MAGNETOSTRATIGRAPHIC INVESTIGATION OF THE UPPER SIVALIKS NEAR PINJOR, INDIA

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Summary. A magnetostratigraphic study on four sections near Pinjor showed that the Tatrot stage falls in the Gauss magnetic epoch and the Pinjor corresponds to most of the Matuyama epoch. A significant faunal change, already observed by other authors in Pakistan, marks the Tatrot-Pinjor boundary and approximately coincides with the Gauss-Matuyama transition. Sedimentation becomes entirely conglomeratic in a positive episode tentatively interpreted as Jaramillo. The time interval represented by this event witnessed a deep climatic change in Europa and an extensive faunal turnover in all Eurasia, and seems also to correspond to the onset of a strong tectonic activity in the Himalayan belt.

Riassunto. Uno studio di magnetostratigrafia su quattro sezioni presso Pinjor ha mostrato che il piano Tatrot cade nell'epoca Gauss e il Pinjor corrisponde alla maggior parte del Matuyama. Un netto cambiamento di fauna, già osservato da altri autori nel Pakistan, segna la transizione da Tatrot a Pinjor e corrisponde all'incirca al limite Gauss-Matuyama. La sedimentazione diviene interamente conglomeratica in coincidenza di un episodio positivo che sembra corrispondere allo Jaramillo. L'intervallo di tempo rappresentato da questo episodio è stato caratterizzato da un profondo cambiamento climatico in Europa e da un esteso rivolgimento faunistico in tutta l'Eurasia, e sembra coincidere anche con l'inizio di un'intensa attività tettonica nella catena himalayana.

Presentation.

This is a first report on studies recently started in India and which the authors hope to extend over a longer period. Results exposed here are provisional but seemed to us relevant enough to warrant publication even in their incomplete form.

The present work was funded by the Ministry of Public Education of Italy and is part of a broader program of research sponsored and financed by the National Council of Research (Consiglio Nazionale delle Ricerche).

Correlation purposes have been achieved in the sediments of several

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stratigraphic sequences where the biozonation has marked the succession of polarity events in the earth's magnetic field. Continental deposits from Arizona (Butler et al., 1977) and hemi-pelagic sediments from northern Spain (Roggenthen, 1977) have been magnetostratigraphically related to the coeval pelagic sequence from Gubbio, Italy where the type-section covers the time span from Upper Cretaceous to Upper Eocene (Alvarez et al., 1977; Napoleone et al., 1980). Since then, most sequences recovered in the DSDP legs have been related to the Gubbio section, including the last and most complete Leg 73 (Tauxe et al., 1980). More recent continental sediments from northern India, reported in the present paper, will be related to their Alpine equivalent of some biostratigraphic type sequences from Italy by means of the recorded magnetic polarity sequence.

Part I - Stratigraphy (A. Azzaroli)

Indian endemism and problems of correlation.

The Pliocene and Pleistocene Vertebrate faunas of the Upper Sivaliks of Northern India and Pakistan are rich and diversified, nevertheless their correlation with the faunas of the rest of Asia and of Europe has not been fully solved. Colbert (1935) summarized the various attempts at correlation made since early in the last century but even his own proposed correlations are broadly approximate.

The reason for this is that the Sivalik faunas are highly endemic. Although they include several taxa in common with Africa and south-eastern Asia they share few genera, and probably not a single species with contemporary faunas of central Asia and of Europe. So, e.g., the Upper Sivalik Proboscideans belong to the genera *Protelephas* (Garutt, 1957) and *Elephas* (or *Hypselephas*), while the European ones belong to *Archidiskodon* (or *Mammuthus*); *Stegodon* does not occur in Europe nor in western Asia; only the bunodont Mastodon *Pentalophodon* may perhaps be united to the European *Anancus* (Tobien, 1978). Carnivores share several genera with Europe but are mostly represented by taxa with a broad stratigraphic range, and their remains are scanty and in general rather poor. The most valid elements for correlation are provided by a small number of Ungulates with a wide geographic distribution: *Equus, Hipparion, Leptobos, Camelus.*

Strangely, European faunas show closer links with some faunas of eastern and south-eastern Asia than with those of India and Pakistan. So, for instance, European Rhinoceroses belong to the genus *Dicerorhinus*

and are related to the living Sumatran *D. sumatrensis*, not to the Indian one-horned *Rhinoceros*. Tapirs occur in the Pliocene of Europe, in the Pliocene and Pleistocene of China and now live in south-eastern Asia but have never been recorded from the Sivaliks. The Pliocene *Sus minor* of southern Europe and south-western Asia and its descendant *Sus strozzii* are related to *Sus verrucosus*, now living in Java (Azzaroli, 1954 a), but not to Indian Suids: the reported occurrence of *Propotamochoerus* in Europe is based on incorrect interpretations (Azzaroli, 1975). Hippopotamids are represented by *Hippopotamus* in the Pleistocene of Europe, by *Hexaprotodon* in the Pliocene and Pleistocene of India.

The Indian subcontinent appears thus to have been a sort of secluded corner, which remained to a large degree cut off from the main routes of migration through Eurasia and provided an opportunity for the development of endemic faunas: one-horned Rhinos, the water Buffalo, the Deer *Rucervus* (Azzaroli, 1954 b), some Giraffids and few others.

The few genera mentioned above — *Equus, Hipparion, Leptobos, Camelus* — are represented in India by endemic species and do not seem to give good clues for detailed correlation. A possible exception is however *Equus*, which is represented in India by species closely similar to those of Europe and central Asia (Azzaroli, in press).

Such being the situation, invaluable help may be offered by palaeomagnetic analysis. This line of investigation was successfully applied by Opdyke et al. (1979) in Pakistan: they showed that the Upper Sivaliks extend through the Gauss and Matuyama until the beginning of the Brunhes magnetic chron.

Stratigraphic setting.

Pilgrim's partitions of the Upper Sivaliks — Tatrot, Pinjor and Boulder Conglomerate — were based both on faunas and lithology. Criteria of stratigraphic subdivisions were then not so detailed and standardized as they are now and it would be futile to discuss whether these subdivisions were intended as formations, biozones, faunal units, stages or else. Gupta (1976) considers them formations, geologists of the Geological Survey of India on the other hand consider them stages and have proposed new formational names for our area (Fig. 1), namely Dhamala Formation for the Tatrot stage, Kansal Formation for the Pinjor stage (Bhatt et al., 1979); the name Tavi Formation was proposed several years earlier by G. E. Lewis for the Boulder Conglomerate, or better for the Lower Boulder Conglomerate.
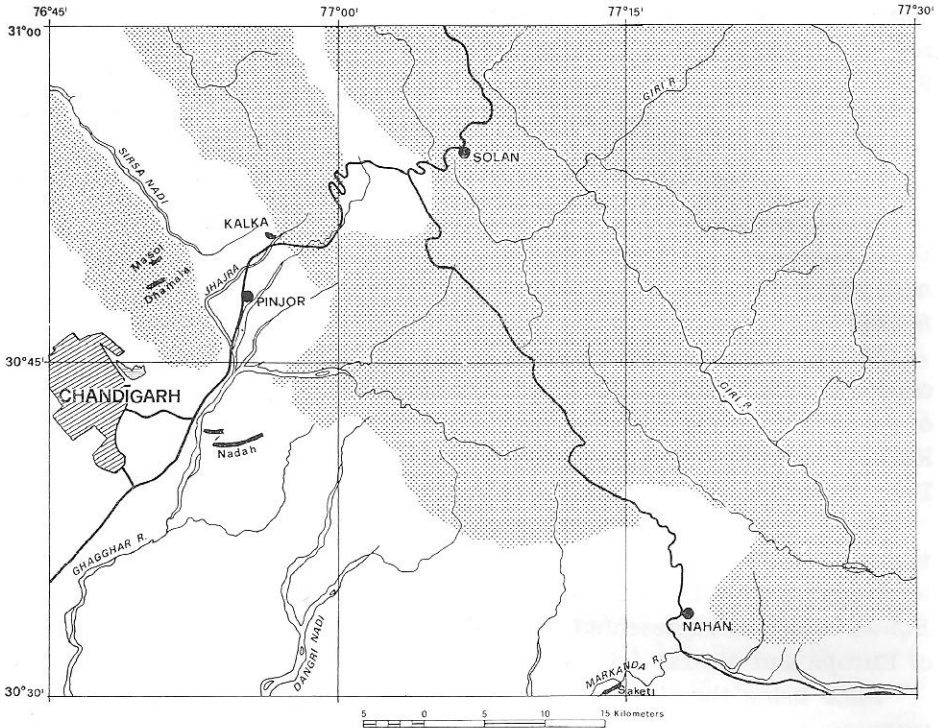
Fig. 1 - Sketch map of the Himalayan foothills near Pinjor and location of sections.

In our area the lithologic transition from the Dhamala to the Kansal Formation coincides with the faunal change from the Tatrot to the Pinjor stages, as defined by several authors, and recently by Opdyke et al. (1979). It should be pointed out, however, that the section exposed at Tatrot village, in the Jhelum district of Pakistan, which should represent the type-section of the Tatrot stage, is only 60 m thick, is not overlain by younger deposits and its base is not exposed; the fauna, moreover, is rather poor. The section is therefore unsuited to define the extent, the boundaries and the fauna of this stage. The section falls in the Gauss magnetic epoch but the term Tatrot was extended by Opdyke et al. to a broader sense, so as to include deposits that range through the Gauss and Gilbert epochs. The upper limit was assumed, arbitrarily perhaps but quite reasonably in view of the inadequacy of the type-section, to correspond to the virtual disappearance of *Hipparion* (there are few records of this genus higher up in the sequence: are they based on reworked fossils?) and the arrival of *Equus*. In Pakistan this happens to correspond

to the Gauss-Matuyama boundary and so it does in our area, although the lithological boundary between Dhamala and Kansal falls in the uppermost part of the Gauss.

The Kansal formation is extensively exposed in a vast area around the little town of Pinjor. The underlying Dhamala formation is exposed at the core of small anticlines in the hills between the Pinjor Dun (the broad valley of the Sirsa and Jhajra rivers) and the plain at Chandigarh (Fig. 1); it is also exposed in the foothills west of the Ghaggar river, but this area was not investigated in our study.

The Kansal formation is a rather monotonous sequence of buff molassic sandstone with sparse pebbles, with thin interbeds of buff and purple mudstone and silt and occasional lenses of pebbles. The Dhamala formation is more varied lithologically and is made of alternating purple mudstone, yellow clayey sands, ash-grey and buff molassic sandstones with rare pebbles and grey silts. The base of the formation is not exposed in the area near Pinjor.

The thickness of the Kansal formation is about 300 m in the Nadah-Mandna section. The Dhamala formation has been measured by the geologists of the Geological Survey of India (Bhatt et al., 1979) on the left bank of the Markanda river at Saketi, where it is 350 m thick. Here the Dhamala is underlain by grey, very thick bedded molasse which has been referred to the Dhok Patan stage of the Middle Sivaliks. Only the lower part of this section was examined in this study.

Sandstones and silts are poorly cemented. Relief is sharp owing to recent tectonics and the area is subject to rapid erosion during the rainy seasons. Fossils are often found loose in the talwegs at the end of the rains.

Distribution of fossils.

In a stratigraphic study the ideal procedure is for the student to collect his own fossils, identify them and plot their occurrence in the sections. For several reasons this was practically impossible in our case. Fossils are rather common in the Pinjor area and the present writer, with students of the Panjab University, collected teeth and bones of Equids, Bovids and Proboscideans, including a skull of *Leptobos* (unfortunately enclosed in a very hard siliceous matrix), a jaw of *Stegodon insignis* and also a skull of a Hippo. However, fossils occur scattered over a wide area: there are no concentrations and consequently no possibility of planned excavations. More important than this, the area has been combed during two centuries of British rule, and since the establishment of the

Panjab University in Chandigarh is being actively searched by parties of the Departments of Geology and of Anthropology and by students of the Geological Survey of India and of the Wadia Institute of Himalayan Geology. Prof. M. R. Sahni and dr. E. Khan, both formerly in the Department of Geology of the Panjab University, made a remarkable collection which includes several skulls, kept accurate records of the occurrences of fossils and wrote a detailed monograph, which unfortunately is still waiting publication. In order to have as complete a record as possible it was therefore unavoidable to make use of the wealth of evidence collected in previous years by all these students.

Fossils from older collections often lack records of their locality and horizon. Barnum Brown made extensive collections near Pinjor, which served as a basis for a monograph by E. H. Colbert (1935) and kept good records of the localities, but seems to have been unaware of the occurrence of two different faunal stages in his area.

In the present work use was made of the data by Barnum Brown and also of data published more recently by M. R. Sahni and Khan (1961 a, 1961 b, 1961 c, 1961 d, 1961 e, 1964 a, 1964 b, 1968), V. J. Gupta (1976), B. C. Verma (1969), K. N. Prasad (1972), R. N. Vasishat et al. (1980), A. C. Nanda (1973, 1976, 1978 a, 1978 b, 1979), R. Gaur et al. (1978), G. L. Badam (1979), Badam and Tewari (1968).

Description of the sections.

THE DHAMALA FORMATION (TATROT STAGE).

M. R. Sahni and E. Khan (1961-1968) recorded many occurrences of fossils in the hills between Pinjor and Chandigarh, most of which are concentrated in the upper part of the formation (Quranwala fossil zone). The following species are restricted to the Tatrot:

Stegodon bombifrons (Falconer & Cautley)
Pentalophodon khetpuraliensis Nanda
Hipparion antelopinum
               (Falconer & Cautley)
Hipparion theobaldi (Lydekker) (referred to *Cormohipparion* by MacFadden & Bakr, 1979)

Probison dehmi Sahni & Khan
Crocuta talyangari (nomen nudum? quoted by Bhatt et al., 1979)
Protachyoryctes tatroti (nomen nudum? quoted by Bhatt et al., 1979)

The following extend through the Tatrot and Pinjor stages:

Protelephas planifrons (Falconer & Cautley)
Stegodon insignis (Falconer & Cautley)
Camelus sivalensis Falconer & Cautley

Cervus punjabensis Brown
Leptobos falconeri (Rütimeyer)
Hexaprotodon sivalensis
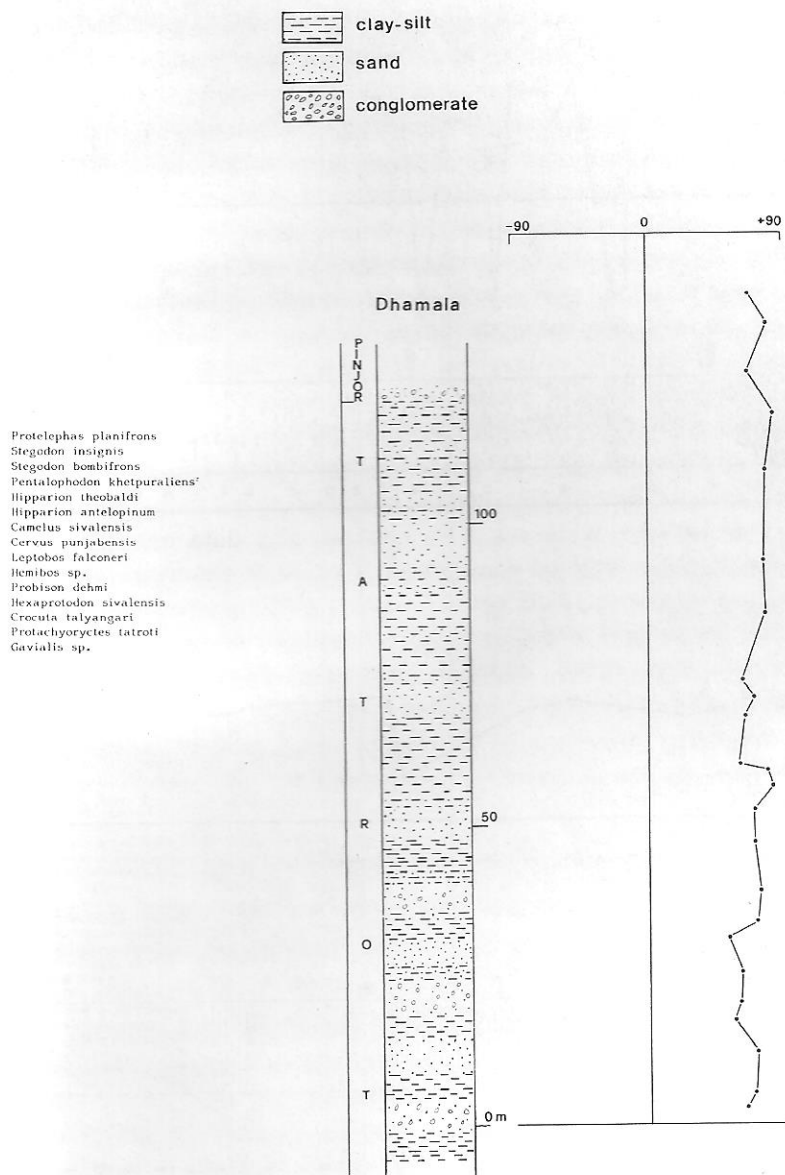   (Falconer & Cautley)

Fig. 2 - Lithology and associated magnetic polarities in the Dhamala section. Palaeontological data from literature (quoted in text).

Gazella has not been recorded from our area but has been recorded from the Tatrot of Pakistan (Opdyke et al., 1979), so that its absence may be purely accidental.
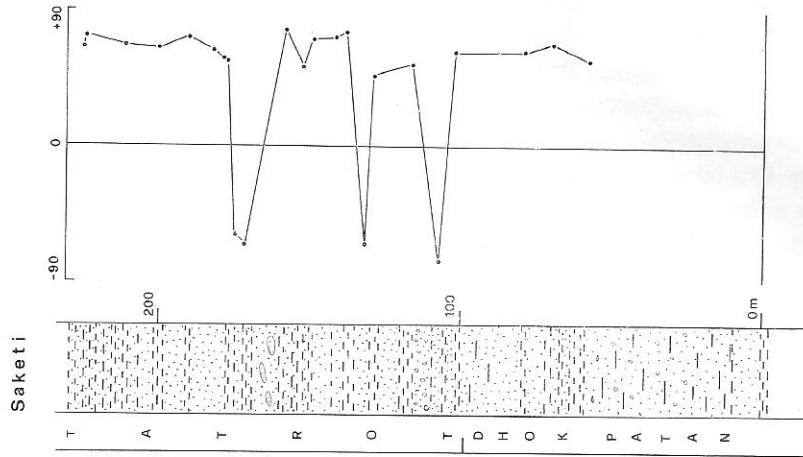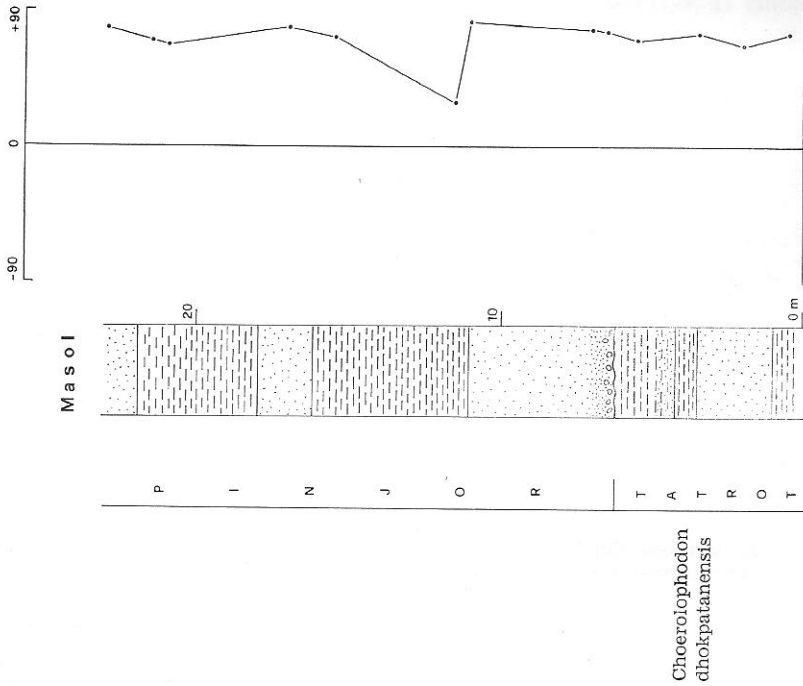
Fig. 4 - Lithology and associated magnetic polarities in the Saketi section. Palaeontological data from literature (quoted in text).

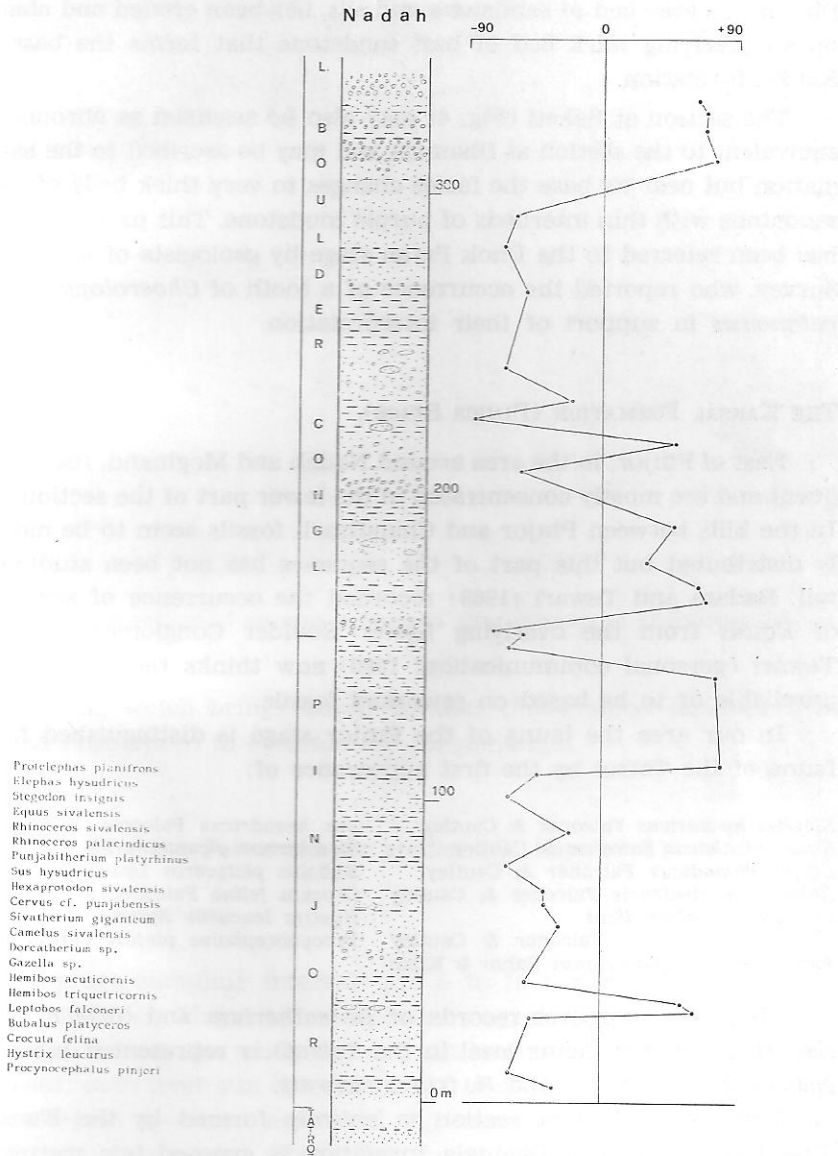Fig. 3 - Lithology and associated magnetic polarities in the Masol section.

Fig. 5 - Lithology and associated magnetic polarities in the Nadah section. Palaeontological data from literature (quoted in text).

The contact between the Dhamala and Kansal formations is well exposed in an anticline near the village of Masol (Fig. 2, 3). On the western limb the junction is conformable but on the eastern limb the top of the

Dhamala, a grey bed of sandstone and silt, has been eroded and channelled by an overlying thick bed of buff sandstone that forms the base of the Kansal formation.

The section at Saketi (Fig. 4) may also be assumed as chronologically equivalent to the section at Dhamala and may be ascribed to the same formation but near its base the facies changes to very thick beds of molassic sandstone with thin interbeds of purple mudstone. This part of the section has been referred to the Dhok Patan stage by geologists of the Geological Survey, who reported the occurrence of a tooth of *Choerolophodon dhokpatanensis* in support of their interpretation.

THE KANSAL FORMATION (PINJOR STAGE).

East of Pinjor, in the area around Nadah and Moginand, fossils are frequent and are mostly concentrated in the lower part of the section (Fig. 5). In the hills between Pinjor and Chandigarh fossils seem to be more evenly distributed but this part of the sequence has not been studied in detail. Badam and Tewari (1968) recorded the occurrence of several teeth of *Equus* from the overlying Lower Boulder Conglomerate but prof. Tewari (personal communication, 1980) now thinks these records to be unreliable or to be based on reworked fossils.

In our area the fauna of the Pinjor stage is distinguished from the fauna of the Tatrot by the first appearance of:

Elephas hysudricus Falconer & Cautley   *Sus hysudricus* Falconer & Cautley
Equus sivalensis Falconer & Cautley   *Sivatherium giganteum* Falconer & Cautley
Equus namadicus Falconer & Cautley   *Bubalus platyceros* Lydekker
Rhinoceros sivalensis Falconer & Cautley   *Crocuta felina* Falconer & Cautley
Rhinoceros palaeindicus   *Hystrix leucurus* Sykes
                     Falconer & Cautley   *Procynocephalus pinjori* Verma
Punjabitherium platyrhinus Sahni & Khan

There are moreover records of *Dorcatherium* and *Gazella*. *Hemibos* (identified only at genus level in the Tatrot) is represented here by two species, *H. acuticornis* and *H. triquetricornis*.

The Nadah-Mandna section is entirely formed by the Kansal and Tavi formations. The Dhamala formation is exposed few metres below the base of the section in the bed of the Ghaggar river near Panchkula but the contact between the Dhamala and Kansal is hidden under the alluvium of the river banks. The faunal assemblage of the Kansal formation provides an easy clue for correlation with the sections studied by Opdyke et al. (1979) in Pakistan.

At its top, the conglomerate is cut by a thrust, well exposed on the
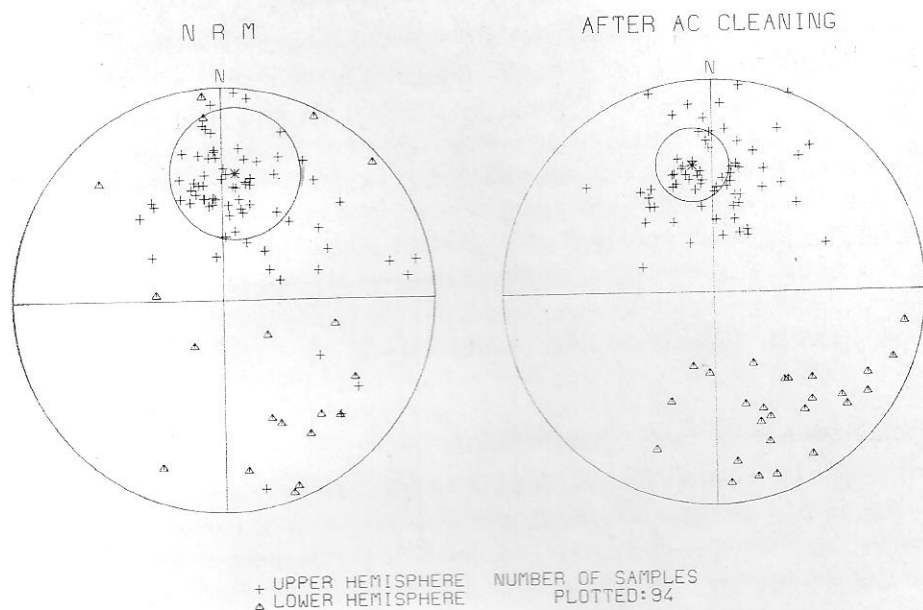
Fig. 6 - Remanence vectors of samples before and after cleaning in alternating fields of 10.0 to 35.0 mT.

road to Morni, which brings Lower Sivaliks (fine-grained sandstones of the Nahan Formation) to override the conglomerate.

Part II - Paleomagnetic studies (G. Napoleone)

Sampling and measurements.

The average sampling intervals are 5 to 10 meters, including sandstones and pebbles. The samples used for magnetic treatments were collected by hand from the mudstone and silt beds, and oriented by magnetic compass; each level was surveyed by at least two samples from which a single one-inch specimen was cored and measured on a fluxgate magnetometer through stepwise alternating current (a.c.) demagnetization.

The overall distribution of magnetic vectors is shown in Fig. 6, where the natural remanent magnetizations (NRM) become better grouped after an optimal a.c. demagnetization at 15.0 mT to 30.0 mT peak values that have reduced in most cases the secondary overprints. Several samples reversely magnetized display a present-time orientation at the NRM level.

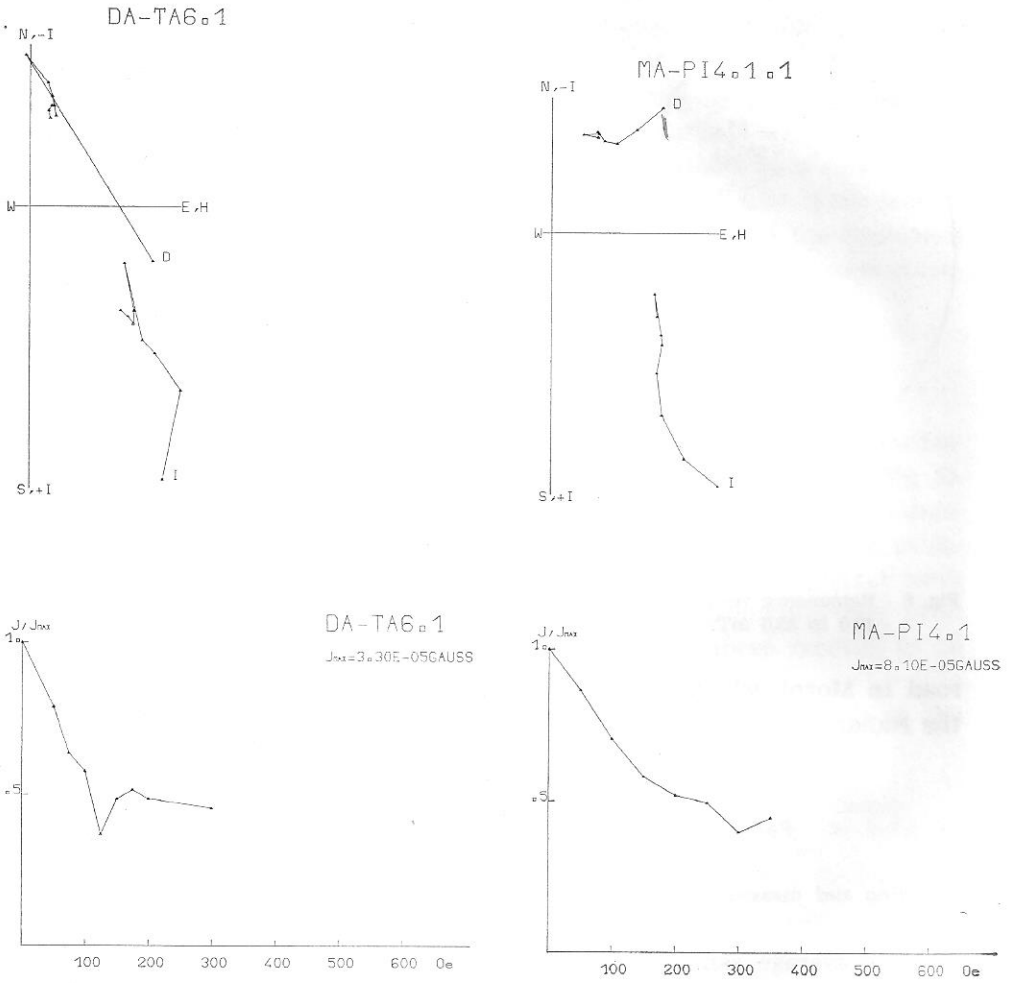For each specimen the whole demagnetization curve has been plotted

Fig. 7.

Fig. 8.

Fig. 7 - Demagnetization curves of a sample from Dhamala section for higher fields (bottom diagram) defining a vector which decreases towards the origin (top diagram). The middle part of the diagram is affected by irregular changes related to the magnetic behaviour of the rock. Numbers on the vector diagram indicate peak field in Oe (10 Oe = 1 mT). Light curve refers to declination (D) changes, heavy solid curve to inclination (I) changes.

Fig. 8 - Demagnetization curves for a sample from Masol section in the Kansal formation (Pinjor stage). Field values as in Fig. 7.
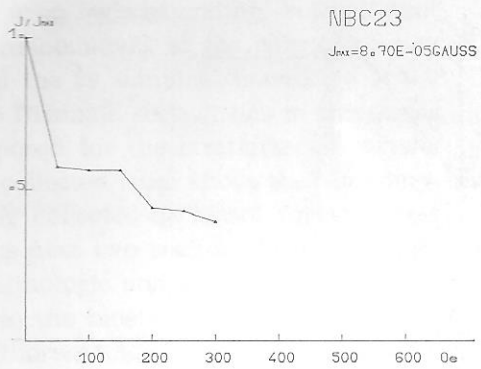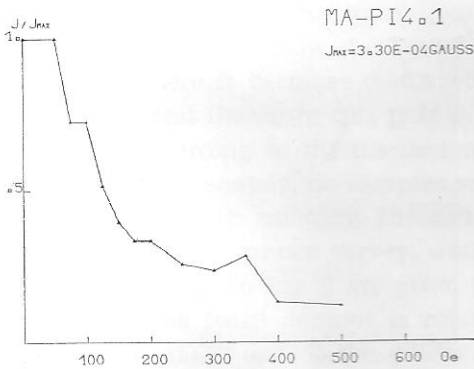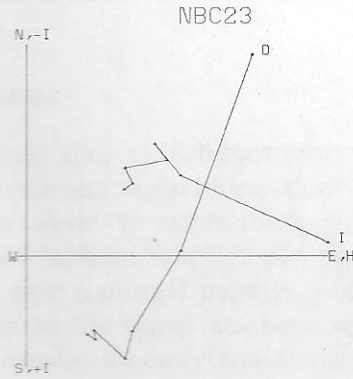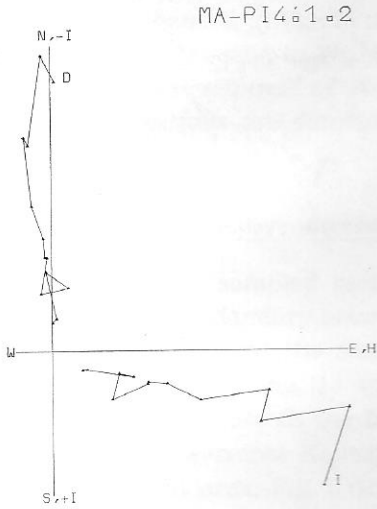
MA-PI4.1.2

Fig. 9.

Fig. 10.

Fig. 9 - Demagnetization curve for a sample from Masol section, at the same level as the sample of Fig. 8, at higher peak field values. The vector trend is towards a flat inclination and north-seeking declination.

Fig. 10 - Demagnetization curves for a sample from Nadah section. After the weakest peak field is applied, the cleaning reveals more consistent vectors.

together with the Zijdelveld vector diagram, of which are shown examples in Figures 3 and 4. The magnetic stability of the minerals appears to be fairly good, in accordance with the equivalent rocks measured by Opdyke et al. (1979) in Pakistan.
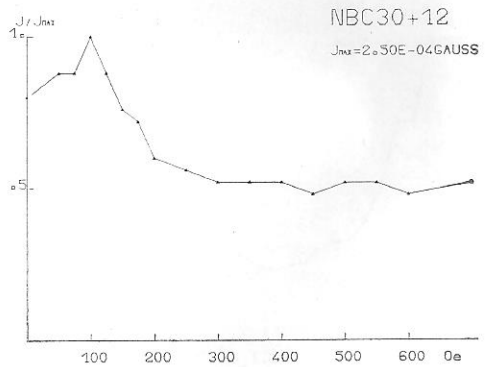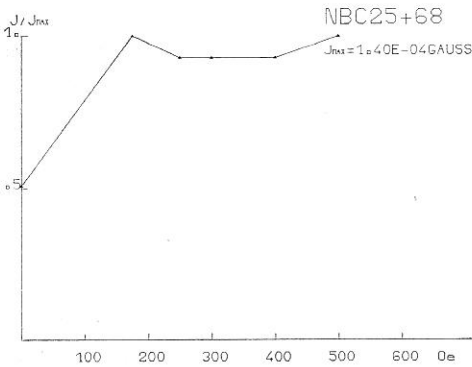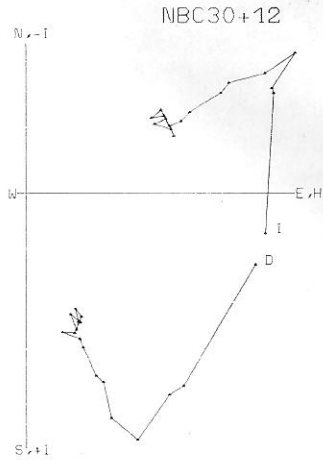
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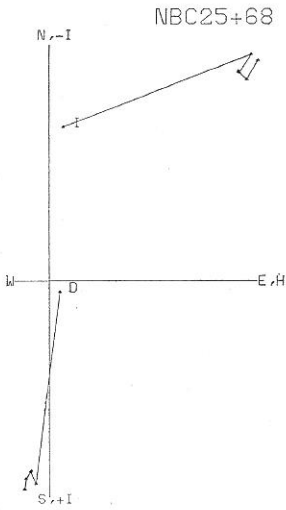
Fig. 11.

Fig. 12.

Fig. 11 - Demagnetization curves with different trends. The sample is from the Nadah section and the strong peak field applied at the first steps removes vectors superimposed upon a reversely oriented primary magnetization.

Fig. 12 - Demagnetization curves for a sample from Nadah section at higher peak field values. The middle portions represent the actual directions in the primary magnetization, after the parasitic vectors have been removed at the lower steps of the AC treatment and before the magnetic behaviour begins to scatter around it.

The intensities, from the same diagrams as in Fig. 7 to 12, range from 15 to 120 X 10^{-3} A/m for the NRMs to 4 to 17 X 10^{-3} for the highest demagnetization step reached. To each specimen has been applied the

bedding correction: most layers are dipping north 10 to 30, while the core of the Dhamala anticline is more disturbed and has not been sampled.

The scattering in Fig. 6 can be partially due to a bedding error and to uncomplete removal of secondary magnetic overprint, but no major tectonic rotations are detectable from such rocks of Plio-Pleistocene age.

Magnetic stratigraphy: discussion and correlations.

The first sampled section, near Masol (Fig. 1), contains what is supposedly the boundary between the Dhamala and Kansal formations. Layers are quite flat and the sampled portion, about 20 meter thick, is several hundred meter long. 13 specimens from samples taken in silt and mudstone layers close to the boundary, all gave a normal polarity, suggesting that the lowermost Kansal still belongs to the Gauss magnetic epoch in the present area. Fig. 3 shows the schematic lithology and the stratigraphic position of the sampling sites; attached to it is also the plot for the latitudes of the virtual geomagnetic poles (VGPs) of each sample.

The Dhamala section is close to the Masol section (2-3 km away) and has been sampled along more than 100 m in beds extending, in the Tatrot stage, from just below the Tatrot-Pinjor boundary to the core of the anticline where it becomes disturbed. All the 29 samples showed a normal polarity and therefore this part of the Dhamala section lies in the Gauss epoch, according to the discussion exposed for the stratigraphic correlations. Unfortunately, no samples were collected from above the boundary, since it seemed sufficient the sampling collected at Masol for the aims of this reconnaissance survey, while the next two sections do not include the boundary. In Fig. 2 are given the lithologic and magnetostratigraphic details. The fossil content is related to the biostratigraphic position reconstructed by one of the present authors (A.A.) from the available informations.

The following two sections are thicker and extend as far as the lowermost and uppermost stages: Saketi section in the Dhok Patan stage and Nadah section in the Boulder Conglomerate. At Saketi, the basal outcropping in the Dhok Patan has not been sampled, due to the vegetation that covers the thick molasse. The actual sampling slightly exceeded 150 meters. The sites show alternate polarities bracketed by two normal intervals, on top and at bottom; two more normals, in between, move to their respective reversals with few samples that therefore mark some not well-defined polarities. The boundaries of the two magnetic zones are tentative, but seem closed within sharp constraints of quite few me-
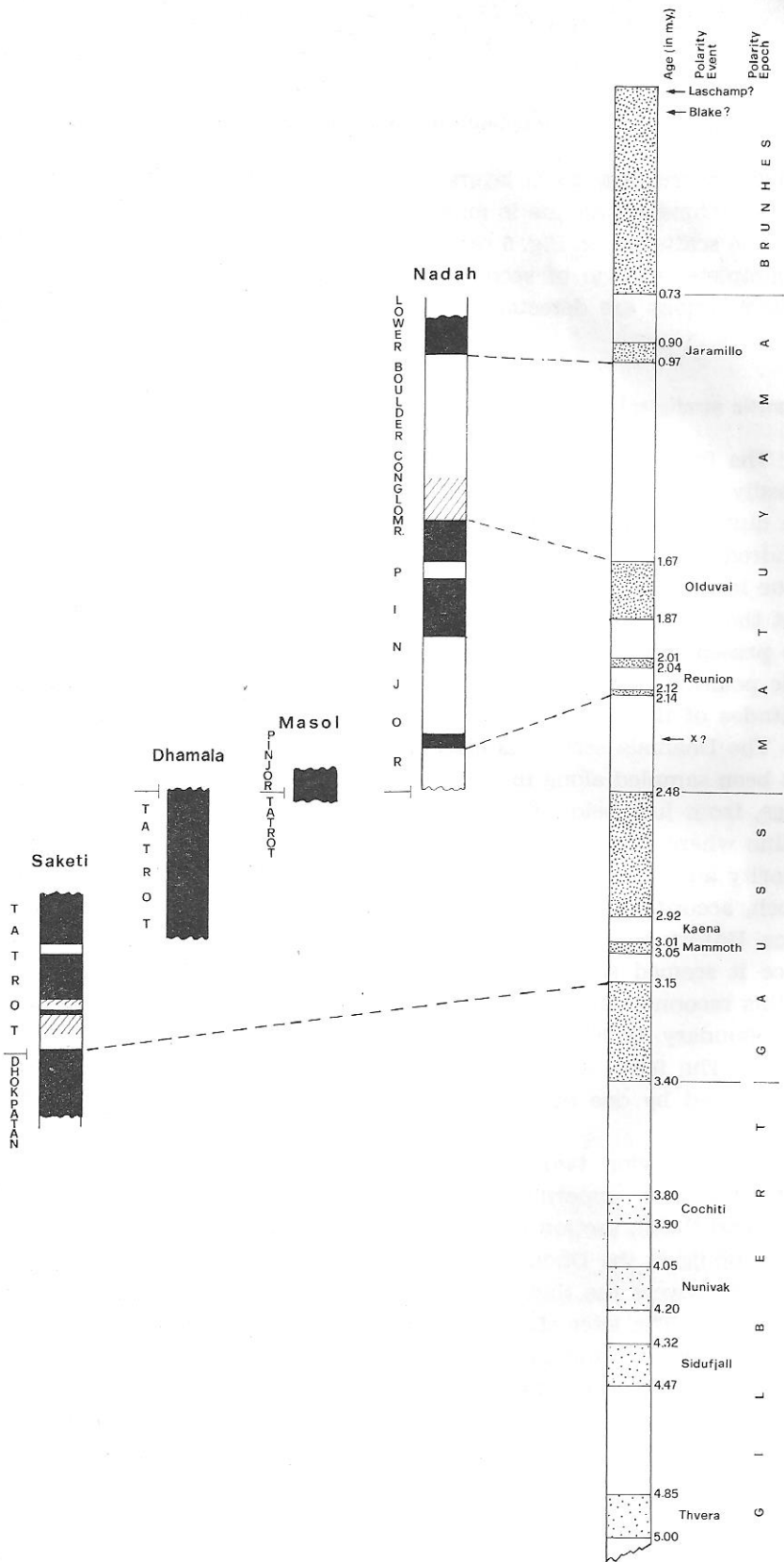
Fig. 13 - Synthetic chart of sections and proposed correlations. Standard magnetic reversal scale after E. A. Mankinen and G. B. Dalrymple (1979).

ters. The Dhok Patan-Tatrot boundary reasonably lies in the Gauss magnetic epoch, marking almost the end of the lowermost normal magnetozone of the Gauss. On the other hand Opdyke et al. (1979) extend their Tatrot stage all the way down through the Gilbert magnetic epoch. We feel unable, at present, to offer an explanation for these contrasting interpretations. Fossils reported by Opdyke and collaborators in the Gilbert interval are scanty and were identified only at genus, or even at family level: perhaps they may not be fully diagnostic for detailed stratigraphic correlation. In Fig. 4 the magnetic reversal sequence is matched with the lithology and no biostratigraphic attempts can be made for correlation with the Dhamala section: the Tatrot stages are likely to overlap, as in next Fig. 13, assumed that the remaining upper portion at Saketi gets to the Pinjor stage in about 100 m section. This, therefore, implies a steady sedimentation rate which is, on the contrary questioned in the next section at Nadah.

The Nadah section, finally, the thickest and more abundantly sampled, begins with a site at 8 m above what is considered the Tatrot-Pinjor boundary visible in the Ghaggar river. Assumed that the Gauss-Matuyama boundary closely marks the stratigraphic boundary of Tatrot and Pinjor stages, this first magnetozone, about 20 m thick, marks the beginning of the Matuyama epoch with a reserved polarity. Discrepancy with the Masol magnetic section could be avoided by checking in the Dhamala section the extention of the « long normal » at the end of Gauss. If the formational boundaries were perfectly correlable, the mismatching in the polarity sequence would be in the order of 10 meters. As in the Saketi section, also in the Nadah section one magnetozone boundary is not sharply defined (within 10 m accuracy). Above this boundary a relatively long reversed interval seems to precede what is tentatively assumed to represent the Jaramillo event, at the base of the Tavi formation.

The sampling is interrupted at the base of the Lower Boulder Conglomerate beds. Fig. 5 summarizes lithology and magnetostratigraphy. The whole Nadah-Mandna section falls in the Matuyama magnetic epoch. A short normal interval, between 30 and 40 m above the base, may represent one of the Réunion events while a longer normal between 160 and 220 m may be equated to the Olduvai event. Two isolated boulder beds occur here, at 160 and 210 m respectively; then the sequence becomes increasingly coarser and grades into the Tavi formation. At 300 m the polarity is again positive and, above this point the sedimentation is entirely conglomeratic.

The overall fitting of the four magnetostratigraphic columns leads

to the polarity sequence as of Fig. 13. The formational boundaries in the sections, and their relative thicknesses, are transferred into the whole succession previously discussed; the revised magnetic time scale, after the Mankinen and Dalrymple (1979) K-Ar re-adjustment, is reported for comprehensive correlation. It appears evident the bearing of missing tie-points from biozonation: while such constraints in the Gubbio type section (Alvarez et al., 1977) allowed a revision of the polarity sequence in the geomagnetic time scale, in the present case the established polarity sequence has to fit stratigraphic sequences tentatively recognized. From the whole available information the Tatrot-Pinjor boundary is identified in all sections even if sampled only in two of them; it fails in marking a sharp boundary and this implies possible changes of the sedimentation rate in places, according to what is generally believed to be the paleoenvironment at the foot-hill of the Himalayas. Even more alternating are the rates above this boundary, in the Nadah section: the boundary itself is only 8 m below the first sampled site and presumably would lie still in the reversed magnetozone, therefore in contrast with the actual data from Masol and Dhamala sections, or again larger changes in the sedimentation rates should be asked for. More dramatic seem the changes in the overlying magnetozones; after the first normal polarity zone the constant-time and constant-spacing scales match with a quite different amount.

The long reversed magnetozone in Nadah would correlate with the short one, between the two Réunion episodes, and the opposite would happen for the next two magnetozones. Then, at the occurrence of Olduvai event, the following polarity zones fit more comparably. Therefore, the data collected from the four sections are summarized in a polarity sequence compatible, at present, with the geomagnetic time scale. They seem to match sufficiently well, at this reconnaissance level, and lead to further considerations about the biogeographic evolution of this part of the Alpine belt after the Tethys was completely closed.

Part III - Intercontinental correlation and dispersal events (A. Azzaroli)

Late Pliocene events.

Lindsay et al. (1980) tried to correlate the Sivalik faunas to those of Europe on the basis of a dispersal event characterized by the appearance of *Equus* in Eurasia, assumed to date approximately from 2.6 Mvr. This dispersal event is called the *Equus-Leptobos-Elephas*, or E-L-E limit.

Equus may be particularly suitable for correlation because of the rapid migration and wide geographic distribution of its species. Lindsay

et al. found that *Equus* appeared in India at about 2.5 Myr. and assume that it appeared in southern Europe approximately at the same time. This may be true, but while the date of the appearance of *Equus* in India is well established in the palaeomagnetic time scale, the date proposed by Lindsay et al. for its appearance in Italy (Montopoli fauna in Tuscany) needs more thorough investigation.

Be this as it may, according to studies by Opdyke et al. (1979) and to the present study, the Pinjor stage appears to correspond to the later part at least of the early Villafranchian (Montopoli unit), to the middle Villa-franchian, and to the late Villafranchian, while the Tatrot stage ranges through the Ruscinian and the earliest Villafranchian (Triversa unit), as defined by Azzaroli (1977 a). The so-called E-L-E limit is in any case of restricted help for correlation. Pliocene and Pleistocene Elephants of the Indian subcontinent are not related to European ones (see above) and ap-pear in India well before *Equus* (E. Khan, personal communication, 1980). *Leptobos* appears in Europe well before *Equus* and Elephants (Azzaroli, 1977 a) and its Indian species seem to need a critical revision before they can correlated with European ones. *Equus*, on the other hand, is repre-sented in the Siwaliks and in Europe by very closely related species and the European species *Equus stenonis* ranges as far east as Central China (Azzaroli, in press), so that Equids offer a reliable basis for correlations.

Beside the dispersal event at 2.6-2.5 Myr., Lindsay et al. (1980) pointed out a dispersal event at 1,9 Myr. In Europe this corresponds with good approximation to the transition from middle to late Villafranchian (Az-zaroli, 1977 a; Arias et al., 1980). No trace of this event has been detected in the Sivalik faunas, and this may be due to lack of detail in the strati-graphic record.

The End-Villafranchian dispersal event.

Another dispersal event was not mentioned by Lindsay et al. (1980) although it marks the greatest faunal turnover in the whole Pleistocene of Eurasia (Azzaroli, 1953, 1962; Azzaroli & Ambrosetti, 1970; Ambrosetti et al., 1972). This is the transition between the early Pleistocene (late Vil-lafranchian) and new faunal assemblages, called Cromerian in the British Isles and Central Europe, Galerian in Italy, Tiraspolian in southern Rus-sia, Olyorian in Siberia (Sher, 1971; Sher et al., 1979) and linked by remarka-ble similarities over this vast area. The faunal change at this event was dra-matic. None of the Villafranchian species survived unscathed: many be-came extinct, others survived at the cost of marked evolutionary changes; several new species and genera appeared, some of these not by simple

immigration but as a result of new, previously unknown evolutionary adaptations.

A full account of this faunal change is beyond the scope of the present paper but some essential features may be mentioned. The highly specialised Villafranchian Elephants of Europe became extinct (Azzaroli, 1977 b), and so did *Protelephas planifrons* in India; they were replaced by *Elephas namadicus* (with its subspecies *antiquus* in Europe and *naumanni* in the Far East) and by *Mammuthus armeniacus-trogontherii*. It is not clear whether *Equus stenonis* became extinct or evolved into *Equus süssenbornensis* (including its subspecies *verae* in eastern Siberia), while *Equus caballus*, with its subspecies *mosbachensis*, reached Europe as an immigrant. *Dicerorhinus etruscus* evolved into primitive subspecies of *D. hemitoechus* and possibly also into *D. kirchbergensis*. *Ursus etruscus* gave origin to *Ursus deningeri*. *Sus strozzii* became extinct and *Sus scrofa* immigrated to take its place. Most of the Villafranchian deer became extinct but *Libralces gallicus* evolved into *L. latifrons* (which eventually gave rise to the American *Cervalces*). The giant deer *Megaceros* (*Megaceroides*) *verticornis*, *M.* (*Megaceroides*) *solilhacus* and *M.* (*Megaceros*) *savini* arrived at this time as immigrants in western Europe and in the Mediterranean basin (Azzaroli, 1979). Although some supposed Megacerines have been reported from the late Villafranchian of southern Russia (Radulesco & Samson, 1967) the origin of Megacerines is not yet clear. Other immigrations of unknown origin are the Roe, a still primitive Stag (*Cervus acoronatus*), the Fallow Deer and other, poorly known species. Immigrant carnivores are *Gulo schlosseri*, *Crocuta crocuta* and others. However, the most spectacular evolutionary event of this time is the sudden appearance of the large, massive Bovids *Bos*, *Bison* and *Ovibos*. They represent a new type of adaptation that did not exist before. In Europe these Bovids suddenly appear at the beginning of the Cromerian and its local equivalents, with somewhat primitive features but with their peculiar adaptations fully developed. Apart from some late Villafranchian fossils which seem to represent a sort of transition, such as the peculiar « *Leptobos* » *vallisarni* of central Italy (Merla, 1949), their appearance was abrupt and their dispersal very rapid.

The dispersal event discussed here may be dated with good approximation between 1.0 and .9 Myr. (Ambrosetti et al., 1972) and corresponds to a cold period and a retreat of the sea called Cassian in Italy, Beestonian in the British Isles, Menapian in the Netherlands; it may perhaps correspond to the Günz glaciation in the Alps, although this is not certain. What is certain is that, within the approximation limits of our palaeonto-

logical correlations, this critical period may be equated with Jaramillo magnetic event (.97-.90 Mys.).

In accordance with these views, studies by Ronai and Cooke on cores from deep boreholes in the Pannonian basin have provided palynological evidence for a marked cooling in the climate of central Europe at the Jaramillo event (Cooke, 1981).

In the Sivalik Hills mammalian faunas extend upwards into the late Villafranchian and fossils disappear with the onset of coarse conglomeratic sedimentation, which obviously marks a period of strong tectonic movements in the Himalayan ranges. In northern India this happens, if our correlations are correct, in the Jaramillo.

The virtual disappearance of fossils is clearly a result of the change in sedimentation, which became unfavourable for preservation. Of course, this does not imply the disappearance of the fauna from the area. There are in fact two records of fossils that seem to be post-Villafranchian: two skulls of the large Bovine *Bos acutifrons* from the Kangra district and another skull of the same species from Hoshiarpur.

Pilgrim (1939) discussed the provenance of these skulls and remarked that, from the character of their matrix, the Kangra skulls seem to come from the Pinjor formation. This however does not settle the matter of their exact horizon, as there may be sandy lenses in the Tavi formation, or the limit between Tavi and Kansal, which is obviously diachronous, may lie higher up in some districts than in others.

The fact remains in any case that the bulk of the Sivalik fauna disappears somewhere between the Olduvai and the Jaramillo events; above the Jaramillo, only scattered occurrences have been reported (see also Opdyke et al., 1979).

Rich post-Villafranchian faunas occur in peninsular India, in the alluvial sediments of the Narmada, Godavari and other large rivers. The faunas are still highly endemic, with the survival of *Hexaprotodon, Bubalus, Rhinoceros, Equus namadicus*, but are distinguished from the Sivalik faunas by the appearance of *Elephas namadicus, Bos namadicus, Bison. Elephas maximus* is also recorded from some sites.

To sum up, it appears that changes of great consequence took place in Eurasia at the Jaramillo event and there are all reasons to think that they were mutually related: strong upheaval movements in the Himalayan ranges, a marked cooling in the climate — at least in some areas — and an extensive renewal in the faunas of terrestrial vertebrates, with the development of new adaptations.

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