Geol. Bull. Univ. Peshawar, 1988, Vol. 21, pp. 85–104

MAGNETOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE HAZARA INTERMONTANE BASIN, PAKISTAN

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ABSTRACT

The Hazara Intermontane Basin (named herein) is nestled within the Hazara Hill Ranges located on the hanging wall of the Main Boundary Thrust. The Havelian Group represents the fill of this basin and consists of unconsolidated silts, sands and gravels. Paleomagnetic investigations of the silts consisted of both thermal and alternating-field demagnetization experiments for nearly all of the sites of the two measured and sampled stratigraphic sections sampled. All sites are normally polarized and correlated with the Brunhes Chron (0.73Ma to present). Sedimentological analysis shows that the Havelian Group was deposited as a sandur, a large, silt-laden plain of glacio-fluvial sediments consisting of fluvial gravels and sands, and windblown loess. It is interpreted that this sandur emerged from valleys of the Hill Ranges which contained Alpine-type glaciers in their upstream reaches. Minimum sedimentation rates determined for the Havelian Group range from 0.07 to 0.27mm/yr, and are remarkably similar to those determined for the Potwar loess (Rendell, 1988). No evidence was found to suggest that the Havelian Group was deposited as a result of tectonic activity in the foredeep.

INTRODUCTION

Intermontane basins located in the hinterland regions and foothill ranges of northern Pakistan have been shown to contain synorogenic and post orogenic sedimentary rocks which have been used to help constrain the timing of uplift and deformation in the northwest Himalaya. Examples include the Kashmir, Campbellpore (present day name is Attock) and Peshawar Basins (Burbank and Johnson, 1982; Burbank and Reynolds, 1984; Burbank and Tahirkheli, 1985; Pivnik, unpublished data), the Jalipur Basin (Olson, 1981), and the Skardu Basin (Cronin, 1982). In each of these areas, chronostratigraphic techniques such as tephrachronology and magnetostratigraphy have been used to pinpoint the ages of the intermontane-basin fill, thus the presumed timing of the tectonic or climatic episodes that influenced their deposition.

Situated on the hanging wall of the Main Boundary Thrust (MBT), one of the four major sutures in the Indian-Asian collisional zone (Fig. 1), is a topographic basin which contains up to 50m of flat-lying, unconsolidated gravel, sand and silt formerly described as the Havelian Group by Latif (1970). Aside from descriptions of the lithology and distribution of these deposits, little to no attention has been paid to the sedimentology or magnetostratigraphy

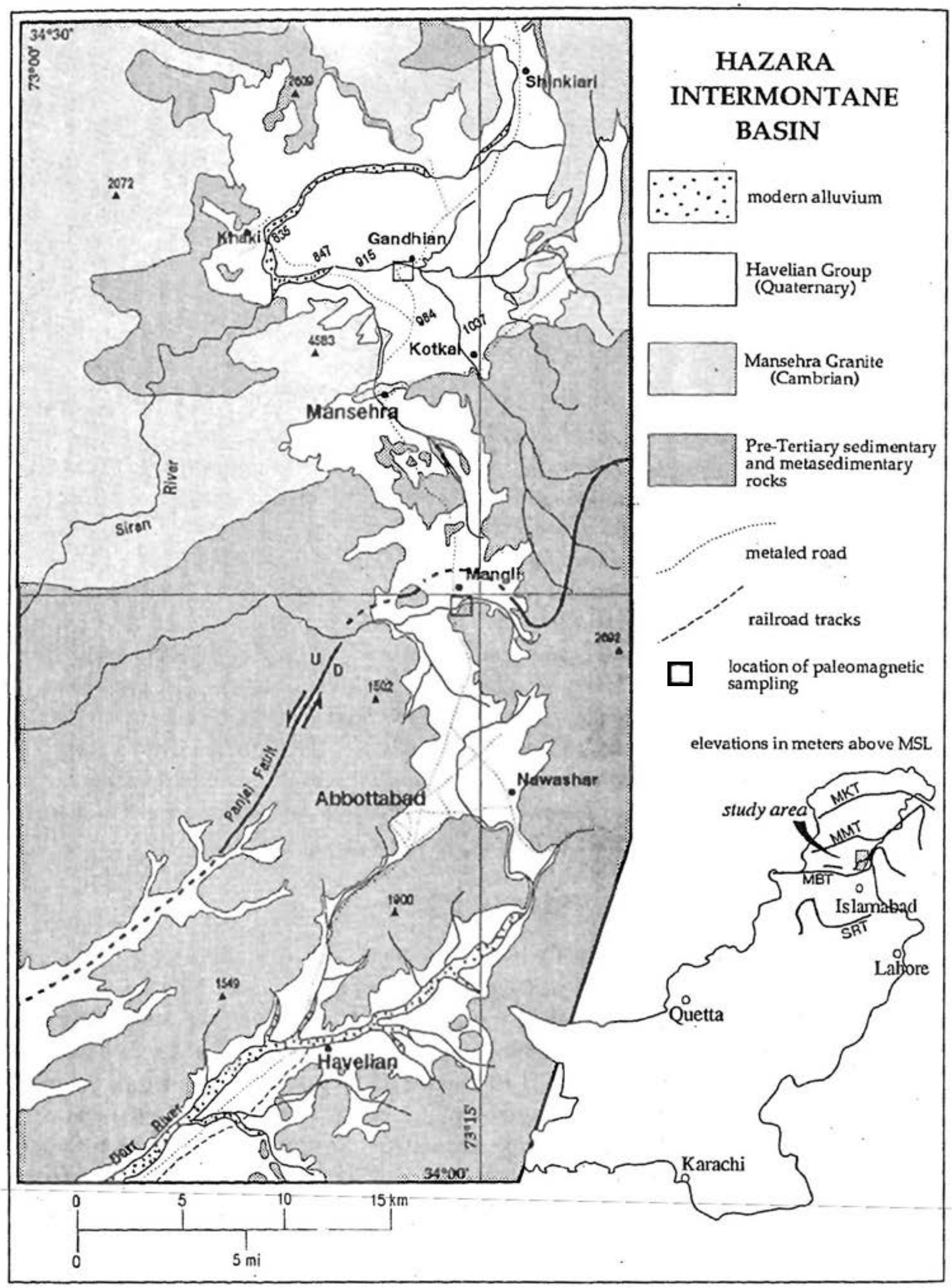


Fig. 1. Generalized geologic map of the Hazara Intermontane Basin and surrounding ranges. Inset at lower right shows location of study area and the four main sutures in the northern Himalaya. MKT- Main Karakoram Thrust, MMT- Main Mantle Thrust, MBT- Main Boundary Thrust, SRT- Salt Range Thrust. Modified from Calkins et al. (1975).

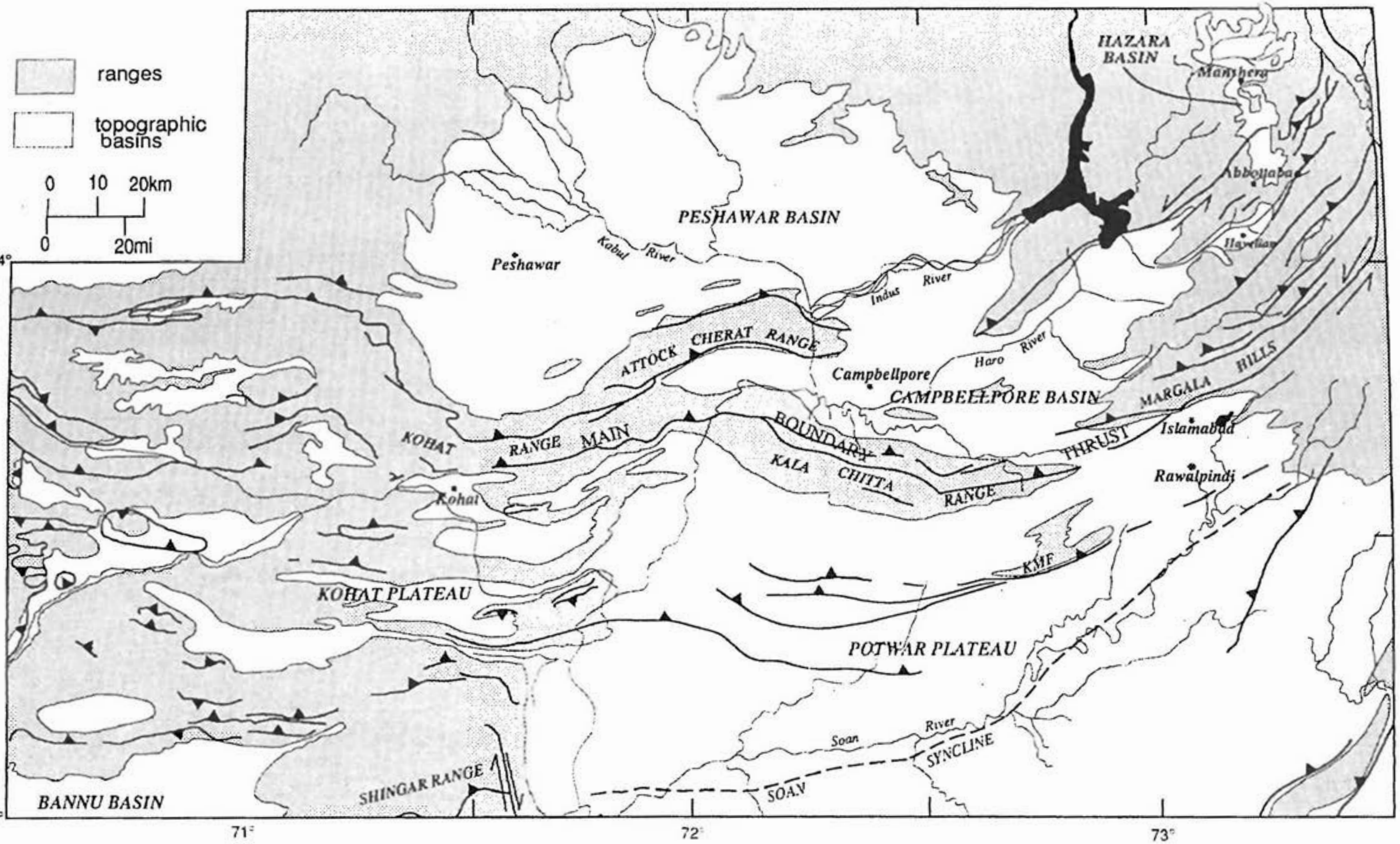


Fig. 2. Regional map showing the distribution of intermontane basins on the hanging wall of the MBT. Modified from Burbank and Tahirkheli (1985), Meissner et al. (1974), Meissner et al. (1975) and various 1:250,000 scale topographic maps

of the Havelian Group. This paper will focus on the sedimentology and magnetostratigraphy of these sediments and the history of the basin, herein referred to as the Hazara Intermontane Basin (HIB), located between and around the cities of Havelian and Mansehra (Figs. 1 and 2). The data and interpretations presented here are part of a larger, ongoing study of Plio-Pleistocene depocenters surrounding the MBT and the adjacent fold-and-thrust belt of the Kohat and northen Potwar Plateaux (Pivnik, unpublished data).

GEOMORPHOLOGY AND REGIONAL GEOLOGY

The geology of the Hazara region has been described by Shams (1961, 1969), Latif (1970), Calkins et al. (1975), Lawrence and Shroder (1985) and others. Only a brief overview of the bedrock that surrounds the HIB is presented here. The rocks of the Hazara region can be grouped into two very broad catagories: folded and faulted sedimentary and metasedimentary rocks of the Indian continental margin and igneous intrusive rocks (Fig.1). The former includes slates, quartzites and marbles ranging in age from Precambrian to late Paleozoic and shales, sandstones and limestones which are predominantly Mesozoic and early Tertiary in age. Intruded into, and folded and faulted with the older metasediments, is the Mansehra Granite, which has been dated as Cambrian by Lefort et al. (1980). The Mansehra Granite outcrops in the northern section of the study area and is absent in the southern portion (Fig. 1).

The HIB and surrounding ranges are situated on the hanging wall of the MBT where it bends to the northeast, following the western limb of the Hazara-Kashmir syntaxis (Calkins et al., 1975; Fig. 2). The Panjal Fault, a left-lateral, north dipping reverse fault trends NE-SW through the central portion of the study area (Fig. 1). The Panjal Fault carries Precambrian and lower Paleozoic rocks over younger Paleozoic rocks. Yeats and Hussain (1987) correlate the Panjal fault with the Khairabad Fault in the Attock-Cherat Range to the west (Fig. 2). According to Yeats and Hussain (1987), motion on the Khairabad Fault could have occurred during the Cretaceous or Paleocene. The MBT brings the late Paleozoic through Eocene assemblages of the Hazara region over Oligocene (?) molasse of the Rawalpindi Group (Calikns et al., 1975). Izaat (unpublished data) gives a detailed account of the styles and possible timing of deformation of the structures on the hanging wall of the MBT in the Margala Hills and the Kala Chitta Range. According to Izaat, the MBT might have been active approximately 8Mya.

Havelian Group gravels, sands and silts constitute the fill of the basins and river valleys in the region. The sediments occur as terrace deposits perched above the valley floors of major rivers which cut the Hazara Hill Ranges (e.g. Margala Hills), and as flat or gently sloping pediment surfaces that are presently being dissected by streams and rivers (Fig. 3). Havelian Group deposits onlap bedrock at all locations examined, and no structural elements such as faults, folds or unconformities were observed at the contacts between bedrock and basin fill. The Pakhli Plain (Shams, 1961), north of Mansehra, slopes gently to the northwest and is underlain by a northwestward-thinning wedge of Havelian Group deposits (Fig. 1). Two major rivers drain the region. The Siran River drains the northern portion of the study area, while the Dorr River serves as the trunk stream for the watershed south of the city of Abbottabad (Fig. 1).

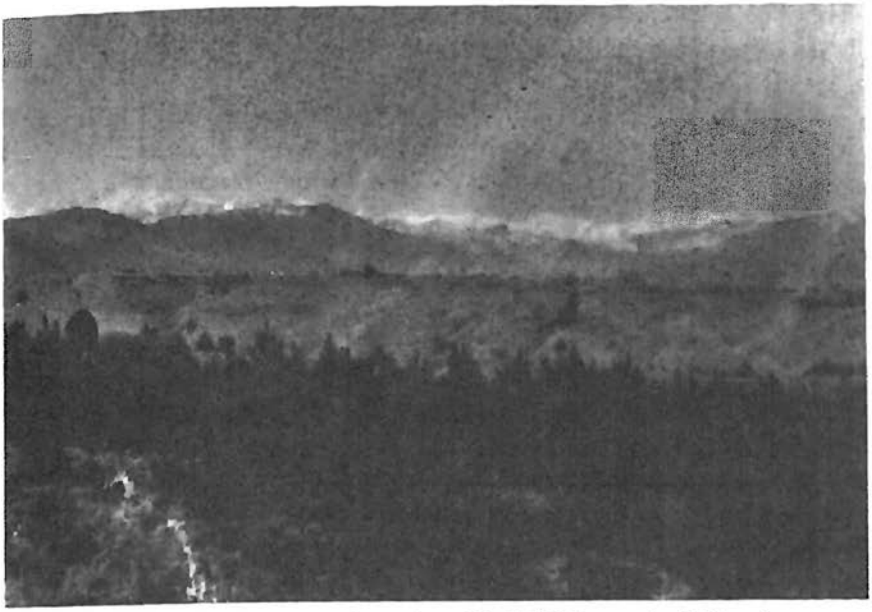


Fig. 3. Photo showing peneplain surface of Pakhli Plain, north of Mansehra.

MAGNETOSTRATIGRAPHY

Methods

Two sections were sampled for paleomagnetic reversal analysis; a section at Gandhian, on the south bank of Ichhar Nala along the road to Mansehra (section M), and south of Mangli, along the nala which crosses under the road to Abbottabad (section R; Fig. 1). In the field, three to five oriented hand-samples were collected from each stratigraphic site, following the methods of Johnson et al. (1975). At Gandhian (M), 4 sites were sampled within a 20m stratigraphic section. At Mangli (R), 7 sites were sampled within a 45m section. In the lab, samples were cut into ~2.5cm cubes. Magnetic vectors were measured on a spinner magnetometer, and all samples were subjected to thermal and/or alternating field demagnetization techniques to isolate the primary component of magnetization.

One cube from 5 of the 7 sites of section R and one cube from 3 of the 4 sites of section M were heated from 100 to 675 or 700°C in 25°, 50° and 100° increments. Two samples, one from each section, were subjected to alternating-field demagnetization (AFD). They were subjected to increasing field strengths in 5-10mT increments from 5 to 95mT.

Results

The thermal demagnetization (TDM) experiments showed that a temperature of ~500°C was needed to reduce magnetic intensity levels to ~10% of the natural remnant magnetism (NRM) levels and to isolate the primary component of magnetization. With only one exception, all samples show a linear decrease in intensity with increasing temperature (Fig. 4). Magnetic inclination and declination did not vary significantly with increasing temperature

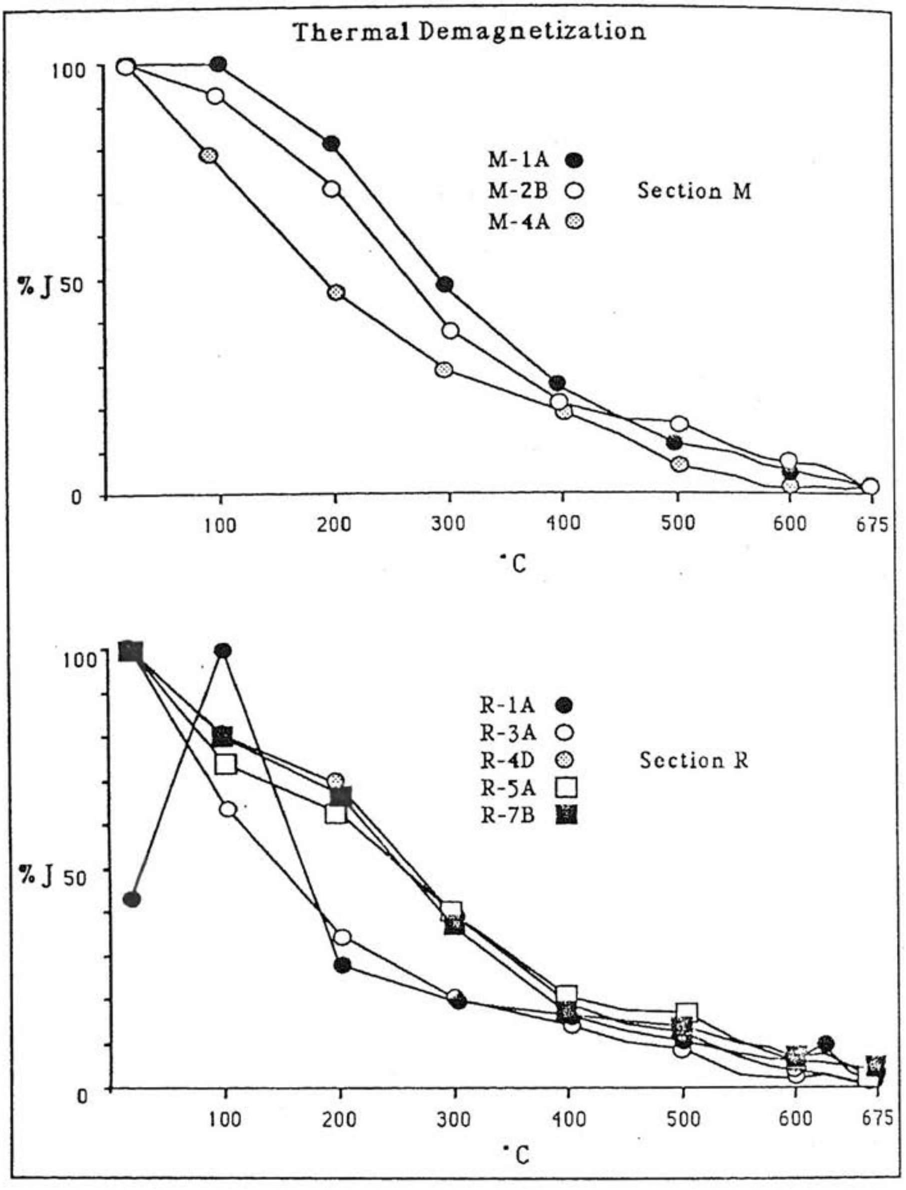


Fig. 4. Step vs. Intensity plots of thermal demagnetization experiments for sections R and M. Y-axis represents percent of original NRM intensity.

(Fig. 5). Only the lowest sites of both sections showed an overprint (in NRM) in a direction that varied from the final, stable directions (Fig. 5). This overprint was removed after heating to 100°C. All remaining samples were heated to 500, 550 and 600°C to verify the stability of the magnetic vector. In AFD experiments, a field strength of ~85mT was required to remove a significant amount of the magnetic intensity, isolating the primary component of magnetization (Fig. 6). As with the TDM experiments, all samples show a linear decrease in intensity with

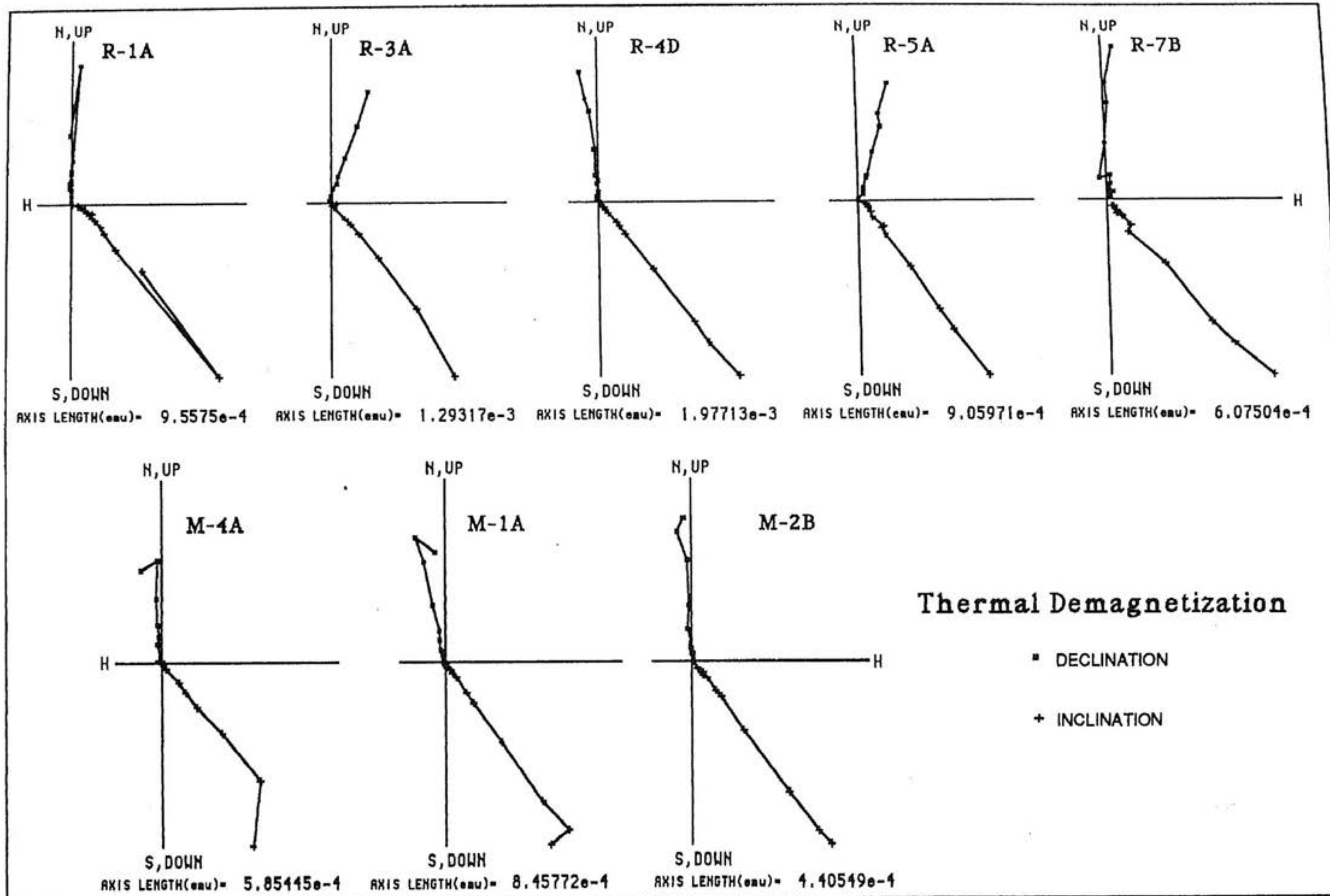


Fig. 5. Zijderveld plots of thermal demagnetization experiments from sections R and M. Axis lengths are given in Gauss. In these plots, downward-pointing declinations are positive, indicating normal polarity. Plots for each section are displayed in ascending stratigraphic order from left to right.

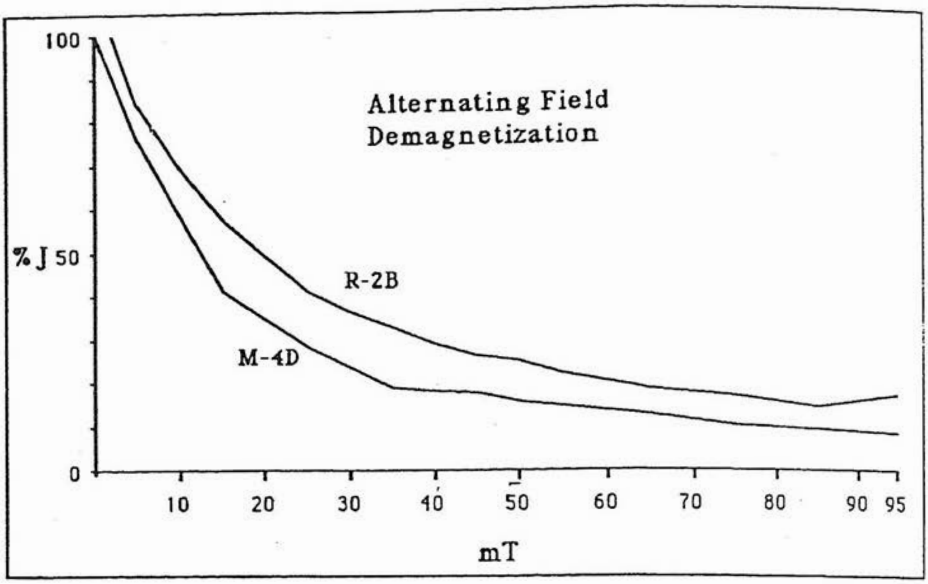


Fig. 6. Step vs. Intensity plots of alternating-field demagnetization experiments for sections R and M.

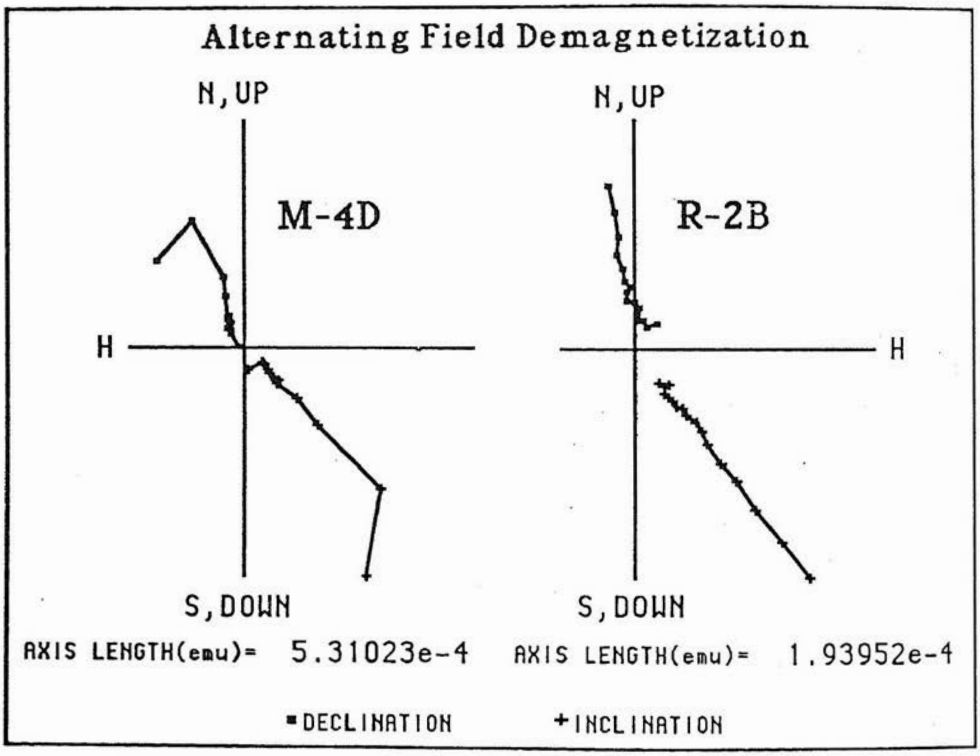


Fig. 7. Zijderveld plots of alternating-field demagnetization experiments from sections R and M. See Figure 8 for additional information.

increasing field strength (Fig. 6), and magnetic inclination and declination did not vary significantly with increasing field strength (Fig. 7). Only the lowest site of section M showed an overprint (in NRM) in a direction that varied from the final, stable directions (Fig. 7). This overprint was removed after being subjected to a field strength of 5mT.

The combination of the TDM and AFD experiments implies that the magnetic carrier is most likely magnetite, as AFD treatment and relatively low (~500°C) temperatures removed most of the magnetic intensities. No significant changes in intensity were observed in the samples heated to 675 and 700°C, implying that hematite is not the main magnetic mineral.

Site mean polarity directions and VGP positions for both the sections are given in Tables 1 and 2. All samples show normal polarity and after applying the satistical analyses of Fisher (1953), and site mean directions show excellent grouping about a mean vector with a declination of 356°, and an inclination of 50° (Fig. 8). Virtual geomagnetic-pole (VGP) positions cluster tightly around the north pole (Fig. 8). All sites were designated class 1 sites, based on their high R values (Tables 1 and 2).

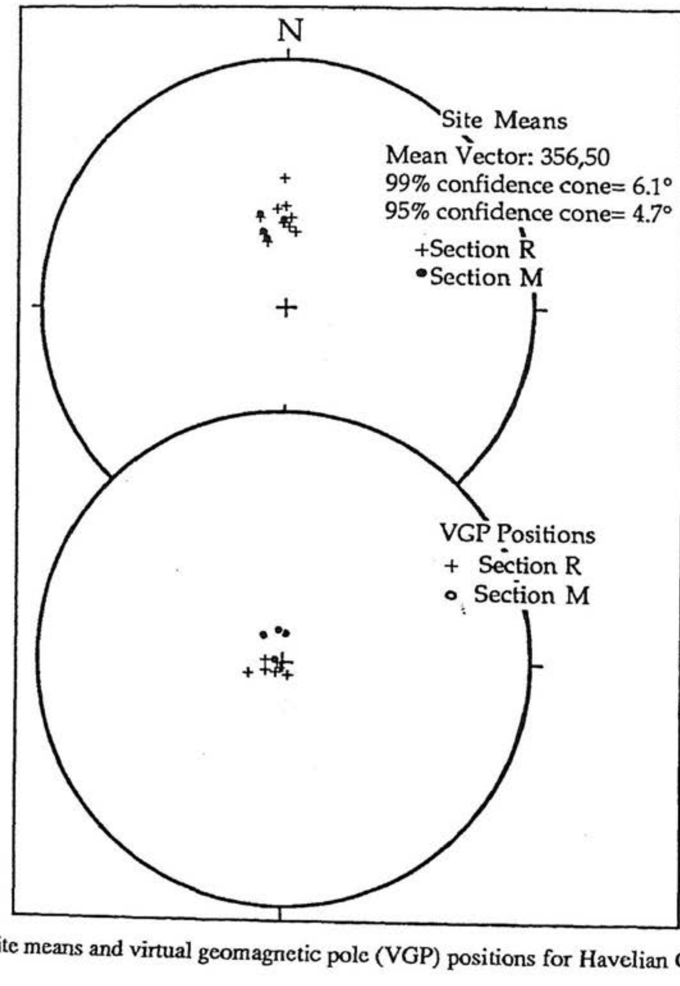


Fig. 8. Site means and virtual geomagnetic pole (VGP) positions for Havelian Group deposits.

TABLE 1. MAGNETIC POLARITY DATA FOR SECTION M

Site	Mean Dec	Mean Inc	N	R	K	A95	VGP Lat	VGP Long	Class	Meters
M–3	345.098	57.7667	4	3.9	39.5	14.8	77.3704	6.04091	N1	11
M–2	358.506	51.1179	4	3	214	6.3	87.1156	279.324	N1	7
M–1	342.803	54.8696	4	4	88.7	9.81	75.878	352.164	N1	4
M–4	344.399	47.481	5	5	222	5.15	75.5113	323.892	N1	0

Columns are, from left to right site mean declination, inclination, number of samples (N), Fisher's (1953) R value, precision parameter (K), 95% confidence cone (A95), virtual geomagnetic pole (VGP) latitude and longitude, class and stratigraphic position in section.

TABLE 2. MAGNETIC POLARITY DATA FOR SECTION R

Site	Mean Dec	Mean Inc	N	R	K	A95	VGP Lat	VGP Long	Class	Meters
R–7	355.014	45.5468	3	2.9	33.5	21.6	81.5833	285.187	N1	33
R–6	359.923	43.9491	3	3	111	11.7	81.4832	253.716	N1	23
R–5	6.60011	54.2846	4	3.9	31.1	16.7	84.5345	155.443	N1	16
R–4	357.924	51.3005	4	4	404	4.58	87.1317	291.142	N1	13
R–3	1.99555	52.5207	3	3	126	11	87.9849	197.201	N1	8
R–2	2.79225	49.1197	3	3	122	11.2	85.1471	223.34	N1	3.5
R–1	359.279	33.483	3	3	357	6.54	74.0377	255.738	N1	0.8

Columns are, from left to right site mean declination, inclination, number of samples (N), Fisher's (1953) R value, precision parameter (K), 95% confidence cone (A95), virtual geomagnetic pole (VGP) latitude and longitude, class and stratigraphic position in section.

The normal polarity expressed by all sites in both sections is correlated to the Brunhes Chron of the Magnetic Polarity Time Scale (MPTS), which began at 0.73Ma and continues to the present (Fig. 9). The rationale for this correlation is presented in the Discussion section.

SEDIMENTOLOGY

Methods

The sedimentological analysis of the Havelian Group consisted of the vertical and lateral measurements of stratigraphic sections located throughout the study area. Data such as sedimentological facies, conglomerate-clast compositions and paleocurrent directions were recorded at Gandhian, along Ichhar Nala and its tributaries; at Kotkal, also along Ichhar Nala; south of the village of Mangli; east of Nawashar in the deeply-incised valley of the Dorr River; and around Havelian, along the Dorr River and its tributaries. Numerous other locations were examined to discern bedrock/basin-fill contacts, conglomerate-clast compositon and paleocurrent directions.

Sedimentological facies

Facies are divided into three groups: gravel facies, sand facies and fine-grained facies. Facies codes similar to those used by Miall (1978) will be used in the following descriptions and interpretations. All of the gravels encountered were unconsolidated and clast supported,

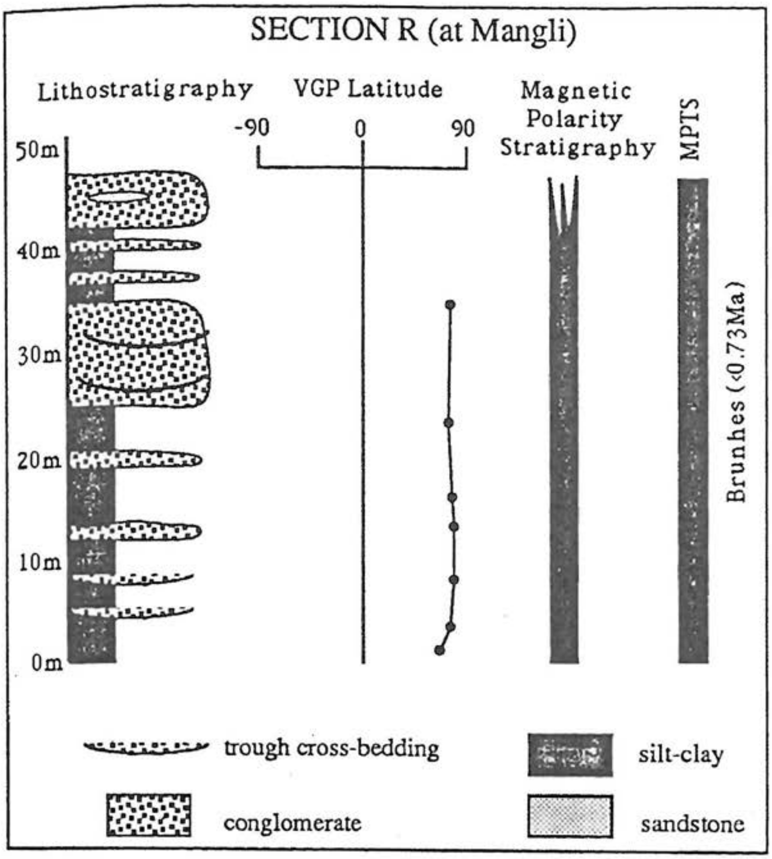


Fig. 9. A) Stratigraphic section, VGP latitude, magnetic ploarity stratigraphy and correlation with the Magnetic Polarity Time Scale (MPTS) for section R. B) Same for section M.

and fall into four facies groups. The most common gravel facies encountered was horizontally-laminated, imbricated gravels (Gchi). Gchi gravels are horizontally laminated and consist of angular to well-rounded, imbricated clasts. Maximum particle sizes are on the order of 30cm. Matrix, when present, consists of coarse- to medium-grained sand. Gchi gravels are interpreted as being the deposits of mid-channel, longitudinal bars. The regularity of the imbrication of the clasts suggests that the dip direction of the imbricated clasts points upstream. No case was found where clasts were imbricated in directions other than what has been interpreted as the main paleoflow direction.

Trough cross-stratified gravels (Gct) are arranged as trough-shaped pods commonly less than 1m in height and 1 to 3m in width. The coarsest clasts are commonly found at the base of the trough. Gct gravels are interpreted as three-dimensional bedforms within the channel thawleg, or as small channels.

The third gravel facies is planar cross-stratified gravels (Gcp). Crossbed cosets are on the order of 1m in height and may be traced for 10's of meters along an outcrop. Upper and lower bounding surfaces of cosets are commonly horizontal, although they may taper along the leading edge, in the downstream direction. Gcp gravels are interpreted as the forset deposits of downstream-accreting bedforms, as the dip-directions of the forsets correspond to paleocurrent directions determined from clast imbrications (discussed below). In some instances, gravel forsets dip in a direction opposite to the paleoflow direction, suggesting that the upstream edge of the bedform was preserved. There were few instances of forset dip-directions being perpendicular to the paleoflow direction, perhaps indicating that lateral accretion of bedforms (pointbars) may not have been important.

Finally, massive gravels (Gcm) occur in tabular or lenticular form and contain no visible sedimentary structures. In their tabular form, they are interpreted as the deposits of overbank gravel sheets that were produced during high flow stages. These sheet gravels are commonly interbedded with fine-grained facies (Fig. 10).

Two sand facies were identified. The first is trough cross-stratified sands (St). Facies St consists of medium to very coarse-grained, unconsolidated sands arranged in trough cross-beds commonly less than 0.5m in height and 1m in width. They are closely associated with gravel facies Gct, and are interpreted as being the deposits of three-dimensional bedforms within the channel. Because St sands are found above Gct gravels, they most likely represent post high-flow stage deposition.

Planar cross-stratified sands (Sp) are less common than St sands, and are commonly interbedded with Gcp gravels. They are therefore interpreted as the finer-grained fraction of downstream-accreting bedforms.

Fine-grained facies are the most abundant facies encountered in the study area. Although the steep cliff-faces along the major rivers of the area consist of roughly equal amounts

Fig. 10. Photo showing overbank lithofacies package from a tributary of the Dorr River near Havelian. Facies Sfm, interpreted as windblown loess is interbedded with facies Gchi and Gcm, interpreted as macroforms and splays that were deposited during high flow events.

of gravels, sands and silts, most of the smaller tributaries are walled by fine-grained material with a thick cover of vegetation. The fine-grained facies are generally massive, tan colored silts (Sfm) mixed with sand and scattered pebbles. Calcite and iron-oxide nodules are common, as well as calcified burrows and root traces. No discrete soil horizons were observed. Distinctive vertical cracks occur on the outcrops. Facies Sfm does not display visible bedding, but is found interbedded with any of the facies described above. Similar lithologies found in the Potwar Plateau have been described as loess, and "fluviatile loess" has been described as filling channels and overbank areas on alluvial fans in Hungary (Pecsi, 1968). Due to the lack of sedimentary structures and the generally massive nature of the silts, facies Sfm is interpreted as being deposited as windblown loess derived from nearby glacial ice. Carbonate nodules ("loess dolls" of Catt, 1988) could have been formed by rising groundwaters (via capillary action) which deposited the carbonate during near-surface evaporation, suggesting an arid climate.

Facies architecture

The facies described above are arranged in packages with discrete facies assemblages. There are two main types of packages; channel and overbank. The channel assemblage contains facies Gchi, Gct, Gcp, Gcm, St and Sp, which are commonly associated with in-channel macroforms. It has a sharp, irregular, erosional lower bounding-surface and a sharp, and at places gradational, upper surface (Fig. 11). No grading was observed, although sand facies generally cap gravel facies. The lack of lateral-accretion surfaces and the generally pod-shaped nature of channel lithofacies packages suggest that these channels were part of a large braidplain, as opposed to a floodplain with more stable channel types. The overbank package contains predominantly facies Sfm with lesser amounts of facies Gchi and Gcm as 0.5-1m thick, tabular beds (Fig. 10). Facies Sfm represents overbank, background, deposition of windblown loess, while the coarser facies most likely were deposited as macroforms and splays that formed during unconfined, high-flow events. Channel lithofacies assemblages seem to "float" within a matrix consisting of overbank lithofacies (Fig. 11), and no systematic distribution of the two assemblages was observed.

Paleocurrent data

Paleocurrent-direction indicators were recorded at various locations and are presented in Fig. 12. The majority of paleocurrent-direction indicators were in the form of imbricated gravels. Dip and dip-directions of clasts, that were unambiguously imbricated, were measured and plotted on equal-angle plots. The limbs of trough cross-stratified sands were also measured and plotted in the same fashion. At all locations, paleocurrent directions closely resemble the present current direction of the streams or rivers along which the basin fill outcrop (Fig. 12). This suggests that drainage patterns during the time of deposition of the Havelian Group were similar to those that exist today.

Composition

Conglomerate-clast counts were conducted on the outcrop, using a minimum of 100 clasts per count (Table 3). Gravels were found to have clasts of rocks of both local and distal, northern provenance. At the Gandhain sections (numbers 1 and 2 on Table 3 and Fig. 12), which are located on opposite sides of Ichhar Nala, clast composition differs significantly.

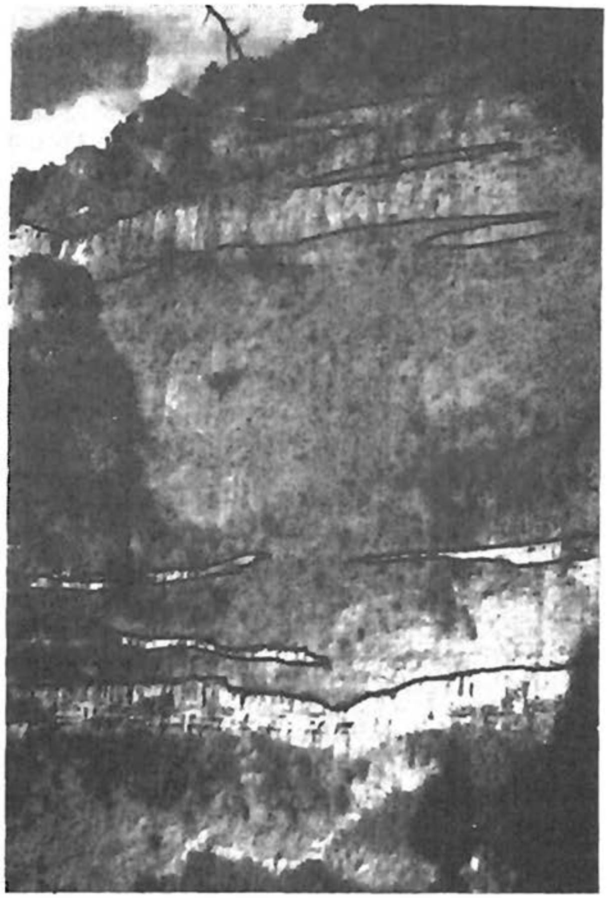
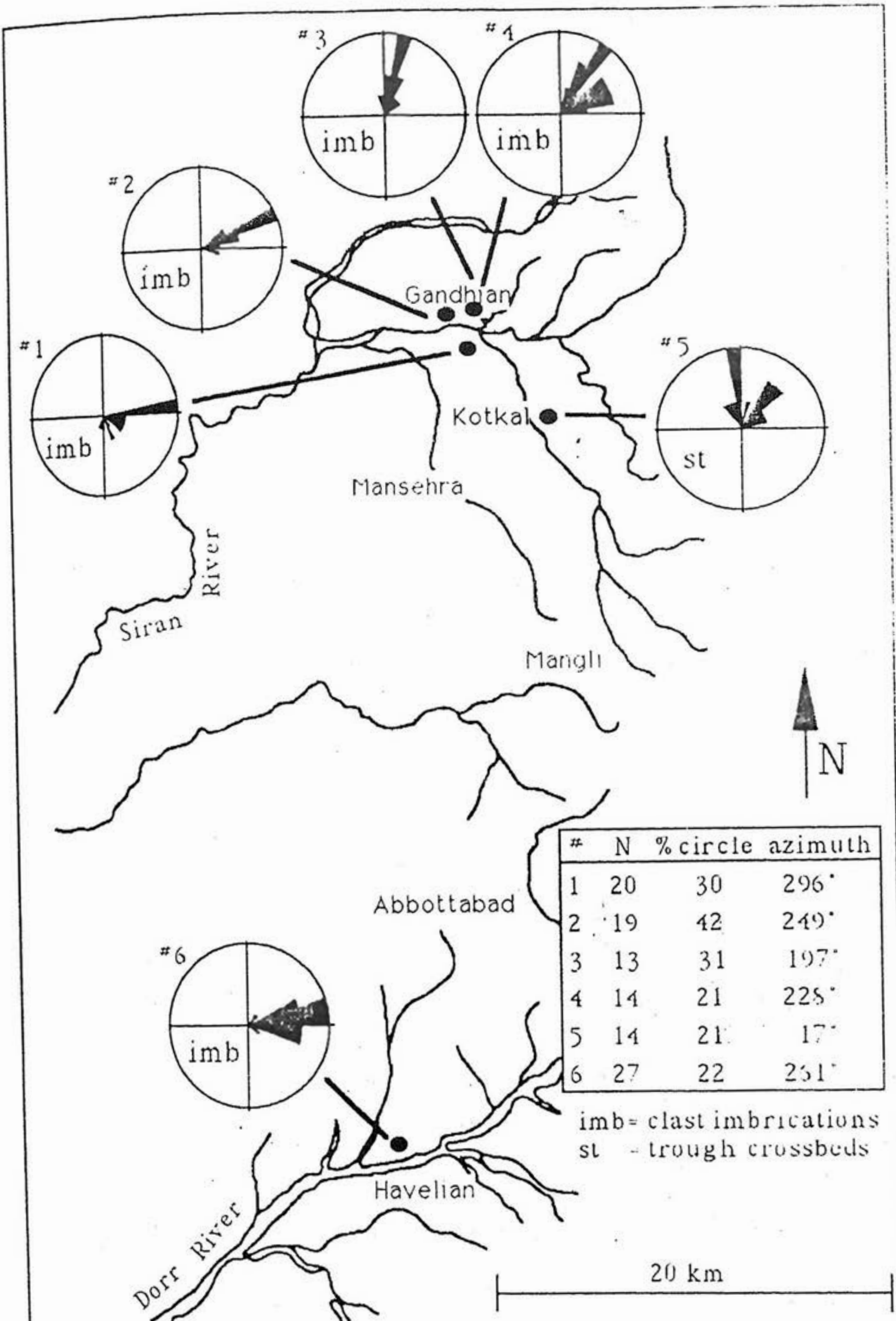


Fig. 11. Photo showing channel and overbank lithofacies packages. Channel lithofacies packages "float" in a matrix of overbank deposits which predominate the HIB, although this view shows mostly channel facies. Cliff face is approximately 45m in height.

TABLE 3. CLAST COUNT DATA FROM HAVELIAN GROUP GRAVELS

Section	meters	lsdol	red ss	ss	gran	vol	gr-phy	sch	qzt	amph	gns	mar	gar-gran
#1(M)	10	75.2	3.31	0	0	0	20.66	0	0	0.83	0	0	0
#2	25	15.7	1.65	2.5	11.6	0	0.826	1.7	52.9	7.44	5.8	0	0
#5	35	85.6	6.25	8.1	0	0	0	0	0	0	0	0	0
#5	6	9.35	0	2.8	40.2	0	0.935	1.9	39.3	5.61	0	0	0
#5	0	8.27	0	5.3	18.8	2.3	3.008	2.3	41.4	13.5	3	1.5	0.75188

Section numbers correspond with numbers of localities on Figure 12. Meters represent stratigraphic position in the section. Lithologies include lsdol-limestone or dolomite, red ss-red sandstone, ss-sandstone, gran-granite, vol-volcanics, grphy-green phyllite, sch-schist, qzt-quartzite, amph-amphibolite, gns-gneiss, mar-marble, gar-gran-garnet granulite. Numbers are expressed in percents.



#	N	% circle	azimuth
1	20	30	296°
2	19	42	249°
3	13	31	197°
4	14	21	228°
5	14	21	17°
6	27	22	261°

Fig. 12. Map of major rivers with rose diagrams showing paleocurrent directions derived from Havelian Group deposits.

Gravels from the section on the north bank of Ichhar Nala (#2 on Table 3 and Fig. 12), which shows paleocurrent directions to the southwest, have, as their dominant lithologies, quartzite, amphiboloite, granite and limestone/dolomite. Gravels at locations #3 and #4 (Fig.12) although not represented on Table 3, have similar compositions to gravels at section #2. These most likely represent the deposits of a paleo-Siran River. The south-bank section (#1 on Table 3 and Fig. 12) has gravels which contain predominantly limestone/dolomite and green phyllite and no granite. The south-bank section represents deposits from a northwest-flowing river that had predominantly metasedimentary rocks as its provenance; most likely a paleo-Ichhar Nala. At Kotkal (#5 on Table 3 and Fig. 12), conglomerate-clast composition changes upsection. The base of the 42m section contains gravels composed of high amounts of granite, quartzite and amphibolite, while the top of the section contains gravels composed chiefly of limestone and dolomite. Paleocurrent directions determined from the top of the section show NNE paleoflow, reflecting present drainage conditions (present- day Ichhar Nala). Although no paleocurrent data were retrieved from the base of the section, it is possible that at the time of deposition of these gravels, drainage patterns that existed during deposition of the upper parts of the section (and other sections in the study area) were not yet established, and rivers (perhaps a paleo-Siran River) that drained northern areas flowed through this point.

Not included in Table 3 are data concerning the deposits near Havelian on the Dorr River. Although no quantitative clast counts were undertaken on the outcrop, it was noted that the clast types were dominated by limestone and dolomite, with subordinate amounts of green phyllite and purple sandstone. No clasts of igneous or high-grade metamorphic rocks were found. This coincides with present drainage patterns, as the Dorr River and its tributaries drain an area that is underlain by only sedimentary and metasedimentary rocks (Margala Hills).

DISCUSSION

Correlation with the MPTS

Based on the stratigraphically short section (47m maximum at section R, Fig. 9), one can advocate that the normal polarity observed could belong to a number of normal polarity events before Brunhes. However, following lines of evidence suggest strongly that the Havelian Group indeed was deposited during the Brunhes chron. First of all, the silts of the Havelian Group bear strong lithologic similarity to the Potwar loess, which has been dated by thermoluminescence (TL) as being 18-170ka (Rendell, 1988). Secondly, the strong normal polarity and intensity (NRM as high as 2.7 x 10-3 Gauss), as well as the tight cluster of VGP positions around the present north pole and the lack of significant magnetic overprinting suggest that these are Quaternary deposits. The undeformed nature of the deposits also suggests that they are Quaternary, as other Plio-Pleistocene deposits positioned about related structural features elsewhere in the foreland are folded and faulted; specifically in the Peshawar Basin adjacent to the Cherat Fault (Burbank and Tahirkheli, 1985; Yeats and Hussain, 1987; Pivnik, unpublished data) and the Campbellpore (Attock) Basin, adjacent to the MBT (deTerra and Paterson, 1939; Johnson et al., 1982; Pivnik, unpublished data). Finally, the strong resemblance of the paleodrainage patterns to modern patterns suggests that the Havelian Group is quite young.

Sedimentation rate

Because of the inherant ability for high-resolution age determinations, paleomagnetic-reversal stratigraphy is an excellent and accurate way to determine rates and variability of rates of sedimentation. Of course, the key variables needed in determining sedimentation rates are the thickness of the sediments and the time elapsed during deposition (disregarding compaction). Because the Havelian Group is normally polarized, and is correlated with the Brunhes chron, an estimate of the lowest possible sedimentation rate can be made using the following simple equation:

$$SR = m/t \qquad (1)$$

where SR is the sedimentation rate, m is the thickness in meters and t is time in years. In this case m is 50m and t is 0.73 Myr (the time since the begining of the Brunhes chron until the present). Using these numbers, a sedimentation rate of .07mm/yr is obtained. This must be a minimum value, and the real value is most certainly higher because it is probable that deposition began sometime after the begining of the Brunhes chron, and that some time must also be alloted for the cessation of sedimentation and the present episode of incision. In an attempt to further define a sedimentation rate for the Havelian Group, the statistical methods of Johnson and McGee (1983) were used in conjunction with a computer program developed by Dr. J. Reynolds (Norwich University, USA). Table 4 shows the results of this model, where N is the number of sites (in this case section R was used with 7 sites), R is the number of reversals (although no reversals were observed, one reversal is assumed so that the model can be applied), is the average length in years of one reversal (obtained by averaging the length of reversals since the Pleistocene) and 2 is the error at the 95% confidence level. The three models used assume that either the samples were collected at stratigraphic intervals spanning uniform amounts of time, random amounts of time or exponentially changing amounts of time (Johnson and McGee, 1983). Although the results are similar for all three models, Johnson and McGee (1983) suggest that the random array is the most realistic because in nature, sedimentation rates are irregular and random.

The computer program created by J. Reynolds utilizes the equations in Johnson and McGee (1983) and results in an amount of time in years and an error, also in years (Table 4). Because the error exceeded the time, only a maximum number of years, thus a minimum sedimentation rate could then be calculated using the equation

$$SR = m/t + 2 \ . \qquad (2)$$

TABLE 4. MINIMUM SEDIMENTATION RATES

Spacing	N	R	$\bar{\tau}$ (years)	Time (years)	Error (2σ) (±years)	Min. Sed. Rate (mm/yr)
Exponential	7	1	415,000	75,413.8	137,686.2	0.23
Random	7	1	415,000	64,403.8	117,584.8	0.27
Uniform	7	1	415,000	58,823.3	107,396.2	0.30

Rates calculated using the methods of Johnson and McGee (1983) and a computer program developed by Dr. J. Reynolds. See text for explanation.

The results range from 0.23 to 0.30mm/yr and are given in the last column of Table 4. Maximum rates are unrealistic; more specifically, they are instantaneous, because if the error is subtracted from the time, SR goes to infinity. Because the rates derived are within the 95% confidence level for this statistical method, the numbers may be regarded as being at least realistic. As a comparison, sedimentation rates calculated for the Potwar loess are remarkably similar. Rendell (1988) used TL to date the loess and derived rates that vary from .06-0.27mm/yr. As mentioned above, the rates determined in this paper are only minimum rates, and rates as high as 7-14mm/yr for windblown glacial deposits have been reported (Catt, 1988).

Depositional model

The prescence of a combination of fluvial and glacial lithofacies described above suggests that the Havelian Group was deposited in a glacial-outwash environment; as braided streams emanating from incised valleys occupied by Alpine-type glaciers further upstream. Overbank facies Sfm , consisting mostly of wind-blown loess was deposited prior to, during and subsequent to the deposition of fluvial gravels and sands. Fluvial channels locally scoured into the loess, while in other areas such as at sections M and R, the loess was preserved beneath and adjacent to fluvial deposits. The Pakhli Plain near Mansehra was most likely a small sandur; an extensive, silt-laden plain of glacio-fluvial sediment emerging from, in this case, an Alpine-type ice sheet (Catt, 1988). Proximal reaches of sandars have been described as containing coarse gravels with well-developed imbrication forming longitudinal bars. Sand and silt occur as lenses, either deposited in abandoned channels or on the tops of bedforms during low-flow stages (Catt, 1988 and references within). Lithofacies assemblages of the Havelian Group are similar to sandur lithofacies assemblages, and the presence of loess throughout the region further attests to the glacio-fluvial nature of these deposits. However, no glacial features such as morraines or kettles have been identified in the Havelain Group. The abscence of structural features such as folds or faults within the sediments suggests that they were probably not deposited as a result of uplift along adjacent faults such as the Panjal Fault or the MBT. Also, independent work by Yeats and Hussain (1987) and Izaat (unpublished) suggest that the Panjal-Khairabad Fault was active in the Cretaceous or Paleocene and that the MBT was active during the Miocene, some 8My before deposition of the Havelian Group.

As shown above, paleocurrent and compositional data suggest that the fluvial deposits of the Havelian Group represent a fluvial system that had dimensions and drainage patterns similar to those that exist today in the region. During deposition of the Havelian Group, a southward flowing paleo-Siran River drained the northern part of the study area, while a paleo-Dorr River drained the southern portions. The westward bend in the Siran River (towards Khaki; Fig. 1) could have been caused by the northwestward progradation of a sediment wedge; a sandur emanating from the mountains to the south. The northwestward deflection of the Siran River can be inferred from paleocurrent and clast compositional data. At Kotkal, gravels at the base of the section have a northern provenance, possibly representing an early position of the Siran River. At Gandhian, southwest-directed paleocurrents and gravels with northern provenance could represent the Siran River at a position intermediate to its original position and its present position. Thus, as the sedimenatry wedge grew, the Siran River was deflected northwestward from an original north- to south-flowing position in the eastern part of the HIB. The present topographic slope of the basin also suggests that the Siran River is flowing around the toe of a large apron of sediment (Fig. 1).

Further Study

X-ray diffraction analysis of the silts and petrographic anlaysis of the sands of the Havelain Group would give further insight to the provenance of these deposits. Both of these analyses are presently underway by the author. TL dating of the silts would be a useful way to determine absolute dates for the Havelain Group deposits and would enable correlation with similar deposits elsewhere in the foreland.

Acknowledgements: I would like to thank Dr. M.J. Khan for his endless help in all aspects of this project. I am also grateful to Dr. R.A.K. Tahirkheli and Dr. M.Q. Jan for geological discussions and logistical help. Dr. Gary Johnson provided a wealth of knowledge and direction without which the project would not have started. Dr. J. Reynolds, Dr. L.E. McRae and J. Swiere are thanked for discussing the derivation and interpretation of the paleomagnetic data. This work was funded by grants from the National Science Foundation, the Geological Society of America, Sigma Xi, the American Association of Petroleum Geologists, and the Albert Cass Fellowship, and by Dartmouth College.

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