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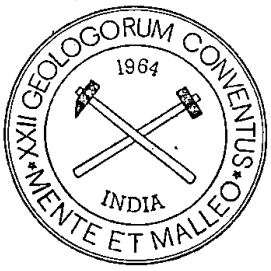

PART XV

PROCEEDINGS OF SECTION 15

SEDIMENTARY GEOLOGY AND SEDIMENTATION

EDITORS : S. M. MATHUR AND V. V. SASTRI

NEW DELHI
1964

SECTION XV
SEDIMENTARY GEOLOGY AND SEDIMENTATION

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THE SIWALIK FORMATION IN NEPAL

K. W. GLENNIE AND M. A. ZIEGLER
NETHERLANDS

ABSTRACT

The Siwalik formation is composed of fluviatile sediments derived from the rising Himalayas and laid down in giant alluvial fans. The grain size of the sediments ranges from a clay fraction to boulders. In recent publications the formation has been subdivided into three on the basis of lithology, but was given a time implication. It was found impossible to apply this three-fold subdivision over the whole country, so a simpler two-fold lithological subdivision is tentatively proposed :

Siwalik Formation { Conglomerate Facies / "Sandstone" Facies

The mode of deposition of fluviatile sediments in giant alluvial fans which interfinger laterally, and in which grain size distribution is dependent upon the rate of flow of the river, is one factor which makes correlation difficult. Another is the formation of tectonic sedimentary traps. A newly uplifted Siwalik range formed a barrier to the southward flow of rivers. The resulting drop in river velocity behind this barrier caused the coarser fractions to be deposited and only the finer sediments to be carried beyond the barrier. Part of the Conglomerate Facies is thought to have been deposited in such sedimentary traps.

INTRODUCTION

During the winter of 1962–1963, the authors carried out a geological reconnaissance in the Siwalik Hills of Nepal in order to study the Upper Tertiary fresh-water Siwalik formation.

In recent literature (Hagen, 1959, and others) the Siwaliks have usually been subdivided into three, roughly as follows :

Upper Siwalik : Conglomerate Facies with minor sandstone and red shale

Middle Siwalik : Sandstone-siltstone Facies with minor conglomerate and red shale

Lower Siwalik : Siltstone-red shale Facies with minor sandstone and pseudo-conglomerate.

A general coarsening of the formation upwards is apparent.

An age inference is implied by this subdivision. Where fossils are present, a time-rock subdivision of the Siwaliks may be correct for a limited area. The authors intend to show that, because of the manner in which the Siwalik formation was deposited, a regional use of this three-fold subdivision with its time implication is neither warranted nor necessarily correct.

Mammalian teeth and bones show that the formation ranges in age from about Middle Miocene to early Pleistocene. Plant fragments and sporomorphs confirm this general age. Rare molluscs and microfauna indicate a fresh-water environment.

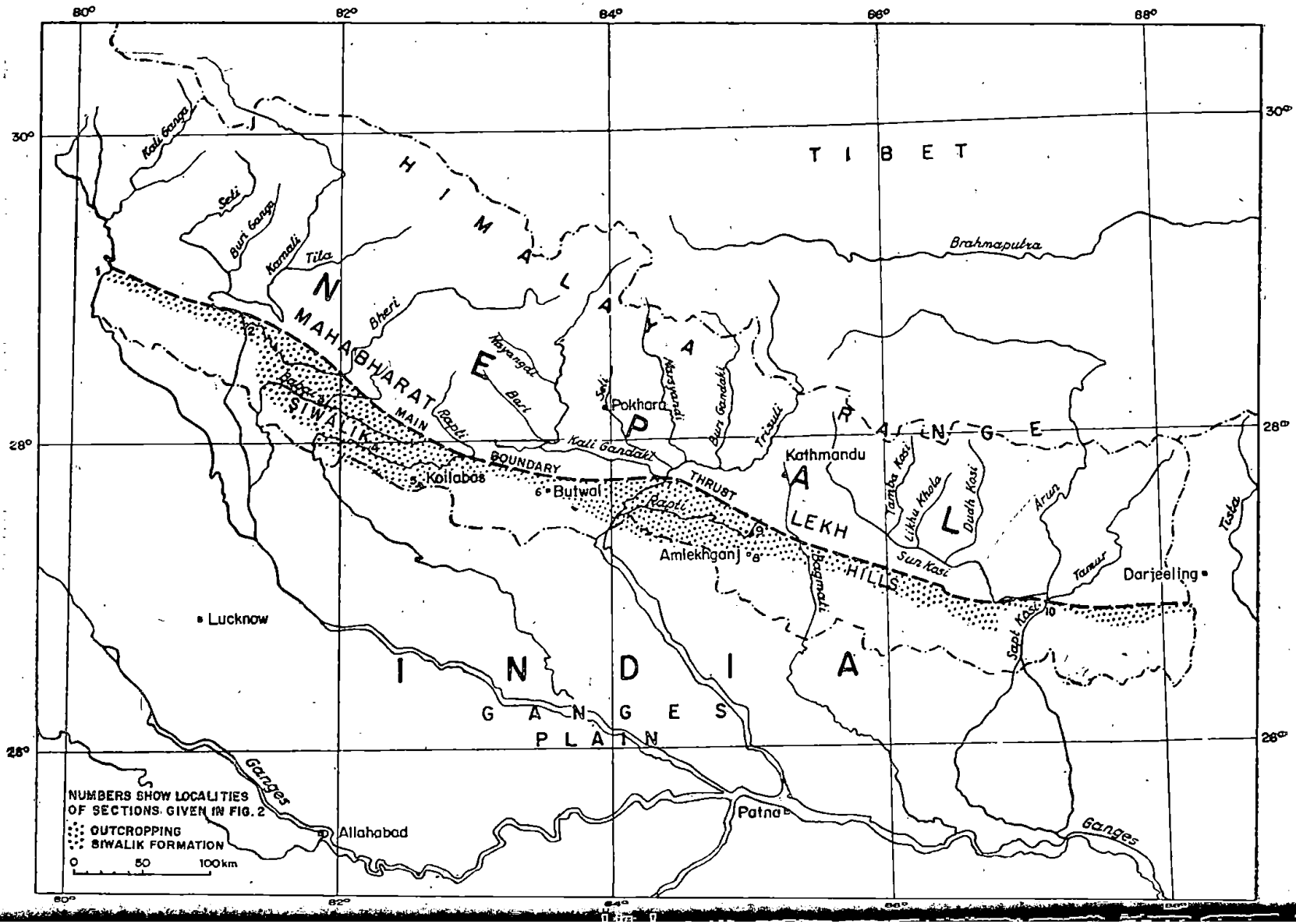
OBSERVATION

The Siwaliks have been compared with the Molasse sediments of the Alps (Swami Nath, 1961) and, in fact, they have been formed as a similar denudation product of the rising Himalayas. In Nepal, the Siwaliks form a highly folded and faulted zone of sediments between the alluvium of the Ganges Plain to the south and the pre-Tertiary low-grade metamorphic rocks of the Mahabharat Lekh to the north. These latter rocks are in fault contact with the Siwaliks along what is known as the Main Boundary Thrust.

The structure of the Siwalik Hills is essentially one of highly faulted anticlines and synclines in which the crest line and southern flank of the anticlines are faulted and downthrown to the south. The northern flank of the synclines is often faulted and overturned.

During the reconnaissance the full width of the exposed Siwaliks was crossed seven times between the Kali Ganga at the western border of Nepal and the Sapt Kosi about 100 kilometres from the country's eastern border (Fig. 1). Ten sections were measured through the exposed Siwaliks. The sections showed a similarity in the type of sediment of which each was composed but a detailed comparison between adjacent areas was not feasible. The choice of a dividing line between the Lower and Middle Siwaliks was always found to be arbitrary and it was impossible to correlate from one section to another on purely lithological grounds. The Conglomerate Facies could always be separated from the non-Conglomerate Facies below (Fig. 2). For these reasons, the authors have abandoned the three-fold subdivision of the Siwaliks. Instead, a simpler two-fold lithological subdivision is tentatively proposed :

Siwalik Formation { Conglomerate Facies
"Sandstone" Facies


80°
82°
84°
86°
88°
30°
28°
TIBET
HIMALAYA
NEPAL
INDIA
GANGES PLAIN
MAHABHARAT RANGE
MAIN BOUNDARY THRUST
SIWALIK
LESSER HIMALAYA
Kali Ganga
Seti
Buri Ganga
Kamali
Tila
Bheri
Rapti
Mayangdi
Buri
Seti
Pokhara
Marsyandi
Kali Gandaki
Burn Gandaki
Trisuli
Brahmaputra
Kathmandu
Tamba Kosi
Likhu Khola
Dudh Kosi
Arun
Tista
Sun Kosi
Tamur
Darjeeling
Sapt Kosi
Bagmati
Amlekhganj
Kailabas
Butwal
Lucknow
Allahabad
Patna
Ganges
NUMBERS SHOW LOCALITIES OF SECTIONS GIVEN IN FIG. 2
OUTCROPPING SIWALIK FORMATION
0 50 100km

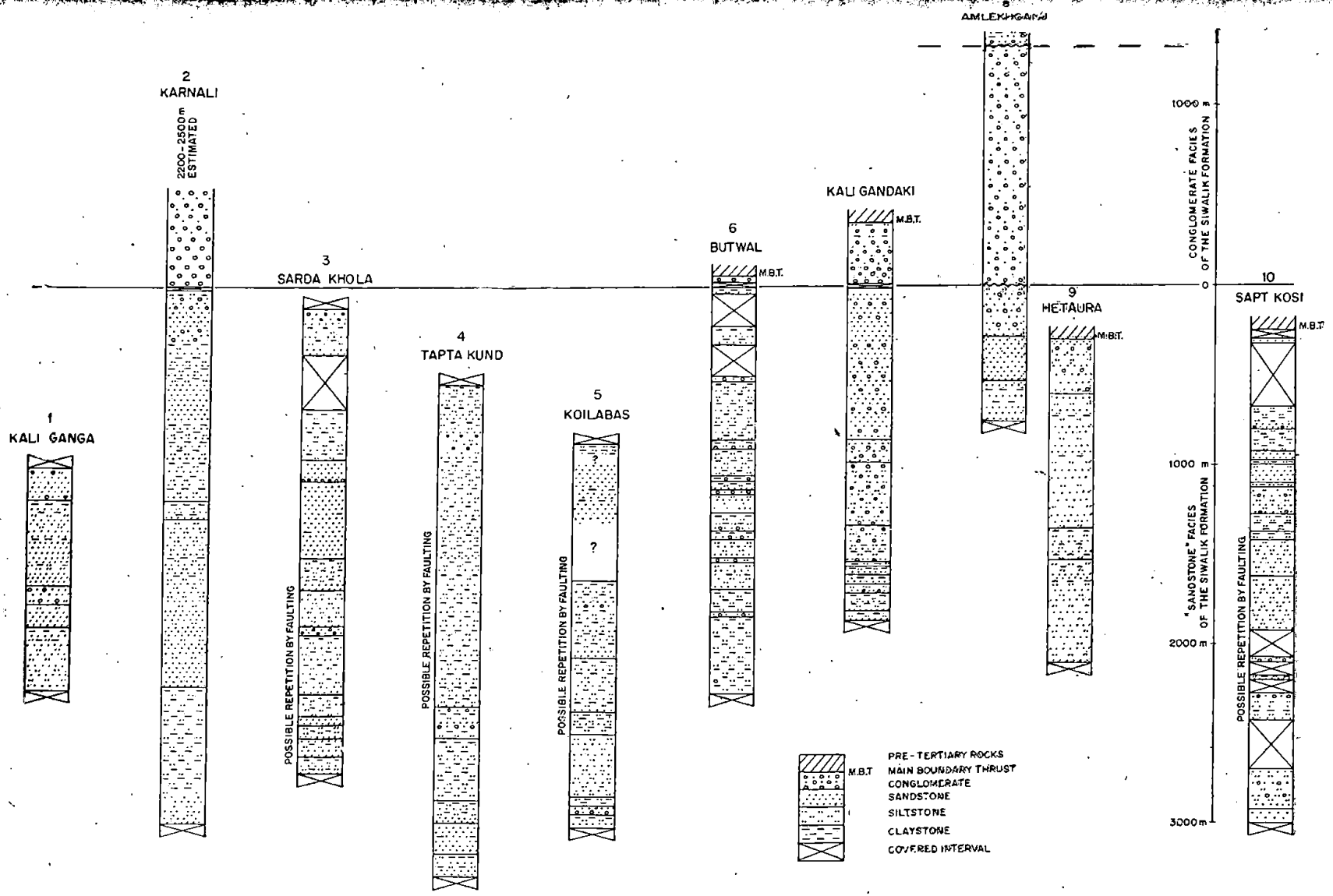


Fig. 2. Suggested correlation of Siwalik sections in Nepal

A further complication results from the complete absence of the Conglomerate Facies in many of the sections. It is not known whether, in the areas where it is absent, the conglomerates are buried tectonically or were never deposited. This problem of the local absence of the conglomerates will be referred to again.

"Sandstone" Facies

Maximum thickness : Measured 2,900 metres
Estimated 3,500 metres.

The "Sandstone" Facies of the Siwalik formation is composed of rhythmic fluviatile cycles ranging in thickness from about 1 to 40 metres. Starting with sandstone—often with thin conglomerates or a few pebble stringers at the base or in the lower portion of the cycle—the sequence fines upward and ends usually with siltstone or claystone. The conglomerates consist mostly of sandstone pebbles and flakes of claystone, although horizons containing pebbles of quartz or quartzite are sometimes found. "Boulders" of claystone up to 50 cm. long have been seen. Slight scouring or channelling of the underlying beds is common. The sandstones and siltstones are often current-bedded; the direction of flow being, in general, towards the south. At the top of the cycle, silty claystone or claystone is usually present. This upper member is often finely laminated, has a dark-grey colour and preserves plant leaves and sometimes shell fragments of fresh-water fossils (e.g. lamellibranchs and gastropods). Burrows are frequently seen in the upper part of a cycle. In the transition zones between the sandstone, silty sandstone and silt, there is often a horizon of irregular cementation which gives a nodular appearance on weathering.

Nearly all the sediments of the Siwaliks appear to be cemented to a greater or lesser extent by calcium carbonate. In the finest grained sediments, the carbonate content is often sufficient for them to be called calcareous claystones or even marls. Calcareous siltstones and marls are referred to throughout as siltstones and claystones.

In general, low in a section, a greater preponderance of fluviatile cycles starts at the base with a fine or very fine sandstone. High in the section, if not actually starting with a band containing metamorphic or claystone pebbles, then the sand at the base of a cycle is likely to be medium-grained. This is fairly well seen on the Karnali River, but the increase in grain size with a decrease in age is by no means regular (Fig. 2).

North of Amlekhganj graded cycles are much less common than is the case farther to the west. The sandstone units tend to be massive,

there is less grain sorting, and convolute bedding occurs frequently. Cementation is, on the whole, poor, although some concretionary horizons can be found. The fresh unweathered colour is grey.

On the other hand, on the Kali Gandaki near its confluence with the Trisuli, north of Butwal and on the Karnali River, many more sedimentary cycles are apparent. Along the Kali Gandaki big cycles between 15 and 40 metres thick have been observed, but smaller cycles of 2 or 3 metres are also present. Cementation of the sandstone is better than that north of Amlekhganj. Predominant colours are grey and green-grey, the latter possibly occurring as a result of a high chlorite content. Quartz and mica (both biotite and sericite) are normally present in large quantities. Concretionary horizons and pebble layers are common. The cycles are usually fully developed and range from coarse sandstone to siltstone and claystone.

North of Butwal there are fewer coarse sands; the grain size varies from fine and very fine sand to a clay fraction. The cycles are smaller, rarely reaching a thickness of 10 metres. Especially near the base and the upper half of the section red oxidized silt and clay horizons are common, a hint, perhaps, that the uppermost portion of these cycles was exposed to post-depositional oxidation.

Conglomerate Facies

Maximum Thickness : Measured 1,300 metres
Estimated 2,500 metres.

This facies of the Siwalik formation has been seen north of Amlekhganj, on the Kali Gandaki just south of the Main Boundary Thrust and on the Karnali and Bheri Rivers, where it reaches a thickness of over 2,000 metres. The presence of conglomerates has also been noted in the valleys of the western Rapti and the Babai, but thicknesses are not known. The conglomerates seem to occur mostly in synclinal locations in the northern half of the Siwalik Hills.

The facies consists of very coarse, massive conglomerates with sandy lenses and layers. The grain size ranges from coarse sand to boulders; the average diameter is 3–15 cm. with a common maximum of 20–25 cm. North of Amlekhganj boulders up to 50 cm. diameter were observed. Most of the pebbles and boulders are of well-rounded quartz and quartzite. Mica is nearly always present. It is characteristic that the coarse components touch each other. In contrast, in conglomerates within the "Sandstone" Facies and also in the Sub-Recent Dun conglomerates, the sandy matrix predominates giving the appearance of pebbles and boulders, 'floating' in sand. Here and there red-coloured claystone lenses and found. Although rich mammalian fauna from the Conglomerate Facies has been described

from elsewhere indicating a late Pliocene to early Pleistocene age for the sediments, none was found during the reconnaissance in Nepal.

INTERPRETATION

The Siwaliks are assumed to have been derived as a denudation product of the rising Himalayan chains in the north. They were deposited in a peri-orogenic depression lying between the orogenic belt and the outcropping Indian Shield to the south.

Climatic conditions during the latter half of the Tertiary are thought to have been rather similar to those existing in the Himalayas today. Torrential monsoonal rainstorms caused rapid erosion of the rising mountains. Rivers, swollen by monsoon rains, were capable of transporting enormous volumes of sediment—both coarse and fine—which were deposited over the early Ganges Plain. During the dry season, river levels dropped and the volume and grain size of the sediment carried by the rivers became smaller.

The mountain ranges which were uplifted and denuded are thought to have been composed of the Cambro—Pre-Cambrian Vindhyan and Aravalli formations which had been overlain by Lower Palaeozoic marine rocks and the Upper Palaeozoic to Lower Mesozoic continental Gondwanaland Series. Marine equivalents of the Gondwanaland Series and younger Mesozoic and early Tertiary marine sediments may also have been subjected to this erosion in places where Tethys had encroached over the Shield. A reworked early Tertiary *Discocyclina* fragment found in the "Sandstone" Facies north of Amlekhganj lends strength to this view.

Palaeozoic and Lower Mesozoic limestones are probably the source of the lime-rich rocks which are common in some areas of the Siwalik formation. Although the individual grains making up a sandstone may consist for the most part of quartz, the calcium carbonate appears to have cemented the grains by coming out of solution. A similar phenomenon can be seen with some modern sediments where sometimes a river gravel, deposited during the previous monsoon, is locally found to have been consolidated by a calcareous cement.

The sandstone pebbles and claystone flakes forming the pseudo-conglomerates of the "Sandstone" Facies are possibly derived from Older Siwaliks which were deposited farther to the north. Erosion of these beds as a result of uplift or the torrential streams of a later monsoon caused these pebbles and flakes to be redeposited to the south.

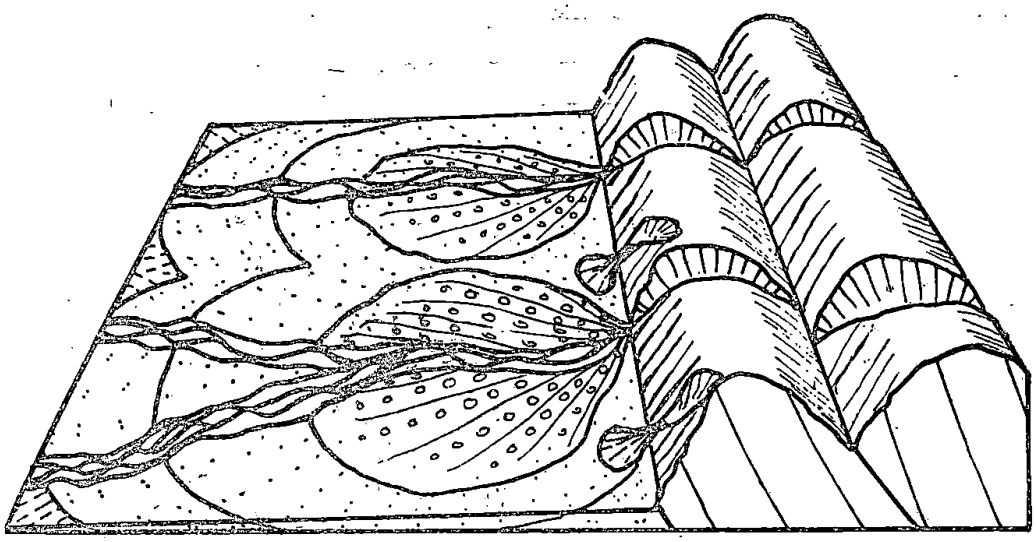


Fig. 3. Perspective sketch illustrating the grain size distribution in alluvial fans

The perspective sketch Fig. 3 depicts the style in which major rivers deposit gigantic alluvial fans over a flat plain. The grain size within the fan diminishes according to the rate of transport and therefore, not only in a N–S direction, but also to the east and west. It is assumed that the Siwaliks were deposited in a series of such fans as the early Himalayan rivers left the confining valleys of the rising hills and spread over the plains. Areas of quieter-water sedimentation—temporary monsoonal mud flats or backswamps—might be present in the inter-fan areas. Similar alluvial fans are being deposited over the Ganges Plain today (Geddes, 1960).

As suggested by Krishnan (1960, p. 36) and others, many of the major rivers of the Himalayas had their origins in the early stages of the emergence of the mountain range as consequent streams. A study of the river systems of Nepal suggests that the later uplift of the Mahabharat Lekh produced a series of barriers in front of these southward flowing rivers which forced them to develop subsequently parallel to the strike.

By capturing several other southward flowing rivers, a river system was formed whose combined waters could cut outlet gorges through these recently formed barriers (e.g. Seti, Buri Ganga, Karnali and Tila, Bari, Mayangdi and Kali Gandaki; Seti, Marsyandi, Buri Gandaki and Trisuli; Sun Kosi, Tamba Kosi, Likhu Khola and Dudh Kosi; Arun and Tamur) (Fig. 1). This would imply the erosion of those parts of the Siwalik formation which were deposited over the Mahabharat Lekh before uplift, and a new distribution of alluvial fans south of the barrier.

Later, folding and uplift of the Siwalik Hills caused a further series of river captures of a similar nature. The Bheri was captured by the Karnali, the Trisuli joined the Kali Gandaki and the Sun Kosi joined the

Arun and Tamur to become the Sapt Kosi. The two Raptis and the Babai developed as subsequent streams flowing parallel to the strike before turning south to the Ganges Plain.

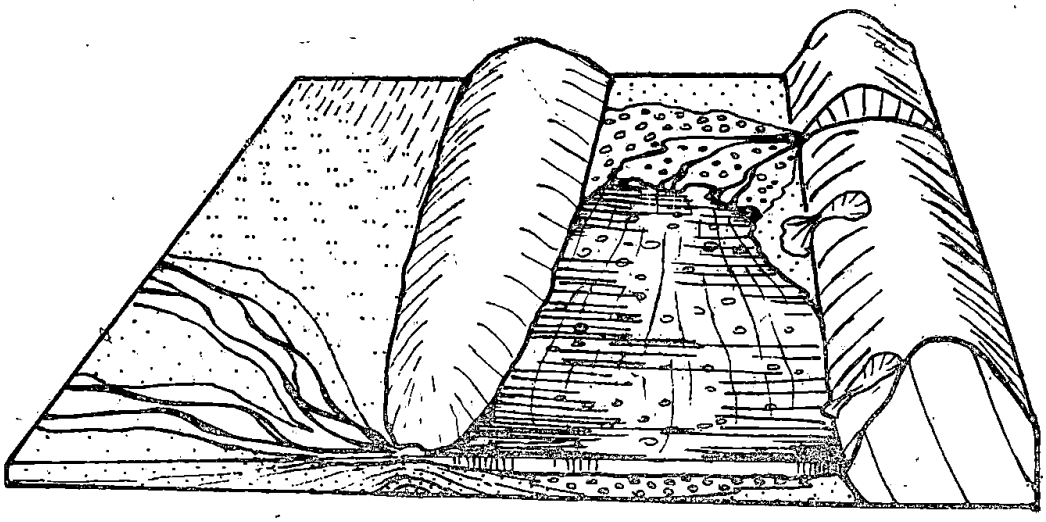


Fig. 4. The Control of grain size distribution by tectonic sedimentary Traps. A sedimentary trap formed behind a recently raised tectonic barrier causes a marked difference in the grain sizes deposited on either side of the barrier

These tectonic barriers to river flow also caused the formation of sedimentary traps. The development of long subsequent streams means a lower rate of flow and rapid deposition of the coarser sedimentary fractions, Only the finer sediments are carried beyond the new barrier. This marked sorting in the distribution of grain sizes is illustrated in Fig. 4. It is thought that the Conglomerate Facies found in the valleys of the Bheri, the Babai and the two Raptis result, at least in part, from tectonic sedimentary traps of this type. The absence of a Conglomerate Facies in most of the southern parts of the Siwalik Hills lends force to this argument. It also suggests the possibility of finding non-conglomeratic sandstones and siltstones in the southern Siwalik Hills which are late Pliocene or early Pleistocene in age. In other words both the Conglomerate Facies and "Sandstone" Facies are formational units. The facies are not bounded by time lines.

It is interesting to note that Kathmandu Valley was once the site of a lake before the Bagmati cut the gorge which drains it, and that the Pokhara Valley was the site of fluviatile conglomerate deposition similar in type to the Conglomerate Facies of the Siwalik formation. Both valleys lie to the north of the Mahabharat Lekh and acted as sedimentary traps.

CONCLUSIONS

The history of Siwalik sedimentation implied in earlier paragraphs may be summarized as follows:

1. South flowing rivers deposited early Siwalik sediments over the area now occupied by the Mahabharat Lekh and Siwalik Hills as the Himalayas began to emerge.
2. Uplift of the Mahabharat Lekh resulted in the formation of river systems by combining individual consequent rivers. This caused a change in the number of alluvial fans as the new river systems deposited fewer but larger fans. Early Siwalik sediments previously deposited over the Mahabharat Lekh were eroded by a new system of consequent streams which deposited their own alluvial fans over the plain to the south.
3. With uplift and folding of the Siwalik Hills, there was a similar series of river captures and redistribution of alluvial fans. The Conglomerate Facies, now found preserved in the Siwalik Hills, had earlier counterparts which were deposited over the Mahabharat Lekh in alluvial fans and tectonic sedimentary traps but have since been eroded.
4. The deposition of the Ganges Alluvium in large alluvial fans is the most recent stage in this process of fluviatile sedimentation.

This progressive sequence of uplift, erosion and sedimentation gave rise to a marked southward migration of the coarser sediments with a decrease in age. The Conglomerate Facies now cropping out in Nepal was deposited more or less contemporaneously with the folding of the Siwalik Hills. This is depicted in a series of schematic cross-sections in Fig. 5.

The uneven way in which most sections exhibit an increase in grain size with a decrease in age may be accounted for by the following factors:

(a) The formation of temporary tectonic sedimentary traps.

(b) The east-west redistribution and reduction in number of alluvial fans resulting from the formation of tectonic barriers to river flow and the collection of individual rivers into river systems.

(c) The development of new consequent rivers on the rising Mahabharat Lekh.

(d) Lateral shifts in the loci of fan development as a result of the breaching of natural levees during flood.

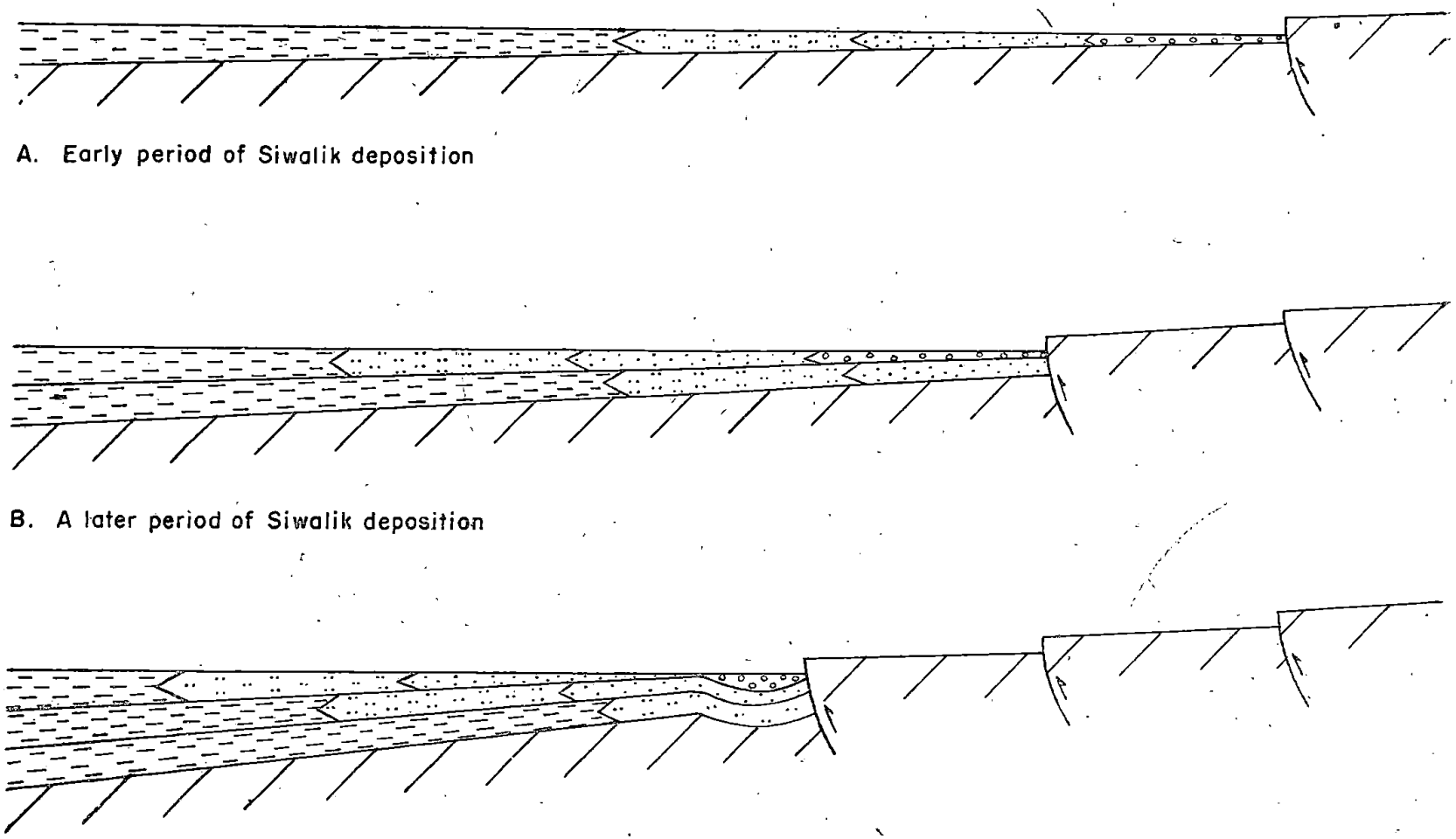


Fig. 5. Schematic cross-sections illustrating the southward migration of the coarser sediments of the Siwalik formation with a decrease in age as a result of the progressive uplift of the Himalayas

An age significance should not be attached to the separation of the Siwalik formation into a Conglomerate Facies and a "Sandstone" Facies. Although the Conglomerate Facies is younger than the "Sandstone" Facies where it directly overlies the latter, in general, the mode of deposition and distribution of fluviatile syn-orogenic sediments defy a regional comparison of lithology and age.

ACKNOWLEDGEMENTS

The authors wish to thank His Majesty's Government of Nepal for permission to undertake geological work in the Siwalik Hills and the directors of the Royal Dutch/Shell Group for permission to publish the results of the survey. Thanks are also extended to Dr. D. N. Rimal of the Nepal Bureau of Mines, who combined his official duties of liaison officer with those of geological colleague.

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(*Manuscript received on December 21, 1963*)

CONTRIBUTIONS TO DISCUSSIONS

Biswas, B., INDIA : What is the nature of the contact of the Siwalik Group with the underlying rocks in Nepal?

Reply : The base of the Siwaliks was not seen in Eastern Nepal. In Western Nepal near Jarbutta, highly cleaved Eocene calcareous shales with limestone lenses overlay older quartzites unconformably and were overlain with apparant conformity by sandstones. It is also not clear whether these sandstones should be correlated with the Siwaliks or an eastern equivalent of the Murrees. They were truncated by a high angle thrust about 300 metres above their base.

Ghosh, A. K., INDIA : From a study of the Siwaliks from Jammu and Kashmir, Punjab, U.P. and Nepal it has been possible to differentiate the Lower and Middle Siwaliks on the basis of polospores. While the Middle Siwaliks sheltered a dominant coniferous vegetation, derived from the coniferous flora established in the Himalayas, the Lower Siwaliks, on the other hand, were dominated by angiospermous vegetation. Recent studies by M. Mathur (paper contributed to the Palaeobotanical Society) has supported the differentiation of Lower and Middle Siwaliks on polospores. Hence it is to be doubted if merging of Lower and Middle Siwaliks would be justified.

Reply : I agree that further subdivision of the Siwaliks is possible by using palynology and palaeobotany. However, this depends upon laboratory work which is not available to the geologist who is still in the field. He must map according to lithological characteristics. As our columnar sections show, we could only distinguish two major subdivisions which applied to the whole of Nepal.

Raju, A. T. R., INDIA : Does it really serve any stratigraphic purpose if Siwaliks are to be mapped only in two facies like a Conglomerate Facies and "Sandstone" Facies ?

Reply : A division of the Siwaliks based on a facies interpretation leads to far better understanding of the meaning behind further subdivisions. Field work showed up two easily recognisable facies which could be followed throughout Nepal and a map could be constructed on this basis. Only with spore and fossil determinations and heavy mineral analyses, can further subdivisions be made and these are beyond the scope of the geologist in the field.

Pradhan, S. R., INDIA : (1) Can we not distinguish the Lower and Middle Siwaliks on the basis of structural disturbances ? (2) Can we use purple claystone as marker horizon for differentiating the Siwaliks ?

Reply : (1) I do not believe that there is any real difference in the degree of structural disturbance between the Lower and Middle Siwaliks except in isolated instances. In the area of Siwaliks presently exposed, both were subjected to the same fold movement and so both should suffer a similar degree of disturbances. From a structural viewpoint, the fact that the Lower Siwaliks underlie the Middle Siwaliks might imply that they suffer from a greater degree of dislocation in the core of a tight anticline, but this has no age significance since, theoretically, the reverse would be the case in a tight syncline. (2) Correlation by means of purple claystone marker horizon might well be possible within one alluvial fan. However, I suspect that this colouration is due to some form of oxidation under subaerial conditions, and that these conditions need not apply in the adjoining

alluvial fan. Correlation over distances equivalent to the east-west length of Nepal by this means is most unlikely since the annual precipitation of rain, and therefore the susceptibility to oxidation of the sediments, is also likely to differ.

Black, C. C., U.S.A. : In the northern Punjab, separation of the Lower, Middle and Upper Siwaliks has been made on the basis of heavy mineral studies. Has heavy mineral analysis been made on the Nepal Siwaliks ?

Reply : Not by the authors; but heavy mineral studies have been carried out by the Indian Oil and Natural Gas Commission (see Sahai and Mathur, Stratigraphy of the Siwalik Group. p. 11).

Dehadrai, P. V., INDIA : Palaeocurrent studies done by the O.N.G.C. do show E–W directional distribution of sediments in parts of the Siwaliks of Punjab.

Reply : I am very pleased to receive confirmation of what, up to now, I had only considered as a theoretical possibility.

Singh, Ashok, INDIA : In your Fig. No. 1 you have shown many rivers. Are these rivers having any present evidence or indication of old river courses ?

Reply : Within the Siwalik Ranges, the Conglomerate Facies often occupies a synclinal position unconformable over the older Siwalik sandstones and siltstones. I suggest that many of these synclinal conglomerates were deposited in a river valley formed by the folding and uplift of a parallel mountain or hill barrier to the south forming tectonic sediment trap. Similarly, the conglomerates of the Pokhara Valley, and sand and silts of the Kathmandu Valley point to a damming back of an older river system by the rising Mahabharat Lekh.

Older high level terraces covered with gravel have also been described from the more northerly Himalayan Ranges and are undoubtedly related in many cases to the rivers which now occupy a much lower position within the same valley.

Alfred, Schreiber, WEST GERMANY : Rocks which can be called the Siwaliks are also known from Northeast Afghanistan. The sequence is lithologically fairly similar to, but a little lesser in thickness than, that which has been presented by Mr. Glennie. Based on some micropalaeontological data it ranges possibly from the uppermost Oligocene, probably from the Miocene upto the Quaternary.