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**PHYLOGENY AND EVOLUTION OF NEOGENE  
MURINE RODENTS FROM THE POTWAR  
PLATEAU OF PAKISTAN AND AZAD KASHMIR  
WITH SPECIAL EMPHASIS ON  
ZOOGEOGRAPHIC DIVERSIFICATION AND  
STRATIGRAPHIC IMPLICATIONS**

**BY**

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**A THESIS SUBMITTED TO THE UNIVERSITY OF THE PUNJAB IN  
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR  
OF PHILOSOPHY IN GEOLOGY**

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**INSTITUTE OF GEOLOGY  
UNIVERSITY OF THE PUNJAB  
LAHORE, PAKISTAN.**

UNRECORDED

*DEDICATED TO*

*My Father Liaquat Hussain Cheema  
&  
My deceased Mother Rasheeda*

for grooming my personality

## CERTIFICATE OF APPROVAL

This is to certify that the research work described in this thesis entitled "*Phylogeny and Evolution of Neogene Murine Rodents from the Potwar Plateau of Pakistan and Azad Kashmir with special emphasis on Zoogeographic Diversification and Stratigraphic Implications*" is the original work of Mr. Iqbal Umer Cheema and has been carried out under my direct supervision. I have personally gone through all the data/results/materials reported in the manuscript and certify their correctness/authenticity. I further certify that the material included in this thesis has not been used in part or full in a manuscript already submitted or in the process of submission in partial/complete fulfillment of the award of any other degree from any other institution. I also certify that the thesis has been prepared under my supervision according to the prescribed format and I endorse its evaluation for the award of Ph.D degree through the official procedures of the University.

Signature \_\_\_\_\_

*Muhammad Nawaz*

Prof. Dr. M. Nawaz Chaudhry  
Supervisor

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## ABSTRACT

One of the most important aspects of the continuing research for the last two decades on the Neogene Siwalik mammal fauna of Pakistan is the recovery of rich small mammal assemblages from almost the entire Siwalik sequence. Rodentia, in general, and its three families, namely the Muridae, Cricetidae, and Rhizomyidae, in particular, have been studied in fair details. Muridae have been found to be the dominant rodent group in the Siwaliks and the ancestor- descendant relation of its various species establishes South Asia as the center of origin and subsequent diversification-dispersal for the family Muridae.

Although broad speciation patterns in Muridae from the early Middle Miocene to the present-day diversity in South Asia have been established, yet important gaps for precise documentation of various speciation events still exist. This study is an attempt to redress the lacuna and a better temporally constrained murid phylogeny is presented based upon four selected time periods, which have been sampled from four different localities in the Potwar Plateau.

A small mammal assemblage from the middle part of the Chinji Formation, locality PMNH 8608 near Bin Amir Khatoon village in southern Potwar contains at least thirteen species that represent nine rodent and insectivore families plus a single specimen of Chiroptera. Cricetids are represented by three species, which resemble those reported from the Banda Daud Shah assemblage. *Antemus chinjiensis* is the only murid recognized but specimens referred to this species include three molars that are apparently atypical in being and having extra cuspules (morphologic variants as yet unrecorded). *Prokanisamys benjavuni* and *Kanisamys indicus* constitute typical Middle Miocene rhizomyids encountered in the Siwalik sequence. *Palaeotupaia* sp. perhaps is a separate species from the Haritalyangar *P. sivalicus*. The lower dentition of the erinaceid *Galerix* shows affinities with the Greek species and has been assigned to *G. aff. symeonidisi*. Comparison with other species composition during most of the Middle Miocene Murid species probably had short longevities and hence their application in biochronology

provides precise faunal dating. The PMNH 8608 locality fauna closely resembles the Daud Khel small mammal fauna and both are correlated with the Late Astracian age of the European sequence.

Isolated deposits near Jalalpur, southeastern Potwar Plateau is the second locality, which yielded a diverse small mammal fossil assemblage. The fossil locality, JAL-101, contains a particularly good sample of a primitive species of the early murid *Progonomys*, which is named herein as *P. Inssani*. This and other elements of the fauna (Cricetidae, Rhizomyidae) argue for an age younger than that of Chinji Formation sites at the Chinji stratotype in southern Potwar. Consequently JAL-101 is important because it improves the sample of fossils representing early Late Miocene time in the Siwaiks. The fauna of 13 mammal species can be used to make an age estimate for JAL-101 by correlation to the Potwar microfauna sequence. Temporal ranges of rodent species, as presently known, constrain JAL-101 to ca. 11 Ma.

Small mammals from two mid-Pliocene localities in Azad Kashmir produce a modern shrew comparable to living *Suncus* and murids assignable to three genera. These are *Golunda kelleri*, a species described previously from an early Pleistocene locality in northern Pakistan, cf. *Hadromys* sp. and *Mus* sp. The murids date to about 3 Ma and thus include the oldest record of *Golunda* and the *Hadromys* lineage.

The Lehri fossil locality, PMNH 93128 in eastern Potwar Plateau contains important material of extinct species earlier based on a few specimens from an early Pleistocene locality in the Pabbi Hills, Pakistan. The material includes upper dentition of *Golunda kelleri*, named for a few lower molars, and lower dentition of *Hadromys loi-jacobsi*, first known by upper molars. These fossils are slightly older, probably only 300,000 years, than the respective hypodigms, and are geographically close. They indicate the likely morphology of the complementary elements of each species. They help to put into focus other material from Pliocene localities in India, and suggest that *Golunda* and *Hadromys* both had complex phylogenetic histories. The locality also produced smaller murids, including at least one species of *Cremnomys* and a mouse near *Mus jacobsi*. The fauna is

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## TERMINOLOGY OF MOLARS ADOPTED IN THIS STUDY

M<sup>1</sup> UPPER FIRST MOLAR

M<sup>2</sup> UPPER SECOND MOLAR

M<sup>3</sup> UPPER THIRID MOLAR

M<sub>1</sub> LOWER FIRST MOLAR

M<sub>2</sub> LOWER SECOND MOLAR

M<sub>3</sub> LOWER THRID MOLAR

Rodents usually have three molars and two incisors. Incisors are utilized for gnawing and the molars for chewing. There is diastama in between incisors and the molars. Incisors are sharp blade like chisel. The morphology of all molars is almost the same as any of the mammals.



## CHAPTER 1. INTRODUCTION

### 1.1 GENERAL INTRODUCTION

The Siwalik Group is a thick sequence of continental molasse sediments, which comprise the foothills of the Himalaya and associated mountain ranges in northern India, Kashmir and Pakistan. They range in age from Miocene through Pleistocene.

Siwalik sediments several kilometers in thickness, are fluvial in origin. They were shed from the rising Himalaya mountain, the result of the collision of the Indian subcontinent with Asia (Eurasian plate) (Gansser, 1966; Powell and Conaghan, 1973). Further movement of the Indian plate has deformed Neogene molasses sequences including the Siwalik Group.

Siwalik sediments generally comprise silt or sandy silt units in various hues of orange, red or brown alternating with more or less persistent whitish or grayish sand units. Typical Siwalik exposures are bad land areas with tilted beds forming cuestas with more resistant sandstones forming the capping dip slope and less resistant silts exposed on steep scraps. Formations of the Siwalik Group are distinguished mainly by the abundance of sand relative to silt and the color of the silts. As with most continental deposits, marked facies changes can and do occur within relatively short distances and fossiliferous strata of similar lithology have been deposited in separate areas at different times.

The most complete representation of Siwalik sediments is found in the Potwar Plateau, Pakistan. The Potwar Plateau, referred to by some authors (e.g., Pilgrim, 1910, 1913) as the Salt Range area is, bounded to the north by the Kala Chitta and Margala Hills, to the south by the Salt Range, to the west by the Indus River and to the east by the Jehlum River and Pabbi Hills (Fig.1). The Pabbi Hills, also known as the Kharian Hills ("Kharean Hills" of Wynne, 1875), lie just outside the Potwar Plateau as recognized by Elahi and Martin (1961) in their physiographic study. However, the Pabbi Hills are certainly more closely related, both structurally and physiographically to the Potwar Plateau than the Punjab Plains to the south. Therefore, Pabbi Hills are here considered part of the Potwar. This is consistent with Pilgrim's (1913) recognition of the Potwar.

The richly fossiliferous, continuous extensive exposures of the Potwar, particularly in the Soan Synclitorium, whose axis roughly parallels to Soan River, prompted Pilgrim (1910) to adopt this area as the type area of Siwaliks. The Siwalik Hills, however, for which the Siwalik Group is named are located to the east, in what is now India, and a separate physiogeographic unit from the Potwar. The Siwalik Hills comprise mainly upper Siwalik Group rocks. The fauna from the Siwalik Hills was studied extensively by Falconer (see Falconer 1868) before Pilgrim began work on the Potwar Plateau.

Vertebrate fossils have been collected from the Siwalik Group since the first half of the nineteenth century. The early history of Siwalik fossil collection has been reported by Colbert (1935) and Sahni (1956). After the initial work of (mainly) Falconer, Cautley and Lydekker in 1800s, palaeontology in the Siwaliks entered a second phase after the turn of the century. Pilgrim, Colbert and Lewis added significantly to our knowledge of Siwalik vertebrates in numerous papers published until about the 1940s. From that time until the 1970s work on the Siwaliks has been minimal. R. Dehm and G.H. Von Koenigswald led expeditions to the Siwaliks during that period.

In 1973 there were three projects underway in the Siwaliks of Pakistan. The Dartmouth College-Peshawar University project was originally concerned with determining the magnetic polarity stratigraphy and biostratigraphy of upper Siwalik deposits but has since expanded to include the study of the magnetic polarity stratigraphy of the entire Siwalik Group. The Yale University-Geological Survey of Pakistan project has been collecting and studying the vertebrate fossils from the lower and middle Siwaliks. These two projects have been working in close associations and share essentially a common goal to understand the chronology, vertebrate paleontology, and paleoecology in general and the evolution of man, in particular. The third project involved in the Siwaliks of Pakistan is the Howard University-Geological Survey of Pakistan project, which is concerned mainly with Trans-Indus Siwaliks (i.e. that portion located west of the Indus River), far western portion of the Potwar Plateau and the Sehwan-Gaj area, Sindh.

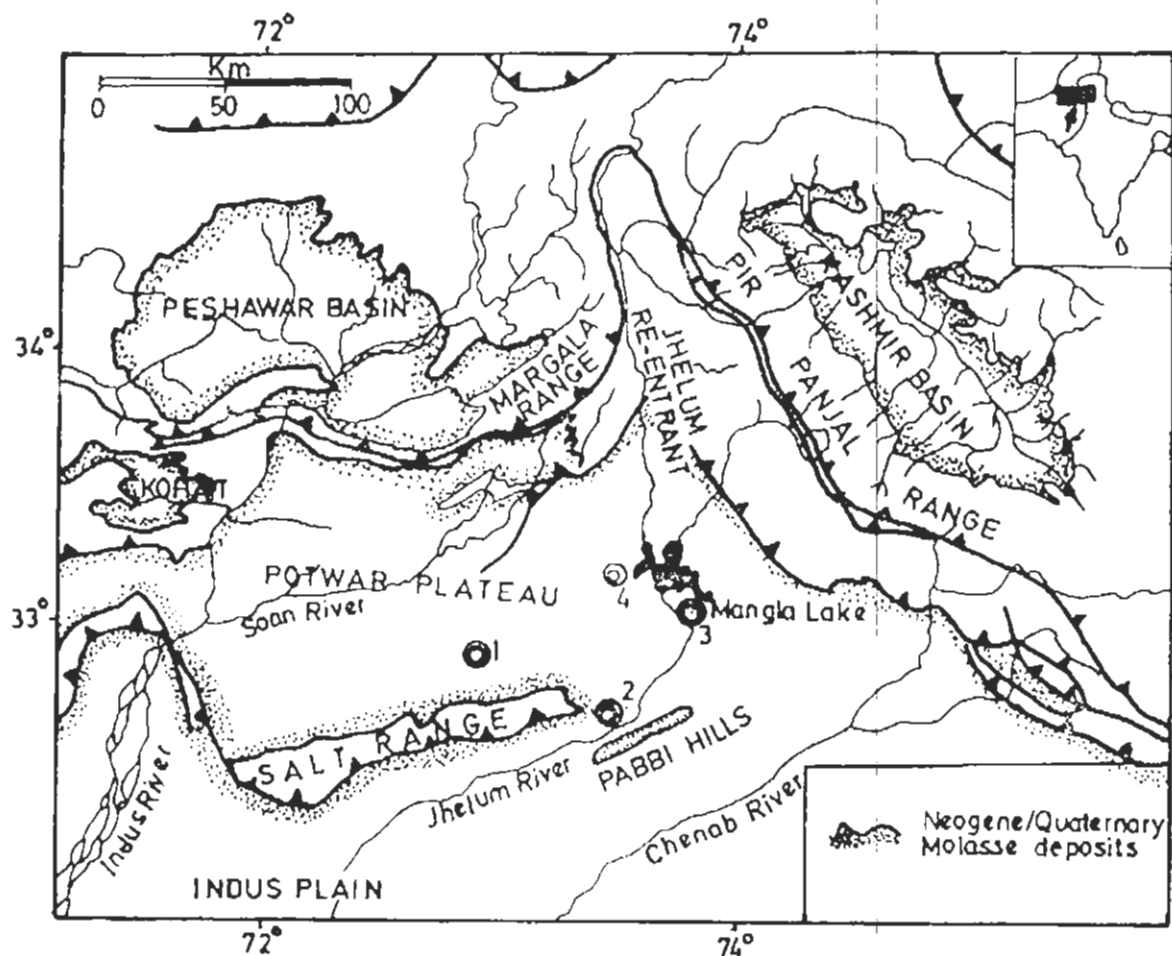


Fig.1. Generalized geological map of northern Pakistan showing the extent of Neogene – Quaternary molasse deposits. The areas studied in this report are: 1. Bin Amir Khatoon, 2. Jalalpur, 3. Mirpur, Azad Kashmir and 4. Lehri (modified after Johnson et al, 1986 and Burbank et al., 1986).

A major strength of the Siwalik fossil record is in the superb temporal control provided by magnetic polarity stratigraphy. No other terrestrial sequence of fossil localities spanning the Neogene has been more precisely dated. The integration of systematics paleontology with temporal control provides a unique insight into the evolutionary and dispersal pattern of some of the more common vertebrate groups from the Siwalik rocks. Rodents are one of those groups, which have been extensively studied in the last two decades. The pioneer studies by Jacobs, Flynn and Lindsay have established broad evolutionary and migration patterns of murids, rhizomyoids and cricetids in the South Asia during the Neogene times.

However, it was felt that the studies so far done on rodent systematics and evolution were taken up in different areas representing successive time periods but with certain important gaps. Therefore, it was felt necessary to select those areas where such gaps can be filled.

With this objective the proposed study has been taken up in the Bin Amir Khatoon area (District, Chakwal), Jalalpur (District, Jhelum), Samwal-Mirpur, Azad Kashmir and Lehri (District, Jhelum). These areas document a continuous Siwalik sequence spanning 18.5-3 Mya. The prime objective of this work is to extend faunal and biostratigraphic framework based upon Muridae paleontology, which in conjunction with adjacent studied areas would become a principal reference region for the continental Miocene-Pliocene in Pakistan.

During the course of geological and paleontological studies of the Siwalik Group rocks in the prescribed areas, special emphasis was placed on the location and collection of sediments with potential for small mammal recovery. This aspect has become more important because the Middle and Late Miocene rodent successions recently established in other parts of the Potwar Plateau and the Schwan-Gaj areas provide another tool for fairly accurate age estimation of isolated localities (see Bruijn and Hussain 1984, Jacobs, Flynn and Down, 1989).

## 1.2 METHODOLOGY

The specimens utilized in this study were collected almost exclusively by screening fossiliferous sediments from four localities. Screening often yields large samples of small mammals from very

limited strata, criteria that are usually not met in surface collections. Sediments were sieved through tandem boxes with screen bottoms, the outer box with a finer 1.0 mm mesh. Boxes were submerged in water or water was run through boxes placed on stands. In the later case matrix disaggregated when soaked initially in buckets filled with water. Sediment from Jalalpur was soaked in water and acetic acid. Dry dirt from other localities broke down readily, when placed in the screen box, soaked in a tub of kerosene, drained and immediately submerged in water and washed by agitation.

Approximately ten tons of sediment was screened from each locality. Most specimens utilized in this study are isolated molar teeth. Measurements were read using a microscope fitted with a reticle. All length and width measurements, recorded in mm, are maximum dimensions.

All specimens are housed in the Pakistan Museum of Natural History, Islamabad.

## CHAPTER-2. REGIONAL STRATIGRAPHIC FRAMEWORK OF THE POTWAR PLATEAU

Siwalik rocks in the Potwar Plateau were, first subdivided into 'Lower', 'Middle' and 'Upper' units by Pilgrim (1910). The subdivisions were then based on both lithological and palaeontological criteria, and clearly were meant to have temporal significance. In 1913, Pilgrim further subdivided the Middle Siwaliks into Dhok Pathan beds and included fauna, making the Dhok Pathan zone, and an underlying Nagri zone. The Lower Siwalik unit was described as the Chinji zone, while Tatrot and Pinjor zones were defined for the Upper Siwaliks. Pilgrim's zones have something of the status of stages (time-rock units) of current stratigraphic usage. In theory, the units were intended to be bounded by isochronous surfaces. Lithology, however, was frequently used together with fauna in classification as though similar rock-type implied similar time. It is now known that because of facies change, gross lithology alone is a poor correlative tool; Pilgrim (1910) noted this although he often ignored its implications.

Anderson (1927) used the terms 'Chinji stage', 'Middle Siwalik' and 'Upper Siwalik' solely in a lithological sense, and included discussions of thickness and facies variation. Essentially his concepts are 'formational' in current stratigraphic usage; however, his 'Middle' and 'Upper Siwalik' categories are different from those of most other workers.

In the early 1930s Cotter and Colbert published slightly different stratigraphic schemes for the Siwaliks. Cotter (1933) used a 'stage' terminology ('Chinji Stage' and so on), the stages being defined on the basis of lithology and fauna. Colbert (1935) subdivided the sequence into zones using the same terminology, based almost exclusively on faunas. Lewis (1937), following Pilgrim, Anderson, Cotter and others, redefined Tatrot, Dhok Pathan, Nagri, Chinji and Kamliyal formations, giving their type localities and key lithological descriptions. But he also included descriptions of faunas as part of the definition, and it seems that the units are stages of current usage, rather than formations. Gill (1952) used a 'stage' terminology for concepts that are basically formational.

In 1973 the Stratigraphic Committee of Pakistan (Fatmi, 1973) formally defined formations solely on lithological criteria. The nomenclature used (Chinji, Nagri and so on) was that introduced by Pilgrim about 60 years earlier on the basis mainly of faunas, and which has since been used by many workers in various ways as rock and time rock units. The use of these identical parallel terminologies has proved extremely confusing. Therefore, the Stratigraphic Committee also suggested that Pilgrim's names should better be confined to properly defined lithological units. It is now being increasingly felt that the formation names should not be used outside the type areas and 'mappably' continuous areas. A separate nomenclature for biostratigraphic and time stratigraphic units is, thus, necessary.

The Stratigraphy Committee of Pakistan divided the entire Neogene molassic sequence of the Potwar Plateau and adjacent Kohat-Kala Chitta areas into a relatively thinner Rawalpindi Group succeeded upwards by thicker Siwalik Group (Fatmi, 1973). The Rawalpindi Group comprises the Murree Formation with gradual upward passage to the Kamrial Formation. The Siwalik Group sequence is divided into four units, which in ascending order are the Chinji, Nagri, Dhok Pathan and Soan Formations (Fig. 2).

Siwalik deposition is mainly fluvial and cyclic (Duff et al. 1967, Johnson, 1977). Typical exposures are characterized by repetitive units, commencing with single sandstone bodies grading upwards into fine grained silts and clays which are in turn abruptly truncated by the sandstone of the succeeding cycle (Johnson, 1977). The sandstones probably represent lateral accretion or point bar, channel lag, cut and fill and channel splay deposits, the finer sediments being vertical accretion or overbank deposits which may preserve paleosols. Other exposures are characterized by sequences almost lacking fine-grained sediments, while multistoried sandstone attains considerable thickness.

The Chinji Formation ( $72^{\circ}22'$  E,  $32^{\circ}41'$  N), is defined south of Chinji village on the southern margin of the Soan synclinorium, and consists of a series of sandstones separated by thick red silts. The succeeding Nagri Formation ( $72^{\circ}14'$  E,  $32^{\circ}45'$  N), defined northeast of Chinji village near Sethi-Nagri, is made up of more massive sandstones with only minor over bank mudstone.

The type section of the Nagri Formation is in the gorge of the nearby Gabhir River, north of Sethi Nagri.

Unfortunately the succeeding Dhok Pathan Formation is not defined in the same area as the Nagri Formation. Its type locality is at Dhok Pathan ( $72^{\circ} 14' E$ ,  $33^{\circ} 8' N$ ) on the northern flank of the Soan synclorium, some 45 km north of Chinji village and 40 km north of Sethi Nagri. The Dhok Pathan Formation is, like the Chinjis, predominantly argillaceous, although the overbank deposits of the former rarely match the rich red hues of the later. Some nine fluvial cycles are recorded by Pilbeam et al. (1977) at the Dhok Pathan stratotype, whereas the formation is unconformably overlain by the much younger, horizontally bedded Potwar silts.

The Soan Formation has the basal portions exposed in the northern Potwar Plateau and consists of alternating conglomerate and sandstone units with subordinate sandy silt interbeds. The conglomerate units contain cobbles and pebbles of limestone, sandstone, quartzites and of other igneous and metamorphic rocks; all being embedded in gritty to coarse sand matrix. The provenance of sedimentary clasts seems to be the nearby Salt Range and Kala Chitta Range whereas igneous and metamorphic pebbles have been derived from the northern crystalline terrane.

The contact of the Soan Formation with the underlying Dhok Pathan Formation has been reported to be unconformable; being of angular type at the Mujahed stratotype ( $72^{\circ} 47' E$ ,  $33^{\circ} 22' N$ ). Study of this contact relationship in southern Potwar on the Chakwal-Choa Saiden Shah Road (near Ejazabad-Jhatla villages) shows a sudden influx of a thick matrix supported conglomerate unit defining the boundary. This basal, about 5 m thick, conglomerate unit is in concordance with the underlying sandy mudstone unit of the Dhok Pathan Formation. The sudden influx of conglomerates and their frequent recurrence further up in the Soan Formation, however, indicates some major shifts in the depositional style, which may have causal relationships with various tectonic events in the Himalaya and in the depositional basin per se.



Group	Formation	Thickness Range (m)	Type Locality (Area)	Lithology	Chronology	Epoch
Post Siwalik	"Potwar Sills" "Deformable Contact" "Late Conglomerate Facies"	Variable	None	Sill mostly basic; some chert and overbank fans. Gravelly matrix composed of Eocene limestone; subordinate coarse sandstone and minor silt interbeds.	0.065-0.018	Late Pleistocene
	Unconformity	Variable	Rawalpindi	At base, medium grained sandstone dominant; mild, yellow and buff mudstone overlain by massive conglomerate on top.	0.7-0.5	
	Upper Soan	30-900	Mujahid Jalalpur Jhelum	Varicoloured mudstones dominant, white and brown sandstones; calcic pebbles common.	5.0-0.7	Plio-Pleistocene
Middle	Dhok Pathan	900-1800	Dhok Pathan Jalalpur Jhelum	Varicoloured mudstones dominant, white and brown sandstones; calcic pebbles common.	8.5-5.0	MIOCENE
	Nagri	840-1700	Sethi Nagri Jalalpur Jhelum	Coarse to medium grained, greenish gray sandstone with subordinate reddish brown mudstone; extra-formational pebbles are common.	10.8-8.5	
	Chungi	200-2000	Chungi Jalalpur Jhelum	Bright red mudstone alternating with medium grained, gray and buff sandstone.	14.3-10.8	
Lower	Kamiali	120-900	Kamiali Jalalpur Jhelum	Grayish green sandstone alternating with subordinate reddish brown mudstone.	18.3-14.3	MIOCENE
	Murree	10-3400	Dhok Maiki Jalalpur Jhelum	Indurated purplish red sandstone alternating with narrow mudstone, subordinate intra-formational conglomerates common.	Older than 18.3(?) 22.2	
RAWALPINDI		Unconformity	Unconformity	Lower Eocene Carbonates		

Fig.2. The litho and chronostratigraphy of the Mollase sediments exposed in the Kohat-Potwar Basin.

## CHAPTER-3. REGIONAL CHRONOLOGICAL FRAMEWORK OF THE SIWALIKS

### 3.1 MAGNETOSTRATIGRAPHY

The Siwaliks of the Potwar Plateau present the best example of a continuous sequence of palaeomagnetically well dated terrestrial deposits spanning most of the Neogene.

Fine grained sediments common as overbank or flood plain facies in Siwaliks; usually preserve a record of geomagnetic reversals prevailing at the time of deposition. Representative sections of virtually the entire Siwaliks Group of the Potwar Plateau have been studied in detail to determine the characteristics of the remnant magnetization of the sediments (Tauxe et al. 1980; Tauxe and Badgley, 1988) and to correlate the local sequences with the geomagnetic polarity time scale (GPTS) Johnson et al. 1979, 1982, 1985; Keller et al. 1977; Khan et al. 1988; Opdyke et al. 1979; Tauxe and Opdyke, 1982. This enables assignment of precise ages to specific horizons and direct correlation to other magnetically dated sequences.

**Table 1. Selected Contribution In Palaeomagnetic And Rock Magnetic Studies On Siwaliks In Pakistan (After Mitsuo Yoshida et al 1994).**

YEAR,	REFERENCE,	MAIN TOPICS,
1970s,	Keller et al. (1977), Johnson et al. (1979), Opdyke et al. (1979),	Up. Siwalik in Pabbi Hills Up. Siwalik in Eastern Salt Range Up. Siwalik
1980s,	Tauxe et al. (1980), Mirza (1980), Tauxe and Opdyke (1982), Behrensmeyer and Tauxe (1982), Barrey et al. (1982), Johnson et al. (1982a), Johnson et al. (1982b), Tauxe and Badgley (1984), Johnson et al. (1985), Raynolds and Johnson (1985), Burbank et al. (1986), Johnson et al. (1986), Badgley (1986), Rendeil et al. (1987), Khan et al. (1988), Tauxe and Badgley (1988),	NRM of Mid Siwalik red beds Soan Formation in Mujahad Siwaliks near Khaur area Application to sedimentology Application to biostratigraphy Siwalik in Potwar Plateau Mid. Siwalik Remanence of Siwalik red beds Siwaliks near Chinji Up. Siwalik in Potwar Application to tectonics and sedimentation Application to tectonics and sedimentation Application to taphonomy Up. Siwalik in Soan Valley Up. Siwalik in Trans-Indus Range Application to sedimentology
1990s,	Tauxe et al. (1990), Opdyke (1990), McRae (1990),	AMS of Siwalik red beds Siwaliks and other terrestrial deposits Application to sedimentation

Table 1 summarizes major work, which contributed to establish local magnetostratigraphy in northern Pakistan. Some typical work on application studies in magnetostratigraphy is also listed in the table. Fig. 3 shows local magnetostratigraphic columnar surveyed by these researchers and correlated with the geomagnetic polarity time scale (GPTS).

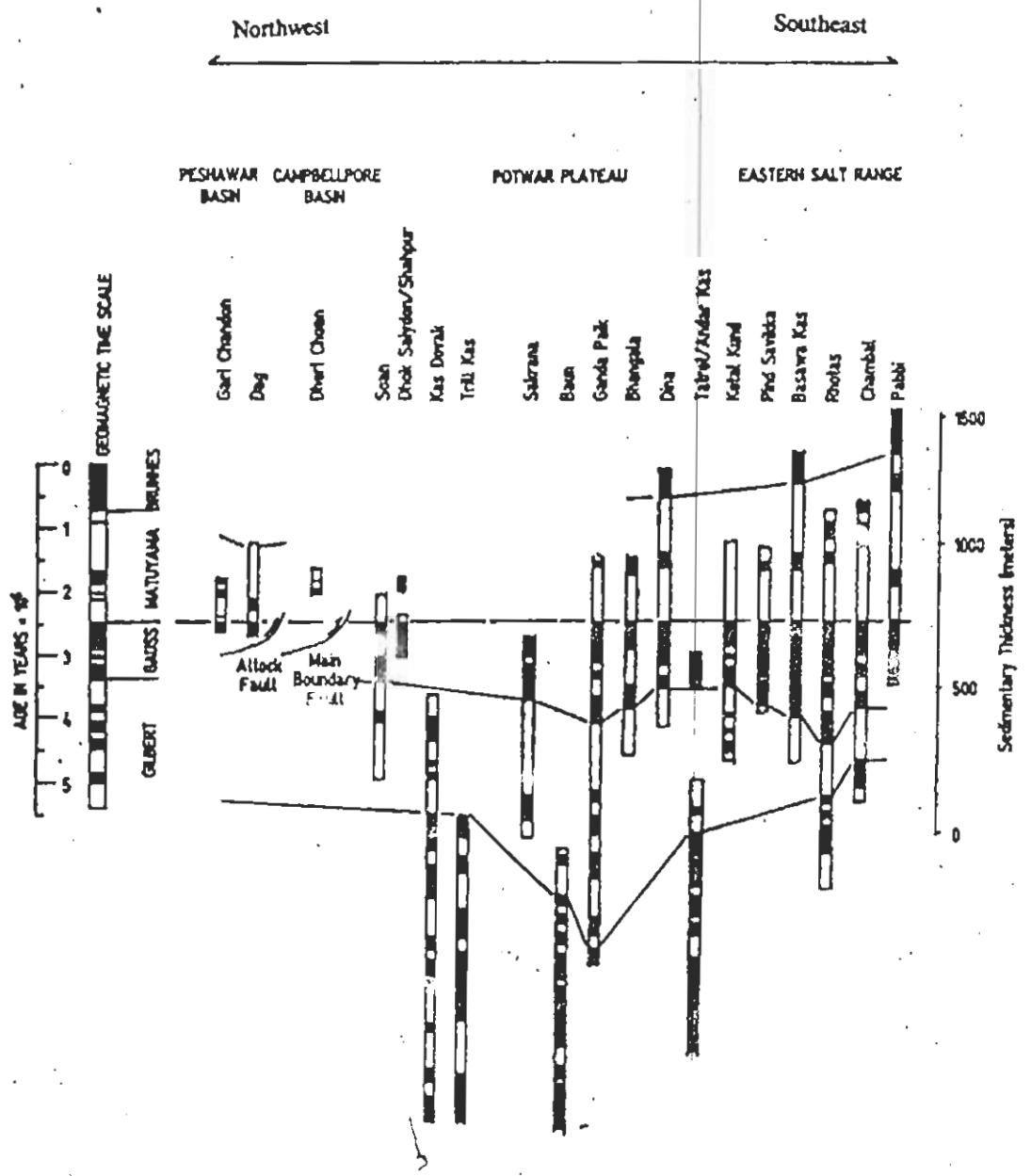
It can be observed that Siwalik deposits in the northern Pakistan almost completely represent the Neogene-Quaternary magnetostratigraphy. The probability of completeness probably reaches on the scale of 0.1 m.y (Flynn et al. 1990). Furthermore, well-dated faunal zones ('interval zones') could be established (Barry et al. 1982).

### 3.2 DYNAMICS OF HIMALAYAN MOLASSE

The time control offered by paleomagnetic analysis of Siwalik sediments has many geological applications. Sedimentation rates reflect the development of fluvial systems, of basin subsidence and shape, unroofing of Himalayan basement, and Himalayan orogeny.

The Siwalik basin is a foredeep (foreland basin) of Himalayan orogenic belt, which migrated from north to south. Therefore, Siwalik accumulation history reveals the history of uplifting of Himalayas. The dynamics of sediment accumulation contributing to an orogenically derived elastic package can be schematically illustrated as in Fig. 4 (Raynolds and Johnson, 1985). At a given site on a distal foreland margin, initial sediment-supply derived from the distant orogenic belt is very low, e.g. present sedimentation around southern margin of Gangetic plain, India. For an initial period of the orogeny (uplifting) the sediment accumulation may be similar to such condition. Subsequently, the growing proximity of the orogenic margin results in an increased sediment supply coupled with increased rate of basin subsidence. These two factors combine to yield a maximum rate of sediment accumulation (Fig. 4).

With continuous convergence of the orogenic belt, more source-proximal sedimentary facies ultimately becomes involved in uplift and deformation.



(after Burbank et al., 1985)

Fig.3. Siwalik deposits in the northern Pakistan surveyed magnetostratigraphically.

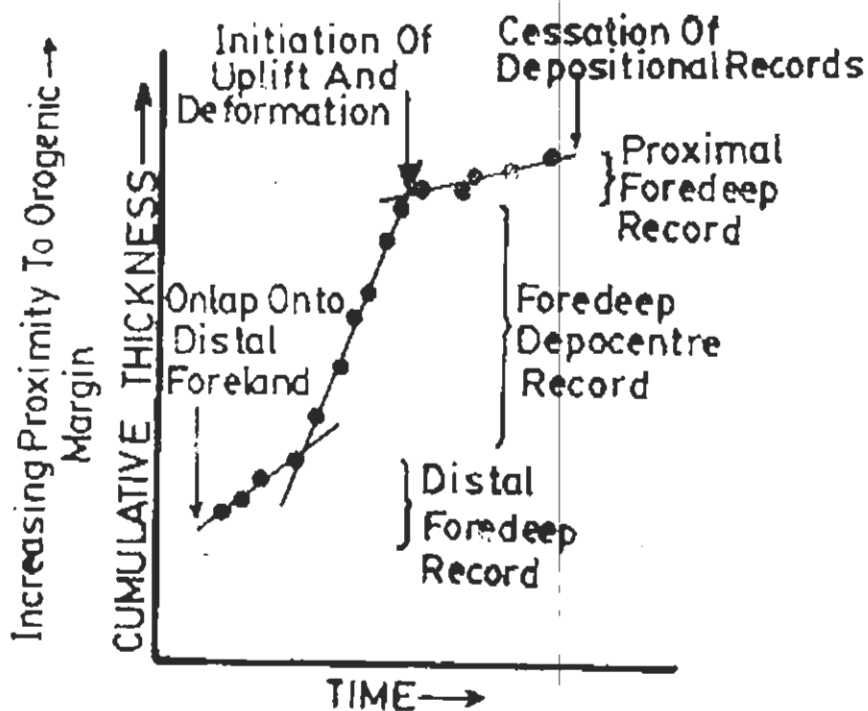


Fig.4. Idealized cumulative sediment accumulation VS time (geomagnetic polarity time scale) illustrating the two principal inflection points related to (1) rate increase associated with the onset of maximum sediment accumulation/foredeep depocentre conditions and (2) rate decrease associated with the onset of uplift and deformation in the proximal foredeep (Raynolds and Johnson, 1985).

Raynolds and Johnson (1985) compiled magnetic polarity stratigraphy of 15 sections in the eastern Potwar and analyzed the sediment accumulation rate. That allows discussing the temporal and spatial sediment accumulation history of this region of the Himalayan foredeep basin.

### 3.3 ACCUMULATION RATE VARIATIONS

The widespread distribution of accumulation rate data permits to examine spatial variation of the rate during selected intervals of time. Raynolds and Johnson (1985) compiled the rate variation in the Jhelum area, Punjab, Pakistan, during Gauss Chron (3.40-2.48 Ma) and early Matuyama Chron (2.48-1.6 Ma) intervals. During the Gauss Chron, the locus of maximum sediment accumulation (or depocenter) occurred in the northeastern portion, near Mawa Kaneli. During this interval the maximum rate exceeded 50 cm/kyr. Subsequently, the depocenter migrated southward in the early Matuyama Chron and the maximum rate decreased (2cm/kyr). During the late Matuyama Chron, the depocenter was located to the south of Jhelum area, Pabbi Hills. According to the southward migration of Siwalik depocenter deduced from rate variation, it was interpreted that a tectonic movement (uplifting) occurred on the axis of Jhelum re-entrant, which ran along the course of the modern Jhelum River. This may reveal a dynamics of Himalayan molasse; a time transgressive phenomenon resulting from the outward displacement of the Himalayan orogenic front.

### 3.4 BIOSTRATIGRAPHY

Pilgrim's classificatory schemes of six faunal zones have been something of the status of "stages" of current stratigraphic usage. The stage is defined as a chronostratigraphic unit of relatively minor rank representing a body of rock strata that is unified by being formed during a specific geological time. Thus, all faunal zones when used as mappable units as well imply an isochroniety of the component formations. The continued usage of Pilgrim's nomenclature as faunal zones and by adding more fauna from separate areas, the definition of each zone became broader and fuzzier.

One of the major developments by the recent researches is new definition of biostratigraphic units and restricting the old nomenclature exclusively as formations. Improved field technique for fossil collection, accurate and better documentation of fossil localities on aerial photographs and topographic sheets in the field, tying up of localities in the composite lithostratigraphic sections of a restricted area by lateral tracing of major sand bodies and systematic revisions of the vertebrate fauna are some of the key factors in evolving new biostratigraphic schemes. A major break-through providing an independent means of establishing ages of various local stratigraphic sections and correlation between different areas in Potwar Plateau is obtained by applying magnetic-polarity stratigraphy and fission track radiometric dating.

A series of biostratigraphic zones, defined and characterized in fossiliferous, well-documented reference sections and correlated to magnetic polarity sequence, are believed to provide a more reliable framework for biostratigraphic division of the Siwalik faunas and should replace Pilgrim's "faunal zones". The units summarized in Table 2 are, the biostratigraphic interval zone where each unit is defined as the stratigraphic interval between two distinctive biostratigraphic units recognized in the Reference Sections, and the base of each succeeding one is the top of the preceding ones. A number of local stratigraphic sections in the Siwaliks of Potwar Plateau and their faunal and temporal correlation provides basis for a composite stratigraphic section, which then is designated as the Reference Section for the particular area. Designating Reference Sections for each biostratigraphic zones allows the stratigraphic horizons of the unit boundaries to be recognized and related to other biostratigraphic and chronostratigraphic units. Three reference sections are designated whose correlations depend solely on the magnetic polarity stratigraphy. These sections are the Hasnot Composite in the Hasnot-Tatrot area, the Kamlial Kas in the Kaur area, and the Chita Parwala-Gabhir section in the Chinji-Nagri area (Barry et al 1982).

Seven biostratigraphic interval zones alongwith of their characteristics fauna are given in Table 2. The first four interval zones between 9.5 to 1.5 Ma, are better defined from the Kamlial Kas and Hasnot Composite Reference Sections. The older three interval-zones are based on the Chita Parwala-Gabhir Reference Section and needs a better secure data points.

Table 2. Biostratigraphic interval-zones schemes with characteristics fauna of the Siwalik Group (and Murree Formation) of the Potwar Plateau (After Shah et al, 1985).

TIME (Ma BP).	BIOSTRATIGRAPHIC INTERVAL-ZONE	CHRACTERISTIC FAUNA
1_		
	(1.5)	
2_	<i>Elephas planifrons</i>	<i>Elephas planifrons</i> , <i>Equus sivalensis</i> , <i>Hyppohyus</i> sp., <i>Sivatherium giganteum</i> , <i>Cervids</i> .
3_		
	(2.9)	
4_	<i>Hexaprotodon sivalensis</i>	<i>Hexaprotodon sivalensis</i> , <i>Proamphibos lachrymans</i> , <i>Stegodon</i> sp., <i>Potamochoerus</i> sp., <i>Dorcatherium</i> sp., <i>Hippopotamodon sivalense</i> , <i>Percrocuta grandis</i> .
5_		
	(5.3)	
6_	<i>Selenoportax lydekkeri</i>	<i>Mus auctor</i> , <i>Protachyoryctes tatroti</i> , <i>Selenoportax lydekkeri</i> , <i>Presbytis sivalensis</i> , <i>Indarctos punjabiensis</i> , <i>Hipparion s.l.</i> , <i>Hominoidea</i> .
7_		
	(7.4)	
8_	" <i>Hipparion s.l.</i> "	<i>Hipparion s.l.</i> , <i>Progonomys</i> spp., <i>Hippopotamodon sivalensis</i> , <i>Propotamochoerus hysudricus</i> , <i>Sivahyus punjabiensis</i> , <i>Dorcabune nagrii</i> , <i>Dorcatherium amajus</i> , <i>Tetracondon magnus</i> , <i>Hominoidea</i> .
9_		
	(9.5)	
10_		
11_		
12_	<i>Giraffokeryx punjabiensis</i>	<i>Giraffokeryx punjabiensis</i> , <i>Antemus chinjiensis</i> , <i>Kanisamys potwarensis</i> , <i>Helicoporatax praecox</i> , <i>Sivoreas eremita</i> , <i>Protragocerus glutens</i> , <i>Percrocuta carnifex</i> , <i>Dorcatherium minus</i> , <i>Dorcabune anthracatherioids</i> , <i>Hominoidea</i> (= <i>Sivapithecus indicus</i> ), <i>Listriodon pentapotamiaë</i> , <i>Conohyus sindiensis</i> .
13_		
14_		
	(14.0)	



15_	" <i>Listriodon</i> sp."	<i>Listriodon</i> spp., <i>Conohyus</i> spp., <i>Eotragus</i> ., <i>Prokanisamys</i> sp., 15_ " <i>Listriodon</i> sp.," <i>Kanisamys indicus</i> , <i>Sayimys</i> sp., <i>Sanitherium</i> sp., <i>Nimravidae</i> , small hominoid, <i>Dorcabune</i> sp., <i>Dorcatherium</i> sp.
16_	----- (16.3) -----	
17_		
18_	" <i>Gomphotherium</i> s.l."	" <i>Gomphotherium</i> s.l.", <i>Dinotherium</i> <i>pentapotamiae</i> , <i>Brachypotherium</i> sp., gigantic anthracothere.
19_		
20_		
21_		

The "*Gomphotherium* s.l. Interval-zone contains the African immigrants such as *Gomphotherium* and *Deinotherium* along with remains of some gigantic anthracotheres, rhinoceroses and carnivores which suggest a mixture of some Central Asian and African elements. In contrast, the "*Listriodon* sp." interval-zone contains a markedly different fauna of bovids, thryonomyid, ctenodaetylid, rhizomyid, and advanced murid rodents as well as species of *Brachypotherium*, *Sanitherium*, *Listriodon*, *Dorcabune*, a gibbon-like hominoid and a large unidentified giraffoid. This is the most important faunal turnover, which essentially sets the typical Siwalik faunal aspect. The other major faunal turnover dated around 9.5 Ma BP with the appearance of hipparionine equids together with the immigration of new giraffids and suids from Eurasia and tragulids and rodents perhaps from Africa. At this time, several of the local herbivores (e.g. *Giraffokeryx*, *Listriodon*, *Conohyus*, several bovids and tragulids species etc.) became extinct. The last episode of faunal turnover at the base of *Elephas planifrons* interval-zones about 2.8 Ma BP was less restricted in time. Several artiodactyl taxa disappeared, as suids and proboscideans of African affiliation and *Equus* and cervids from Eurasia make their first appearance. The modern Indian subcontinent fauna had its origin probably in this faunal change.

It is believed that the major faunal turnovers were regional events, which can be related to similar, but not necessarily contemporaneous, turnovers in Europe and Africa. These major

changes in the Siwalik biostratigraphic record correspond closely to major global climatic, oceanographic, and tectonic events.

## CHAPTER-4. GEOLOGY, STRATIGRAPHY AND MAGNETOSTRATIGRAPHY OF BIN AMIR KHATOON & MIRPUR, AZAD KASHMIR

### 4.1 BIN AMIR KHATOON, SOUTHERN POTWAR PLATEAU

The Bin Amir Khatoon area (District Chakwal) exposes the most complete Siwalik Group sequence in the southern Potwar Plateau. In a cumulative stratigraphic thickness of 2.0 – 2.5 km and composing all the five component formations of the Siwalik Group, the Bin Amir Khatoon area contains an almost continuous geological record spanning from approximately 18.5 Ma to 4.5 Ma BP (Johnson et al. 1982).

The Siwalik Group rocks form an east-west trending exposure with relatively steeper dips. The structural complications, i.e. high-amplitude folds and strike-slip faults, are common in the western part, whereas, the eastern-half of the area is relatively free of any major diastrophic disturbances.

### 4.2 STRATIGRAPHY

The Siwalik Group in the Bin Amir Khatoon area is composed of five lithostratigraphic units, which are (in ascending order) the Kamliyal, Chinji, Nagri, Dhok Pathan and Soan Formations. The overall lithological composition of these component formations, are fairly identical with those described from their respective stratotypes. However, in comparison with the stratotype areas, all the Siwalik formations of the Bin Amir Khatoon area are relatively less thicker and contain more mudstones. The Chinji Formation, because of its good exposure and being relatively more fossiliferous has received most attention. A section in Kas Kuthan was measured to provide the lithofacies details of the Chinji formations (Fig. 10).

#### 4.2.A SOAN FORMATION

The Pliocene Soan Formation has the basal portions exposed in the Bin Amir Khatoon area and consists of alternating conglomerate and sandstone units with subordinate sandy silt interbeds. The conglomerate units contain cobbles and pebbles of limestones, sandstones, quartzites and of

other igneous and metamorphic rocks; all being embedded in gritty to coarse sand matrix. The provenance of sedimentary clasts seems to be the nearby Salt Range and the Kala Chitta Range whereas igneous and metamorphic pebbles have been derived from the northern crystalline terrane.

The contact of the Soan Formation with the underlying Dhok Pathan Formation on the Chakwal-Choa Saiden Shah Road (near Ejazabad-Jhatla villages) show a sudden influx of a thick matrix supported conglomerate unit defining the boundary. This basal, about 5 m thick, conglomerate unit is conformable with the underlying red-brown mudstone unit of the Dhok Pathan Formation. The sudden influx of conglomerates and their frequent recurrence further up in the Soan Formation, however, indicates some major shifts in the depositional style, which is related with the uplift of the nearby Salt Range. Therefore, the contact with the Dhok Pathan-Soan Formations in this area is conformable but sharp.

#### **4.2.B DHOK PATHAN AND NAGRI FORMATIONS**

The lithological composition of the Dhok Pathan and Nagri Formations are quite similar to their respective type areas, i.e. the Dhok Pathan-Khaur area for the former and the Gabhir River Section area for the later. The Dhok Pathan Formation consisting of thick alternating units of gray sandstones and dull red brown mudstone is about 700 m thick and has gradational contact with the underlying Nagri Formation. The Nagri Formation is composed dominantly of 15 m or more thick multi-storied sandstone units with subordinate red-brown mudstone interbeds. Conglomerate pockets and thin interbeds within the sand-bodies are common, and are composed dominantly of extra-formational clasts of igneous and metamorphic rocks. The Nagri Formation in the Khokher Zer area has faulted contact with the Dhok Pathan Formation. The lower contact with the Chinji Formation is gradational and the boundary is usually placed at the first appearance of laterally persistent sandstone unit of more than 15 m thickness.

#### 4.2.C CHINJI FORMATION

The Chinji Formation, because of its good exposures and being relatively more fossiliferous, has received most attention.

It is composed of red-brown mudstone with common gray sandstone inter-beds (Fig. 10). The Chinji Formation, about 500 m in average thickness in Bin Amir Khatoon area, is composed of 11 to 15 m fining-upward sequences. Each fining upward sequence is marked at the base by a fine conglomerate or gritty coarse sandstone unit, gradually changes sandstone and finally to silt (or occasionally clay) in the upper portion. The sand to silt ratio in the Chinji Formation is 1:3 whereas in each fining upward unit this may vary from 1:2 to as much as 1:5. The sand-bodies geometry and other sedimentary characteristics indicate that the sandstones are mostly channel-sands with a few thin beds but with vast lateral spread being of crevasse-splay types. The colour and compositional variations in the mudstone units suggest that some of these may well have been deposited within channels by rivers carrying appreciable suspended mud-load.

The Chinji Formation of the Bin Amir Khatoon area is in strike continuation with its stratotype in Chinji area located about 50 km due west. The Bin Amir Khatoon-Chinji outcrop belt shows a decrease due east in the thickness of the Chinji Formation but also substantial increase in the mudstone proportions. The sandstone units are thinner being usually in the range of 1.5 to 4.5 m with only three units each of which exceed 10 m in thickness. Contrary to the type-area exposure, there does not seem to be increase in thickness or frequency in sandstone units in the upper part of the Chinji Formation.

#### 4.2.D KAMLIAL FORMATION

The Kamlial Formation consists of grey to brownish sandstone with red brown sandy mudstone interbeds. The sandstone units are usually more than 5 m thick and often have conglomerate lenses and thin interbeds. The mudstones are more common in the middle and upper parts and are often of maroon and purple colours. The fining-upward sequences which are better-developed in the Chinji Formation, are not easily distinguishable in the Kamlial Formation. The

lower contact of the Kamli Formation, mark one of the major unconformities of the Indus Basin. The top-most limestone beds of the underlying early Eocene Chorgali Formation show a weak development of karst topography, cavernous or pitted surfaces and occasionally have 2-5 cm thick lateritic patches. The basal 10-30 m of the Kamli Formation contains abundant broken foraminifera and marine bivalve shells derived from the underlying Eocene Formations.

### 4.3 MAGNETOSTRATIGRAPHY

Johnson et al. (1982) described the magnetic polarity stratigraphy of the entire Siwalik Group rocks exposed in Sauj Kas, 8 km west of Bin Amir Khatoon. Fig. 5 shows, the paleomagnetic data and stratigraphic log for this section. The Chinji-Nagri boundary is unusual in that, it is a fault contact indicating that some of the Chinji and/or Nagri may be missing in this section.

Sediments of the Soan Formation are well exposed in Sauj Kas, a valley immediately south of Bhaun village. The brown coloured Soan Formation in this basin lies disconformably upon Dhok Pathan Formation beginning with a ridge forming conglomerates. The sequence dips gently toward the north and is capped by the Potwar Silt. Opdyke et al. (1979) earlier studied in detail the paleomagnetic behavior of the Soan Formation in the Sauj Kas section. They sampled nine paleomagnetic sites through 70 m section of the Soan Formation. All sites were partially demagnetized. The resulting magnetic stratigraphy was marked by two normally magnetized magnetic polarity zones ( $N_2$ ,  $N_3$ ) 100-200 m above the base of the Soan Formation. Since the section was predominantly of reversed polarity, it was expected that the sediments would be either of Matuyama or Gilbert age.

A large lineament cuts across the Salt Range in a WNW direction, passing close to Kallar Kahar Lake, west of Bin Amir Khatoon. Dislocation of strata and the structural trend indicate that this is a major fault. The lake is straddled by smaller faults, and itself appears to be a fault lake, a feature, which indicates that these faults are probably recent. A right-lateral movement is apparent along most of these faults.

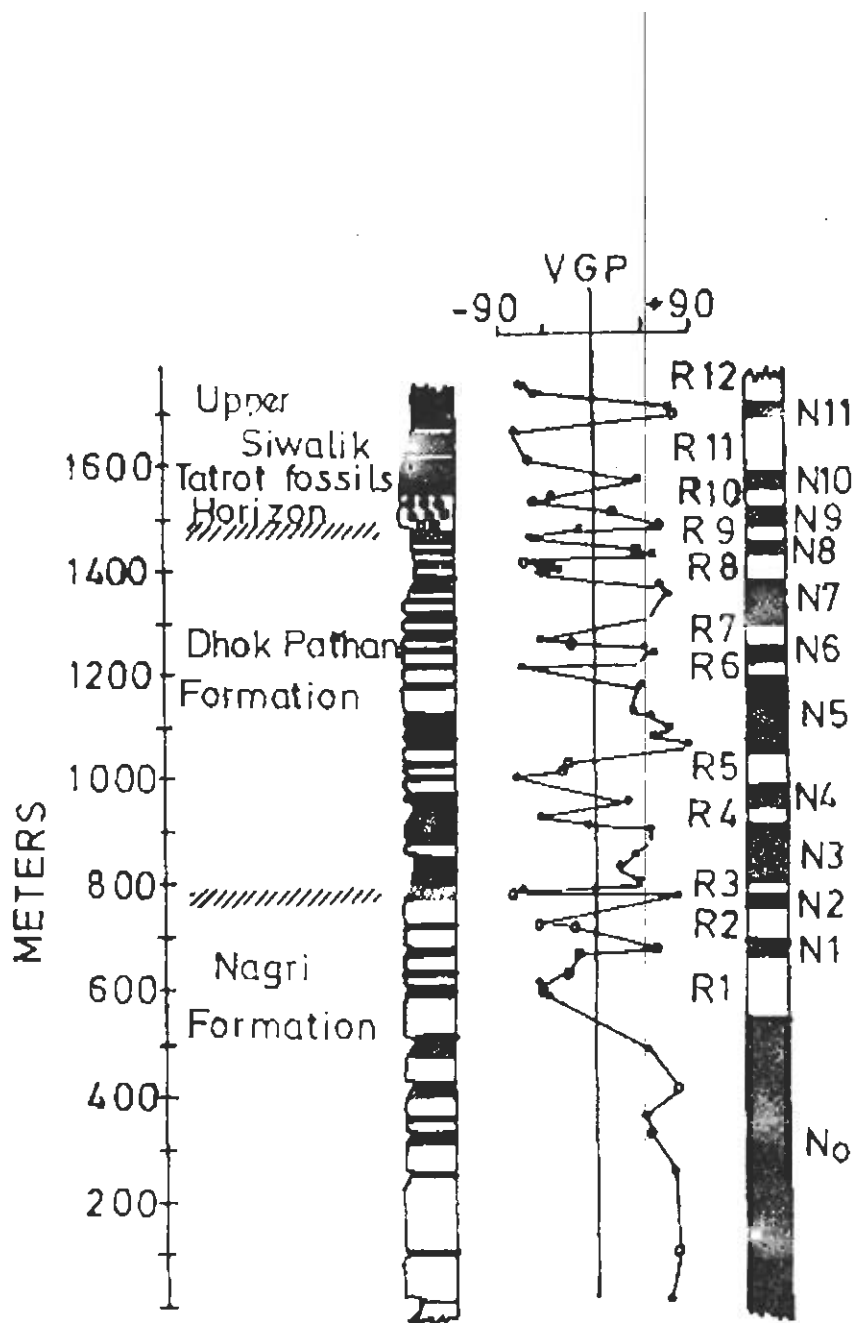


Fig.5. Magnetic polarity stratigraphy from Sauj Kas near the village of Bhaun, Chakwal (after Johnson et al., 1982).

#### 4.4 MIRPUR, AZAD KASHMIR AREA

#### 4.5 GEOLOGICAL BACKGROUND

The Mangla-Samwal Anticline is located in the Jhelum Re-entrant molasse basin. The Jhelum Re-entrant is the northwestern extension of the Indo-Gangetic foredeep and is enclosed by the Margala Range in the west and the Pir Panjal Range in the east.

Repeated phases of uplift of the Pir Panjal Range and the Margala Range in combination with a detachment and thrust development in the underground caused a southward migration of the deformation front and has influenced the sedimentation within the re-entrant molasse basin during the Plio-Pleistocene (Burbank and Reynolds, 1984; Burbank et al., 1986; Johnson et al., 1986). In the Mangla-Samwal Anticline tectonic influence on the deposition is first recorded between 2.9 Ma and 2.4 Ma BP, when a shift occurs from sand dominated sediments (lower Samwal Formation) to mud dominated sediments (upper Samwal Formation).

Further up in the sequence, thick conglomerate unit becomes a conspicuous lithofacies. The development and spreading of conglomerate units in the Jhelum re-entrant molasse basin is considered to be directly related, with various uplift phases of the Pir Panjal Range during the late Pliocene-Pleistocene times. The exact timing of the appearance of thick conglomerate units in the Mirpur-Samwal area is dated to be either 2.1 Ma BP (Burbank et al. 1986) or 1.6 Ma BP (Hussain et al. 1992); the later more plausible.

Folding of the Mangla-Samwal Anticline resulted in the development of a progressive unconformity southeast of Samwal village (Hussain et al. 1992). The folding resulted in a strongly asymmetrical anticline with a steeply sloping (60-90 degrees) southern limb and a gently dipping (10-30 degrees) northern limb (Fig. 6). Both limbs are without faults.



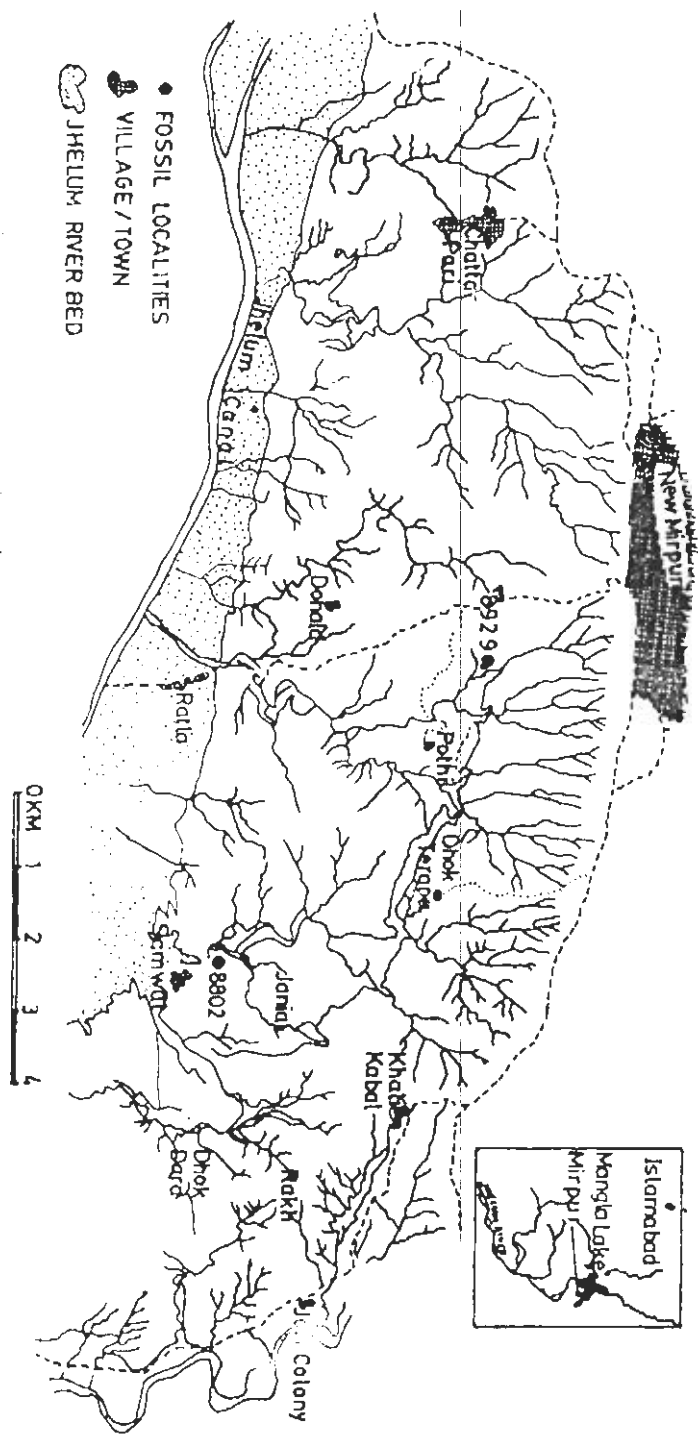


Fig.6. Location map of the Mangla Samwal anticline's with two fossiliferous rich localities (i) PMNH 8802 and (ii) HGSP 8929 (After Hussain et al., 1992).

#### 4.6 STRATIGRAPHY

The sediments of the Mangla-Samwal Anticline belong to the Upper Siwalik Subgroup which has commonly been referred to as Soan Formation (Fatmi, 1973). The Mangla-Samwal sequence, however, has altogether different lithofacies combination from that of the stratotype Soan Formation. Therefore, Arif (1985) defined a different set of three formations for this area: namely, from bottom to top, the Samwal, the Kakra and the Mirpur Formations.

Five sections were measured, described and correlated by Hussain et al. (1992) to establish a lithostratigraphical framework, which are the Samwal, Jhal Kas, Dhok Dara, the Jhelawala Kas and the Rakh section (Fig. 7). The Samwal and Dhok Dara sections are located on the southern flank of the Mangla-Samwal Anticline, whereas the Jhal Kas, Jhelawala Kas and Rakh sections are located on the northern flank of the anticline. The Jhal Kas section was also measured by Opdyke et al. (1979) and Johnson et al. (1982), in which they also established magnetic polarity stratigraphy. Hussain et al. (1992) correlated these five sections using two widespread bentonite layers, which are dated with fission tracks of zircon (Johnson et al. 1982). In addition, several sandstone beds were traced in the field from one section to the other some of which appeared to wedge out laterally, whereas other could be traced over a distance of upto 8 km.

The Samwal Formation consists of an alternation of brown coloured sandstone and red or brown coloured fine grained sediments of clay, silt, silty clay and sandy silt composition. The formation can be divided into lower sand dominated and an upper mud dominated parts. The upper bentonite layer defines the boundary between the two parts, though the transition is gradual (Arif 1985).

The sandstone beds of the lower Samwal Formation have a higher average thickness (9.3 m) than those of the upper part (about 3 m). The lower sandstones are medium to coarse, they are cross-bedded, show parallel laminations and tend to be multistoried with erosional source at the base. The sandstone units generally thin towards the east. The upper part of the Samwal Formation contains sheet-type fine-grained sandstone bodies that are frequently massive without sedimentary structures or internal surfaces.

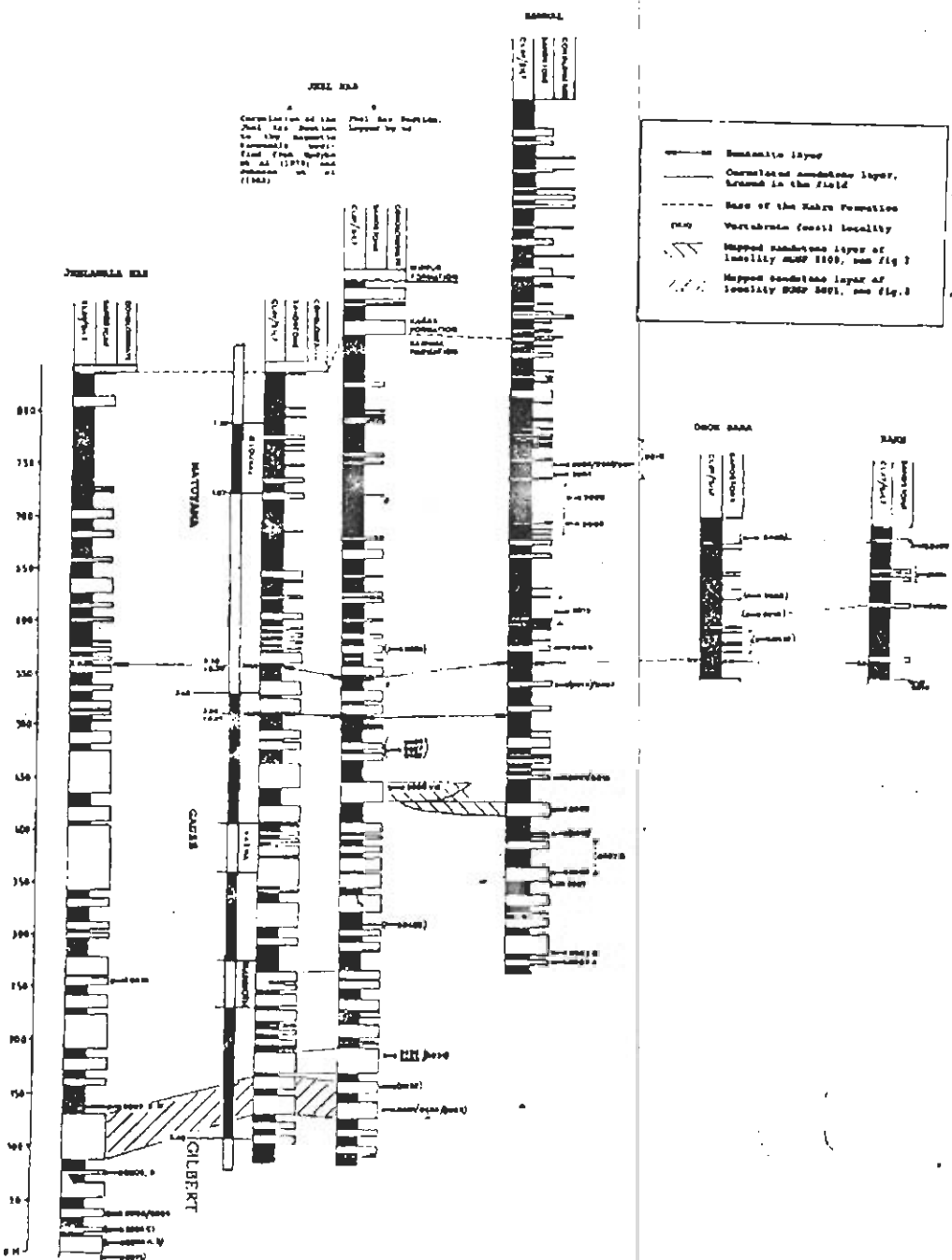


Fig.7. The section measured by Hussain et al., (1992) in the Jhal, Kas (Jhal Kas section B) is correlated with the paleomagnetic Jhal section (A) of Opdyke et al., (1979) and Johnson et al., (1982), showing 8802 and HGSP 8929 localities.

The fine-grained intervals of lower part are dominated by silty clay or clays, whereas those of the upper part are usually somewhat coarser (clayey silt and sandy silt). The total amount of the fine grain sediment is less in the lower part than in the upper part (34-55% versus 72-79%). Bioturbation and pedogenic features, like mottling and the presence of calcium carbonate nodules occur more often in the upper part than in the lower part.

In the Jhelawala Kas section, the Samwal-Kakra Formation transition is abrupt. Here the base of the Kakra Formation is erosive and the conglomerates are thick and massive. In the Jhal Kas section the total thickness is 46.5m, and the formation, is unconformably overlain by conglomerates of the Mirpur Formation (Arif, 1985).

However, in the southern Samwal section the transition is more gradual, since isolated pebbles of up to 13 cm in diameter are already present in the upper part of the Samwal Formation. Here the thickness of Kakra Formation is at least 200 m. The conglomerates gradually disappear upwards and mudstones become dominant. The southward dip decreases gradually higher up in the sequence and the upper part of the Kakra Formation passes into the Jhelum River Plain towards the south. The conglomerates of the Mirpur Formation are not developed along the southern flank of the anticline.

In all the sections the conglomerates of the Kakra Formation contain quartzite, chert and some metamorphic and volcanic clasts. In addition, only in the southern Samwal section upto 50% of the clasts are intrabasinal sandstone fragments.

The thick multistorey sandstone beds of the lower Samwal Formation, which are dominant in the western part of the Mangla-Samwal Anticline, are thought to have been deposited by a braided trunk river system of which the course was constrained by the Jhelum Re-entrant. The thinner multistoried sandstone bed presumably laid down by braided streams on inland fans, which originated from the Pir Panjal Range in the northeast. The upper part of the Samwal Formation was deposited by a system of small-scale streams on inter-fans. The transition between the lower

and upper Samwal Formation marks a southward shift of the sedimentary facies in the molasses basin. This shift has been related to a relative uplift of the Pir Panjal Range as a result of continuing compression of the Himalayan Mountain Range (Burbank and Reynolds, 1984; Burbank et al. 1986).

A major uplift of the Pir Panjal Range, which resulted in the basin-wards spreading of coarse conglomerate, is documented in the study area by the deposits of the Kakra Formation (Burbank and Reynolds, 1984; Burbank et al., 1986). The difference in development of the Kakra Formation between the northern and southern section is the result of contemporaneous folding and uplift of the Mangla-Samwal Anticline. The northern flank of the sequence has been eroded due to this uplift at the beginning of the deposition of the Kakra Formation. The high amount of intrabasinal sandstone clasts in the conglomerates of the Kakra Formation along the southern flank of the anticline reflects the erosion of the rising anticline. The folding and the uplift of the anticline started after 1.6 Ma BP as the palcomagnetic data of Johnson et al. (1979) show the youngest preserved deposits below the Kakra Formation in the Jhal Kas section to have an age of 1.6 Ma BP.

The Mirpur Formation is mainly composed of conglomerate and mudstone. The conglomerate consists of well-rounded pebbles and boulders of limestones, sandstone, quartzite and volcanic materials, which range in size from 5 mm to 200 mm in diameter. The conglomerate is loosely set in mudstone matrix and, hence, can be termed as muddy conglomerate. The mudstone mostly of silt composition contains frequent sandstone lenses.

#### 4.7 MAGNETOSTRATIGRAPHY

Opdyke et al. (1979) measured an excellent section with 700m of Upper Siwalik sediments exposed in the Jhal Kas in the northeast limb of the Mangla-Samwal Anticline, directly southwest of New Mirpur. Jhal Kas is a tributary of the Jhelum River. The Jhal Kas section consists of alternating sandstones and mudstones, with the percentage of finer grained material increasing higher in the section. The section is capped by a massive conglomerate correlated in the past to the boulder conglomerate of De Terra and Teilhard de Chardin (1936).

Fig. 8 shows a plot of the latitudes of the virtual geomagnetic poles (VGP's) as a function of the stratigraphic position of the sampling site above the base of the section at the axis of the anticline. Eight clear reversals of the field present in the section define the limits of seven magnetic polarity zones. Each magnetozone is defined by more than one site. Above and below the boundary of magnetozones  $N_3$  and  $R_4$  at 450 m above the axis of the anticline are two prominent bentonitized tuffs shown in the measured section. Fission track dates on zircon phenocrysts from these tuffs of  $2.3 \pm 0.4$  Ma BP (upper) and  $2.5 \pm 0.4$  Ma BP (lower) were determined by Nacser (Johnson et al. 1979). These radiometric dates securely correlate the magnetic reversal between the two tuffs to the magnetic transition between the Gauss normal polarity epoch and, the Matuyama reversed polarity epoch. This allows an easy correlation of the reversal sequence in the Jhal Kas section to the standard magnetic time scale (Cox, 1969; Opdyke, 1972; McDougall, 1979). The Kaena and Mammoth reversed events are both present within the Gauss normal epoch and so is the transition from the Gauss normal magnetic epoch to the Gilbert reversed magnetic epoch which occurs near the base of the section in the center of the anticline. If the rate of sedimentation for the Gauss is extrapolated to the sediments of the overlying Matuyama epoch, the normal event observed near the top of the section would span age from 1.9 to 2.1 Ma BP. These dates are similar to the known boundaries of the Olduvai event.

Johnson et al. (1982) measured the same Jhal Kas section of Opdyke et al. (1979). They observed that the Mangla-Samwal Anticline records continuous sedimentation lasting from 3.3 Ma BP to about 1.7 Ma BP.

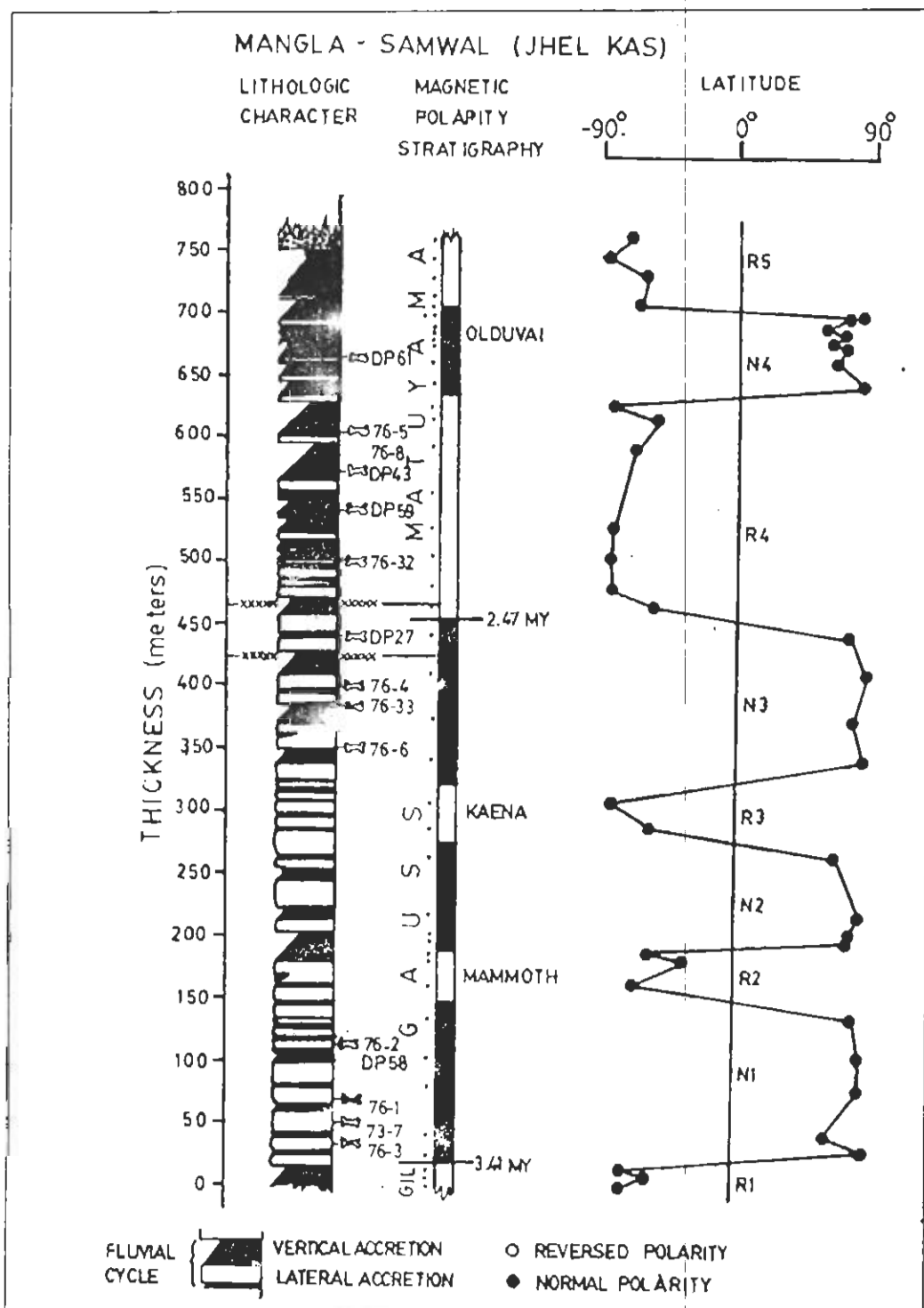


Fig.8. Plot of VGP latitude, sedimentary cycles and correlation of the magnetozones at the Mangla Samwal section to the standard magnetic time scale (After Opdyke, 1979).

Later on Hussain et al. (1992) correlated their Jhal Kas section with the magnetic polarity section of Opdyke et al. (1979) and Johnson et al. (1982), for comparison see Fig. 8. They correlated most of their sandstone beds with those sampled by Opdyke et al. (1979) by following the same section line. The bentonite layers were traced in the field and the correlation was extended by tracing some individual sandstone bodies. According to them, the rocks exposed in the Mangla-Samwal Anticline range in range from the Upper Gilbert magnetic chron ( $\pm 3.4$  Ma BP) to approximately the Upper Matuyama magnetic chron ( $\pm 1.1$  Ma BP).

Two bentonitized tuff complexes within the Jhal Kas section and the paleomagnetic correlation of the Upper Siwalik stratigraphic sections of northeast Pakistan reveal that the Gauss/Matuyama boundary can be traced throughout the whole area. Above this reveal a prominent normal magnetozone can be correlated with the Olduvai event. The Olduvai event has previously been shown correlative with the Pliocene-Pleistocene boundary on the basis of change of marine biota (Haq et al. 1977). It is therefore, possible to precisely determine the Pliocene-Pleistocene boundary in the Upper Siwalik deposits in the Mangla-Samwal Anticline.



## CHAPTER-5. SYSTEMATIC PALEONTOLOGY

### 5.1 *BIN AMIR KHATOON*

### 5.2 INTRODUCTION

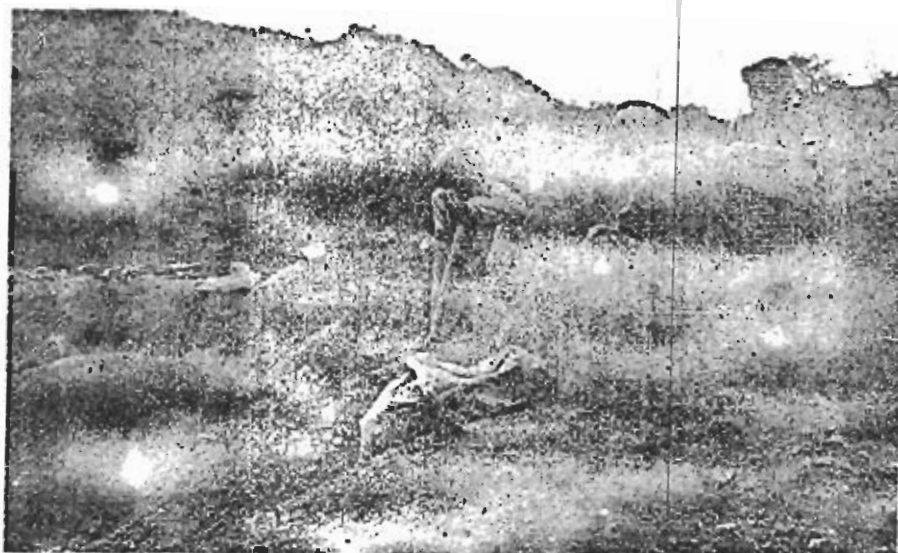
The Bin Amir Khatoon area (District Chakwal) exposes the most complete Siwalik Group sequence in the southern Potwar Plateau (Fig. 9). In a cumulative stratigraphic thickness of 2.0 – 2.5 km and comprising all the five component formations (e.g. Kamliyal, Chinji, Nagri, Dhok Pathan and Soan) of the Siwalik Group, the Bin Amir Khatoon area contains an almost continuous geological record spanning from (approximately) 18.5 Ma BP to 4.5 Ma BP (Johnson et al. 1982). The overall lithological composition of these component formations are fairly identical with those described from their respective stratotype areas all Siwalik Formations of the Bin Amir Khatoon area are relatively less thicker and contain more mudstones. A section in Kas Kuthan was measured to provide the lithofacies details of the Chinji Formation. Thus, a long-term project for the study of stratigraphical and paleontological aspects of the Siwalik group in this area has been initiated. The main objective of the research in this area is to develop a comprehensive lithostratigraphic, faunal, and biostratigraphic framework, which in conjunction with adjacent better-studied areas would later become a principal reference region for the continental Miocene in Pakistan.

The Bin Amir Khatoon area does not seem to be as fossiliferous as those of the adjoining Chinji-Nagri areas. However, the fact, that the eastern part (i.e. the Bin Amir Khatoon area) has yielded more fossils than the western Khokher Zer area. It is plausible that high dips and structural complications as witnessed in the western part may also have increased the paucity of fossil localities. After a brief faunal search in the Dhok Pathan, Nagri, and Chinji Formations, I concentrated Ma efforts to the Chinji Formation, because of its good exposures and relatively being more fossiliferous. It is composed of red brown mudstone with common grey sandstone interbeds. The Chinji Formation is about 500m thick in average thickness in Bin Amir Khatoon. Each finning upward sequence is marked at the base by a fine conglomerate or gritty coarse sandstone unit, gradually changing to sandstone and finally to silt (or occasionally clay) in the upper portion. The sand to silt ratio in Chinji Formation is 1:3 whereas in each finning upward

unit, this may vary from 1:2 to as much as 1:5. The sandbodies geometry and other sedimentary characteristics indicate that the sandstones are mostly channel-sands with a few thin beds but with vast lateral spread being of crevasse-splay types. The color and compositional variations in the mudstone unit suggest that some of these may well have been deposited within channels by rivers carrying appreciable suspended mud-loads.



General view of the Miocene rocks exposed near Bin Amir Khatoon area showing the location 8608.



Closer view of the locality 8608

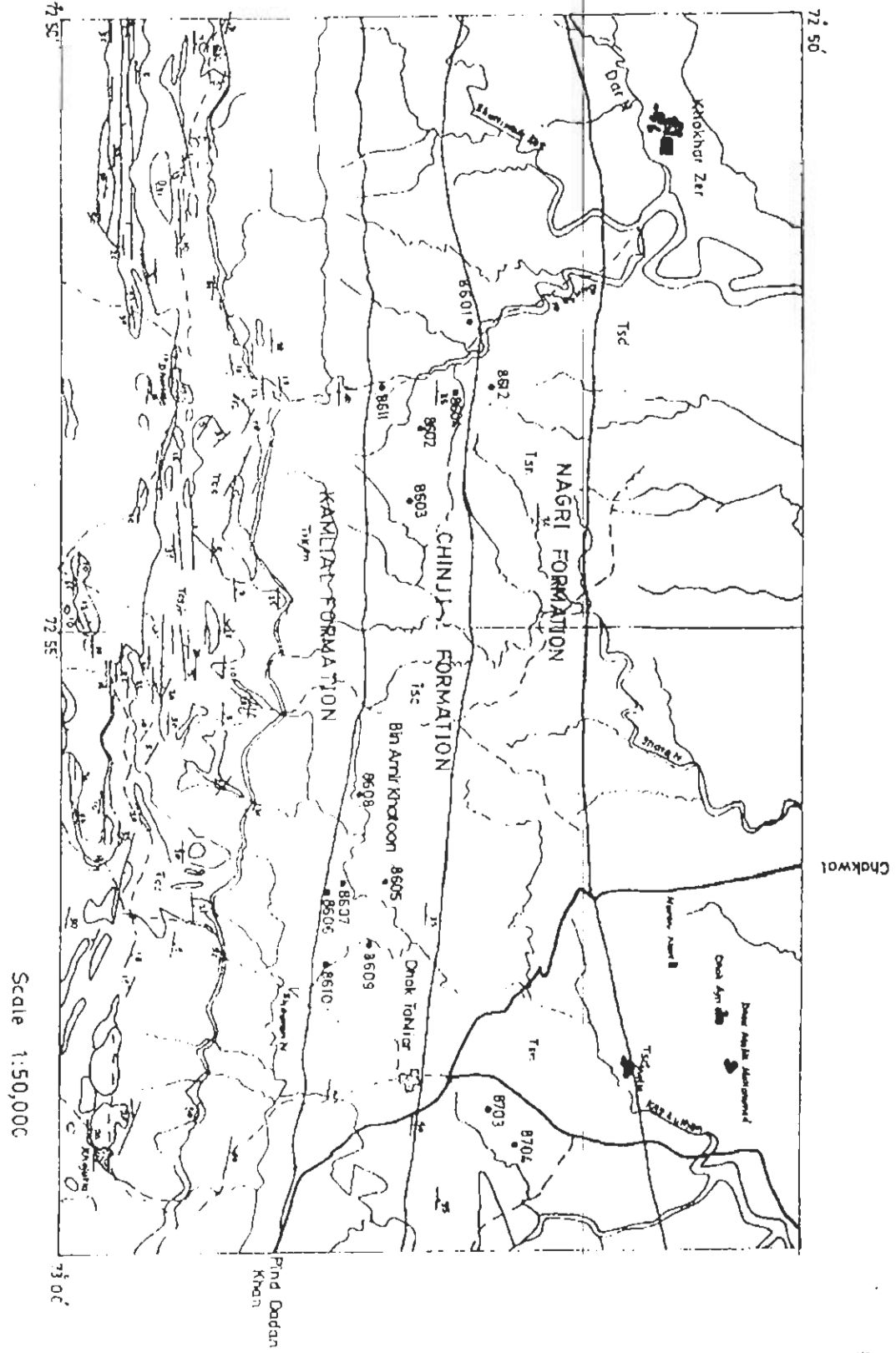


Fig. 9. Geological map of the Bin Amir Khatoon area.

The Chinji Formation of Bin Amir Khatoon area is in stike continuation with its stratotype in Chinji area located about 50 km due west. The Bin Amir Khatoon-Chinji outcrop belt shows a decrease due east in the thickness of the Chinji Formation but also records substational increase in the mudstone proportions. The sandstone units are thinner being usually in the range of 1.5 to 4.5 m with only three units each of which exceed 10 m in thickness. Contrary to the type area exposure, there does not seem to be increase in thickness or frequency in sandstone units in the upper part of the Chinji Formation.

The macro-vertebrate assemblage consists of fragmentary dentary and other skeletal elements of *Deinotherium pentapotamiae*, *Giraffokeryx punjabiensis*, *Dorcatherium* sp. aff. *Helicportax tragelaphoides*, crocodiles and ophidians. The locality PMNH 8608 micro-vertebrate assemblage consists of isolated teeth and fragmentary skeletal elements. In addition to broken small mammal limb elements and a few of reptilian affinity, the assemblage includes many fish spines and varanid mandibular fragments. The taxonomy described here, however, is based entirely on isolated teeth of relatively high quality preservation.

A total of six fossil localities at different stratigraphic levels have been discovered from which almost 250 vertebrate fossils are collected (Fig. 10). Two of these localities have been intensively sampled for small mammal analyses in the laboratory.

### 5.3 FAUNAL ANALYSIS

Seventy percent of fossil specimens collected in the field are identifiable to family and lower taxonomic levels. The following frequencies of various vertebrate groups are given in Table 3.

**Table 3. Frequency data of various groups of vertebrates.**

GROUP	NUMBER OF SPECIMENS	FREQUENCY (%)
Mammalia	194	90.2
Reptilia	14	6.5
Pisces	3	1.4
Aves	2	0.9
"Coprolites"	2	0.9

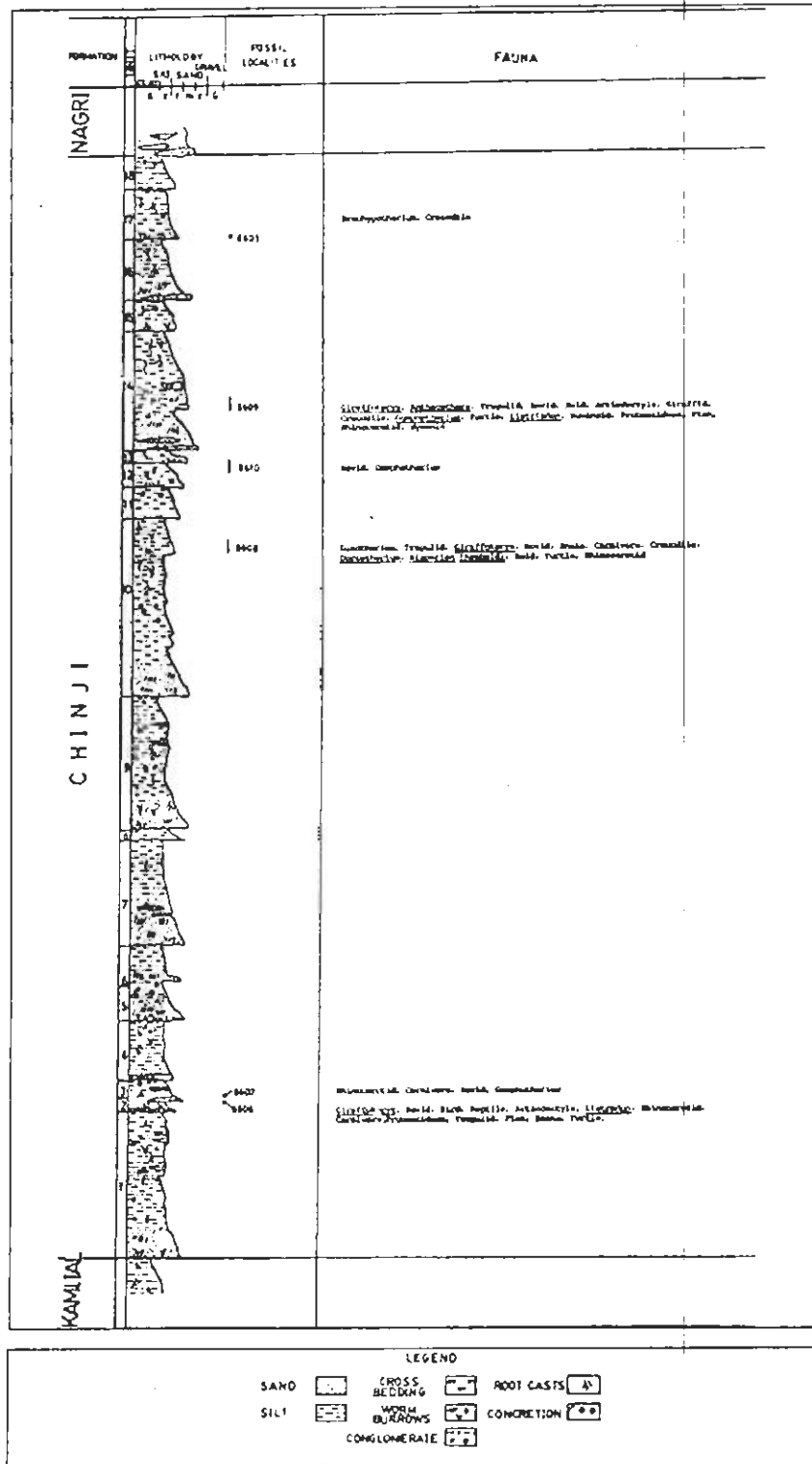


Fig.10. Lithostratigraphic section of Bin Amir Khatoon showing localities.

## 5.4 MAMMALS

Mammal remains dominate all faunal assemblages and constitutes 90% of all fossils identified in the area. The Chinji mammal fauna of the Bin Amir Khatoon-Kokher Zer area include at least eleven families of medium and large size mammals and nine families of small mammals. Table 3 provides the family distribution of the mammalian assemblage on the basis of fauna collected.

Bovidae, Giraffidae, Suidae and Rhinocerotidae make-up 58.6% of the mammal assemblage (Table 6) and this phenomenon is very typical of the Chinji assemblages in the stratotype Chinji-Kanatti areas as well. Chalicotheres, anthracotheres, and hominoids are usually among the least common groups represented in any assemblage.

### 5.4.A HOMINOIDEA

Two complete right upper canines of the order Primates are (PMNH-EV 3247) from the locality PMNH 8609 and (PMNH-EV3248) from the locality PMNH 8702 identified as *Sivapithecus indicus*. They are long rooted and short crowned specimens whose tips have been fairly worn-out. They are identical with those of other Chinji *Sivapithecus indicus* canines but smaller in size than the GSP15000, cranium from the late Miocene Siwalik rocks of the Khaur area (Pilbeam et al., 1980). This is the first record of hominoids from this horizon.

### 5.4.B PROBOSCIDEA

*Gomphotherium browni* is the common species among Proboscidea. An almost complete tusk of *Choerolophodon corrugatus* from the locality PMNH 8611, located in the basal most sandstone unit of the Chinji Formation is the first record of such a complete specimen at this stratigraphic level. Only one specimen, a half lower molar of *Dinotherium pentapotamiae* represents the Dinotheriidae.

### 5.4.C CARNIVORA

The total carnivore fossils recovered are six in number but each of them is from six different localities. Two specimens, a P2 (PMNH-EV3298) and a calcanium (PMNH-EV 3312) belong to family Hyaenidae. The P2 is of *Percrocuta carnifex* whereas the calcanium has also been tentatively ascribed to this species.

Two small molars of two different carnivores were collected and identified respectively from PMNH 8604 and PMNH 8606 localities. The RM1 from the locality PMNH 8604 has been identified as *Herpestes* sp. PMNH-EV 3348. This will be the first record of *Herpestes* from such an old stratigraphic level, tentatively dated as about 13 Ma B.P. Barry (1982) has earlier described first occurrence of *Herpestes* from 10 Ma BP. beds of Khaur area. The *Herpestes* sp. lower molar from Bin Amir Khatoon area thus extends the first appearance to at least 13 Ma BP. and may suggest that the migration from Africa which has introduced many new genera at 13 Ma BP. datum also brought the first mongoose in south Asia.

Similarly the M2 of a Gen. et sp. indet. from locality 8606, which comes from the basal part of the Chinji Formation, belongs to family Mustelidae, PMNH-EV 3354. This also seems to be the first record of genus and species indeterminate from the Potwar Plateau, Pakistan (John Barry personal communication) as compared to earlier Mustelidae reported from local faunal zone 2, 3, 5, 6 and 10 defined in the Siwalik rocks of the Potwar Plateau (Table 4), which have been dated as 11, 10, 9.5, 8.6 and 8.2 Ma BP, respectively (Pilbeam et al. 1979).

An upper canine PMNH-EV 3192 is a complete specimen with some wear on the inside of the tooth. The canines are difficult to identify to family level.

#### 5.4.D PERISSODACTYLA

With the exception of one phalanx of *Chalicotherium*, rest of the twenty-three specimens belongs to rhinocerotidae. Fourteen specimens consist of isolated (and mostly) fragmentary molar (and also one incisor and a P<sub>3</sub>) whereas nine specimens are of podial and limb bones. Preliminary identifications indicate common presence of *Brachypotherium perimense*. Other Chinji species reported from elsewhere in Potwar Plateau such as *Gaiotherium browni* and *Chalicotherium intermedium* may also be present in the Bin Amir Khatoon area.

**Table 4. Distribution of Carnivores in different Faunal Zones in the Siwalik rocks, Potwar Plateau.**

Species	Zone (Z)/ Locality (Y)	Age (Ma)	Reference
<i>Enhydriodon</i> sp.	Z11	4.7	Pilbeam et al., 1979
<i>Sivaonyx bathygnothus</i>	Z6	6.5	Pilbeam et al., 1979
<i>cf. Ischyrictis</i>	Z6	6.5	Pilbeam et al., 1979
<i>Eomellivora</i> sp.	Z6	6.5	Pilbeam et al., 1979
<i>Herpestes</i> , large sp.	Y 19	7.0	Barry, 1983
<i>Plesiogula crossa</i>	Z 10	7.8	Pilbeam et al., 1979
<i>Herpestes</i> medium sp.	Y 327, 310	8.0	Barry, 1983
<i>Herpestes</i> small sp.	Y 259	9.5	Barry, 1983
<i>Eomellivora</i> sp.	Z 3	10.6	Pilbeam et al., 1979
<i>Vishnuonyx chinjiensis</i>	Z 3	10.6	Pilbeam et al., 1979
<i>Eomellivora</i> sp.	Z 2	11.5	Pilbeam et al., 1979
<i>Martes lydekkeri</i>	Z 2	11.5	Pilbeam et al., 1979
<i>Herpestes</i> sp.	PMNH 8604	13.0	
<i>Mustelidae</i> , gen. et sp. indet.	PMNH 8606	16.0	

#### 5.4.E ARTIODACTYLA

The artiodactyles are well-represented diverse group ranging in size from small tragulids (*Dorcatherium minor*) and a very small bovid (*Elachistoceras* sp.) to the okapi-size *Giraffokeryx punjabiensis*.



*Listriodon pentapotamiae* and *Conohyus sindliensis* are the two common suids in the Chinji Formation of the Bin Amir Khatoon area. This is also true for the Chinji Formation in other areas of the Potwar Plateau. *Dorcatherium minus* and a few *Dorcatherium majus* represent Tragulids. The post-cranials can be attributed to the two species but it appears that most of them are also of *D. minus*. Giraffidae are the second most common group and are mostly represented by podials, isolated teeth, and few limb elements. On the basis of teeth and an ossicone they have been identified as *Giraffokeryx punjabiensis*.

## 5.5 NON-MAMMAL GROUPS

The lower vertebrates (fishes and reptiles) of the Chinji Formation in the type Chinji and Khaur areas have remained largely unstudied mainly because of being too fragmentary. It is true for the Bin Amir Khatoon fauna as well.

In Reptilia and Pisces, fossil specimens reported in Table 3 are not the real representation. It is mainly due to the fact that one big size carapace or scute piece can be fragmented into several small bits and thus can skew the statistics substantially. Therefore, only representative and bigger-sized fragments have been collected. It is true for fish specimens which are mostly represented by vertebrate or spine fragments. Care has been taken to piece together broken fragments to avoid the over representation of some skeletal units. Reptilian teeth and skeletal and dental fragments of fishes make up more than 50% of the total micro-vertebrate assemblages analyzed in the laboratory.

### 5.5.A PISCES

The vertebrate and spine fragments belong to the catfish family Siliuriformes, which is the commonest fish group in the Chinji Formation.

### 5.5.B REPTILES

Reptiles are ubiquitous in all stratigraphic levels throughout the Siwalik rocks. Crocodylians, Chelonian, and Ophidians are common in all of the Chinji Formation assemblages. Abundant scute fragments and isolated teeth of *Crocodylus* and *Gavialis*, and carapace fragments of

*Trionyx* usually constitute the Chinji reptilian assemblages. Vertebrae of relatively medium size snakes (*Ophidia* sp.) have also been found.

### 5.5.C AVES

Only two incomplete limb bones have been found. The presences of pelicans, vultures, pheasants, and rails have been reported in Chinji Formation from elsewhere in Potwar Plateau. The fragmentary tibia and the podial bone from the study area have not yet been identified.

### 5.6 REMARKS ON MAMMALIAN FAUNA

The fauna of Bin Amir Khatoon area includes Bovidae, Giraffidae, Rhinocerotidae, Tragulidae, Suidae, Proboscidae, Carnivora, Antracotheriidae and Hominoidea. Table 5 shows the number of relatively frequency of identified elements for each of taxa found in the area.

Chinji Formation is the earliest lithostratigraphic unit of the Muree-Siwalik complex to record an abundance and species diversity of bovids. Although the first appearance of bovidae is recorded from the middle Kamli Formation in the Chinji-Kanatti areas, the lower third of the Chinji Formation document sudden diversity of bovid genera/species as well as becomes the dominant group in the assemblage. Same trend is witnessed in the Chinji assemblage of Bin Amir Khatoon area where bovid remains contribute 26% of the total mammalian fauna. (see Table 5). For taxonomic identifications of bovids, horn-cores are the most diagnostic to be followed by complete mandible and maxillary part. Post-cranials can also be categorized by size and certain elements (e.g. femur, humerus, radius, innominates) are useful for understanding the locomotion and thus of knowing the habitat preferences. *Protragocerus glutens*, *Elachistocerus* aff. *E. khauristanesis* and *Sivoreas eremita* have been identified on the basis of horn cores, representing PMNH-EV 3152, EV 3227 and EV 3233, respectively.

Bovid is the most common group and is followed by Giraffidae, Suidae, Rhinocerotidae, Tragulidae, Hipparian, Carnivora, Proboscidea, Reptilia, Pisces, Aves, Hominoidea, Anthracotheriidae and Chalcotheriidae (Table 6).

The high percentage (16.36%) of taxonomically unidentifiable elements is indicative of the fragmentary nature of many of the bones collected from the area.

The preliminary identifications of the Chinji fauna from the Bin Amir Khatoon area are given in Table 5.

**Table 5. Preliminary faunal list of the Chinji Formation from Bin Amir Khatoon area.**

MAMMALIA
PRIMATES
HOMINOIDEA
<i>Sivapithecus indicus</i>
INSECTIVORA
SORICIDAE
Gen. et sp. indet.
ERINACEIDAE
<i>Galerix rutlandae</i>
SCANDENTIA
TUPAIIDAE
<i>Palaeotupaia</i> sp.
CHIROPTERA
Gen. et sp. indet.
RODENTIA
SCIURIDAE
<i>Eutamias urialis</i>
CTENODACTYLIDAE
<i>Sayimas</i> sp.

## GLIRIDAE

Miomimus sumbalenwalicus

## RHIZOMYIDAE

Prokanisamys benjavuni

Kanisamys indicus

## CRICETIDAE

Democricetodon kohatensis

*Megacricetodon* sp.

*Dakkamys* sp.

## MURIDAE

Antemus chinjiensis

*Antemus* sp.

*Progonomys* sp.

## THRYONOMYIDAE

Kochalia geespei

## CARNIVORA

## MUSTELIDAE

Gen. et sp. indet.

## VIVERRIDAE

*Herpestes* sp.

## HYAENIDAE

Percrocuta carnifex

## PROBOSCIDAE

## DEINOTHERIIDAE

Deinotherium pentapotmiae

## GOMPHOTHERIDAE

*"Gomphotherium" browni*

*Choerolophodon corrugatus*

PERISSODACTYLA

CHALICOTHERIIDAE

*Chalicotherium* sp.

RHINOCEROTIDAE

*Brachypotherium perimense*

*Gaiotherium browni*

ARTIODACTYLA

SUIDAE

*Listriodon pentapotamiae*

*Conohyus sindiensis*

ANTHRACOTHERIIDAE

Gen. et sp. indet.

TRAGULIDAE

*Dorcatherium majus*

*Dorcatherium minus*

*Dorcatherium* sp.

GIRAFFIDAE

*Giraffokeryx punjabiensis*

BOVIDAE

*Protragocerus glutens*

*Sivoreas eremita*

*Elachistocerus khauristanensis.*

Gen. et sp. indet.

REPTILIA

## CHELONIA

*Trionyx* sp.

## CROCODILIA

*Crocodylus* sp.*Gavialis* sp.

## OPHIDIA

Gen. et sp. indet.

## AVES

Gen. et. sp. indet.

## PISCES

## SILURIFORMES

Gen. et sp. indet.

## 5.7 TAPHONOMY OF FAUNAL ASSEMBLAGE

The faunal listed in Table 5 and discussed above is based on the surface collections of vertebrate bones from six localities. These assemblages are composed of disarticulated and fragmented bones, which have been transported to variable extent before burial. These fossil localities occur in all the three lithofacies type of the Chinji Formation with some preference to coarser lithofacies (i.e. sandstone). This tendency is suggestive of the fluvial agencies being the main agent of bone concentration in forming all fossil localities. However, the lithological make up of the richest locality, PMNH 8609, indicate in addition to the main channel the riverbanks and adjoining flood plain may also be contributing bone materials by bank cannibalization and flood of the plains.

The relative abundance of different skeletal elements in fossil assemblages is a reflection on the mode of bone concentration at a locality and helps in assessing the proportion of in situ (or with short transportation) bone input from those transported from a farther area. These parameters become important when reconstruction of fossil communities and/or paleoecologic interpretation

is to be attempted. The skeletal elements frequency data from four localities (PMNH 8602, 8608, 8609 and 8612) is collected in terms of six skeletal groups, which represent different disarticulation and dispersal units. These groups are teeth (isolated), vertebrate, forelimb, hindlimb, podials, and phalanges. It shows, that all localities, in general, have a similar pattern. While teeth are the most resistant element, podials preponderance can be due to their shape enhancing easy fluvial transportation and also that they remain covered with skin and ligaments for much longer time than any other body part in a carcass. The locality PMNH 8609 having a good sample size is a true reflection of a typical bone accumulation in a fossil locality. The high percentage of podials, phalanges, and limb elements as compared to their relative proportions in a single mammalian skeleton suggest that they have undergone some fluvial transportation and sorting. It is also likely that fore and hind limbs may have been added by bank collapse during flood seasons. Teeth with high density usually are the least transportable elements. Since most of the PMNH 8609 teeth are of medium to small size mammals, they could also have been added from nearby areas, during high flow regimes.

The similar faunal composition of each locality with variable proportions of skeletal elements suggest that though intensity of fluvial sorting of the death assemblages influenced the formation of a locality but the assemblages are fair reflection of the then existing wildlife populations. Thus, the absence of a particular mammalian group in a locality and its presence in another may be a pure coincidence. On the other hand, if other taphonomic parameters suggest that the fossil assemblage portray the autochthonous death assemblage(s), then appearance of any faunal group may indicate their first appearance datum. For example, a single mandibular fragment of *Herpestes* sp. in the locality PMNH 8604 assemblage may be the real earliest record of this genus in the Potwar Plateau and also in north Asia.

**Table 6. Total number of specimens and frequency of various large mammal taxa from the Chinji Formation of Bin Amir Khatoon.**

<b>Taxon</b>	<b># Specimen</b>	<b>Frequency (%)</b>
Bovidae	50	26.0
Giraffidae	43	22.4
Rhinocerotidae	23	12.0
Tragulidae	13	07.8
Suidae	12	06.3
Proboscidea	10	05.2
Carnivora	06	03.1
Anthracotheriidae	01	00.5
Chalicotheriidae	01	00.5
Hominoidae	01	00.5
Mammal indeterminate	30	15.6



## 5.8 SYSTEMATIC PALEONTOLOGY OF SMALL MAMMALS

### INSECTIVORA

#### Family Soricidae Gray, 1821

**Description:** An isolated  $M_2$  is referable to this family and because of lack of additional material, sub-family or generic assignment is not attempted. The  $M_2$  has a trigonid and talonid of equal width. Protoconid is relatively tall and the entoconid is isolated. It closely resembles the  $M_2$  described from Daud Khel (Munthe and West, 1980).

Family Erinaceidae Bonaparta, 1838  
 Sub family Echinosoricinae Cabrera, 1925  
 Genus *Galerix* Pomel, 1848  
*Galerix rutlandae* Munthe and West, 1980  
 (Plate 1, fig. a)

**Referred material:** PMNH 4001 isolated  $M_2$ .

**Key reference:** Munthe, J., 1980. Rodents of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. Part 1: Sciuridae, Gliridae, Ctenodactylidae and Rhizomyidae. *Contribution in Biology and Geology. Milwaukee Public Museum, USA, No. 34:4.*

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Description:** The echinosoricine *Galerix* is the only genus defined in the assemblage. It is represented by well-preserved upper  $P^3$  and  $M^3$  and by lower  $P_3$ ,  $M_1$  and  $M_2$ . The  $M^3$  in occlusal morphology and dimensions is identical with *G. rutlandae* (Munthe and West, 1980). The upper left  $P^3$  is broken antero-lingually at the protocone. It has a high, sharp paracone with a narrow crest extending posteriorly to a less distinct, somewhat blade like metacone, at the postero-labial border. An indistinct narrow shelf is present posterolingually.

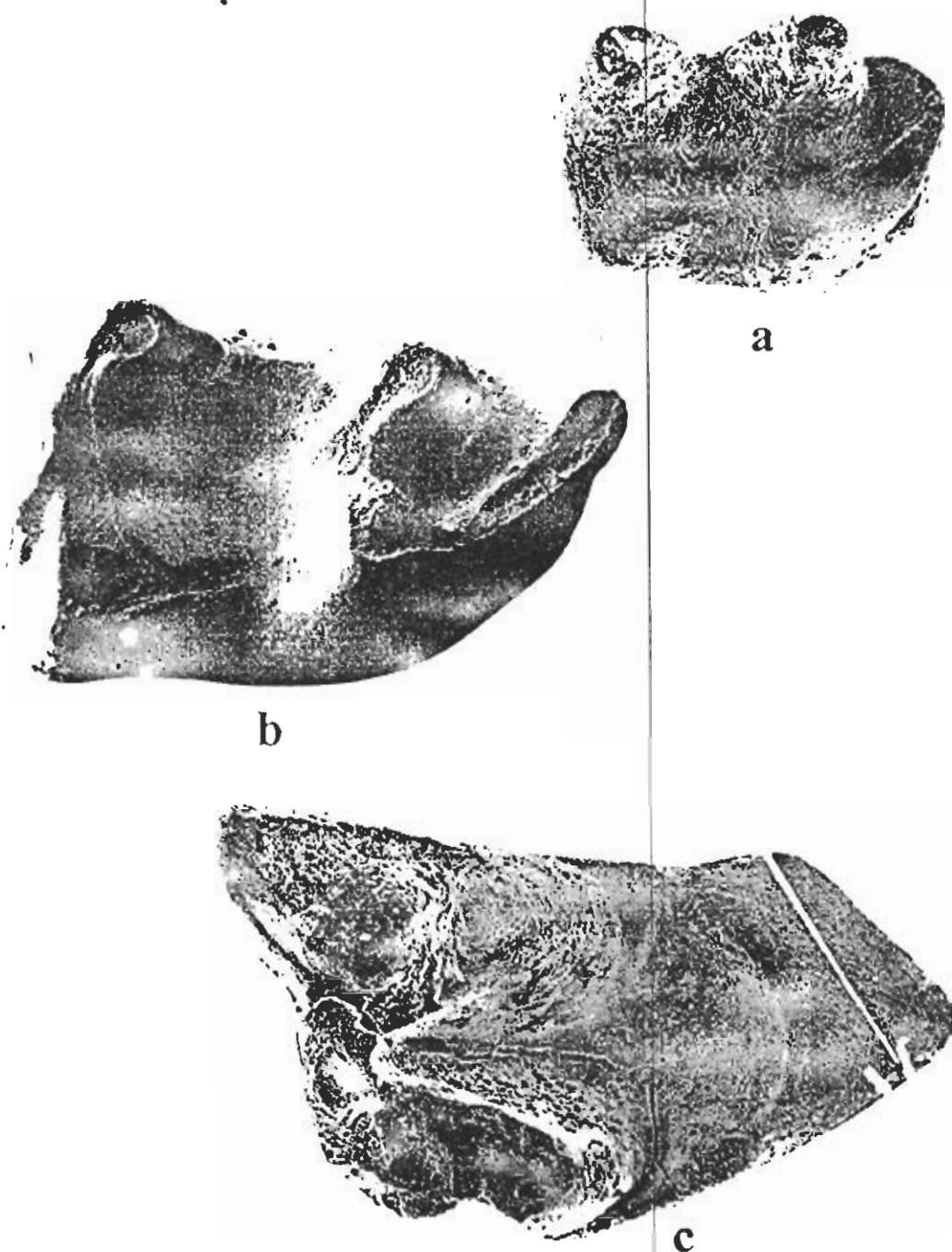


Fig. (a) *Galcrix rutlandae* PMNH 4001 M<sub>2</sub>, Fig. (b-c) *Palaeotupia* sp. (b) PMNH 4002 M<sub>1</sub>, (c) PMNH 4003 M<sup>1</sup>.

This  $P^3$  also resembles that *G. rutlandae*. The lower dentition, consisting of right  $P_3$ ,  $M_1$  and  $M_2$  although isolated teeth may belong to the same individual. The  $M_1$  and  $M_2$  have similar morphology but  $M_1$  is larger. They have narrow trigonid and deep, relatively wider talonid valleys. Protoconid, metaconid and entoconid are almost the same size. The paraconid on  $M_1$  is a low cusp connected with the protoconid. On  $M_2$  the paraconid is somewhat blade-like and turns in the direction of the metaconid. The posterior arm of the entoconid and the posterior cingulum meet in the middle of the posterior end of the tooth. In  $M_1$  the posterior arm of the hypoconid ends halfway across the tooth whereas on  $M_2$  the posterior arm of the hypoconid is joined to the entoconid by a low crest. The anterior cingulum is connected with the labial cingulum. The  $P^3$  has a prominent, high protoconid and distinct low paraconid. It has a wide posterior end with a short talonid. The lower dentition has interesting similarities with other Eurasian *Galerix* species as discussed below.

**Discussion:** Erinaceids from the Chinji Formation of Daud Khel include three species, *Galerix rutlandae* and cf. *Echinosorex* sp. in the Echinosoricinae, and the Erinaceinae *Amphechinus kreuzae* (Munthe and West, 1980). The PMNH 8608 assemblage contains *Galerix* only. The isolated right upper  $M^3$  and the broken left upper  $P^3$  are comparable to specimens of *G. rutlandae* from Daud Khel. The lower dentition of *G. rutlandae* in the hypodigm from Daud Khel is unknown with the exception of the lower  $P_4$ . The lower isolated molars and premolars from PMNH 8608, therefore, have been compared with lower dentitions of other Eurasian *Galerix* species.

The lower  $M_1$ ,  $M_3$  and  $P_3$  compare closely with the Alivieri *G. symeonidisi* and also (particularly the molars) with the Pikermi *G. moedlingensis* (Doukas 1986, Runke 1976). The  $M_1$  paraconid in *G. symeonidisi* is not well differentiated whereas in the first molars of PMNH 8608 and *G. moedlingensis* it is clearly individualized. It also appears that the entoconid and hypoconid are connected by a weak crest in the  $M_1$  of *G. symeonidisi* (see Plate 1, fig 11 in Doukas 1980). But in the case of *G. moedlingensis*, the posterior arm of the hypoconid hereby touches the entoconid at the midline of the posterior end of the  $M_1$ . The anterior cingula connects labial cingula in all the three species while the posterior cingula are often isolated. Other details of crown morphology of the lower  $M_1$  and  $M_2$  are similar in all three species. PMNH 8608 molars and

those of *G. symeonidisi* have comparable dimensions whereas *G. moedlingensis* molars are relatively bigger.

The upper teeth in the hypodigm of *G. rutlandae* and in the present sample are very different from the respective teeth of *G. symeonidisi* and *G. moedlingensis*. The length/width measurements of the upper dentitions of *G. rutlandae* and *G. symeonidisi* are similar.

Two alternative interpretations of the affinity of the 8608 *Galerix* lower  $M_1$ ,  $M_2$  and  $P_3$  are considered here. The teeth could represent *G. symeonidisi* and if so, they extend the geographic and temporal range of this Greek species, which as yet is only known from the lower Miocene rocks of Aliveri and from Kilcak, Turkey (Doukas, 1986). The other possibility is that the lower dentition is unspecialized and represents *G. rutlandae*, which would be the first record of the lower dentition of this species. I favour the second hypothesis. Munthe and West (1980) emphasized that *G. rutlandae* is virtually identical with *G. exilis* excepting its smaller size and absence of protoconules on the upper  $M^1$  and  $M^2$ . I am not in a position to confirm this proposition for the lower dentition because of the non-availability of comparative material and relevant literature on *G. exilis* in Ma laboratory.

Doukas (1986) in comparing the *Galerix* with *Schizogalerix* mentioned the strong connection between the posterior cingulum and posterior arm of the entoconid in  $M_1$  and  $M_2$  as one of the primary characteristics of the later genus. Given that the exact meaning of strong connection is ambiguous, this feature could be recognized in *G. symeonidisi*, *G. moedlingensis* and the PMNH 8608 molars.

SCANDENTIA  
 Family Tupaiidae  
 Subfamily Tupaiinae  
 Genus *Palaeotupaia* Chopra et al., 1976  
*Palaeotupaia* sp.  
 (Plate 1, fig. b-c)

**Referred material:** PMNH 4002  $M_1$ , isolated teeth.

**Key reference:** Jacobs, L. L., 1980. Siwalik fossil tree shrews. (in) *Comparative biology and evolutionary relationship of tree shrew* (eds) W. P. Luckett. Plenum Publishing Corporation: 205-216.

**Other reference:** Chopra, S. R. K., and Vasishat, R. N., 1979. Miocene tree shrews from the Indian Siwaliks. *Nature* vol. 281: 213.

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Description:** An upper left  $M^1$  or  $M^2$  is referred to *Palaeotupaia* sp. It is similar to *P. sivalicus*, Chopra and Vasishat (1979) in having a wide stylar shelf and a well-developed mesostyle. It differs in having a small hypocone, which warrants its indet terminate specific status. Size is comparable to that of *Palaeotupaia sivalicus*, although Chopra and Vasishat (1979) give no accurate measurements. A broken right lower  $P_3$  has a very high protoconid with an indistinct tiny cusp on the narrow anterior border. This has been tentatively assigned to *Palaeotupaia* sp. The right  $M^2$  fragment from Daud Khei identified as *Talpiidae* indet. (Munthe and West, 1980) is probably a Tupaiid and is similar in general shape to the Bin Amir Khatoon molar.

## CHIROPTERA

**Family Indet.** A single lower molar fragment is the only chiropteran specimen found from this locality. This fragment is a trigonid with a well-developed cingulum bordering the anterior and labial sides. Paraconid, metaconid and protoconid are well developed. The small specimen is certainly a micro chiropteran but assignment at lower rank is not possible.

## RODENTIA

Family Sciuridae Gray, 1821  
 Subfamily Sciurinae Baird, 1857  
 Genus Eutamias Trouessart, 1880  
*Eutamias uralis* Munthe, 1980  
 (Plate 2, fig. a)

**Referred Material:** PMNH 4004, isolated  $M_3$ .

**Key reference:** Munthe, J., 1980. Rodents of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. Part 1: Sciuridae, Gliridae, Ctenodactylidae and Rhizomyidae. *Contribution in Biology and Geology. Milwaukee Public Museum, USA, No. 34:4.*

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Description:** A single  $M_3$  of *Eutamias uralis* Munthe (1980) shows a blend of features exhibited by two third molars of different sizes from the Jalalpur area (Cheema et al. 1983). The hypoconid, being close to the protoconid is separated from it by a narrow internal valley. In these features, this  $M_3$  is similar to the larger  $M_3$  identified as *cf. E. uralis* by Cheema et al., 1983. However the Bin Amir Khatoon  $M_3$  resembles the smaller Jalalpur  $M_3$  in size and in having a small mesoconid in the valley.

**Family Ctenodactylidae**  
**Genus Sayimys Wood, 1937**  
*Sayimys* sp.

**Description:** A single molar fragment showing the labial half of the metalophid and hypoconid with a well-developed postero-labial cingulum is identified as *Sayimys* sp.

**Family Giliridae Thomas, 1897**  
**Sub family Gilirinae Thomas, 1897**  
**Genus Myomimus Ognev, 1924**  
*Myomimus sumbalenwalicus* Munthe, 1980  
(Plate 2, fig. b)

**Referred material:** PMNH 4005 isolated  $M_1$ .

**Key reference:** Munthe, J., 1980. Rodents of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. Part 1: Sciuridae, Gliridae, Ctenodactylidae and Rhizomyidae. *Contribution in Biology and Geology. Milwaukee Public Museum, USA, No. 34:4.*

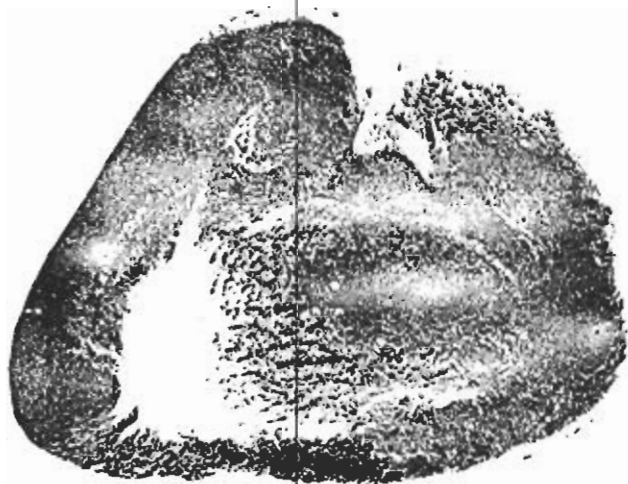
**a****b**

Fig. (a) *Eutamias uralis* PMNH 4004 M<sub>3</sub>; Fig.(b) *Myomimus sumbalewalicus* PMNH 4005 M<sub>1</sub>.

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Pakistan.

**Age:** Middle Miocene.

**Description:** *Myomimus sumbalenwalicus* Munthe (1980) is represented by an  $M_1$ . The posterolophid and mesolophid run parallel to each other, making U form and uniting at the labial margin of the tooth. The posterior extra ridge is short, isolated and not as high and wide as the ridges surrounding it. Protoconid, mesoconid and hypoconid are of same size and reach the labial margin of the tooth at the same angle of inclination. The metalophid joins the anterolophid lingually to form a weak loop. The metalophid has no connection with the metaconid at the labial margin. The tooth is relatively simple and smaller in size.

**Family Rhizomyidae**  
**Genus Prokanisamys de Bruijn et al., 1981**  
*Prokanisamys benjavuni* (Mein and Ginsburg, 1985)  
 (Plate 3, fig. a)

**Referred Material:** PMNH 4006, isolated  $M_3$ .

**Key reference:** Flynn, L. J., 1982. Systematic revision of Siwalik Rhizomyidae (Rodentia). *Geobios*, 15: 327-389.

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Description:** *Prokanisamys benjavuni* is recognized in the assemblage on the basis of size. A single relatively short  $M_3$  showing weak development of anterolophid and the absence of mesolophid is identified as *P. benjavuni*. Further more, it has the same dimensions and the same dental characteristics as reported from the Li Basin (Mein and Ginsburg, 1985) and the Chinji area (Flynn, 1986).



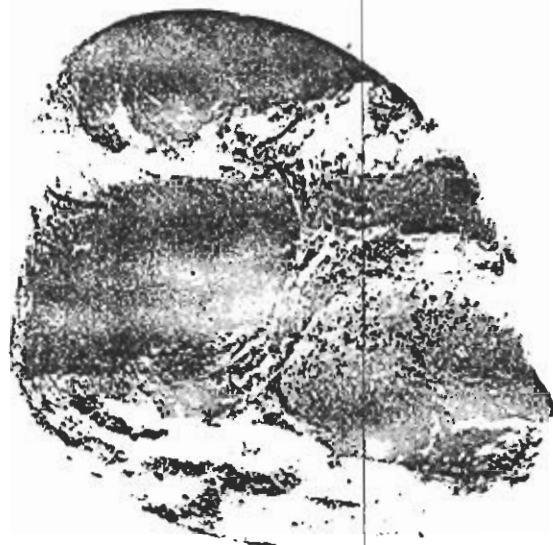
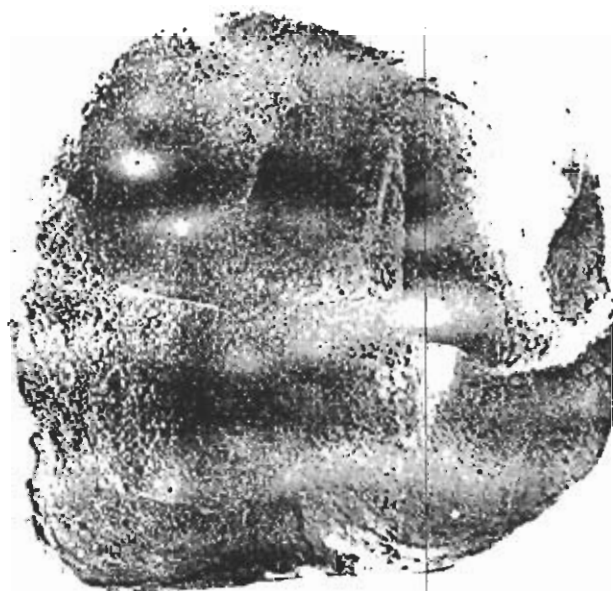
**a****b**

Fig (a) *Prokanisamys benjavuni* PMNH 4006 M<sub>3</sub> Fig (b) *Kanisamys indicus* PMNH 4007 M<sub>2</sub> .

Genus *Kanisamys* Wood, 1937  
*Kanisamys indicus* Wood, 1937  
(Plate 3, fig. b)

**Referred material:** PMNH 4007, isolated M<sub>2</sub>.

**Key reference:** Wood, A. E., 1937. Fossil rodents from the Siwalik beds of India. *Amer. Jour. Science*. Vol XXXIV: 68-70.

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Description:** The *K. indicus* is represented by an almost unworn M<sub>2</sub>, which has a well-developed mesolophid and hypolophid. All lophids appear to be interconnected labially.

Family Cricetidae  
Genus *Democricetodon*  
*Democricetodon kohatensis*  
(Plate 4, fig. a-f)

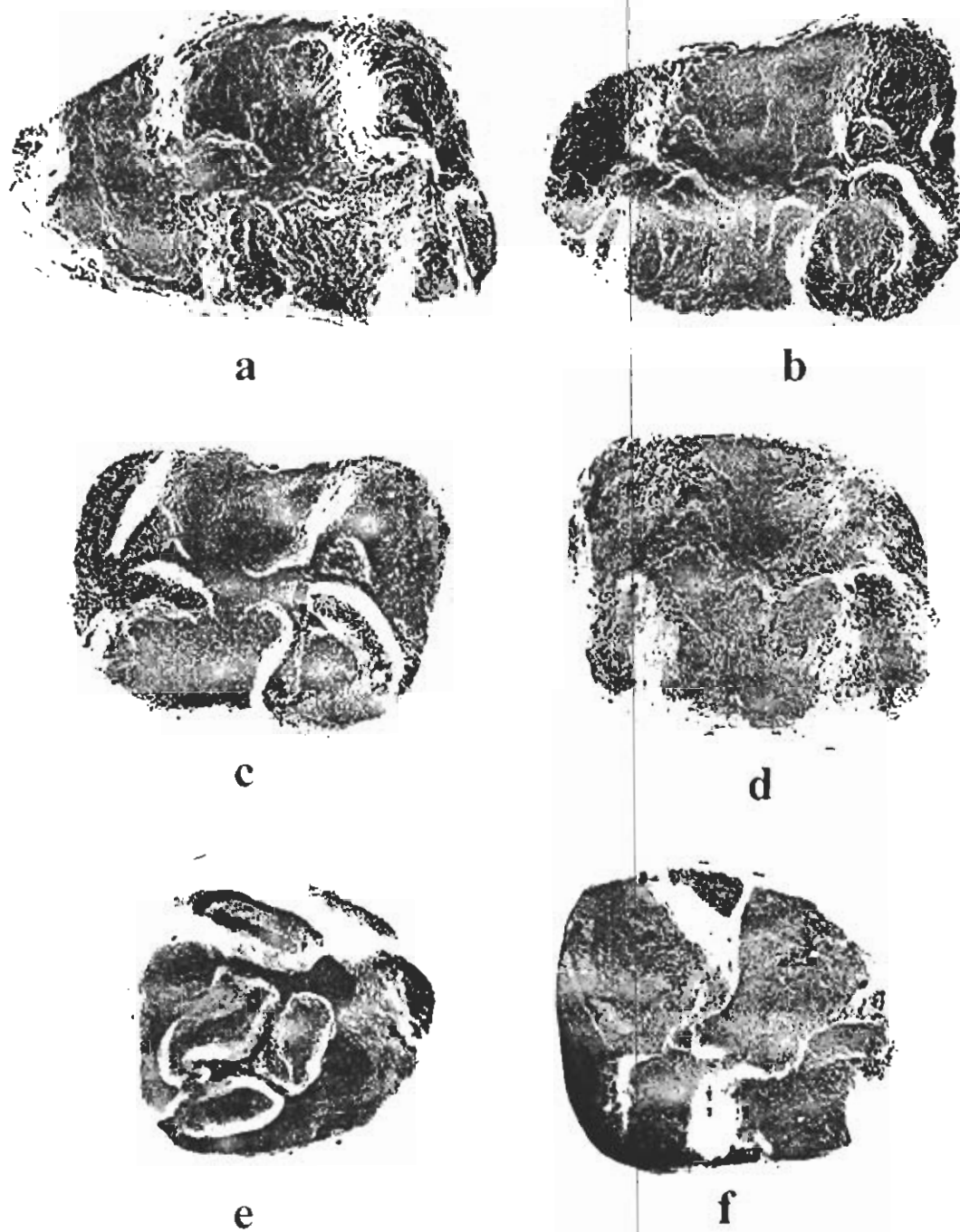


Fig (a-f) *Democricetodon kohatensis* (a) PMNH 4008 M<sup>1</sup>, (b) PMNH 4009 M<sub>1</sub>, (c) PMNH 4010 M<sub>2</sub>, (d) PMNH 4011 M<sub>2</sub>, (e) PMNH 4012 M<sup>3</sup>, (f) PMNH 4013 M<sub>3</sub>.

*Megacricetodon* sp.

(Plate 5, fig. a-c)

**Description:** Cricetids are represented by *Democricetodon kohatensis*, *Megacricetodon* sp., and by a single molar of *Dakkamys* sp. The differentiation between molars of *D. kohatensis* and *Megacricetodon* sp. is in some cases tentative since molars within each group show much variation in size, shape and occlusal morphology. Major features considered for generic identifications are the bicuspid or unicuspid anterocone of the  $M^1$ , shape of the anterior end of  $M_1$  and the relative size of the third molar (for details see de Bruijn et al. 1981; Wessels et al. 1982). Mesoloph (id) developed in both genera. The labial extension and the degree of development of the mesoloph show variation within the sample.

## Subfamily Dendromurinae Jaeger et al., 1985

Genus *Dakkamys* Jaeger 1977*Dakkamys* sp.

(Plate 5, fig. d)

**Referred material:** PMNH 4018, isolated  $M^2$ .

**Key reference:** Lindsay, E. H., 1988. Cricetid rodents from Siwalik deposits near Chinji village, part 1. Megacricetodontinae, Maocricetodontinae and Dendromurinae. *Paleovertebrata, Montpellier, France*, 18(2): 128-130.

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

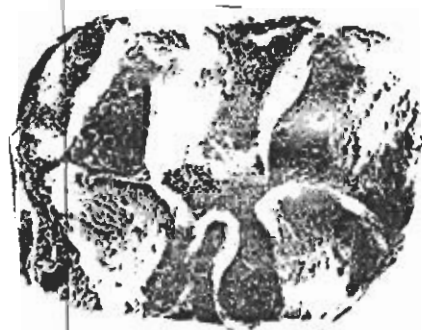
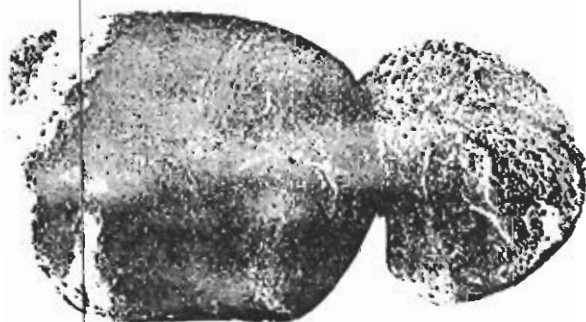
**a****b****c****d**

Fig. (a-c) *Megacricetodon* sp. (a) PMNH 4014  $M_1$ , (b) PMNH 4015  $M_2$ , (c) PMNH 4016, 4017  $M^{2-3}$ , (d) *Dakkamys* sp PMNH 4018  $M^2$ .

**Description:** A single  $M^2$  of *Dakkamys* sp. is the only representative of the subfamily Dendromurine in this fauna. The overall morphology is similar to that of *Dakkamys zaiani* from Beni Mellal (Jaeger, 1977). However, this molar has a small accessory cusp just posterior to the protocone and the valley between protocone and the hypocone extends posterior to this extra cusp. The anterior arm of the hypocone is highly inflated to the extent that it looks like an extra cusp. Samples of *Dakkamys* sp. from the Chinji Formation described to the present do not include any upper  $M^2$  (Cheema et al. 1983; Wessels et al. 1982). However, this  $M^2$  may represent the same species as that named by Wessels et al. (1982) like the Bin Amir Khatoon  $M^2$ , the upper first molar of Wessels et al. (1982) has necessary cusp between the protocone and hypocone and the anterior arm of its hypocone is inflated.

Family Muridae  
Subfamily Murinae Murray, 1866  
Genus *Antemus* Jacobs, 1977  
*Antemus chinjiensis* Jacobs, 1977  
(Plate 6, fig. a-c)

**Referred material:** PMNH 4019-4022  $M^1$ ,  $M_1$ ,  $M_{2-3}$ .

**Key reference:** Jacobs, L. L., 1977. A new genus of murid rodents from the Miocene of Pakistan and comments on the origin of the Muridae. *Paleobios*, 25: 12p

**Referred material occurrence:** Locality PMNH 8608, Chinji Formation, Bin Amir Khatoon, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Discussion:** The murids are represented by only one genus, *Antemus*. Four specimens are identical with known samples of *A. chinjiensis* (Jacobs 1978; Jacobs et al. 1989; Wessels et al. 1982). The three other isolated molars have developed accessory cusp, which raises the question of their separate identity at the species level.

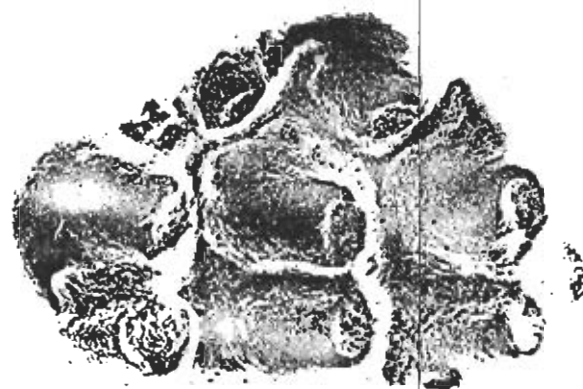
**a****b****c**

Fig. (a-c) *Antemus chinjiensis* (a) PMNH 4019 M<sup>1</sup>, (b) PMNH 4020 M<sub>1</sub>, (c) PMNH 4021, 4022 M<sub>2-3</sub>.

All the seven murid specimens have been identified as *Antemus chinjiensis* though at least three specimens show a few new characters, which may warrant their separate identity.

Jacobs et al. (1990) have reviewed the status of *A. chinjiensis* and have brought forward many hitherto unknown dental variations in cusps and style morphology as well as size ranges. The key characters present in *A. chinjiensis* (and defining the family Muridae *sensu* Jacobs et al. 1990) are the presence of two lingual cusps  $t_1$  and  $t_4$  with  $t_1$  joined to  $t_2$  by a low ridge. The isolation of  $t_4$  which is characteristic for *A. chinjiensis* is regarded as primitive for the murid family. Development of other features such as the separation of  $t_3$  from  $t_8$  and  $t_6$  from  $t_9$ , or their connection through longitudinal swellings, are of secondary importance. Following this definition, neither *Antemus primitivus* (Wessels et al. 1982) nor *Antemus* sp. 1 (Bruijn and Hussain 1984) can be included in the genus *Antemus* nor belong to the murid family, *sensu* Jacobs et al. (1990).

Three variant specimens include two upper first molars and one lower first molar. Their length-width dimensions are on the larger end of the size range given by Jacobs et al (1990). The  $M^1$  with maxillary fragment has a well-developed precingulum and also  $t_0$  (i.e. enteroconule). Jacobs et al. (1990) have reported that the precingulum is a common feature whereas  $t_0$  has only been observed in 10% of the individuals in their samples. The distinctive feature is the presence of a well-developed ridge connecting the  $t_1$  and  $t_4$ . The other  $M^1$  is broken anteriorly and thus presence/absence of precingulum and  $t_0$  cannot be ascertained. In this molar there is a well-developed, small style present between  $t_1$  and  $t_4$  respectively. The third specimen is the  $M_1$ , which closely resembles *A. chinjiensis* in size and cusp morphology.  $C_4$  and  $C_1$  are clearly developed on the labial margin. The unique feature is the presence of two cusps on the lingual side in close proximity of  $td$  and  $tf$ , respectively. These two cusps occupy approximately the same position on the lingual shelf as the  $C_4$  and  $C_1$  do on the labial margin.

These features, ridge or style between  $t_1$  and  $t_4$ , lingual cusps on  $M_1$  distinguish these three specimens and have not been reported for *Antemus*, *Progonomys* or *Karnimata*. I consider the development of extra cusps/style and the overall larger dimensions as advanced characters within the genus *Antemus*. It is possible that these three specimens represent yet another species of



*Antemus* but if so, because *Progonomys* and *Karnimata* lack the derived features, this new species would not be considered as their ancestor. In that sample sizes are so small, I hesitate to name a new species, but I suspect that *Antemus* may be more diverse than previously seen.

## 5.9 AGE OF THE CHINJI FORMATION LOCALITIES AND CONCLUSIONS

Among individuals in the PMNH 8608 assemblage, Cricetids are the most common element and are followed (in decreasing abundance) by the murids, erinacids, rhizomyids and tupaiids (Fig. 11). The Ctenodactylid, glirid, sciurid, soricid and chiropotera is represented by one specimen each. The faunal association, in comparison with other Neocene assemblages of the Indus Basin, has a distinct middle Miocene affinity (Bruijn and Hussain 1984, Jacobs et al. 1989). Chronologic ranges of taxa identified in the PMNH 8608 assemblages as reported in other Siwalik sequences of the Potwar Plateau have been plotted in Fig. 12. It appears that the middle Miocene has a rather stable association with a few new members appearing at different times (for details see de Bruijn and Hussain 1984; Jacobs et al. 1989).

It has been observed that by about 11 Ma, the middle Miocene cricetid-dominated association gave way to murid-dominated assemblages (see figure 9 in Jacobs et al. 1989). Nevertheless, *Antemus chinjiensis* has a record beginning probably before 14 Ma with no definite record after 12 Ma. A faunal change around 7 Ma records the local extinction of erinaceids and tupaiids and also of various species of murids, cricetid and rhizoMaidis. Comparable faunal turnovers among the Siwalik larger mammals have also been noted (Barry et al. 1982).

The locality PMNH 8608 has a cricetid dominated assemblage. The absence of *A. primitivus* and advanced murids *Progonomys* and *Karnimata*, together with the presence of *A. chinjiensis* suggest the locality to be between 14 and 12 Ma. The presence of *Myomimus sumbalenwalicus* and Chiroptera, as well as the advanced nature of the three molars tentatively included in *Antemus chinjiensis* suggest the age to be toward the late end of this range. The locality PMNH 8608 thus is dated to be between 12.8 to 11.8 Ma corresponding approximately to the late Astracian of Europe.

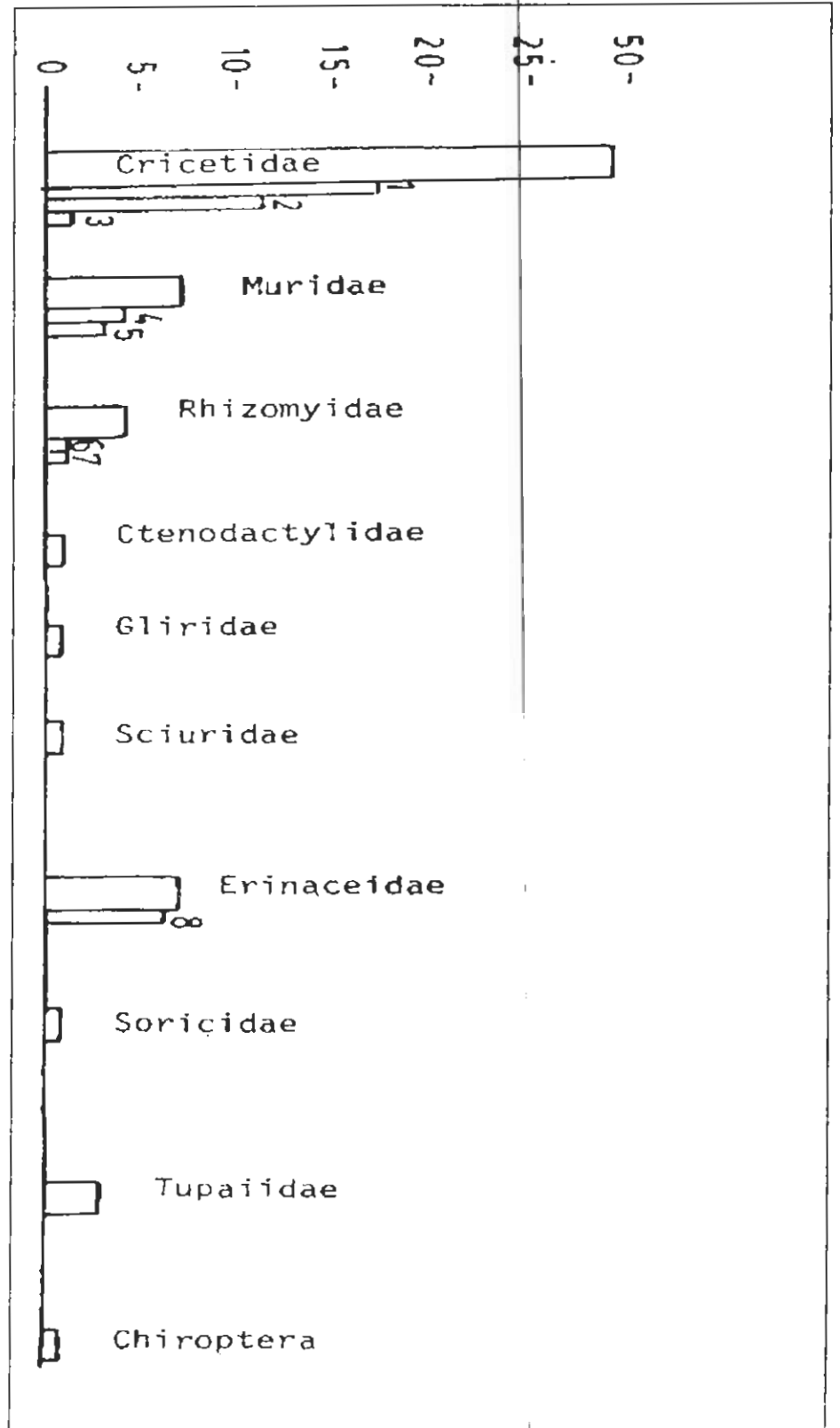


Fig. 11. Histogram showing the number of specimens at the family level

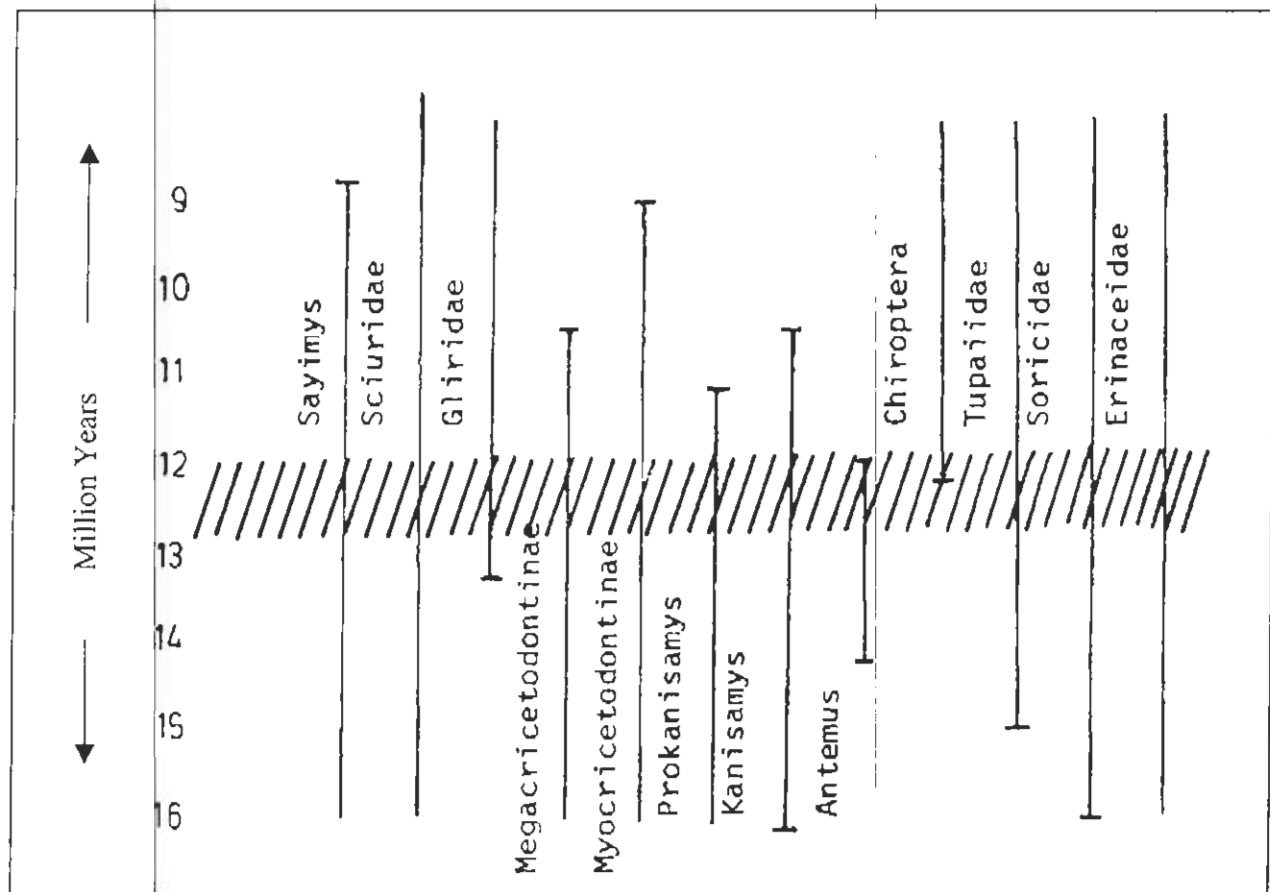


Fig.12. Chronologic ranges of taxa from the Siwalik rocks of the Potwar Plateau.

Table 7. Small mammal fauna of the locality PMNH 8608, Bin Amir Khatoon area.

ORDER	FAMILY	GEN. & SPECIES
INSECTIVORA	Soricidae	Gen. et sp. indet.
	Erinaceidae	<i>Galerix rutlandae</i>
SCANDENTIA	Tupaiaidae	<i>Palaeotupaia</i> sp.
CHIROPTERA	Family indet.	Gen. et sp. indet.
RODENTIA	Sciuridae	<i>Eutamias urialis</i>
	Ctenodactylidae	<i>Sayimys</i> sp.
	Gliridae	<i>Myomimus sumbalenwalicus</i>
	Rhizomyidae	<i>Prokanisamys benjavuni</i>
		<i>Kanisamys indicus</i> ;
	Cricetidae	<i>Democricetodon kohatensis</i>
		<i>Megacricetodon</i> sp. <i>Dakkamys</i> sp.
	Muridae	<i>Antemus chinjiensis</i>

The rodent fauna of the locality PMNH 8608 follows the same trend of high diversity as reported for other Chinji Formation assemblages (Jacobs 1978; Hussain et al. 1979; Munthe 1980; Dehm et al. 1982; Wessels et al. 1982; Jacobs et al. 1989). But the families are usually represented by one or two species throughout the formation (with the usual exception of cricetids). This low species diversity per family is not so obvious in the lower Manchar Formation associations

although it is regarded as chronologically equivalent to the Kamlial and Chinji Formations of the type Chinji area (Bruijn and Hussain 1984).

*Prokanismys benjavuni* at the PMNH 8608 and another nearby locality PMNH 8609 has also been reported from the Kamlial and Chinji Formations in the Chinji type area (Flynn 1986). The lower right  $M_3$  identified as *Kanisamys* sp. in the Banda Daud Shah assemblage (see Plate 3, Fig. 7 in Wessels et al. 1982) also appears to be *P. benjavuni*. Flynn (1986) has reported the chronologic occurrence of *P. benjavuni* from about 16 to 11 Ma in the Chinji area.

The unstudied locality PMNH 8609 occurs near the Chinji/Nagri formational boundary and contains *Kochalia gespei*, *Antemus chinjiensis* and, a broken murid upper first molar with  $i^1$  connected to  $i^5$  tentatively identified as *Progonomys* sp. This single molar of *Progonomys* sp. is somewhat different from the Jalalpur *Progonomys* n. sp. (Cheema et al. 1983). This is the first report of co-occurrence of *A. chinjiensis* with *Progonomys* sp. in the Siwalik sequence.

The faunal assemblage of the PMNH 8608 is strikingly similar to the Daud Khel fauna (Hussain et al. 1979, Munthe 1980, Munthe and West 1980). Given that the circetids are being studied (T. Hussain verbal comm.) all other species present in the Daud Khel also occur at the PMNH 8608 with two major differences. The Daud Khel murid identified as *Antemus* cf. *A. chinjiensis* (Hussain et al. 1979) is now considered as *Progonomys* sp. by Jacobs et al. (1989). Erinaceids of Daud Khel are more diverse than those of the PMNH 8608. However, the *Galerix* sample from PMNH 8608 included teeth that may represent two species *G. rutlandae* and *G. aff. symeonidisi* which so far was only known from the early Miocene of Greece and Turkey (Doukas 1986).

Another important Chinji Formation locality is from Jalalpur which Cheema et al. (1983) have shown to contain a different species composition with the exception of *E. uralis* and *D. kohatensis*. The Jalalpur locality has different cricetids (both are *Sayimys* sp.), advanced murids and rhizomyids. Differences from PMNH 8608 are due to younger age. The Jalalpur murids *Progonomys* sp. and *Karnimata* sp. seem more primitive than the 8 Ma Y-GSP 182 species of those genera (Jacobs 1978).

The small mammal fauna associations of the Chinji Formation can be chronologically arranged on the basis of overall similarities and also on the basis of appearances and evolutionary grades, particularly in murids. The lower Siwalik sequence of the Chinji type area has the additional advantage of paleomagnetic dates. Keeping the chronologic order of various faunal associations, established in the Chinji type area, the other well-known Chinji Formation, assemblages in the Potwar Plateau and adjacent areas are perhaps of the following ages.

Jalalpur locality	(Between 11 and 10 Ma)
Daud Khel local Fauna H-GSP 18	( $\sim$ 12 Ma)
Bin Amir Khatoon PMNH 8609	(12 Ma)
Bin Amir Khatoon PMNH 8608	( $\sim$ 12.5 Ma)
Banda Daud Shah H-GSP 107	(Between 15 and 14 Ma)

## 5.10 SUMMARY.

1. The geological studies of the Siwalik Group rocks of Bin Amir Khatoon area have been done to gather information from an area, whose nearby western and eastern regions are well studied. The motivation has been to extend studies eastwards in subsequent years so as to obtain a physical lithostratigraphic framework established for the whole area, extending from Bin Amir Khatoon to Mirpur Bhimber, Azad Kashmir areas.
2. The Siwalik Group formations in the Bin Amir Khatoon area are not as thick as in the adjoining Chinji-Kanatti areas. For instance, Chinji Formation is estimated to be between 510 to 550 m thick in this area whereas it is 600-500 m thick in its stratotype Chinji-Kanatti area.
3. Preliminary stratigraphic analyses indicate a general increase in mudstone proportions relative to sandstone thickness in the Chinji, Nagri and Dhok Pathan Formations of the Bin Amir Khatoon area. For example, the mudstone to sandstone ratio in the Chinji Formation ranges between 4:1 and 3:1.

4. In spite of adequate exposures, fossils are not easily found in the area. It is particularly because of steeper dips and some structural complication, thus reducing the area of exposure per bed, and also increase in mudstone indicates existence of flood plains, which relatively have lesser potentials for fossilization.
5. The Chinji Formation proved to be the most fossiliferous unit from which 215 specimens from 12 localities have been identified. This is exclusive of rich microvertebrate fauna recovered in the laboratory by analyzing nearly 1000 kg sediments from four localities.
6. A single left canine of *Sivapithecus indicus* from the locality PMNH 8609 is the first record of hominoid from this area.
7. A lower molar (partially complete) from the locality PMNH 8604 is identified as *Herpestes* sp. This is the earliest record of mongoose from south Asia and perhaps documents the immigration datum from Africa, which also includes aardvark and hominoids in other areas of the Potwar Plateau. This migratory event took place some time around  $12(\pm 0.5)$  Ma BP.
8. A single horn core has recorded the smallest bovid from the Siwalik Group rocks, named *Elachistoceros*. This discovery extends the range of this bovid, which hitherto has been described from the upper Nagri Formation of Khaur area (northern Potwar Plateau).
9. Among the small mammals, an assemblage from the locality PMNH 8608 records presence of at least 13 species including three species each of Muridae, Tupaiidae, and Erinaceidae; some of which may prove to be new with increased sample size.
10. Another locality PMNH 8609 records the co-occurrence of *Antemus chinjiensis* and *Progonomys* sp., which so far have been documented to succeed each other in time with a gap of at least one million years. The murid *A. chinjiensis* has been regarded to be extinct by 11 Ma BP, whereas *Progonomys* sp. first appearance is dated to be at 10 Ma BP. Moreover, *A. chinjiensis* is regarded ancestral to *Progonomys* sp. The Chinji Formation fauna from Jalalpur of early Vallesian age also contains *Progonomys* sp. but with no *Antemus*.

11. The stratigraphic and faunal analyses of the Chinji Formation presented in this report is the first ever detailed studies done on the Siwalik Group rocks of the Bin Amir Khatoon area.

## LITHOSTRATIGRAPHIC DESCRIPTION OF CHINJI FORMATION IN BIN AMIR KHATOON SECTION.

The section was measured around the Kas Kuthan and its tributaries (Lat:  $32^{\circ}46'N$ , Long:  $72^{\circ}55'E$ ). It is located at approximately 2 km west of Bin Amir Khatoon village (Fig. 10).

### NAGRI FORMATION

Sandstone, grey to greenish grey medium to coarse grained, poorly sorted and cemented, forms cliffs and flat hill tops; conglomeratic lenses common, conglomerate consists of igneous and metamorphic pebbles ... not measured.

### CHINJI FORMATION

Unit 18. Sandstone in basal part, grading up into sandy silt, sandstone olive to yellowish grey, fine grained, medium to thin bedded, moderately cemented, lower contact sharp, upwards grades into sandy silt, reddish brown, bedding clear, concretionary in upper portion, sharp upper contact; sandstone (1.5 m) and mudstone (13.5 m) ... 15m.

Unit 17. Sandstone basal portion, grades up into thick sandy silt and silt; sandstone blue-grey, fine to medium grained, trough cross bedded, partly thin bedded; grades into sandy silt and silt, red-brown and at places olive-grey, partly thin bedded; root-casts and worm-burrows common, bioturbated in parts; locality PMNH 8605 in the basal sandstone; sandstone (2.5 m) and mudstone (19.5 m) ... 22 m.

Unit 16. Sandstone constituting basal 5 m and rest sandy silt and silt, topmost 3 m clayey, lower and upper contacts sharp; lower with slight erosional surface; conglomerate present at the base, comprising mostly of small pebbles of mudstone concretionary mudstone, rarely sandstone; silt



in parts thin bedded but mostly bioturbated with occasional root casts and variegated mottling ... 28 m.

Unit 15. Sandstone and sandy silt; sandstone greenish grey, silty highly bioturbated with abundant root casts and worm burrow upwards grade into sandy silt, reddish brown; concretionary and often bioturbated; sandstone (4.5 m) and mudstone (9.5 m) ... 14 m.

Unit 14. Sandstone constituting the lower 15 m; greenish grey, medium bedded to massive, medium grained, finning upwards, two conglomerate beds, laterally pinches, trough cross bedded; upwards silt, finning up to clayey silt; reddish brown, highly bioturbated, common root casts and worm burrows; burrows and root casts filled with fine grey silty sand; locality PMNH 8609 in the top part of sandstone unit; sandstone (15 m), mudstone 39 m) ... 54m.

Unit 13. Sandstone and sandy silt; sandstone, silty, light grey to yellow grey, laterally passes into silt but outwards has upto 1 m conglomerate lense; upper sandy silt unit, bioturbated, laterally thickness; ? Crevasse splay channel; sandstone and mudstone equal proportion ... 6m.

Unit 12. Sandstone with sandy silt; sandstone, greenish grey medium grained, cross bedded, planar and trough type, in parts silty; sandy silt, brownish red, common carbonate concentration,? Channel fill .... 10.5 m.

Unit 11. Sandstone and silt; upper and lower sharp contacts, sandstone, light olive grey, thin to medium bedded, fine grained, upper part silty; reddish brown, concretionary, sandstone (6 m) and mudstone (8 m) ... 14 m.

Unit 10. Silt with sandstone in the base, silt, to clayey, multistoried with frequent concretionary and mottled beds, in parts bioturbated, at least seven well defined silt units; sandstone in the basal part, grey, fine to medium grained, thin bedded, cross bedded, trough type at the base, planar above, laterally persistent; PMNH 8608 located at about 60 m above base; sandstone (12 m) and mudstone (68 m) ... 80 m.

Unit 9. Sandstone in the lower 13.5 m, rest silt sandstone, greenish grey, thin bedded, trough cross bedded in the lower portion, worn burrows and root casts in the upper part; grades upward quickly into sandy silt; reddish brown, at places bioturbated, occasional concretion and root casts; laterally persistent; sandstone (13.5 m) and mudstone (45 m). 58.5 m.

Unit 8. Sandstone grading upto into sandy silt, lower and upper contacts sharp and erosional; sandstone grey, silty, silt well bedded, reddish brown; sandstone (1.5 m), mudstone (4.0 m) 5.5 m.

Unit 7. Sandstone the lower 20 m grading up into silt, sandstone, light greenish grey, fine to medium grained, thin bedded in the upper portion, trough cross bedded, poorly cemented, top 6 m contains sandy silt lenses; silt, sandy in the lower part and clayey in the top 3 m, reddish brown, thin bedded in parts, bioturbated occasionally ... 46.5 m.

Unit 6. Silt with sandstone in the basal 1.5 m; silt reddish brown, sandy in parts; sandstone with erosional base, light grey, medium to fine grained, planar cross bedded ... 15.5 m.

Unit 5. Sandstone with sandy silt in the upper third; sandstone with basal conglomerate, greenish grey to grey, trough cross bedded, massive in the lower part; conglomerate with sand and reddish brown concretionary silt pebbles, sandstone laterally continuous; silt reddish brown, and finally fine upwards; common carbonate concretions and root casts .. 17.5 m.

Unit 4. Silt, dominantly sandy, with 1.5 m sandstone in the base; silt, reddish brown, much sandy in the middle part, concretionary in the upper portion, top surface erosional; basal sandstone, light grey, fine grained, upwards silty ... 27 m.

Unit 3. Conglomerate with sandstone forming the basal 1.5 m laterally grades into silty sandstone; conglomerate, rusty brown with pebbles and clasts of mudstone, calcarete and grey sandstone; conglomerate maximum thickness in the section line; silt, sandy, reddish brown root casts common, a thin bed of paleosol in the upper part; localities PMNH 8608 and 8607 in the basal unit ... 9 m.

Unit 2. Sandstone and sandy silt; sandstone greenish grey, top part gradational with reddish brown silt, common rhizoliths and worm burrows ... 4.5 m.

Unit 1. Sandstone forming lower 12 m; rest sandy silt to silt; sandstone, grey to olive grey, fine to medium grained, cliff forming, cross bedded in parts, fining upwards; silt and sandy silt with thin interactions of fine silty sandstone in parts, reddish brown, weathering same, concretionary at places, rhizoliths and worm tubes common; sandstone (11.5 m) and mudstone (53.5 m) ... 65 m.

## **KAMLIAL FORMATION**

Sandstone and silt, sandstone grey to coarse grained, massive partly well cemented, cliff forming; silt, sandy, purplish and reddish brown, clayey in upper part; carbonate concretion ... not measured.

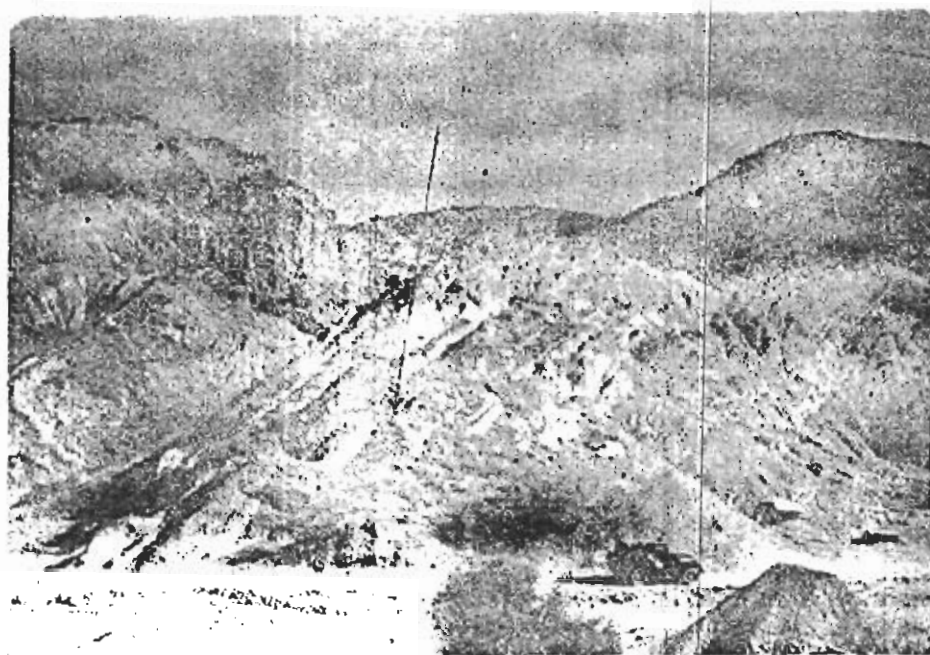
### **5.11 JALALPUR**

#### **5.12 INTRODUCTION**

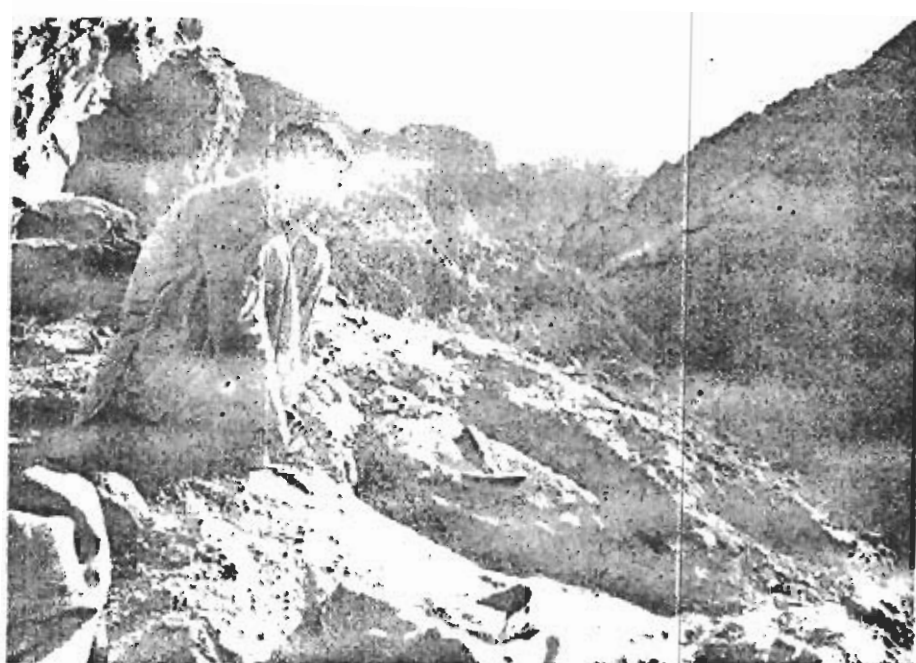
The rodent material described here was collected from isolated redbeds considered correlative to the upper part of the Chinji Formation or the lower part of the Nagri Formation. The fossil deposit is an isolated outcrop of steeply dipping redbeds northeast of Jalalpur, called locality JAL-101 (Fig. 13). It was investigated during two field excursions in 1982 and 1984, during which bulk samples were quarried for later screening of microfossils. On the basis of the field work carried out in 1982, preliminary results were published by Cheema et al. (1983), but most of the determinations were incomplete due to small sample size, and no species were recognized with certainty. The muroids were apparently new, but too poorly represented to be characterized. Faunal comparison was also difficult because of the incomplete small mammal fauna record then known from upper Chinji horizons. Fieldwork in 1984 improved samples, permitting a more informed discussion of the fauna, including diagnosis of a new species. Meanwhile, the

biostratigraphy of the type areas of the Chinji and Nagri Formations became more refined, and with its magnetostratigraphy (Flynn et al. 1995) we can estimate the age of JAL-101.

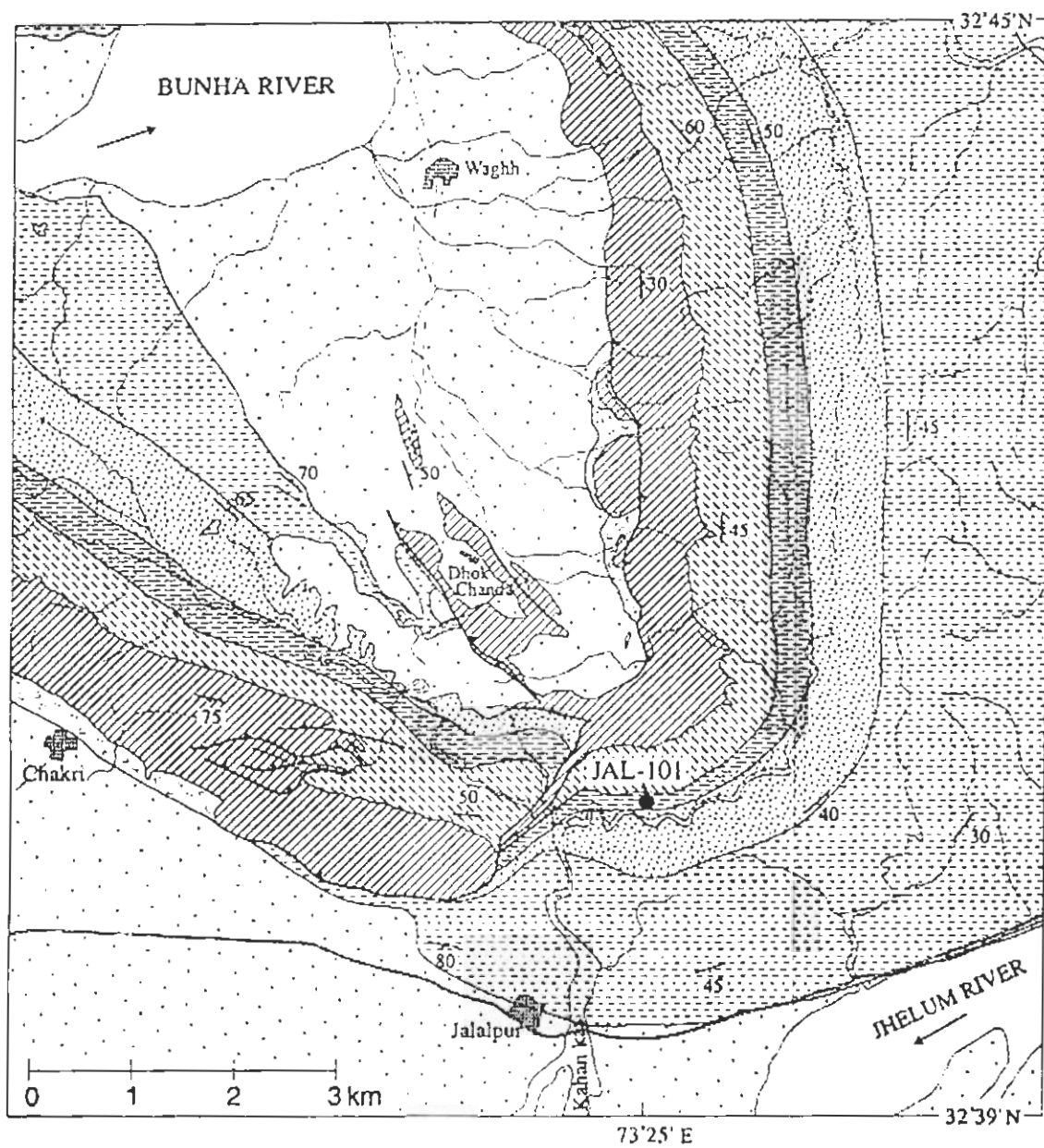
The present work considers all small mammal fossils from 1982 and 1984 collections, but detailed comments are restricted to those taxa for which better representatives are now available. The 1984 collection yielded a surprisingly abundant assemblage of murid teeth, which can now be considered at the species level. Other rodent groups such as Cricetidae, Rhizomidae and Sciuridae are not significantly improved by the 1984 collection, but comments on these taxa are revised in light of other recent work.



General view of the Miocene rocks exposed near Jalalpur area showing the location JAL-101



Closer view of the locality JAL-101.



### LEGEND

▲▲▲ Fault

■ Village

— Road

- - - Track

□ Alluvium

□ Soan Formation  
□ Dhok Pathan Formation

□ Nagri Formation

□ Chinji Formation

□ Kamli Formation

□ Jutana Formation  
□ Kussak Formation  
□ Khewra Formation

□ Formation hidden by scree

Fig.13. Geological Map of the Jalalpur area showing location of JAL-101.

### 5.13 SYSTEMATIC PALEONTOLOGY

**Order Erinaceomorpha Gregory, 1910**  
**Family Erinaccidae Fisher de Waldheim, 1817**  
**Genus Galerix Pomel, 1848**  
*Galerix cf. G. rutlandae* Munthe and West, 1980  
 (Plate 7, fig. a)

**Referred material:** PMNH 5001, lower molar fragment.

**Key reference:** Munthe, J & R. M. West, 1980. Insectivora of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. *Contribution in Biology and Geology, Milwaukee Public Museum, USA. No. 38:* 1-17.

**Referred material occurrence:** Locality JAL-101, in the upper part of the Chinji Formation or lower part of the Nagri Formation, Jalalpur area.

**Age:** Middle Miocene.

**Description:** The Jalalpur fauna includes two insectivore-like molars. A single fragmentary lower molar (PMNH 5001, Plate 7, fig. a) is appropriate in size and morphology for *Galerix rutlandae* (see Munthe and West, 1980). The other tribosphenic specimen (PMNH 5002) is too large to pertain to this species.

**Order Scandentia Wagner, 1855**  
**Family Tupaiidae Gray, 1825**  
**Gen. et sp. indet.**

**Referred material:** PMNH 5002, damaged trigonid of left M<sub>1</sub> or M<sub>2</sub>.

**Referred material occurrence:** Locality JAL 101, in the upper part of the Chinji Formation or lower part of the Nagri Formation, Jalalpur area.

**Age:** Middle Miocene.

**Description:** The specimen is cracked and fragmented, but shows a weak buccal cingulum. At the main cusp, the protoconid, the trigonid wall is high. The paraconid diverges widely from the metaconid. The greater size of PMNH 5002 (trigonid width= 1.6 mm) than that of PMNH 5001 and open trigonid basin confirm comparison with Tupaiidae. Further identification requires more material.

**Order RODENTIA Bowdich, 1821**  
**Suborder SCIUROMORPHA Brandt, 1855**  
**Family SCIURIDAE Gray, 1891**

Eleven teeth in the total Jalalpur collection represent this family. Sciuridae are an old group of rodents with distinctive masseteric musculature (sciuromorphy; see McKenna and Bell, 1997, for discussion on the logic of subordinal divisions of the Order). Sciuridae include terrestrial to arboreal squirrels, and occur throughout the Siwalik sequence, but always in low abundance. Numerically, the dominant rodents of higher category in the Siwalik record are the Maomorphs (see below).

Sciuridae are represented in the Siwalik record mainly by chipmunks, indicating vegetational cover (but not necessarily closed canopy), by a few ground squirrels, and by flying squirrels (usually indicating trees). Cheema et al. (1983) indicated that two taxa are represented in the Jalalpur collection, a smaller gracile and a robust form. The gracile form corresponds to the type material of the chipmunk *Eutamias urialis*.



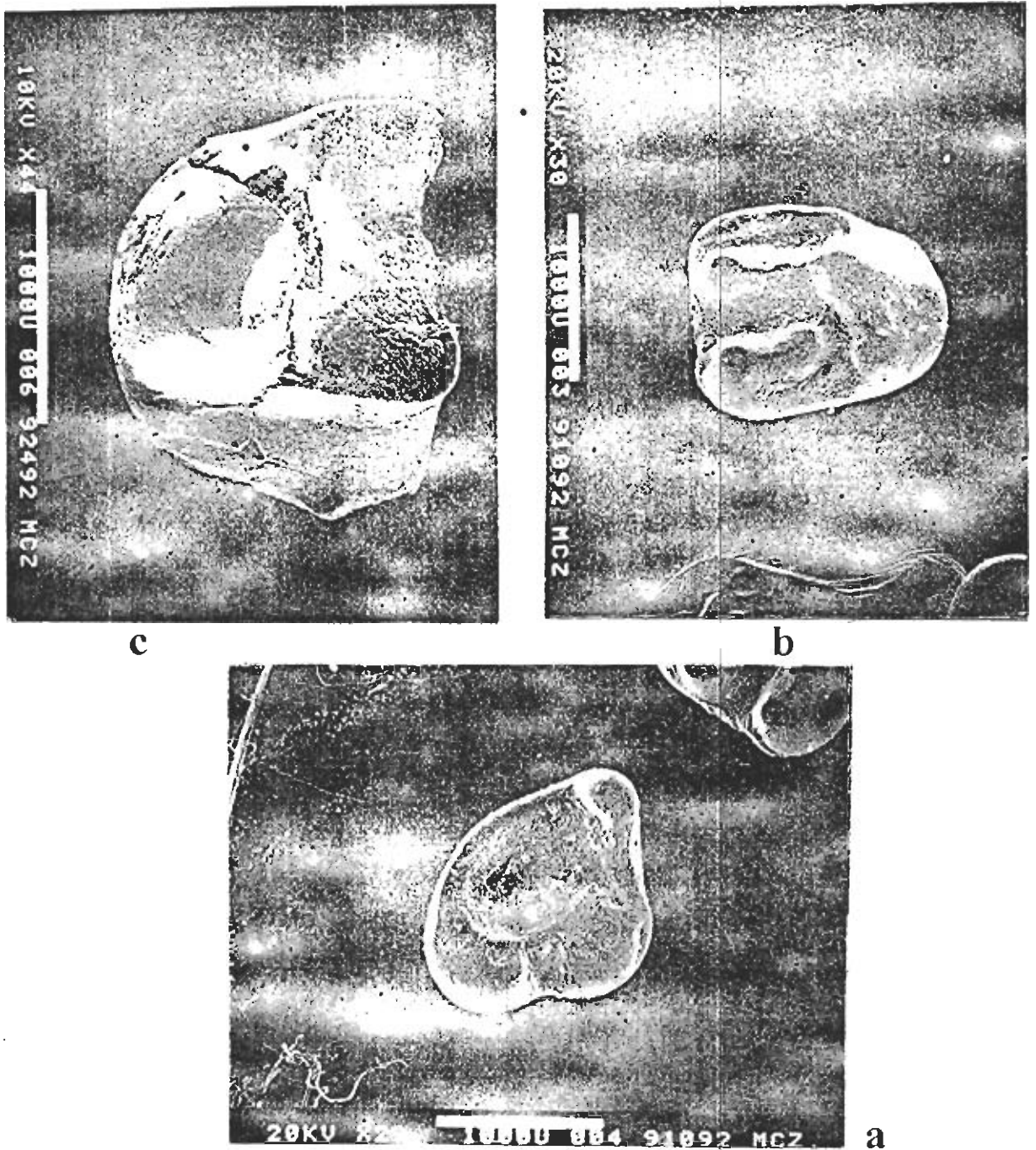


Fig. (a) *Eutamias urialis* PMNH 5003 RM<sup>1-2</sup> (x 30); (b) *Eutamias urialis* PMNH 5006 RM<sub>3</sub> (x 29); (c) *Galarix* cf. *G. rutlandae* 5001 LM<sub>3</sub> (x 44).

**Subfamily SCIURINAE Baird, 1857**  
**Genus Eutamias Troussart, 1880**  
*Eutamias uralis* Munthe 1980  
 (Plate 7, fig. b-c)

**Referred material:** Four isolated teeth, PMNH 5003 ( $M^{1-2}$ ), 5004 (damaged  $M_{1-2}$ ), 5005 ( $DP_4$ ), and 5006 ( $RM_3$ ).

**Key reference:** Munthe, J., 1980. Rodents of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. Part 1: Sciuridae, Gliridae, Ctenodactylidae and Rhizomaidae. *Contribution in Biology and Geology. Milwaukee Public Museum. USA. No. 34:4.*

**Referred material occurrence:** Locality JAL-101 in the upper part of the Chinji Formation or lower part of the Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** The upper molar has high, thin crests (protoloph, metaloph, and anteroloph). The straight, transverse protoloph shows a minute protoconule. The metaloph, with strong metaconule, is incomplete. An indistinct hypocone is partially merged with the sloping posterior wall of the protocone. Lower molars show well separated protoconid and hypoconid, which are joined by a thin, longitudinal crest. The anteroconid is thin, as is the posterolingual wall, which incorporates an indistinct entoconid. The short posterior arm of the protoconid is low and terminates abruptly.

**Discussion:** The morphology of the specimens corresponds closely to that of the hypodigm for this species (Munthe, 1980). Measurements are also consistent, although at the upper end of the range for the hypodigm (for example, PMNH 5003 length (1.5) and width (1.8) are near the upper limits observed by Munthe, 1980). Jal-101 is likely younger than Daud Khel, type locality for this species, and larger observed size is consistent.

*Eutamias uralis* is the only formally named squirrel of the Lower and Middle Siwaliks. Other taxa, and probably younger chipmunks can be described in the future, but at present the limiting

parameter is lack of good comparative material. Because squirrels are always uncommon, the stratigraphic range of *E. uralis* could be extended upward. Consequently, this species, by itself, does not constrain precisely the age of JAL-101.

**Subfamily SCIURINAE gen. et sp. indet.**  
(Plate 8, fig. a-b)

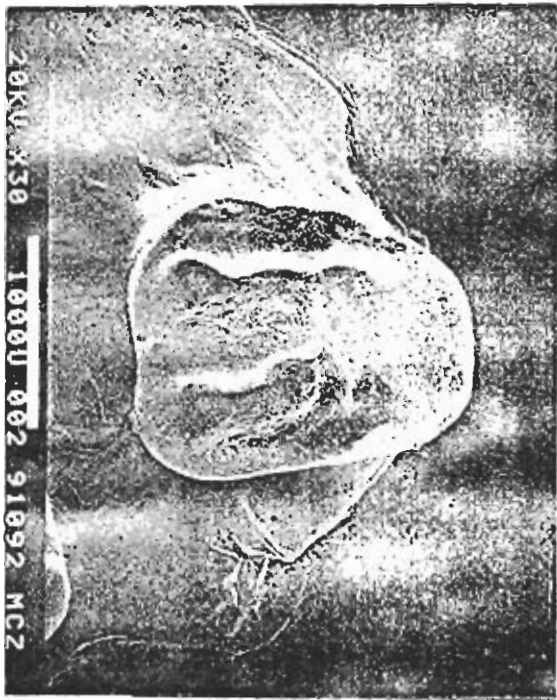
**Referred material:** PMNH 5007(P4), 50089 (M<sup>1-2</sup>), 5009-5012 (M<sub>1-2</sub>), 5013 (M<sub>3</sub>).

**Referred material occurrence:** Locality JAL-101 in the upper part of the Chinji Formation or lower part of the Nagri Formation, Jalalpur area., Distt. Chakwal, Potwar Plateau, Punjab, Pakistan

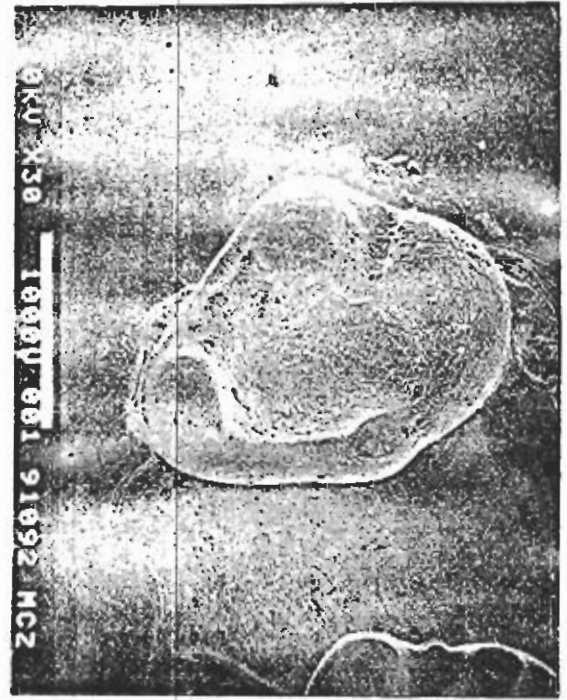
**Age:** Middle Miocene.

**Description:** Compared to *E. uralis*, these cheek teeth are larger, higher crowned, and with major cusps more inflated and relatively closer. Crests joining cusps are correspondingly less sharp (more inflated) than those of *Eutamias uralis*. The conules are undeveloped; the metaloph thins near the protocone, but is complete. The protocone is near the center of the internal side of the tooth; its lingual wall slopes strongly. The hypocone is well developed. On lower molars, the bulbous protoconid and hypoconid nearly touch. Entoconids are variably developed. M<sub>3</sub> is triangular in shape.

**Discussion:** Because so few sciurid taxa from the Siwaliks have been adequately described, with range of variation characterized, it is not possible to determine the affinities of this larger squirrel precisely, or even to ascertain whether more than one species is represented. For comparison, dimensions of PMNH 5008 are 1.75 mm long, 2.3 wide. Because this record cannot affect the biochronology until squirrel biostratigraphy is better understood, it is not considered further here.



a



b



c

Fig.(a) *Sciurinae* gen. & sp. indet PMNH 5007 RM<sup>2</sup> (x 30), (b) *Sciurinae* gen. & sp. indet PMNH 5013 RM<sub>3</sub> (x 30), (c) *Myomimus sumbatenwalicus* PMNH 5019 RM<sup>2</sup> (x 56)

**Suborder Hystricomorpha Brandt, 1855**  
**Superfamily Ctenodactyloidae Tullberg, 1899**  
**Family Ctenodactylidae Zittel 1893**  
**Genus Sayimys Wood, 1937**  
*Sayimys sivalensis* Baskin, 1996.

**Referred material:** PMNH 5014 DP<sup>4</sup> fragment, 5015, well preserved M<sup>1-2</sup> ; 5016, worn M<sup>1-2</sup> ; 5017 and 5018 , two lower molar fragments. Measurements of M<sup>1-2</sup> (PMNH 5015): Length x Posterior width x Anterior Width = 2.041 x 2.13 x 2.22 mm.

**Key reference:** Baskin, 1996.

**Referred material occurrence:** Locality JAL 101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** The lingual flexus of the single complete specimen extends almost to the base of the crown, while the buccal flexus is very deep in the center of the tooth but relatively shallow at the buccal margin. Unilateral hypsodonty of the lingual part of the M<sup>2</sup> has developed to the same degree as in *Sayimys obliquidens* (Bohlin, 1946) and wear is relatively equal on the lingual surface. The protoloph is simple, without a distinct anteroloph. The protoloph and the metaloph unite centrally very early in wear. The metaloph comprises the hypocone and metacone and a small posteroloph, which are quickly fused with wear. The protoloph is slightly wider than the metaloph.

These specimens compare well with Chinji Formation *Sayimys* and cannot be differentiated from the type material of *S. sivalensis* or from the Daud Khel locality H-GSP 247 sample of Munthe (1980). *S. sivalensis* is also reported from the Chinji Formation at Banda Daud Shah by Wessels et al. (1982) who cite comparable measurements.

**Family GLIRIDAE Thomas, 1897**  
**Subfamily Glirinae Thomas, 1897**  
**Genus Myomimus Ognev 1924**  
*Myomimus sumbalenwalicus* Munthe 1980  
 (Plate 8, fig. c)

**Referred material:** PMNH 5019, an upper molar fragment.

**Key reference:** Munthe, J., 1980. Rodents of the Miocene Daud Khel Local Fauna, Mianwali District, Pakistan. Part 1: Sciuridae, Gliridae, Ctenodactylidae and RhizoMaidae. *Contribution in Biology and Geology. Milwaukee Public Museum, USA. No. 34:4.*

**Referred material occurrence:** Locality JAL 101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** The single specimen, PMNH 5019, is an upper molar fragment that agrees with the holotype of this species in morphology and size (width = 1.2 mm; fig. c). The anteroloph is isolated and PMNH 5019 shows a low, hooked necessary crest posterolingual to the paracone.

**Family RHIZOMYIDAE Miller and Gidley 1918**  
**Subfamily Tachyoryctinae Miller and Gidley, 1918.**  
**Genus Kanisamys Wood, 1937**  
*Kanisamys nagrii* Prasad 1968

**Referred material:** PMNH 5020, left M<sub>2</sub>, 5021 and 5022, M<sub>1</sub> fragments; 5023-5025, three upper molar fragments.

**Key reference:** Prasad, K. N., 1968. The vertebrate fauna from the Siwalik beds of Haritalyanger, Himachal Pradesh, India. *Mem. Geol. Surv. India Paleontologica indica, new series, 39: 1-56.*

**Referred material occurrence:** Locality JAL-101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** The small sample of *Kanisamys* includes only one complete tooth, PMNH 5020, M<sub>2</sub> figured and described by Cheema et al. (1983). I note here its moderately well developed mesolophid located close to the hypolophid. Being worn, its width dimension is slightly greater than length (length, 2.1, width, 2.25). One M<sub>1</sub> fragment shows its metaconid to be isolated, except anteriorly, where it joins the anterolophid. A labial fragment of upper molar is unworn and measures ca. 2 mm high, suggesting a lingual crown of near 3 mm.

**Discussion:** Flynn (1982) revised rhizomyid systematics, clarifying the status of *Kanisamas nagrii*, whose relationship to *K. indicus* and *K. sivalensis* named by Wood (1937) had been in question. The closeness of the mesolophid to the hypolophid on PMNH 5020 is advanced feature, characteristic of *K. nagrii* and *K. sivalensis*, in contrast to the older *K. indicus*. So, too, the anterior connection of the metaconid on M<sub>1</sub> separates the species from *K. indicus*. Flynn (1986) applied metric data to diagnose *K. nagrii*, as well. The dimensions of PMNH 5020, and the crown height of the upper molars are all characteristic of *K. nagrii*. The temporal range of *K. indicus* overlaps slightly with *K. nagrii*. *K. indicus* persists in the Potwar Plateau up to about 11 Ma, and *K. nagrii* appears at 11 Ma, an age which is tightly constrained (see Flynn et al., 1995).

**Superfamily MUROIDAE Miller and Gidley, 1918**  
**Family CRICETIDAE Rochebrune 1883**

The Cricetidae are characterized by presence of only three molars in each cheek tooth row. Molar crown pattern is conservative, basically four cusps and connecting crests, but some species possess extra cusps and ridges. None have the extra row of cusps on upper molars so distinctive of Muridae. Cricetids have a strong anterocone or anteroconid on the first molar. The *cricetids* collected in 1984 improved the sample previously available, and confirmed my suspicion that more than one species of *Democricetodon* was present at JAL-101. Much of my ambivalence in Cheema et al., (1983) was due to the fact that most of the specimens then known did not compare well to *D. kohatensis*, the only other Siwalik *Democricetodon* then described. I saw two Jalalpur forms, one apparently like *D. kohatensis*, and one much larger. Now molars of

three sizes and morphologies can be distinguished, the smallest one comparing well with *D. kohatensis*.

**Subfamily CRICETODONTINAE Stehlin and Schaub 1951.**

**Genus *Democricetodon* Fahlbusch 1964.**

***Democricetodon kohatensis* Wessels et al., 1982.**

**Referred material:** PMNH 5026, left M<sup>1</sup>; 5027, left M<sup>2</sup>; 5028, right M<sup>3</sup>; 5029, left M<sub>1</sub>; 5030, right M<sub>1</sub>; 5031 broken left M<sub>1</sub>; 5032, left M<sub>2</sub>; 5033, left M<sub>2</sub>.

**Key reference:** Wessels, W., Bruijn, H. de, Hussain, S. T., and Leinders, J. J. M., 1982. Fossil rodents from the Chinji Formation, Banda Daud Shah, Kohat, Pakistan. *Proc. Kon. Ned. Akad. Wet.*, 85 (3): 337-364.

**Referred material occurrence:** Locality JAL-101, in the upper Chinji Formation or lower Nagri Formation, Jalalpur area, Distt: Chakwal, Potwar Plateau, Punjab, Pakistan.

**Age:** Middle Miocene.

**Description:** These specimens agree in size with the type material from Banda Daud Shah. On M<sup>1</sup>, the anterocone is doubled and the mesoloph is short. On M<sup>2</sup> the protolophule is double. On M<sub>1</sub> the anterconid is short, its labial arm is low, and its lingual arm is high.

***Democricetodon* "B-C" sensu Lindsay, 1994**

**Referred material:** PMNH 5034, right M<sub>1</sub>; 5035, right M<sub>2</sub>; 5036, broken left M<sub>2</sub>; 5037, left M<sub>1</sub>; 5038, left M<sub>1</sub>; 5039, broken right M<sub>1</sub>, 5040, right M<sub>2</sub>.

**Key reference:** Cheema et al. 1983. Early Vallesian small mammals from the Siwaliks of northern Pakistan. *Bull. Mus. Natn Hist.nat.Paris. 4e, ser:5, section 6, no:3: 277-278.*

**Referred material occurrence:** Locality JAL-101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.



**Age:** Middle Miocene.

**Description:** These specimens of this large *Democricetodon* are relatively low cusped and the crown height is brachydont. The molars are relatively slender, and their cusps show oblique offset, rather than directly opposite position. The anterocone of M1 is weakly doubled. The M1 anteroconid is elongate with moderately developed labial and lingual arms. The teeth agree in morphology and size (see Table 1) with Potwar Plateau samples that have been designated *Democricetodon* sp. B-C ((Lindsay, 1994). See discussion under *Democricetodon* sp.G detailed below.

***Democricetodon* sp. "G" sensu Lindsay, 1994**

**Referred material:** PMNH 5041, right M<sup>1</sup>; 5042, right M<sup>1</sup>; 5043, broken right M<sup>1</sup>; 5044, left M<sup>2</sup>; 5045, right M<sup>2</sup>; 5046, right M<sup>3</sup>; 5047, left M<sup>3</sup>; 5048, right M<sub>1</sub>; 5049, right M<sub>1</sub> fragment; 5050, right M<sub>2</sub>; 5051, right M<sub>3</sub>.

**Key reference:** Cheema et al. 1983. Early Vallesian small mammals from the Siwaliks of northern Pakistan. *Bull. Mus. Natn Hist.nat.Paris, 4e. ser:5, section 6, no. 3: 277-278.*

**Referred material occurrence:** Locality JAL-101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** This material, mainly described by Cheema et al. (1983), consists of stout molars. Crown height and cusp height are robust, and the enamel on the major cusps is somewhat wrinkled. M<sup>1</sup> has a doubled anterocone. Mesolophs and mesolophids are always present, but usually do not cross the teeth. The anteroconid on M<sub>1</sub> is relatively blunt. The material corresponds to *Democricetodon* sp. G. of Lindsay (1994).

**Discussion:** *Democricetodon* is a diverse genus in the Siwaliks of Pakistan. Up to six species have been recognized at a single horizon (Lindsay, 1994). At JAL-101, *D. kohatensis* is distinctive by its small size. That there are two other larger species became evident when bigger samples were attained. *Democricetodon* sp. B-C is the informal name for a single species that is nearly as large as *Democricetodon* sp. G (Lindsay, 1994). Lindsay (1994) provides the temporal ranges of these three species.

**Subfamily DENDROMURINAE Lindsay, 1988.**

**Genus *Dakkamys* Jaeger, 1977**

***Dakkamys asiaticus* Lindsay 1988**

**(Plate 9, fig. a-b)**

**Referred material:** PMNH 5052, partial right  $M^1$ ; 5053, upper molar fragment; 5054, right  $M^1$ ; 5055 and 5056, right and left  $M_2$ .

**Key reference:** Lindsay, E. H., 1988. Cricetid rodents from Siwalik deposits near Chinji village, Part 1: Megacricetodontines, Myocricetodontinis, and Dendromurines. *Paleovertebrate, Montpellier, France, 18(2):* 134-135.

Cheema et al. 1983. Early Vallesian small mammals from the Siwaliks of northern Pakistan. *Bull. Mus. Natn Hist.nat.Paris, 4e, ser:5, section 6, no. 3:* 277-278.

**Referred material occurrence:** Locality JAL-101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:**  $M^1$  shows a broad anterocone with central mure joining protocone and short crest from protocone to paracone; the lingual enterostyle joins the protocone posteriorly. The cusps of  $M^1$  (2.2 X 1.4mm), except for the anteroconid, are strongly inclined; the labial arm of the anteroconid as a small cusp and the lingual arm is short. The cusps of  $M^1$  are alternate, the mure is low, there is no mesolophid, and there are minute cusplets between the major cusps, both lingually and labially. The cusps of  $M_2$  (1.8 x 1.5 mm) are alternate, and joined longitudinally by a sloping central mure.  $M_2$  has a strong anterolabial cingulum and posterolophid that expands in a terminal cusp; no mesolophid is present.

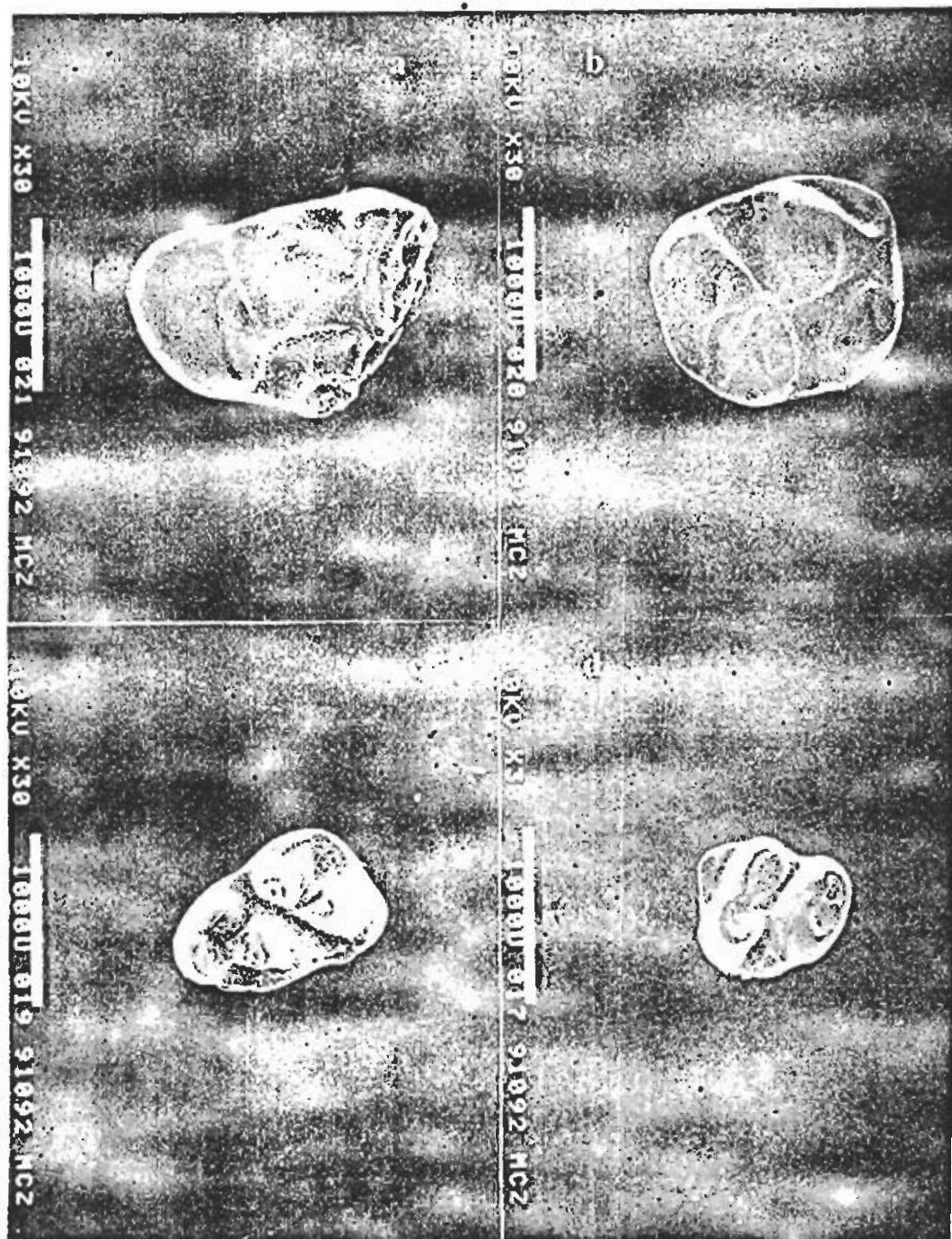


Fig.(a) *Dakkamys asiaticus* PMNH 5052 RM<sup>1</sup> (x 30), (b) *Dakkamys asiaticus* PMNH 5056 LM<sub>2</sub> (x 30), (c) *Parakakkamys chinjiensis* PMNH 5057 LM<sup>1</sup> (x 30), (d) *Parakakkamys chinjiensis* PMNH 5061 LM<sub>2</sub> (x 30)

**Discussion:** This taxon includes PMNH 5054, the  $M^1$  described by Cheema et al. (1983; fig. 7a) under the name *Dakkamys* sp. The specimens are the same size and morphology as for the sample named *D. asiaticus* by Lindsay (1988). The range of *D. asiaticus* as determined on the Potwar Plateau is from about 13 to 10 Ma.

**Genus Paradakkamys Lindsay, 1988**  
***Paradakkamys chinjiensis* Lindsay 1988**  
 (Plate 9, fig. c-d)

**Referred material:** PMNH 5057, left  $M^2$ ; 5058, left  $M_1$ ; 5059, fragmentary  $M_1$ ; 5060 and 5061, two right  $M_2$ .

**Key reference:** Lindsay, E. H., 1988. Cricetid rodents from Siwalik deposits near Chinji Village, Part 1: Megacricetodontines, Myocricetodontines and Dendromurines. *Paleovertebrate*, 18 (2): 134-135.

Cheema et al., 1983. Early Vallesian small mammals from the Siwaliks of northern Pakistan. *Bull. Mus. Natn Hist.nat.Paris*, 4e. ser. 5, section 6, no. 3: 277-278.

**Referred material:** Locality JAL-101, in the upper part of Chinji Formation or lower part of Nagri Formation, Jalalpur area, Potwar Plateau.

**Age:** Middle Miocene.

**Description:** Offset cusps that make oblique pairs and weak longitudinal crests characterize this small murid. On  $M^2$  the metacone and hypocone are closely appressed, there is a strong anterolingual cingulum, and the small enterostyle is low and isolated. On  $M_2$  the mure joins cusp pairs only after advanced wear, and the anterolabial cingulum is strong.  $M_1$  is represented by a fresh, well-preserved specimen, and by a worn fragment that is damaged anteriorly. The former measured 1.55 mm in length x 0.95mm in width. Metaconid and entoconid are anterior to the protoconid and hypoconid, respectively, yielding oblique cusp pairs that are weakly joined traverse ridges. The protoconid and hypoconid are asymmetrically pinched. The metaconid is close to the simple, conical anteroconid. The mure is only emergent after advanced wear. The posterior arm of the hypoconid is a strong posterolingual cingulum. There is a labial cingulum

anterior and posterior to the protoconid. Unlike this tooth, which lacks a mesolophid, the damaged specimen allocated here has a short mesolophid.

**Discussion:** The JAL-101  $M^2$  and  $M_2$  of this species were described and figured by Cheema et al. (1983) under the name "*Maocricetodon* sp". I report here their major features, and discuss in some detail the new  $M_1$ , PMNH 5058. PMNH 5059, a worn specimen with a mesolophid, is questionably assigned here since it is too slender to pertain to *Democricetodon*. Otherwise this sample compares well with Chinji area specimens described and named *Paradakkamys chinjiensis* by Lindsay (1988), except that the JAL-101  $M_1$  lacks an ectostylid. The temporal range of this species in the Potwar Plateau is nearly the same as for *Dakkamys asiaticus*, that is 13 to 10 Ma.

Family MURIDAE Gray 1821

*Progonomys* Schaub 1938

*Progonomys hussaini* sp. nov.

(Plate 10, fig. a-d; Plate 11, fig. e-h; Plate 12, fig. i-m)

**Holotype:** PMNH 5062, left  $M^1$ . (Plate 10, fig. a)

**Hypodigm:** PMNH 5062-5118, fifty-seven isolated molars representing  $M^{1-3}$  and  $M_{1-3}$  (see Table 9) and thirty unnumbered molar fragments.

**Type locality:** JAL-101, upper part of the Chinji Formation of the Jalalpur area, Potwar Plateau.

**Etymology:** Named for Prof. Syed Taseer Hussain, in recognition for his promotion of scientific research in Pakistan, and especially for his work on Siwalik fossils.

**Age:** Early Late Miocene.

**Diagnosis:** *Progonomys* with cusps relatively low and not strongly inclined; cusps of upper molars joined by low crests in chevrons and the second and third chevrons of  $M^1$  are weakly connected lingually; anterostyle of  $M^1$  variable in degree of posterior position and lateral pinching;  $M_1$  with centrally connected anteroconids.

**Description:**  $M^1$  is oval but varies in degree of elongation in occlusal outline. It is low crowned and the cusps are slightly inclined posteriorly. Anterostyles vary in degree of anteroposterior pinching. Although the anterostyle and enterostyle are generally located posteriorly, their position is observed to be variable. In one specimen, the anteriorly placed enterostyle makes the second chevron almost straight. In another the anterostyle is anterior and conical (Plate 10, fig. b). A low crest to the hypocone joins the enterostyle; the metacone and paracone are well separated. The posterior cingulum is well developed. The precingulum is absent to weak; a minute prestyle is present in two of eight teeth.

$M^2$  varies continuously in size and robusticity. The enterostyle is always firmly linked with the protocone, and joins the hypocone by means of a low crest (Plate 11, fig. e-f). The metacone and paracone are well separated. The posterior cingulum is well developed. The two  $M^3$  differ in overall size and in development of the anterostyle (Plate 12, fig. j-k).

The anteroconids of  $M_1$  are always double and closely appressed (Plate 10, fig. c-d). They vary from equal in size to strongly asymmetrical, and join near the midline of the tooth. They always connect posteriorly via a low to well developed anterior mure to the protoconid and metaconid. In only one specimen is there a minute anterior prestylid. The posterior cingulum varies in size of its cusp. The labial cingulum varies greatly in its development and the number of cusps present on it, but  $C_1$  (classic murid terminology; see Jacobs, 1978) appears to be developed to some degree in all cases. One very small  $M_1$  lacks well-developed labial and posterior cingula, and the anterior mure; it may be missing enamel due to corrosion from digestive processes of a predator.

$M_2$  shows a broad, continuous range of sizes. The labial anteroconid is moderately to well developed (Plate 11, fig. g-h; Plate 12, fig. i). The labial and posterior cingula and cingular cusps vary also.  $M_3$  size variation is about 20%. The labial anteroconid is small, the labial cingulum weak. One specimen (Plate 12, fig. m) shows a swelling on the lingual arm of the hypoconid, which may be an entoconid homologue.

**DISCUSSION:** This new species is assigned to *Progonomys* based on the shared features of the genus, including enterostyles linked to protocones and the anteroconids stable in twinning (in distinction from *Antemus*), and anterostyle posteriorly shifted (usually) and posterior cingulum well developed (in distinction from other murids).

*Progonomys hussaini* sp. nov. is primitive in low crown height without strong inclination of cusps, in weak connections, and in the broad posterior lobe of  $M_3$ , which may indicate homology with the entoconid. It is smaller than *P. woelferi*, about the size of *P. cathalai*. In contrast to *P. cathalai*, the anterostyle is usually more posterior and the anterior mure on  $M_1$  is less developed. *P. hispanicus* is somewhat smaller, with higher and more inclined cusps (Michaux, 1971). *P. yunnanensis* (also somewhat smaller) is more stephanodont, with anterior posterostyle, higher cusps, and other advanced features (Qiu and Storch, 1990).

*Progonomys hussaini* is an early representative of the genus, and is correspondingly primitive. The sample from JAL-101 shows considerable variations, leading to the suspicion that more than one taxon could be present. Some teeth seem unusual in size (contrast the two  $M^3$  in Plate 12, fig j-k). Morphology also varies, but not in a way congruent with size. Indeed, the odd  $M^1$  (Plate 10, fig. b) seems incongruent with the usual morphology (posterior and lophate anterostyle), and Cheema et al. (1983) felt that it might represent a primitive *Karnimata*. Despite considerable size variation, the samples do not indicate two clusters. Given larger samples now, the murid variations appear to intergrade and I take the conservative view that only one species is present. Consequently, I assign all murid specimens from JAL-101 to *Progonomys hussaini*, and observe a broad range of variation for the species.

McKenna and Bell (1997) submerged *Karnimata* with *Progonomys* without justification. Clearly the type species differ at the generic rank, and they were distinct at 9 Ma (Jacobs, 1978). One question for the Siwaliks is "what is the earliest record of each genus?" The origin of *Karnimata* is a somewhat different question. The Jalalpur assemblage shows considerable variation. That variation could encompass the origins of both *P. debruijini* and *Karnimata*, as implied by Jacobs et al. (1990). Alternatively, *Karnimata* could indeed be present at JAL-101 in low abundance, but I cannot defend this at present. Earlier *Progonomys* and *Karnimata* were close in size, and

later *Progonomys* likely was smaller, converging on *Mus* size (Jacobs, 1978). Early *Karnimata* would be difficult to recognize on the basis of size.

A morphometric approach to analyzing successive samples of Siwalik murids could clarify this problem.



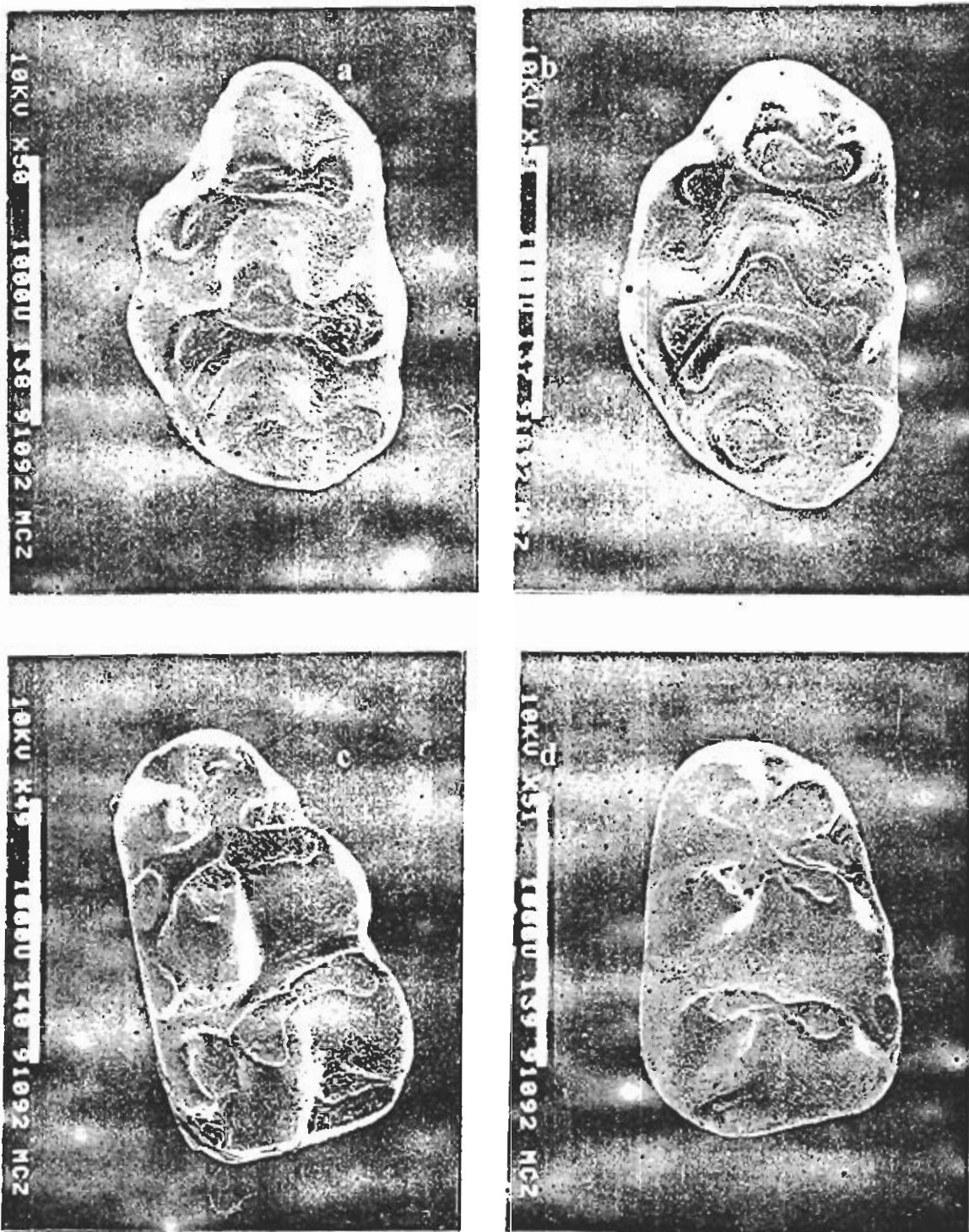


Fig. (a) *Progonomys hussaini* new species PMNH 5062 LM<sup>1</sup> (Holotype) (x 50), (b) *Progonomys hussaini* PMNH 5063 LM<sup>1</sup> (x 51), (c) *Progonomys hussaini* PMNH 5085 RM<sub>1</sub> (x 49), (d) *Progonomys hussaini* PMNH 5086 LM<sub>1</sub> (x 51)

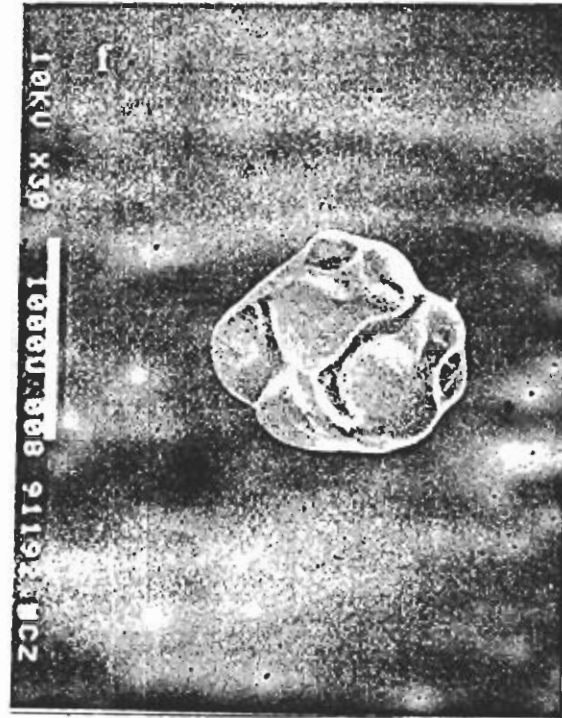


Fig. (e-h) *Progonomys hussaini* new species, (e) PMNH 5070 LM<sup>2</sup> (x 30), (f) PMNH 5071 LM<sup>2</sup> (x 30), (g) PMNH 5095 RM<sub>2</sub> (x 49), (h) PMNH 5094 LM<sub>2</sub> (x 50)

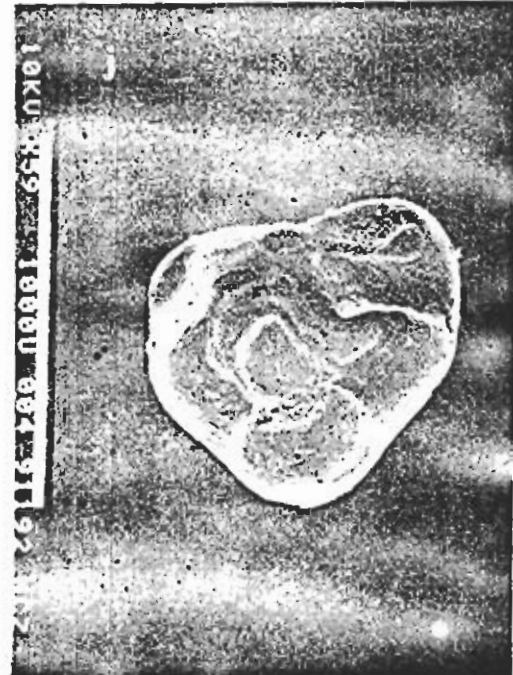
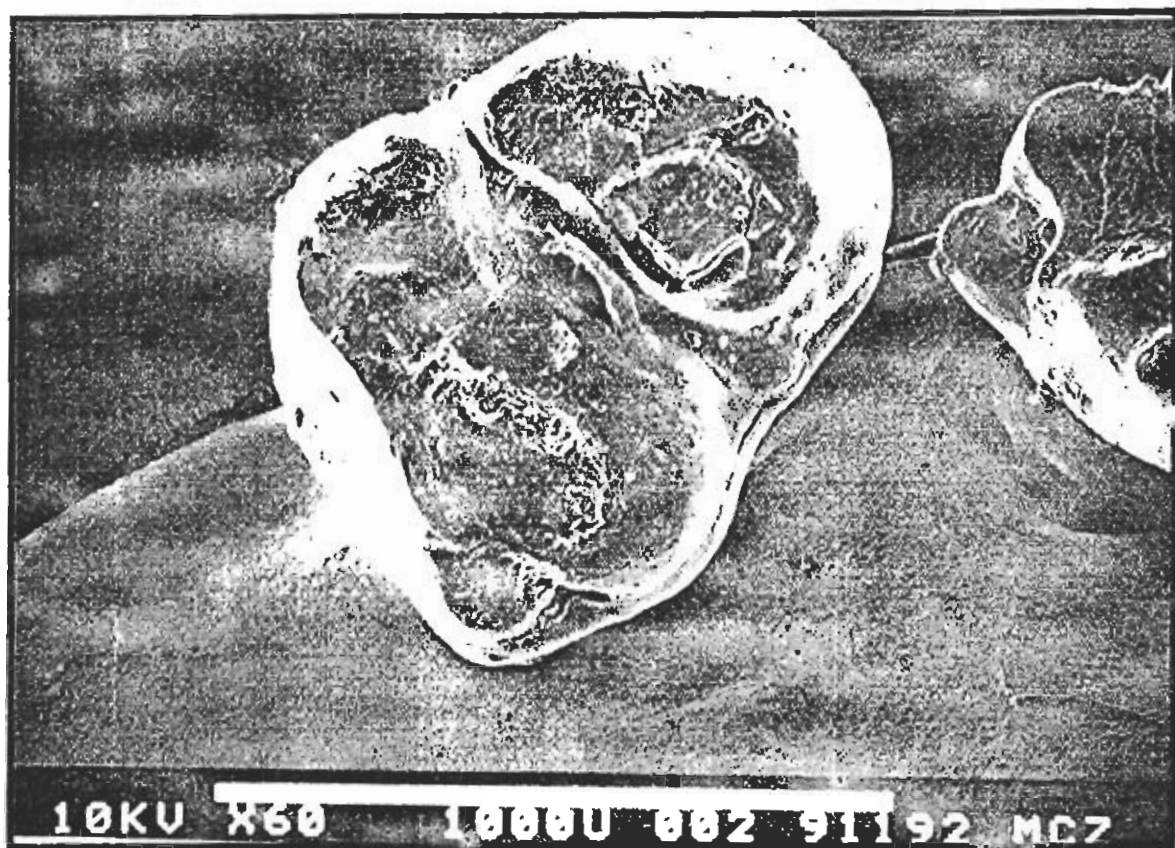


Fig. (i-l) *Progonomys hussaini* new species, (i) PMNH 5096 RM<sub>2</sub> (x 60), (j) PMNH 5083 LM<sub>3</sub> (x 59), (k) PMNH 5084 RM<sub>3</sub> (x 70), (h) PMNH 55115 RM<sub>3</sub> (x 60).



m

Fig. (m) *Progonomys hussaini* new species, PMNH 5116 RM<sub>3</sub> (x 60).

## 5.14 CONCLUSION

The Jalalpur locality JAL 101 is important because it represents heretofore poorly sampled strata correlative to the upper part of the Chinji Formation or the lower part of the Nagri Formation. Its mammal fauna is diverse, the 148 numbered specimens representing 13 species. More identifiable specimens would likely increase the faunal list. Almost all of the material consists of isolated teeth (dominantly molars), but five postcranial elements, a rib and four podial fragments, were also retrieved. The micromammal assemblage from JAL-101 with number of specimens of each taxon is given in Table 8.

The enhanced rodent fauna of JAL-101 confirms the earlier appearance of the *Progonomys* lineage than was known when Jacobs (1978) conducted his pioneering study. Since then, Jacobs et al. (1989, 1990) argued that *Progonomys* and *Karnimata* appeared much earlier than previously recognized in the Indian Subcontinent. *Karnimata* is not clearly represented in the fauna, but some specimens suggest that this lineage possibly began to differentiate at this time. The cricetid species resemble those reported from elsewhere in the Chinji Formation of the southern Potwar Plateau and Kohat area (Dehm et al. 1982, Wessels 1982). However, the co-occurrence of *Progonomys* with a species of *Kanisamys* advanced over *K. indicus* of the lower Chinji Formation and with typical upper Chinji/lower Nagri formation cricetids suggests an early Late Miocene age for the fauna. The earlier assertion (Cheema et al., 1983) of an early equivalence is consistent with these results

Table 8. Micromammal assemblage of JAL-101, Jalalpur area.

FAMILY	SPECIES	NUMBER OF SPECIMENS
Erinaceidae, Tupaiidae	I and II	02
Sciuridae	<i>Eutamias urialis</i>	04
	Tamiinae indet.	04
Ctenodactylidae	<i>Sayims sivalensis</i>	05
Gliridae	<i>Maomimus somblenwalicus</i>	01
Rhizomyidae	<i>Kanisamys nagrii</i>	06
Cricetidae	<i>Democricetodon kohatensis</i>	08
	<i>Democricetodon</i> "B-C"	07
	<i>Democricetodon</i> "G"	11
	<i>Dakkamys asiaticus</i>	05
	<i>Paradakkamys chinjiensis</i>	05
Muridae	<i>Progonomys hussaini</i>	87

The 1984 collection helps to refine faunal correlation to the Potwar Plateau sequence. Flynn et al. (1995) plot the known temporal ranges of all Potwar species, which are dated paleomagnetically. They show the first occurrence of *Maomimus* at 13.8 Ma and last occurrence of *Eutamias urialis* at 10.6 Ma, although as noted above, these chipmunks may well have persisted later in time. *Megacricetodon*, distinctive by its absence from JAL-101, last occurs at 12.5 Ma elsewhere on the Potwar Plateau. *Kanisamys nagrii* is known from 11.1 Ma to 8.8 Ma. *Dakkamys asiaticus* and *Paradakkamys chinjiensis* are known in excess of 12 Ma to about 10 Ma. *Karnimata* becomes recognizable in murid samples around 10 Ma, possibly as old as 10.6 Ma. *Sayimys sivalensis* is confined to ca. 12 Ma to 9.5 Ma. In summary, the likely age of JAL-101 is constrained to circa 11 Ma to perhaps as young as 10 Ma (Fig. 14), which corresponds to the uppermost part of the Chinji Formation in its type area.

**Table 9.** Measurements for molars of *Progonomys hussaini* from Jalalpur Locality JAL-101 (in mm).

Element	Catalogue #	Length	Width		
M <sup>1</sup>	5062	1.80	1.10	(Holotype, (Plate 10, fig. a)	
	5063	1.85	1.15	(Plate 10, fig. b)	
	5064	1.80	1.20		
	5065	2.00	1.20		
	5066	2.05	1.15		
	5067	2.20	1.25		
	5068	2.00	1.30		
	5069	2.05	1.20		
	M <sup>2</sup>	5070	1.30	1.25	(Plate 11, fig. e)
		5071	1.35	1.30	(Plate 11, fig. f)
5072		1.20	1.10		
5073		1.20	1.20		
5074		1.20	1.15		
5075		1.20	1.05		
5076		1.40	1.20		
5077		1.25	1.15		
5078		1.20	1.20		
5079		1.40	1.25		
M <sup>3</sup>	5080	1.35	1.20		
	5081	1.40	1.20		
M <sub>1</sub>	5082	1.15	1.30		
	5083	0.95	0.95	(Plate 12, fig. j)	
M <sub>2</sub>	5084	0.75	0.80	(Plate 12, fig. k)	
	5085	1.60	0.95	(Plate 10, fig. c)	
	5086	1.45	0.95	(Plate 10, fig. d)	
	5087	1.70	1.05		
	5088	1.60	1.00		
	5089	1.50	0.95		
	5090	1.80	1.10		
	5091	1.75	1.15		
	5092	1.60	1.10		
	5093	1.50	0.95		
M <sub>2</sub>	5094	1.25	1.10	(Plate 11, fig. h)	
	5095	1.25	1.15	(Plate 11, fig. g)	
	5096	1.15	1.10	(Plate 12, fig. i)	
	5097	1.20	1.10		
	5098	1.30	1.05		
	5099	1.25	1.05		
	5100	1.30	1.05		
	5101	1.35	1.05		
	5102	1.25	1.05		

	5103	1.20	1.05	
	5104	1.45	1.15	
	5105	1.35	1.15	
	5106	1.30	1.15	
	5107	1.40	1.15	
	5108	1.30	1.10	
	5109	1.30	1.20	
	5110	1.30	1.15	
	5111	1.30	1.15	
	5112	1.35	1.10	
	5113	1.30	1.15	
	5114	1.35	1.15	
M <sub>3</sub>	5115	1.00	0.90	(Plate 12, fig. l)
	5116	1.20	0.95	(Plate 12, fig. m)
	5117	0.95	0.85	
	5118	1.10	0.90	

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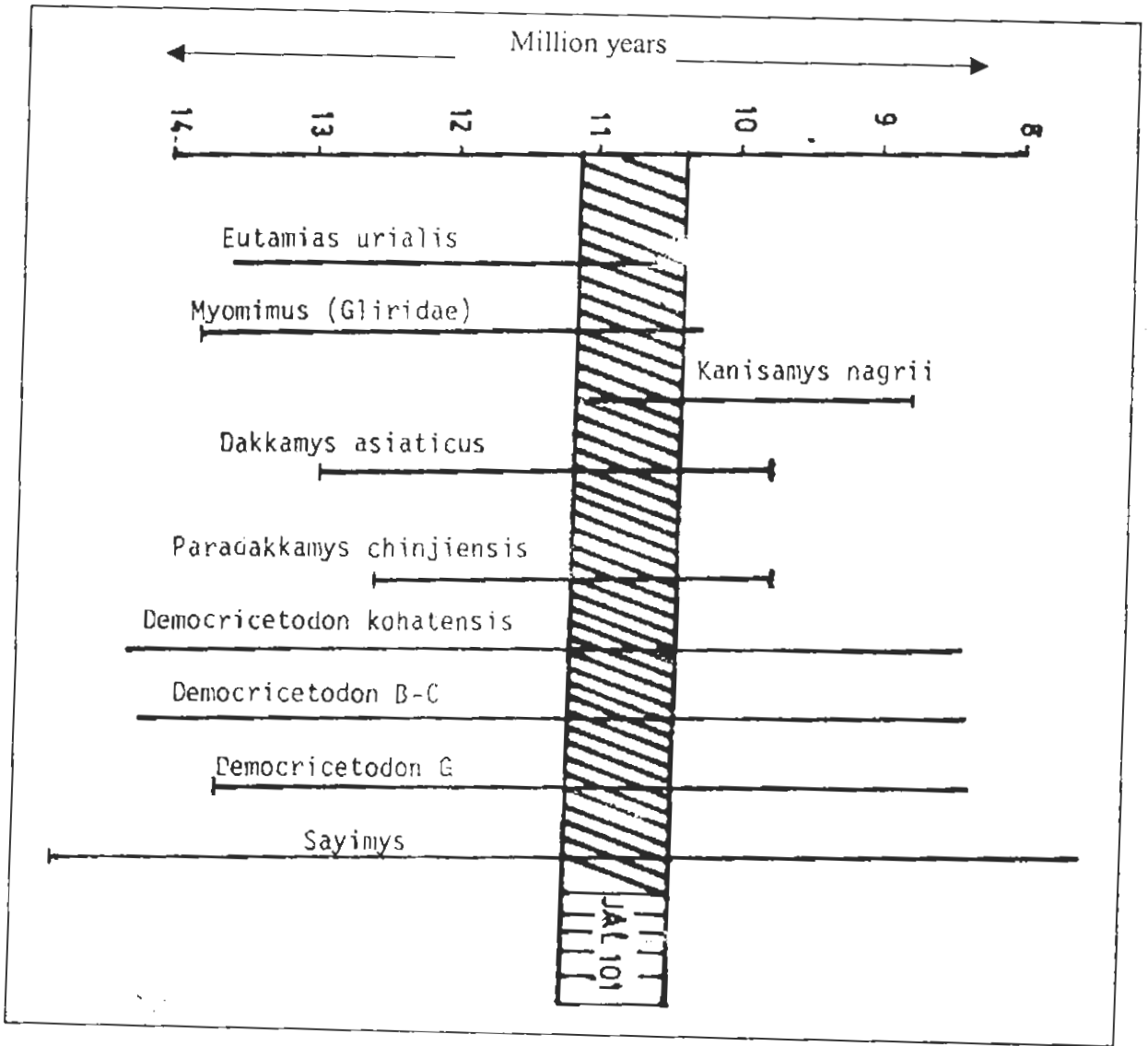


Fig.14. Stratigraphic ranges of rodent species of the JAL-101.

## 5.15 MIRPUR, AZAD KASHMIR

### 5.16 INTRODUCTION

An approximately one-kilometer thickness of Upper Siwalik sub-Group rocks in the southeastern Potwar Plateau and adjacent southwestern Kashmir record the Plio-Pleistocene mammalian and tectono-geomorphic history of the Himalayas (Opdyke et al., 1979; Burbank and Beck, 1989; Hussain et al; 1992). Careful stratigraphically controlled faunal collection integrated with local magnetic reversal stratigraphy (correlated with the Geomagnetic Time Scale) has provided a unique fine-tuned calibration for estimating species longevities, deciphering faunal diversity patterns, and for establishing a firm biostratigraphic zonation of the Neogene Siwalik sequence in the Potwar Plateau (see for example Barry et al. 1982, 1991; Flynn et al., 1990; Jacobs et al., 1989).

Recent studies of the Upper Siwalik rocks have centered mainly in the Rohtas, Pabbi Hills and Mangla-Samwal area (Keller et al., 1977; Opdyke et al., 1979; Hussain et al., 1992). Thick alternations of grey and brown sandstone and red and brown mudstone with prominent conglomerate interbeds in the uppermost parts characterize the Upper Siwalik sequence. The lithofacies changes from multi-storey extensive sheet sandbodies in the lower parts to the mudstone dominated upper part, and the varying composition and proportional increase of conglomerate interbeds in the higher parts of the sequence reflect changing patterns of the fluvial system in the area. These phenomena have been interpreted to be controlled by appearances of tectonic elements in the Himalayas, such as the uplift of the Pir Panjal and the Margalla hills in the immediate northern vicinity of the area.

### 5.17 PALEONTOLOGY

The 850-meter thick upper Siwalik rocks in the Mangla-Samwal anticline have been divided into a lower Samwal Formation, middle Kakra Formation and an upper dominantly conglomeratic Mirpur Formation (Arif 1985). The entire sequence ranges in age from ca. 3.4 Ma to 1.0 Ma (Johnson et al. 1979): the Samwal-Kakra Formation boundary is at around 1.6 Ma (Arif, 1985). Hussain et al. (1992) have reported a rich mammalian fauna from the Samwal Formation including *Crocota*, *Stegodon*, *Elephas*, *Equus*, *Sivatherium*, *Hexaprotodon*, and *Hemibos* besides

other bovines, antelopes, giraffes, and rhinoceroses. This assemblage corresponds with the *Elephas planifrons* Interval Zone of Barry et al. (1982). Hussain et al. (1992), however, suggested a subdivision into a lower *E. planifrons* Range Zone (between 3.3 Ma to 2.7 Ma) and an upper *E. hysudricus* Range Zone (between 2.7 Ma to 1.6 Ma).

The small mammals reported here come from two localities, PMNH 8802 and HGSP 8929, in the Samwal Formation (Fig. 15). The PMNH 8802 site includes a few fragmentary localities vis-à-vis the Johnson et al. (1979) magnetic polarity stratigraphy of the Mangla-Samwal area suggests an age for PMNH 8802 of ca. 3.0 Ma and for HGSP 8929 an age of 2.6 Ma. This is the first report of a small mammal fauna from the Mangla-Samwal area and also for the late Pliocene of the Potwar-Kashmir area. Paleontologists in India are actively investigating late Pliocene rocks of the Karewas (Kotlia, 1992) and around Saketi Park (Patnaik, 2001).

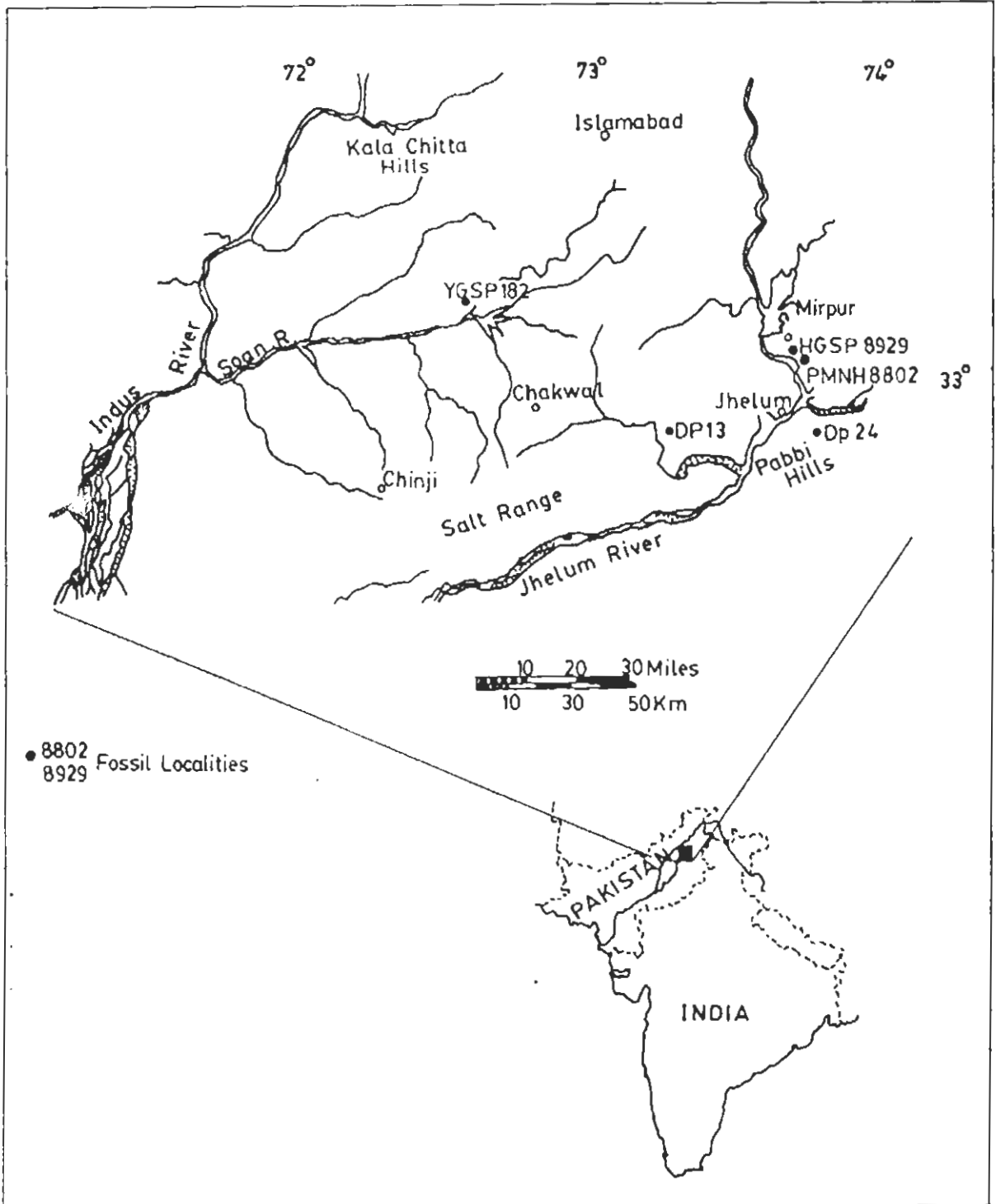


Fig.15. Map of parts of eastern Potwar Plateau, southwestern Kashmir showing the fossil sites (PMNH 8802 and HGSP 8902).

## 5.18 SYSTEMATIC PALEONTOLOGY

**Order INSECTIVORA**  
**Family SORICIDAE Gray, 1821**  
**Genus Suncus Ehrenberg, 1833**  
 cf. *Suncus* sp.  
 (Plate 13, fig. a-b)

**Referred material:** PMNH 6001, right dentary fragment bearing M<sub>3</sub>.

**Referred material occurrence:** Locality HGSP 8929, Samwal Formation, Mirpur, Azad Kashmir.

**Age:** ± 2.6 Ma Pliocene.

**Description:** This specimen has a distinctive presentation. It is a lustrous red-brown, thin bone being translucent; there is no indication of original tooth pigmentation. The coronoid and condyle are broken, so identification is based on the molar. The tooth is relatively unreduced, but very narrow. Its well-developed trigonid blade between protoconid and paraconid curves gently anterolingually. The much shorter protoconid-metaconid blade is transverse in orientation and the metaconid is the smallest of these three cusps. The moderately short talonid is modified in structure. Its large single cusp, posterior in position, is nearly on a level with the metaconid. A major crest dips from it to the base of the metaconid. A second low crest descends anteriorly down the lingual side of the talonid cusp. There is a posterolabial cingulum on the talonid, none lingually, and a heavy anterolabial cingulum continuous with a distinct ridge anterior to the paraconid.

**Order RODENTIA Bowdich, 1821**  
**Family MURIDAE Gray, 1821**  
**Genus Golunda Gray, 1837**  
*Golunda kelleri* Jacobs, 1978  
 (Plate 13, fig. c-f)

**Referred material:** Four isolated teeth, PMNH 6002, 6003, 6004 and 6005. left for M<sub>1</sub>, M<sub>2</sub> and M<sub>3</sub>, and right M<sup>1</sup>, respectively.

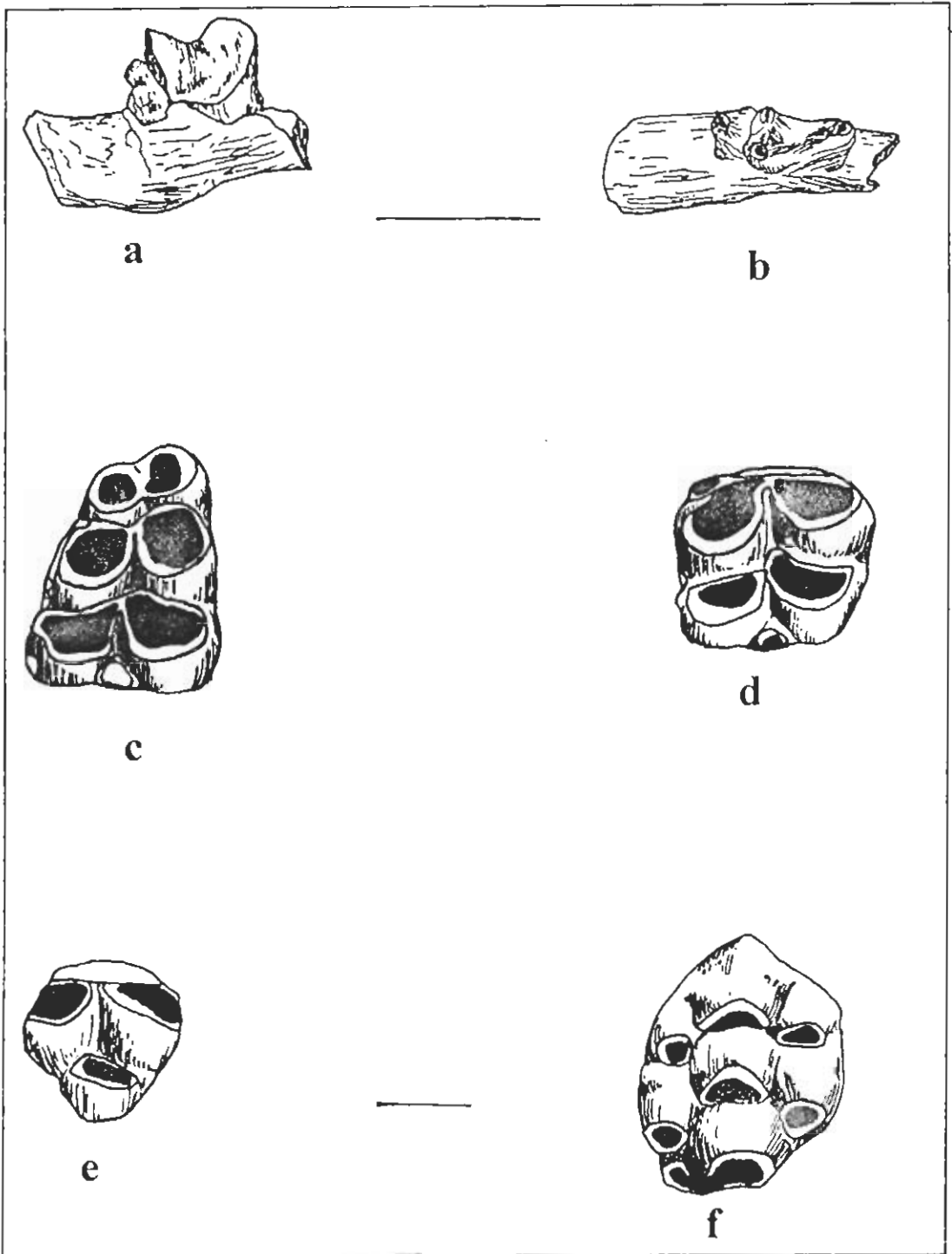


Fig. (a-b) cf. *Suncus* sp. (a) PMNH 6001 RM<sub>3</sub>, (b) PMNH 6001 RM<sub>3</sub>, Fig. (c-f) *Golunda kelleri* (c) PMNH 6002 LM<sub>1</sub>, (d) PMNH 6003 LM<sub>2</sub>, (e) PMNH 6004 LM<sub>3</sub>, (f) PMNH 6005 RM<sub>1</sub>

**Key reference:** Jacobs L. L., 1978. Fossil Rodents (Rhizomyidae and Muridae) from Neogene Siwalik deposits, Pakistan. *Museum Northern Arizona, Flagstaff, Bulletin series 52: 67-68.*

**Referred material occurrence:** Locality PMNH 8802, Samwal Formation, Mirpur, Azad Kashmir.

**Age:**  $\pm 3.0$  Ma Pliocene.

**Description:** The teeth range in color from light to dark chocolate brown. The  $M_1$  and  $M_2$  are similar in light brown coloration and moderately advanced wear. Root ends are broken. Cusps are arcuate to subcircular and positioned as Jacobs (1978) described.

The labial anteroconid of  $M_1$  is smaller and posterior to the lingual anteroconid, and there is no anteromedial cusp between them. The metaconid touches the lingual anteroconid. The hypoconid and entoconid converge in a remnant of the medial mure. A labial bulge in the hypoconid may represent a worn  $C_1$ . The posterior cingulum is a small oval. The labial cingulum is greatly reduced, but there are small cusps between labial anteroconid and protoconid, protoconid and hypoconid and posterior to the hypoconid. There are six roots, a large anterior and two posterior roots, and three across the middle of the tooth.

The protoconid and metaconid of  $M_2$  join anteriorly, but the hypoconid, the smallest cusp, does not touch the entoconid. There is a small labial anteroconid and weak labial cingulum. There is a low anterior cingulum and small, oval posterior cingulum. A large root occurs at each corner of the square tooth, and a fifth small root is anteromedial in position.

The triangular  $M_3$  is lightly worn but corroded. There are three cusps, unconnected protoconid and metaconid, and medially placed entoconid. The anterior cingulum is clear but a posterior cingulum is not evident. A small, labial cuspsule is considered the hypoconid (see Musser, 1987). Although damaged,  $M_3$  appears to have had two large anterior roots and one or two posterior roots.

The upper first molar is rounded in outline with high, strongly inclined cusps. They are weakly joined in early wear. Medial cusps are the largest and most arcuate. The anterostyle and lingual and labial anterocones compose the first chevron; both anterostyle and labial anterocone are slightly posterior to the lingual anterocone. In the second chevron, the enterostyle and paracone are both slightly posterior to the protocone. The third chevron includes only two cusps, a large hypocone and very small metacone joined by a narrow posterior connection. The metacone is lateral to the hypocone and abouts the back of the paracone. There is no posterior cingulum. The base of this specimen is damaged and slightly corroded but at least five major roots were present.

**Genus *Hadromys* Thomas, 1911**  
*cf. Hadromys sp.*  
 (Plate 14, fig. a-b)

**Referred material:** PMNH 6006, left M<sup>1</sup> fragment.

**Referred material occurrence:** Locality PMNH 8802, Samwal Formation, Mirpur, Azad Kashmir.

**Age:** ± 3.0 Ma Pliocene.

**Description:** This dark brown tooth fragment shows light wear. Its cusps are tall and slightly inclined. The first chevron is broken away. Cusps of the second chevron are strongly joined by high connections. The protocone is the biggest cusp in the second chevron, followed by enterostyle, then paracone. Both enterostyle and paracone are slightly posterior to the protocone. The conical hypocone dominates the third chevron, which is well separated by a deep cleft from the second. There is a small metacone oppressed to the labial side of the hypocone; there is no lingual style. There is no posterior cingulum.

**Genus *Mus* Linnaeus, 1758**  
*Mus sp.*  
 (Plate 14, fig. c)

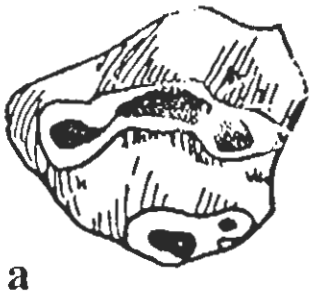
**Referred material:** PMNH 6007, left M<sup>1</sup> fragment.



**Referred material occurrence:** Locality PMNH 8802, Samwal Formation, Mirpur, Azad Kashmir.

**Age:**  $\pm 3.0$  Ma Pliocene.

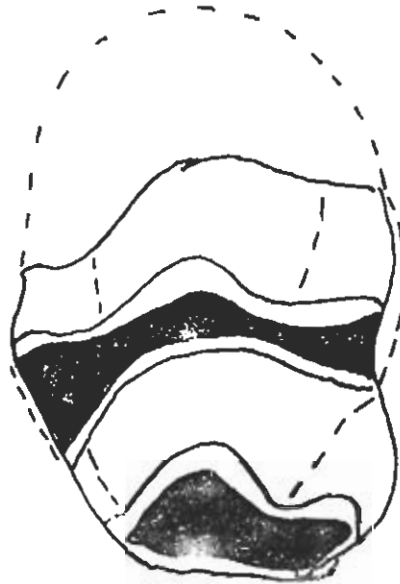
**Description:** This small specimen lacks its first chevron. The paracone is firmly joined to the protocone. The enterostyle is more separated and more posterior than paracone and a posterolingual spur. The hypocone is large and weakly joined to the enterostyle spur. The posterolabial metacone is unreduced. There is no posterior cingulum.



a



b



c

Fig. (a-b) cf. *Hadromys* sp. (a) PMNH 6006 LM<sup>1</sup>, (b) PMNH 6006 LM<sup>1</sup>, Fig. (c) *Mus* sp. PMNH 6007 LM<sup>1</sup>.

## 5.19 DISCUSSION

The specimens described here come from two localities in the Mirpur area and indicate considerable potential to build a Pliocene biostratigraphy for small mammals of northern Pakistan. Only one identifiable specimen, the shrew *cf. Suncus sp* comes from locality 8929. . The Mirpur shrew  $M_3$  is very narrow, with a simple talonid dominated by a single cusp and high crest. The trigonid arms diverge broadly and the protoconid is high. The anterolabial cingulum is prominent. The specimen resembles some of the smaller species of *Suncus*, but its  $M_3$  is distinctive in its narrowness and broad trigonid.

The six murid specimens indicate three species, all from locality PMNH 8802. This locality correlates roughly to the top of the Mammoth event in the section of Hussain et al. (1992), ca. 3 Ma. Four specimens are assigned to *Golunda kelleri*, a species recorded in the younger locality DP24 in Pabbi Hills (Jacobs, 1978), which occur magnetostratigraphically above the Olduvai event. Whether slight morphological differences in molars of the two samples reflect individual variation or time remains to be seen. The Mirpur  $M_{1-2}$  has a slightly stronger labial cingulum and is possibly lower crowned, although wear stage makes this uncertain. This sample shows the diagnostic feature of *G. kelleri*, a centrally placed entoconid on  $M_3$ .

The Mirpur *Golunda* adds the upper first molar, which was lacking in the original hypodigm. This tooth differs from that of extant *G. ellioti* in that it is more elongated anteroposteriorly, with chevron less crowned, and its metacone is less reduced. It is smaller in length/width proportions to *Golunda gurai* Sabatier (1982), but at the small end of the size range for that species. Central cusps on  $M^1$  are more crescentic in *G. kelleri*, labial cusps are smaller and rounder, and the metacone is smaller than in *G. gurai*. Musser (1987) rejected the latter as a member of *Golunda*.

The *cf. Hadromys sp.* is smaller, low crowned, has more bent, less crowned chevron, and a less anterior metacone than *Hadromys loujacobsi*. Whether it precedes or is a contemporary of early *Hadromys* awaits more fieldwork. In any case, it indicates that the *Hadromys* lineage was present by 3 Ma. The third murid from PMNH 8802 represents a species of *Mus* based on cusp

morphology and lack of a posterior cingulum, and is slightly smaller than *Mus auctor* and *Mus* sp. of DP 24.

With reference to murids from localities DP 13 and DP 24 (Jacobs, 1978), 5.7 and 1.6 Ma, respectively, the fauna of PMNH 8802 is consistent with its intermediate age. All three sites contain *Mus*. DP 13 is characterized by the presence of *Parapelomys robertsi* and the last record of *Karnimata*. DP 24 contains *Hadromys* and *Golunda*. The PMNH 8802 site contains a *Hadromys* like form more primitive than *H. loujacobsi*, and also the first record of *Golunda*.

That *Golunda kelleri* is known from localities at 3.0 and 1.6 Ma shows that this species survived the end-Pliocene interval of climatic change that affected much of the globe. It also establishes an earlier Asian record of *Golunda*, consistent with postulated origin of the genus on that continent (Jacobs, 1978).

**Table 10. Measurements (mm) of molars described from localities PMNH 8802 and H-GSP 8929.**

Species	Element	Length	Width
cf. <i>Suncus</i> sp.	M <sub>3</sub>	1.15	0.45
<i>Golunda kelleri</i>	M <sup>1</sup>	2.80	2.05
	M <sub>1</sub>	2.60	1.90
	M <sub>2</sub>	1.95	2.00
	M <sub>3</sub>	ca. 1.70	ca. 1.70
cf. <i>Hadromys</i> sp.	M <sup>1</sup> (2 <sup>nd</sup> chevron)		1.70
<i>Mus</i> sp.	M <sup>1</sup> (2 <sup>nd</sup> chevron)		1.03

## 5.20 LEHRI

### 5.21 INTRODUCTION

The post-Miocene sequence of molasse sediments preserved in the Lehri - Ganda Paik area, eastern Potwar Plateau, Punjab, Pakistan, consists of over 1500 m of fluvial deposits laid down by rivers flowing from the northwestern Himalayas. This set of deposits is usually assigned to the Soan Formation. Structural, paleomagnetic, and paleoenvironmental studies of 12 anticlines between Dina and Jhelum were reported by Reynolds (1980).

The rodent material described here was collected from an isolated outcrop exposed in the drainages of streams feeding Mangla Lake (Figure 16 a). The Lehri fossil locality was given a formal number in the Pakistan Museum of Natural History system: PMNH 93128. The relief near the site is low, so it is not possible to trace lithostratigraphic units on the ground. Air photos show general stratigraphy and Reynolds (1980) mapped the area, overlaying his paleomagnetic analysis of the deposits (Figure 16 b). Consequently, the age of the rocks of the Lehri-Ganda Paik area is tightly constrained. Locality 93128 occurs in a gentle syncline. The syncline occurs on the eastern flank of the Domeli anticline, and falls high in the 1500 m section measured by Reynolds (1980). The section is characterized by alternating sandstones and mudstones. The sandstones are generally representative of the light brown upper Siwalik sandstones. High in the section, there is a gradual facies change to include thin conglomerates composed of reworked upper Siwalik sandstone clasts, and several altered volcanic ash horizons.

Reynolds (1980) reported several vertebrate fossils from the area. E.H. Lindsay (University of Arizona) and J.C. Barry (Harvard University) identified *Equus*, *Hyaena*, and *Canis*, which are Late Pliocene/Pleistocene elements of the Siwalik faunas. Near the top of his section, at the 1375 m level, and just below the Olduvai event, a prolific occurrence of small mammal bone debris was located. This locality, PMNH 93128, is a light brown, fine grained sand, poorly sorted and with mudclasts and pebble zones. Locally it is muddy and includes bone fragments. About 300 kg of sediment collected and screen washed produced 19 murid rodent specimens, including two jaw fragments. These are described below.

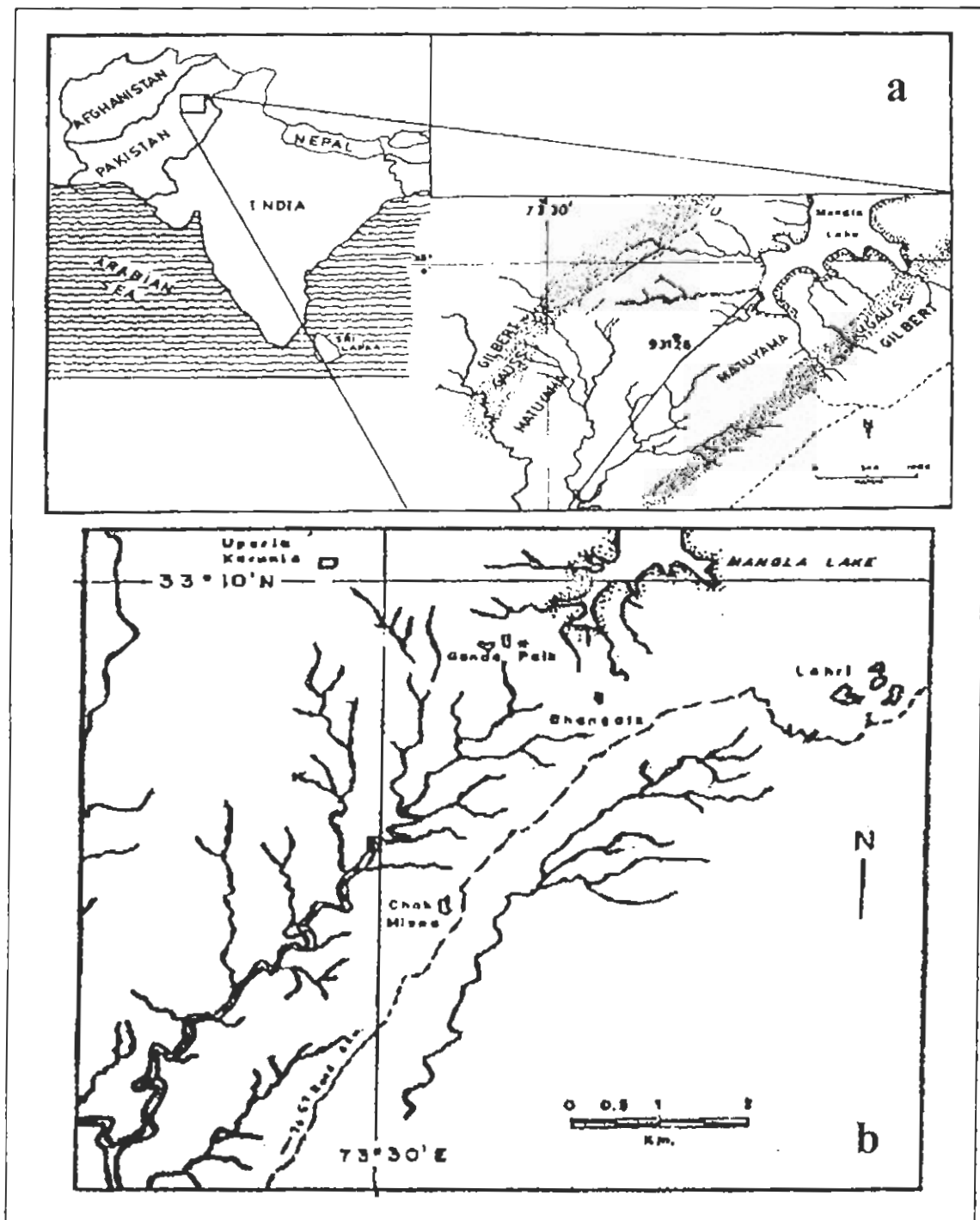


Fig.16. (a) Location Map of the Lehri fossil locality, with plot of the magnetozones in the small, local anticline. Locality 93128 falls high in the lower reversed magnetozones of the Matuyama Chron (modified from Reynolds, 1980)  
 (b) General view of the Mangla Lake area, showing location of Lehri and the village, Ganda Paik.

## 5.22 SYSTEMATIC PALEONTOLOGY

**Order Rodentia Bowdich, 1821**  
**Family Muridae Gray, 1821**  
**Genus Golunda Gray, 1837**  
*Golunda kelleri* Jacobs, 1978  
 (Plate 15, Fig. a-d)

**Referred Material:** L001, left maxilla with molars; L002, left M<sup>3</sup>; L003, left M<sub>1</sub>; L004, right M<sub>3</sub> (Measurements see Table 11)

**Key Reference:** Jacobs, L. L., 1978. Fossil rodentia (Rhizomyidae and Muridae) from Neogene Siwalik deposits, Pakistan. *Mus North Ariz. Pr. Bull.*, 52: 1-103.

**Referred Material occurrence:** PMNH 93128, Ganda Paik.

**Age:** Late Pliocene.

**Description:** The broken maxilla shows the zygomatic plate rising labial to the anterior part of M<sup>1</sup>. Anteromedial to M<sup>1</sup>, the margin of the maxilla is complete, showing no breakage. It preserves the posterior extent of the incisive foramen, demonstrating penetration beyond the anterior limit of the alveolus (condition unlike *G. ellioti*, more like *Malomys*; see Musser, 1987). Medial to the posterior end of M<sup>2</sup> the maxilla is indented, which may represent the location of the suture with the palatine.

The damaged first molar preserves a large, rounded anterostyle (t1), which is close to and somewhat posterior to the larger, rounded lingual anterocone (t2). There are small cusps on the precingulum. Posterior to t1 is a larger enterostyle (t4), which slopes more strongly anteriorly than the other cusps. In this moderately advanced wear stage, t4 posteriorly joins the hypocone (t<sup>8</sup>). There is a strong anteriorly projecting root and two roots lingually.

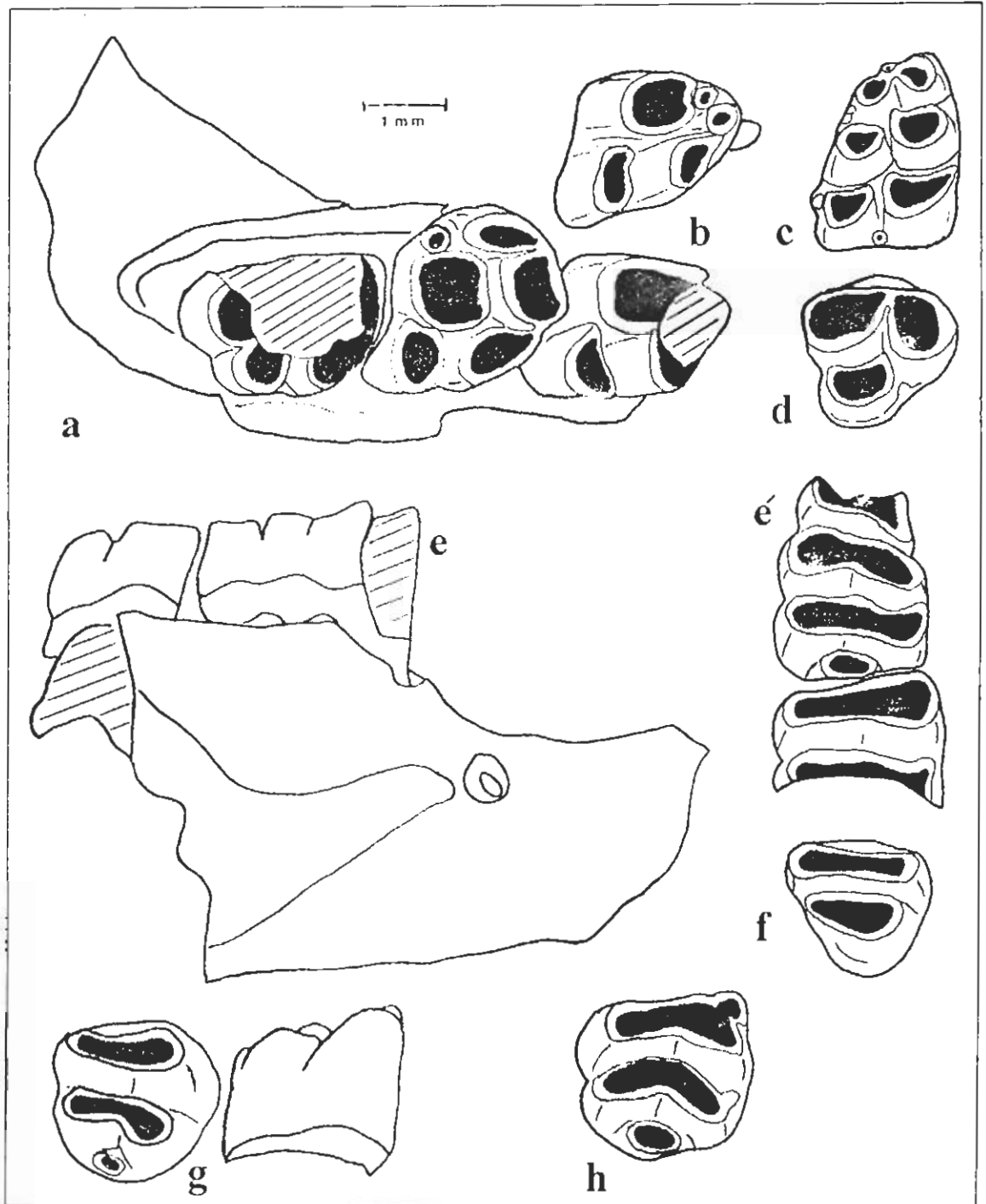


Fig. (a-d) *Golenda Kelleri*, (a) L001 maxilla with molars, (b) L002  $M^3$ , (c) L003  $M_1$ , (d) L004  $M_3$ , Fig. (e-h) *Hadromys loujacobsi*, (e) L005 dentary fragment with broken  $M_{1-2}$ , (f) L009  $M_3$ , (g) L006  $M_2$ , (h) L007  $M_2$ .



M<sup>2</sup> preserves six cusps, the largest being the central protocone and hypocone (t5, t8). The cusps are swollen, and closely positioned at their bases such that with wear they are closely packed. Generally, major cusps are inclined, and posterior cusps crowd into the backs of anterior cusps, lending a lunate appearance. The large anterostyle (t1), although smaller than the protocone, juts anterolingually to t5. The sloping enterostyle (t4) is elongated posteriorly to connect with t8. The labial anterocone (t3) is quite small, vertical and appressed to the labial margin of t5. The larger paracone (t6) is elongated anteroposteriorly and separate from the protocone; its posterior end would join the hypocone in later wear, without suggestion of a metacone (no t9). At least five roots are present.

M<sup>3</sup> is represented by a damaged tooth in the maxilla and an isolated specimen with two anterior roots, a large posteriorly projecting root, and a small posterolingual root. Although smaller than M<sup>2</sup>, it is not reduced to the extent seen in some murines, and is anteroposteriorly elongated as in living *G. ellioti*. There are three major, sloping cusps, t5 (the largest), t1, and t4. There is no indication of t3. Posterior to t5 are two small, round, vertical cusps the postermost of which represents a reduced hypocone (t8). The other small cusp has been homologized with t9 (Musser, 1987; Patnaik, 1997), which is reasonable given the location of this cusp in *Arvicanthis*. However, we maintain that this small cusp could represent t6. In this interpretation, the distorted, elongated but posteriorly pinched structure of M<sup>3</sup> would include a tiny paracone (rather than metacone) shifted posterior to the protocone.

The lower first molar comprises three cusp pairs (lingual and labial anteroconid, protoconid and metaconid, hypoconid and entoconid). The cusps slope posteriorly and increase in size posteriorly. Lingual cusps are larger in size than their labial pairs. The cusps are isolated from each other, but their bases converge. Complementary to upper molars, the anterior cusps impinge on the fronts of posterior cusps, lending a lunate (D-shaped) appearance to posterior cusps. A small medial anteroconid is present, as are C4 at the base of the labial anteroconid and C1 at the base of the hypoconid. The labial cingulum is weak and a posterior cingulum is present as a tiny cusp. Both the medial anteroconid and posterior cingulum show wear. Five roots are present, a small one in the middle of the labial side and the middle of the lingual side.

The  $M_3$  has a triangular occlusal outline and is composed of three cusps. Protoconid and metaconid are connected anteriorly, and the hypoconid is isolated. The hypoconid is posterior to the metaconid, located somewhat labial to the metaconid center, not as far labially as in the specimen from Pabbi Hills (Jacobs, 1978). The apex of the tear-drop hypoconid extends between the anterior cusps; the shape is derived from the lunate cusps of anterior molars. There is a small C1 attached to the labial side of the hypoconid. There is a distinct, low anterior cingulum, and a faint posterior cingulum. The tooth has accessory roots; three major roots exist one below each cusp, and a small root (plus rootlet) lies near the midline at the anterior margin of the tooth.

**Discussion:** The interpretation of cusp homologies is based on reference to the primitive condition as presented by *Antemus* (Jacobs et al., 1989).  $M_3$  of early murids includes a posterior lobe that is clearly a fused hypoconid-entoconid located near the tooth midline. *Golunda kelleri* retains the primitive location of the hypoconid-metaconid complex, and presents a minute cingulum with C1. The latter is not an isolated hypoconid (which Musser, 1987, prefers) but is possibly a neomorph.  $M_3$  assigned to *G. kelleri* up to now demonstrate some variation in location of the posterior lobe, but Jacobs (1978) and Musser (1987) note that *G. ellioti* is derived in lingual shift of the posterior lobe, accommodating a larger C1.

The Lehri material increases the representation of Plio-Pleistocene *Golunda* specimens. The original material described by Jacobs (1978) as *G. kelleri* included only three specimens representing lower dentition. While distinctive, it could not delimit variation for the fossil species. Kotlia (1992) recognized *Golunda* in the 2.4 Ma Karewa Formation, Kashmir Basin. Subsequently, older *Golunda* has been found in Pakistan (Cheema et al. 1997) and material from India has been recognized to represent more than one species. *Golunda* specimens from Jammu region (Gupta and Prasad, 2001) and from the Tatrot Formation (Patnaik, 1997, 2001) have been referred to *G. kelleri*; both samples are presumed to be about 2.5 Ma in age. Older material from Moginand (also Tatrot Formation) was recognized as a distinctive species *G. tatroticus* (Patnaik, 1997).

*G. tatroticus* is primitive in a number of features. Major cusps are not as inclined or lunate as in samples of later age. The anterostyle on  $M^2$  is not as expanded and anteriorly-jutting as in extant

*G. ellioti*. M<sup>3</sup> retains a small labial anterocone (t3) and primitive morphology posteriorly (unelongated, strong t4-5 connection).

The Karewa fragments are like the hypodigm of *G. kelleri* in the weak labial cingulum in evidence on lower molars. Older Indian material reasonably presumed to represent *G. kelleri* suggested that the typical upper dentition of the species showed an M<sup>2</sup> with unexpanded anterostyle, and retained small metacone. Unelongated M<sup>3</sup> showed a small t3 and joined t4-5. Lower molars of older samples often show a stronger labial cingulum than the type material. The mid-Pliocene material of *Golunda* from Mirpur (Cheema et al., 1997) shows strong cingula on M<sub>1</sub>. None of these conditions appear to characterize the Lehri material.

I suggest that the Lehri material better represents the condition for upper molars of Plio-Pleistocene *G. kelleri*. The Lehri material comes from deposits only ca. 300,000 years older and 30 km northwest of the type area of *G. kelleri*. The type locality in Pabbi Hills lies stratigraphically just above the Olduvai event, and is therefore about 1.7 Ma. The Lehri material is stratigraphically just below the Olduvai, and is therefore about 2.0 Ma.

The observed condition for *G. kelleri* from Lehri is a derived taxon with jutting anterostyle, reduced metacone on M<sup>2</sup> and labial anterocone on M<sup>3</sup>, isolated cusps, and reduced labial and posterior cingula on M<sub>1</sub>. The somewhat older material from Mirpur, Jammu and the Tatrot Formation in Himachal Pradesh shows differences possibly due to geological age and perhaps geography. Possibly there is more than one lineage of *Golunda* in evidence in the fossil record, a conservative lineage and precocious *G. kelleri*. It is very important to test these ideas with more fossils, because all of these statements are based on tiny samples.

The Lehri material also tests some of the discussion presented by Musser (1987) concerning *Golunda* and its relatives. Musser (1987) evaluated his restricted arvicanthine group to assess relationships of *Hadromys* and *Golunda*. Jacobs (1978) had proposed that *Golunda* was likely closely related to African *Malomys*, likely more closely than African *Pelomys*. Musser's (1987) comparisons suggested to him that the former genera do not demonstrate relationship to the exclusion of *Pelomys*, rather that probably the African genera are most closely related. The fossil

record may be arguing that the arvicanthine radiation did not follow a simple unrolling of living genera. Indo-pakistani fossils include forms with strong labial cingula in lower molars, as well as weak (as in *Malomys*). The maxillary fossil shows the posterior margin of the incisive foramina reaching beyond the molars, as in *Malomys*. The scenario we favor is that *Golunda* evolution from the African arvicanthine group began upon entry into southern Asia in the early Pliocene, and began with a constellation of arvicanthine traits that evolved divergently in multiple lineages.

**Genus *Hadromys* Thomas, 1911**  
***Hadromys loujacobsi* Musser, 1987**  
 (Plate 15, Fig e-h)

**Referred Material:** L005, right dentary fragment with broken M<sub>1</sub> and partial M<sub>2</sub>; L006, right M<sub>2</sub>; L007, right M<sub>2</sub>; L008, left M<sub>2</sub>; L009, left M<sub>3</sub>; L010, right M<sub>3</sub> (Measurements see Table 11)

**Key Reference:** Musser, G. G., 1987. The occurrence of *Hadromys* (Rodentia; Muridae) in early Pleistocene Siwalik strata in northern Pakistan and its bearing on biogeographic affinities between India and northeastern African murine fauna. *Amer. Mus. Nov.*, 2883: 1-36.

**Referred material occurrence:** PMNH 93128, Ganda Paik.

**Age:** Late Pliocene.

**Description:** The dentary fragment is robust and relatively deep (at least 4 mm preserved below M<sub>1</sub>). It has a strong masseteric crest with upper and lower portions meeting anterior to the root of M<sub>1</sub>. The mental foramen is anterior to this junction and below the dorsal surface of the diastema. The diastema is over 3 mm long.

The M<sub>1</sub> is high crowned and longer than wide, tapering in width anteriorly. Cusps are joined transversely such that three inclined laminae are almost straight, less arcuate than in most murids. There are no longitudinal connections (no hint of the murid "x" pattern in the first to laminae). The first lamina is broken, but includes a posterolabial spur and its back wall slants posterolabially. The second lamina, a confluent protoconid-metaconid angles slightly.

posterolabially and shows the posterior wall to be slightly indented at the midline. The posterior lamina is slightly indented posteriorly, hinting of its hypoconid-entoconid components, is more nearly transverse, and has a short anterolabial spur. The spur could represent C1 in less worn condition. The transverse cusp of the posterior cingulum is well developed. As in *Golunda*, there are five roots in  $M_1$ , including two divergent posterior roots and small roots in the middle of both labial and lingual sides.

$M_2$  consists of two laminae. The anterior wall of the first lamina is transverse, but the posterior margin runs posterolabially oblique. The anterolabial cingulum is variable ( $n=4$ ), from undeveloped (one) to a compressed lobe (two) to a distinct cusp (L006). The anterior lobe is composed of a pinched metaconid and larger protoconid, and its posterior wall is slightly indented. The posterior lamina, strongly indented posteriorly and thus a chevron, is more cusped than any other lamina, and includes a larger hypoconid and pinched entoconid. The base of the hypoconid impinges on the protoconid, such that as the lamina wears an anterolabial spur becomes more pronounced. The abrasion surface of the prominent transverse cusp of the posterior cingulum also becomes larger with wear. There are at least three roots, although the rear root is represented only by a broad base, which may bifurcate distally.

The two  $M_3$  show a tightly folded, transverse anterior lamina composed of compressed protoconid and metaconid, the protoconid being somewhat larger and possibly including a poorly defined, confluent anterolabial cingulum. It is weakly indented posteriorly. The wide posterior lobe is central and relatively unreduced. It is broader in the area of the entoconid. The base of the pinched hypoconid impinges on the protoconid. One of two teeth shows a weak posterior cingulum. Three roots are apparent.

**Discussion:** Musser (1987) named *Hadromys loujacobsi* based on the material described originally by Jacobs (1978) as cf. *Rattus* sp. That material from the Pabbi Hills is early Pleistocene, ca. 1.7 Ma, about 300,000 yrs younger than the material described here, and geographically nearby. We take the Lehri sample to complement knowledge of the species. It adds information on the lower dentition and dentary, heretofore unknown. The association is

made on the basis of comparable large size and great crown height, and of cross laminae developed from chevrons.

Musser (1987) carefully reviewed relationships of both *Golunda* and *Hadromys*, noting their affinity with the "arvicanthine group" of murines. Musser (1987) reserved judgement on how closely *Hadromys* associates with other arvicanthines, but agreed with Jacobs (1978) that at least *Golunda* shows faunal connection with Africa. Musser went on to acknowledge other reputed arvicanthines, particularly the several species of *Saidomys* from the early Pliocene of Afghanistan (Sen, 1983). The question of affinity of Asian and African arvicanthines must apparently be traced to the likely Mio/Pliocene boundary emigration of the group from Africa (as opposed to migration *to* Africa). One or more arvicanthine may be involved in one or more events. Subsequent evolution in Asia is evidenced by the *Golunda* record (above) and by the evolution of the very large, multi-rooted rat *Dilatomys* Sen, 1983.

The Pliocene arvicanthines of Asia need review. The Afghan record (primarily Sen, 1983) reveals interesting, possibly endemic, *Saidomys* evolution. Fossils occurring in the Indian subcontinent should be compared directly with the Afghan material. We noted indeterminate material of *Hadromys* in the earlier Pliocene Mirpur fauna, based mainly on crown height (Cheema et al., 1997). Subsequently, material from the Tatrot Formation near Saketi, Himachal Pradesh, was published (Patnaik, 2001) as *Hadromys*, and fossils from Jammu were referred to *Dilatomys* (Gupta and Prasad, 2001).

Published accounts do not allow comprehensive revision of these taxa, and our comments here are tentative. Patnaik (2001) described "cf. *Hadromys*", flagged in part by its crown height. His typescript (written in the mid-90's) also recognized a different, larger species as *Hadromys moginandensis*, n. sp. Apparently Patnaik (1997) changed the latter to *Dilatomys*. Both Tatrot taxa were considered *Dilatomys* by Gupta and Prasad (2001). We suspect that these are different genera, based on size, crown height and structures of  $M^1$ . Transfer of *H. moginandensis* to *Dilatomys* seems reasonable based on large size ( $M^1$  length, width; 3.77, 2.66), broad chevrons, and strong posterior cingulum. The other taxon is said to be high crowned, and it does share some features with *Hadromys*, but anterior cusps do not make laminae in  $M^1$  as in *Hadromys*

*loujacobsi*. Gupta and Prasad (2001) went on to name *Dilatomys pilgrimi* for their large murine from Jammu. The single  $M^1$  and  $M_1$  are small for *Dilatomys*, and relatively too narrow; the  $M_1$  has a stronger style (C1) and the roots are too few. This species probably is arvicanthine, and seems to be close to *Saidomys afghanensis* (Brandy, 1979).

Arvicanthine diversity is, therefore, evident in southern Asia, but up to now, only *Hadromys loujacobsi* is demonstrated to approach a living form. Musser (1978) noted that *Hadromys* upper molars are characterized by crown height, simple cuspidation yielding laminae, no posterior cingulum, labial coalescence after wear of second and third chevrons, and 4-5 roots in  $M^1$ . Still, there are considerable differences of the fossil species from living *H. humei*. Jacobs (1978) noted that chevrons in  $M^1$  are less approximated in the fossil. Musser (1978) added that the laminae are straighter in the fossil (derived),  $t_6$  is more cusped, and root structure is more primitive.

The Lehri fossil material adds information on the lower dentition (the dentary is comparable to that of *H. humei*). In keeping with the upper molars having straighter crests, lower molars also have suppressed, thinner laminae rather than cusped chevrons. The first two laminae of  $M_1$  are well separated in the fossil and the last lamina, as well as the first of  $M_2$  are only slightly indented posteriorly.  $M_3$  appears shorter, with appressed, thin laminae. The posterior cingulum cusp on  $M_1$  is possibly stronger in the fossil. Oddly, the root structure is more derived than in *H. humei*, which has but three roots in  $M_1$  and  $M_2$  (Musser, 1987).

cf. *Cremnomys* sp.  
(Plate 16, Fig a-e)

**Referred Material:** L011, right maxilla fragment with broken  $M^1$ ; L012, left  $M_2$ ; L013, right  $M_1$ ; L014, right  $M_1$ ; L015, left  $M_3$ ; L016 corroded right  $M^1$  fragment; L017, left  $M^1$  fragment (Measurements see Table 11).

**Referred material occurrence:** PMNH 93128, Ganda Paik.

**Age:** Late Pliocene.

**Description:** The maxilla fragment indicates that the zygomatic plate ascends anterior to  $M^1$ , beginning opposite the anterior root of the tooth. Its incisive foramen penetrates posteriorly past the anterior part of the tooth. It is not clear that the three  $M^1$  all represent the same species. Taken together, however, they indicate a conservative murine dentition with standard chevron development. The anterostyle is large, uncompressed, and not shifted strongly posteriorly. Slightly worn L017 reveals a separate, thin posterior cingulum opposite the small metacone. Five roots are visible on L011.

The worn  $M^3$  is small with respect to  $M^1$ , but has a large anterostyle. The sloping anterior wall has no anterolabial style. The enterostyle is large and posterior, making an asymmetrical chevron with the protocone-paracone. The enterostyle merges with the hypocone in advanced wear, isolating a large posterior enamel lake. This tooth displays three large roots plus a small one below the enterostyle.

$M_1$  has six inclined major cusps, the anterior four uniting in an X-pattern with central union. The "X" is asymmetrical, however, because the labial anteroconid is smaller than the other cusps and retracted relative to them. There is no medial anteroconid, and the labial cingulum is undeveloped, but the labial cusp C1 is evident and shows a wear facet when the posterior chevron is worn down to its level. Entoconid and hypoconid are compressed and join without central mure; their chevron becomes more pronounced with wear. The large posterior cingulum cusp is slightly closer to the hypoconid than the entoconid. In addition to large anterior and posterior roots are two small roots, one each on the labial and lingual sides of  $M_1$ .

$M_2$  has two inclined chevrons and no mure. The large anterolabial style merges with the protoconid in wear. There is a faint, low anterior cingulum, and a prominent, short labial cingulum between protoconid and hypoconid. The posterior cingulum wears to reveal dentine. There are three roots, the largest being the transversely elongated posterior root, and the smallest being under the anterolingual corner.



**Discussion:** I follow Patnaik (2001) in referring these medium-sized Pliocene murines of the Indian subcontinent foothills to the genus *Cremnomys*. However, Musser (1987) remarked that there exists no review and careful diagnosis to differentiate *Millardia* from *Cremnomys* and indeed some researchers have utilized *Millardia* for fossil species (e.g., Sabatier, 1982). Like the arvicanthines, this group of murines shows intriguing affinities between East Africa and the Indian subcontinent.

The Lehri murine shows some of the characters that Gupta and Prasad (2001) recognized as useful. On  $M^1$  its labial anterocone is reduced, its anterostyle is conical and vertical and not shifted posteriorly, and the fragment L017 shows a thin posterior cingulum. On  $M_1$  the labial cingulum is weak and there is no medial anteroconid. As noted above, there is no assurance that all teeth represent one species, but these features are consistent with *Cremnomys* as presently understood. Root structure could be consistent with either genus as presently understood.

**cf. *Mus jacobsi* Kotlia, 1992**  
(Plate 16, Fig f-g)

**Referred Material:** L018, left  $M^2$ ; L019, left  $M_1$  (Measurements see Table 11).

**Key Reference:** Kotlia, B. S., 1992. Pliocene murids (Rodentia, Mammalia) from Kashmir Basin, northwestern India. *Neues Jahrbuch für Geologie und Paläontologie, Abh.* 184: 339-357.

**Referred material occurrence:** PMNH 93128, Ganda Paik.

**Age:** Late Pliocene.

**Description:** These two small specimens are referred tentatively to *Mus jacobsi* based on size. The  $M^2$  has a large anterostyle and small labial anterocone. The asymmetrical chevron is composed of a large anterostyle in posterior position and a small paracone close to the protocone. Posteriorly, the hypocone is large and continuous with a small metacone (t9). There is one large lingual root; others are broken.  $M_1$  has an asymmetrical X-pattern with cusps uniting slightly

labial to the midline of the tooth; the labial anteroconid is smallest. The oblong cusp of the posterior cingulum is well below the level of the posterior chevron. There is no labial cingulum, nor any labial or medial accessory cusp. There are two roots only.

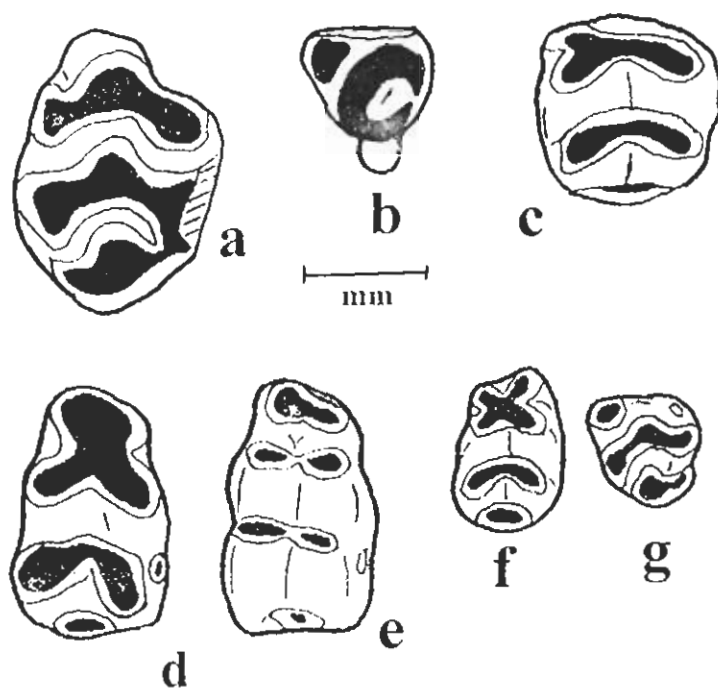


Fig. (a-c) *Cremonomys* sp. (a) L011  $M^1$ , (b) L015  $M^3$ , (c) L012  $M_2$ , (d) L013  $M_1$ , (e) L014  $M_1$ , Fig. (f-g) cf. *Mus Jacobsi* (f) L019  $M_1$ , (g) L018  $M^2$ .

### 5.23 CONCLUSIONS

The Lehri assemblage includes important material that complements knowledge of two large murine taxa of the late Neogene deposits of the Indian Subcontinent. The *Golunda* specimens offer fuller knowledge of the upper dentition and maxilla of *G. kelleri*. In light of these specimens, fossils from India appear to represent more than one lineage and suggest that *Golunda kelleri* was not necessarily ancestral to *G. ellioti*, as suspected by Jacobs (1978) and Musser (1987). The Lehri material also suggests that traits observed in extant arvicanthines (such as depth of the incisive foramen) do not necessarily distribute along generic lines. The incisive foramen of *G. kelleri* is more like that of *Malomys dybowskii* than that of *G. ellioti*. This means only that we do not understand the pattern of the arvicanthine radiation in Asia; likely it was complex.

That radiation may have involved origin of *Hadromys*, although Musser (1987) argues that the case for arvicanthine affinity of the genus is not yet convincing. The Lehri material complements knowledge of the Plio-Pleistocene *Hadromys loujacobsi*. Originally known only from upper dentition, it is now represented by lower molars and a dentary fragment. In some features such as the straight, laminar form of the chevrons, this species is more derived than living *H. humei*. Both share, however, distinctively great crown height, markedly greater than that of comparable murines. For the moment, the species are treated as congeneric; more material could test justification for splitting them.

The composition of the late Pliocene small mammal fauna appears to be consistent across the northern part of the Indian subcontinent. From Mirpur, Lehri, and the Pabbi Hills on the west, through Jammu, and to the Pliocene deposits of Himachal Pradesh, one finds an assemblage dominated by diverse murines. These include, in relatively constant proportion, remains of the large genera *Hadromys* and *Golunda*, at least one member of the *Cremnomys-Millardia* group, and one or more species of the ubiquitous *Mus*. In low abundance, one encounters modern shrews (variously, *Crocidura* or *Suncus*), the occasional bamboo rat related to *Rhizomyides sivalensis* (Lydekker, 1884), the gerbil *Abudhabia* De Bruijn and Whybrow, 1994, and

sometimes leporids (e.g. *Pliosiwalagus* Patnaik, 2001). Our knowledge of these assemblages is limited of course by small sample size. Larger samples reveal the presence of other murines, for example *Dilatomys* and *Bandicota* recognized by Patnaik (1997). Still, no squirrels or porcupines are yet recorded from these Pliocene sites, but we expect these (and possibly also dormice) to emerge as more assemblages are described.

Kotlia (1992) has demonstrated that arvicolines occur during the late Pliocene, but these are found at higher elevations. The modern fauna (e.g. Roberts, 1977) also records dipodoids (jerboas and relatives), hamsters, and diverse gerbils. Possibly these are later Pleistocene arrivals reflecting increasingly open habitat.

Musser (1987) noted the different habitats preferred by living *Hadromys* and *Golunda*. Whereas *Hadromys* today occurs at moderate elevations in monsoonal habitat, *Golunda* is characteristic of more open to rocky terrain with thorn scrub and grass. Interestingly, the Pabbi Hills co-occurrence of the genera is repeated at Mirpur, Lehri, and apparently in northern India. Possibly local habitat was highly varied across the Indian subcontinent, offering both open terrain and patchy, dense growth, or the preferences of extinct species varied from those of modern relatives. This simply demonstrates change in climate patterns and/or species preferences, both topics that can be constrained and better understood by continued field research.

**Table 11.** Measurements of murid molars from Lehri, PMNII 93128 (in mm). Measurements of damaged specimens are approximate (approx) or indicated by "+", meaning that the undamaged specimen would be somewhat larger than the figure given).

Taxon	Catalogue No.	Element	Length	Width
<i>Golunda kelleri</i>	L001 (maxilla)	M <sup>1</sup>	2.7	2.0+
		M <sup>2</sup>	2.3	2.4
		M <sup>3</sup>	2.3	1.8
	L002	M <sup>3</sup>	2.1	2.0
	L003	M <sub>1</sub>	2.5	1.8
	L004	M <sub>3</sub>	1.9	1.8
<i>Hadromys loujacobsi</i>	L005 (dentary)	M <sub>1</sub>	2.8 (approx)	1.9

		M <sub>2</sub>	--	2.2 (approx)
	L006	M <sub>2</sub>	2.1	2.1
	L007	M <sub>2</sub>	2.0	2.0
	L008	M <sup>1</sup>	2.1	2.1
	L009	M <sub>3</sub>	1.7	1.9
	L010	M <sub>3</sub>	1.8	1.8 (approx)
<i>Cremonomys</i> sp.	L011	M <sup>1</sup>	2.6	1.8
	L012	M <sub>2</sub>	1.7	1.6
	L013	M <sub>1</sub>	2.4	1.3
	L014	M <sub>1</sub>	2.4	1.3
	L015	M <sup>3</sup>	1.0	1.0
	L016	M <sup>1</sup>	1.7+	1.2+
	L017	M <sup>1</sup> (fragment)		
<i>cf. Mus jacobsi</i>	L018	M <sup>2</sup>	0.9	1.0
	L019	M <sub>1</sub>	1.4	0.9

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## CHAPTER-6. FAUNAL DIVERSITY IN MUROIDS DURING MIOCENE

A major strength of the Siwalik fossil record is the superb temporal control provided by magnetic polarity stratigraphy. The integration of systematic paleontology with well-constrained temporal control provides a unique insight into the evolutionary and dispersal pattern of some of the more common vertebrate groups found in the Siwalik rocks. Rodents are one of those groups, which have been extensively studied in the last two decades. The extensive studies of Jacobs (1978), Flynn (1982) and Lindsay (1988) have established broad evolutionary and migration patterns of murids, rhizomyidae and cricetids in the South Asia during the Neogene times.

### 6.1 EVOLUTION PATTERN IN THE MUROIDS

The base of terrestrial Miocene sequence in Potwar Plateau, Pakistan is older than 18.3 Ma. and the top is less than 0.6 Ma (Early Miocene through Pleistocene). In this nearly 19 million years interval muroid rodents are very common fossil. Muroids comprise five groups (1) *Copemyines* (or *Democricetodon*), (2) *Megacricetodon*, (3) *Myocricetodon*, (4) *Potwarmus* and other *Dendromurine*, and (5) Murids. However, the first four groups have been collectively referred to as "Cricetids" (Fig. 17).

### 6.2 DIVERSITY IN CRICETIDS IN SOUTH ASIA

The Miocene is certainly the acme of Cricetids in Asia. Lindsay (1994) divided the 19 million years long Miocene interval into five divisions, to better show diversity, sequence of appearances and faunal turnover (Table 12). Chronologic resolution for these divisions is based primarily on the Siwalik sequence of the Potwar Plateau, where the sites are correlated by magnetostratigraphy. The five divisions are as follows:

**I. Early Miocene** (24-22 Ma) records the appearance of *Primus*, *Spanocricetodon* and *Prokanisamys* along with *Eucricetodon* from Chitarwata and Murree Formations. Both *Primus* and *Eucricetodon* are primitives.

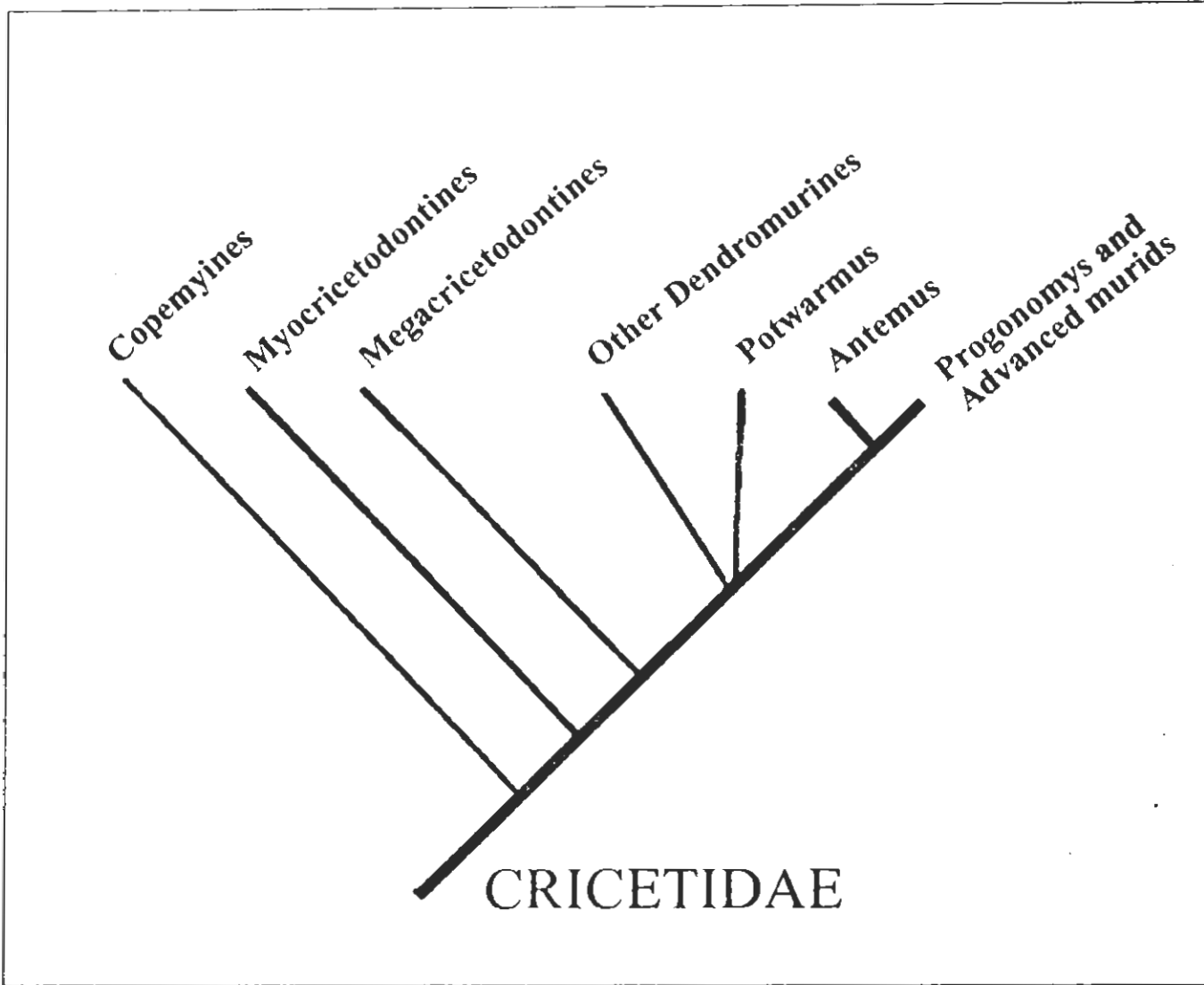


Fig. 17. Postulated phylogenetic relationship of Muroid rodents. Dendromurines include *Potwarmus*, Murids include *Antemus* (after Barry et al., 1991).



Table 12. Siwalik cricetid record in Miocene of Pakistan (modified after Lindsay, 1994).

**EARLY MIOCENE (24 – 22 Ma)**

**Upper Chitarwata Formation, Zinda Pir Dome**

*Eurericetodon* sp.

*Primus* sp.

*Spanocricetodon* sp.

**Murree Formation, Banda Daud Shah**

*Spanocricetodon khani*

*Spanocricetodon lii*

*Primus microps*

*Prokanisamys arifi*

**EARLY MIDDLE MIOCENE (22 – 18 Ma)**

**Lower Vihowa Formation, Zinda Pir Dome**

*Spanocricetodon* sp.

*Democricetodon* sp.

*Myocricetodon* sp.

**Manchar Formation, Sehwan-Gaj River**

*Spanocricetodon lii*

*Democricetodon* cf. *franconicus*

*Myocricetodont* gen. 1

*Myocricetodont* gen. 2

*Prokanisamys arifi*

**MIDDLE MIOCENE (18 – 14 Ma)**

**Kamlial Formation, Potwar Plateau**

*Democricetodon* sp. A.

*Democricetodon* sp. B-C

*Democricetodon kohatensis*

*Democricetodon* sp. E

*Megacricetodon aguilari*

*Megacricetodon mythikos*

*Megacricetodon downsi*

*Punjabemys mikros*

*Myocricetodon sivalensis*

*Myocricetodon* sp.

*Dakkamyoides lavacoti*

*Potwarmus primitivus*

#### **Manchar Formation, Sehwan-Gaj River**

*Democricetodon* cf. *franconicus*

*Democricetodon* aff. *kohatensis*

*Myocricetodon* cf. *parvus*

? *Potwarmus* sp.

*Antemus chinjiensis*

*Prokanisamys arifi*

#### **LATE MIDDLE MIOCENE (14 – 10 Ma)**

##### **Chinji Formation, Potwar Plateau**

*Democricetodon* spp. B-C

*Democricetodon kohatensis*

*Democricetodon* sp. E

*Democricetodon* sp. F

*Democricetodon* sp. G

*Democricetodon* sp. H

*Megacricetodon aguilari*

*Megacricetodon daamsi*

*Megacricetodon mythikos*

*Punjabemys downsi*

*Punjabemys mikros*

*Myocricetodon sivalensis*

*Dakkamyoides lavacoti*

*Dakkamyoides perplexus*

*Dakkamys baaryi*

*Dakkamys asiaticus*

*Paradakkamys chinjiensis*

*Antemus chinjiensis*

**Manchar Formation, Schwan-Gaj River**

*Democricetodon kohatensis*

*Myocricetodon* gen. 1

*Myocricetodon* gen. 2

*Potwarmus* sp. *primitivus*

*Dakkamys* ? sp.

*Antemus chinjiensis*

**Nagri Formation, Daud Khel**

*Democricetodon* sp.

*Myocricetodon*.

*Antemus* cf. *chinjiensis*

**Middle Siwalik (Nagri and Dhok Pathan Formation), Potwar Plateau**

*Democricetodon* spp. B-C

*Democricetodon kohatensis*

*Democricetodon* sp. E

*Democricetodon* sp. F

*Democricetodon* spp. H

*Dakkamys asiaticus*

*Paradakkamys chinjiensis*

**II. Early Middle Miocene (22-18 Ma).** *Megaericetodon*, *Democricetodon*, and *Myocricetodon* appear in southern Asia from lower Vihowa Formation (Zinda Pir Dome) and Manchar Formation (Schwan-Gaj River). This interval also includes the last appearance of *Primus* and *Spanocricetodon*.

**III. Middle Miocene:** The Siwalik rodent record begins at 18.3 Ma, which also approximates the Middle Miocene interval (18-14 Ma). The Siwalik Kamliak Formation record includes 4 species of *Democricetodon*, 2 species of *Megaericetodon*, 2 species of *Punjabemys*, 3 species of

*Dendromurine*. *Potwarmus primitivus* gave rise to the murids in the Middle Miocene, the 14-10 Ma interval. *Punjabemys*, *Dakkamyoides* and *Antemus* also appear in southern Asia during the same interval.

**IV: Late Middle Miocene:** In (14-10 Ma) interval 6 species of *Democricetodon*, 4 species of *Megacricetodon*, 2 species of *Punjabemys*, 2 genera of *Myocricetodon* and 3 species of *Dakkamyoides* are widely distributed in Siwaliks. In this time *Dakkamys*, *Paradakkamys* and *Protatera* appear in southern Asia.

Cricetids are poorly represented from Siwaliks during the early Pliocene, also probably the result of increasing competition with murid rodent in southern Asia.

### 6.3 DIVERSITY IN MURIDS

The most primitive murine species known is *Antemus chinjiensis*, whose oldest certain record is 13.75 Ma. This is based on a monophyletic definition of murids as having two lingual cusps associated with the anterior two chevrons on the upper first molars (Jacobs, 1977).

*Antemus chinjiensis* persists for 1.3 Million years than a similar anagenetic pattern occurs at the transition from *Antemus* to *Progonomys*, the genus that first exhibits an essentially modern grade of murine dental morphology. The youngest *Antemus* (12.5 Ma) is separated from the oldest *Progonomys* (11.8 Ma). This transformation took no more than 700,000 years (Fig. 18).

*Progonomys* is first clearly present in the Potwar Plateau at locality Y-634 at 11.6 Ma age. The last record of *Antemus* and first record of *Progonomys* are close temporally. Based on these Siwalik record, *Progonomys* is very likely to have evolved in South Asia, probably at ca 11.8 Ma. However, the first definite *Progonomys* species, the *Progonomys hussaini* comes about 11 Ma old locality JAL-10 in Jalalpur area. It is primitive in low crown height without strong inclination of cusps, in weak cusp connections and in the broad posterior lobe of lower third molar, which may indicate homology with entoconid.

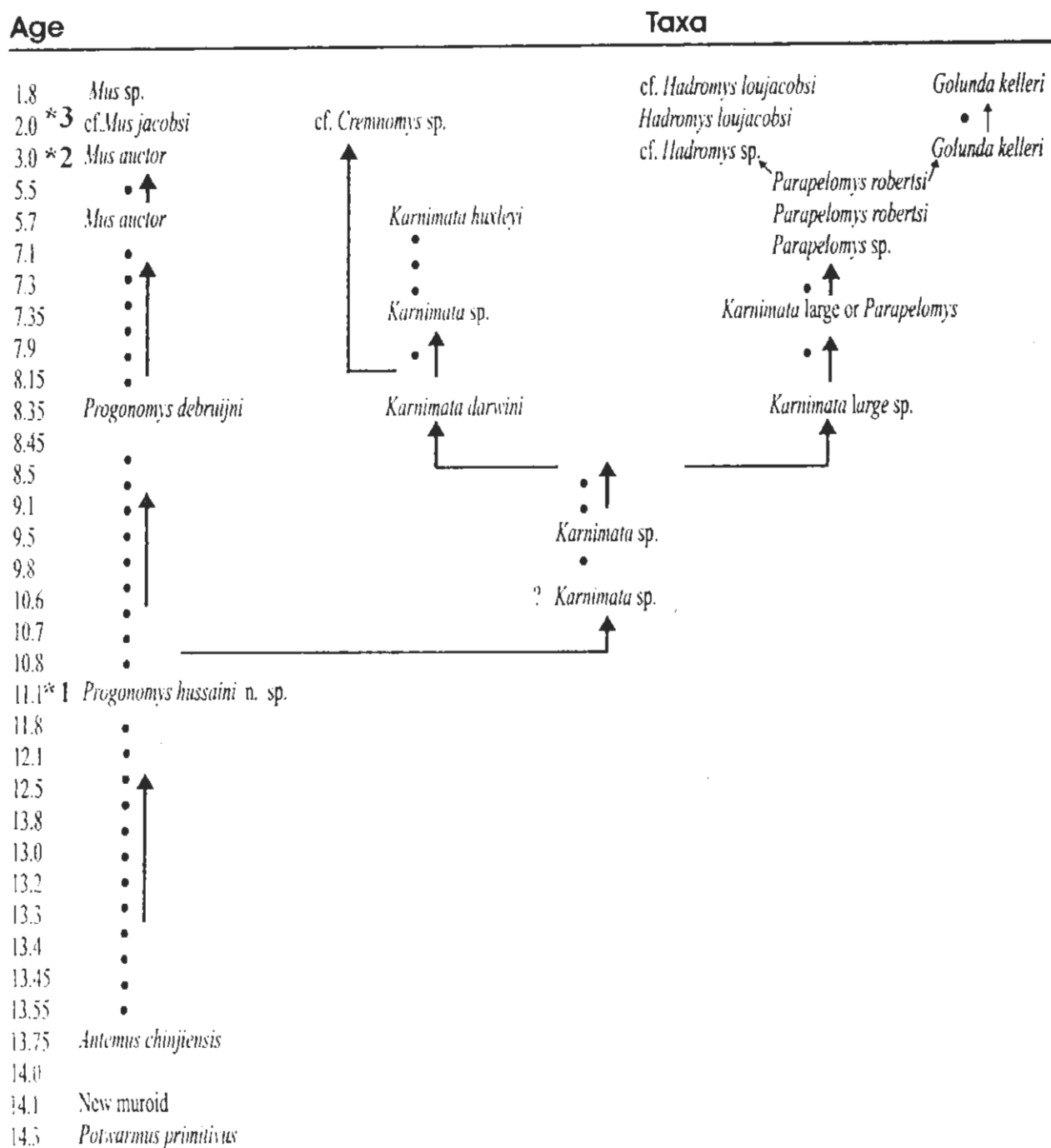


Fig.18. Distribution of Siwalik murie taxa and localities through time. Arrows show hypothesized evolutionary lineages. Dots signify a taxon present at the locality that is similar to the preceding sample (Adapted from Jacobs and Downs 1994).

\* 1 = Jalalpur area \* 2 = Mirpur area \* 3 = Lehri area

The last record of Siwalik *Progonomys* is *P. debruijii* at 7 Ma. The evolution of *Mus* from *Progonomys* probably is documented in the Siwalik rocks of the Potwar Plateau. It perhaps evolved from *Progonomys* by 5.7 Ma in an anagenetic transition that took no more than 600,000 years.

*Progonomys debruijii* and *Karnimata darwini* were first described from a locality dated 8.35 Ma. Two morphologically similar taxa can also be recognized in two older sites dated as 9.1 and ca 9.5 Ma, respectively. A similar cladogenetic pattern of *Parapelomys* from *Karnimata* between 8.45 and 8.6 Ma has also been recorded. During the interval in which *Parapelomys* evolved, the size range of Siwalik murine increased.

Faunal turnover can also be investigated using biostratigraphic ranges to determine number of appearance and extinction over specified intervals. In this study, published updated information on the number of species of muroid rodents has been used as well as new data on their relative abundance.

Faunal turnovers in Siwaliks resulted from local extinction, immigration, anagenetic evolution and cladogenetic speciation. The last two are referred to as *in situ* speciation. Immigrants are species or lineages that dispersed from other geographic regions during periods of biotic interchange. By contrast, *in situ* speciation, whether anagenetic or cladogenetic, takes place within the province. When close related ancestral species are known from older horizons within the province, a species is presumed to have arisen through *in situ* speciation.

#### 6.4 MUROID DIVERSITY

The number of species Table 13 is shown in Fig. 19, where the most important features is the contrast between then low diversity and the larger more variable numbers in the cricetid subfamilies. Muroid diversity peaks at 13 Ma with 18 species and subsequently falls into steps as first *Megaericetodon* and *Myocricetodon* and then *Dendromurine* and *Copemyine* decline. During the period of higher diversity, the changes are largely due to the *Megaericetodon* and *Dendromurine*, which rise from 4 to 9 species between 16 and 13 Ma. After 9 Ma, species diversity does not exceed seven species and murids are more dominant than cricetids by this

time, both in diversity and abundance. Table 13 gives the composition of Cricetid subfamilies at different time intervals in the Miocene mollasic sequence from different key areas in Pakistan.

**Table 13.** Number of Muroid species (sp) and number of individual (Ind), based on the total number of molars. There are no sites with rodents in the 9.5, 11.5, 15.0 and 17.5 Ma levels. P., present; T. sp., total species and T. ind., total individuals (after Barry et al., 1991).

Interval	Copemyines		Myocricetodontines		Megacricetodontines		Dendromurines		Murids		T. sp.	T. ind.
	Sp	ind	sp	ind	sp	ind	sp	ind	sp	ind		
7.0	0	0	0	0	0	0	0	0	4	80	4	80
7.5	0	0	0	0	0	0	0	0	3	295	3	295
8.0	3	43	0	0	0	0	0	0	4	212	7	212
8.5	0	0	0	0	0	0	0	0	4	298	4	298
9.0	1	7	0	0	0	0	0	0	2	123	3	123
9.5	-	-	-	-	-	-	-	-	-	-	-	-
10.0	6	98	0	0	0	0	3	9	2	395	11	502
10.5	6	7	1	3	0	0	3	4	2	41	12	55
11.0	6	40	1	2	1	4	3	18	2	223	13	287
11.5	-	-	-	-	-	-	-	-	1	57	1	57
12.0	5	51	1	12	1	5	2	8	1	137	10	213
12.5	?	22	?	1	?	41	?	12	1	11	?	87
13.0	6	263	2	64	6	267	3	170	1	69	18	883
13.5	6	155	2	21	7	219	2	11	1	289	18	695
14.0	5	42	1	40	6	215	2	40	1	33	15	370
14.5	5	97	1	23	5	131	2	210	0	0	13	461
15.0	-	-	-	-	-	-	-	-	-	-	-	-
15.5	5	14	1?	3	5	24	2	11	0	0	13	52
16.0	5	9	2?	6	3	5	1	1	0	0	11	21
16.5	5	23	2	34	3	27	1	4	0	0	11	99
17.0	?	3	?	1	?	P	?	1	0	0	?	5
17.5	-	-	-	-	-	-	-	-	-	-	-	-
18.0	?	18	?	5	?	6	?	1	0	0	?	30

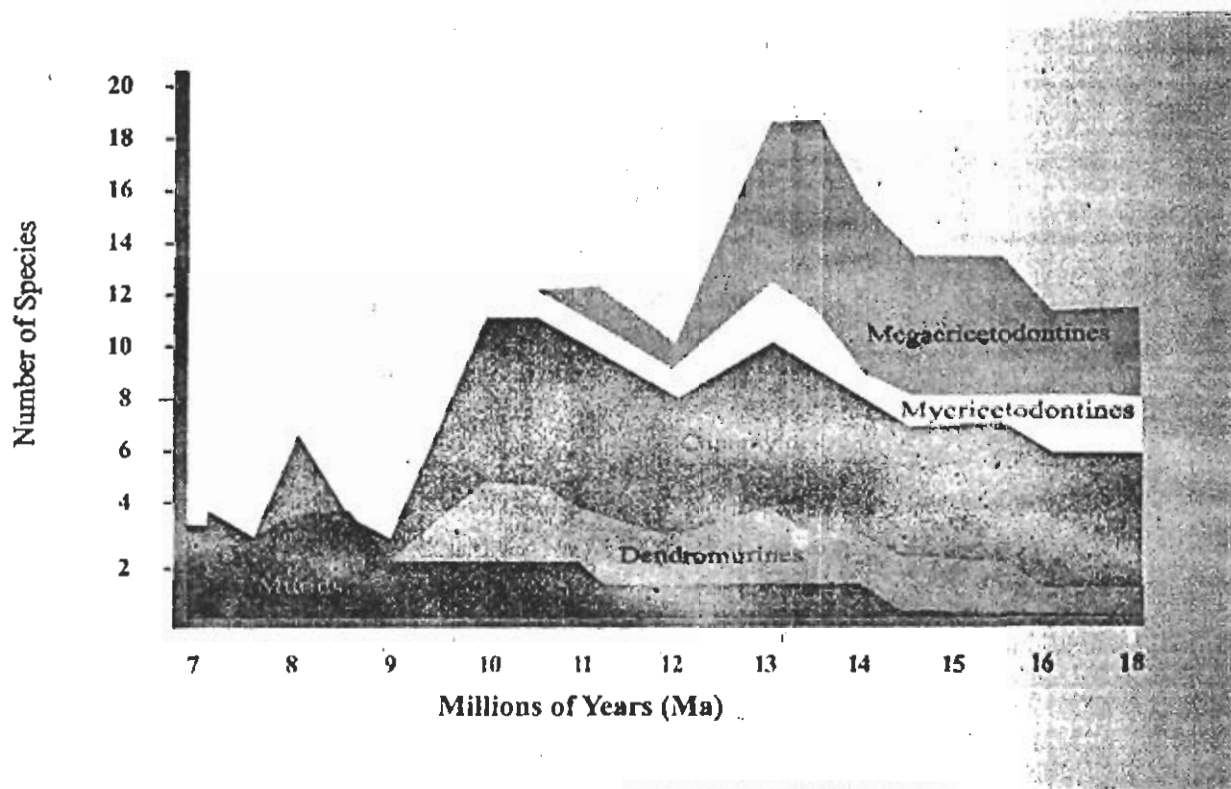


Fig. 19. Number of Species of Muroids rodents found or inferred to be present in each 0.5 m.y interval (after Barry et al., 1991)



## 6.5 RELATIVE ABUNDANCE OF MUROIDS

The relative abundance of the muroids is computed from the number of molars in each interval. Table 13 is shown in Fig. 20. The important feature of Fig. 20 is the abrupt jump in the relative abundance of muroids at 12 Ma, followed by a steady rise until they comprise 80-100% of the assemblages. Among the cricetids, the Copemyines and Myocricetodon are most abundant in the oldest levels but first decline abruptly between 16 and 15.5 Ma and then more gradually until the late Miocene. The Myocricetodon in particular becomes a very minor group. The Dendromurine and Megacricetodon are most abundant between 15.5 and 12.5 Ma and then decline very rapidly. It is also noted that the abundance of muroids appears inversely correlated to that of their sister group Dendromurine, and both together are inversely correlated to the more distantly related Megacricetodon.

## 6.5 SPECIES ORIGIN

To understand how diversity and abundance trends are related to biotic interchange, it is first necessary to decide which species were immigrants and which evolved *in situ*, the status of each species is indicated in Table 14.

**Table 14.** Ages of first and last appearances of muroid rodents in the Siwalik formations of Potwar Plateau, Pakistan. Is, *in situ*; Im, immigrant; >, appears before. The ranges of the muroids are from Lindsay (1988) and Jacobs et al. (1990). (after Lindsay et al., 1991).

Family/species	First appearance (Ma)	Last appearance (Ma)	Duration (m. y. a)	Status
Copemyinae				
<i>Democricetodon kohatensis</i>	> 16.3	9.8	6.5	-
<i>Democricetodon</i> , sp. A	> 16.3	13.2	3.1	-
<i>Democricetodon</i> , sp. B	> 16.3	9.2	7.1	-
<i>Democricetodon</i> , sp. C	> 16.3	9.8	6.5	-
<i>Democricetodon</i> , sp. E	> 16.3	9.8	6.5	-
<i>Democricetodon</i> , sp. E?	7.9	7.8	0.1	Im
<i>Democricetodon</i> , sp. F	12.0	9.8	2.2	Is
<i>Democricetodon</i> , sp. F?	7.9	7.8	0.1	Im
<i>Democricetodon</i> , sp. G	11.1	9.8	1.3	Im
<i>Democricetodon</i> , sp. G?	7.9	7.8	0.1	Im
<i>Democricetodon</i> , sp. H	13.7	13.2	0.5	Is

## Megaericetodontinae

<i>Megaericetodon aguilari</i>	> 16.3	13.6	2.7	-
<i>Megaericetodon sivalensis</i>	13.7	13.2	0.5	Im
<i>Megaericetodon daamsi</i>	15.3	10.8	4.5	Im
<i>Megaericetodon nythikos</i>	> 16.3	13.2	3.1	-
<i>Punjabemys downsi</i>	14.1	13.2	0.9	Is
<i>Punjabemys leptos</i>	15.3	13.2	2.1	Is
<i>Punjabemys micros</i>	> 16.3	13.2	3.1	-

## Myoericetodontinae

<i>Myoericetodon sivalensis</i>	> 16.3	? 15.3	1.0	-
? <i>Myoericetodon</i> , indet.	16.3	? 10.6	5.7	-
<i>Dakkamyoides lavocati</i>	13.7	13.5	0.2	Im ?
<i>Dakkamyoides perplexus</i>	13.7	12.8	0.9	Im ?

## Dendromurinae

<i>Dakkamys asiaticus</i>	11.1	9.8	1.3	Im
<i>Dakkamys barryi</i>	13.7	12.8	0.9	Im
<i>Dakkamys</i> , small sp.	12.8	9.8	3.0	Im
<i>Paradakkamys chinjiensis</i>	13.7	9.8	3.9	Is ?
<i>Potwarmus primitivus</i>	> 16.3	14.0	2.3	-
<i>Potwarmus minimus</i>	15.3	14.0	1.3	Im

## Muridae

<i>Antemus chinjiensis</i>	14.1	12.5	2.1	Is
<i>Progonomys</i> , spp.	12.0	7.1	4.8	Is
<i>Karnimata</i> , small spp.	10.6?	8.2	2.4	Is
<i>Karnimata</i> , large sp.	8.4	7.1	1.3	Is
<i>Parapodemus</i> , sp.	8.4	7.1	1.3	Im
cf. <i>Parapelomys</i> , sp.	7.1	-	-	Is

I interpret the appearance and most of the subsequent evolution of the murids as *in situ* speciation. In all, murids had five or more *in situ* speciation events and in the late Miocene, one immigration that is *Parapodemus*. The status of *Potwarmus primitivus* is uncertain, but the later appearing *Potwarmus minimus* is more primitive and consider it an immigrant. The remaining *Dendromurine*, *Dakkamys* and *Paradakkamys* are most similar species in Turkey. It is assumed that the two lineages were immigrant. Subsequently there may have been an additional immigration and one *in situ* speciation within *Dakkamys*. The *Myoericetodon* also have *in situ* and immigrant species, with two immigration events and one *in situ* speciation. Early Siwalik *Megaericetodon* share many similarities with species in Europe and China, suggesting they are mostly immigrant taxa and four species appear after 16 Ma, two of *Punjabemys* that may have

evolved *in situ* and two *Megacricetodon* that are more likely to be immigrants. Finally, the *Copemyine* have not yet been analyzed in detail but appear to be a complex of long ranging species having three *in situ* speciations. The reappearance of 3 species at 8 Ma after their apparent extinction is most likely due to immigration.

## 6.7 MECHANISMS AND CAUSES OF BIODIVERSITY

The above discussion has clearly indicated the tempo and mode of taxonomic diversity, relative abundance and speciation events of muroids during Miocene in the Potwar Plateau. This also reflects a general pattern prevailing in other parts of South Asia during the Miocene, where from not so complete rodent record is available. In this context these are the following three principal concerns.

1. How diversity relates to the changes in the ecological structures of the fossil assemblages?
2. How diversity is related to immigration?
3. How diversity is related to speciation?

### 1. Diversity and Ecological structure

Two major revolutions transform Siwalik assemblages during Miocene. (a) The middle Miocene (14-18 Ma) radiation of ericetids and murids. (b) The late Miocene (10-14 Ma) domination of rodent assemblages by murids. It is therefore, expected that change in relative abundance should accompany change in diversity. This expectation is met by the *Megacricetodon* and *Dendromurine*, whose abundance tracks diversity. However, there are exception such as at 14 Ma murid has shown significant increase in abundance without apparent change in diversity. *Copemyine*, *Myocricetodon* exhibits the same pattern to a lesser extent, at times decreasing in abundance but not diversity.

### 2. Diversity and Immigration

The first question is whether the observed diversity increase was principally due to *in situ* speciation or immigration. For all time interval, the ratio between *in situ* speciation and immigration event is 11:12 indicating both process were of equal importance overall.

The conclusion is that taxa increase in diversity by means of immigration, not *in situ* radiation. This principle is best illustrated by *Dendromurine* and *Megacricetodon*. Murids are an exception, although their diversification came long after their initial appearance.

### 3. Diversity and Speciation

Between 15.5 and 7 Ma there were 11 *in situ* speciation events, an average of 1.5 event per 0.5 million years interval. In the five intervals of increasing diversity encompassing 15.5 to 13.5 Ma, there are 3 *in situ* speciation events. It is concluded that, the rate of speciation did not increase with rising diversity.

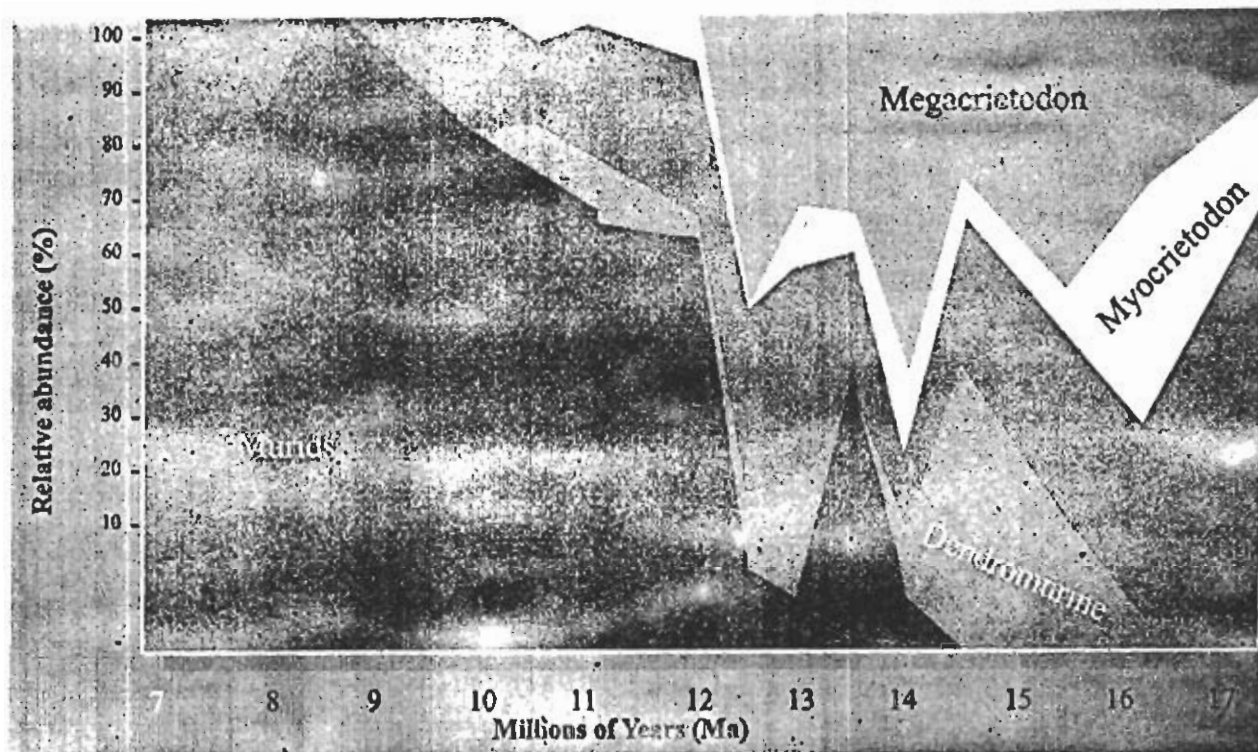


Fig. 20 Relative abundance of muroid rodents (after Barry et al., 1991).

## 6.8 CONCLUSION

Changes in the number of species and relative abundance for muroid rodent in a Siwalik sequence are documented. Between 18 and 7 Ma the diversity of Muroid varied considerably. The most important changes include an abrupt rise in the diversity of Megacricetodon between 15 and 13 Ma, and a decline in cricetid diversity in two steps after 13 and 10 Ma. Among muroid an abrupt increase in relative abundance of murids and decrease of Megacricetodon at 12 Ma is very striking. Decreases in the relative abundance of Myocricetodon and Copemyine after 16 Ma and an increase for Dendromurine at 15.5 Ma are also noteworthy.

It is concluded that the rapid increase in diversity documented in Siwalik was largely due to immigration of lineages; *in situ* speciation had only a secondary role. The temporal patterns of speciation event suggest intervals of increasing diversity the rate of *in situ* speciation with resident lineage was unchanged. It is evident that greater extinction did not accompany increasing diversity. Finally, changes in diversity are not necessarily linked to changes in other aspects of ecological structure.

## CHAPTER-7. SYNTHESIS

The purpose of this research work is to understand the origin and early evolution of murine rodents in South Asia with special emphasis on Siwalik rodents from Pakistan and Azad Kashmir. Also discussed briefly is the implications of that history for biogeography and diversity within the Rodentia group.

Murine rodents are myomorph rodents with three cheek teeth, like cricetines and most other muroids. They are a monophyletic group based on an easily observed derived dental pattern of three transverse chevrons of cusps in the upper first molar. The anterior two chevrons have three cusps aligned across the tooth while the posterior chevron (primitively) has only two cusps (Jacobs et al. 1989).

A phylogenetic systematic framework for all murines does not exist, yet murines are the most diverse monophyletic group of mammals living today. Their diversity is roughly estimated to comprise some 500 extant species in 120 genera including the genera *Mus* and *Rattus*. The fossil record of the subfamily Murinae is rich but it is composed predominantly of isolated teeth, rather than skulls or skeletons. In fact, the subfamily is defined primarily on the morphology of cheek teeth.

Murine are widely distributed in the Old World, but they are not native to the western hemisphere. Neogene fossils of the subfamily are known from Europe, Africa and Asia. By far the best historical record of their evolution is from the Siwalik Group rocks in the Potwar Plateau, northern Pakistan. So far the Siwalik record appears to document (1) the origin of murines in southern Asia at about 13.75 Ma; (2) the attainment of an essentially modern grade of dental morphology by 11.8 Ma; and (3) the first record of the modern genus *Mus* by 5.7 Ma (Jacobs, 1977; Jacobs and Downs, 1994).

Based on the distribution through time in the Siwalik fossil sequence of morphological features in murine dentitions, Jacobs (1978) proposed two fundamental lineages that diverge after the origin of the family. Figure 21 shows the distribution through time of all Siwalik localities with

murine rodents. While the lineages proposed by Jacobs (1978) and Jacobs and Downs (1994) still appear realistic and also that the stratigraphic gaps in the fossil record among the type localities of Siwalik murines have largely been filled, yet the recent discoveries of fossil murids described here from the Siwaliks of the Potwar Plateau and Mirpur (Azad Kahsmir) allow significant modification in the formal taxonomic units.

The most primitive and most ancient species known is *Antemus chinjiensis*, whose oldest record is 13.75 Ma from the stratotype Chinji Formation in southern Potwar Plateau (Jacobs, 1977, Jacobs and Downs, 1994). A similar type of murid was described by Wessels et al. (1982) from H-GSP 10 in the basal Chinji Formation near Banda Daud Shah, about 30 km south west of Kohat. They assigned this taxon to *Antemus*, and considered it the most primitive murid known, but closely related to *Antemus chinjiensis*. Subsequently, additional fossils have been collected from Siwalik deposits near Chinji village which forced re-evaluation of the genus and especially of *Antemus primitivus*. Based on a larger fossil sample Jacobs et al. (1989) removed, *A. primitivus* from the genus *Antemus* (and the Muridae) because it lacks three cusps on the anterior chevron (or equivalent structure) of  $M^1$ . The lingual cusp on  $M^1$  of *A. primitivus* (*sensu* Wessels et al., 1982) is connected to the anterior cingulum in some specimens; however, this cusp must be the enterostyle (equivalent to  $t_3$ ) because it is always located between the protocone and hypocone. This taxonomic re-assignment erected a new taxon, *Potwarmus*, for *A. primitivus*, which Lindsay (1988) placed in the Dendromurinae of the Cricetidae, a subfamily whose members are characterized by having a bilobed anterocone single lingual cusp (enterostyle) on the  $M^1$ .

Another species from Southeast Asia (*Antemus thailandicus*) has been assigned to *Antemus* (Jaeger et al. 1985, Mein and Ginsburg, 1985). *A. thailandicus* is clearly closely related to *A. primitivus* and is transferred to *Potwarmus* for the same reasons. *A. thailandicus* was considered more primitive than *A. primitivus* by Jaeger et al. (1985) and by Mein and Ginsburg (1985). All of the researchers who have studied these rodents agree that *Potwarmus primitivus* is probably ancestral to *Antemus chinjiensis*, the most primitive member of the Muridae.

Intervening sample (14.1 and 14.0 Ma) with reduced longitudinal crests involve a transitional phase from *Potwarmus* (14.3 Ma) to *Antemus* (13.75 Ma). The transition from *Potwarmus* to



*Antemus* took no more than 550,000 years. Jacobs et al. (1994) have reviewed the status of *A. chinjiensis* and have brought forward many hitherto unknown dental variations in cusps and style morphology as well as size ranges. The key characters present in *A. chinjiensis* (and defining the family Muridae *sensu* Jacobs et al., 1994) are the presence of two lingual cusps  $t_1$  and  $t_4$ , with  $t_1$  joined  $t_2$  by a low ridge. The isolation of  $t_4$ , which is characteristic for *A. chinjiensis*, is regarded as primitive for the family Muridae. Development of other features such as the separation of  $t_5$  from  $t_8$  and  $t_6$  from  $t_9$  or their connection through longitudinal swellings, are of secondary importance. Following this definition, neither *Antemus primitivus* (Wessels et al. 1982) nor *Antemus* sp. 1 (Bruijn and Hussain 1984) can be included in the genus *Antemus* nor belong to the murid family *sensu* Jacobs and Downs (1994).

All the seven-murid specimens from PMNH 8608 in Chinji Formation of Bin Amir Khatoon are represented by only one genus *Antemus*. Four specimens are identical with known samples of *A. chinjiensis* (Jacobs, 1978, Jacobs et al. 1994, Wessels et al. 1982). The three other isolated molars show a few new characters, which may warrant their separate identity.

The three variant specimens from Bin Amir Khatoon include upper first molars and one lower first molar. Their length-width dimensions are on the larger end of the size range given by Jacobs and Downs, (1994). The  $M^1$  with maxillary fragment has a well-developed precingulum and also  $t_6$  (i.e. enteroconule). Jacobs and Downs (1994) have reported that the precingulum is a common feature whereas  $t_6$  has only been observed in 10% of the individuals in their samples. The distinctive feature is the presence of a well-developed ridge connecting the  $t_1$  with  $t_4$ . The other  $M^1$  is broken anteriorly and thus presence/absence of precingulum and  $t_6$  cannot be ascertained. In this molar there is a well-developed, small style present between the  $t_1$  and  $t_4$ . This style touches the peripheries of  $t_1$  and  $t_4$ , respectively. The third specimen is the  $M_1$  which closely resembles to *A. chinjiensis* in size and cusp morphology.  $C_4$  and  $C_1$  are clearly developed on the labial margin. The unique feature is the presence of two cusps on the lingual side in close proximity of  $td$  and  $tf$ , respectively. These two cusps occupy approximately the same position on the lingual shelf as the  $C_4$  and  $C_1$  do on the labial margin.

These feature, ridge or style between  $t_1$  and  $t_4$ , lingual cusps on  $M_1$  distinguish these three specimens and have not been reported for *Antemus*, *Progonomys*, or *Karnimata*. I consider the

development of extra cusps/style and the overall larger dimensions as advanced characters within the genus *Antemus*. It is possible that these three specimens represent yet another species of *Antemus* but if so, because *Progonomys* and *Karnimata* lack the derived features, this new species would not be considered as their ancestor. In that samples, sizes are so small, I hesitate to name a new species, but suspect that either *Antemus* may be more diverse than previously seen or this assemblage really represents a new species.

If the sample of *Antemus* from 14 to 12.1 Ma (see Fig. 3 in Jacobs and Downs, 1994) is an accurate representation of the true population, the range of size suggests at least two entirely different species of *Antemus*.

The youngest *Antemus* (12.5 Ma) is separated from the oldest *Progonomys* (11.8 Ma) by an intermediate sample (12.1 Ma). *Progonomys* is a particularly informative genus. It is relatively easy to identify because it has a derived connection of lingual cusps not seen in the older and more primitive *Antemus*. Murines become numerically dominant in the Siwaliks near the origin of *Progonomys* around 11.8 Ma BP (see Fig. 2 in Jacobs et al. 1989). Interestingly the first record of murines outside the Siwaliks is *Progonomys*, which is known from Europe, Africa and China. No record of *Progonomys* in any of these places is older than the first record of the genus in the Siwaliks and no murine is known from anywhere that is older than *Progonomys* except for *Antemus* in the Siwaliks.

The primitive *Progonomys* reported to occur between 11.8 Ma and 9.1 Ma has not yet been formally named by Jacobs and his associates (see Jacobs and Downs, 1994).

The first record of well-defined, two evolutionary lineages represented by *Progonomys* and *Karnimata* respectively comes from the locality Y-GSP 182 in northern Potwar at 8.35 Ma BP (Jacobs, 1978). The root species are the *Progonomys debruijni* and *Karnimata darwini*. The *Progonomys debruijni* lineage is defined by having the anteriostyle in a posterior position and by having simple roots on molars. The second lineage *Karnimata darwini* was a direct comparison of the Jalalpur murids locality JAL 101 (age 11 Ma) as reported by Cheema et al. (1983) with the species described by Jacobs (1978) from the locality YGSP 182A (8.5 Ma) of Siwalik showed that the Jalalpur forms belonged to the same genera (*Karnimata* and *Progonomys*) but not the same species. Jalalpur fauna looked more primitive than the YGSP 182A fauna on the basis of

size variation and teeth morphology. At that time most of the determinations were incomplete because of poor material.

Additional sampling of JAL-101 in 1984 yielded a much better preserved and more diverse small mammal fossil assemblage supplementing the 1982 collection. It contains particularly good sample of a primitive species of the early murid *Progonomys*, which is named herein as *Progonomys hussaini*.

*Progonomys hussaini* is primitive in low crown height without strong inclination of cusps, in weak cusp connections, and in the broad posterior lobe of  $M_3$ , which may indicate homology with entoconid. It is smaller than *P. woelferi*, about the size *P. cathalai*. In contrast to *P. cathalai*, the anterostyle is usually more posterior and the anterior mure on  $M_1$  is less developed. *P. hispanicus* is somewhat smaller, with higher and more inclined cusps (Michaux, 1971). *P. yunnanensis* (also somewhat smaller) is more sthepanodont, with anterior posterostyle, higher cusps, and other advanced features (Qiu and Storch, 1990).

*Progonomys hussaini* is an early representative of the genus, and is correspondingly primitive. The sample from JAL-101 shows considerable variation, leading to the suspicion that more than one taxon could be present. Some teeth seem unusual in size (contrast the two  $M^3$  in Plate 12, Fig. j and k). Morphology also varies, but not in a way congruent with size. Indeed, the odd  $M^1$  (Plate 10, Fig. b) seems incongruent with the usual morphology (Plate 10, Fig. a), and Cheema et al. (1983) felt that it might represent a primitive *Karnimata*. Given higher samples now, the murid variation appears to intergrade and a conservative viewpoint will be that only one species is present. Consequently, we assign all murid specimens from JAL-101 to *Progonomys hussaini*, and observe a broad range of variation for the species. That variation could encompass the origins of both *P. debruijini* and *Karnimata*, as implied by Jacobs et al. (1990). Alternatively, *Karnimata* could indeed be present at JAL-101 in low abundance.

Some of the specimens which indeed morphologically grade towards *Karnimata* in Jalalpur samples differ from *K. darwini* by its small size, a large  $t^3$  relative to  $t^2$  in  $M^1$ , lower crown and cusps more rounded and weakly connected. This form cannot be included in any (known) species of *Karnimata*. The structure of  $M^1$  and  $M_2$  suggest, that *Karnimata n. sp.* is more primitive than *K. darwini*. If *Karnimata n. sp.* were ancestral to *K. darwini*, the evolution of this lineage would

include increase in size. Later *Karniamata* had a more complex history. *K. huxleyi* decreased in size relative to *K. darwini* (Jacobs, 1978), while *Karnimata* in Afghanistan increased in size relative to *K. darwini* (Sen, 1983).

According to Jacobs (1978) *Mus auctor* from locality DP 13 is morphologically very similar to *Progonomys* and quite possibly is a direct descendant. This *Progonomys-Mus* lineage is characterized by having the anterostyle in a posterior position and by having simple roots on molars. Locality DP 13 is greater than 5 m.y. in age, thus *Mus auctor* is the earliest record of that genus yet reported. Similarly *Mus* is present in upper Siwalik deposits (Pleistocene) of the Pabbi Hills from locality DP 24, which is 1.8 Ma old.

The *Karnimata-Golunda* lineage of Siwalik murids is characterized by having anterostyle anterior in position and by the multiplication of roots on molars. *Karnimata huxleyi* and *Parapelomys robertsi* occur at locality DP 13, both derived with *Karnimata* stock. *Golunda* from locality DP 24 seems to be closely related to *Parapelomys*.

Small mammals from mid-Pliocene locality PMNH 8802 in Mirpur, produced six murid specimens which indicate three species belonging to *Golunda*, *Hudromys* and *Mus*. This locality correlates roughly to the top of the Mammoth event (ca 3 Ma) in the section of the Hussain et al. (1992). Four specimens are assigned to *Golunda kelleri*, a species recorded in the younger locality DP 24 in Pabbi Hills area by Jacobs (1978), which occurs magnetostratigraphically above the Olduvai event age. Whether slight morphological differences in molars of the two samples reflect individual variation or time remains to be seen. The Mirpur  $M_{1,2}$  have a slightly stronger labial cingulum and are possibly lower crowned, although wear stage makes this uncertain. This sample shows the diagnostic feature of *G. kelleri*, a centrally placed entoconid on  $M_3$ .

The Mirpur *Golunda* adds the upper first molar, which was lacking in the original hypodigm. This tooth differs from that of extant *G. ellioti* in that it is more elongated anteroposteriorly, with chevrons less crowned, and its metacone is less reduced, It is smaller in length/width proportions to *Golunda gurai* Sabatier (1982), but at the small end of the size range for that species. Central cusps on  $M_1$  are more crescentic in *G. kelleri*, labial cusps are smaller and rounder, and the metacone is smaller than in *G. gurai*. Musser (1987) rejected the later as a member of *Golunda*.

The cf. *Hadromys* sp. is smaller crowned, has more bent, less crowned chevrons, and a less anterior metacone than *Hadromys loujacobsi*. Whether the Mirpur taxon is genetically distinct from *Hadromys* awaits more fossil finds. Whether it precedes or is a contemporary of early *Hadromys* awaits more field work. In any case, it indicates that the *Hadromys* lineage was present by 3 Ma. The third murid from PMNH 8802 represents a species of *Mus* based on cusp morphology and lack of a posterior cingulum, and is slightly smaller than *Mus auctor* and *Mus* sp. of DP 24.

With reference to murids from localities DP 13 and DP 24 (Fig. 15) dated by Jacobs (1978) at 5.7 and 1.6 Ma, respectively, the murid fauna of PMNH 8802 is consistent with its intermediate age. All the three sites also contain *Mus*. The presence of *Parapelomys robertsi* and the last record of Karnimata characterize the locality DP 13. The locality DP 24 contains *Hadromys* and *Golunda*. The PMNH 8802 site contains a *Hadromys*-like form more primitive than *H. loujacobsi*, and the first record of *Golunda*.

That *Golunda kelleri* known from localities PMNH 8802 and DP 24 at 3.0 and 1.6 Ma, respectively shows that this species survived the end-Pliocene interval of climatic change that effected much of the globe. It also establishes an earlier Asian record of *Golunda*, consistent with postulated origin of the genus on that continent (Jacobs, 1978).

The Lehri assemblage includes important material that complements knowledge of two large murine taxa of the late Neogene deposits of the Indian Subcontinents. The *Golunda* specimens offer fuller knowledge of the upper dentition and maxilla of *G. kelleri*. In light of these specimens, fossils from India appear to represent more than one lineage and suggest that *Golunda kelleri* was not necessarily ancestral to *G. ellioti*, as suspected by Jacobs(1978) and Musser(1987). The Lehri material also suggests that traits observed in extant arvicanthines( such as depth of the incisive foramen) do not necessarily distribute along generic lines. The incisive foramen of *G. kelleri* is more like that of *Myiomys dybowski* than that of *G. ellioti*. That means only that we do not understand the pattern of the arvicanthine radiation in Asia; likely it was complex.

That radiation may have involved origin of *Hadromys*, although Musser (1987) argues that the case for arvicanthine affinity of the genus is not yet convincing. The Lehri material complements

knowledge of the Plio/ Pleistocene *Hadromys loujacobsi*. Originally known only from upper dentition, it is now represented by lower molars and a dantary fragment. In some features such as the straight, laminar form of the chevrons, this species is more derived than living *H. humei*. Both share, however, distinctively great crown height, markedly greater than that of comparable murines. For the moment, the species are treated as congeneric; more material could test justification for splitting them.

The composition of the late Pliocene small mammal fauna appears to be consistent across the northern part of the Indian subcontinent. From Mirpur, Lehri, and the Pabbi Hills on the west, through Jamma to the Pliocene deposits of Himachal Pradesh in the east, one find an assemblage dominated by diverse murines. These include, in relatively constant proportion, remains of the large genera *Hadromys* and *Golunda*, at least one member of the *Cremnomys-Millardia* group, and one or more species of the ubiquitous *Mus*. In low abundance, one encounters modern shrews (variously, *Crocidura* or *Suncus*), the occasional bamboo rat related to *Rhizomyides sivalensis* (Lydekker, 1884), the gerbil *Abudhabia* (Bruijn and Whybrow, 1994), and sometimes leporids (e.g. *Pliosivalagus* Patnaik, 2001). Our knowledge of these assemblages is limited of course by small sample size. Larger samples reveal the presence of other murines, for example *Dilatomys* and *Bandicota* recognized by Patnaik (1997). Still, no squirrels or porcupines are yet recorded from these Pliocene sites, but we expect these (and possibly also dormice) to emerge as more assemblages are described.

Kotila (1992) has demonstrated that arvicolines occur during the late Pliocene, but these are found at higher elevations. The modern fauna (e.g. Roberts, 1977) also records dipodoid (jerboas and relatives), hamsters, and diverse gerbils. Possibly these are later Pliocene arrivals reflecting increasingly open habitat.

Musser (1987) noted that the different habitats preferred by living *Hadromys* and *Golunda*. Whereas *Hadromys* today occurs at moderate elevations in monsoonal habitat, *Golunda* is characteristic of more open to rock terrain with thorn scrub and grass. Intrestingly, the Pabbi Hills co-occurrence of the genera is repeated at Mirpur, Lehri, and apparently in northern India. Possibly local habitat was highly varied across the Indian subcontinent, offering both open terrain and patchy, dense growth, or the preferences of extinet species varied from those of

modern relatives. This simply demonstrates change in climate patterns and/or species preferences, both topics that can be constrained and better understood by continued field research.

## CHAPTER- 8. SUMMARY

1. This study has been undertaken to improve the current knowledge of the Family Muridae in the Neogene fossil record of South Asia.
2. Four areas were carefully chosen from the Siwalik Group rocks in the Potwar Plateau and Azad Kashmir to bridge the existing temporal gaps in understanding the evolution of Murine rodents.
3. The four study areas include two in the Miocene (namely, Bin Amir Khatoon, ca. 12 Ma and Jalalpur, 11-10 Ma), and two in the Pliocene (namely, Mirpur, ca. 3 Ma and Lehri, ca. 2 Ma).
4. Murines are a monophyletic group defined on dental characters, which mainly evolved in South Asia.
5. The most primitive and ancient species known is *Antemus chinjiensis*, whose oldest record is 13.75 Ma from the stratotype Chinji Formation in the southern Potwar Plateau.
6. *Antemus primitivus* reported from basal Chinji Formation near Banda Daud Shah having dental characters more primitive than *A. chinjiensis* has recently been grouped with ericetids as *Potwarmus primus*.
7. *Antemus chinjiensis* evolved from *Potwarmus primitivus*, a near murid ericetid.
8. The transition from *Potwarmus* to *Antemus* took no more than 550,000 years.
9. All the seven murid specimens from PMNH 8608 in the Chinji Formation of Bin Amir Khatoon, are represented by only one genus *Antemus*. Four specimens are identical with known sample of *Antemus chinjiensis*. The three older isolated molars (two  $M_1^l$  and one  $M_1^i$ ) show a few new characters including larger length-width dimensions than so far known which may warrant their separate identity.



10. Development of extra cusps/style and the larger dimensions are considered as advanced characters within the genus *Antemus*. Therefore, it is possible that these three Bin Amir Khatoon specimens represent yet another species of *Antemus*.
11. *Progonomys* evolved from *Antemus* by 11.8 Ma in a transition that occurred over an interval of no more than 700,000 years.
12. The Jalapur murids dated around 11 Ma contain a diverse assemblage consisting dominantly of *Progonomys* and few specimens tentatively assigned to *Karnimata*.
13. Based upon first sampling of the Jalapur site, Cheema et al (1983) described new species each of *Progonomys* and *Karnimata* arguing that they look more primitive than their counterparts from YGSP 182 A (8.5 Ma) on the basis of size and teeth morphology.
14. Additional sampling of JAL-101 yielded good sample of a primitive species of the early murid *Progonomys* which is named herein as *Progonomys hussaini*.
15. *Progonomys hussaini* has given rise to *P. debruijni* and could also be the most plausible ancestor for the genus *Karnimata*.
16. Small mammals from mid-Pliocene (ca 3 Ma) locality PMNH 8802 in Mirpur indicate three species belonging to *Golunda*, *Hadromys* and *Mus*.
17. In comparison with other two Pliocene sites i.e. DP 13 (5.7 Ma) and DP 24 (1.7 Ma), the Mirpur locality records the first appearance of *Golunda* and *Hadromys*.
18. The Mirpur *Golunda kelleri* contain the first record of its upper first molar which was lacking in the regional hypodigm.
19. The cf. *Hadromys* described from the Mirpur PMNH 8802 has more primitive characters than *Hadromys loujacobsi* from DP 24 (ca 1.6 Ma).

20. *Golunda kelleri* and *Hudromys loujacobsi* from Lehri fossil locality PMNH 93128 help to put into focus other material from Pliocene localities in India and suggest that *Golunda* and *Hudromys* both had complex phylogenetic histories. This locality also produced smaller murids like *Cremnomys* and a mouse near *Mus jacobsi*. This fauna is like other Pliocene assemblages encountered across the Indian subcontinent and indicating zoogeographic ties to East Africa.
21. This research focusing upon the temporal gaps in working out the phylogenetic relationship of Siwalik murines has established a continuous chronologic record beginning from Middle Miocene (14 Ma) to Early Pleistocene (1.6 Ma).

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