Neogene molasse sedimentation in a portion of the Punjab-Himachal Pradesh Tertiary re-entrant, Himalayan foothill belt, India: a vertical profile of Siwalik deposition

Gary Dean Johnson

Iowa State University

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NEOGENE MOLASSE SEDIMENTATION IN A PORTION OF THE PUNJAB-HIMACHAL PRADESH TERTIARY RE-ENTRANT, HIMALAYAN FOOTHILL BELT, INDIA: A VERTICAL PROFILE OF SIWALIK DEPOSITION.

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A vertical profile of Siwalik deposition

by

Gary Dean Johnson

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Geology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

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Dean of Graduate College

Iowa State University
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Gary Dean Johnson

Under the supervision of C. F. Vondra
From the Department of Earth Science
Iowa State University of Science and Technology

Neogene sedimentation in the vicinity of Haritalyangar, Bilaspur Dis-
trict, Himachal Pradesh, India (a portion of the Gumbhar-Sarkaghat fault
block of the paraautochthonous-autochthonous foredeep) is represented by
5000 meters of Late Cenozoic fluvial molasse (the Siwalik "Series") which
reflects the complex denudation of adjacent allochthonous thrust plates
developed within the Himalayan orogen.

The earliest molasse phase, represented by the Nahan Sandstone, is
chiefly a multistoried, multilateral fluvial complex composed primarily of
channel lag and lateral accretion deposits. In the vicinity of Haritalyangar,
H. P., thirteen composite fluvial cycles evidence a greater relative
thickness for the lateral accretion sandbodies than for the associated
floodbasin sediments, suggesting quite rapid aggradation by a loosely
sinuous stream regime in a rapidly subsiding basin analogous to the modern
Indoganetic Plain. Mineralogically, these sediments are poorly sorted,
fine-skewed, and predominantly phyllarenites with polymictic extraforma-
tional lag gravels. The mineralogical composition of framework grains
reflects denudation of a stratigraphically normal metasedimentary terrane
(Main Central Thrust Sheet) yielding high-rank detritus. Sedimentary debris is also present, but decreases considerably upwards in the molasse sequence.

The "Lower Alternations" reflect the development of a distinct meander belt facies distribution as a result of increased sinuosity and decreased basin subsidence. Paleosol development is noted and prolific fossil vertebrate occurrence is noted in some vertical accretion deposits. Mineralogically, the "Lower Alternations" are somewhat more mature, being predominantly poorly sorted, more strongly fine-skewed than the Nahan, and quartzose phyllarenites. A higher grade metamorphic accessory mineral suite (kyanite), in addition to the epidote and staurolite of the Nahan, evidences continued unroofing of the metamorphosed Main Central Thrust Sheet.

The "Upper Alternations" are sedimentologically similar to the "Lower Alternations" except being somewhat more immature. Polymictic extraformational channel lag is again evident, the channel sands being less quartzose than below. Carbonates increase noticeably and a new metamorphic suite is introduced (chlorite-sericite) possibly related to the initial unroofing of the reversely metamorphosed Chail Thrust Sheet. Granitic and gneissic detritus and plutonic plagioclases having compositions and twin-law relationships similar to the Outer Himalayan intrusions (e.g. the Chor Massif) support this conclusion.

Pedogenic modification of most proximal and distal floodplain deposits of the "Lower Alternations" and "Upper Alternations" is present. Although hydromorphic paleosols are most abundant and are associated with the most fossiliferous horizons, some pedogenic alteration seems to suggest oxisol development. In all cases, pedogenic modification is masked by the primary depositional character of the parent material.
Fossiliferous horizons appear to be generally proximal, poorly drained sites with pedogenically immature parent material. Older, well drained, pedogenically mature horizons appear poorly fossiliferous. The interrelationships of carbon, silica (soluble), modification of sesquioxides by certain drainage characteristics, and re-arrangement of soil structure is useful in developing a model of the fossiliferous, fluventic soils of the "Lower Alterations".
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INTRODUCTION

The Middle Miocene to Lower Pleistocene Siwalik fluvial molasse deposits of the Siwalik Hills of West Pakistan, India, and Nepal record an almost continuous sequence of terrestrial vertebrate evolution from Sarmation to Villafranchian and later. As a result, many paleontologic investigations have been carried out with the intent of unraveling this history. This investigation is a direct outgrowth of one such study (The Chandigarh-Yale Project).

The study was initiated at the invitation of Professor Elwyn L. Simons of Yale University in the fall of 1967, with field work being carried out from February - June, 1968 and March - May, 1969 in the Bilaspur District of Himachal Pradesh, India, a locality long known to be rich in Tertiary vertebrate fauna, particularly dryopithecine and early hominoid primates (Figure 1). The classic localities in the vicinity of the village complex of Haritalyangar, Bilaspur District, yielded over 1000 vertebrate specimens including several primates from some 2500 meters of strata during the two seasons of collecting. Unfortunately, the majority of the collection has not as yet been studied. The results of the important primate discoveries have, however, been recently published (Simons and Chopra, 1969a, 1969b; Simons and Ettel, 1970).

Prior published geologic studies have produced only a cursory knowledge of the Siwalik molasse deposits at a few localities. The order of superposition, lithology, and lateral and vertical facies relationships were poorly understood. Therefore, there was little basis for accurate stratigraphic documentation of the prolific fauna collected and for
Figure 1. Index map showing the area of study and illustrating the major tectonic features of South Asia. Base after Butt (1968)
adequate paleoenvironmental interpretations.

Paleontologic investigations have been carried out in exposures of the Siwalik molasse in the Siwalik Hills of Himachal Pradesh, India, and the extensive exposures of the same sequence from south of Rawalpindi, West Pakistan. The studies of the Geological Survey of India (Pilgrim, 1910-1938; Prasad, 1962-1964), the Yale North India Expedition of 1932-1934 and the Yale-Cambridge India Expedition of 1935 (Lewis, 1934-1937; Gregory et al., 1935-1936; Colbert, 1935), and the Paleontological Society of India-Punjab University (Sahni and Khan, 1961-1964) deserve mention for contributing important biostratigraphic data to the Indian Siwalik strata. Important geologic contributions to the problems of the stratigraphy of the Siwalik molasse and the Himalayan foredeep have been made by the Indian Oil and Natural Gas Commission (Babu and Dehadrai, 1958; Dehadrai, 1958; Raju, 1967; Raiverman, 1968; and Sinha, 1970), the former Attock Oil Company (Gill, 1951a, b), the Yale North India Expedition (Krynine, 1937), the Geological Survey of India (Wadia, 1931-1932), Panjab University (Sahni and Khan, 1961-1964; Chaudhri and Chaudhri et al., 1968-1970), and Lucknow University (Misra and Valdiya, 1961). Further reference is made to a summary published during the 22nd International Geological Congress (New Delhi, 1964) for a detailed discussion of the problem of lithologic correlation and nomenclature of the Siwalik strata along the foothill belt (Sahni and Mathur, 1964).

During the first field season of the present study, 2800 meters of stratigraphic section were measured in a vertical stratigraphic traverse from the Gumbhar Fault along the Makhan Khad (see Figure 4, southwestern margin of thrust plate B) to the Sir Khad (see Figure 4) in the vicinity
of the village of Bam. Due to Government of India restrictions on the use of any aerial photography and topographic maps at scales larger than 1:250,000, this entire study was conducted with minimum surveying instrumentation. No aerial photography or topographic maps were used. Stratigraphic traverses were controlled by, and the topographic map of Figure 17, was constructed from data obtained by a theodolite.

The second field season experienced similar research restrictions, but a second 3000 meters of stratigraphic section were measured along the Kunah Khad near the villages of Bahota-Didwin-Mehal. In addition, "non-essential" reconnaissance of outcrops in areas other than in the immediate vicinity of Haritalyangar was held to a minimum at the request of the host organization (Department of Anthropology, Panjab University, Chandigarh).

It might be noted that as of this writing, Government of India restrictions on the use and purchase of large-scale topographic maps (up to 1:48,000) of certain areas has been lifted. This came too late for the present study.
MAJOR TECTONIC ELEMENTS OF THE PUNJAB HIMALAYAS

The Punjab Himalayas consist of a complex of allochthonous and par-autochthonous thrust sheets in close proximity to a complexly folded and faulted foredeep (Figure 2).

In the Inner Himalayas, in the upper reaches of the Beas River, the Main Central or Jutogh Thrust displaces southwards a complex suite of the high grade metamorphics of the Jutogh "Series".* In the Punjab, these strata are composed of interbedded quartzites, schists, phyllites (garnetiferous) and slates with associated amphibolites. Displacement of this sequence, termed the Jutogh Nappe (Pilgrim and West, 1928), but now considered to be a thrust sheet (Gansser, 1964b) is in excess of 100 kilometers from the Sutlej River to the vicinity of the Chor granitic massif in the Simla Himalayas (Berthelsen, 1951). Here the thrust sheet is exposed as a klippe overlying the Chail, Simla, Jaunsar, and Blaini "Series" of the Chail Thrust Sheet.

The Chail Thrust Sheet (originally termed the Chail Nappe, Pilgrim and West, 1928) is displaced southwards by the Shali and Giri thrusts of the Simla Himalayas and can be traced northwestwards towards the Dhauladhar Range near Dharmshala just west of Mandi (the intersection of the Beas River and the Main Boundary Fault) where it becomes undiscernable.

*Throughout this text, Indian lithostratigraphic and chronostratigraphic nomenclature is used. It may be noted that in several instances, this usage does not conform to the guidelines set forth by the International Subcommission on Stratigraphic Terminology. Many chronostratigraphic terms should probably be replaced by lithostratigraphic terms having similar hierarchical position. I have chosen not to modify this terminology at present.
Figure 2. Generalized tectonic map of the Punjab Himalayas, showing interpretation of thrust plate geometry within the foredeep
The thrust sheet is characterized by interbedded quartzites, quartzose schists and phyllites, arkoses, conglomerates and basic eruptives (Darang volcanics).

Metamorphism in the Main Central Thrust sheet is normal, and decreases in stratigraphically younger metasediments. Metamorphism in the Chail Thrust sheet is reversed, with stratigraphically younger sediments having higher metamorphic grade. This phenomenon is interpreted as reflecting proximity to the Main Central Thrust (Gansser, 1964b).

The Krol belt (Auden, 1934), bounded by the Giri Thrust on the northeast and floored by the Krol Thrust on the southwest consists of a series of interbedded shales, slates, and metaquartzites (Infra-Krol "Series") overlain by a transgressive sequence of poorly sorted quartzarenites (Krol Sandstone) followed by some 600-1500 meters of interbedded limestones and calcareous shales (Krol Limestones). The entire sequence is conformably overlain by a possible regressive cycle of litharenites, carbonaceous shales, micaceous shales and orthoquartzites of the Tals "Series".

Further north, in the fenster developed by the Sutlej and limited by the Shali Thrust, the stratigraphic equivalent of the Krols, the Shali sequence (West, 1939) is developed. In each area, the Krol or Shali units form the southwestern-most limit of the Outer Himalayas and are thrust over the predominantly Tertiary deposits of the foredeep along the Main Boundary Fault (Plates A1 and A2 of map, Figure 2).

Parautochthonous Thrusts of the Foredeep

The Punjab re-entrant represents the widest exposure (about 50 kilometers) of the Himalayan foothills along its 800 kilometer strike in
Figure 3. Geologic map of the sub-Himalayan Tertiary re-entrant, Punjab and Himachal Pradesh, India. (Compiled after numerous sources)
MAP OF SUB-HIMALAYAN TERTIARY RE-ENTRANT
PUNJAB AND HIMACHAL PRADESH, INDIA

INDEX MAP SHOWING AREA COVERED
Sources of information used in compiling map. Complete references are listed at end of report:

1. A. Cameron (1966)
2. W.B. Gill (1951)
4. V.S. Kothawale and R.B. Mukherjee (1964)
5. L.F. Mathur and P. Evans (1964)
6. H.B. Medlicott (1864)
7. J.R. Sahni and L.P. Nathwani (1964)

Maps compiled by Indian Oil and Natural Gas Commission

Compiled by: G.D. Johnson
Table 1. Tertiary stratigraphic nomenclature of the parautochthonous thrust plates of the Punjab re-entrant
northern India. In response to tectonic breakup, no less than eight imbricate thrusts plates, each involving progressively younger Tertiary sediments southward from the Main Boundary Fault, are present.

The eight tectonic plates distinguished (Figure 2), have been labeled Plates A1, A2, A3, B, C, D1, D2, and D3. Plate A1 is the lowest. Plates D1, D2, and D3 may be more appropriately termed autochthonous, but in consideration of the total tectonic style of this foredeep, they are included with the older thrusts.

Similar stratigraphic sequences are noted within each thrust unit, but lithostratigraphic terminology varies considerably. Figure 3 illustrates the geology of the foredeep (thrust plates are not labeled); Table 1 summarizes the nomenclature and relative movements of thrust plates within the foredeep.

Although numerous exposures of the Neogene in North India have proven fossiliferous, most stratigraphic detail during the Chandigarh-Yale Project was directed towards the fossiliferous sediments of the Gumbhar-Sarkaghat Thrust unit (designated Plate B in this report).

Plate B, bounded on the northeast by the Paror and Sarkaghat structures, for the most part, is monoclinally folded, bounded on the southwest by the Gumbhar Fault (sometimes termed Jawalamukhi Fault). By far the most complete exposures of the fluvial Siwalik molasse of the Himalayas is exposed along this plate. An aggregate thickness of some 3000 meters of Neogene sediments is present (Vondra and Johnson, 1968).

The stratigraphic sequence exposed in Plate B from the base upwards is: 1) interbedded quartzarenites giving way to moderate brown litharenites
and siltstones of the Kasauli Formation (infra-Nahan of Gill, 1951b); 2) massive sublitharenites and litharenites with occasional interbedded polymictic conglomerates and moderate brown siltstone lenses of the Nahan Sandstones; 3) interbedded sublitharenites and moderate brown to variegated siltstones of the Middle Siwalik "Lower Alternations" (Gill, 1951b); 4) interbedded sublitharenites and litharenites and variegated siltstones of the Middle Siwalik "Upper Alternations" (Gill, 1951b); 5) massive polymictic fanglomerates of the Upper Siwalik "Boulder Conglomerate Stage".
SIWALIK SEDIMENTATION: EVIDENCE FROM THE
GUMBHAR-SARKAGHAT THRUST UNIT
(PLATE B)

Age and Correlation of the Gumbhar-Sarkaghat Unit

Stratigraphic terminology

The problem of terminology of the fluvial molasse of the Himalayan foredeep has been one of correlation of similar stratigraphic intervals from widely separate areas, which due to the nature of the sedimentation, are lithologically quite different.* The lowest lithostratigraphic unit of Plate B (Figure 4) belonging to the Siwalik "Series" is the Nahan Sandstone (named after exposures near Nahan, Himachal Pradesh; Medlicott, 1864). For the most part, this 500 meter plus sequence of interbedded litharenites, sublitharenites and mudstones has been interpreted interbedded fluvial channel lag and lateral accretion deposits of a loosely sinuous stream with few preserved floodbasin deposits (Vondra and Johnson, 1968). It has been earlier differentiated on its resistant, ridge-forming character. The Nahan are differentiated in the field from the underlying Kasauli Formation of the Dharmsala Subgroup on the relative proportion of sandstones and an increase in the percent of heavy minerals (plus lithic fragments), giving them a "salt and pepper" appearance (Pascoe, 1963).

*As previously mentioned, lithostratigraphic and chronostratigraphic terminologies are not consistent with the Code of Stratigraphic Nomenclature. The term "Siwalik Series" should probably be replaced by Siwalik Group, and the various subdivisions re-named accordingly. This paper will use the established terminology: the "quotes" will be mine.
Figure 4. Geologic sketch map of the Hamirpur-Haritalyangar region, Gumbhar-Sarkaghat thrust plate (Plate B), Bilaspur District, Himachal Pradesh, India
The Nahan are transitional with the overlying Middle Siwalik "Lower Alternations" of Gill (1951b). Previous investigations have differentiated these units on the basis of the lack of resistant, ridge-forming sandstones and the increased frequency of occurrence of interbedded siltstones in the overlying unit. Vondra and Johnson (1968), explain this change in lithologic character as a response to a change in the fluvial regime, such that definite meander belt deposits were developed. In addition to a sequence of interbedded lateral accretion deposits, a much greater amount of vertical accretion floodbasin deposits were preserved. This would account for the change in the geomorphic expression of Plate B in its central portion and the occurrence of the scarp and dip-slope topography mentioned by Gill (1951b). (See Figure 5a).

The "Upper Alternations" ("Upper Sandy Alternations" of Gill, 1951b) lie conformably above the "Lower Alternations" and are sedimentologically similar to them. A change in the composition of the channel lag gravels and channel sandstones is noted, thus making a field division possible on the basis of increased variety of mixed lithic fragments.

Both the "Lower Alternations" and "Upper Alternations" of the Middle Siwalik sequence of Plate B have been given lithostratigraphic nomenclature comparable to the faunal zones of the Siwalik Series of the type area in the Attock District, West Pakistan. The use of the South Asian faunal zone terms Nagri and Dhok Pathan for lithostratigraphic units of the Middle Siwalik sediments of Plate B is untenable for obvious reasons. The use of this terminology by Chaudhri and Gupta (1969) and others implies lithostratigraphic significance although it can be demonstrated that these
Figure 5. General overview of the Middle Siwalik sequence of Plate B

A. Overview of the "Lower Alternations" and "Upper Alternations" of Plate B from a vantage point above the village of Dhanghota (see Figure 4) on the crest of the ridge (Janghar Dhar) formed by the upthrust Nahan Sandstone adjacent to the Gumbhar Fault. View is to the northeast; the village of Haritalyangar is situated above the road in foreground.

B. Overview of the "Lower Alternations" one kilometer northwest of Haritalyangar. The productive fossil horizons of cycles #37-38 are in the foreground and those of cycles #42-43 are in the central background. The "Boulder Conglomerate Stage" is exposed along the horizon to the right; the upthrust Chail Thrust sheet of the Dhauladhar Range beyond the Main Boundary Fault is the snow-capped peaks in the horizon (at 22,000 feet).
zones transgress field mappable or true lithostratigraphic units.

Pascoe (1963) and Sahni and Mathur (1964) provisionally included the Middle Siwalik succession in Plate B with the Middle Siwalik succession in Plate C near Nurpur, and proposed the use of the term Nurpur beds for this sequence. This use would include those sediments, i.e., the "Lower" and "Upper Alternations", lying above the Nahan Sandstone and below the Upper Siwalik "Conglomerate Stage".

No attempt will be made to justify this proposed terminology in view of the fact that the writer has not made an extensive study of the Nurpur area. The use of Nurpur as a formational name with the "Lower" and "Upper Alternations" designated as members could be acceptable terminology. In this paper "Lower Alternations" and "Upper Alternations" will continue to be used as informal lithostratigraphic divisions of the Middle Siwalik sequence in Plate B, i.e., the area designated in Figure 4.

Occurring disconformably above the "Upper Alternations" are some 1000 meters of polymictic conglomerates with interbedded, loosely consolidated sublitharenites and minor amounts of grayish-orange siltstones. This sequence has been termed the Upper Siwalik "Boulder Conglomerate Stage" and represents a proximal to medial position fanglomerate corresponding to Plio-Pleistocene uplift along the Main Boundary Fault to the northeast. Considerable confusion has arisen concerning the stratigraphic occurrence of the "Boulder Stage" relative to other Upper Siwalik sediments exposed in the outer foothills. The paucity of fauna in the "Boulder Stage" makes correlation imprecise, but some workers favor an Early to Medial Pleistocene age.
The important primate and equid associations of the Haritalyangar sequence in perspective with their stratigraphic occurrence and inferred limits of the South Asian faunal zones, have recently been re-evaluated in light of new data. Recent reviews of the major collections from the Miocene-Pliocene of North India (Simons, 1964; Simons and Pilbeam, 1965; Simons and Ettel, 1970; Simons et al., 1971) have clarified the encumbering synonomy and confusion as to stratigraphic occurrence. These results are summarized in Figure 6.

**Sedimentology**

**Distribution of lithologic features - sedimentologic**

The recognition of ancient fluvial deposits on the basis of their sedimentological character rather than their contained fauna is still a rather new approach (summarized in Allen, 1965b). Although there has never been much problem in the recognition of such deposits developed from alluvial systems possessing a definite meander belt structure, i.e. high sinuosity (Fisk, 1947; Leopold and Wolman, 1957, 1960; Wolman and Leopold, 1957; Lattman, 1960; and Iowa State University\(^1,\)\(^2\)), this is not the case with those streams having low sinuosity. A loosely sinuous stream may deposit channel lag and lateral accretionary sand bodies several

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### South Asian Faunal Zones

<table>
<thead>
<tr>
<th>Plio-Pleistocene</th>
<th>Middle Pliocene</th>
<th>Late Early Pliocene</th>
<th>Important Faunal Associations</th>
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<tr>
<td>&quot;Boulder Stage&quot;</td>
<td>&quot;Upper Alternations&quot;</td>
<td>9-10my</td>
<td>Hipparion theobaldi H. antilopinum Cigantopithecus bilaspurenseis</td>
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<td>Nagri</td>
<td>&quot;Lower Alternations&quot;</td>
<td>13-14my</td>
<td>Hipparion antilopinum Ramapithecus punjabicus** Drzyopithecus indicus**</td>
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</tbody>
</table>
| Chinji           | Nahan Sandstone | 14-15my*** | }

*from Simons and others
**sensu Simons and Pilbeam (1965)
***equivalent to Ft. Ternan strata, dated at 14my

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**Figure 6.** Faunal zonation, lithostratigraphic nomenclature, and important faunal associations of the Siwalik sequence exposed near Hari-talyangar, H.P., India (Plate B, this report)
kilometers or more wide and up to ten or more meters thick in addition to destroying the floodbasin deposits in its path. This model can be illustrated in the Holocene of the North American Gulf Coast deltaic plain (Bernard et al., 1970; Bernard and LeBlanc, 1965) and in the Brahmaputra riverine plain of East Pakistan (Coleman, 1969). This is precisely the problem encountered with some previous interpretations of the mode of deposition of the earliest Siwalik molasse (the Nahan Sandstone).

The paucity of well preserved terrestrial fauna and flora in the Nahan, and the preponderance of (compositional) litharenites are not the only factors which have led some investigators to conclude the "marine" nature of these sediments (Sikka et al., 1961; Saxena, et al., 1968). The interpretation that the Subathu/Dagshai-Kasauli/Siwalik transition is one of evaporite and black shale (exunic)/graywacke (flysch)/subgraywacke (molasse) facies transition within a geosynclinal cycle (Swaminath, 1961; Saxena et al., 1968) is completely unfounded (Ganju and Srivastava, 1962; Cummins, 1962; Gansser, 1964a, b, 1966). The geosynclinal cycle of Pettijohn (1957) is not applicable here, since no eugeosynclinal phase preceeded the molasse phase as in the Alpine geosyncline. The sediments of the so-called Himalayan exunic and flysch facies are deposited on and involved with sediments of the Gondwanan shield margin in the most recent Himalayan thrusting.

In spite of the "uncontrovertable" evidence that the Dagshai-Kasauli sequence is definitely of marine origin, based on its boron content (Saxena et al., 1968), enough analyses have been made (Cody, 1970) to indicate that this paleosalinity test is unreliable in ancient sediments
without additional evidence. In view of these problems of interpretation, other data is needed to substantiate the fluvial nature of the Siwalik molasse.

**Fining-upward cycles** Ideally, fluvial cycles are characterized by an erosional base cut into (and possibly through) the underlying cycle, and upon which may be developed various small scour features. Deposition of a coarse-grained channel lag containing both extraformational debris from upstream, and intraformational debris fragmented bone and wood derived locally by bank caving and erosion during channel meandering follows (Figure 8B). This grades vertically into finer-grained, lateral accretion (sub-stratum) point bar sandstones. The internal geometry of these sands reflects not only the fining-upward nature of the sediment, but also the stratification associated with the changing flow regime. Large-scale trough cross-stratification gives way to horizontal bedding with parting lineations and finally small-scale trough or ripple-drift stratification. The final phase in the cycle is the fine-grained vertical accretion (top-stratum) deposits, floodbasin siltstones and splay sands in the more proximal portions of the floodplain. Pedogenic modification, usually present in the vertical accretion deposits, will be discussed in a later section.

The frequency of fining-upwards fluvial cycles from the Siwalik molasse exposed in Plate B near Haritalyangar is illustrated in Figure 7; all cycles encountered in the Nahan Sandstone, "Lower Alternations" and "Upper Alternations" being numbered in sequence from the Gumbhar Fault to the disconformity with the "Boulder Stage".
Figure 7. Fluvial fining-upward composite cycles present in the Hamirpur-Haritalyangar region of Plate B. (Important hominoid levels are indicated. One composite cycle is made up of channel lag, lateral accretion, and vertical accretion deposits)
GUMBHAR FAULT

Composite Cycle Thickness (Feet)

- Mahan Sandstone
- Lower Alternations
- Upper Alternations
- Boulder stage

- Composite Cycle Number

- Vertical accretion deposits
- Lateral accretion deposits
- Polymictic reworked va dep
Figure 8. Sedimentologic features of the Nahan Sandstone and "Lower Alternations"

A. Flute casts from a basal channel sand directly overlying flood-basin siltstones in the Nahan

B. Basal lateral accretion sandstone exhibiting large-scale trough to horizontal stratification transition. Porous texture is due to weathering out of intraformational mudstone clasts. From the "Lower Alternations". Scale, three feet

C. Multistoried channel filling in the Nahan. Outcrop height is eight feet

D. Clay drap occurring at channel margin in the "Lower Alternations"

E. Interbedded floodplain siltstones and fine-grained splay sandstones. Exposed along Haritalyangar road in outcrops of the "Lower Alternations". Outcrop is eight feet high

F. Ferruginous concretions developed in an inferred paleosol from the "Lower Alternations". Unit is not fossiliferous
The Nahan Sandstones at the base of Plate B are not simple cycles, the initial erosional channel cuts down below underlying vertical accretion deposits. As a result, many sand bodies within the Nahans are multi-storied (Figure 8C) and laterally complex. It is, however, possible to differentiate each phase based on the above criteria (see also Allen, 1965b; Bernard et al., 1970) if these are traced laterally.

The thirteen composite, multistoried, fluvial cycles representing the Nahan, individually evidence a greater relative thickness for the lateral accretions sand bodies than for the associated floodbasin intervals, suggesting quite rapid aggradation. Where floored in a rather cohesive bed (floodbasin siltstones) the base of the cycle usually exhibits current scouring (Figure 8A).

The overlying "Lower Alternations", reflect drastic changes in stream regime, the development of a meander belt, and distinct distal to proximal facies variations within the vertical accretion floodplain deposits. With few exceptions the channel sand bodies of the "Lower Alternations" are not multistoried but reflect single phase erosion and lateral accretion (Figure 8D). This is not the case with the floodplain mudstones; multi-storied alluvium and splay sandstones (Figure 8E) often reach unusual thicknesses (as in the important hominoid-bearing vertical accretion deposits up-section from and to the East of Haritalyangar) (Figures 7, 17, and 18). The semi-permanence of the floodplain landscape during Nagri times is reflected in the abundant faunal remains from these strata in contrast to the less stable and, therefore, more barren Nahan sequence below.
The cycles of the "Upper Alternations" reflect the continued "multi-storied nature" of the vertical accretion deposits with occasional multi-storied channel sands. On the basis of the field interpretation of the fining-upwards cycles alone, however, not enough variation can be noted. Beerbower (1964) related alluvial depositional morphology to basin subsidence and concluded that unless subsidence and floodplain alluviation are extremely rapid, definite meander belt deposits are likely to form. Proximal and distal depositional environments will be differentiated, successive channels in the belt will be wider and shallower, and channels can be diverted within the belt more often. Channel fills may be more numerous, but shallower, so that the sandy member of each fluvial cycle will display sheet sand characteristics. Deep channel fills, therefore, are restricted to more rapidly subsiding and aggrading basins.

This phenomena has been observed by the writer in the Bhabar (the Recent coalesced alluvial apron at the foot of the Siwalik Hills) and Indogangetic Plain. Here, due to continued rapid subsidence of the Indogangetic Plain paired with an accompanying uplift of the outermost Siwalik Hills (autochthonous Plates D1, D2, and D3 of Figures 2 and 3) along an inferred thrust, rapid modification is noted. Above the so-called "hinge" or fault line, the alluvial apron is segmented, giving rise to the small sloping paired terraces termed "bhangar". Below the "hinge" the apron is buried by younger alluvial fill. In the area of subsidence, below the hinge, the entire fluvial sequence is preserved, with individual sand bodies reflecting this rapid aggradation. This feature is illustrated in Figure 9. Continued subsidence and thrusting results in a subsequent
Figure 9. Sedimentologic development of the Bhabar

A. Inferred structural development of the Bhabar and its influence on terrestrial sedimentation in the northern portion of the Indogangetic Plain

B. Overview of the Bhangar (segmented terraces) and the Bhabar (alluvial apron) from a vantage point above the Nalagarh Fault on autochthonous thrust plate D1
movement outward, away from the uplift, of the zone of maximum sediment accumulation in the Indogangetic Plain -- a process not unlike the development of the entire foredeep itself.

A mechanism similar to the Himalayan example is seen in the Texas Gulf Coast, where Late Tertiary and Pleistocene alluvial deposits have been segmented above a hinge line coincident with or slightly offshore from the present coastline. The sediments are preserved offshore below the hinge (Bernard and LeBlanc, 1965).

In view of these processes, the Nahan Sandstones were deposited in a rapidly subsiding basin by aggrading streams of low sinuosity. Meander belt deposits are poorly developed and preserved and terrestrial faunal and floral remains are not abundant due to this depositional mechanism. The "Lower Alternations" reflect a period of quiescence with decreased basin subsidence, definite meander belt construction in response to increased channel sinuosity (decreased gradient), and decreased multi-storied construction of channel sandstones. The "Upper Alternations" in Plate B continue to reflect quiescence or slow rate of subsidence. Floodplain construction is evident and there is preservation of floral and faunal remains.

Grain-size analysis The analysis of grain-size statistics has proven to be a useful tool in differentiating between many Holocene environments. Scatter diagrams which compare various combinations of the parameters, mean, standard deviation, skewness, and kurtosis have been used by Friedman (1961), Moiola and Weiser (1968), and McGowen and Garner (1970) on fluvial sands and other terrestrial environments. Some environments may now be defined on the basis of clustering.
Disaggregated channel sandstones and floodplain siltstones of the Nahan, "Lower Alternations" and "Upper Alternations" were sieved and the fine fraction analysed by standard hydrometer methods. Scatter diagrams of the three most useful combinations of the above parameters for fluvial sediments (graphic mean, $M_z$, vs. inclusive graphic standard deviation, $\sigma_I$ (Folk); $M_z$ vs. inclusive graphic skewness, $Sk_I$ (Folk); $\sigma_I$ (Folk) vs. $Sk_I$ (Folk)) were plotted. The standard plot of graphic kurtosis, $G_k$ (Folk) vs. $Sk_I$ was of little help in differentiating individual environments an observation made also by others, (Moiola and Weiser, 1968).

A plot (Figure 10) of $M_z$ vs. $\sigma_I$ (Folk) shows definite clustering of all samples within the fluvial field defined by Friedman (1961) and the less restrictive field defined by Moiola and Weiser (1968). This is true for all Nahan sandstones as well. Texturally, they are not related to flysch-related sediments as previously suggested. The field of clustering of similar data from Alpine flysch studied by Hubert (1967) is plotted for comparison. The Nahan channel sands examined display an average mean size of 2.80 with a standard deviation of 1.60 units. Floodplain deposits exhibit a similar degree of sorting (1.80) and have an average mean of 5.90.

The "Lower Alternations" are generally more moderately sorted in the channel sands (average, 1.40 units standard deviation). Mean grain size is somewhat smaller (3.10) evidencing a greater degree reworking of the sediment. This relationship has been observed for other fluvial sands (Folk and Ward, 1957); with decreased mean particle size sorting is better, independent of distance transported.

The "Upper Alternations" reflect a similar pattern of textural
Figure 10. Composite plot of inclusive graphic standard deviation vs. graphic mean for Nahan, "Lower Alternations", and "Upper Alternations" samples.
variation with one exception: extreme distal floodplain sediments (back-swamp environments) are finer-grained (average 6.90). This may represent sampling variation, however, since the number of total samples from this environment in both the "Lower Alternations" and "Upper Alternations" is only 18 samples.

The plot of $Sk_I$ against $M_z$ (Figure 11) provides better differentiation of specific fluvial facies. However, since most Holocene terrestrial sediments are positively skewed in nature (Folk, 1968), Friedman's cluster obtained with $\sigma_I$ vs. $Sk_I$ aids little in specific facies differentiation (Figure 12).

Large scale trough cross and horizontally stratified sands of the Nahan are generally near symmetrical to fine-skewed. Sorting is poor. Floodplain sediments, where present, are fine-skewed to slightly strongly fine-skewed, whereas, in the overlying "Lower Alternations", channel sands and floodplain deposits are more strongly fine-skewed. Back swamp deposits from both units are uniformly fine-skewed. The channel sands of the "Upper Alternations" become less strongly fine-skewed with the floodplain siltstones being similar to the "Lower Alternations".

Changes in stream competency and alluvial facies variability based solely on particle size distributions cannot be demonstrated effectively for the Middle Siwalik sequence due to the great amount of overlap noted in the above textural parameters.

There is a tendency for the trough cross-strata of each cycle in each formation to be more platykurtic and slightly finer-skewed than the overlying horizontally stratified sands. However, between the Nahan and the
Figure 11. Composite plot of inclusive graphic skewness (Folk) vs. graphic mean for Nahan, "Lower Alternations", and "Upper Alternations" samples.
Figure 12. Composite plot of inclusive graphic standard deviation vs. inclusive graphic skewness (Folk) for Nahan, "Lower Alternations", and "Upper Alternations" samples.
"Lower Alternations" there is a change, all sand bodies becoming more leptokurtic. The trend reverses somewhat higher in the section, with the sands of the "Upper Alternations" being on the whole more platykurtic. Floodplain siltstones from all three formations become more platykurtic and fine-skewed in distal floodplain positions.

**Petrology**

Point-count modal analyses based on 300+ counts in traverses normal to bedding, were made of oriented thin-sections from selected sandstones of the Nahan, "Lower Alternations" and "Upper Alternations". Both calcareous and non-calcareous sands were selected. For the purpose of comparison, the petrographic composition of a number of sands from similar fluvial facies (large scale trough stratified) is summarized in Table 2 and a ternary scatter diagram (Figure 13).

Most Siwalik sands are litharenites, the exception is the Nahan which include some intermediate feldspathic litharenites. The mean composition (40% quartz, 15% feldspar, 45% rock fragments) for the Nahan field closely approximates the compositional average of typical Siwalik "schist arenites" from the Potwar region of West Pakistan (Krynine, 1937). Krynine's work describes the petrology of sediments from the type area of the Siwalik biostratigraphic zones, 300 kilometers to the west of Haritalyangar. The compositional mean for the "Lower Alternations" (60% quartz, 6% feldspar, 34% rock fragments) and the "Upper Alternations" (43% quartz, 7% feldspar, and 50% rock fragments) deviate somewhat from this average.

The lithostratigraphic divisions of the Siwalik sequence in Plate B can also be considered valid petrologic units; they are separable on petrographic data alone. Quartz-type variation among framework grains sets
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Table 2. Compositional make-up of selected sandstones from the same facies (large-scale trough stratified) in the Nahan, "Lower Alternations", and "Upper Alternations"
Figure 13. Ternary compositional plot of sandstones from the Nahan, "Lower Alternations", and "Upper Alternations"
the "Lower Alternations" apart from either the Nahan below or the "Upper Alternations" above. Straight to slightly undulose extinction varieties increase relatively some 200-300% from an average of 11% in the Nahan to 24% in the "Lower Alternations". A relative decrease in occurrence of this extinction type is noted again in the "Upper Alternations". The disproportionately increase in single-grain quartz varieties in the "Lower Alternations" appears directly related to a decrease in the percentage of lithic fragments (metasedimentary, metavolcanic, detrital). Composite quartz varieties having either simple undulose or complexly undulose extinction are proportionally persistent throughout the entire Siwalik sequence, no apparent decrease noted in the "Lower Alternations". The balance of all quartz types within the "Lower Alternations" suggests some moderate sediment reworking prior to final deposition. With little or no preferential destruction of metaquartzite debris, only the least stable metasediments appear to have been destroyed.

The proportional increase in biotite mica during the "Lower Alternations" interval seems to substantiate this. It might be noted that the unstable chlorite mica suite encountered in the "Upper Alternations" was not yet being eroded or brought to the basin during "Lower Alternations" or Nagri time (Table 2).

The paucity of detrital feldspar throughout the entire Siwalik sequence is further enhanced by the conditions of sedimentation during the "Lower Alternations" interval. There is an expected decrease in relative percent of feldspar occurring as framework grains which corresponds to the observed decrease in unstable rock fragments. Even in channel sands, argillation of
feldspars occurs in more than 50% of all samples. Sericitization and kaolinitization are both present, with sericitization being dominant.

A determination of twin law, composition, and structural state was made of 23 coarse-fraction detrital plagioclase crystals selected at random from the Nahan, "Lower Alternations" and "Upper Alternations". Analysis was by a standard technique outlined by Turner and Weiss (1963, pp. 200-202) with the resulting indicatrix data referred to Slemmons (1962) for interpretation. The results are summarized in Figure 14.

Although it is not possible to be quantitative with such few determinations there is a persistence of certain structural states within different portions of the Siwalik sequence at Haritalyangar. Twin law relationships are not precise enough to differentiate between igneous and metamorphic suites completely since both of the two dominant twin types, albite and manebach, occur in volcanic and plutonic igneous and metamorphic rocks (Gorai, 1951).

Most twins were composed of few sub-individuals, with a prevalence of simple twins. This suggests a preponderance of metamorphic plagioclase (Turner, 1951) a factor not inconsistent with the high occurrence of other lithic fragments in these sediments. The percent of anorthite (An) is generally low, ranging from 3-36%. Sodic rich volcanic populations occur at 3-8% An and at 15-18% An; three plutonic populations occur at 9-12% An, 20-23% An, and 28-36% An. The volcanic populations are persistent from the Nahan to the "Lower Alternations", whereas, the plutonic populations are persistent throughout the entire sequence. In the "Upper Alternations", only the 28-36% An plutonic field was found.

Accessory detrital minerals have been evaluated by Dehadrai (1958),
Figure 14. Frequency of occurrence of plebitolactase twin type
Raju and Dehadrai (1962a), Raju (1967) and Raiverman (1968). The results of these workers are summarized in Figure 15. The most apparent relationship between heavy mineral suites of the Siwalik sequence is the presence of the high-rank metamorphic minerals of the almadine-amphibolite facies. Progressively younger Siwalik sediments reflect more complex suites and higher-grade metamorphic detritus. The impersistence of epidote and staurolite in the Kasauli and a corresponding greater abundance in the Nahan serves to provide a local marker for the base of the Nahan Sandstone. Kyanite is locally abundant from the base of the Middle Siwalik sequence ("Lower Alternations") upwards. The base of the "Boulder Stage" is similarly differentiated on the presence of hornblende and sillimanite. The entire sequence seems to suggest progressive unroofing of a metasedimentary terrane which exhibits stratigraphically normal metamorphism. As mentioned previously, the Main Central Thrust sheet of the Inner Himalayas displacing southwards the metamorphic mudstones of the Jutogh Series exhibits this character.

In addition, relative abundance of rutile and zircon increases within the "Lower Alternations". Raiverman (1968) found a similar increase in stratigraphically equivalent strata (Petrographic Zone D$_2$) in the Sarkaghat Anticline to the east of Plate B. [The Sarkaghat Zone D$_2$ was similarly characterized by reduced mean grain size, decreased quantity of rock fragments and feldspar, increased quantity of quartz, matrix, and grain roundness (Raiverman, 1968, p. 44)].

The amount of clay matrix increases considerably in the "Lower Alternations". Both the Nahan and "Upper Alternations" sequence reflect this difference in the higher proportion of carbonate matrix present (Table 2).
Figure 15. Heavy mineral persistence in the Siwalik sequence of Plate B. (In part from data in Sinha and Khan (1965) and Sinha (1970)).
Although some sparry calcite can be seen replacing detrital quartz in the "Upper Alternations" most occurs in the Nahan Sandstones which are almost always calcareous. An unfortunate consequence of this is the selective replacement of detrital grains by carbonate. As a result, the gross compositional plot for these sands (Figure 13) may be misaligned.

Detrital carbonate clasts constitute most of the reworked chemical sediments in the Nahan, and are recrystallized so that the original texture has been obliterated. Carbonate clasts are not abundant again until the "Upper Alternations" where they account for about 50% of chemical sedimentary rock fragments. The remaining chemical clasts in the "Upper Alternations" and most of those from the "Lower Alternations" are crypto-crystalline quartz. Both chert and chalcedony are present, chalcedony abundantly so.

**Summary** Siwalik sandstone petrology appears to reflect significant changes in the character of both the basin of deposition and the mineralogic provenance: 1) rapid deposition, minimal reworking, and a very complex suite of detritus characterize the phyllarenites of the Nahan Sandstone; 2) considerable reworking and subsequent loss of the more liable fraction characterizes the "Lower Alternations"; and 3) increased immaturity of the sediment characterizes the "Upper Alternations", petrographically somewhat similar to the Nahan.

Progressive unroofing of a stratigraphically normal metamorphic provenance is apparent from the higher-grade metamorphic detritus encountered in younger Siwalik sediments. Although no extant Himalayan volcanic plagioclases have been analysed which suggest composition and twin law similar to those described from the Siwalik sequence, Bisaria and Saxena
(1968) describe intrusions within the Jutogh metamorphics of the Chor area (Simla Himalayas) which are quite similar to the 28-36% An type plagioclases found in the "Upper Alternations". This occurrence coincides with the highest grade metamorphic assemblage of the Chor area and similarly the highest-grade metamorphic suite in the unstable detrital minerals of the Siwalik sequence.

Distribution of lithologic features - pedogenic

Soil development in multistoried parent material - alluvium

The 'normal' pedological concept of soil profile development imposed upon previously unaltered parent material encounters some problems when applied to the environmental conditions in which fresh, unweathered parent material is added to the surface in varying increment amounts. Complicating factors, such as insufficient time for detectable horizonation, nonuniform parent material addition, lack of distinct lithologic breaks (gradational boundaries), irregular distribution of sedimentary bodies, and a depositional regime contemporary with pedogenesis, may also exist.

The concept that parent material accumulation and its association with alluvial soil is somewhat unique and is different from the standard ABC concept of soil horizonation is not a new one. Nikiforoff (1949) differentiated non-cumulative and cumulative soil types and thereby opened up a sensible approach to the study of alluvial soils. The typical ABC soil or non-cumulative type develops from parent materials which are more or less static in relation to further addition of parent material to the profile. Cumulative soils, on the other hand, are those which develop on parent material which is not static but is undergoing a slow but steady
process of upbuilding by increment additions of sediment (alluvium, collu-
vium, wind-blown sediment). As suggested by Folks (1954), Poetsch (1956),
Plyusnin (1960), and Riecken and Poetsch (1960), the path of horizonation
is not simply C transformed to an A or B directly, but rather genesis of
new surficial C into a new A and the former A into a B horizon. A
former B horizon, therefore, becomes a highly modified substratum which
cannot be confused with C material. To simplify,

\[ A^c \]
\[ B^c \]
\[ C \]
\[ C \]
\[ C \]

(modified from Poetsch, 1956)

Modification of prior sola into undifferentiated subhorizons, C^c, proceeds
at obviously different rates depending on a wide variety of factors, par­
ticularly climate and degree of weathering of the fresh material.

In general, there has been mixed progress in developing a sound
concept of evolution of alluvium-derived soils. Initial studies (Sibertzev,
in Glinka, 1927) implied that no pedologic evolution could be expected to
occur, but rather that the geologic process of sedimentation was the prin­
ciple factor characterizing alluvial soils. Later, Glinka (1927), Kellogg
(1941), and Dobtovolsky (1958) stressed the influence of soil forming pro­
cesses over geologic, with the result that most modern concepts specifi-
cally relate a particular form of horizonation to pedogenesis.

**Landscape position (natural drainage)**  The influence that construc­
tional landform has on soils of the floodplain is considerable. Abandoned
channelways (oxbow cutoff), the low-level backswamp, and other low energy
depressional landforms of the floodbasin are almost always filled by fine-to very fine-grained overbank vertical accretion material. As a result, and due to their low-lying position, they are invariably poorly- to very poorly-drained. Conversely, the higher constructional landforms (natural levee, crevasse splay, and fan) are almost always well-drained. This is a function of both relief relative to the water table of the region (river level), and the coarse texture exhibited by these proximal landforms.

**Increment addition**  Increment addition of new parent material to the profile, if in relatively small quantities and of fine-grained size, may in some distal positions on the floodplain not greatly affect the character of the soil sola other than to effectively 'overthicken' the A horizon. More than likely, however, this increment addition will impose a new initial condition with subsequent change in the profile. In the environment distal to the influence of the main channel, pedogenic processes are in pace with sedimentation; in the more proximal localities, sedimentation overshadows pedogenesis, thus, the A horizon is immature. Other studies tend to support this observation (Folks, 1954; Poetsch, 1956; Simonson, 1960; deLeon, 1961; Dietz, 1966; Ledesma, 1969). Soil maturity in the cumulative environment is an extremely variable factor; adjacent landforms on the alluvial plain may have grossly different histories in terms of their sedimentation record and the extent to which increment addition has taken place.

**Soil formation**  In terms of the soil forming processes within cumulative environments, only a few are considered: $A_1$ formation; pH and removal of soluble components; clay transformation, accumulation and translocation; and oxide translocation (Simonson, 1960; Dietz, 1966;
Ledesma, 1969). Organic matter accumulation is generally considered to be the initial response to pedogenesis, equilibrium being established rather quickly.

The loss of soluble components from the profile is a natural response to conditions of drainage and depositional landform. Poorly-drained, low-level floodbasin areas are not highly leached; where partial leaching does occur, the upper sola are leached, and concretions are developed lower in the profile (Ledesma, 1969). In well drained areas where drainage is unrestricted, the soluble components are completely lost. As expected, there is a direct correlation between landscape position and clay accumulation. Soils formed on summit positions have developed deeper A horizons than soils on low landscape positions for synchronous deposits according to Ledesma (1969). When considering proximity to the stream course and time since increment addition, most workers have observed higher and deeper minimum and maximum peaks of clay accumulation.

Data from numerous sources (summarized in Simonson, 1960; deLeon, 1961), suggest that there is a direct relationship between iron and manganese oxides and natural drainage (as influenced by depositional morphology). Low-level soils of the floodbasin show lower free iron contents than adjacent higher-level floodplain features. Within these higher-level well-drained soils, the free iron distribution is commonly associated with the zone of maximum clay distribution. Corliss (1958), however, observed that in poorly drained soils there was no observed parallelism of clay and iron oxides. deLeon (1961), using Fe-Mn ratio; Fe-clay ratio; Mn-clay ratio, was able to differentiate drainage classes and relative mobilities of various floodplain environments (Figure 16).
Figure 16. Soil profile variation as a function of depositional form on alluvial floodplains. (From data by L.V. deLeon)
SOIL PROFILE VARIATION AS A FUNCTION OF DEPOSITIONAL FORM ON ALLUVIAL FLOODPLAINS

Interpretation by: Gary D. Johnson
Data from: L. V. de Leon (Unpublished)
Application

Definite relationships become apparent when clay distribution and oxide data from alluvial soils are plotted relative to depositional landforms in the cumulative system (Figure 16): 1) Clay distribution within alluvial soil profiles reflects depositional processes, proximity to, and energy relationships of the depositional medium, with little pedogenic alteration. Pedogenic clay translocation is most evident in distal floodplain environments on high-level sites; 2) Free iron oxide distribution is generally a reflection of clay content. Even in young, immature sediments the oxide distribution follows the clay curve; 3) Manganese distribution reflects a greater degree of leaching within the profile. In the more poorly drained low-level sites, there is a direct response of manganese to pH, suggesting increased mobility with lower pH.

Thus certain properties, such as clay distribution and interrelationships between the mobile oxides can be used as criteria for the recognition of not only ancient alluvial soils, but also their drainage class. Position on the paleo-landscape is not difficult to differentiate from observational field data.

Floodplain deposits of the "Lower Alternations" In view of the possibility of using pedological evidence, in addition to normal sedimentological evidence, to establish an independent line of reasoning concerning the paleoecology of the Ramapithecus-yielding sediments (Tattersall, 1969a, b, Leakey, 1969; and some earlier observations, Colbert, 1935c) a preliminary analysis of the character of pedologic alteration of the floodplain deposits of the "Lower Alternations", in the vicinity of Haritalyangar, was conducted. These sediments have yielded the dryopithecine and hominid fauna mentioned previously and are considered to be Nagri in
age, correlating with the type Nagri area in the Potwar plateau, West Pakistan.

Floodplain sediments which appeared to have been modified by post depositional (pedogenic) processes were selected from 12 separate composite fluvial cycles within both the "Lower" and "Upper Alternations". Specific detail, however, was attended to the unusually fossiliferous cycles exposed near Haritalyangar (#37-38, and 42-44) which have yielded Dryopithecus and Ramapithecus (Figure 17). Figure 18 shows outcrop of cycles 42-44 near Haritalyangar.

Analysis Determination of free oxides (Al, Fe, Mn) was accomplished by atomic absorption spectoscopy (Perkin-Elmer, 1968) from extracts prepared according to Holmgren's (1967) sodium dithionite-citrate method (Huddelston, 1969). In this context, free oxides are defined sensu Olson (1965) and Blume and Schwertmann (1969) to include the anhydrous and hydrous oxides occurring as discrete particles, grain coatings and "cement" which are affected by pedogenic processes, notably translocation. The data obtained are not for total elemental analysis; values indicate the dithionite-citrate extractable oxides only. Soluble (dithionite-citrate extractable) silica was similarly determined from the above extracts. Total carbon was analysed by thermal-conductivity of evolved CO₂ from high-temperature sample combustion. Analysis was instrumented on a LECO (Laboratory Equipment Corp., St. Joseph, Mich.) automatic 70-second carbon analyser according to procedure outlined by Tabatabai and Bremner (1970). Sample size was increased on an average of 25% above that used by Tabatabai and Bremner (0.2-0.3g) due to the low values encountered. Samples larger than 0.5g were judged too large due to incomplete combustion
Figure 17. Topographic map of the "Lower Alternations" exposures in the vicinity of Haritalyangar, Bilaspur District, H.P., India. Fluvial cycles #23-48 with the important primate-bearing floodplain deposits of cycles #37-38 and #42-43 occur in the area. Cycle #23 is exposed in the Makan Khad to the west; #47 is exposed just below the Hari Mandar temple to the east.
Figure 18. Overview of the southwestern scarp of Hari Mandar Dhar, the cuesta scarp near Haritalyangar (300 meters to the right). (Fluvial cycles #42-44 are exposed below the massive sandstone at left. View to the south)
during heating (above 1650°C).

Standard particle size determination of both coarse and fine fraction plus thin section analyses of selected horizons in each paleosol were made in order to characterize the fabric of the sediments.

Finally, porosity characteristics (effective porosity, bulk density (bulk specific weight), rock specific weight, and pore size distribution) were determined on paleosols from cycles #37-38 and #42-44 using a Ruska Mercury Capillary Apparatus (mercury porosimeter) with an operational pressuring capacity of 2000 psi. This gives an equivalent diameter minimum pore size resolution of 0.060 μ (600Å), a value including most capillarity in modern soils (Diamond, 1970).

**Physical data** Profile data on less than 2 μ clay seems to suggest little evidence of translocation in each cycle illustrated (Figures 19 and 20). The occurrence of three possible argillic horizons in profile #38 and four in profile #43 can be verified or denied on the basis of field observation. Profile #38 lies in a proximal position to an adjacent channel; stratification suggests a definite floodbasin environment near the toe-slope of a natural levee. As a result, clay distribution in this profile appears to be more closely related to sedimentologic processes than pedogenic. Although there is no great difference in bulk density (bulk specific weight averaging 2.57 throughout the profile), effective porosity seems to further corroborate the immature nature of the pedogenesis in this profile.

Data on sequence #43 similarly reflects proximity to channel influence. The paleosol was developed on distal levee sediments. The four possible argillic horizons show little evidence of being more than sedimentologic
Figure 19. Profile variation of pedogenic oxides, clay, and porosity in a paleosol sequence from fluvial cycle #38 in the "Lower Alternations" near Haritalyangar.
Figure 20. Profile variation of pedogenic oxides, clay, and porosity in a paleosol sequence from fluvial cycle #43 in the "Lower Alternations" near Haritalyangar
clay-rich layers. Bulk density (bulk specific weight) variation and porosity data supports this contention. Textural and fabric data from thin-sections indicate no translocated clay, showing clay skins and the oriented fabric which are diagnostic properties of argillic horizons in modern soils (USDA, 1960, p. 37). This does not negate the possibility of in situ clay transformation in the profiles, but does further substantiate the inferred immaturity of the two soils mentioned.

The problem of compaction and change in bulk specific weight due to diagenesis was not studied. It was assumed, however, that for each profile, the variance of physical properties among different levels within the profile was at a minimum, the entire profile being affected essentially the same during compaction and lithification.

**Pedogenic oxides** Data on the dithionite-citrate extractable oxides points up a disparity in the two profiles under consideration: profile #38 shows an irregular, poorly developed sesquioxide profile peaking at the 5-foot depth (0.99% free Al₂O₃; 2.89% free Fe₂O₃), decreasing downward towards the base of the vertical accretion deposits, and showing no general parallelism to the clay curve. There is, however, a general parallelism to the less than 2 u clay + medium and fine silt curve.

Free manganese oxide distribution generally reflects a maximum profile occurrence at a level below both the free aluminum and free oxide peaks (Figures 19 and 20). There is, however, no apparent relationship between free manganese and clay content in these paleosols an observation shared by other students at this laboratory on similar paleosols from the Eocene of the western U. S. (Neasham, 1970; and personal communication), and in modern soils of temperate flood plains (deLeon, 1961). Effective
porosity values of the lithified floodplain deposits and percent free manganese oxides exhibit a positive correlation, which is a probable relict pedogenic property (Figure 21). Poorly drained (low porosity) soils exhibit high mobility of several pedogenic oxides with the result of greater depletion of these oxides with decreased drainage. Figure 21 illustrates this response; with low porosity (aeration), there is low free Mn retention; with high porosity, there is high retention of free Mn.

deLeon (1961) points to several interesting relationships in modern soils which appear to be demonstrated in the two profiles in question. A ratio of maximum percent free Mn oxides to minimum percent free Mn oxides (Max. % Mn/Min. % Mn) in some modern soils can be used to define drainage class. In the case of profile #38; this ratio is 4.8, poorly drained according to the same scheme. One restriction placed on this interpretation is that the soils must exhibit near neutral pH (undeterminable for fossil soils) and fairly high organic matter in the A₁. Organic carbon was detectable (0.018-0.200% C) at several levels in profiles #38 and #42 which correspond to inferred upper solum positions in these two paleosols. Diagenesis has driven off most volatile hydrocarbon compounds from these sediments, but the detectable carbon, plus observable carbonaceous stringers (plant rootlets), lend support to this conclusion. Fairly high ratios (ranging from 47 to 81) of Fe to Mn (% free Fe/% free Mn) give further evidence of differential mobility and depletion of Mn than Fe. Further, the lack of parallelism between Fe and clay distribution mentioned earlier, supports the concept of poorly drained soils.

Coloration Variegated coloration of ancient floodplain sediments has been previously used as evidence of soil weathering. Several
Figure 21. Plot of free Mn oxides (dithionite-citrate extractable) vs. effective porosity for pedogenically altered floodplain siltstones of the "Lower Alternations"
other studies have favored the polygenetic formation of variegated floodplain mudstone: 1) erosion, transport, and deposition of soil sola from highly weathered upland surfaces to the floodbasin: hence, the floodplain paleosols have derived, sedimentologic properties (Van Houten, 1948, 1961, 1964); 2) in situ weathering of the floodplain material (Walker, 1967a, b).

Walker's argument rests on the fact that red sediments, specifically soil-derived sediments, are not transported as red, but as brown, therefore, making Van Houten's derived coloration improbable. The writer is of the opinion that this observation is categorically wrong, having personally observed alluvial transport and lacustrine deposition of red, latosol-derived sediment in the Omo River of Ethiopia and its delta at Lake Rudolf, Kenya. This problem will not be dealt with here; suffice it to say that both explanations are probable.

Figure 22 illustrates the relationship between the dithionite-citrate extractable free sesquioxides and Munsell color hue. As noted, the redder hues (7.5YR and 10YR) exhibit greater sesquioxide values. These values are for non-mottled sediments and include none of the pisolitic iron concretions (pea-iron) or incipient plinthite horizons encountered in several of the twelve paleosols. Coloration of those materials was of hue 5YR. For field recognition of probable pedogenic horizons in the Middle Siwalik "Lower Alternations" and "Upper Alternations", these data appear to be useful. No analysis of these sediments was made to verify the possible increase in (OH)-Fe proportion of free iron oxide (goethite) with increasing yellow color, and an increase in anhydrous forms (hematite) in the strongly red hues.

Clay mineralogy Illite, montmorillonite, expandable mixed-
Figure 22. Plot of free Al oxides (dithionite-citrate extractable) vs. free Fe oxides (dithionite-citrate extractable) relative to Munsell color hue. (From "Lower Alternations" and "Upper Alternations" near Haritalyangar)
layer, degraded (?) chlorite and minor amounts of kaolinite are present in these mudstones. Montmorillonite and expandable mixed-layer clays are dominant. No detectable difference among different variegated mudstones was observed in the samples analysed.

**Evidence of biologic activity** Although mottled coloration has generally been considered evidence of "bioturbation" of sediment following deposition, few observations have been made on modern alluvial soils to characterize this process. It must occur early in the development of a soil and continue as long as the soil remains an integral part of the landscape. Figure 23 illustrates a lateral sequence of fresh to bioturbated sediment occurring in one floodplain sequence from just below cycle #38 in the "Lower Alternations". The micromorphological evidence may be interpreted as fabric disruption or homogenization of original sedimentary structures by biologic activity (organisms and plant rootlets). As can be seen in Figure 23, A-C, original slack-water vertical accretion siltstones (23A) are homogenized (23B, C) such that only some relict texture is present. Earthworm borrows and plant rootlets are evident in part of the homogenized unit (23C & D). Many of the mudstones exhibit small carbonaceous tubules (plant rootlets) throughout their entire thickness. These are surrounded by a small tubular zone (0.25-1.00 cm dia) of reduced (Munsell color 5B7/1) coloration.

Large tubular structures (up to 5 cm dia) have been noted, although rare, and occur within variegated mudstones containing the potamonid crab *Potamon emphysisethum* Alcock, 1909 (identified by Dr. R. Bott, Natur-Museum und Forschung-Institut Senckenberg, Frankfurt am Main, Germany).

Recent sediment data on the initial changes occurring in newly-
Figure 23. Bioturbation and associated features in floodplain paleosols of the "Lower Alternations". (Negative prints of thin-sections)

A. Undisturbed slack-water siltstones occurring in proximal position on the floodplain. From cycle #18

B. Bioturbated slack-water siltstones occurring five meters laterally from 23A. Note relict texture is still preserved in top center

C. Completely bioturbated siltstone sequence from same horizon, but in more distal position on floodplain. New increment addition of clay occurs at top. *Lumbricus (?)* burrows at bottom

D. Bioturbated ripple-drift sediment on levee deposit. Small, round white objects with black centers are root channels

E. Homogenized floodplain siltstones with little relict texture preserved. Bioturbation is complete
deposited alluvium (Pons and Zonneveld, 1965) strongly suggests that the fabric of most paleosols occurring in the more fossiliferous horizons in the "Lower Alternations" and "Upper Alternations" are juvenile, since many of the structures preserved are the result of the earliest stages of "soil ripening" (for definition, see Pons and Zonneveld, 1965).

According to Pons and Zonneveld (1965), the first event in homogenization or destruction of depositional fabric is brought about by burrowing organisms, notably fresh-water crabs and lumbricid worms. Although this occurs while some sediments are still water-logged following flood and/or poorly-drained, the effect is generally noted in that portion of the profile lying above the normal saturated zone (Figure 24). The zone of bioturbation can be quite deep depending on proximity to the water table, for as Sanders (1963, p. 224) points out, during the dry season, some modern Indian lumbricids migrate over 10 feet vertically in the soil profile.

Paleobotanical evidence Relatively few botanical remains have been studied from the "Siwalik Series" of the Punjab, most studies having been carried out to the southeast in Assam and the Northeast Frontier Agency in equivalent strata, but with so-called Burmese affinities. Fortunately, several recent investigations have shed some light on probable associations in the Siwaliks, specifically the "Lower Alternations" floodplain mudstones and their equivalents in adjacent thrust plates (Lakhanpal, 1967; Banerjee, 1968).

Although collections are small and from limited, scattered areas, all appear to have been collected from the more (drab yellowish hued, 2.5Y) floodplain mudstones. Carbonaceous plant impressions are not abundant in the red sediments. Most are found in the most distal, yet pedogenically
Figure 24. Relationship between high water level, groundwater table, soil condition and vertical distribution of some soil organisms. (From Pons and Zonneveld (1965))
immature sediments of the floodplain. In these environments, bioturbation would macerate all larger foliage; only microflora would remain identifiable.

Lakhanpal (1967, 1968) reports the following from the "Lower Alternations":

- Rhamnaceae
  - Zizyphus sp.
  - Berchemia sp.
  - indet. dicotyledonous wood
- Poaceae
  - ?Poacites sp.
- Moraceae
  - Ficus sp.

Banerjee (1968), reporting on Siwalik microflora, found the following assemblage from the Middle Siwaliks:

- Asteraceae indet.
- Poaceae indet.
- Pinaceae
  - Pinus sp.

From the above small population little specific environmental data can be gleaned. Both upland (Pinus sp., Ficus sp.) and floodplain (Ficus sp., and the rest) representatives are present. Well-drained and poorly-drained site flora are apparently represented, all being equivalent to sub-tropical extant species.

An idea which may merit more detailed analyses is the accumulation of amorphous silica phytoliths (cystolith; Esau, 1965) at the surface of buried soil horizons. Any increment addition of new parent material to the floodplain environment will effectively concentrate these siliceous (opaline; Baker, 1960) silt-sized particles in horizons representing buried land surfaces.

The Poaceae (grasses) and fresh-water algae are not the only abundant plant form possessing secretory cells (lithocyst) producing fine-silt
sized (0.006-0.008 mm (7ø)) particles. Most species of Ficus exhibit cystolith-containing cells which may produce detrital particles as large as 0.0625 (4ø) in diameter (Esau, 1965; Ajello, 1941). It would appear that any reasonable period of organic litter accumulation of this type on a landscape could result in a considerable concentration of these organo-clastic particles to the point where cyclicity of overbank flooding may be determined from these buried surfaces.

The geochemical stability of these clasts in soil horizons has not been tested, but would be unstable and soluble above pH 10. The effects of diagenesis also have not been evaluated, but other studies show at least some conversion to chalcedony. The significant frequency of detrital chalcedony in the "Lower Alternations" may be related to just this. It is felt, however, that regardless of the degree to which diagenesis and chalcedonic conversion has taken place, the entire profile would be similarly affected with residual variations still apparent.

With these possibilities in mind, analysis of soluble silica (dithionite-citrate extractable) was made from samples from each of the twelve paleosols. The results of the analyses on profiles #38 and #43 are illustrated in Figures 19 and 20. Percent soluble silica ranges from 0.020 to 0.255 in the samples tested. Only in a few instances do maximum silica deflections correspond to inferred near-surface positions of possible buried horizons. There is, however, a fair degree of parallelism between increased silica content and sediments with a hue of 7.5YR. This level of coloration corresponds closely to inferred upper profile position in these buried soils. The general increase in silica, although not limited to one specific layer, may reflect a response to the bioturbation
or biologic reworking of the upper sola as mentioned above.

Weaver, et al. (1968), although not considering pytolithic silica, observed a relationship between soluble silica and the supply of Al, Fe, and Mg in the soil matrix solution. In the cases illustrated, silica was maintained in solution by acidity, reduction of free iron oxides and hydrolysis of mafic minerals in soil materials occurring in positions of slow drainage. Accordingly, this leads to the crystallization of expansible layer silicate clays (montmorillonite) in these poorly drained sites (Weaver et al., 1968). Although no quantitative evaluation of montmorillonite occurrence in the "Lower Alternations" profiles has been carried out, the abundance of montmorillonite and other mixed-layer expansible clays may tend to support evidence for such clay transformation taking place, even in these immature soils.
SUMMARY AND CONCLUSIONS

Neogene sedimentation in a portion of the Punjab Himalayas (the Gumbhar-Sarkaghat fault block) is represented by 5000 meters of late Cenozoic (Sarmatian-Villafranchian) fluvial molasse reflecting the complex denudation of adjacent thrust plates developed within the Himalayan orogen.

1) The earliest molasse phase, represented by the Nahan Sandstone, is chiefly a multistoried, multilateral fluvial complex composed primarily of channel lag and lateral accretion deposits. In the vicinity of Haritalyangar, H. P., thirteen composite fluvial cycles evidence a greater relative thickness for the lateral accretion sandbodies than for the associated floodbasin sediments, suggesting quite rapid aggradation by a loosely sinuous stream regime in a rapidly subsiding basin analogous to the modern Indogangetic Plain. Mineralogically, these sediments are poorly sorted, fine-skewed, and predominantly phyllarenites with polymictic extraformational lag gravels. The mineralogical composition of framework grains reflects denudation of a stratigraphically normal metasedimentary terrane (Main Central Thrust sheet) yielding high-rank detritus of an inferred almadine-amphibolite facies. Sedimentary detritus is also present, but decreases considerably upwards in the molasse sequence.

2) The "Lower Alternations" reflect the development of a distinct meander belt facies distribution as a result of increased sinuosity and decreased basin subsidence. Paleosol development is noted and prolific fossil vertebrate occurrence is noted in some vertical accretion deposits. Mineralogically, the "Lower Alternations" are somewhat more mature, being predominantly poorly sorted, more strongly fine-skewed than the Nahan, and
quartzose phyllarenites. A higher grade mineral suite (kyanite), in addition to the epidote and staurolite of the Nahan, evidences continued unroofing of the metamorphosed Main Central Thrust sheet.

3) The "Upper Alternations" are sedimentologically similar to the "Lower Alternations" except being somewhat more immature. Polymictic extraformational channel lag is again evident, the channel sands being less quartzose than below. Carbonates increase noticeably and a new metamorphic suite is introduced (chlorite-sericite) possibly related to initial unroofing of the reversely metamorphosed Chail Thrust Sheet. Granitic and gneissic detritus and plutonic plagioclases having compositions and twin-law relationships similar to the Outer Himalayan intrusions (e.g. the Chor Massif) support this conclusion.

4) Pedogenic modification of most proximal and distal floodplain deposits of the "Lower Alternations" and "Upper Alternations" is present. Although hydromorphic paleosols are most abundant and are associated with the most fossiliferous horizons some pedogenic alteration seems to suggest oxisol development. In all cases, pedogenic modification is masked by the primary depositional character of the parent material.

Fossiliferous horizons appear to be generally proximal, poorly drained sites with pedogenically immature parent material. Older, well-drained pedogenically mature horizons appear poorly fossiliferous. The inter-relationships of carbon, silica (soluble), modification of sesquioxides by certain drainage characteristics, and re-arrangement of soil structure is useful in developing a model of the fossiliferous, fluventic (U.S.D.A., 1960) soils in the "Lower Alternations".
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