Journal of Nepal Geological Society, 1996, Vol. 14, pp. 11-19

The Cenozoic of Nepal: mountain elevation and vertebrate evolution*

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ABSTRACT

The Cenozoic of Nepal was a time of great activity, in terms of both the establishment and uplift of the Himalaya and the development of a vertebrate fauna which changed through time in response to the environmental events caused by the elevation of the mountains. Field work conducted over the past twenty years has generated a body of data which brings together palaeontological, ecological, and tectonic interpretations of the Cenozoic history of Nepal Himalaya.

Palaeontological data from Nepal are geographically limited. At this time, the early Cenozoic is represented by modest marine and terrestrial mammal remains found near Tansen. The middle and late Cenozoic is also documented from abundant materials found in the Siwaliks in a broad band of Sub-Himalayan sedimentary rocks between Butwal and Nepalganj and north of Jaleswar. Ice Age in Nepal may be interpreted from several Pleistocene localities in the Kathmandu Valley.

Nepal's Cenozoic palaeoenvironments are interpreted in large from the fossils found in the areas mentioned above, by analogy to India and Pakistan, and by study of the sedimentology of the enclosing rocks. It is possible to document the arrival of the Indian tectonic plate in South Asia in the early Cenozoic using palaeontologic, sedimentologic and tectonic data. At this time the broad open seaway (the remnant of Tethys) which occupied much of Nepal until the early Cenozoic closed and terrestrial communication with other areas became possible. By the middle Cenozoic, Nepal was the site of major erosional deposition from the rising Himalaya. This palaeoenvironment is indicated by both the terrestrial clastic sedimentary rocks which dominate the Nepal middle and late Cenozoic sequences as well as by the particular vertebrate taxa which have been recovered from the Siwaliks in western Nepal. Nepal's Pleistocene was a time of cool and dry environments; Kathmandu Valley deposits have yielded vertebrate remains which are indicative of this environment.

Of particular interest are efforts to relate Himalayan Cenozoic tectonics to the palaeobiological record of Nepalese environments. There are strong indications that the primary elevation of the Himalaya was a mid to late Cenozoic event; this correlates well with the environmental evidence from the fossil assemblages. This paper is devoted to review of palaeontologic, sedimentologic and tectonic data which are used to interpret the Cenozoic history of Nepal Himalaya.

INTRODUCTION

Cenozoic rocks and the record of Cenozoic vertebrate evolution in Nepal are concentrated in four areas. Small exposures of Palaeogene marine sedimentary rocks in the vicinity of Tansen permit some insights into the vertebrate fauna of Nepal prior to the opening of the Tethys Sea.

Thick deposits of the middle to late Cenozoic Siwalik Group can be traced throughout the whole length of Nepal, merging westward into the extensive exposures in India and, especially, in the Potwar Plateau of Pakistan. Structural complexity and vegetative cover are greater in the easternmost Siwalik exposure. In Nepal, the more prominent Siwalik exposures are in the western end of the

* Key note paper, 1st Nepal Geological Congress

country where the climate is drier and erosion is more intensive.

As the Himalaya rose, mountain basins became sediment traps. The Kathmandu Valley sediments have revealed the ice-age fauna of the high mountains, providing information on yet another Himalayan palaeoecosystem. The collision of the Indian subcontinent with Asia and the subsequent disappearance of the Tethys Sea and rise of the Himalaya are the fundamental cause of the vast amounts of sedimentary rocks (Sub-Himalaya) where Nepal's Cenozoic vertebrates are enclosed. The process of Himalayan uplift, thus, is an essential part of the story of vertebrate evolution along the mountain front. Toward the end of the Cenozoic, the mountains reached a high enough elevation to alter wind circulation patterns and to create the current monsoon pattern.

This paper reviews the various vertebrate faunas of Nepal and attempts to place them within the geological and geophysical framework of the elevation of the Himalayas during the Cenozoic. Thus, we explore two simultaneous events - the evolution of South Asian vertebrates and the elevation of the Himalayan mountain system.

PALEOGENE VERTEBRATE FOSSILS

Early Cenozoic vertebrates are known from several localities within the Tansen Synclinorium in south-central Nepal. Sakai (1983), engaged in detailed mapping of this Carboniferous to Cenozoic structure in the Lesser Himalaya, established a stratigraphy which includes the late Cretaceous to Palaeogene Amile Formation, the Eocene Bhainskati Formation and the Oligocene to early Miocene Dumri Formation as the upper three formations within the Tansen Group. Vertebrate fossils are reported from all the three units. The Middle Member of the Amile Formation has produced bone fragments from marine rocks which also yielded bivalves, gastropods and corals.

Sakai reports fragmentary vertebrate bones from marine rocks in the lower and middle parts of the Bhainskati Formation; bivalves, gastropods and foraminifera also are present, indicating a middle to late Eocene age. Of particular interest is the occurrence of land mammal remains in this assemblage. This fauna is not described by Sakai, but he suggests (Sakai, 1983, p. 56) that it is equivalent to the well-known assemblages from the Subathu Formation in India. The unconformably overlying Dumri Formation also consists of fragmentary vertebrate remains in sandstones and shale-pebble conglomerates. While the fossils are definitive, Sakai (1983, p.59) notes considerable lithologic similarity to the late Oligocene to early-middle Miocene Murree Group in Pakistan, well known in India as the Dharamsala Group, and particularly to the late Oligocene Dagshai Formation of the Simla Himalayas.

Sah and Schleich (1990) reported a pristichampsine crocodile from the Bhainskati Formation near the village of Dumri. By comparison of dental characters, they regard these crocodiles as terrestrial, consistent with Sakai's interpretation of the Bhainskati Formation.

MIDDLE TO LATE CENOZOIC – THE SIWALIK GROUP

The Siwaliks or Churia Hills extend northwest to southeast across the entire length of Nepal. While investigation of their geology began in the 1960's (Sharma, 1973), early emphasis was on their natural resources. Some remains of fossil plants were discovered during these explorations.

Extensive field work over the past two decades by American, German, Indian and Nepalese geologists has revealed the presence of fossiliferous Siwalik rocks from middle Miocene to Pleistocene in age.

Teams led by the author between 1976 and 1982 discovered lower and middle Siwaliks vertebrate fossils at a series of sites from Tinau Khola, north of Butwal on the east to the western Dang Valley, south of Tulsipur, on the west (Conroy et al., 1985; Munthe et al., 1983; West et al., 1978, 1983, 1991). Between 1983 and 1991, Corvinus and colleagues have developed a series of middle and late Siwaliks vertebrate localities between Shivpur and Bhalubang (Corvinus 1988a, 1988b, 1993; Corvinus and Nanda, 1994; Nanda and Corvinus, 1992). More recently, Texaco Oil teams have made collections of vertebrate fossils in the Dang Valley area (N. B.

Kayastha, pers. comm., August 15, 1995); the specimens are kept in Kathmnadu and, because of the proprietary nature of the investigation, have not been published.

The complex of localities on the south edge of the Dang Valley, above the Tui Khola, as well as along the north side of the Rapti Dun (Fig. 1) and the first line of hills north of the east-west highway west of Butwal consists of vertebrates that are readily comparable to those from the Chinji Formation of India and Pakistan. This represents the early Siwaliks. The fauna is characterized by the rhinoceros *Brachypotherium perimense*, the small artiodactyl *Dorcatherium*, and the absence of the abundant middle Siwalik horse *Hipparion* (West et al., 1978, 1991). Fish, snakes, turtles and crocodilians are abundant.

A younger assemblage, referred to the middle Siwaliks and comparable to the Nagri Formation of Pakistan and India, is found in the Tinau Khola between Butwal and Dobhan and in the hills a few hundred meters south of the Tui Khola near Majghatwa Village. The Tinau Khola localities have produced Nepal's only fossil primate specimen (a molar of *Sivapithecus punjabicus*), the pig *Conohyus sindiense*, and a rhyzomyid rodent (Munthe et al., 1983). A magnetostratigraphic study conducted along the Butwal-Dobhan highway corroborates the middle Siwalik age. East of Dobhan, the bovid *Pachyportax* has been collected, and a bedding-plane exposure revealed footprints attributed to a small anthracothere (West et al., 1983). A single locality several hundred meters southeast of Majghatwa yielded *Hipparion* and *Giraffokeryx*, both middle Siwalik marker fossils (West et al., 1991).

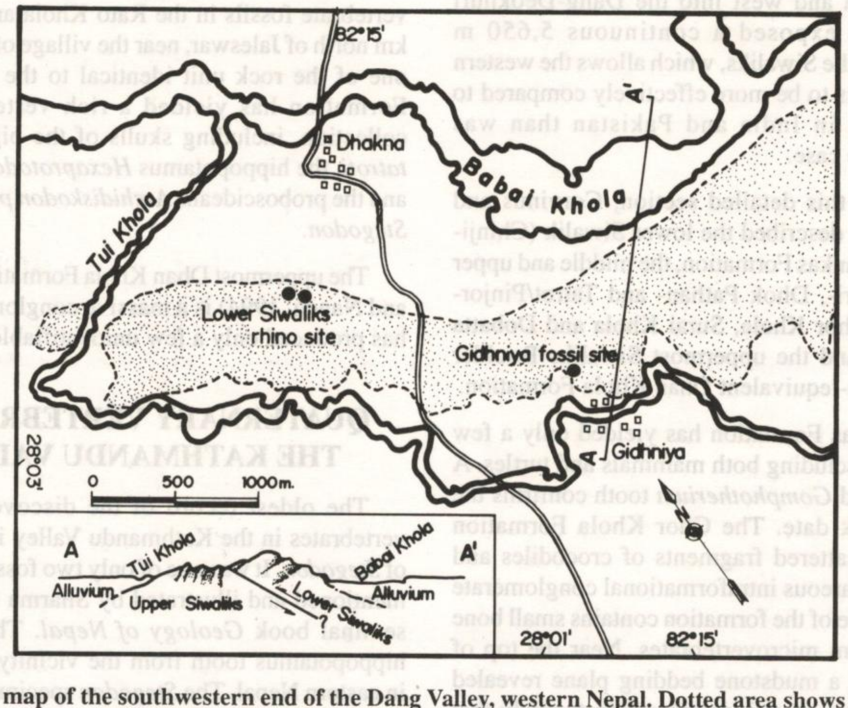

Fig. 1: Sketch map of the southwestern end of the Dang Valley, western Nepal. Dotted area shows the outcrop of Siwalik rocks, with a primary Badai Khola site and the Gidhniya site. Cross-section 'A-A' is constructed from both field data and aerial observations.

West and Munthe (1981, 1983, and 1984) reported on a Upper Siwalik fauna reportedly collected by V.J. Gupta near Ghidniya. Persistent field work failed to locate any upper Siwalik rocks near Ghidniya, so, upon learning of Corvinus' finds in the Surai Khola, we proposed (West et al., 1988) that Gupta was not aware of his whereabouts when the collection was made. Subsequently, Gupta was accused, by a number of his co-authors, of having falsified locality data.

While this does not *a priori* confirm that what we called the Upper Rapti fauna is fraudulent, it introduces enough suspicion for that presumed assemblage to be ignored in all further discussions of Nepal's vertebrate palaeontology.

Apart from the Tinau Khola, the localities studied by the author were not placed within a continuous section. They were correlated biostratigraphically and lithostratigraphically only. Thus, their actual relations to one another are just approximations.

Corvinus' work took advantage of roadcuts made during the construction of the road from the Terai at Shivpur north and west into the Dang-Deokhuri Valley. This exposed a continuous 5,650 m succession of the Siwaliks, which allows the western Nepal Siwaliks to be more effectively compared to the Siwaliks in India and Pakistan than was previously the case.

Based on this detailed section, Corvinus and Nanda (1994) described the lower Siwalik (Chinji-equivalent) Bankas Formation, the middle and upper Siwalik (Nagri-, Dhok Pathan- and Tatrot/Pinjor-equivalent) Chor Khola, Surai Khola and Dobatta Formations, and the uppermost Siwaliks Boulder Conglomerate- equivalent Dhan Khola Formation.

The Bankas Formation has yielded only a few vertebrates, including both mammals and turtles. A well-preserved *Gomphotherium* tooth confirms the lower Siwalik date. The Chor Khola Formation consists of scattered fragments of crocodiles and turtles. A calcareous intraformational conglomerate near the middle of the formation contains small bone fragments from microvertebrates. Near the top of the formation a mudstone bedding plane revealed hoofprints of small artiodactyls; unfortunately that slab was destroyed during blasting.

Sah et al. (1995), in describing a disjunct section in the Kamala River area of eastern Nepal, named six formations covering a 6,100 m section of the Siwalik Group. They discovered an isolated crocodile tooth in the Ghurmi Formation, regarded as laterally equivalent to Corvinus and Nanda's (1994) Chor Khola Formation. This specimen has not yet been studied.

The Surai Khola Formation contains the most abundant and best preserved vertebrate fossils yet found in Nepal. Particularly abundant in Surai Khola are Elephantidae and Hippopotamidae (*Hexaprotodon*), while bovids (cattle), suids (pigs) and cervids (deer) are common. The crocodilians *Crocodylus* and *Gavialis*, and turtles (including the giant tortoise *Emyda*) are particularly abundant. All these taxa are typical of the Tatrot/Pinjor faunas of India and Pakistan. The overlying Dobatta Formation likewise produces abundant crocodiles and turtles, as well as the mammals *Archidiskodon planifrons, Hexaprotodon sivalensis*, *Equus*, cattle, antelope and anthracotheres.

In east-central Nepal, Corvinus has collected vertebrate fossils in the Rato Khola area, about 60 km north of Jaleswar, near the village of Patu. There, one of the rock unit identical to the Surai Khola Formation has yielded a rich vertebrate fossil collection, including skulls of the pig *Hippohyus tatroti*, the hippopotamus *Hexaprotodon sivalensis*, and the proboscideans *Archidiskodon planifrons* and *Stegodon*.

The uppermost Dhan Khola Formation (Corvinus and Nanda, 1994) is a massive conglomerate which has produced only a few unidentifiable bones.

QUATERNARY VERTEBRATES – THE KATHMANDU VALLEY

The oldest record of the discovery of fossil vertebrates in the Kathmandu Valley is a mandible of *Stegodon*. It was one of only two fossil vertebrates mentioned and illustrated by Sharma (1973) in his seminal book *Geology of Nepal*. The other is a hippopotamus tooth from the vicinity of Janakpur in eastern Nepal. The *Stegodon* specimen is referred to again by Corvinus and Nanda (1994, p. 45). They suggest that it was burnt in the great fire of the Singha Durbar in 1973, at which time records of its provenance were lost.

Gupta (1975) and Fort and Gupta (1981) mention, in addition to *Stegodon*, the occurrence of *Hexaprotodon sivalensis*, *Archisdiskodon planifrons* and *Crocodylus* from what is now called the Lukundol Formation. They suggest a locality in the Nakkhu Khola; Dongol (1985) confirms the productive area to be in the Bagmati Valley.

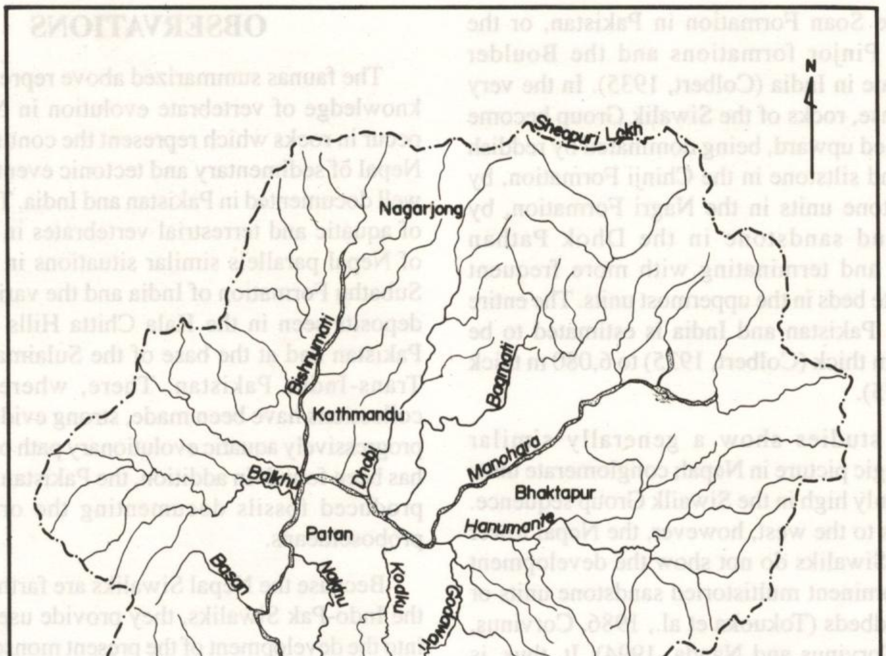

Fig. 2: Location of fossils in Kathmandu Valley.

Dongol (1985) and West et al. (1988) have done the most recent study of sedimentary rocks and their included fossils in the Kathmandu Valley. His primary large-vertebrate collecting area is along the lower reaches of the Bagmati River, downstream of Chobar Gorge (Fig. 2). The Lukundol fauna now includes the proboscideans *Elephas* cf. *hysudricus*, *E.* cf. *planifrons*, the pig *Potamochoerus palaeindicus*, bovids and cervids. A discovery of the bovid *Bos namadicus* was reported near Bhadrabas village, north of Baktapur.

The final vertebrate occurrence in the Kathmandu Valley is that of pharyngeal teeth of the cypriniformid fish *Tor* and a jaw and scales of another teleost fish from a diatomaceous unit, within the Lukundol Formation near the village of Chapagaon (West et al., 1988). All of the materials collected in the Kathmandu Valley are suggestive of a Pleistocene age, generally equivalent to the Pinjore of India.

NEPAL SIWALIK STRATIGRAPHY

Pilgrim (1910) divided the Siwaliks of India and Pakistan, on the basis of mammalian fossils, into lower, middle and upper units. These units subsequently were improperly formalized into formations and given presumed lithologic and chronostratigraphic significance. The lower Siwaliks include the Chinji Formation, the middle Siwaliks the Nagri and Dhok Pathan formations, and the upper

Siwaliks the Soan Formation in Pakistan, or the Tatrot and Pinjor formations and the Boulder Conglomerate in India (Colbert, 1935). In the very broadest sense, rocks of the Siwalik Group become coarse grained upward, being dominated by reddish claystone and siltstone in the Chinji Formation, by thick sandstone units in the Nagri Formation, by siltstone and sandstone in the Dhok Pathan Formation, and terminating with more frequent conglomerate beds in the uppermost units. The entire sequence in Pakistan and India is estimated to be from 4,865 m thick (Colbert, 1935) to 6,080 m thick (Wadia, 1975).

Recent studies show a generally similar sedimentologic picture in Nepal; conglomerate units are known only high in the Siwailk Group sequence. Unlike areas to the west, however, the Nepal lower and middle Siwaliks do not show the development of either prominent multistoried sandstone units or extensive redbeds (Tokuoka et al., 1986, Corvinus, 1988, and Corvinus and Nanda, 1994). It, thus, is not possible to correlate the Nepal Siwaliks with the Indo-Pakistan Siwaliks on the basis of gross lithologies, despite the subformation level units proposed by Corvinus (1988).

My field groups substantiated Glennie and Zielger's recognition of a thick (at least 3,000 m) lower sandstone/shale unit, overlain by at least 1,300 m of conglomerate. The Department of Mines and Geology estimates the total thickness as up to 8,200 m. Corvinus has measured a 5,650 m section in the Surai Khola, where the bottom of the Siwaliks is not exposed.

The terminologies currently in use for the Nepal Siwaliks are confusing. Across just a few hundred kilometers of strike, no less than three formation-level stratigraphic schemes have been proposed beyond the traditional lower/middle/upper approach (Tokuoka et al., 1986, Sah et al., 1994, and Corvinus and Nanda, 1994). Such confusion often is the case in an area which is being examined by investigators with different philosophies, and especially in a region where travel and comparisons are difficult. It is likely that continued attention to the Nepal Siwaliks will resolve these ambiguous terminologies and a coherent framework for the Nepal Siwaliks will ultimately emerge.

OBSERVATIONS

The faunas summarized above represent current knowledge of vertebrate evolution in Nepal. They occur in rocks which represent the continuation into Nepal of sedimentary and tectonic events which are well documented in Pakistan and India. The presence of aquatic and terrestrial vertebrates in the Eocene of Nepal parallels similar situations in the Eocene Subathu Formation of India and the various Eocene deposits seen in the Kala Chitta Hills of northern Pakistan and at the base of the Sulaiman Range in Trans-Indus Pakistan. There, where far better collections have been made, strong evidence for the progressively aquatic evolutionary path of the whales has been found. In addition, the Pakistan Eocene has produced fossils documenting the origin of the proboscideans.

Because the Nepal Siwaliks are farther east than the Indo-Pak Siwaliks, they provide useful insights into the development of the present monsoon weather pattern. It is well-documented that at about 8 million years ago the environments of the Punjab of India and the Potwar Plateau of Pakistan were becoming drier. This is reflected in the nature of the grasses, understood from their pollen, as well as a rapid evolution of xeric rodents and the general reduction in the abundance of obligatorily aquatic fish, turtles, crocodiles and snakes. The faunas from Nepal, however, as shown in this review, continue to have high proportions of aquatic vertebrates throughout the deposition of the Siwaliks. This strongly suggests that the current monsoon precipitation and vegetation patterns had been established by then.

MOUNTAIN ELEVATION DURING THE CENOZOIC

Although the initial purpose of this paper was to summarize the current state of knowledge of the Cenozoic evolution of vertebrates in Nepal, it is useful to stand that evolutionary sequence against the physical setting in which it was occurring. The rise of the Himalaya to its current altitude was a major feature of the South Asian environment throughout the Cenozoic. The animals and plants that lived on the vast fans of sediment pouring from the rising mountains responded to the environmental changes produced by the Himalaya.

The Himalaya rose and the sedimentary rocks of the Siwaliks were generated as a consequence of the collision between the Indian plate and Eurasia. The northward drift of India began in the Mesozoic, caused the closure of Tethys in the Cretaceous/Palaeogene, and rise of the Himalaya during the Neogene. While there is general agreement on this framework, there are varying views and conflicting data regarding its rate and the evenness of the event. There are strong indications that the uplift of the Himalaya, with the attendant erosion and deposition along the southern flank of the mountains, was episodic rather than smooth and gradual (Sorkhabi and Stump, 1993).

The continental collision occurred between 65 and 45 Ma. It is likely that contact was made first in the northwest, with the eastern edge of the Indian plate encountering Eurasia toward the end of the Eocene. Klootwijk et al. (1992), using palaeomagnetic results from ODP Leg 121 along the Ninetyeast Ridge, detected an abrupt slowdown of India's northward movement at 55+ Ma, which they interpret as the initial suturing with Asia, probably in the Kohistan (Western Himalaya) area. The eastern part of India sutured with Asia somewhat later. Beck et al. (1995), working in northern Pakistan (Waziristan and Kurram), suggest that suturing was complete there by 49 Ma.

The palaeontological consequence of this suturing was elimination of the Tethys Sea and its replacement by an initially shallow-water to low-elevation emergent area. Sakai's studies near Tansen indicate that as late as middle Eocene, there were north-flowing streams in his Cretaceous-Palaeogene Amile Formation and Eocene Bhainskati Formation (1983, p. 72); this flow was reversed to the southward (away from the developing Himalaya) in the Oligocene-Miocene Dumri Formation. The fauna from the Tansen area supports this scenario.

Three episodes of major Himalayan uplift, followed by denudation of the elevated rocks, likely occurred. The first, 21 to 17 Ma, resulted in the early Miocene Murree, Dharamsala and early Siwalik deposition. Stratigraphy of the submarine Bengal Fan and subsidence of the western margin of India, a result of Indus Fan loading, support this, as does the mineralogy of the terrestrial formations. A second, late Miocene episode occurred from 11-7 Ma. This is indicated by increased sedimentation onto the Bengal Fan. In addition, ODP Leg 117 results (ODP 1988a, 1988b) recovered biogenic deposits with radiolaria and foraminifera which are associated with monsoon-driven ocean upwelling. This data suggests that the development of the Himalayan barrier to the monsoon is correlated with this uplift. The final uplift episode is Quaternary, during which the major Himalayan basins (Kashmir), Skardu and Kargil (India), and Thakkhola, Pokhara and Kathmandu (Nepal) were formed. This uplift episode also accounts for the antecedent stream drainage pattern shown by the Indus and Bramaputra Rivers.

The northern side of the Himalaya is less understood than is the southern, Siwalik, side. Coleman and Hodges (1995) suggest that the Tibetan plateau achieved its high elevation well before Miocene time. This suggestion runs counter to the occurrence of the Hipparion fauna in later Miocene and Pliocene rocks of the Jilong and Bulong Basins of southern Tibet (Huang et al., 1980; Ji et al., 1980; Zheng, 1980). Harrison et al. (1992) had suggested Tibetan elevation beginning about 20 Ma, with the plateau reaching its current level about 8 Ma, closer to conforming with the fossil evidence.

Palaeontologic and palaeoecologic studies of the tectonic style of the Cenozoic Himalaya are developing a physical model which supports fossil evidence from Pakistan, India and Nepal. Prell and Kutzbach (1992) have demonstrated that the Himalayan elevation threshold for inducing a strong monsoon response was not exceeded until late Miocene. They correlate this critical elevation with marked changes in the grass, fauna and the organization of small mammal ecology of the Potwar Plateau and conclude that the balance was tipped toward the modern monsoon system around 8 Ma. Bourbon et al. (1993) concur with this conclusion.

CONCLUSIONS

The history of vertebrate fossils in Nepal is becoming more clear as Cenozoic rocks throughout the country are explored more thoroughly. There are two episodes of vertebrate evolution present in Nepal: a) that representative of the final closing of the Palaeogene Tethys Sea; and b) that representative of events associated with the elevation of the

Himalaya. Stratigraphic nomenclature of the Nepal Siwaliks is in a state of flux. Future synthetic studies will bring order to this chaos. The Nepal vertebrate fossil and sedimentologic record is consistent with mineralogic, tectonic and oceanographic models of the evolution of the Himalayas and surrounding areas.

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