27 Introduction to Siwaliks

The composition of the Siwalik deposits shows that they are nothing else than the alluvial detritus derived from the subaerial waste of the mountains, swept down by their numerous rivers and streams and deposited at their foot.

—D.N. Wadia (1926, p. 231)

The Siwaliks (Box 27.1) represent one of the largest fluvial deposits in the world. They are equally famous globally for the occurrence of vertebrate fossils, leading to the investigation on the evolution of hominid and anthropoid lineages (Wadia 1926; Johnson et al. 1982a). They also enclose a rich collection of plant and mollusc remains. The Siwalik (or Churia) Group of rocks extends from the Mahakali River on the west frontier of Nepal to the Mechi River on the east, making an uninterrupted foothill belt throughout the country. In fact, the Sub-Himalayan belt, made up of the Siwaliks and allied rocks, stretches from the Salt Range (Pakistan) and Kumaun (India) on the west to Darjeeling on the east. With some interruptions in Bhutan (Chap. 5), they continue farther east to Arunachal Pradesh of India, and even beyond.

The Siwaliks (Box 27.2) constitute a very thick (4,000–6,000 m) molasse-like sedimentary succession, comprising a coarsening-upwards sequence as a whole, which reflects the rising history of the Himalaya (Gansser 1964a). The volume of Alpine molasse is double the volume of the present Alps, whereas the Siwalik Molasse represents only a fraction of the Himalayan Range (Gansser 1964b, p. 387).

Box 27.1: Origin of the Term Siwalik

The name Sewalik has been in use for the tract between the Sutlej and the Ganga at Haridwar since as early as 1796 by Rennel (Falconer 1868, p. 6). Concerning the name Siwalik, Falconer and Cautley (1836, p. 38) wrote the following:

> We have named the fossil, *Sivatherium,* from Siva, Hindú god, and *θηριον bellua.* The *Sivâlik* or Sub-Himálayan range of the hills, is considered in the Hindú mythology, as the *Lútiah* or edge of the roof of Siva's dwelling in the *Himálaya,* and hence they are called the *Siva-ala* or *Sib-ala,* which by an easy transition of sound became the *Sewálik* of the English. The fossil has been discovered in a tract which may be included in the *Sewálik* range, and we have given the name of *Sivatherium* to it, to commemorate this remarkable formation so rich in new animals.
>
> Another derivation of the name of the hills, as explained by the *Mahant* or High Priest at *Dehra,* is as follows: *Sewálik* a corruption of *Siva-wála,* a name given to the tract of mountains between Jumna and Ganges, from having been the residence of Iswara Siva and his son Ganès, who under the form of an Elephant had charge of the Westerly portion from the village of *Dúdhli* to the Jumna, which portion is also called *Gangaja, gaja* being in Hindí an Elephant. That portion Eastward from *Dúdhli,* or between that village and *Haridwár,* is called *Deodhar,* from its being the especial residence of *Deota* or Iswara Siva: the whole tract however between the Jumna and Ganges is called *Siva-ala,* or the habitation of Siva: under *Sewálik.*

Subsequently, Cautley and Falconer, the two pioneers in the study of Siwalik vertebrates (e.g., Cautley and Falconer 1835; Falconer 1837, 1868), applied the term to the entire mammal-bearing zone.

Strachey (1851) and Colbert (1935) also discuss how the name Siwalik (*Sivâlik* or *Sewalik*) was originally given by Dr. Hugh Falconer. Captain Proby T. Cautley in 1831 was supervising the Ganga canal construction work at Haridwar, India, and discovered the vertebrate fossils (Johnson et al. 1982a) near a Shiva (or Siva) temple (Vaidyanadhan and Ramakrishnan 2008). According to Falconer (1868), laborers working on the canal, under the direction of Feroz the Third, encountered, in the course of their excavation, the bones of human giants in the unbedded mound. Hence, he gave the name Sivâlik to the sedimentary rocks entombing the fossils. But, it was Medlicott (1864, p. 5, 10) who formally designated the rocks constituting a well-marked outer Himalayan geological succession as the Sivâlik series. He also noted that, on the whole, and as not involving an idea of geological age, the most general term of Sub-Himalayan series would be more suitable.

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These freshwater soft rocks contain interbedded conglomerates (mainly in the upper part), sandstones, siltstones, pseudo-conglomerates, and mudstones. Their great aggregate thickness and general coarseness give evidence of continuous deposition in a shallow body of water, whose depth kept pace with the accumulation of sediments (Krishnan 1956). These rocks are very fragile and get easily weathered and disintegrate in no time. Hence, good exposures of the Siwaliks are spared mainly along river- or stream-cut banks and in fresh road or canal excavations.

In Nepal, the Siwaliks range in age from the Middle Miocene (about 16 Ma) to early Pleistocene (less than 1 Ma). They invariably have a faulted upper contact with the overriding Lesser Himalayan succession. However, most of the time their lower contact is concealed, yet it represents an erosional disconformity on the Proterozoic slices present in the Siwalik belt of central and east Nepal (Chaps. 10 and 11). In India and Pakistan, there are areas where the Siwaliks transitionally overlie the older rocks (Wadia 1926). In the Punjab and Simla Himalaya, the Tertiary rocks constitute two broad belts, an outer and an inner, formed, respectively, of the Miocene–Pliocene and Paleocene–Oligocene strata.

27.1 Early Investigations in India and Pakistan

Medlicott (1864, pp. 10–11) noted that, because the Siwaliks are separated throughout the Himalaya by a well-marked fault, it is not possible to observe the relationship between these rocks and the older successions. However, he also mapped an extensive outlier of the Tertiary rocks, overlying the older (i.e., Lesser Himalayan) succession and nearly occupying the whole length between the Sutlej and Yamuna Rivers in the Northwest Himalaya. In this area, the bottom beds (Nummulitic strata) of the outlier rest unconformably on a denuded surface of the older rocks, and have been folded up with them in the same contortions.

Box 27.2: Main Characteristics of Siwaliks

- The Siwaliks are made up of mudstones, siltstones, sandstones, and conglomerates. They were deposited in a variety of fluvial environments, including piedmonts, outwash plains, channels, floodplains, and oxbow lakes.
- They comprise a fining-upwards sequence on the scale of individual cycles, but a coarsening-upwards succession as a whole.
- The deposits are frequently divided into the Lower, Middle, and Upper Siwaliks, ranging in age from the Middle Miocene to early Pleistocene. Such lithological subdivisions are diachronous, and the equivalent units become successively younger from the northwest towards the southeast.
- The thickness of a given lithostratigraphic unit of the Siwaliks may change significantly in its lateral direction (i.e., within a few tens of kilometers).
- The Upper Siwaliks exhibit disconformable contacts in a number of places. In a few locations, they are transgressive over the Middle and Lower Siwaliks, indicating past prodigious tectonic movements.
- The Siwaliks are very incompetent (soft), and have buckled into noncylindrical plunging folds with curved hinges in map view (i.e., concave or convex towards the foreland).
- There are areas with overturned Siwalik strata. Such beds are sometimes found just at the boundary with the Terai plain.
- The Siwalik beds are frequently truncated by north- as well as south-dipping thrust faults. Like the folds, the thrusts too are convex or concave towards the foreland.
- Some intermontane valleys are located within the Siwalik belt.
- There are a few Proterozoic outliers in the Siwalik belt of central and east Nepal.
- Contrary to a general belief, there is no single and continuous Himalaya Front Tectonic Line (Nakata 1972) or Main Frontal Thrust (Gansser 1983) outcropping throughout the Nepal Himalaya and beyond; in a number of locations, the Siwalik folds abruptly disappear in the Terai plain.
- The geomorphology of the Siwalik Hills is strongly controlled by their rock texture and structure.

Middlemiss prepared an excellent geological map of the Siwaliks of the Kumaun Himalaya bordering west Nepal. He applied a simple classification scheme of the following equivalent lithostratigraphic terms: Siwalik conglomerate for the Upper Siwaliks, sand-rock stage for the Middle Siwaliks, and Nahan sandstone for the Lower Siwaliks (Middlemiss 1890, p. 19). He minutely worked out their mineralogical and petrographic details, and showed that the rocks are thrown into complex folds (even with overturned limbs) and supervened by various dislocations. Based on the experience gained in this portion of the Sub-Himalaya, he formalized the concept of the Main Boundary Fault proposed by Medlicott (1864).

The first systematic and detailed stratigraphic investigation of the Siwaliks began in the Potwar Basin of Pakistan at the end of the nineteenth century. While working in the Potwar Plateau, Pilgrim (1910, 1913) divided the Siwalik succession into three units, and assigned them the Middle Miocene, Late Miocene to Early Pliocene, and Late Pliocene to early Pleistocene, respectively. Anderson (1927) and Pascoe (1964) provide detailed descriptions of the Siwaliks in India and Pakistan. Gee (1989) deals with the geology and structure of the Salt Range. Colonel McMahon was one of the earliest researchers to microscopically examine the Siwaliks and associated rocks. In the Siwaliks south of Nainital, he observed mainly angular pieces of quartz, with bits of slate and a little mud. Also present in the rock are flakes of muscovite, greenish mica, and fragments of schorl (McMahon 1883, p. 188). Krynine (1937) investigated the petrography of Siwalik sandstones and pseudo-conglomerates. Gill (1952a, b) carried out a detailed study of the Siwaliks in the eastern side of the Punjab Sub-Himalaya.

27.2 Stratigraphic Classification of Northwest Sub-Himalaya

Medlicott (1864, p. 17) differentiated the Northwest Sub-Himalayan rocks into the following units.

- Upper (Sivâlik: conglomerates, sandstones, clays)
- Middle (Nahun: lignites, sandstones, and clays)
- Lower (Nummulitic Subathu: fine silty clays with limestone, followed by Dugshai: purple sandstones and red clays, and Kasaoli: gray and purple sandstones).

Subsequently, Medlicott and Blanford (1879, p. 524) further proposed the following classification (Table 27.1) for the Sub-Himalayan formations.

In the Salt Range, Wynne (1878, 1880) identified the Miocene (Nahan or Murree) beds and Pliocene (Lower and Upper Siwalik) series. Blanford (1879a) carried out more detailed work in western Sindh, where he classified the Late Miocene rocks under the Lower Manchhar and the Pliocene rocks under the Upper Manchhar beds. Subsequently, he continued further investigations in the hills from Quetta to Dera Ghazi Khan (Sindh and Punjab), and showed that the Manchhar beds are equivalent to the Siwalik beds. From the latter area, Blanford (1883, p. 34) mapped the Late Miocene (Lower Manchhar or Lower Siwalik) and Pliocene (Upper Manchhar or Middle and Upper Siwalik) subdivisions.

Table 27.1 Classification of Sub-Himalayan formations

Sub-Himalayan system	Siwalik series	Upper
		Middle
		Lower (Náhan)
	Sirmúr series	Upper (Kasauli)
		Middle (Dagshai)
		Lower (Subáthu: nummulitic)

Source Medlicott and Blanford (1879)

While studying the Tertiary and post-Tertiary deposits of Baluchistan (Bugti Hills) and Sindh, Pilgrim (1908) described in detail the lithology and fossils of the Lower and Upper Siwaliks. Although he mentioned the name Middle Siwaliks, he did not deal with it in much detail. He also observed that, in the Lower Siwalik sandstones and conglomerates from that area, Nummulitic limestone pebbles are absent, contrary to the case in their upper part. Based on this, he inferred that much of the Nummulitic limestone was covered by other deposits during Lower Siwalik time. Subsequent uplift and erosion of the land area exposed the limestone hills to contribute to the Upper Siwalik boulder deposits.

27.3 The Threefold Classification of Siwaliks

In his classic work on the Siwalik vertebrates and their correlation with European counterparts, Pilgrim (1910, 1913) classified the fluvial deposits in the Potwar Plateau into the Lower, Middle, and Upper Siwaliks from bottom to top, respectively. Gansser (1964a) summarized the Siwaliks of the Punjab Himalaya in two lithostratigraphic columns. Following the earlier workers, he described them in terms of the threefold classification.

27.3.1 Lower Siwaliks

Pilgrim (1908) observed that in the Bugti Hills, the base of the Lower Siwaliks is characterized by red or gray clays, intercalated in soft, gray, brittle, well-bedded sandstones containing "bone conglomerates". These conglomerates are concretionary and contain pellets of red clay and calcareous matter, with occasionally small ferruginous nodules in a sandy matrix.

Actual pebbles, which are infrequent, are invariably of sandstone. The bone conglomerates occur very frequently and, from their superior hardness, give rise to a series of scarps. These concretionary conglomerates continue to occur as lenticular beds in the next higher member of the "series," made up of a massive sandstone, in which the calcareous segregation has taken place to such an extent that Blanford (1883, p. 57) designated it as the pseudo-conglomerate. Presumably, he borrowed this term from the lithological descriptions of similar older sequences, such as the upper

Nummulitic series and Tertiary sandstones, where the term was in wider use (e.g., Wynne 1877, p. 118, 1878, p. 108). This pseudo-conglomeratic sandstone weathers in a characteristic columnar and nodular fashion. In addition to the concretionary conglomerates, there are calcareous nodular beds and clays, the whole deeply tinted red (Pilgrim 1910). Pilgrim (1913, 1925) further subdivided the Lower Siwaliks into the Kamlial (named after a place located at 33°15′ N, 72°30′ E and Chinji (32° 42′ N, 72° 22′ E) "stages." Ironically, Pascoe (1964) noted that the Kamlial village itself is on Chinji rocks, whereas Johnson et al. (1985) stated that the Chinji village is situated on a cuesta of younger Nagri sandstone.

The Kamlial is composed of fine- to medium-grained, gray, green-gray, and sporadically red or brown sandstones. Some of the sandstones are soft, and others are well indurated (Johnson et al. 1982b). The sandstones are interbedded with purple shales, mudstones, and pseudo-conglomerates. Pilgrim (1913) assigned a Middle Miocene age for this "stage," based on the mammalian fossils. On the other hand, Johnson et al. (1985) paleomagnetically dated this unit and defined its lower and upper limits between 18.3 and 14.3 Ma (Early to Middle Miocene), respectively.

The transitionally overlying Chinji stage comprises mainly bright yellow and brown nodular mudstones and claystones, with subordinate amounts of gray to brown sandstones and pseudo-conglomerates (Pilgrim 1910). According to Pilgrim, it belongs to the Middle Miocene. However, further paleomagnetic studies by Johnson et al. (1985) have yielded an age range from 14.3 to 10.8 Ma (Middle to Late Miocene).

27.3.2 Middle Siwaliks

Pilgrim (1910) subdivided the Middle Siwaliks into the Nagri (32° 46′ N, 72° 21′ E) and Dhok Pathan (33° 8′ N, 72° 21′ E) stages. Medium- to coarse-grained, friable, thick sandstones with lenticular, hard, gray carbonate-cemented beds and subordinate gray and brown mudstones and conglomerate constitute the Nagri stage. On the basis of vertebrate fossils, this unit was assigned a Late Miocene age (Pilgrim 1910, 1913; Pascoe 1964). Magnetostratigraphically, it belongs to an interval between 10.8 Ma and about 8.5 Ma (Johnson et al. 1985).

The Dhok Pathan unit consists of very thick-bedded, massive, friable, calcareous, gray and light gray sandstones and sandy beds with fewer mudstones, orange clays, and shales of pale and drab colors (Pilgrim 1910). Based on vertebrate fossils, it was assigned a Late Miocene age (Pilgrim 1910, 1913). On the other hand, Johnson et al. (1982b, 1985) paleomagnetically dated this unit between about 8.5 Ma and about 5.1 Ma.

At the end of Dhok Pathan time, some uplift occurred, and the strata were folded and eroded before the deposition of Tatrot beds. This erosion interval is thought to cover the Late Pliocene (Krishnan 1956). Such an erosional gap is attested by the local geological features, for instance, the distribution of the Upper Siwaliks only along basins and stream channels and not on the Potwar Plateau. This uplift accentuated the Kala Chitta Range and extended it eastwards (Krishnan 1956).

27.3.3 Upper Siwaliks

The Upper Siwaliks in the Bugti Hills rest with a sharp unconformity on the Lower Siwaliks, whereas in Sindh and other parts of Baluchistan, the Middle Siwaliks are observed between them. Pilgrim (1908) subdivided the Upper Siwaliks into the Tatrot (32° 52′ N, 73° 21′ E), Pinjor (30° 47′ N, 76° 55′ E), and Boulder Conglomerate stages, respectively, from the bottom upwards. The Tatrot is made up of conglomerates, soft sandstones, and orange and brown clays or mudstones. The conglomerates contain pebbles derived from igneous, metamorphic, and sedimentary rocks. The sandstones are gray and medium- to coarse-grained. This zone is rich in vertebrate fossils, belonging to the middle Pliocene (Pilgrim 1910, 1913). The Pinjor stage consists of coarse-grained, light gray to white sandstones, light pink siltstones, and conglomerates of Late Pliocene age (Pilgrim 1910, 1913). The Boulder Conglomerate stage consists of boulder- and pebble-conglomerates, containing clasts derived from igneous, metamorphic, and sedimentary rocks. In many places, these deposits are time transgressive (Gill 1952a). Pilgrim (1913) assigned them an early Pleistocene age.

27.4 Problems of Threefold Usage and Terminology

Colbert (1935, pp. 13–19) deals in detail with the issue of nomenclature of the Siwaliks. Following the recommendations of the Committee on Stratigraphic Nomenclature, he alluded to the possibilities of using such terms as system, group, formation, series, or zones. He concludes that the threefold classification is neither purely lithostratigraphic nor biostratigraphic, and recommends applying the terms Lower, Middle, and Upper Siwaliks, without any further descriptive words. On the other hand, to the Kamlial, Chinji, and other subdivisions, he suggested applying the term "zone."

This initially developed threefold classification was based primarily upon vertebrate fossil findings in a set of distinct sedimentary sequences from the Potwar Plateau. Consequently, these units reflected the lithostratigraphic as well as biostratigraphic divisions. Inasmuch as the Siwaliks were originated from various rivers and streams, operating within a wide geographic span of more than 2,500 km, there are inherent inhomogeneities and lithofacies differences. G.E. Lewis, a prominent American paleontologist engaged in the collection of Siwalik fossils in India (e.g., Lewis 1933a, b), noted in a letter to Colbert (1935),

> Two parallel sections 100 m apart usually give utterly different results as to lithology and fauna; suids predominate in one, proboscideans in the other. At a given level or group of levels, a massive stratum of sandstone up to 20 or 30 m thick may lens out on either side within a distance of 80 m.

Furthermore, the vertebrate index fossils are scanty, and frequently confined to some specific horizons and pockets. As a result, it is not easy to biostratigraphically correlate the distant rock sequences. On the other hand, the paleomagnetic studies have shown a diachronous nature of the lithofacies, essentially becoming successively younger from the west towards the east. Therefore, it is not possible to assign a uniform age to each of these lithological divisions. Despite these limitations, the threefold classification is simple and in wide use throughout the Himalaya. The terms Lower, Middle, and Upper Siwaliks are considered hence as pure lithostratigraphic units.

27.5 Other Classifications

Not all investigators agree with the threefold classification. For example, Glennie and Ziegler (1964) classified the Siwaliks of Nepal into the lower Sandstone Facies and the upper Conglomerate Facies, owing to the difficulty in applying threefold subdivision over the whole country. According to them, the Sandstone Facies corresponds to the lower and middle formations, and is composed of fine-grained sandstone, conglomerate, and pebble-bearing sandstone. The upper portion of the Sandstone Facies consists of claystone or siltstone, and contains leaf imprints and shell fragments. Similarly, the Conglomerate Facies, representing the upper formation, is made up of a very coarse and massive conglomerate with layers of sandstone in between.

Raiverman (2002, 2007) classified the Siwaliks of Northwest India into various "energy sequences." His energy sequences are based primarily on grain-size-trend curves, geomorphic features, seismic reflection properties, and heavy mineral distribution. By applying these criteria, he identified the following nine energy sequences, respectively, from bottom upwards: Dharampur (E1: Late Paleocene to Middle Eocene), Kumarhatti (E2: Late Eocene to Oligocene), Makreri (E3: Oligocene to Early Miocene); Jawalamukhi (E4: Early to Middle Miocene); Kalidhar (E5: Late Miocene); Sadhot: (E6: Late Miocene to early Pleistocene); Batwan (E7: middle Pleistocene); Wah Devi (E8: late Pleistocene); and Sarda (E9: late Pleistocene to Holocene). He applied these sequences to map the entire Northwest Sub-Himalaya of India, primarily for the purpose of petroleum exploration.

27.6 Investigations in Nepal

The first geologist to describe the Nepalese Siwaliks and associated rocks was Medlicott (1875), who identified the Siwalik beds to the south and north of Hetaunda. Auden (1935) investigated the Siwaliks of central Nepal around Hetaunda and Udaipur Gadhi. He classified them into the Lower Siwaliks (Nahans) of brown-weathering sandstones, chocolate clays, and some inconsistent beds of impure limestone; the Middle Siwaliks of thick beds of feldspar and mica sandstones; and the Upper Siwaliks consisting of conglomerates. He also described the foothills of Hetaunda while visiting Kathmandu, and separated the Upper Siwaliks from the Lower Siwaliks by a sharp fault. It was the first record of such an intra-Siwalik (or Dun) fault from Nepal.

Hagen, at first as an employee of Swiss businessmen, then as an employee of the Government of Nepal, and finally as a United Nations expert (Hagen 1994), worked in this mountainous and remote country for a long period of 9 years. Hagen (1951, 1959, 1969), investigated the Nepal Himalaya in detail and adopted the threefold classification. According to him, the Lower Siwaliks are composed of siltstones, red shales with minor sandstones, and pseudo-conglomerates; the Middle Siwaliks consist of sandstones and siltstones with minor conglomerates and red shales; and the Upper Siwaliks contain the conglomerates. Similarly, Lombard (1958), Bordet and Latreille (1955), and Itihara et al. (1972) investigated the Nepalese Siwaliks in some detail. The petrographic classification of Siwalik rocks in Nepal was initiated by Chaudhri (1982). According to him, the sandstones of the Lower Siwaliks are represented by quartz arenites, the Middle Siwaliks are characterized by lithic arenites, and the Upper Siwaliks are composed of boulder-conglomerates, with subangular to subrounded metamorphic and crystalline rock fragments.

After the establishment of the paleomagnetic polarity stratigraphy in the Potwar Plateau in Pakistan by Opdyke et al. (1979, 1982), Johnson et al. (1982b), and others, the Siwaliks have attracted the attention of a wide geoscientific community, resulting in a detailed investigation in the past three decades. Based on fossil findings and preliminary paleomagnetic investigations in west Nepal, West and Munthe (1981), and Munthe et al. (1983) drew a conclusion that the rocks cannot be correlated with the Siwaliks of India and Pakistan solely on their lithological basis. Tokuoka et al. (1986) mapped the Siwaliks of the Arung Khola area (Chap. 30). They also carried out detailed paleomagnetic investigations and correlated the Siwaliks of the Arung

Khola area with those of Potwar Plateau. Further paleomagnetic studies in various parts of Nepal were carried out by Appel et al. (1991), Gautam and Appel (1994), Gautam (2008), Ojha et al. (2000), and many others (Fig. 27.1). Corvinus (1988, 1993) studied the Siwaliks of the Surai Khola, whereas Dhital et al. (1995) worked out its litho-stratigraphic and structural details (Chap. 29).

27.7 Fossil Occurrence

Falconer and Cautley carried out the first detailed investigations on the Siwalik fossils (Box 27.3). Pilgrim (1908, 1910, 1913, 1925) and Pascoe (1964) included detailed lists of the Siwalik mammalian fossils. Pilgrim (1932) gave a comprehensive and systematic description of fossil carnivora

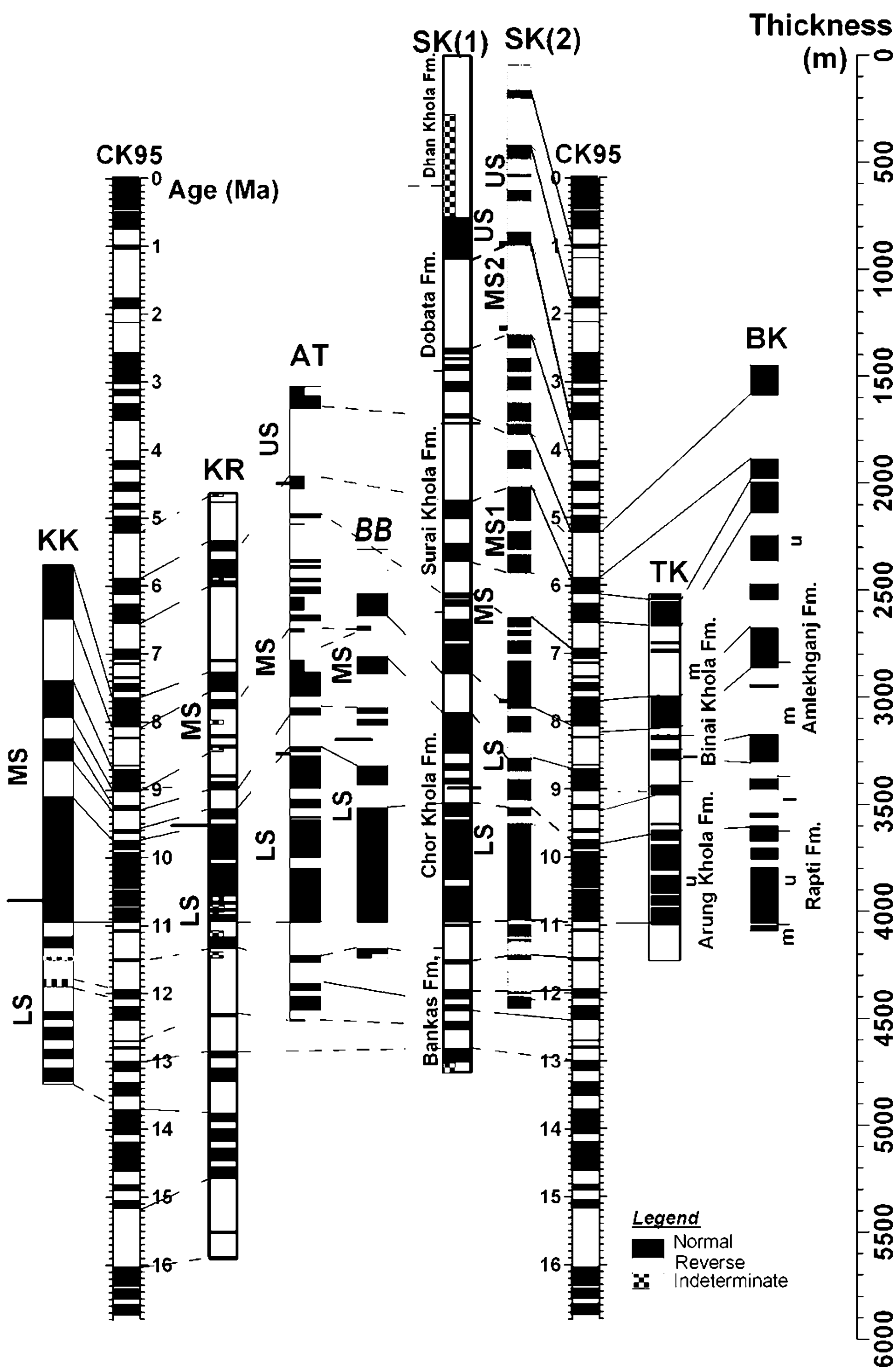

Fig. 27.1 Compilation of magnetic polarity sequences established for the Siwalik sediments in Nepal. Abbreviations for sections (from east to west) and data sources are as follows. *BK* Bakiya Khola (Harrison et al. 1993); *TK* Tinau Khola (Gautam and Appel 1994); *KK* Khutia Khola (Ojha et al. 2000); *SK* Surai Khola (*SK1* Rösler et al. 1997; *SK2* Hoorn et al. 2000); *BB* Bhalubang (Rösler et al. 1997); *AT* Amilia–Tui (Rösler et al. 1997); *KR* Karnali River (Gautam and Fujiwara 2000). CK95 used as standard geomagnetic polarity timescale for calibration is after Cande and Kent (1995). *Source* Gautam (2008). © Nepal Geological Society. Used by permission

from the Siwaliks of India, with impressive sketches and photographs. There is also a complete list of literature on Siwalik mammals. Colbert (1935) provided an exhaustive list of Siwalik mammalian fauna. He also gave a systematic description (with sketches and photographs) of most of the fossils stored in the American Museum of Natural History, New York. The Siwalik fossils are also summarized by Wadia (1926), Krishnan (1956), and recently by Prasad (2001). Barry et al. (1982) discussed the biostratigraphic zonation of the Middle and Upper Siwaliks of the Potwar Plateau in Pakistan. Wadia (1926, 1976) gave a list of some important genera and species of the Mammalia found in the Siwaliks of India and Pakistan (Box 27.4).

Box 27.3: Early Fossil Discovery from Siwalik Range

One of the earliest discoveries of fossils from the Siwalik ranges was made by Lieutenant Proby T. Cautley. Medlicott (1879, p. 522) discusses the discovery of Siwalik fossils by Cautley prior to 1832, as published in the first volume of the *Journal of the Asiatic Society of Bengal*.

Because there arose some confusion when Dr. Royle (Anonymous 1832) reported that Dr. Hugh Falconer was the first discoverer of these fossil bones, Falconer (1832, p. 249) responded with a letter stating the following:

> In No. 3 of the Journal of the Asiatic Society, p. 97, Mr. Royle has announced the discovery by me of the fossil bones in the range of hills which skirts the Valley of Dehra on the south-west… I conceive it necessary to state that Lieut. Cautley, Superintendent of the Doab Canal, is the original discoverer of fossils in these hills. The most perfect portion I have yet seen of these fossil bones, has been in his possession several years…

Murchison (1868) compiled the famous work of Falconer, called the *Fauna Antiqua Sivalensis*. The early summary of fossil vertebrates of India is given by Blanford (1879b) and Lydekker (1883).

27.7.1 Fossils from the Nepalese Siwaliks

Sharma (1973) mentioned the occurrence of vertebrate fossils in the Churia Range of Nepal. West et al. (1978) as well as West and Munthe (1981) reported various fossils from the Lower Siwaliks of the Babai Khola and Tinau Khola areas. Munthe et al. (1983) reported the upper molar of *Sivapithecus punjabicus* from the Tinau Khola area (Chap. 30). West et al. (1991) gave a systematic description of fossils obtained by their team around the Dang Valley and near Butwal (Fig. 27.2, Box 27.5). They compared this fossil record with that of India and Pakistan, and concluded that the mammalian assemblage collected from Nepal was similar to that of the Chinji and Nagri stages.

In the Surai Khola section, Corvinus (1988, 1993) and Corvinus and Nanda (1994) carried out detailed investigation of fossils. On the basis of the fossil record of *Gomphotherium* sp., they correlated the lowest Siwalik beds of the Surai Khola area with those of the Chinji Formation. The massive and very coarse-grained, pepper-and-salt sandstones of the Surai Khola Formation yielded a good collection of fauna, akin to those of the Tatrot and Pinjor zones. The fossils include a large number of mammals, reptiles, fish, and other invertebrates. Most common are the reptiles (Crocodylidae and Trionychidae). A big collection of mammals of the family Elephantidae, Hippopotamidae, Suidae, Cervidae, Giraffidae, and Bovidae was found in these multi-storied sandstones. These fossils point to a thickly forested environment with wide and meandering rivers (Box 27.6). Nanda and Sehgal (2005) describe the mammalian fauna of the Northwest Himalaya and remark that the lithological boundaries of the Siwalik Group are time-transgressive, because the enclosed fossils within a given lithological unit indicate different ages. Takayasu (1988) collected a large number of molluscs from the Nepalese Siwaliks and described their provenance in a regional frame (Fig. 27.3). Gurung (1998) studied various freshwater molluscs from the Siwaliks of the Surai Khola area.

Box 27.4: Some Fossils from India and Pakistan. *Source* Wadia (1926, 1976)

UPPER SIWALIK MAMMALIA

Primates: *Simia, Semnopithecus, Gigantopithecus, Papio*

Carnivora: *Hyaenarctos sivalensis, Mellivora, Mustela, Canis, Vulpes, Hyaena, Viverra, Machaerodus, Felis cristata*

Elephants: *Mastodon sivalensis, Stegodon ganesa, S. clifti, S. insignis, Elephas planifrons*

Ungulates: *Rhinoceros palaeindicus, Equus sivalensis, Sus falconeri, Hippopotamus, Camelus antiquus, Giraffa, Indratherium, Sivatherium giganteum, Cervus, Buffelus palaeindicus, Bucapra, Anoa, Bison, Bos, Hemibos, Leptobos*MIDDLE SIWALIK MAMMALIA

Primates: *Pliopithecus, Semnopithecus, Cercopithecus, Macacus, Sivapithecus*

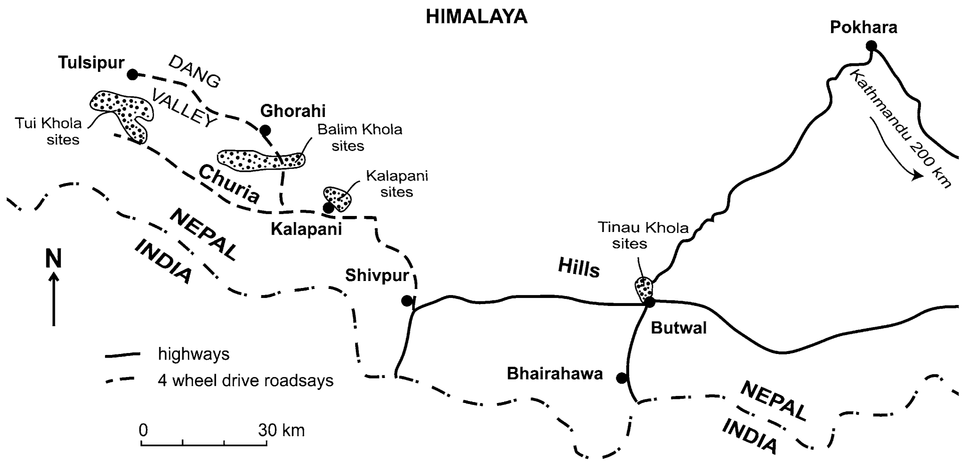

Fig. 27.2 Location of vertebrate fossils in west Nepal. *Source* modified from West et al. (1991)

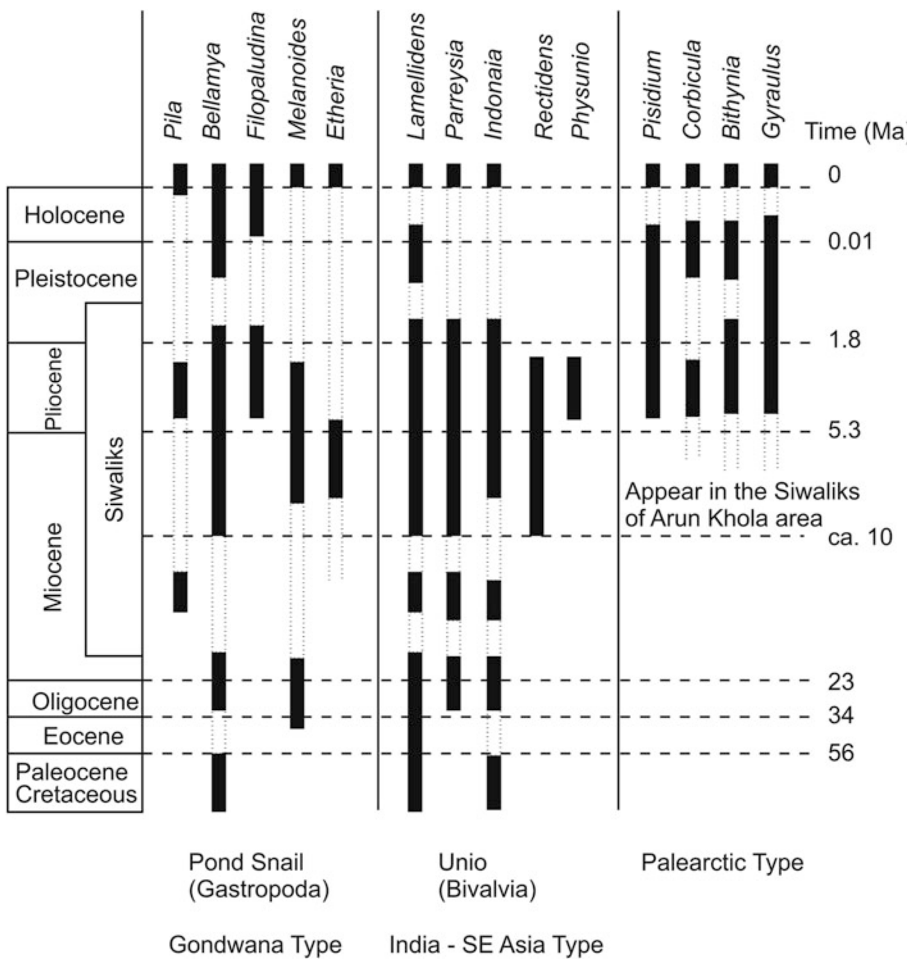

Fig. 27.3 Distribution of freshwater molluscs in the Siwaliks of Nepal. *Source* based on Takayasu (1988)

Carnivora: *Hyaenarctos, Mellivorodon, Lutra, Amphicyon, Machaerodus, Felis*
Rodents: *Hystrix, Rhizomys*
Elephants: *Prostegodon cautleyi* and *P. latidens, Stegodon clifti, Mastodon hasnoti*
Ungulates: *Teleoceras, Hipparion, Merycopotamus, Tetraconodon, Hippohyus, Sus punjabiensis, Hippopotamus irravaticus, Tragulus, Hydaspitherium, Vishnutherium, Cervus simplicidens, Gazella, Tragoceras, Anoa*

LOWER SIWALIK MAMMALIA

Primates: *Sivapithecus indicus, Dryopithecus, Ramapithecus, Paleosimia*
Carnivora: *Dissopsalis, Amphicyon, Palhyaena*
Proboscidians: *Dinotherium indicum, Gomphotherium, Tetrabelodon angustidens, Mastodon*
Ungulates: *Aceratherium, Hyotherium, Anthracotherium, Dorcatherium, Hemimeryx, Giraffokeryx, Conohyus, Listriodon, Telmatodon, Brachyodus, Hyoboops, Sanitherium*

Apart from them, the following vertebrate fossils were also found in the Siwaliks.
Birds: *Phalacrocorax, Pelecanus, Struthio, Mergus*
Reptiles: (Crocodiles) *Crocodilus, Ramphosuchus;* (Lizard) *Varanus;* (Turtles) *Colossochelys atlas, Bellia, Trionyx, Chitra,* Snakes, Pythons
Fish: *Ophiocephalus, Chrysichthys, Rita, Arius.*

Box 27.5: Vertebrate Fossils Discovered in West Nepal. *Source* West et al. (1991)

OSTEICHTHYES

Channiformes *Channa,* n. sp.2

REPTILIA

Testudines *Lissemys punctata*
Chitra cf. *C. indica*
Cuora or *Chinemys* sp. indet.
Geochelone sp. indet.
Squamata *Acrochordus dehmi*
Crocodilia *Gavialis* sp. indet.
Crocodylus sp. indet.

MAMMALIA

Carnivora *Amphicyon palaeindicus*
Creodonta Indeterminate remains of Hyaenodontidae
Proboscidea *Dinotherium pentapotamiae*
Indeterminate remains of Gomphotheriidae
Perissodactyla *Brachypotherium perimense*
Artiodactyla *Conohyus sindiense*
Hemimeryx pusillus
Dorcatherium sp.
Giraffokeryx punjabiensis
Protragoceras gluten
Sivoreas eremita
Rodentia Indeterminate remains of Rhizomyidae
Primates *Sivapithecus punjabicus.*

Box 27.6: Vertebrate Fossils from the Surai Khola and Ratu Khola Areas. *Source* Corvinus and Rimal (2001)

Dhan Khola Formation: Mammalian bone fragments
Dobata Formation: *Elephas planifrons, Equus* sp., *Hexaprotodon sivalensis,* Cervidae, Bovinae, *Crocodylus, Gavialis,* tortoise, and fish
Surai Khola Formation: *Stegodon insignis, St. bombifrons, Hippohyus tatroti,* anthracothere, *Hexaprotodon sivalensis, Cervus* sp., *Giraffa punjabiensis, Proamphibos lachrymans, Crocodylus, Gavialis, Trionys* sp., *Colossochelys, Emyda,* fish, and microvertebrates
Shivgarhi Member of Chor Khola Formation: *Crocodylus,* tortoise, mammalian bone fragments, and microvertebrates
Jungli Khola Member of Chok Khola Formation: Vertebrate bone fragments
Bankas Formation: *Gomphotherium* sp. and tortoise carapace.

Awasthi and Prasad (1990) as well as Prasad (1995) investigated the Siwalik plant fossils from the Surai Khola and Koilabas areas in west Nepal. They classified the leaf impressions into 21 species, belonging to 19 genera and 13 families of monocotyledons and dicotyledons. The assemblage consists mostly of plants growing in tropical evergreen to semi-evergreen forests with a warm and humid climate. Their investigation indicated that the climate gradually changed from humid tropical conditions to dry tropical conditions, respectively, from the Lower Siwaliks to Upper Siwaliks.

27.8 Depositional Environment and Sedimentation Rates

Falconer (1868, p. 33) observed that the Siwalik conglomerates were very similar to the present deposits of the rivers Yamuna and Ganges. He wrote that if their riverbeds were to undergo upheaval in the same manner as those of the

Siwaliks, the appearance of the strata would be quite similar. Medlicott (1864, p. 19) remarked that the Ganga Valley deposits are the temporal continuation of the Siwaliks, and can be ranked as a fourth and uppermost member of this series. Medlicott (1879, p. 541) also pointed out that the Siwalik deposits exposed between the rivers Ganga and Yamuna practically lack fines and are composed mainly of quartzite pebbles, similar to those of the shingles now found in the mountain torrents. He stressed that the Siwalik conglomerates of that tract were laid down on ancient alluvial fans of the rivers Tons, Yamuna, and Ganga.

The Siwalik sediments were deposited in the foreland by numerous rivers originating in the hinterland (and beyond) and flowing into a long narrow depression, called the foredeep (Chap. 3), in front of the rising mountains, that is, towards the side of the Indian Peninsula (Krishnan 1956). Wadia (1976, p. 342) remarked that the Siwaliks on the whole show uniformity of lithological composition for several hundred kilometers with a striking structural unity. This negates any theory of the deposition of these strata in a multitude of isolated basins.

As stated earlier, the depositional environment during the Siwalik time varied significantly in the lateral as well as vertical direction. The fluvial Siwaliks were deposited mainly in these four broad environmental settings: (1) piedmont, (2) outwash plains, (3) channels and floodplains, and (4) lakes (Vaidyanadhan and Ramakrishnan 2008). These environments shifted in space and time and gave rise to the very thick molassic sediments. The Siwalik succession deposited east of the Ravi River in Northwest India exhibits three dominant facies associations: trunk river, piedmont, and alluvial fan (Sinha et al. 2007). The trunk river association consists of multi-storied sandstones of 10–40 m thickness, with a basal erosional contact and a sharp contact with the overlying deposits. The piedmont river displays a heterogeneous facies. In it, the sandstones are less than 4 m thick, have a sharp base, and the grain size increases upwards. The alluvial fan facies is characterized by the deposition of thick conglomerate beds with nonerosive and planar basal contacts, whereas the upper contact is gradational to sharp.

McMahon (1883, p. 192) discussed the source of detritus in the Tertiary rocks. He remarked that much of the material in the sandstones was directly derived from the waste of the granitic and gneissic rocks of the Himalaya. As the Siwalik conglomerates contain boulders of rocks undistinguishable from Himalayan granites and gneisses, he further concluded that these rocks were already extensively exposed and the conglomerates were laid down from these local sources. The freshness of the material also indicated that the detritus was derived from nearby areas (Middlemiss 1890, p. 112). The Lower Siwalik sandstones in the Krol Belt frequently contain fragments of volcanic rock, representing andesites and basalts. They also contain garnet, tourmaline, and microcline (Auden 1934, pp. 388–389).

In Nepal, Hagen (1969, p. 98) found, in the very thick Middle Siwalik sandstones, the detritus derived from the crystalline nappes. He identified feldspar, quartz, muscovite, biotite, hornblende, tourmaline, magnetite, garnet, kyanite, epidote, rutile, and zircon. He also noted that some Middle Siwalik rocks superficially resemble granite.

Raju (1967) investigated the petrography and heavy mineral assemblages (of about 15,000 samples) of the Tertiary rocks from Northwest India. He found in the Siwaliks the following detrital minerals, reflecting a successive exhumation of a progressive metamorphic sequence: (1) epidote and staurolite occur consistently in the Lower Siwaliks; (2) kyanite (with staurolite) occurs frequently from the base of the Middle Siwaliks, and (3) hornblende and sillimanite are prominent in the Upper Siwaliks. Chaudhri and Gill (1981) studied the heavy minerals from the Sub-Himalaya of Nepal. According to them, staurolite serves as an important mineral to identify the Lower Siwalik Formation, and kyanite and sillimanite serve as the markers for the Middle and Upper Siwaliks, respectively. However, this type of normal metamorphic sequence is inconsistent with the observations that a good part of the Himalayan isograds is inverted (Le Fort 1975, p. 16).

In the northern Potwar Basin, near the Indus River, the uppermost 1,000 m of the Middle Siwalik sequence contain thick beds of conglomerate, which die out eastwards and southeastwards into sandstones and clays. Farther eastwards, a clay facies develops at progressively lower horizons, replacing a considerable portion of massive sandstones. The facies change is accompanied by a reduction in thickness. The Lower Siwalik rocks show a development of coarser facies in the opposite direction to that noted in the Middle Siwaliks (Gill (1952a).

In the Potwar Plateau, the Siwalik Group is subdivided into a series of lithostratigraphic units, formalized by the Stratigraphic Committee of Pakistan (Fatmi 1973). The oldest unit is the Kamlial Formation, made up of deep red mudstones and sandstones, representing a combination of upper delta plain sedimentary environment. The Chinji Formation transitionally overlies the Kamlial Formation, and its type section is designated south of the Chinji village (32° 41′ N, 72° 22′ E). This unit consists of a series of lateral accretion sandstones, interbedded with thick dark red vertical accretion silts. The Nagri Formation conformably overlies the Chinji Formation. Its type area is near Sethi Nagri (32° 46′ N, 72° 30′ E). The Nagri Formation is composed of a series of very thick multi-storied sandstones, separated by thin red overbank mudstones and siltstones. The Dhok Pathan Formation has been defined from a region near Dhok Pathan (33° 8′ N, 72° 31′ E). In its type locality, the multi-storied sandstones of the Nagri Formation pass into the thinner sandstones and more massive overbank muds and silts of light red color. The Upper Siwalik sediments, represented by sandstones, mudstones, and conglomerates (towards the top), were accumulated in a generally well-developed meander belt regime. The stream systems existing at the time of their deposition were characterized by a laterally meandering channel, in association with a trailing floodplain (Fatmi 1973; Opdyke et al. 1979, 1982).

The detailed paleomagnetic and sedimentological investigation carried out by Johnson et al. (1985) near the Chinji village, Pakistan, revealed that the sedimentation in that area spanned about 10.4 Ma. In accordance with the investigation on fluvial systems by Schumm (1977), they are of the opinion that the sedimentation followed a four-stage cyclic pattern. The first-order cycle was on the order of 10^7 years (governed by tectonics); a second-order cycle was about 10^6 years long and produced the large-scale fining-upwards divisions, such as the Lower and Middle Siwaliks; the duration of a third-order cycle spanned 10^4–10^5 years and it produced the basic fining-upwards units; and a fourth-order sedimentation cycle lasting 10^0–10^4 years had a wide-ranging periodicity and was related to river channel shifting and climatic factors.

West et al. (1991) remarked that the depositional environment of the Nepal Lower and Middle Siwaliks was markedly different from that of the homotaxial rocks in India and Pakistan. Most of the Northwest Himalayan Lower and Middle Siwaliks were accumulated as channel bars and overbank deposits of several major braided and meandering river systems, whereas in Nepal the equivalent fossil-bearing rocks were formed in poorly drained areas, characterized by ponds, sloughs, and sluggish streams. The Nepalese fauna are dominated by aquatic taxa, in contrast to predominating terrestrial fauna found in equivalent horizons of India and Pakistan.

Tokuoka et al. (1990), Hisatomi and Tanaka (1994), Ulak and Nakayama (1998), Nakayama and Ulak (1999), and Ulak (2002) carried out detailed paleohydrological analysis of the Siwalik sediments from various sections of Nepal. According to them, the Lower Siwaliks were deposited in a meandering system and a flood-flow dominated meandering system; the Middle Siwaliks were accumulated in a flood-flow dominated meandering system and a sandy braided system; whereas the Upper Siwaliks were laid down in a gravelly braided system, followed by a debris flow-dominated system.

The sediment accumulation rates in the Potwar Plateau during the Chinji, Nagri, and Dhok Pathan interval ranged from 13 to 52 cm/ka (Johnson et al. 1982b). Sedimentation rates in the Chinji village area increased gradually through time, going from 12 cm/ka in the Lower Siwaliks to 30 cm/ka in the Middle Siwaliks (Johnson et al. 1985).

For the Bakiya Khola section of southeast Nepal, Harrison et al. (1993) established highly fluctuating sediment deposition rates (between 10 and 150 cm/ka) in a cyclic fashion, with a period fluctuating between 0.4 and 1.5 million years. According to them, the high accumulation rates may reflect episodic thrusting events in the Himalaya. Gautam (2008) summarized the sedimentation rates from the Nepalese Siwaliks and showed that the rates vary considerably from place to place. In the Nepalese Siwaliks, the mean sediment deposition rate was about 32 cm/ka between 16 and 11 Ma, it increased to about 40 cm/ka between 11 and 5 Ma, attained a peak value of about 55 cm/ka between 5 and 3.5 Ma, and then rapidly decreased to about 27 cm/ka between 3.5 and 1 Ma.

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