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Miocene Sediments and Faunas of Pakistan

Edited by **David R. Pilbeam**
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(Received 8 March 1979)

Abstract

The results of five field seasons of work on the Siwalik sediments of Northern Pakistan have greatly expanded our knowledge of these Miocene sediments and their vertebrate faunas. We have measured six long stratigraphic sections on the north limb of the Soan synclinorium near the town of Khaur. These columns, the longest of which is over 3,000 meters, provide the stratigraphic framework for our paleontological studies and give a detailed description of the lithological sequences in the Khaur region. We have concluded that the formational units of previous workers are poorly defined and of little practical value for biostratigraphy or chronostratigraphy. We recognize three major lithological facies: a blue-gray sand facies; a buff sand facies; and a silt/clay facies. The results of intensive paleomagnetic sampling allow a provisional correlation to the La Brecque magnetic time scale. The paleomagnetic sampling has also defined a series of isochrons, one of which we have followed laterally along a 30 km-long belt of outcrop. Certain lithological horizons may also be reliable chronostratigraphic markers.

We hypothesize that the two sand facies correspond to two separate river systems which co-existed for millions of years. The characteristics of the blue-gray sandstones suggest a large braided river carrying sediment derived from a freshly weathered terrain. The buff sandstones display characteristics of both meandering and braided channels. The sediments of this river system were derived from an area of intense weathering. The silt/clay facies represent levee and floodplain deposition. The pattern of interfingering of the two sandstone facies, with broad overlap on a scale of at least 30–40 km, indicates periodic fluctuations in the dominance of one or the other river system. These fluctuations are seen as the result of periodic, extensive influxes of the blue-gray system. Increased production of sand in the source area might have been the result of climatic or tectonic changes.

Fossils are usually found only in the buff sands or their laterally equivalent fine-grained floodplain and levee deposits. We recognize three types of fossil localities based on the characters of the fossil assemblages and the sediments. Localities in channel-related deposits were formed as composite events averaged over time and space, and therefore provide information suitable for paleoecological reconstructions. On the basis of appearances of key species we are provisionally defining a series of eleven biostratigraphic zones. These span the sequence from the Lower Siwaliks to the base of the Upper Siwaliks. The faunas of the three lowest zones show similarities to the Asteracian faunas of Europe and to the East African middle Miocene faunas. Zones 4 through 8 appear to be a period of faunal endemism although there are some resemblances to European and Asian faunas. Correlations of these middle zones are to Eurasian

localities dated between 10 and 8 million years (m.y.). Beginning in Zone 9 the faunal endemism is disturbed by a series of immigrations and emigrations. Most of the interchanges seem to be with Africa. Correlations suggest ages of 8 to 6 m.y. for Zones 9 and 10. Paleomagnetic evidence places the base of Zone 11 at 5.1 m.y.

Particularly important among the many thousands of fossils we have found are over one hundred new specimens of the hominoids *Ramapithecus, Gigantopithecus,* and *Sivapithecus.* Among the new finds are postcranial elements which can be attributed to these three hominoids. The bulk of the hominoid collection comes from a stratigraphic level provisionally dated at 9 m.y.

From the geological evidence we infer the large river systems were not stable through time. River floodplains were well drained with few lakes or ponds except in cut-off channels. Most of the time the shifting, braided channels of the buff river system were dominant, creating a mosaic of habitats by constant destruction and renewal of plant successions resulting in a vegetational mosaic of grassland, bush, and woodland. There is little detectable change in the trophic structure of the herbivores from Zone 1 through Zone 8. The faunal change in Zone 9 does suggest an underlying habitat change.

Foreword

Since 1973 many people have been involved in the Yale Peabody Museum-Geological Survey of Pakistan Siwalik Project. Simply listing them cannot possibly convey my debt to them.

1973–74 party: Glenn Conroy, Tony Gaston, Phillip Gingerich, Margaret Egan Gingerich, Grant Meyer, Mahmood Raza

1974–75 party: Grant Meyer, Tony Gaston, Martin Pickford, Jeff Barndt, Fred Sibley, John Barry, Wendy Barry, Mohammed Iqbal, Mahmood Raza, Catherine Badgley, Horace French;

1975–76 party: Grant Meyer, John Barry, Wendy Barry, Herbert Thomas, Mahmood Raza, Martin Pickford, Horace French, Mohammed Iqbal, Jane Conroy, Glenn Conroy, Tauqir Shuja, Louis Jacobs, Robert J. Poreda, Jeff Barndt, Holt Ardrey, W. William Bishop;

1976–77 party: John Barry, W. William Bishop, Andrew Hill, John Damuth, Martin Pickford, Grant Meyer, Louis Jacobs, Everett Lindsay, Iqbal Cheema, Lisa Tauxe, Mahmood Raza, Bruce MacFadden, Kay Behrensmeyer, Catherine Badgley, Horace French, Herbert Thomas, Pascal Tassy;

1977–78 party: Horace French, Iqbal Cheema, Louis Jacobs, Martin Pickford, John Barry, Kay Behrensmeyer, Pat Shayler, Marc Monaghan, Andrew Hill, Catherine Badgley, Lisa Tauxe, Mahmood Hassan, Bruce MacFadden, Bonnie Lipschutz.

I am especially indebted to Dr. A.N. Fatmi, then Director, Geological Survey of Pakistan, with whom I began this collaborative project in 1973, and to Dr. S.M. Ibrahim Shah, Director, Geological Survey of Pakistan, my current collaborator and Codirector with whom I have worked so amicably since 1974. The then Director General, Geological Survey of Pakistan, Mr. A.N. Khan, now Joint Secretary, Ministry of Fuel, Power, and Natural Resources, and the subsequent Directors General, Mr. S. Tayyab Ali and Dr. Asrakullah have been of tremendous assistance. The Geological Survey and the Ministry have given us their fullest cooperation at all stages. Various U.S. Government agencies have also been of great help.

I feel it necessary to single out a few people for special thanks. Mahmood Raza and Grant Meyer made it possible to begin and sustain the project. Martin Pickford performed prodigious feats of collecting and mapping. Horace French was always dependable. John

Barry was quietly efficient and creative throughout and now forms, with Kay Behrensmeyer, a productive team here at Yale as well as in the field. To these, and many, many others, I am eternally grateful.

The report is edited by me, Ibrahim Shah, Kay Behrensmeyer, and John Barry; substantial portions were written by Drs. Behrensmeyer and Barry. It benefited greatly from the attention of the "Khaur Collective," especially Drs. Lindsay and Jacobs, and Marc Monaghan. Names in parentheses following section titles indicate authors, or those with primary responsibility.

The work has been supported throughout by the National Science Foundation and the Smithsonian Foreign Currency Program: current grants are NSF BNS 772 5984 and SFCP FC80254100.

This report was completed in December 1978, after five seasons.

David R. Pilbeam

1. Introduction (Pilbeam)

It has been known for more than a century that the Neogene Siwalik Group rocks of Indo-Pakistan contained abundant faunal remains, including hominoid primates. In the past two decades particular attention has focussed on one of the Siwalik hominoids, *Ramapithecus punjabicus,* considered by many to be a likely early hominid. Whether hominids or not, the Siwalik primates were sampled from a time period during which hominids evidently differentiated (5 to 15 m.y.), and the demonstrable completeness of the sedimentary sequence is therefore particularly important.

Initial and quite detailed Siwalik faunal analyses were completed before the 1940s, and although there have been a few studies since then there is a considerable need for modern comparative and functional work on the fauna. In addition, earlier reports and syntheses concentrated on integrated faunal studies, little attempt being made to elucidate precise biostratigraphic ranges or to reconstruct species associations. Further, the geological surveys completed prior to 1973 were generally of extremely broad scope.

We began work in the Potwar Plateau of Pakistan (Figs. 1 and 2) in 1973 and have now completed five seasons. The research has involved collaborative field work by groups from the Geological Survey of Pakistan (GSP) led by Dr. S. M. Ibrahim Shah and the Peabody Museum of Natural History, Yale University (YPM). We have concentrated our efforts on Lower and Middle Siwalik rocks (roughly, those spanning middle and late Miocene and early Pliocene time), and have collaborated with a group from Howard University, also working with GSP and led by Dr. S. Taseer Hussain, who have worked on similar age rocks outside the Potwar Plateau. In addition, we have worked closely and exchanged personnel with a team from Peshawar–Dartmouth–Lamont–Arizona that has concentrated its efforts on Upper Siwalik rocks (late Pliocene and early Pleistocene).

The advantages of working in Siwalik Group rocks are considerable. They offer a virtually continuous record of the last 14 or 15 million years of Neogene time and make possible the potential definition of faunal community structures and habitats at a particular time, and of changes in communities and habitats through time, within a sequence that can be calibrated independently from the faunas. The disadvantages are that the predominantly fluvial sediments preserve relatively incomplete vertebrate remains, and that the tremendous scope of the project involves such a long term commitment of time, effort, and money.

The Potwar Plateau (Fig. 2) is a folded and faulted block of Neogene molassic sediment, roughly 20,000 km^2 in area. Much is covered by late Pleistocene alluvium, but middle Miocene through early Pleistocene sediments are widely exposed both on the Plateau and in river and stream channels. Sedimentation is repetitive, consisting in any one section of

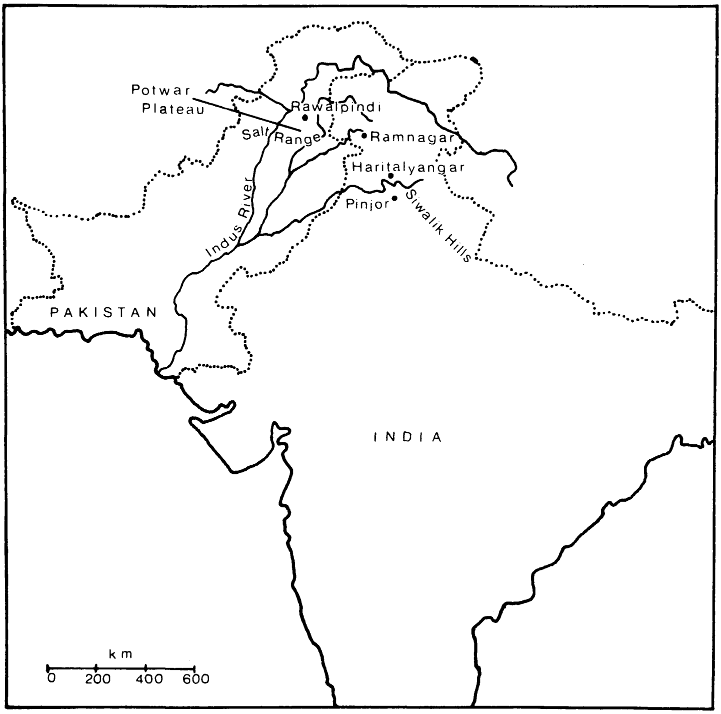


Fig. 1
Map of Indian subcontinent showing the location of the Potwar Plateau.

alternating silts/clays and sandstones. The sequence was divided by earlier workers into a series of formations (from oldest to youngest: Kamlial, Chinji, Nagri, Dhok Pathan, Tatrot, Pinjor; see, for example, Cotter, 1933) and into a set of successive faunas and time zones with the same sequence of names. With the recognition that the formational boundaries are frequently highly time-transgressive, and that a series of four or five discrete faunal units may underestimate the modality or complexity of faunal changes, we have tried to make a more realistic assessment of the situation by adopting an informal faunal zone terminology, tied to accurate and detailed stratigraphic mapping; we have also proposed new informal chronostratigraphic terms.

The classic faunas from the Potwar Plateau come mainly from three areas: Chinji-Nagri, Hasnot-Tatrot, and Dhok Pathan (Fig. 2). We have greatly expanded collecting in areas to the north and east of Dhok Pathan, around Khaur and Kaulial. Unfortunately, until recently collections from the three areas have been lumped together in faunal analyses; when they are separated it becomes clear that in each area somewhat different time periods are probably represented by the bulk of particular local samples. Thus collections from Chinji-Nagri largely antedate those from Dhok Pathan-Khaur and those in turn are mostly older than those from the Hasnot-Tatrot area.

Our first field season in 1973–74 involved reconnaissance around Chinji and Dhok Pathan, this being extended to the Khaur area in 1974–75. In 1975–76 and 1976–77 more systematic collecting and geological efforts were concentrated around Khaur and at Nagri. In 1977–78 preliminary work began at

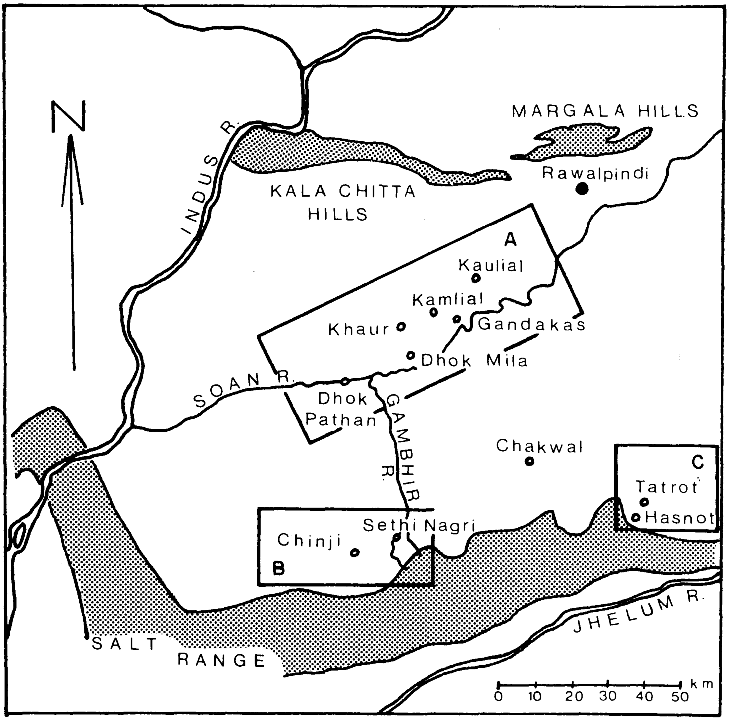


Fig. 2
Map of the Potwar Plateau showing the location of the three major research areas.
A) Dhok Pathan-Khaur-Kaulial; B) Chinji-Nagri;
C) Tatrot-Hasnot.

Hasnot-Tatrot. Our aims have been as far as possible to locate previously known sites, to fit these and any new localities to local and regional stratigraphic columns, to date the rocks and their contained faunas, to reconstruct past habitats, and to elucidate changing habitat and faunal patterns through time; all this we see as absolutely essential to a clearer understanding of hominoid evolution.

We believe that we have been relatively successful in achieving many of these aims. Results of the first four seasons were summarized in Pilbeam et al. (1977a, b) and a more expanded account of all five seasons is included here. We have a fairly good understanding now of the stratigraphic relationships of many earlier fossil discoveries, of Potwar lithostratigraphy and magnetostratigraphy, and an expanded knowledge of paleogeography and paleohabitats. In addition, we have collected many new fossils and are beginnig to understand better the patterns of faunal evolution and migration. Also, we have doubled the previously known collections of hominoid primates, expanding our knowledge of those species by perhaps an order of magnitude because many of the new specimens are significant in their completeness or in adding information about new body parts (postcranials, for example).

The first part of this paper surveys the geological work and is followed by a paleontological summary.

2. Geology

a. **Potwar Geology and Stratigraphy of Khaur Region** (Monaghan)

The Potwar Plateau of the Punjab Province, Pakistan (72° 30′ E, 33° 00′ N) is an elevated area of some 20,000 km^2, bounded to the north by the Kala Chitta and Margala Hills, south by the Salt Range, east by the Jhelum River and west by the Indus River. The plateau is underlain by Neogene molasse which was deposited in subsiding basins on the southern flanks of the rising Himalayas. After deposition the area was folded, eroded, and covered by Pleistocene alluvium. Substantial amounts of the Neogene rocks are exposed in canyons cut through the plateau. In the study area Neogene sediments form the Soan synclinorium, the axis of which runs roughly east-west, and are also exposed in anticlinal and monoclinal belts along its northern and southern margins. Sediment thickness in the study area exceeds 5,000 m.

Neogene sediments in the Potwar Plateau have been described and subdivided by a number of authors (Pilgrim, 1910 and 1913; Anderson, 1927; Cotter, 1933; Colbert, 1935; Lewis, 1937; Gill, 1952; Fatmi, 1973; and Pilbeam et al., 1977a and b). The work by Cotter, as represented in a geological map of the Khaur area (Fig. 3), reflects the results of work done by many of these authors and the framework within which many more recent workers discuss these sediments. To construct this map, particular lithological boundaries (e.g., Nagri-Dhok Pathan) assumed to be isochronous were strike-mapped out of an area of clear vertical lithofacies contrast into other areas where the vertical contrast was not always so clear (see Fig. 4).

In 1973 the Stratigraphic Committee of Pakistan formally defined purely lithostratigraphic nomenclature for these Neogene sediments:

Age	Formation	Lithology
early Pleistocene to late Pliocene	Soan (includes Tatrot and Pinjor of earlier workers)	Conglomerate, Sandstone, Siltstone and Clay
middle Pliocene to middle Miocene	Dhok Pathan	Sandstone and Clay
	Nagri	Sandstone
	Chinji	Claystone and Sandstone
middle Miocene to early Miocene	Kamlial	Sandstone
	Murree	Sandstone and Claystone

The lithostratigraphic nomenclature defined by the Stratigraphic Committee of Pakistan is virtually the same as that which was often used by earlier workers when describing bio- or chronostratigraphic units. This has resulted in some confusion.

The Khaur Area

The Khaur area lies on the northern flank of the Soan synclinorium. The major structures of the area are the Khaur and Dhulian anticlines (Fig. 3). Bedding plane dips vary between vertical and horizontal. In the fossiliferous part of the section, dips vary between 0 and 25° (to the southeast). Reverse faults of minor throw (1 to 20 feet) are uncommon but do occur throughout the study area.

Six long stratigraphic sections (2,000 meters) and many more short sections were measured by G. Meyer, M. Raza, A.K. Behrensmeyer, J. Barry, M. Monaghan and P. Shayler. Details are available on request from the archives of the Yale Peabody Museum. A summary of portions of the measured sections is given in Figure 5.

On the basis of studies done in 1978, sediments can be grouped into three lithofacies associations:

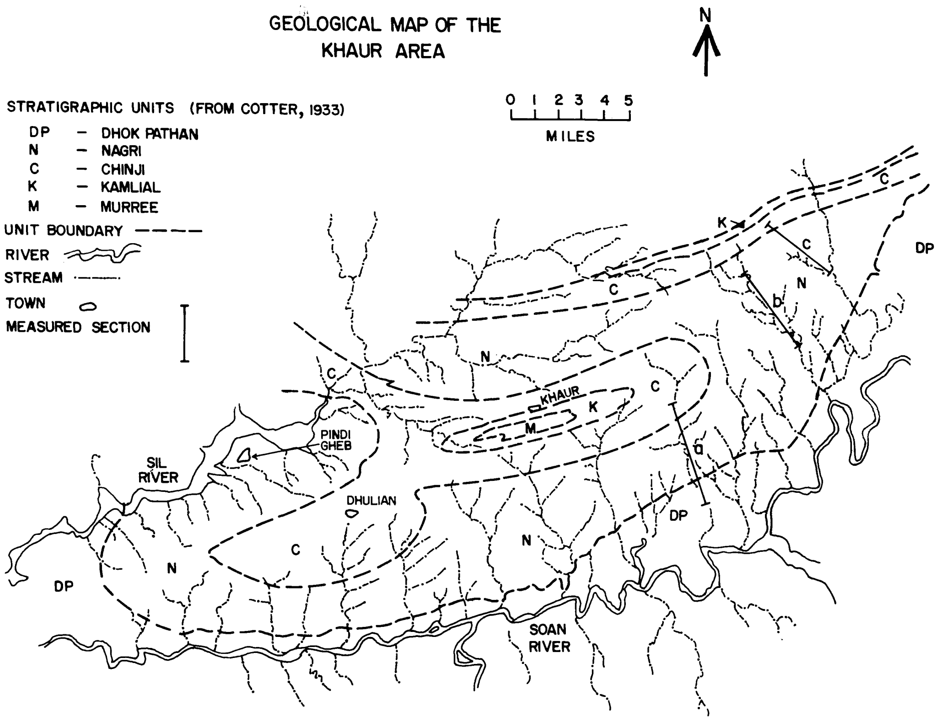


Fig. 3
Map of Dhok Pathan-Khaur-Kaulial area (*A* of Fig. 2) showing lithological units according to Cotter (1933) and location of measured sections.

1) The Blue-Gray Sand Facies, consisting of quartz, feldspar, hornblende, garnet, mica, and schist-clast rich, arenitic, angular, medium to fine grain, blue-gray sandstone and gray-green to blue-gray silts. The sandstones extend as sheets which laterally grade into silts over distances of several kilometers. Individual sandstones are up to 20 m in thickness. In some areas multistoried sandstones are formed by individual sandstones laid one upon another. These multistoried sandstones may be over 125 m in thickness. The sandstones are often cross and planar bedded, overwise massive. Conglomeratic layers are rare. The sheetlike nature of the sandstones and the continuity over great areas of paleosol horizons lying beneath and within a few feet of the base of these sheets indicate that the sandstones were laid down quickly and may be used as isochronous units.

2) The Buff Sand Facies, consisting of quartz, feldspar and garnet-rich, silty, subrounded, medium to fine grain, buff to yellow-brown sandstone. The sandstones are lenticular and complexly layered. Individual sandstones are rarely greater than 15 m in thickness. The sandstones are cross-bedded, and carbonate nodule conglomerate interbeds are common. The complex juxtaposition of buff sandstones and adjacent silt/clay layers indicates that

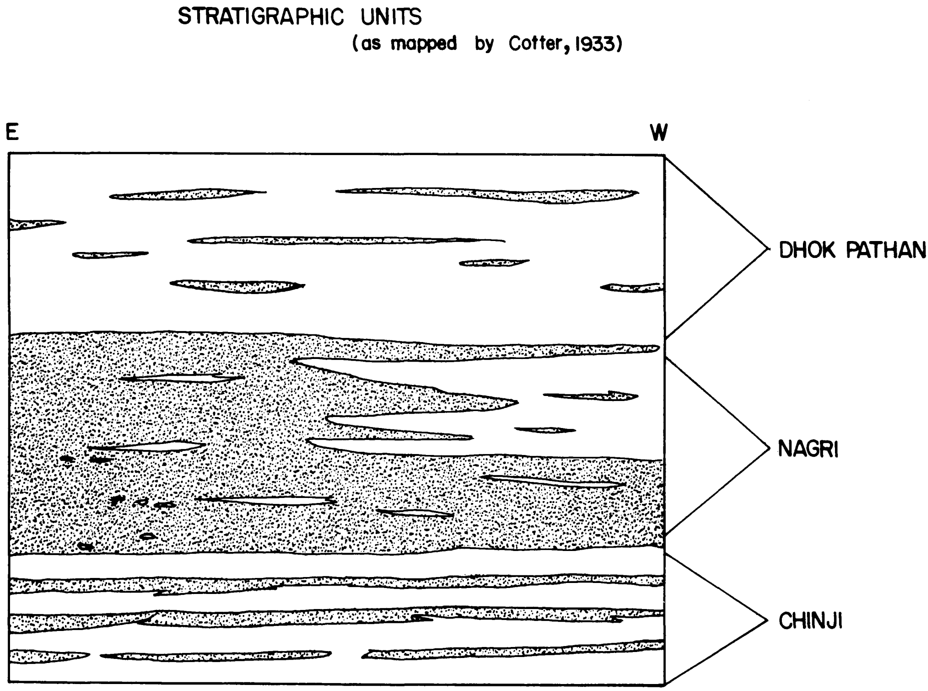


Fig. 4
Schematic diagrams showing the chronostratigraphic units mapped by Cotter (1933) and others. Major lithostratigraphic boundaries interfinger and if adhered to in mapping would not follow the chronostratigraphic boundaries (i.e., Nagri-Dhok Pathan boundary). Sand is stippled, silt-clay blank.

these sediments cannot be used as isochronous units.
3) The Silt/Clay Facies, consisting of indistinctly bedded, poorly sorted, red, brown and brown-orange silts and clays. Paleosol horizons are delineated by hematite and carbonate concretions, textural and color variations. This lithofacies is volumetrically dominant in the eastern part of the study area.

The Blue-Gray Sand Facies and the Buff Sand Facies interfinger and are interbedded. In general, the Buff Sand Facies and the Silt/Clay Facies are predominant lower in the section and eastward across the mapped area. Previous work by Gill (1951) and Cotter (1933) indicates that there is a west to east fining trend in the region. Thick, cobble conglomerates are found to the west of the town of Pindi Gheb in the unit mapped as Nagri by Cotter (Fig. 3).

At the present time our group uses lithofacies in a descriptive and environmental context and not in a chronostratigraphic context. More field mapping and section measuring is needed before we can describe and map boundaries of lithostratigraphic units on a regional scale. Further discussion on lithofacies is presented in a following section.

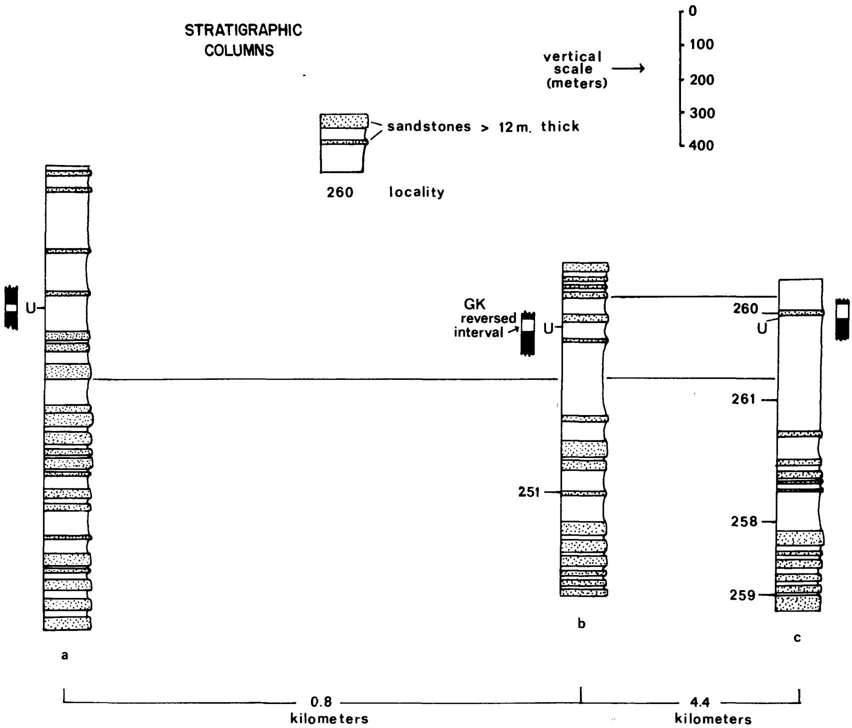


Fig. 5
Simplified measured sections corresponding to locations given in Figure 3. The position of the "U" sandstone, Ganda Kas reversed intervals, and representative fossil localities are shown. Solid lines connecting the columns are lithologically continuous horizons walked out between sections. Only sands thicker than 12 m are shown; thinner sands occur throughout the columns (i.e., "U").

b. Paleomagnetic Stratigraphy (Tauxe, Behrensmeyer)

Work is still in progress, but much has already been accomplished in identifying reversals of the Earth's magnetic field as preserved in the Siwalik rocks. The reversal pattern in stratigraphic sections, or paleomagnetic stratigraphy, is useful both in local and regional correlation.

The paleomagnetic stratigraphy of the Siwalik Group in the Khaur area (Figs. 6, 7, 8) has been studied by J. Barndt of Dartmouth College (1977) and L. Tauxe of Yale. Reconnaissance sampling by Barndt was done at widely spaced intervals through 3500 m of section to establish the broad pattern of polarity changes (Fig. 6). A general pattern consisting of a long period of dominantly normal polarity punctuated by several short reversals was identified on the northern rim of the Soan Syncline in the area mapped by Cotter as Nagri (Fig. 3). During 1976–77 and 1977–78, Tauxe sampled a second long column and also traced laterally several of the reversed

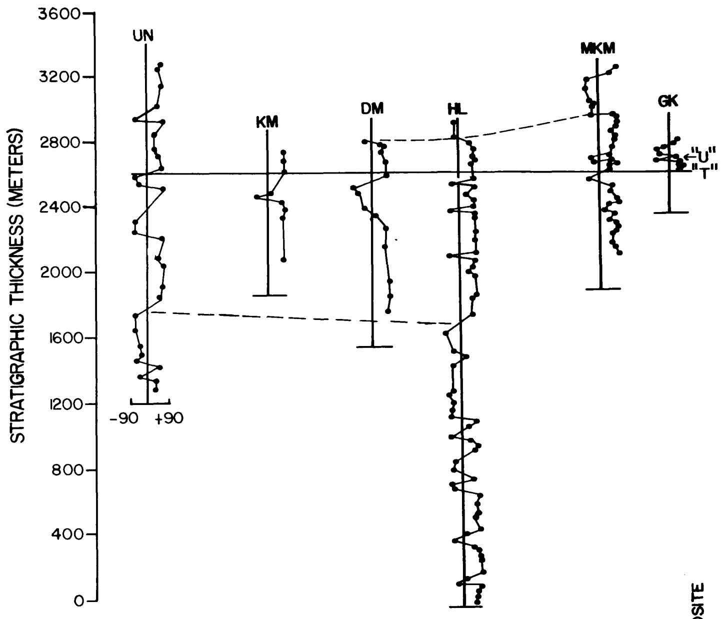


Fig. 6
Magnetic polarity sections from the Dhok Pathan-Khaur-Kaulial area. Positive values indicate normal polarity, negative values reversed (revised from Barndt et al., 1978).

UN) Utran Kas; *KM)* Khot Maliaran Kas; *DM)* Dhok Mila Kas; *HL)* Hasal Kas; *MKM)* Malhuwala Kas; *GK)* Ganda Kas. "U" and "T" are major blue-gray sand units.

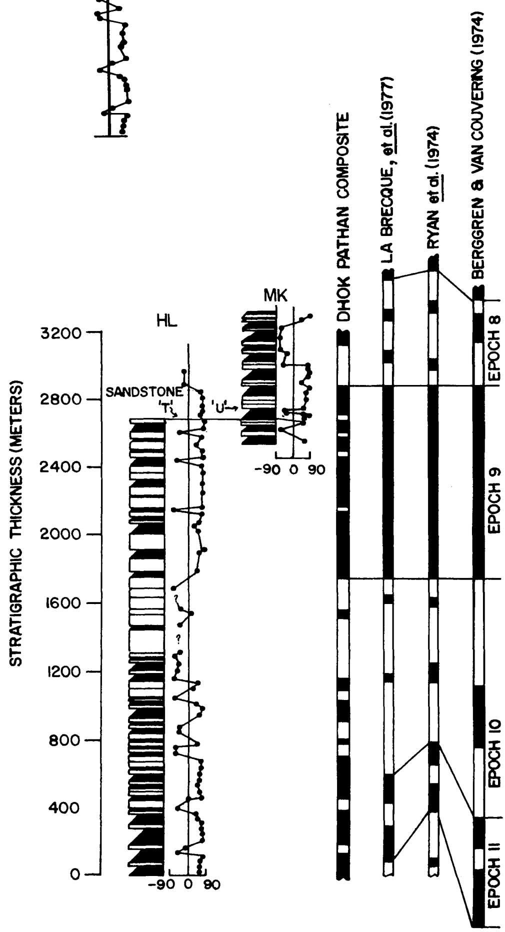


Fig. 7
Dhok Pathan-Khaur-Kaulial area composite section (Hasal Kas and Malhuwala Kas sections) compared with three published reversal scales (modified from Barndt et al., 1978).

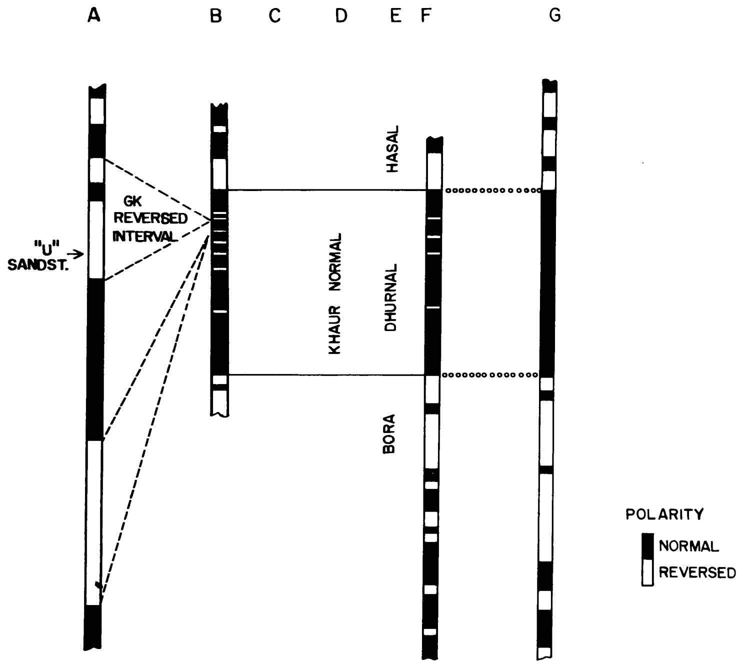


Fig. 8
Middle Siwalik magnetostratigraphy and probable correlation to standard magnetic polarity sequence, noting different levels of resolution.
A) composite of detailed sections (Tauxe, B.S. thesis, also Fig. 9); *B)* composite of regional magnetic stratigraphy (Tauxe, RK and KUL sections); *C)* magnetic subzones; *D)* magnetic zone; *E)* chronostratigraphic units; *F)* composite of regional magnetic stratigraphy (Barndt et al., 1978, HL and MKM sectional); *G)* magnetic polarity time scale (see Barndt et al., 1978).

events within the long normal zone of Barndt, using closely spaced vertical sampling to establish the details of the paleomagnetic record.

The magnetic memory, or remanence, of these rocks is carried by hematite, a highly stable iron-oxide. A complete study of the magnetic mineralogy is underway in order to determine definitely the time of acquisition of the remanence, but we presently believe that it was acquired either during or soon after deposition (Tauxe, in preparation).

Sampling of the Siwalik sediments for paleomagnetic purposes is constrained by a number of factors which ultimately affect the detail of local columns and therefore the reliability of magnetostratigraphic correlations. In the Khaur area, fine-grained lithologies suitable for paleomagnetic sampling make up less than 50% of the stratigraphic column. Sandstones up to or more than 125 m thick occur throughout the section, and sampling is restricted to the fine-grained sequences between them. Thus, due to the nature of the sedimentary record, it would be relatively easy to miss short-term polarity changes if sandstones represent significant segments of time. The working assumption has been that the dominant long-term reversal pattern should still be apparent in long stratigraphic sections, even at low sampling densities, and correlations can be made using "broad" patterns. However, lateral correlation of specific polarity changes can easily be complicated by the combined sampling problems, even over distances of a few kilometers.

Barndt (1977) sampled in five river channels (*kas*) which cut through the south-dipping sediments, from Utran Kas at Dhok Pathan to Ganda Kas (Figs. 6, 11). His longest paleomagnetic record is from Hasal Kas. This column includes a stratigraphically thick segment of normal polarity, with three reversed events, overlying a considerable thickness of alternately normal and reversed sediments. Using faunal correlations which suggest that the normal polarized section should be in the range of 8–11 m.y. in age, Barndt, et al. (1978) correlate the "long normal" in Hasal Kas to Epoch 9 and marine magnetic Anomaly 5 of the magnetic time scale (LaBrecque et al., 1977). Epoch 9 is thought to span some 1.5 m.y. and to fall between about 10.0 m.y. and 8.5 m.y.

A system of nomenclature for the magnetic stratigraphy is presented in Figure 8. We propose the name "Khaur Normal" for the long normal unit in the Khaur area, together with a local chronostratigraphic unit, which contains the Khaur Normal, called the "Dhurnal unit."

Tauxe concentrated her sampling further to the east from Ganda Kas, where fine-grained sediments make up more of the stratigraphic column. In Ratha Kas, 1300 m of section were sampled at an average density of 1 sample per 15–20 m. The upper and lower boundaries of the Khaur Normal have been identified in Ratha Kas and the Kaulial section has extended the paleomagnetic stratigraphy into younger rocks than Barndt's Malhuwala section (Fig. 8). Eight other short sections were sampled at higher densities (up to 1 per 2–3 m) along approximately 25 km of outcrops spanning the so-called "U" sandstone (Fig. 9). This sandstone has been used by us as a marker horizon for placing widely separated fossil localities in a stratigraphic framework. The "U" sandstone occurs in the sixth reversed "event" (from the bottom) in the composite section representing the Dhurnal unit (Fig. 9).

Samples spaced at intervals of 2–3 m spanning the "U" sandstone event in Ganda Kas show that the "event" is actually composed of two reversed and one short normal periods (Figs. 8, 9). These have been referred to informally as the Ganda Kas (GK) reversed interval. At least seven major reversed intervals characterize the Khaur Normal overall, rather than the four revealed by lower sampling density (Fig. 8). Tauxe has found that the number of reversals documented in a stratigraphic column increases with sampling density. Thus, there may be many more reversals in the Khaur Normal than have been detected so far. This presumably reflects the fact that sedimentation rates for fine-grained Siwalik sediments were often relatively higher than in the marine sediments where the current "standards" for the Miocene magnetostratigraphic record have been established. If so, then the reversal record in the Siwalik Group may eventually be more detailed than in marine deposits (though less continuous overall) and this must be taken into account in making correlations from region to region.

The paleomagnetic patterns vary laterally for the reversed interval (GK) which spans the "U" sandstone (Fig. 9). However, the initial reversal after a relatively thick sequence of normally polarized sediments can be identified within a few meters of the base of "U" in most of the laterally correlated sections. This correlation establishes the closest approximation yet possible for an isochron through the fluvial sediments. This isochron is essentially parallel to the base of the "U", which therefore appears to be isochronous in the study area. Lateral variation in thickness and

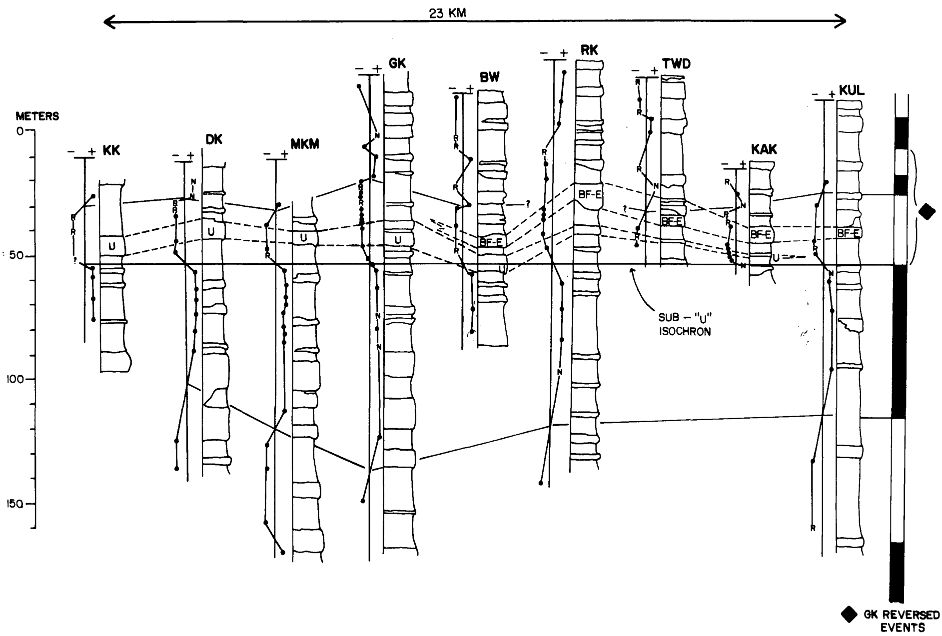


Fig. 9
Composite of all stratigraphic sections bracketing "U" and "Buff-E" sandstone horizons showing associated virtual geomagnetic pole latitudes. The dots (three specimens in good agreement using criteria of Irving, 1964) are Class I data; letters (*R* and *N*) are Class II data. For section abbreviations see Figure 6. Solid lines indicate paleomagnetic correlations, dashed lines lithologic correlations.

lithology of the "U" sandstone are described in the following section.

The stratigraphic and paleomagnetic records for the "U" level east of Ganda Kas lie in a direction nearly perpendicular (S–N) to the depositional axis (W–E, as indicated by paleocurrent directions; see Figs. 11, 12). The isochron indicates that lateral spread of sand away from this axis was not time transgressive, and that "U" (and presumably other similar sandstones) can be used as time markers in north-south exposures. However, the sands may be more time transgressive west to east, parallel to the depositional axis, and therefore less precise as chronostratigraphic markers in these directions.

The sediments included in the reversed interval discussed above can be compared laterally as representing contemporaneous sedimentary environments. Likewise, fossil localities included in these sediments can be compared for faunal differences that are due to ecological or taphonomic factors rather than evolutionary ones. This part of the analysis in the Khaur area remains to be done. It would be helpful to know the time represented by the entire reversed event, but at present there is no reliable information on the absolute time spanned by reversed events in the Khaur Normal. However, relative rates of sedimentation in the various laterally equivalent sections can be calculated, and this should provide some information on local areas of rapid ver-

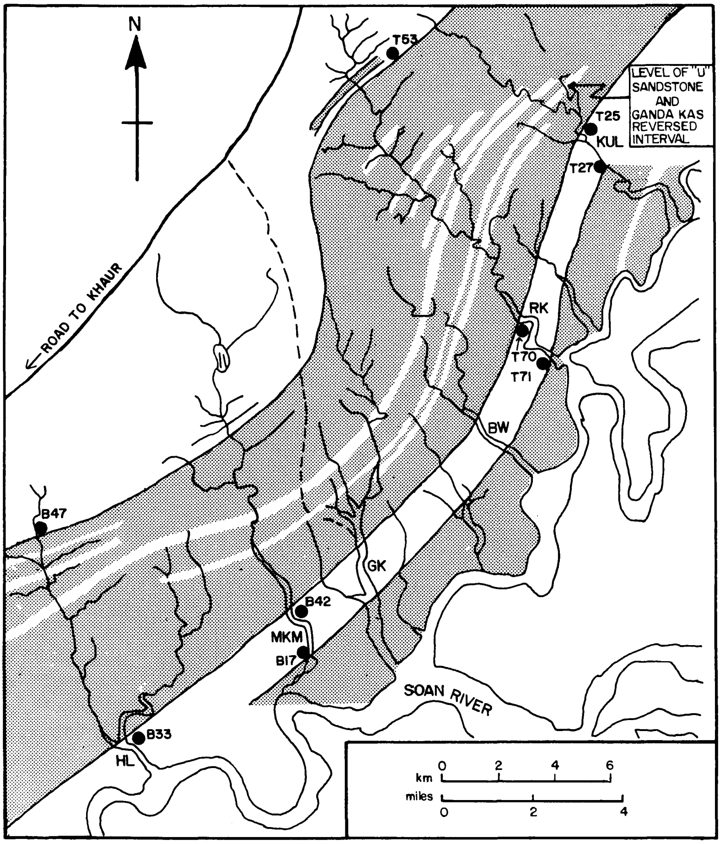


Fig. 10
Map of Khaur area showing normal (dots) and reversed areas; major normal region is the Khaur Normal zone. Letter abbreviations are as in Figure 6. Circles indicate polarity changes documented in long columns by Barndt (*B*) and Tauxe (*T*) The narrow reversed bands within the Khaur Normal zone are Tauxe's interpretation of the most probable correlations between reversed events in the various sections (see also Barndt et al., 1978, fig. 6).

sus slow sediment accumulation. This, in turn, should be interesting in relation to fossil-bearing horizons.

Accurate identification of field reversals in several columns spanning the Khaur Normal in addition to that at the "U" level will eventually permit other isochrons to be drawn through the section. The faunas and sediments in the Khaur area will then have a firmer chronostratigraphic framework which it is hoped can be extended to other areas. Patterns of evolution, community succession, extinction, and environmental change can be worked out in more detail using this relative time reference, even if its precise correlation to absolute time scales remains uncertain.

c. Lateral Lithofacies Relationships and Paleogeography (Behrensmeyer)

A study of lateral lithofacies variation in the fossil-bearing Siwalik sediments of the Khaur area (Fig. 11) was undertaken in 1978. The purposes of this study were to: 1) test the lateral continuity of prominent sandstone units used as local stratigraphic markers; 2) coordinate lateral stratigraphic sections with paleomagnetic sampling in order to identify isochronous surfaces in relation to the sediments; 3) provide information on the nature and scale of lateral variation in lithofacies in order to reconstruct paleogeography; 4) establish the relationship between "Nagri" and "Dhok Pathan" lithofacies in an area where they appear to interfinger (Pilgrim, 1910, 1913; Cotter, 1933; Lewis, 1937; Gill, 1951).

Previous work on lateral relationships of facies and sandstone correlations between the canyons or kas in the Khaur area by M. Pickford indicated that a number of the "blue-gray sandstones" could be followed along strike for many kilometers. Two of these sandstones, "U" and "T" originally designated by Pickford, were chosen for the 1978 study. In the type area of Pickford's sandstone units, Malhuwala Kas, these two units are interbedded in a sequence of buff-sand and silt-sand facies which include many of the important Miocene fossil localities. The methods used for study included mapping of the "U" sandstone and associated red beds over a distance of 30 km and measuring detailed sections through "U" at intervals along strike (Figs. 11, 12).
A total of 15 sections spanning 50 to over 100 m of stratigraphic thickness were measured (Fig. 12). Documented rock characteristics included texture, color, sedimentary structures, bedding thickness, diagenetic features such as carbonate nodules, and fossil content.

As noted by Monaghan in Section 2a, there are two distinctive types of sandstone in the Khaur area Middle Siwaliks sequence. The *blue-gray sandstone* is characterized by its distinctive color and is well sorted, clean and immature with angular quartz, chert and feldspar grains and abundant fresh mafic minerals and rock fragments. The *buff sandstone* is typically buff to gray-brown, more mature in composition with fewer mafic minerals and more weathered rock fragments and feldspars. Rock fragments are commonly permeated by hematite, and some hematitic staining occurs in the carbonate cement. The blue-gray sandstones occur as extensive sheets which grade laterally into finely bedded gray sands and silts. The buff sandstones occur as sheets and as lenses that abruptly thicken or thin and occasionally pass laterally into interbedded fine brown to red sands and silts. For the most part the two lithologies are distinct throughout the study area although a few occurences of apparent mixing have been noted. The blue-gray facies occurs more commonly low in the section (relative to the "T–U" level) and in the west toward Chouktriwali Kas (Fig. 11). Buff sandstones dominate the upper part of the section and are more common east of Ganda Kas.
In addition to the sandstones, the sedimentary sequence includes fine-grained deposits. These sediments are highly variable in texture and sorting, but all contain a significant amount of silt or clay. Color is typically red-brown but can vary from gray-brown to red-orange and yellow-brown. Bedding is variable but usually is indistinct in fine-scale, and there is evidence for extensive bioturbation and physical soil-forming processes.

In summary, the Siwalik sediments of the Khaur area can be characterized in terms of at least three major lithofacies:
1) the Blue–gray Sand Facies,
2) the Buff Sand Facies,
3) the Silt Clay Facies.
These lithological components are convenient in describing vertical and lateral variations in the overall stratigraphy. At finer levels of resolution they include significant degrees of variability which forms a limitless source of information for fine-scale paleoenvironmental and paleoecological studies.

The blue-gray sandstones allow definition of what have been informally called "cycles" in

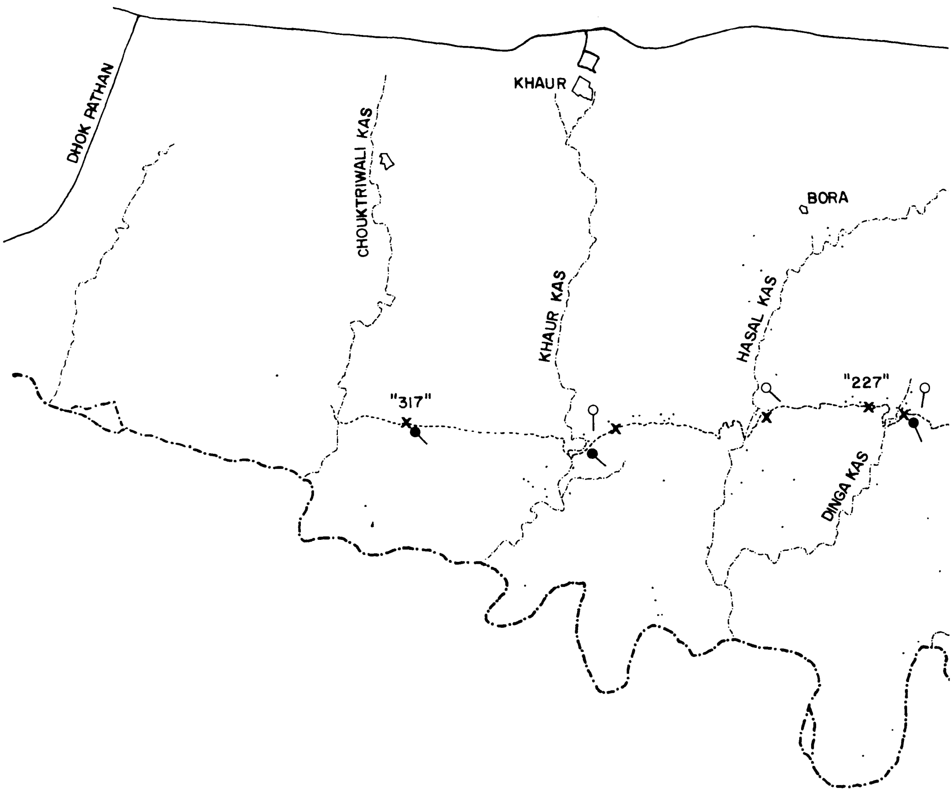
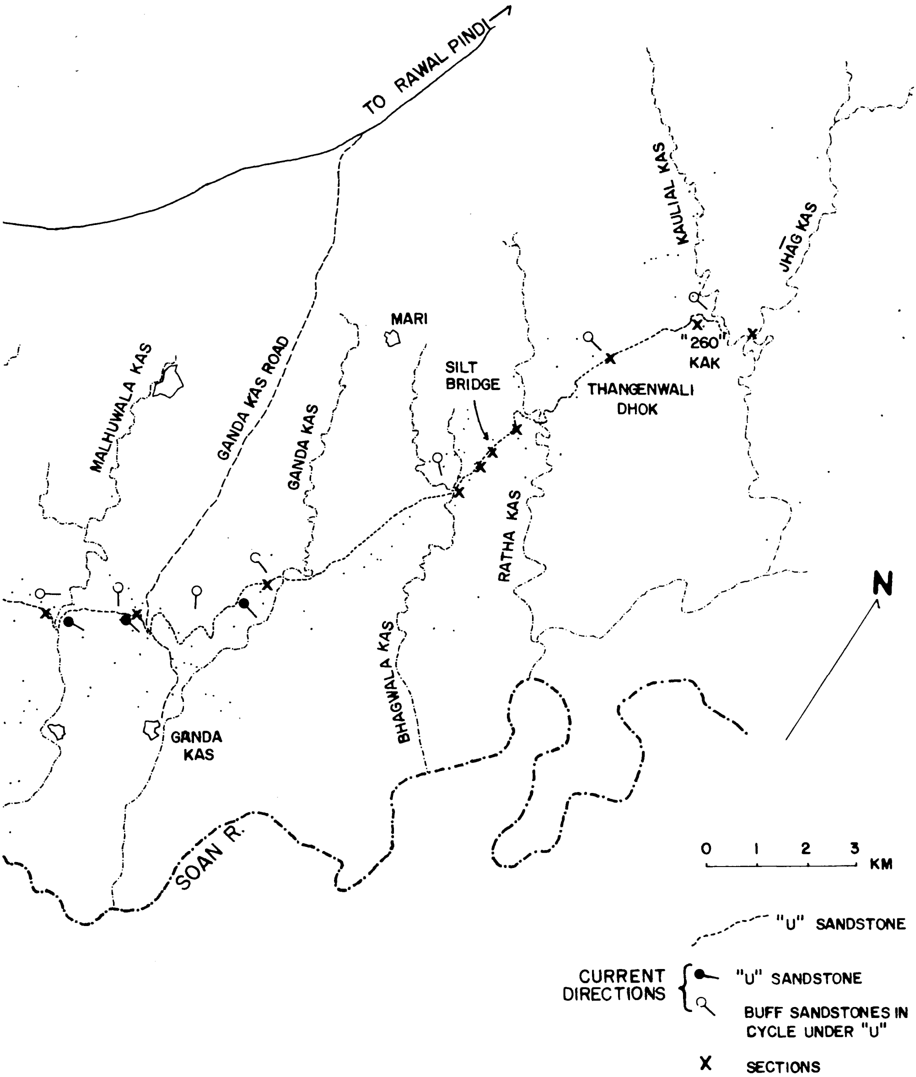


Fig. 11
Map of Khaur area showing positions of lateral sections ("Xs") along the "U" sandstone. Small dots indicate fossil localities. Current directions suggest that the trend for "U" (blue-gray) system is east-south-east while that for underlying buff sandstones is more southeast (current indicators averaged for each kas).


TO RAWAL PINDI
KAULIAL KAS
JHAG KAS
MARI
"260" KAK
SILT BRIDGE
THANGENWALI DHOK
MALHUWALA KAS
GANDA KAS ROAD
GANDA KAS
RATHA KAS
N
BHAGWALA KAS
GANDA KAS
SOAN R.
0 1 2 3 KM
"U" SANDSTONE
CURRENT DIRECTIONS
"U" SANDSTONE
BUFF SANDSTONES IN CYCLE UNDER "U"
X SECTIONS

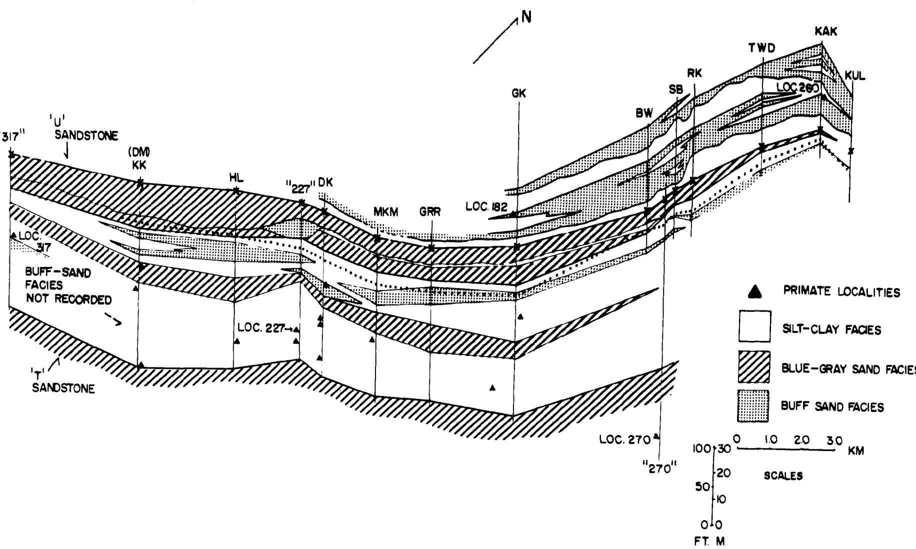


Fig. 12
Fence diagram showing the "U" sandstone and major overlying buff sandstones toward the northeast. Some of the buff sand bodies under "U" are indicated. Dotted line under "U" is the paleomagnetic isochron determined by Tauxe for the base of a reversed event in the Khaur Normal magnetozone as it related to the various lithofacies. Points at the top of "U" marked by "X" correspond to points marked by "X" on the map in Figure 11. Letter abbreviations for sections also correspond to kas or localities indicated in Figures 6 and 11.

the Khaur area. In the lower part of the section in Malhuwala Kas, a typical cycle consists of a 10–50 m thick blue-gray sandstone conformably overlain by 60–80 m of clay-silts which include buff sandstone lenses, interbedded red to buff silts and sands, thick beds of red, brown and orange silty clays and occasional units of drab gray to green thinly bedded sand and silt. The next blue-gray sandstone overlies these clay-silts on an erosional contact (generally with less than 3 m of relief).

The Middle Siwalik deposits have long been recognized as fluvial, and attempts have been made to designate the fluvial regime(s) as meandering and/or braided. In the Khaur area detailed study has shown that the depositional system was complex and was probably influenced by a number of factors including intrinsic cycling mechanisms of the river systems, tectonics, climate, and source materials. The sand deposits primarily represent river channel deposition. The blue-gray sandstone sheets, with their lateral continuity and complex bedding, suggest a braided river carrying a high proportion of sand. The buff sandstone lenses display characteristics of both meandering and braided channels, with cutbank and oxbow features, variable current directions, abrupt vertical alternation of sand and silt, and some point-bar facies. However, classic upward-fining fluvial bedding sequences are not common. The fine-grained deposits ("red beds") represent levee and floodplain deposition. Evidence for persistent floodplain swamps or lakes is notably scarce. Most of the silt and clays represent overbank deposition on land surfaces where bioturbation permitted relatively few primary bedding features to survive. The fine-grained sediments were contributed by overbank flow from both the braided and meandering channels.

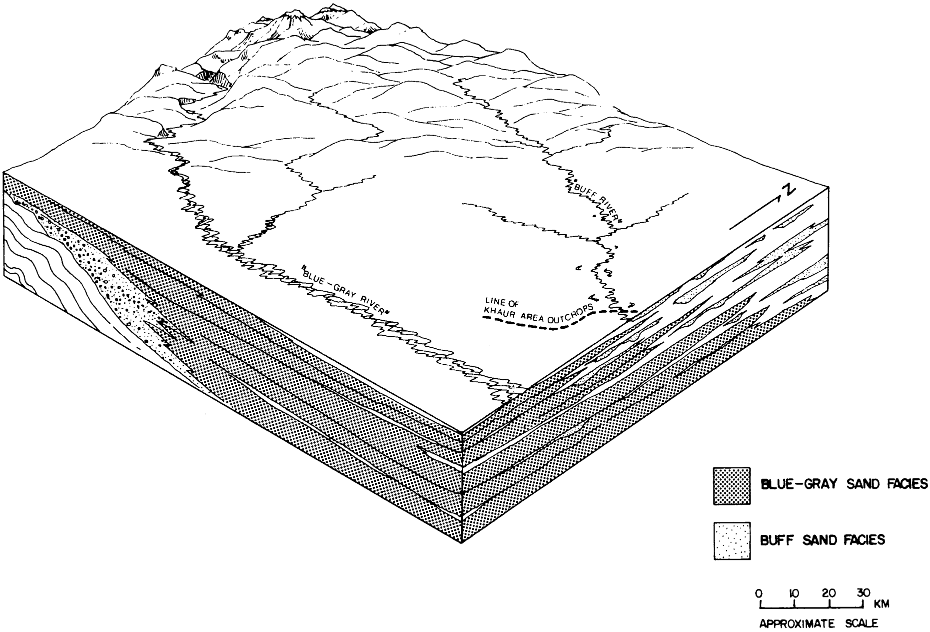


Fig. 13
Preliminary interpretation of the paleogeography of Khaur area Middle Siwalik deposits. Heavy dashed line indicates line of sections in Figure 12. Relative distance to mountain ranges is conjectural.

In the Khaur area, the sand deposits toward the west and the finer sediments toward the northeast apparently kept pace with each other as each system continued to aggrade. This balance probably was controlled by the rate of subsidence and the base level which both regimes shared.

The two sandstone types may represent two different paleo river systems in the Khaur area. In addition to the distinctive lithologies, other evidence supports this hypothesis: 1) current directions for the buff sandstones around the "U" sandstone level are consistently more variable and trend south to southeast, whereas those for the blue-gray sandstones are east to southeast (Fig. 11); 2) the tabular shape of the blue-gray sand bodies indicates a different fluvial regime from that of the more lenticular buff sand bodies; 3) the blue-gray sandstones at the "T–U" level thin and pass laterally into finely bedded sand and silt and eventually pinch out in a direction (N–NE) perpendicular to the east-trending currents (Figs. 11 and 12). Thickening of blue-gray sands south and west suggests that the main axis of blue-gray sand deposition lies in that direction, while that of the buff sand lies toward the north or east. Following the two-river hypothesis, a tentative overall paleogeography of the Khaur area at the "T–U" sandstone level is reconstructed in Figure 13.

Both river systems were contributing to aggradation in the same subsiding trough. Therefore, their differences are likely to be due to different conditions in the source areas. Braided streams indicate a load larger than the river is competent to transport, meandering streams are either at grade or are locally undersupplied in terms of sediment load. It seems that the source of the "blue-gray river" provided abundant fresh sand and little by way of chemical weathering products (clay, etc.), whereas the "buff river" drained an area of soils and sedimentary deposits with more fine-grained and chemically weathered material. Taking modern Himalayan geography as a model, the blue-gray river may have drained a high relief area from within the mountain ranges, such as the modern Indus does today, whereas the buff river drained a lower relief region on the southern margin of the mountains, as does the modern Jhelum. Current directions and depositional strike suggest that in the Miocene these rivers trended locally more southeast, perhaps following the axis of a trough formed by the junction of the Indian and Asian continental plates.

The pattern of interfingering of the two sandstone facies, with broad overlap on a scale of at least 30–40 km, indicates periodic fluctuations in the dominance of one or the other river system. Paleomagnetic sampling of the sediments associated with blue-gray sandstone "U" show that its base is essentially isochronous in the study area (Fig. 12). Thus it appears that the blue gray river occasionally swamped the region with great influxes of sand. These varied in lateral extent and decreased in importance upward in the middle Siwaliks deposits. The pulses of sand created the boundaries for the "cycles" which characterize these deposits near Khaur. The buff river seems to have been more persistent in its sedimentation patterns, dominating the Khaur area except when "displaced" by the blue-gray river.

Causes of the punctuated, extensive blue-gray sand influxes could be extrinsic (e.g., climatic, tectonic), intrinsic to the river system, or possibly a combination of both. Extrinsic effects, such as increased sand production in the source area, are attractive hypotheses because such controls on stratigraphic sequence imply a dominance of mega processes, which therefore could be inferred from local stratigraphy. However, more proximal, intrinsic processes must also be considered in explaining the blue-gray sandstones. Such intrinsic controls would include periodic "waves" of headward erosion (as suggested by Schumm, 1977) which might result in increased sand deposition relative to silt and also increased lateral spread of sands from river channels. Continuing work on both field evidence and sedimentation models will it is hoped develop ideas to help discriminate between intrinsic and extrinsic controls on the Siwalik stratigraphic sequences.

The lateral lithofacies study provides geological evidence for the paleoenvironments and paleogeography of the Miocene ecosystems of the Khaur area. There appear to have been at least two major rivers within 50–100 km of each other, the sandy and more braided blue-gray river to the southwest and the more meandering buff river to the northeast. Other smaller streams were present as well, and all drained off the rising Himalayan hills and mountains across what must have been a broad, coalescing piedmont fan (Fig. 13). Floodplains were relatively well drained with few lakes or ponds except in cut-off channels. Periodically sand from the blue-gray river spread across the Khaur area, temporarily altering the soil conditions and thereby affecting vegetation and fauna. For most of the time, however, the shifting channels of the buff river were dominant, creating a mosaic of habitats through constant renewal of plant successions near the channel axes. Most of the vertebrate fossils in the Khaur area are derived from deposits of the buff river system; thus it appears that either ecologic or taphonomic factors (or both) have favored preservation in this paleoenvironmental setting. From the paleogeographical reconstruction of the Khaur area we can infer that the fluvial environments associated with the Miocene faunas of the Dhurnal chronostratigraphic unit were homogeneous on a large scale and probably also through time. There may have been gradual ecological change toward the blue-gray river system, and relatively sudden shifts during periods of lateral spread of the blue-gray sands. On a smaller scale, the buff river system provided a mosaic of depositional environments and habitats. Habitats used by vertebrates probably varied over distances of 10–1,000 m, but were recurrent and relatively homogeneous over larger distances across the piedmont fan system.

d. Microstratigraphy and Taphonomy (Badgley)

In 1976 we began taphonomic field studies of the fossil accumulations and sediments at selected Potwar localities. This work has concentrated on analysis of both the sedimentary environments in which fossils occur and the characteristics of bone assemblages from different sedimentary environments. The purpose of these studies is to determine the nature of the preservational biases and how they affect the reconstruction of the Miocene community from fossil assemblages.

Most of the studied localities are in the Khaur region, although a few are near Chinji, Sethi Nagri, or Dhok Pathan. All of the Khaur area localities are in the upper half of the Dhurnal chronostratigraphic unit, as depicted in Figures 12 and 14. Although the Dhurnal chronostratigraphic unit spans about 1.5 m.y., there is little faunal change during this time period. Thus the studied fossil assemblages are derived from a single chronofauna. Study of the lateral variation of the representation of this fauna allows us to define taphonomic and ecologic effects on the faunal composition of the fossil localities.

We have made detailed field analyses of the stratigraphic and sedimentary features of 40 localities. Field data includes: composition and grain size, sorting, color, texture, bedding features, geometry, extent of bioturbation, lateral and vertical variation of fossiliferous units, and the relationships of fossiliferous units to adjacent strata.

At 14 of the 40 localities we made systematic surface samples of the fossils. Taphonomic information recorded from these samples includes: faunal and skeletal-part composition, variation in weathering stages present, completeness of each specimen, presence or absence of articulated material, signs of bone damage caused by carnivores or rodents, and (where possible) orientations of bones in the sediment. From these data the minimum number of individuals and the number of specimens per individual were calculated.

The results of the lateral lithofacies and microstratigraphic studies suggest that while isolated fossils are sparsely distributed throughout the stratigraphic interval studied, concentrations containing remains of more than one individual are regularly associated with only a few of the many lithologies present. In the Khaur area such concentrations seem to occur most often in the sediments of the buff-sand complex. Few concentrations are known from the extensive blue-gray sandstones or the laterally equivalent thin-bedded gray silts. This disparity may be partly related to the greater volume and areal exposure of the exposure of the buff sands and associated fine-grained deposits.

All fossil concentrations generally fall into one of three sedimentary contexts. This pattern is thought to reflect the transport history of each fossil assemblage. Within the sediments of the buff-sand system, the large concentrations of fossils tend to occur in the coarser-grained facies within, or close to, the domain of greatest current activity.

The most common deposits containing large bone concentrations are the intraformational conglomerates which usually occur within cross-bedded sandstones. These conglomerates and their fossils are interpreted as lag deposits associated with persistent current activity. The conglomerates are mixtures of clay- and silt-clasts derived from previously deposited floodplain deposits, plus calcareous nodules and algal oncolites of local origin, sand pebbles, and occasional pebbles foreign to the system. The matrix varies from moderately sorted sand to poorly sorted mixtures of clay, silt, and sand. Bioturbation of the sediments is minimal. Most of the bones are broken and show a wide variety of weathering stages. Animals of a large size range are present; the average number of bones per individual is low; and bones are never articulated.

The second most common fossil-bearing deposits are heterogeneous silty-sandy sediments marginal to cross-bedded sand bodies interpreted as channel axes. These channel margin deposits may have been formed in topographic depressions within a large sandstone body which were filled with finer, more heterogeneous sediment. Bioturbation structures are extensive, occurring as root casts, burrows, mottling, and footprints. Primary bedding features such as mud drapes, silt lenses, and thin sandy-silt layers are usually still in evidence. Most of the bones from localities in this lithology are broken and show a mixture of weathering states. Animals from a large size range are present and the average number of bones per individual is low, but slightly greater than in the conglomerate localities. Articulation of bones is rare. While the intraformational conglomerate localities show predominantly the influence of fluvial processes and little or no evidence of exposure as land-surfaces, the channel margin environments show the results of the operation of both fluvial and land-surface processes. This suggests an alternation between periods of fluvial deposition and periods of dessication which may have been accompanied by occupation of the site by plants and animals.

The third type of fossil-bearing deposit is the fine-grained floodplain sediments of the buff-sand system. The predominant lithologies are silt and clay with variable amounts of sand, so that the deposits vary from slightly sandy silt to silty clay and clayey silt. Colors include numerous hues of orange-brown, yellow-brown, red-brown, maroon-brown, and dark brown. Gray and gray-green fine-grained units are uncommon and rarely contain fossils. These fine-grained beds attain great thicknesses between prominent sandstones but few clues to their primary depositional mode are evident. The contacts between fine-grained units indicate both gradational and sudden changes in depositional mode but are never erosional. Primary bedding features are rare and presumably have been erased by bioturbating agents. The activity of these agents is evidenced by abundant small root casts and scars, burrows, and horizons of blue-gray mottling. All identified paleosol horizons occur within the fine-grained sequences and various soil-forming processes must also have affected the sediments. Taken together the features of the fine-grained units indicate they formed on aggrading land surfaces. Such localities sometimes contain many bones from a single individual. These bones are often intact and sometimes articulated.

The preliminary analysis of the microstratigraphic and surface-sampling data from 14 localities suggests to us several of the processes and events which may have been important in forming the fossil concentrations. For example, unusual breakage of large mammal bones indicates that the fresh bones were trampled before burial, while the presence in a fossil assemblage of specimens with different degrees of weathering indicates that a bone assemblage was formed over a substantial period of time. Similarly, the activities of carnivores and rodents are clearly shown by tooth marks and breakage patterns, and one unusual accumulation with several relatively complete small animals may have been a carnivore's food cache.

There are pronounced taphonomic differences between fossil assemblages from channel-related and floodplain-related localities. The effects of fluvial transport in accumulating bones from a large geographic area, thereby removing them from the site of death and possibly even reworking them from previously deposited sediments, dominate the intraformational conglomerate localities. In channel margin localities such effects are incomplete and there is a mixture of transported and untransported elements. In channel deposits skeletons may be widely dispersed and, while there may be large numbers of bones with many individuals and species, rarely is an individual represented by more than five bones and equally rarely are specimens articulated. In the fine-grained deposits, however, fluvial transport was weak or nonexistent and skeletons were widely dispersed only through the activities of predators and scavengers.

The sedimentary and taphonomic features indicate that channel-related localities were formed as composite events averaged over time and space. There is no evidence that any channel-related accumulations resulted from catastrophic mortality. The most common taxa in channel-related localities, as expressed by minimum numbers, are medium-sized bovids and equids (40–200 kg weight class), with tragulids, suids, giraffes, elephants, and rhinos well dispersed (present in many localities) but less abundant than bovids or equids. Carnivores are slightly less well dispersed but are often common where they occur. Hominoids follow the same pattern as carnivores but are generally rarer. Anthracotheres are uncommon and chalicotheres are very rare.

Large, high diversity localities in fine-grained deposits are uncommon. Most floodplain accumulations contain only a few taxa, but certain rare taxa have only been found in such localities. This distinction may be the result of habitat separation or differences in the preservation processes associated with fine-grained versus coarse-grained facies. The direct record of the biological properties of the preserved animals, such as habitat preference or behavior of predators is, we believe, best preserved in the floodplain localities, perhaps partially perserved in the channel margin deposits, and poorly preserved in the channel conglomerate deposits. However, since channel-related concentrations are time- and space-averaged, they may best record the species compositions and relative abundances of the Dhurnal chronofauna as a whole.

e. Summary

The essential descriptive framework for geological interpretation is now complete enough in the Khaur area to permit some preliminary interpretations and to indicate the most important directions for further research.

Long stratigraphic columns in six kas show that a broad pattern of vertical change occurs from lower through Middle Siwalik facies, corresponding to the Chinji-Nagri-Dhok Pathan Formations, as described by Fatmi (1973). Lateral variation in lithology on both a large and small scale makes boundary definition extremely difficult, however, and the three distinctive lithofacies cannot be regarded as simple, successive time-rock units in the Khaur area, or mapped in the sense of "proper" formations.

In the Khaur area, large-scale lithostratigraphic units are most easily defined on the basis of the thickness and lateral extent of the sandstones. Thin tabular sandstones are characteristic of the lower part of the section and are comparable to sandstones of the Chinji Fm. in its type area. These are overlain by a sequence of thick, blue-gray sandstones comparable to those of the Nagri Fm. in its type area. Thinner blue-gray and buff sandstones characterize the upper part of the Khaur sequence, and these can be traced laterally to the type section of the Dhok Pathan Fm. Over approximately 40 km of laterally continuous exposures in the Khaur area, there is a marked decrease in the proportion of sand in section from west to east, and the transition zone between thick, Nagri-type sandstones and the Dhok Pathan lithofacies drops lower in the section in this direction as well. Because of the problems in mapping boundaries between the three dominant lithofacies and in correlating them to the type areas for the Chinji and Nagri Fms., at present we prefer to use "Chinji lithofacies" and "Nagri lithofacies" rather than "formation" in referring to these divisions of the Khaur section.

Measured stratigraphic sections document between 1,000 and 2,000 m of continuous deposits bearing Miocene faunas. Work aimed at dividing this long column into bio- and chronostratigraphic units is well under way. Paleomagnetic reversal patterns have established a provisional temporal framework for environmental and faunal studies in the Khaur area. If a relatively long normal period, locally named the Khaur Normal, is equivalent to Epoch 9 of the marine sedimentary paleomagnetic record and to Anomaly 5 of the marine magnetic anomaly time scale (Barndt et al., 1978), then many of the fossil localities are between about 8 and 10 m.y. in age. Informal biostratigraphic zonation of the section based on the mammalian faunas will be discussed later.

Detailed study of lateral facies near the top of the Dhurnal chronostratigraphic unit (which records the Khaur Normal period) shows that the sedimentary deposits resulted from a complex of fluvial systems rather than a single aggrading river. The rivers responsible for the Khaur area sediments probably drained topographically different areas of the rising Himalayas. Evidence suggests that the Khaur area lay on the distal portions of coalescing, low-angle alluvial fans in a subsiding trough which paralleled the suture line of the Indian and Asian plates. East to southeast current directions indicate that the rivers at this time may have flowed along this trough rather than southward as does the modern Indus River. One of the major river systems in the Khaur area periodically deposited widespread sheets of blue-gray sand and sandy silt. One of these sand sheets, the "U" sandstone, appears to be essentially isochronous based on paleomagnetic correlations, and others probably are as well. The other major system deposited buff sands and red-brown, fine-grained sediments in a less clearly repetitive pattern than the blue-gray river system. Differences in the patterns of sedimentation may be related to source area tectonics and climate, or both, or to processes intrinsic to the river systems.

Nagri lithofacies in the Khaur area correspond to thick, multistoried sand deposits of the blue-gray river system. The Dhok Pathan Fm. consists of interfingering deposits of the buff and blue-gray river systems. Thus, the terms "Nagri" and the "Dhok Pathan," which have been used not only as formational names but also as bio- and chronostratigraphic entities, actually appear to be rock bodies that represent the fluctuations in space and time of two (or more) contemporaneous river systems draining different parts of the rising Himalayas.

Fossil vertebrates are found primarily associated with the buff sand system, in discrete patches or low density scatters in specific microfacies. The densest concentrations occur in carbonate-clast conglomerates in channels, in mixed sand and silt facies at the tops of channels and occasionally in fine-grained overbank deposits. Low-density scatters are found in most channel sands, and isolated bones occur rarely in the fine-grained red beds. The taxa represented tend to be more diverse in the channel-related deposits. Skeletal part ratios indicate that assemblages in channel lag sediments are most altered by fluvial sorting. The localities in the upper part of the Dhurnal unit are usually characterized by numerous remains of *Hipparion* and medium-sized bovids; suids, elephants, rhinos, tragulids, and giraffes are also present. Anthracotheres, primates, and chalicotheres occur less commonly. The patterns of occurrence of these groups may reflect characteristics of the original mammal community.

The geological evidence for paleoenvironments indicates broadly homogeneous, well-drained fluvial plains with smaller-scale environmental mosaics associated with the channel axes. Sands at or near the ground surface were probably important as aquifers and their areal distribution may have exerted considerable control on vegetational patterns, particularly if the climate was strongly seasonal.

3. Paleontology

a. Introduction

A general outline of biostratigraphy and biochronogy has been given in Pilbeam et al., 1977a. Since that report was compiled we have collected more specimens, expanded our stratigraphic knowledge, and become aware of several new problems and issues. What follows is a brief account of our knowledge of the fauna, first assessed by taxonomic group: almost all of the groups are undergoing revision and reanalysis and we can expect significant advances in our knowledge soon. At the moment, these brief accounts should be regarded as provisional. Second, we discuss biostratigraphic and biochronologic implications before analyzing the possible significance of the fauna in assessing intercontinental migrations and past habitats. However, before the faunal analyses we start with sections describing our progress in electronic data processing, and follow this with a general discussion of our approach to geochronology.

b. Electronic Data Processing (Barry)

I. Introduction

With nearly 15,000 specimens from over 350 localities and an ever increasing complexity of relevant data even the most basic analysis is a formidable task. Therefore, one objective of the YPM-GSP Siwalik Project has been the development of a computer-based data retrieval system which would serve not only as a collection management tool but also as an aid to research.

Data retrieval, as distinct from other aspects of electronic data processing, is the searching of a file of data records by a computer for those records that contain some particular item of information — for example, records of specimens found at one particular locality. A data retrieval system uses logical expressions to select a record that meets the stated conditions; it may then print the entire record or abstract some part of it. A computer thus can be used to organize the data, and because of the speed at which it operates, a computer-based data retrieval system can efficiently sift through a file containing thousands of individual records.

To date the following has been accomplished:
1) We have determined the categories of information needed in the specimen file and developed a workable coding system.
2) We have collected data on approximately 4,000 fossils including all those found during the 1977 and 1978 field seasons plus all of the primates, carnivores, giraffes and anthracotheres. In addition, records are now being compiled for all of the bovids, suids, tragulids, rodents, rhinos, proboscideans, birds, and a large fraction of the equids. When completed, this will bring the specimen file up to approximately 10,000 records. Data have also been collected on part of the 1932 Lewis (YPM) collection.
3) Over 4,000 of these records are now written on magnetic disks and are available for use.
4) We have written and proofed a series of system programs (Barry, n.d.). These include file creation and maintenance programs as well as sorting and retrieval programs.

The Society of Vertebrate Paleontologists has published guidelines (S.V.P. News Bulletin No. 97) concerning data conventions in vertebrate paleontology. Those guidelines recommend several categories of data which we find are not relevant to our proposed research although some are implicit in our locality category (i.e., all levels of geographic and stratigraphic data). Furthermore, we have made major modifications in recording other categories, principally the skeletal element descriptions. Three of our categories (Taphonomic Indicators, Size, and Hydraulic Sorting Factors) are entirely new.

Each record is a fixed length, alphanumeric character string 84 characters long. Data categories are organized as fields having a fixed position within the record, whereas the file is a matrix with individual records as rows. Thus any one value can be accessed by indexing both row and columns. Indexing for row alone accesses an entire record and indexing for column accesses all values for any category.

Information is generally coded either directly with a numeric code, or with a binary present/absent code. The third data category is something of an exception and because of its complexity needs special comment. In this category, information is coded with a series of abbreviations in seven separate fields, four of which are independently searchable (Primary, Side, Condition, and Wear). The other three subcategories modify the Primary field and can only be used in conjunction with it. They may be used either separately or in combinations.

Currently we have four specimen files: 1) PRIMATE, which contains only the records of the Primates; 2) CARNIVORE, which contains only the records of carnivores; 3) MAMMAL, which contains the records of all the mammals; and 4) MASTER, which contains the records of all catalogued specimens. We also contemplate using locality files in the future but the data standards for them are still being developed. Data files are stored in on-line disk storage and are accessible from the APL (A Programming Language) language through the APL auxiliary processors. Small data files may also be stored in on-line storage as part of named APL workspaces which also contain processing programs. With files of more than 1,000 records, however, this is not a cost-effective technique. We also maintain backup copies of the files and programs on magnetic tape. These could be used for jobs run in batch.

In the field, data are recorded on computer-printed worksheets. Records are then entered into disk storage through a remote terminal using an APL program. Other APL programs will display, correct, add, or delete data from individual records.

II. Data Standards and File Organization

Data standards refer to the type of information collected and the manner in which it is coded.

In our system all specimens have their own record, even if they are articulated bones of one individual, and within each record there are seven basic categories of information, six of which have individually searchable subcategories. These categories and searchable subcategories are:

1) Specimen identification:
    A. Collection identification letter
    B. Specimen identification number
2) Taxonomic identification: As stored in the data file these are expressed as numbers but on either input or output scientific names are used; the system automatically converts from names to numbers and back again. Taxonomic categories are hierarchical and allow a specimen to be identified at various levels within the hierarchy.
    A. "Highest Taxon," generally class
    B. Order
    C. Family
    D. Subfamily
    E. Tribe
    F. Genus
    G. Species
3) Element description:
    A. Anatomical description
        1. Primary
        2. Side
        3. Secondary: In three separate fields which can be linked to the

primary field either individually or in combinations. These hold two types of data:
  - a. Completeness
  - b. Further anatomical description
- B. Condition of specimen
- C. Wear (for teeth only)

4) Locality number

5) Taphonomic indicators
- A. Indicators of predepositional transport (graded sequence):
  - 1. Abrasion
  - 2. Rounding
  - 3. Polishing
- B. Indicators of predepositional weathering (graded sequence):
  - 1. Cracking
  - 2. Checking
  - 3. Exfoliation
- C. Toothmarks:
  - 1. Parallel (caused by rodents)
  - 2. Nonparallel (caused by carnivores?)
  - 3. Feathering (caused by carnivores?)
  - 4. Puncture
- D. Predepositional fractures:
  - 1. Spiral (green bone)
  - 2. Local crushing
  - 3. Fibrous (green bone?)
  - 4. Regular [= step] (dry bone?)
  - 5. Irregular
- E. Specimen articulated with another specimen
- F. Evidence of a pathological condition
- G. Evidence of etching by stomach acids

6) Hydraulic Sorting Factors:
- A. Density (scaled from 0–10)
- B. "Volume"
- C. Shape indices

7) Size:
- A. Size estimate based on specimen
- B. Size estimate based on average for taxon to which it belongs

III. Command Language

We have written a series of computer programs that will accept a set of logical instructions, check their syntax, and then do a search through the data file and print the requested information. The command language in which the logical instructions are written is rigorous but English-like in syntax and vocabulary. To begin, the user writes a sentence indicating which subprogram he wants to use, what item of information he wants compiled, and what logical conditions he wants to impose on the search. Each instruction begins with the name of the subprogram, followed by the requested item and a conditional statement. Conditional statements are constructed from three clauses (the IF, FOR, and WITH clauses). These clauses are written with parentheses, logical connectors, and certain keywords. An example of a valid instruction is:

"LIST GENERA IF LOCALITIES ARE Y311 OR Y182."

These instructions would cause the subprogram LIST to search the data file for all records of specimens from localities Y311 and Y182. From these records LIST would compile (retrieve) a list of genera found at either locality Y311 or locality Y182 or both. This list would then be printed showing the number of specimens at each locality for each genus. In this instance "IF," "LOCALITIES," and "ARE" are keywords and "OR" is a logical connector.

Our programs are written in APL and stored as named APL workspaces on accessible disk memory. Currently there is one master program which coordinates one or more subprograms (LIST, SORT, and PLOT) plus a set of programs to create and maintain the data files. These programs are accessible through either TSO (Time-Sharing Option) or batch. From TSO, jobs may be submitted to batch and printed on the system printer, or run in TSO and printed at the terminal. By using various APL auxiliary processors, the results of any job or the data file itself may be passed to any other program in the operating system for secondary analysis.

IV Subprogram Functions and Organization

The three current subprograms and their functions are:

1) LIST — compiles and prints lists of requested data items plus accumulated counts;
2) SORT — sorts data records by stated criteria; and
3) PLOT — determines stratigraphic ranges of taxa or sets of taxa as controlled by the conditional statement; prints as a graphic display.

In addition, a fourth subprogram (CALCULATE) is contemplated. This will perform standard or user-specified calculations on the results of LIST and SORT.

c. Geochronology (Barry, Lindsay)

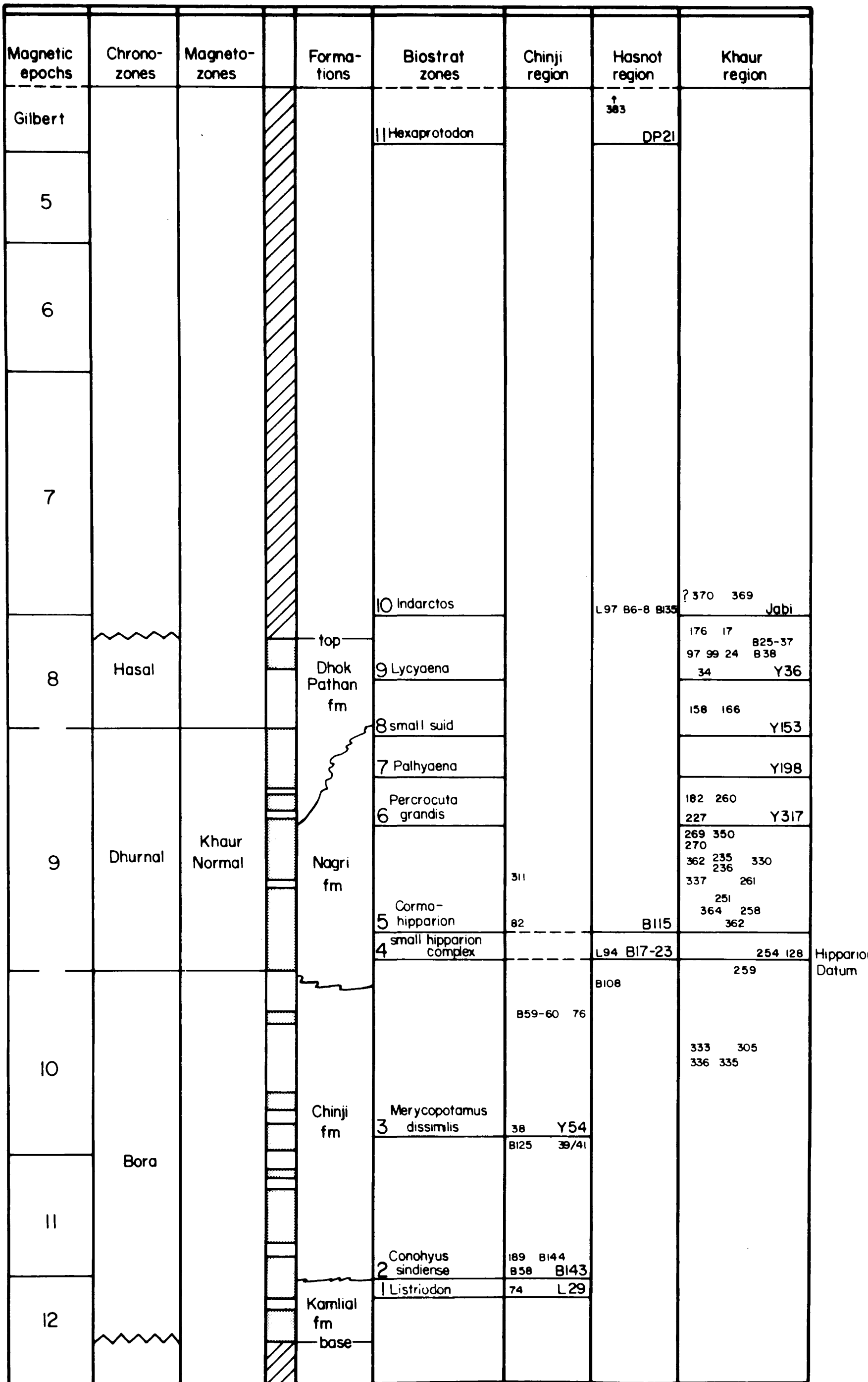
The key to understanding many of the paleontological problems of the Siwaliks lies in the development of a reliable chronostratigraphic framework, which in turn depends on the resolution of the lithostratigraphic and biostratigraphic problems. Many of these problems are discussed in Pilbeam et al. (1977a), but no final solutions have yet been presented as our studies in these areas are in an early stage of development. Good progress has been made on the lithostratigraphy and we now have a collection adequate for generally characterizing the faunal sequences, although this collection is still sparse at the bottom and top of the sequence. Until all the faunal revisions are completed, it is difficult to define and characterize adequately biostratigraphic and chronostratigraphic units; however, some preliminary attempts are in order.

Because of the nature of fossil occurrences in the Potwar Plateau, it may be possible to define formal biostratigraphic and chronostratigraphic units such as is frequently done with invertebrate assemblages but rarely with vertebrates (James, 1963; Lindsay, 1972). In the Khaur region alone there is a continuous rock sequence spanning nearly ten million years and, although not uniformly fossiliferous throughout, this sequence does preserve mammalian fossils at nearly every level. By strike mapping it is possible to determine the stratigraphic relationships of nearly all collecting localities so that we are able to establish the true stratigraphic ranges of many of the mammalian taxa. On this basis then, we will be able to erect a series of biostratigraphic zones, defining and characterizing them principally on the successive appearances (generally immigration events) of faunal elements (Murphy, 1977; Woodburne, 1977).

These biostratigraphic zones can be broadened and correlated by physical stratigraphy

Fig. 14 ➧

Correlations of the magneto-, litho-, and biostratigraphic zones of the Chinji, Hasnot, and Khaur regions. Two vertical scales are used. The scale for the magnetic epochs is in millions of years; the scale for the rest of the figure is in meters and is based on the thicknesses of the formations in the Khaur region. Correlation between these scales is based on the correlation of the top and bottom of the Khaur Normal Magnetozone to the top and bottom of Magnetic Epoch 9. The dates for these boundaries, as marked by broken lines, are generally put at around 8.5 and 10.0 million years. Each biostratigraphic zone is numbered and labeled with the name of the taxon whose local appearance marks the lower boundary. Large-face numbers indicate localities at which the various taxa appear and in effect define the lower boundaries of the zones. Small-face numbers are additional localities we have tentatively placed in the stratigraphic sequence. Letters prefixing the numbers refer to localities found by G. E. Lewis (*L*), Barnum Brown (*B*), the Yale-GSP group (*Y*), and the Dartmouth-Peshawar-Arizona group (*DP*). Those without letter prefixes are also Yale-GSP localities. Zone 11 is placed in this scheme on the basis of the first appearance of *Hexaprotodon* relative to the paleomagnetic sequence. All other zones are placed on the basis of the position of the large faced localities in the lithostratigraphic sequence.


Magnetic epochs
Chrono-zones
Magneto-zones
Forma-tions
Biostrat zones
Chinji region
Hasnot region
Khaur region
Gilbert
5
6
7
8
9
10
11
12
Hasal
Dhurnal
Bora
Khaur Normal
top
Dhok Pathan fm
Nagri fm
Chinji fm
Kamlial fm
base
11 Hexaprotodon
10 Indarctos
9 Lycyaena
8 small suid
7 Palhyaena
6 Percrocuta grandis
5 Cormo-hipparion
4 small hipparion complex
3 Merycopotamus dissimilis
2 Conohyus sindiense
1 Listriodon
383
DP21
L97 B6-8 B135
B115
L94 B17-23
B108
311
82
B59-60 76
38 Y54
B125 39/41
189 B144
B58 B143
74 L29
? 370 369
Jabi
176 17
B25-37
97 99 24 B38
34 Y36
158 166
Y153
Y198
182 260
227 Y317
269 350
270
362 235 236 330
337 261
251
364 258
362
254 128
259
333 305
336 335
Hipparion Datum

and paleomagnetic zonation to establish a chronostratigraphic framework reliable for the Khaur area and other areas of Siwalik deposition. The resulting chronostratigraphic framework should be useful beyond the limits of the Siwalik deposits because of the duration and completeness of those deposits and the appearances of mammalian immigrants.

The informal units discussed in Pilbeam et al. (1977a) (Dhok Mila, Utran, Gandakas, and Kundvali "units") represent an early attempt at defining chronostratigraphic units. Although these units were discussed in terms of lithology, they were meant to have a strictly time value. (In fact, the defining time-event boundaries were sandstone bodies which were, and still are, thought to be minimally time-transgressive.) We have revised this earlier lithologic frame of reference to one based on more generally applicable time-events such as magnetic reversals and faunal changes.

A preliminary biostratigraphic zonation is shown in Figure 14. In this scheme the bottom of each interval-zone (Hedberg, 1976) is defined solely by the appearance of some particular taxon (listed on Fig. 14), whereas the top is defined by the bottom of the succeeding zone. As a means of emphasizing that this biostratigraphic scheme is highly provisional we have chosen to refer to the zones by numbers rather than formal names. The ranges of the zone-delimiting taxa are not necessarily restricted to one zone and, in fact, most of these taxa range considerably higher than just one zone. Our faunal studies are still in progress and our analyses are incomplete; therefore we have not attempted fully to characterize these zones (Murphy, 1977), nor have we established complete reference sections, although the Khaur region may be taken as the primary reference area for all but the oldest and youngest zones. In time we expect to refine and improve this scheme by the addition of more taxa and events, and will formally define and characterize the zones and designate stratotypes. These zones will then serve as the basis for a series of chronostratigraphic zones.

For now, the main purpose of the zones is to provide an internal biostratigraphic framework for current research and later chronostratigraphic reference. The framework is meant to be time-significant, for although these proposed zones are biostratigraphic we have based the boundaries on what we believe are time-dependent events. We recognize, however, that when all the faunal studies are completed, these biostratigraphic units may be equally significant for paleoecological studies and geochronology.

In addition to the biostratigraphic zonation we are also proposing an informal and preliminary chronostratigraphic zonation for the Khaur area which is based on the local paleomagnetic sequences. As shown in Figure 14 the boundaries between the Bora and Dhurnal chronostratigraphic units and the Dhurnal and Hasal chronostratigraphic units are marked by the top and bottom of the Khaur normal magnetozone.

d. Mammals

As noted above, these brief summaries are quite preliminary and will be considerably expanded as various specialists complete their reports.

1. Primates (Pilbeam, Rose)
A very brief report on new primate material from Pakistan was published by Pilbeam et al. (1977b). Other discussions have also appeared (Pilbeam, 1978a, b) or are in press (1979); a detailed description is in preparation (Pilbeam et al).

Previously, four species of hominoid primate have been described from the Indo-Pakistan Miocene: *Ramapithecus punjabicus, Dryopithecus (Sivapithecus) sivalensis, D. (S.) indicus,* and *Gigantopithecus bilaspurensis.* In addition, a prosimian *(Indraloris lulli)*, a colobine *(?Presbytis sivalensis)*, and a cercopithecine (*Macaca paleindicus*) are also known.

We have recovered more prosimian material, including a possible prosimian specimen from locality 259 in ?zone 3, a small lorisid lower molar from locality 182a in zone 6, and associated jaws, cranial, and postcranieal parts of a small lorisid from locality 363 in ?zone 9. Associated lower teeth of a colobine were also found at locality 370 in ?zone 10 or 11.

Remains of at least three hominoid primate species, totaling over 100 specimens from more than 50 individuals, have been found during the past four seasons. They represent *Ramapithecus, Gigantopithecus,* and *Sivapithecus indicus* (previously *D.* (*S.*) *indicus*), although other species may be sampled.

Of particular interest are postcranial remains which seem also to represent at least three species. They are the first recovered from Indo-Pakistan and some of the first middle Miocene hominoid postcranials ever found.

Although these were previously divided into two groups, Hominidae and Pongidae, Pilbeam et al. (1977b) proposed classification in a single family, Ramapithecidae. Ramapithecids are characterized by thick-enameled cheek teeth, some or all have enlarged cheek teeth, some have relatively reduced canines; postcranially some were probably similar to the African apes.

Stratigraphically, almost all our hominoids come from zones 5 and 6. Previous collections probably also sample zones ?2, 3, and perhaps 7 or 8.

2. Small Mammals: Insectivora, Tupaiidae, Chiroptera, and Rodentia (Jacobs)
Small mammals are conspicuously rare in previous Siwalik collections (see Black, 1972). However, we have been successful in recovering numerous small mammal taxa from many horizons, many of which are represented by large samples recovered by screening from a few key localities. Many of these taxa have been or are being described by Jacobs (1977a, b; 1978; 1979a, b, c).

Our localities Y41 and Y39 in the Chinji Formation at Chinji are possibly in zone 2 and have yielded *Antemus chinjiensis, Kanisamys* sp., *Rhizomyoides* sp., *Copemys* sp., *Megacricetodon* sp., *Sayimys* sp., and a soricid. Black (1972) described *Paraulacodus indicus, Sivacanthion complicatus, Rhizomyoides punjabiensis,* and *Kanisamys indicus*, all of which probably come from zone 2 or 3. From locality Y259, which is probably in zone 3, we have a ?tupaiid, an erinaceid, a glirid, a flying squirrel, a tree squirrel, a ctenodactylid, a cricetid, *Kanisamys* sp., and the murid cf. *Progonomys* sp. Locality Y450 in zone 4 has yielded the anterior portion of a tupaiid skull (Jacobs, 1979a) and a ctenodactylid molar.

Our locality Y311, which we tentatively place in zone 5, yielded a microchiropteran, a soricid, a sciurid, a ctenodactylid, a new species of cricetid, a rhizomyid, a murid, and a grooved rodent incisor similar to that reported in *Paraulocodus* (but see Black, 1972). Locality Y182a in zone 6 has yielded a tupaiid, a soricid, a glirid, a sciurid, *Kanisamys sivalensis, Progonomys debruijni, Karnimata darwini, Parapodemus* sp., and *Rhizomyoides* cf. *nagrii.*

At localities Y24 and Y34 in zone 9 we have recorded *Kanisamys* sp., *Progonomys* sp., and *Karnimata* sp. Locality Y369, which is in either zone 10 or 11, produced one *Protachyoryctes tatroti,* while locality DP13, probably in zone 10, has a soricid, a leporid, *Rhizomyoides* cf. *nagrii, Mus auctor, Karnimata huxleyi,* and *Parapelomys robertsi.* A Pleistocene locality in the Pabbi Hills, DP24, yielded a soricid, a modern *Mus,* cf. *Rattus* sp., and *Golunda kelleri.*

We plan extensive sampling for small mammals and hope eventually to record small mammals from all zones in the Khaur and Chinji areas. Present collections suggest that the rodent faunas change radically at the levels of zones 2, 6, and 10. Although the tempo and mode of change in the Siwalik small mammal faunas is still poorly resolved, the basically ctenodactylid-cricetid-rhyzomyid faunas of zones 2 and 3 are clearly different from the murid-dominated faunas of younger zones. At least two groups of murids can be distinguished in these later faunas, and are also usually found with rhizomyids. Changes in the two major groups of murids apparently do not occur simultaneously nor do changes in the murids necessarily coincide with changes in the rhizomyids.

3. Carnivora and Creodonta (Barry)
For the purposes of this discussion we have divided the Siwalik carnivores into three size groups: 1) the large carnivores being those over approximately 40 kg; 2) the small carnivores those much less than 40 kg; and 3) an intermediate-sized group. This division is based on the preservational biasing effect of size (Behrensmeyer and Dechant, 1979) which is, we believe, reflected in the nature and detail of our knowledge of these forms.

Large carnivores are fairly commonly found and we have relatively complete knowledge of them. For the stratigraphic levels most intensely collected we have probably recorded most of the large carnivore taxa, know something of their stratigraphic ranges, and may even be able to determine their relative abundances. The large carnivores are, as a result, of some use in stratigraphic correlations and paleoecological reconstructions. The preservation and discovery of a small carnivore, on the other hand, has a much greater element of chance and, although we have found a number of very interesting small species, our knowledge of this part of the fauna is very incomplete. Small carnivores are valuable ecological indicators, however. The third, intermediate-sized group has characteristics of both the others.

The following lists of carnivores are based mostly on the GSP, YPM, and American Museum of Natural History collections. Additional taxa are known but are not listed because they either are of questionable status or our knowledge of their stratigraphic ranges is too imperfect.

Large carnivores

Hyaenodontidae	
Dissopsalis carnifex	zones 2 and 3
Hyainailouros sulzeri	zones 1 and 3
Amphicyonidae	
Amphicyon sp.	zones 2, 3, 6, 8 and 9
Vishnucyon chinjiensis	zone 2
Agnotherium n. sp.?	zone 2 or 3?
Hyaenidae	
Percrocuta carnifex	zones 2, 3, 4, 5 and 6
Percrocuta grandis	zones 6, 7, 8 and 9?
Lycyaena macrostoma	zones 9 and 10?
Felidae	
Sansanosmilus sp.	zone 2 or 3
Paramachaerodus sp.	zone 6
Megantereon sp.	zone 9

Other large carnivores are: *Vinayakia* sp., which is probably a hyaenodontid and not a felid; *Arctamphicyon lydekkeri; Agriotherium palaeindicum;* and *Indarctos punjabiensis.*

Intermediate-sized carnivores These are estimated to be slightly smaller than 40 kg but are commonly enough found that we can probably determine their stratigraphic ranges. Collecting has not been intense enough at most levels to ensure that we have sampled adequately.

Hyaenodontidae
- *Metapterodon?* n. sp. — zones 2 and 5

Mustelidae
- *Plesiogulo crassa* — zone 10
- *Eomellivora* sp. — zones 2 or 3 as well as 5 and 6
- *Enhydriodon* sp. — zone 11

Hyaenidae
- *Progenetta,* 3 species — zones 3 through 7
- *Palhyaena sivalense* — zones 7, 8 and 9. May be succeeded by *Palhyaena indicum* in zone 10?

Felidae
- *"Sivaelurus" chinjiensis* — zone 3
- *Sivasmilus copei* — zone 2 or 3

Small carnivores. At this stage it is difficult to say anything about the small carnivores other than to make a list and a few comments.

Mustelidae
- Lutrinae: There are several otters present, the most common being *Sivaonyx bathygnathus* in zone 6.
- *Vishnuonyx chinjiensis:* not an otter but rather a ferret badger, zone 3.
- *"Martes" lydekkeri:* more similar to *Enhydricitis,* zone 2.
- cf. *Ischyrictis:* three species; one in zone 3? plus small species in zone 6 and a large species at Hari Talyangar.

Viverridae
- Pilgrim's "Lutrinae genus indet. *hasnoti"* is a large, probably new viverrid genus. We have excellent material from zone 5.
- *"Viverra" chinjiensis:* zone 3 and perhaps zone 5
- ?Paradoxurinae: zone 5
- ?Hemigalinae: zone 9
- Herpestinae: two species from zones 3 and 6

Felidae
- small felid from Hari Talyangar
- *Felis* sp.: zone 10

Comments The carnivore fauna as a whole has a number of interesting peculiarities. Among these are the absence of canids from the pre-Pinjor faunas and the apparent absence of a number of mustelids characteristic of the Vallesian/Turolian faunas of Europe, Turkey, and China (i.e., *Proputorius, Parataxidae, Melodon, Trocharion, Trochictis, Promeles,* and *Promephities).* Combined with these intriguing absenses is the relatively late survival of a number of archaic forms, principally the amphicyonids and creodonts. The cooccurrence of hipparions and a creodont at about 10 m.y. is of particular interest. Finally we have found no evidence of any procyonids and are in agreement with Tattersall (1968) that the Siwalik species of *Sivanasua* are referable to the Primates (cf. *Indraloris).*

4. Pholidota (Pickford)
A single specimen of a small pholidote is known from zone 9. This specimen, a medial phalanx, is referred to *Manis* sp. (Pickford, 1976a) and is the earliest record for the pangolin in the Indian subcontinent.

5. Tubulidentata (Pickford)
Aardvarks also comprise a very rare element of the Siwalik fauna. Pickford (1978) now recognizes only one large species instead of two (Colbert, 1933, 1935a, and Lewis, 1938). Remains of this species have been found in zones 2, 3, 5, and ?9. In addition we have found remains of a smaller, undescribed species from zones 1 and 2 (Pickford, 1978).

6. Proboscidea (Tassy)
Trilophodont Gomphotheriinae (two taxa) and Amebelodontinae (at least one taxon) are present in the Chinji Fm. Choerolophodontinae (one genus: *Choerolophodon=Syncono-*

lophus) specimens, which are rare, are somewhat comparable to the Fort Ternan/ Ngorora species *Ch. ngorora* from East Africa. A small *Choerolophodon* species, which is similar to the Siwalik *Ch. palaeindicus* and the East African *Ch. kisumuensis,* may be represented by a molar fragment from the Kamlial Fm. (?zone 1). In contrast to its occurrences in the Chinji Fm., *Choerolophodon* is common in the Nagri and Dhok Pathan Fms. with one species *(Ch. corrugatus* Pilgrim) being close to *Ch. pentelici* of the Vallesian/Turolian beds of the eastern Mediterranean basin. This species is known from zones 5 through 9. A part of a molar from the Chinji Fm. (zone 3) is a possible early *Stegolophodon* and could be related to a *Stegolophodon* sp. known from zones 6 and 7. This latter form is clearly a gomphotheriid close to the European *Tetralophodon.* A lower tusk with tubular dentine from zone 8 is referred to cf. *Platybelodon.* The cross-section of this tusk is different from *Pl. grangeri* from Tung Gur and it could be related to the tusk of *"Tetralophodon" grandincisivus* from Maragha. The Maragha tusk is the type of the species and it has tubular dentine.

7. Equidae (MacFadden)
As is true of most of the Siwalik taxa, increasingly detailed knowledge of the stratigraphic occurrence of these forms has led to an increasingly complex story of their phylogeny and paleoecological associations. We now believe that the Siwalik hipparions represent at least two genera and three species and their first appearance may well involve a different taxon than is found in Europe (MacFadden and Bakr, 1979). The only certainly identified species is *Cormohipparion theobaldi* which defines the base of zone 5 and may persist into zone 11. The small species *"Hipparion" antilopinum* is of uncertain generic assignment (*contra* Skinner and MacFadden, 1977), whereas a second small species appears to be a true *Hipparion* (MacFadden and Bakr, 1979). These last two are not easily separated on dental criteria and it is not clear which is present at any stratigraphic level. Small hipparions define the base of zone 4 (which may be equivalent to the *Hipparion* datum of Berggren and Van Couvering, 1974) and are abundantly present throughout the section to about the level of at least zones 9 and 10. Small and large hipparions are often associated at the same localities. *Equus* has not been found in any of our sections.

Once hipparions appear they rapidly become an abundant part of the large mammal fauna.

8. Chalicotheriidae (Pickford)
Pickford (ms.) notes that the chalicothere material from the Siwaliks can be considered as belonging to a single, quite variable species, *Chalicotherium salinum,* from zones 2 through 9 or 10. It is possible that two species are being sampled.

9. Rhinocerotidae (Guérin)
Rhinocerotids have been provisionally assigned by Guérin (in preparation) to four groups, with some specimens remaining indeterminate. The groups are: *Gandaitherium browni* and *G. vidali* (zones 3 through 8); *Aceratherium* sp. cf. *A. simorrense* (zone 6); *Chilotherium intermedium* (ones 5 through 9); and *Brachypotherium perimense* (zones 6 through 8). Relative abundances of the various species differ between zones, and this probably has some paleoecological significance. Zone 5 is noteworthy since rhinocerotids are both abundant and diverse.

10. Suidae and Tayassuidae (Pickford)
The eleven genera of Siwalik suids are readily divisible into three age groups (Pickford, ms.): an older group with *Listriodon pentapotamiae, Conohyus sindiensis,* and *Hyotherium pilgrimi* ranges from zones 1 through 3 (but not all occur in all zones). A younger group includes *Tetraconodon magnus, Hippopotamodon sivalense, Lophochoerus nagrii,* and *Propotamochoerus hysudricus* from zones 4 through 9. *Hippohyus sivalensis* and *H. lydekkeri, Sivachoerus prior,* ?*Sus,* and *Sivahyus punjabiensis* appear or become abundant only in ?zone 10 and above. There is a very small suid of uncertain affinities from zone 8.

The peccaries *Pecarichoerus orientalis* and *Schizochoerus gandakasensis* are known from zone 2 and zones 5 and 8 respectively (Pickford, 1976b and in press). The last-named species may also occur in zone 6.

It remains to be seen how abruptly the transitions between suid assemblages occur, identifications of specimens are now virtually complete, making stratigraphic range data for this important group possible to compile.

11. Anthracotheriidae (Barry)
Anthracotheres are fairly common but the fragmentary nature of our material makes specific identifications difficult. Several species are found from zones 2 through 11.

12. Hippopotamidae, Camelidae and Cervidae (Barry)
The sole hippopotamus, *Hexaprotodon sivalensis,* is limited to the uppermost of our defined zones (zone 11). We have found remains of *Hexaprotodon sivalensis* at Tatrot and they are common in the younger parts of the Siwalik section. We have not found remains of either the Camelidae or the Cervidae (*contra* Brown, 1927 and Colbert, 1935a) in our areas.

13. Tragulidae (Hamilton)
The tragulids of the Siwaliks are represented by at least two and possibly three genera. Of the primitive *Dorcabune,* we have in our collections material of two species: the very large *D. anthracotheroides,* found so far only in zones 2 and 3, and the somewhat smaller *D. nagrii* from zone 6. *Dorcatherium* has four species. Two of these are the very large *D. majus* which ranges from zone 2 into zone 5, and the smaller *D. minus* which appears to be restricted to zones 2 and 3. A third and as yet unnamed species is much smaller than *D. minus* and appears to have a long geological history, while a fourth very small species, also unnamed, has been found in rocks from zone 8. This last species may be close to *Tragulus sivalensis.* These tragulids, particularly the larger ones, may be much more common than generally thought since fragmentary specimens are easily confused with both bovids and anthracotheres.

14. Giraffidae (Barry)
The giraffe family holds considerable promise for biostratigraphy in the Siwalik but before this potential can be realized it will be necessary to develop taxonomic diagnoses based on the teeth and postcranials as well as on horncores. As the matter stands now, it is only possible to state a few generalities on the basis of the GSP and YPM collections and the published information in Colbert (1935a). The relatively small *Giraffokeryx punjabiensis* is restricted to zones 2 and 3 where it is a common element in the fauna. All the larger giraffes are absent from these levels, first appearing *(Bramatherium megacephalum)* in zone 5. (The range of *Giraffokeryx* may extend upward and that of the larger taxon downward into zone 4. There may also be more than one species of *Giraffokeryx* present (Hussain et al., 1977).) The *Sivatherium giganteum* specimens collected by Barnum Brown came from the "upper Siwaliks" (Colbert, 1935a). It would appear that this species is restricted to our zone 11 or even younger sediments. Two other taxa, the *"Giraffa" punjabiensis* and *Giraffa sivalensis* of Colbert (1935a) are also known; the former from zone 10? and the latter from the Upper Siwaliks (zone 11 or younger?).

15. Bovidae (Thomas)
Lower and Middle Siwalik bovids can be subdivided into three groups, with little stratigraphic overlap. The oldest group consists of *Protragocerus gluten, Miotragocerus gradiens, Kubanotragus sokolovi, Pseudotragus potwaricus, Sivoreas eremita,* and a *Gazella* sp., and ranges through zones 1 through 3. A second group consists of *Miotragocerus punjabicus, Selenoportax vexillarius, ?Pseudotragus* sp., *Elachistoceras khauristanensis,* and a second *Gazella* sp., and is found in zones 4 through 8.

The third and youngest of the lower and middle Siwalik groups contains, among other forms, *Kobus* sp. and cf. *Prostrepsiceros* *houtumschindleri,* and apparently comes from zone 9. Other bovids remain to be identified.

Earlier studies by Pilgrim are currently under revision by Thomas (1977 and in preparation); when identification of bovid material is complete it will be possible to compile more complete stratigraphic range information.

e. Nonmammal Groups

1. Aves

Birds found by this expedition are the first to be reported from the lower and middle Siwaliks. Seven species have been identified from material collected prior to 1978 (Harrison and Walker, in preparation). These include a pelican *Pelecanus* cf. *cautleyi* from either zone 3 or 4, a stork *Leptoptilos siwalikensis* from zone 6, and a vulture *Torgos* cf. *tracheliotus* from zone 3. Four new species are also being described by Harrison and Walker (in preparation), for the stork genus *Xenorhynchus* (from zone 9), the pheasant genus *Lophura* (zones 3, 5, and 6) and the rail genera *Urmornis* (zones 3 and 5) and *Porphyrio* (zone 6).

2. Amphibia and Reptilia

J. C. Rage has identified the following amphibia, lizards, and snakes from the Yale-GSP collections, expanding on previously known material (Hoffstetter, 1964):

- Anura, genus and species indeterminate
- *Varanus* sp.
- *Acrochordus* sp.
- *Python* sp.
- Colubridae, genus and species indeterminate

The following turtles have been identified by F. de Broin:

- *Geochelone* (s.l.) sp. zone 5?
- *Testudo* sp. zones 5 and 6

Emydidae, genera indeterminate, zones, 5, 6, and 8. These terrapins represent three generic groups: *Kachuga, Geomyda,* and either the *Batagur* or *Hardella* groups.

- *Trionyx* (s.l.) sp., zones 2, 3, 5, 6 and 8
- *?Chitra* sp., zones 2, 3 and 6
- *Lissemys* cf. *punctata,* zone 8
- cf. *Lissemys* sp. 1, zones 5 and 6
- cf. *Lissemys* sp. 2, zones 2, 3, 5 and 6

The many crocodilian teeth and postcranial fragments recovered to date and studied by E. Buffetaut establish the presence of crocodilians at almost all stratigraphic levels in the Siwaliks but rarely allow the identification of species. However, sufficiently complete remains have been assigned to four species, two crocodiles and two gavials. These are *Crocodylus palaeindicus* from zone 6, *?Crocodylus sivalensis* from zone 1, *Gavialis gangeticus* from either zone 6 or 7 and zone 9, and finally, *Gavialis hysudricus* from zone 5.

f. Correlation and Intercontinental Connections

Pilbeam et al. (1977a) briefly discussed correlation of the faunas from the Potwar Plateau with those elsewhere in Eurasia and Africa. Since then some further progress in our understanding has been made, although it should be clearly stated that until more identifications are completed and until we have a better understanding of stratigraphic ranges, reliable correlations will not be possible. At present several important groups (bovids, suids, rodents) give the impression that there are a few rather distinct faunal units separated by periods of rapid change, although the picture from other groups (carnivores) suggests a series of more gradual and less clear-cut changes. Presumably the issue of tempo and mode of faunal change will be clarified in the future.

Faunas of zones 1, 2, 3 show a number of similarities to Astaracian faunas in Europe, Barstovian faunas in North America, and East African middle Miocene faunas. Thus, rodent faunas with cricetids are similar to those in Europe (Anwil in Switzerland, for example) and North America, dated at 11 to 15 m.y. Three or four species of bovid are identical to those from Fort Ternan and Ngorora in Kenya, with an age range of 14 to around 10 m.y., while the suids resemble Astaracian forms. Similar ties are to be seen in some other groups (i.e., proboscideans) and it seems likely therefore that zones 1 through 3 fall with in the 11 to 15 m.y. span. At that time, faunal resemblances of Pakistan and other south Asian faunas were fairly general, showing ties to North America, west and central Eurasia, and Africa. Possibly we are witnessing a period of moderate endemism following the initial mixing of African and northern faunas but before significant barriers to migration developed.

Zone 4 is poorly sampled, as is zone 5, although zones 6, 7, and 8 are becoming well-documented. The south Asian faunas at this stage show few similarities to those in Africa or North America (except for hipparions which originate in the New World and are first abundant in zone 4). There are some resemblances to European and west Asian faunas, particularly among rodents and suids. Correlations are to localities in Eurasia dated between 10 and 8 m.y. The first appearance of *Hipparion* species in Europe is now thought to be at a little under 11 m.y., in East Africa at around 10 m.y.; if correlative with zone 4 this matches the approximate age estimates for our first hipparions.

This relative faunal endemism is disturbed by a faunal change, involving both emigration and immigration, recorded in zone 9. Several groups document changes, among them primates, carnivores, suids, bovids, and rodents. Thus hominoids are apparently greatly diminished in diversity or disappear entirely, to be replaced (apparently) by colobine monkeys; relatively more modern hyenids turn up, as do pigs of more modern aspect; a reduncine species similar to that from Mpesida and Lukeino in Kenya appears, as does one found at Samos and Maragha; new rodents may indicate ties with Africa. There is evidence of interchange with North America, although at present most of the exchanges (emigrants as well as immigrants) seem to be with Africa. Correlations to dated localities suggest ages of perhaps 8 to 6 m.y. for zone 9 and younger zones.

As noted above, this very simple scheme may well need modifying in the direction of increased complexity, although we believe that the age estimates are unlikely to be significantly in error.

g. Paleoecology (Badgley, Behrensmeyer)

Ideally, we would like to understand the ecological factors involved in both the succession of faunas through time and the composition of the fauna at any single level in the Siwalik section. Such questions concerning paleoecology must be designed with the fossil record and its limitations in mind, since information about past communities of plants and animals differs substantially from information available for living communities. Recent studies in vertebrate paleoecology and taphonomy have attempted to define questions that can be answered using the small and often highly biased subset of data available in the fossil record.

With regard to the 12 to 10 m.y. of faunal succession represented in the Siwalik section of the Potwar Plateau, we have concentrated our research on both the "vertical" (succession through time) and the "horizontal" (single level) paleoecology. In the first case, our goal is to interpret broad faunal changes through time from an ecological perspective, considering possible interactions of the faunas, their habitats, and climatic change. In the second case, the goal in studying horizontal paleoecology is to define limits of variation (e.g., in the faunal composition of fossil assemblages) so that this can be distinguished from variation due to evolutionary change through the section.

At present, the sources of data for these two goals are rather different. We shall summarize the available information and preliminary conclusions regarding them separately in the following paragraphs.

Broad interpretations of paleoecology over the entire Siwalik section in the Potwar Plateau must be based on what we know of the taxonomic composition of the fauna and the overall paleoenvironments since detailed lithofacies and taphonomic studies are presently available for only one level. Biostratigraphic reference sections for the vertebrate faunas are in a preliminary state for the Potwar Plateau as a whole, but superposition of fossil localities within each of the three major regions (Khaur, Chinji-Nagri, Hasnot) is clear. The interpretations of faunal patterns given below are based on this superpositional evidence plus inferred feeding and locomotor behaviors, the array of herbivore body sizes, and known habitats of modern relatives for mammals represented in the Middle Siwalik fossil assemblages.

The Siwalik vertebrate fauna included few medium or large mammals that might have been exclusively forest species, although some of the small species probably were forest forms. There were also few species that appear to represent adaptations to open grassland. Rather, we seem to be dealing with an assemblage of forms sampled from a "mixed" woodland-grassland habitat. If this hypothesis is to be further justified, we must address several potential interpretive problems. First, there are few analogues today of such mixed habitats that have been left undisturbed yet still contain a good sample of their natural faunas. Second, many members of mixed habitat faunas of the middle and late Miocene may have been ecologically different from modern descendants or presumed analogues. Third, mixed habitats are, because of their mosaic nature of "graininess," likely to support a similarly mosaic fauna with more forest-adapted species living quite close to more open country forms. Fossil samples thus may easily represent many different microhabitats. However, if particular depositional environments tend to sample particular microhabitats, then we may be able to distinguish taxonomic groups representing different portions of the overall ecological mosaic through time. Until we have detailed lateral sampling at a number of levels, we shall not be able to resolve this problem.

There is little detectable change in taxa regarded as paleoecological faunal indicators from zone 1 through zone 8. Prehipparion faunas contain more "primitive" elements, but these are not necessarily "forest" species. Leinders has argued (1976) that *Listriodon,* for example, was likely to have been an open woodland form. The appearance of hipparions is almost certainly due to their rapid spread throughout the Old World following immigration from North America of already evolved lineages. Although not itself necessarily indicating habitat change, the introduction of the equids, as important new grazing elements, may have spurred some habitat shifts or may have initiated a "grazing succession" among the large herbivores. The faunal changes marking zone 9 do suggest an influx of somewhat more open country species, perhaps recording a habitat change.

Our second, horizontal approach to paleoecology has both geological and taphonomic components; most of the work aimed at detailed reconstruction of paleoenvironments and communities has focused on the sediments and fossils of zones 5–6 (defined in this paper), in part because of the high density of fossil localities at this level and in part because most of the hominoids recovered by this expedition come from this level. Here, there has been an attempt to integrate the study of lateral lithofacies variation with the microstratigraphic and taphonomic work on individual fossil localities. The resulting paleoecologic reconstructions can be done at various levels of resolution. At the scale of 30 km, the lateral lithofacies work establishes the overall physiographic character (an "aerial photograph view" of the Siwalik environment) with the inferred presence of two large river systems whose courses were not stable through time, well-drained floodplains and laterally shifting sedimentary environments which probably caused a constant renewal of vegetational habitats in these areas. At the other end of the scale, with resolution on the order of 10's of meters, the microstratigraphic study indicates fluvial and postdepositional processes including bioturbation by plants and animals that may have acted over as little as a year's time. These geological and taphonomical analyses are not completed, but we advance preliminary interpretations below (Badgley and Behrensmeyer, ms.).

Fossil localities in zones 5–6 are dominated by medium-sized mammals within the size range of 20–200 kg. The lack of abundant smaller mammals is probably due to taphonomic size bias at every stage of preservational process. The lower representation of the larger mammals is probably due both to ecological (lower density and lower turnover rates) and preservational factors. For species within the "common" size range, it may be possible to estimate relative abundances; analysis awaits completion of taxonomic identifications. The fossil assemblages do not appear to indicate differences in fine-scale habitats and habitat associations per se; that is, species with more open-country adaptations, such as the hipparions, cooccur with browsing herbivores. Perhaps these cooccurrences reflect an original patchiness of canopied and open areas. Certain bone concentrations appear to be predator accumulations or sites of repeated predation, including one of the spectacular hominoid localities (Locality 260). The size structure of the herbivore trophic level, with the predominance of small to medium-sized ungulates, indicates an abundance of browse and suggests a vegetational mosaic of different successional stages, including grassland, bush, and woodland; this view based on the herbivores is harmonious with paleoenvironmental reconstruction based on the fluvial sedimentary regime.

In summary, our present view of Siwalik paleoecology is broader than many previous interpretations in that we see evidence in both faunas and geology for a habitat mosaic including everything from forest and woodland to open grassland. The scale or "graininess" of this mosaic was such that faunal elements were consistently sampled from different parts of it to make up the fossil assemblages found in typical channel (i.e., transported) contexts. Thus, the habitat "grain" was probably on the order of tens to hundreds of meters rather than kilometers. The degree of mixing of different faunal "subcommunities" may have changed through time but in order to see this, lateral analyses of several levels are needed throughout the section. For zones 5 and 6, our present evidence allows us to define a consistently cooccurring group of taxa that made up the overall large mammal "paleocommunity" of the fluvial system. This was dominated by *Hipparion* and *Miotragoceras* and included other bovids, proboscideans, suids, giraffes, and rhinos as the most common major taxa. Less common taxa, including anthracotheres, tragulids, carnivores, primates, and chalicotheres, were either absolutely less abundant or had different, more restricted patterns of occurrence indicating that they represent partially distinct subcommunities. This interesting possibility can only be resolved through further sampling and taphonomical analysis.

4. Summary and Conclusion (Pilbeam)

The classic Siwalik faunas from the Potwar Plateau of Pakistan come from fluvial sediments in three major areas, separated from each other by significant distances. These areas are around Chinji and Sethi Nagri, type areas of the Chinji and Nagri Fms.; Dhok Pathan to the north, where the Dhok Pathan Fm. lies above Nagri equivalent rocks; and to the east around Tatrot and Hasnot where the bulk of the Middle Siwalik faunas come from the Bhandar Beds which are probably younger than those of the Dhok Pathan Fm.

This project began in 1973 with work at Chinji and at Dhok Pathan. Since then we have greatly expanded our geographical range. Our initial aims were to get a broad overview of regional geography and stratigraphy; locate and, where possible, recollect earlier localities; and place them stratigraphically as best as possible. This we have achieved reasonably well in the Chinji and Dhok Pathan areas, and with less success around Hasnot. New collections, now yielding well over 10,000 specimens from more than 400 localities have been made in all major areas, but particularly around Khaur.

However, it is around Khaur that we have concentrated and will continue to concentrate our efforts, in the belief that a detailed sequence of rocks and faunas is best defined in one area, and then extended to others.

The progress we have made towards defining litho-, magneto-, bio-, and chronostratigraphic units in the Khaur area, and extending them elsewhere, is summarized in sections 2 and 3 and in Figure 14. We still have a great deal of work to do, but a clearer picture is beginning to emerge of an evolving series of interlocking fluvial systems close to the emergent Himalayas, covered with a mosaic of mostly woodland-type habitats. Faunas included a wide variety of forms, and among the browsing element there were probably several species of hominoid primates. These primates were of diverse ecological character; some at least were relatively terrestrial forms, perhaps spending a good deal of their time feeding on the ground. They document a significant shift of hominoids from a mainly forest, arboreal style of life to one in more mixed open and forest conditions. Included among them may well be the earliest recognizable human ancestor, or a species closely related to that ancestor. The Siwalik rocks of Pakistan are one of the few places where these earliest traces of the process of "becoming human" can be documented.

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