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PLIO-PLEISTOCENE BOUNDARY IN THE INDIAN SUBCONTINENT, WITH COMMENTS ON BOUNDARIES WITHIN THE PLEISTOCENE

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ABSTRACT

The Plio-Pleistocene boundary has been defined on the basis of evolutionary changes in the fossil biota, particularly the foraminifera, the appearance of some land mammals, and climatic changes. Based on major marine researches, the boundary has normally been placed either at 2.8 Ma, penecontemporaneous with the Kaena event, at 2.0 Ma when *Arctica islandica* first appeared, or at the Olduvai event or at 0. 73 Ma. The terrestrial records likewise suggest that the boundary should be placed at 2.5 Ma (Gauss/Matuyama boundary) or at the Olduvai event.

The Lower/Middle Pleistocene boundary is marked by the palaeontological, palaeoclimatic and palaeoenvironmental changes at the Matuyama/Brunhes transition (0.73 Ma). The beginning of the last interglacial period and high sea-level at about 127 Ka corresponding to the stage 5 of the oxygen isotope 18 scale may represent the Middle/Upper Pleistocene boundary. Based on the global climatic changes, the 10 Ka period is taken as lower boundary of the Holocene.

The author discusses the biostratigraphy and palaeoecology at the possible boundaries based on available mammalian faunas and sea- core data, and brings together the data on some well studied Plio-Pleistocene sequences of India.

INTRODUCTION

The Plio-Pleistocene boundary has proceeded along various lines of investigations, such as immigration of some mammalian genera, changes in marine fauna, palaeomagnetic changes, inferred climatic changes etc. The climatic changes alone can hardly be considered suitable for marking the boundary, although there are numerous oscillatory climatic cycles both below and above this boundary in the marine records (Hays, Saito, Opdyke and Bruckle, 1969). The correlation of only climatically defined boundary with first marked Late Cenozoic cooling can not be taken as the beginning of the Pleistocene as it took place in the Late Miocene. Furthermore, the initiation of glaciation plays no role in the definition and determination of the boundary (Hays and Berggren, 1971). The biochronology alone can assist only in correlating the regional sequences such as the rapid spread of a taxon. Therefore, the concepts such as; that the Pleistocene corresponds to the period of glaciations in northern continents, and, that it can be identified by the occurrence of *Bos, Equus and Elephas* (Haug, 1911) stands no more correct. It is more likely that a succession of phylozones is the most reliable tool in correlation and age determination because it directly reflects the irreversible evolution of life on earth. The time scale is based upon the radiometrically controlled palaeomagnetic time scale and the calibrations to it of biostratigraphic events.

The author believes that the integration of modern palaeomagnetic, marine biostratigraphic zones, geochronology and biochronological age corroborated by the deep-sea palaeoclimatological record can provide a better understanding of the Plio-Pleistocene boundary. The aim of this work is to identify the major events in the Upper Pliocene and Pleistocene along which the geological, palaeontological and climatic changes took place, and which can be used as the boundaries within that period.

The Plio-Pleistocene boundary in India has been drawn mainly on the basis of the Siwalik vertebrate assemblages and on glacial sequences at the base of Tatrot (Matthew, 1929; Lewis, 1937; Hooijer, 1952), at the base of Pinjor (Sahni and Khan, 1964; Nanda, 1976; Ranga Rao, Khan, Venkatachala and Sastry, 1981), and at the base of Boulder Conglomerate (Pilgrim, 1913; Wadia, 1951; Satsangi and Dutta, 1971; Sastry and Dutta, 1977; Badam, 1988). Matthew (1929) emphasised the joint occurrence of *Equus* and *Camelus* as rationale for recognition of the Pleistocene. Later on, *Elephas* was recorded by Lewis (1937) from the Tatrot which he directly included in the Pleistocene. Keeping in mind the Villafranchian fauna of the southern Europe, earlier workers suggested that beginning of the Pleistocene in the Siwaliks should be characterised by the occurrence of *Equus*, *Elephas* and *Bos* (Haug, 1911) — a view later on endorsed by the 18th International Geological Congress (1950). Koenigswald (1956) justified that the *Equus* and *Leptobos*, the guide fossils of Villafranchian of Europe, mark the beginning of the Pleistocene; true elephants (*Archidiskodon*) indeed occurring in all these faunas (some authors use *Elephas* to include what others describe as *Archidiskodon* and *Mammuthus*). The traditional principles on which the Plio-Pleistocene boundary was drawn in Europe were; immigration of new mammalian genera (E- L-E group), disappearance/ extinction of mastodonts, *Hipparion, Trilophomys* etc, and in-place evolution of morphogenetic lineages, e.g., *Mimomys* group (Tobien, 1970). The decisions of the 18th International Geological Congress had to be modified when the base of the marine Calabrian was found to be at a time interval equivalent to high in terrestrial Villafranchian. Therefore, the discussion of *Bos, Equus* and *Elephas* earlier in the Villafranchian becomes redundant to the boundary question. In the Indian subcontinent, the appearance of *Equus, Elephas* and *Leptobos* mark the beginning of the Pinjor faunal zone. However, the suggestion of marking the start of Pinjor faunal zone by appearance of *Equus* and *Bubalus* with complete absence of *Hipparion* and *Proamphibos* (Sahni and Khan, 1964) was revised by Opdyke, Johnson, Johnson, Tahirkheli and Mirza (1979) who announced the joint occurrence of *Equus, Proamphibos* and *Elephas* at 2.4 Ma and suggested that this might approach the joint occurrence of *Equus, Leptobos* and *Elephas* in the Villafranchian or Biharian deposits of Europe.

The study of magnetic polarity stratigraphy in the Siwaliks (Opdyke *et al.*, 1979; Azzaroli and Napoleone, 1982; Tandon, Kumar, Koyama and Nitsuma, 1984; Ranga Rao, Agrawal, Sharma, Bhalla and Nanda, 1988) demonstrated that the Tatrot/Pinjor boundary is correlatable with the Gauss/Matuyama boundary (2.48 Ma) and that the earliest appearance of *Equus* coincides with this boundary. Further data on the magnetic stratigraphy of fluvio- lacustrine sediments of Kashmir (Burbank and Johnson, 1982, 1983; Kusumgar, Kotlia, Agrawal and Sahni, 1986; Agrawal, Dodia, Kotlia, Razdan and Sahni, 1989; Kotlia, 1990), and of Kathmandu valley (Yoshida and Gautam, 1988) indicated that the Tatrot/Pinjor boundary coincided with the Gauss/Matuyama boundary when the first *Equus* appeared in the Indian subcontinent.

DATA FROM OCEAN CORES

The 18th International Geological Congress (1948) recommended that the Lower Pleistocene should include the marine Calabrian Formation in type area as its basal member and the boundary be defined by the base of the Calabrian Stage - the beginning of Golden Spike Concept. This approximates the first evolutionary appearance of some planktic foraminifers and abrupt extinction of discoasters like *Discoaster brouweri* at the Olduvai event (Berggren, Olsson and Reyment, 1967). It is very interesting to note that the first discoasters appeared about 75 Ma ago and flourished in equatorial and mid-latitude waters all through the pre-Pleistocene times but suddenly died out due to the possibility of fall in temperature of greater severity (Ericson, Ewing and Wollin, 1963). Saito (1969) noted that the extinction of *Globigerinoides obliquus* occurs near the Plio- Pleistocene boundary, dated as 1.9 Ma, the Olduvai event. Hays and Berggren (1971) concluded that the boundaries defined in the Pacific (Riedel, Parker and Bramlette, 1963), in the Atlantic (Ericson, Ewing, Wollin and Heezen, 1961), and in the Antarctic (Hays, 1965) were correlatable and dated as 1.8 Ma.

In New Zeland, while the climatically determined boundary is Late Pliocene Waipipian Stage at 2.5 Ma, the palaeontologically defined boundary is at the base of Hautawan Stage (basal Gilsa normal event) between 1.63 and 1.79 Ma (Watkins and Kennet, 1972). In the equatorial Pacific sediments, many species of foraminifers, diatoms and radiolarians became extinct around this time (Bruckle, 1969). Initial evolutionary appearances of *Globorotalia truncatulinoides* and *Gephyrocapsa* and extinction of *Globigerinoides obliquus* and discoasters are closely associated with the Olduvai-Gilsa event (1.61-1.82 Ma), hence these events offer more reliable means of correlating the boundary at the Olduvai event (Berggren and Van Couvering, 1974). Two more dates for the boundary were given, one in the Virca section, Calabria (studied by Selli, 1977) with an age of 2.0 Ma (Arias, Azzaroli, Bigazzi and Bonadonna, 1980; Harland, Cox, Llawellyn, Pickton, Smith and Walters, 1982), and other of 0.73 Ma (Bolli, Boudreau, Emiliani, Hay, Hurley and Jones, 1968). However, the level (dated to 0.73 Ma by Bolli *et al.*, 1968) was re-dated by Bruckle (1969) to 1.8 Ma accepting it as the Plio-Pleistocene boundary. Arias *et al.* (1980) found that *Arctica islandica*, the marker species for the beginning of Pleistocene, occurs in the clay pits of Rome, Italy at about 2.0 Ma. Most workers therefore marked the Olduvai event (preferably lower part) as the Plio-Pleistocene boundary till Haq, Berggren and Van Couvering (1977) gave further date of 1.6 Ma at Le Castella. Berggren, Kent, Flynn and Van Couvering (1985) confirmed this date for the boundary. The boundary has been placed at the top of Olduvai event (Aguirre and Pasini, 1985). Based on palaeomagnetic data from the Virca section in southern Italy, Tauxe, Opdyke, Pasini and Elmi (1983) proposed that the boundary should be placed immediately below the first appearance of *Cytheropteron testudo* at about 1.6 Ma. In Java, the Plio-Pleistocene chronology (fig. 1) has been worked out on the basis of the planktic and benthic foraminifera (Itihara, Kadar and Watanabe, 1985).

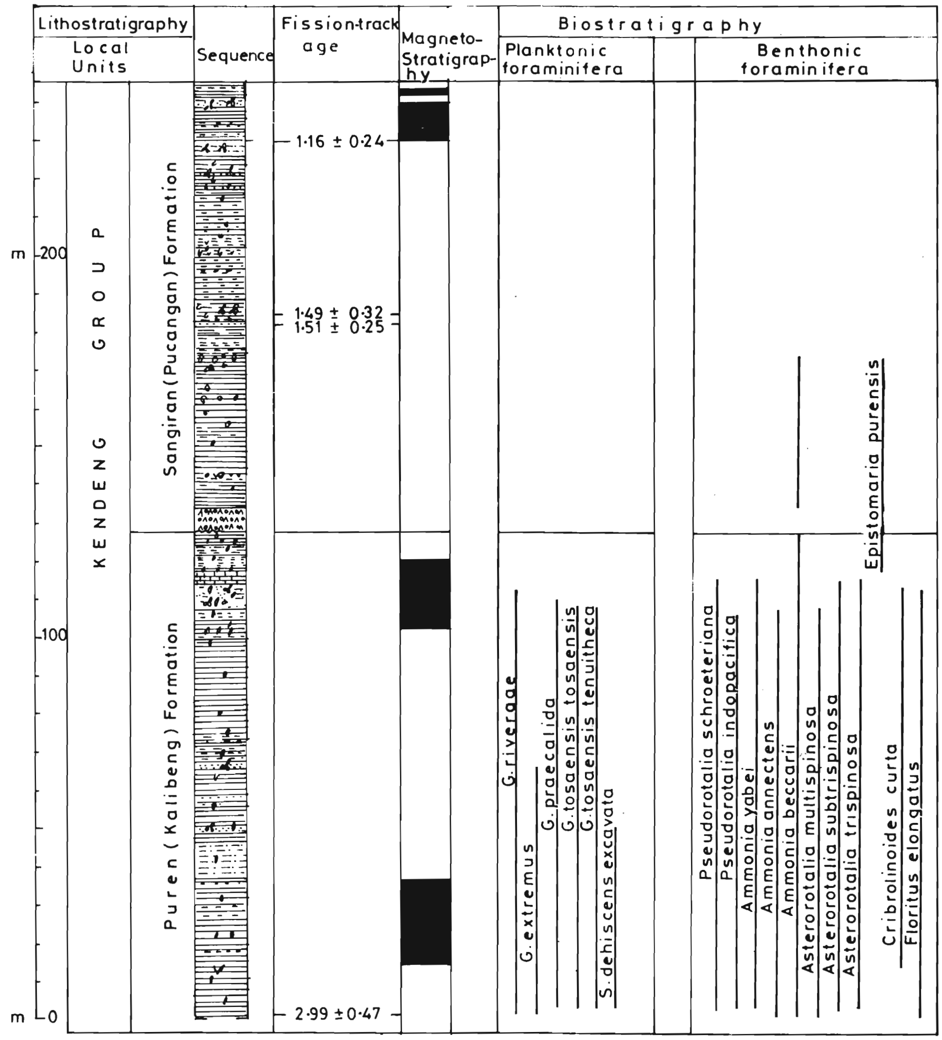

Fig. 1. Plio-Pleistocene chronology in the Sangiran area, Central Java (After Itihara *et al.*, 1985). *Globorotalia* occurs only in the Puren Formation.

The first attempt to demarcate the Plio-Pleistocene boundary in the Indian marine sediments was made by Srinivasan and Azmi (1976) who placed it at the level of the first appearance of *Globorotalia truncatulinoides* between the Shompenian and Taipian marine stages. The FAD of *G. truncatulinoides* was later on dated as 1.9 Ma (Srinivasan (1988). Based on the frequency, various curves of selected foraminiferal taxa showing significant changes, the base of Quaternary (the Olduvai event) is marked by a sharp decrease in abundance of *Uvigerina* and *Globocassidulina* due to drop in bottom water circulation (Gupta and Srinivasan, 1990). The *Globigerinoides fistulosus* last appeared at 1.6 Ma indicating this level as the boundary of Pliocene and Pleistocene (Singh and Srinivasan, 1993).

It is obvious that the oceanic data suggest dramatic climatic variation at the Olduvai event. A cooling trend (Ericson *et al.*, 1963) or warming (Hays *et al.*, 1969) or cooling with high salinity and high seasonality peaks (Haq *et al.*, 1977) has been observed following the Olduvai event. This palaeo-oceanic feature is contemporaneous with the Nebraskan glaciation in North America (Berggren and Van Couvering, 1974) and a period of erosion--the Aullan erosional phase (Arias *et al.*, 1980). The cold fauna consisting of *Cytheropteron testudo* appeared above the Olduvai event (Tauxe *et al.*, 1983). Bakeman, Shackleton and Tauxe (1983) proposed that the extinction of *Macintyrei* at 1.6 Ma was a good biostratigraphical approximation to the boundary.

DATA FROM TERRESTRIAL SEDIMENTS

In terrestrial sediments, specially those of the Indian subcontinent, the Plio-Pleistocene boundary is drawn at the Olduvai event (Keller, Tahirkheli, Mirza, Johnson, Johnson and Opdyke, 1977; Flynn and Jacobs, 1982; Kusumgar *et al.*, 1986; Badam, 1988; Kotlia, 1990), either at the top of Olduvai event or at Gauss/Matuyama

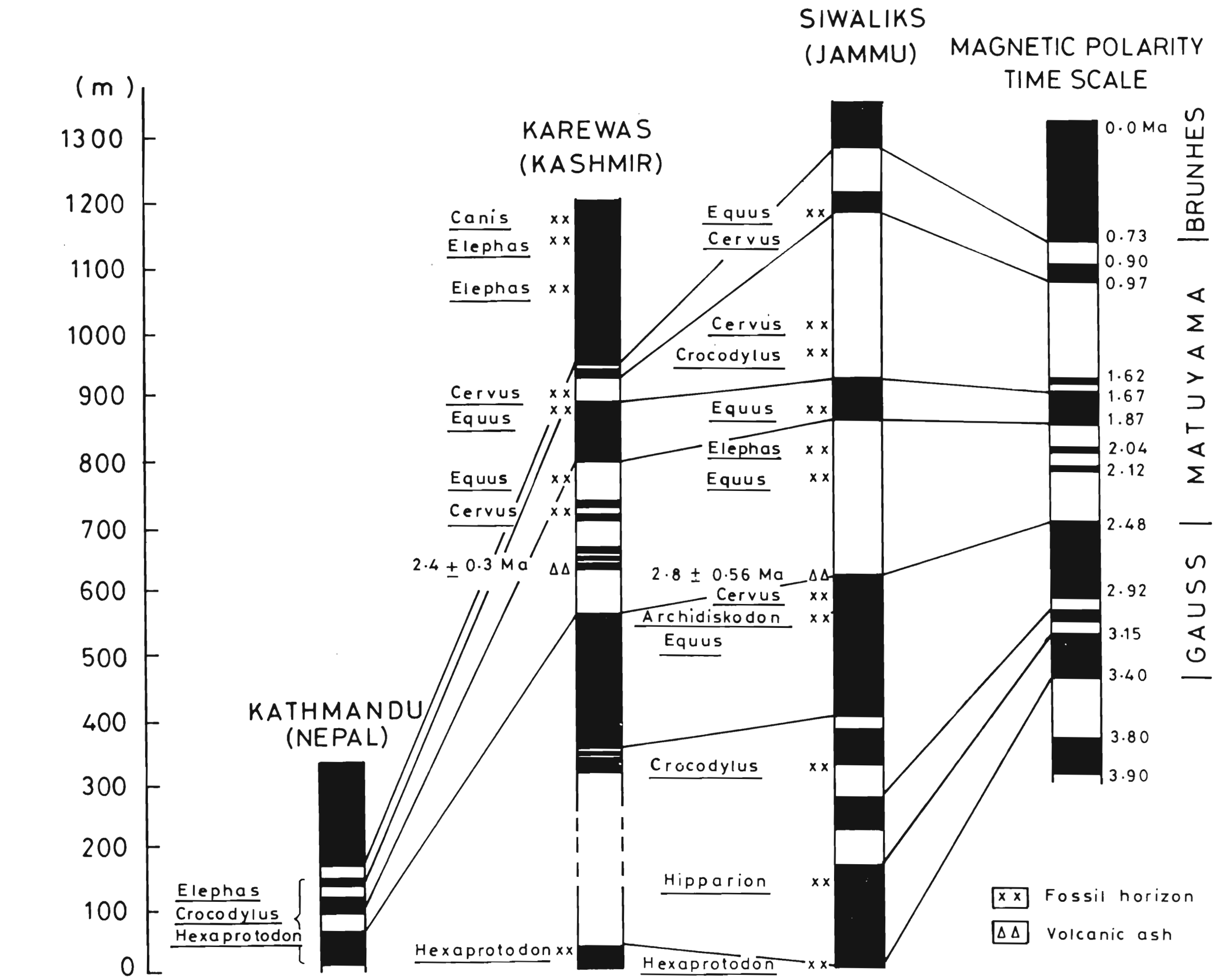

Fig. 2. Bio- and magneto-stratigraphy of the Siwaliks, Karewa and lacustrine deposits of Central Nepal (After Sahni & Kotlia, 1993).

boundary (Ranga Rao, 1988; Ranga Rao *et al.*, 1988). The boundary has been discussed on the basis of, (i) the occurrence of *Equus* in Pakistan Siwaliks (Keller *et al.*, 1977), (ii) major dispersal of large mammals such as *Mammuthus* (*Archidiskodon*) to North America and of *Equus* to Africa (Lindsay, Opdyke and Johnson, 1980), and (iii) the attainment of modern evolutionary grade in the rodent fauna of the Potwar Plateau with advanced *Mus* and modern *Golunda* without rhizomyids (Flynn and Jacobs, 1982). In India and Pakistan, *Elephas* (*Archidiskodon*) has various records in various places (fig. 2). In addition to the Pinjor, it is reported from Tatrot (Lewis, 1937), from the Kaena event (Opdyke *et al.*, 1979; Barry, Lindsay and Jacobs, 1982), surprisingly even from the Gilbert epoch (Ranga Rao, 1988, fig. 6), and also from the Brunhes chron (Kotlia, 1990; Sahni and Kotlia, 1993). If the date on *Elephas* goes down as far as to the Gilbert epoch (Ranga Rao, 1988, fig. 6), then it could not have played very important role with *Equus* and *Cervus* in the "faunal change" at the beginning of the Pinjors. *Equus* and *Cervus* with antlers, on the other hand, appeared in the subcontinent at about 2.5 Ma coinciding with Tatrot/Pinjor or Gauss/Matuyama boundary (fig. 2). A few important vertebrate fossils from Tatrot and Pinjor formations of the Siwaliks are given in Table 1. Regarding the vertebrates, Opdyke *et al.* (1979) listed a number of taxa including *Canis*, *Mustela*, Viverridae, *Hyaena*, *Felis* and *machairodus* which appeared following the Olduvai event. The micromammals like Soricidae, Leporidae and Muridae appeared slightly later. Some micromammals (*Mus*, *Golunda*, cf. *Rattus*) appeared at the Olduvai event (Flynn and Jacobs, 1982). In the Kashmir basin, the arvicolids have been reported from the Olduvai event (Kotlia, 1985; Sahni and Kotlia, 1985). A single horizon in the Karewas after the Olduvai event has yielded the fossil fishes in comparison to fourteen horizons below this level (Kotlia, 1989).

Table 1: Stratigraphic distribution of some important fossils from the Tatrot and Pinjor Formations (After Gaur, Vasishat & Chopra, 1978)

Name of genus/ speciess	Upper Siwalik Sub Group	
	Tatrot Formation	Pinjor Formation
RODENTIA		
Rhizomyoides pilgrimi	A	P
Rhizomyoides pinjoricus	A	P
PROBOSCIDEA		
Archidiskodon planifrons	P	P
Hypselephas hysudricus	P	P
Elephas hysudricus	A	P
Elephas maximus	A	P
PERISODACTYLA		
Hipparion theobaldi	P	A
Equus sivalensis	A	P
Equus namadicus	A	P
ARTIODACTYLA		
Hexaprotodon sivalensis	P	P
Cervus sivalensis	P	P
Cervus punjabiensis	P	P
Cervus triplidens	A	P
Giraffa sivalensis	A	P
Leptobos falcorni	A	P
Bos planifrons	A	P
Bison planifrons	A	P
REPTILIA		
Crocodylus sivalensis	P	P
Crocodylus palaeindicus	A	P

In North America, the boundary is placed at the bottom of Olduvai event marked by the appearance of *Lepus* at about 1.9 Ma (Johnson, Opdyke and Lindsay, 1975). In Europe, the boundary is at about 1.85 Ma near the base of Olduvai event (Brunnacker, Loscher, Tillmans and Urban, 1982). The mammalian fauna of the Astian (Upper Pliocene) in France lacks *Equus* whose appearance elsewhere is thought to be the beginning of the Quaternary (Kowalski, 1971). However, stratigraphic equivalents of *Equus* occur in the eastern Europe and Asia (Nikiforova, 1969). Based on this fact, the Soviet palaeontologists have included the Astian period in the Quaternary. In Japan, the Olduvai event has been considered as a convenient starting point for the Pleistocene at which point climatic deterioration eliminated the Pliocene flora (Sohma, 1986). There, the boundary has been placed at the Olduvai event (Itihara *et al.*, 1986; Kawamura, 1991).

It is obvious that the Olduvai event is tied with a faunal change- from the Villanyian to the Biharian times in Europe, and from the Blancan to the Irvingtonian times in North America. This event of change is characterised by the most dramatic dispersal of Holarctic arvicolids (Repenning, 1983).

The arvicolids belong to a fast evolving group which is closely associated with plant cover, and for this reason they are more useful than the large mammals in palaeoclimatic and biochronologic studies. The presence of *Allophiaomys* (Martin, 1979) has helped fix the bound-

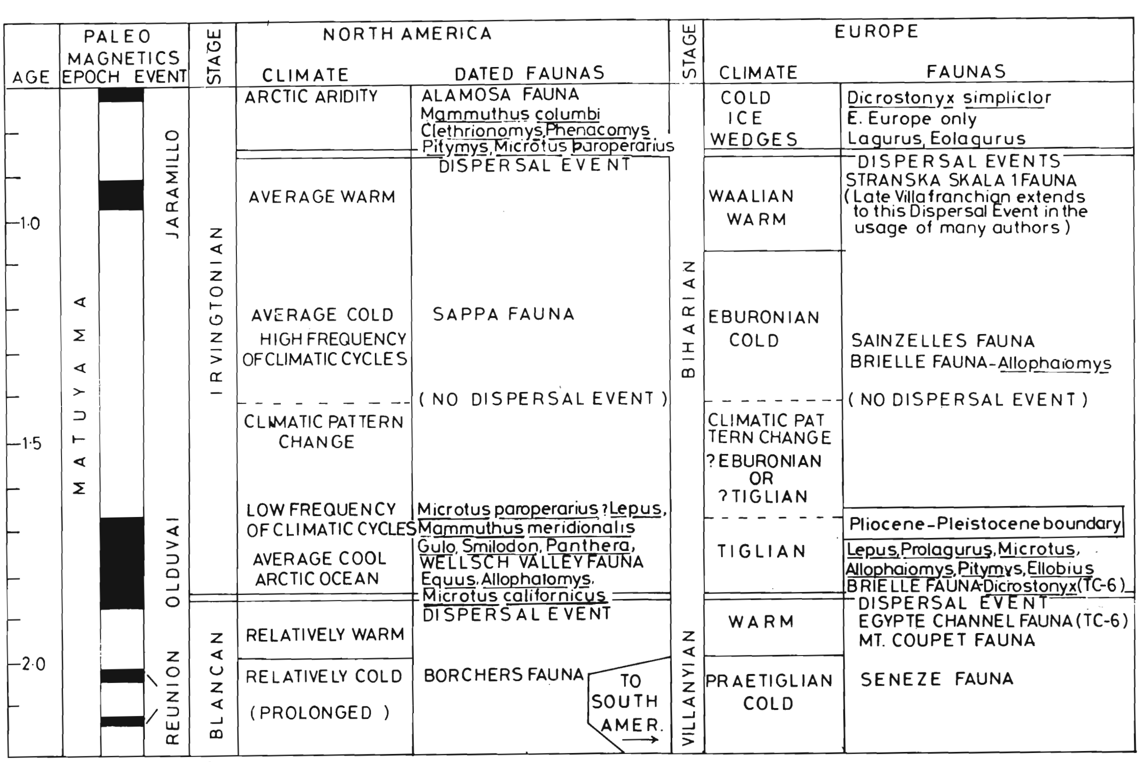

Fig. 3. Correlation of European and North American Pleistocene events with time (After Repenning, 1983). The Early Pleistocene arvicolid dispersal event separates the Blancan from the Irvingtonian.

ary in North America between Blancan and Irvingtonian fauna (fig. 3). The beginning of the Pleistocene (1.7 Ma) is correlated with part of Tiglian flora of Europe, return of arboreal vegetation to northeastern Siberia and the introduction to both North America and Europe the most distinctive arvicolid rodent fauna ever evolved (Repenning, 1985). During the uppermost Pliocene, there was conspicuous arvicolid (*Mimomys*) radiation in Europe (Steininger, Rabeder and Rögl, 1985). The Early Pleistocene is characterised by a prominent faunistic event- the *Allophaiomys* horizon, and *Microtus* obtaining a remarkable distribution throughout the Northern Hemisphere (fig. 3). The Early Pleistocene *Mimomys* lineage (*Mimomys occitanus- ostramosensis*) is characterised by an important increase in hypsodonty, change in occlusal pattern and appearance of cement. These characters seem to be a response to adaptive disequilibrium induced by a global climatic change (Chaline and Laurin, 1986). At the Olduvai event, many rootless arvicolids (e.g., *Allophiaomys, Microtus* etc.) appeared, and there was a first major arvicolid dispersal southward from Beringia to the Rocky Mountains. The change in the arvicolid rodent community above the Olduvai event in western Siberia corresponds to the Neogene/Quaternary boundary (Zazhigin, 1991). In India, the Olduvai event is marked by the extinction of *Kilarcola* (Kotlia and Koenigswald, 1992; Kotlia and Mathur, 1992). The combined data on both mega and micromammals therefore suggest that a major microfaunal change occurred during the Olduvai event at which time a similar faunal change took place throughout the world.

CLIMATIC INTERPRETATIONS

The oldest appearance of arvicolids in Kashmir is dated as about 2.5 Ma (Kotlia and Koenigswald, 1992). The palaeoclimatic results obtained from the Kashmir Karewas by using various techniques are given in fig. 4. The arvicolid level, earlier described as marking the N/Q boundary (Kusumgar *et al.*, 1986), now seems to represent the re-appearance of this fauna. The Karewa arvicolid biochronology thus starts from about 2.5 Ma (Gauss/Matuyama boundary) when the first glaciation took place in the Northern Hemisphere (Repenning, 1983). Pollen data from the Karewas show that this period is characterised by progressive cooling (Agrawal *et al.*, 1989). The ocean core data (Shackleton *et al.*, 1984) bear testimony to the onset of glaciation between 1.7 and 1.8 Ma. Then followed a prolonged cold phase, resulting in an extensive continental ice sheet in North America (Repenning, 1983), and extinction of the freshwater malacofauna in the western Siberian plains (Zykina & Kazanskiy, 1991).

In the northern Indian Ocean, a major shift in the isotopic signal has been recorded at 1.6 Ma (Singh and Srinivasan, 1993). On the basis of carbon isotope studies of the Karewa deposits, (Krishnamurthy, Bhattacharya and Kusumgar, 1986) have shown that there was a cold phase during the Olduvai event (fig. 5). The occurrence of arvicolids (Kotlia and Koenigswald, 1992) confirms this. The cold climate at about 1.9 Ma has been established in the Karewas by analysis of clay minerals (Jonathan, 1992). It may be mentioned that the Kashmir basin was affected by a very strong tectonic event 1.7 Ma ago (fig. 4) when the Karewa sediments uplifted (Burbank and Johnson, 1983). In the Kathmandu valley of Nepal, a distinct climatic deterioration at the Olduvai event has been established on the basis of palynological work (Igarashi, Yoshida and Tabata, 1988).

DISCUSSION

The vertebrates are ideally suited as time markers for Neogene/Quaternary sediments. Unfortunately, there is still a lack of systematic biostratigraphical data based on the testimonies of mega and microvertebrates. So far, this has not been obtained because of the lack of measured sections, the absence of information about migration time lags for biostratigraphically significant markers such as *Equus*, and the occurrence of holdovers in more modern faunas as indicative of an older age for those fauna. A striking example of this may be the occurrence of *Hipparion* in younger beds, 1.5 Ma in age (Opdyke *et al.*, 1979; Barry *et al.*, 1982). Both *Hipparion* and *Equus* invaded Eurasia from North America and suddenly became the dominant faunal elements. Although stratigraphers have regarded them as firm boundary markers, this can only be supported by other evidence.

We conclude that *Equus* is pre-Pleistocene. In the Karewas, *Equus* and *Cervus* with antlers appeared a little later than in the Siwaliks. The Plio-Pleistocene boundary in the Kashmir intermontane basin lies at the Olduvai event coinciding with a cold period (Krishnamurthy *et al.*, 1986) and is marked by the occurrence of Holarctic arvicolids (Kotlia and Koenigswald, 1992; Kotlia and Mathur, 1992; Sahni and Kotlia, 1993). This event may be correlated with tectonic activity along the Main Boundary Thrust Complex that was a precursor to the major uplift in the Pir Panjal range which led to the cessation of widespread intermontane sedimentation at about 1.7 Ma (Burbank and Johnson, 1983). The clay mineral analysis of the Lower Karewas indicates a significant decrease in chlorite at about 1.8 Ma which may coincide with a phase of rapid uplift and can be interpreted in terms of source-area change (Jonathan, 1992). In the Siwaliks, following Pilgrim (1913) and Satsangi and Dutta (1971), the boundary may be correlated with the commencement of Boulder Conglomerate deposition which according to Ranga Rao (1988) took place at about 1.7 Ma. In the Soan valley, Pakistan, this event may be

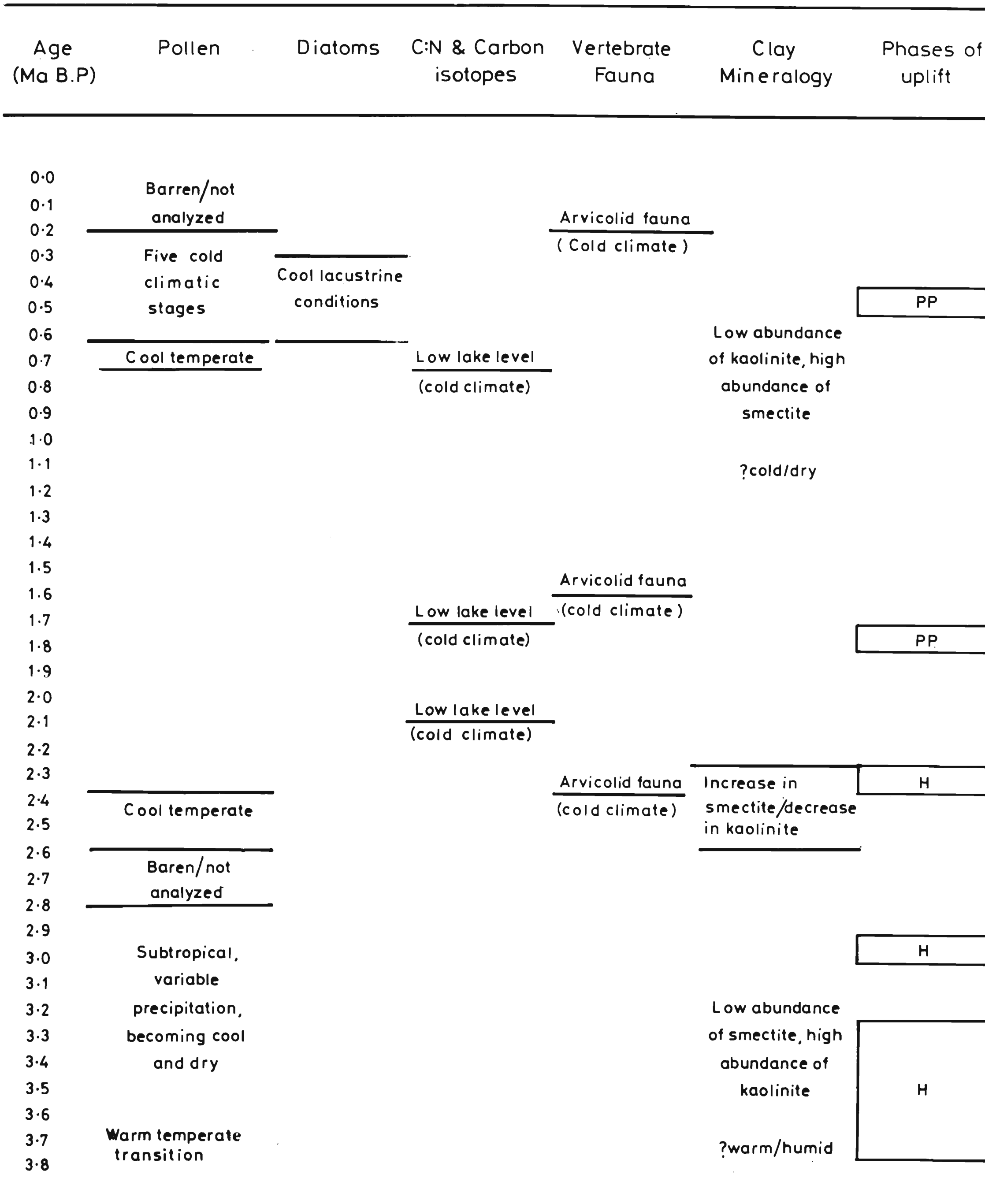

Fig. 4. Palaeoclimatic interpretations in Kashmir Karewas based on various methods (data taken from Burbank & Johnson, 1982, 1983; Krishnamurthy *et al.*, 1986; Agrawal *et al.*, 1989; Jonathan, 1992). H= uplift of Himalayan margin; PP= uplift of Pir Panjal margin.

correlated with the silt and claystone sequence with the ash layer dated to 1.6+0.18 Ma (Johnson, Zeitler, Naeser, Johnson, Summers, Frost, Opdyke and Tahirkheli, 1982), overlain by a massive Lei Conglomerate, lower contact of which is marked by a sharp erosional break (Rendell, 1988). In the Kathmandu Valley, the event may be coeval with the change to a cold climatic phase (Yoshida and Gautam, 1988). The 1.6 Ma event may further be correlated with the global climate cooling, northward expansion of Antarctic waters and major Northern Hemisphere ice accumulation (Singh and Srinivasan, 1993). All these dates are very close to the revised Neogene/Quaternary boundary (1.6 Ma) in the ocean sediments and a level coeval with the earliest climatic deterioration in the Pleistocene (Haq *et al.*, 1977; Tauxe *et al.*, 1983).

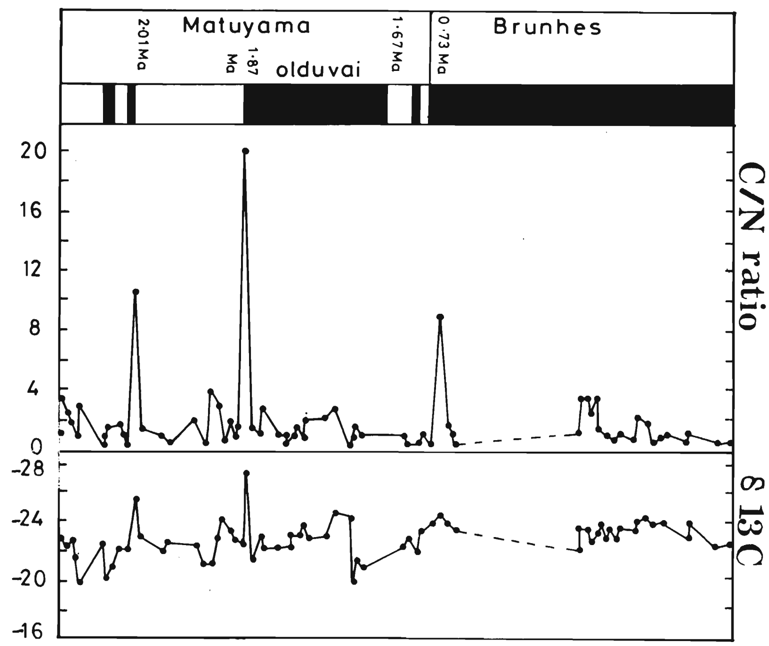

Fig. 5. C and C/N ratio of lignites in the Karewas (After Krishnamurthy *et al.*, 1986). High C/N ratio and low C coincide to mark cold conditions.

BOUNDARIES WITHIN THE PLEISTOCENE

Before the precise use of modern dating techniques, the Lower/Middle Pleistocene boundary was defined on the basis of the microvertebrate fauna. For example, the boundary in Hungary was taken as the base of Tarko phase, i.e., at the time when the genus *Mimomys* vanished (Janossy, 1970). Based on the chronologic, palaeoclimatic and sedimentary data, the Lower/Middle Pleistocene boundary is dated as 1.0 Ma and the Middle/Upper Pleistocene boundary as 0.4 Ma (Jianru and Weizhou, 1991). In southeast Asia, the lower boundary of the Middle Pleistocene has been placed at the Brunhes/Matuyama boundary (0.73 Ma) as witnessed by the palaeoclimatic and palaeoenvironmental changes (Zigeng and Hemao, 1991). In eastern Asia, the beginning of stage 5 of the oxygen isotope 18 scale corresponding to the beginning of the last interglacial period with global high sea level (date to 127 Ka) may be considered as the lower limit of the Upper Pleistocene (Zigeng and Hemao, 1991). The Middle/Upper Pleistocene boundary is also represented by the Blake event of Brunhes epoch with an age of 108 Ka (Meqing and Shi, 1991). In Siberia, the Lower/Middle Pleistocene boundary has been placed near the Jaramillo event (0.97 Ma) and the Middle/Upper Pleistocene boundary at about 130 Ka (Arkhipov, 1991).

The 10 Ka period is taken as the lower limit of the Holocene by the INQUA Sub-commission. In China, the climate began to become warm around 10.7 (Pelying, Qiyong and Shuji, 1991). In Siberia, the larch and birch forests began to dominate and the temperature rose around this time (Andreev, 1991). In China, the 11-10 Ka period is characterised by dominance of herbaceous plants and rapid sediment accumulation (Xu, 1991). The results obtained by Rong-hua (1991) in southwest China confirm the warmer climate around 10 Ka ago. The work by Tungsheng, Zhaoyan, Jiaqi, Baoyin, Rongmo and Yu (1991) confirms climate warming and the development of vegetation and expansion of lakes at about 10 Ka to 9.6 Ka in Tibet. Further work in Tibet by Gasse, Arnold, Fort, Gibert, Huc, Li, Liu, Massault, Van Campo, VanVleit, Wang and Zhang (1991) shows the maximum lacustrine deposition with climate optima at 10.8-6.0 Ka. Bard, Labeyrie, Arnold, Labracherie, Pichon, Duprat and Duplessy (1989) showed that the sedimentation rate in Indian sector of the Southern Ocean was comparatively much more around 10 Ka ago than in the earlier time. The low salinity and higher monsoon runoff in the Bay of Bengal (Cullen, 1980), increased Indian monsoon and humid tropical pollen in the Arabian sea (Van Campo, Duplessy & Rossignal-Strick, 1982), rise in wetland taxa and humid monsoonal conditions in Rajasthan, northwestern India (Singh, Joshi, Chopra & Singh, 1974; Singh, Wasson & Agrawal, 1990), dominance of C3 type of vegetation and peak phase in summer monsoonal rains in south India (Sukumar, Ramesh, Pant & Rajagopalan, 1993) and cool/moist climate in north India (Kotlia *et al.*, 1994) around 10 Ka period show warmer climate in India. A comparative analysis of climatic trends in various parts of India is given in Table 2. In Africa, this period is marked by the occurrence of permanent freshwater lakes (Gasse and Fontes, 1991). In South America, formation of the palaeosols at 10 Ka B. P. has been correlated with the climatic amelioration (Coltrinari, 1991). All these data show that the 10 Ka period is indicative of climatic change and may represent the Upper Pleistocene/Holocene boundary. Climate warming around this time has been observed throughout the world.

the large mammals (Lindsay *et. al.*, 1980) and climatic deterioration (Krishnamurthy *et. al.*, 1986; Igarashi *et. al.*, 1988).

Table 2: Data obtained on the Pleistocene/Holocene boundary (around 10 Ka) in various parts of India

Authors/Area	Techniques used	Period (Ka)	Observations
Cullen, 1980, Bay of Bengal	Oxygen isotope 14 C dating	11.5	Low salinity and higher monsoon runoff
Van Campo *et al.*, 1982, Arabian Sea	Oxygen isotope and Pollen	12.5	Increased moisture & humid tropical pollen
		10.6	Strengthening of the summer monsoon
Singh *et al.*, 1990, Rajasthan	Pollen	13.0-9.4	Rise in wetland taxa, and in precipitation
		9.3-6.0	Very high precipitation-highest during mid-Holocene
Sukumar *et al.*, 1993, Nilgiri	Carbon isotope	11.0	Summer monsoon at peak
		10.6	Higher precipitation & Higher soil moisture
Kotia *et al.*, 1994, Bhimtal	14 C dating, carbon isotope, etc.	ca. 10.0	cool/moist climate

CONCLUSIONS

1. The biostratigraphic events such as initial evolutionary appearance of *Globorotalia truncatulinoides* and of *Gephyrocapsa* ssp., the extinction of discoasters and *Globigerinoides obliquus* are closely associated with the Olduvai-Gilsa normal event (1.8- 1.6 Ma). This close coincidence may offer a more relaible means of correlating the Plio-Pleistocene boundary. In the type section (Le Castella section of Calabrian Formation), the boundary is marked at a disappearance level of *Globigerinoides extremus* at the top of the Olduvai event (Haq *et. al.*, 1977). In the Virca section which has been considered more suitable for defining the base of the Calabrian Stage, the boundary has been placed at about 1.6 Ma (Tauxe *et. al.*, 1983; Berggren *et. al.*, 1985).

2. In Indian subcontinent, the boundary can be placed at the Olduvai event marking the last appearance of *Globigerinoides fistulosus* (Singh and Srinivasan, 1993) in the Indian marine sections. Among megavertebrates, *Equus*, *Elephas* and *Cervus* are pre-Pleistocene, and the E-L-E limit may not be considered as customary to define the boundary. The Olduvai event is tied with a major shift in the isotopic signal in Indian Ocean and major Northern Hemispheric ice accumulation (Singh and Srinivasan, 1993), a strong tectonic upliftment (Jonathan, 1992; Burbank and Johnson, 1983), commencement of Boulder Conglomerate deposition (Sastry and Dutta, 1977), extinction of *Kilarcola* (Kotlia and Koenigswald, 1992), one of the major dispersal events of

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