Indian Neogene Siwalik Mammalian Biostratigraphy: An Overview

Chapter · May 2013

DOI: 10.7312/columbia/9780231150125.003.0017

1 author:

Rajeev Patnaik
Panjab University

Chapter 17

Indian Neogene Siwalik Mammalian Biostratigraphy: An Overview

RAJEEV PATNAIK

Almost 6000 m thick, Siwalik freshwater deposits exposed all along the Himalayan foothills are famous for their great wealth of mammalian fossils ranging in age from ~18 Ma (Johnson et al. 1985) to 0.22 Ma (Ranga Rao et al.1988). These deposits were formed by rivers that were precursors to the present-day mighty Indus, Ganges, and Brahmaputra of the Indian subcontinent. The excellent fossil and sediment record of the Siwaliks has attracted the interest of earth scientists and palaeoanthropologists for the past 150 years. Medlicott (1879) followed by Pilgrim (1910, 1913) classified the Siwaliks as Lower, Middle, and Upper Siwaliks, further divided as the Kamlial, Chinji, Nagri, Dhok Pathan, Tatrot, Pinjor, and Boulder Conglomerate formations, based mainly on their faunal content. Colbert (1935) preferred calling them zones. Over the years, extensive fieldwork has revealed that the boundaries between most of the Siwalik formations are time transgressive and that temporal ranges of mammals are not usually fixed within the time limits of these formations. Therefore, these formations are now largely referred as lithounits (figure 17.1). Type sections of the Lower and Middle Siwalik formations lie in Pakistan, and those of Upper Siwaliks are mostly in India (figure 17.2). In recent years, extensive multidisciplinary studies, particularly in Pakistan, have resolved several issues concerning biotic changes in the Late Miocene and how they interplay with fluvial dynamics and climatic trends (Pilbeam et al. 1977; Keller et al. 1977; Opdyke et al. 1979; Badgley and Behrensmeyer 1980; Barry, Lindsay, and Jacobs 1982 Barry et al.1985; Flynn and Jacobs 1982; Johnson et al. 1982; Johnson et al. 1985; Quade et al. 1989; Barry and Flynn 1990; Willis 1993; Behrensmeyer, Willis, and Quade 1995; Flynn et al. 1995; Quade and Cerling, 1995; Barry et al. 2002; Badgley et al. 2005; Badgley et al. 2008).

India has some of the classic Siwalik fossil mammal localities (Pilgrim 1910, 1913; Lewis 1934; Colbert 1935; Prasad 1970), situated along the Himalayan foothills around Jammu (state of Jammu and Kashmir), Nurpur and Haritalyangar (Himachal Pradesh), Chandigarh (Union Territory), Kala Amb-Saketi (Haryana and Himachal Pradesh), and Kalagarh (Utter Pradesh). In India, several significant contributions have been made to understand the fauna (Sahni and Khan 1964; Nanda and Sehgal 1993), geology (Karunakaran and Ranga Rao 1979; Vasishat 1985; Parkash et al. 1980; Kumar and Tandon 1985), magnetostratigraphy (Johnson et al. 1983; Ranga Rao et al. 1988; Tandon et al.1984; Kotlia et al. 1999; Sangode and Kumar 2003) and tephrochronology (Mehta et al. 1993). Barring a few instances where magnetostratigraphy has been tied to fossil occurrences (Agarwal et al. 1993; Basu 2004; Ranga Rao et al. 1988; Patnaik and Nanda 2010), the mammalian faunal assemblages are largely differentiated only according to formation (Vasishat et al. 1983; Nanda and Sehgal 1993, 2005).

While Neogene mammal fossils of India occurring in the Siwaliks can be assigned to lithostratigraphic units, nomenclature of the units is problematic, and utilization of classic formation names sometimes leads to errors. As most of the formation boundaries have been found to be

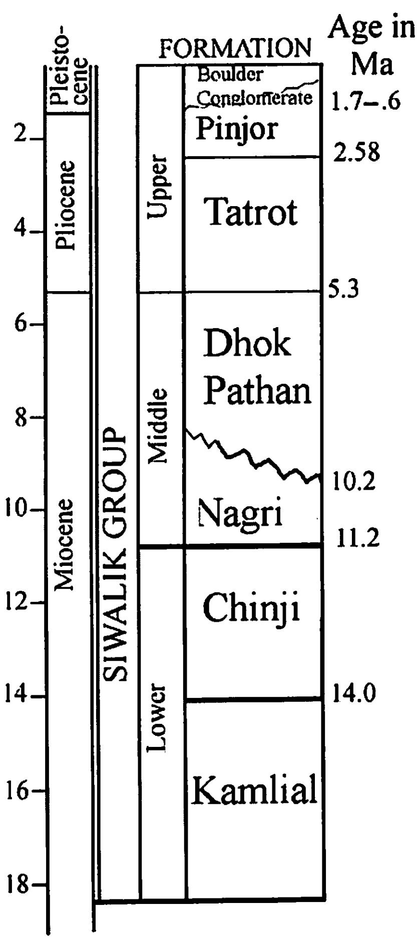

Figure 17.1 A generalized stratigraphic framework of the Siwalik sequence (not applicable everywhere). Modified after Behrensmeyer and Barry 2005; dates from Johnson et al. 1985, Ranga Rao et al.1988, and Barry et al. 2002).

time transgressive and faunal ranges often extend beyond these boundaries, the common practice of assigning faunal assemblages after various formations, as in "Chinji Fauna" or "Pinjor Fauna," has hindered developing a high-resolution biostratigraphic framework. The present chapter makes an attempt to reevaluate the mammalian biostratigraphy of the Indian Siwaliks by integrating the available mammalian locality data to sections with independent dating using magnetostratigraphy and tephrochronology. A few other important sections that have not been geochronologically dated are placed here in the temporal framework using mammal biochronology already well established in the Pakistan Siwaliks. The present exercise of compiling the data and putting the mammal record in a chronological framework has facilitated a revision of the first and last appearances of several Neogene Siwalik mammals, including those of the Miocene apes, allowing a better intraregional correlation with localities situated in Pakistan and Nepal. Two major faunal turnovers—one at the Late Miocene (8–9 Ma) and the other at the Gauss-Matuyama boundary (2.6 Ma)—coincide with global climate and local tectonic events. Many gaps still exist in the Indian fossil record, and several mammalian lineages are yet to be taxonomically resolved; therefore, interpretations made here are tentative.

The present approach is to reassess the various key sections: (1) Lower Siwalik Ramnagar section in the Jammu sub-Himalaya, (2) Middle Siwalik Haritalyangar and Nurpur sections in the Himachal Himalayas, and (3) Upper Siwalik Uttarbeni–Parmandal section in the Jammu and Haripur Khol, Khetpurali, Markanda, Patiali Rao, and Ghaggar River sections exposed near Chandigarh. Other important assemblages recorded from various Siwalik sections exposed in India and Nepal are also reviewed.

BIOSTRATIGRAPHIC APPRAISAL

Lower Siwalik Ramnagar Locality

The Ramnagar locality is situated in the Jammu region where the Lower, Middle, and Upper Siwaliks are fairly well exposed (figure 17.3). Ramnagar is famous for its Miocene apes (Brown et al. 1924; Lewis 1934; Colbert 1935; Dutta et al. 1976; Vasishat et al. 1978), and in recent times many workers have contributed significantly toward understanding its vertebrate palaeontology and stratigraphy (Thomas and Verma 1979; Nanda and Sehgal 1993; Verma and Gupta 1997; Basu 2004; Parmar and Prasad 2006; Sehgal and Patnaik 2011).

A diverse fossil assemblage is now known from the upper 350 m of the Ramnagar section (figure 17.4; table 17.1). The large mammalian fauna, which includes Miocene apes such as *Sivapithecus sivalensis* and *Sivapithecus* cf. *simonsi*, and the lithology of Ramnagar show striking resemblance to those of the Chinji type area in the Potwar Plateau (Vasishat et al. 1978; Nanda and Sehgal 1993; Verma and Gupta 1997; Basu 2004). This strong faunal similarity (see table 17.1) has been used for tentatively placing the Ramnagar assemblage between 11 Ma and 13 Ma (Vashishat et al. 1978; Nanda and Sehgal 1993; Basu 2004). Recently, a report of the short-ranging rhizomyid rodent *Kanisamys* cf. *potwarensis* from near Dehari (Parmar and Prasad 2006) suggests that these deposits could be a little older than previously estimated, because the range of this species in Pakistan is about 14.2 Ma to 13.4 Ma on the time scale of Gradstein et al. (2004) (see figure 17.4).

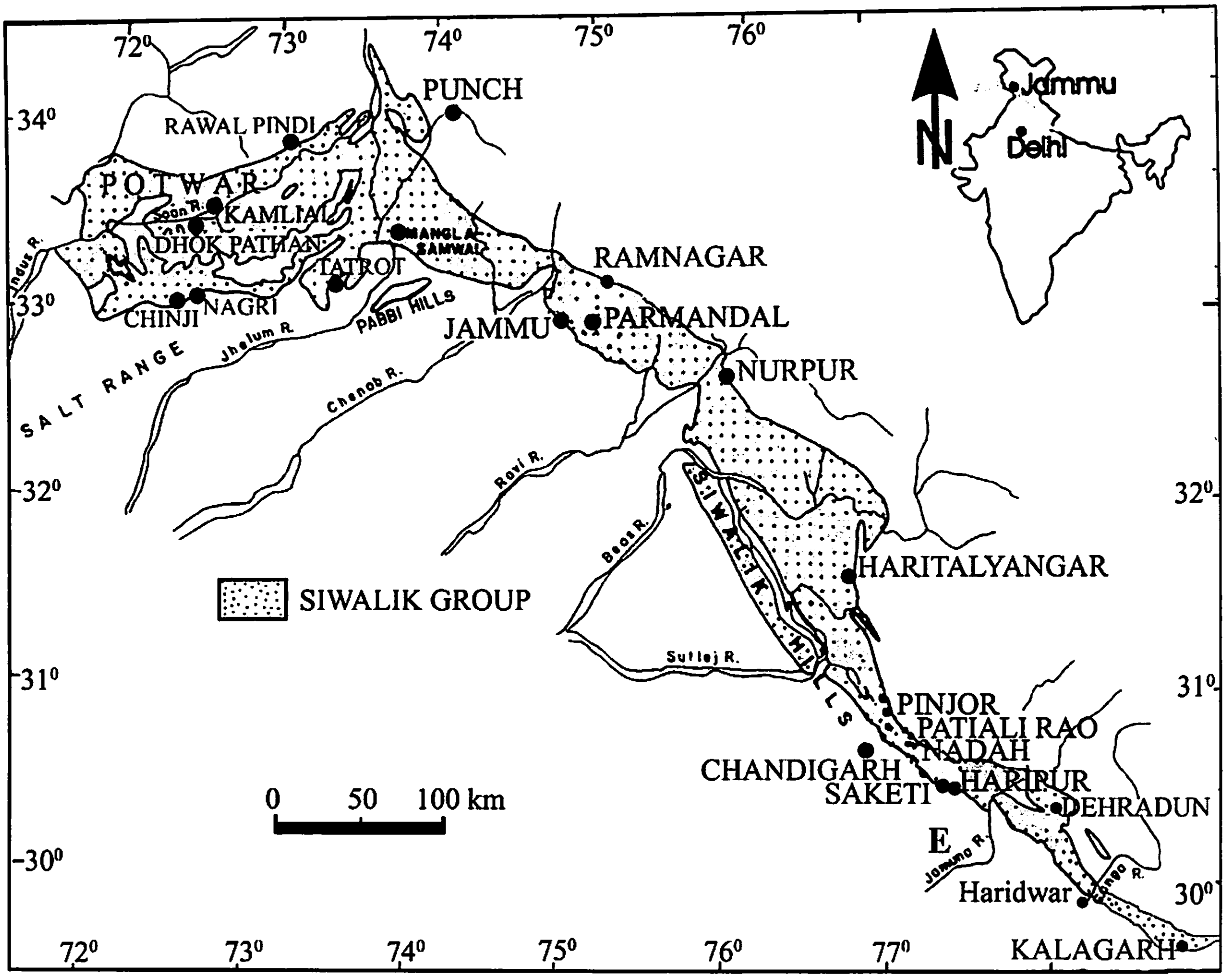

Figure 17.2 Distribution of the Siwaliks showing the localities discussed in this chapter as well as the type localities of various formations in Pakistan.

Sehgal and Patnaik (2011) discuss index fossils that support this older age estimate, the murid rodent *Antemus chinjiensis* and the cricetid rodent *Megacricetodon* cf. *sivalensis* from the stratigraphic level of *Sivapithecus* at Ramnagar. The Ramnagar assemblage can now be constrained between ~13.2 Ma and ~13.8 Ma using the well-established high-resolution Siwalik rodent biochronology. This biochronological framework has the potential of increasing the first appearance datum (FAD) of *Sivapithecus* from the presently estimated 12.8 Ma to at least 13.2 Ma (see figure 17.4).

Kalagarh

The so-called Lower Siwalik fauna reported from Kalagarh, Uttaranchal (Tiwari 1983) includes *Sivapithecus indicus, Viverra chinjiensis, Sivameryx (=Hyoboops) minor, Hipparion (Cormohipparion) antilopinum, Dienotherium* sp., *Dorcadoxa porrecticornis, Conohyus* sp., *Giraffokeryx* sp., *Dicoryphochoerus* sp., *Propotamochoerus* sp., *Dorcatherium nagrii*, and *Dorcatherium majus*. Nanda and Sehgal (1993) are of the opinion that this assemblage contains both Lower and Middle Siwalik elements. The short-ranging bovid *Dorcadoxa porrecticornis* (in Pakistan) may constrain this locality between 9.3 Ma and 8 Ma. This estimate is well supported by age ranges of other associated species such as *Hipparion* spp. (10.7–5.8 Ma), *Dorcatherium nagrii* (9.3–6.8 Ma), and *Dorcatherium majus* (10.4–7 Ma; dates unmodified from Barry et al. 2002). Therefore, Kalagarh appears to be of late Miocene in age.

Dang Valley, Nepal

Further east, the Dang Valley sections of Nepal have yielded both Lower and Middle Siwalik mammalian

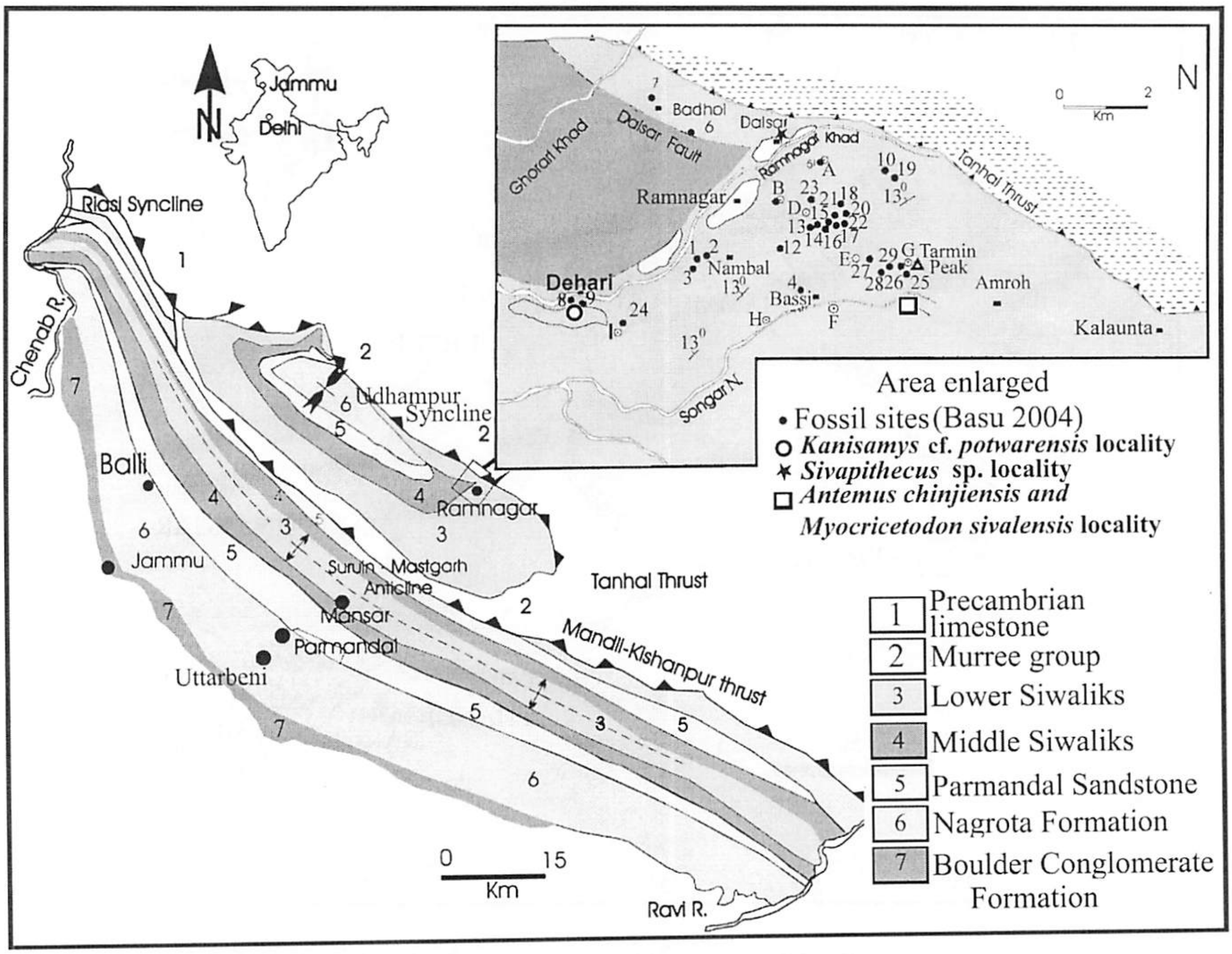

Figure 17.3 Location and geological map of the Siwaliks of Jammu sub-Himalaya (modified after Gupta and Verma 1988; Basu 2004). The subgroups and the lithostratigraphic units of the Siwaliks and the pre-Siwaliks are indicated as follows: *1*, Great Limestone (Precambrian); *2*, Murree Group; *3*, Lower Siwalik; *4*, Middle Siwalik; *5*, Parmandal Sandstone; *6*, Nagrota Formation; and *7*, Boulder Conglomerate Formation. Numbers *1–29* on the inset represent the fossil localities tied to the section as shown in figure 17.4, after Basu (2004).

assemblages (West et al. 1978; West, Hutchison, and Muthe1991). Both magnetostratigraphic (Munthe et al. 1983) and biostratigraphic zonations (Pre-*Hipparion* and *Hipparion* Zone of Barry, Lindsay, and Jacobs 1982) have been used to assign these rocks to the Lower and Middle Siwaliks. Taxa that have been found from Dang Valley include *Sivapithecus punjabicus, Amphicyon palaeindicus, Deinotherium pentapotamiae, Brachypotherium perimense, Conohyus sindiensis, Hemimeryx pusillus, Giraffokeryx punjabiensis, Protragocerus gluten, Hipparion* sp., *Dorcabune* sp., *Dorcatherium* sp., and *Pachyportax* sp. (West et al. 1978; West, Hutchison, and Munthe 1991).

Middle Siwalik Haritalyangar Locality

Haritalyangar is one of the best-studied Siwalik localities in India (figure 17.5). The reasons for such attention are obvious. The 1600-m-thick section has yielded some of the best primate specimens anywhere from the Siwaliks. These include apes such as *Sivapithecus sivalensis, Sivapithecus indicus,* and *Indopithecus bilaspurensis,* the small primates *Pliopithecus* (*Dendropithecus*) *krishnaii, Indraloris himalyaensis,* and *Sivaladapis palaeindicus,* and the tupaiid *Palaeotupia sivalicus* (Simons and Chopra 1969; Simons and Ettel 1970; Simons and Pilbeam 1973; Gingerich and Sahni 1979, 1984; Chopra and Kaul 1979;

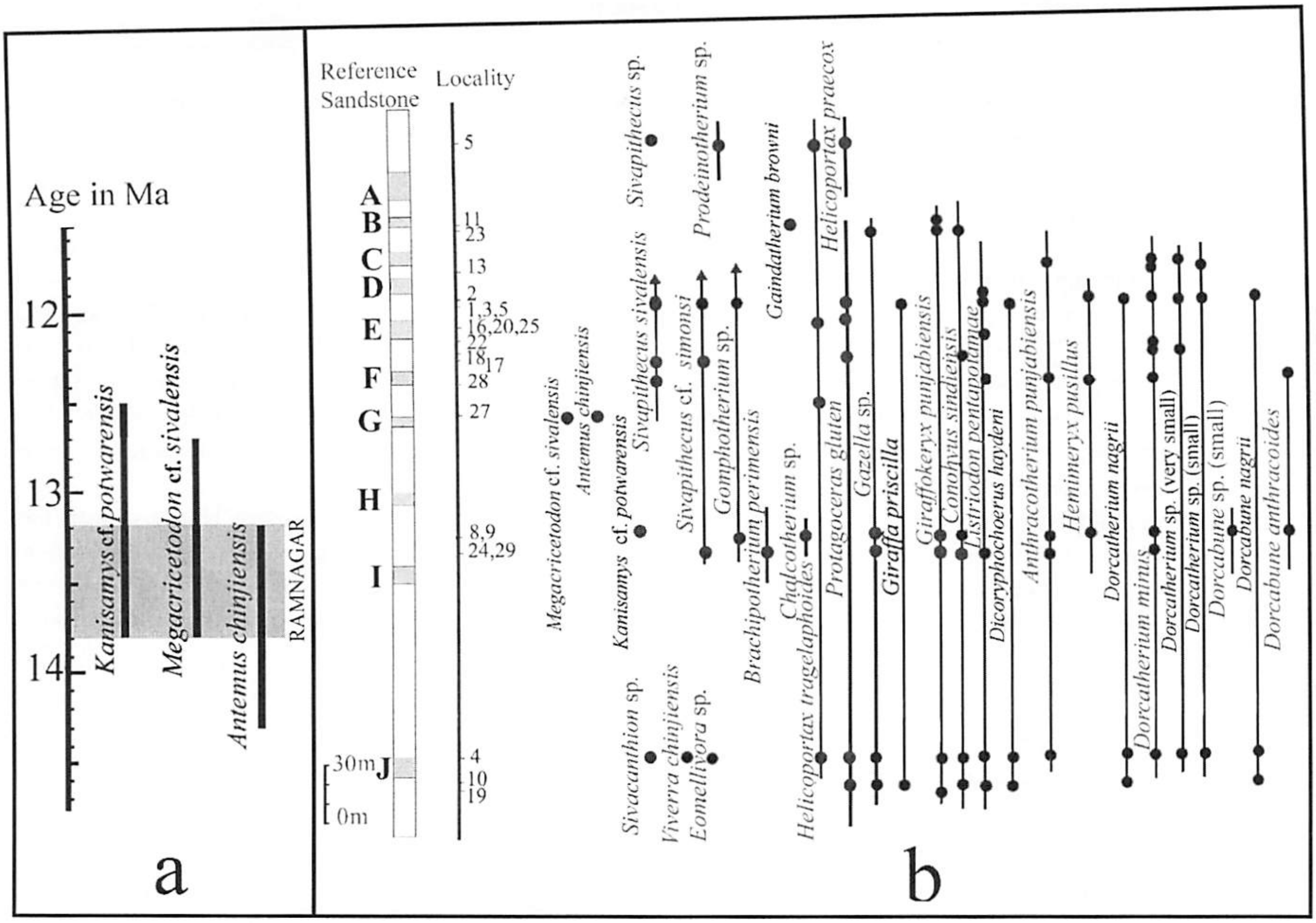

Figure 17.4 Ramnagar biostratigraphy: (*a*) stratigraphic ranges of key rodents observed in the Siwaliks of the Potwar Plateau, Pakistan (Flynn et al. 1995; Jacobs and Flynn 2005); (*b*) Ramnagar section with biostratigraphic occurrences of mammals in the upper 350 m interval of the Lower Siwaliks (modified after Basu 2004). Occurrence levels of species are indicated by black dots (data from Nanda and Sehgal 1993, Basu 2004, and Parmar and Prasad 2006). This figure is adopted from Sehgal and Patnaik (2011:fig. 3).

Table 17.1

Mammalian Species Recorded from the Upper Interval of the Lower Siwaliks, Ramnagar

Primates	*Sivaladapis palaeindicus, Sivapithecus indicus, S. sivalensis, S.* cf. *S. simonsi*
Rodentia	*Sivacanthion complicatus, Rhizomyides sivalensis, Rhizomyides punjabiensis, Sayimys sivalensis, Kanisamys* cf. *K. potwarensis, Antemus chinjiensis,* cf. *Myocricetodon* sp.
Carnivora	*Dissopsalis* sp., *Dissopsalis carnifex, Amphicyon* sp., *Viverra chinjiensis, ?Eomellivora sp., Eomellivora necrophila, Vishnufelis* sp., *Percrocuta carnifex, Vishnuonyx chinjiensis*
Proboscidea	*Prodeinotherium* sp., *Gomphotherium* sp., *Tetralophodon* sp. *Deinotherium pentapotamiae*
Perissodactyla	*Aceratherium perimense, Gaindatherium browni, Brachypotherium* sp. *Brachypotherium perimense, Chilotherium? intermedium, Chilotherium* sp., *Chalicotherium* sp.
Artiodactyla	*Listriodon pentapotamiae, Dicoryphochoerus haydeni, Conohyus chinjiensis, Conohyus sindiensis, Propotamochoerus* sp., *Sus* sp., *Hippopotamodon haydeni, Anthracotherium punjabiense, Hemimeryx pusillus, Dorcabune anthracotherioides, Dorcabune nagrii, Dorcatherium majus, D. minus, D. nagrii, D. sp. (small), D.* sp. (very small), *Giraffokeryx punjabiensis, Progiraffa priscilla, Progiraffa* sp., *Protragocerus gluten, Miotragocerus gradiens, Gazella* sp., *Helicoportax tragelaphoides, H. praecox, Miotragoceras* sp.?, *Kubanotragus sokolovi*

SOURCES: After Vasishat et al. (1978); Gaur and Chopra (1983); Nanda and Sehgal (1993); Sehgal (1998); Sehgal and Nanda (2002); Basu (2004); and Parmar and Prasad (2006).

Chopra and Vasishat 1979; Patnaik and Cameron 1997; Patnaik et al. 2005; Pillans et al. 2005). Johnson et al. (1983) carried out a detailed palaeomagnetic stratigraphy of the Haritalyangar region and found that the *Sivapithecus* fossils occur between 850 m and 1100 m above the base of the Haritalyangar section. They placed *Indopithecus bilaspurensis* (formerly *Gigantopithecus*, includes *G. giganteus*) at the 1200 m level, which they projected as 6.3 Ma. Sankhyan (1985) recorded *Sivapithecus* from the 1500 m level as well. Therefore, these fossil apes appeared to show a young age range (~7.5–5.5 Ma) with respect to the Pakistan record. Recently, Pillans et al. (2005) revised the chronology of Haritalyangar based on a new correlation of this section to the GPTS. The main hominoid interval has now been placed between 9.2 Ma and 8.85 Ma, and the *Indopithecus bilaspurensis* level at 8.6 Ma (figure 17.6). With these new dates, the full range of hominoids at Haritalyangar falls between 9.2 Ma and 8.1 Ma.

Beside primates, Haritalyangar has yielded a diverse mammalian assemblage (table 17.2). Pillans et al. (2005) reported some faunal material from specific horizons, used here for determining first and last occurrences of several mammals (see figure 17.6). Some of the mammals reported by Vashishat (1985) from specific levels have also been integrated with the well-dated section. Other mammals are of uncertain age between 9.23 Ma and 8.10 Ma, as their exact position in the stratigraphic column is not known (see table 17.2).

Ladhyani, a site situated east of Haritalyangar, has yielded several small mammals. These include *Sivalikosorex prasadi* (Sahni and Khare 1976), *Progonomys debruijni*, *Parapelomys robertsi*, *Karnimata darwini*,

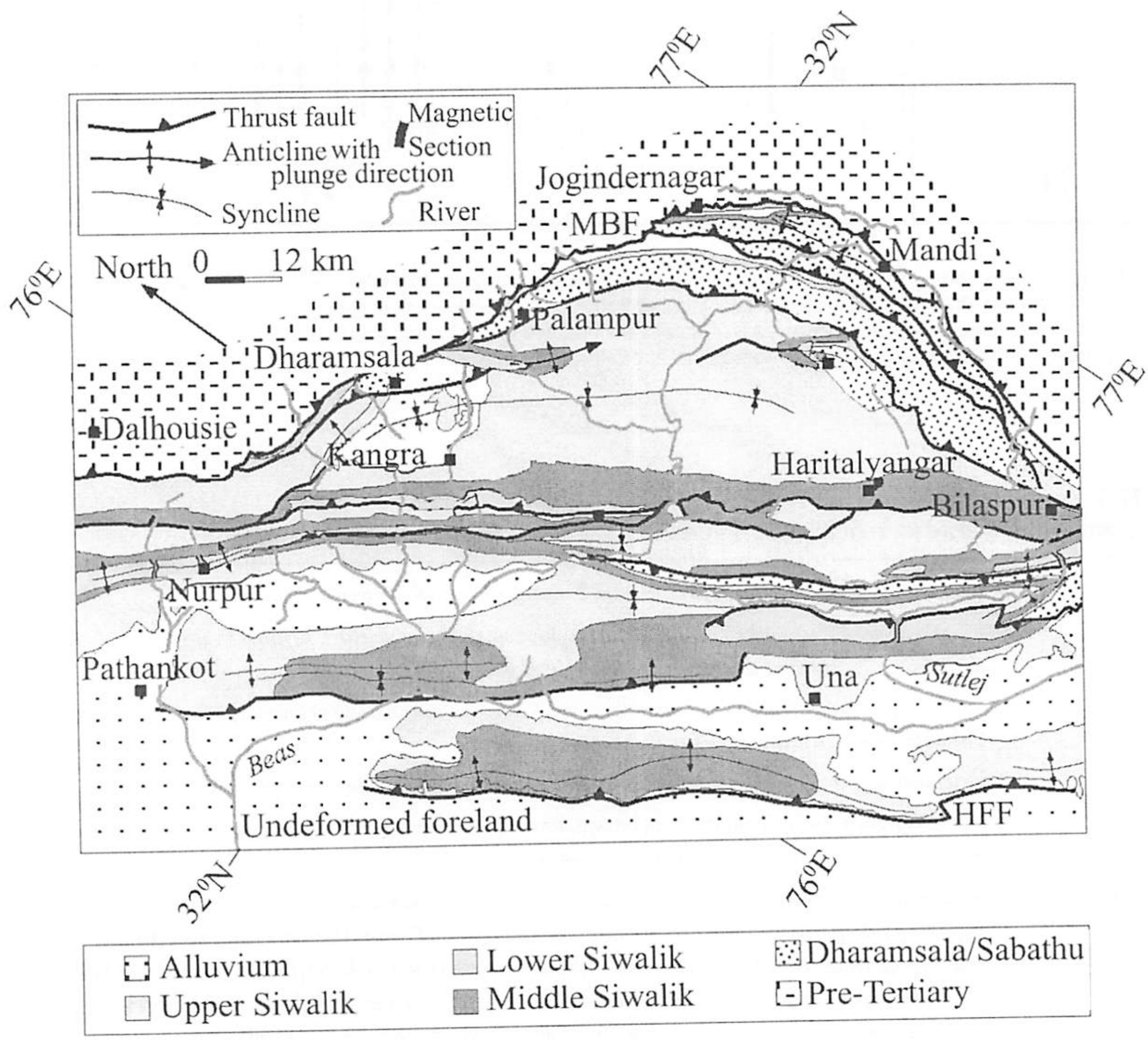

Figure 17.5 General location map of the Himachal Pradesh reentrant, modified from Brozovic and Burbank (2000). MBF = main boundary fault; HFF = Himalayan frontal fault.

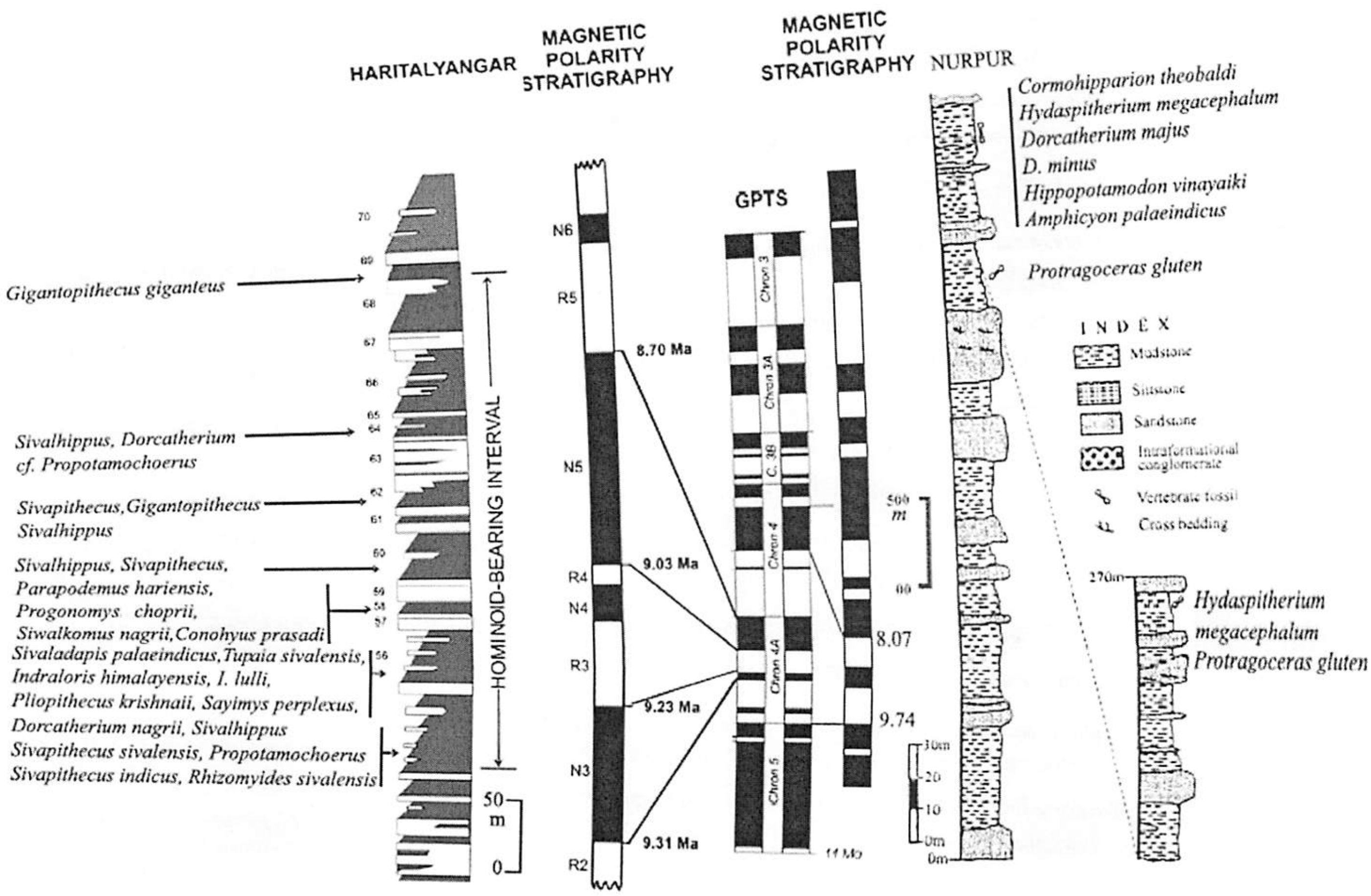

Figure 17.6 Haritalyangar and Nurpur section showing stratigraphic occurrences of mammals; data from Vashishat (1985), Pillans et al. (2005), Sangode and Kumar (2003), and Nanda and Sehgal. (2007).

Palaeotupia sivalicus (Tiwari 1996), and *Karnimata* cf. *intermedia* (tentative identification of a nondiagnostic M2–3; Flynn et al. 1990). In comparing the murine assemblage in Ladhyani to that of Pakistan (Jacobs and Flynn 2005), the co-occurrence of *Progonomys debruijni* and *Karnimata darwini* suggests an upper age limit of ~8 Ma to 9 Ma for Ladhyani. *Parapelomys robertsi* has a younger age range in the Potwar area (Barry et al. 2002) and should be reevaluated.

Middle Siwalik Nurpur Locality

The lower 270 m of red beds exposed near Nurpur, Himachal Pradesh, have yielded a diverse assemblage (see figure 17.6; table 17.3). Initially, these beds were considered Lower Siwalik (Vasishat et al. 1983; Gaur et al. 1985). Subsequently, based on new findings of *Hipparion*, Nanda and Sehgal (1993) placed them in the Middle Siwaliks.

The magnetostratigraphy developed for Nurpur section (Ranga Rao 1993), as recently reinterpreted (Sangode and Kumar 2003), indicates that the assemblage should fall in the 9.7–10.1 Ma interval (see figure 17.6). This rough estimate correlates fairly well considering temporal occurrences of *Hipparion*, *Propotamochoerus hysudricus*, and *Dorcatherium majus* established in Pakistan (Barry et al. 2002; Badgley et al. 2008). As per the sediment accumulation rate at this interval (Sangode and Kumar 2003), the lower 270-m-thick fossil-yielding sequence should represent ~500,000 yr. However, it may be noted that Nanda and Sehgal (2005) placed this assemblage between 8.14 and 7.51 Ma, following Ranga Rao (1993).

A site near Palampur yielding the short-ranging rhizomyid *Brachyrhizomys micrus* (Tiwari 1990) constrains the site to about 9.2 Ma based on its isolated occurrence in Pakistan (Flynn et al. 1990) (see figure 17.5). Other isolated Middle Siwalik mammal occurrences are from

Table 17.2
Mammalian species recorded from Haritalyangar

Primates	*Indopithecus bilaspurensis* (8.6 Ma)
	Palaeotupaia sivalicus, Indraloris lulli [syn. *I. himalayensis*], *Sivaladapis palaeindicus, Pliopithecus krishnaii, Sivapithecus indicus, Sivapithecus sivalensis* (8.85–9.23 Ma)
Insectivora	*Sivalikosorex prasadi* (~8.9 Ma)
Rodentia	*Progonomys debruijni, Parapelomys robertsi, Karnimata darwini, Karnimata* cf. *K. intermedia* (~8.9 Ma)
	Dakkamys nagrii, Rhizomyides sivalensis, R. lydekkeri, Miorhizomys nagrii, M. pilgrimi, M. harii, M. choristos, M. tetracharax, K. sivalensis, K. nagrii, Parapodemus hariensis, Progonomyus choprii, Siwalikomus nagrii, Sayimys perplexus, S. badauni, Sivacanthion complicatus, Mastomys (Karnimata) colberti (8.85–9.23 Ma)
Carnivora	*Sivanasua himalayaensis, Sivaonyx bathygnathus, Viverra nagrii, Vishnuictis hariensis, Ictitherium nagrii, Megantereon praecox, Vinayakia intermedia* (8.85–9.23 Ma)
	Percrocuta gigantea, P. mordax, Enhydriodon falconeri, Lycyaena macrostoma (8.1–9.23 Ma)
Proboscidea	*Deinotherium indicum, Gomphotherium hasnotensis, Anancus sivalensis, Tetralophodon falconeri, Choerolophodon dhokpathanensis, Stegolophodon bombifrons* (8.1–8.6 Ma)
Perissodactyla	*Hipparion antelopinum, Cormohipparion theobaldi, Brachypotherium perimense, Sivalhippus sp.* (8.1–9.23 Ma)
	Gaindatherium browni (8.85–9.23 Ma)
Artiodactyla	*Lophochoerus nagrii, Hippopotamodon robustus, Conohyus prasadi, Sus advena, Anthracotherium punjabiense, Anthracodon hariensis, Anthracothema dangari, Giraffokeryx punjabiensis, Pachyportax nagrii* (8.85–9.23 Ma)
	Tetraconodon mirabilis, Hippopotamodon vagus, Hippopotamodon titanoides, Propotamochoerus uliginosus, Dorcatherium nagrii, Dorcatherium minus, Vishnutherium iravaticum, Hydapsitherium megacephalum, Gazella lydekkeri, Miotragoceras punjabicus, Selenoportax vexillarius, Pachyportax latidens (8.1–9.23 Ma)

SOURCES: After Colbert (1935), Pilgrim (1939), Prasad (1970), Vasishat et al. (1978), Vasishat (1985), Nanda and Sehgal (2005), and Pillans et al. (2005).

the Jammu and Poanta regions (Gupta and Verma 1988; Nanda et al.1991). Gupta and Verma (1988) reported *Gomphotherium* (=*Trilophodon*) sp., *Gomphotherium* cf. *G. falconeri, Tetralophodon* cf. *T. iongirostris, Choerolophodon* (=*Synconolophus*) cf. *C. dhokpathanensis, Elephas* cf. *E. hysudricus*, and *Hippopotamodon* sp. from the Jammu region. Nanda and Sehgal (2007) opine that of the this assemblage only *C. dhokpathanensis* is characteristic of the Middle Siwaliks. On the other hand, Siwaliks exposed west of Paonta Saab have yielded typical Middle Siwalik *Hippopotamodon titan*, as well as *Hippohyus* cf. *H. grandis* and *Propotamochoerus* cf. *P. salinus* (Nanda et al.1991).

Upper Siwalik Localities Around Chandigarh

Several localities have yielded diverse fossil mammal assemblages around Chandigarh since the report of Colbert (1935; figure 17.7). Azzaroli and Napoleone (1982) were the first to put them in a chronological framework, followed by Tandon et al. (1984). A decade later, Ranga Rao et al. (1995) and Sangode, Kumar, and Ghosh (1996) carried out extensive magnetostratigraphic work in the Upper Siwaliks. The Haripur section has been well dated and has yielded large mammals and pollens (Sangode, Kumar, and Ghosh 1996; Phadtare et al. 1994; figure 17.8). Tuffaceous mudstone discovered from the Ghaggar river section (Tandon and Kumar 1984; Mehta et al. 1993) helped in placing the local magnetic reversals in the GPTS. Recently, Kumaravel et al. (2005) have provided the most comprehensive magnetostratigraphic data on sediments exposed around Chandigarh. The Tatrot Formation and Pinjor Formation boundary of the Indian Subcontinent is close, temporally, to the Gauss–Matuyama magnetic reversal dated to 2.58 Ma (Ranga Rao et al. 1995; Cande and Kent 1995). Tatrots are characterized by the presence of thin grey sandstones, variegated mudstones, and siltstones; this lithology gradually changes upward into brownish sandstones and mudstones characterizing the Pinjors. The Pinjor Formation and Boulder Conglomerate boundary has been found to be time

Table 17.3
Mammalian Species Recorded from Nurpur

Carnivorans	*Dissopsalis carnifex*, *Amphicyon palaeindicus*
Proboscidea	*Tetralophodon* sp., *Deinotherium* sp.
Perissodactyla	*Aceratherium perimense*, *Gaindatherium* sp., *Hipparion antelopinum*, *Cormohipparion theobaldi*
Artiodactyla	*Listriodon pentapotamiae*, *Propotamochoerus hysudricus*, *Sus* sp., *Hippopotamodon vinayaki*, *Anthracotherium* sp., *Merycopotamus dissimilus*, *Dorcabune* sp., *Dorcatherium majus*, *D. minus*, *D. nagrii*, *Giraffokeryx punjabiensis*, *Hydapsitherium megacephalum*, *Bramatherium megacephalum minus*, *Protragocerus gluten*

SOURCES: After Vasishat et al. (1983); Gaur et al. (1985); Nanda and Sehgal (1993); and Sehgal and Nanda (2002).

transgressive, ranging in age from 1.77 Ma to .63 Ma (Ranga Rao et al. 1988; Ranga Rao 1995; Nanda 2002; Kumaravel et al. 2005). An attempt has been made to integrate the mammalian faunal material to well-dated sections (see figure 17.8). The assemblages representing Tatrot and Pinjor formations are given in table 17.4.

Upper Siwalik Localities Around Jammu Region

Upper Siwalik exposures around Parmandal and Nagrota are fairly well studied for magnetostratigraphy, tephrochronology, and vertebrate paleontology (Yokoyama et al. 1987; Gupta and Verma 1988; Ranga Rao et al.1988; Agarwal et al. 1993; Nanda 1997, 2002; Basu 2004; Nanda and Sehgal 2005; see figure 17.9). Nagrota Formation deposits contain two volcanic tuff horizons, dated to 2.8 ± 0.56 Ma and 2.31 ± 0.54 Ma (Agarwal et al. 1993; Ranga Rao et al. 1988). *Anancus* sp., *Stegodon bombifrons*, *Stegodon insignis*, *Stegolophodon*, *Elephas planifrons*, *Hipparion antelopinum*, *Cormohipparion theobaldi*,

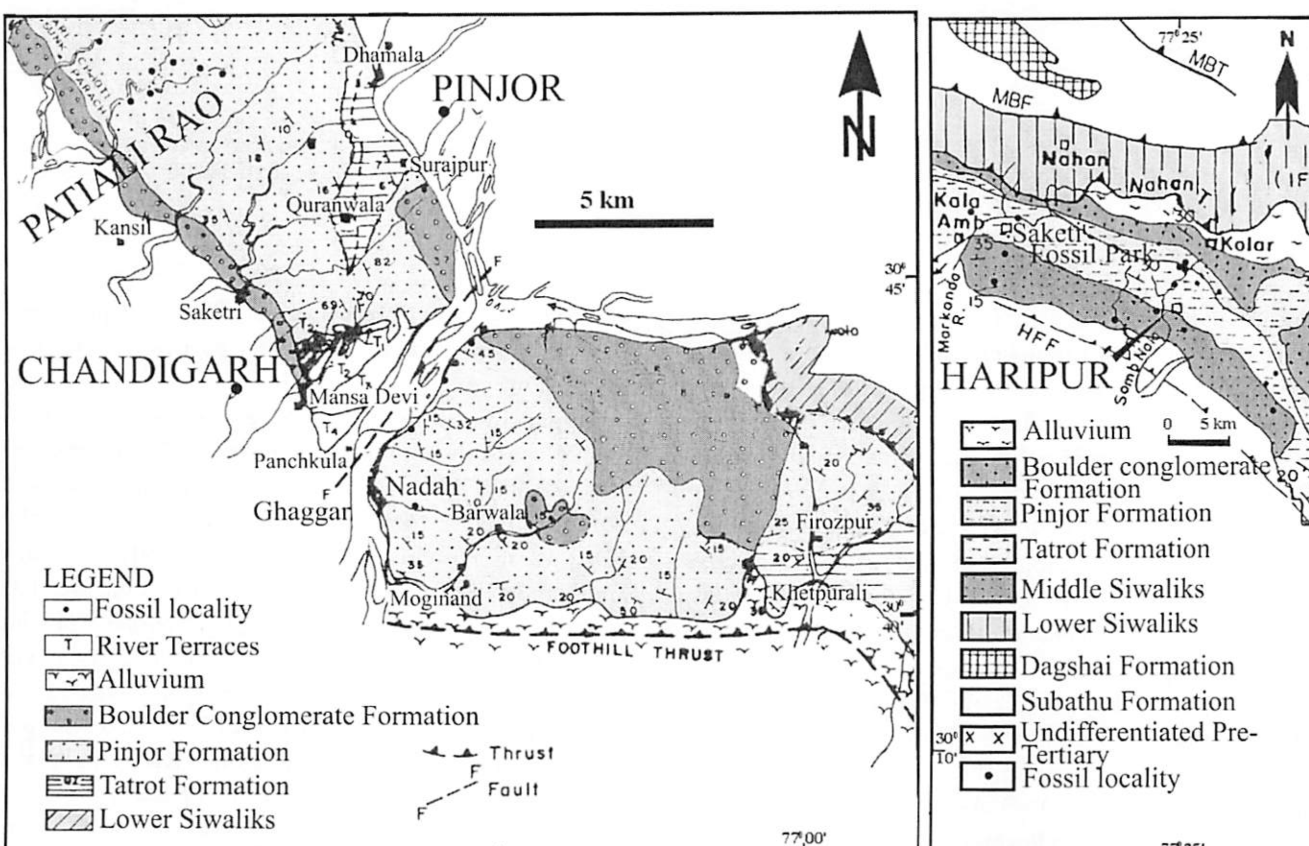

Figure 17.7 Geological map of the Chandigarh region and Haripur Khol area (modified after Sahni and Khan 1964, Nanda 2002, and Kumar et al. 2002).

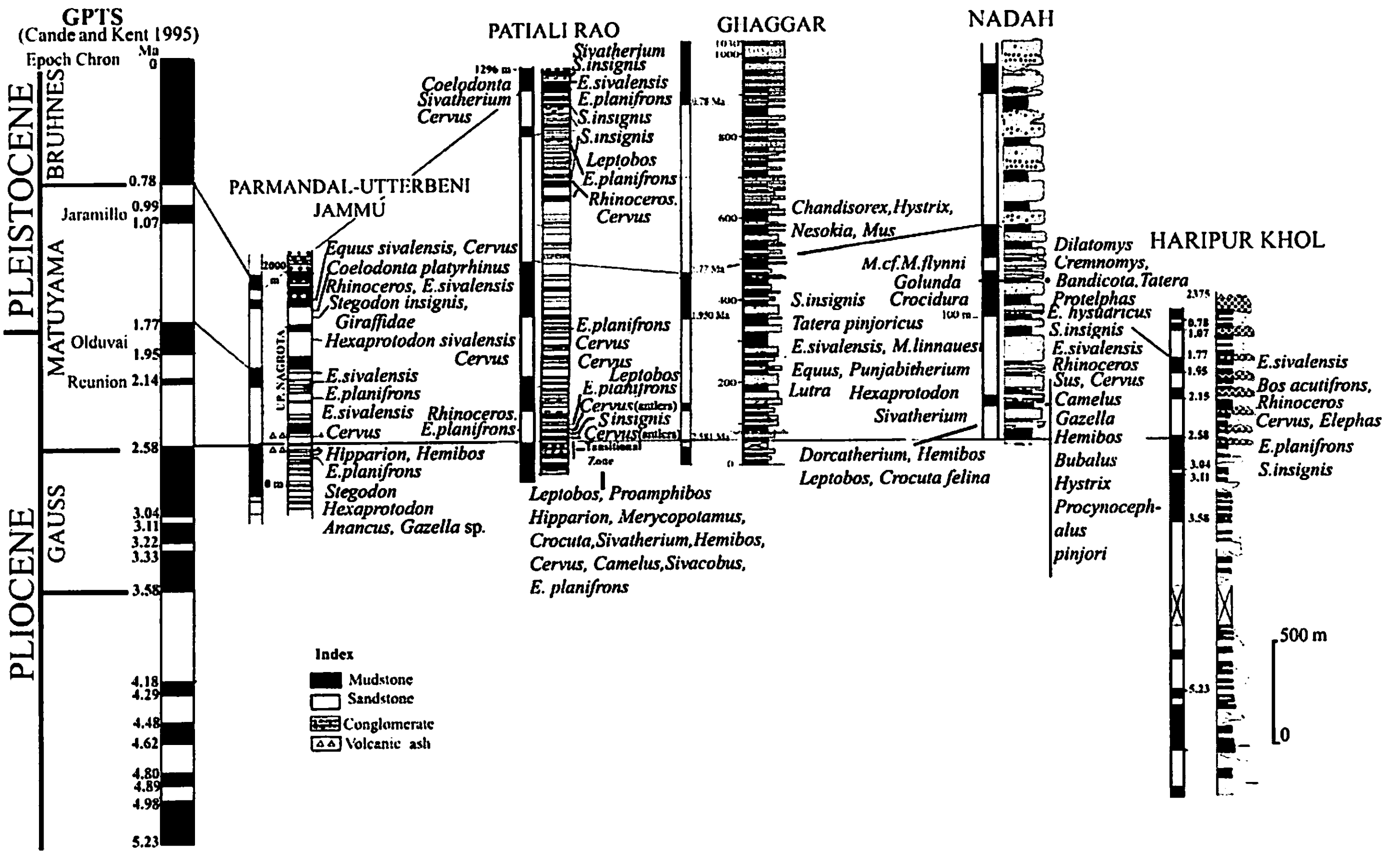

Figure 17.8 Dated Plio-Pleistocene Siwalik sections with mammal-bearing levels exposed near Jammu and Chandigarh. Modified after Patnaik and Nanda (2011) and data compiled from Azzaroli and Napoleone (1982), Tandon et al. (1984), Ranga Rao et al. (1988, 1995), Agarwal et al. (1993), Sangode et al. (1996), and Kumaravel et al. (2005).

and *Propotamochoerus hysudricus* are some of the common taxa found in the lower part (Nanda and Kumar 1999; Basu 2004; Nanda and Sehgal 2005). The upper assemblage, above the tuffs, is a bit depleted in the number of proboscidean remains, with only *Elephas hysudricus*, *E. planifrons*, and *Stegodon insignis* (Basu 2004). Other taxa characterizing the upper zone are *Equus sivalensis*, *Hemibos acuticornis*, *Antilope* sp., *Cervus* sp., *Rhinoceros* sp., *Coelodonta* sp., *Sivatherium giganteum*, *Panthera* sp., *Viverra* sp., *Crocuta feline*, and *Hexaprotodon* (Agarwal et al.1993; Ranga Rao et al.1988; Basu 2004). Agarwal et al. (1993) correlated the lower and upper faunal zones of the Nagrota Formation to the Tatrot faunal zone (Potwar Plateau, Pakistan) and the Pinjor faunal zone (Indian Siwaliks). Basu (2004) observed that the lower faunal zone of the Nagrota Formation correlates partly with the *Hexaprotodon sivalensis* Interval Zone and partly with the *Elephas planifrons* Interval Zone proposed by Barry, Lindsay, and Jacobs (1982). Basu (2004) went on to propose a new interval zone, the *"Antilope-Equus-Bovine"* faunal zone for the upper part of the Nagrota Formation.

Upper Siwalik mammals have also been recovered from Nepal sub-Himalayan exposures. These areas are Rato Khola, Gidhniya-Surai Khola, and the Lokundol Formation of Kathmandu Valley (West and Munthe 1981; West, Hutchison, and Munthe 1991; Corvinus and Nanda 1994; West 1996). The Rato Khola area has yielded pre-Pinjor fauna, including *Stegodon bombifrons*, *Elephas planifrons*, ?*Stegotetrabelodon*, *Hippohyus tatroti*, *H. sivalensis*, and *Proamphibos* cf. *P. lachrymans* (Corvinus and Rimal 2001; Corvinus 2006). The upper part of the Upper Siwalik succession at Rato Khola falls into the *E. planifrons* Interval Zone of Barry, Lindsay, and Jacobs (1982), according to Corvinus and Rimal (2001) and Corvinus (2006). The lower boundary of this interval zone is 3.4 Ma (Flynn et al., chapter 14, this volume).

Table 17.4
Mammalian Species Recovered from Upper Siwaliks of Chandigarh and Jammu Region

Primates	*Procynocephalus pinjori, Theropithecus delsoni*
Insectivora	*Chandisorex punchkulaensis, Crocidura* sp.
	Crocidura sp.*
Rodentia	*Hystrix leucurus, Mus linnaeusi, Mus* cf. *M. flynni, Hadromys* sp., *Cremnomys* cf. *C. blanfordi, Tatera pinjoricus, "Rhizomys" pinjoricus, Dilatomys sp., Golunda* sp., *Bandicota* sp.
	*Rhizomyides saketiensis**, *R. sivalensis**, cf. *R. sivalensis**, *Mus flynni**, cf. *M. flynni**, *M. jacobsi**, *Parapelomys robertsi**, cf. *P. robertsi**, *Cremnomys* cf. *C. cuthicus**, *Bandicota sivalensis**, *Golunda tatroticus**, *G. kelleri**, *Dilatomys moginandensis**, *D. pilgrimi**, *Millardia* sp.*, *Abudhabia* cf. *A. kabulense**, *Hystrix* sp.*
Lagomorpha	*Caprolagus* sp.
	*Pliosiwalagus whitei**
Carnivora	*Canis pinjorensis. Mellivora sivlensis, Crocuta felina, C. colivini, Panthera* cf. *P. cristata, Lutra palaeindica, Amblonyx* sp.
Proboscidea	*Pentalophodon sivalensis, Stegolophodon stegodontoides, Elephas hysudricus, Elephas planifrons, Elephas platycephalus, Stegodon insignis*
	*Pentalophodon khetpuraliensis**, *Stegodon bombifrons**, *Stegodon insignis**, *Stegodon* sp., **Stegolophodon* sp.*, *Elephas planifrons**, *Elephas hysudricus**, *Anancus* sp.*
Perissodactyla	*Equus sivalensis, Coelodonta platyrhinus, Rhinoceros palaeindicus, Rhinoceros sivalensis*
	*Rhinoceros palaeindicus**, *Rhinoceros* sp.*, *Coelodonta* sp.*, *Coelodonta platyrhinus**, *Chilotherium intermedium**, *Cormohipparion theobaldi**, C. sp.*, *Hipparion antelopinum**, *Hipparion* sp.*
Artiodactyla	*Potamochoerus theobaldi, Propotamochoerus hysudricus, Sus falconeri, S. hysudricus, S. choprai, S. giganteus, Hippohyus sivalensis, Hexaprotodon sivalensis, Rucervus simiplicidens, Cervus punjabiensis. Sivatherium giganteum, Sivacapra subhimalayaensis, Oryx sivalensis, Damalops palaeindicus, Sivacobus palaeindicus. Hemibos acuticornis, H. triquetricornis, H. antilopinus, Bubalus palaeindicus, B. platyceros, Leptobos falconeri, Bison sivalensis, Bos acutifrons, Camelus sivalensis*
	*Merycopotamus dissimilus**, *Hippohyus tatroti**, *Proamphibos kashmiricus**, *Probison dehmi**, *Cervus* sp.*, *Sivatherium giganteum**, *Hemibos triquetricornis**, *Bos* sp.*, *Sivacapra* sp.*, *Propotamochoerus* sp.*, *P. hysudricus**, *Hemibos acuticornis**, *Gazella* sp.*, *Hippohyus* sp.*, *Hexaprotodon sivalensis**, *Cervus* cf. *punjabicus**, *Camelus* sp.*, *C. sivalensis**, *Sivachoerus* sp.*, *Hydaspitherium megacephalum**

NOTE: * = taxa that occur in sediments older than 2.6 Ma.
SOURCES: After Gaur (1987), Yokoyama et al. (1987), Gupta and Verma (1988), Ranga Rao et al. (1988), Nanda (1997, 2002), Nanda and Kumar (1999), Gupta and Prasad (2001), Basu (2004), Nanda and Sehgal (2005, 2007), and Patnaik and Nanda (2010).

Other mammal occurrences including *Elephas hysudricus, Equus sivalensis, Cervus* sp., *Potamochoerus palaeindicus,* cf. *P. theobaldi,* and *Hemibos* cf. *H. acuticornis* have been assigned as "Pinjor Fauna" (Nanda 2002).

DISCUSSION

Gaps in the Fossil Record

The present assessment recognizes several gaps in the Indian Siwalik fossil record. Ramnagar can now be regarded as the oldest locality yielding a diverse mammalian assemblage. Based on the rodent biochronology established in Pakistan, the Ramnagar locality can now be placed safely in the middle Miocene, in the ~13.2 to ~13.8 Ma range (see figure 17.4). With this age estimation, the first appearance of *Sivapithecus* in the Siwaliks may be older than that perceived in Pakistan, about ~13.2 Ma (Sehgal and Patnaik 2011). However, this is still within the inferred maximum limit (14 Ma) of the *Sivapithecus* FAD (Barry et al. 2002; Badgley et al. 2008). The Nurpur assemblage represents a small window, probably around 9.7 Ma to 10.1 Ma. This estimate accords with age

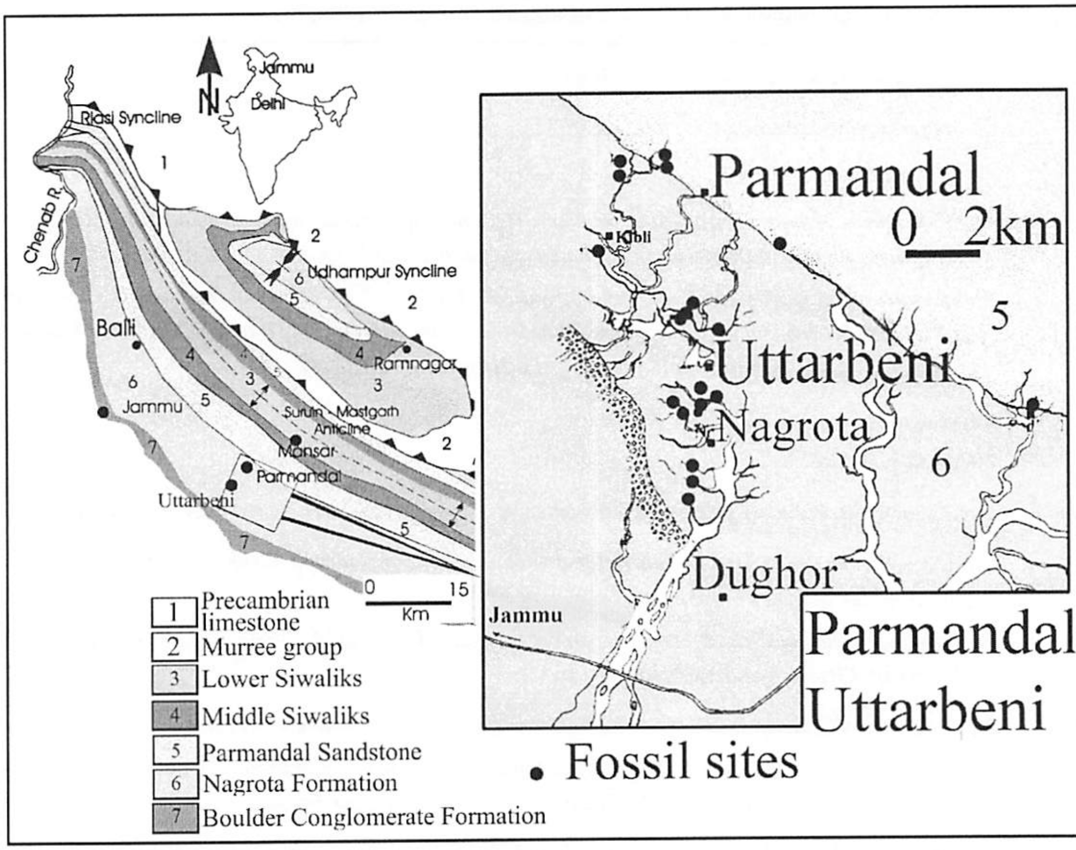

Figure 17.9 Location and geological map of the Upper Siwaliks of Jammu sub-Himalaya (modified after Gupta and Verma 1988 and Basu 2004).

ranges (established in Pakistan; Barry et al. 2002) of the characteristic fauna it contains: *Hipparion* sp. (10.7–5.8 Ma), *Propotamochoerus hysudricus* (10.2–6.2 Ma), *Bramatherium megacephalum* (10.3–7.1 Ma), *Giraffokeryx punjabiensis* (13.6–10.4 Ma), *Dorcatherium majus* (10.4–7.0 Ma), *Dissopsalis carnifex* (16.3–9.1 Ma), and *Deinotherium* sp. (12.9–8.0 Ma). There exists in India a gap from ~12.5 Ma to ~10.1 Ma, apparently unrepresented by a mammalian record.

Combining the famous Haritalyangar sequence with the nearby Ladhyani site, the late Miocene fossil-producing interval has been constrained to between 10.1 Ma and 8.1 Ma. The age ranges of most mammals in the Haritalyangar assemblage compare very well with their age ranges observed in Pakistan (table 17.5), but there are some differences, mostly explained by incompleteness of the records in the two regions. In India, there is a late Neogene gap in the vertebrate record, without well-dated mammal assemblages between 8 Ma and 4 Ma. In the Potwar, late Neogene deposits are poorly represented, but the Upper Siwalik record of India, combining both the Jammu and Chandigarh regions, is fairly continuous and well represented from ~4 Ma to .78 Ma. Some remaining differences in taxon ranges are noted here.

Comparison with the Potwar Record

As better chronology of the fauna has been achieved by recent magnetostratigraphic data from India, the mammalian record of India has started to tally fairly well with the observed Pakistan Neogene Mammalian Biochronology (see table 17.5). However, several differences exist between these two regions. For example, the last appearance of *Sivaladapis palaeindicus* in India extends to 9.1 Ma, whereas in Pakistan its range stops at 11.5 Ma (Flynn and Morgan 2005). *Sivapithecus parvada* has not been found in India, and *Sivapithecus simonsi* is yet to be recorded reliably from Pakistan. There is a good match in murine rodent content, but there are several cricetid taxa known from Pakistan yet to be recovered from India.

Table 17.5
First and Last Occurrences Observed in India for Common Mammalian Taxa, Compared with Ranges Observed in Pakistan

	Species	FO Indian	LO Siwaliks	FO Pakistan Siwaliks	LO
	Primates				
1	*Sivapithecus indicus/sivalensis*	~13	8.85	12.5	8.5
2	*Sivapithecus* cf. *simonsi*	~13.2	8.85		
3	*Sivaladapis palaeindicus*	13	9.1	15.6	11.5
4	*Palaeotupaia sivalicus*	9.1	9.1		
5	Tupaiidae spp.			13	8.1
	Rodentia				
	Ctenodactylidae				
6	*Sayimys perplexus*	9.1	9.1	~18	9.1
7	*Sayimys sivalensis*	13	~9	15.2	12.7
8	*Sayimys chinjiensis*			12.3	10.0
	Rhizomyidae				
9	*Kanisamys indicus*	9.1	9.1	17	10.8
10	*Kanisamys nagrii*	9.1	9.1	11.5	9.6
11	*Kanisamys sivalensis*	9.1	9.1	9.3	7.3
12	*Kanisamys* cf. *potwarensis*	~13.2	~13.2	14.3	13.2
13	*Rhizomyides sivalensis*	9.1	8.9	7.1	6.4
14	*Miorhizomys nagrii*	9.2	9.2	11.5	9.6
15	*Rhizomyides punjabiensis*	~10.0	~10.0	10.4	10.2
16	*Miorhizomys choristos*	9.0	9.0	8.4	8.2
17	*Miorhizomys tetracharax*	9.0	9.0	9.3	7.9
18	*Miorhizomys micrus*	9.2	9.2	9.2	9.2
	Muroidea				
19	*Antemus chinjiensis*	~13	~13	13.8	12.7
20	*Progonomys debruijni*	8.9	8.9	9.3	8.9
21	*Parapelomys robertsi*	8.9	~2.5	7.0	6.4
22	*Karnimata darwini*	8.9	8.9	9.3	8.9
23	*Mus jacobsi*	2.5	2.5		
24	*Mus flynni*	2.5	1.8		
25	*Golunda kelleri*	2.5	2.5	3	2
26	*Golunda* sp.	2.5	2.5		
27	*Hadromys* sp.	1.8	1.8	3	3
28	*Hadromys loujacobsi*			2	1.7
29	*Cremnomys* sp.			2	2
30	*Cremnomys* cf. *C. cutchicus*	4	1.8		
31	*Dakkamys nagrii*	9	9		
32	*Megacricetodon* cf. *sivalensis*	~13	~13	16.1	13
33	*Dakkamys asiaticus*			11.5	10.4
	Leporidae				
34	*Pliosiwalagus whitei*	~4	2.5		
35	*Alilepus* sp.			7.4	6.5
	Carnivora				
36	*Dissopsalis carnifex*	13	9.8	16.3	9.1
37	*Percrocuta carnifex*	13	13	12.7	9.0

(continued)

Table 17.5
(continued)

	Species	FO Indian	LO Siwaliks	FO Pakistan Siwaliks	LO
38	*Panthera*	2	2		
39	*Panthera uncia*			1	1
40	*Panthera* cf. *cristata*	2	2		
41	*Mellivora sivalensis*	2	2		
42	*Crocuta colivini*	2	2		
43	*Crocuta felina*	2	2		
44	*Crocuta crocuta*			1	1
45	*Canis pinjorensis*	1.5	1.5		
46	*Canis cautleyi*			1.8	1.8
	Proboscidea				
47	*Prodeinotherium* sp.	~12.5	~12.5		
48	*Deinotherium pentapotamiae*	13	13	18.3	6.9
49	*Deinotherium* sp.	13	9.8	12.9	8.0
50	*Choerolophodon* cf. *dhokpathanensis*	8.9	8.6		
51	*Choerolophodon corrugatus*			13.5	6.5
52	*Stegodon* sp.	3.4	1.5	1.8	.78
53	*Stegolophodon stegodontoides*			13.5	4.2
54	*Elephas hysudricus*			1.7	1
	Perissodactyla				
	Rhinocerotidae				
55	*Brachypotherium perimense*	13.2	13.2	16.0	7.1
56	*Brachypotherium sp.*	13	13		
57	*Chilotherium intermedium*	3	3	16.3	7.6
58	*Chilotherium sp,*	13.2	13.2		
59	*Gaindatherium* spp.	13	13	16.0	7.3
60	*Gaindatherium browni*	12.7	8.85		
61	*Gaindatherium vidali*			11.5	8.1
62	*Chalicotherium sp.*	13.2	13.2		
63	*Chalicotherium salinum*			12.9	8.0
64	*Aceratherium perimense*	13	9.8		
65	*Rhinoceros palaeindicus*	3	1.5		
66	*Rhinoceros sivalensis*	2	1	1.7	1
	Equidae				
67	*Hipparion antilopinum*	9.8	3		
68	*Cormohipparion theobaldi*	9.8	3		
69	*Hipparion* spp.			10.7	5.8
70	*Hipparion* sp.	3	2.5	2.5	1.6
71	*Cormohipparion* sp.	3	2.5		
72	*Equus sivalensis*	2.5	.78	2.5	.78
	Artiodactyla				
	Suidae				
73	*Conohyus sindiensis*	13.6	12.7	13.1	10.3
74	*Hippopotamodon sivalense*			10.2	7.2
75	*? Hippopotamodon* Y450 sp. indet			11.2	10.2
76	*Hippopotamodon haydeni*	13	13		
77	*Hippopotamodon vagus*	9.23	8.85		
78	*Hippopotamodon robustus*	9.23	8.85		

Table 17.5
(continued)

	Species	FO Indian	LO Siwaliks	FO Pakistan Siwaliks	LO
79	*Tetraconodon magnus*			10.0	9.3
80	*Tetraconodon mirabilis*	9.23	8.1		
81	*Listriodon pentapotamiae*	13.6	9.8	13.7	10.3
82	*Propotamochoerus* sp.	13	3	5.8	5.1
83	*Propotamochoerus hysudricus*	9.8	1.5	10.2	6.8
84	*Sus* sp.	13	9.8	6.4	3.3
	Tragulidae				
85	*Dorcabune nagrii*	13.6	12.8	10.4	8.5
86	*Dorcabune anthracotheroides*	13.2	12.9	12.8	10.5
87	*Dorcatherium nagrii*	13.6	12.8	9.3	6.8
88	*Dorcatherium minus*	9.23	8.1	13.9	11.5
89	*Dorcatherium majus*	13	13	10.4	7.0
	Antrhacotheriidae				
90	*Anthracotherium punjabiense*	9.23	8.85	~18	8.3
91	*Hemimeryx pusillus*	13.2	12.8	18	5.5
92	*Hemimeryx* spp.			13.6	6.2
93	? *Merycopotamus dissimilus*			5.8	3.3
94	*Merycopotamus dissimilus*	13	3	13.9	3.3
95	*Hexaprotodon sivalensis*	4	1.5	5.9	3.5
	Giraffidae				
96	*Sivatherium giganteum*	2.5	.75	2.2	1.7
97	*Giraffokeryx punjabiensis*	13.6	9	13.6	10.3
98	*Giraffa punjabiensis*			8.9	7.2
99	*Bramatherium megacephalum*	9.8	9.8	10.3	7.1
	Bovidae				
100	*Gazella lydekkeri*	9.23	8.1	10.2	6.1
101	*Gazella* spp.	13	3	11.3	6.2
102	*Dorcadoxa porrecticornis*	9	9	9.3	8.0
103	*Tragoceridus* spp.			11.2	6.2
104	*Pachyportax nagrii*	9.23	8.85		
105	*Pachyportax sp.*			7.3	7.2
106	*Protragoceras gluten*	13.6	9.8	13.9	10.8
107	*Kubanotragus sokolovi*	13	13	13.8	13.8
108	*Helicoportax tragelophoides*	13.6	12.6	13.1	10.8
109	*Selenoportax vexillarius*	9.23	8.10	10.2	9.8
110	*Selenoportax falconeri*			9.5	8.9
111	*Selenoportax* spp.			10.2	7.9
112	*Selenoportax giganteus*			8.8	7.1
113	*Hemibos acuticornis*	3	1.5		
114	*Hemibos triquetricornis*	3	3	2.2	.78
115	*Damalops (Proamphibos) palaeindicus*	2	.78	2.2	.78
116	*Proamphibos*	3.5	2.5	2.5	1.6
117	*Proamphibos kashmiricus*	3	3		
118	*Bubalus (Hemibos) palaeindicus*	1.5	1.5		
119	*Gazella* sp.	13	3	1.9	.78
120	*Cervus* sp.	3	1.5	2.5	1.6

SOURCES: First and last occurrence data from Pakistan are from Barry et al. (2002) and Badgley et al. (2008).

A recent revision of the Upper Siwalik biostratigraphy of Pakistan by Dennell, Coard, and Turner (2006) revealed some regional differences with India (figures 17.10 and 17.11). For example, *Theropithecus* and *Camelus* occur in India but appear to be absent from Pakistan. Dennell, Coard, and Turner (2006) perceived the absence of *Megantereon, Pachycrocuta, Ursus,* and anthracotheres from the Indian part, whereas they have confirmed records in Pakistan. In contrast, it may be noted that *Megantereon falconeri, Pachycrocuta, Ursus,* and the anthracothere *Merycopotamus dissimilis* have been reported from India (Colbert 1935; Gaur 1987; Lihoreau et al. 2007), but probably some of these records need taxonomic review. The baboon *Procynocephalus subhimalayanus* from the Pinjor deposits of India (Verma 1969; Szalay and Delson 1979) has not been found in Pakistan. Nevertheless, the well-dated mammalian localities in India can now be correlated with those of Pakistan on a nonarbitrary footing (see figure 17.10).

Climate Change vs. Major Faunal Turnover

The great mammalian diversity observed in the Ramnagar and Haritalyangar localities (see tables 17.1 and

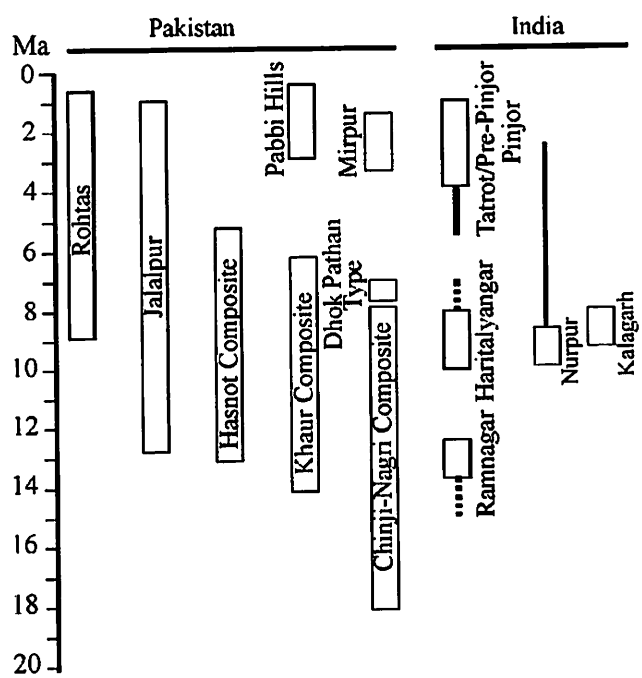

Figure 17.10 Stratigraphic correlation of important mammal-yielding dated sections in Pakistan and India (modified after Barry 1995). Empty boxes denote known dated mammal occurrences, dark solid bands denote dated sequence but no mammalian assemblages, and dashed bands represent possible age extension.

17.2) does not extend to sediments younger than 7 Ma. Relatively few taxa, such as *Hipparion, Propotamochoerus, Stegolophodon, Anancus, Dorcatherium, Gazella, Merycopotamus,* and *Parapelomys,* characterize the Late Miocene. This cannot be demonstrated in the Indian region, as there is a lack of well-dated localities, but a far better record for this interval available from Pakistan attests to such a faunal change (Barry et al. 2002; Badgley et al. 2008). The kind of resolution Barry et al. (2002) observed in interpreting three very brief periods of high Siwalik faunal turnover at 10.3 Ma, 7.8 Ma, and 7.37–7.04 Ma cannot be achieved in the Indian context at the moment due to gaps among well-dated fossil sites. Paleosol and paleobotanical data suggest warm and humid climatic conditions and evergreen to deciduous tropical forests covering a large part of the northwestern Indian Subcontinent in the Middle Miocene (Prasad 1993; Ashton and Gunatilleke 1987; Nanda and Sehgal 1993; Thomas, Parkash, and Mohindra 2002). The advent of Late Miocene global cooling and the spread of drier conditions caused the forests to shrink (Scott, Kappelman, and Kelley 1999; Kennett and Hodell 1986). An intensification of the Asian monsoon due to late Miocene Tibetan-Hiamlayan uplift would also have contributed to this ecological change (Ruddiman and Kutzbach 1989; Raymo and Ruddiman 1992; Kutzbach, Prell, and Ruddiman 1993; Hay 1996; Ramstein et al. 1997), which eventually led to the replacement of subtropical to temperate broadleafed and tropical forest taxa by grasslands through the late Late Miocene (~8–6.5 Ma; Hoorn, Ojha, and Quade 2000). The Siwalik palaeosols showed marked seasonality in rainfall in the Late Miocene (Retallack 1991, 1995), and their stable isotope content reflected presence of a C3 dominant vegetation prior to 8 Ma and a C4 grass dominated landscape by 7 Ma (Quade et al. 1989; Cerling et al. 1997).

A distinct faunal as well as floral turnover is observed at the Gauss-Matuyama boundary, coinciding with the Tatrot–Pinjor boundary in India (Ranga Rao et al. 1988; Verma 1988; Phadatre, Kumar, and Ghosh 1994; Nanda and Sehgal 2005). In the Haripur locality, Phadatre, Kumar, and Ghosh (1994) noticed dominance of a piedmont drainage system and the first appearance of prominent conglomerate facies in the Pinjor lithology. Also, at around 2.4 Ma, volcanic ash beds (tuffaceous mudstones/bentonitic clays) have been found near the Rohtas anticline, Chambal, Mangla Samwal, Jehl Kas, and Bhimbur (Pakistan; Opdyke et al. 1979), Jammu, Chandigarh, Kala Amb, and Haripur (India; Tandon and Kumar 1984; Patnaik 1995; Phadatre, Kumar, and Ghosh 1994). This time coincides with disappearance of *Hipparion* and

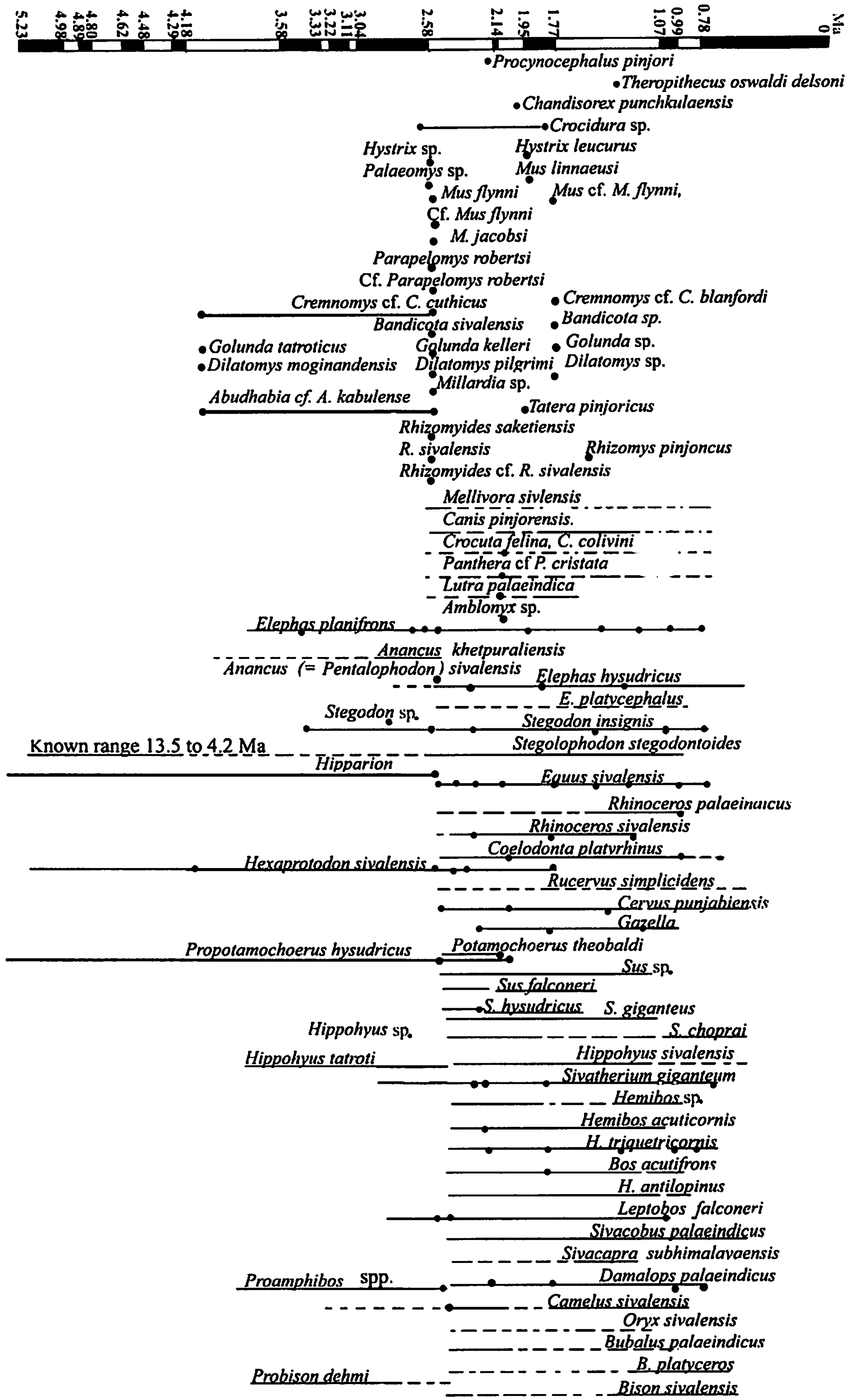

Figure 17.11 Temporal ranges of various Plio-Pleistocene Siwalik mammals of Indo-Pakistan (data from Nanda 2002, Dennell 2004, and Dennell et al. 2006). Filled dots represent known sites, complete lines represent known ranges, and dotted lines represent uncertain ranges.

the appearance of *Equus*. Several modern carnivore forms appear in Pinjor beds, and murine rodents, especially living genera, diversified around this time (see figure 17.11). At about this time (2.6 Ma), a global change toward a cooler, drier, and more variable climate associated with the Northern Hemisphere glaciations has been observed (Mangerud et al. 1996; Williams et al. 1999), and in Africa a major turnover in land mammals occurred after 2.5 Ma (Behrensmeyer et al. 1997). Also, monsoonal circulation was also greatly strengthened by the Plio-Pleistocene uplift of the Himalaya (Dewey et al. 1988).

CONCLUSION

Though gaps occur in the Neogene mammal record of India, notably the ~12.5 Ma to ~10.1 and ~8 Ma to ~4 Ma intervals, the present reassessment of Indian Siwalik biochronology has allowed a better correlation with the already well-established Pakistan biochronology. Comparison of these two regions reveals that the observed age ranges of almost 100 taxa overlap (see table 17.5). The rodent biochronology of the Lower Siwalik Ramnagar locality has constrained its age between ~13.2 Ma and ~13.8 Ma, which may indicate an older first appearance datum for *Sivapithecus* than previously in evidence. Two major faunal turnovers have been identified, one in the Late Miocene, around 8 Ma, and the other one after 2.6 Ma, coinciding fairly well with global tectonic and climate changes.

ACKNOWLEDGMENTS

I would like to extend my gratitude to the organizers of the Asian Mammalian Biochronology Workshop, particularly to Drs. Xiaoming Wang, Larry Flynn, and Mikael Fortelius for inviting me to present this work. I would like to thank Dr. Larry Flynn, who encouraged me to write this paper and very kindly helped improve the manuscript. Financial support by DST, New Delhi, to the ongoing Siwalik project (SR/S4/ES-171/2005 and PURSE) and by Wenner-Gren Foundation to the Pinjor Primate Project is thankfully acknowledged.

REFERENCES

Agarwal, R. P., A. C. Nanda, D. N. Prasad, and B. K. Dey. 1993. Geology and biostratigraphy of the Upper Siwalik of Samba area, Jammu Foothills. *Journal of Himalayan Geology* 4:227–236.

Ashton, P. S. and C. V. S. Gunatilleke. 1987 New light on the plant geography of Ceylon, Historical plant geography. *Journal Biogeography* 14:249–285.

Azzaroli, A. and G. Napoleone. 1982. Magnetostratigraphic investigation of the Upper Siwaliks near Pinjor, India. *Rivista Italiana di Paleontoligia e Stratigrafia* 87:739–762.

Badgley, C., J. C., Barry, M. E., Morgan, S. V., Nelson, A. K., Behrensmeyer, T. E., Cerling, and D. Pilbeam. 2008. Ecological changes in Miocene mammalian record show impact of prolonged climatic forcing. *Proceedings of the National Academy of Sciences* 105(34):12145–12149.

Badgley, C. and A. K. Behrensmeyer. 1980. Palaeoecology of Middle Siwalik sediments and faunas, northern Pakistan. *Palaeogeography, Palaeoclimatology, Palaeoecology* 30:133–155.

Badgley, C., S. Nelson, J. C. Barry, A. K. Behrensmeyer, and T. E. Cerling. 2005. In *Interpreting the Past: Essays on Human, Primate, and Mammal Evolution*, ed. D. E. Lieberman, R. H. Smith, and J. Kelley, pp. 29–46. Boston: Brill Academic Publishers.

Barry, J. C. 1995. Faunal turnover and diversity in the Terrestrial Neogene of Pakistan. In *Paleoclimate and Evolution with Emphasis on Human Origins*, ed. E. S. Vrba, G. H. Denton, T. C. Partridge, and L. H. Burckle, pp. 115–134. New Haven: Yale University Press.

Barry, J. C. and L. J., Flynn. 1990. Key biostratigraphic events in the Siwalik sequence. In *European Neogene Mammal Chronology*, ed. E. H. Lindsay, V. Falbusch, and P. Mein, pp. 557–571. New York: Plenum Press.

Barry, J. C., E. H. Lindsay, and L. L. Jacobs. 1982. A biostratigraphic zonation of the Middle and Upper Siwaliks of the Potwar Plateau of northern Pakistan. *Palaeogeography, Palaeoclimatology, Palaeoecology* 37:95–130.

Barry, J. C., N. M. Johnson, S. M. Raza, and L. L. Jacobs. 1985. Neogene mammalian faunal change in southern Asia: Correlations with climatic, tectonic, and eustatic events. *Geology* 13:637–640.

Barry, J. C., M. E. Morgan, L. J. Flynn, D. Pilbeam, A. K. Behrensmeyer, S. M. Raza, I. Khan, C. Badgley, J. Hicks, J. Kelley. 2002. Faunal and Environmental change in the Late Miocene Siwaliks of Northern Pakistan. *Paleobiology* 28(*Memoir* 3):1–71.

Basu, P. K. 2004. Siwalik mammals of the Jammu Sub-Himalaya, India: An appraisal of their diversity and habitats. *Quaternary International* 117:105–118

Behrensmeyer, A. K., B. J. Willis, and J. Quade. 1995. Floodplains and paleosols of Pakistan Neogene and Wyoming Paleogene deposits: A comparative study. *Palaeogeography, Palaeoclimatology, Palaeoecology* 115:37–60.

Behrensmeyer A. K., N. E. Todd, R. Potts, and G. E. McBrinn. 1997. Late Pliocene Faunal Turnover in the Turkana Basin, Kenya and Ethiopia. *Science* 278(5343):1589–1594

Brown, B., W. K. Gregory, M. Hellman.1924. On three incomplete anthropoid jaws from the Siwaliks, India. *American Museum Novitates* 130:1–8.

Brozovic, N. and D. W. Burbank, 2000. Dynamic fluvial systems and gravel progradation in the Himalayan foreland. *Geological Society of America Bulletin* 112:394–412.

Cande, S. C. and D. V. Kent. 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research* 100:6093–6095.

Cerling, T. E., J. M. Harris, M. G. MacFadden, M. G. Leakey, and J. Quade. 1997. Global vegetation change through the Miocene/Pliocene boundary. *Nature* 389:153–158

Chopra, S. R. K. and S. Kaul. 1979. A new species of *Pliopithecus* from the Indian Siwaliks. *Journal of Human Evolution* 8:475–477.

Chopra, S. R. K. and R. N. Vasishat. 1979. Siwalik fossil tree shrew from Haritalyangar, India. *Nature* 281:214–215.

Colbert, E. H. 1935. Siwalik mammals in the American Museum of Natural History. *Transactions of the American Philosophical Society* 26:1–401.

Corvinus, G. 2006. The Siwalik stratigraphy of Surai Khola, Nepal: a reevaluation of the stratigraphy and original road traverse. *Himalayan Geology* 27:41–71.

Corvinus, G. and A.C. Nanda. 1994. Stratigraphy and palaeontology of the Siwalik Group of Surai Khola and Rato Khola in Nepal. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen* 191:25–68.

Corvinus, G. and L. N. Rimal. 2001. Biostratigraphy and geology of Neogene Siwalik Group of Surai Khola and Rato Khola areas in Nepal. *Palaeogeography, Palaeoclimatology, Palaeoecology* 165:251–279.

Dennell, R. W. 2004. Early Hominin Landscape in the Northern Pakistan. Investigations in the Pabbi Hills. *BAR International Series* 1265:1–454.

Dennell, R.W., R. Coard, and A. Turner. 2006. The biostratigraphy and magnetic polarity zonation of the Pabbi Hills, northern Pakistan: An Upper Siwalik (Pinjor Stage) Upper Pliocene–Lower Pleistocene fluvial sequence. *Palaeoecology, Palaeoclimatology, Palaeogeography* 234:168–185.

Dewey, J. F., R. M. Shakelton, C. Chengfa, and S. Yiyin. 1988. The tectonic evolution of the Tibetan Plateau. *Philosophical Transactions of the Royal Society London* A327:379–413.

Dutta, A. K., P. K. Basu, and M. V. A. Sastri. 1976. On the new finds of hominoids and additional finds of Pongidae from the Siwaliks of Ramnagar area, Udhampur district, J and K State. *Indian Journal of Earth Science* 3:234–235.

Flynn, L. J., J. C. Barry, M. E. Morgan, D. Pilbeam, L. L. Jacobs, and E. H. Lindsay. 1995. Neogene Siwalik mammalian lineages: Species longevities, rates of change and modes of speciation. *Palaeogeography, Palaeoclimatology, Paleoecology* 115:249–264.

Flynn, L. J. and L. L., Jacobs. 1982. Effects of changing environments on Siwalik rodent faunas of northern Pakistan. *Palaeogeography, Palaeoclimatology, Palaeoecology* 38:129–138.

Flynn, L. J. and M. E. Morgan. 2005. New Lower Primates from the Miocene Siwaliks of Pakistan. In *Interpreting the Past: Essays on Human, Primate and Mammal Evolution*, ed. D. Lieberman, R. Smith, and J. Kelley, pp. 81–101. Boston: Brill Academic Publishers.

Flynn, L. J., A. Sahni, J. J. Jaeger, B. Singh, and S. B. Bhatia. 1990. Additional fossil rodents from the Siwalik Beds of India. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen* 93:7–20.

Gaur, R. 1987. *Environment and Ecology of Early Man in Northwest India*. Delhi: B. R. Publishing Corporation.

Gaur, R. and S. R. K. Chopra. 1983. Palaeoecology of the Middle Miocene Siwalik sediments of a part of Jammu and Kashmir State (India). *Paleogeography, Paleoclimatology, Palaeoecology* 43:313–327.

Gaur, R., R. N. Vasishat, and S. R. K. Chopra. 1985. New and additional fossil mammals from the Middle Siwaliks exposed at Nurpur, Kangra (HP) with remarks on Siwalik giraffids. *Journal of the Palaeontolological Society of India* 30:42–48

Gingerich, P. D. and A. Sahni. 1979. *Indraloris* and *Sivaladapis*: Miocene adapid primates from the Siwaliks of India and Pakistan. *Nature* 279:415–416.

Gingerich, P. D. and A. Sahni. 1984. Dentition of *Sivaladapis nagrii* (Adapidae) from the Late Miocene of India. *International Journal of Primatology* 5(1):63–79.

Gradstein, F. M., J. G. Ogg, and A. G. Smith. 2004. *A Geologic Time Scale 2004*. Cambridge: Cambridge University Press.

Gupta, S. S., and G. V. R., Prasad. 2001. Micromammals from the Upper Siwalik subgroup of the Jammu region, Jammu and Kashmir State, India: Some constraints on age. *Neues Jahrbuch für Geologie und Paläontologie* 220:153–187.

Gupta, S. S. and B. C. Verma, 1988. Stratigraphy and vertebrate fauna of the Siwalik Group, Mansar–Uttarbani section, Jammu District, J & K. *Journal of the Palaeontological Society of India* 33:117–124.

Jacobs, L. J. and L. J. Flynn. 2005. Of mice again: The Siwalik rodent record, murine distribution, and molecular clocks. In *Interpreting the Past: Essays on Human, Primate and Mammal Evolution*, eds. D. Lieberman, R. Smith, and J. Kelley, pp. 63–80. Boston: Brill Academic Publishers.

Johnson, G. D., N. D. Opdyke, S. K. Tandon, and A. C. Nanda. 1983. The magnetic polarity stratigraphy of the Siwalik Group at Haritalyangar (India) and a new last appearance datum for *Ramapithecus* and *Sivapithecus* in Asia. *Paleogeography, Paleoclimatology, Palaeoecology* 44:223–249.

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

Johnson, N. M., J. Stix, L. Tauxe, P. F. Cerveny, and R. A. K. Tahirkheli.1985. Paleomagnetic chronology, fluvial processes, and tectonic implications of the Siwalik deposits near Chinji village, Pakistan. *Journal of Geology* 93:27–40.

Hay, W. W. 1996. Tectonics and climate. *Geologische Rundschau* 85:409–437

Hoorn, C., T. Ojha, and J. Quade 2000. Palynological evidence for vegetation development and climatic change in the Sub-Himalayan Zone (Neogene, Central Nepal). *Palaeogeography, Palaeoclimatology, Palaeoecology* 163:133–161.

Karunakaran, C. and A. Ranga Rao. 1979. Status of exploration for hydrocarbon: The Himalayan region. *Geological Survey of India, Miscellaneous Publication* 41:1–66.

Keller, H. M., R. A. K. Tahirkheli, M. A Mirza, G. D. Johnson, N. M. Johnson, and N. D. Opdyke. 1977. Magnetic polarity stratigraphy of the Upper Siwalik deposits, Pabbi Hills, Pakistan. *Earth and Planetary Science Letters* 36:187–201.

Kennett, J. P. and D. A. Hodell. 1986. Major events in Neogene oxygen isotopic records. *South African Journal of Science* 82: 497–498

Kotlia, B. S., K. Nakayama, B. Phartiyal, S. Tanaka, M. S. Bhalla, T. Tokuoka, and R. N. Pande. 1999. Lithology and magnetostratigraphy of the upper Siwaliks. *Memoir of the Geological Society of India* 44:209–220.

Kumar, R., S. K. Ghosh, S.J Sangode, and V. C. Thakur. 2002. Manifestation of Intra-Foreland Thrusting in the Neogene Himalayan Foreland Basin Fill. *Journal of the Geological Society of India* 59:547–560.

Kumar, R. and S. K. Tandon. 1985. Sedimentology of Plio-Pleistocene late orogenic deposits associated with interplate subduction. The Upper Siwalik Subgroup of a part of Panjab Sub-Himalaya, India. *Sedimentary Geology* 42:105–158.

Kumaravel, V., S. J. Sangode, R. Kumar, and N. S. Siddaiah. 2005. Magnetic polarity stratigraphy of Plio-Pleistocene Pinjor Formation (type locality), Siwalik Group, NW Himalaya, India. *Current Science* 88(9):1453–1461.

Kutzbach, J. E, W. L. Prell, and W. F. Ruddiman. 1993. Sensitivity of Eurasian climate to surface uplift of the Tibetan Plateau. *Journal of Geology* 101:177–190

Lewis, G.E. 1934. Preliminary notices of new man-like apes from India. *American Journal of Science* 27:161–179.

Lihoreau, F., J. Barry, C. Blondel, Y. Chaimanees, J. J. Jaeger, and M. Brunet. 2007. Anatomical revision of the genus *Merycopotamus* (Artiodactyla; Anthracotheriidae): Its significance for Late Miocene Mammal dispersal in Asia. *Palaeontolgy* 50(20):503–524.

Mangerud, J., E. Jansen, and J. Y. Landvik. 1996. Late Cenozoic history of the Scadinavian and Barents Sea ice sheets. *Global Planetary Change* 12:11–26.

Medlicott, H. B. 1879. Manual of the Geology of India. *Geological Survey of India, Publication* 2:1–524.

Mehta, Y. P., A. K. Thakur, Nand Lal, B. Shukla, and S. K. Tandon. 1993. Fission track age of zircon separates of tuffaceous mudstones of the Siwalik Subgroup of Jammu Chandigarh sector of the Punjab Sub-Himalaya. *Current Science* 64:519–521.

Munthe, J., B. Dongol, J. H. Hutchison, W. F. Kean, K. Munthe, and R. M. West. 1983. New fossil discoveries from the Miocene of Nepal include a hominoid. *Nature* 303:331–333

Nanda, A. C. 1997. Comments on Neogene/Quaternary Boundary and associated faunas in the Upper Siwalik of Chandigarh and Jammu. In *Proceedings of the First Regional GEOSAS Workshop on Quaternary Geology of South Asia*, pp. 120–136. Madras, India: Anna University.

Nanda, A. C. 2002. Upper Siwalik Mammalian faunas of India and associated events. *Journal of Asian Earth Sciences* 21:47–58.

Nanda, A. C. and K. Kumar. 1999. *Excursion Guide. The Himalayan Foreland Basin (Jammu-Kalakot-Udhampur Sector).* Wadia Institute of Himalayan Geology, Special Publication 2:1–85.

Nanda, A. C., D. C. Sati, and G. S. Mehra. 1991. Preliminary report on the stratigraphy and mammalian faunas of the Middle and Upper Siwalik, west of Yamuna River, Paonta, Himachal Pradesh. *Journal of Himalayan Geology* 2(2):151–158

Nanda, A. C. and R. K. Sehgal. 1993. Siwalik mammalian faunas from Ramnagar (J & K) and Nurpur (H.P.) and lower limit of *Hipparion*. *Journal of the Geological Society of India* 42:115–134.

Nanda, A. C. and R. K. Sehgal. 2005. Recent advances in palaeontology and magnetostratigraphic aspects of the Siwalik group of Northwestern Himalaya. *Himalayan Geology* 26 (1):93–102.

Nanda, A. C. and R. K. Sehgal. 2007. Geology and Mammalian fauna of the Siwalik Group of India. In *Human Origins, Genome and People of India*, ed. A. R. Sankhyan and V. R. Rao, pp. 77–90. New Delhi: Allied Publishers Pvt. Limited.

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

Parkash, B., R. P. Sharma, and A. K. Roy. 1980. The Siwalik Group (molasse)-sediments shed by collision of continental plates. *Sedimentary Geology* 25:127–159.

Parmar, V. and G. V. R. Prasad. 2006. Middle Miocene rhizomyid rodent (Mammalia) from the Lower Siwalik Subgroup of Ramnagar, Udhampur District, Jammu and Kashmir, India. *Neues Jahrbuch für Geologie und Paläontologie Mh.* 6:371–384.

Patnaik, R. 1995. Micromammal-based palaeoenvironment of Upper Siwaliks exposed near Village Saketi, H.P. *Journal of the Geological Society of India* 46:429–437

Patnaik, R. and D. W. Cameron. 1997. New Miocene fossil ape locality, Dangar, Hari-Talyangar region, Siwaliks, northern India. *Journal of Human Evolution* 32:93–97.

Patnaik, R., D. Cameron, J. C. Sharma, and J. Hogarth. 2005. Extinction of Siwalik fossil apes: A review based on a new fossil tooth and on palaeoecological and palaeoclimatological evidence. *Anthropological Science* 113:65–72.

Patnaik, R. and A. C. Nanda. 2010. Early Pleistocene Mammalian Faunas of India and Evidence of Connections with Other Parts of the World. In *Out of Africa I: The First Hominin Colonization of Eurasia*, ed. J. Fleagle, J. Shea, F. E. Grine, A. L. Baden, and R. Leakey, pp. 129–143. Vertebrate Paleobiology and Paleoanthropology Series. New York Springer.

Phadatre, N. R., R. Kumar, and S. K. Ghosh. 1994. Stratigraphic palynology, floristic succession and the Tatrot/Pinjor boundary in Upper Siwalik sediments of Haripur Khol Area District Sirmuar (H.P.) India. *Himalayan Geology* 15:69–82.

Pilbeam, D., J. C. Barry, G. E. Meyer, S. M. I. Shah, M. H. L. Pickford, W. W. Bishop, H. Thomas, and L. L. Jacobs. 1977. Geology and paleontology of Neogene strata of Pakistan. *Nature* 270: 684–689.

Pilgrim, G. E. 1910. Preliminary note on a revised classification of the Tertiary freshwater deposits of India. *Record of the Geological Survey of India* 40:185–205.

Pilgrim, G. E. 1913. The correlation of the Siwaliks with mammal horizons of Europe. *Record of the Geological Survey of India* 43:264–326.

Pilgrim, G. E. 1939. The Fossil Bovidae of India. *Memoirs of the Geological Survey of India* (New Series) 26(1):1–356.

Pillans B., M. Williams, D. Cameron, R. Patnaik, J. Hogarth, A. Sahni, J.C. Sharma, F. Williams, and R. Bernor. 2005. Revised correlation of the Haritalyangar magnetostratigraphy, Indian Siwaliks: Implications for the age of the Miocene hominids *Indopithecus* and *Sivapithecus*, with a note on a new hominid tooth. *Journal of Human Evolution* 48:507–515.

Prasad, K.N. 1970. The vertebrate fauna from the Siwalik Beds of Haritalyangar, Himachal Pradesh. *Palaeontologia Indica* (New Series) 39:1–55.

Prasad, M. 1993. Siwalik (Middle Miocene) woods from the Kalagarh area in the Himalayan foot hills and their bearing on paleoclimate and phytogeography. *Review of Paleobotany and Palynology* 76:49– 82.

Quade, J. and T. E. Cerling 1995. Expansion of C4 grasses in the late Miocene of northern Pakistan: Evidence from paleosols. *Palaeogeography, Palaeoclimatology, Palaeoecology* 115:91–116.

Quade, J., T. E. Cerling, and I. R. Bowman. 1989. Development of the Asian monsoon revealed by marked ecologic shift in the latest Miocene of northern Pakistan. *Nature* 342:163–166.

Ramstein, G., F. Fluteau, J. Besse, and S. Joussaume. 1997. Effect of orogeny, plate motion and land-sea distribution on Eurasian climate change over the past 30 million years. *Nature* 386:788–795.

Ranga Rao, A. 1993. Magnetic polarity stratigraphy Upper Siwaliks in the NW Himalaya, India. *Current Science* 64:863–873.

Ranga Rao, A., R. P. Agarwal, U. N. Sharma, M. S. Bhalla, and A. C. Nanda. 1988. Magnetic polarity stratigraphy and vertebrate paleontology of the Upper Siwalik Subgroup of Jammu Hills, India. *Journal of the Geological Society of India* 31:361–385.

Ranga Rao, A., A. C. Nanda, U. N. Sharma, and M. S. Bhalla. 1995. Magnetic polarity stratigraphy of the Pinjor Formation (Upper Siwalik) near Pinjor, Haryana. *Current Science* 68:1231–1236.

Raymo, M. E. and W. F Ruddiman. 1992. Tectonic forcing of late Cenozoic climate. *Nature* 359:117–122.

Retallack, G. J. 1991. *Miocene Paleosols and Ape Habitats of Pakistan and Kenya*. New York: Oxford University Press.

Retallack, G. J. 1995. Palaeosols of the Siwalik Group as a 15 My record of South Asian Palaeoclimate. *Memoir Geological Society of India* 32:36–51.

Ruddiman, W. F. and J. E. Kutzbach. 1989. Forcing of late Cenozoic northern hemisphere climate by plateau uplift in Southern Asia and the American West. *Journal of Geophysical Research* 94: 18409–18427.

Sahni, A. and S. K. Khare. 1976. Siwalik insectivore. *Geological Society of India* 17:114–116.

Sahni, M. R. and E. Khan. 1964. Stratigraphy, structure and correlation of the Upper Shivaliks east of Chandigarh. *Journal of the Palaeontological Society of India* 4:61–74.

Sangode, S.J. and R. Kumar. 2003. Magnetostratigraphic correlation of the Late Cenozoic fluvial sequences from NW Himamalaya. *Current Science* 84(8):1014–1024.

Sangode, S. J., R. Kumar, and S. K. Ghosh. 1996. Magnetic polarity stratigraphy of the Siwalik sequence of Haripur area (H. P.), NW Himalaya. *Journal of the Geological Society of India* 47:683–704.

Sankhyan, A. R. 1985. Late Occcurrence of *Sivapithecus* in Indian Siwaliks. *Journal of Human Evolution* 14:573–578.

Scott, R., S. J. Kappelman, and J. Kelley. 1999. The paleoenvironment of *Sivapithecus parvada*. *Journal of Human Evolution* 36:245–74.

Sehgal, R. K. 1998. Lower Siwalik carnivores from Ramnagar, Jammu and Kashmir, India. *Himalayan Geology* 19(1):109–118.

Sehgal, R. K. and A. C. Nanda. 2002. Palaeoenvironment and palaeoecology of the Lower and Middle Siwlaik Subgroups of a part of Northwest Himalaya. *Journal of the Geological Society of India* 59:517–529.

Sehgal, R. K. and R. Patnaik. 2011. New muroid rodent and *Sivapithecus* dental remains from the Lower Siwalik deposits of Ramnagar (J & K, India): Age implication. *Quaternary International*; http://dx.doi.org/10.1016/j.quaint.2011.01.043.

Simons, E. L. and P.C. Ettel. 1970. *Gigantopithecus*. *Scientific American* 222:77–85.

Simons, E. L. and S. R. K. Chopra. 1969. *Gigantopithecus* (Pongidae, Hominoidea): A new species from Northern India. *Postilla* 138:1–8.

Simons, E. L. and D. Pilbeam. 1973. A gorilla-sized ape from the Miocene of India. *Science* 173:23–27.

Szalay, F. S. and E. Delson. 1979. *Evolutionary History of the Primates*. New York: Academic Press.

Tandon, S. K. and R. Kumar. 1984. Discovery of tuffaceous mudstones in the Pinjor Formation of Panjab Himalaya, India. *Current Science* 53(18):982–984.

Tandon, S. K., R. Kumar, M. Koyama, and N. Niitsuma. 1984. Magnetic polarity stratigraphy of the Upper Siwalik Subgroup, east of Chandigarh, Punjab Sub-Himalaya, India. *Journal of the Geological Society of India* 25(1):45–55.

Thomas, H. and S. N. Verma. 1979. Découverte d'un primate Adapiforme (Sivaladapinae Subfam. Nov.) dans le Miocène moyen des Siwaliks de la region de Ramnagar (Jammu et Cachemire, Inde). *Comptes Rendus de l'Académie des Sciences Paris* 289:833–836.

Thomas, J. V., B. Parkash and R. Mohindra. 2002. Lithofacies and palaeosol analysis of the Middle and Upper Siwalik Groups (Plio–Pleistocene), Haripur-Kolar section, Himachal Pradesh, India. *Sedimentary Geology* 150(3–4):343–366.

Tiwari, B. N. 1983. Lower Siwalik faunas of the Indian subcontinent with special reference to Kalagarh Fauna. *Publications of the Centre of Advanced Study in Geology, Panjab University, Chandigarh* 13:98–112.

Tiwari, B. N. 1996. Middle Siwalik murid rodents from Ladhyani, Bilaspur, Himachal Pradesh. In *Contributions to XV Indian Colloquium on Micropalaeontology and Stratigraphy*, eds J. Pandey, R. J. Azmi, A. Bhandari, and A. Dave, pp. 513–518. Dehra Dun: Wadia Institute of Himalayan Geology.

Tiwari, B. N. 1990. Late Miocene rhizomyid rodent-bearing faunule from the Siwalik of Palampur, Himachal Pradesh. *Current Science* 59(9):460–463.

Vasishat, R. N. 1985. *Antecedents of Early Man in Northwestern India: Paleontological and Paleoecological Evidences*. New Delhi: Inter India Publications.

Vasishat, R. N., R. Gaur, and S. R. K. Chopra. 1978. Geology, fauna and palaeoenvironments of Lower Siwalik deposits around Ramnagar, India. *Nature* 275:736–737.

Vasishat, R. N., I. J. Suneja, R. Gaur, and S. R. K. Chopra. 1983. Neogene mammals (equids, rhinocerotids, suids and anthracotheriids). *Publication of the Centre for Advance Study in Geology* 13:207–215.

Verma, B. C. 1969. *Procynocephalus pinjori* sp. nov., a new fossil primate from the Pinjor beds (Lower Pleistocene) east of Chandigarh. *Journal of the Palaeontological Society of India* 13:53–57.

Verma, B. C. 1988. Search for microvertebrates in the Upper Siwaliks of Markanada Valley, Sirmur District, Himachal Pradesh and development of Upper Siwalik biostratigraphy. *Records Geological Survey of India* 122:309–312.

Verma, B. C. and S. S. Gupta. 1997. New light on the antiquity of Siwalik Great apes. *Current Science* 72(5):302–303.

West, R. M. 1996. The Cenozoic of Nepal: mountain evolution and vertebrate evolution. *Journal of Nepal Geological Society* 14:11–19.

West, R. M., J. H. Hutchison, and J. Munthe. 1991. Miocene vertebrates from the Siwalik Group, Western Nepal. *Journal of Vertebrate Paleontology* 11(1):108–129.

West, R. M., J. R. Luckas, J. Munthe, and S. T. Hussain 1978. Vertebrate fauna from Neogene Siwalik Group, Dang Valley, western Nepal. *Journal of Paleontology* 52:1015–1022

West, R. M. and J. Munthe. 1981. Neogene vertebrate paleontology and stratigraphy of Nepal. *Journal of Nepal Geological Society* 1:1–14.

Williams, M. D., D. Dunkerley, P. D. Decker, P Kershaw, and J. Chappel 1999. *Quaternary Environments*. New York: Arnold.

Willis, B. J. 1993. Ancient river systems in the Himalayan Foredeep, Chinji Village area, northern Pakistan. *Sedimentary Geology* 88:1–76.

Yokoyama, T., B. C. Verma, T. Mastuda, S. S. Gupta, and A. P. Tewari. 1987. Fission-track age of a bentonitized ash bed and mammalian fauna from Nagrota Formation (Upper Siwalik) of Jammu District (J & K). *Indian Minerals* 41:13–18.