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Upper Siwalik mammalian faunas of India and associated events

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Abstract

Tatrot and Pinjor mammalian faunas are well known from the Chandigarh and Jammu regions of India. The Pinjor Formation of the type area in the Chandigarh region has been dated by magnetostratigraphy and ranges from 2.48 to 0.63 Ma. The pre-Pinjor beds of the Upper Siwalik Subgroup are referred to as the Saketi Formation and are characterized by the presence of the Tatrot Fauna. These are well exposed in the type area of the Pinjor Formation. The Pinjor Mammalian Fauna marks the end of the record of the Siwalik vertebrate faunal succession since the overlying Boulder Conglomerate Formation, the youngest formation of the Siwalik Group, is devoid of fossils. About 49 mammalian taxa are restricted to the Pinjor Formation. The Saketi beds are differentiated from the Pinjor beds by 30 Tatrot taxa. In the Jammu region, the Nagrota Formation of the Upper Siwalik Subgroup contains both the Tatrot and Pinjor faunas; however both faunas are not as well developed as compared to those of the Chandigarh region. The extinction or migration of the Pinjor Mammalian Fauna began near the Olduvai subchron (i.e. near Neogene\Quaternary boundary). However, in the Parmandal-Utterbeni (Jammu) and Patiali Rao (Chandigarh) sections, the fauna survived well after the Olduvai subchron, and extinction in various sections ranges in age from 1.72 to 0.6 Ma. Near the Olduvai subchron, the last phase of the Himalayan orogeny was marked by initial deposition of the Boulder Conglomerate Formation and was probably one of the reasons for the gradual extinction of the Pinjor Mammalian Fauna. Two biostratigraphic interval-zones, *Elephas planifrons* Interval-Zone (3.6–2.6 Ma) and *Equus sivalensis* Interval-Zone (2.6–0.6 Ma) are also recognized on the basis of mammalian fossils and magnetostratigraphy. Twenty-five taxa made their first appearance in the older zone whereas forty-eight taxa are restricted to the younger zone.

Keywords: Upper Siwalik; Mammalian faunas; Biostratigraphy; Interval-zones

1. Introduction

The Siwalik Group, exposed along the southern foothills of the Himalaya, ranges in age from 18.3 Ma (Johnson et al., 1985) to 0.22 Ma (Ranga Rao et al., 1988) and is well known for its abundance in vertebrate fossils. Pilgrim (1913) initially classified the Siwalik succession into the Lower, Middle and Upper divisions and further divided these into subdivisions. These subdivisions, referred to as 'zones', include the Kamlial, Chinji (Lower Siwalik); Nagri, Dhok Pathan (Middle Siwalik); and Tatrot, Pinjor and Boulder Conglomerate (Upper Siwalik). Thus, he presented a biostratigraphic classification and based the subdivisions on mammalian faunas. Distinctions between lithostratigraphic, biostratigraphic and chronostratigraphic units and entities were not developed when Pilgrim defined the Siwalik divisions and subdivisions. We still use these terms, but try to apply them according to modern stratigraphic codes. In the present usage, the three divisions of the Siwalik Group are given the status of 'Subgroup' whereas the zones are referred as 'Formation' or 'Fauna'. The threefold classification is useful in mapping various units in the field, despite their time transgressive character. The faunas with their fixed age limits have correlative value but also have limitations as they are not uniformly distributed in the Siwalik succession. Therefore, the recognition of the precise zones of Pilgrim is difficult. For time correlation the workers in the Potwar Plateau, Pakistan, replaced lithology with magnetostratigraphy and dated the appearance or extinction of mammalian taxa and used these for correlation (Keller et al., 1978; Opdyke et al., 1979; Barry et al., 1982).

The various divisions and subdivisions of the Siwalik sediments in this paper are based on the mammalian faunas. For example the Pinjor Fauna refers to Pinjor Mammalian Fauna, whether derived from the Pinjor Formation of the type area, or from the equivalent beds in the Potwar Plateau in Pakistan. The 'type' Pinjor Fauna, however, is from the Pinjor Formation in India.

The Boulder Conglomerate Formation, the youngest subdivision of the Siwalik Group, is mainly a conglomerate dominated facies and has not yielded fossils. Thus the Pinjor Fauna marks the end of the Siwalik faunal succession that

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Table 1
Distribution of various genera/species in the Pinjor and Saketi beds (= Tatrot beds, = pre-Pinjor beds of the Upper Siwalik Subgroup) of Chandigarh region (based on collection of last 40 years)

Pinjor Beds	
Primates:	*Procynocephalus pinjorii*, ?*Homo erectus*
Lagomorpha:	*Caprolagus* sp.
Rodentia:	*Rattus* sp., *Hystrix leucurus*, *Mus linnaeusi*, *M.* cf. *M. flynni*, *Cremnomys* cf. *C. blanfordi*, *Golunda* sp., *Dilatomys* sp., *Hadromys loujacobsi*, *Tatera pinjoricus*, *Rhizomys pinjoricus*, *Bandicota* sp.
Carnivora:	*Canis pinjorensis*, *Mellivora sivalensis*, *Crocuta felina*, *C. colvini*, *Panthera* cf. *P. cristata*
Proboscidea:	*Pentalophodon sivalensis*, *Stegolophodon stegodontoides*, *Elephas hysudricus*, *E. platycephalus*
Perissodactyla:	*Equus sivalensis*, ? *E. namadicus*, *Coelodonta platyrhinus* (= *Punjabitherium platyrhinus*), *Rhinoceros palaeindicus*, *R. sivalensis*
Artiodactyla:	*Potamochoerus theobaldi*, *Hippohyus sivalensis*, *Sus falconeri*, *S. hysudricus*, *S. giganteus*, *S. choprai*, *Rucervus simiplicidens*, *Cervus punjabiensis*, *Sivatherium giganteum*, *Sivacapra subhimalayaensis*, *Damalops palaeindicus*, *Oryx sivalensis*, *Sivacobus palaeindicus*, *Hemibos acuticornis*, *H. triquetricornis*, *H. antilopinus*, *Bubalus palaeindicus*, *B. platyceros*, *Leptobos falconeri*, *Bison sivalensis*, *Bos acutifrons*
Extend from the Saketi to Pinjor beds	*Golunda kelleri*, *Crocidura* sp. *Elephas planifrons*, *Stegodon insignis*, *S. katliensis*, *Potamochoerus palaeindicus*, *Hexaprotodon sivalensis*, *Camelus sivalensis*
Saketi Beds	
Insectivora:	*Suncus* cf. *S. murinus*
Lagomorpha:	*Pliosiwalagus whitei*
Rodentia:	*Palaeomys* sp. *Rhizomyoides saketiensis*, *Rhizomyides* cf. *R. sivalensis*, *Mus flynni*, *M. jacobsi*, *Parapelomys robertsi*, *Hadromys primitivus*, *H. moginandensis*, *Cremnomys* cf. *C. cutchicus*, *Bandicota sivalensis*, *Protatera* cf. *P. kabulense*, *Golunda tatroticus*, *Dilatomys moginandensis*, *Brachyrhizomys pilgrimi*, *Abudhabia* cf. *A. kabulense*
Proboscidea:	? *Anancus perimensis*, *Pentalophodon khetpuraliensis*
Perissodactyla:	*Cormohipparion theobaldi*, *Hipparion antilopinum*, ? *Chilotherium intermedium*
Artiodactyla:	*Merycopotamus dissimilis*, *Hippohyus tatroti*, *Proamphibos kashmiricus*, *Probison dehmi*
Additional characteristic taxa for Saketi beds (= Tatrot beds)[a]	*Stegodon bombifrons*, *Sivachoerus* sp., *Hydaspitherium megacephalum*, *Gazella* sp.

[a] These taxa are known from the Dhok Pathan Formation and extend into Saketi beds, but absent in the Pinjor beds.

began with the Kamlial Fauna in the early Miocene, about 18 million years ago. Pilgrim (1913) recognized the type areas of the Kamlial, Chinji, Nagri, Dhok Pathan and Tatrot faunas in the Potwar Plateau, Pakistan whereas type areas of the Pinjor Fauna and Boulder Conglomerate were recognized by him in the Siwalik Hills near Chandigarh, India. Thus the type area of the Pinjor Formation lies about 400 km southeast of the type area of the underlying Tatrot Formation. For the first time in India, Sahni and Khan (1964) recognized the Tatrot Fauna near Chandigarh. Subsequently, a number of workers carried out investigations near Chandigarh. It is now clear that the type area of the Pinjor Formation of Pilgrim (1913) has fossils belonging to both the Tatrot and Pinjor faunas.

The Tatrot Fauna in India is not as well developed as in the type and other localities in the Potwar Plateau, Pakistan; it is known in India primarily from Jammu and Chandigarh regions. However, a rich Pinjor Fauna is well developed in India and has been discussed in detail.

2. Distribution of the Pinjor Fauna

The Pinjor Fauna is well developed in the Chandigarh (type area) and Jammu regions of India (Sahni and Khan, 1964; Badam, 1979; Nanda, 1981; Gupta and Verma, 1988; Ranga Rao et al., 1988; Nanda, 1997a,b) and also from various localities in the Potwar Plateau, Pabbi Hills and Mangla-Samwal areas of Pakistan (Keller et al., 1978; Barry et al., 1982; Hussain et al., 1992), though less abundant as compared to Indian locations. It therefore seems that the record of the last three million years is better preserved in India than in Pakistan. Initially, Pilgrim (1910, 1913) provided the details of his three fold biostratigraphic classification of the Siwalik 'group' and used the 'Pinjor zone' (in present usage refers to both Fauna and Formation) for the middle part of the Upper Siwalik Subgroup. Opdyke et al. (1979, p.1) used magnetostratigraphy and considered the first appearance of *Equus*, *Elephas*, *Bos* and *Cervus* (cervid with antlers) as marking the beginning of the 'Pinjor Fauna'. This event coincided with the Gauss-Matuyama (Chron C2An\C2r) magnetic boundary at 2.48 Ma (2.58 Ma by Cande and Kent, 1995). However, Opdyke et al. (1979, p. 30) erroneously replaced *Bos* with *Proamphibos*. *Elephas* is now known far below the Gauss-Matuyama magnetic boundary (Hussain et al., 1992; Agarwal et al., 1993). Opdyke et al. (1979, pp. 29–30), discussed the Pinjor Fauna and Tatrot–Pinjor faunal contact. The type area of the Pinjor Formation lies near Chandigarh and is dated from 2.48 to 0.63 Ma by Ranga Rao et al. (1995). The Pinjor Formation of the Chandigarh region cannot be correlated to the Upper Siwalik successions of Jammu or the Potwar Plateau by strike mapping, but these successions produce fauna, which includes *Equus* and *Cervus*. These successions in Jammu or Potwar, lying 300 or 400 km northwest of Chandigarh should not be named the Pinjor Formation,

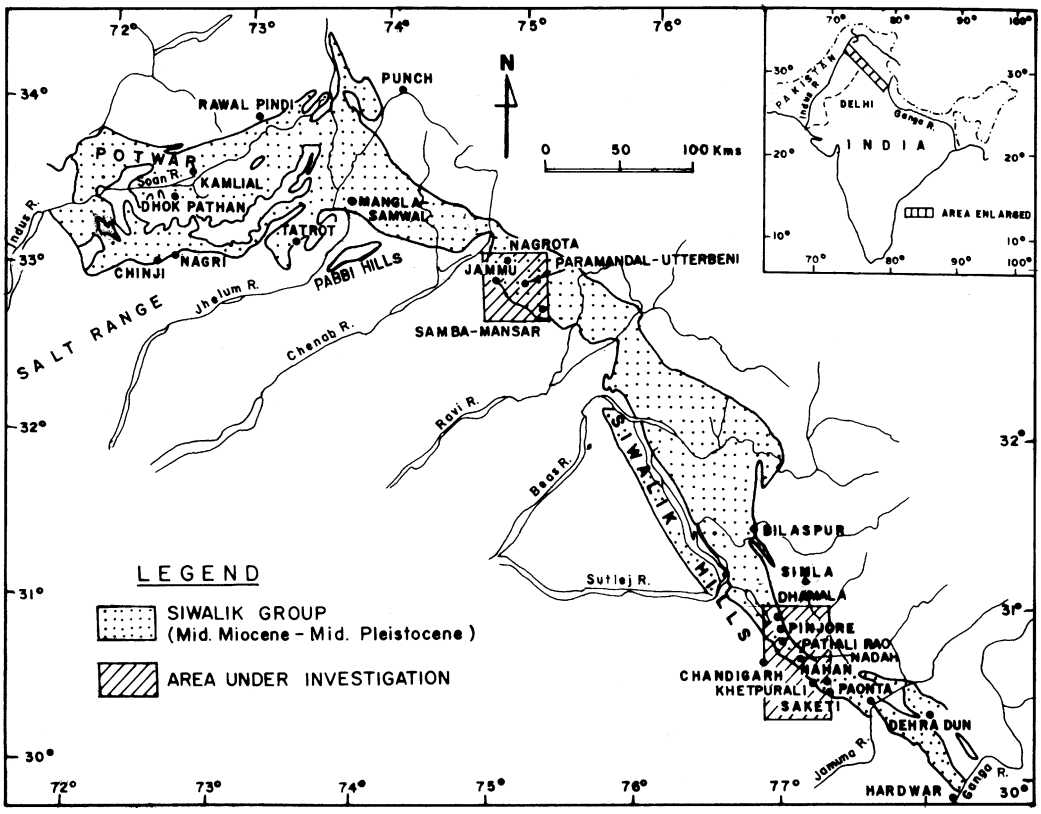

Fig. 1. Portion of the Siwalik belt showing the various stratigraphic localities.

but are correlated with the Pinjor Fauna of the type area by faunal similarities. In the present contribution, the first appearance of *Equus* and *Cervus*, that virtually coincides with the Gauss-Matuyama magnetic boundary, marks the beginning of the Pinjor Fauna. After this appearance, a number of taxa made their first appearance in younger successions and these marker taxa are referred as the Pinjor Fauna. In short, marker taxa of the Pinjor Formation may occur in other parts of the basin, such as Jammu, and these may be referred to as the Pinjor Fauna. The marker taxa reported during the last forty years are tabulated in Table 1.

The Pinjor Fauna is discussed here with the underlying Tatrot Fauna for the Chandigarh and Jammu regions. Details of the various stratigraphic localities are shown in Fig. 1.

2.1. Chandigarh region

Pilgrim (1913) suggested the type area for the Pinjor Formation near Chandigarh, although he did not specify any type section. The name 'Pinjor' is derived after the township of 'Pinjore' (also spelled as 'Pinjaur'), which lies on alluvium about 15 km northeast of Chandigarh.

Pilgrim (1932, pp. 2–3; 1938, p. 446) was aware of the presence of Tatrot fossils, (e.g. *Hipparion*, *Pentalophodon sivalensis*, *Hippohyus* and *Sivachoerus*) in the Indian Siwalik Hills, but he did not know the exact locations of the beds that yielded these fossils. On the basis of both lithology and fauna, Sahni and Khan (1964, pp. 62, 67) recorded the Tatrot fossils from the basal beds of the Upper Siwalik Subgroup exposed east of Chandigarh. They attributed the older succession to the 'Tatrot Stage' and the younger succession to the 'Pinjor Stage'. The Tatrot Stage of Sahni and Khan, (1964, p. 67) was characterized by the presence of *Hipparion* and *Proamphibos* and the absence of *Equus* and *Bubalus*. Nanda (1981, 1994) reported Tatrot Fauna from the Khetpurali area of the Chandigarh region (Fig. 2) and added *Stegodon bombifrons*,?*Anancus perimensis*, *Pentalophodon khetpuraliensis*, *Cormohipparion theobaldi*, *Hippohyus tatroti* and *Merycopotamus dissimilis* to this list. He later compiled a list of characteristic Tatrot taxa for the Indo-Nepal region (Nanda, 1997a, table 5). Azzaroli and Napoleone (1982, p. 744) also added *Probison dehmi*, *Crocuta talyangari* (*nomen nudum*) and *Protachyorycytes tatroti* (*nomen nudum*) to the list. It is now evident that in the type area of the Pinjor Formation, there are two distinct stratigraphic intervals. The older one has the Tatrot Fauna whereas the younger one has the Pinjor Fauna. Nanda (1994, p. 41, fig. 3) reported the transitional zone between the sediments yielding the Tatrot and Pinjor faunas. Within this zone, some marker taxa of both the Tatrot and Pinjor faunas are found together. In other words, the contact between the Tatrot and Pinjor faunas in the Siwalik Hills near Chandigarh is not sharp.

In the type area of the Pinjor zone of Pilgrim (1913) and Sahni and Khan (1964) reported the occurrence of the older

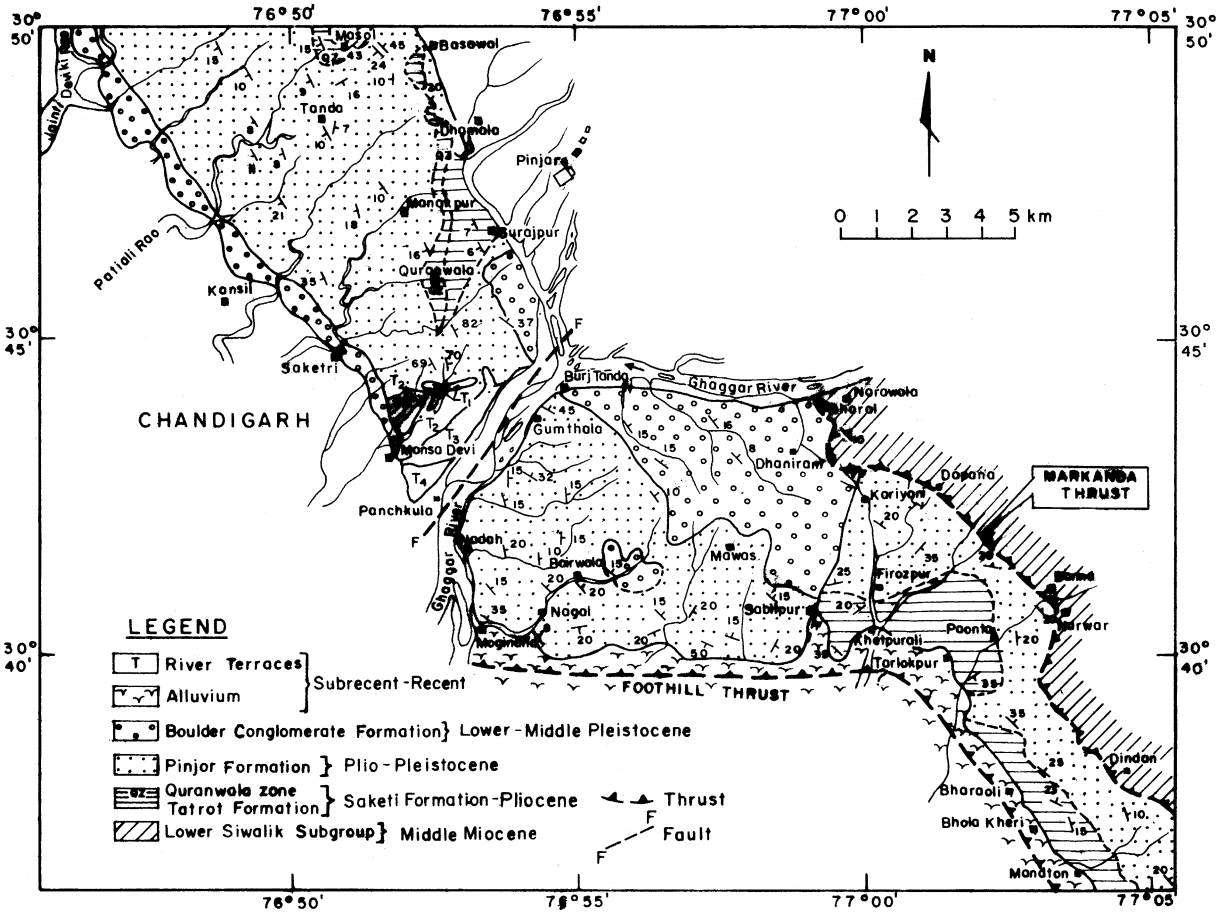

Fig. 2. Geological map of the Chandigarh region (Modified after Nanda, 1994). Area on the right hand side of the Ghaggar river was mainly mapped by Sahni and Khan (1964). Location of Chandigarh is also shown in Fig. 1.

succession, which they referred to as the Tatrot Stage and called the upper part the 'Quaranwala zone' (Fig. 2). Pandey (1971) referred these to the 'Masol Member' and equated it with the lower part of the Tatrot Formation of the type area. Sastry (1981) called these beds the Dhamala Formation after the village Dhamala near Pinjore township. Verma (1988) referred to the succession near Saketi village as the Saketi Formation. In the Siwalik Hills of Chandigarh, beds yielding Tatrot Fauna occur in isolated scattered outcrops and to assign a new name to each outcrop is confusing. To overcome this confusion, Nanda (1981) tentatively referred to these as pre-Pinjor beds until the 'Standard Reference Section' in Indian Siwalik is proposed. These beds can not be referred to as the Tatrot Formation or 'Stage'. As mentioned earlier, type area of the Tatrot Formation lies about 400 km northwest of Chandigarh and can not be traced by strike mapping. Lithology is not a good criteria for correlation since it may be time transgressive. Enclosed fauna and magnetostratigraphic data are the best parameters for correlation. The presence of the pre-Pinjor beds of the Upper Siwalik Subgroup is supported by both fauna and magnetostratigraphic data. The other names suggested for this older succession such as the Dhamala or Masol have limitations. Excellent successions are exposed around the villages of Dhamala, Masol and Khetpurali. However at each place, the base, i.e. the contact with the Middle Siwalik Subgroup, is not exposed. In the immediate vicinity of Chandigarh, the contact of the Middle and Upper Siwalik subgroups is exposed at Saketi and a nearly complete succession of pre-Pinjor beds of the Upper Siwalik Subgroup is exposed. This succession has already been referred to as the Saketi Formation (Verma, 1988). In the present contribution, the older succession in the Siwalik Hills of Chandigarh, which yielded Tatrot Fauna, is referred to as the Saketi Formation. This formation is equivalent to the Tatrot Stage of Sahni and Khan (1964), Masol Member of Pandey (1971), 'pre-Pinjor beds' of Nanda (1981) and 'Dhamala Formation' of Sastry (1981).

The Pinjor Fauna is very diverse and Colbert (1935, pp. 29–36) alone listed 57 taxa, excluding Bovidae, which are restricted to the Pinjor Formation. Pilgrim (1939, pp. 5–7) added 22 Bovidae taxa to this list. Thus, 79 taxa were considered restricted to the Pinjor Formation. Following the work of Sahni and Khan (1964), various workers (Pandey, 1971; Nanda, 1973, 1981, 1994, 1997a,b; Gupta et al., 1976, 1978, 1981; Badam, 1979; Azzaroli and Napoleone, 1982; Azzaroli, 1985; Gaur, 1987; Verma, 1988; Flynn et al., 1990; Patnaik, 1995, 1997, 2001, etc.) collected

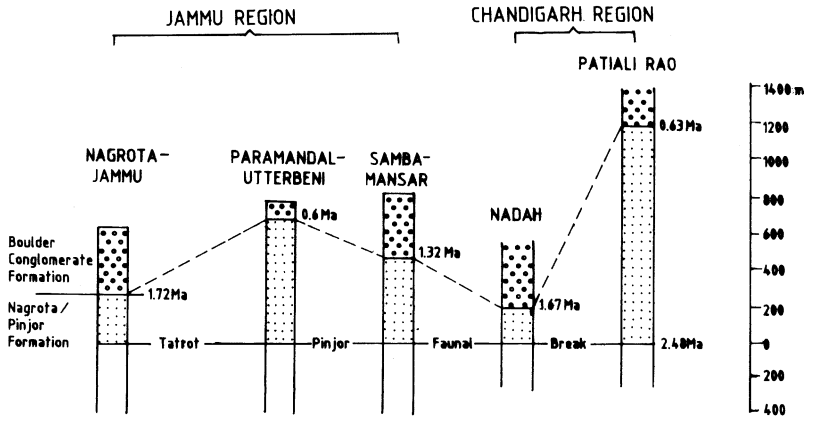

Fig. 3. Position of the base of the Boulder Conglomerate Formation or the upper limit of the successions, which yielded Pinjor Fauna in various sections of the Jammu and Chandigarh regions. Magnetostratigraphic dates for the Jammu region are based on the work of Ranga Rao (1986), Ranga Rao et al. (1988) and Agarwal et al. (1993) whereas those of the Nadah and Patiali Rao sections of the Chandigarh region are after Azzaroli and Napoleone (1982) and Ranga Rao et al. (1995) respectively. Various localities are marked in Fig. 1.

fossils from the Siwalik Hills of Chandigarh. A rich rodent fauna, comprising about two dozen taxa, was recently recorded by Flynn et al. (1990) and Patnaik (1995, 1997, 2001). Besides these, two genera of small mammals, *Caprolagus* and *Palaeomys*, were reported by Verma (1988) from the upper part of the Saketi Formation. Considering their known distribution in Asia, *Caprolagus* belongs to the Pinjor Fauna and *Palaeomys* to the Tatrot Fauna or to the Saketi beds. Singh (*fide* Singh et al., 1988) reported *Homo erectus*, but Badam (personal communication) doubts the identification and believes that better samples are required for precise identification. Azzaroli (1985) listed *Equus namadicus* in the Pinjor beds. Badam (personal communication) considered this finding in the Pinjor Formation accidental as only one tooth is reported and he does not favour its inclusion in the Pinjor Fauna. More specimens of these two taxa are required to verify their record. Therefore in the compiled list, both *H. erectus* and *E. namadicus* are indicated with question marks. Certain Middle Siwalik taxa, reported by various workers, from the Pinjor Formation are suspect; these include *Machairodus* and *Gazella* (Gaur, 1987), *Dicoryphochoerus* (Verma, 1988) and *Dorcadoxa porrecticornis* (Pandey, 1971). These taxa are not included in the list of various taxa in the Pinjor beds (Table 1). These are removed because they have not been reported subsequently by very vigorous collections made by various workers. Except for *Gazella*, there is no record of these taxa from the Saketi beds (Verma, 1988). Since the work of Sahni and Khan (1964), 49 marker taxa (including the rodent taxa) have been assigned to the Pinjor Fauna compared to 79 taxa known to Colbert (1935) and Pilgrim (1939). Thirty taxa are found restricted to the Saketi beds. These include four taxa, *Stegodon bombifrons*, *Sivachoerus* sp., *Hydaspitherium megacephalum* and *Gazella* sp., which are reported from different exposures of the Saketi Formation (Pandey, 1971; Nanda, 1981; Verma, 1988). These are also well known from the Dhok Pathan Formation. Their stratigraphic record distinguishes the Tatrot Fauna of the Saketi Formation from the Pinjor Fauna of the Siwalik Hills of Chandigarh. Thus, as now understood, 30 taxa differentiate the Tatrot Fauna from Pinjor Fauna near Chandigarh. Eight taxa are found both in the Saketi and Pinjor beds. The distribution of the various taxa, including characteristic Pinjor taxa, are given in Table 1, which is based mainly on all the collections made by various workers referred to in this contribution.

2.2. Jammu region

The Siwalik succession near Jammu forms an anticlinal structure known as the Surin-Mastgarh Anticline (Karunakaran and Ranga Rao (1976, sheet A). The Upper Siwalik succession of the southern limb of the anticline has yielded both the Tatrot and Pinjor faunas.

In the Jammu region, the Upper Siwalik succession is divided into three formations—Parmandal Sandstone, Nagrota Formation and Boulder Conglomerate. Only the Nagrota Formation has yielded identifiable fossils, which belong to both the Tatrot and Pinjor faunas. The middle part of the Nagrota Formation has two bentonitic tuff beds, which have been dated as 2.8 ± 0.56 and 2.31 ± 0.54 Ma (Ranga Rao et al., 1988). The Tatrot–Pinjor faunal break nearly coincides with the Gauss-Matuyama magnetic boundary and with the lower bentonitic bed. The fauna occurring above the bentonitic beds is considered belonging to the Pinjor Fauna whereas the fauna below represents the Tatrot Fauna. This has been discussed by Ranga Rao et al. (1988). The fauna of the Upper Siwalik succession has been discussed by Yokoyama et al. (1987), Gupta and Verma (1988), Ranga Rao et al. (1988), Agarwal et al. (1993), Nanda (1994, 1997a,b) and Nanda and Kumar (1999). The Tatrot Fauna in the Jammu region is represented only by three taxa, namely, *Stegodon bombifrons*, *Cormohipparion theobaldi* and *Propotamocherus hysudricus*. The

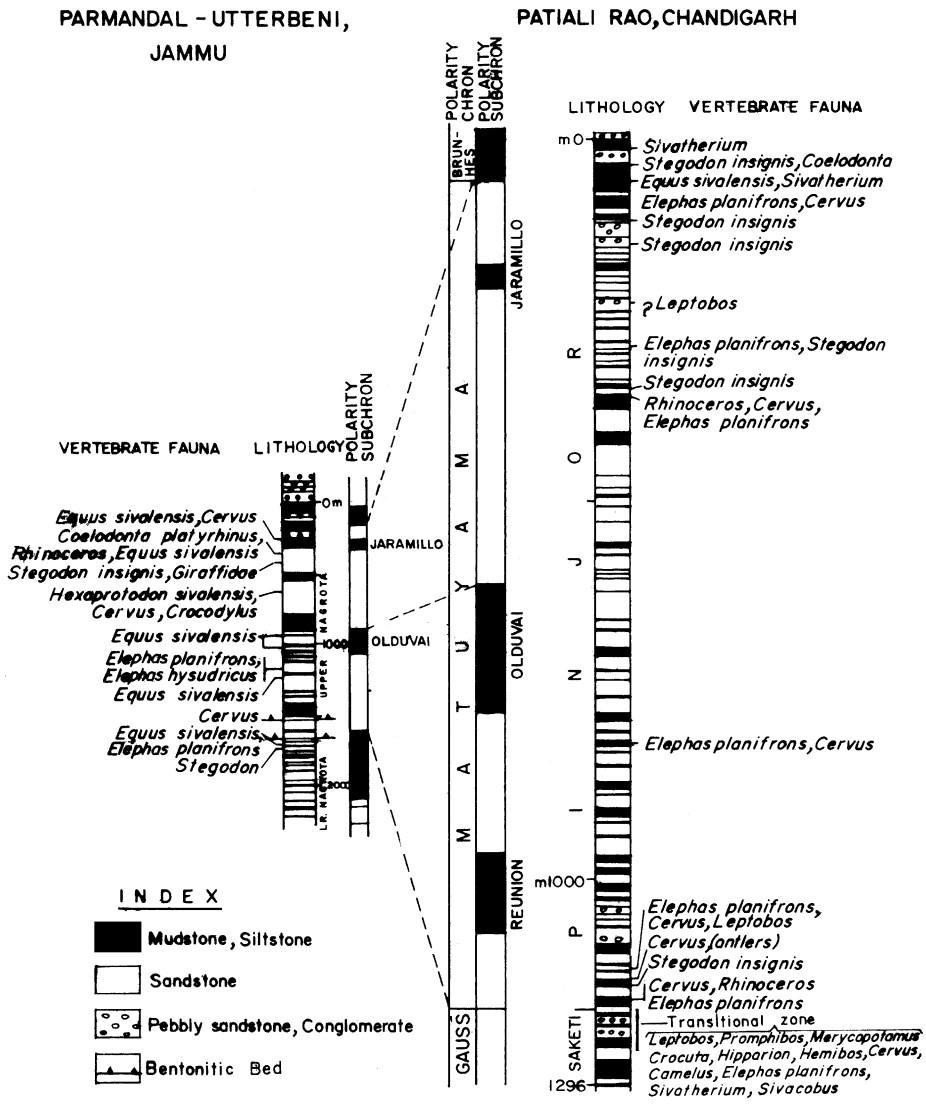

Fig. 4. Succession of the Pinjor Fauna in Parmandal-Utterbeni section of Jammu and Patiali Rao section of Chandigarh. (Modified after Ranga Rao et al., 1988, fig. 4; 1995, fig. 11).

Pinjor Fauna in the Jammu region is better developed but very scarce as compared to the Pinjor Fauna of Chandigarh; only 11 characteristic taxa for the Pinjor Fauna are presently known. These are *Panthera* cf. *P. cristata*, *Crocuta felina*, *Elephas hysudricus*, *Equus sivalensis*, *Rhinoceros palaeindicus*, *Coelodonta platyrhinus*, *Cervus* (with antlers), *Sivatherium giganteum*, *Hemibos triquetricornis*, *Bos* and *Sivacapra*.

In the Jammu region, the upper part of the Nagrota Formation, which yielded the Pinjor Fauna, shows lithological resemblance with the Pinjor Formation of the type area. In both regions, dull, brown and pink mudstones alternate with medium to coarse grained, pebbly, soft, grey, greenish and brown sandstones. In Jammu, this characteristic lithology also occurs in the successions younger than the bentonitic beds. The lithology below the bentonitic beds resembles the Saketi beds of the Chandigarh region, and in both regions, grey and variegated mudstones are found interbedded with grey and brown sandstones. Grey mudstones are virtually lacking in both the Pinjor Formation of Chandigarh and the upper part of the Nagrota Formation, which yielded the Pinjor Fauna in these regions.

3. Range and extinction of the Pinjor Fauna and associated Upper Siwalik events

Magnetostratigraphic studies in the Chandigarh region indicate that the lower limit of the Pinjor Formation coincides with the Gauss-Matuyama boundary at 2.48 Ma (Azzaroli and Napoleone, 1982; Tandon et al., 1984; Ranga Rao et al., 1995). This age is the same as given in the Jammu region by Ranga Rao et al. (1988) and Agarwal et al. (1993), or in the Potwar Plateau by various workers including Opdyke et al. (1979), Barry et al. (1982) and Johnson et al. (1982a,b), and in the Mangla-Samwal section

of Pakistan by Hussain et al. (1992). However, Yokoyama et al. (1981) correlated the uppermost part of the Tatrot beds with the Olduvai subchron in the Chandigarh region. Yokoyama et al. (1987, pp. 13, 19) also dated the bentonitic beds in the Parmandal-Utterbeni section of the Jammu region as coinciding with the Olduvai subchron (Chron C2n of Cande and Kent, 1995). Thus, these authors placed the Tatrot\Pinjor faunal break near the Olduvai subchron and assigned a different age to the Tatrot\Pinjor contact whereas all the other Siwalik workers of the Indo-Pakistan subcontinent have placed this boundary at the Gauss-Matuyama transition. Mehta et al. (1993) dated the bentonitic bed occurring in the Jammu region at 1.59 ± 0.32 Ma. Earlier, Ranga Rao et al. (1988, p. 365) determined the Fission Track age of two bentonitic beds as 2.8 ± 0.56 and 2.31 ± 0.54 Ma. Thus, there is variation in the Fission Track ages of volcanic ashes. Ranga Rao et al. (1988) also carried out the detailed magnetostratigraphic and faunal studies of the Jammu region. According to these workers, the Gauss-Matuyama boundary, Tatrot\Pinjor faunal break and F.T. ages of the bentonitic beds virtually coincide with each other. Moreover, on the basis of magnetostratigraphic data, faunal studies and the ages of volcanic ashes, Ranga Rao et al. (1988, fig. 11) correlated the various sections of the Jammu region with those of the Potwar Plateau. More data is required to resolve the discrepancy in F.T. ages, but magnetostratigraphic and faunal data show remarkable similarity in a wide area from the Potwar Plateau, Pakistan to the Chandigarh region, India.

The Siwalik workers in India and Pakistan discussed the lower boundary of the Pinjor Formation near Chandigarh (or Pinjor Fauna in Jammu and Potwar Plateau, Pakistan), but did not discuss the upper limit. Despite scanty magnetostratigraphic data in India, it has thrown significant light on the upper limit of the Pinjor Fauna. The contact of the Pinjor (or Nagrota Formation) and Boulder Conglomerate formations in the Jammu–Chandigarh region is time transgressive and ranges from 1.72 to 0.6 Ma (Nanda, 1997b, figs. 4 and 5). The upper limit of the Pinjor Fauna (or the base of the Boulder Conglomerate) has been plotted in Fig. 3. In the Jammu region, the base of the Boulder Conglomerate is dated at 1.72 Ma in the Nagrota-Jammu section. However, 20 km southeast in the Parmandal-Utterbeni section, it is dated at 0.6 Ma (Ranga Rao et al., 1988, fig. 12). Thus, it is time transgressive by 1.12 Ma. The Samba-Mansar section lies 20 km southeast of the Parmandal-Utterbeni section and this boundary is dated at 1.32 Ma. Thus it is time transgressive by 0.72 Ma. The Chandigarh region lies approximately 300 km southeast of Jammu. Here in the Patali Rao section, the base of the Boulder Conglomerate is dated at 0.63 Ma (Ranga Rao et al., 1995) whereas 16 km southeast in the Nadah section, it is dated at 1.67 Ma (Azzaroli and Napoleone, 1982). Thus, within 16 km in the Chandigarh region, it is time transgressive by 1.04 Ma. This time transgressive nature of the contact between the Boulder Conglomerate and the succession yielding the Pinjor Fauna (called Pinjor Formation in Chandigarh or upper part of the Nagrota Formation in Jammu) is very significant and sheds light on the various aspects concerning the Neogene\Quaternary boundary, sedimentation pattern, the extinction and migration of the Pinjor Fauna, and the intensification of the last phase of the Himalayan orogeny.

The Neogene\Quaternary boundary is placed at the top of the Olduvai subchron, which is now dated at 1.77 Ma by Cande and Kent (1995). In both the Nagrota-Jammu and Nadah sections, the Neogene\Quaternary boundary virtually coincides with the base of the Boulder Conglomerate Formation. Near the Neogene\Quaternary boundary, changes in the sedimentation pattern from alternating mudstone–sandstone (i.e. of Pinjor Formation or Nagrota Formation) to the conglomeratic intervals (i.e. of the Boulder Conglomerate) is indicated. The presence of thick succession of conglomerates (clasts mainly of boulder or cobble size) indicates intensification of the Himalayan orogeny within the provenance area and its signature was evident within the foothills. The extinction or migration of the Pinjor Fauna also started close to the Neogene\Quaternary boundary. The work carried out by Nanda, (1997b) reveals that in only two sections, the Parmandal-Utterbeni and Patiali Rao, vertebrate fossils are found in strata younger than the Olduvai subchron. In these two sections, the Pinjor Fauna continued uninterrupted without any change (Fig. 4). However, the presence of boulder or cobble conglomerates in the Jammu-Nagrota and Nadah sections indicates that the extinction or migration of the Pinjor Fauna began near the Olduvai subchron. The very coarse lithology of the Boulder Conglomerate Formation was definitely not suitable for the preservation of fossils and was also a threat to the vertebrate habitat. Consequently, the animals either became extinct or migrated to other regions.

Three major dispersal events of large mammals during the Pliocene (at 3.7, 2.6 and 1.9 Ma) are noted by Lindsay et al. (1980). Azzaroli and Napoleone (1982, pp. 757–758) added one younger faunal dispersal event at 1.0–0.9 Ma. The 3.7 Ma dispersal was for North America where several immigrants (from Eurasia) characterize the beginning of the Blancan land mammal age. As a result, the beginning of the Blancan is now considered at about 5.0 Ma. The 1.9 Ma dispersal event was not for Europe, but was for *Mammuthus* in North America and for *Equus* in Africa. It now appears that the dispersal of *Equus* to both Europe and the Siwaliks at about 2.60 Ma is one of the most reliable and widely recognized dispersal events of Eurasia in the late Cenozoic (Lindsay, personal communication). In India, only one dispersal event coinciding with the Tatrot and Pinjor faunal break, characterized by the first appearance of *Equus* at 2.60 Ma, is recognized by all the Siwalik workers of the Indian subcontinent. A second dispersal event is indicated by the presence of *Elephas* in the Jammu region at around 3.60 Ma (Agarwal et al., 1993, p. 235) in contrast to the earlier known dates of 2.9 Ma (Barry et al., 1982, p.122) and 3.35 Ma (Hussain et al., 1992, p. 74). The available

Table 2
Various events associated with the Upper Siwalik faunas

Events occurred at (Ma)	Comments with reference to the Siwalik
1.0–0.9	End Villafranchian event, not known in India
1.9	Near top of Olduvai subchron—change in sedimentation pattern, intensification of tectonic activity, and migration or extinction of Pinjor Fauna began
2.6	Gauss-Matuyama break, prominent faunal and sedimentological breaks, between the Tatrot and Pinjor beds, are recognized
3.7	Arrival of *Elephas* from Africa at 3.6 Ma

magnetostratigraphic data provide information about the extinction and migration events around 1.9 Ma. The dispersal event at 1.9 Ma coincides with the Neogene\Quaternary boundary or with the beginning of the extinction or migration of the Pinjor Fauna. Intensification of the last phase of the Himalayan orogeny also began at this time as discussed above. The end of the Villafranchian dispersal event at 1.0–0.9 Ma, as noted by Azzaroli and Napoleone (1982), is not apparent in the Siwalik. At this time, fossils were not preserved in most of the Siwalik sections, except the Parmandal-Utterbeni and Patiali Rao sections, and deposition of the thick conglomeratic succession of the Boulder Conglomerate Formation was in progress.

The various events associated with the Upper Siwalik Subgroup are tabulated in Table 2.

4. Biostratigraphic zones based on magnetostratigraphy and relation to the Tatrot and Pinjor faunas

As stated above, Pilgrim (1913) recognized various faunal zones on the basis of lithology (which is time transgressive) and faunal change. This caused considerable confusion for later workers. This problem is well known and has been discussed by Opdyke et al. (1979) and Barry et al. (1982). To overcome this problem, Barry et al. (1982) replaced the lithology with magnetostratigraphy and proposed four biostratigraphic interval-zones for the Middle and Upper Siwalik subgroups. These interval-zones, particularly those belonging to the Upper Siwalik, are discussed here. Azzaroli (1985, p. 28) referred to the biostratigraphic interval-zones of Barry et al. (1982) as 'mammal units' whereas Hussain et al. (1992) preferred to consider these as 'range-zones'. The four interval-zones of Barry et al. (1982) are '*Hipparion s.l.*' Interval-Zone (9.5–7.4 Ma), *Selenoportax lydekkeri* Interval-Zone (7.4–5.3 Ma), *Hexaprotodon sivalensis* Interval-Zone (5.3–2.9 Ma) and *Elephas planifrons* Interval-Zone (2.9–1.5 Ma). The last two, younger zones belong to the Upper Siwalik Subgroup. Hussain et al. (1992) modified the range of the *Elephas planifrons* Interval-Zone from 2.9–1.5 to 3.4–2.7 Ma and proposed a fifth zone called the *Elephas hysudricus* Range-Zone (2.7 –? Ma). Nanda (1997a) proposed the upper limit of the fifth zone to be 0.6 Ma as better controls of the Pinjor fossils were available in the Indian Siwalik. Similarly the lower limit of the *E. planifrons* is dated by Agarwal et al. (1993, p. 235) at 3.6 Ma and this limit of the *E. planifrons* Interval-Zone is modified to 3.6 Ma. Thus two biostratigraphic interval-zones corresponding to the Upper Siwalik, *Elephas planifrons* Interval-Zone (3.6–2.6 Ma) and *Elephas hysudricus* Interval-Zone (2.6–0.6 Ma), were recognized by Nanda (1997a) but many details were not provided. The younger zone, *Elephas hysudricus* Interval-Zone, is very rich in fossils and is renamed the *Equus sivalensis* Interval-Zone (2.6–0.6 Ma). This is necessary as the dispersal event of *Equus* at 2.6 Ma is one of the most distinctive faunal events of the Upper Siwalik. As compared to *Elephas hysudricus*, *Equus sivalensis* occurs profusely and is the most common taxon of this range. Moreover, the *Elephas planifrons* Interval-Zone and *Elephas hysudricus* Interval-Zone could be distinguished by generic rather than specific differences. The faunal contents of these zones are abundant and are modified in light of the discoveries made in the Indian Siwalik and details are provided in this contribution. Various dates given below are based on magnetostratigraphic studies. Further mammalian collection and magnetostratigraphic data may modify the details of these zones. The faunal contents of all the workers for the last 40 years are considered for better resolution.

4.1. *Elephas planifrons* Biostratigraphic Interval-Zone (3.6–2.6 Ma)

Reference Section. Verma (1988) measured the Saketi section, which is 240 m thick, and provided a faunal list. No detailed magnetostratigraphic studies were carried out in the Saketi area. However in the nearby Khetpurali section, the Tatrot\ Pinjor faunal contact is dated at 2.48 Ma (Tandon et al., 1984). On the bases of lithologic and faunal correlation, the top of the Saketi Formation is considered to be 2.48 Ma. The top of the *Elephas planifrons* Biostratigraphic Interval-Zone lies 80 m below the top of the Saketi Formation. Azzaroli and Napoleone (1982) dated the contact between the Middle and Upper Siwalik subgroups in the Saketi section at 3.15 Ma. However, Johnson et al. (1982b) have dated this contact in the Potwar plateau at 5.1 Ma. Thus the lower boundary of the *Elephas planifrons* Biostratigraphic Interval-Zone lies in the multistoried sandstone bodies, which are referred to as the Middle Siwalik Subgroup. Additional magnetostratigraphic data is required for precise demarcation of the contact between the Middle and Upper Siwalik subgroups.

Faunal Characterization. Magnetostratigraphic data by various authors (except Ranga Rao et al., 1995) failed to place the individual taxon stratigraphically, but general faunal occurrences in separate sections are usually known or listed. Verma (1988) listed the first appearance of *Rhizomyoides saketiensis*, *Palaeomys*, *Stegodon insignis*, *Proamphibos* and *Elephas planifrons* in the Saketi section. He

marked the presence of several taxa, which probably appeared in the uppermost part of the Saketi Formation, including *Elephas hysudricus*, *Anancus sivalensis*, *Cervus*, *Bison*. As the taxa are not dated, it appears that the earliest record of these species may be between 2.7 and 2.5 Ma and they belong to the *E. sivalensis* Interval-Zone. Hussain et al. (1992) dated the oldest occurrence of *E. hysudricus* at ±2.7 Ma in Mangala-Samwal area of Pakistan. As the precise dating of this taxon is not done in Indian Siwalik and this taxon is considered characteristic for *Equus sivalensis* Interval-Zone, the appearance of *Elephas hysudricus* in India is interpreted about 2.6 Ma.

First appearance. Twenty-five taxa make their first appearance or are restricted to this zone. These are: *Suncus* cf. *S. murinus*, *Pliosiwalagus whitei*, *Rhizomyoides saketiensis*, *Rhizomyides* cf. *R. sivalensis*, *Mus flynni*, *M. jacobsi*, *Parapelomys robertsi*, *Hadromys primitivus*, *H. moginandensis*, *Cremnomys* cf. *C. cutchicus*, *Bandicota sivalensis*, *Protatera* cf. *P. kabulense*, *Golunda tatroticus*, *Dilatomys moginandensis*, *Brachyrhizomys pilgrimi*, *Abudhabia* cf. *A. kabulense*, *Palaeomys* sp., ?*Anancus perimensis*, *Pentalophodon* (=*Anancus*) *khetpuraliensis*, *Hippohyus tatroti*, *Propotamochoerus hysudricus*, *Camelus sivalensis*, *Sivatherium giganteum*, *Proamphibos kashmiricus* and *Probison dehmi*.

Last appearance. *Stegodon bombifrons*, *Sivachoerus*, *Hydaspitherium megacephalum* and *Gazella* have their last appearance in this zone.

Common Taxa. The most common taxa include *Elephas planifrons*, *Stegodon insignis* and *Hexaprotodon sivalensis*. *Sivatherium* is common only in the uppermost part. Hipparionines are very rare.

4.2. *Equus sivalensis* Biostratigraphic Interval-Zone (2.6–0.6 Ma)

Reference Section. The Patiali Rao section is located west of Pinjore township near Chandigarh. The first appearance of *Cervus* is dated at 2.55 Ma in this section. However, Hussain et al. (1992) dated the first appearance of *Cervus* and *Elephas hysudricus* at 2.56 ± 0.21 and ±2.7 Ma, respectively, in the Mangla-Samwal area in Pakistan. The top of the Patiali Rao fossiliferous section is dated at 0.63 Ma by Ranga Rao et al. (1995) and this lies just below the thick conglomerates of the Boulder Conglomerate Formation. However, the top of the fossiliferous section at Parmandal-Utterbeni, Jammu is dated at 0.60 Ma (Ranga Rao et al., 1988). According to Ranga Rao et al. (1995) the Patiali Rao section is about 1296 m thick and its basal bed is dated at about 2.66 Ma. The first appearance of *Equus sivalensis* coincides with Gauss-Matuyama boundary, which is now dated at 2.58 Ma (Cande and Kent, 1995) and thus lies in the lowermost beds exposed at Patiali Rao.

Faunal Characterization. Ranga Rao et al. (1995) showed only selected taxa in their measured stratigraphic column. However, they have limitations for the probable appearance of various other taxa reported by other workers since data from these workers were not available.

First appearance. Forty-eight taxa made their first appearance. These are *Procynocephalus pinjorii*, ?*Homo erectus*, *Mus linnaeusi*, *Mus*. cf. *M. flynni*, *Caprolagus* sp., *Cremnomys* cf. *C. blanfordi*, *Golunda* sp., *Dilatomys* sp., *Rattus* sp., *Hystrix leucurus*, *Hadromys loujacobsi*, *Tatera pinjoricus*, *Rhizomys pinjoricus*, *Bandicota* sp., *Mellivora sivalensis*, *Canis pinjorensis*, *Panthera* cf. *P. cristata*, ?*Crocuta felina*, *C. colvini*, *Stegolophodon stegodontoides*, *Pentalophodon* (= *Anancus*) *sivalensis*, *Elephas hysudricus*, *E. platycephalus*, *Equus sivalensis*, ?*E. namadicus*, *Rhinoceros palaeindicus*, *R. sivalensis*, *Coelodonta platyrhinus* (= *Punjabitherium platyrhinus*), *Rucervus simplicidens*, *Cervus punjabiensis*, *Potamochoerus theobaldi*, *Sus falconeri*, *S. hysudricus*, *S. giganteus*, *S. choprai*, *Hippohyus sivalensis*, *Hemibos acuticornis*, *H. triquetricornis*, *H. antilopinus*, *Leptobos falconeri*, *Sivacobus palaeindicus*, *Sivacapra subhimalayaensis*, *Damalops palaeindicus*, *Oryx sivalensis*, *Bubalus palaeindicus*, *B. platyceros*, *Bos acutifrons*, *Bison sivalensis*.

Last appearance. *Cormohipparion theobaldi*, *Hipparion antilopinum*, ?*Chilotherium intermedium*, *Merycopotamus dissimilis* and *Proamphibos* made their last appearance near 2.5 Ma. The available magnetostratigraphic data indicates that at 0.60 Ma, the entire fauna became extinct or migrated as no taxon has yet been reported from the overlying Boulder Conglomerate Formation. However, a few taxa survived in Peninsular India and these occur in the Narbada and Godavari beds (both post-Siwalik) and include *Homo erectus*, *Elephas hysudricus*, *Stegodon insignis*, *Equus namadicus*, *Cervus* sp. and *Bubalus* sp.

Common Taxa. The most common taxa include *Elephas hysudricus*, *Stegodon insignis*, *Equus sivalensis*, *Rhinoceros palaeindicus*, *R. sivalensis*, *Coelodonta platyrhinus*, species of *Cervus* including *Rucervus*, *Sus* spp., *Sivatherium giganteum*, *Hemibos* spp. and *Bos acutifrons*.

Barry et al. (1982, pp. 122–123) discussed the relation of the interval-zones with those of Pilgrim's faunal zones (Nagri, Dhok Pathan, Tatrot and Pinjor). The boundaries of these faunal zones are generally recognized on the basis of lithology, which in some cases is time transgressive. However, in the Siwalik interval-zones, the lower and upper limits are marked magnetostratigraphic ages (Barry et al., 1982). In the present context, the upper limit of the Pinjor Formation is variable and ranges from 1.72 to 0.6 Ma, with two included interval-zones with more securely fixed boundaries. These interval-zones are placed in reference sections whereas Pilgrim (1913) did not specify any reference sections for his faunal zones (now designated as Formation). The boundaries or even the name of the interval-zones may be modified by additional fossil collection and magnetostratigraphy as has been discussed by Barry et al. (1982). The older zone, *Elephas planifrons* Interval-Zone, contains most of the taxa of the Tatrot Fauna whereas the younger zone, *Equus sivalensis* Interval-Zone, includes most of the taxa of the Pinjor Fauna.

Table 3
Range of various Siwalik biostratigraphic zones, based on magnetostratigraphy, as proposed by different workers

Barry et al. (1982)	Hussain et al. (1992)	Nanda (1997a)	Present contribution
	Elephas hysudricus Range-Zone (2.7–? Ma)	*Elephas hysudricus* Interval-Zone (2.7–0.6 Ma)	*Equus sivalensis* Interval-Zone (2.6–0.6 Ma)
Elephas planifrons Interval-Zone (2.9–1.5 Ma)	*Elephas planifrons* Range-Zone (3.4–2.7 Ma)	*Elephas planifrons* Interval-Zone (3.6–2.7 Ma)	*Elephas planifrons* Interval-Zone (3.6–2.6 Ma)
Hexaprotodon sivalensis Interval-Zone (5.3–2.9 Ma)			
Selenoportax lydekkeri Interval-Zone (7.4–5.3 Ma)			
'*Hipparion* s.l.' Interval-Zone (9.5–7.4 Ma)			

The ranges of the various zones as suggested by different workers are tabulated in Table 3.

5. Conclusions

In the Indian Siwaliks, both the Tatrot and Pinjor faunas are well developed in the Chandigarh region. The Tatrot Fauna is confined to the Saketi Formation (= pre-Pinjor beds of the Upper Siwalik Subgroup). As presently understood, thirty taxa distinguish the Tatrot Fauna from Pinjor Fauna and these include four taxa known earlier from the Dhok Pathan Formation but now also recorded from the Saketi Formation. Forty-nine taxa represent the Pinjor Fauna. Eight taxa extend from the Tatrot Fauna to the Pinjor Fauna (Table 1).

In the Jammu region, the Tatrot Fauna is scanty and represented by three marker taxa (*Stegodon bombifrons*, *Cormohipparion theobaldi*, *Propotamocherus hysudricus*). The Pinjor Fauna is better developed and is represented by 11 marker taxa, which are *Panthera* cf. *P. cristata*, *Crocuta felina*, *Elephas hysudricus*, *Equus sivalensis*, *Rhinoceros palaeindicus*, *Coelodonta platyrhinus*, *Cervus* (with antlers), *Sivatherium giganteum*, *Hemibos triquetricornis*, *Bos* and *Sivacapra*.

The upper limit of the Pinjor Mammalian Fauna is variable and ranges from 1.72 to 0.6 Ma. The lower limit of the Pinjor Fauna, or Tatrot\Pinjor faunal transition, virtually coincides with the Gauss-Matuyama boundary, which is now dated at 2.58 Ma.

In two sections (Parmandal-Utterbeni, Jammu and Patiali Rao, Chandigarh), the Pinjor Fauna occurs in strata younger than the Neogene\Quaternary Boundary (i.e. at the top of the Olduvai subchron) but does not show any change above or below the boundary.

Magnetostratigraphic data indicate that extinction or migration of the Pinjor Fauna virtually coincided with the Neogene\Quaternary boundary. In addition, this event is also marked by the change in sedimentation pattern from alternating sandstone–mudstone (Pinjor Formation in Chandigarh and Nagrota Formation in Jammu) to a conglomeratic succession (Boulder Conglomerate Formation). This event is also marked by the intensification of the last phase of the Himalayan orogeny, which is indicated by the presence of a thick succession of boulder and cobble conglomerates in the foothills.

Based on magnetostratigraphy, two biostratigraphic interval-zones, the *Elephas planifrons* Interval-Zone (3.6–2.6 Ma) and *Equus sivalensis* Interval-Zone (2.6–0.6 Ma), are recognized near Chandigarh. The older zone contains most of the taxa of the Tatrot Fauna and twenty-five taxa made their first appearance in this interval-zone. The younger interval-zone includes most of the taxa of the Pinjor Fauna and forty-eight taxa marked their first appearance in this interval-zone.

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