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THE LATE CENOZOIC CHRONOLOGIC AND STRATIGRAPHIC DEVELOPMENT OF THE KASHMIR INTERMONTANE BASIN, NORTHWESTERN HIMALAYA

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ABSTRACT

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The intermontane basin of Kashmir developed within the thrust-faulted, southern margin of the Himalayan Range. Detailed lithostratigraphies, magnetic-polarity stratigraphies, and fission-track dates on enclosed volcanic ashes were determined at four separate localities in order to develop a chronology of the Late Cenozoic evolution of the Kashmir Basin.

The results indicate that sedimentation had commenced by about 4 m.y. ago. Since then, over 1300 m of sediments have aggraded at inferred average rates varying from 16 to 64 cm per 1000 yr. Lacustrine and deltaic sediments dominate the Kashmiri sequences and appear to respond sensitively to tectonic events along the basin margins. Conglomerates shed from the faulted basin margins at about 1.7, 2.1, 2.7, and 3.0—3.5 m.y. ago punctuate the predominantly low-energy, fluviolacustrine depositional record. Paleocurrent analyses indicate a switch from northeasterly derived conglomeratic facies to southwesterly derived ones about 1.7 m.y. ago. This transition reflects enhanced activity along the Main Boundary Thrust complex to the southwest and an apparent diminution of faulting along the northeastern margin of the basin. In the Pir Panjal Range, 1400—3000 m of uplift at inferred rates of up to 10 mm yr^{-1} have terminated widespread sedimentation within the Kashmir Basin since the middle Pleistocene.

INTRODUCTION

Intermontane basins often develop during the late stages of an orogeny. The synorogenic sediments that accumulate in these basins preserve a record of varied depositional environments that respond to and are largely controlled by tectonic events along the basin margin and within the basins themselves. As a result, the interpretation of the sedimentary record within a basin provides an understanding both of the tectonic history of the enclosing

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structures, as well as of the paleogeography during deposition. Along the southern margin of the Himalayan collisional belt (Fig.1), several intermontane basins are embedded in the still-developing *Schuppenstruktur* (Burbank, 1983). Tectonic depressions created on the back side of active thrust sheets aggrade with sediments resulting from ponding of the preexisting fluvial systems.

Recent uplift in the Kashmir Basin in the northwestern Himalaya has exposed over 1000 m of intermontane-basin sediments known as the "Karewas". Since the 1800s these sediments have been informally classified in two divisions (the Lower Karewas and Upper Karewas), which in most places are separated by an unconformity and frequently a boulder conglomerate (Lydekker, 1876). Generally, the Lower Karewas are many times thicker than the overlying Upper Karewa sediments.

Following the early descriptions by Godwin-Austin (1859, 1864), nearly all subsequent stratigraphic studies (Lydekker, 1876, 1883; Middlemiss, 1911; Dainelli, 1922; De Terra and Paterson, 1939; Farooqi and Desai, 1974; Bhatt, 1975, 1976; Bhatt and Chatterji, 1976; Singh, 1982) emphasize the dominance of lacustrine sedimentation in the Lower Karewas. The rich floral record that has been extracted from the Lower Karewas reveals major vegetational changes frequently inferred to result from uplift and glacial—interglacial climatic variations (Puri, 1947, 1948; Vishnu Mittre, 1964; Dodia et al., 1982).

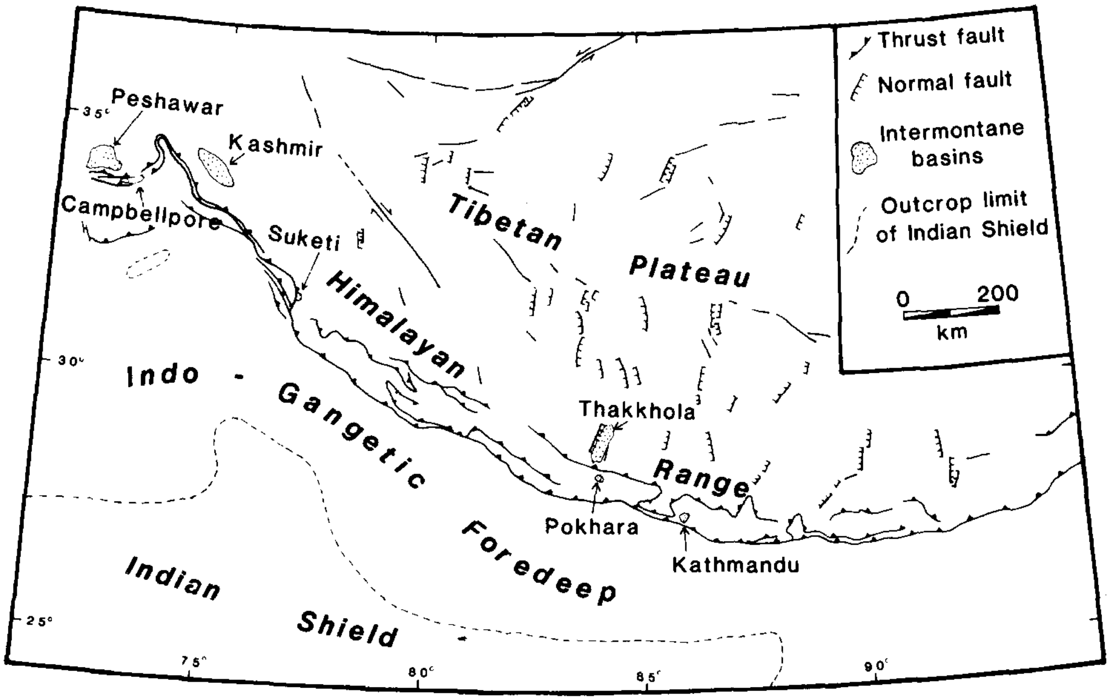


Fig.1. Overview of the structural setting of the intermontane basins in the Himalaya and the southern Tibetan Plateau. Along the northern margin of the Indo-Gangetic Foredeep, intermontane basins are enclosed in a narrow zone of imbricate thrust faults. Farther to the north, grabens bounded by normal faults define the intermontane basins.

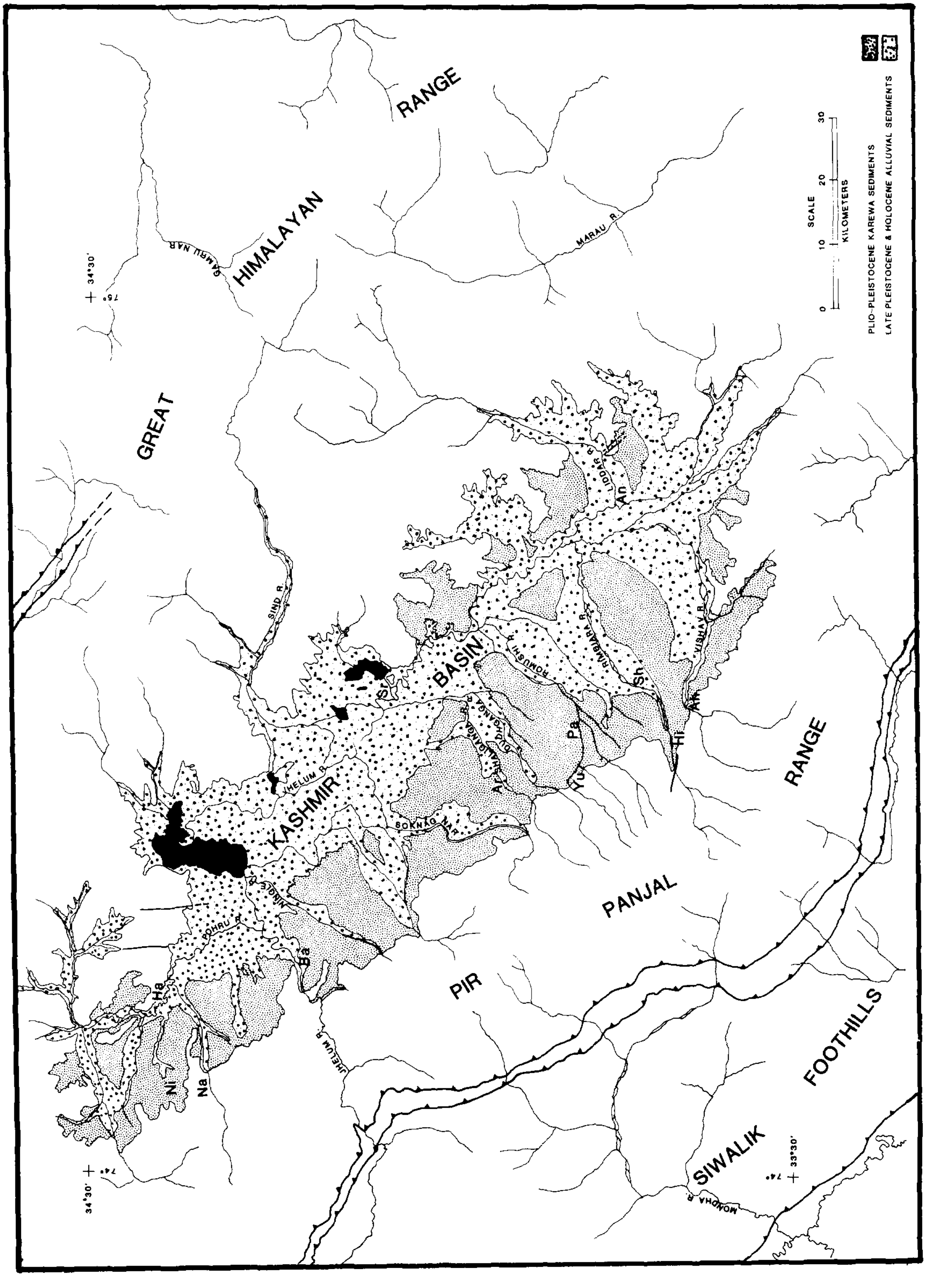
Despite attempts to formalize the stratigraphic status of the Karewas (Farooqi and Desai, 1974; Bhatt, 1976), no reliable stratigraphic framework has been erected for them due to the lack of accurate correlations between exposures. The uncertainties of correlations between sections are exemplified by the range of estimated thicknesses for the Karewas which vary from 900 m (De Terra and Paterson, 1939; Roy, 1975) to 1950 m (Farooqi and Desai, 1974) to 2755 m (Bhatt, 1976). In the absence of good chronologic control, the age of the Karewas has been interpreted as being solely Pleistocene (De Terra and Paterson, 1939; Vishnu Mittre, 1964), as spanning the Pliocene/Pleistocene boundary (Wadia, 1951; Farooqi and Desai, 1974; Bhatt, 1976), and as perhaps extending to the late Miocene (Roy, 1975; Singh, 1977).

Resolution of these chronologic uncertainties has been achieved in the present study through the conjunctive use of magnetic-polarity stratigraphy (MPS) and fission-track dating of intercalated volcanic ashes. In this paper, the temporal constraints imposed by these new data are combined with detailed stratigraphic analysis to offer a new synthesis of the chronologic, stratigraphic and tectonic development of the Kashmir Basin. The research reported here is an outgrowth of a continuing effort to provide reliable chronologic and stratigraphic control for Neogene, terrestrial, Himalayan molasse sequences in northern Pakistan and India (Keller et al., 1977; Barndt et al., 1978; Visser and Johnson, 1978; G. D. Johnson et al., 1979, 1982; Raynolds, 1980; N. M. Johnson et al., 1982; Opdyke et al., 1982; Raynolds and Johnson, in press).

MAGNETIC-POLARITY STRATIGRAPHY AND FISSION—TRACK DATING

The Kashmir Basin (Fig.2) is a northwest—southeast, elongate depression about 140 km long and up to 60 km wide. To the northeast, the Himalayan Range rises abruptly to well over 4000 m. The southwest margin of the basin is delineated by the Pir Panjal Range which contains numerous summits around 4000 m high. The southern margin of the Pir Panjal Range is defined along the northern edge of the Siwalik molasse by a set of large imbricate thrusts that include the "Main Boundary Fault" (Gansser, 1964). Quaternary uplift along these thrust faults has elevated the Pir Panjal Range and caused incision of the Karewas along the northeast flank of the range.

Near the villages of Hirpur, Pakharpur, Arigam, and Baramula (Fig.2) over 2000 m of Karewa sediments were measured, described at a scale of 1:200, and sampled. A full description of procedures and techniques is given in Burbank (1982). In brief, more than 200 magnetic sampling sites were placed in these sections at 5- to 15-m intervals. In accordance with the procedures of N. M. Johnson et al. (1975), triplicate, oriented samples of non-pedogenically altered mudstone were collected at each site. The remanent magnetization of each sample was measured using a cryogenic magnetometer at the Woods Hole Oceanographic Institute. The results of progressive thermal and


GREAT
HIMALAYAN
RANGE
KASHMIR
BASIN
PIR
PANJAL
RANGE
SIWALIK
FOOTHILLS
SCALE
0
10
20
30
KILOMETERS
PLIO-PLEISTOCENE KAREWA SEDIMENTS
LATE PLEISTOCENE & HOLOCENE ALLUVIAL SEDIMENTS
34°30'
75°
34°30'
74°
33°30'
74°
JAMRU NAR
MARAU R.
SIND R.
LIDDAR R.
An
JHELUM R.
ROMUSHI R.
RAMBIARA R.
VISHAV R.
DUDHGANGA R.
ALISHALIGANGA R.
BOKNAG NAR
NINGLE R.
POHRU R.
JHELUM R.
MONDHA R.
Sr
Pa
Yu
Sh
Hi
Ah
Ba
Ha
Ni
Na

alternating-field demagnetization (AFD) indicated that these samples had experienced very little post-depositional magnetic overprinting that was not readily removable at low levels of demagnetization (200°C or 150 Oe) (Burbank, 1982). Consequently, all samples were blanket demagnetized at 150 to 200 Oe. After demagnetization, the data from each section passed the reversal and fold tests (McElhinny, 1973). Although the data reported here are those obtained after AFD at 150 Oe, normally magnetized samples were subsequently demagnetized to 600 Oe, and some were thermally demagnetized at 550°C. None showed polarity changes at these higher demagnetization levels.

The resulting data were used to classify each site according to the k statistic for dispersion on a sphere (Fisher, 1953). If the measured magnetic vectors of the three samples at a site were tightly grouped ($k > 10$), the site was termed "Class I". Class II sites ($k < 10$) comprised two samples in good agreement, while the third was either lost or destroyed in shipping or at variance with the other two. Class III sites had little or no agreement between the three samples. The latitude of the paleopole that was calculated for each site formed the basis of the MPS developed for each section of superposed sites.

Volcanic ashes were discovered in each of the measured sections in Kashmir. Zircons extracted from several of the ashes were dated using the fission-track method. The techniques for sample preparation, irradiation, and counting are those described by Naeser (1978). The fission-track dates provide an absolute age for a portion of each stratigraphic section and facilitate an unambiguous correlation of each local MPS with the magnetic-polarity time scale (MPTS).

The magnetic-polarity stratigraphies for each section in Kashmir are depicted in Figs.3—6. Each figure shows the schematic lithologic column, the stratigraphic level of magnetic sites, the paleolatitude of each site, and the derived MPS in which each magnetozone is labeled according to its position and polarity. An α_{95} confidence envelope is plotted around the Class I data to indicate the reliability of the paleolatitude determinations. Fission-track dates with 2σ errors are depicted at their appropriate stratigraphic level.

The Romushi section was measured along the Romushi River (Fig.2) in the vicinity of Pakharpur (detailed location maps for each section are given in Burbank, 1982). Of the 70 magnetic sites (Fig.3), 61 are Class I (87%) and 9 are Class II (13%) after AFD. The Romushi MPS comprises ten magnetozones, of which one, N1, is based on a single-point reversal. All others are well established by multiple sites. Several samples in magnetozones N2 and

Fig.2. Map of the Kashmir Basin based on 1:250,000 LANDSAT imagery. Fault locations from Middlemiss (1910) and Wadia (1934). *Ah* = Aharbal; *An* = Anantnag; *Ar* = Arigam; *Ba* = Baramula; *Ha* = Handwar; *Hi* = Hirpur; *Na* = Naugam; *Ni* = Nichahom; *Pa* = Pakharpur; *Sh* = Shupian; *Sr* = Srinagar; *Yu* = Yusmarg.

N3 were thermally demagnetized at 550°C after which their magnetic orientations still showed no significant departure from those obtained through AFD. Magnetozone N5 encompasses an angular unconformity near its top.

Five volcanic ashes were discovered in the lowermost 70 m of the section. The lower three form a widespread ash triplet that was recognized in the Dudhganga valley to the northwest and near Hirpur to the southeast (Fig.2). One of the ashes in the triplet was dated at 2.4 ± 0.3 m.y. (Table I). This date indicates that the lower reversed magnetozones (R1, R2) belong to the lower Matuyama chron (Fig.7). N2 to N4 are interpreted as representing the Reunion and Olduvai normal subchrons. The R5/N5 boundary is taken as the base of the Brunhes chron. This correlation with the MPTS is further substantiated by the fossil occurrences of *Equus* and *Cervus* (Kotlia et al., 1982) in the lower part of the Romushi section (Fig.3). Because the Pinjor fauna (of which *Equus* and *Cervus* are characteristic members) commences around 2.5 m.y. ago in the nearby Siwalik molasse (Opdyke et al., 1979), the base of the Romushi section should also post-date the Gauss chron. Under this interpretation, the Jaramillo subchron does not appear in the Romushi MPS (Fig.7), perhaps due to inaccessible strata or unsuitable lithologies for magnetic sampling in the upper portions of the section.

Although most terrestrial sedimentation is decidedly episodic, long-term average rates of sedimentation and of basin subsidence, as well as changes in these rates through time, provide useful comparisons between different portions of a basin and yield data on migrating depocenters and facies through time (Opdyke et al., 1979; Raynolds, 1980; Raynolds and Johnson, in press).

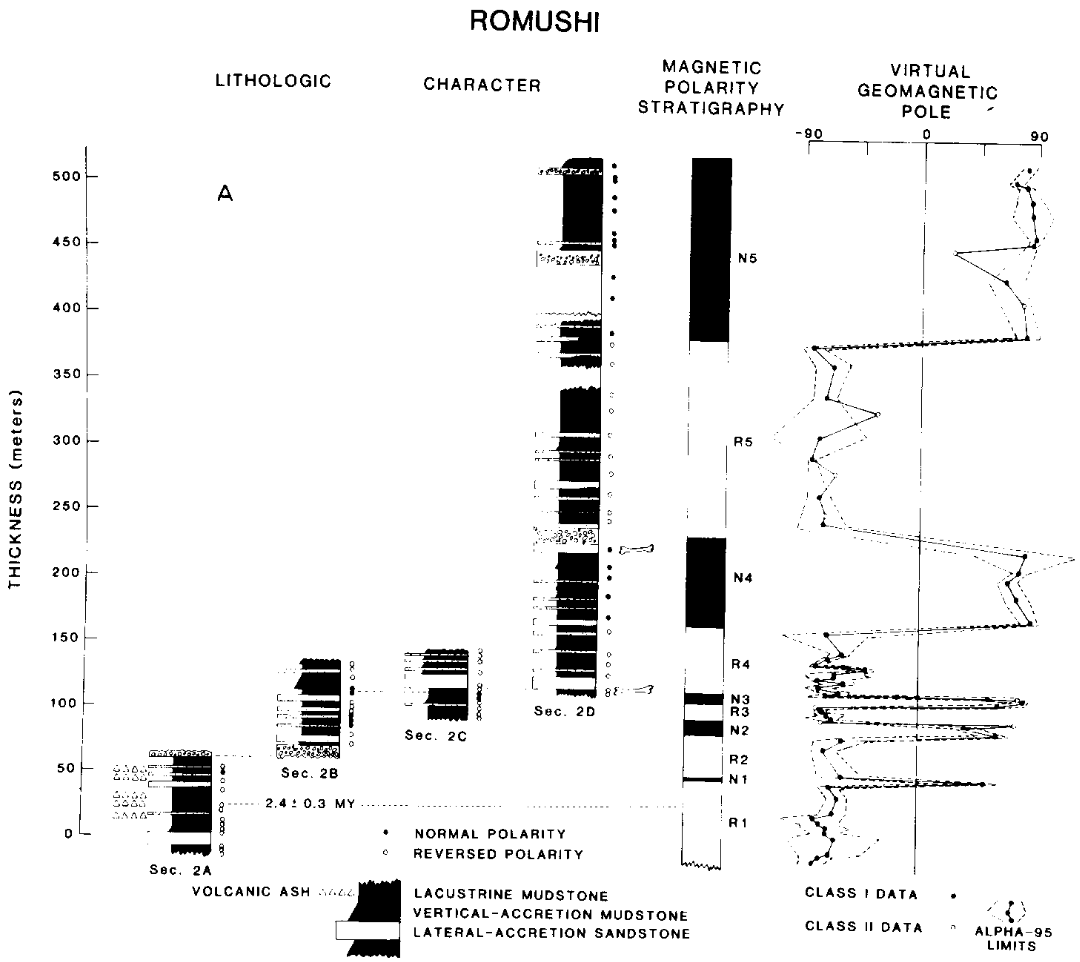
TABLE I

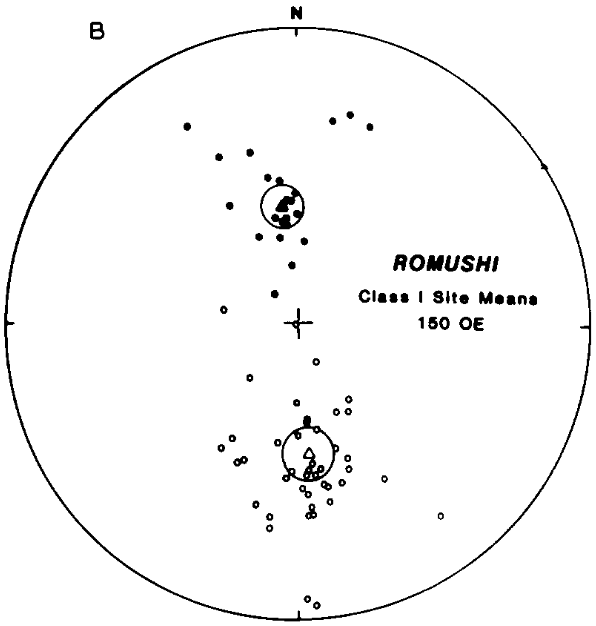
Fission-track age determinations

Sample	Location	Grains counted	Fossil tracks		Induced tracks		r	Neutron Dose (e14)	Age (m.y. ± 2σ)
			Total	Density (e3 tr/cm^2)	Total	Density (e3 tr/cm^2)			
KG8	Romushi	11	85	529.2	418	5204.9	0.91	3.89	2.4 ± 0.3
SG3	Shaliganga	11	79	1114.5	437	12330	0.93	4.87	2.6 ± 0.4
BG12	Baramula	15	164	696.5	1919	16300	0.88	9.54	2.4 ± 0.3

$\lambda_F = 7.03 \times 10^{-17}$ yr^{-1} ; $\sigma = 580 \times 10^{-24}$ cm^2 ; $\lambda_D = 1.551 \times 10^{-10}$ yr^{-1} ; $I = 0.007252$.

Fig.3. A. Magnetic-polarity stratigraphy, lithologies, fossil sites, volcanic-ash occurrences, and magnetic-site locations from the Romushi section in the vicinity of Pakharpur. Fossil remains of *Cervus* and *Equus* (Kotlia et al., 1982) were recovered from the 120-m and 220-m levels, respectively. In this and succeeding figures, the α_{95} confidence envelope on the Class I sites is shown by the dashed lines and emphasizes the unambiguous polarity stratigraphy. Fission-track dates are reported with a 2σ error and are depicted at the level of the dated ash horizon. Magnetozones are labeled according to polarity and stratigraphic position and are interpreted in the text. B. Stereonet plot of the mean vectors of the Class I sites from Romushi indicating antipodal distribution.


ROMUSHI
LITHOLOGIC
CHARACTER
MAGNETIC POLARITY STRATIGRAPHY
VIRTUAL GEOMAGNETIC POLE
-90
0
90
A
THICKNESS (meters)
500
450
400
350
300
250
200
150
100
50
0
Sec. 2A
Sec. 2B
Sec. 2C
Sec. 2D
2.4 ± 0.3 MY
N5
R5
N4
R4
N3
R3
N2
R2
N1
R1
• NORMAL POLARITY
○ REVERSED POLARITY
VOLCANIC ASH
LACUSTRINE MUDSTONE
VERTICAL-ACCRETION MUDSTONE
LATERAL-ACCRETION SANDSTONE
CLASS I DATA •
CLASS II DATA ○
ALPHA-95 LIMITS


B
N
ROMUSHI
Class I Site Means
150 OE

In the interpretation offered here, the Romushi section commences around 2.4 m.y. From then through the Olduvai subchron (1.67 m.y.), an average sedimentation rate of about 32 cm per 1000 yr was sustained. These rates diminished markedly in the post-Olduvai period to about half of their earlier value. Extrapolation of the post-Olduvai sedimentation rate to the top of the section would suggest that sedimentation ceased about 100,000 yrs ago. However, due to the uncertainties regarding the Jaramillo subchron, a more conservative estimate of 300,000 to 400,000 yr is preferred.

A 515-m-long section was measured along the Shaliganga River (Fig.2) near the village of Arigam. The section is cut by a fault at the 355-m level, and stratigraphic continuity above this is based on correlation between adjacent blocks. Of the 38 magnetic sites established in this sequence, 31 are Class I (84%), 5 are Class II (13%), and 2 are Class III (3%). Six magnetozones are represented in the Shaliganga MPS (Fig.4). However, R2 is based on a single Class II site. Two ashes, each 4—6 cm thick, were discovered near the base of the section. The lower ash yielded a fission-track date of 2.6 ± 0.4 m.y. (Table I). This date is not statistically different from the date from Romushi.

Because the ash is also enclosed in reversely magnetized strata, the base of the section (R1) is interpreted as the lower Matuyama chron (Fig.7). Magnetozones N1 and N2 are inferred to represent the Reunion subchrons and N3 is depicted as Olduvai subchron. If N3 were to represent the Brunhes chron, magnetozones N1 and N2 could not be reasonably matched with the MPTS. Under the interpretation offered here, the Shaliganga section extends from about 2.4 m.y. to about 1.7 m.y. During this period the sedimentation rate averaged about 64 cm per 1000 yr.

The Baramula sequence spans an aggregate thickness of about 400 m (Fig.5). Of the 55 magnetic sites, 40 were Class I (73%), 13 were Class II (23%), and 2 were Class III (4%). Four volcanic ashes were found in the lower 140 m. One near 50 m was dated at 2.4 ± 0.3 m.y. (Table I), indicating that this ash also belongs to the same family of ashes seen at Shaliganga and Romushi and that magnetozone R1 must belong to the lower Matuyama chron (Fig.7). Magnetozone N2 is interpreted as representing the Olduvai subchron. The normally magnetized sites of N1 form a tight cluster in section 4b (Fig.5) that was not found in the correlative, well-sampled, lacustrine strata of section 4c. Consequently, although it is possible that N2 could be the Brunhes and N1 could be the Olduvai, this seems less likely, unless erosion has removed a normally magnetized portion of section 4c below the conglomerate. Thus, the Baramula sections are interpreted to span from about 2.4 m.y. to about 1.8 m.y. The average sedimentation rate during this period of Lower Karewa deposition would be about 57 cm per 1000 yr. The upper part of magnetozone N2 unconformably overlies the main Baramula section. It comprises Upper Karewa conglomerates and loess. Dated paleosols in the loess (Kusumgar et al., 1980) indicate it is late Pleistocene or Holocene in age.

The Hirpur section in southeast Kashmir (Fig.2) was measured along

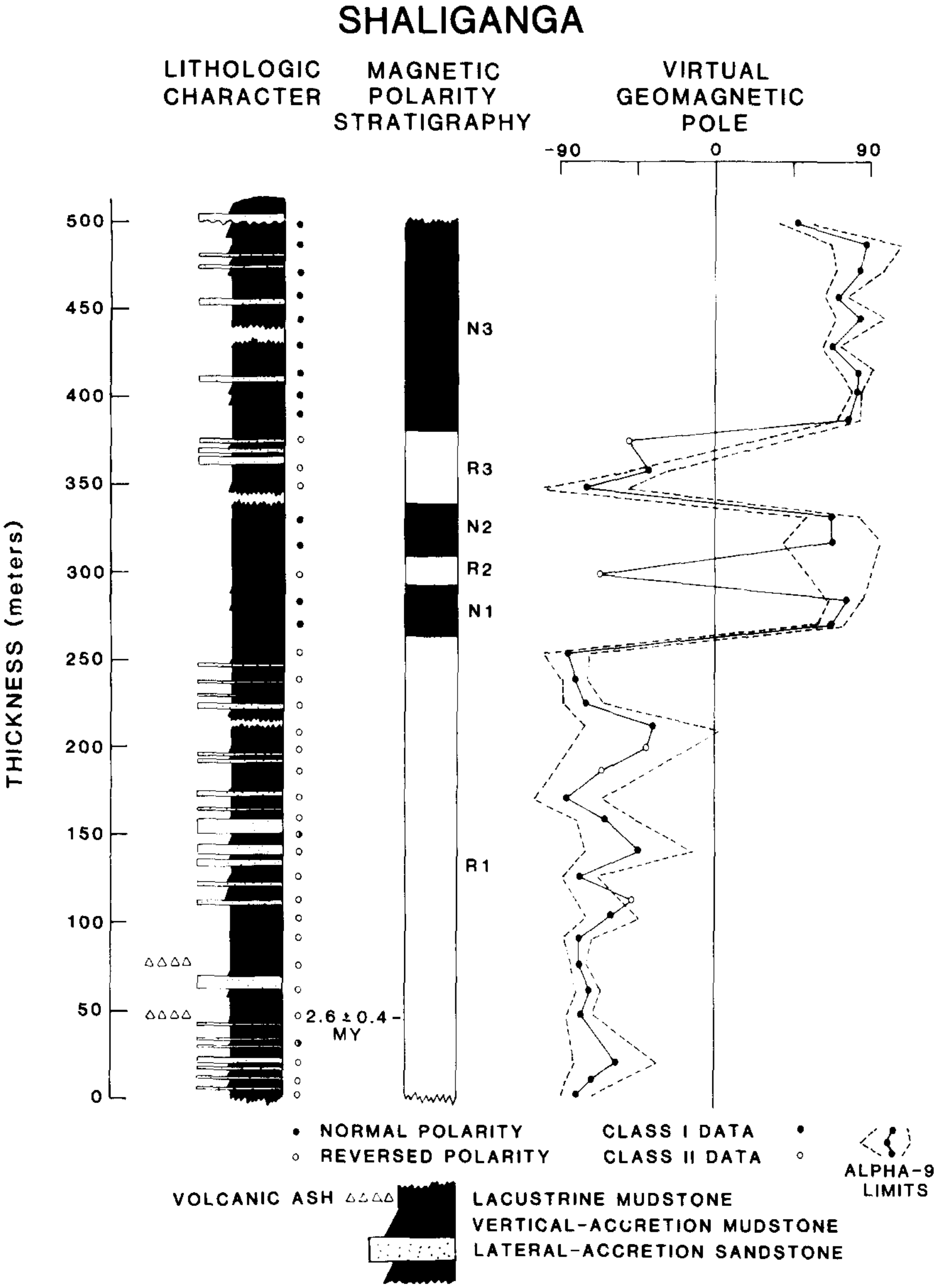


Fig.4. Magnetic-polarity stratigraphy, lithologies, volcanic-ash occurrences, and magnetic-site locations from the Shaliganga section in the vicinity of Arigam. See Fig.3 for description of symbols.

tributaries of the Rimbiara River near the village of Hirpur. The measured section of 425 m is underlain by about 550 m of unsampled sediments. These basal sediments consist of an estimated 250 m of contorted mudstones, siltstones, and sandstones (Bhatt and Chatterji, 1976; Singh, 1982). These are succeeded by about 300 m of coarse conglomerates that terminate

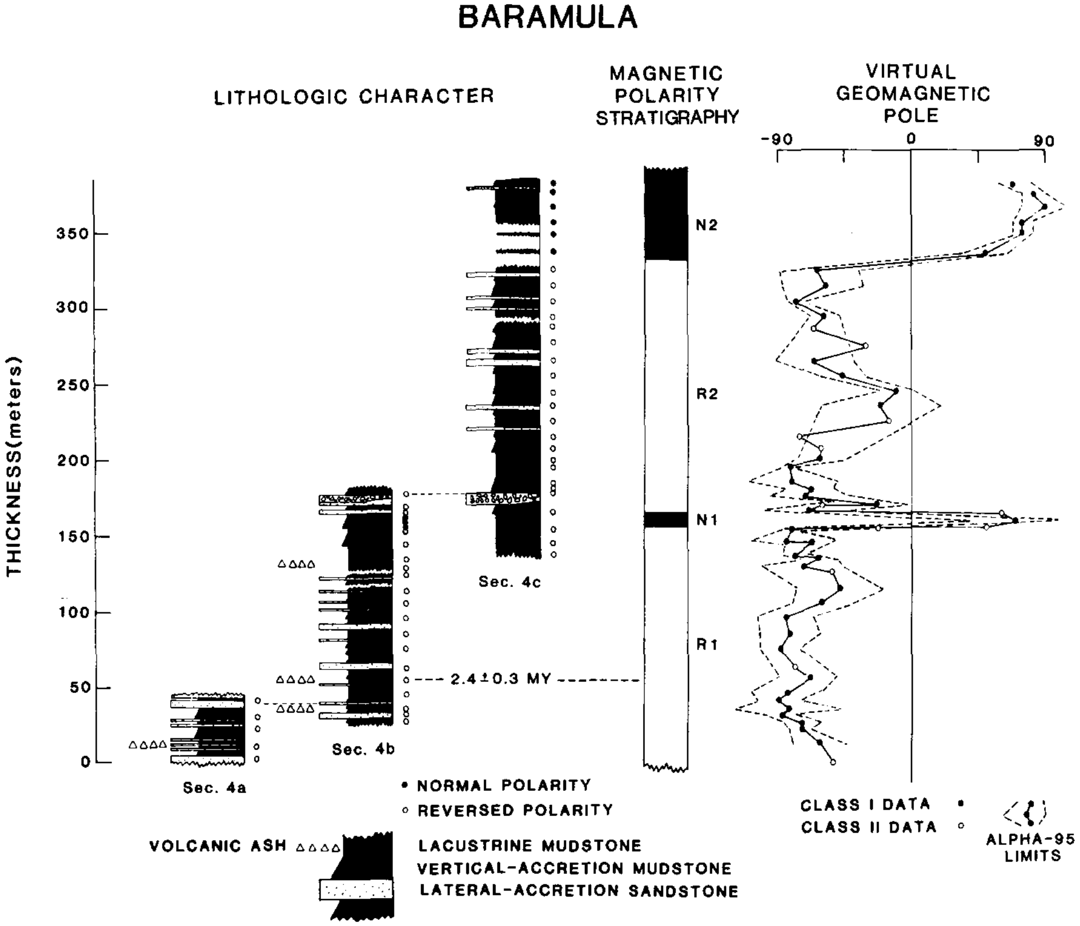


Fig.5. Magnetic-polarity stratigraphy, lithologies, volcanic-ash occurrences, and magnetic-site locations from the Baramula section. See Fig.3 for description of symbols.

at the base of the measured section. The depositional base of the Karewa sequence is not exposed, because faulting has truncated the section.

At Hirpur, 46 magnetic sites were established. All, except one, were Class I, and three magnetozones were defined from these data (Fig.6). A triplet of volcanic ashes, each about 1 cm thick, was discovered about 60 m below the top of the section. Although insufficient zircons for fission-track dating were recovered from these ashes, both their lithologic context and their stratigraphic spacing suggest they are the downwind equivalent of the ash triplet at Romushi and Dudhganga (Fig.8). Consequently, R2 is assigned to the lower Matuyama chron. In contrast to the interpretations of Agrawal et al. (1981) and Kusumgar et al. (1982), N1 is interpreted as representing only the upper Gauss chron, because reversals representative of the Kaena and Mammoth subchrons do not appear in this rather densely sampled normal chron. R1 is interpreted as the upper Gauss chron. Given this interpretation, the sampled Hirpur sequence extends from about 3 m.y. to about 2.1 m.y. The mean sedimentation rate during this interval would be 50 cm per 1000 yr.

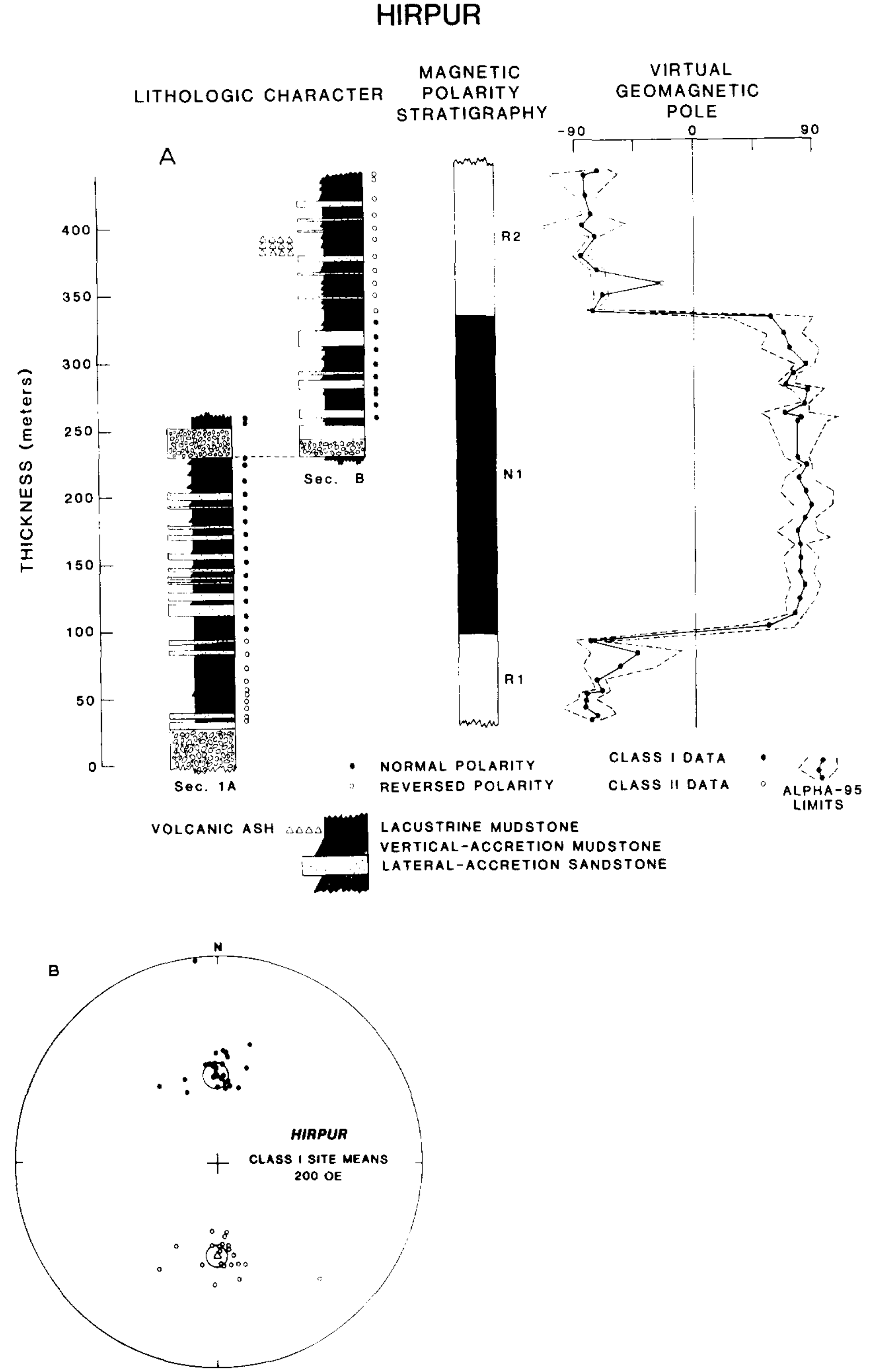


Fig.6. A. Magnetic-polarity stratigraphy, lithologies, volcanic ash occurrences, and magnetic-site locations from the Hirpur section along the Rimbiara River. See Fig.3 for description of symbols. B. Stereonet plot of the mean vectors of the Class I sites from Hirpur indicating antipodal distribution.

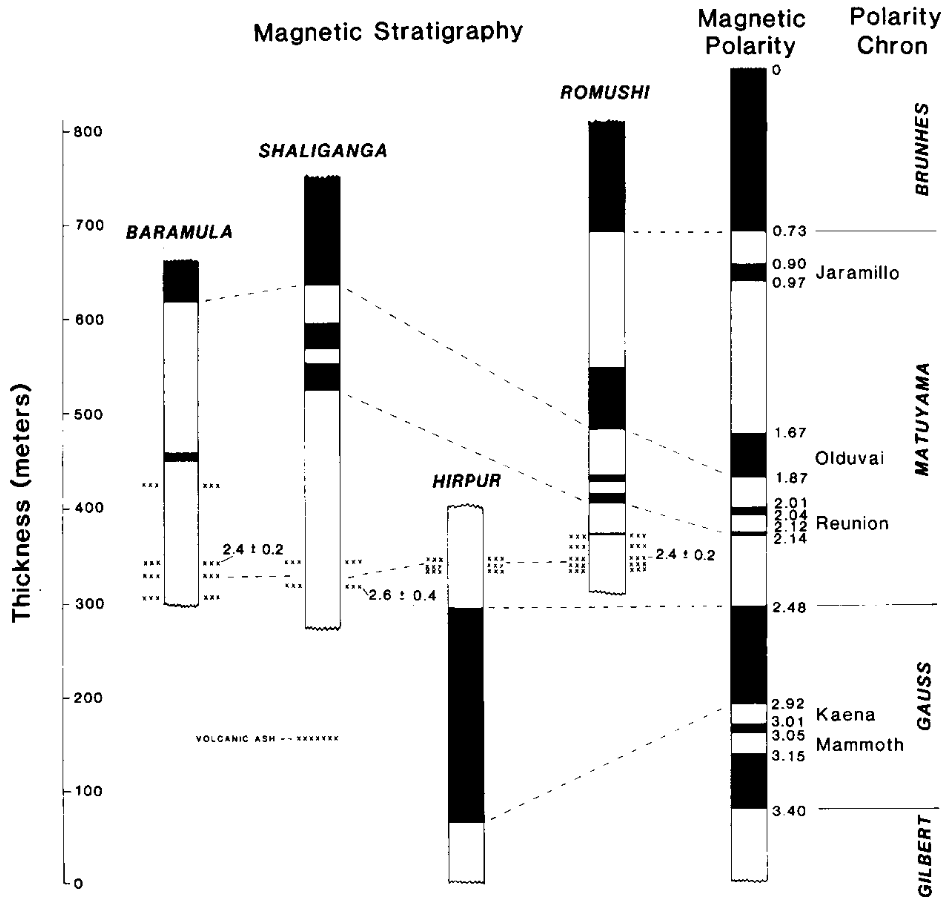


Fig.7. Correlation of the magnetic-polarity stratigraphies from Kashmir with the MPTS. Fission-track dates on volcanic ashes are shown adjacent to the dated horizons.

If this rate is extrapolated through the underlying 550 m of strata, the exposed base of the Hirpur sequence would be expected to date from about 4 m.y. Extrapolation of this rather higher rate probably underestimates the true age of the sediments, since sedimentation rates in the early and late stages of molasse sedimentation tend to be less than in the main phase of basin filling (G.D. Johnson et al., 1979; Raynolds and Johnson, in press). If a rate twice as great as the highest rate determined thus far in Kashmir is extrapolated to the base of the sequence, its age would be about 3.5 m.y., or only about 0.5 m.y. younger than the linear assumption. Rates this high are improbable in this setting. Consequently, the estimate of 4 m.y. is considered conservative and constitutes a minimum-age estimate for the initiation of the development of the intermontane basin of Kashmir.

PHYSICAL STRATIGRAPHY

In contrast to the sediments of the coeval Siwalik molasse to the south, which are characterized by the alternation of fluvial sandstones and overbank

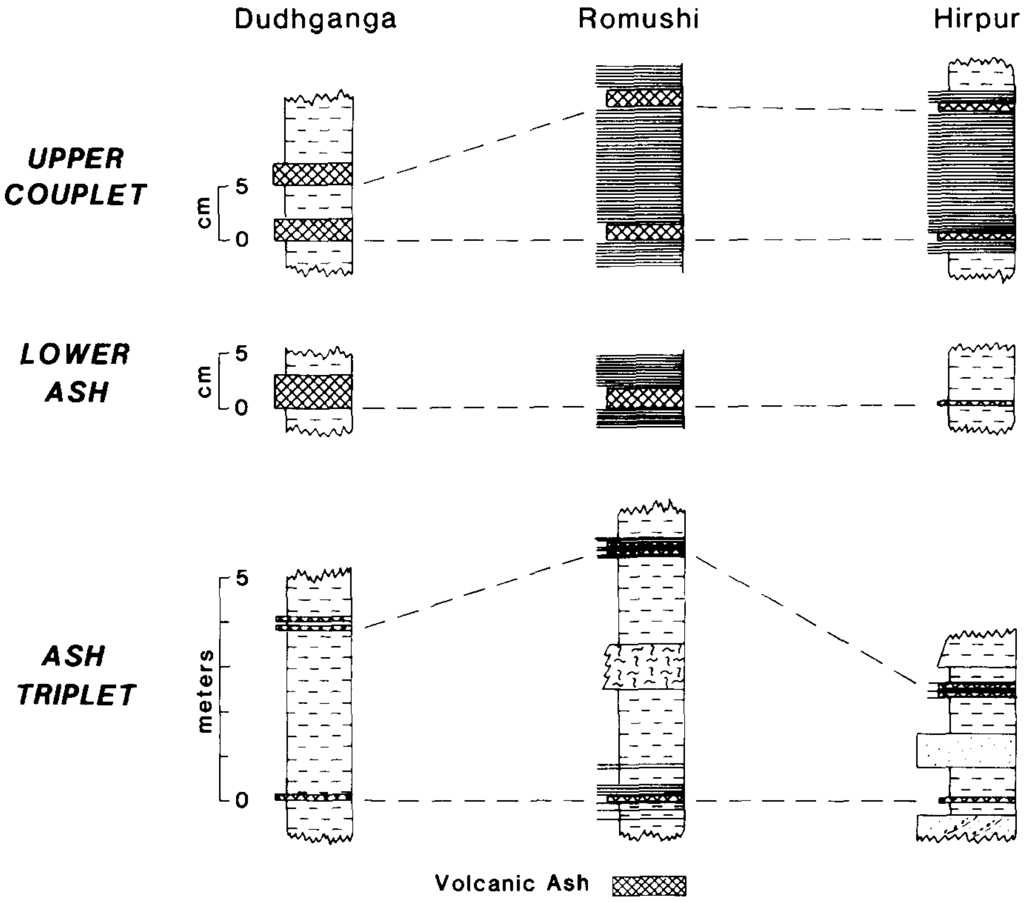


Fig.8. Detailed stratigraphic distribution and thickness of ashes within the ash triplet, as observed at three localities in Kashmir.

siltstones (G. D. Johnson et al., 1979), the Karewas are dominated by mudstones, frequently well laminated, that are inferred to result from lacustrine deposition. This contrast implies a fundamental difference in the nature of deposition between these adjacent settings along the southern margin of the Himalaya.

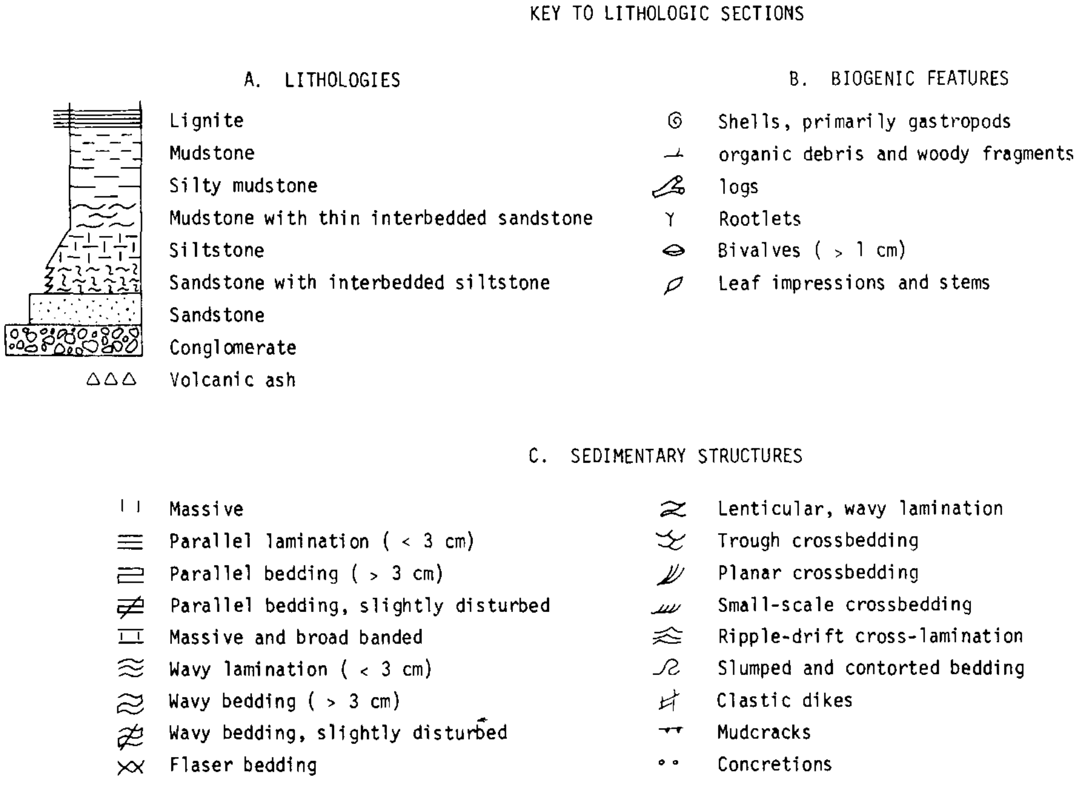
The physical stratigraphies from the Kashmiri sections are depicted in Figs.9—12 and are interpreted to represent four major depositional settings: braided rivers, meandering rivers, deltas, and lakes (Fig.13). Within each setting, several subenvironments can also be discerned. In the field, each rock body was assigned to a lithofacies on the basis of its characteristic grain sizes, sedimentary structures, and geometry (Table II). Groupings of lithofacies (Table III) were used to define the depositional environment of each sequence.

The braided-river facies assemblage (Fig.13) is intermediate between the "Scott" and "Donjek" models of Miall (1978). Whereas meandering-river sediments are uncommon within much of the Siwalik molasse (Raynolds, 1980), the Jhelum River provides a modern analogue for deposition in

Kashmir by sandy bedded meandering rivers. Extensive overbank mudstones and siltstones displaying pedogenic alteration are common within this depositional setting, as are inferred levee and splay deposits.

Subaerial fluvial environments are transitional to the deltaic setting. Oftentimes, an individual facies cannot be assigned unambiguously to one depositional environment. Hence, the environment is partly based on associated rock units. In this study, fluvial and deltaic environments are distinguished by differences in pedogenic features and bioturbation in the fine-grained deposits, the degree of oxidation of the deposits (as evidenced by their color), the abundance of organic debris, the association with lacustrine strata, and the tendency to fine or coarsen upwards. Deltaic deposits (Fig.13) tend to coarsen upwards, to be spatially related to lacustrine sediments and to be organic-rich, unoxidized, and nonpedogenically altered.

The lacustrine environment is interpreted here to be dominated by mudstones. Bioturbated, carbonaceous, and shell-rich muds are inferred to represent swamps and shallow lake margins. Well-laminated, organic-rich muds are inferred to represent pro-delta and intermediate-depth environments. Deeper waters are represented by broadly banded, organic-poor mudstones.


KEY TO LITHOLOGIC SECTIONS

A. LITHOLOGIES

Lignite
Mudstone
Silty mudstone
Mudstone with thin interbedded sandstone
Siltstone
Sandstone with interbedded siltstone
Sandstone
Conglomerate
△△△ Volcanic ash

B. BIOGENIC FEATURES

Shells, primarily gastropods
organic debris and woody fragments
logs
Rootlets
Bivalves (> 1 cm)
Leaf impressions and stems

C. SEDIMENTARY STRUCTURES

Massive
Parallel lamination (< 3 cm)
Parallel bedding (> 3 cm)
Parallel bedding, slightly disturbed
Massive and broad banded
Wavy lamination (< 3 cm)
Wavy bedding (> 3 cm)
Wavy bedding, slightly disturbed
Flaser bedding

Lenticular, wavy lamination
Trough crossbedding
Planar crossbedding
Small-scale crossbedding
Ripple-drift cross-lamination
Slumped and contorted bedding
Clastic dikes
Mudcracks
Concretions

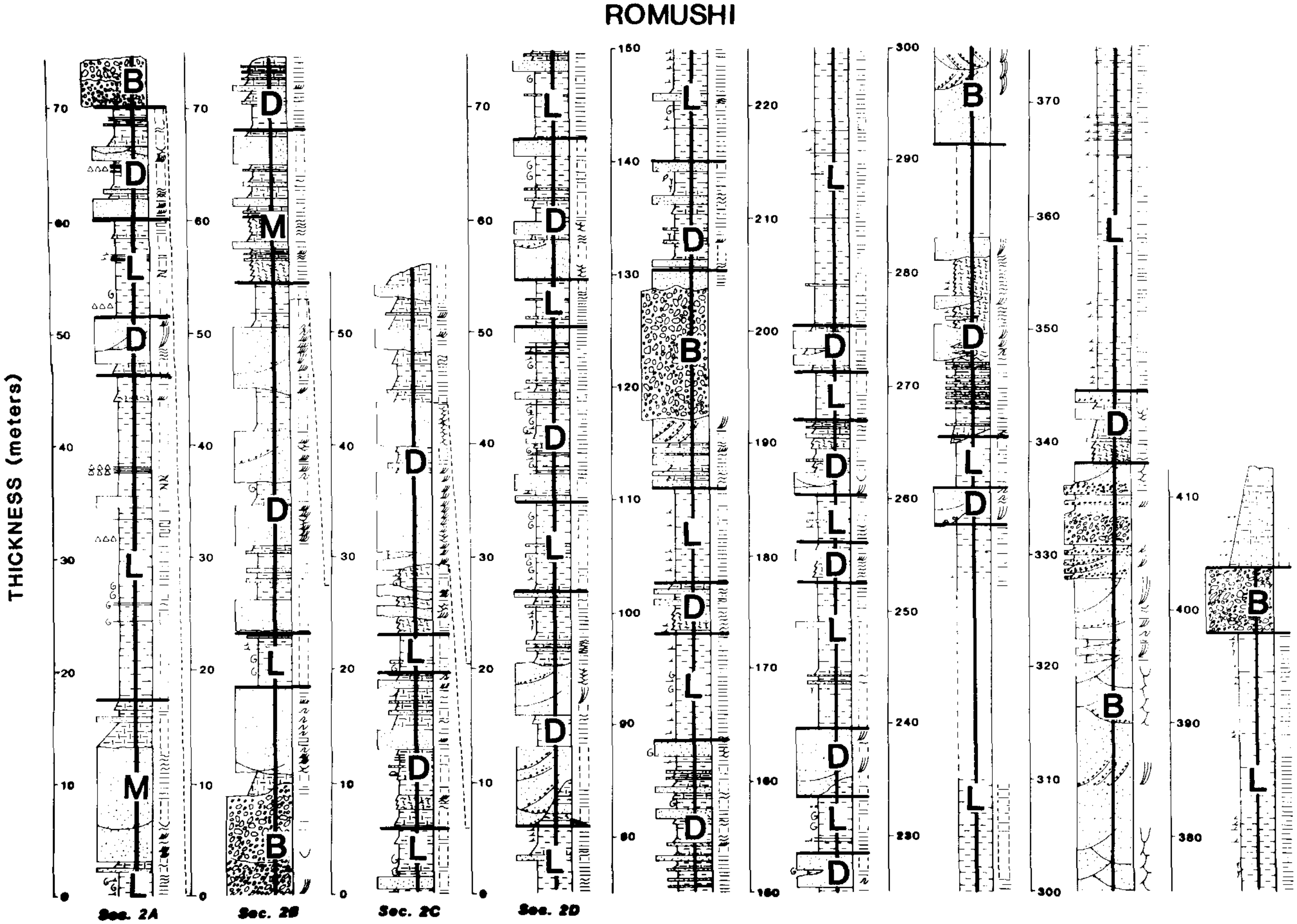


Fig.9. Lithologies and inferred depositional environments from the Romushi section. For this and subsequent figures: *B* = braided river; *M* = meandering river; *D* = delta; and *L* = lake.

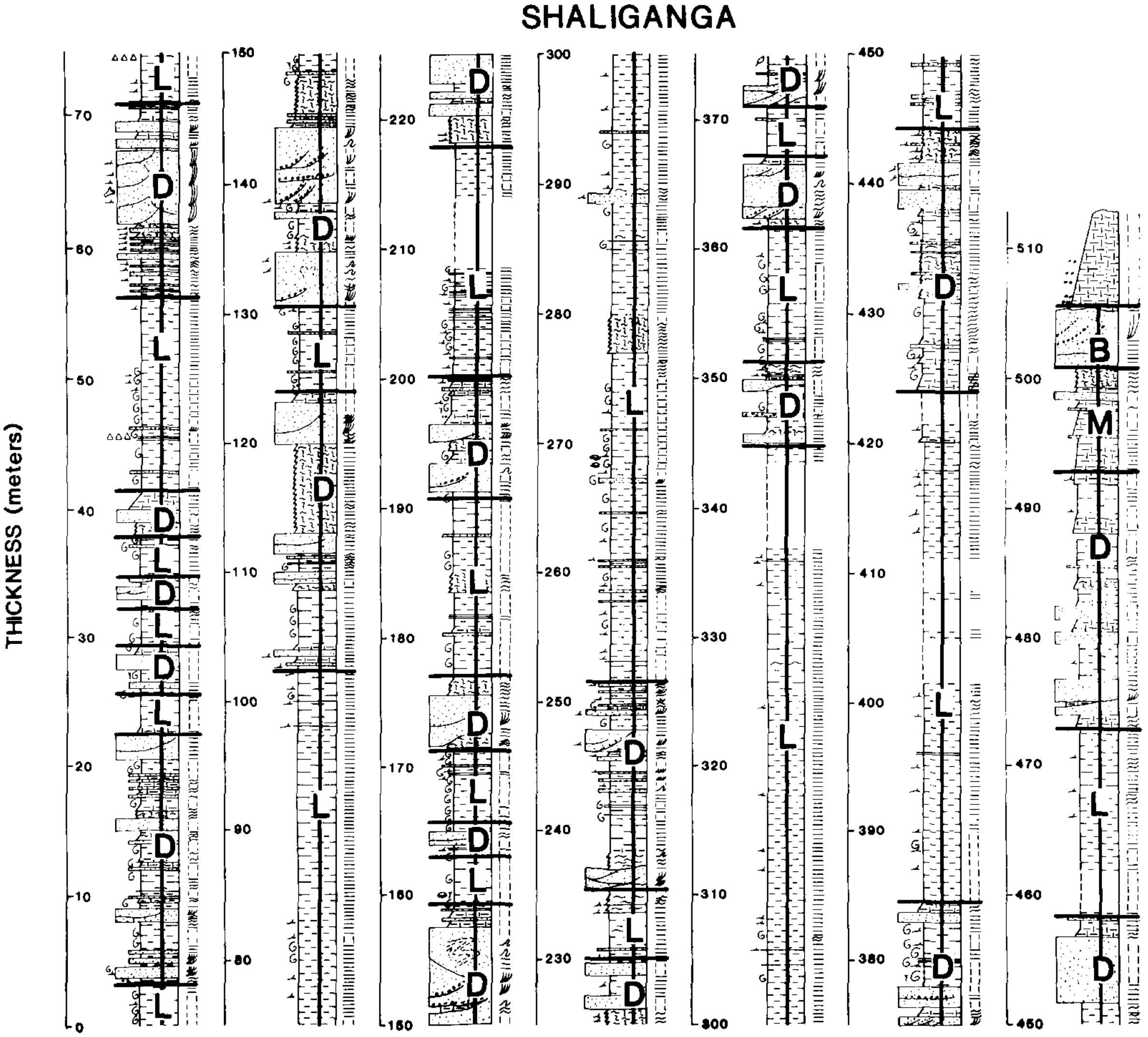


Fig.10. Lithologies and inferred depositional environments from the Shaliganga section. Note the well-developed, coarsening-upwards deltaic sequences, such as from 60 to 70 m, and the prolonged intervals of inferred lacustrine sedimentation.

HISTORY OF THE KASHMIR BASIN

Joint consideration of the magnetic-polarity stratigraphies, fission-track dates, and detailed lithologic descriptions permits the elucidation of the developmental history of the intermontane basin of Kashmir. In contrast to many previous investigations of the Lower Karewas, the improved control conferred by the chronometric studies facilitiates more reliable correlations between stratigraphic sections and places temporal constraints on the interpretations of the depositional and tectonic history of Kashmir. Close agreement between the aggregate exposed Karewa thickness (1350 m) and geophysical assessments of thickness near the edge and center of the basin (Karunakaram and Rao, 1976) suggest that the thickness of the unexposed

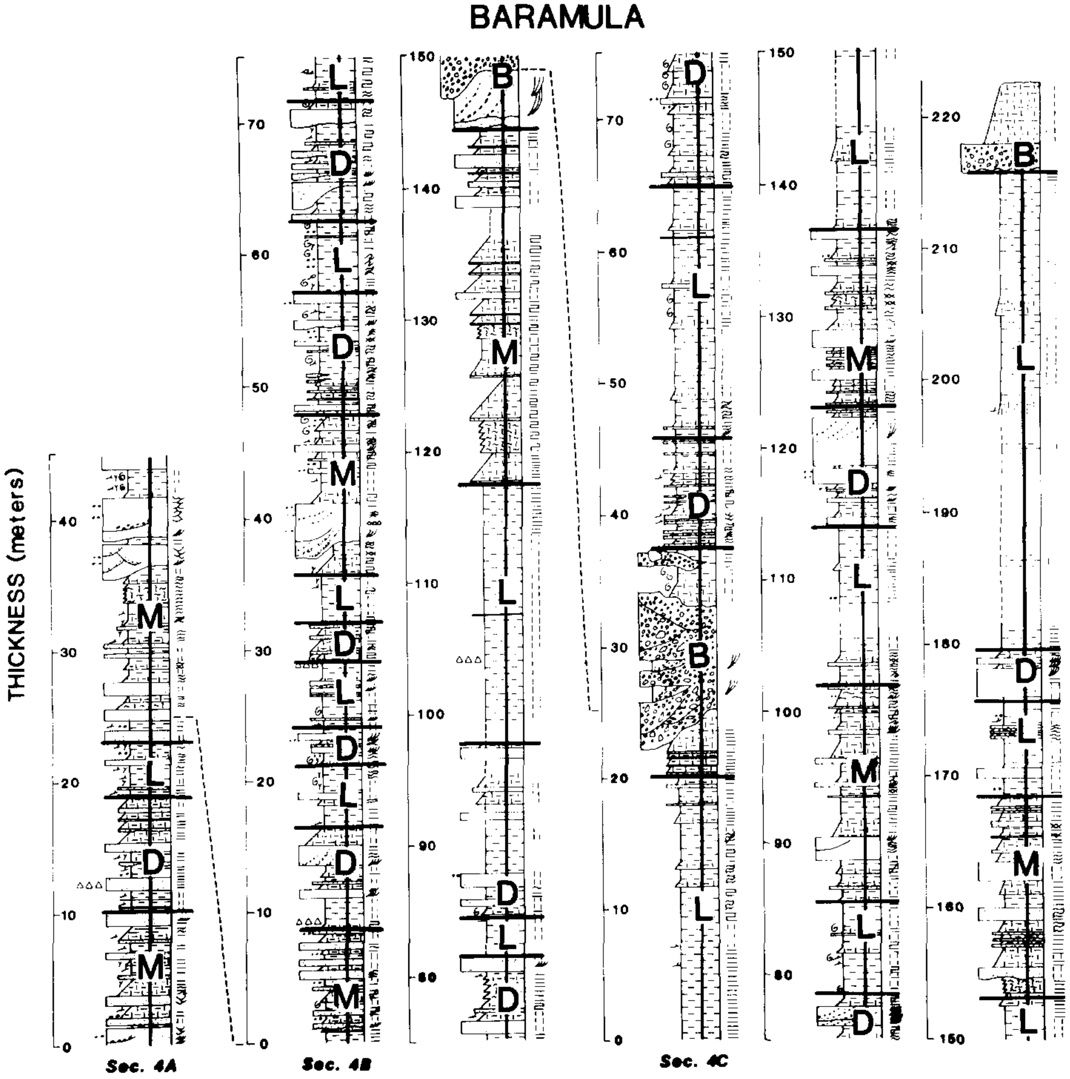


Fig.11. Lithologies and inferred depositional environments from the Baramula section. Correlations between sections 4B and 4C are based on the traceable conglomeratic horizon. Meandering-river deposits are more prevalent in this section than in the other Kashmiri sections.

Karewa sediments at the base of the Hirpur section may be less than a few hundred meters. Consequently, the Hirpur and Romushi sections probably encompass nearly the entire interval of intermontane-basin sedimentation.

The combined magnetic-polarity stratigraphies from Hirpur and Romushi span the last 3 m.y. (Fig.7). The exposed, but undated, basal sediments at Hirpur are likely to encompass an additional million years, and perhaps more, if the average sedimentation rate during the middle Pliocene was significantly lower than the assumed rate.

Additional supportive evidence for the inception of the structural development of the Kashmir Basin by at least 4 m.y. ago comes from studies of the

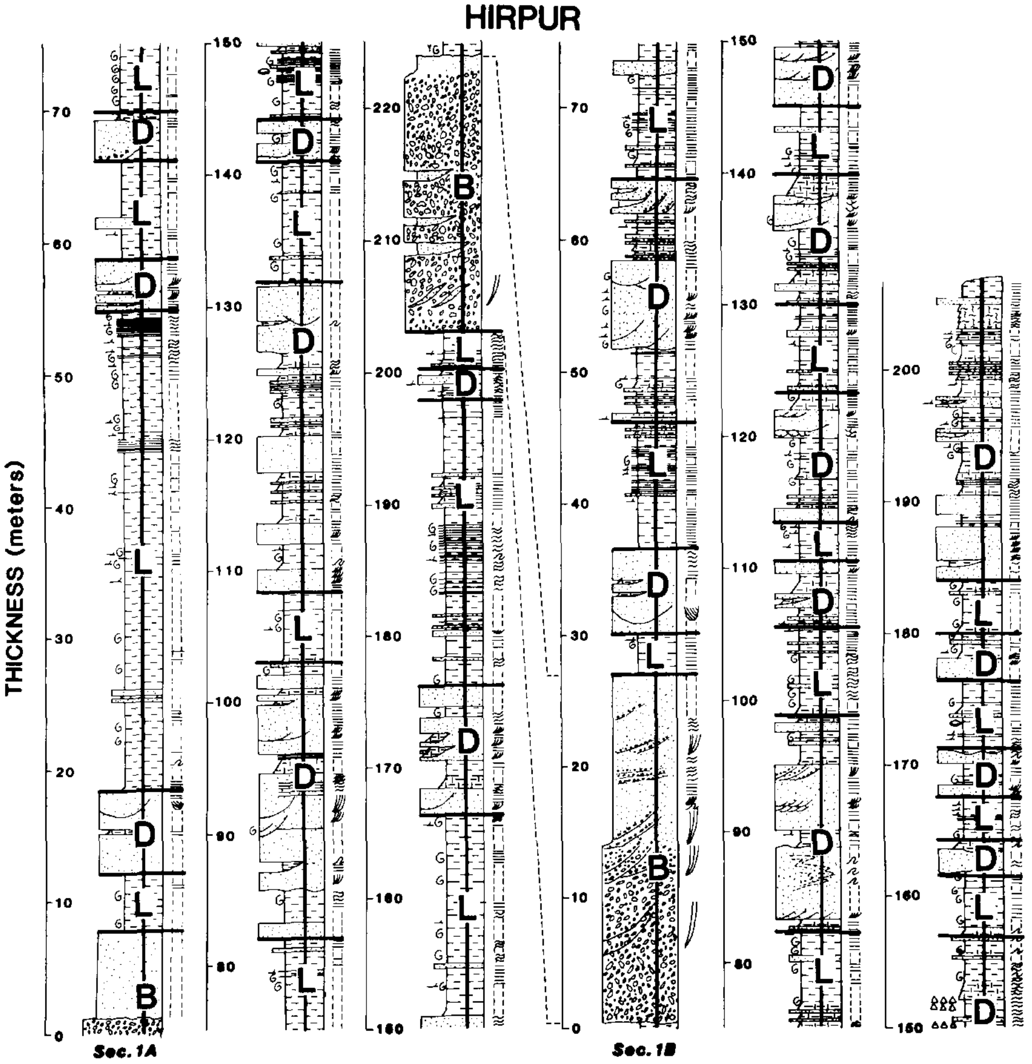


Fig.12. Lithologies and inferred depositional environments from the Hirpur section. The measured section is underlain by about 300 m of coarse conglomerates and an additional 250 m of deformed mudstones and sandstones.

Siwalik molasse directly to the southwest of the basin (Raynolds, 1980, 1982). Major changes in sandstone lithologies and paleocurrent directions occur between 4 and 5 m.y. ago in the Siwalik sediments. Prior to this time, the fluvial network was oriented subparallel to the axis of the foredeep and flowed towards the east. By 4 m.y., this easterly flowing system had been replaced by southerly flowing rivers bearing clasts probably derived from the ancestral Pir Panjal Range. Both paleocurrent and facies-distribution data indicate the increasingly strong control exerted by the structural development of the Jhelum Re-entrant, beginning about 5 m.y. ago. The localization of southerly flowing rivers, the development of the re-entrant, and the introduction to the molasse of clasts derived from Kashmir are contemporaneous with the inferred morphotectonic emergence of the ancestral Pir Panjal Range.

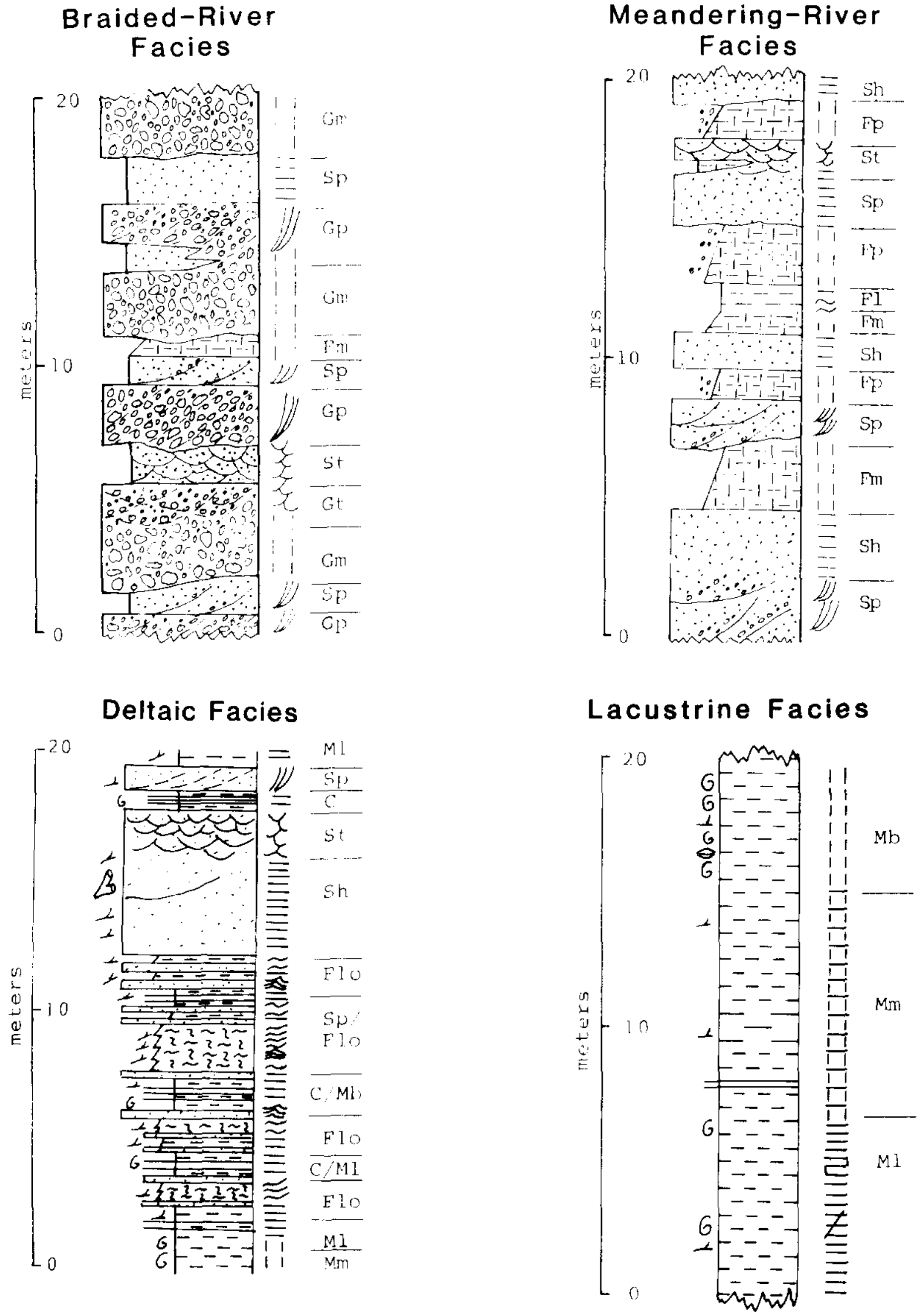


Fig.13. Facies assemblages used to define various depositional environments.

The Hirpur sequence is the only major section that preserves the early record of intermontane-basin deposition. The basal 250 m of exposed Karewas comprise sands, sandy muds, and lignites (Bhatt and Chatterji, 1976) that are very similar to those preserved in the overlying measured section (Fig.12) and that are interpreted as representing primarily lacustrine and deltaic environments (Singh, 1982). Conditions at the actual inception of the Karewa sedimentation, corresponding to the unexposed sediments

TABLE II

Facies classification

Facies code	Lithofacies	Sedimentary structures	Interpretation
Gm	massive or weakly bedded gravel	horizontal bedding, clast imbrication	longitudinal bars
Gp	gravel, bedded	planar crossbeds	linguoid bars and bar accretion
Gt	gravel, bedded	trough crossbeds	channel fills
Sh	sand, bedded	horizontal lamination, parting lineation	planar bed flow
Sp	sands, bedded	planar crossbeds	linguoid, transverse bars, sand waves
St	sands, bedded	trough crossbeds	dunes
Fm	silt, mud	massive	overbank deposits
Fl	sand, silt, mud	thinly interbedded, ripple-drift cross lamination, flaser bedding	levee and splay deposits
Flo	sand, silt, mud	as above, organic-rich, carbonaceous drapes cover many laminae	deltaic levee and overbank deposits
Fp	silt, mud	massive, pedogenic carbonate	pedogenic alteration of overbank deposits
L	lignite	lenses and seams, fissile	interdistributary swamps, shallow lacustrine deposits
Mm	mud	massive or broad banded (5—15 cm), thin (<5 cm) graded laminae	distal lacustrine deposits
Ml	mud	horizontal and wavy lamination (<5 cm), organic-rich (<5 cm)	pro-delta, shallow lacustrine deposits
Mb	mud	massive muds, abundant shells	estuary and swamp deposits

beneath the Hirpur sequence, may be recorded by a short, undated section along the Vishav River near Aharbal (Figs.2 and 14). Here, the weathered Paleozoic bedrock is overlain by a 10-m thick, oxidized paleosol. The upward diminution in clast size and the concomitant increase in clay content, pedogenic mottling, calcareous concretions, and preserved rootlets suggest that this paleosol represents a prolonged period of soil development just prior to the initiation of intermontane-basin development.

The mudstones, sandstones, and lignites that overlie the basal paleosol (Fig.14) suggest that development of the Kashmir Basin began with ponding of pre-existing fluvial drainages within a generally low-relief landscape where thick soils had developed on interfluves. This ponding probably resulted from initial uplift along the marginal thrust faults lying to the south of the present Pir Panjal Range (Figs.1 and 2).

TABLE III

Facies associated with depositional environments

Environment	Dominant facies	Associated facies
Braided river	Gm, Gp, Sh	Gt, St, Sp, Fm
Meandering river	Fp, Fm, Sh	St, Sp, Fl
Delta	Flo, Sh	L, St, Sp
Lake	Ml, Mm, Mb	L

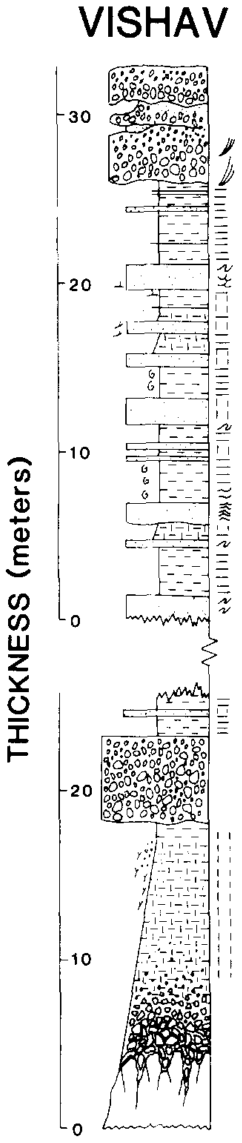


Fig.14. Lithologies from the measured section along the Vishav River near Aharbal. This sequence commences with a thick regolith developed on Panjal trap and is succeeded by typical Karewa low-energy facies.

Such ponding is fundamentally different from typical molasse sedimentation where deposition occurs in elongate, subsiding basins on the distal side of the uplifted terrain (Van Houten, 1974). The intermontane basins appear to aggrade largely through "backfilling" behind the upthrust, outer basin margin. Uplift of variable intensity continues throughout most of the period of basin development and provides aggrading sediments that record the tectonic activity along the margins of the basin.

Given the correlation of the Hirpur MPS with the MPTS offered here, depositional conditions in the southeastern Kashmir Basin between 3.0 and 2.1 m.y. ago (Fig.7) are illustrated by this section (Fig.12). Following the abrupt termination of conglomeratic sedimentation, the section is dominated by organic-rich strata laid down in swamps and shallow lakes and by subordinate deltaic sands.

At about 2.7 m.y., an influx of conglomerates overwhelmed the fine-grained sedimentation at Hirpur and deposited a coarse-grained stratum about 20 m thick. The remainder of the section above the conglomerates (2.6—2.2 m.y.) shows deltaic sedimentation becoming more prevalent than lacustrine deposition. The juxtaposition of conglomeratic strata in the midst of lacustrine mudstones indicates dramatic variability in the depositional environment of the Lower Karewas. However, similar changes are not uncommon in fault-bounded basins where uplift along the basin margin can profoundly influence sedimentation in the adjacent lacustrine environment (Link and Osborne, 1978; Miall, 1980).

All four Kashmiri sections encompass the interval from about 2.4 to 2.1 m.y. All, except Hirpur, extend at least as far as the mid-Olduvai (Fig. 7). In the lower Matuyama chron, each section shows a large component of lacustrine sediments. Based on the previously estimated average sedimentation rates, the greatest uninterrupted accumulations of lacustrine mudstones (30—40 m in thickness) probably represent intervals of at least 50,000 to 100,000 years. This indicates that these sediments did not accumulate in ephemeral ponds on a floodplain, but rather, they were quite long-lived phenomena. On the other hand, the complex interfingering of lacustrine, deltaic, and fluvial sediments that typifies much of the lower Matuyama interval suggests that these lakes were frequently quite shallow, such that small oscillations in lake level strongly influenced the sedimentary record. However, the Shaliganga section, lying closer to the basin center (Fig.2), comprises sediments that show greater persistence of individual lithologies. These suggest that Shaliganga was farther moved from former shorelines and, consequently, was less sensitive to variations in lake levels.

Between 2.5 m.y. and 2.1 m.y., a series of volcanic ashes were deposited across the Kashmir Basin and were preserved within the low-energy Karewa deposits. The individual ashes tend to decrease in thickness from northwest to southeast (Fig.8). This thinning is interpreted as representing downwind attenuation along the distal margin of eruptive plumes probably derived from the Dasht-e-Nawar volcanic complex in east-central Afghanistan (G.D. Johnson et al., 1982).

Trough- and planar-crossbedded sandbodies within the deltaic and fluvial sequences yield paleocurrent directions that can be used to infer the paleodrainage configuration of the Kashmir Basin (Fig.15). With the exception of the Baramula section, the paleocurrents derived from sandstones are seen to have been flowing towards the north and northeast from a presumed topographic high to the south. The crossbedding directions (Fig.15) show significant dispersion in their directional vectors that is not unexpected in low-gradient fluvial or deltaic sequences in which the locus of deposition and the position of channels change repeatedly (Schwartz, 1978).

The paleocurrents derived from clast imbrications within the braided-river conglomerates from Hirpur and from the lower half of the Romushi section (Fig.16) indicate a strongly contrasting sedimentary regime. The rivers that laid down these strata appear to have flowed out of the northeast and east from the region that the Great Himalayan Range occupies today (Fig.2). The magnetostratigraphic chronologies indicate that these conglomerates were probably deposited between 3.5 and 3.0 m.y. at Hirpur and, subsequently, at about 2.7 m.y. (Hirpur) and at 2.2 m.y. (Romushi).

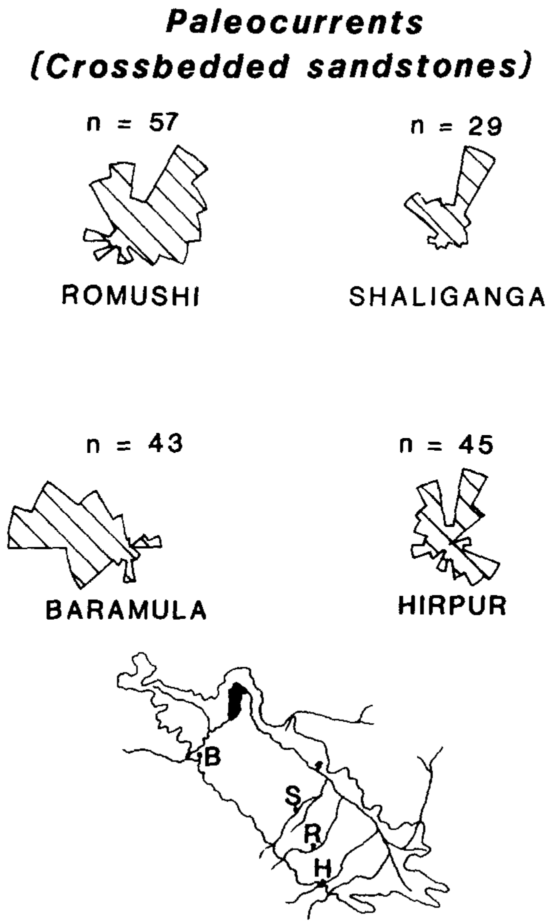


Fig.15. Paleocurrents determined from cross-bedded sandstones in Kashmir. Sketch map depicts section locations.

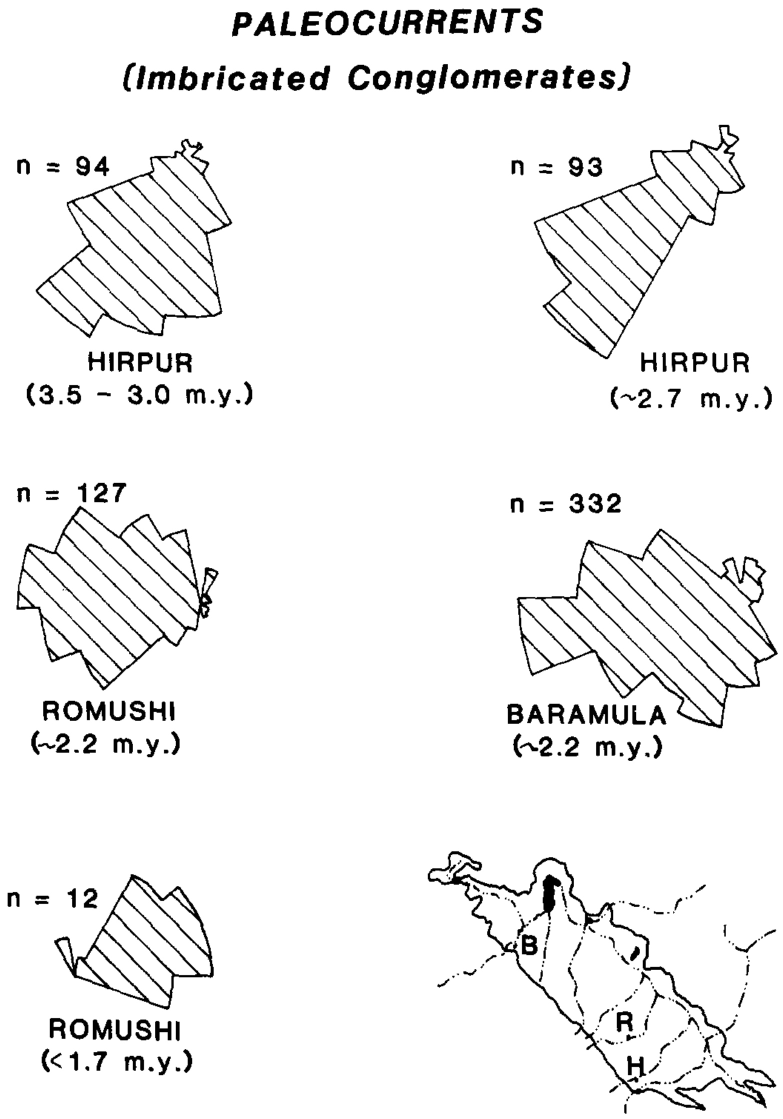


Fig.16. Paleocurrents determined from imbricated conglomerates in Kashmir. The measurements that are from sediments less than 1.7 m.y. old at Romushi represent both clast imbrications and cross-beds in interbedded coarse sandstones and conglomerates.

What caused the incursion of these higher-energy fluvial sediments into a depositional setting dominated by lacustrine and deltaic sedimentation? Seeber et al. (1981) have suggested that the abrupt topographic front along the northeastern margin of the Kashmir Basin is a fault-line scarp. Past pulses of major uplift along the underlying fault(s) would be expected to have shed aprons of coarse clastics southward into the basin. Similar phenomena are recorded in the intermontane Uinta Basin, Utah (Anderson and Picard, 1974), the Ridge Basin, California (Link and Osborne, 1978), and the Judge Daly Basin, Ellesmere Island (Miall, 1980), where fault-controlled uplifts shed coarse detritus across contemporaneous lacustrine deposits. Thus, the sections at Hirpur and Romushi appear to record the delicate interplay between sediments derived from southerly and northeasterly sources.

The paleocurrent data from Baramula (Figs.15 and 16) indicate that dominantly easterly flowing rivers prevailed during the lower Matuyama chron. In comparison to the other sections, the lithostratigraphy from Baramula (Fig.11) indicates a higher proportion of subaerially exposed floodplain sediments and reduced importance of persistent lacustrine strata. The inferred depositional environments at Baramula resemble those of the modern Jhelum River in much of Kashmir. In combination with the paleocurrent data, this suggests that, by 2.4 m.y. ago, the ancestral Jhelum River had established an easterly flowing occurs through this portion of the Kashmir Basin.

Paleocurrent measurements taken from the multistoried sandstone/conglomerate strata in the upper 300 m at Romushi indicate that these beds were deposited by northeasterly flowing braided rivers (Fig.16). This suggests that, during the upper Matuyama chron, significant, but sporadic, uplift occurred in the ancestral Pir Panjal Range. This source-area uplift apparently steepened the courses of the pre-existing drainages and caused the influx of higher-energy sediments into the low-relief basin. The overall sense of coarsening upwards, as depicted in the upper Romushi section (Fig.9), suggests an increasing degree of topographic relief along the southwestern margin of the Kashmir Basin during the period interpreted to include the upper Matuyama and lower Brunhes chrons. Rates of sedimentation from Hirpur and Romushi show decreases that, by analogy with the adjacent Himalayan foredeep (G. D. Johnson et al., 1979; Raynolds, 1980; Raynolds and Johnson, in press), are interpreted to reflect enhanced tectonic activity towards the close of widespread sedimentation.

On the floodplains of the Jhelum and Pohru Rivers and in the Kashmiri lakes, fluvial and lacustrine sediments are aggrading at present. Paleosols within the loess that caps most "Karewa" surfaces have been dated as ranging from 15,000 to >35,000 yr (Kusumgar et al., 1980). However, basin-wide sedimentation as typified by the Lower Karewas was terminated when the Pir Panjal Range was uplifted.

As a result of this uplift, the Karewas along the northeast flank of the range were folded and partially eroded. The conglomerate marking the base of the Upper Karewa sediments appears as a broad apron spread across the Lower Karewa surfaces. This conglomerate thins towards the basin center and shows a concomitant diminution in clast size. It truncates each of the previously described sections, but at a different level as a function of the intensity of folding and erosion at each locality. The youngest preserved Lower Karewa sediments at various sections are interpreted to range from about lower Matuyama at Hirpur to about 0.4 m.y. at Romushi.

The maximum age of the conglomerate at Romushi has additional relevance with respect to the rate of uplift of the Pir Panjal Range. Because Lower Karewa sediments contain a high proportion of lacustrine sediments, the depositional dip of these strata would be expected to be negligible. Consequently, altitudinal differences between equivalent-aged strata can be interpreted to represent post-depositional movements.

The altitude of the youngest Lower Karewa beds in the Romushi section is about 1800 m and is attained nearly 6 km downstream from Pakharpur (Fig.2). Presumably, about 1300 m of Lower Karewa sediments underlie this site, such that basement would be encountered around 500 m a.s.l. Nine km southwest of Yusmarg (Fig.2), Lower Karewa sediments occur at an elevation of 3250 m. Additional Lower Karewa occurrences have been reported from as high as 3500 m (Middlemiss, 1911; Bhatt, 1978). The altitudinal differences between these elevated remnants on the flanks of the Pir Panjal Range and the Lower Karewas along the Romushi River imply a minimum of 1400—1700 m of post-depositional, differential movement (Fig.17). The amount of actual uplift is dependent on the age of the elevated remnants. For example, if these were 4-m.y.-old Karewa sediments and, hence, were correlative with the base of the Karewa sequence, the amount of uplift would be expected to range up to 2700—3000 m.

Although significant Pleistocene uplift of portions of the Karewas has been recognized previously (De Terra and Paterson, 1939; Puri, 1947), the timing and rate of uplift have not been well constrained. According to the interpretation presented here, the youngest Lower Karewa strata from Romushi date to about 0.4 m.y. If magnetozone N5 (Fig.3) is considered to encompass the Jaramillo subchron, this minimum date would become about 0.9 m.y. Although it is possible that gradual uplift occurred over a longer span of time, the proximity of the youngest strata to the uplifted strata (<20 km) suggests that, if even a third (500—1000 m) of the total uplift had been achieved earlier, the resulting steep fluvial gradients should be reflected by conglomeratic deposition similar to that occurring today in Kashmiri rivers with comparable or shallower gradients. If 0.4 m.y. is chosen

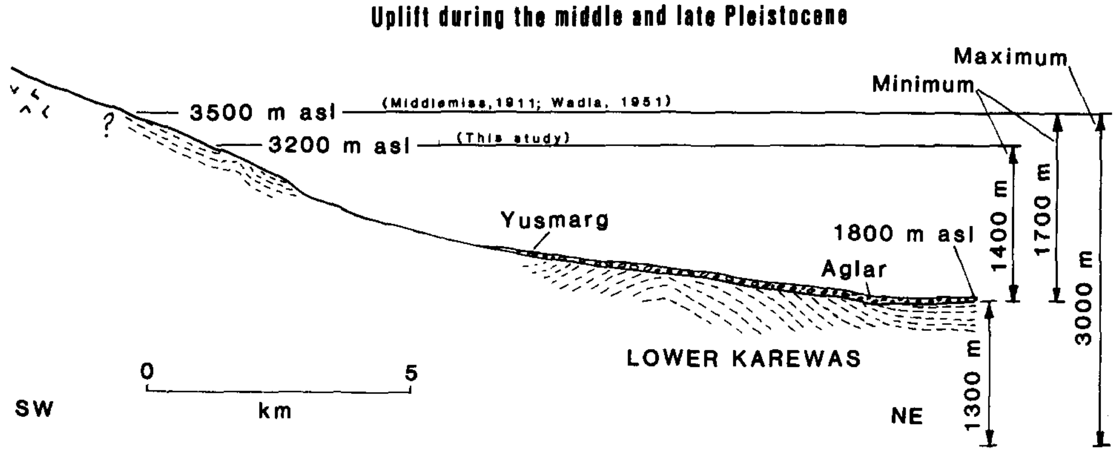


Fig.17. Estimates of uplift during the middle and late Pleistocene. About 1300 m of Lower Karewa sediments are likely to underlie the section at Aglar. Depending on the highest occurrence of Karewas on the flanks of the Pir Panjal, the minimum estimate of uplift is 1400—1700 m. If the age of the elevated Karewa remnants were about 4 m.y., they would represent early stages of deposition in the basin and would suggest a maximum of 3000 m of uplift in comparison to similarly aged Lower Karewa sediments presumed to underlie the Aglar exposures.

as the date of initiation of deformation, rates of uplift would range from about 3.5 to 10 mm per year. This is similar to recently inferred rates for the Nanga Parbat massif to the north of Kashmir (Zeitler et al., 1982). Choice of either an older age for the cessation of sedimentation at Romushi or longer, more gradual uplift would reduce this rate correspondingly.

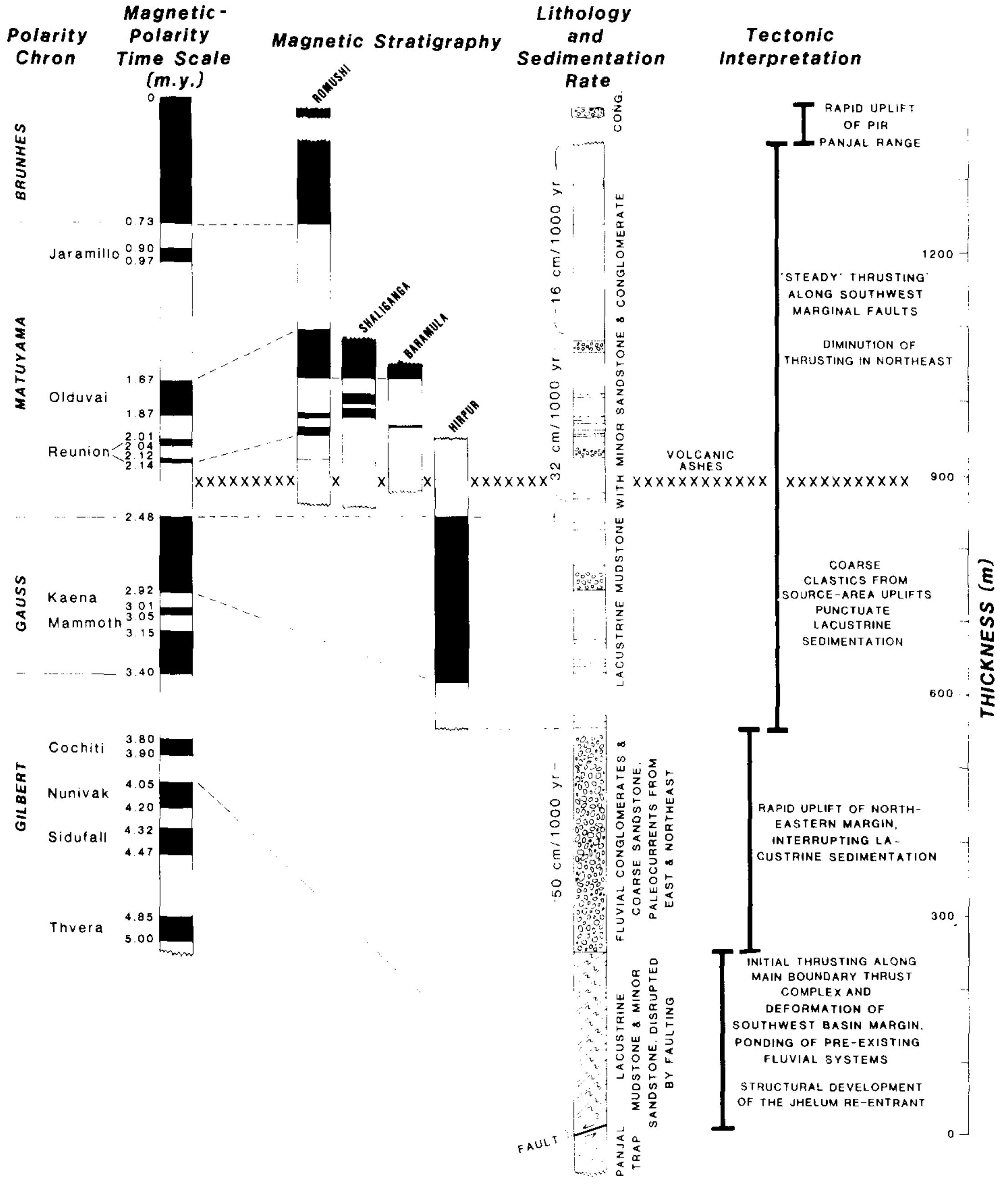


Fig.18. Summary of magnetic stratigraphies and lithologies from the measured sections in Kashmir with the tectonic interpretation shown on the right. The depositional rates and thicknesses are those that are calculated from the Romushi and Hirpur sections.

SUMMARY

The depositional and tectonic history of the intermontane basin of Kashmir is summarized in Fig.18. The record is about 4 m.y. long and is likely to encompass nearly the entire interval of basin development. Throughout the Pliocene and Pleistocene epochs, the sediments show a complex interfingering of lacustrine, deltaic, and fluvial deposits that appear to respond in a sensitive fashion to tectonic activity along the basin margin. The dominantly lacustrine intervals reflect the maintenance of an elevated local base level that sustains continued ponding of the fluvial system. This is thought to be a response to fairly uninterrupted thrusting along the Main Boundary Thrust complex such that the rate of uplift due to thrusting equals or exceeds the average rate of downcutting at the watergap.

The influxes of coarse clastics that punctuate the sedimentary record result from thrusting in the source areas of rivers that were tributary to the Kashmir Basin. From 4 to 1.8 m.y., paleocurrent data indicate that conglomerates were derived primarily from the northeast due to inferred faulting along the northeastern border faults. After mid-Olduvai time, the conglomerates were shed primarily from the south and southwest margin of the basin. These conglomerates reflect the enhanced tectonic activity along the Main Boundary Thrust complex that was a precursor to the major uplift of the Pir Panjal Range and to the subsequent cessation of widespread intermontane-basin sedimentation. Since the middle Pleistocene, 1400—3000 m of uplift has occurred along the southwest margin of the Kashmir Basin. The minimum rate of uplift during this interval is inferred to be about 4 mm per year.

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