the end of a prolonged sedimentational cycle in the upper part of Pinjor. Erosion followed the Lohgarh Thrust and the Upper Boulder Conglomerate was deposited showing prominent unconformity with underlying Lower Boulder Conglomerate. The tectonic activity reached its climax after the first terrace and Dun were deposited unconformably over Upper Boulder Conglomerate, by which the Upper Siwalik beds were thrusted over first terrcae and Dun on a high angle plane that became shallower in the upper part indicating a vertical uplift. This Basawlan Thrust runs for miles and swerves near Surajpur Cement Factory. This uplift resulted in the existing drainage system as shown by the Sirsa and Jhajra rivers originating in the Kalka hills flowing Southwestward parallelly take opposite courses near Lohgarh village, the Sirsa river strictly following the Basawlan Thrust north-northwest wards. The point of bifurcation of rivers near Lohgarh shows a structural knob due to the interference of different phases of movements.

It is thus evident that a remarkable change in the environment of deposition accompanied by intermittant tectonic activity started in the upper part of Pinjor and continued with pauses till the end of Dun or beginning of Second terrace.

Palaeontologic aspects :

The mammalian distribution plays the most important role in defining the Plio-Pleistocene boundary in the Siwalik. The species population though fluctuated with time in the Siwalik there does not exist any break in their development. The population growth was maximum in Dhok Pathan Zone, which occupies more or less the middle part of the Siwalik, then declined in Tatrot and again became prolific in Pinjor zone. The fauna met almost a total extinction in the Lower Boulder Conglomerate. Uptil now no fossil mammal has been reported from higher horizon of river terraces, while some equivalent Pleistocene deposits in Peninsular India have yielded a few Siwalik forms. Thus it is quite likely that in the later phases of Pinjor the change in environment was not congenial for mammals which resulted in migration and extinction. Some species of Pinjor zone are reported to be 'holdovers' from Dhok Pathan and are not reported from Tatrot. This may be due to chance missing or misreport of horizon which are not uncommon. Thus the apparent decline of species in Tatrot may be much less.

The differentiation of Tatrot and Pinjor on the basis of mammalian finds is difficult particularly in the Pinjor area, because of the presence of such important forms as *Archidiskodon planiforns*, *Elephas hysudricus*, *Leptobos falconeri*, *Hemibos triquetricornis* and also *Equus sivalensis* in both Tatrot and Pinjor (Sahni and Khan, 1964 ; Verma 1971). None of the recent workers point out any definite record of mammals from the Boulder Conglomerate. However, it may be emphasised here that though the above said species first appeared in Tatrot their population growth reached the peak, along with the proliferation of many other species, in the mid-Pinjor time. The recent finds of micro-mammalian fossils from upper part of Tatrot in Pinjor area indicate that further search should prove fruitful in the precise differentiation and detailed classification of Upper Siwalik.

It is intriguing that none of the palynological samples has yielded any positive result. The explanation of rapid deposition as a cause of destruction of spore-pollen does not hold good in case of quiet sedimentation of Tatrot beds. It is, therefore, expected that further studies will help in future.

Palaeoclimatic interpretation :

The palaeoclimatic conditions as deduced from mammalian fauna, from sedimentary characters, from the nature of palaeosol etc. point to climatic fluctuations right from Tatrot. The fluctuations of palaeotemperature and humidity was cyclic in Tatrot, more or less uniform in Pinjor, changing abruptly in Lower Boulder Conglomerate. Tatrot witnessed a fluctuation from warm-humid to cool-humid climate as indicated by cyclic repetition of successive development of warm-humid loving mammals and reptiles, an oxidized zone underlying a palaeosol containing moderately high percentage of humus. Pinjor zone witnessed a warm-humid in the lower part, warm semi-arid to arid in the middle part and colder-humid in the upper part. The Boulder Conglomerate experienced a cold-humid climate which was sufficiently intense to result in almost a total extinction and part migration of mammals during this period. This condition persisted in the later river terraces, the condition slightly changing only during the formation of Dun which formed in a drier climate and later deposited by rain-wash on the hill-slopes.

The third and fourth terraces containing loess indicate fluctuation between warm humid and hot arid conditions. Thus the most prominent change in the climatic condition has been demonstrated during the close of Pinjor.

Palaeomagnetic considerations :

The usefulness of palaeomagnetic studies has been found to be fruitful in the Siwalik, especially in solving the Neogene/Quaternary boundary problem. A pilot sampling done recently in the Upper Siwalik of Pinjor and Moginand areas by M. N. Alekseev and S. Tseitlin with the junior author, and studied in USSR by M. A. Pevzner resulted in some tentative correlation with the standard palaeomagnetic events of the world. Alekseev (personal communication) opines that Tatrot is likely to correspond to Gauss Normal magnetic epoch. The upper part of the Tatrot near Masol gives reversed magnetisation as also the samples of same horizon in Moginand area.

Thus the upper part of Tatrot may indicate the beginning of Matuyama Reverse epoch. The uppermost part of Pinjor is found to be normally magnetised. The vertical span between the two levels showing the duration of normal magnetisation as given by Alekseev is probably correlatable with the Gilsa Normal event (formerly Olduvai) of Matuyama Reverse epoch, and is likely to be longer than Reunion or Jaramillo Normal events of Matuyama epoch.

These geomagnetic events can be definitely matched with established world events. Systematic sampling at regular vertical intervals from Tatrot to Lower Boulder Conglomerate was done in the Pinjor area and the study of the same is in progress.

DISCUSSION :

At this stage the problem associated with the recognition of the Pliocene/Pleistocene Boundary in the Siwalik lies in the absence of any definite basic criteria. The conception of climatic cooling in the Siwalik as ushering in of Pleistocene has been demonstrated to be without any valid evidence, as also the criteria of appearance of E-L-E group. However, it is expected that Palaeomagnetic and micro-mammalian studies would provide the necessary solution.

With the present knowledge it is evident that there does not exist any datum plane which can demarcate Pliocene and Pleistocene in the Siwalik. The suggestion of Wadia to put Pinjor as a passage from Pliocene to Pleistocene is quite probable. The gradual passage may include any part of Pinjor. The recognition of the boundary at the top of Pinjor as suggested by Pilgrim, Gill, Balasundaram and Sastry based on the evidences of synchroneity of discontinuity in sedimentation, faunal development and climatic condition is quite convincing.

That there was no such climatic deterioration to the extent of glaciation in Pinjor is evident from the proliferation of warm-loving fauna in mid-Pinjor time.

It is discussed in the earlier chapters that the upper part of Pinjor represented by rhythmic pebble/sand alternation devoid of any fossil shows the first indication of change of climate, life, environment and initiation of final phase of Himalayan orogeny that became most intense in post-Boulder Conglomerate period with definite evidence of vertical uplift. This synchroneity of events and the precise correlation of Pinjor with Lower-Middle Villafranchian suggest that untill the multidisciplinary study is complete in the Siwalik the Neogene/Quaternary boundary may be tentatively placed in the upper part of Pinjor, if the base of Calabrian dated at 1.8 m.y. is taken as the Neogene/Quaternary boundary.

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