Bulletin of the Geological Survey of Japan, vol. 33 (12), p. 593–617, 1982 553.495: 551.3.051 (541.35)

Sedimentology and Uranium Prospecting of the Siwaliks in Western Nepal*

Terumasa NAKAJIMA**

NAKAJIMA, Terumasa (1982) Sedimentology and uranium prospecting of the Siwaliks in Western Nepal. *Bull. Geol. Surv. Japan*, vol. 33 (12), p. 593–617.

Abstract: The Siwaliks (Miocene to Pleistocene) distributed along the southern side of the Main Boundary Thrust in Nepal are composed of conglomerates, sandstones, mudstones and lignites. The Lower and Middle Siwaliks show various kinds of cyclic repetition in their lithofacies and sedimentary structures. A generalized unit of the cycles consists of sandstones, mudstones and lignites from bottom to top. The sandstones are well-stratified and frequently cross-bedded while the mudstones exhibit massive aspect occasionally with lenticular bedding. In the unit, each lithofacies gradually change into overlying one whereas the boundaries between units are mostly discontinuous and erosional. These cyclic sedimentation, sedimentary structures and fossil evidence suggest the Siwaliks to have been deposited in coastal environments of a fresh water basin.

The conglomerates of the Middle and Upper Siwaliks of the investigated area do not contain any High Himalayan rocks such as gneisses and granites. The composition of the conglomerates combined with the palaeocurrent data reveals the sediments to be derived mainly from the Lesser Himalayas just north of the Main Boundary Thrust. As in Pakistan, uranium deposits are expected to occur in the Siwalik sandstones in Nepal. In most places, however, the Siwaliks would have less possibility of uranium occurrence because the Lesser Himalayas do not contain big granite bodies from which uranium minerals are supposed to be originated. In the High Himalayas, granitic rocks are widely distributed, and three big rivers of Nepal have percolated through them and transported the sediments into the Siwalik basin from the ancient time. It seems to be more effective to concentrate our uranium prospecting to the area where these rivers have descended into the Siwalik basin.

Introduction

Since 1950, when Nepal opened its country to foreigners, the government has made effort to search for natural resources to develop the country. So far, no economic mineral resources have been found except for an enormous amount of carbonate rocks and crushed-stones for construction. As people's life is rapidly modernized, the country is suffering from greater shortage of fuel. Recently, uranium deposits were found in the Pakistan Siwaliks, and the government of Nepal came to be concerned about them.

The Department of Mines and Geology of Nepal has started the uranium prospecting project from fiscal year 1980–1981. The author had a chance to participate in this project and surveyed the Siwaliks of Western Nepal in 1981. Uranium deposits in the Pakistan Siwaliks occur in the sandstone beds and are supposed to be a Himalayan source (MOGHAL, 1974). If the Siwaliks represent Molasse-like deposits, originating from the uplifting Himalayas where gneisses and granitic rocks with relatively high uranium content came to be exposed on the surface, it is highly possible that uranium in the Siwalik sediments

* This paper is published by permission of the Department of Mines and Geology, Nepal.

** Mineral Deposits Department

was also derived from those rocks. In this point of view, the author has carried out the sedimentological investigation of the Siwaliks to evaluate the possibility of the occurrence of uranium deposits.

Stratigraphy

Along the foothills of the Himalayas, the Siwaliks (Miocene to Pleistocene) are distributed on the southern side of the Main Boundary Thrust (Fig. 1). They are generally thought as the Molasse-like sediments associated with the Himalayan Orogeny. The name, Siwaliks, was derived from the Siwalik Hills near the Dehra Dun north of Hardwar in Uttar Pradesh of North India (MEDLICOTT, 1864). The Siwaliks of the type area are subdivided into the Lower, Middle and Upper Siwaliks. The Lower Siwaliks which are called Nahans in the Simla area, are wide-spread along the Kumaon foothills. They show an alternation of massive, soft green-brown sandstones with chocolate to green, somewhat concretionary clays (GANSSER, 1964). The purple or red aspect of the Lower Siwaliks is useful to distinguish it from the overlying Middle and Upper Siwaliks. The Middle Siwaliks consist of thick, massive, rather soft micaceous sandstones with subordinate clays, and the Upper Siwaliks include mainly coarse clastic deposits such as boulder conglomerates, ordinary conglomerates, grits, sands and earthy clays.

These lithological features of the Lower, Middle and Upper Siwaliks are persistent from the type area to the Kali River at the Nepalese frontier (MISRA and VALDIYA, 1961). In Western Nepal, the Siwaliks are widely exposed around the Dang area west of Butwal. The investigated area lies at the eastern end of the Dang belt. The Siwaliks in this area, as a whole, are composed of an alternation of sandstones and mudstones with intervening conglomerates, lignites and limestones, and can be subdivided into the Lower, Middle and Upper Siwaliks as in the type area (Table 1). The Lower Siwaliks are characterized by quartzose fine sandstones interbedded with reddish brown and greenish grey mudstones while the Middle Siwaliks consist of arkosic fine to coarse sandstones with intercalations of greenish grey to dark grey mudstones. In contrast to these two parts, the Upper Siwaliks contain mainly coarser sediments represented by conglomerates

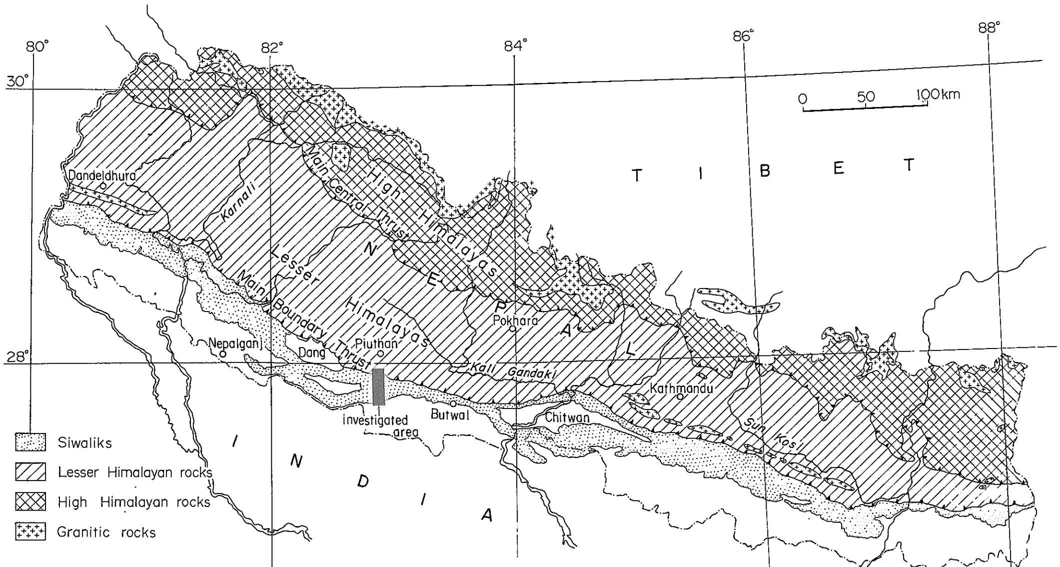


Fig. 1 Distribution of the Siwaliks in Nepal and investigated area.

Table 1 Stratigraphy of the Siwaliks in the Sithdhara region west of Butwal.

Age	Formation	Thickness	Lithology
Middle Miocene—Lower Pleistocene	Upper Siwaliks	450 m+	Pebble and cobble conglomerates, fine to very coarse sandstones, subordinately pebbly mudstones and sandy mudstones
	Middle Siwaliks	2700 m	bedded fine to coarse arkosic sandstones, greenish grey and dark grey mudstones, lignites, pebble conglomerates, occasionally limestones
	Lower Siwaliks	2650m+	bedded fine to medium sandstones, reddish brown, purplish, greenish grey and dark grey mudstones, lignites, occasionally limestones
			Main Boundary Thrust
	Nawakot Group (undifferentiated)		black carbonaceous shales, dark grey dolomites, purplish shales, pinkish quartzites

and sandstones.

1) Lower Siwaliks

The formation is well exposed on both flanks of the Kusum Khola Syncline in the southern part of the project area (Figs. 2 and 3). Another narrower belt of the formation occurs along a E–W fault from the Rapti River to Sit Khola in the northern part of the area.

The Lower Siwaliks consist mainly of bedded fine- to medium-grained sandstones of greenish grey or brown color, sometimes mottled with red, with intercalations of reddish brown, purplish, greenish grey and dark grey mudstones. Occasionally, lignites or muddy lignites overlie the mudstones or are intercalated in them. Thin beds, lenses and pockets of limestones are subordinately found.

The sandstones of the Lower Siwaliks are generally very-fine- to fine-grained while medium-grained sands are less frequent. They have much quartz grains with minor micas and small, red and black rock fragments, and high carbonate contents in the matrix. Most of the sandstones are well-bedded, and show cross-bedding and various kinds of current ripple lamination. Thickness of one unit is 10 to 200 cm.

The grain size of the mudstones ranges from coarse silt, sometimes sandy silt, to clay. Usually, the mudstones exhibit a gradation or multiple gradation. The contact of the mudstones with the underlying sandstones is gradational. The reddish coloration is characteristic of the Lower Siwalik mudstones and a useful criterion to distinguish them from the Middle Siwalik mudstones. Calcareous concretions of 1 mm to 10 cm in diameter are frequently found in the mudstones. In part the mudstones are calcareous and contain thin beds or lenses of limestones. Lenticular lamination, parallel lamination and bioturbation are partly recognized in the fresh outcrops of the mudstones.

The lignites are sometimes muddy and sandy with well-preserved plant fossils. Fine parallel lamination is predominant in them but current ripple lamination is rare.

The thickness of the Lower Siwaliks is estimated to be more than 2650 m.

2) Middle Siwaliks

The sediments of this formation are widely distributed in the project area. They are repeated four times mainly by the strike faults. In the southern area they occupy the axial part of the Kusum Khola Syncline (Figs. 2 and 3). Three other Middle Siwalik belts of the northern area show north-dipping monoclines with partly inverted strata along the faults.

The formation is composed of bedded fine- to coarse-grained arkosic sandstones intercalated with greenish grey and dark grey mudstones (Plate I-a). Lignites, pebble conglomerates

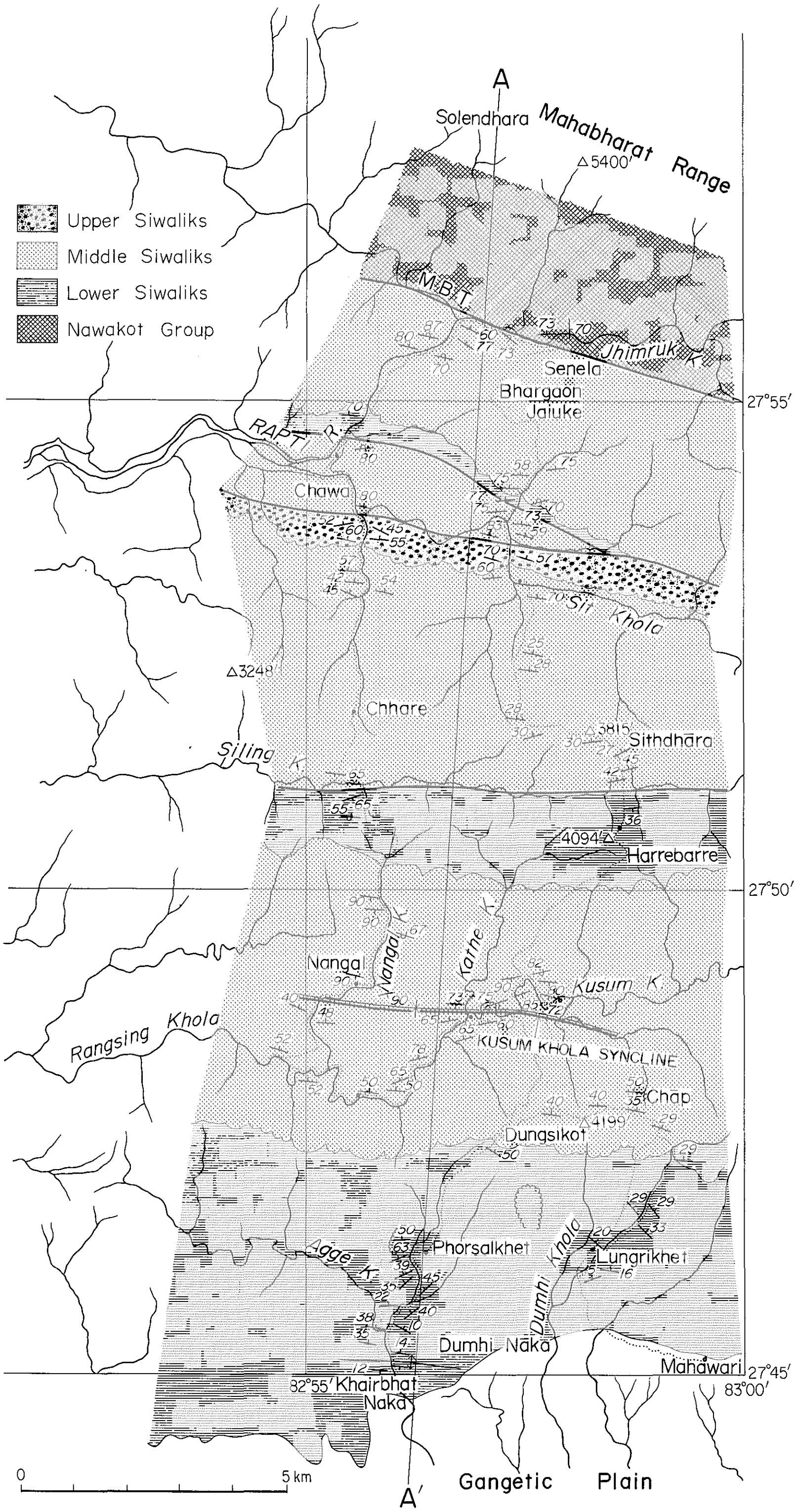


Fig. 2 Geological map of the Sithdhara region west of Butwal.

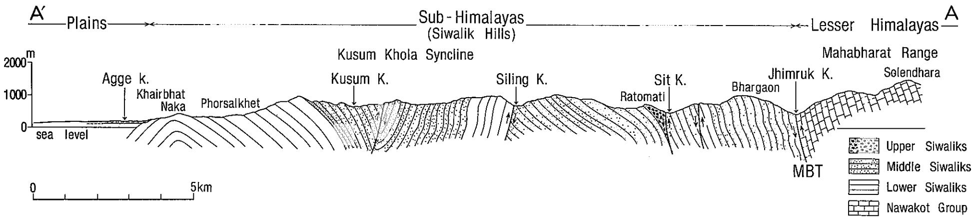


Fig. 3 Geological section across the Siwalik foothills between Solendhara and Khairbhat Naka.

and limestones are also found in it.

The sandstones of the Middle Siwaliks have a wide range of grain size from very fine sand to very coarse sand. Occasionally pebbles of the Lower Siwalik sandstones and the Nawakot Group distributed in the Lesser Himalayas, and intraformational mudstone clasts occur in the coarse-grained sandstones. The sandstones show more or less feldspathic and micaceous character responsible for their arkosic aspect. The concretionary bands are developed parallel to the bedding plane in some places. The thickness of one unit of the sandstone ranges from a few centimeters to a few meters. Thin sandstone lenses and pockets are also found in the mudstones. On the fresh outcrops in rivers, cross-bedding, current ripple lamination and other sedimentary structures are well visible (Plates I-b and II). While on the exposures of hills and ridges, these sedimentary structures are not recognizable because of weathering.

Color of the Middle Siwalik mudstones is usually greenish grey and in more carbonaceous parts, dark grey. The reddish or purplish color is rare. Except for the difference in color, the Middle Siwalik mudstones have almost the same features as those of the Lower Siwaliks.

Thin lignite beds usually occur on the top of the mudstones and less frequently in them (Plates III-b and IV-a, and Figs. 4 to 7). In the upper part of the Middle Siwaliks, pebble conglomerates appear as thick beds in the sandstones or as thin lenses in the mudstones. The limestone beds have been seen at a few places. The color is light grey in fresh outcrops but in weathered state it has orange tint. They are well banded and display current ripple lamination in places (Fig. 7).

The contact between the Lower and Middle Siwaliks is conformable and gradational without any sharp change in lithology. The formation reachs a thickness of 2700 m.

3) Upper Siwaliks

In the northern part of the project area, the Upper Siwaliks crop out along E–W-fault in a narrow belt of about 0.6 km in width (Fig. 2). The formation consists mainly of pebble and cobble conglomerates with fine- to very-coarse-grained sandstone intercalations (Plate IV-b). Subordinately pebbly mudstones and sandy mudstones occur in the lower part. The conglomerates are well-bedded and a unit bed is a few decimeters to a few meters in thickness. In fresh outcrops they are compact and tinged with pink color. The matrix contains calcareous medium- to very-coarse-grained sands. The pebbles and cobbles are subrounded to rounded and 1 cm to 1 m in diameter. They are composed of fine-grained sandstones of the Lower Siwaliks, grey dolomites, white quartzites and purplish calcareous quartzites (Plate V-a). In a outcrop at the Sit Khola distributary, the ratio of the components is as follows.

Sandstones of the Lower Siwaliks	...50%
Grey dolomites	...30%
White quartzites	...13%
Purplish calcareous quartzites	...7%

Except for the Lower Siwalik sandstones, these rocks are commonly distributed in the Mahabharat Range of the Lesser Himalayas north of the investigated area.

The sandstones are 10 to 50 cm thick with pale brown and grey color. They occur frequently in the conglomerates as thin lenses and pockets. The average grain size is medium to coarse sand. Cross-bedding and current ripple lamination can be visible in the sandstone and conglomerate also.

A pebbly mudstone bed of 3 to 4 m in thickness was found in the Sit Khola distributary. The pebbles embedded in the sandy mud matrix are 1 to 10 cm in diameter and consist of the same rock types as the conglomerates.

The boundary between the Upper and Middle Siwaliks is gradational, with the mudstones of the higher part of the Middle Siwaliks becoming coarser and sandy with thin pebble conglomerate intercalations. The accurate thickness of the Upper Siwaliks is unknown in this area as the upper part is lost by the strike fault, but at least 450 m are present.

Geologic Structure

As the result of folding, the Siwaliks are exposed repeatedly across 40 to 50 km in the Chitwan and Dang areas (Fig. 1). Between these areas they form a narrow belt of only 5 km in width near Butwal and the folds pinch out into a system of thrust faults. In the investigated area the folds in the Dang area are still traceable.

The Kusum Khola Syncline in the southern part of the area is a direct extension of a big syncline from the Dang area. The southern flank of the syncline is somewhat gentle but the northern flank has steep inclinations near vertical or even inverted in some places. In the Kusum Khola, a longitudinal fault exists along the synclinal axis (Fig. 2). The northern margin of the syncline is also faulted along the Siling Khola but this longitudinal fault may represent an anticlinal axis because the Middle Siwaliks north of the fault are dipping north. The strata in the northern part of the area are monoclinal although they are steepened or inverted along faults in places.

In the project area, five longitudinal faults are found including the Main Boundary Thrust (MBT). All of the longitudinal faults may be genetically similar. In the Jhimruk Khola, the MBT strikes in N 70°W which is a general trend of the Himalayan front, and dips with 80° toward north. Thus, the MBT appears to be a reverse fault or steep upthrust, but generally it is interpreted as a gently-dipping thrust which represents a deep crustal fracture produced by underthrusting of the Indian plate (Le Fort, 1975).

The northern side of the MBT is the Lesser Himalayan black carbonaceous shale with intercalations of dark grey dolomites, and the southern part well-bedded very fine sandstones of the Middle Siwaliks. Along the MBT the black shale is sheared and becomes graphitic in the 10 to 30 m-wide fault zone but the Siwalik sandstones are not affected by the MBT.

Any big transverse fault is not noticed in this area but in some outcrops, minor faults striking oblique or perpendicular to the general trend of the Siwaliks are found.

Sedimentology

There are few contributions to the sedimentology of the Siwaliks. Bordet (1961) described the Middle Siwaliks east of the Arun Gorge in Eastern Nepal, and noted that one cyclic unit begins with coarse sandstones, which grade upwards into cross-bedded micaceous sandstones, and ends with greenish to blackish clays. A similar cyclic development of sedimentary beds was reported from the Lower and Middle Siwaliks exposed between the Yamuna and Gola Rivers, Uttar Pradesh, North India (Parkash *et al.*, 1974).

The depositional cycle described by Bordet (1961) is observed in the investigated area together with many other incomplete or complete cyclic depositional sequences. Although Gansser (1964) noted that regular cyclic sedimentation seems restricted to certain horizons within the molasse-like Siwaliks, the whole sections of the Lower and Middle Siwaliks in the project area show cyclic sedimentation. As will be mentioned below, cyclic sedimentation in this area exhibits many variations from a complete cyclic sequence. The cycles, therefore, look like irregular at a glance but after recognition of the varieties, it can be noticed that the succession built of the repetition of the cycles formed under the similar sedimentary environments.

1) Sedimentary cycles and facies

The Lower and Middle Siwaliks show similar lithofacies in spite of some differences in coloration of the mudstones and in mineral composition of the sandstones. The upper contact of the mudstone with the overlying sandstone in these two formations is usually sharp, abrupt or erosional while its lower contact is gradational (Figs. 4 to 8). Also, in many cases lignite layers overlie the mudstones with transitional contacts (Plate IV-a). These features can be interpreted as a kind of the progradational vertical sequence beginning with the sandstones grading upwards into the mudstones and then into lignites. In this sequence other sedimentary features also change regularly from bottom to top. Based on the vertical change of the sedimentary features, several types of lithofacies units or cycles can be distinguished as follows.

Unit S_1

This unit is a complete sequence (Figs. 9 and 10). The lower part consists of well-bedded fine- to coarse-grained sandstones which show cross-bedding and current ripple lamination (Figs. 4 to 7 and Plates I-b and II). Current ripple lamination is predominant in fine sandstones and coarse siltstones; sometimes climbing-ripple lamination is well developed in them (Figs. 5 and 6). The sandstones grade upwards into the siltstones at the top where current ripple lamination, small scale cross-bedding and fine parallel lamination are visible. Concretionary calcareous bands also occur in them. In parts the sandstones become coarser and conglomeratic, occasionally containing mudstone fragments of 1 cm to 3 m in diameter (Fig. 6). The coarse or conglomeratic sandstone usually occupies the bottom of the single graded sandstone bed. The thickness of individual sandstone beds is 5 cm to 5 m. As far as the author observed in long outcrops along the strike-trending rivers, the individual sandstone beds can be traced over one hundred meters (Plate V-b).

The middle part of the unit is mudstones

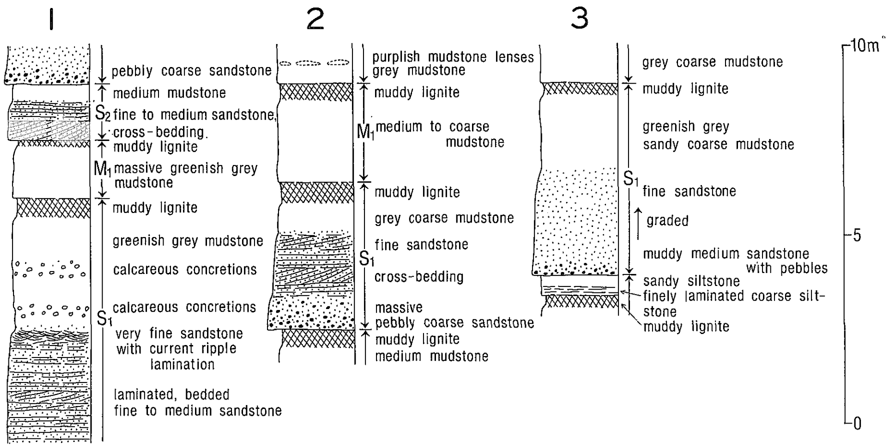


Fig. 4 Columnar sections of the Siwaliks.

1. Upper part of the Middle Siwaliks, Sit Khola.
2. Upper part of the Middle Siwaliks, Sit Khola.
3. Upper part of the Middle Siwaliks, Sit Khola.

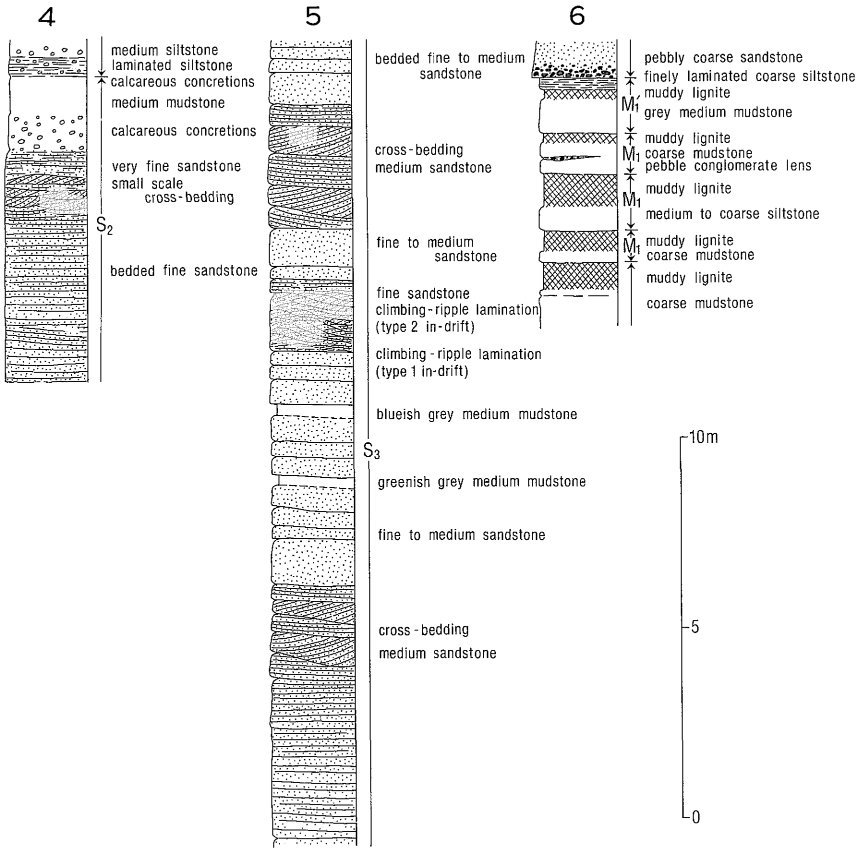


Fig. 5 Columnar sections of the Siwaliks.

4. Middle Siwaliks, Sit Khola.
5. Middle Siwaliks, Rapti River.
6. Upper part of the Middle Siwaliks, Distributary of the Sit Khola.

which grade upwards from coarse siltstones or sandy siltstones to fine or medium siltstones, sometimes up to claystones at the top. Lenticular bedding, bioturbation, well-preserved molluscan shells and calcareous pellets of 5 mm to 20 cm in diameter can be found in the mudstones (Plate III-a). Occasionally, the upper part of the mudstones displays fine lamination of carbonaceous fine silts, and the sun crack can be found on the top surface. The upper part of the Unit S_1 is occupied by lignites or muddy lignites (Plate IV-a). This part is usually finely laminated and between the laminae well-preserved plant fossils occur.

The thickness of the lower sandstone part is variable, ranging from a few centimeters to about 20 m. The middle mudstones varies from a few centimeters to 5 m in thickness and the upper lignite thickness is in the order of cm to dm, exceptionally reaching 1.5 m.

Unit S_2

This is an incomplete sequence where the upper lignite portion is missing (Fig. 10). Well-bedded sandstones form the lower part of the Unit S_2, and graded massive mudstones represent the upper part. The character of the Unit S_2 is almost the same as that of the Unit S_1 except for the absence of the upper lignite bed. The total thickness of the Unit S_2 varies between a few meters and about 20 m.

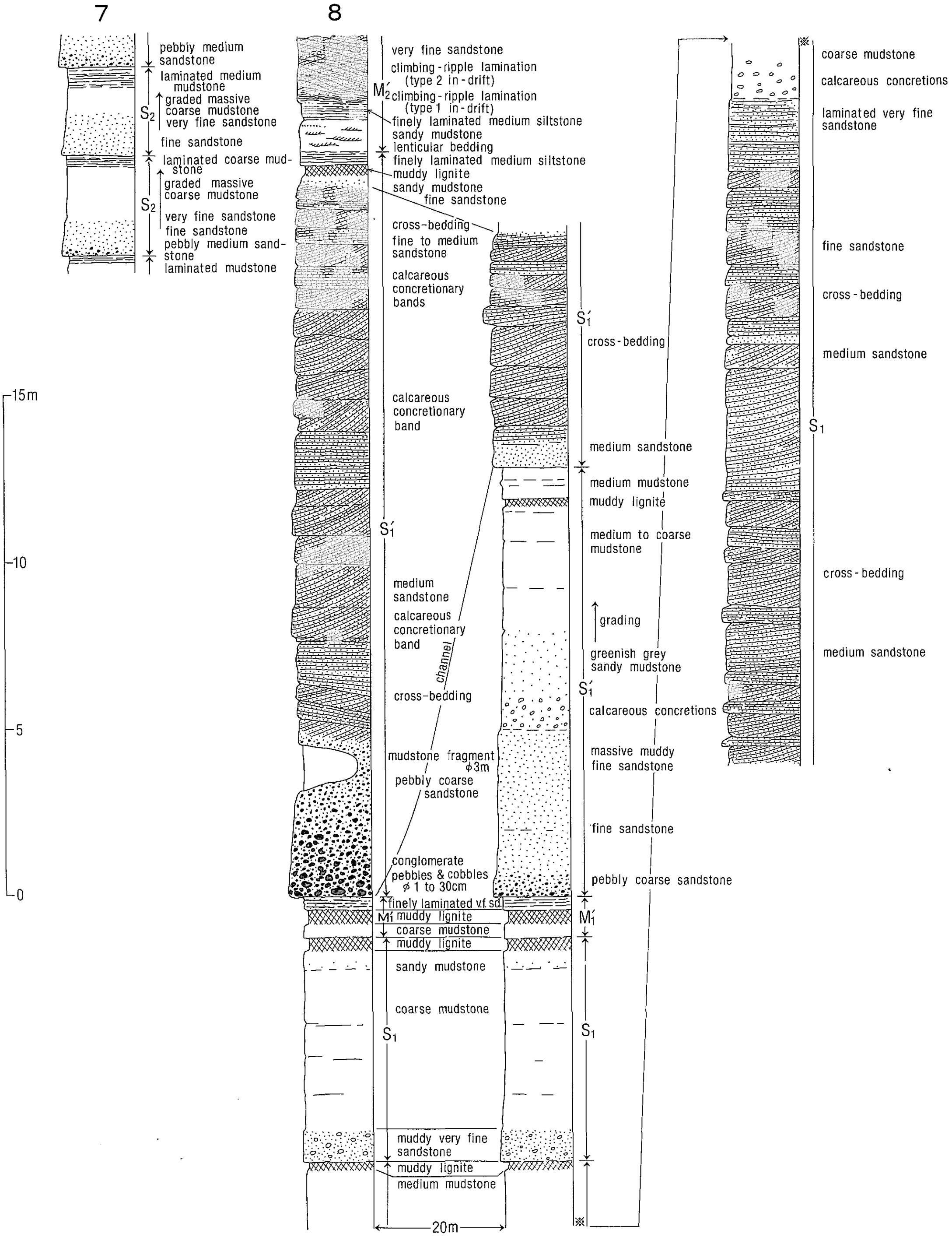


Fig. 6 Columnar sections of the Siwaliks.

7. Upper part of the Middle Siwaliks, Distributary of the Sit Khola.
8. Middle Siwaliks, Siling Khola.

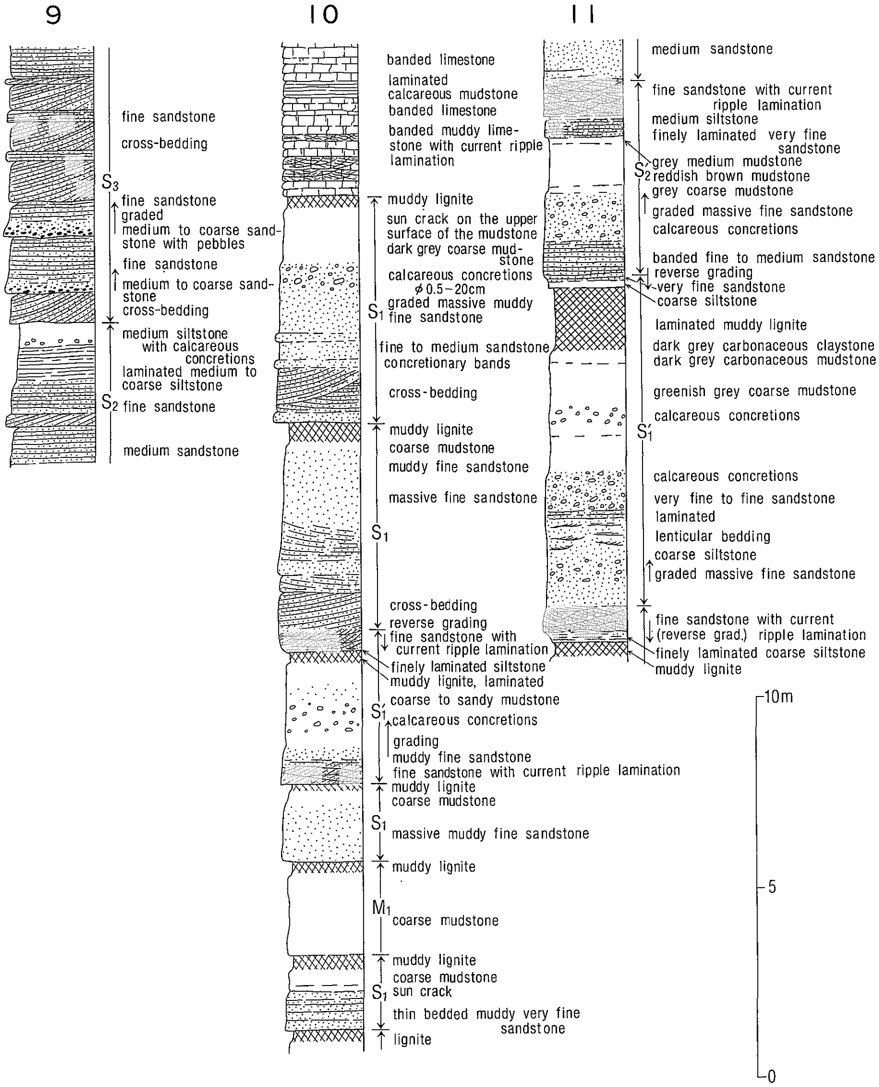


Fig. 7 Columnar sections of the Siwaliks.

9. Middle part of the Middle Siwaliks, Nangal Khola.
10. Lower part of the Middle Siwaliks, Kusum Khola.
11. Lower Siwaliks, Distributary of the Agge Khola.

Unit S_3

This type exhibits a thick sequence made up of bedded sandstones. It might be an extremely incomplete sequence in which the mudstone portion is absent. The sandstones of the Unit S_3 have the same sedimentary features as those of the Units S_1 and S_2.

Unit M_1

The Units S_2 and S_3 are truncated types while this type is a base-cut type which lacks the lower sandstone part (Figs. 9 and 10). A pile of repetition of this unit looks like a simple alternation of the mudstones and the lignites (Fig. 5). In this case, the contact between the lignites and the overlying mudstones of the

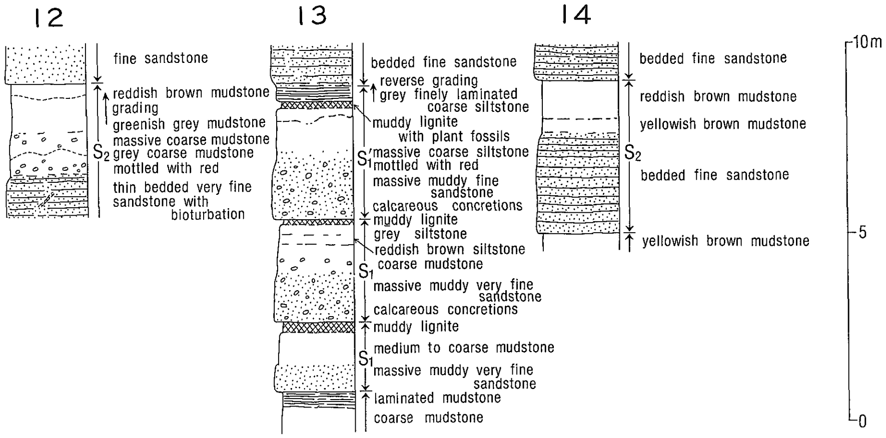


Fig. 8 Columnar sections of the Siwaliks.

12. Lower Siwaliks, Distributary of the Agge Khola.
13. Lower Siwaliks, Distributary of the Agge Khola.
14. Lower Siwaliks, Agge Khola.

next units is sharp or gradual but the contact of the lignites with the underlying mudstones is gradational. The thickness of the Unit M_1 is 50 cm to 3m.

Unit M_2

This is a repetition of the graded mudstones. Sometimes, it is closely associated with the Unit M_1.

Unit C_1

Near the boundary between the Middle and Upper Siwaliks the conglomerate layers appear in the sandstone part of the Unit S_1 and S_2. The conglomerate layers sometimes produce channel shapes, and have eroded away the underlying layers. In such a case, the upper and middle parts of the Units S_1 and S_2 are missing so that the succession is composed of an alternation of conglomerates and sandstones. In the Upper Siwaliks, thick bedded conglomerates with intercalated sandstones are predominant. The sandstones show the same features as those of the sandstones in the Units S_1, S_2 and S_3. This lithofacies may be regarded as a coarse-grained type of the Unit S_3. Here, it is named Unit C_1 (Fig. 10).

Units S'_1, S'_2, M'_1 and M'_2

Although it is a general rule for the above-mentioned units that the boundaries between the units are sharp and abrupt, there also exist exceptional examples, where the contacts are more or less transitional through a thin reverse graded zone. This reverse graded zone can be find in the succession built of the Units S_1, S_2, M_1 or M_2. In the case of the Unit S_1, the upper lignite layer is covered by claystones, siltstones or sandy siltstones with a gradual contact. The clayey and silty layers are a few decimeters in thickness and show fine parallel lamination in many cases but massive layers also occur (Figs. 5 to 8). This fine layers change into the medium- to coarse-grained sandstones of the next units through the very-fine- to fine-grained sandstones with current ripple lamination. The thickness of the reverse graded transitional zone is much smaller than that of the normal graded units. The Units S_2, M_1 and M_2 can also be overlain by the sandstones of the next units with the reverse graded transitional zone. Here, the Units S_1, S_2, M_1 and M_2 with the transitional zones are named S'_1, S'_2, M'_1 and M'_2, respectively.

2) Dispersal pattern of sediments

The Siwalik sandstones often show cross-bedding and current ripple lamination which

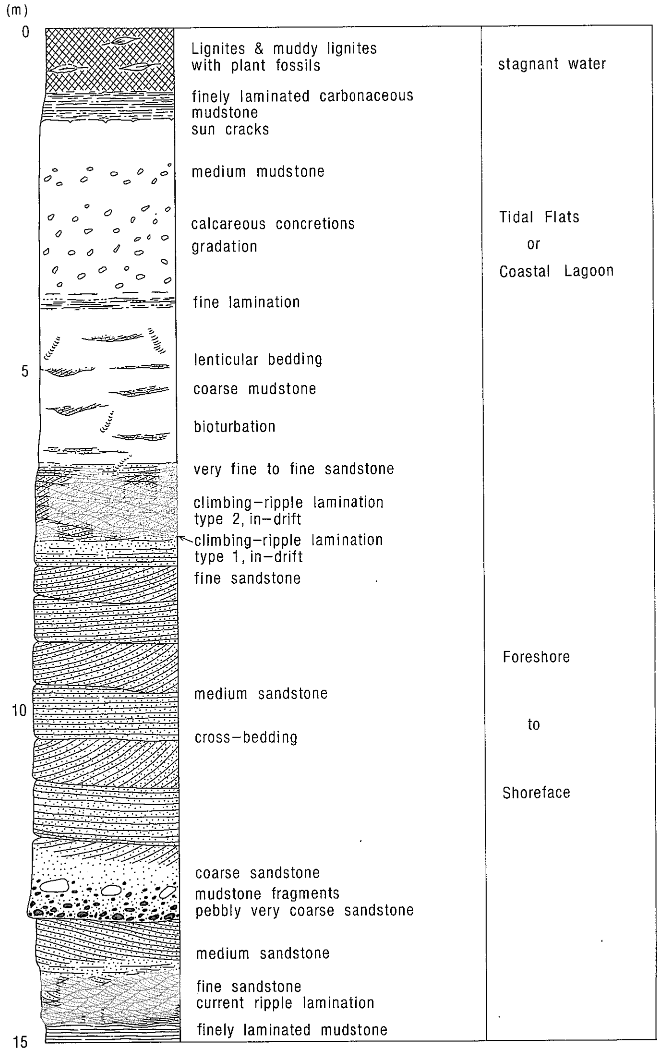


Fig. 9 Idealized complete sequence of the Siwalik deposits.

give us information on the palaeocurrent directions. Imbrication of pebbles and cobbles in the pebbly sandstones and the conglomerates is also a good indicator of the depositional current directions.

Figure 11 shows the current directions in the Siwalik deposits. Although the collected samples are not enough, the southward supply of sediments is suggested as a whole. In regard to each formation, the Lower Siwaliks have a few data of transverse currents from north, the Middle Siwaliks show the currents toward south and east, and the uppermost Middle Siwaliks and the Upper Siwaliks reveal westward currents. No northward direction has been observed in the project area. Considering this together with the occurrence of the Lesser Himalayan origin pebbles and cobbles in the Middle and Upper Siwaliks, it may be safely concluded that the hinterland which supplied the sediments into the Siwalik basin existed to the north of the basin.

3) Sedimentary environment

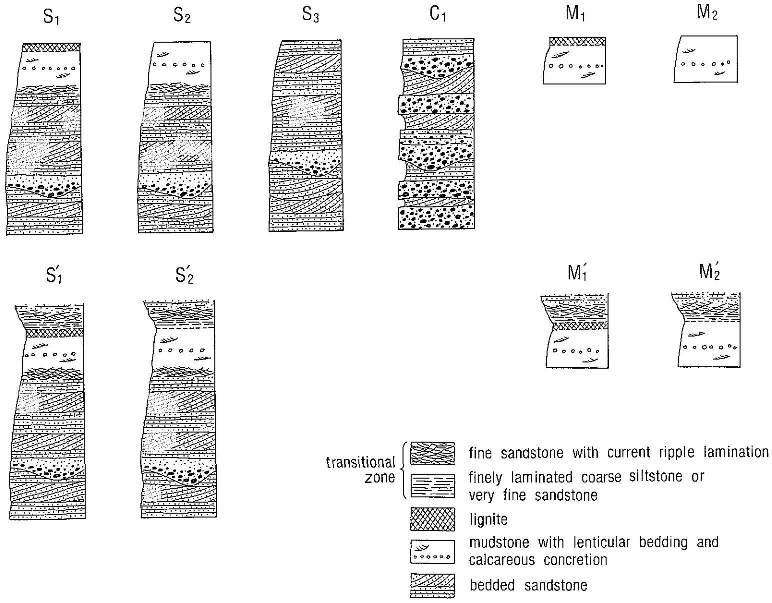


Fig. 10 Classification of the cyclic units.

The Siwaliks cover the Sub-Himalayas from Pakistan in the west to Assam in the east with a stretch of more than 3000 km. The lithofacies is not so different over most of the area. As fossils of fresh water molluscs and mammals were found from some places, the Siwaliks have been regarded as fluviatile sediments deposited from a big river or a network of rivers (PILGRIM, 1919; GLENNIE and ZIEGLER, 1964; JOHNSON and VONDRA, 1972; PARKASH *et al.*, 1974). However, the uniform lithofacies and the continuity of individual beds along outcrops suggest the Siwaliks not to be fluviatile sediments. Besides, the Siwaliks in the investigated area do not contain any land indicators such as soils, silts and clays with rootlets which are commonly associated with the sediments of rivers, alluvial funs and deltas (REINECK and SINGH, 1975; READING, 1978). Thus, these facts suggest that the Siwaliks are the sediments deposited in a big fresh water basin lying between the Indian continent and the Himalayas.

The sedimentary cycles and facies of the Siwaliks such as S_1, S_2, S_3, M_1, M_2 and C_1 seem to be varieties derived from the similar sedimentary environments. The Unit S_1 represents a typical series of sedimentary processes in the Siwalik basin (Fig. 9), and the other units are lacking in some of them.

Cross-bedding and current ripple lamination occurring in the sandstones of the Units S_1, S_2, S_3 and C_1 can originate in several genetically different ways. In most cases they are a result of the migration of small and megaripples, dunes and micro-deltas. In other cases they are the result of scour and channel-fill features and deposition on the point bars of small meandering channels or on the inclined surfaces of beaches and bars (REINECK and SINGH, 1975). Taking their areal extent into consideration, the Siwalik sandstones may have been deposited in the coastal environment of the basin. As a whole, the complete sequence demonstrates a progradational one and toward the top the sediments become shallower facies.

The mudstones show upward-fining, and are finally overlain by the lignites with well-preserved plant leaves. This fact does not mean the basin deepened upwards, but means it rather shallowed. The lenticular bedding and the sun crack occurrence of the mudstones suggest mud flats or lagoonal environments.

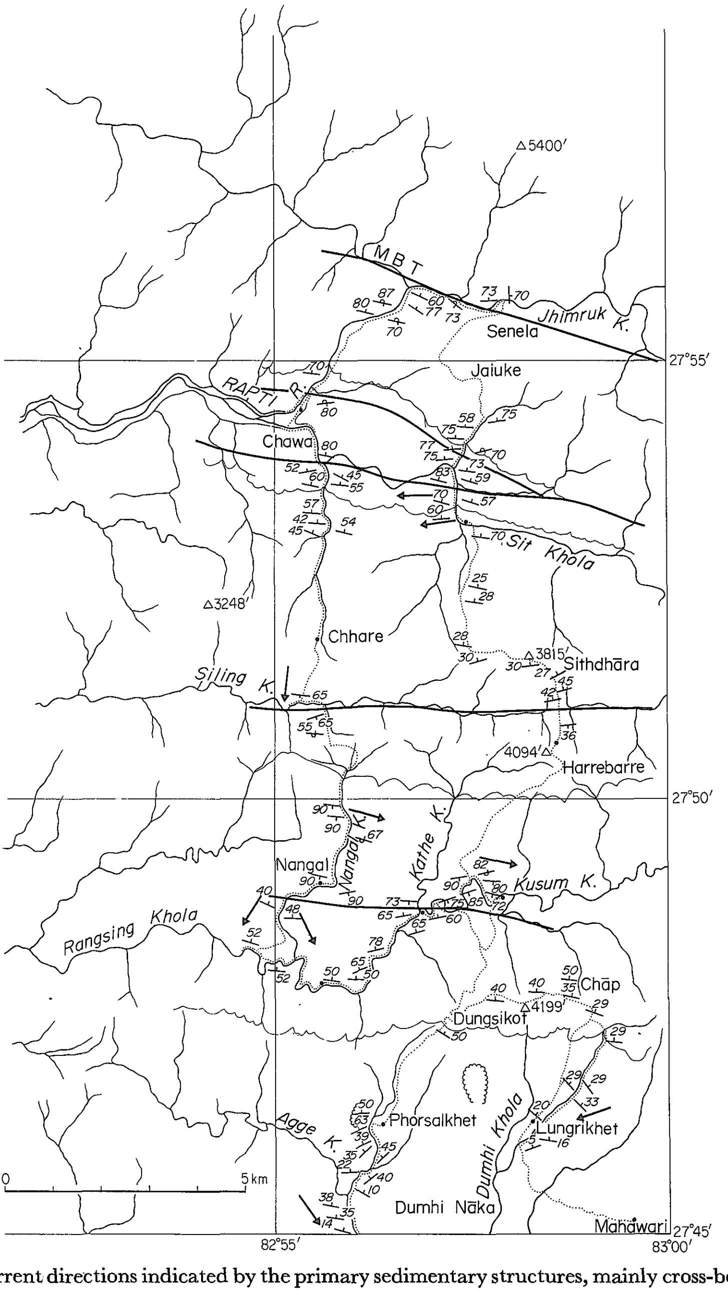


Fig. 11 Current directions indicated by the primary sedimentary structures, mainly cross-bedding.

The sandstones of the Siwaliks must have been deposited under the conditions of more active currents or waves in the somewhat deeper part of the basin, compared with the mudstones and lignites which seem to have accumulated over the shallower part of the basin under the calm and stagnant conditions. The progradational change of the sequence suggests that the sandstones have been formed through the progradational burying of the basin (Fig. 12). After the accumulation of the some sandstone beds, a flat and shallow platform emerged

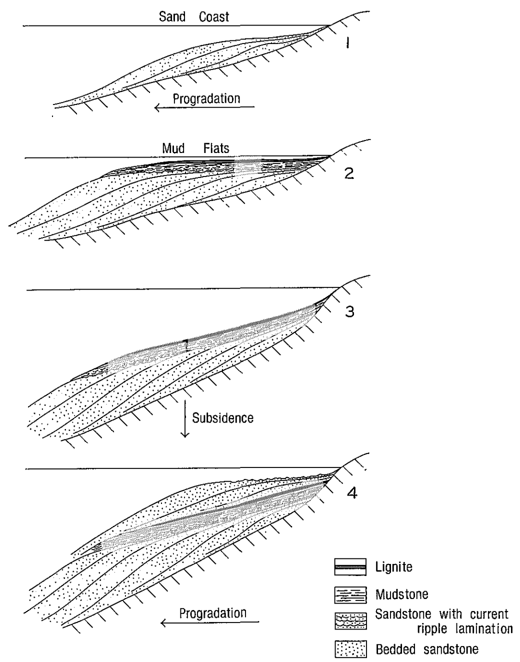


Fig. 12 Sedimentary environments and depositional process.

along the coast. As fine materials cannot be easily dispersed seawards in this condition, the environments became suitable for the deposition of muds. In the final stage, the water condition became much more stagnant, decreasing the depositional rate of clastic materials, and the lignites settled over the mudstones.

In the case of the incomplete sequences, some of the environments or processes involved in the complete sequence are missing, but the change in their depositional environments are essentially the same as that of the complete sequence. As already mentioned, the units are usually covered by the sandstones of the next units with sharp, erosional contacts. This means transgressive overlying of the next cycles took place discontinuously. In other words, relatively rapid water level rising or subsidence of the basin must have occurred. According to Curray (1964), the progradation process represents the stable water level stage (Fig. 13). The succession of the Siwalik deposits, therefore, indicates episodic water level rising or subsidence of the basin; in the Siwalik case the latter might be the case.

On the other hand, the reverse graded tran-

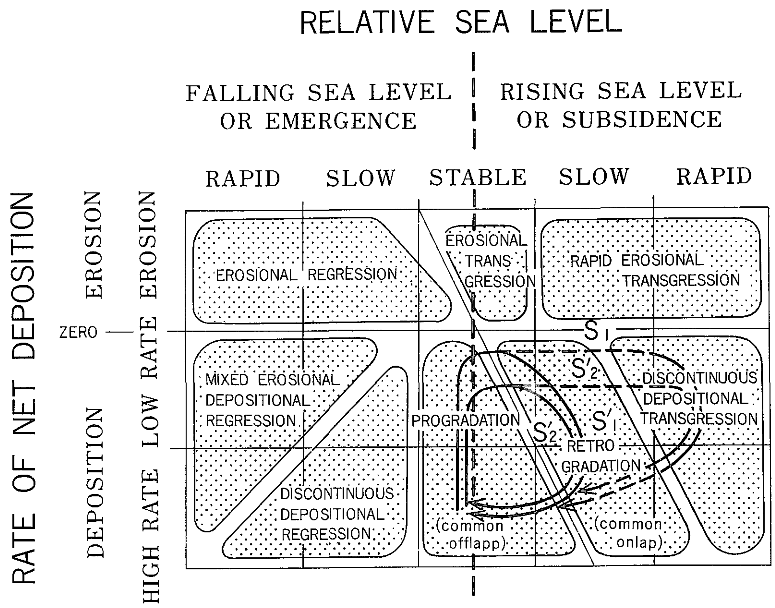


Fig. 13 Depositional processes of the cyclic units shown on the Curray's diagram.

sitional zone of the Units S'_1, S'_2, M'_1 and M'_2 corresponds to on-lap or retro-gradation (Fig. 13). Such sequences are produced during a slow and gradual subsidence (depositional transgression in Curray's terminology). Figure 13 shows the depositional process of each unit in the Siwalik sediments on the Curray's diagram.

Contrasting with the Lower and Middle Siwalik sediments, the Upper Siwaliks have the coarser sediments such as conglomerates and sandstones. These coarse sediments seem to be a reflection of the beginning of the rapid Himalayan uplift and denudation. The Siwalik basin might have had adjoining mountainous hinterlands which resemble the present Lesser Himalayan view. The coarse detritus such as pebbles and cobbles which are commonly seen along the foothills of the Lesser Himalayas, would have reached the coast of the Siwalik basin. The landscape of the Upper Siwalik hinterlands must have considerably differed from those of the Lower and Middle Siwaliks but the sediments of the Upper Siwaliks might have been deposited in similar coastal environments.

Uranium Prospecting

1) Results

In this field survey, the author tried to search for uranium deposits and to measure the radioactivity of the Siwalik rocks. For detecting uranium deposits, nine geiger counters and one scintillation counter were used. Detailed geological route maps on a scale of 1 : 3,500 were made to know the extent of the sediments and describe radioactivity measurements of the rocks in each outcrops. If more detailed measurement was necessary, the author recorded 1 : 20 columnar sections and investigated the difference of radioactivity between rock types.

The radioactivity measurements along the main routes are shown in figure 14. Most of the values indicate only a background one and any abnormally high radioactivity could not be found. The maximum radioactivity is three times as much as the background value. Such values were recognized in some lignites, coarse sandstones and conglomerates. Usually, the mudstones do not show any high radioactivity. In the Sit Khola, wood fragments in the channelized pebbly sandstones of the Middle Siwaliks showed twice to three times as much as the background value.

2) Suggestions for target areas

Recently, uranium deposits were found in the Siwaliks distributed along the Dera Ghazi Khan District of Pakistan (BASHAM and RICE, 1974; MOGHAL, 1974). Uranium lenses occur in the cross-bedded sandstones with the intercalations of siltstones, clay pebbles and quartzite conglomerates of the Middle Siwaliks. The lenses contain uraninite and coffinite in the non-oxidized zone, and tyuyamunite in the oxidized zone. These uranium deposits can be classified as the peneconcordant sandstone type deposits (DAHLKAMP, 1978). The lithofacies of the Lower and Middle Siwaliks in Nepal are essentially the same as the Pakistan Middle Siwaliks, so that we can expect the same type uranium deposits in the Nepalese Siwaliks. The source area for the Pakistan Siwaliks lay to the north, and a possible source of the uranium is thought to exist in the Himalayas (BASHAM and RICE, 1974). Also in Nepal, the source of uranium is supposed to be in the Himalayan rocks, especially in granitic rocks which have much higher uranium contents among commonly distributed rocks and are widespread in the High Himalayas (Fig. 1).

The Siwalik sediments in the project area were supplied mainly from the Lesser Himalayas although the arkosic character of the Middle Siwalik sandstones suggests some inflow of clastic material from the High Himalayas. The Lesser Himalayas north of the area has no granitic rock occurrence, and any pebbles of the granitic rocks are not contained in the Siwalik sediments. These facts may be

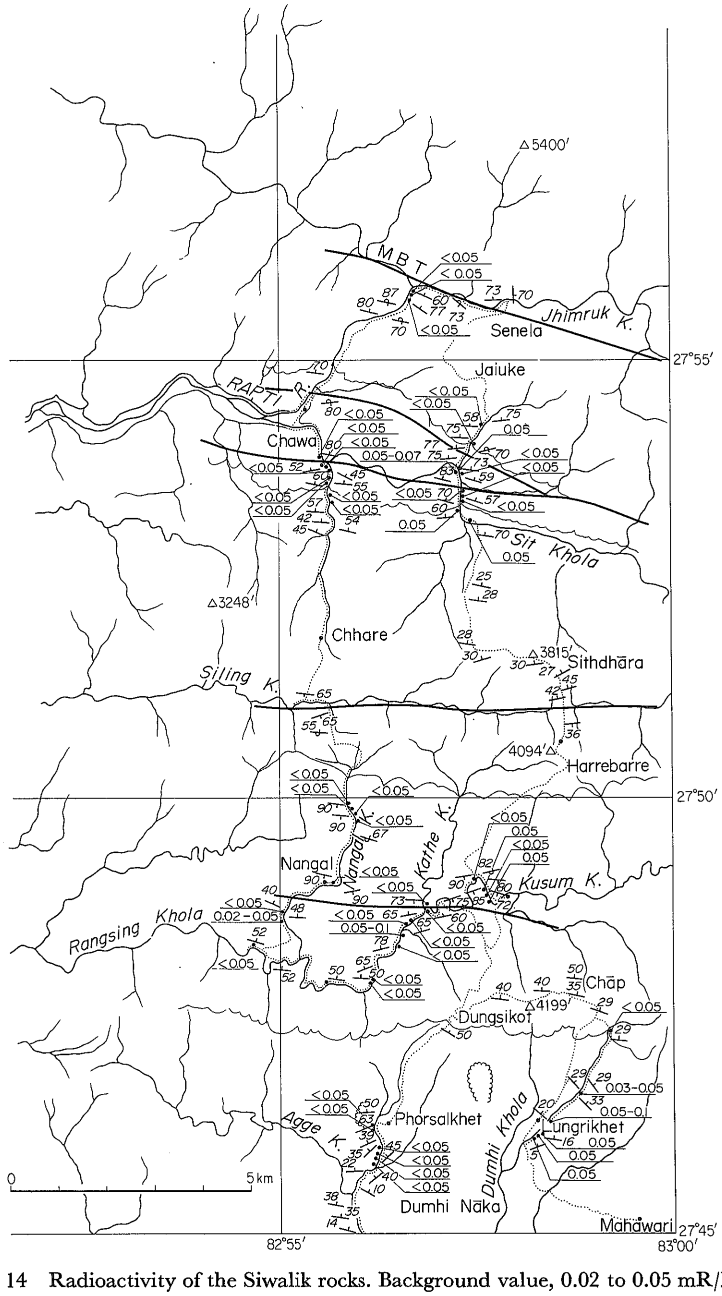


Fig. 14 Radioactivity of the Siwalik rocks. Background value, 0.02 to 0.05 mR/h.

the main reasons we could not find any indication of uranium occurrence.

Hence, we should pay greater attention to the areas where the big rivers descend from the High Himalayas. The big rivers such as the Sun Kosi, Kali Gandaki and Karnali Rivers might have been originated in the ancient time. If they drained the big granitic bodies of the High Himalayas, uranium may have transported into the Siwalik basin, and precipitated in the permeable sediments near the mouth of the rivers. Thus, the areas where the big rivers cross the Siwalik hills have the greatest probability of uranium occurrence.

Acknowledgements

This work was aided greatly by Japan International Cooperation Agency(JICA). The field survey was done under the Uranium Prospecting Project of the Department of Mines and Geology (DMG) of Nepal. The author expresses his gratitude to Mr. M. N. RANA, Director General of DMG and Mr. J. M. TATER, Deputy Director General of DMG who have kindly given him opportunity to participate in the project and permission to publish the data. My special thanks go to Mr. R. N. YADAV and Mr. B. L. SHRESTHA, counterparts from DMG who assisted the author in the field.

References

BASHAM, I. R. and RICE, C. M. (1974) Uranium mineralization in Siwalik Sandstones from Pakistan. *Vienna, Internat. Atomic Energy Agency*, SM-183/20, p. 405–418.

BORDET, P. (1961) Recherches géologiques dans l' Himalaya du Népal, région du Makulu. *Edit. Cent. Nat. Rech. Sci.*, Paris, 275p.

CURRAY, J. R. (1964) Transgressions and regressions. *Papers in marine geology*, Shepard Commemorative volume (R. L. MILLER ed.), p. 175–203, New York.

DAHLKAMP, F. J. (1978) Classification of uranium deposits. *Mineral Deposita*, vol. 13, p. 83–104.

GANSSER, A. (1964) *Geology of the Himalayas*. John Wiley & Sons, London, 289p.

GLENNIE, K. W. and ZIEGLER, M. A. (1964) The Siwalik Formation in Nepal. *Int. Geol. Congr.*, 22nd Session, New Delhi, p. 82–95.

JOHNSON, G. C. and VONDRA, C. F. (1972) Siwalik sediments in a portion of the Punjab Reentrant: the sequence at Haritalyangar, District Bilaspur, H. P. *Himalayan Geology*, vol. 2, p. 120–144.

LE FORT, P. (1975) Himalayas: The collided range. Present knowledge of the continental arc. *Am. Jour. Sci.*, vol. 275-A, p. 1–44.

MEDLICOTT, H. B. (1864) On the geological structure and relations of the southern portion of the Himalayan ranges between the rivers Ganges and the Ravee. *Mem. Geol. Surv. India*, vol. 3, p. 1–212.

MISRA, R. C. and VALDIYA, K. S. (1961) Petrology and sedimentation of the Siwaliks of the Tanakpur Area, District Nainital, U. P. *Indian Mineralogist*, vol. 2, p. 7–35.

MOGHAL, M. Y. (1974) Uranium in Siwalik Sandstones, Sulaiman Range, Pakistan. *Vienna, Internat. Atomic Energy Agency*, SM-183/41, p. 383–403.

PARKASH, B., BAJPAI, I. P. and SAXENA, H. P. (1974) Sedimentary structures and palaeocurrents of the Siwaliks exposed between the Yamuna and Gola Rivers, U. P., India. *Geol. Mag.*, vol. 111, p. 1–14.

PILGRIM, G. E. (1919) Suggestions concerning the drainage of northern India. *J. As. Soc. Bengal*, vol. 15, p. 81–99.

READING, H. G. (1978) *Sedimentary Environments and Facies*. Blackwell Scientific Publications, Oxford, 557p.

REINECK, H. -E. and SINGH, I. B. (1975) *Depositional Sedimentary Environments*. Springer-Verlag, Berlin, 439p.

西部ネパール，シワリーク層の堆積作用とウラン探査

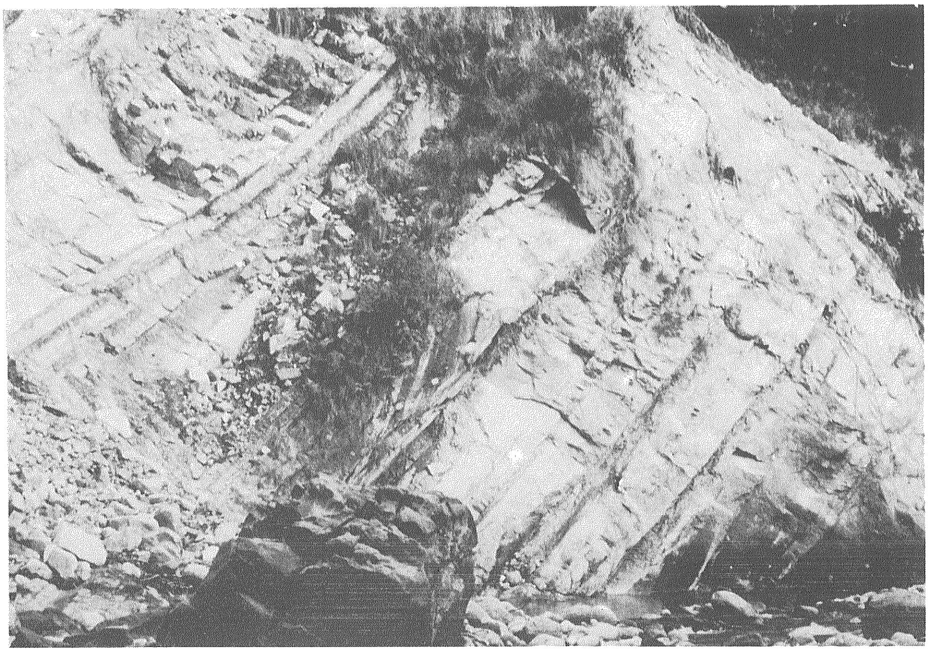
中　嶋　輝　允

要　旨

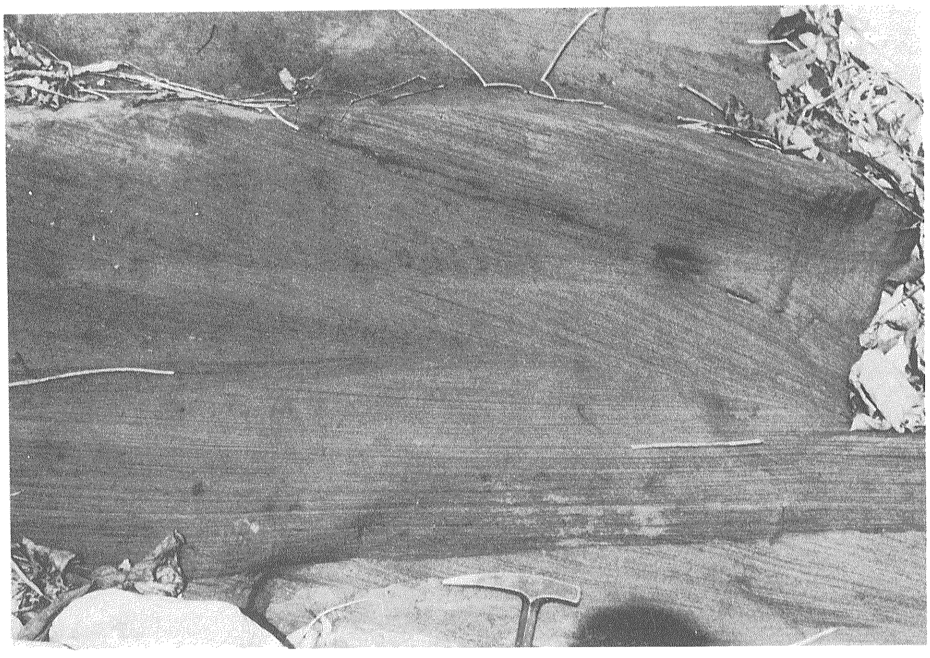
ネパール南部の Main Boundary Thrust の南に沿って分布するシワリーク層(中新世-更新世)は，礫岩，砂岩，泥岩及び亜炭からなる．下部及び中部シワリーク層には，岩相や堆積構造の周期的な繰返しが観察される．周期を示すユニットには，いろいろあるが，もっとも一般的なものは，下から上に，砂岩-泥岩-亜炭の順に重なる．砂岩層は，一般に，よく成層し，しばしば斜層理を示す．これに対して，泥岩層は塊状で，時に，その中に lenticular bedding がみられる．ユニットの中では，各岩相の境は漸移的であるが，ユニットとユニットの境は不連続的，すなわち侵食面であることが多い．周期的な堆積の仕方や堆積構造，含有化石などから，シワリーク層は淡水性の沿岸堆積物であると考えられる．

調査地域の中部及び上部シワリーク層の礫岩には，片麻岩や花崗岩のようなハイヒマラヤの岩石が含まれていない．このような礫岩の組成と古流系に関するデータは，シワリーク層砕屑物の供給源が，主に Main Boundary Thrust のすぐ北側のレッサーヒマラヤにあったことを示している．ネパール・シワリーク層の砂岩層には，パキスタン・シワリーク層と同様のウラン鉱の産出が期待されるが，ネパールのレッサーヒマラヤには，ウランの供給源となりうる花崗岩類の分布が狭いので，ウラン鉱の産出する可能性は一般に少ない．一方，ハイヒマラヤには花崗岩類が広く分布していて，ネパールの三大河川は，その中を通ってシワリーク堆積盆へと砕屑物を供給してきた．したがって，ウラン探査は，これらの川がシワリーク堆積盆へ流入する地域に，的を絞った方がより効果的と考えられる．

(受付：1982年5月10日；受理：1982年8月2日)

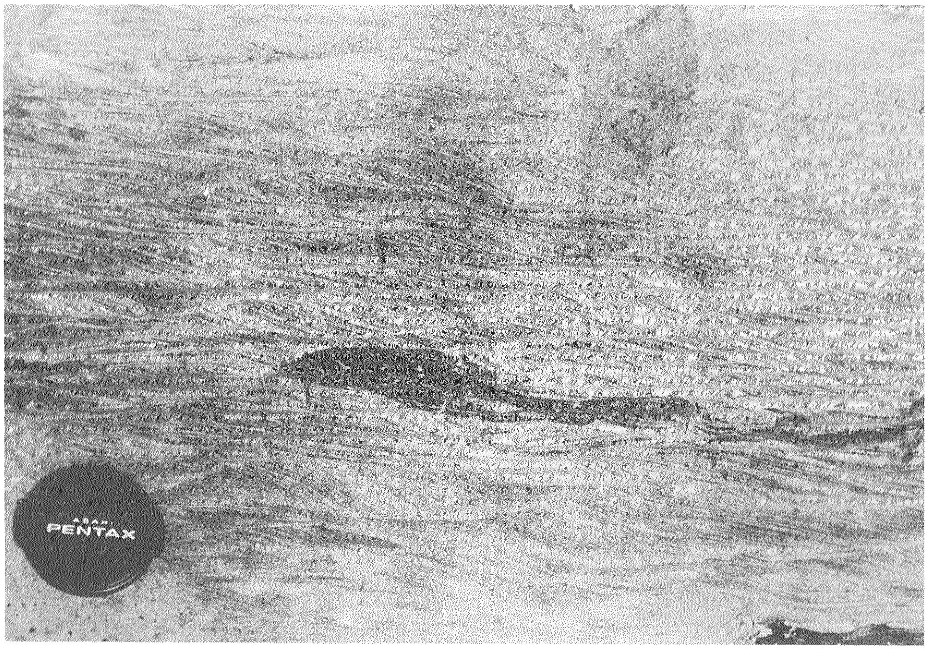


a. Alternation of sandstones (light color part) and mudstones (grey part)with thin intercalation of lignites (grey part). The Middle Siwaliks in the Kusum Khola.



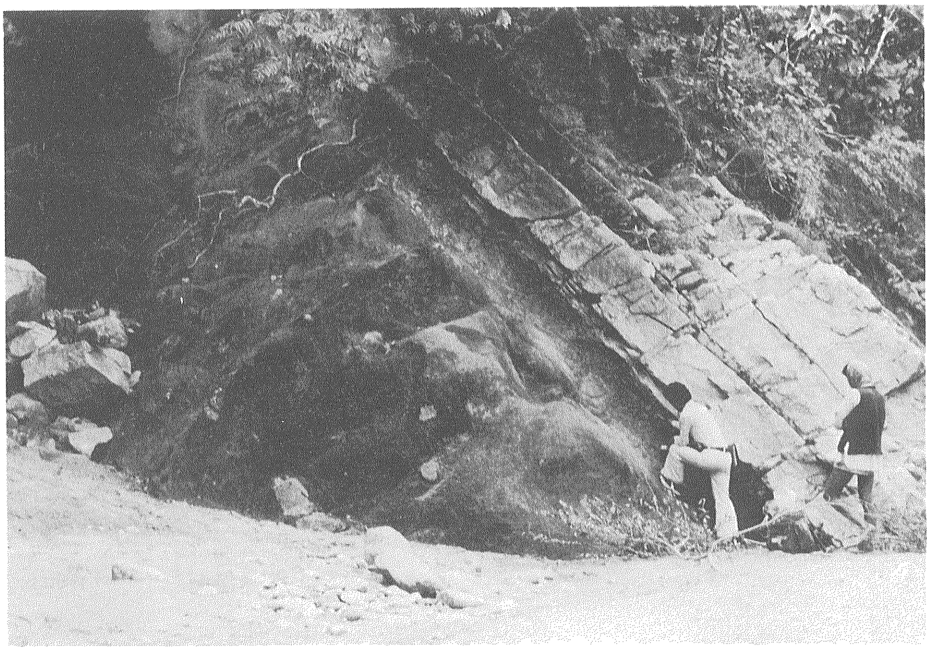
b. Cross-bedded sandstones of the Middle Siwaliks in the Siling Khola.

a. Cross-bedding (left) and current ripple lamination (right) of the Middle Siwalik sandstone in the Kusum Khola.

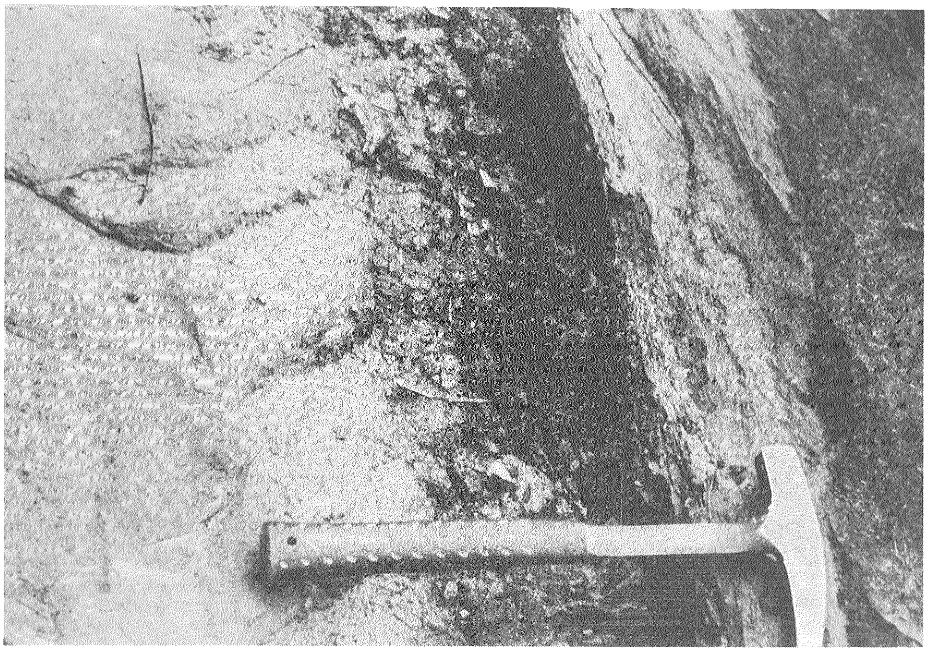


b. Climbing-ripple lamination of the Middle Siwalik sandstone in the Kusum Khola.

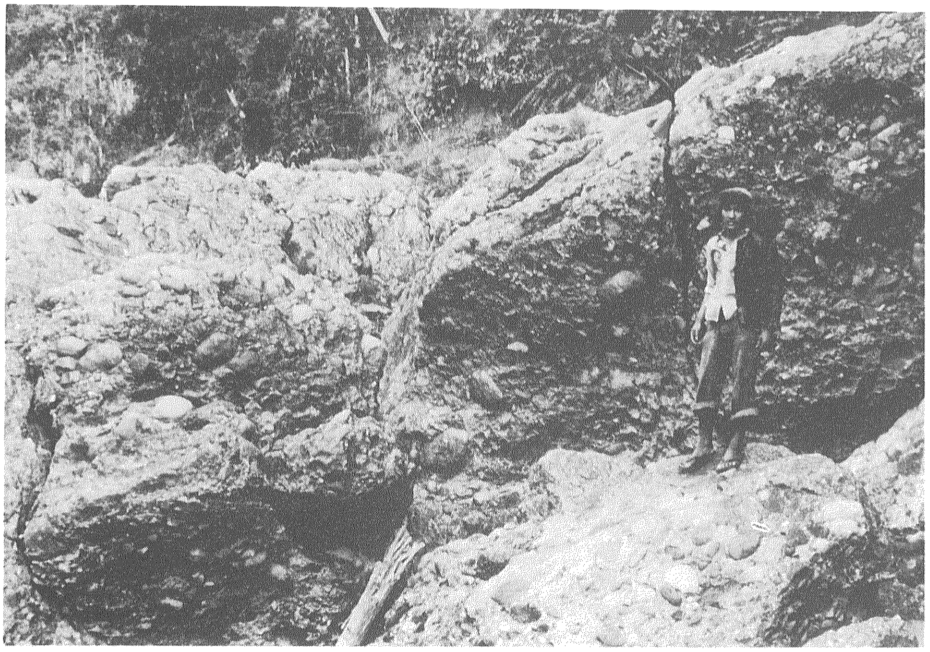
a. Calcareous pellets in the mudstone. The Middle Siwaliks in the Kusum Khola.



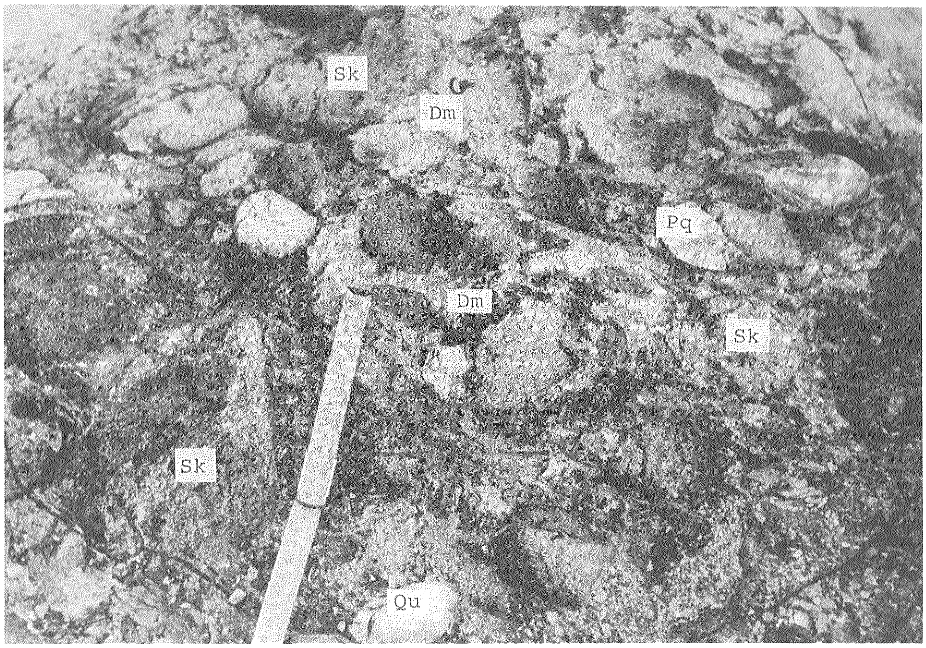
b. Bedded sandstones (right) and a massive mudstone (left) with overlying lignites. The Middle Siwaliks in the Kusum Khola.



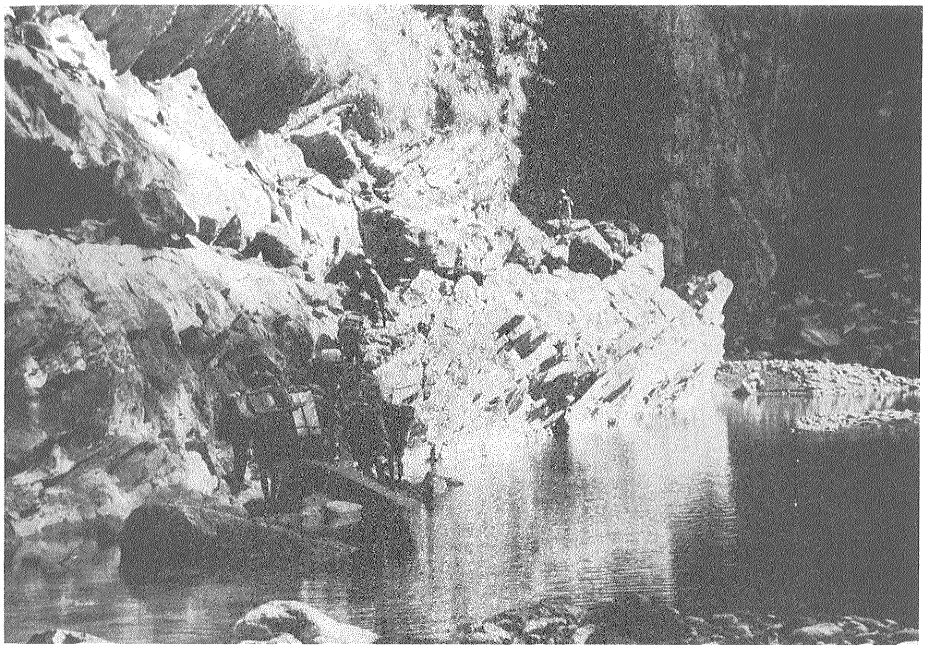
a. Lignite layer overlying the mudstone of the Middle Siwaliks in the Sit Khola. Note the sharp boundary of the lignite with the overlying sandstone (right).



b. Conglomerate of the Upper Siwaliks in the Sit Khola.



a. Conglomerate of the Upper Siwaliks in a distributary of the Sit Khola. SK: Lower Siwalik sandstone, Dm: grey dolomite, Qu: white quartzite, Pq: purplish calcareous quartzite.



b. Bedded sandstones of the Middle Siwaliks distributed along the Kusum Khola.