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MAGNETIC-POLARITY STRATIGRAPHY OF THE SIWALIK GROUP OF THE SHINGHAR AND SURGHAR RANGES, PAKISTAN

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ABSTRACT

Four stratigraphic sequences were measured and sampled from the Shinghar and Surghar Ranges, Pakistan, for detailed magneto-stratigraphic studies of the fluviatile Neogene and Quarternary Siwalik Group. The samples were subjected to blanket thermal demagnetization at 500°C. Some of the samples, particularly those from the pale brown siltstone/claystone units, were further subjected to 600°C to isolate the stable primary component of magnetization used to established the magnetic-polarity-reversal sequences. This sequence was correlated to the MPTS with the aid of fossils collected from the nearby Dawood Khel area (Hussain et al., *1977) and from the Shinghar Range during paleomagnetic sampling. This correlation suggests that deposition of the Siwalik Group in this area began during basal Chron 11 (11.8 m.y.B.P.) and continued till the late Matuyama Chron (0.85 m.y.B.P.). These studies indicate that the Siwalik sedimentation in this area started later than that of the Potwar Plateau.*

INTRODUCTION

The Siwalik Group of the Surghar-Shinghar Ranges is composed of Neogene and Quarternary fluviatile sedimentary rocks exposed along the northern and western flanks of the arcuate and asymmetric Makarwal anticline (Fig. 1), which forms the northwestern part of the Trans-Indus Salt Range. The Makarwal anticline extends between the Indus and the Kurram Rivers. The Siwalik Group overlies, with angular unconformity, the Sakessar Limestone of Early Eocene age. However, in the southern part of the Makarwal anticline the Siwalik sediments are thought to overlie the Mitha Khattak Formation conformably (Danilchik and Shah, 1976). Throughout the extent of the Makarwal anticline, the Siwalik Group consists of three distinct lithologic units from base to top these units are :–

Red bed zone

This part of stratigraphic sequence consists of dark reddish-brown claystone/siltstone units, each 10m to 60m thick, alternating with light-brown and grayish-brown sandstone units each 2m to 20m thick. The thickness of sandstones increases, whereas that of the claystone decreases towards the upper part of the redbed zone. Caliche zones are abundant in the overbank deposits of the lower part, but less common in the upper part. Two sections measured and sampled from this zone are named as Khora Baroch and Chichali: their locations are shown in Fig. 1. It is this basal redbed zone of the Siwalik Group which gives the name to the Surghar Range (Red mountain, in local language).

Multistoried sandstone

The redbed zone is overlain by a sequence of light-grey sandstone, 4 to 6km thick, with no over bank deposits at all. In the upper part, however, sandstones 100m to 200m thick alternate with conglomerate units up to 100m thick. These conglomerate units are only present in the northwestern part of the Makarwal anticline, and are absent in the southern part of this anticline. Due to the lack of overbank deposits in this part of the stratigraphic sequence it was not sampled for paleomognetic studies.

Siltstone/sandstone/conglomerate

The multistoried sandstone is conformably overlain by a sequence of light-grey sandstone units alternating with pale-brown and yellowish-orange siltstone/claystone units. Thickness of sandstone and siltstone units ranges between 5m and 100m. Towards the upper part the siltstone units become sandy and the thickness of sandstone units increases. The upper most 200m to 300m of the stratigraphic sequence is mainly composed of light-brownish-grey coarse-grained sandstone overlain by conglomerate. It is the multistoried sandstones and this part of alternating sandstones and siltstones which collectively constitute the Shinghar Range (white/green mountain. In local language). Two sections measured and sampled from the Shinghar Range are the Spalmai Tangi and the Chani Khel. Their locations are shown in Fig. 1.

PALEOMAGNETIC SAMPLING

Three to five oriented samples were collected from each site. From the Spalmai Tangi section, 1500m thick, 41 sites were sampled and 21 sites were sampled from 325m thick Khora Baroch section. Whereas only 11 sites were sampled from 200m thick Chani Khel section and from a 900m thick stratigra-

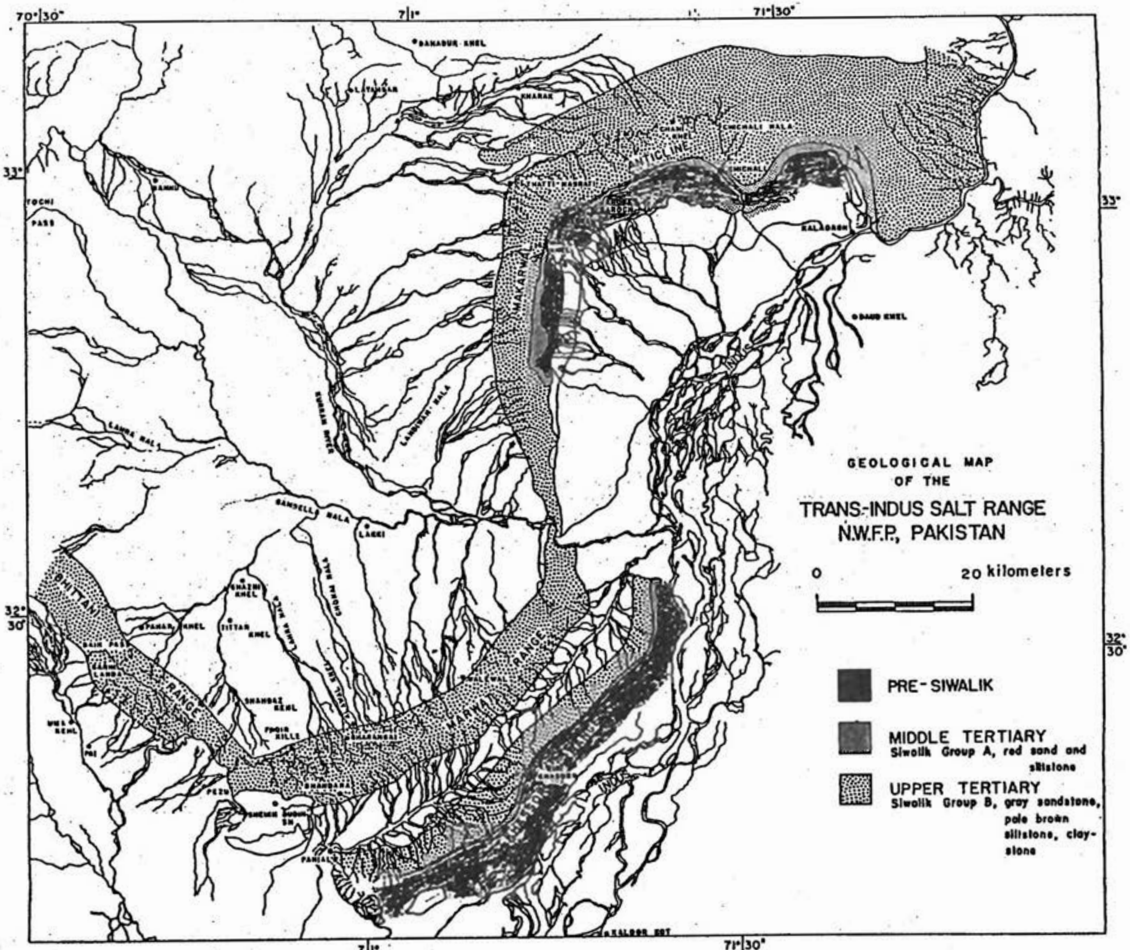

Fig. 1. Geologic map of the Trans-Indus Salt Range, northwestern Pakistan. Siwalik Group A, red sandstones and siltstones, are also exposed in the axial part of the Bhittani Range, but are not shown in this map because of their small thickness.

phic sequence of the Chichali section 50 sites were sampled. The strata generally strike ENE–WSW in the northern part of the Makarwal anticline, and N–S in the southern part of the anticline. Their average dip ranges between 25°—35°NW in the northern part and 25°—35°NW in the southern part.

N. R. M.

The intensity of NRM of samples collected from the four sections ranged between $1x10^{-6}$ Gauss to $8x10^{-5}$ Gauss. However, most of the samples had NRM intensity ranging from 1 to $5x10^{-5}$ Gauss.

THERMAL DEMAGNETIZATION

After measuring the NRM some of the samples were selected for partial thermal demagnetization from 100°C to 660°C, with intervals of 25°C to 100°C. Some of the typical results are shown in Fig. 2. The behaviour of many samples suggest the presence of secondary component of magnetization carried by magnetic grains with blocking temperatures of 300°C to 400°C. The magnetization vector decays linearly towards the origin from 400°C to 660°C. This suggested that a temperature of 400°C is required to isolate the primary component of magnetization. Knowing this, all samples were subjected to a single step demagnetization at 500°C, whereas some of the samples were further subjected to 600°C heating just to verify the stability of the directions of magnetization. However, no significant change in direction was observed. The results of thermal demagnetization are given in Table 1.

TESTS OF DATA RELIABILITY

Correction for bedding tilt was applied to the stable directions of magnetization obtained after thermal demagnetization and these directions were used to calculate the site-mean directions using Fisher's (1953) statistics. All site-mean directions were classified as class–A, –B, or –C following Khan *et al.*, (1988). From the Spalmai Tangi section 37 (90%) sites are class–A and 4 (10%) are class–B. From the Khora Baroch section 16 (76%) sites are class–A and 5 (24%) are class–B. From the Chani Khel section all of the 11 sites sampled are class–A. Whereas from the Chichali section 36 (67%) sites are class–A, 14 (26%) are class–B, and 4 (7%) are class–C sites. The data of class–C sites was not used for further studies. The means of all normal-polarity sites from the Spalmai Tangi, Khora Baroch, and the Chichali section are almost antiparallel to the means of all reversed-polarity sites, correspondingly (Fig. 3). Whereas from the Chani Khel section the means of all reversed-polarity sites is antiparallel to the present-day earth's magnetic field for this location (Fig. 3). These results indicate that the stable direction of magnetization was acquired under the influence of earth's magnetic field and has been successfully isolated. Knowing the young age of the rocks sampled from these sections it is confidently argued that the stable directions of magnetization were acquired during the process of deposition of these sediments.

TABLE 1. DIRECTIONS OF REMENENT MAGNETIZATION.

	N	D	I	K	α 95	Nc	Dc	Ic	Kc	α 95c
Spalmai Tangi	4	342.1	38.4	4.9	46.3	4	334.3 (347.7)*	24.0 (26.9)*	8.9 (61.8)*	32.6 (15.8)*
	37	201.1	–41.5	18.2	5.7	37	177.0	–39.5	17.7	5.8
Khora Baroch	16	1.8	52.9	16.5	9.3	16	340.7	27.5	18.7	8.7
	5	209.2	–50.7	5.1	37.5	5	174.4	29.1	7.6	29.4
Chichali	39	5.6	51.2	6.0	10.2	37	354.3	30.9	8.4	8.7
	11	214.9	–53.0	3.3	29.7	13	195.9	–38.0	5.7	19.0
Chani Khel	2	37.7	–61.0	6.9	>90	0	—	—	—	—
	9	219.2	–69.2	33.8	8.9	11	179.1	–51.5	10.4	14.8

Explanations : N = Number of Sites, D = Declination, I = Inclination, Nc = Number of sites after bedding connection, Dc = Declination corrected for bedding tilt, Ic = Inclination corrected for for bedding tilt, K = Precision parameter, α 95 = 95% confidence level (Fisher, 1953), all sites thermally demagnetized.

* Directions obtained after one site with intermediate directions is excluded.

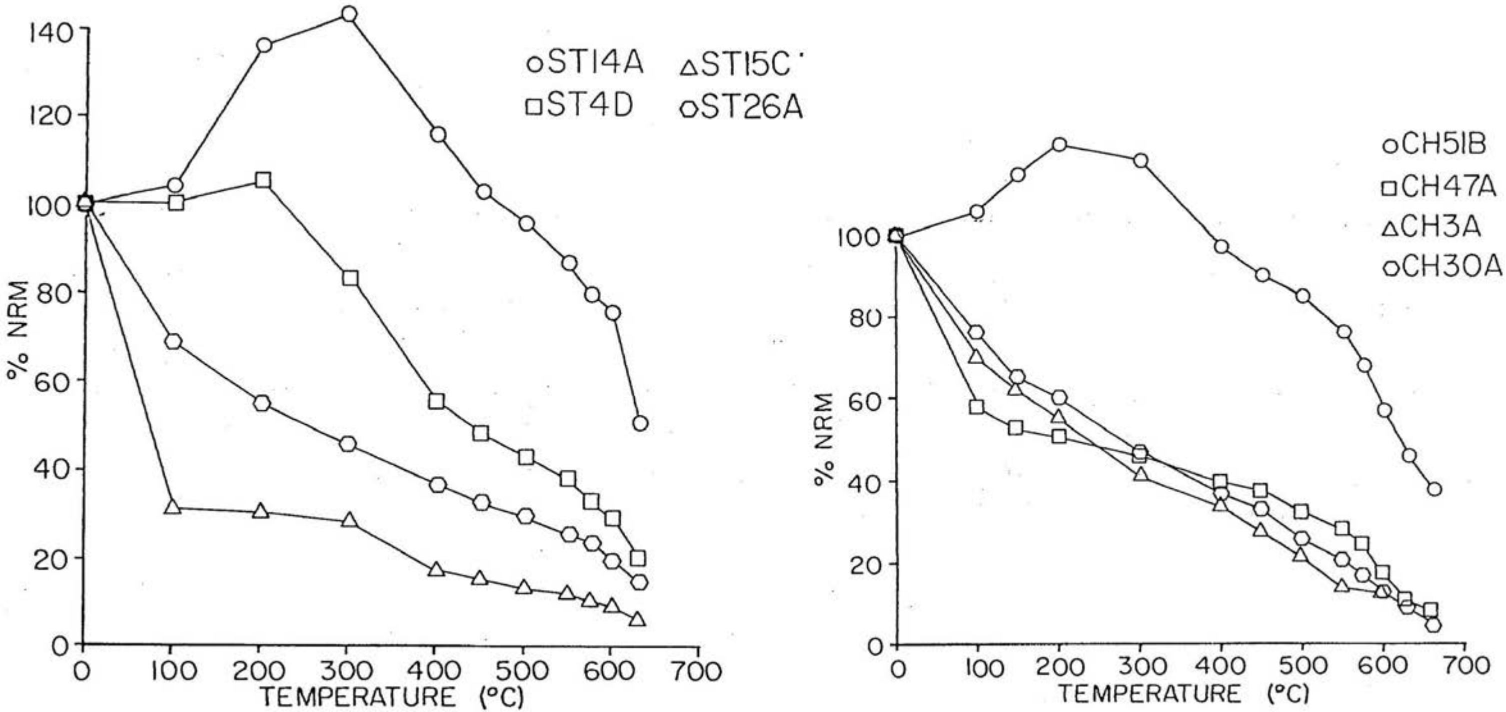
○ST14A △ST15C
□ST4D ⬡ST26A
% NRM
TEMPERATURE (°C)
○CH51B
□CH47A
△CH3A
⬡CH30A
% NRM
TEMPERATURE (°C)

Fig. 2.

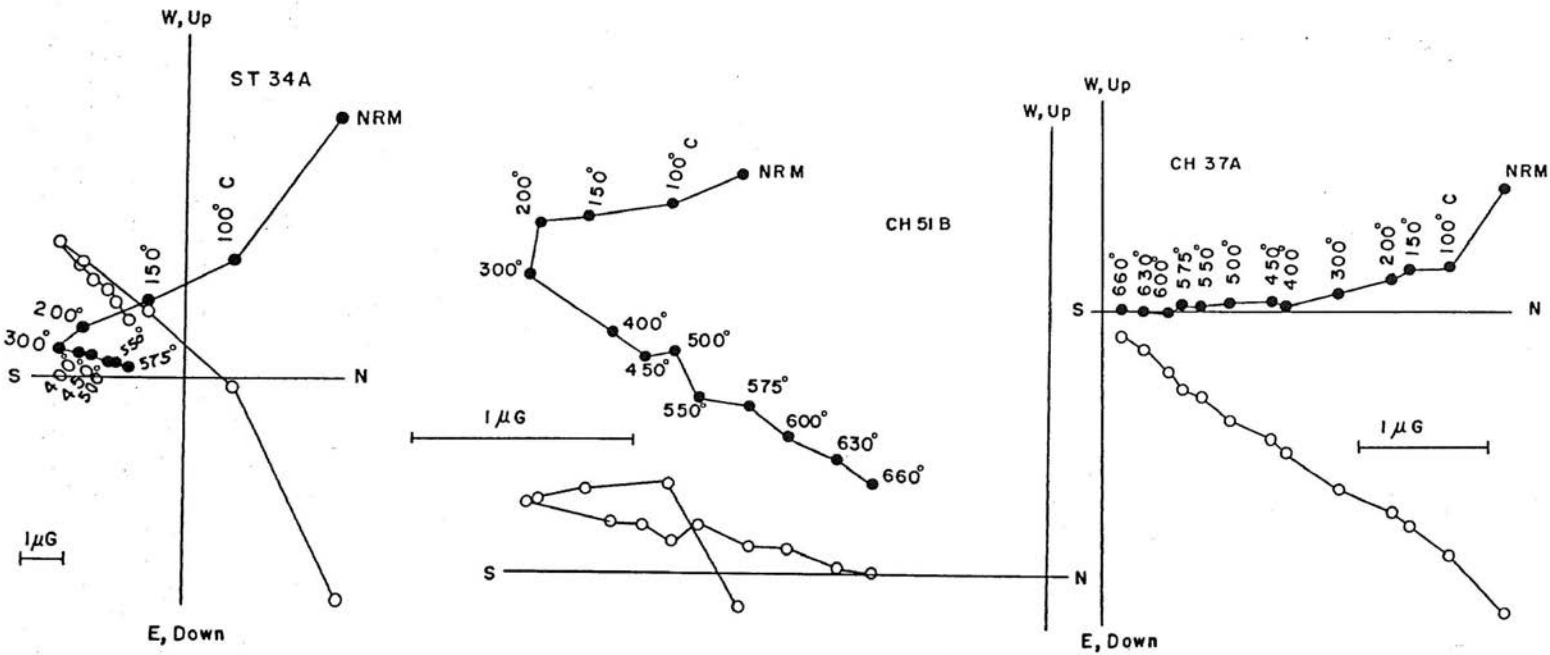

Fig. 2. Typical results of partial thermal demagnetization: orthogonal diagrams (Zijderveld diagrams) based on successive end points of partial thermal demagnetization vectors. Solid (open) circles are plotted on a horizontal (vertical) plane. Short bars indicate the scale for remanant magnetization intensity, all of these plots are based on bedding-corrected directions of magnetizations.

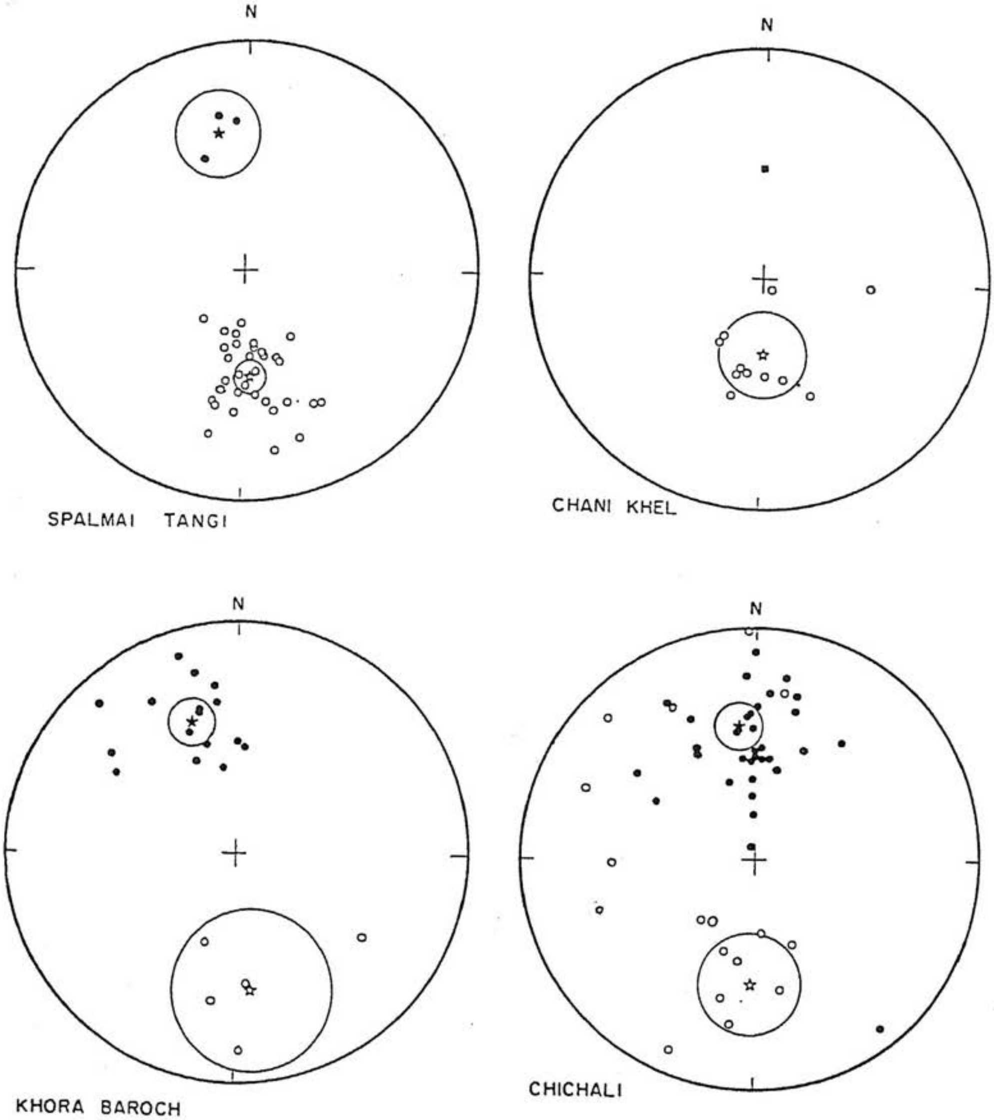

Fig. 3. Equal-angle stereographic projections of bedding-corrected site-mean directions obtained after thermal demagnetization at 500°C, and 600°C. Solid (open) circles are plots on the lower (upper) hemisphere. Solid (open) stars are the mean of normal (reversed) polarity sites. and the large circles represent limits of 95% confidence level.

MAGNETIC-POLARITY STRATIGRAPHY

The bedding-corrected site-means directions of magnetizations obtained after thermal demagnetization ofthe samples were used to calculate the latitudes of Virtual Geomagnetic Poles (= VGPs). The latitudes of VGPs were plotted against stratigraphic thickness which resulted in the establishment of magnetic-polarity-reversal sequence for each section, described individually as follows.

Spalmai Tangi

A plot of VGP latitudes versus stratigraphic thickness (Fig. 4) shows the establishment of five magnetozones marked by four magnetic-polarity-reversal boundaries. This section is dominantly marked by reversed magnetic polarity and only two short normal polarity magnetozones (N1 and N2) are observed. The diamictite unit (similar to the Bain Diamictite of Bhittani Range and Pezu Pass; Khan, et al., 1986) appears about 200m below magnetozone N1. Because of the presence of multistoried sandstone units in this section, the boundaries of N1 and N2 magnetozones may actually be slightly different than those shown in Fig. 4, but significant difference is most unlikely. However, as each polarity zone is marked by two sites, these short polarity zones are true polarity zones.

During the course of paleomagnetic sampling an Elephas sp. jaw was collected from the lowerpart of measured section. This suggests the presence of Pinjor-stage fauna. Following the work of Opdyke *et al.* (1979) in the Potwar Plateau it is most likely that the stratigraphic sequence of this section is younger than 3 MYBP. This is also plausible because it is the upper most part of the entire Siwalik sequence in this area. Another important point for correlation of this section is the fact that Siwalik sediments in the Bhittani, Marwat, and Khasor Ranges are of Plio-Pleistocene age (Khan *et al.*, 1988). Keeping these observation in mind, the observed magnetic-polarity stratigraphy is correlated with the standard MPTS of Mankinen and Dalryml e (1979) as shown in Fig. 4.

The dominance of reversed magnetic polarity suggests its assignment to the Matuyama Chron. The short polarity zones N1 and N2 are correlated with the Olduvai and Jaramillo subchrones, respectively. This correlation indicates that the measured section ranges in age from about 2.4 MYBP to about 0.74 MYBP. Sediments younger than 0.74 MYBP are present and form the top of stratigraphic sequence. However, these younger sediments consist predominantly of coarse-grained sandstones and conglomerate, and thus are not suitable for present paleomagnetic studies. It is therefore most likely that sedimentation continued till late Pliestocene (or during the Brunhes Chron). Prior to this study the stratigraphic sequence measured in this section has been correlated with the Dhok Pathan formation of the Potwar Plateau, based on the lithologic similarities and homotexial relationship (Fatmi, 1974; Danlichik and Shah, 1976; Shah, 1977). This implies an age of 7.9 MYBP to 5.1 MYBP (Johnson *et al.,* 1982) for this part of the stratigraphic sequence. Whereas the upper most sandstone and conglomerate have been correlated with the Soan Formation of the Potwar Plateau, implying younger than 5.1 MY age. Present work, however, unambigously indicates that the stratigraphic sequence above the 4 to 6km thick sandstone sequence

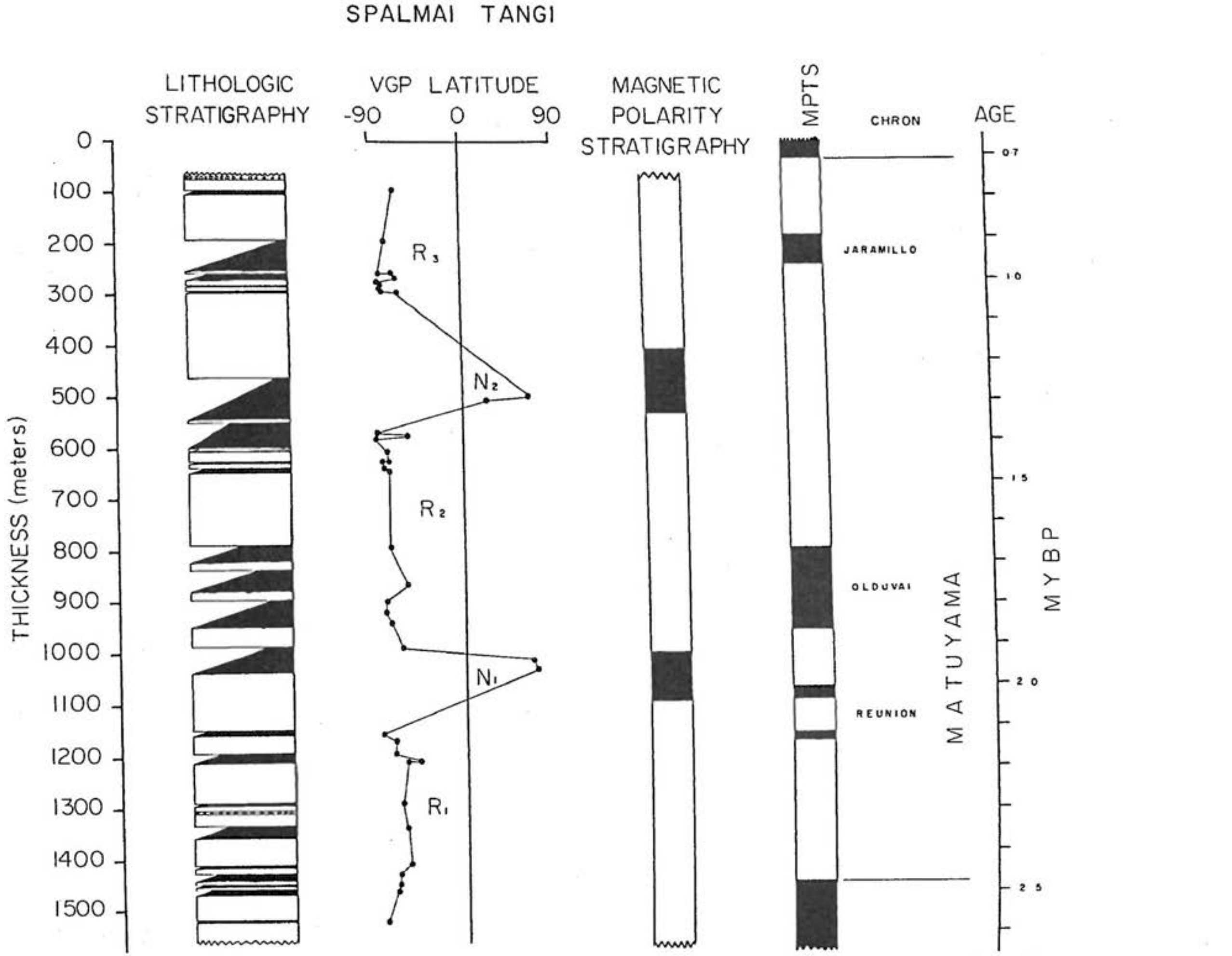

Fig. 4. Plot of **VGP** latitude against stratigraphic thickness. Dark (white) blocks in the lithologic stratigraphic column represent vertical accretion-siltstone/claystone (lateral accretion-sandstone) deposits of the molasse sequence. Dark (white) columns of MPS represent normal (reverse) magnetic polarities. The boundaries of magnetic-polarity reversals are placed at intermediate position between the successive sites having opposite polarities.

was deposited at time younger than 2.4 MYBP. Whereas top of the stratigraphic sequence, made by sandstone and conglomerate, is younger than 0.85 MY.

Khora Baroch

Plot of VGP latitudes against stratigraphic thickness (Fig. 5) shows the establishment of three magnetozones marked by two magnetic-polarity-reversals. All magnetozones are marked by more than one site and thus represent true magnetic-polarity zones. A precise correlation is not possible because only three magnetozones are observed in this section. Work done by Berry *et al.* (1982) near Khaur in the Potwar Plateau has shown that Hipparion first appeared at about the middle of Chron 9. From a short section near Mitha Khattak, Hipparion fossiles were collected, which implies that base of the Siwalik Group is younger than 10 MY near the Mitha Khattak area. Further work done in the Potwar Plateau (Johnson *et al.,* 1982) has shown that the basal Siwalik sediments are older than 15 MY. Recent studies in the Khasor and Marwat Ranges suggest that the basal Siwalik sediments are younger than 5 MY (Khan *et al.,* 1988). This indicates a general westward younging of the onset of Siwalik sedimentation. Because of the intermediate location of the Surghar Range, it is most plausible that the Siwalik sedimentation in this area started post 15 MYBP, but prior to 5 MYBP. This conclusion, therefore, substantially supports the above idea that the base of the Siwalik sediments of the Mitha Khattak section is younger than 10 MY. Based on these evidences the MPS of the Khora Baroch section (less than 15 km north of Mitha Khattak section) is correlated with the standard MPTS of Mankinen and Dalrymple (1979).

Three alternatives for correlation are possible within the time range involved (Fig. 5). The presence of Hipparion in the Mitha Khattak section suggests that alternative III is not plausible. Whereas correlation of this section with the Chichali section, considering the above-mentioned evidence for westward younging of Siwalik sedimentation, suggests that the N1 magnetozone can be correlated with Chron 9. This implies that R1 and R2 magnetozones are Chrons 8 and 7, respectively. This forms the basis of alternative II of Fig. 5. The alternative II therefore suggests that Siwalik sedimentation at Khora Baroch started about 2 MY later than at Chichali. Alternative I is based on assumption of simultaneous onset of Siwalik sedimentation in the Chichali and Khora Baroch areas. However, because alternative II agrees well with the general westward younging of Siwalik sedimentation, we consider it to be the most plausible correlation.

Above discussion suggests that the stratigraphic sequence is younger than 11.8 MY and older than 7.5 MY considering alternatives I and II. As alternative II is considered more appropriate, it is most likely that these sediments are older than 7.5 MY but younger than 10 MY, which is also substantiated if the 5 km-thick sandstone is considered to have been deposited at a rate of 1m/1000yrs, and the results of the Spalmai Tangi section where base of the section is older than 2.4 MY.

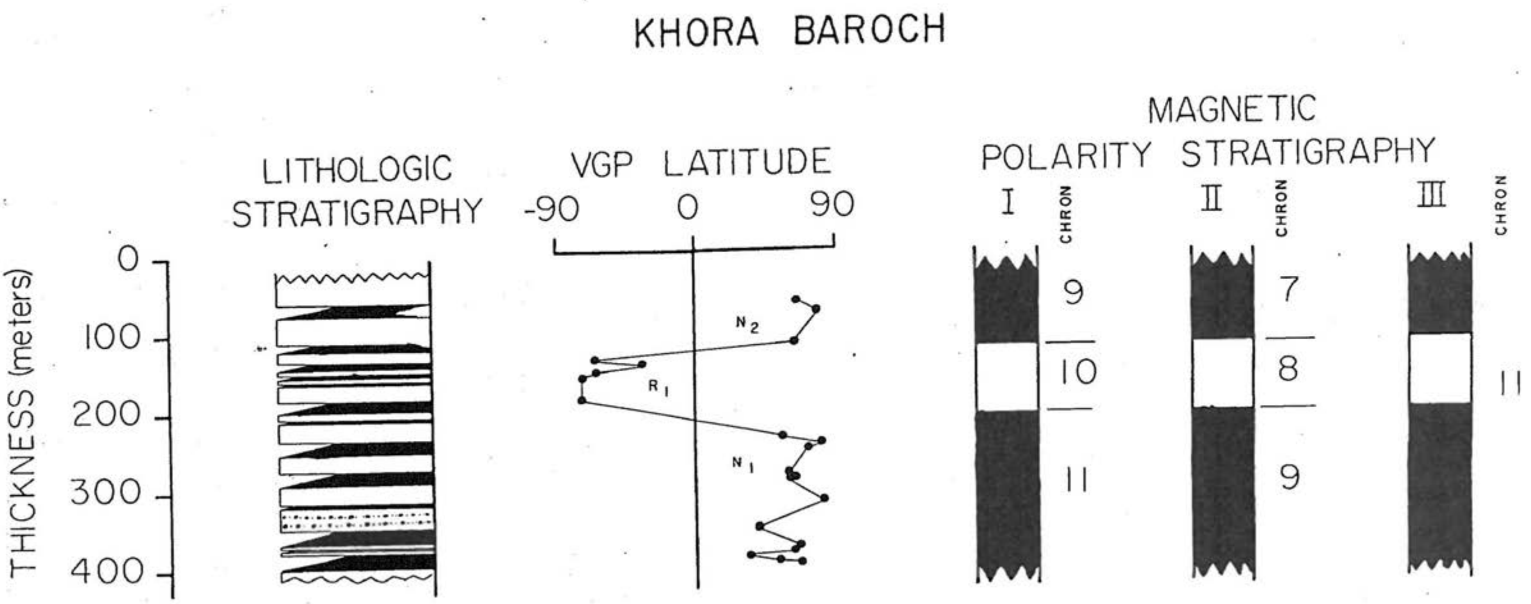

Fig. 5. Plot of **VGP** latitude versus stratigraphic thickness. Plotting conventions are same as for Fig. 4.

Chani Khel

A plot of VGP latitudes versus stratigraphic thickness (Fig. 6) suggests that this short section represents only one reversed-polarity magnetozone; no polarity reversal is observed. As this section is not far away from the Spalmai Tangi section, and forms the upper part of stratigraphic sequence of the Siwalik Group, it is most likely that the reversed polarity represents the Matuyma Chron. Therefore, it is younger than 2.5 MY and older than 0.72 MY. As the section conformably lies about 200m below the top of stratigraphic sequence, it is possible that the R1 magnetozone is the reversed-polarity zone between the Olduvai and Jaramillo Subchrons. This correlation implies that the stratigraphic sequence measured in this section is younger than 1.67 MY, i.e. its age is early to medial Pleistocene.

Chichali

A plot of latitudes versus stratigraphic thickness (Fig. 7) allows 17 magnetozones marked by 16 magnetic polarity-reversal boundaries to be established. Although most of the magnetozones are marked by more than one site, some are marked by one site. However, the polarity zones marked by one site are considered valid, because the results are based on class–A and class–B sites. Establishment of many polarity reversals is of great significance for the purposeses of correlation with standard MPTS. Also this section is of great importance for correlation with the lower Siwalik sediments of the Potwar Plateau.

Due to the lack of plaeontologic work in tre Chichali area the vertebrate fossils collected by Hussain *et al.* (1977) in the vicinity of Daudkhel (just east of the Indus River) are of great significance for the purposes of correlation. Close proximity of the Chichali section to the Daud Khel area suggests absence of drastic age difference in the Siwalik sediments of these two areas. However, because of the general westward younging of the onset of Siwalik sedimentation it is likely that basal Siwalik sediments of Chichali area are younger than the basal Siwalik sediments of Daud Khel. Besides other vertebrate fauna, Hussain *et al.* (1977) collected a possible Hipparion fossil leg bone just below the sandstone. Whereas definite Hipparion tooth was collected 413m stratigraphically above this site. Other fauna collected from Daud Khel area and their comparison with those collected from Khaur area (Berry *et al.,* 1982) suggest that Siwalik sediments at Daud Khel can not be older than 14 to 15 MY. Considering the westward younging of the onset of Siwalik sedimentation, it is most likely that basal Siwalik sediments of the Chichali section are younger than 14 to 15 MY. Based on the fauna collected by Hussain *et al.* (1977) in the vicinity of Daud Khel, it is also most likely that the stratigraphic sequence measured in the Chichali section is older than 5 to 6 MY. Based on these observations, the MPS of Chichali section is correlated with the MPTS of Mankinen and Dalrymple (1979).

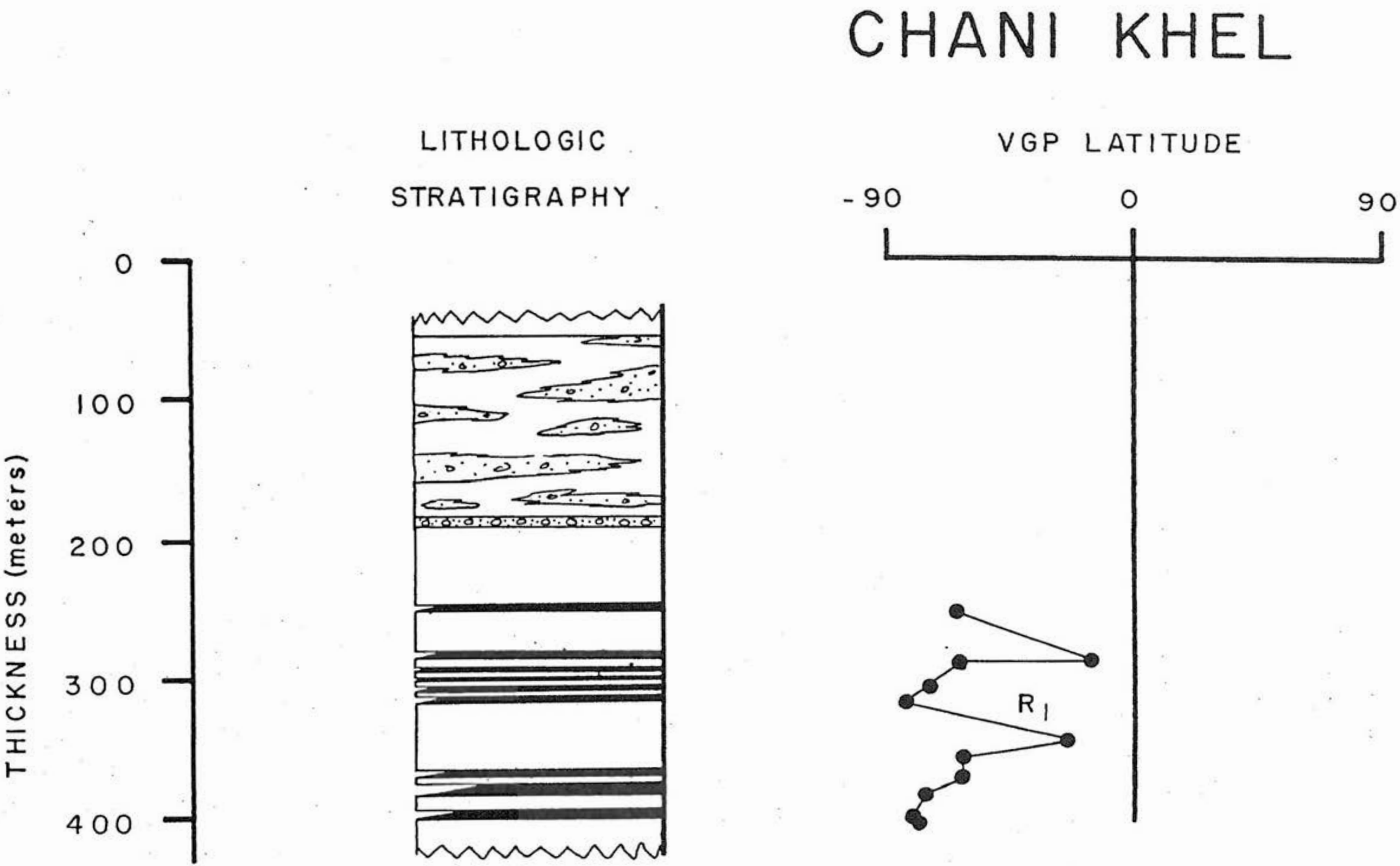

Fig. 6. Plot of VGP latitude versus stratigraphic thickness. Plotting conventions are same as for Fig. 4.

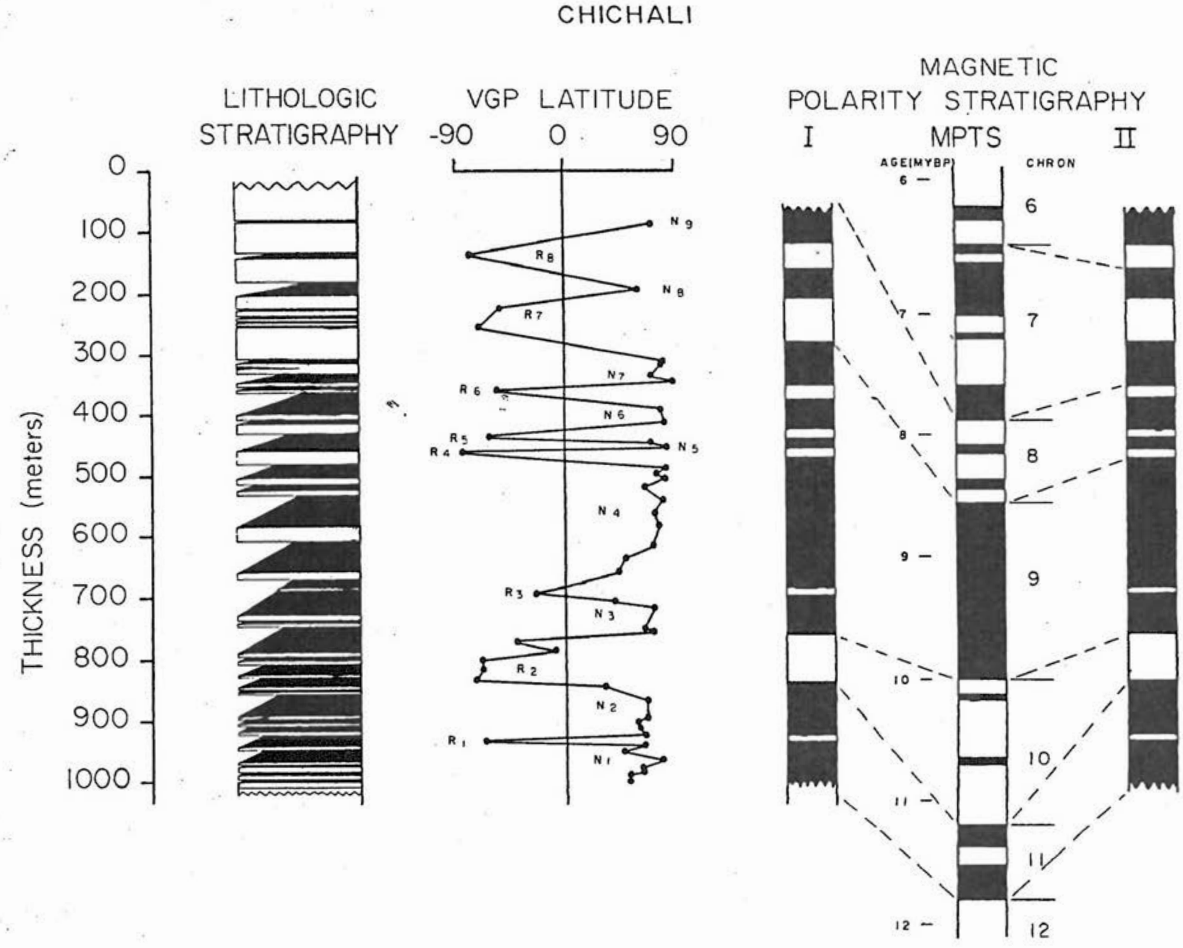

Fig. 7. Plot of VGP latitude versus stratigraphic thickness. Plotting conventions are same as for Fig. 4.

The presence of dominantly normal-magnetic polarity suggests the presence of Chron 9 in the Chichali section. However, two alternatives are possible for correlation, as shown in Fig. 7. According to alternative I, magnetozones N3 to N7 are correlated with Chron 9. This suggests the correlation of R2 magnetozone with Chron 10, and N1, R1 and N2 magnetozones with Chron 11. Whereas R7, R8 and N9 magnetozones are correlated with Chron 8.

Alternative II is based on work done in the Potwar Plateau by Tauxe (1979, 1982) and Johnson *et al.* (1982) which suggests that all of the Subchrones of Chron 9 are not easily observed, whereas 4 short reversed-polarity zones are observed between magnetozones N3 and N7 of the Chichali section. Considering this fact, N3 to N4 magnetozones are correlated with Chron 9; the R4 to R6 magnetozones are correlated with Chron 8; with Chron 7; and R8 to N9, with the lower part of Chron 6. Alternative II, however, does not effect the correlation of the N1 to R2 magnetozones; they remain the same as that of alternative I.

The above-mentioned MPS correlations suggest that the base of Siwalik Group in the Chichali section is not older than 11.8 MY. Whereas the top of the measured stratigraphic sequence may be of 8 MYBP age according to alternative I and as young as 6.4 MYBP according to alternative II. This also suggests that sedimentation of multistoried sandstone started 8 MYBP according to alternative II. This is in contrast with the observation in Potwar Plateau, where deposition of multistoried sandstone started about 10 MYBP (Johnson *et al.*, 1982; Tauxe, 1982). This clearly indicates the westward trangressive nature of the Siwalik sedimentation.

CONCLUSION

Paleomagnetic studies show that, in the case of the Siwalik Group sediments PTD successfully isolates the stable component of remenant magnetization. In most samples stable component of remenant magnetization is isolated at 400°C, but 600°C heating is useful to isolate the primary component of magnetization in case of samples collected from brownish-colored siltstone/claystone units. The stable and primary component of magnetization isolated after 500°C and 600°C heating were used for establishing the magnetic-polarity stratigraphy of the Siwalik Group of Shinghar/Surghar Ranges. Correlation of the observed MPS with the standard MPTS shows that the age of the Siwalik Group of this area ranges between 11.8 MYBP (basal Chron 11) and 0.85 MYBP (upper Matuyama Chron). This indicates that the sedimenttion in this area began later than the deposition of basal prt of the Siwalik Group in the Potwar Plateau, and thus suggests westward transgression of the Siwalik Group molasse facies.

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