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# THE MAGNETIC POLARITY STRATIGRAPHY AND CORRELATION OF THE UPPER SIWALIK SEDIMENTS FROM THE BHITTANI RANGE, NORTH WEST FRONTIER PROVINCE, PAKISTAN *

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Two sections were sampled in the Bhittani Range, the first at Bain Pass consisting of 60 sites through 2200 m of section and the second along the North West Frontier Province Road north of Pezu consisting of 25 sites through 1000 m. Both sections are in rocks known to range in age from the late Pliocene and Pleistocene based on a vertebrate fauna of Pinjor age. After partial thermal demagnetization a series of magnetozones were established, ten at Bain Pass and six at Pezu, which can be correlated to each other and to the standard magnetic time scale. The sediments from the long section at Bain Pass span the time from the middle Gauss to the uppermost Brunhes Chron. The Jaramillo and Olduvai subchrons are present within the Matuyama Chron. A short normal magnetozone is present in the section preceding the Olduvai subchron which corresponds in age to the Réunion subchron. Based on the rate of sedimentation during lower Matuyama time which would be 0.95 m/1000 y for the Bain Pass section, the Réunion subchron would span at least 25 000 y. The section at Pezu Pass begins within the Olduvai and ends between the Jaramillo and the Brunhes/Matuyama boundary. The sedimentation rate determined at this section is 0.77 m/1000 y. The rate of sedimentation in this region was much higher than over comparable time spans previously determined from the eastern Salt Range. The folding of the Bhittani Range must have occurred less than 730 000 years ago, since Brunhes-age sediments have been deformed.

## 1. Introduction

The Himalayan mountain chain has been attributed to the effects of the collision of the Indian and Eurasian plates over a span of time ranging from Eocene to the present. The most rapid uplift of the Himalayas took place in mid-Miocene time, and it was during this time that large amounts of fluvial sediments were deposited in a narrow depression along the foothills of the rising Himalayas. Increased amounts of detritus accompanied by a gradual subsidence of the foredeep have resulted in an excellent record of the geological history of the region. Through the upper Cenozoic, a succession of vertebrate faunas, demarcated by extinction and migration, serve as a means of correlation of these fluviatile sediments, collectively called the Siwalik System.

By virtue of vast exposures and abundant vertebrate fossils, the rocks of the Siwalik System have attracted the attention of various workers since the end of the 19th century (Wynne, 1875; Pilgrim, 1913; De Terra and Teilhard de Chardin, 1936) and an age range of Miocene to Pleistocene has been assigned to these rocks. The correlation of these sediments on the Potwar Plateau, based on magnetic reversal stratigraphy, has been worked out by Opdyke et al. (1979) and Keller et al. (1977). The present work is part of the effort to extend the correlation of Siwalik sediments across the Indus reentrant into the Trans-Indus Salt Range (Fig. 1). Initially the Siwalik sediments of the Bhittani Range are studied. On one section 60 sites were taken along the road at Bain

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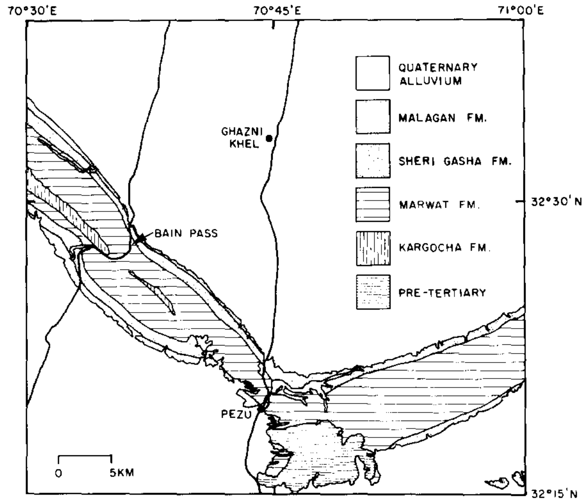


Fig. 1. Locations of the Bain Pass and Pezu sections.

Pass, through a section measuring 2200 m. The second section studied was along the road north of Pezu, consisting of 25 sites through 1000 m of section.

The sediments exposed in the Bhittani Range have previously been described by Morris (1938) and Hemphill and Kidwai (1973). The Bain Pass section begins in rocks which consist of thick reddish-brown claystone in zones up to 100 m in thickness separated by gray and brown crossbedded sandstone up to 10 m in thickness, which Morris called the Kargocha formation. This formation is followed conformably by a thick series of brown silty claystones alternating with massive gray sandstone up to 20 m thick. This formation, which in the Bain Pass area is up to 1800 m in thickness, was called the Marwat formation by Morris (1938). Conformably succeeding this formation is a thinner sequence of brown claystone with subordinate sandstone, about 400 m in thickness, which represents the Sheri Gasha formation of Morris. This is succeeded by a thin unit of coarse brown sandstone and conglomerate called the Malagan formation. This formation is in turn overlain by Quaternary alluvium.

Vertebrate fossils have been obtained by Morris (1938) from the Marwat formation of the Bhittani Range. These fossils are typical of the Pinjor faunal stage, shown by Opdyke et al. (1979) to be confined to sediments in the eastern Potwar area which are younger than 2.8 My, i.e. late Pliocene and Pleistocene in age.

Recently, Hemphill and Kidwai have attempted to rename the Kargocha, Marwat and Sheri Gasha formations as the Chinji, Nagri and Dhok Patham formations respectively, based on the lithologic similarities of the Kargocha, Marwat and Sheri Gasha formations to these three formations, whose type sections are on the Potwar Plateau far to the east. We prefer Morris's original terminology for two reasons. First of all the Kargocha, Marwat and Sheri Gasha formations are Pliocene and Pleistocene in age, whereas the Chinji, Nagri and Dhok Patham formation in their type sections are middle late Miocene in age (Pilbeam et al. 1977; Tauxe, 1979); also it is not possible to physically trace these formations from their type sections into the Bhittani Range. We therefore retain the terminology of Morris (1938).

## 2. Paleomagnetic studies

Three, and in some cases four to five oriented hand samples per site were collected from silstone

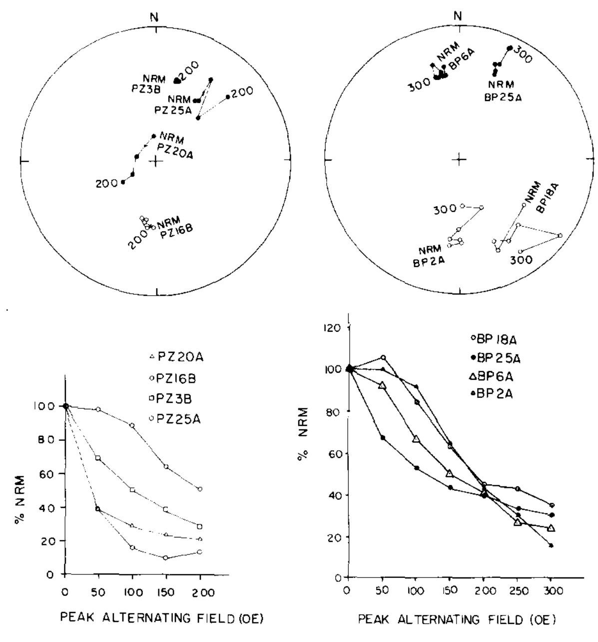


Fig. 2. Alternating field demagnetization for samples from Pezu on the left and Bain Pass on the right. The directions are plotted on equal angle stereographic projections. The intensity decrease with increasing alternating field is shown for each sample plotted on the stereonet.

TABLE I

Results for Bain Pass and Pezu samples

| | $N$ | Declination | Inclination | $k$ | $\alpha_{95}$ |
|---|---|---|---|---|---|
| Bain Pass | | | | | |
| NRM | | | | | |
| Normal sites | 20 | 20.4 | 32.7 | 15.3 | 8.6 |
| Reversed sites | 20 | 158.4 | −28.8 | 6.6 | 13.6 |
| After AF demagnetization at 250 Oe | | | | | |
| Normal sites | 19 | 13.6 | 35.1 | 13.5 | 9.4 |
| Reversed sites | 20 | 165.6 | −35.3 | 12.1 | 9.5 |
| After thermal demagnetization at 430°C | | | | | |
| Normal sites | 16 | 3.7 | 32.0 | 10.9 | 11.6 |
| Reversed sites | 24 | 177.8 | −35.1 | 16.1 | 7.5 |
| Pezu | | | | | |
| NRM | | | | | |
| Normal sites | 15 | 17.6 | 93.5 | 10.9 | 12.1 |
| Reversed sites | 11 | 153.7 | −32.9 | 6.9 | 18.6 |
| After thermal demagnetization at 450°C | | | | | |
| Normal sites | 7 | 359.4 | 30.7 | 25.1 | 12.1 |
| Reversed sites | 19 | 170.2 | −35.3 | 7.4 | 13.1 |
| After thermal demagnetization at 600°C | | | | | |
| Normal sites | 7 | 0.5 | 29.7 | 25.6 | 12.1 |
| Reversed sites | 19 | 176.7 | −29.6 | 7.9 | 12.7 |

beds lying between sandstone units. Each sample was then cut into a cube 2.5 cm on a side. Directions of magnetization were measured by using a fluxgate spinner magnetometer described by Molyneux (1971). The intensity of Natural Remanent Magnetization of samples from Bain Pass varies from $1 \times 10^{-5}$ to $1 \times 10^{-8}$ Gauss with an average intensity of $4.4 \times 10^{-6}$ Gauss. The intensity of NRM of samples from Pezu varies from $1 \times 10^{-6}$ to $1 \times 10^{-8}$ Gauss, with an average intensity of $4.09 \times 10^{-6}$ Gauss. Directions of magnetization for both sections are given in Table 1.

### 2.1. *AF Demagnetization*

After measuring the NRM directions of all samples, some samples from both sections were arbitrarily selected for AF demagnetization. Samples from Bain Pass showed a gradual decrease in intensity and in most cases less than 50% of the total NRM intensity remained after a peak alternating field of 300 Oe was applied. Plots of intensity curves for these samples (Fig. 2) suggested that most of the samples behave similarly. Some samples showed an increase in intensity after 100 Oe field was applied (Fig. 2, sample BP18A). This is attributed to the removal of a secondary normal component of magnetization superimposed on an original reversed direction. Directions of remanent magnetization obtained were plotted on a stereonet (Fig. 2). Although directions changed with the application of higher field, no systematic change was observed after 250 Oe. With this in mind two samples from each site were subjected to a peak field of 250 Oe. Mean directions obtained for all normal samples are given in Table I.

Pilot samples from Pezu section behaved very differently compared to those of the Bain Pass section. Many of the samples showed an abrupt decrease in intensity after an 100–150 Oe field was applied, some retained less than 40% of total NRM intensity after 100 Oe while others still retained more than 50% of total NRM intensity even after treatment in a 200 Oe peak field (Fig. 2). It was observed that although the directions do change with higher field, no change in polarity is observed up to 200 Oe. The very different behavior of these samples suggested that secondary magnetic minerals are of very high coercivity and are therefore hard to isolate from their characteristic magnetization by AF demagnetization techniques.

### 2.2. *Thermal demagnetization*

Selected samples from both sections were subjected to thermal demagnetization in temperatures from 100–675°C at intervals of 30–50°C.

The samples from Bain Pass showed a systematic and uniform behavior. Most of these were reduced to less than 50% of total NRM intensity after temperatures of 400–450°C (Fig. 3). An increase in intensity was also observed at 100–200°C (Fig. 3, sample BP38C) which suggested the removal of a secondary component of magnetization with opposite polarity. The directions of remanent magnetization were plotted on a stereonet (Fig. 3) and no significant change in directions was observed after 450°C. So all samples from each site (including those which had already been subjected to AF demagnetization at 250 Oe) were then thermally demagnetized at a peak temperature of 430°C. It was observed that the polarity

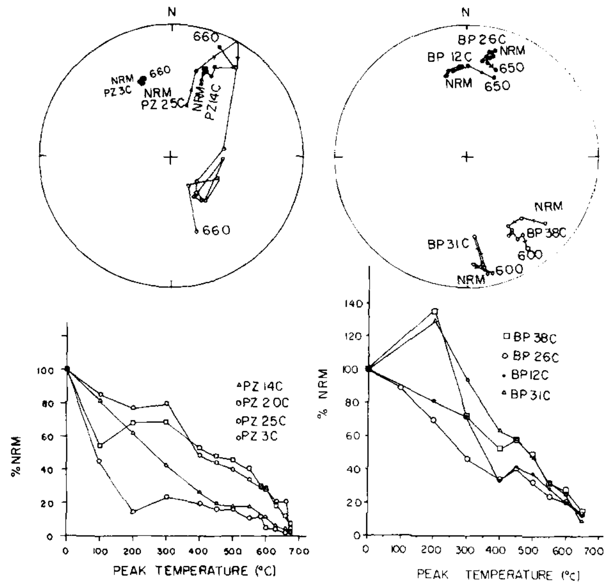


Fig. 3. Thermal demagnetization of samples from Pezu (left) and Bain Pass (right). The directions are plotted on an equal angle stereographic projection. Lower diagrams show the decrease in intensity with increasing temperature on the samples plotted on the stereonet.

changed from normal to reverse in three sites (Nos. 15, 16, 17), while no change of polarity was observed for the rest of the sites. Site mean directions obtained for all normal and reversed sites are given in Table I.

Thermal demagnetization of pilot samples from the Pezu section showed an interesting response to thermal demagnetization. The intensity of remanent magnetization decreased gradually in a few samples up to 400°C, beyond which they showed rapid decreases of intensity. In other cases a rapid decrease in intensity was observed at 100–200°C, followed by a more or less stable intensity up to 570°C, then a rapid decrease in intensity of remanent magnetization up to 675°C, where in most cases less than 5% of the total NRM intensity remained (Fig. 3). Directions of magnetization obtained after thermal demagnetization at each step were plotted on a steronet (Fig. 3). It was observed that some directions change rapidly up to 300°C and in some cases with a change of polarity from normal to reversed, while little or no change at all was observed after 300°C. Other samples (e.g. PZ3C, PZ14C) however showed no change in the directions of magnetization even up to 675°C, although intensity decreased to less than 5% of total NRM intensity.

It is probable that the very low blocking temperature component isolated may be due to the presence of goethite, while the moderate blocking temperature component, isolated at 400–450°C, might be due to the magnetization of magnetite in the Earth's present dipole field direction, and the high blocking temperature component may be the detrital magnetization, carried by hematite. Keeping this in mind all samples were subjected to thermal demagnetization at two steps of 450°C and 600°C. The mean site directions of all normal and reversed sites are given in Table I.

## 3. Reliability of data

Site mean NRM directions were plotted and it was observed that normally magnetized sites lie close to the Earth's present dipole field, and those with reversed polarity do not lie on the same axis. However, the plot of site mean directions obtained after thermal demagnetization (Fig. 4) showed much improvement of grouping around the respective mean directions, which in turn are almost 180° apart. This indicates that magnetization directions obtained after thermal demagnetization were acquired prior to the folding of these sediments. This observation, combined with the youthfulness of the structure (see below) suggests that magnetization directions were acquired during the deposition of these sediments.

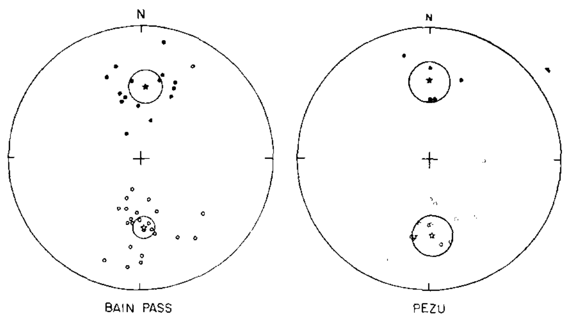


Fig. 4. Site mean direction after thermal demagnetization for Bain Pass and Pezu section sites indicated by the filled and open circles, respectively. The mean directions of magnetization and circles of 95% confidence (Fisher, 1953) are shown for the normal and reversed cases (filled and open stars, respectively).

## 4. Bain Pass section

The southeastern part of the Marwat–Kundi anticline in the Bhittani Range exposes a thick sequence of Siwalik sediments. A section more than 2200 m thick was measured along the Bain Pass across the northern limb of the anticline (Fig. 1). The entire section consists of alternating sandstone and siltstone beds of varying thickness and hardness. Sandstone beds are brown at the base of the section and dark

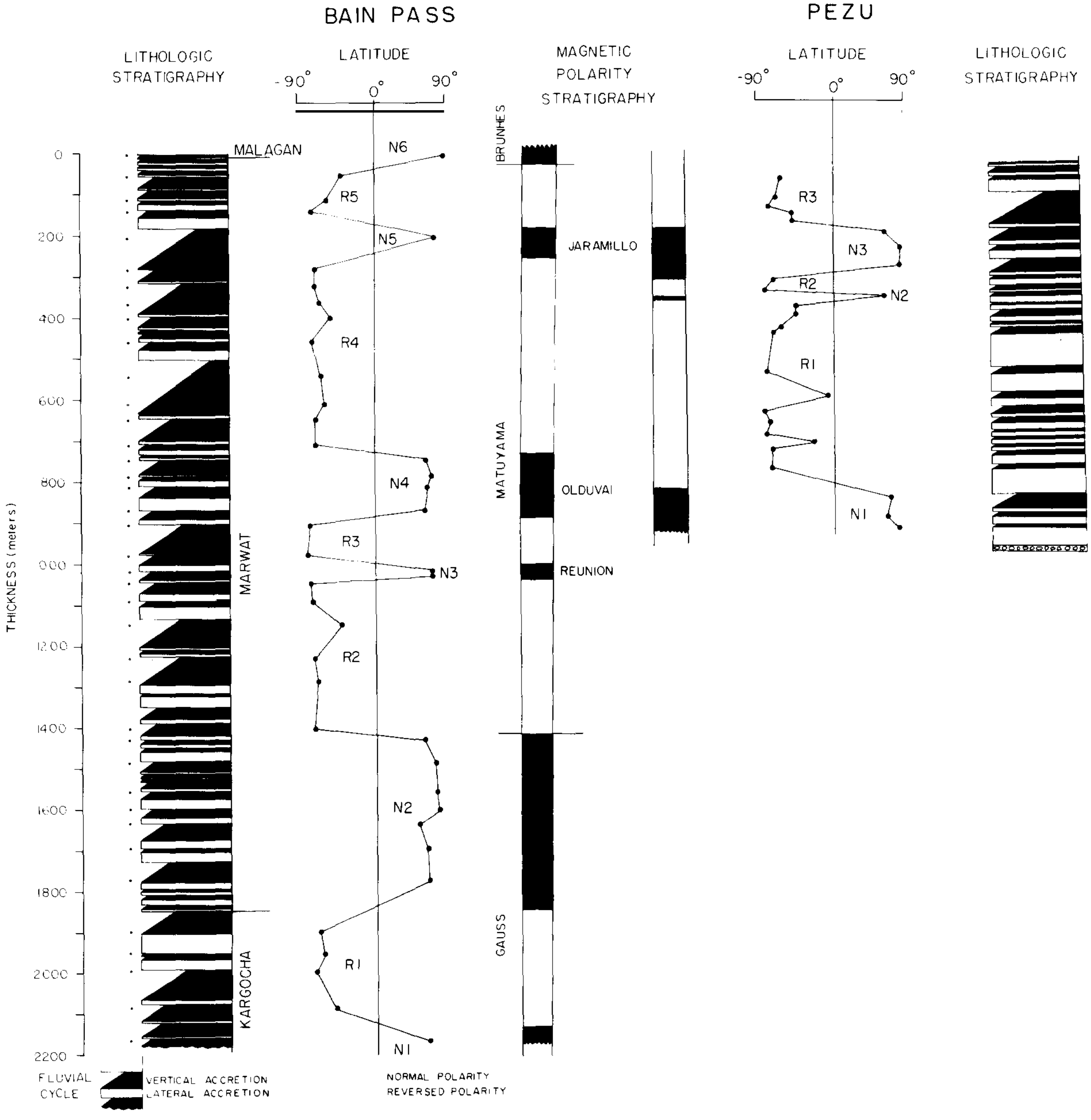


Fig. 5. Stratigraphic sections and magnetic stratigraphy of the Bain Pass and Pezu sections. The latitude of the virtual geomagnetic pole position for each site is plotted with respect to its position on the measured section. Normal polarity is indicated by black bars and reversed polarity by open bars. The correlation with the magnetic polarity time scale is given in the central columns.

to light gray at the top. Siltstone beds are brownish red at the base and pale brown in the upper part of the section. Two distinct, but thin units of conglomerate were noticed 700 and 975 m from the top of the section. The stratigraphically-lower conglomerate unit might be the equivalent of the Bain Boulder Bed (see below) of Morris (1938).

Site mean directions obtained after thermal demagnetization at 430°C, for all Class I sites, are plotted in Fig. 4. The mean directions for all normal and reversed sites do not differ significantly and are close to the direction of the Earth's present dipole field, at this locality shallower in inclination by about 15°. This difference in inclination may be due to the bedding error (King, 1955). It is also noted that mean declination at all sites is close to a north–south axis, suggesting no or negligible rotation of this part of the Indian plate since 3.10 My ago (see below).

Magnetic polarity stratigraphy is established on the basis of mean site directions obtained after thermal demagnetization at 430°C, and latitudes of virtual geomagnetic poles (VGP's) are plotted with respect to the relative stratigraphic position of each site (Fig. 5). Ten reversals are observed marking the boundaries of nine magnetozones. Except for N5, all polarity events are marked by more than one site. In order to confirm the validity of the N5 polarity event, the samples were separately subjected to thermal demagnetization at 600°C. As no change in direction was observed, the polarity is regarded as valid. Vertebrate fossils reported by Morris (1938) from Siwalik sediments in Bhittani Range are of Pinjor age, and the recent work done by Opdyke et al. (1979) and Keller et al. (1977) in the Potwar Plateau has shown that these sediments cannot be older than late Pliocene (Gauss Chron, Hedberg et al. 1979) in age. Comparison of the observed reversal sequence with the magnetostratigraphic time scale of Mankinen and Dalrymple (1979) suggests that the measured stratigraphic section spans a time ranging from lower Gauss (about 3.10 My BP) to lower Brunhes (about 0.70 My BP). A plot of thickness vs. time (Fig. 6) suggests a sedimentation rate of 0.95 m/1000 y from lower Gauss to the upper Olduvai and of 0.62 m/1000 y from upper Olduvai to lower Brunhes. This is a high sedimentation rate as compared with those observed by Opdyke et al. (1979) and suggests a more rapid subsidence of the basin of deposition and a higher

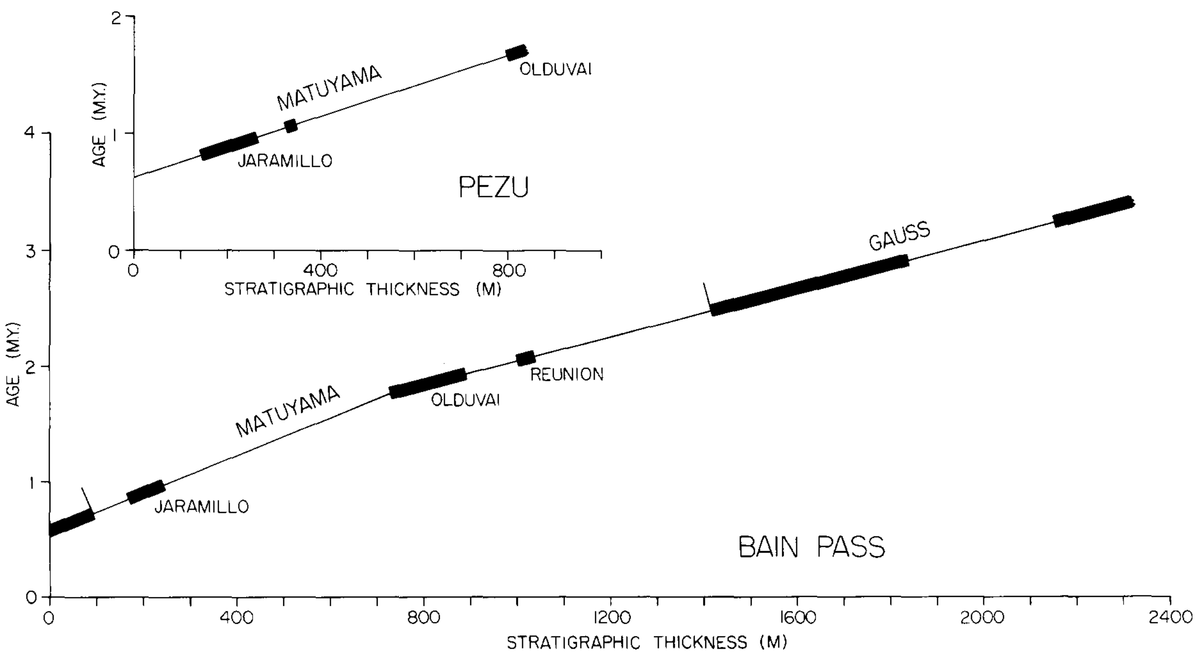


**Fig. 6. Time vs. depth plots of Bain Pass and Pezu sections. Normal polarity is indicated by the broad black bar and reversed polarity by the slender line.**

amount of sediment supply than in the Upper Siwalik sections further to the east.

In order to establish the validity of magnetozone N3, which is coincident in time with the proposed Réunion event, additional samples were collected from four sites within one siltstone bed. One sample from the uppermost site and another from the lowermost site were subjected to thermal demagnetization from 100 to 650°C at steps of 50°C. A Zijderveld diagram for one of these two samples is plotted in Fig. 7.

No change in polarity was observed up to 650°C although intensity dropped to less than 14% of total NRM intensity. These observations suggest that the directions obtained after 430°C represent the stable directions of magnetization. Exact upper and lower limits of this event could not be determined due to the fact that both boundaries lie within coarse-grained sandstone beds. On the basis of the approximate time involved in the deposition of one fluvial

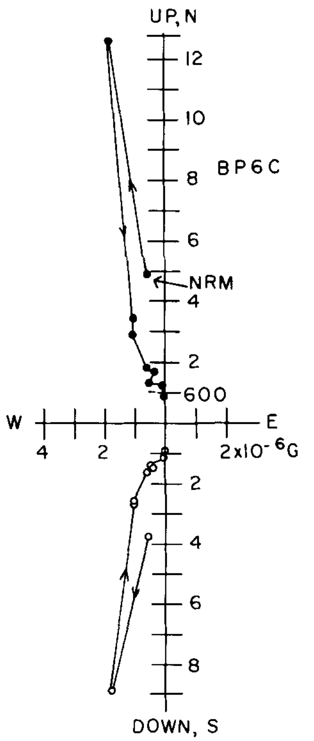


Fig. 7. Zijderveld (1967) diagram of thermal demagnetization of normally magnetized sample from the Réunion event. The filled and open circles are vector end points on the horizontal and vertical planes, respectively. Demagnetization was taken to 600°C.

cycle it is estimated that the Réunion polarity event as observed in this section lasted for at least 25 000 y.

## 5. Pezu section

The easternmost part of the Marwat–Kundi anticline in the Bhittani Range is exposed north of Sheikh Budin, where the Siwalik sediments are traversed by the North West Frontier Road (Fig. 1). A section about 1000 m thick consisting of alternate sandstone and siltstone beds was measured and sampled. The sandstones are gray in color and compact at the base as compared to the beds at the top of the section. The siltstone beds are brown at the base and pale brown in the upper part. The section is entirely within the Marwat and Sheri Gasha formations. The general ratio of thickness of siltstone to sandstone is higher in the upper part of the section (Sheri Gasha formation) as compared to the lower part (Marwat formation). The Bain Boulder Bed (Morris, 1938) lies below the measured section but it is not exposed in Pezu nala (stream) where the section was measured.

Mean site directions for all Class I and Class II sites are plotted in Fig. 4. Mean directions of all normal and reversed sites do not differ significantly. However, the mean NRM directions lay slightly to the east of the north–south axis. After demagnetization at 600°C this slight deviation is eliminated. The mean direction of all normal and reversed sites is close to a north–south axis and suggests that this part of the Indian plate does not show observable rotation since 1.88 My ago.

Magnetic polarity stratigraphy is established based on directions obtained after thermal demagnetization at 600°C. Latitudes of VGP's are plotted relative to the location of their sites in the stratigraphic sequence (Fig. 5). A total of five changes of polarity are observed, marking the boundaries of four magnetozones. All, except one, magnetozones are marked by more than one site. A good correlation can be made with the Bain Pass locality which lies to the North West. Correlation of the Bain Pass section with the standard polarity time scale is based on the fact that the Bain Boulder Bed definitely underlies the section measured in Pezu nala and the gap is not more than 2–3 fluvial cycles, and samples from one site above the Bain Boulder Bed, collected from the south limb of the anticline from Bain Pass section, show reversed polarity. Therefore, consideration of polarity event N1 as Olduvai is the best interpretation. Thus it is evident that the section spans a time ranging from lower Olduvai (1.86 My BP) to upper Matuyama (0.74 My BP). A plot of stratigraphic thickness vs. age suggests an overall sedimentation rate of 0.77 m/1000 y (Fig. 6) during the deposition of entire thickness of sediments, which is very close to the average sedimentation rate calculated for the Bain Pass section.

A short magnetozone N2 below the Jaramillo event may be equivalent to the one observed by Mankinen et al. (1978), dated at 1.1 My BP. However, its presence must be confirmed by further work.

## 6. Correlation of magnetic polarity stratigraphy

Magnetic polarity stratigraphy obtained for the two sections shows that a good record of polarity reversals is preserved. Correlation of two sections relative to the Olduvai event, which marks the Pliocene–Pleistocene boundary (Haq et al., 1977), is shown in Fig. 5. On the basis of evidence cited above, the Bain Boulder Bed is assigned an age somewhere between the Réunion and Olduvai magnetozones, and hence it marks deposition during uppermost Pliocene time. Confirmation of the age assigned to the Bain Boulder Bed will be possible after collection of samples from a section which contains a well-developed part of this unit.

## 7. Sedimentary tectonics

Plots of time vs. stratigraphic thickness suggests an overall sedimentation rate of 0.78 m/1000 y for the Bain Pass section and 0.77 m/1000 y for the Pezu section. It is also evident that the youngest rocks exposed in the Bain Pass section were deposited later than 700 000 y BP. This suggests that the structures now exposed to the effects of denudation, are youthfull. This is also evident from the fact that there is a well-marked angular unconformity between the youngest sediments exposed and the alluvium of the Bannu plain, suggesting that the last tectonic activity in this area took place later than 700 000 y BP.

Another important feature observed is the sedimentation rate, which is higher than those observed for any section in the Potwar Plateau (Opdyke et al., 1979). This suggests that the basin of sedimentation was rapidly subsiding; however, absence of multistoried sandstones in these sections suggests that the location of the basin of sedimentation was out of the axial zone of the major stream responsible for the deposition of these Siwalik sediments.

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