model[15]. If we accept a model with cosmological constant $\Lambda = 0$ and $0 < q_0 \leqslant \frac{1}{2}$ as a good first choice, then Fig. 4 shows that the absorbers causing the LLS do not evolve significantly over the redshift range $0.4 \leqslant z \leqslant 3.5$, or ~50% of the history of the Universe.

The LLS absorption may arise from material in the outer regions of galaxies or in intergalactic material. In either case there has apparently been little evolution since $z \simeq 3.5$. This is a clear indication that galaxy formation occurred at $z > 3.5$, because gaseous protogalaxies with radii ~100 kpc would be highly conspicuous in absorption; even though absorption by dust may make them inconspicuous at optical wavelengths. Alternatively, if essentially all the dust and gas has been processed (necessarily at $z > 3.5$) into stars before collapse, then the protogalaxies are likely to be conspicuous in emission and should have been seen in recent searches[23]. Low redshift ($z \leqslant 3$) protogalaxies will only be hard to detect if they are optically thin to absorption before collapse and become dusty and optically thick during collapse, concealing any bright phase of early star formation. In this case we should be looking for IR emission from sources of small angular size.

The present analysis shows that the QSOs and LLS are apparently separate, uncoupled populations. There is then every reason to expect the LLS to exist at $z > 3.5$, and perhaps continuing to show little evolution. This being the case I predict that little radiation (QSO, protogalaxy or otherwise) will be observed in the optical U, B, V, or R bands originating from $z \geqslant 3.5, 4.2, 5.3$ or 6.9, due simply to absorption by high redshift LLS. Such are the limits of optical astronomy.

This article has only considered the gross redshift distribution of the LLS. Their physical nature will be discussed elsewhere.

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1. Burbidge, G. *IAU Symp.* No. 92, 99–105 (1980); *Nature* **282,** 451–455 (1979).
2. Weymann, R. J., Carswell, R. F. & Smith, M. G. *A. Rev. Astr. Astrophys.* **19,** 41–76 (1981).
3. Sargent, W. L. W., Young, P. J., Boksenberg, A. & Tytler, D. *Astrophys. J. Suppl.* **42,** 41–81 (1980).
4. Weymann, R. J., Williams, R. E., Peterson, B. M. & Turnshek, D. A. *Astrophys. J.* **234,** 33–46 (1979).
5. Young, P., Sargent, W. L. W. & Boksenberg, A. *Astrophys. J.* (in the press).
6. Tytler, D., Boksenberg, A., Sargent, W. L. W. & Young, P. *Astrophys. J.* (submitted).
7. Bahcall, J. N. & Spitzer, L. *Astrophys. J. Lett.* **156,** L63–L65 (1969).
8. Bregman, J. N. *Astrophys. J.* **250,** 7–17 (1981).
9. Young, P., Sargent, W. L. W., Boksenberg, A. & Oke, J. B. *Astrophys. J.* **249,** 415–421 (1981).
10. Goldreich, P. *Phys. Scr.* **17,** 225–228 (1978).
11. Weymann, R. J. *IAU Symp.* No. 92, 107–117 (1980).
12. Smith, M. G. *et al. Mon. Not. R. astr. Soc.* **195,** 437–449 (1981).
13. Coleman, G. *et al. Astrophys. J.* **207,** 1–15 (1976).
14. Morton, D. C., Chen, J-S., Wright, A. E., Peterson, B. A. & Jauncey, D. L. *Mon. Not. R. astr. Soc.* **193,** 399–413 (1980).
15. Tytler, D. *Nature* **291,** 289–292 (1981).
16. Gross, A. J. & Clark, V. A. *Survival Distributions* (Wiley, New York, 1975).
17. Kalbfleisch, J. D. & Prentice, R. L. *The Statistical Analysis of Failure Time Data* (Wiley, New York, 1980).
18. Bartholomew, D. J. *J. Am. stat. Ass.* **52,** 350–355 (1957).
19. Burbidge, E. M. & Burbidge, G. R. *Astrophys. J.* **202,** 287–295 (1975).
20. Drew. J. E. *Astr. Astrophys.* **66,** 343–354 (1978).
21. Prentice, R. L. & Marek, P. *Biometrics* **35,** 861–867 (1979).
22. Bahcall, J. N. & Peebles, P. J. E. *Astrophys. J. Lett.* **156,** L7–L10 (1969).
23. Ellis, R. S. *Lectures at the VIIth course of the International School of Cosmology and Gravitation,* Erice (1981).
24. Davis, M. *IAU Symp.* No. 92, 57–64 (1980).
25. Sargent, W. L. W. *et al. Astrophys. J.* **230,** 49–67 (1979).
26. Osmer, P. S. *Astrophys. J.* **227,** 18–29 (1979).
27. Wolstencroft, R. D., Arp, H. C., Ku, W. H-M. & Scarrott, S. M. Preprint (Royal Observatory of Edinburgh).
28. Green, R. F. *et al. Astrophys. J.* **239,** 483–494 (1980).
29. Grandi, S. A. & Tifft, W. G. *Publ. astr. Soc. Pacif.* **86,** 873–884 (1974).
30. Wright, A. E., Peterson, B. A., Jauncey, D. L. & Condon, J. J. *Astrophys. J. Lett.* **226,** L61–L64 (1978).
31. Carswell, R. F., Strittmatter, P. A., Williams, R. E., Beaver, E. A. & Harms, R. *Astrophys. J.* **195,** 269–277 (1975).
32. Oke, J. B. *Astrophys. J. Lett.* **161,** L17–L20 (1970).
33. Chen, J-S., Morton, D. C., Peterson, B. A., Wright, A. E. & Jauncey, D. L. *Mon. Not. R. astr. Soc.* **196,** 715–730 (1980).
34. Beaver, E. A. *et al. Astrophys. J. Lett.* **203,** L5–L8 (1976).
35. Snijders, M. A. J. *Proc. 2nd European Conf. on IUE,* Tübingen (ESA SP-157, 1980).
36. Boksenberg, A. *et al.* (in preparation).
37. Carswell, R. F., Whelan, J. A. J., Smith, M. G., Boksenberg, A. & Tytler, D. *Mon. Not. R. astr. Soc.* **198,** 91–110 (1982).
38. Boksenberg, A. & Snijders, M. A. J. *Mon. Not. R. astr. Soc.* **194,** 353–364 (1981).
39. Young, P. J., Deverill, R. S., Gunn, J. E., Westphal, J. A. & Kristian, J. *Astrophys. J.* **244,** 723–735 (1981).
40. Snijders, M. A. J., Pettini, M. & Boksenberg, A. *Astrophys. J.* **245,** 386–395 (1981).
41. Peterson, B. A., Jauncey, D. L., Wright, A. E. & Condon, J. J. *Astrophys. J. Lett.* **222,** L81–L83 (1978).
42. Baldwin, J. A. *et al. Astrophys. J.* **193,** 513–523 (1974).
43. Jauncey, D. L., Wright, A. E., Peterson, B. A. & Condon, J. J. *Astrophys. J. Lett.* **223,** L1–L3 (1978).
44. Hewer, A., Boksenberg, A., Carswell, R. F., Smith, M. G. & Whelan, J. A. J. (in preparation).
45. Bregman, J. N., Glassgold, A. E. & Huggins, P. J. *Astrophys. J.* **249,** 13–16 (1981).
46. Boksenberg, A., Carswell, R. F. & Sargent, W. L. W. *Astrophys. J.* **227,** 307–379 (1979).
47. Hewitt, A. & Burbidge, G. *Astrophys. J. Suppl.* **43,** 57–158 (1980); **46,** 113–115 (1981).
48. Evans, A. & Hart, D. *Astr. Astrophys.* **58,** 241–245 (1977).
49. Wilson, R., Carnochan, D. J. & Gondhalekar, P. M. *Nature* **277,** 457–458 (1979).

Intermontane-basin development in the past 4 Myr in the north-west Himalaya

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Through the combined use of magnetic-polarity stratigraphy with fission-track dating of volcanic ashes, a new chronology, spanning 4 Myr, has been developed for the intermontane basin of Kashmir in the northwestern Himalaya.

SUPERIMPOSED intermontane basins in collisional tectonic settings typically develop during the late stages of an orogeny and are frequently transient phenomena. In the Himalaya, sedimentary basins, such as Peshawar, Campbellpore, Kashmir, Suketi and Kathmandu, evolve as tectonic depressions on the back side of listric thrust-bounded sheets that constitute the schuppenstruktur on the outer, southern margin of the orogenic belt. As structural deformation migrates towards the bounding foredeep, continued uplift and erosion often obliterate the record of intermontane-basin sedimentation. Evaluating the sedimentary record within young basins in presently growing mountain ranges helps to delineate the history of basin evolution and place constraints on the tectonic activity of the enclosing structures.

The Kashmir Basin in the northwestern Himalaya (Fig. 1) is an intermontane basin presently experiencing rapid uplift along its southwestern margin. However, synorogenic sediments spanning nearly the entire period of basin development have not yet been eroded. These sediments, known collectively as the 'Karewas' or Karewa Group[1–5], have been examined many times, because they contain late Cenozoic mammalian fossils[2,6,7] and a diverse invertebrate fauna[8,9], they interfinger with glacial and periglacial deposits along the basin margin[2,10–12], and they constitute a sedimentary sequence 1,300 m thick that potentially records the history of basin development[1–5,12–17]

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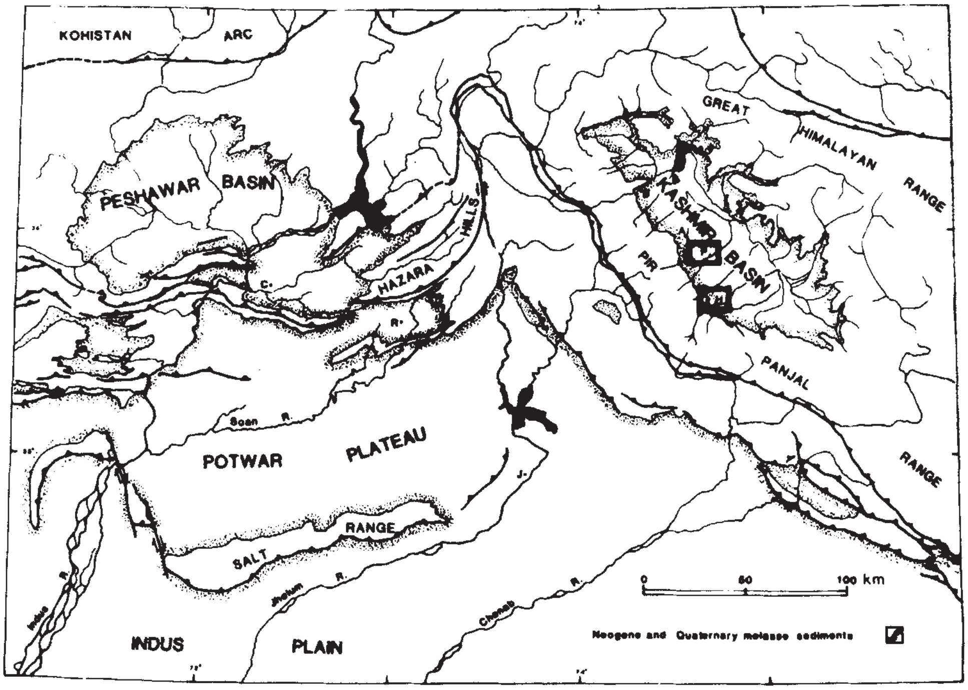
Fig. 1 Map of the Kashmir and Peshawar intermontane basins of the northwestern Himalaya, symmetrically oriented around the North-west Syntaxis, a structural re-entrant defined by acute bends in the marginal thrusts (barbed lines). Movement along the imbricate thrusts on the southwestern margin of the Kashmir Basin has elevated the Pir Panjal Range and created the structural basin in which the intermontane sediments described herein have accumulated. A, Arigam; B, Baramula; C, Campbellpore; H, Hirpur; J, Jhelum; P, Pakharpur; R, Rawalpindi; S, Srinagar. Boxes show study areas.



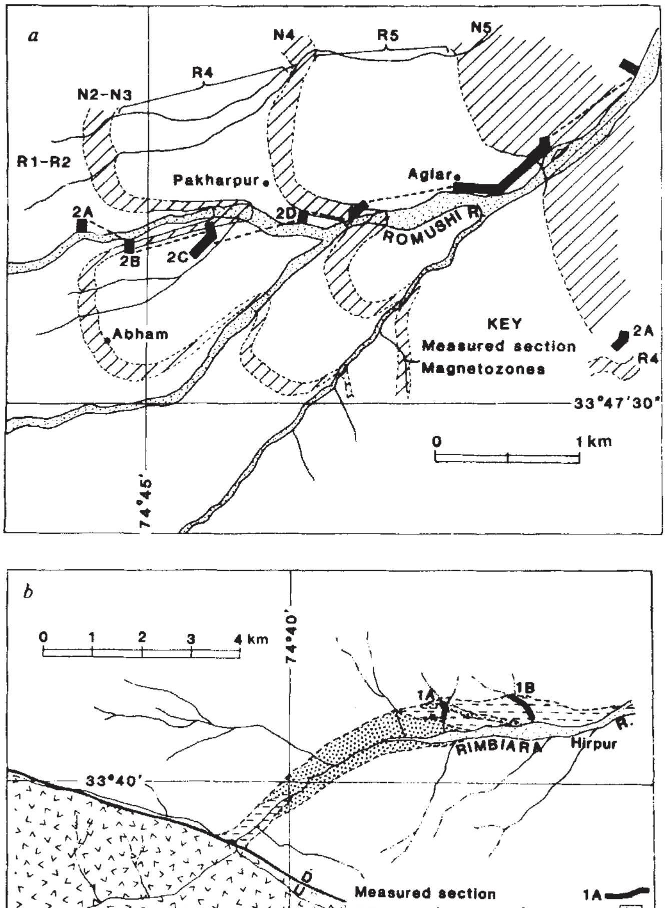


Fig. 2 *a*, Location map of the Romushi section near Pakharpur, indicating measured sections and magnetozones (R1–N5). *b*, Map of exposures of the basal portions of the Karewa sequence along the upper Rimbiara River. The measured sections overlie >500 m of conglomerates and contorted mudstones, faulted against Palaeozoic bedrock.

Little agreement exists among earlier studies concerning the absolute chronology of the Karewa sequence. Recently, preliminary magnetic-polarity studies in portions of the Karewas along the southern end of the Kashmir Basin[14] have suggested that they span the late Gilbert to early Matuyama magnetic-polarity chrons, ranging from ~3.5 to 2 Myr ago. The Karewas have previously been interpreted as being solely Pleistocene in age[2,7,11], as spanning the late Pliocene and much of the Pleistocene[3,5,12,13,15,16], and as extending from perhaps late Miocene to the Pleistocene[8,7]. We describe here our efforts to date the Karewa sequence through the combination of detailed stratigraphical analysis, magnetic-polarity stratigraphy (MPS) and fission-track dating of enclosed volcanic ashes, and to correlate the Karewa sequence with the late orogenic, molasse sediments of the Himalayan foredeep to the south-west[18–20]

Magnetic stratigraphy and fission-track chronology

Rapid uplift of the Pir Panjal Range (Fig. 1), after deposition of the Karewas, has led to their dissection along the north-east flank of the range. More than 1,300 m of folded Karewa sediments are exposed along the Rimbiara and Romushi rivers in southwestern Kashmir (Figs 1, 2). Sixty-seven magnetic sites were established in these sediments along the Romushi River near Pakharpur (Fig. 2*a*), where an aggregate thickness of 530 m was measured. An additional 46 magnetic sites were established in a 425-m sequence along the upper Rimbiara River, upstream from Hirpur (Fig. 2*b*). Three, oriented samples were collected at each site and analysed following the techniques described in ref. 21.

Occasional, post-depositional magnetic overprinting observed in some samples was removed by demagnetization in an alternating field (a.f.) of 150–200 Oe. After such demagnetization, the magnetic vectors for 59 sites from the Romushi section were statistically significant ($K > 10$) and yielded class I data[20,22]. The sample vectors of the eight other sites were more dispersed ($K < 10$). For these latter sites (class II), the most deviant magnetic vector was disregarded when calculating the site virtual geomagnetic pole (VGP). The palaeolatitude of the site VGP forms the basis of the MPS of the Romushi section (Fig. 3). The dominantly reversely magnetized sediments (magnetozones R1–R5; Fig. 3) are punctuated by brief normal intervals (N1–N4) and capped by 140 m of normally magnetized rocks (N5 and N6).

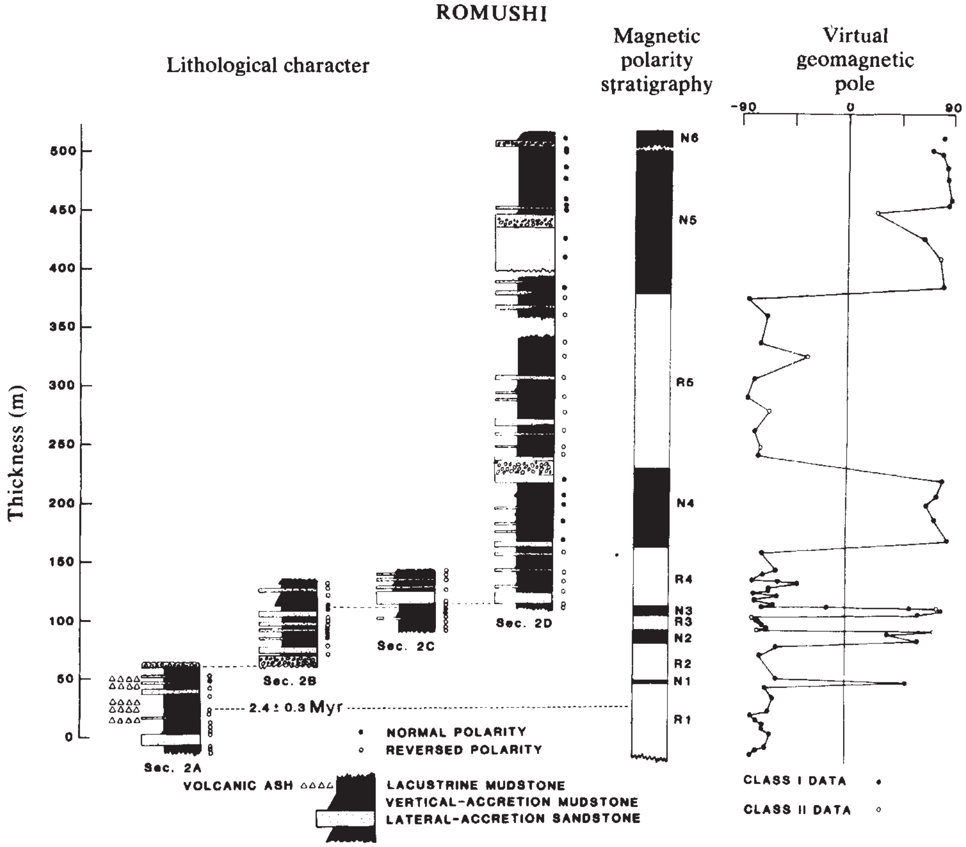


Fig. 3 Lithological character and MPS of the Romushi section, Kashmir. MPS based on virtual geomagnetic pole plot of class I and II data. Volcanic ash at 35 m dated at 2.4 Myr. Magnetozones labelled at right of MPS column. Interpretation: N2 and N3, Reunion subchrons; N4, Olduvai subchron; N5, Brunhes normal chron; R1–R5, Matuyama reversed chron.

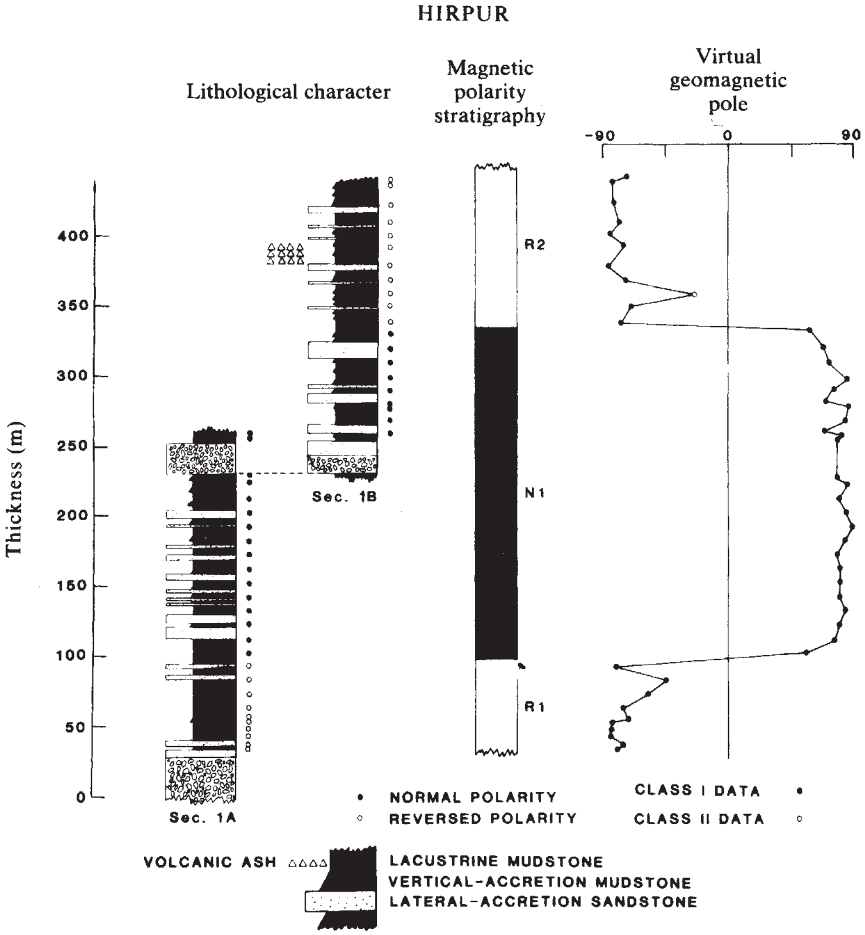


Fig. 4 Lithological character and MPS of the Hirpur section, Kashmir. Triplet of volcanic ashes at 380 m correlates with ash triplet at Romushi (30–40 m, section 2A, Fig. 3). Interpretation: R1, Kaena subchron; N1, upper Gauss normal chron; R2, lower Matuyama reversed chron.

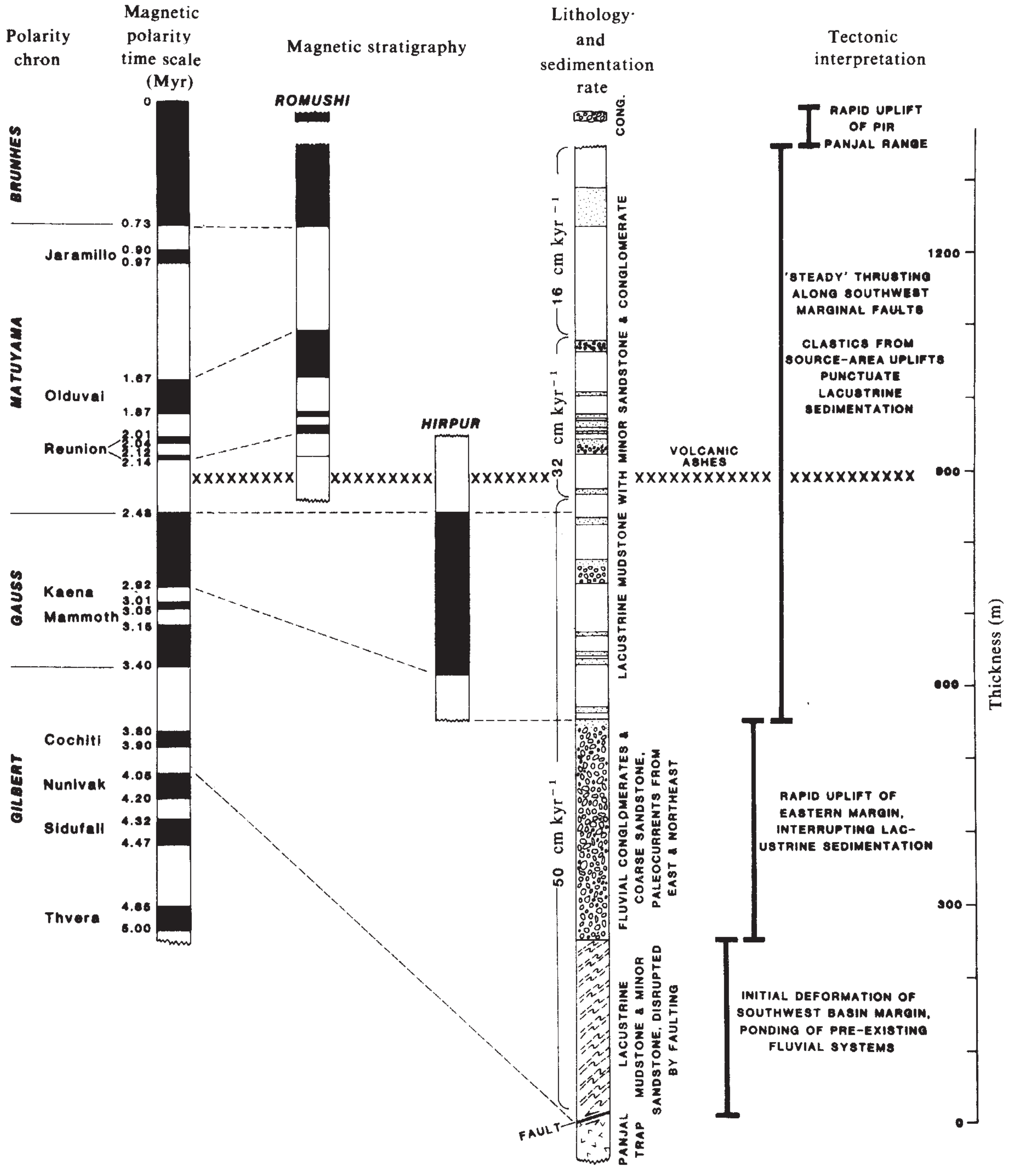


Fig. 5 Correlations of the magnetic-polarity time scale with the local MPS of Romushi and Hirpur place temporal controls on the record of intermontane-basin sedimentation. Depositional conditions are inferred to respond to tectonic deformation along the basin margin. Temporal constraints provided by the local MPS limit the duration of each tectonic interval. Extrapolation of sedimentation rates from the upper Gauss chron indicates that the basal mudstones at Hirpur were deposited at least 4 Myr ago. During the Matuyama chron, diminishing sedimentation rates precede the cessation of intermontane-basin sedimentation due to rapid uplift of the Pir Panjal Range.

Five volcanic ashes, some highly bentonitic, were discovered in the lowermost 70 m of the section (Fig. 3). Whereas the upper two ashes were thin (<0.5 cm) and discontinuous, the lower three, each 2–4 cm thick, span a 6-m interval and form an ash triplet. This triplet was recognized in the Dudhganga valley 10 km north-west of Pakharpur and the Rimbiara valley to the south-east. Zircons extracted from one of the lower ashes yielded a fission-track age of 2.4 ± 0.3 (2σ) Myr. Details of the magnetic and fission-track methodology and results are described elsewhere[23].

This date indicates that magnetozones R1 and R2 represent the lower Matuyama reversed chron (Fig. 5). Magnetozones N2, N3 and N4 are interpreted as depicting the Reunion and Olduvai subchrons. The upper Matuyama chron (R5) is followed by the Brunhes chron (N5 and N6). The Jaramillo subchron has not been found in the Romushi MPS, perhaps because of inaccessible, unsampled strata (340–360 m, section 2D, Fig. 3) or insufficient sample density. With this exception, the MPS from Romushi records all of the recognized polarity zones of the magnetic time scale[24] since 2.4 Myr ago. Comparison of the Romushi MPS with the magnetic time scale (Fig. 5) shows that sedimentation rates slowed after the Olduvai subchron. Consequently, N5 seems likely to represent at least half of the Bruhnes magnetic chron.

The conglomeratic facies separating magnetozones N5 and N6 (Fig. 3) truncates folded Karewa sediments throughout south-west Kashmir. It records the rapid uplift of the Pir Panjal Range and concurrent cessation of widespread sedimentation in the Kashmir Basin during Brunhes time. Remnants of tilted, lacustrine Karewa strata above 3,150 m a.s.l. on the flanks of the Pir Panjal, 14 km west of Pakharpur, probably have been differentially uplifted a minimum of 1,500 m above their counterparts along the Romushi River since mid-Brunhes time. These data suggest from 4 to 10 mm yr^{-1} of vertical uplift has occurred in the past 350,000 yr. Similar rates ($\sim$7 mm yr^{-1}) for the nearby Nanga Parbat massif[25] suggest that broad areas of the northwestern Himalaya have undergone rapid uplift in the recent past. The post-Olduvai diminution of sedimentation rates at Romushi (Fig. 5) probably reflects earlier stages of uplift. In the Siwalik molasse, similar diminishing sedimentation rates have been caused by initial folding and progressive deformation of nearby foredeep structures before the termination of molasse sedimentation[18].

Whereas the Romushi section spans most of the Brunhes and Matuyama magnetic chrons, the Hirpur section along the Rimbiara River (Fig. 2*b*) records an earlier period of intermontane-basin development. The sampled sections overlie more than 300 m of coarse conglomerates (Fig. 5), whose probable source lay to the east and north-east, as shown by palaeocurrent directions based on clast imbrications and crossbeds. These beds succeed an estimated 250 m of contorted mudstones and sandstones[16] that are faulted against Palaeozoic basement. Of the 46 magnetic sites (Fig. 4), 45 yielded class I data. Above the massive conglomerate near the base, the Hirpur MPS reveals a 70-m-thick sequence of reversed polarity (R1), followed by 238 m of normally magnetized rocks (N1). The upper 115 m of reversed rocks (R2) are truncated by the conglomerate analogous to that at the top of the Romushi section (N6; Fig. 3).

In the absence of other temporal constraints, the Hirpur MPS cannot be unambigously placed within the magnetic-polarity time scale. However, a triplet of volcanic ashes, each 1–2 cm thick, was discovered 60 m below the top of the section (Fig. 4). These ashes are equivalent to the Romushi ash triplet discussed above, and were also deposited during the lower Matuyama chron (R2; Fig. 4). The two ash triplets bracket similar thicknesses of Karewa sediments and are nearly identical in appearance. At the three sites in Kashmir where the triplet was identified, there is a progressive thinning of the individual ashes from north-west to south-east, probably due to downwind attenuation. These Kashmir ashes have similar ages to many of the late Pliocene and Pleistocene ashes found in the Siwalik Group in northern Pakistan and India[26]. Their probable source lay to the west in the Dasht-e Nawar volcanic complex in central–eastern Afghanistan[26].

Agrawal *et al.*[14] have recently suggested that the normally magnetized sediments in the vicinity of Hirpur (analogous to our N1) probably encompass the entire Gauss chron. However, we did not uncover reversed intervals representative of the Kaena and Mammoth subchrons in this rather densely sampled section (Fig. 4). The presence of only two magnetic reversals among these 46 sites implies that the section spans a relatively brief time interval. In quantitative terms, when the random sampling model of McGee and Johnson[27] is applied to this palaeomagnetic data set, the time interval represented by this section should be <500,000 yr. Therefore, we interpret N1 as the uppermost part of the Gauss chron, not the entire Gauss. R1 would represent a portion of the Kaena subchron (Fig. 5).

Extrapolation of the sedimentation rate (50 cm kyr^{-1}) at the sampled sequence at Hirpur to the underlying 550 m of conglomerates and mudstones yields an estimated age of 4 Myr for the base of the sequence. No older sediments attributable to the Karewa Group have been located in the Kashmir Basin. If the sedimentation pattern in Kashmir is similar to that observed in the Siwalik molasse[18–20], the rate would be expected to accelerate in the early basin-filling stages and then decelerate in the waning phases as deformation intensified. Hence, the extrapolation of the maximum observed rate of 50 cm kyr^{-1} to the base of the sequence at Hirpur probably underestimates the true age of the initiation of basin development.

Conclusions

The Romushi and Hirpur sections, including the underlying strata at Hirpur, encompass virtually the entire interval of intermontane-basin sedimentation in Kashmir (Fig. 5). Initial ponding of pre-existing fluvial systems led to deposition of the basal Hirpur mudstones some 4 Myr ago. Strong uplift along the eastern basin margin caused an influx of conglomerates during the lower Gauss chron. This influx probably initiated in the upper Gilbert chron. Widespread lacustrine sedimentation began $\sim$3 Myr ago and continued until $\sim$0.3–0.4 Myr ago. During the lower Matuyama chron, volcanic ashes, probably erupted from the Dasht-e Nawar volcanic complex to the west, were deposited in coherent strata that thin to the south-east.

This new chronology from Kashmir demonstrates that, since $\sim$4 Myr ago, intermontane-basin development, Karewa sedimentation and deposition of the Siwalik molasse to the south of the Pir Panjal Range have been concurrent. Deformation of the Siwalik molasse in the Potwar Plateau and the Jhelum re-entrant[18–20] during the Plio–Pleistocene is, in part, a response to continued thrusting and uplift of the south-west edge of the Kashmir basin along the marginal faults south of the Pir Panjal (Fig. 1). Whereas thrusting deforms the proximal foredeep margin south of the faults, it enhances lacustrine sedimentation in the intermontane basin by raising the local base-level. Consequently, the long lacustrine interval in the Karewa sequence between 3 and 1 Myr probably does not reflect quiescence, but is rather a response to continued tectonism along the basin margin. During the past 350,000 yr, very rapid uplift of the Pir Panjal Range has terminated widespread sedimentation in the Kashmir Basin.

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1. Godwin-Austin, H. H. *Q. Jl geol. Soc. Lond.* **15,** 221–229 (1859).
2. Terra, H. de & Paterson, T. *Carnegie Instn Washington Publ.* **493,** 80–251 (1939).
3. Farooqi, I. A. & Desai, R. N. *J. geol. Soc. India* **15,** 299–305 (1974).
4. Bhatt, D. K. *Himalayan Geol.* **6,** 197–208 (1976).
5. Bhatt, D. K. & Chatterji, A. K. *Geol. Sur. India misc. Publ.* **41,** 191–200 (1979).
6. Badam, G. L. *Curr. Sci.* **41,** 529–530 (1972).
7. Tewari, B. S. & Kachroo, R. K. *Recent Res. Geol.* **3,** 468–477 (1977).
8. Roy, D. K. *Geol. Sur. India misc. Publ.* **24,** 204–221 (1975).
9. Singh, D. *Bull. Ind. geol. Ass.* **7,** 99–122 (1974).
10. Kusumgar, S., Agrawal, D. P. & Krishnamurthy, R. V. *Radiocarbon* **22,** 757–762 (1980).
11. Vishnu-Mittre *Geol. Surv. India misc. Publ.* **15,** 89–96 (1972).
12. Wadia, D. N. *Int. geol. Congr.*, London **10,** 43–48 (1951).
13. Lydekker, R. *Rec. geol. Surv. Ind.* **11,** 30–69 (1876).
14. Agrawal, D. P., Bhatt, D. K., Kusumgar, S. & Pant, P. K. *Proc. Ind. Acad. Sci.* **90,** 111–123 (1981).
15. Bhatt, D. K. *Geol. Surv. Ind. misc. Publ.* **24,** 188–204 (1975).
16. Bhatt, D. K. & Chattergi, A. K. *Proc. VI Ind. Colloq. Micropaleontological Stratigraphy,* 11–21 (1976).
17. Singh, D. *Recent Res. Geol.* **3,** 79–86 (1977).
18. Johnson, G. D., Johnson, N. M., Opdyke, N. D. & Tahirkheli, R. A. K. in *Geodynamics of Pakistan*, 149–165 (eds Farah, A. & deJong, K.) (Geological Survey of Pakistan, Quetta, 1979).
19. Opdyke, N. D. *et al. Palaeogeogr. Palaeoclimatol. Palaeoecol.* **27,** 1–34 (1979).
20. Johnson, N. M. *et al. Palaeogeogr. Palaeoclimatol. Palaeoecol.* **37,** 17–42 (1982).
21. Johnson, N. M., Opdyke, N. D. & Lindsay, F. H. *Bull. geol. Soc. Am.* **86,** 5–12 (1975).
22. Fisher, R. A. *Proc. R. Soc.* A**217,** 295–305 (1953).
23. Burbank, D. W. thesis, Dartmouth College (1982).
24. Mankinen, F. A. & Dalrymple, G. B. *J. geophys. Res.* **84,** 615–627 (1979).
25. Zeitler, P. K., Johnson, N. M., Tahirkheli, R. A. K. & Naeser, C. W. *Geol. Soc. Am. Abstr. Prog.* **13,** 587 (1981).
26. Johnson, G. D. *et al. Palaeogeogr. Palaeoclimatol. Palaeoecol.* **37,** 63–93 (1982).
27. McGee, V. F. & Johnson, N. M. *Trans. Am. geophys. Un.* **61,** 215 (1980).