The magnetostratigraphy, fission-track dating, and stratigraphic evolution of the Peshawar intermontane basin, northern Pakistan

DOUGLAS W. BURBANK *Department of Geological Sciences, University of Southern California, Los Angeles, California 90089-0741*
R. A. KHAN TAHIRKHELI *University of Peshawar, Peshawar, Pakistan*

ABSTRACT

The Peshawar basin is situated along the junction of the northern margin of the Indo-Gangetic foredeep and the southern margin of the Hindu Kush–Himalayan Ranges. During the late Cenozoic, southward encroachment of tectonic disruption into the foredeep terminated molasse deposition and delineated the Peshawar intermontane basin through uplift of the Attock Range along the southern margin of the basin. In this study, magnetostratigraphy, fission-track dates on volcanic ashes, and stratigraphic data are used to define the chronologic and stratigraphic evolution of the basin.

Following a late Miocene to Pliocene interval of folding and thrusting of the preexisting molasse sediments, deposition began in the Peshawar basin by at least 2.8 m.y. ago. Subsequently, >300 m of basin-filling sediments accumulated at rates averaging 15 cm/1,000 yr. Northward progradation of alluvial-fan deposits from the uplifted basin margin had begun by ~2.6 m.y. ago and continued at an inferred rate of 2 cm/yr. Proximal to the Attock Range in the south, alluvial-fan facies persisted until ~0.6 m.y. ago. Contemporaneous sediments closer to the basin center demonstrate the presence of rapid facies transitions to extensive floodplain and shallow-lacustrine depositional environments. Widespread intermontane-basin sedimentation was terminated by accelerated uplift of the Attock Range after ~0.6 m.y. ago. Subsequently, during the Brunhes chron, catastrophic floods have periodically inundated the Peshawar basin. Continuing tectonic deformation of the basin is indicated by uplifted flood deposits, offset terraces, and modern seismicity.

INTRODUCTION

Along the southern margins of the Himalaya and Hindu Kush Ranges, migrating tectonic deformation has progressively encroached upon the northern portions of the Indo-Gangetic foredeep. This migration is evidenced by the gradual displacement of molasse depocenters to the south, by folding in the foredeep which decreases in intensity to the south, and by the progressive southward disruption of the former foredeep by an intricate array of generally north-dipping thrust faults. Extensive uplift along some of these thrusts has exposed the basement complexes that formerly underlay the foredeep. In addition, these uplifts have generated large intermontane basins along the northern foredeep margin. The chronologic and stratigraphic evolution of these intermontane basins provides critical constraints on the timing and nature of the Indo-Asian collision during the late Cenozoic.

The Peshawar and Kashmir intermontane basins are symmetrically oriented on opposite sides of the Northwest Syntaxis (Fig. 1). Comparative studies of these basins provide the opportunity to contrast their developmental histories and to examine the temporal coherence of tectonic deformation along the southern margin of the Himalayan and Hindu Kush Ranges (Burbank and Raynolds, 1984). Unlike the Peshawar basin, the Kashmir basin developed within a terrane that lay slightly to the north of the mid-Tertiary foredeep (Burbank, 1983a). Recent chronologic and stratigraphic studies have served to delineate the history of the Kashmir basin (Kusumgar, 1980; Agrawal and others, 1981; Burbank, 1983a; Burbank and Johnson, 1982, 1983). This paper describes similar, recently completed studies in the Peshawar basin in which magnetic-polarity stratigraphies and fission-track dates are combined with alluvial stratigraphies to develop a chronology for the development of the Peshawar intermontane basin.

PREVIOUS INVESTIGATIONS AND GEOLOGIC SETTING

Although considerable mapping of the bedrock along and within the margins of the Peshawar basin has been completed (Fig. 2) (Cotter, 1933; Latif, 1970; Tahirkheli, 1970; Calkins and others, 1974; Meissner and others, 1974; Hussain and Karim, 1982), the basin-filling sediments themselves have received little detailed analysis. Following an early traverse of these basins, Vicary (1851) made prescient observations on the "deep-bedded and extensive Pliocene formations extending from the Jhelum River to Khyber Pass." Wynne (1877) and Waagen (1884) described north-to-south traverses from the Peshawar basin into the Punjab. In these and most subsequent accounts, however, the basin-filling sediments are described merely as "old gravels" or alluvium. Their potential as a record of intermontane-basin development is largely ignored.

The tectonic framework of the Peshawar basin has been delineated through surficial mapping, geomorphic analysis, and seismic and gravity data. Large-scale mapping efforts centered on Kohat (Meissner and others, 1974), the Hazara (Latif, 1970; Calkins and others, 1974), and the northern Punjab (Pascoe, 1921; Cotter, 1933), and many of the more detailed maps of the Attock Range (Tahirkheli, 1970; Hussain and Karim, 1982) delineate the composite nature of the bedrock along the northern margin of the foredeep. With the exception of the intermontane-basin-filling sediments, the youngest sedimentary rocks exposed along the margins of the Peshawar basin belong to the Murree Formation (Meissner and others, 1974). The Murree rocks are heavily oxidized, mid-Tertiary aged, molasse sediments that accumulated in the early stages of foredeep subsidence. Beneath the Murrees, Eocene and older limestones, shales, and sandstones overlie undetermined thicknesses of Paleozoic slates.

North-dipping, imbricate thrusts and sinistral strike-slip faults disrupt exposed basement along the margins of the intermontane basins and the northerly edge of the Siwalik molasse. Recent activity along some of these faults, as well as disturbance of the basin fills, is evidenced by observable offsets (Kazmi, 1979), knickpoints in stream gradients (Gornitz and Seeber, 1981; Seeber and Gornitz, 1983), and by modern seismic data (Molnar and others, 1973;

Geological Society of America Bulletin, v. 96, p. 539–552, 12 figs., 2 tables, April 1985.

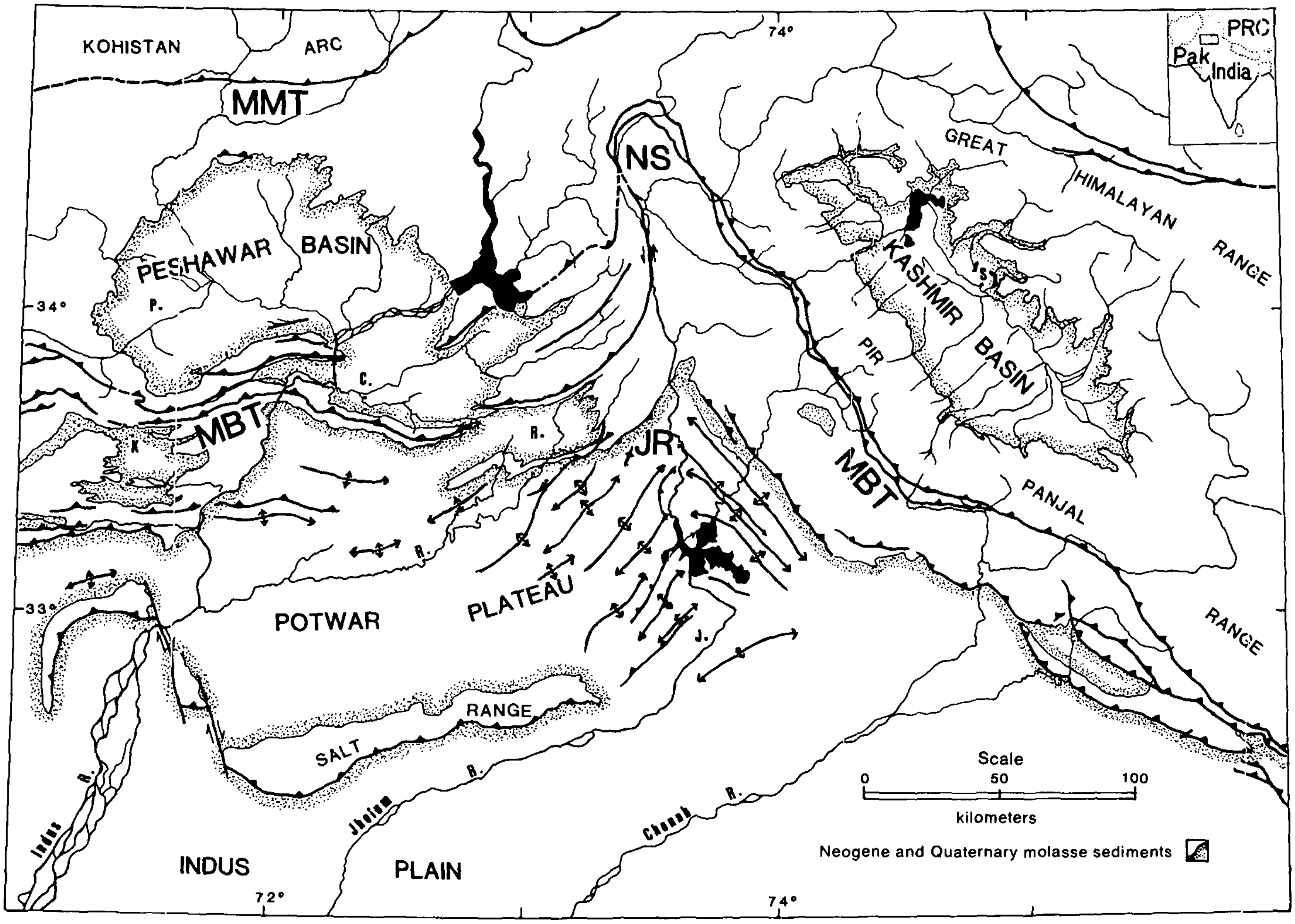

Figure 1. Map of the southern margin of the Himalaya and Hindu Kush. The Peshawar and Kashmir intermontane basins are symmetrically oriented about the Northwest Syntaxis (NS) and lie along the northern edge of the bounding Himalaya foredeep. C = Campbellpore; J = Jhelum; JR = Jhelum Re-entrant; K = Kohat; MBT = Main Boundary Thrust complex; MMT = Main Mantle Thrust; P = Peshawar; R = Rawalpindi; S = Srinagar.

Seeber and Armbruster, 1979; Pennington, 1979; Quittmeyer and others, 1979).

Recent interpretations of gravity data emphasize the apparent northward dip of the major thrusts located to the south and north of the Peshawar basin (Malinconico, 1982). Seeber and Armbruster (1979) have proposed a model in which a low-angle detachment surface extends from below the eastern Peshawar basin to the south beneath the Potwar Plateau to the Salt Range (Fig. 1). Splays off the master detachment fault have defined the intermontane basin of Peshawar by uplifting the Attock Range (Fig. 2).

The surficial deposits of the southern part of the Peshawar basin are presently being mapped by the Geological Survey of Pakistan (A. Hussain, 1981, personal commun.). Recent reconnaissance studies of the geology in and around the Peshawar basin have focused on the sequential migration of thrust-related deformation (Yeats, 1982); however, the stratigraphy, chronology, and tectonic implications of the basin fill have remained largely unknown. These aspects of the Peshawar basin have been examined in this study.

METHODOLOGY

With the exception of some restricted tribal regions, nearly the entire Peshawar basin was examined in an attempt to locate the thickest exposures of basin-filling sediments. Throughout the northern two-thirds of the basin, exposed sequences rarely exceed 50 m. Paleomagnetic samples were collected from multiple horizons at each of four of the thickest sections in the north. All of these samples were normally magnetized and were interpreted as being of Brunhes age (<730,000 yr); consequently, it appears that these exposures cannot serve to define the early stages of basin sedimentation.

In the southern third of the Peshawar basin, extensive exposures are found along the north flank of the Attock Range, where uplift has caused gentle folding of the basin fill. Near the villages of Dag and Garhi Chandan (Fig. 2), sections spanning most of the interval of basin development were measured and described. A younger sequence, but one important to the description of the more recent stages of basin sedimentation and tectonism, was studied near Piran, 10 km southeast of Nowshera (Fig. 2).

The measured sections were described on a 1:200 scale. Where possible, paleocurrent directions were determined from clast imbrications and cross-bedded sandstones. Groups of associated strata or unique lithologic types were used to define facies that characterize specific depositional environments, as well as the changing patterns of intermontane-basin sedimentation.

After measurement and description of the sections, paleomagnetic collection sites were placed

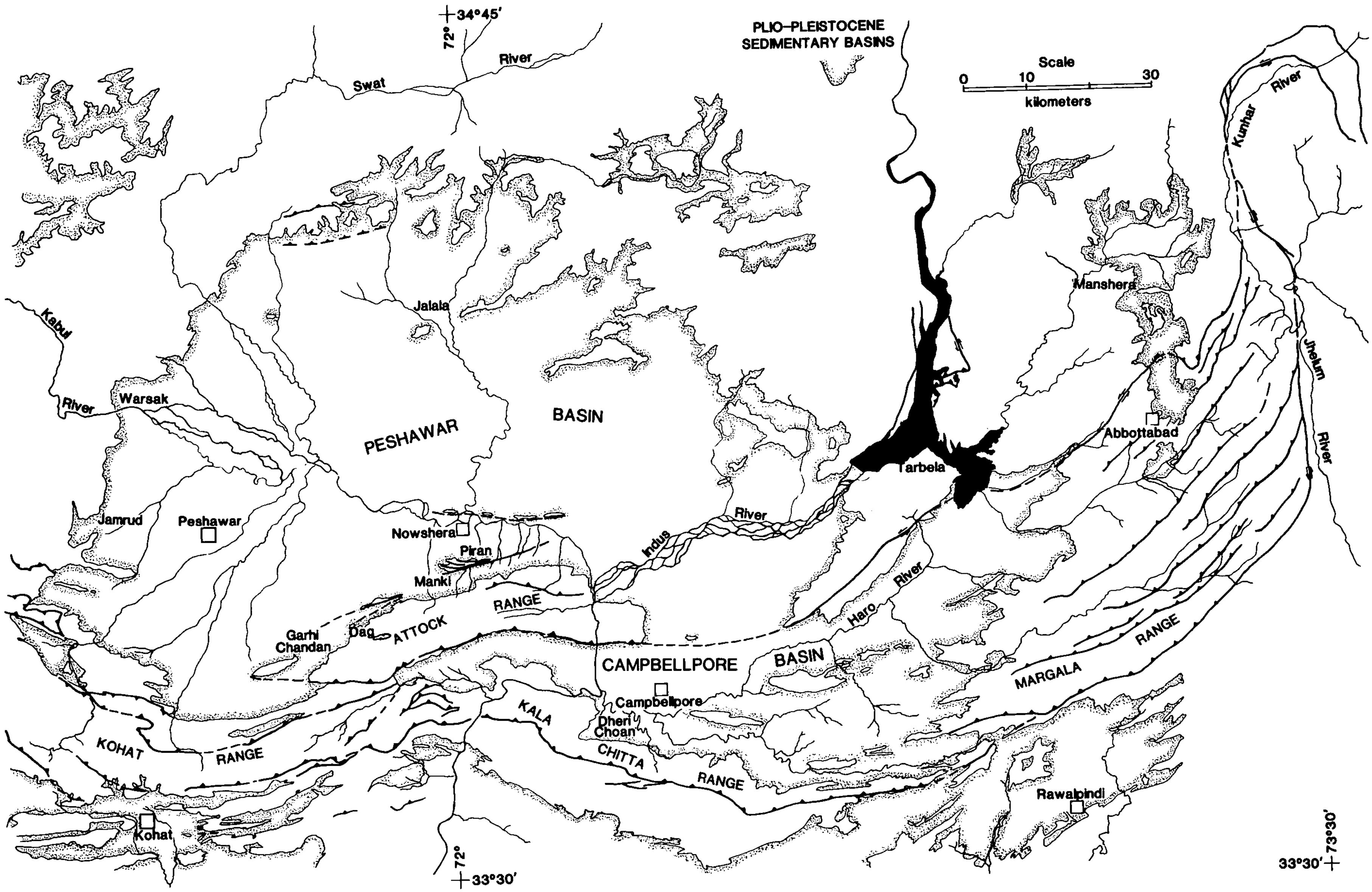

Figure 2. Map of the Peshawar and Campbellpore basins and the western portion of the Northwest Syntaxis. Map is based on field observations, interpretation of 1:250,000 LANDSAT images, and the geologic maps of Latif (1970), Calkins and others (1974), and Meissner and others (1974).

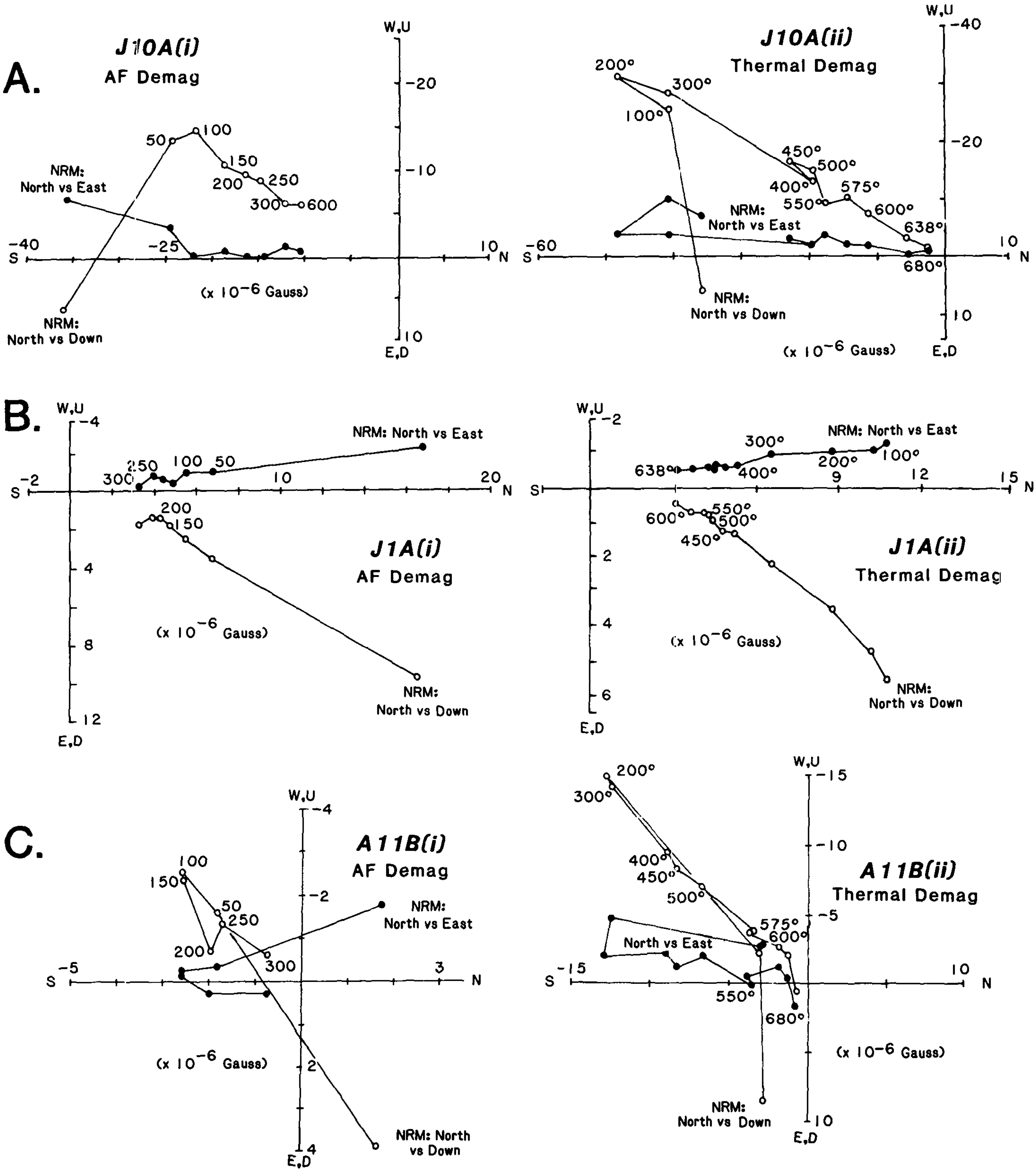

Figure 3. Zijderveld plots comparing results of alternating-field and thermal demagnetization on adjacent, paired samples from Dag (A and B) and from Garhi Chandan (C). The numbers adjacent to the data points in the left-hand plots indicate the peak demagnetizing field in oersteds. The NRM directions after low levels of demagnetization (100 oe or 200 °C) are not significantly different between each set of paired samples for either of the demagnetization procedures.

in suitable strata at intervals ranging typically from 5 to 15 m. Unsuitable lithologies or covered portions of the sections sometimes dictated larger site spacings. In accordance with previously described techniques (Johnson and others, 1975; N. Johnson and others, 1982), at least three oriented samples were collected from siltstones or mudstones at each site (magnetic-sampling level). The sample localities were selected to avoid pedogenic mottling or disturbed depositional fabrics. The natural remanent magnetization (NRM) of the samples was analyzed using a Superconducting Technologies cryogenic magnetometer at the Woods Hole Oceanographic Institute. Alternating-field demagnetization (AFD) and thermal demagnetization (TD) were used to remove postdepositional magnetic overprinting in order to expose the original depositional remanent magnetization (DRM).

Many of the basin-filling sediments have a pale red to moderate reddish brown color (Munsell colors 10 R 6/2 and 10 R 6/4, respectively). This suggests that postdepositional chemical overprinting could have occurred in a fashion analogous to that observed in some of the Siwalik sediments due to the *in situ* development of red pigmentation (Tauxe and others, 1980). Alternatively, the coloration could be due to the presence of detrital hematite derived from the oxidized Murree Formation nearby, which contributed large quantities of sediment to the basin fill.

If the former possibility were correct, then magnetic cleaning procedures and interpretation of the results could be greatly complicated. In order to discriminate between these possibilities, paired samples collected adjacent to each other in the same strata were subjected to progressive AFD and TD procedures. The results (Fig. 3) indicate that (1) a viscous component of overprinting is easily removed at low levels of demagnetization (100 oe or 200 °C); (2) the magnetic carrier is likely to be some combination of magnetite and hematite; (3) following removal of low-coercivity overprinting, the samples demonstrate very clear reversed or normal polarities that are virtually indistinguishable when the two procedures are compared; and (4) the NRM directions of the demagnetized samples align quite closely with the axial dipole field at this latitude. The results suggest that *in situ* development of postdepositional magnetic components has not significantly overprinted the DRM.

Because both AFD and TD techniques appear capable of revealing the DRM at low demagnetization levels, and because many of the poorly consolidated samples could not withstand repeated handling, the simpler AFD procedures were used to treat most of the samples. The results reported here represent the NRM after AFD at 150 oe. Most samples, particularly normally polarized ones, were also demagnetized up to 600 oe. Select ones were also thermally demagnetized at 450 and 550 °C. Very few of these samples showed significant changes in NRM direction, and none reversed their polarity at these higher demagnetization levels.

After demagnetization, dispersion between the sample NRM vectors at each site was evaluated using Fisher statistics (Fisher, 1953). When the Fisher "k" was >10, the site was termed "Class I," indicating good agreement between the individual samples. Forty-eight of fifty (96%) of the sites were Class I. Most of the Class I sites had k values >30. Sites with k <10, but with two of three samples in good agreement, were termed "Class II." The antipodal distribution of the site means (Fig. 4) shows that these samples pass the reversal test (McElhinny, 1973). The site means were used to calculate the latitude of the virtual geomagnetic pole (VGP). This latitude forms the basis of the magnetic-polarity stratigraphy (MPS) for each section. To permit further evaluation of the quality of the magnetic data, an alpha-95 confidence envelope around the VGP latitude was plotted for the Class I data points in each MPS.

Often, in the absence of other chronologic data, a MPS cannot be matched unambiguously with the magnetic-polarity time scale (MPTS) (Mankinen and Dalrymple, 1979); however, in both the Dag and Garhi Chandan sections, at least two volcanic ashes were discovered. Zircons extracted from these ashes were dated using the fission-track method (Naeser, 1978; G. Johnson and others, 1982). These dates were used to determine the optimal correlation of each local MPS with the MPTS.

RESULTS

Dag Section

The Dag section comprises tilted, poorly consolidated strata exposed on the lower, northern flank of the Attock Range. Bedrock is not exposed at the base of the section, but within 500 m of the section, there are extensive outcrops of limestones, turbidites, and the Murree Formation. The basal portion of the Dag section (Figs. 5 and 6) displays massive siltstones and mudstones with subordinate thin, massive sandstones. The silts contain rootlets, abundant calcareous concretions, and occasional coherent limey horizons that are 3–5 cm thick.

The remainder of the Dag section is dominated by coarse, clast-supported conglomerates. The component clasts are subangular to subrounded, as much as 50 cm in diameter, poorly sorted, and occasionally imbricated. The conglomerates are either massive or display faint parallel bedding with occasional planar cross-beds. Frequently, strata coarsen upwards through individual units that are 1–10 m thick. Interbedded with the conglomerates are lenses of coarse-grained, subangular litharenites and beds of massive, gritty silts that contain rootlets and calcite-filled burrows. Four other lithologies occur infrequently within the section: matrix-supported conglomerates with angular clasts (98 m); massive silts (99 m); well-laminated, silty mudstones with local rootlets (240 m); and

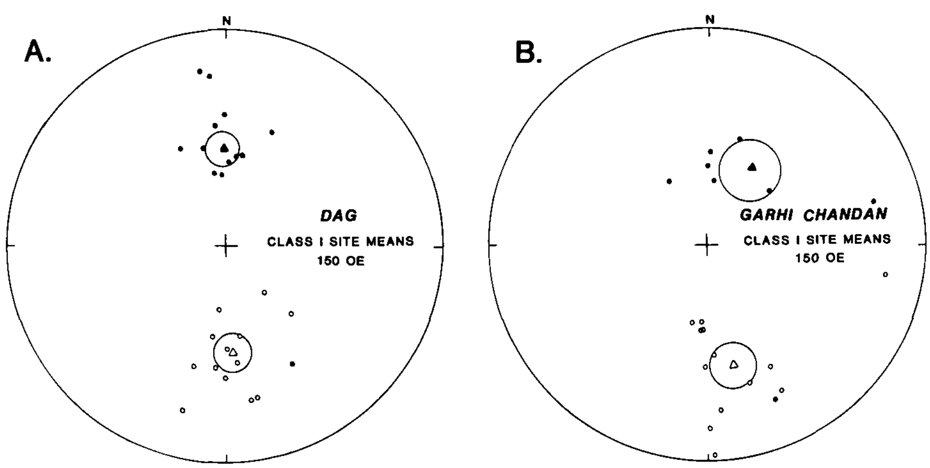

Figure 4. Stereonet plot of the mean directions of Class I sites from (A) Dag and (B) Garhi Chandan. The sites from each area plot generally antipodally and pass the reversal test. They also suggest that there has been no significant postdepositional tectonic rotation of these areas.

medium-grained, well-sorted sandstones (36 m). Portions of the Dag section are obscured by colluvium (for example, 150–210 m, Fig. 6). In these areas, the horizontal separation of the beds and the observed dip of the strata were used to estimate the stratigraphic separation.

Two volcanic ashes were discovered in the lowermost 50 m of the section. Both ashes were dated via the fission-track method. The lower ash yielded an age of 2.6 ± 0.2 (2σ) m.y. (Fig. 7 and Table 1). The upper one was dated at 2.6 ± 0.3 m.y. (Fig. 7 and Table 1).

Although the section is dominated by conglomerates, thin, fine-grained strata are locally preserved. Twenty-six magnetic sites were placed in the Dag section within these fine-grained strata. Following AFD at 150 oe, all sites yielded Class I data. Seven magnetozones were uncovered by this sampling program (Fig. 7). Two magnetozones, N2 and R2, are based on single Class I sites. These magnetozones, as well as others based on single sites in the subsequently described section, were reconfirmed by further stepwise thermal demagnetization. The remaining magnetozones are represented by two or more sites of the same polarity.

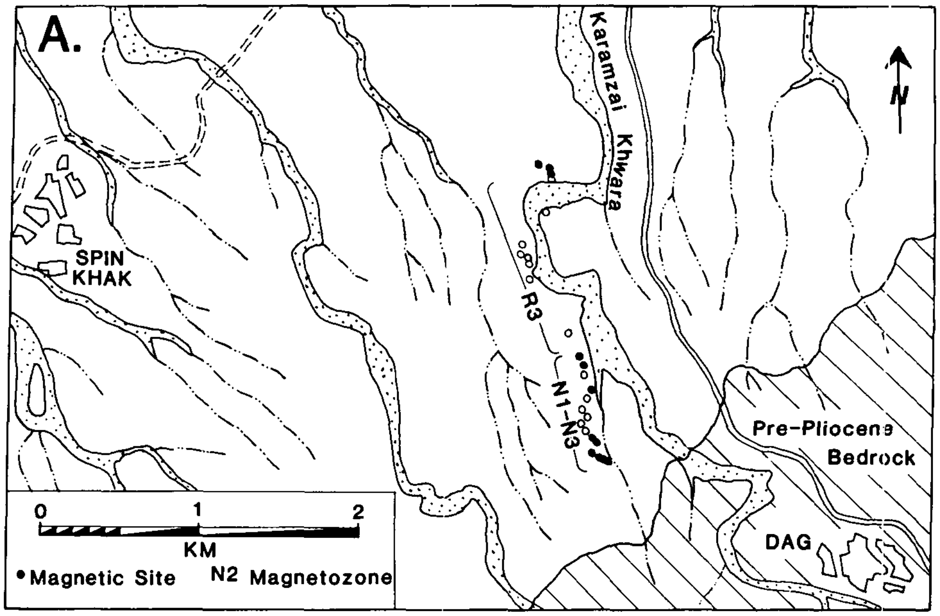

Figure 5A. Location map of the measured section at Dag based on Survey of Pakistan 1:63,360 topographic quadrangle (0/13, 1949). Magnetic-sampling sites and magnetozones are indicated.

Garhi Chandan Section

Near the village of Garhi Chandan, two sections were measured and described (Figs. 5 and 8). The lower section (2A) begins at the depositional contact of the folded and highly dissected Murree Formation with the overlying intermontane-basin sediments. The upper section (2B) begins ~1 km farther north and is correlated on the basis of a traceable conglomerate. The lower 60 m of section 2A is dominated by pale red and grayish yellow mudstones that display thin (1–3 mm), wavy, and parallel laminations. The mudstones preserve numerous burrows (2–4 mm in diameter) and minor organic debris. Interbedded with the mudstones are three coarse-grained volcanic ashes (12, 28, and 38 m; Fig. 8), as well as thin, medium-grained, massive sandstones. The remainder of section 2A displays an alternation between massive, multicolored, concretion-bearing siltstones and coarse, clast-supported conglomerates with subordinate medium-grained, moderately sorted sandstones.

Section 2B contains a thick sequence of finely laminated, silty muds (Fig. 8) that preserve small rootlets. Interbedded with the muds are many thin (5–15 cm) beds of massive, silty, fine-grained sands. Micaceous, medium-grained sands as much as 3 m thick are associated with massive, gritty siltstones bearing calcareous concretions. Two additional sand-sized volcanic ashes are located at 35 and 43 m. The section terminates at the top of a gentle cuesta, where it is capped by a limestone-dominated conglomerate. Of the five volcanic ashes discovered in the Garhi Chandan sections (Figs. 5B and 8), the upper two form sandy, biotite-rich beds as much as 25 cm thick. The lower three volcanic ashes are as much as 2 m in thickness and can be traced for more than 1 km. One of the lower ashes (Fig. 9) was dated via the fission-track method at 2.4 ± 0.2 (2σ) m.y. (Table 1). Twenty-four magnetic sites were established in the Garhi Chandan sections. Following AFD at 150 oe, the section comprises 22 Class I sites (92%) and 2 Class II sites (8%). The Class I sites show considerable scatter but still pass the reversal test (Fig. 4). Eight magnetozones were uncovered by this sampling program (Fig. 9). Three magnetozones were based on isolated, Class I sites, whereas all others were based on several adjacent sites of the same polarity.

Piran Section

An elongate band of Paleozoic(?) slates (Tahirkheli, 1970) has been uplifted along an east-northeast–west-southwest–trending fault zone south of Nowshera (Fig. 2). On the southern margin of the slates near the village of Piran, young, unconsolidated basin-filling sediments are exposed in many gullies where they are in direct contact with the bedrock. A 23-m-thick section (Fig. 10) was measured in the stream wash crossed by the main road to Nowshera. With the exception of a 3-m-thick horizon of angular, clast- and matrix-supported colluvial debris (4 m, Fig. 10), the section comprises a repetitive sequence of upward fining cycles (graded beds) that are typically 30–60 cm thick. The beds pinch and swell over the bedrock topography. Individual cycles commence with massive, medium- to fine-grained, poorly sorted sandstones. These are overlain by fissile, sandy silts that are finely laminated with individual laminae typically 2–3 mm thick. Each cycle is capped by massive, bioturbated, silty muds containing abundant rootlets and burrows. Lithologic contacts are abrupt at the boundaries of each cycle but are gradational within each unit.

The colluvial zone at 4 m delineates an angular unconformity. The basal cycles dip at 10° to the north, whereas the upper sequence dips at only 2–3° to the north. The entire sequence is capped by a second colluvial zone of angular clasts. No volcanic ashes were found in this section. Magnetic samples were collected above and below the lower colluvial zone. All samples are normally magnetized and are interpreted as belonging to the Brunhes chron.

DISCUSSION

Stratigraphic Correlations

In the Dag section (Fig. 7), the fission-track dates of 2.6 m.y. B.P. for the ashes adjacent to the N1/R1 transition indicate that this is most likely to be the Gauss/Matuyama boundary. Given this absolute age, N3 is interpreted as representing the Olduvai subchron, and N2 is seen as one of the Reunion subchrons. The normal magnetozone (N4) at the top of the section is interpreted as being the Brunhes chron. The Jar-

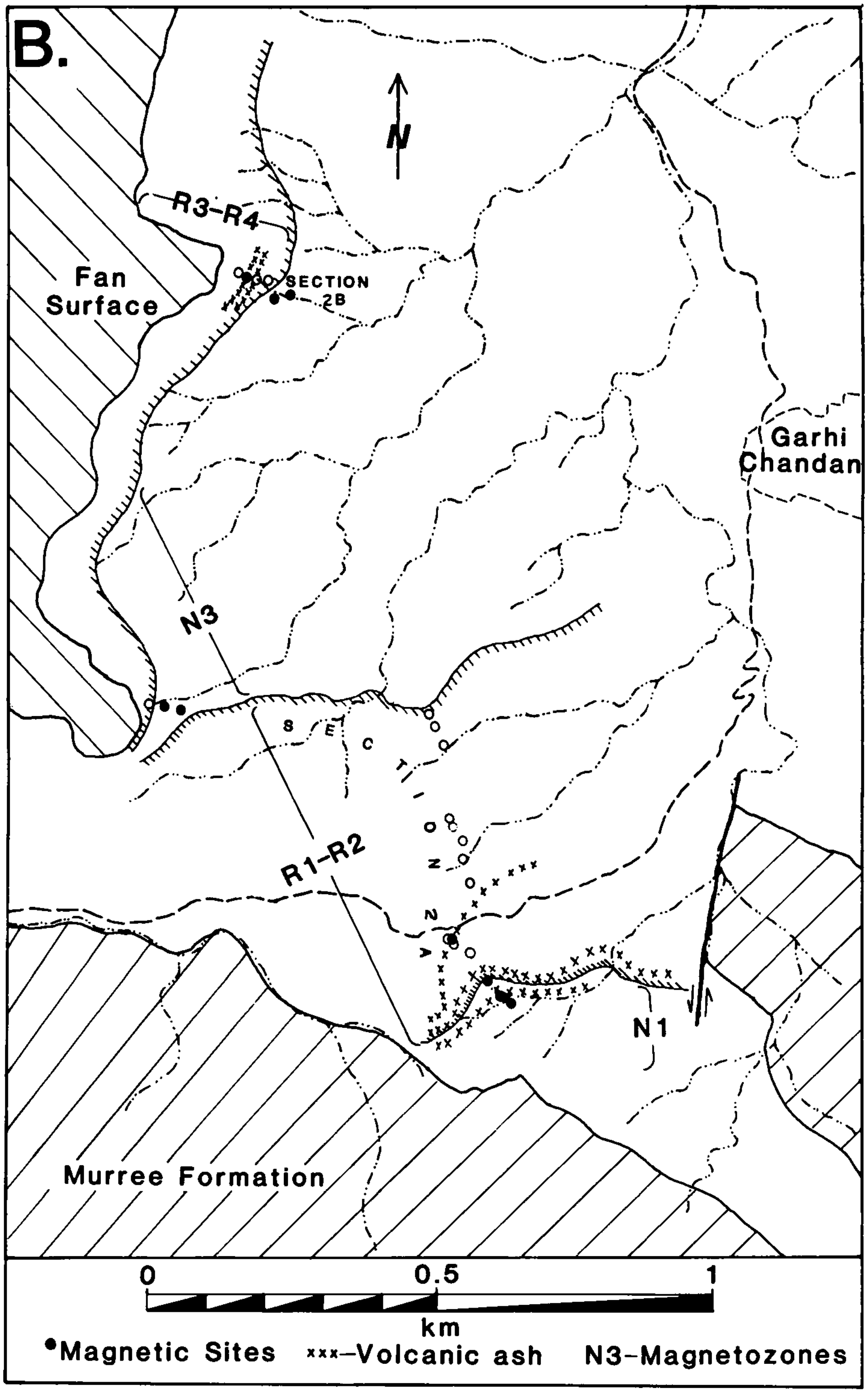

Figure 5B. Location map of the measured section at Garhi Chandan based on 1:50,000 aerial photographs. Section 2A begins at the unconformable contact with the underlying Murree Formation.

amillo subchron is not believed to have been detected. Its absence is probably due to the covered strata near the top of the section.

By this interpretation, the Dag section spans ~2.2 m.y, from the upper Gauss (2.8 m.y.) to the lower Brunhes (0.6 m.y.). The average sediment-accumulation rate over this period is ~15 cm/1,000 yr. Statistical evaluation of the sampling density based on methods of Johnson and McGee (1983) indicates that, for a magnetic section spanning 2.2 m.y. and comprising 26 sites, 8.3 ± 2.4 reversals would be expected to be manifested in the local MPS (Table 2). The agreement between the number of observed reversals (6) in the Dag section with the predicted number of reversals lends support to the interpretations presented here.

The fission-track date of 2.4 m.y. B.P. from the basal portion of the Garhi Chandan section indicates that the N1/R1 transition represents the Gauss/Matuyama boundary (Fig. 9). Like the ashes in the Dag section, those at Garhi Chandan straddle this magnetic transition. Many of the ashes in the Potwar Plateau are also clustered near the Gauss/Matuyama boundary (Visser and Johnson, 1978; Opdyke and others, 1979; Raynolds, 1980; G. Johnson and others, 1982). N2 is an uninterpreted, short magnetozone based on a single site that exhibits a low, positive VGP latitude and that might correlate with the "X" subchron (Heirtzler and others, 1968) or to an unnamed normal subchron observed in Iceland (Kristjansson and others, 1978). N3 is interpreted as representing the Olduvai subchron. Although N4 might correlate with the Jaramillo subchron, this would require the existence of an unrecognized major unconformity or a very large change in sedimentation rates. The stratigraphy suggests that neither of these possibilities is correct. Instead, N4 is probably a short duration, post-Olduvai normal subchron that has not been widely recognized but which has appeared in some recent paleomagnetic studies (Tauxe and others, 1983; Castro and others, 1983). A similarly placed post-Olduvai subchron has been described in three sections in the nearby Campbellpore Basin (Fig. 2) (Opdyke and others, 1979; G. Johnson and others, 1982; Burbank, 1984). In Campbellpore, this subchron is also closely associated with underlying volcanic ashes, two of which have been fission-track dated at 1.6 ± 0.1 (G. Johnson and others, 1982) and 1.8 ± 0.2 m.y. B.P. (Burbank, 1982).

Given these interpretations, the sediment-accumulation rate during the lower Matuyama chron averages ~15 cm/1,000 yr. The entire section is estimated to span ~1.2 m.y., ranging from 2.6 m.y. to 1.4 m.y. ago. Statistical assessment of the sampling program indicates that 6.0 ± 2.1 reversals would be expected to be discovered among 24 magnetic sites placed within a 1.2-m.y.-long interval (Table 2). The agreement of expected reversals with the observed number (7) supports the interpretation offered here.

Basin Evolution

Although the lack of extensive exposures precludes lengthy consideration of the history of the northern part of the basin, the sedimentary rec-

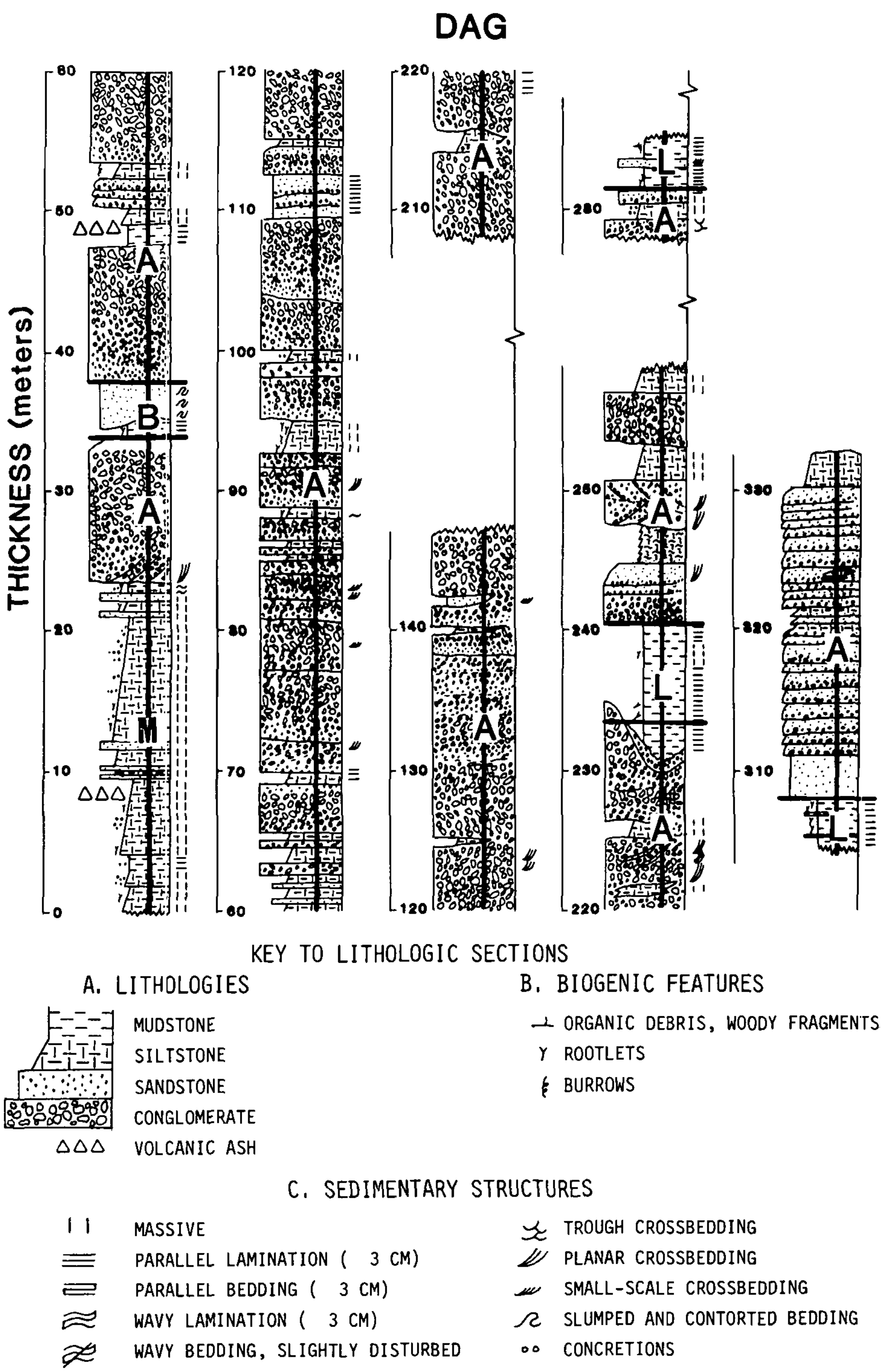

Figure 6. Lithologies and interpreted depositional environments from the Dag section. Three covered intervals occur between 145 and 305 m. A = alluvial fan, B = braided river, L = lacustrine, M = meandering river and floodplain. Above 23 m, alluvial fanglomerates dominate the section as tectonically controlled fans prograded northward across the southern edge of the Peshawar basin behind the newly uplifted Attock Ranges.

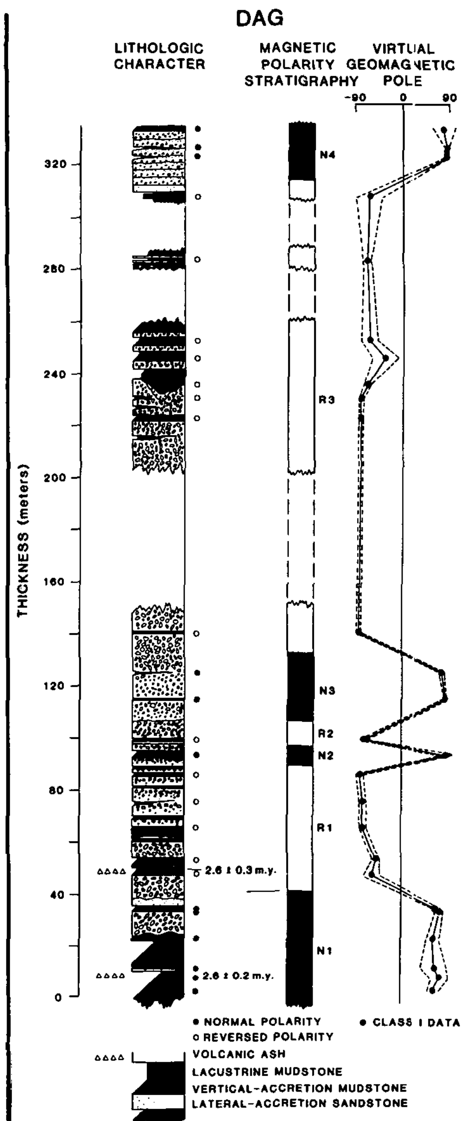

Figure 7. Magnetic-polarity stratigraphy from Dag. Stratigraphic locations of magnetic sites are indicated adjacent to the lithologic column. VGP latitudes form the basis for the magnetic zonation. The dashed lines define an alpha-95 error envelope on the VGP latitude determined for Class I sites. The ages (with a 2σ error) of volcanic ashes dated via the fission-track method are shown in their stratigraphic positions. These ages indicate that the N1/R1 transition is very likely to be the Gauss/Matuyama boundary. N3 is interpreted as the Olduvai subchron, N2 as one of the Reunion subchrons, and N4 as the lower part of the Brunhes chron.

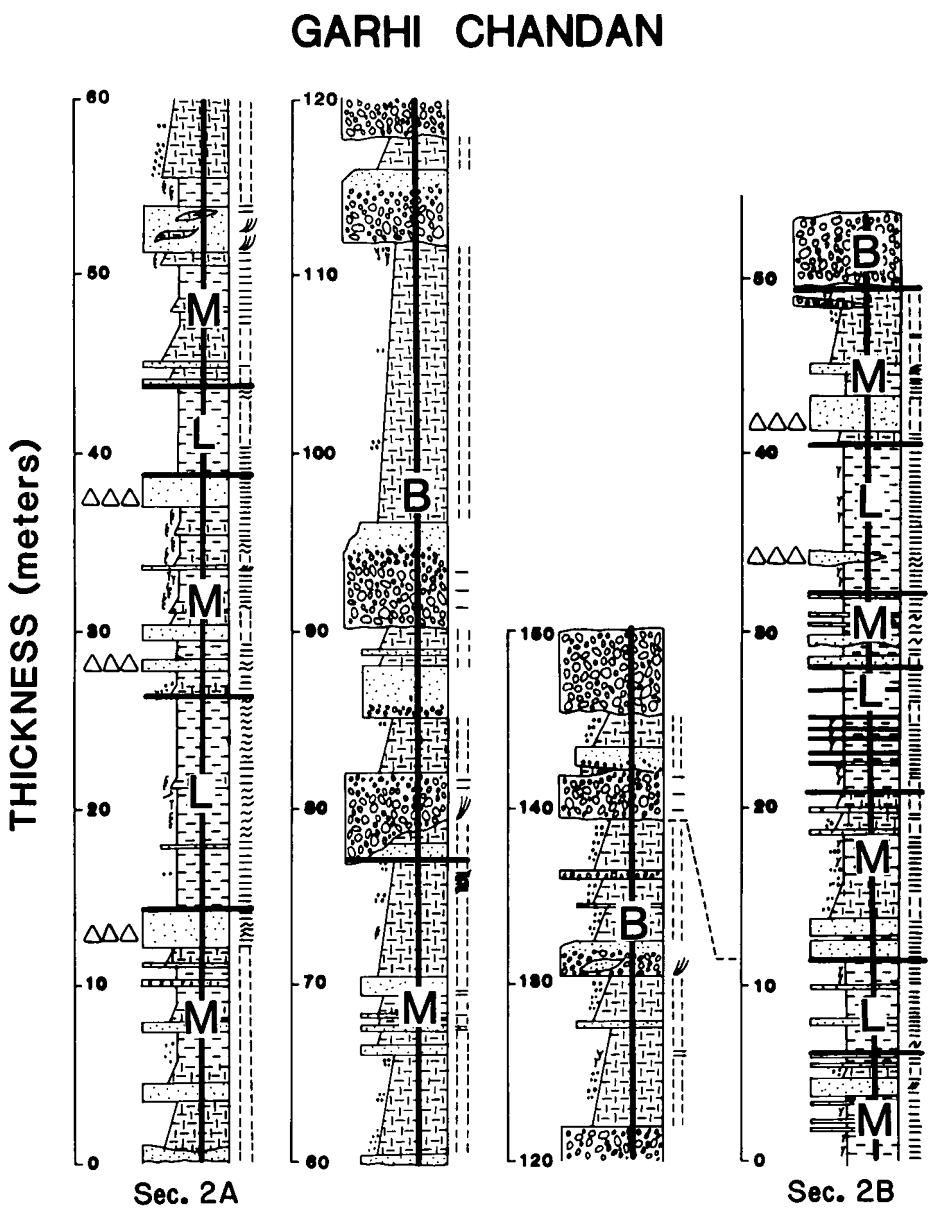

Figure 8. Lithologies and interpreted depositional environments from the Garhi Chandan sections. Symbols are the same as in Figure 6. The conglomerate at the 140-m level in section 2A can be traced to the sandstone at the 12-m level in section 2B. Coarse-grained, high-energy sedimentation commences here above 75 m and is intermittent in nature. The more distal section (2B) largely comprises low-energy sediments.

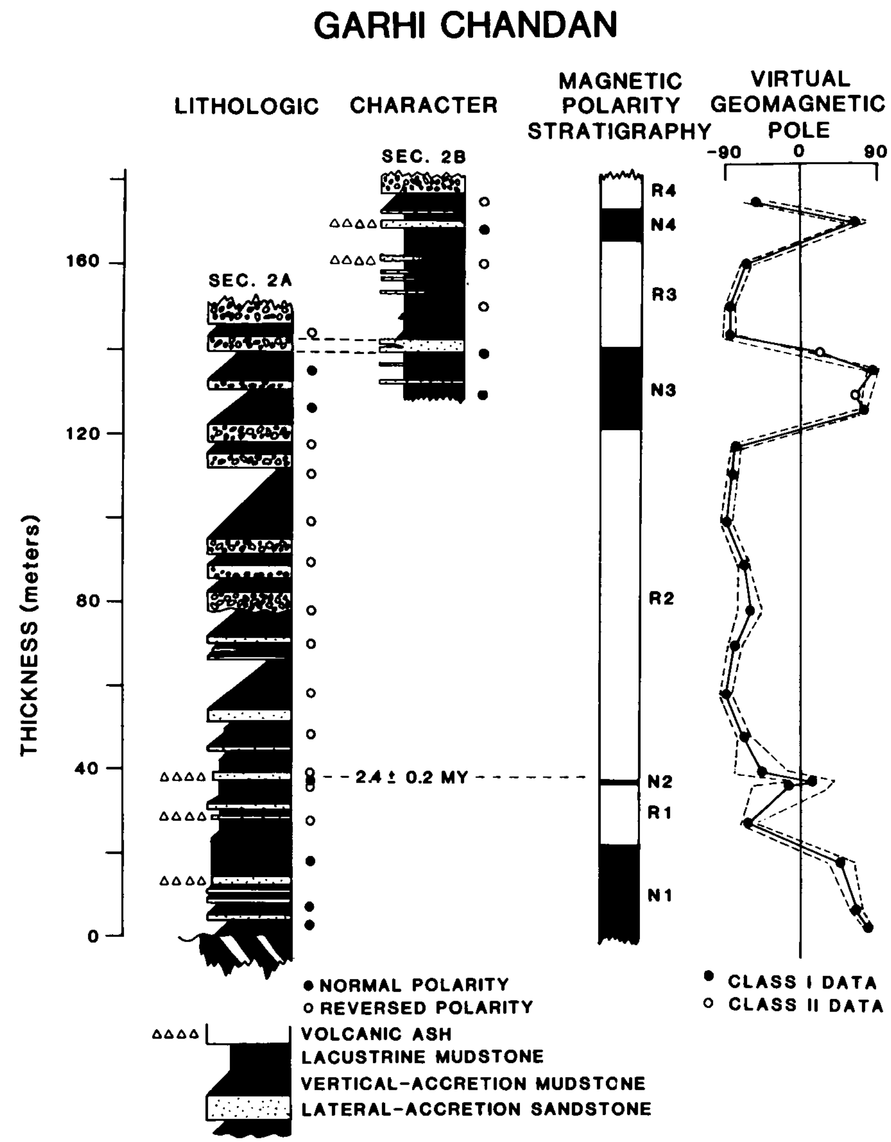

Figure 9. Magnetic-polarity stratigraphy from Garhi Chandan. The occurrence of volcanic ashes straddling the N1/R1 boundary, as also seen at Dag (Fig. 7) and on the Potwar Plateau (G. Johnson and others, 1982), and the fission-track date of 2.4 ± 0.2 m.y. B.P. indicate that this transition is likely to be the Gauss/Matuyama boundary. N4 is a short-lived, normal magnetozone interpreted to succeed the Olduvai subchron (N3). A similarly positioned, normal magnetozone has been found in three sections in the nearby Campbellpore basin (Burbank, 1982).

TABLE 1. FISSION-TRACK AGE DETERMINATIONS

Sample	Location	Grains counted	Fossil (total)	Tracks (density) (10^3tr/cm^2)	Induced (total)	Tracks (density) (10^3tr/cm^2)	r	Neutron dose (10^{15})	Age (m.y. $\pm 2\sigma$)
JG1	Dag	6	206	1272.9	909	11234	0.95	3.89	2.6 ± 0.2
WG3	Dag	12	216	1293.8	959	11489	0.84	3.89	2.6 ± 0.3
AG1	Garhi Chandan	8	164	949.4	809	9366.9	0.93	3.89	2.4 ± 0.2

Note: constants utilized in fission-track age calculations:
Lambda-F = 7.03 × 10^{-17} yr^{-1}; Lambda-D = 1.55 × 10^{-10} yr^{-1}; Sigma-n = 580 × 10^{-24} cm^2; I = 0.00725.

TABLE 2. STATISTICALLY EXPECTED VERSUS OBSERVED REVERSALS

Location	T	N	T/aN	p	C(exp) ± 1σ	C(obs)
Dag	2.2	26	0.710	0.33	8.3 ± 2.4	6
Garhi Chandan	1.2	24	0.417	0.26	6.0 ± 2.1	7

T = duration of sedimentation (m.y.)
N = number of magnetic sites
a = mean duration of an interval of constant polarity = 120,000 yr
T/aN = sampling frequency
p = probability of finding a reversal at a given site
C(exp) = number of expected reversals in a MPS, given T and N
C(obs) = number of reversals observed

Note: data are based on models of Johnson and McGee (1983).

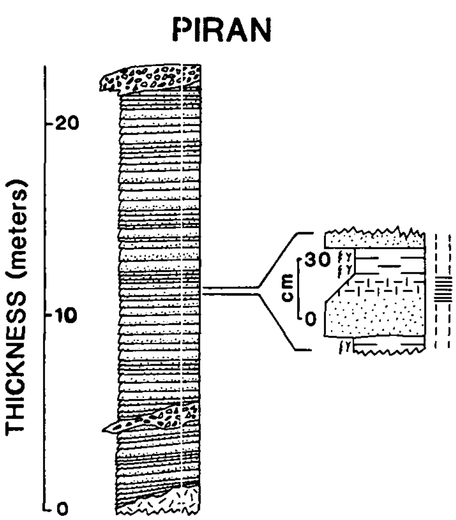

Figure 10. Measured section of cyclical sediments at Piran. Lithologies and sedimentary structures of a typical depositional unit are illustrated at the right. Below the colluvial zone at 4 m, the beds dip to the north at 10°, whereas above it, they dip at only 2° to the north.

ords from Dag and Garhi Chandan can be used to synthesize a record of basin development for at least the southern portion of the Peshawar basin. The highly deformed Murree sediments that underlie both sections dictate that significant disruption of the pre-existing foredeep basin occurred prior to the initiation of sedimentation in the newly formed Peshawar basin. No upper Miocene and lower Pliocene sediments that would be laterally equivalent to the Siwalik molasse of the Potwar Plateau (Fig. 1) have been observed within the Peshawar basin.

The basal Dag section (Fig. 6), dated at ~2.8 m.y. B.P., is interpreted as representing floodplains subjected to extensive pedogenic alteration. The mottling, coloration, and secondary carbonate accumulations resemble features attributed to "soil ripening," such as is observed in the Potwar Plateau (Visser and Johnson, 1978). A semi-arid to arid environment is suggested by the presence of abundant accumulations of secondary carbonate. These low-energy sediments are abruptly succeeded by subangular conglomerates that are inferred to represent alluvial-fan deposits. Paleocurrent directions determined from numerous imbricated clasts and local crossbeds indicate that these fans prograded to the north from the uplifting, ancestral Attock Range. The fanglomerates continue with only minor interruption to the top of the Dag sequence at 0.6 m.y. The proximity of the Dag section to the thrusted basin margin is reflected by the generally coarse nature of sedimentation. Short transport distances are indicated by the angularity of the conglomeratic clasts and by the local presence of matrix-supported debris flows (98 m, Fig. 6). This fan setting appears analogous to the "Trollheim-type" fan described by Miall (1978). Uplift and tilting of the intermontane-basin sediments terminated sedimentation at Dag sometime after ~0.6 m.y. ago.

A distinctive, white sandstone (35 m, Fig. 6) deposited ~2.5 m.y. ago is lithologically dissimilar to the enclosing reddened strata and resembles modern Indus River and Kabul River sediments. This suggests that, during initial stages of uplift of the ancestral Attock Range, the gradient near Dag was slight, such that rivers entering the Peshawar basin from the north were capable of transgressing across the gentle toes of the fans in the subsiding central basin. This interplay between local and far-traveled fluvial sequences is analogous to similar successions in the foredeep which comprise two distinctive components, each of which reflects either local or distant tectonic controls (Behrensmeyer and Tauxe, 1982; Raynolds and Johnson, in press).

Within strata <1.5 m.y. old, laminated lacustrine strata were deposited in several places in the Dag section, notably at 235 m, 285 m, and 305 m (Fig. 6). Although some clearly were deposited in abandoned channels, the cause of the other laminated mudstones is less clear. They may represent locally filled depressions on a distal fan surface. Alternatively, they may result from ponding caused by fluctuating local base levels within the Peshawar basin due to intermittent movement along the thrusts bordering the southern basin margin.

Rapid facies changes occur along traverses perpendicular to the basin margin. Because the Garhi Chandan section is contemporaneous with the Dag sequence but is located several kilometres farther north of the thrusted margin of the Attock Range (Fig. 2), it is possible to delineate clearly the changes in depositional environments that are encountered farther from the basin margin. The sedimentation at Garhi Chandan is more diverse and less dominated by fanglomerates than at Dag. Although the base of the Garhi Chandan sequence is in direct depositional contact with the underlying folded Murree rocks, no conglomerates are present in the basal 70 m of the section. The early stages of deposition at Garhi Chandan are estimated to have begun 0.1 to 0.2 m.y. after the oldest exposed sediments at Dag were deposited. Between 2.6 and 2.2 m.y. ago, pedogenically altered siltstones (Fig. 8) aggraded on low-relief floodplains, while laminated, but highly burrowed, mudstones accumulated in shallow lakes. Several pumiceous volcanic ashes, as much as 2 m thick and laterally extensive, are preserved within these fine-grained deposits. Off-lapping relationships with some of the exposed Murree rocks indicate that irregular topography existed on the basin floor at the inception of aggradation of the Garhi Chandan sequence. After 2.2 m.y. ago (above 70 m, Figs. 8 and 9), the character of sedimentation changed dramatically. In the more southerly section, lacustrine deposits are virtually absent, and sheet-like conglomerates alternate with pedogenically altered siltstones throughout the remainder of the section. This lithologic transition represents the initial progradation of the proximal, coarse-grained facies across the Garhi Chandan site. This change occurred ~400,000 years after the analogous event at Dag (Figs. 6 and 7) and represents a basinward progradation of high-energy conglomeratic facies. Based on the greater distance of the Garhi Chandan section from the mountain front, the mean rate of northward migration of the fan facies can be inferred as being ~2 cm/yr.

Analysis of >500 conglomeratic clasts shows that, although the basement directly below the section comprises Murree bedrock, the conglomerates are dominated by limestone clasts (67%) with subordinate quantities of Murree sediments (19%), chert and quartzite (6%), and metamorphic and igneous rock fragments (6%). Even where the conglomerates are in direct contact with the Murree bedrock (in areas adjacent to the measured sections), the limestone-to-Murree clast ratio is ~2:1. These compositions attest to the primary derivation of the conglomerates from the limestone-rich Attock Range that lies several kilometres to the south (Fig. 2).

The depositional setting envisioned for this portion of the section is a distal, coarse-grained braidplain characterized by gradual, lateral channel migration and broad interfluves that accumulated siltstones representing variable intervals of subaerial exposure and soil development. The upward fining cycles from coarse gravels to silts seen at Garhi Chandan (Fig. 8) are similar to those described for distal braided gravels of the Donjek River, Yukon (Williams and Rust, 1969; Miall, 1978). Based on the mean sediment-accumulation rate, channel migration across the Garhi Chandan area occurred every 70,000 yr, on the average.

Several conglomeratic layers that are traceable toward the basin center are seen to thin over a distance of a few kilometres (Fig. 5B) and become medium-grained sandstone units in the more northern section (Fig. 8). Over this distance, the conglomerate/siltstone alterations more proximal to the basin margin yielded to an environment dominated by lacustrine mudstones with minor sandstones and siltstones. If the average sediment-accumulation rate for the Gauss-to-Olduvai interval is applied to the post-Olduvai sediments, the shallow lacustrine and

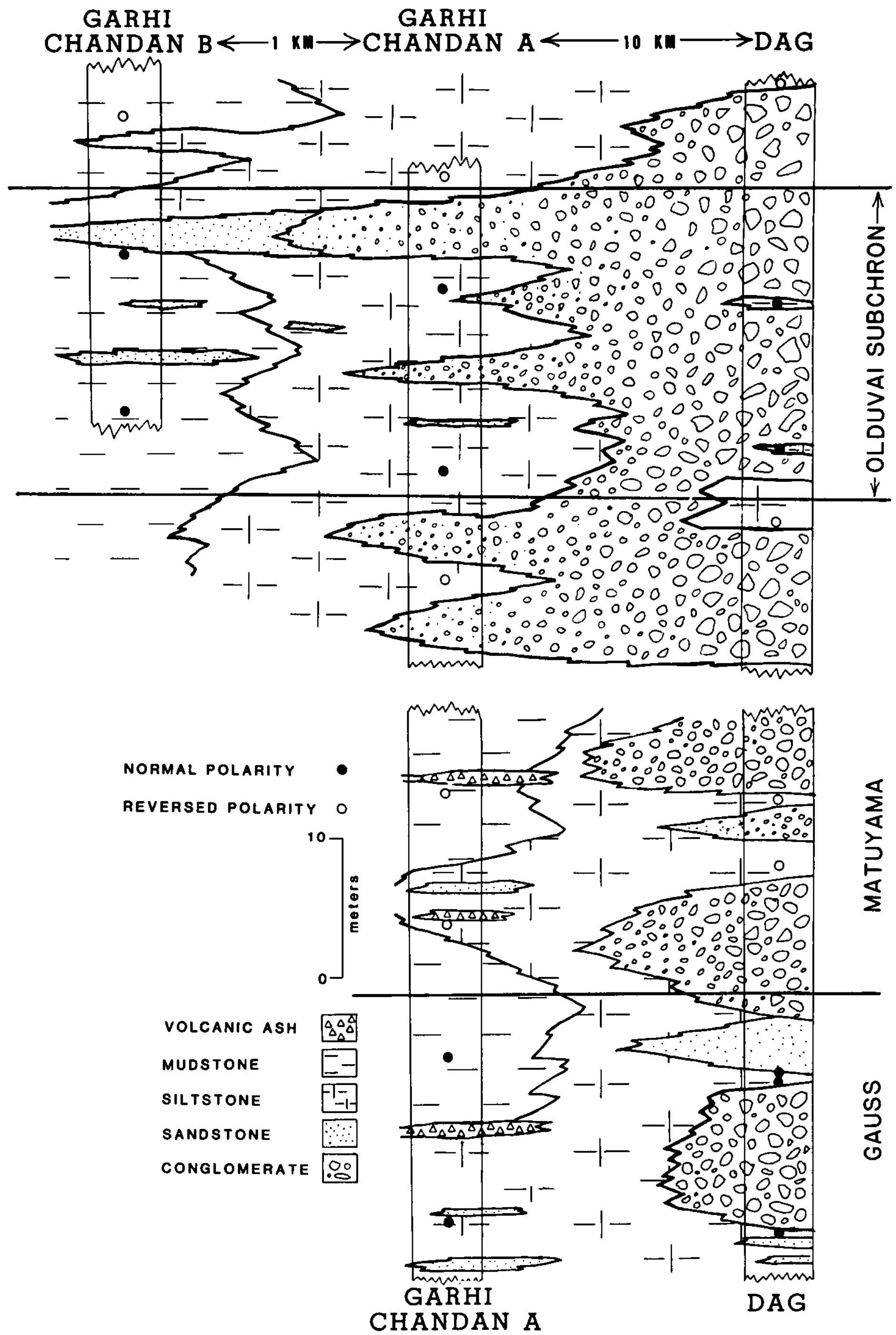

Figure 11. Time-transgressive facies relationships illustrated from dated sections at Dag and Garhi Chandan. Correlations between the sections are based on isochronous magnetic boundaries interpreted to be encompassed by each section. Around 2.5 m.y. ago, alluvial-fan sedimentation is confined to the more proximal Dag area, while lacustrine mudstones and low-energy fluvial sandstone and siltstone facies dominate the more distal Garhi Chandan area. Around the Olduvai subchron, 700,000 yr later, the distal fan facies have prograded sufficiently to cover intermittently the more proximal Garhi Chandan area with coarse conglomerates. However, rapid facies transitions occur between Garhi Chandan sections A and B such that only low-energy deposition is recorded in the more distal sequence despite the coarse conglomerates 1 km farther south.

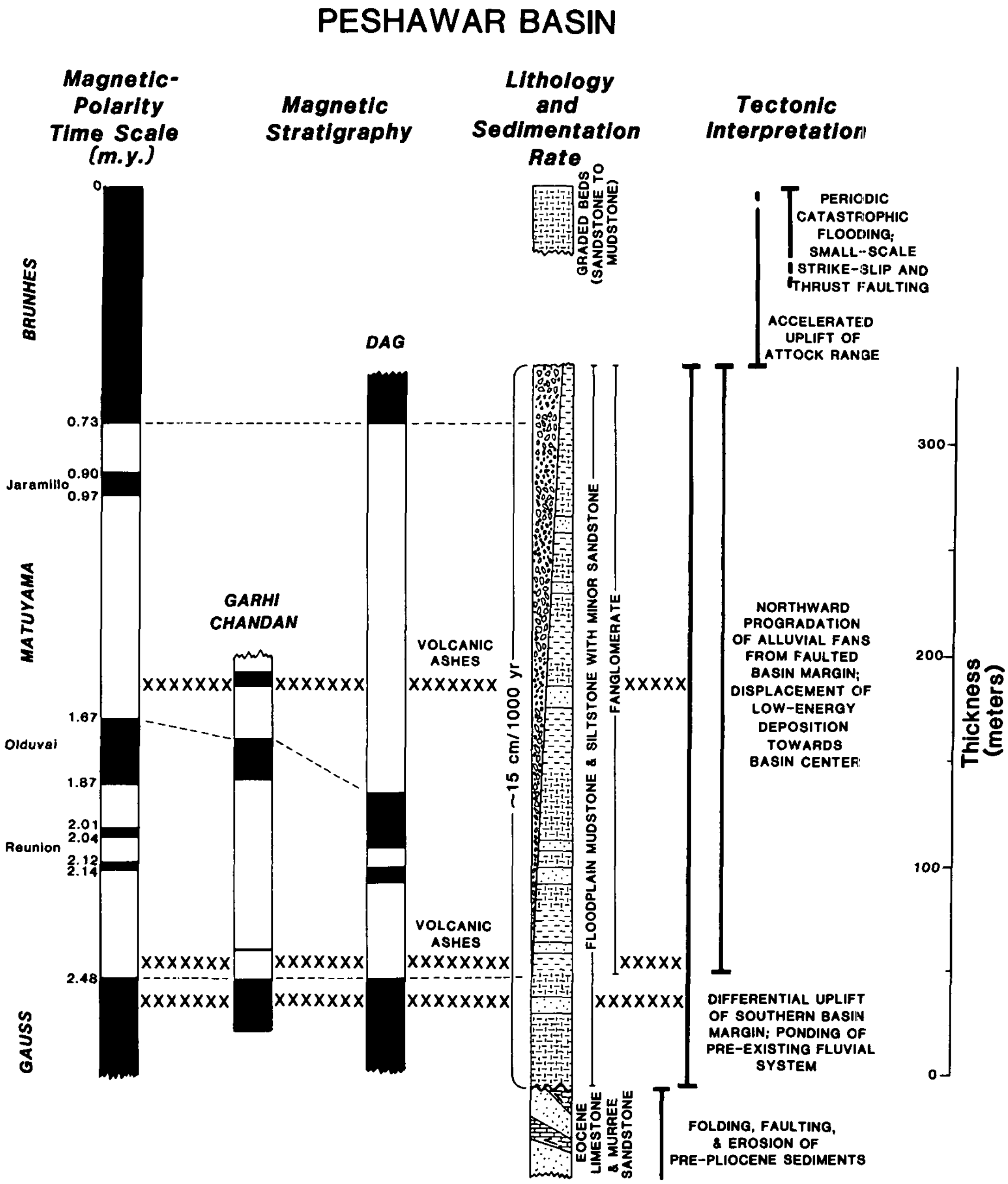

Figure 12. Summary diagram of the chronologic and stratigraphic data from the Peshawar basin. A tectonic interpretation of the lithofacies is presented on the right. Intermontane-basin development is initiated by differential uplift of the ancestral Attock Range. The resultant ponding of fluvial sediments within the Peshawar basin begins in the late Pliocene and continues through much of the Pleistocene. During this interval, tectonically modulated fanglomerates prograde northward across the basin margin and gradually displace the lower-energy environments toward the basin center. Accelerated uplift of the Attock Range terminated widespread intermontane-basin deposition after 600,000 yr ago. Subsequently, the catastrophic floods have periodically inundated the basin, and recent faulting has disrupted young, basin-filling sediments.

floodplain sediments at Garhi Chandan (sec. 2B, Figs. 8 and 9) would be expected to encompass ~150,000 yr.

During this post-Olduvai interval, two additional volcanic ashes were deposited in this area. These ashes are likely to be the stratigraphic equivalents of ashes dated at 1.6–1.8 m.y. B.P. in the Campbellpore basin and of other, immediately post-Olduvai ashes found in several additional localities across the Potwar Plateau (G. Johnson and others, 1982). This group of ashes, as well as the underlying cluster associated with the Gauss/Matuyama boundary, are inferred to have been erupted from the Dasht-e Nawar volcanic complex in east-central Afghanistan (G. Johnson and others, 1982). The ashes at Garhi Chandan are coarser-grained and more pumiceous than are ashes farther east in the Potwar. This supports the concept of an eruptive source to the west of the Peshawar basin.

The combined Dag and Garhi Chandan sections illustrate a systematic progression from medium-gradient alluvial fans proximal to the uplifted basin margin to extensive floodplains with increasingly abundant, shallow lacustrine environments toward the basin center. These facies relationships are convincingly illustrated through comparison of contemporaneous strata deposited ~2.5 m.y. ago (Gauss/Matuyama boundary) and deposited during the Olduvai subchron (Fig. 11). Although the record at Garhi Chandan is truncated by erosion of sediments that are less than ~1.4 m.y. old, the Dag sequence suggests that similar conditions persisted into the Brunhes chron.

The repetitive cycles of weakly consolidated graded beds found at Piran (Fig. 10) and along much of the northern margin of the exposed slates near Manki (Fig. 2) are interpreted as being catastrophic-flood deposits (Burbank, 1983b). The characteristics of the Piran deposits that resemble catastrophic-flood deposits recognized elsewhere (Waitt, 1980; Bunker, 1982) include the repetitive nature of the beds in which nearly all structures and textures are very similar from one cycle to the next; the bioturbated, mottled, and burrowed upper layer which suggests subaerial exposure between floods; the tendency to pinch and swell over bedrock irregularities; and the lateral continuity and largely unvarying character of each stratum.

Historical accounts (Abbott, 1848; Cunningham, 1854; Belcher, 1859) report catastrophic floods of the Indus River that occurred in 1826, 1833, 1841, and 1857. Consideration of the sedimentary characteristics of the Piran deposits and of the historical accounts of repeated inundations of the Peshawar basin during the last century strongly suggests that these beds resulted from catastrophic floods that were hydraulically ponded behind the Indus water gap at Attock. Although several floods may have resulted from glacial outburst floods in the higher mountain drainages (Cunningham, 1854), most were probably caused by landslides that blocked drainages in the high-relief areas north of the basin. This damming mechanism has been verified for at least the 1841 and 1858 floods (Belcher, 1859; Drew, 1875, p. 417).

The accelerated uplift during the Brunhes that caused folding and dissection of the Dag sediments is likely to have been associated with the emergence of the present Attock Range as a high-standing crest that attained elevations nearly 1,000 m above the adjacent valley floors. The minimum amount of uplift documented by the folded intermontane-basin sediments is ~300 m. This displacement yields an average uplift rate of 0.5 mm/yr for the past 600,000 yr. It is likely that total uplift of the Attock Range was considerably faster in rate and larger in magnitude.

The sediments at Piran (Figs. 2 and 10) provide a window on the depositional conditions that have existed during the later part of the Brunhes chron. The angular unconformity and the overlying colluvial layer within the Piran sequence (Fig. 10) demonstrate the presence of two generations of flood deposits separated by uplift along the Manki fault (Fig. 2) and by tilting and erosion of the underlying deposits. More recent, but undated, uplift has terminated fluvial deposition in the vicinity of Piran. Catastrophic floods of recent centuries have flooded only the lower-lying regions of the Peshawar basin.

Comparison with the Kashmir Basin

When the results from the Peshawar basin are compared with similar studies in the Kashmir basin (Fig. 1) (Burbank and Johnson, 1982, 1983), several notable contrasts are evident. Present-day exposures, drill holes, and geophysical data (Karunakaran and Rao, 1976) suggest a much thicker accumulation of basin-filling sediments in the Kashmir basin (>1,300 m) than in the Peshawar basin (>300 m). The Kashmir sequence, comprising the Karewa Formation, is dominated by lacustrine and deltaic sediments, whereas the Peshawar sediments are more fluvial and alluvial in nature where presently exposed. However, the abundance of floodpond and lacustrine sediments in both basins stands in stark contrast to the predominantly fluvial sedimentation that prevailed in the adjacent foredeep. Although both basins have experienced significant uplift along their southern margins during the Brunhes chron, late Pleistocene disruption of the basin fill through strike-slip and thrust faulting has been much more prevalent in the Peshawar basin. Finally, it has been conjectured that a coherent pulse of Pleistocene uplift created both basins (Wadia, 1928, 1931; de Terra and Paterson, 1939); however, the chronologic data indicate that the Kashmir basin began accumulating sediments at least 4 m.y. ago, about 1 m.y. earlier than did the Peshawar basin. Discrete and separate orogenic events on opposite sides of the Northwest Syntaxis thus were responsible for initiating formation of these two basins during the Pliocene. Additional chronologic data from the subsidiary Campbellpore basin south of the Attock Range (Opdyke and others, 1979; Johnson and others, 1982; Burbank, 1982) indicate that ~2 m.y. ago, a new episode of tectonism uplifted the Kala Chitta Range along the MBT (Figs. 1, 2), and, subsequently, sediments began to aggrade in this newly formed basin.

CONCLUSIONS

Recently acquired geochronologic and stratigraphic data can be used to synthesize the depositional and tectonic history of the Peshawar basin (Fig. 12). After a prolonged interval of folding, faulting, and erosion during the late Miocene and early Pliocene, intermontane-basin sediments began to aggrade in the Peshawar basin at least 2.8 m.y. ago. Since that time, >300 m of sediments have accumulated at rates averaging ~15 cm/1,000 yr along the southern margin of the basin. Beginning ~2.5 m.y. ago, alluvial fans derived from the uplifting Attock Range prograded northward at an inferred rate of ~2 cm/yr into the Peshawar basin near Dag. Prior to ~2.2 m.y. ago, low-relief surfaces existed and low-energy floodplain and floodpond sediments accumulated in the western part of the basin near Garhi Chandan. Subsequently, braided rivers, representing the distal, fluvial component of the prograding alluvial fans, repeatedly traversed the Garhi Chandan area. Concurrently, but closer to the center of the basin, lacustrine sediments aggraded in shallow lakes on extensive floodplains.

This pattern of sedimentation appears to have persisted into the early Brunhes chron. Extrabasinal, explosive volcanism spread ashes in two clusters across the Peshawar basin. The first group straddles the Gauss/Matuyama boundary, whereas the younger group follows immediately after the Olduvai subchron (Fig. 12). Accelerated uplift of the Attock Range after 0.6 m.y. ago caused folding and dissection of the sediments filling the Peshawar intermontane basin. Since that time, catastrophic floods have periodically inundated the basin. Tectonic disturbance of the basin fill has continued to the present time and is evidenced by tilted catastrophic-flood deposits, offset streams, disrupted terrace surfaces, and modern seismic activity.

Comparison of the chronologic data from Peshawar basin with other nearby intermontane basins indicates that it is intermediate in age between the Kashmir basin (>4 m.y.) and the Campbellpore basin (~2 m.y.). Rather than a coherent orogenic event leading to synchronous basin formation along the southern margin of the Himalaya-Hindu Kush Ranges, three separate episodes of thrusting and basin formation thus occurred during the Pliocene along the northern margin of the Indo-Gangetic foredeep.

ACKNOWLEDGMENTS

Logistical support and advice were received from colleagues at Dartmouth College, Peshawar University, and the Geological Survey of Pakistan at Peshawar. Thermal-demagnetization studies were conducted at the Lamont-Doherty Geological Observatory with the aid of N. D. Opdyke and D. V. Kent. All other magnetic measurements were made at the Woods Hole Oceanographic Institute with the generous assistance of C. R. Denham. Irradiation and calibration of the fission-track samples were provided by C. W. Naeser and P. K. Zeitler. The data presented herein are drawn largely from doctoral studies by one of us (D.W.B.) at Dartmouth College under the direction of Gary D. Johnson. Stimulating conversations with R.G.H. Raynolds, N. M. Johnson, P. K. Zeitler, and C. L. Drake are gratefully acknowledged. Reviews and suggestions by N. D. Opdyke and R. F. Butler improved this manuscript. This research was supported by National Science Foundation grants (EAR8018779, INT8019373) to Dartmouth College and by grants from the Richard E. Stoiber Field Fund, Amoco International; the Geological Society of America; and Marathon Oil to D. W. Burbank.

A. Hussain of the Geological Survey of Pakistan generously provided aerial photographic coverage of the northern margin of the Attock Range; R.G.H. Raynolds, R. Bloch, A. Hussain, T. Karim, F. Haqqani, and Mujeeburrahman assisted in the field studies.

REFERENCES CITED

Abbott, J., 1848, Report on the cataclysm of the Indus taken from the lips of an eyewitness: Asiatic Society of Bengal Journal, v. 17, p. 231–233.

Agrawal, D. P., Bhatt, D. K, Kusumgar, S., and Pant, R. K., 1981, The Neogene/Quaternary boundary in India: A review: Indian Academy of Sciences (Earth and Planetary Sciences) Proceedings, v. 90, p. 111–123.

Behrensmeyer, A. K., and Tauxe, L., 1982, Isochronous fluvial systems in Miocene deposits of northern Pakistan: Sedimentology, v. 29, p. 331–352.

Belcher, M., 1859, The flooding of the Indus; letter addressed to R. H. Davies: Asiatic Society of Bengal Journal, v. 27, p. 219–228.

Bunker, R. C., 1982, Evidence of multiple late-Wisconsin floods from glacial Lake Missoula in Badger Coulee, Washington: Quaternary Research, v. 18, p. 17–31.

Burbank, D. W., 1982, The chronologic and stratigraphic development of the Kashmir and Peshawar intermontane basins, northwestern Himalaya [Ph.D. thesis]: Hanover, New Hampshire, Dartmouth College, 291 p.

——— 1983a, The chronology of intermontane-basin development in the northwestern Himalaya and the evolution of the Northwest Syntaxis: Earth and Planetary Science Letters, v. 64, p. 77–92.

——— 1983b, Multiple episodes of catastrophic flooding in the Peshawar basin during the past 700,000 years: University of Peshawar Geological Bulletin, v. 16, p. 43–49.

——— 1984, A brief, normal-polarity magnetozone in the post-Olduvai sediments of northern Pakistan [abs.]: EOS (American Geophysical Union Transactions), v. 65, p. 864.

Burbank, D. W., and Johnson, G. D., 1982, Intermontane-basin development in the past 4 Myr in the northwest Himalaya: Nature, v. 298, p. 432–436.

——— 1983, The late Cenozoic chronologic and stratigraphic development of the Kashmir intermontane basin, northwestern Himalaya: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 43, p. 205–235.

Burbank, D. W., and Raynolds, R.G.H., 1984, Sequential late Cenozoic disruption of the northern Himalayan foredeep: Nature, v. 311, p. 114–118.

Calkins, J. A., Offield, T. W., Abdullah, S.K.M., and Ali, S. T., 1974, Geology of the southern Himalaya in Hazara, Pakistan, and adjacent areas: United States Geological Survey Professional Paper 716-C, 27 p.

Castro, J., Brown, L., and Condit, C., 1983, Paleomagnetic results from the Springervale-Show Low volcanic field, east-central Arizona [abs.]: EOS (American Geophysical Union Transactions), v. 64, p. 689.

Cotter, G. P., 1933, The geology of the part of the Attock District west of longitude 72 degrees, 45 minutes: Geological Survey of India Memoir, v. 55, p. 63–156.

Cunningham, A., 1854, Ladak, physical, statistical, historical, with notices of the surrounding countries: Sagar, Delhi, 483 p.

de Terra, H., and Paterson, T., 1939, Studies on the ice age in India and associated human cultures: Carnegie Institute of Washington Publication 493, 354 p.

Drew, F., 1875, Jammu and Kashmir state territories: London, Stanford, 234 p.

Fisher, R. A., 1953, Dispersion on a sphere: Royal Society of London Proceedings, v. A217, p. 295–305.

Gornitz, V., and Seeber, L., 1981, Morphotectonic analysis of the Hazara Arc region of the Himalayas, north Pakistan and northwest India: Tectonophysics, v. 74, p. 263–282.

Heirtzler, J. R., Dickson, G. O., Herron, E. M., Pitman, W. C., III, and Le Pichon, X., 1968, Marine magnetic anomalies, geomagnetic field reversals, and motions of the ocean floors and continents: Journal of Geophysical Research, v. 73, p. 2119–2136.

Hussain, A., and Karim, T., 1982, Geological map of the Attock Range: Geological Survey of Pakistan unpublished map.

Johnson, G. D., Zeitler, P. K., Naeser, C. W., Johnson, N. M., Summers, D. M., Frost, C. D., Opdyke, N. D., and Tahirkheli, R.A.K., 1982, Fission-track ages of late Neogene and Quaternary volcanic sediments, Siwalik Group, northern Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 37, p. 63–93.

Johnson, N. M., and McGee, V. E., 1983, Magnetic polarity stratigraphy: Stochastic assessment of data sets and sampling strategies: Journal of Geophysical Research, v. 88, p. 1214–1221.

Johnson, N. M., Opdyke, N. D., and Lindsay, E. H., 1975, Magnetic polarity stratigraphy of Plio-Pleistocene terrestrial deposits and vertebrate faunas, San Pedro Valley, Arizona: Geological Society of America Bulletin, v. 86, p. 5–12.

Johnson, N. M., Opdyke, N. D., Johnson, G. D., Lindsay, E. H., and Tahirkheli, R.A.K., 1982, Magnetic polarity stratigraphy and ages of Siwalik Group rocks of the Potwar Plateau, Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 37, p. 17–42.

Karunakaram, C., and Rao, A. R., 1976, Status of exploration for hydrocarbons in the Himalayan region—Contributions to stratigraphy and structure: New Delhi, 1976, Geological Survey of India Himalayan Geology Seminar Pamphlet, 72 p.

Kazmi, A. F., 1979, Active fault systems in Pakistan, *in* Farah, A., and de Jong, K., eds., Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, p. 285–294.

Kristjansson, L., Fridleifsson, I. B., and Watkins, N. D., 1978, Paleomagnetism of the Esja area, southwest Iceland [abs.]: EOS (American Geophysical Union Transactions), v. 59, p. 270.

Kusumgar, S., 1980, Geochronology of the palaeoclimatic events of the late Cenozoic period in the Kashmir Valley [Ph.D. dissert.]: Bombay, India, University of Bombay, 172 p.

Latif, M. A., 1970, Explanatory notes on the geology of southeastern Hazara to accompany the revised geological map: Jahrbuch der Geologischen Bundesanstalt, Sonderband 15, p. 5–19.

Malinconico, L. L., 1982, Structure of the Himalayan suture zone of Pakistan interpreted from gravity and magnetic data [Ph.D. dissert.]: Hanover, New Hampshire, Dartmouth College, 128 p.

Mankinen, E. A., and Dalrymple, G. B., 1979, Revised geomagnetic polarity time scale for the interval 0–5 m.y.B.P.: Journal of Geophysical Research, v. 84, p. 615–626.

McElhinny, M. W., 1973, Paleomagnetism and plate tectonics: Cambridge, England, Cambridge University Press, 358 p.

Meissner, C. R., Master, J. M., Rashid, M. A., and Hussain, M., 1974, Stratigraphy of the Kohat quadrangle, Pakistan: United States Geological Survey Professional Paper 716-D, 30 p.

Miall, A. D., 1978, Lithofacies types and vertical profile models in braided river deposits: A summary, *in* Miall, A. D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 597–604.

Molnar, P., Fitch, T. J., and Wu, F. T., 1973, Fault plane solutions of shallow earthquakes and contemporary tectonics in Asia: Earth and Planetary Science Letters, v. 19, p. 101–112.

Naeser, C. W., 1978, Fission-track dating: United States Geological Survey Open-File Report 76-190, 60 p.

Opdyke, N. D., Lindsay, E. H., Johnson, G. D., and Johnson, N. M. 1979, Magnetic polarity stratigraphy and vertebrate paleontology of the Upper Siwalik Subgroup of northern Pakistan: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 27, p. 1–34.

Pascoe, E. A., 1921, Petroleum in the Punjab and northwest frontier province: Geological Survey of India Memoirs, v. 40, p. 330–493.

Pennington, W. D., 1979, A summary of field and seismic observations of the Pattan earthquake, 28 December, 1974, *in* Farah, A., and deJong, K., eds., Geodynamics of Pakistan: Quetta, Geological Society of Pakistan, p. 143–148.

Quittmeyer, R. S., Farah, A., and Jacob, K. H., 1979, The seismicity of Pakistan and its relation to surface faults, *in* Farah, A., and deJong, K., eds., Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, p. 271–284.

Raynolds, R.G.H., 1980, The Plio-Pleistocene structural and stratigraphic evolution of the eastern Potwar Plateau, Pakistan [Ph.D. thesis]: Hanover, New Hampshire, Dartmouth College, 265 p.

Raynolds, R.G.H., and Johnson, G. D., Rates of Neogene depositional and deformational processes in the Himalayan foredeep, Pakistan: Geological Society of London Special Publication (in press).

Seeber, L., and Armbruster, J., 1979, Seismicity of the Hazara Arc in northern Pakistan: Decollement versus basement thrusting, *in* Farah, A., and deJong, K., eds., Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, p. 131–142.

Seeber, L., and Gornitz, V., 1983, River profiles along the Himalayan Arc as indicators of active tectonics: Tectonophysics, v. 92, p. 335–367.

Tahirkheli, R.A.K., 1970, The geology of the Attock-Cherat Range: University of Peshawar Geological Bulletin, v. 5, p. 1–26.

Tauxe, L., Kent, D. V., and Opdyke, N. D., 1980, Magnetic components contributing to the NRM of Middle Siwalik red beds: Earth and Planetary Science Letters, v. 47, p. 279–284.

Tauxe, L., Opdyke, N. D., Pasini, G., and Elmi, C., 1983, Age of the Plio-Pleistocene boundary in the Vrica section, southern Italy: Nature, v. 304, p. 125–129.

Vicary, M., 1851, On the geology of the Upper Punjab and Peshawar: Geological Society of London Quarterly Journal, v. 7, p. 38–46.

Visser, C. F., and Johnson, G. D., 1978, Tectonic control of late Pliocene molasse sedimentation in a portion of the Jhelum Re-entrant, Pakistan: Sonderdruck aus der Geologisches Rundschau, v. 67, p. 15–37.

Waagen, W., 1884, Section along the Indus from the Peshawar valley to the Salt Range: Geological Survey of India Records, v. 17, p. 118–123.

Wadia, D. N., 1928, The geology of Poonch State (Kashmir) and adjacent portions of the Punjab: Geological Survey of India Memoirs, v. 51, p. 2–155.

——— 1931, The syntaxis of the northwest Himalaya: Its rocks, tectonics, and orogeny: Geological Survey of India Records, v. 65, p. 189–220.

Waitt, R. B., 1980, About forty last-glacial Lake Missoula jokulhlaups through southern Washington: Journal of Geology, v. 88, p. 653–680.

Williams, P. F., and Rust, B. R., 1969, The sedimentology of a braided river: Journal of Sedimentary Petrology, v. 39, p. 649–679.

Wynne, A. B., 1877, Note on the Tertiary zone and underlying rocks in northwest Punjab: Geological Survey of India Records, v. 10, p. 107–132.

Yeats, R. S., 1982, Neotectonic setting of the southern Himalaya, northern Pakistan: Geological Society of America Abstracts with Programs, v. 14, p. 650.

MANUSCRIPT RECEIVED BY THE SOCIETY DECEMBER 9, 1983
REVISED MANUSCRIPT RECEIVED JULY 27, 1984
MANUSCRIPT ACCEPTED SEPTEMBER 11, 1984

Geological Society of America Bulletin

The magnetostratigraphy, fission-track dating, and stratigraphic evolution of the Peshawar intermontane basin, northern Pakistan

DOUGLAS W. BURBANK and R. A. KHAN TAHIRKHELI

Geological Society of America Bulletin 1985;96, no. 4;539-552
doi: 10.1130/0016-7606(1985)96<539:TMFDAS>2.0.CO;2

Notes