CHAPTER II

RESUME OF THE PREVIOUS WORK

In this chapter an attempt is made to list the more important contributions on paleontological and paleobotanical aspects and summarise the work on stratigraphical and sedimentological aspects of the Siwalik Group. Greater emphasis is laid on the Siwalik rocks exposed between the rivers Ghaggar and Markanda and in the adjoining regions. A critical evaluation of the observations recorded by the various workers has been made at the appropriate places in the thesis.

PALEONTOLOGY AND PALEOBOTANY

The fossil vertebrate finds by Falconer (1832, 1868), Baker (1834, 1835a, 1835b), Baker and Durand (1836), Falconer and Cautley (1836a-e, 1837, 1845), Lydekker (1877-1883), Pilgrim (1910-1944), Matthew (1929), Colbert (1933a-f, 1934, 1935a, 1935b) and Lewis (1933a, 1933b, 1934) diverted the attention of geologists working in the Himalaya to the rich fossil fauna of the Siwalik Group. Since then, a number of workers have made significant contributions to the vertebrate paleontology of the Siwalik sequence. Some of the

Khan (1962), Badam (1973a) and Nanda (1973a) worked out the paleontology of the Upper Siwalik Formation and submitted the results of their investigations in the form of Doctoral theses.

The invertebrate remains of Bivalvia and Gastropoda were reported from the Siwalik sequence by Lydekker (1882), Prashad (1925, 1927), Vokes (1935, 1936), Das and Hazra (in West, 1949), Bhatia and Khosla (1967), Bhatia and Mathur (1971, 1973) and others. Bhatia and Khosla (1967)
and Mathur (1972) recorded for the first time the presence of freshwater ostracods from the Upper Siwalik sequence exposed near Chandigarh.


Bhatia and Mathur (1970) recorded the presence of fossil charophytes from the Siwalik rocks. Subsequently, Tewari and Sharma (1972), Lakhanpal, Kapoor and Jain (1976) and Bhatia and Mathur (1978) studied the charophytic flora of the Siwalik Group.


**STRATIGRAPHY**

Medlicott (1864) remains the pioneer worker who initiated systematic stratigraphical investigations of
the Siwalik sequence. He subdivided the Sub-Himalayan Series into three divisions (Text Table I). He considered the Nahun (Nahan) and the Sivalik (Siwalik) as separate entities and suggested a hiatus at the base of the Nahan sequence. He did not refer to the age of the various units and found it difficult to distinguish the Nahan and Siwalik groups on the basis of any primary character.

**TEXT TABLE I**

**CLASSIFICATION PROPOSED BY MEDLICOTT (1864)***

<table>
<thead>
<tr>
<th>Sub-Himalayan Series</th>
<th>Upper</th>
<th>Sivalik</th>
<th>Conglomerate, sandstones and clays.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Middle</td>
<td>Nahun</td>
<td>Lignites, sandstones and clays.</td>
</tr>
<tr>
<td></td>
<td>Lower</td>
<td>Subathu</td>
<td>Kasauli Dugshai Subathu</td>
</tr>
</tbody>
</table>

Medlicott observed a marked uniformity throughout the sub-Himalaya in the composition of Nahan rocks which he described as '... massive beds of sandstones with frequent lignites and interstratified clays.' He concluded that the depositional limits during the sub-Himalayan

*Spellings the same as used by Medlicott (1864).*
period had remained constant and the present mountain streams are the same as were during the deposition of the upper group of the Sub-Himalayan Series. He (Medlicott, 1881) proposed an unconformity between the Nahan and the Siwalik in the northwestern Himalaya. Later on, he (Medlicott, 1889) included the Nahan in the Siwalik Group and proposed a threefold classification of the latter, viz., Lower (Nahan); Middle; and Upper. The classification remained the basis of stratigraphical investigations for the subsequent workers.

Wynne (1877) described the Siwalik rocks as 'white grey sandstones and red clays' and placed them into two divisions, namely, the Lower Siwalik and the Upper Siwalik. He observed that the Siwalik constitutes a conformable sequence with the underlying Murree. The conformable nature of the contact between the Siwalik and the underlying Murree/Dharmshala has also been advocated by Pilgrim (1910, 1913), Pinfold (1918), Anderson (1927), Wadia (1928), Bhandari (1963), Sahni and Mathur (1964), Sen (1971), Chaudhri (1971a, 1976) and others. Mathur and Evans (1964), however, recorded that the Siwalik beds rest directly on the basement rocks without any intervening Tertiary sequence.

Theobald (1881) described the Siwalik Group of the sub-Himalaya as 'Pliocene Group of India.' He recorded that the Siwalik rocks rest conformably on the Gaj Series (Miocene) in Sind and on the Eocene strata in the Punjab.
and all along the Himalaya. He could not find any intervening Miocene bed and suggested the existence of an unconformity between the Siwalik and the pre-Siwalik sequences. He divided the Siwalik Group into the Murree and the Kharian. He preferred to drop the term Nahan altogether. He traced the geological limits of the Siwalik along the flanks of the Himalaya and attempted to study the structural history of the rocks. According to him, the entire belt consists of vertical slices separated by faults.

Middlemiss (1889a) observed that the margin of the Himalaya in all ages of the Tertiary Period had been a line of weakness advancing slowly towards the South. He (Middlemiss, 1890) suggested a nomenclature based on dominant lithology, viz., 'Nahan Sandstone' for the Lower Siwalik, 'Sand Rock Stage' for the Middle Siwalik and 'Siwalik Conglomerate' for the Upper Siwalik.

Pilgrim (1910, 1911, 1913b) proposed an elaborate chronostratigraphic classification of the Siwalik rocks and correlated the various units with the mammal horizons of Europe. He placed these rocks under three divisions, viz., the Lower, the Middle and the Upper. In each division, he further differentiated three horizons, namely Lower Manchar, Lower Chinji and Upper Chinji in the Lower Siwalik; Nagri, Dhok Pathan and Bhander in the Middle Siwalik and Tatrot, Pinjore and Boulder Conglomerate in the Upper Siwalik. While discussing the stratigraphical relationship between
the Lower and the Middle Siwalik, he recorded that a Hipparian bearing passage bed of red calcareous nodular clays occurs between the Upper Chinji and the Middle Siwalik. Later on, he (Pilgrim, 1925) made some modifications in his classification and dropped the Lower Manchar horizon and Bhandar beds from the Lower and the Middle Siwalik units respectively and called the horizons as stages.

Pilgrim (1938) observed that the correlation of the Siwalik as proposed by Lewis (1937) on the basis of first appearance of Hipparian and Equus in North America, is not acceptable due to the difficulties arising out of the probable dual origin of Hipparian. Teilhard and Stirton (1934) also made identical observation. Pilgrim could not subscribe to the view of Lewis (1937) and opined that the Tatrot and the Pinjore stages are independent units. He assigned these units Roussillon and Villarsfranchian ages respectively. Sahni and Khan (1963a) also considered Tatrot as a distinct horizon and demarcated a fossiliferous zone in it.

Pilgrim (1938) did not support a Middle Pleistocene age for the Upper Siwalik Boulder Conglomerate (cf. De Terra and Teilhard De Chardin, 1936). He observed that the Boulder Conglomerate shares completely the folding which has affected the underlying Pinjore beds. Subsequently,
Pilgrim (1944) introduced the Bain Conglomerate horizon below the Upper Siwalik Boulder Conglomerate and divided the latter into the Lower Boulder Conglomerate (Lower Pleistocene) and the Upper Boulder Conglomerate (Middle Pleistocene). Sahni and Khan (1963a) observed that the Lower and the Upper Boulder Conglomerates represent the accumulations of Gunj and Mindel glaciations respectively.

Pinfold (1918) recorded a continuous succession from the Lowest Murree to the Upper Siwalik and distinguished the various stages on the basis of lithology. He correlated these rocks with the Upper Tertiary deposits of Sind and Simla region.

Anderson (1927), while describing the Tertiary stratigraphy of northern Punjab, placed the Murree and the Siwalik of the Potwar Plateau under Nimadric System and divided the Siwalik Series into the Lower, Middle and Upper units. He observed that the junction between the successive units is gradational.

Weller (1928) studied the Cenozoic stratigraphy of northwest Punjab and concluded that the Lower Siwalik sequence lies conformably on the Murree. He postulated the existence of active streams in the Late Tertiary time and violent activities at the close of the Tertiary Period.

Matthew (1929) assigned Miocene age to the Lower Siwalik, Lower Pliocene-Middle Pliocene to the Middle
Siwalik and Lower Pleistocene to the Upper Siwalik. Colbert (1933a-f, 1934, 1935), on the basis of occurrence of vertebrate fossils, suggested Upper Miocene-Lower Pliocene age for the Lower Siwalik, Middle Pliocene-Upper Pliocene for the Middle Siwalik and Upper Pliocene-Lower Pleistocene for the Upper Siwalik. Lewis (1933a) recorded the presence of a new genus Lemuroid from the Siwalik and suggested a Middle Miocene-Middle Pleistocene age for the sequence. Subsequently he (Lewis, 1937) attempted a correlation of the Siwalik sequence.

Hayden (1933) divided the rocks of the sub-Himalayan zone into two broad units, namely, the Siwalik Series and the Sirmur Series. According to him, the Siwalik Series comprises Sandstone, Sand Rock and Conglomerate stages. Hayden observed that the northern boundary and the original limit of deposition of the Siwalik Series throughout the Himalaya is marked by 'the Main Boundary Fault'. He redesignated the tectonic junction as 'Reverse Fault'. Auden (1935) placed on record the probable occurrence of a thrust between the Nahan and the Upper Siwalik rocks. Heim and Zurich (1938) redesignated the 'Main Boundary Fault' as 'Relief Thrust'.

De Terra (1935) and De Terra and Teilhard De Chardin (1936) correlated the Uppermost Siwalik with the second glacial advance. According to them, the Siwalik
sedimentation did not continue beyond Middle Pleistocene. This, however, was contended by Pilgrim (1938) and Wadia (1940).

Gill (1951a) grouped the Siwalik sequence of Potwar region and Kangra District of Punjab into five local lithological units. He concluded that many of the steeply inclined faults in the Siwalik rocks are related to the vertical tectonic force which operated during the Siwalik orogeny. He recorded the presence of an unconformity between the Siwalik and the post-Siwalik formations. Gill (1951b) discussed the tectonics of the sub-Himalaya in the Kangra District and suggested the presence of three structural units. He proposed three fold classification for the Siwalik sequence.

Evans (1958, 1964) studied the stratigraphy and tectonics of the Cenozoic sequence of the Assam Himalaya. He worked out the sedimentation history and recorded that the Assam-Arakan basin was uplifted during the Miocene-Pliocene time.

Sahni and Mathur (1964) preferred heavy minerals to vertebrate fossils for correlation purpose due to greater uniformity of the former along the strike of the Himalaya. The authors divided the Siwalik rocks of Jwalamukhi area into Lower, Middle and Upper units. According to them, the contact between the Lower and the Middle
Siwalik is gradational - a fact recorded earlier by Dehadrai (1958). Sahni and Khan (1964a) divided the Lower Siwalik of Kalka area into three units. Sahni and Khan (1964b) and Khan (1966, 1968) studied the Upper Siwalik rocks around Chandigarh in respect of their stratigraphy, structure and correlation.

Sinha and Khan (1965) suggested that heavy mineral suites offer a workable basis for classification and correlation of the Siwalik. They correlated Nahan Series with the Lower Siwalik of other areas. Subsequently, Sinha (1970), on the basis of heavy mineral suite, grouped the Middle and the Upper Siwalik rocks of Mohand into two and three zones respectively.

Bhatia (1966) found it difficult to correlate the Siwalik rocks on paleontological and mineralogical basis. He (Bhatia, 1976), however, observed that it was possible to draw the boundary between the Upper Murree and the Lower Siwalik on the basis of sedimentological parameters.

Murti, Popav and Karsakof (1967) called the Siwalik as 'molasse shevalik' and correlated them with the Cenozoic molasse of Central Asia. They assigned a Middle Miocene age to the Lower Siwalik, Upper Miocene to the Middle Siwalik, and Pliocene-Lower Pleistocene to the Upper Siwalik.

Pande and Saxena (1968) observed that the Siwalik sediments were uplifted during the last phase of the
Himalayan orogeny. Rao, Saxena and Dhar (1968) placed on record that the first phase of folding in the Tertiary Belt was experienced during the sedimentation of the Upper Siwalik. Bhandari (1970) discussed the structure of Siwalik rocks of the Punjab reentrant and suggested the presence of an antiform in the area and a set of reverse faults in the south central part of the area. He called these faults as 'Back Thrusts' because they dip in opposite direction to the one in which the Himalayan thrusts normally do.

Eames (1970) remarked that the Tertiary-Mesozoic boundary, the Neogene-Paleogene boundary and the Pliocene-Pleistocene boundary represent three orogenic movements in the Tethyn region. Ray (1971), while discussing the tectonic movements in the outer Himalaya, suggested that lithological boundaries between Dharmasala and the Siwalik and between the three subgroups of the Siwalik are tectonic. The thrusts, in most of the cases, are parallel to the bedding of the rocks. Mitra (1971) described the structure of Tripura-Surma valley of Assam Himalaya. He attributed parting to differential vertical movements.

Chaudhri (1971a) pointed out that the orogenic movements at the close of the Miocene Epoch were mainly responsible for the upheaval and folding of the Nahan along with the underlying older Tertiary rocks. He attributed the present position of the Nahan to the differential movement along a fracture which developed all along the northwestern Himalayan foothills. Chaudhri (1976) discussed the stratigraphy of the Cenozoic sediments. He observed that the chronostratigraphic classification proposed by earlier workers for the Siwalik rocks of the type areas (West Pakistan) should be used for the purpose of correlation only. For all practical purposes, he recommended the adoption of the lithostratigraphic classification proposed by him. His investigations revealed that the contact between the Lower Siwalik Formation and the Lower Tertiary rocks, at most of the places, is of tectonic nature. According to him, the Middle Siwalik rocks have a conformable and gradational junction with the Lower Siwalik sequence. He worked out a conformable junction between the Middle and the Upper Siwalik formations which at places is modified by local faulting and local unconformities.

Hussain (1971) reported the presence of an unconformity between the Chinji and the Nagri stages. Sastri et al. (1971), on the basis of subsurface data, concluded
that the Siwalik sediments continue below the Gangetic Alluvium. He observed that the Siwalik, in some parts, rest unconformably on the Vindhyan and their homotaxial rocks.

Pandey (1971) reviewed the classification of Siwalik formations in the light of geological mapping and fossil collection made by the Oil and Natural Gas Commission. He suggested that the various units of the Siwalik Group should be correlated independently with the European Time Scale. He assigned a Pliocene, Villafranchian and Gunz-Mindel age to the Masol, Pinjore and Rupar members of the Siwalik sequence respectively. The Masol and basal Pinjore members, however, correspond to the Tatrot Member of the Potwar Plateau. Satsangi and Dutta (1971) also discussed the stratigraphy of the Siwalik rocks. Srivastava (1972) observed that the Lower and the Middle Siwalik formations in the Almora and Nainital districts of Uttar Pradesh have a conformable junction. He pointed out that the Upper Siwalik sequence is separated from the older horizons by a thrust. Misra (1971) discussed the status of some of the lithostratigraphic units on the basis of vertebrate fossils and heavy mineral assemblages.

Kamei and his group in 1973 carried out magnetostratigraphic study of the Upper Siwalik sediments of northwestern India. Keller et al. (1977), Barndt (1977),
Barndt et al. (1979), Opdyke et al. (1977a, 1977b, 1979), Johnson et al. (1977), Visser and Johnson (1978), Dodonov et al. (1979), Johnson et al. (1979) and Yokoyama (1979) worked on the paleomagnetic polarity reversal stratigraphy of the Siwalik Group of India and Pakistan. Johnson et al. (1979) observed that the Upper Siwalik sequence of southeastern Potwar and of the southwestern Kashmir was deposited during the past 5 to 6 million years. Opdyke et al. (1979) pointed out that the change from the Tatrot fauna to the Pinjore fauna took place about 2.47 million years B.P.

Desikachar (1974), Shrivastava, Ganeshan and Ray (1974) and Baruah, Mukhopaddya and Baishya (1975) discussed the stratigraphy and tectonics of the Tertiary rocks of Assam Himalaya.

Acharyya, Dutta and Sastri (1976) were unable to differentiate the Lower Siwalik from the Dharmala and Murree groups. The authors suggested that the northern limit of the Siwalik is delineated by the Murree-Krol Thrust. The authors also classified the Siwalik rocks into three subdivisions, viz., the Lower, the Middle and the Upper. Nanda and Tandon (1976) pointed out the problems in stratigraphy and sedimentation of the Siwalik Group and proposed that the older names should not be replaced by new ones.
Raiverman, Ganju and Misra (1976) gave a fresh thought to the stratigraphy of the Cenozoic sediments of the Himalayan foothills. They used the grain size parameters to distinguish the various sedimentation cycles.

Vasishat, Gaur and Chopra (1978) recognised four paleocommunities in the Middle Siwalik vertebrates of which the megaterrestrial community is the most abundant. The authors on the basis of fossil fauna have suggested the occurrence of dense forests during the Early Middle Siwalik and the reduction of forests and appearance of open grassland in the Late Middle Siwalik times. They assigned a Middle Miocene to Late Miocene age to the Middle Siwalik of Haritalyanger.

Valdiya (1979) described the Siwalik as an autochthon separated from the Gangetic Plains by a deep Himalayan frontal fault. He noticed Jura type folding in the Siwalik rocks of the western sector and recorded that the Siwalik are cut by numerous transverse faults.

Sahni and Mitra (1980) observed that the climatic conditions of the Indian subcontinent during the Neogene varied from warm tropical rain-forest conditions throughout the Miocene up to the Early Pliocene, a drier climate in the Pliocene which gradually changed into glacial condition.
by the Middle Pleistocene. They concluded that the depositional basins of India were stable and moved towards continentality during the Neogene Period.

In 1979, a Field Conference of the International Geological Correlation Programme was held at Chandigarh to discuss the boundary problem between the Neogene and the Quaternary. Valuable contributions were made by a number of geologists including Ranga Rao et al. (1979), Sastry (1979), Suneja et al. (1979), Tandon and Ranga Rao (1979), Verma (1979), Yokoyama (1979) and others, but no consensus of opinion was arrived at.

The exact demarcation of the Neogene-Quaternary boundary in the Siwalik sequence thus remains a matter of conjecture. The boundary has been placed at the base of Tatrot on the basis of paleoclimatic and paleontological considerations by Matthew (1929), Lewis (1937), De Terra and Paterson (1939) and Colbert (1951). Sahni and Khan (1964) and Prasad (1970) placed the Neogene-Quaternary boundary between the Tatrot and the Pinjore on paleontological considerations. Wadia (1934) on the basis of field disposition, stratigraphy and structure considered the Pinjore as transitional between the Pliocene and the Pleistocene. Yet another school of thought led by Pilgrim (1938-1944), Gill (1951a), Balasunderam and Sastri (1972) placed the boundary between the Pinjore and the Lower
Boulder Conglomerate, mainly on the basis of stratigraphic, sedimentological, structural, paleontological and paleoclimatological considerations. Kamei (1977) also commented on the Plio-Pleistocene boundary.

SEDIMENTOLOGY

Although Medlicott (1861), McMahon (1883) and Middlemiss (1889a) commented on the provenance and environments of sedimentation of the detritus constituting the Siwalik Group, it was Pascoe (1919) who for the first time put forward a hypothesis to explain the uniform nature of the Siwalik rocks from Jammu and Kashmir in the West to Assam in the East and further beyond. According to him, the Siwalik sediments are floodplain deposits of a single river which flowed westwards from Assam to Potwar region all along the foot of the Himalaya. The hypothesis embodies that towards the end of the Murree Epoch, the then existing lakes and lagoons gave place to the great river - 'Indobrahm'. The river followed the course of the present Soan River and flowed from Assam to the Arabian Sea. He traced the course of the river through Bhutan, Bengal, Nepal, Kumaon, Dehra Dun, Sirmur, Kangra and Jammu up to the Sind estuary. He was of the view that the material carried by the 'Indobrahm' must have been largely derived from the older ferruginous rocks of the Indian Peninsula.
Pilgrim (1919) also put forward a similar hypothesis but he was more concerned with the later history of the Siwalik River in order to explain the mode of deposition of a great thickness of the Boulder Conglomerate. While Weller (1928) supported the existence of such a river, Krishnan and Aiyenger (1940) and Gupta (1970) did not subscribe to it.

Wadia (1932) recorded that sandstones of the Siwalik Group are white or light coloured as compared to those of the Murree and are probably made up of water worn debris derived from the granitic core of the Central Himalayan ranges. According to him, the share of the detritus derived from the Gondwana Mainland in building up of the Siwalik sequence is very little.

The credit for initiating the systematic sedimentological investigations of the Siwalik Group goes to Krynine (1937) who studied 35 thin sections of the Siwalik rocks and concluded that the sedimentation took place on a broad and flat flood-plain under tropical humid and temperate to moderately humid climate.

Krishnan and Aiyenger (1940) recorded that the Siwalik sediments were deposited in the furrow formed after the second upheaval. Commenting upon the provenance and environments of sedimentation, they observed that the ferruginous matter of the Lower Siwalik was derived from
Peninsular Shield. According to them, the detritus was deposited under fluviatile conditions in large freshwater lakes.

Babu and Dehadrai (1958) studied the mineral assemblage of the Siwalik rocks of Mohand and worked out a metamorphic and granitic provenance. According to them, the sediments were derived from a continuous mountain chain.

Mehdiratta (1959), on the basis of surface features on boulders and pebbles of the Upper Siwalik Boulder Conglomerate, postulated the advent of glacial conditions at the time of deposition of the megaclasts. He further observed that the Pinjore zone belongs to the first interglacial and the underlying Tatrot zone to the first glacial period. Thus, the Tatrot and the Pinjore zones have been assigned an Early Pleistocene age on glacial evidence. He (Mehdiratta, 1960), studied the Boulder Conglomerate of Kashmir and called them fluvio-glacial deposits. He suggested that the megaclasts were transported and deposited by the streams originated as a sequel of the melting of Mindel Ice. He postulated similar conditions for the deposition of the Upper Siwalik Boulder Conglomerate of outer Himalaya.

Misra and Valdiya (1961) studied the petrology and sedimentation of the Lower Siwalik of Tanakpur area, Uttar Pradesh. They concluded that the polymodal sediments were deposited in marginal shallow shelf under tropical climatic
conditions. The consanguineous association of subgraywacke and red siltstones/shales has been attributed to turbidity flow. They worked out a granitic and metamorphic provenance for the sediments which represent more than one cycle of sedimentation.

Sikka et al. (1961) reported the occurrence of graywacke in the Nahan Series of Kalka region. They studied the grey micaceous sandstones and recorded that the rock contains about 50 per cent angular grains of quartz embedded in a "matrix composed of fragments of schist, slate, quartzite, chert, felspar, chlorite and authigenic sericite." They expressed their doubt about the Siwaliks being entirely of freshwater origin.

Cummins (1962) and Ganju and Srivastava (1962) did not agree with the view that the presence of graywacke serve as an evidence for marine depositional environment for the Lower Siwalik. Ganju and Srivastava suggested that the so called graywacke of the Siwalik may in fact be 'subgraywacke' or 'Low rank graywacke' of Krynine (1937). They stressed that the detritus constituting the Siwalik Group was deposited under shallow water conditions as evidenced by sedimentary structures, sorting, and fossil content. Sehni and Khan (1963a) described the Siwalik of Pinjore area as freshwater deposits on the basis of floral and physical evidences. Saxena, Bhatia and
Pande (1968), however, maintained that the entire Siwalik sequence is not of freshwater origin and is partially marine. They further observed that the graywacke of the Lower Siwalik are characteristic of geosynclinal belt.

Swaminath (1961) correlated the periods of sedimentation with the phases of Himalayan orogeny. He described the Siwalik as 'Molasse facies' deposited in an exogeosyncline and representing the last phase of Himalayan orogeny. He observed that the sediments in the Tertiary basins thicken towards the Himalaya and thin out towards the Peninsular Shield.

Raju and Dehadrai (1962a) attempted a correlation of the Siwalik sediments on the basis of heavy mineral assemblages. They (Raju and Dehadrai, 1962b) suggested two basins of sedimentation for the detritus constituting the Upper Siwalik Formation. They grouped the sediments accumulated in each basin into different zones on the basis of heavy mineral suites. They opined that during the Upper Siwalik time, the basinal topography exerted its influence and controlled sedimentation and structure to a large extent. Raju and Dehadrai (1962c) prepared the CM patterns for the Siwalik sediments and concluded that the sediments were deposited under varying conditions. They
worked out that the Lower Siwalik sediments were deposited in fluvio-deltaic and shallow-basinal environments while the detritus constituting the Middle and the Upper Siwalik was deposited mainly in fluviatile conditions.

Bhattacharya and Misra (1963) worked out a fluviatile environment for the Middle Siwalik sediments of Mohand area, Uttar Pradesh. According to them, the sediments were deposited in stream channel which were flooded from time to time. According to Sahni and Kathur (1964), the deposition of the Siwalik sediments has taken place in varied environments including piedmonts, outwash plain, channel and lacustrine which kept on shifting in space and time. They postulated that the sediments were derived from active orogenic belt exposed in the North. According to them, the increasing complexity of the heavy mineral suite with decreasing age of the sediments suggests that deeper seated, more metamorphosed or igneous rocks were exposed to denudation with the passage of time.

Sinha and Khan (1965) worked out an igneous and metamorphic provenance for the detritus of the Siwalik Group. Sinha (1970) recorded that the Siwalik sediments of the Mohand Anticline were deposited in a single basin. According to him, the appearance of heavy mineral markers in the Siwalik sequence reflects the uplift and unrooing of successively higher grade metamorphic rocks in the distributive province.
Kumar (1966) carried out paleocurrent investigations of the Siwalik rocks of the Jwalamukhi region and concluded that a major part of the sediments was derived from newly risen mountain chains. Wakhaloo and Bhatia (1966, 1968, 1971) studied zircon types and grain size of the Siwalik sediments of Jammu region.

Raju (1967, 1972) discussed the conditions of deposition of the Tertiary clastic sediments. He found an increasing complexity of heavy mineral suite and rock fragment assemblage in younger horizons. He attributed this to the unroofing of new rock types in the source area due to progressive denudation and tectonic disturbances. Anand (1968) discussed the petrography of the Lower Siwalik Formation.

Raiverman (1968) observed that the Lower Siwalik are subaqueous deposits accumulated by suspension (turbidity) currents and that the Middle and the Upper Siwalik are lacustrine and fluviatile deposits where both suspension and traction have played a more prominent role. He worked out that the sediments were contributed by sedimentary and metamorphic rocks. In a subsequent communication, he (Raiverman, 1972) recognized eight megacycles in the entire Cenozoic sequence of the foothills of northwestern Himalaya.

Mukherjee and Subramaniam (1968) suggested that the eastern Himalayan Tertiary and the Siwalik are of freshwater
origin and are made up of the sediments derived from the rising Himalayas.

Vondra and Johnson (1968) described the Siwalik sequence of Gumber-Sarkaghat Fault Block as composed of fluviatile, molasse-like deposits derived from the rising Himalayan mountains. Johnson (1971, 1977) suggested change in climate and provenance during the sedimentation of the detritus constituting the Siwalik sequence.

Johnson and Vondra (1977) noticed considerable lateral and vertical lithological variation in the Siwalik sequence of Haritalyangar. They described the sequence as fluvial molasse which reflects the complex denudation history of the adjacent thrust plates developed within the Himalayan orogen. The authors recorded that the Mahan sandstone is chiefly composed of channel lag and lateral accretion deposits. They have postulated that the detritus of the entire Siwalik sequence was deposited in terrestrial environments.

Kharkwal (1969) carried out petrological study of the Tatrot and Pinjore stages of the Upper Siwalik exposed near Chandigarh. He observed that the sediments have not attained high degree of textural and mineralogical maturity. He worked out a sedimentary and metamorphic provenance for
the Upper Siwalik sediments with supplementary contributions from igneous rocks. Chaudhri and Gupta (1969) also observed that the sediments were derived from the rising Himalaya. They concluded that the Siwalik sediments were deposited in shallow basins located to the South of the Himalaya.


Mehrotra and Chandra (1968) carried out intensive study of Red Beds of India and concluded that the molasse red bed facies of the Siwalik was deposited in piedmont-valley-flat environment.

Bhattacharya (1970) recorded that the dominant clay minerals of the Siwalik Group are montmorillonite, Kaolinite and highly degraded illite/chlorite. He remarked that the sediments were derived from highly weathered source rocks and clays were formed by extensive leaching in regions of high relief and tropical climate. According to him, the greater part of the Siwalik clays might represent reworked Subathu and Dharamsala sediments unaltered by diagenesis.

Chaudhri (1970) studied the petrology of the Siwalik formations of northwestern Himalaya. He worked out a common provenance and identical depositional environments for the Lower Siwalik and the Lower Tertiary rocks. According
to him, the sediments constituting the Middle and the Upper Siwalik were derived from medium and high grade metamorphic, plutonic, sedimentary and trap rocks exposed in the nearby Himalaya region. The detritus was deposited after a short transport in shallow fast sinking basin(s). He did not subscribe to the accumulation of sediments in lacustrine environment.

Chaudhri (1971a) worked out sedimentology of the Nahan Formation with a view to ascertain the exact stratigraphic position of the sequence and its relationship with the Lower Tertiary rocks. He postulated a continuous sedimentation from the Upper Paleocene to the close of Miocene. He recorded that the Nahan belongs to Dagshai-Kasauli sedimentation unit. According to him (Chaudhri, 1971b), the sediments constituting the Kasauli and the Lower Siwalik were deposited in a shallow fast sinking basin and the detritus was derived from the rising Himalaya rather than from the Peninsular Shield. Trap rocks were exposed in the source area(s) during the Upper Siwalik time as is evidenced by the presence of fragments of basalt in the arenaceous rocks of the Upper Siwalik Formation.

Chaudhri (1972a) worked out the heavy mineral assemblage of the Siwalik Group of northwestern Himalaya and concluded that a large proportion of the sediments has been derived from metamorphic rocks. He advocated the
exposure of deeper seated and more metamorphosed rocks to
denudation with progressive erosion and sedimentation.
Chaudhri and Gill (1981) arrived at nearly identical results
from the heavy mineral study of the Siwalik sequence of
Nepal Himalaya. In subsequent publications, Chaudhri
(1972b, 1975) discussed the petrogenetic aspects of the
Siwalik sediments.

Parkash and Bajpai (1970a) and Bajpai (1971) noticed
a fining upward sequence in the Middle Siwalik rocks exposed
between the rivers Ganga and Jamuna. Parkash and Bajpai
(1970b, 1971) carried out the paleocurrent studies of the
Middle and the Upper Siwalik exposed in the above area and
concluded that the Siwalik sediments, in general, were
derived from the rising Himalaya. According to them
(Parkash and Bajpai, 1970c), the shape analysis of the
pebbles from the Upper Siwalik exposed North of Mohand also
suggested that the detritus was derived from the North. The
fact has been supported by Sinha (1970) also. According to
Parkash, Bajpai and Saxena (1974) the direction of paleo-
currents was southwesterly during the Lower Siwalik,
southerly during the Middle Siwalik, and both North-South
and East-West during the Upper Siwalik times. They have
suggested fluviatile flood plain depositional environment.

Das and Narayan (1971) described the Nahan sandstone
of Nainital District and suggested that the sediments were
derived from schistose and granitic rocks of the Himalaya. Sen (1971) reported the presence of large scale current bedding and ripple marks in the Lower Nahan rocks and sole markings in the Upper Nahan rocks of Kalka area.

Tandon (1971a) studied the direction of elongation of quartz grains in the Lower and the Middle Siwalik sandstones and pebble orientation in the Upper Siwalik conglomerates. He worked out southerly and southeasterly currents during the Lower and the Middle Siwalik respectively and both southwesterly and southeasterly during the Upper Siwalik. He (Tandon, 1971b) noted the presence of coaly matter in the Siwalik sequence of Kumaon-Garhwal Himalaya. Subsequently, Tandon (1972a) worked out the heavy mineral assemblage and quartz axial ratios of the Siwalik rocks exposed around Ramnagar and suggested that the sediments have been derived from metamorphic rocks. He (Tandon, 1972b, 1972c) carried out size and shape analysis of the Siwalik sediments of Kumaon Himalaya and worked out the bimodal nature of the Middle and the Upper Siwalik sediments. He (Tandon, 1972d) recorded that the matrix of the Middle and the Upper Siwalik rocks is primary while that of the Lower Siwalik is both primary and secondary. Tandon (1976) postulated fluviatile depositional environments for the Middle and the Upper Siwalik and border line fluvio-deltaic environment for the Lower Siwalik.
Bhandari and Singh (1972) observed rilled earth buttresses in the Upper Siwalik Boulder Conglomerate and attributed their development to surface run off. Krishna-swami (1972) worked out an outwash origin for the fanglomerates and clays of the Upper Siwalik Formation.

Chaturvedi and Singh (1972) recorded the presence of calcareous boulders in the Middle Siwalik of Kalagarh and designated them as pseudoconglomerates. Sahay and Verma (1973) also noticed some hard and highly calcareous concretionary bodies in the Middle Siwalik sandstones. According to them, the concretions are of inorganic origin and formed in situ by diagenetic changes taken place at relatively low temperature and pressure. Earlier, Pilgrim (1913) had also mentioned the presence of concretionary beds in the Middle Siwalik Formation and attributed their origin either to penecontemporaneous processes or to post depositional factors.

Halstead and Nanda (1973) placed on record that the environment of deposition of the Pinjore sediments was flood-plain across which large rivers meandered. According to them, the sand-clay alternations in these beds have been produced by channel-fill and overbank deposits. They described the Boulder Conglomerates as alluvial fans and piedmonts "which existed at the foot of mountains".
Bhushan (1973) differentiated the Upper Murree, Kamlial and Chinji on the basis of zircon types. He suggested an igneous provenance for the Upper Murree and Kamlial and metamorphic source for the Chinji sediments. Regarding the direction of currents, he observed that the sediments constituting the Upper Murree and the Kamlial were derived from northern and eastern directions and the Chinji sediments were mainly derived from the northern direction.

Soman (1973) studied the heavy minerals from the Lower and the Upper Siwalik rocks exposed in the Ramnagar area of Nainital District and worked out a metamorphic provenance. He recorded that the rounded grains of tourmaline, zircon and garnet have undergone more than one cycle of erosion, transportation and sedimentation and have been derived from the Peninsular Shield. According to him, the euhedral grains of zircon and tourmaline were supplied by younger Himalayan rocks. Sahay (1973) studied the textural parameters of the Siwalik sediments exposed in the neighbourhood of Kotdwara.

According to Singh and Rastogi (1973), Siwalik sediments were deposited by fluvial process in a foredeep similar to the present day Gangetic Alluvium. The shear zones were active during the Siwalik sedimentation. Sahni,
Kumar and Srivastava (1974) suggested the prevalence of definite nonmarine conditions from the early Siwalik time.

Nandi (1975) concluded that the paleoclimate kept on changing during the deposition of the Siwalik sediments. She suggested warmer and humid climate during the Lower Siwalik, comparatively colder and drier climate during the Middle Siwalik and colder climate during Upper Siwalik times. Singh, Khanna and Sah (1973) observed that the Pinjore sediments were deposited in sub-temperate to temperate climate.

Parkash, Bajpai and Saxena (1974) studied the sedimentary structures of the Lower and Middle Siwalik Formations and worked out that a major proportion of the sediments was derived from the North. Parkash, Goel and Sinha (1975) also recorded that the southward currents were active during the sedimentation of the Siwalik sequence. They advocated the existence of only one basin of deposition. Singh (1975) has given a model for the sedimentation of the Siwalik. According to him, the upward fining of grain size in the Lower Siwalik sequence suggests a fluvial environment.

Pandey (1975a) carried out sedimentological study of the Middle and the Upper Siwalik formations exposed southwest of Dehra Dun. His investigations have revealed that the detritus was derived from the pre-Siwalik
formations located to the northeast of the site of deposition. On the basis of sedimentary structures, he inferred a shallow subsiding basin for the accumulation of the Middle and the Upper Siwalik sediments. According to him, the conglomerates were deposited in fluviatile to subaerial environments. He observed that the wedging and thinning of sandstones, clays and conglomerates indicate channel-filled deposits. In another publication, he (Pandey, 1975b) recorded considerable variation in the sphericity and roundness parameters of the Middle and the Upper Siwalik sediments.

Sahay and Verma (1975) studied the surface textures of quartz grains and diagenesis of the Siwalik sandstones. Sharda (1975) also studied the diagenetic changes in the Siwalik sandstones of Udampur region. Shukla (1975) on the basis of grain shape analysis of the Middle and the Upper Siwalik sediments at Doon Valley postulated a metamorphic provenance. Shukla and Verma (1976) described the Siwalik sediments as diagenetically modified river sands derived from metamorphic rocks of the Himalaya. Nanda and Tandon (1976) and Prasad and Verma (1976) also worked out fluviatile depositional environments for the Siwalik Group.

Prasad (1977) recorded that the paleocurrent directions show a divergent pattern radiating from a common
source located to the northeast of the Siwalik Belt. According to him, the Lower Siwalik were deposited in deeper condition, the Middle Siwalik in the mixed environment and the Upper Siwalik in shallow basins. The present day streams along which the Siwalik rocks crop out, according to him, are following the course of the rivers which transported the Siwalik sediments.

Parkash and Goel (1977) reviewed the stratigraphy, structure and paleocurrents of the Siwalik Group and concluded that the Lower and the Middle Siwalik were deposited in overlapping mega alluvial cones of the rivers emerging from the Himalaya and the Upper Siwalik accumulated as piedmont deposits near the foothills. According to them, the present geographic set up in the Indogangetic Plain is essentially the same as that which originated during the early Siwalik time.

In an attempt to decipher the source rocks and the environments of deposition of the Siwalik sediments, Sahay and Verma (1977) carried out X-ray investigation of clay minerals from the Siwalik rocks of Kotdwara. They recorded that montmorillonite, illite and kaolinite are present throughout the Siwalik sequence except for the Upper Siwalik where montmorillonite is absent. The authors have suggested that the Tertiary, Mesozoic and Paleozoic rocks of the Lesser Himalayan Zone exposed to the North of Kotdwara have
contributed the clay minerals. Sharda and Verma (1977), on the basis of grain size parameters, concluded that the conditions of deposition were fluctuating from fluvio-deltaic during the Lower Siwalik to fluvio-continental during the Middle and the Upper Siwalik.

Chaudhury and Das (1978) recorded that the pebble beds of the Subansari District have close similarity with the pebble beds of Upper Assam (equivalent to Upper Siwalik) and proposed a freshwater origin for them.

Chaudhri and Gill (1979) worked out sedimentology and fabric of the Upper Siwalik Boulder Conglomerate exposed near Pinjore. According to them, the megaclasts and finer sediments constituting the Boulder Conglomerate Member were derived from the Lower Tertiary rocks exposed to the North of the Conglomerate outcrops. The fabric data and imbrication pattern revealed the prevalence of southwesterly flowing currents. Shape of the megaclasts indicated a moderate distance of transport.

Chaudhri and Dhanoa (1980) studied sedimentology of the Pinjore sediments and worked out a metamorphic, sedimentary and volcanic provenance and a shallow rapidly subsiding basin.

Parkash, Sharma and Ray (1980) suggested that the composition of sandstones and conglomerates of the Siwalik Group reflects a phenomena of uplift by collision
of plates and that the Siwalik sediments were derived from the raised portion located to the North of an East-West elongated trough. During the deposition of the Siwalik sediments, more areas South of the elevated mass were raised which acted as additional sources for the Siwalik. The authors have expressed the view that the modern sedimentation in the Indogangetic Plains can be used as a model for interpreting the deposition of the Siwalik sediments which accumulated in two coarsening up cycles. According to them, the Siwalik Group came into being as a result of collision between India and China plates, whereby the India plate was fractured along the Main Central Thrust and the Main Boundary Fault. The area North of the Main Boundary Fault was uplifted and the one South of it was downwarped to form a basin of deposition.

Sahni and Mitra (1980) tried to reconstruct the paleoenvironments of the Neogene of the Indian subcontinent on the basis of sedimentological, paleontological and paleobotanical evidences. According to them, the sedimentation in the Indian subcontinent has progressively approached the continental conditions during the course of geologic time. The basin of sedimentation has been remarkably stable. The Himalaya remained the supplier of sediments for North India from Miocene onwards.
Qidwai and Swarnkar (1980) described the distribution, sedimentology and sedimentary structures of the rocks exposed in the Morni region. They described the well established Lower Siwalik sequence as Middle Siwalik without assigning any reason for the change.

Pandey, Verma and Anantharaman (1981) divided the Middle and the Upper Siwalik of Mohand region into six units based on the heavy mineral suites. The authors have postulated shallow water conditions for the deposition of the Middle Siwalik and partly subaerial condition for the detritus of the Upper Siwalik.