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Magnetic polarity stratigraphy of the Pinjor Formation (Upper Siwalik) near Pinjore, Haryana

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The magnetostratigraphic and vertebrate faunal studies were carried out in the type section of the Pinjor Formation (Pinjor Faunal Zone of Pilgrim[1]) near Pinjore township, Haryana. The Patiali Rao section exposes both Pinjor and pre-Pinjor beds with a thickness of 1296 m. Oriented samples were collected from 52 sites. The data permit one to conclude that the type Pinjor Faunal Zone of Pilgrim covers the entire Matuyama reverse chron and lower part of Bruhnes normal chron with a time span from 2.47–0.63 Ma. Fresh vertebrate fossil collection indicates that the Pinjor Faunal Zone is marked by the first appearance of *Equus, Cervus* and *Leptobos*.

IT is now established that 'faunal zones' of Pilgrim[1] are very vaguely defined and their boundaries can neither be located in the field nor be used in mapping. For this reason ONGC workers[2] subdivided the outcropping sequence on lithological basis for purposes of mapping. In the vicinity of Chandigarh, they divided the Upper Siwalik sequence into five lithounits and designated the basal part as 'Masol Formation' overlain successively by Rupar I, II, III and IV formations. The subdivision of the Rupar Formation is based on the presence of pebble beds. The Masol Formation was correlated on faunal evidences to the Tatrot Faunal Zone and Rupar I, II and III to the Pinjor Faunal Zone of Pilgrim[1]. The conglomeratic facies of the Rupar IV was correlated to the Boulder Conglomerate. Present investigations are confined to a section along stream, locally known as Patiali Rao, which is a part of the type area of the Pinjor Faunal Zone of Pilgrim[1]. Patiali Rao section exposes 1296 m of sediments. Vertebrate fossils were collected, identified and clubbed with the magnetostratigraphic studies. The geological map of the area is given in Figure 1.

Not much data on the magnetostratigraphic studies of the Upper Siwalik subgroup are available from India. However, studies were conducted in the Chandigarh region by Yakoyama[3], Azzaroli and Napoleone[4] and Tandon *et al.*[5]. Ranga Rao *et al.*[6] carried out magnetostratigraphic studies in the Upper Siwalik sequence exposed in the vicinity of Jammu Hills. Ranga Rao[7] synthesized the magnetostratigraphic data of various Siwalik sections.

Faunal findings in Pinjore area

Sahni and Khan[8] carried out stratigraphic and vertebrate palaeontologic studies of the area lying east of Chandigarh, including Patiali Rao section. Later, Badam[9] and Gaur[10] also made collections, but Sahni and Khan's work formed the base. On the basis of fauna as well as lithology Sahni and Khan[8] for the first time recognized pre-Pinjor or the Tatrot beds (= Masol Formation of ONGC) and Lower Boulder Conglomerate (Rupar IV of ONGC). They further identified about 80 m thick succession, characterized mainly by grey clays towards the top of the Tatrot Formation which yielded rich vertebrate fossils (yielding 98% of their fossil collection), and named it as 'Quaranwala Zone'. This zone was

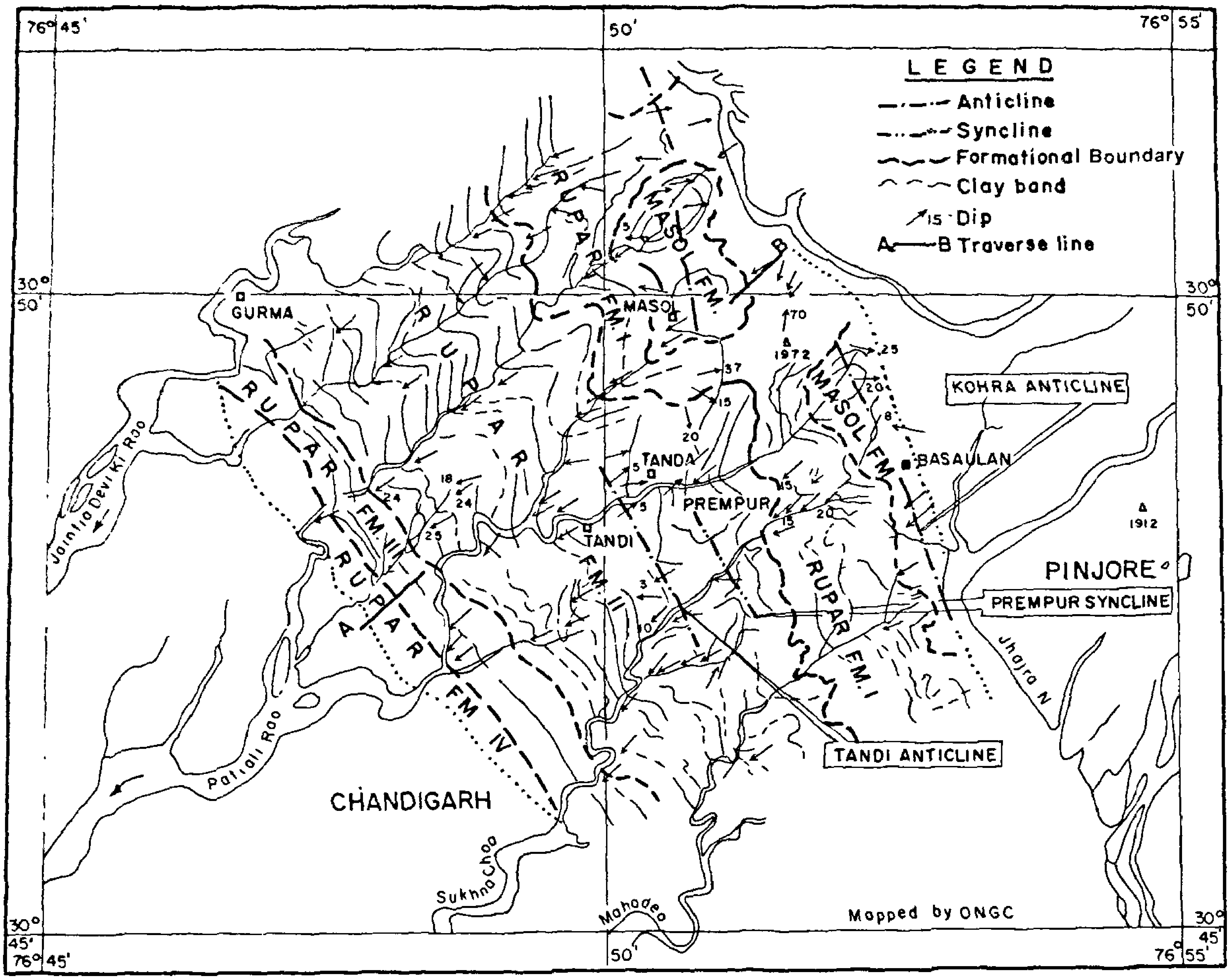

Figure 1. Geological map of Chandigarh–Pinjor area showing the location of the Patiali Rao section

reported to have yielded the following mammalian genera: *Stegodon*, *Archidiskodon* (now referred as *Elephas*), *Hipparion*, *Hexaprotodon*, *Cervus*, *Camelus*, *Sivatherium*, *Proamphibos*, *Hemibos*, *Leptobos* and *Sivacobus*. Nanda[11, 12], who analysed this faunal list provided by them, concluded that the upper part of the Tatrot beds, i.e. the Quaranwala Zone, contains genera characteristic of both the Tatrot and the Pinjor Faunas. Thus, the Quaranwala Zone, in fact, represents a transitional zone. This means the faunal change from the Tatrot to the Pinjor is not abrupt but one of continuity. In other localities studied by us in Jammu Hills[6, 13], the characteristic genus of the Tatrot – *Hipparion* – is replaced rather abruptly by younger Pinjor characteristic genera such as *Equus* and *Cervus* (cervid with antlers). Since our collection in the Tatrot Formation of Patiali Rao is very poor, it cannot be confirmed whether or not the typical Tatrot and Pinjor genera coexisted in the Pinjor area. Only a fresh, carefully recorded, *in situ* fossil collection in either Patiali Rao or in an adjacent area would provide the answer.

General lithological succession

The litho-succession exposed in the Pinjor area is as follows

Masol Formation (Tatrot Formation)

The formation consists of alternations of sandstones and claystones. Claystones predominate over sandstones and are maroon, grey-brown, yellow-brown and orange in colour. Sandstones are grey in colour, medium- to coarse-grained and are pebbly at the upper horizons. The pebbles are of different-coloured quartzites of

Himalayan source and purple sandstones are of the Dagshai Formation, which now crops out in the northern part of the Siwalik foredeep.

Rupar I to Rupar III (Pinjor Formation)

The subdivision of the Rupar Formation into Rupar I to Rupar III by ONGC geologists is based on the presence of pebble and conglomerate beds. Our earlier studies in the Surin–Mastgarh area of Jammu Hills showed that appearance of pebbles in the Siwalik succession is not isochronous and hence not of stratigraphic importance. In the present study Rupar I to Rupar III are grouped together under the Pinjor Formation.

In the Pinjor Formation, sandstones predominate over claystones upwards in the sequence. Sandstones are coarser-grained and are brown in colour. Pebble and conglomeratic bands are present locally. Sandstone pebbles of Dagshai–Kasauli aspect appear in increasing numbers upwards in the succession.

Rupar IV (Boulder Conglomerate Formation)

Along Patiali Rao only a small thickness of this sequence is exposed and is represented by conglomerate beds with sandstone pebbles of Dagshai–Kasauli aspect predominating over those of other lithologies.

The whole sequence is inclined southwesterly with dip amount ranging from 7 to 10°.

Palaeomagnetic studies

The section was first surveyed by a tape and prismatic compass on 8 in to a mile scale. Geology encountered along the traverse line was plotted on the survey sheets and the thickness of each lithology was computed and finally a stratigraphic column was erected.

Fifty-two sites were selected for sampling in a total thickness of 1296 m. At each site 3–4 oriented blocks were collected from siltstone–claystone lithologies. Each block was cut into 2.5 cm cubes in the laboratory.

Samples were measured on an Astatic Magnetometer for their declination, inclination and intensity of magnetization at National Geophysical Research Institute (NGRI), Hyderabad.

AF demagnetization

To determine the stability of magnetization selected samples were chosen for stepwise alternating field (af) demagnetization in steps of 2.5, 5, 10, 15, 20, 40, 60 and 80 mT field in order to choose a field for blanket demagnetization. Figure 2 shows the demagnetization

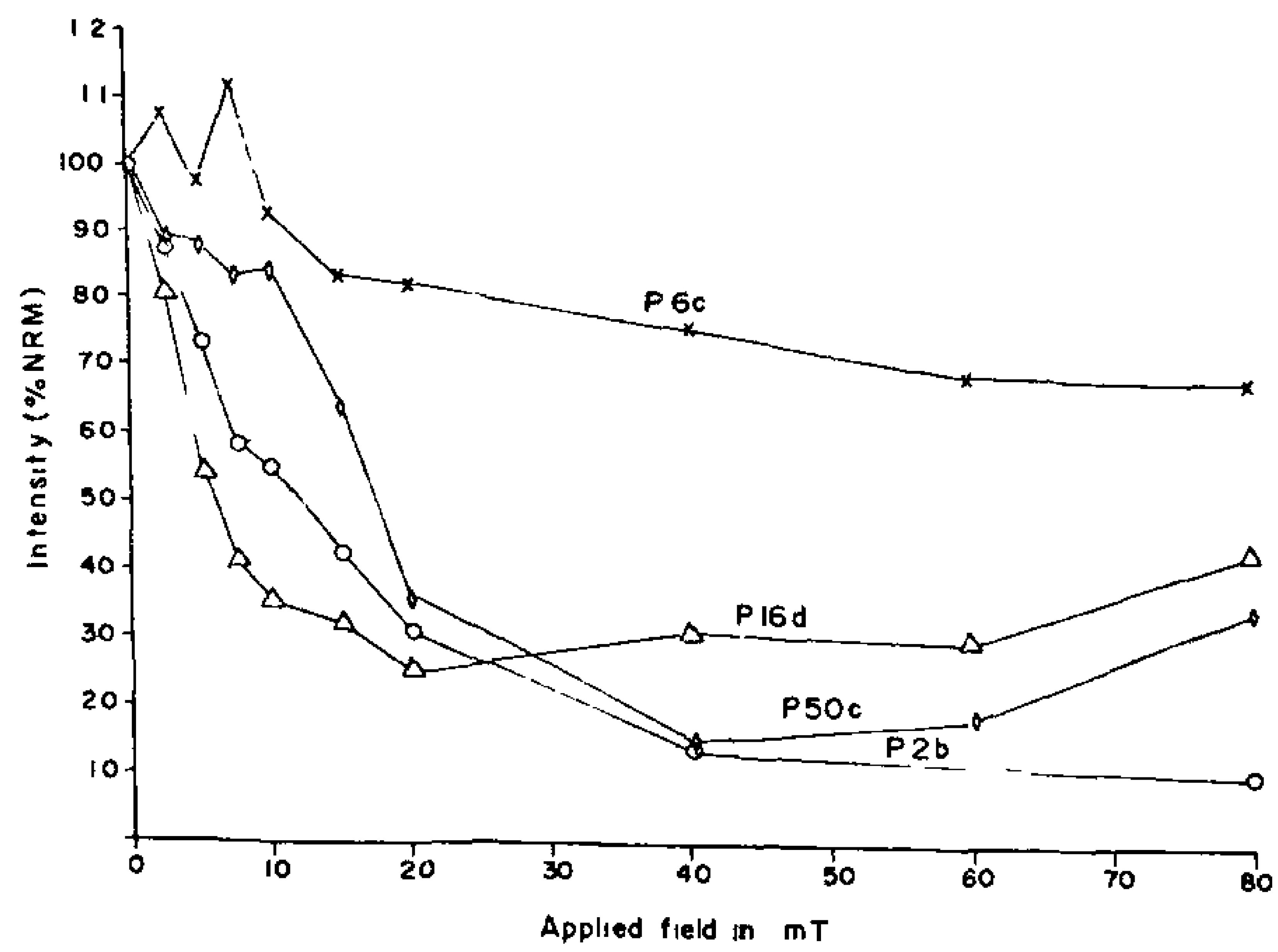

Figure 2. Intensity decay curves for four samples from Patiali Rao during af demagnetization.

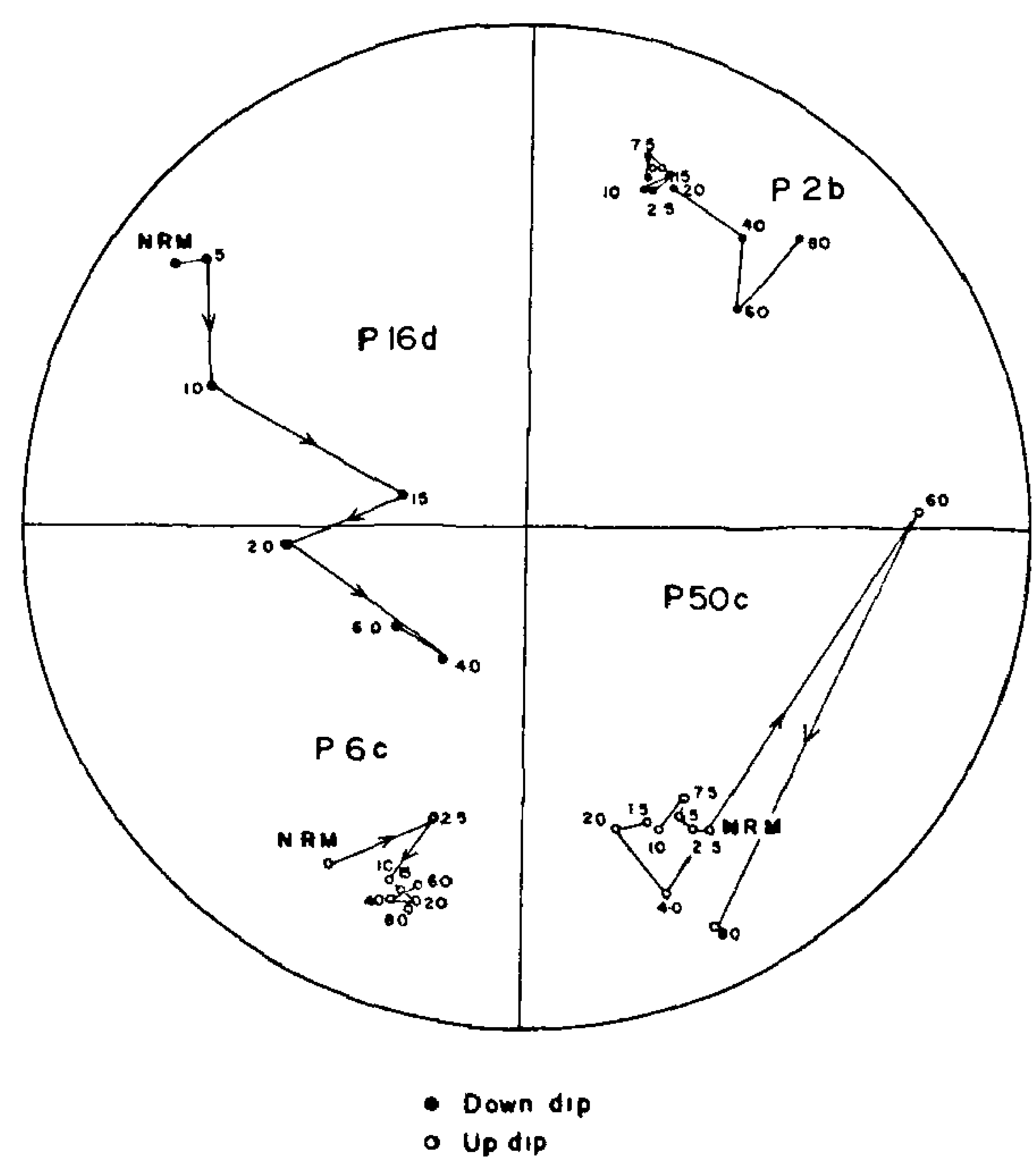

Figure 3. Migration plot during af demagnetization of four specimens from Patiali Rao

curves and Figure 3 is a plot of vector migration of various specimens with increasing field. It is seen from the af demagnetization curves that there is a steep fall in the intensity up to 20 mT, suggesting removal of the secondary unstable component, and thereafter there is little change in the intensities. In the vector migration diagram it is observed that in certain cases the normal vector with down dip becomes reverse (P16) in fields

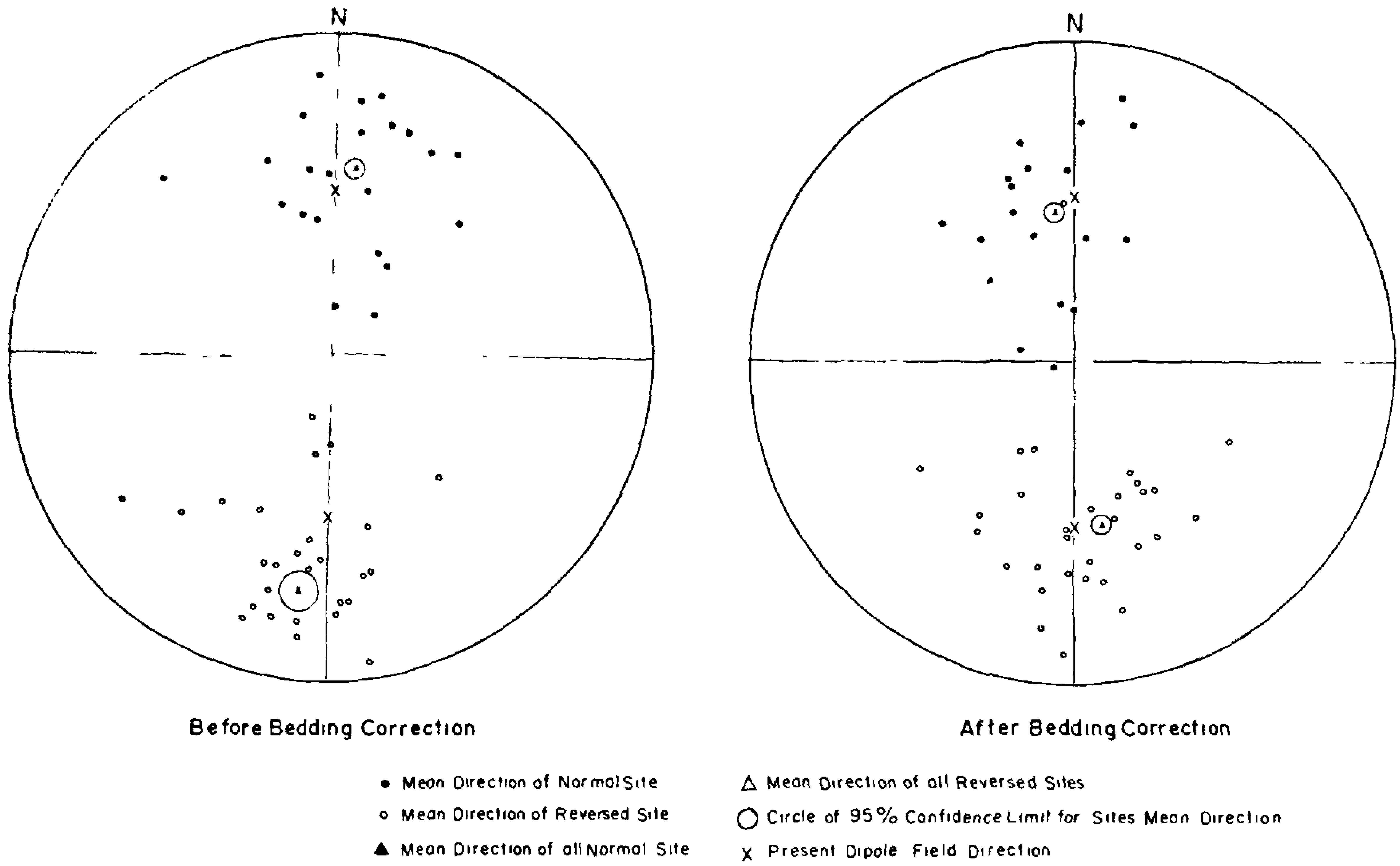

Figure 4. Stratigraphic projection of the sites' means from Patiali Rao after demagnetization up to 40 mT

varying from 10 to 40 mT. Therefore, all the specimens were cleaned at 10, 20 and 40 mT and the mean with best statistical parameter was selected for computation of virtual geomagnetic pole (VGP) latitudes.

VGP latitudes were calculated for each site. If the site's mean polarity was significant, i.e. if $K > 10$, the sites were designated as class I, and if $K < 10$, as class II Sites whose site means are statistically random were designated as class III. Our sites fall in class I and II and none in class III.

The site mean directions of all the sites are plotted on steronet (Figure 4) before and after bedding correction. VGP latitudes calculated for each site were plotted against their position in the stratigraphic column (Figure 5). Eight magnetic reversals are present in the section defining three normal and four reversed magnetozones.

No ash bed was detected in the section during the present survey, which could have provided an age control for the correlation of the local magnetic polarity stratigraphy (MPS) with the magnetic polarity time scale (MPTS). We, therefore, used the palaeontological criteria for the correlation. However, in Ghaggar river section Mehta *et al.*[14] dated a thin band of volcanic ash belonging to the Pinjor Formation and assigned an age of 2.14 ± 0.51 Ma. At N1–R1 boundary our vertebrate fossil collection records the presence of *Cervus* with *Leptobos* (Figure 5). These genera are characteristic of the Pinjor Faunal Zone and were found in Nagrota–Jammu and Parmandal sections at the Gauss–Matuyama chron transition[6]. *Equus*, another characteristic taxa of the Pinjor Faunal Zone, occurs at the top of the Pinjor in the present section. Opposite N1, no fossil was found during our survey excepting *Stegodon* sp. Earlier, Sahni and Khan[8] reported the presence of *Hipparion* and *Hemibos*, characteristic genera for the Tatrot Faunal Zone. With these controls, N1–R1 magnetic transition can be correlated to the Gauss–Matuyama transition presently dated at 2.47 Ma and R4–N5 boundary to the Matuyama–Brunhes transition dated at 0 73 Ma. These age controls yield an average sedimentation rate of 0.63 m/1000 a for the Patiali Rao section. The ages of the normal magnetizones N2 and N4 computed from the above-mentioned sedimentation rate come to 2.1 and 1.0 Ma. These ages are close to the ages suggested for Renunion and Jaramillo subchrons and may well correlate with them. N3 would then represent Olduval normal subchron with an age of 1.86–1.67 Ma.

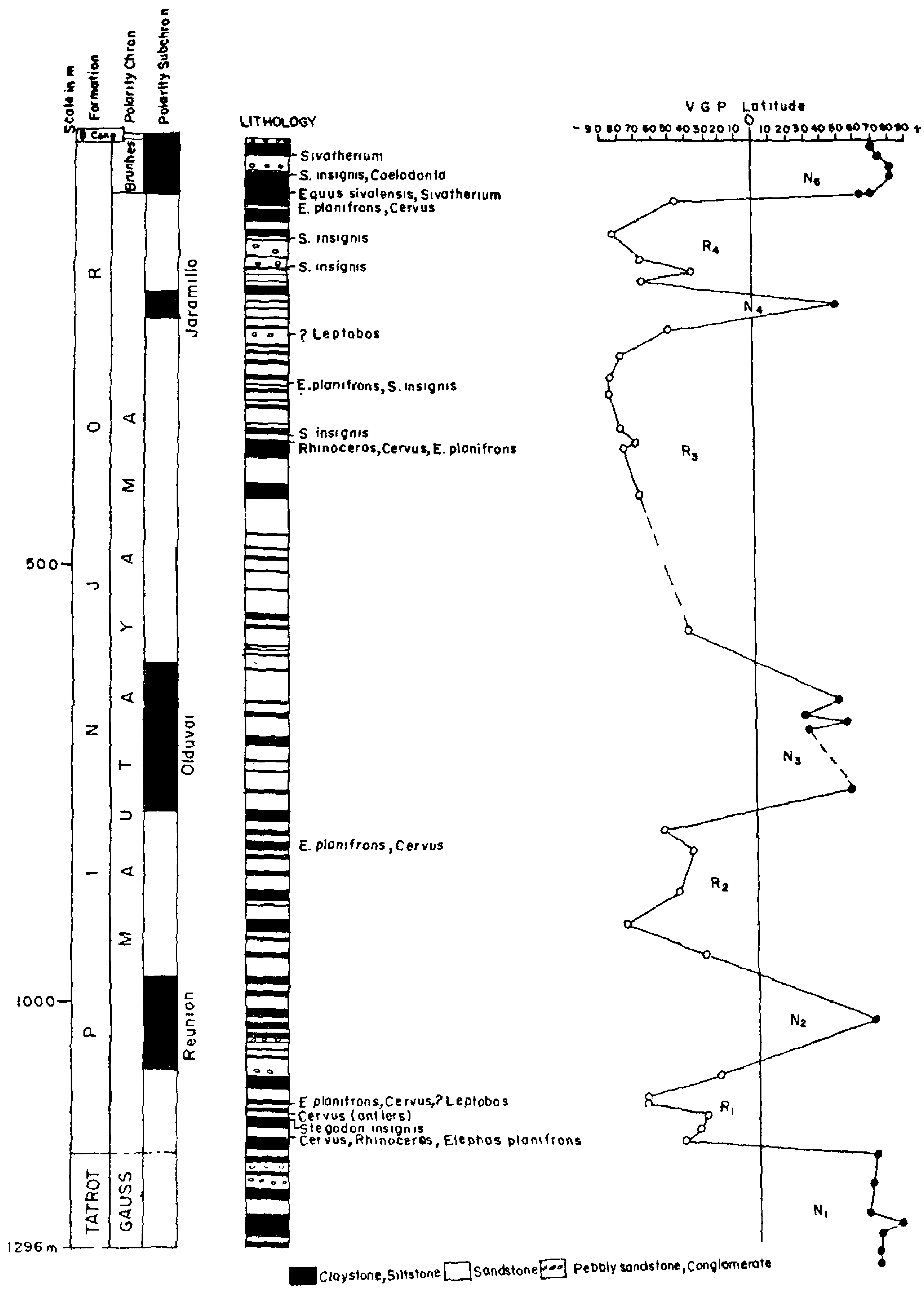

Figure 5. Plot of VGP latitude against the lithological column of the Patiali Rao section

Conclusion

The data permit one to conclude that the type Pinjor Faunal Zone of Pilgrim[1] comprises the entire Matuyama reversed chron and the lower part of the Bruhnes normal chron with a time span extending from 2.47 to 0.63 Ma.

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RESEARCH COMMUNICATIONS

Bispectra of a tropical coupled ocean–atmosphere system

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It has recently been proposed that the broad spectrum of interannual variability in the tropics with a peak around four years results from an interaction between the linear low-frequency oscillatory mode of the coupled system and the nonlinear higher-frequency modes of the system. In this study we determine the bispectrum of the conceptual model consisting of a nonlinear low-order model coupled to a linear oscillator for various values of the coupling constants.

IT has been well-established that the tropical ocean and the atmosphere interact strongly on time scales larger than a season and that the El Nino and Southern Oscillation (ENSO), an irregularly fluctuating interannual phenomenon, is a result of such interactions between the atmosphere and the ocean. For time scales in which the atmosphere cannot be considered in isolation, say time scales of the order of a season or longer, one must consider the tropical coupled ocean–atmosphere system. Only a few studies[1–3] have attempted to make a quantitative estimate of the predictability of the coupled ocean–atmosphere system. Goswami and Shukla[1] showed that the growth of small errors in the coupled system is governed by two time scales. The fast time scale has an error-doubling time of about 5 months while the slow time scale has an error-doubling time of about 15 months. The slow time scale appears to arise as a result of the dominant four-year cycle of the system while the fast time scale appears to arise due to the aperiodicity of the system.

In general, aperiodicity may be attributed to nonlinear interaction between more than one mode (or degrees of freedom) of the system. Early instability analysis[4] shows that the tropical coupled ocean–atmosphere system possesses an unstable coupled low-frequency mode having a period of 26 months and an e-folding time of 5 months. Recent studies[5] have shown that the convergence feedback mechanism included in the parameterization of atmospheric heating introduced some higher-frequency intraseasonal unstable modes. The existence of more than one unstable mode can lead naturally to nonlinear interaction between them and thereby explain the existence of the aperiodicity. One of the efficient means of studying the existence of nonlinear interaction between different modes is by the determination of the bispectrum. For a normal random process the third moments are zero. The bispectrum is a decomposition in the frequency domain of the third moments and thus provides information on the nonlinear characteristics.

Krishnamurthy *et al.*[6] have recently proposed a conceptual model for the aperiodicity of the interannual variability of the tropics. The model consists of a nonlinear system (the Lorenz model[7]) coupled to a linear oscillator. The nonlinear system represents some aspects of the general circulation of the atmosphere and the equations are the same as those of Lorenz[7]. The linear part represents the dominant four-year oscillation of the