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Paleopedology of *Ramapithecus*-bearing sediments, North India

By Gary D. Johnson, Hanover *)

With 12 figures and 2 tables

Zusammenfassung

Es wird untersucht, inwieweit es für die Rekonstruktion des früheren Bildungsmilieus sinnvoll ist, in Verbindung mit anderen sedimentologischen Erscheinungen fossile Böden mit heranzuziehen, und zwar nach einer Analyse der Merkmale pedogenetischer Veränderungen in bestimmten Ablagerungen der Alluvialebenen in der Umgebung von Haritalyangar, Bilaspur, H. P., Indien, in denen die hominoiden Primaten *Ramapithecus* und *Dryopithecus* gefunden worden sind. Die untersuchten alluvialen Paleoböden zeigen, verglichen mit der ursprünglichen Ablagerungsstruktur, Abweichungen in ihren Eigenschaften, die durch sekundäre pedogenetische Prozesse bestimmt sind.

Die Paleoböden der Nagri-Stufe von Haritalyangar sind eisenreiche tropische Böden oder schwächere Oxiböden, die in den typischen Toposequenzen der Alluvialebenen entstanden sind und die aufgrund ihrer verschiedenen Entfernung zu alten Flußläufen alle eine etwas unterschiedliche Vergangenheit widerspiegeln.

Abstract

The utility of using fossil soils in addition to other sedimentologic evidence in reconstructing past environments is considered with a preliminary analysis of the

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character of pedogenic alteration of selected floodplain deposits which have yielded the hominoid primates *Ramapithecus* and *Dryopithecus* in the vicinity of Haritalyangar, District Bilaspur, H. P., India. The alluvial paleosols studied reflect variance of properties which are related to original depositional fabric modified by secondary pedogenic processes. The Nagri aged paleosols of Haritalyangar are ferruginous tropical soils or low-grade oxisols developed on typical floodplain toposequences, all reflecting somewhat varied histories as a function of proximity to ancient active stream courses.

Résumé

On considère ici la possibilité d'utiliser des sols fossiles en plus d'autres évidences sedimentologiques pour reconstruire les environnements du passé. On présente aussi une analyse préliminaire des caractéristiques de modifications pédogéniques de certains sédiments de plaines alluviales, qui ont livré les primates hominoïdes *Ramapithecus* et *Dryopithecus*, au voisinage de Haritalyangar, district de Bilaspur, H. P., Inde. Les paléosols alluviaux étudiés révèlent diverses propriétés caractéristiques de dépôts originaux, modifiés par des processus pédogéniques secondaires. Les vieux paléosols de Nagri, aux environs de Haritalyangar, sont des oxisols peu évolués, formés sur des séquence topographique typique de plaines alluviales. Tous reflètent quelque peu des stages divers selon leur proximité d'anciens cours fluviatiles actifs.

Краткое содержание

Проверили насколько является необходимым для реконструкции прежней среды привлекать, наряду с иными седиментологическими проявлениями, и вмещающие окаманелости древние почвы, и именно после оценки педогенетических изменений в известных отложениях аллювияльной равнины, в которых у Haritalyangar'a, Bilaspur'a H.P., Индия, обнаружили останки гоминоидных приметов рамапитека и дриопитека. Исследования древних аллювиальных палеопочв показало, что изменения их характеристик по отношению к первичным отложениям, вызваны вторичными педогенетическими процессами.

Древние почвы яруса Нагри в Haritalyangar являются или же богатые железом тропические почвы, или же слабо окисленные почвы, возникшие в типичных свитах аллювиальной равнины и, в результате их близости к древним речным руслам, могут до некоторой степени отражать их различное прошлое.

Introduction

Alluvial facies form a substantial part of the molasse deposits associated with the South Asian alpide system. In the northern part of the Himalayan exogeosyncline upwards of 7000 meters of alternating sandstone/mudstone couplets record the progressive unroofing of the Himalayas during the Neogene and Quaternary. These sediments, the Siwalik Group of North India and Pakistan, known from various localities along the Himalayan foothills, additionally represent one of the most continuous and complete records of mammalian faunal evolution recognized in the world.

The Siwalik Group as exposed in the Potwar Plateau area of Pakistan and in the Siwalik Hills of the Himalayan foothill belt of India (Fig. 1), have long been considered both the stratatype for South Asia Land Mammal Ages, and an important fossil hominoid primate-yielding sedimentary interval. As a result, considerable interest in the vertebrate paleontology of this sequence has been maintained over the years with the result that several rather extensive faunal

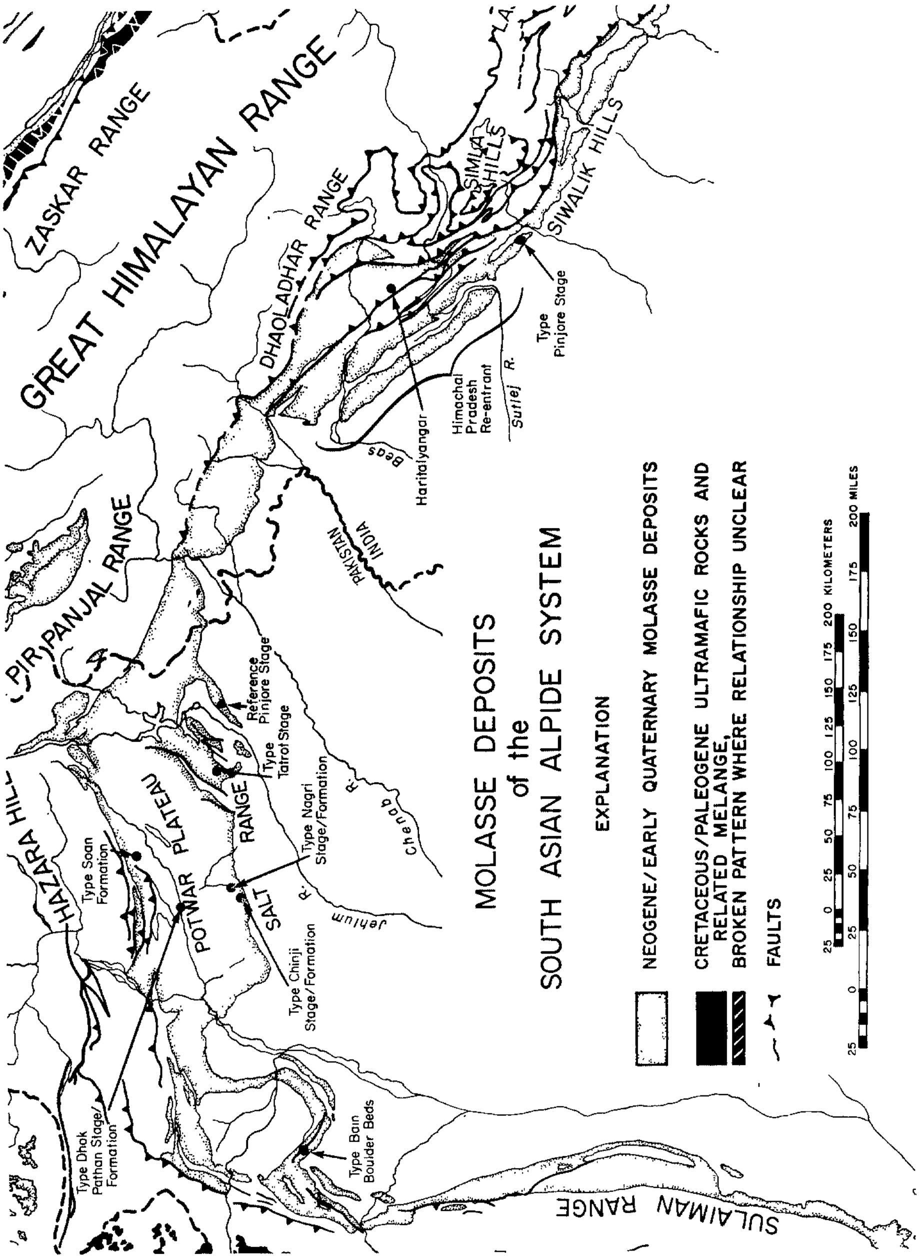

Fig. 1. Molasse deposits of the South Asian alpide system showing the distribution of Neogene/Early Quarternary fluvial molasse in the faulted and folded northern margin of the Himalayan exogeosyncline.

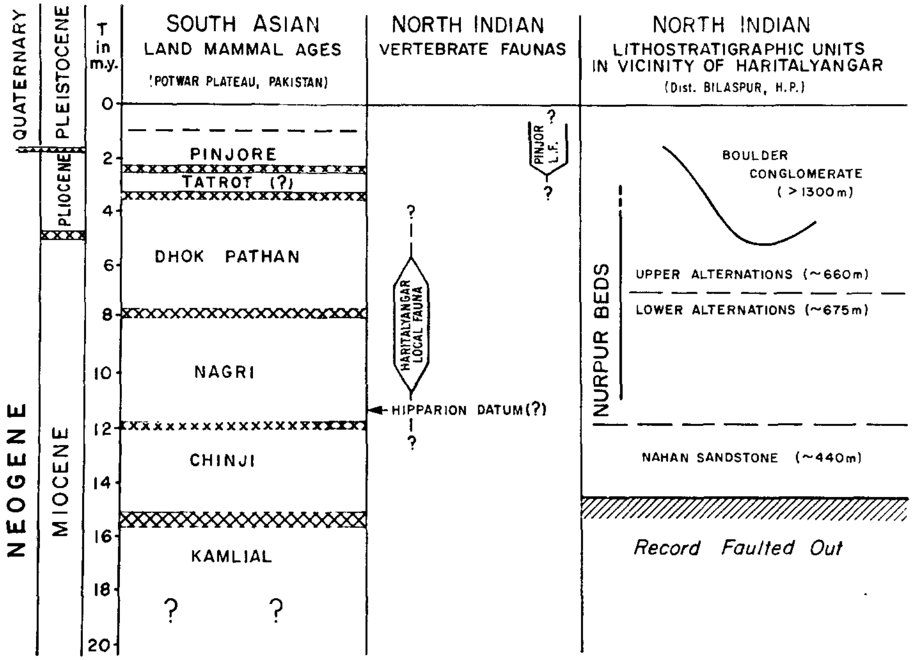

Fig. 2. Relationship of South Asian Neogene/Quaternary mammalian biochronology to the Haritalyangar (India) local fauna and the lithostratigraphic sequence exposed near Haritalyangar.

collections have been made and intensively studied (PILGRIM, 1910, 1913; MATTHEW, 1929; COLBERT, 1935; LEWIS, 1937; DEHM et al., 1958, 1963; HUSSAIN, 1971; HEISSIG, 1972).

Unfortunately the same intensity of the study has not been afforded the lithostratigraphy of the Siwalik Group. Aside from several studies of the gross sedimentological character of the sequence (COTTER, 1933; KRYNINE, 1937; GILL, 1951; MISRA & VALDIYA, 1961; SAHNI & MATHUR, 1964) only a few have attempted to characterize the specific mode of deposition of Siwalik rocks (JOHNSON & VONDRA, 1972; HALSTEAD & NANDA, 1973).

Recent interpretations of the paleoecology of *Dryopithecus* and *Ramapithecus*-bearing sediments from the middle part of the Siwalik Group (the Nagri Formation and equivalent intervals) have been made based on the comparison of fossil mammalian assemblages with their modern extant counterparts (TATTERSALL, 1969 a, 1969 b; LEAKEY, 1969; PRASAD, 1971). These interpretations, based on the composition of Nagri fauna (Fig. 2) from localities in the southern Potwar Plateau (Pakistan) and from the vicinity of Haritalyangar, District Bilaspur, H. P. (India), erect a paleosynecology suggestive of gallery forests developed along streams meandering through a rather closed mixed grassland-tree savanna (TATTERSALL, 1969 a). The lack of an open grassland vegetative physiognomy in Nagri time is fairly well agreed upon by the above workers, including KRYNINE (1937), in his treatment of Siwalik sedimentological trends. Just when in the sequence a typical open savanna physiognomy developed is not well documented, but the general consensus (Krynine, 1937; Tattersall, 1969 b; Prasad, 1971) places this within the Dhok Pathan. The Nagri therefore must record this transition from presumably grassy woodlands to grassland savanna — a record of increased seasonality of rainfall distribution.

Although the alluvial character of the Siwalik sequence is well established, little specific paleoenvironmental/paleoclimatic data exists to aid in the interpretation of the compositional changes which are observed in the faunal succession. Many of the individual fluvial lithosomes of the Siwalik Group however contain evidence of postdepositional "overprinting" of original depositional fabric by soil forming processes such that the original depositional character of these sediments is modified. It is with this in mind that data are presented concerning the fossil soils associated with Nagri aged alluvial sediments in hopes of providing a faunally independent interpretation of the paleoenvironment/paleoclimate of the time.

Alluvial Morphology and Soil Development

Soil development on an alluvial landscape stands apart from pedogenesis in "upland" environments in several ways. Insufficient residence time on the landscape for detectable horizonation, non-uniform parent material addition, variable lithologic boundaries, irregular distribution of alluvial lithotopes, and a depositional mechanism contemporary with soil formation all contribute to complicate the genetic interpretation of alluvial or cumulative soils (Nikiforoff, 1949; Soil Survey Staff, 1960, 1967).

Cumulative soils develop on parent material which is not static, but which is undergoing a slow and steady process of upbuilding by increment additions of sediment (alluvial, colluvial, eolian). Additionally, the sequence of subsequent soil horizonation differs from the ABC horizonation of non-cumulative soil types. It is more than just C horizon material (alluvium in the sense of this discussion) being transformed to an A_1 or B horizon directly; it involves the transformation of new surficial parent material into a new A_1 and transformation of the former A_1 into a B horizon (Folks, 1954; Plyusnin, 1960; Riecken & Poetsch, 1960; Dan & Yaalon, 1971). Such modification of prior sola (A and B horizons) into undifferentiated subhorizons may be just the reason why many paleopedological studies recognize only B or C horizons and consider the lack of an A horizon to be due to subsequent erosional loss from the profile (Gibbs, 1971).

Increment addition of new parent material to the soil 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 (Soil Survey Staff, 1960, 1967). More than likely, however, increment addition will impose a new initial condition with the subsequent changes mentioned above affecting the profile. In the environment distal to the influence of the main fluvial channel, pedogenic processes are in pace with sedimentation; in the more proximal localities, sedimentation overshadows pedogenesis, with the resultant horizonation being less well-developed (Folks, 1954; Plyusnin, 1960). Soil development in the cumulative environment is an extremely variable factor; adjacent landforms on the alluvial plain may

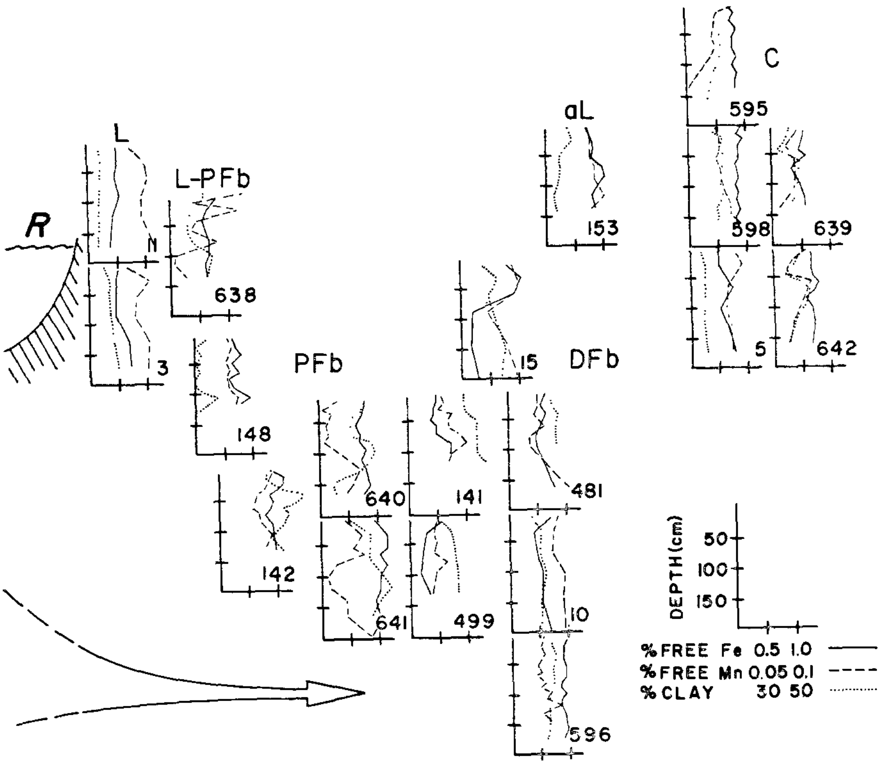

Fig. 3. Clay and Na-dithionite-citrate extractable oxide variation within soil profiles developed on Missouri River floodplain toposequence, U.S.A. (Lat. 42° N; Long. 96° 15′ W). Brunizem and humic-gley soils are potential in the area. Sites for individual profiles positioned on diagram according to principal physiographic feature with which they are associated: L, levee; L-PFb, levee-proximal floodbasin; PFb, proximal floodbasin; DFb, distal floodbasin; aL, abandoned levee; C, colluvium. Depth and parameter values for ordinate and abcissa of each profile are the same. See lower right for explanation. Arrow points in direction of decreasing influence by stream, R, on floodbasin. Soil names as follows: 3, 11, Kennebec zl; 5, Napier zl; 10, 598, Colo zcl; 15, McPaul zl; 141, Lutton zc; 142, Albaton zc; 148, Haynie zl; 153, Salix zcl; 481, 499, Zook zcl; 595, Ely zcl; 638, 639, 642, Coppock zl; 640, Chequest zcl; 641, Carlow zcl. Interpretation by G. D. J. Original profile data from de Leon (1961).

have grossly different histories in terms of their sedimentation record and the extent to which increment sediment addition has taken place.

An example of this variability in coexisting soils from adjacent sites is illustrated in Fig. 3. In this example, modern, temperate climate, floodplain soils developed within a stream reach of well-developed meander belt physiognomy show considerable compositional variation. Texture and Na-dithionite-citrate-extractable (di-Fe_2O_3, di-MnO) oxide distribution within individual profiles and among adjacent profiles are extremely variable.

Clay distribution within alluvial soil profiles generally tends to reflect the depositional process, proximality and energy relationships of the depositing medium and minor evidence of pedogenic processes. Pedogenic clay translocation where identifiable is most evident in distal floodbasin environments. di-Fe_2O_3 distribution generally mirrors clay content, depositional or pedogenic. Even with young sediments, the oxide distribution follows the clay curve.

di-MnO distribution reflects a greater degree of leaching within most profiles. In the more poorly drained, topographically low-level sites, there is a direct response of Mn to pH of the soil water: i. e., increased mobility with lower pH.

If preserved in the rock record, these soils — as paleosols — would be most difficult to interpret without knowledge as to their position on the ancient alluvial landscape. The properties illustrated in Fig. 3, however, can be observed in most ancient soil profiles. Indeed, the distribution of mobile oxides and various fabric traits in paleosols reflect the relict results of earlier pedogenesis.

Stratigraphy of the Siwalik Succession at Haritalyangar

The sequence of fossilferous pedogenically modified fluvial sediments of the Siwalik Group exposed in the vicinity of Haritalyangar, District Bilaspur, H. P. (India) represents nearly 3000 meters of freshwater molasse, the product of the complex denudation of adjacent thrust masses in the Himalayan orogen during the Neogene (Johnson, 1971). In northern India the Siwalik Group is exposed in several thrust plates developed in the folded and faulted northern margin of the Himalayan exogeosyncline. One of these thrust plates carries the Haritalyangar sequence, which is one of the most fossiliferous and best exposed in the entire foothill belt.

Prior stratigraphic studies in this region (Lewis, 1932; Gill, 1951; Chaudhri & Gupta, 1969; Johnson & Vondra, 1972) aimed at elucidating the paleoenvironment of these important hominoid primate yielding sediments have differentiated several distinct lithostratigraphic units which are locally mappable, but which are of questionable use in regional lithologic correlations due to the usual quirks of fluvial sedimentation.

Useful lithostratigraphic units which are recognizable in the field have been proposed by Gill (1951) for the region of Plate C (Fig. 4) and have been extended earlier to the Haritalyangar sequence (Vondra & Johnson, 1968).

The principal fossiliferous horizons of the Haritalyangar area occur within the "Lower" and "Upper Alternations" (Figs. 5 and 6). Specific sites yielding the aforementioned dryopithecine and hominid fauna are restricted to the "Lower Alternations" [1]).

Paleopedology of Ramapithecus-and-Dryopithecus-Yielding Sites

In an effort to systematically study the fluvial sediments of the Haritalyangar area, the known genetic relationships of fluvial sand bodies to immediately over-

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[1]) The recovery of one specimen of *R. punjabicus* (form. *R. brevirostris*) (YPM 13 799) which was initially reported (Lewis, 1934) to have been found from a horizon near the top of the "Upper Alternations" (fluvial cycles 71—73) may be an exception. Subsequent study of this specimen (Lewis, 1937; Simons, 1968), however, has suggested that, it probably came from the fossiliferous "Lower Alternations", specifically, the cuesta scarp which has yielded most of the prior primate collections, up-section from and to the east of Haritalyangar (fluvial cycles 37—38; 42—44) (Figs. 6, 7 and 8).

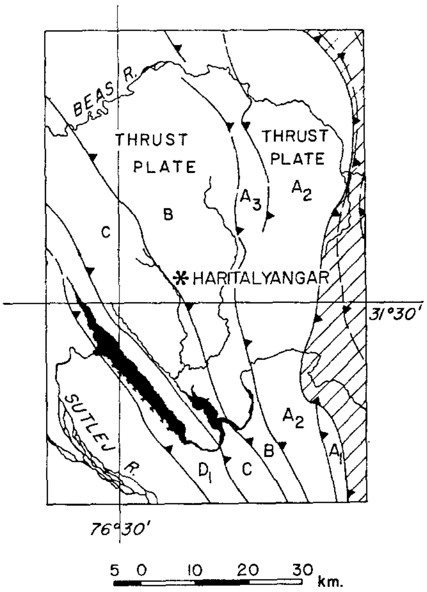

Fig. 4. Tectonic sketch map of the Haritalyangar (India) area. Individual thrust plates of the Himalayan paraautochthon are labeled. Undifferentiated thrust plates of the Himalayan allochthon are represented by "hatchered" pattern.

lying mudstone intervals was utilized (see Allen, 1965). Any sedimentary unit can thus be discussed in terms of its position in a sandstone-mudstone couplet, that is, a fluvial cycle. In all about 80 fluvial cycles can be recognized in the Siwalik interval at Haritalyangar (Johnson & Vondra, 1972). Those of the "Lower Alternations" (fluvial cycles 13—52) (Fig. 5) reflect the development of a well defined meander belt physiognomy with distinct proximal to distal facies variability within the vertical accretion floodplain (overbank) deposits. With few exceptions, the channel sand bodies of the "Lower Alternations" are not multistoried but reflect single phase erosion and lateral accretion (Fig. 7). This is not the case with the floodplain mudstones; multistoried alluvium and splay sandstones often reach considerable thickness as in the hominoid-bearing vertical accretion deposits along Hari Mandar dhar (the cuesta scarp of some workers) (Figs. 5, 6 and 8).

Field evidence from fluvial cycles No. 37—38 and No. 42—44 (Figs. 5 and 6) indicates that the most fossiliferous localities of the Haritalyangar sequence lie in proximal position to adjacent channels, stratification indicating a definite floodbasin environment. Few lateral accretionary facies yielded bone. Apparent fossil soils exist within much of the "Lower Alternations" interval and were sampled frequently.

From what limited catenary relationships which can be deduced (due to conditions of outcrop), paleosol profile No. 54 (selected from fluvial cycles No. 37 to 38) lies in near toe-slope position lateral from an adjacent levee deposit. Intercalated within the cycle are several thin (0.3—0.8 m) splay sands. Paleosol profile No. 60 (selected from fluvial cycles No. 42—44) was developed in a more

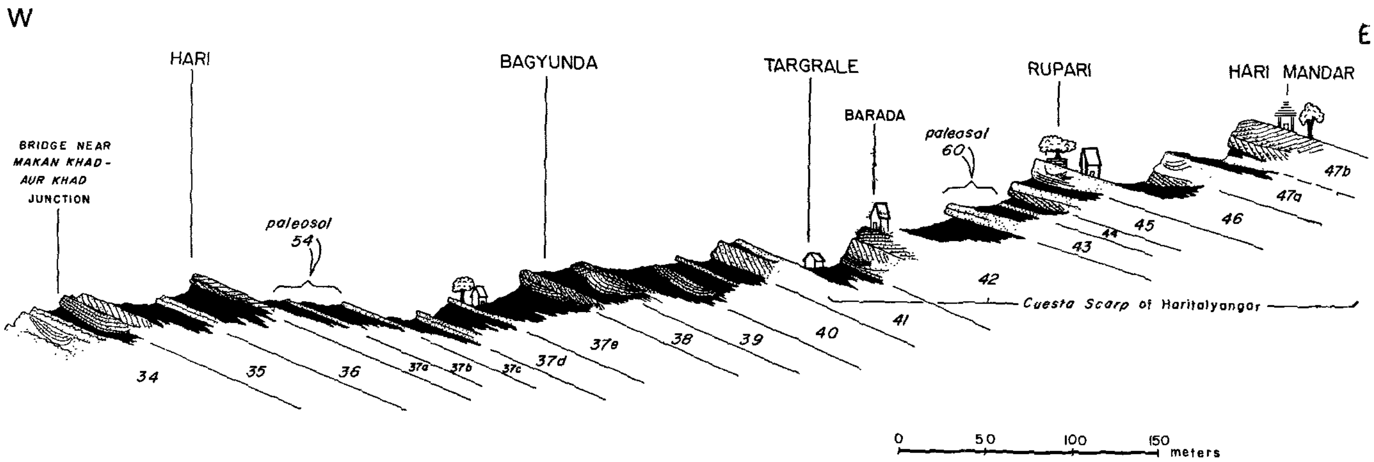

Fig. 5. Schematic profile of "Lower Alternations" outcrop in the vicinity of Haritalyangar (India).

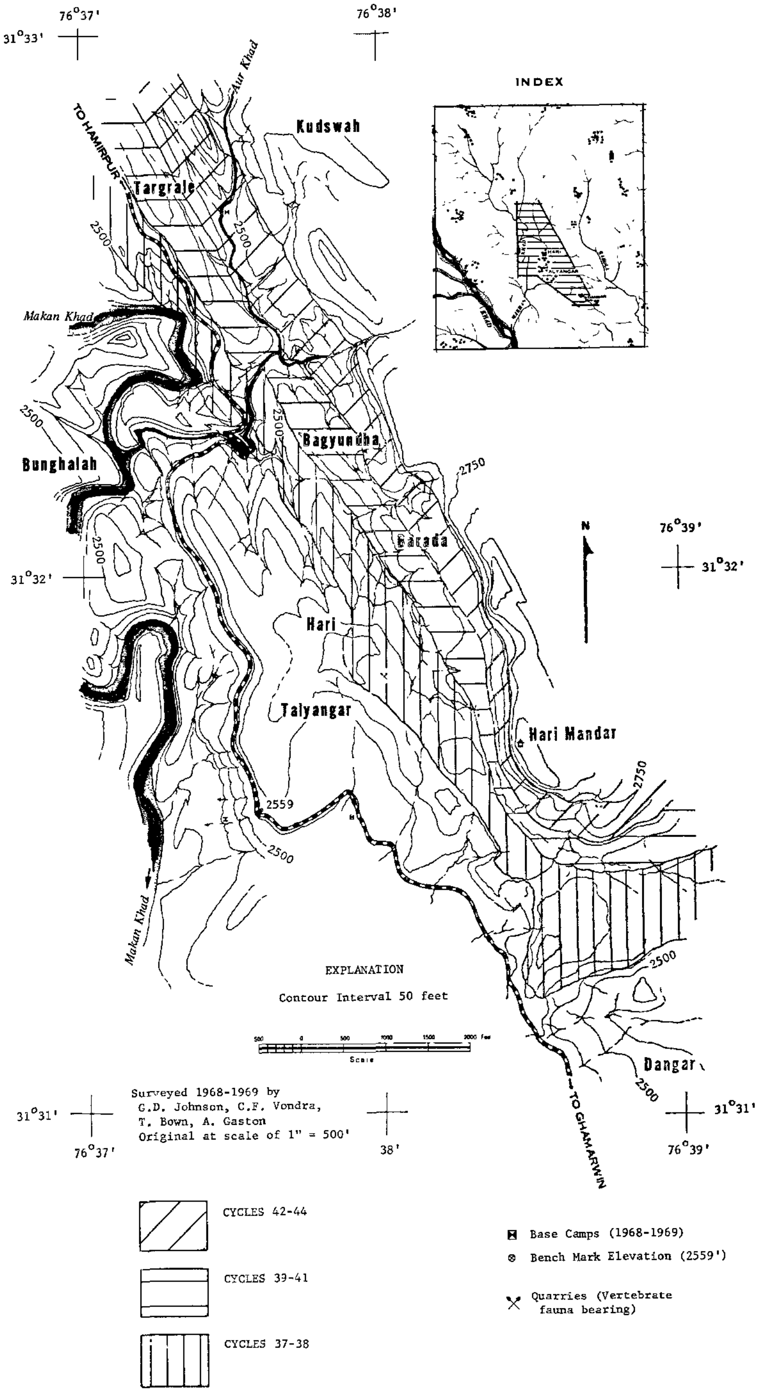

Fig. 6. Areal distribution of important hominoid-bearing fluvial sediments in the vicinity of Haritalyangar (India). Channel lag, lateral accretion, and genetically related vertical accretion facies are recognized and are represented in the map units indicated. See Fig. 5 for cross-sectional representation of the interval from fluvial cycle No. 37 to No. 44.

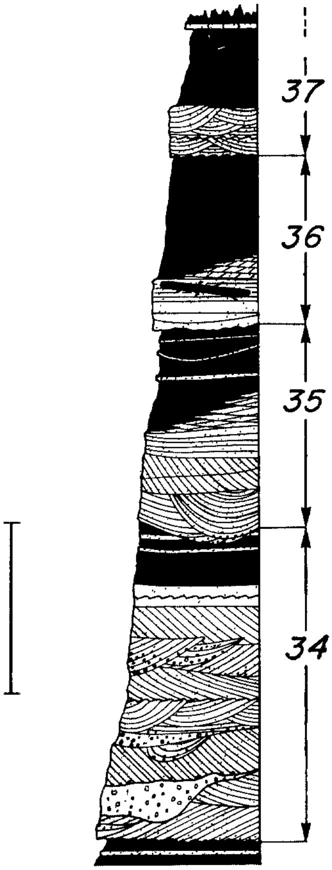

Fig. 7. Schematic representation of a portion of the "Lower Alternations" sequence exposed near Haritalyangar (India). Fluvial cycles No. 34, No. 35, and No. 36 are illustrated. Channel lag and lateral accretion deposits represented by dominant bed form. Vertical accretion (overbank or flood basin) deposits and associated paleosols are in black. Length of vertical bar 16 meters.

distal position on the floodplain and involved the increment addition of sediment to an abandoned levee deposit. With these two examples defined, subtantive soil genetic evaluation of the Nagri floodplain environment and its catenary limits is attempted.

Determination of free (Na-dithionite-citrate-extractable) oxides (Al, Fe, Mn) was accomplished by atomic absorption spectroscopy (PERKIN-ELMER, 1968) from extracts prepared according to Holmgren's (HOLMGREN,1967) sodium dithionite-citrate method. In this context, free oxides are defined *sensu* OLSON (1965) and BLUME & 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 element analysis; values indicate the Na-dithionite-citrate extractable

Fig. 8. The cuesta scarp (Hari Mandar Dhar) up section and to the east of Haritalyangar (India). View is to south. Fluvial cycles No. 42 to No. 46 are exposed. Prominent sandstone in upper left represents the channel lag and lateral accretion (point bar) facies of fluvial cycle No. 45.

oxides only. Soluble (Na-dithionite-citrate extractable) silica was similarly determined from the above extracts. Total carbon was analyzed by thermal-conductivity of evolved CO_2 from high-temperature sample combustion. Analysis was instrumented on a LECO (Laboratory Equipment Corp., St. Joseph, Mich.) automatic 70-second carbon analyzer according to procedure outlined by (Tabatabai & Bremner, 1970, and Foscolos & Barefoot, 1970). Sample size was increased on an average of 25% above that used by Tabatabai & Bremner (0.2—0.3 g) due to the low values encountered. Samples larger than 0.5 g were judged too large due to incomplete combustion 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 fluvial cycles No. 37—38 and No. 42—44 using a Ruska Mercury Capillary Apparatus (mercury porosimeter) with an operational pressuring capacity of 2000 psi. This provided an equivalent diameter minimum pore entry radii resolution of $0.60\,\mu$ (600 A), a value including most capillarity in modern soils (Diamond, 1970).

Profile data on less than $2\,\mu$ clay seems to suggest little evidence of translocation in each fluvial cycle illustrated (Figs. 9 a and 9 b). The occurrence of three possible argillic horizons in profile No. 54 and four in profile No. 60 can be verified on the basis of field observation. Profile No. 54 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), a mean effective porosity of 1.80% seems to further corroborate the immature nature of the pedogenesis in this profile.

Data on sequence No. 60 similarly reflect proximity to channel influence. The paleosol was developed on distal levee sediments. The four possible argillic horizons show little evidence of being more than sedimentological layers. Bulk density (bulk specific weight) variation and porosity data supports this contention. Textural and fabric data from thin-sections indicate no translocated clay which show clay skins and the oriented fabric, the diagnostic properties of argillic horizons in modern soils (Soil Survey Staff, 1960, 1967). 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 variability of physical properties at different levels within the profile was minimal, the entire profile being affected essentially the same during compaction and lithification.

Data on the Na-dithionite-citrate extractable oxides points up a disparity in the two profiles under consideration: profile No. 60 shows an irregular, poorly developed sesquioxide profile peaking at the 1-meter depth (0.99% di-Al_2O_3; 2.89% di-Fe_2O_3), 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 $2\,\mu$ clay + medium and fine silt curve.

Free di-MnO distribution generally reflects a maximum profile occurrence at a level below both the free aluminum and free oxide peaks (Figs. 9 a and 9 b). There is, however, no apparent relationship between di-MnO and clay content in these paleosols, an observation shared on other paleosols from the Eocene of the western U.S. (NEASHAM & VONDRA, 1972), and in modern soils of temperate floodplains (DE LEON 1961). Effective porosity values of the lithified floodplain deposits and percent di-MnO exhibit a positive correlation, which is a probable relict pedogenic property. Poorly drained (low porosity) soils exhibit high mobility of several pedogenic oxides with the result of greater depletion of these oxides with decreased drainage.

Several interesting relationships observed in modern soils (DE LEON, 1961) are replicated in the two profiles in question. A ratio of maximum percent di-MnO to minimum percent di-MnO (Max. % Mn/Min. % Mn) in some modern soils can define drainage class. In the case of profile No. 54, 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 A_1. Organic carbon was detectable (0.018—0.200% C) at several levels in profiles No. 54 and No. 60 (Table 1) 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) and root (see Fig. 11 D), lend support to this conclusion. Fairly high ratios (ranging from 47 to 81) of Fe to Mn (% di-Fe_2O_3/% di-MnO)

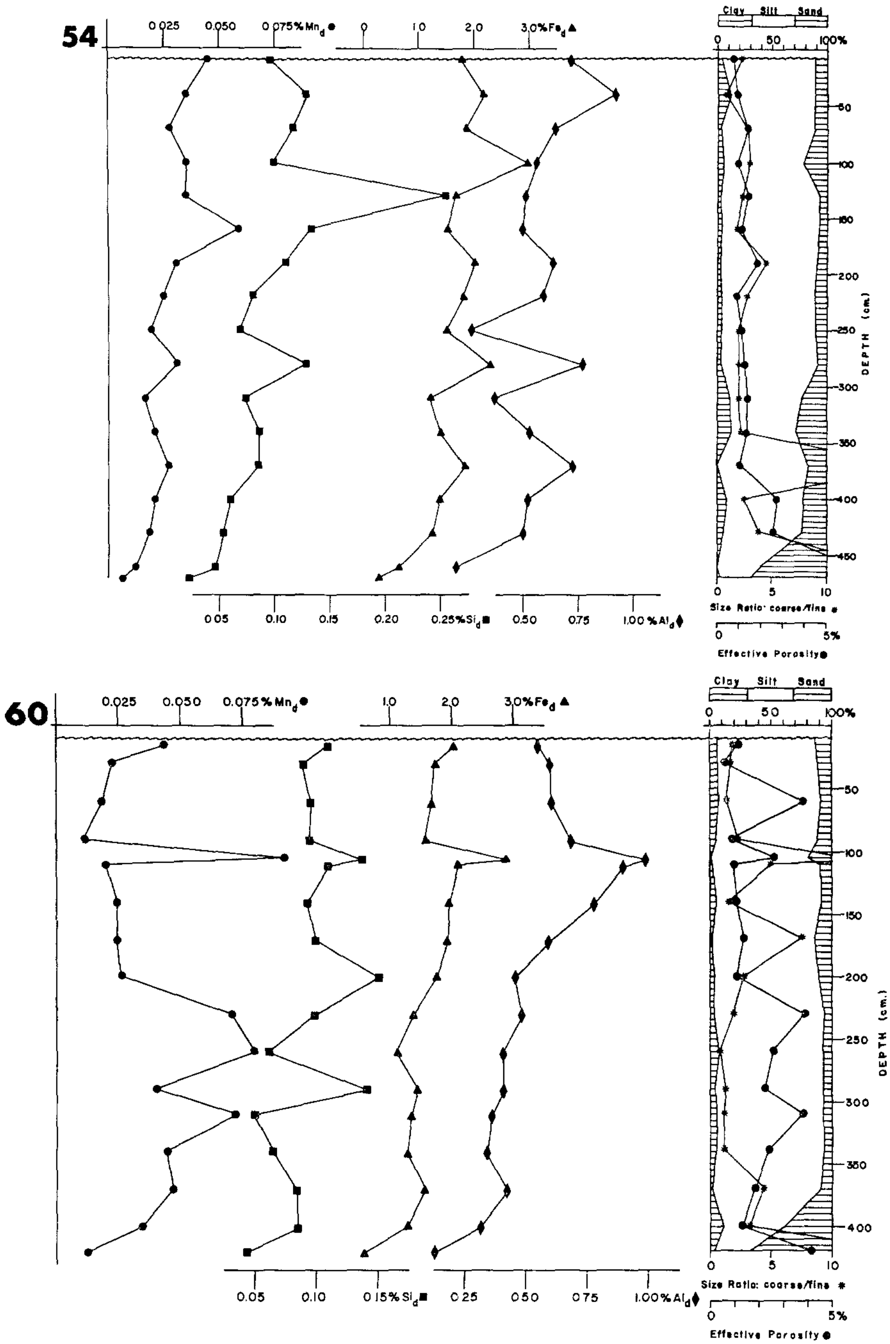

Fig. 9 a and 9 b. Particle size, effective porosity and Na-dithionite-citrate-extractable oxide distribution within profiles selected from two Nagri-aged paleosols near Haritalyangar (India). 9 a). Profile No. 54 from fluvial cycle 37. 9 b). Profile No. 60 from fluvial cycle 42.

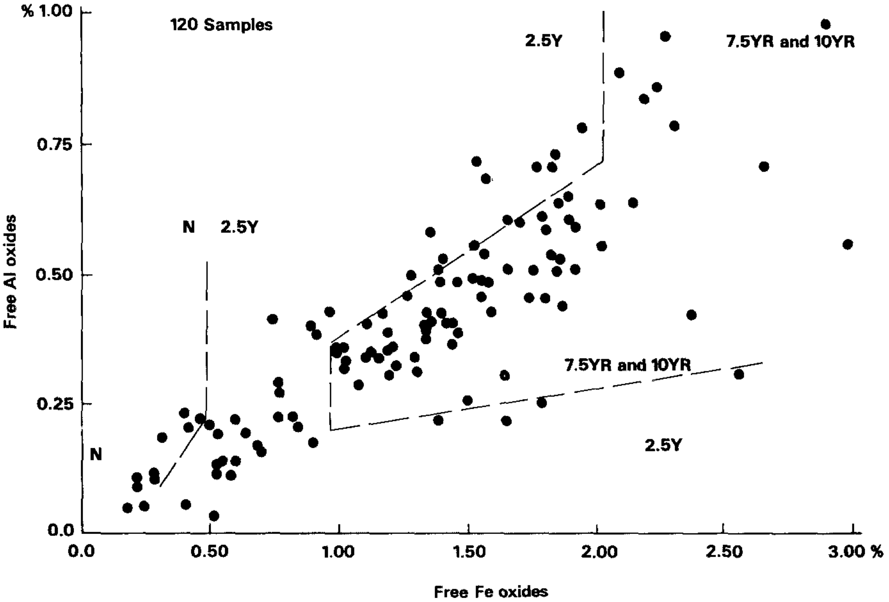

Fig. 10. Plot of Na-dithionite-citrate-extractable Al_2O_3 (di-Al_2O_3) vs. Na-dithionite-citrate-extractable Fe_2O_3 (di-Fe_2O_3) relative to Munsell color hue. From the "Lower Alternations" and "Upper Alternations" near Haritalyangar (India).

gives 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.

Variegated coloration of ancient floodplain sediments has been previously used as evidence of soil weathering. The relationship between the Na-dithionite-citrate-extractable sesquioxides and Munsell color hue is illustrated in Fig. 10. As noted, the redder hues (7.5 YR and 10 YR) exhibit greater sesquioxide values. These values are for non-mottled sediments. 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.

Fig. 11 indicates a lateral sequence of fresh to bioturbated sediment occurring in the proximal floodplain sequence just below cycle No. 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). Original slack-water vertical accretion siltstones (Fig. 11 a) are homogenized (Figs. 11 b and 11 c) such that only some relict texture remains. Earthworm burrows and plant rootlets are evident in part of the homogenized unit (Figs. 11 c and 11 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 coloration (Munsell color 5 B 7/1). Large tubulars structures (up to 5 cm dia.) have been noted, although rare, and occur within variegated mudstones containing the potamonid crab *Potamon emphysetum* (Alcock 1909) 2).

Since detrital carbonate clasts constitute a minor component (~ 7% of the lithic fraction of "Lower Alternations" sandstones (compositional average: Q = 60%; F = 5%; RF (L) = 35% [Johnson & Vondra, 1972]), most of the variation of $CaCO_3$ in the profiles, while not following a regular trend, probably reflects parent material variation. The major differences noted in the two catenary extremes (paleosols No. 54 and No. 60) (Table 1) are interpreted as reflecting textural variation on the paleo-landscape and its subsequent influence on drainage characteristics.

Table 1. Co$_3$-C and organic-C content of Nagri paleosols ("Lower Alternations", Siwalik Group).

Physiographic Unit	Profile Number	Depth (cm.)	CO_3-C (pct)	Organic-C (pct)
Floodbasin, proximal	54	10	2.754	Tr
		40	0.011	
		70	0.020	
		100	0.011	
		130	0.029	
		160	0.143	Tr
		190	Tr	
		220	0.024	
		250	0.019	Tr
		280	0.013	
		310	0.140	
		340	0.011	
		370	0.012	
		400	0.007	
		430	0.006	
		460	0.017	
		470	0.038	
Levee, abandoned distal	60	15	0.105	
		30	0.147	
		60	0.013	Tr
		90	0.141	
		105	0.094	
		110	0.044	
		140	0.025	
		170	0.013	
		200	0.012	
		230	2.648	Tr
		260	2.155	Tr
		290	0.066	
		310	0.402	Tr
		340	0.367	Tr
		370	0.537	Tr
		400	0.080	
		420	0.031	

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2) Specimens identified by Dr. R. Bott, Natur-Museum und Forschungs-Institut Senckenberg, Frankfurt am Main, Germany.

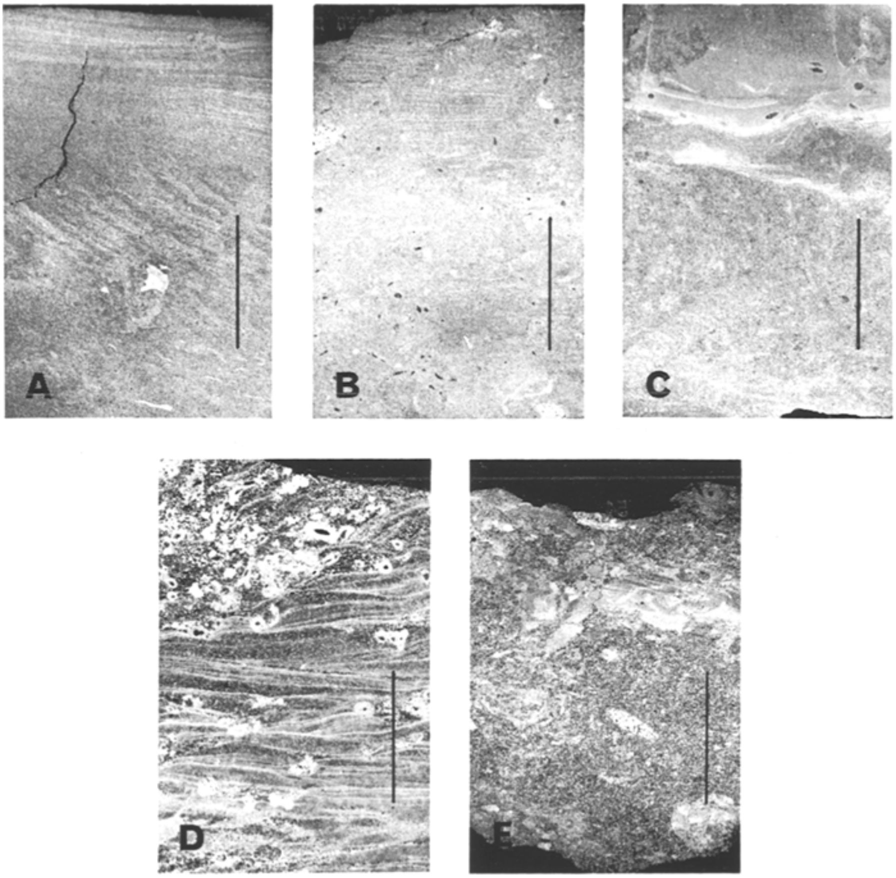

Fig. 11. Bioturbation and associated fabric features in floodplain paleosols of the "Lower Alternations". (Negative prints of thin-sections.) Length of vertical bar 1 cm. A. Undisturbed slack-water siltstones occurring in proximal position on the floodplain. B. Bioturbated slack-water siltstones occurring five meters laterally from A. 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.

The occurrence of silica in the form of amorphous silica phytoliths (material formed in and around plant cells from soluble silica taken up by plants as silicic acid) is common in most plants, being a very abundant constituent in grasses (BAKER, 1959). Leaf litter and other plant debris accumulating on a land surface will therefore contribute abundant phytoliths to the sedimentary record (SMITHSON, 1956). Increment addition of new parent material to the floodplain environment will result in the concentration of these siliceous silt-sized particles in horizons representing buried land surfaces.

The grasses and fresh-water algae are not the only abundant plant form possessing secretory cells (lithocysts) producing fine-silt sized (0.006—0.008 mm [7 ϕ]) particles. Most plant taxa exhibit cystolith-containing cells which may produce detrital particles as large as 0.0625 (4 ϕ) in diameter (Esau, 1965). It would appear that any reasonable period of organic litter accumulation on a landscape could result in a considerable concentration of these organoclastic particles to the point where cyclicity of overbank flooding may be determined from these buried accumulations.

The geochemical stability of plant silica under variable soil conditions has not been fully tested, but is quite soluble above pH 9.0 (Pease, 1967). The effects of diagenesis also have not been evaluated, but there is at least some conversion to chalcedony. 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 (Na-dithionite-citrate extractable) was made from samples from each paleosols sampled. The results of the analyses on profiles No. 54 and No. 60 are illustrated in Figs. 9 a and 9 b. Percent di-SiO_2 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 di-SiO_2 content and sediments with a hue of 7.5 YR. 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 phytolithic 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 is 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 clays may tend to support evidence for such clay transformation taking place, even in these immature soils.

Discussion

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. Clay distribution within soil profiles reflects dominant depositional processes, proximity to, and energy relationships of the depositional medium, with little pedogenic alteration. Pedogenic clay translocation appears most evident in distal floodplain environments on high-level sites.

The influence that depositional landforms have on soils of the floodplain is considerable. Abandoned channelways (oxbow cutoffs), 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 (ALLEN, 1965). Because of their low-lying position, they invariably are 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 texture exhibited by these alluvial landforms.

The loss of soluble components from the profile is a natural response to these 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. In higher level areas where drainage is unrestricted, the soluble components are completely lost. As expected, there is a direct correlation between landscape position and clay translocation. Soils formed on summit positions have developed deeper A horizons than soils on low landscape positions for synchronous deposits. With proximity to the stream course and time since increment sediment addition, most workers have observed stratigraphically higher minima and stratigraphically lower maxima in the clay curve.

Data from numerous sources 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. In poorly-drained soils, however, there may be no observed parallelism of clay and iron oxides. Using Fe-Mn ratio, Fe-clay ratio, Mn-clay ratio, it has been possible to differentiate drainage classes and relative mobilities of components in various floodplain environments.

Data on the initial changes occurring in Recent alluvium (PONS & ZONNEVELD, 1965), when applied to the Siwalik sequence, strongly suggest 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 of this, see PONS & ZONNEVELD, 1965). Accordingly, the first event in homogenization or destruction of depositional fabric is brought about by burrowing organisms notably freshwater crabs and lumbricid worms. Although this occurs while some sediments are water-logged following flood and/or are poorly-drained the effect is generally noted in that portion of the profile lying above the normal saturated zone (PONS & ZONNEVELD, 1965). The zone of bioturbation, however, can be quite deep depending on the depth to the water table: during the dry season some modern Indian lumbricids migrate over 10 feet vertically in the soil profile (BARNES, 1968).

In general the immaturity of the Nagri aged soils is supported by the clay distribution data. Most temperate and tropical soils show a positive relationship of depth of the clay maxima to relative soil age. In profiles No. 54 and No. 60 the relatively flat clay curves preclude very old soils. The apparent occurrence of free Fe_2O_3 minima in presumed A-horizon strata (e. g. from 0—90 cm depth in profile No. 60) and maxima in presumed B-horizon strata (e. g. from 95 to 260 cm depth in profile No. 60) indicates illuviation of iron within the profile.

In this instance Fe_2O_3 behaves as a discrete particulate phase (probably in the silt-sized fraction) subject to translocation, a relationship not uncommon in extant red savanna soils (Blume & Schwertmann, 1969; Asamoa, 1973).

The similarity of Nagri aged paleosols to extant ferruginous tropical soils developed under a savanna-woodland vegetative physiognomy is striking. Red alluvial soils of the mixed grassland/semi-deciduous forest zone of Ghana (Asamoa, 1973), the cerradâo and campo cerrado Brazil, the humid savannas of the Columbian Llanos, and the mixed deciduous woodland of the Sudan all seem to typify this development.

Relatively few botanical remains have been studied from the Siwalik Group of Northwestern India, most studies having been carried out to the southeast in Assam and the Northeast Frontier Agency in equivalent strata. Several recent investigations have shed some light on probable, vegetative associations in the Siwaliks, specifically the "Lower Alternations" floodplain mudstones and their equivalents in adjacent thrust plates (Bannerje, 1968; Lakhanpal, 1967, 1968).

Although collections are small and from limited, scattered areas, all have been collected from (drab, yellowish-hued, 2.5 Y) floodplain mudstones. Carbonaceous plant impressions are not abundant in the red sediments. Most are found in the more distal, yet pedogenically immature sediments of the floodplain. In these environments, bioturbation macerates most larger foliage, but much remains identifiable.

The data summarized in Table 2 suggests that upland taxa, mainly the Coniferae and Dipterocarpaceae with subordinate Rhamnaceae, may be good indicators of the regional vegetative structure. Taxa associated with more hydromorphic soils (Moraceae, etc.) reflect more local edaphic variation. The overall structure of this somewhat ill defined plant community does show definite similarity to the above mentioned mixed semi-deciduous forest/savanna complexes of Africa and South America. Certainly the persistence of such forms as *Ficus cunia, Zyzyphus incurva* and *Berchemia floribunda* in the moist sub-Himalayas of Nepal to Burma and of the large *Dipterocarpus* and *Anisoptera* gallery forest components in Assam and Burma complement these interpretations

Summary

For the Siwalik Nagri Zone paleosols, sedimentologic and pedogenic evidence suggest low-lying, sub-tropical to tropical alluvial plain environments. The multivertical overbank alluvial deposits contain composited or superimposed evidence of fairly intense weathering associated with each increment parent material addition. Similarity to modern soils of like environments suggests a ferrugenous tropical or low grade oxisol soil type developed under alternating wet and dry seasons. Prolonged residence time of some paleosols on the Nagri paleolandscape contributed to an increased intensity of development. This interpretation can be summarized in Fig. 12.

Although the increasing influence of the Himalayan orogen to the north of the Siwalik molasse basin is a factor to be reckoned with in any paleoenvironmental-paleoclimatic reconstruction of the South Asian Neogene, Nagri time is early in its eventual development as an orographic barrier to the seasonal monsoon. A prograding alluvial-deltaic system in the Indus and the Bramaputra/Ganga allu-

Table 2. List of fossil flora found in Nagri-aged sediments of the northern Punjab and Himachal Pradesh, India. Inferred habitat for each fossil form is based on known distribution of extant counterparts.

Floral List	Edaphic Habit			
	Upland		Lowland		
	Well Drained Site	Poorly Drained Site	Well Drained Site	Poorly Drained Site	Ripparian
Coniferae					
cf *Dacrydium* sp. 5)	XX				
Pinus sp. 5) (Pine)	XX				
Gramineae (Poaceae) 5) (grasses)					
cf. *Poa* sp. 3) *)	XX	XX	XX	XX	
Palmae					
cf. *Cocos* sp. 5) (Pineapple)	XX		XX		
Palmoxylon sps. 3) (Palm)		XX	XX	XX	XX
Compositae 5) (herbs)	XX	XX	XX	XX	
Moraceae					
Ficus sp. 6) (Fig)		XX		XX	XX
Rhamnaceae					
Phyllogeiton (Berchemia) sp. 4)		XX		XX	
Zyzyphus sp. 4)	XX		XX		
Dipterocarpaceae 1) (large resinous trees)					
cf. *Dipterocarpus* sp. 2)	XX		XX		
cf. *Anisoptera* sp. 1)	XX		XX		XX
Polypodiaceae 5) (Pteridophytes)	XX	XX	XX	XX	XX

1) Ghosh & Ghosh, 1958; Floral list, Middle Siwaliks, Jawalamukhi, H. P.
2) Rawat, 1964; Floral list, Middle Siwaliks, Kumaon Himalaya, U. P.
3) Sahni, 1964; Floral list, Middle Siwaliks, H. P.
4) Lakhanpal, 1967; Floral list, Middle Siwaliks, Jawalamukhi, H. P.
5) Banerjee, 1968; Floral list, Middle Siwaliks, Bhakra-Nangal, Punjab.
6) Lakhanpal, 1968; Floral list, Middle Siwaliks, Jawalamukhi, H. P.
*) The grasses identified here as cf. *Poa* (i. e., *Poacites*, sensu Sahni, 1964) are not presently a common tropical taxa, but rather an abundant temperate Asian form.

vial systems, may have contributed to the replacement of a predominantly low coastal savanna physiognomy in pre-Nagri times with the more continental alluvial plain mixed savanna of Nagri times. Coincident with this. decreased moisture availability and an increased seasonality to the moisture distribution affected the total vegetative physiognomy creating a mixed deciduous woodland/grassland savanna. As the dominant vegetative structure of the open floodplain,

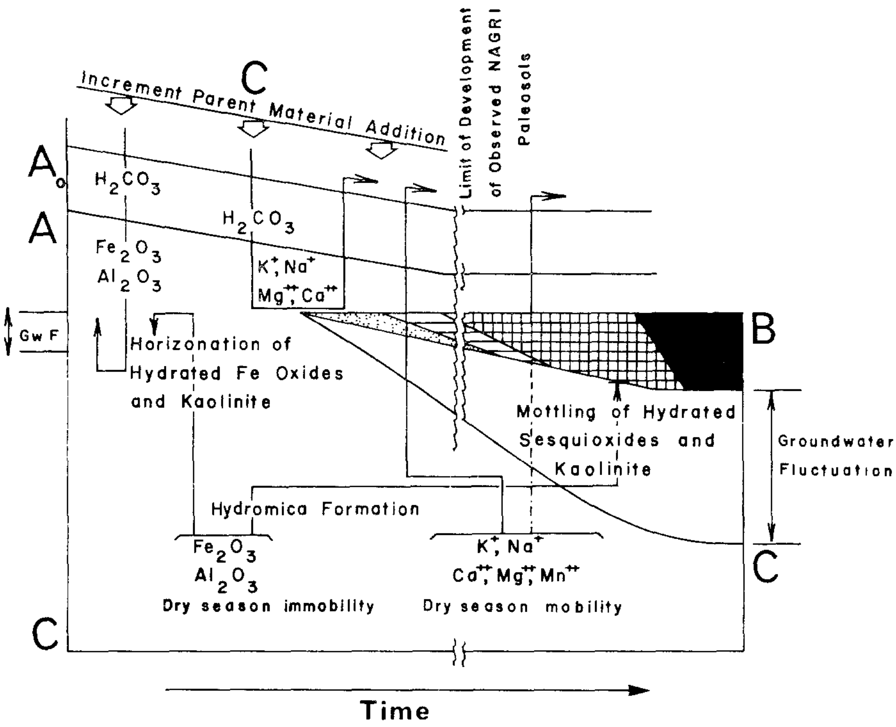

Fig. 12. Schematic summary of oxisol profile development induced by an alternating wet and dry season climatic regime during Nagri time, a model of Siwalik paleopedlogy. "B" horizonation as follows: hydrated iron oxide additions (stippled); concretionary iron oxide additions (horizontally ruled); permeable hardpan-"ironstone" (cross ruled); impermeable hardpan (black). Presumed behavior of transferred soil components as follows: dry season mobility [pH > 7] (dashed line pathway); wet season mobility [pH < 7] (solid line pathway); immobility at beginning of dry season (terminated arrow, →|).

the grassland savanna would give way laterally, via a vegetative catena, to a typical forested riparian fringe or gallery forest in proximity to stream courses.

The *Ramapithecus*-bearing sediments of Haritalyangar collectively provide evidence via stratigraphic and pedologic means to support this contention. The actual taphonomic relationships of Nagri faunal associations may lend additional credence to this interpretation provided those specimens having no stratigraphic documentation can be culled. This necessary documentation cannot be provided for most of the early collections, however.

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