MIOCENE FLUVIAL FACIES AND VERTEBRATE TAPHONOMY IN NORTHERN PAKISTAN

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ABSTRACT: The deposits of the Potwar Plateau in northern Pakistan show large-scale changes in fluvial deposition during the period between 14 and 6 my BP in three superimposed formations (Chinji, Nagri, Dhok Pathan) approximately 2700 m in total thickness. Five cross sections spaced throughout this sequence document intervals 30–80 m thick over lateral distances of 3–5 km. These show the architectural relationships of sand bodies, fine-grained facies, pedogenic horizons, and vertebrate fossil occurrences within floodplain deposits between major channel belt sandstones. Vertebrate fossil localities are particularly frequent within the fine-grained fill of different scales of abandoned floodplain channels (crevasse-splay and/or tributary channels). Such channels are larger and more common in the lower part of the sequence where average rates of sediment accumulation were 0.14–0.32 m/1000 yrs. as determined from the Siwalik magnetostratigraphic time framework. Higher average accumulation rates of 0.46–0.48 m/1000 yrs for the upper part of the sequence correspond to fewer fine-grained channel fills and lower fossil abundance. Changes in type and frequency of floodplain channels are attributed to a combination of differences in the fluvial regimen and in sediment accumulation rates. The quality of the vertebrate record is linked to the frequency and/or magnitude of abandoned channels on the sub-Himalayan alluvial plain and thus to large-scale tectonic and climatic controls on the fluvial systems.

INTRODUCTION

The Siwalik deposits of the Potwar Plateau in northern Pakistan have been subjected to intensive study and fossil collecting since 1973 by members of the Joint Geological Survey of Pakistan—Harvard University Research Project and other affiliated groups. This has resulted in well established lithostratigraphy and magnetostratigraphy for large areas of Siwalik exposures in the Soan Synclinorium, which lies between the Salt Range and the Himalayan foothills (Barry and others, 1980; Tauxe and Opdyke, 1982; Behrensmeyer and Tauxe, 1982; Raza, 1983; Johnson and others, 1985). The non-marine deposits span Miocene through Pleistocene time and are well over 3000 m thick. Fossil vertebrates occur throughout and provide a record of evolution, immigration and extinction in the Indian subcontinent over the past 18 my (Barry and others, 1982; Barry and others, 1985).

The vertebrate record varies in the degree of concentration of fossils in different lithofacies and stratigraphic levels. The sediments also vary through time in average rates of accumulation, ratios of sandstone to mudstone, and lateral relationships of the course and fine-grained units. The focus of this paper is how occurrences of vertebrate fossils are related to changing fluvial environments within the sub-Himalayan deposits. A more general goal is to understand how conditions leading to fossil preservation may be linked to large-scale controls on fluvial sedimentation.

OVERALL SEDIMENTARY CONTEXT AND METHOD OF STUDY

The Siwalik formations used for this study are distinguished primarily by gross sandstone percentages, with the Chinji Formation <50 percent sand, the Nagri >50 percent sand, and the Dhok Pathan <50 percent sand (in ascending stratigraphic order) (Fatmi, 1973; Pilbeam and others, 1979). The deposits consist of alternating sandstones and finer grained sediments which represent large-scale "cycles" of channel and floodplain deposition. The major sand bodies are tabular units 10–30 m thick which extend tens of kilometers along strike in directions oblique or roughly parallel to the dominantly east-southeast current direction. The floodplain deposits are primarily silt but include significant amounts of clay, marl, pedogenic carbonate, sand, and intraformational conglomerates. They are internally complex, including channel, levee, and overbank facies that represent a variety of smaller scale depositional systems (crevasse-splays, tributaries) which were active on the floodplain(s) of the major rivers.

Since nearly all of the vertebrate fossils occur in the floodplain deposits, these have been the focus for study of the relationships between sediments and fossils. Previous work has been done at a fine level of resolution on specific intervals within the Dhok Pathan Formation (Badgley, 1982) and the Chinji Formation (Raza, 1983). The goal of this study is to gain an overview of large scale patterns of vertebrate preservation throughout the Chinji, Nagri and Dhok Pathan Formations.

Lateral facies studies were done at five different levels within these formations, which total about 2700 m of thickness in the correlated sections from the northern and southern limbs of the Soan Synclinorium (Fig. 1). The exposures are nearly continuous, and documentation consisted of vertical lithologic logs spaced 250 to 700 m apart and detailed mapping of all contacts and sedimentary units that could be traced between the logs. This resulted in five panel sections which show sedimentary relationships within 30- to 80-m-thick intervals over distances of 3.1 to 4.2 km (Fig. 2). Current indicators (large-scale trough cross-stratification, directions of channel axes) were measured wherever possible in the sandstone bodies, and pedogenic horizons (identified by color zonation, ped structure, cutans, carbonate and/or limonite glaebules, rhyzoliths, lack of primary bedding) were documented within both fine- and coarse-grained units. The sedimentary context of all vertebrate fossils was also recorded.

The sections shown in Figure 2 represent sand bodies and finer grained units which are typical of the fossil-bearing floodplain deposits for each level through the sequence of formations. The sand bodies vary from sheet to ribbon geometry (width/depth ratios <50 for ribbon sands); some are quite large (e.g., 10 m thick, >1 km wide normal to current direction) but still distinct from the major channel belt sands. In the following discussion, these will be referred to as secondary versus major sand bodies. The pack-

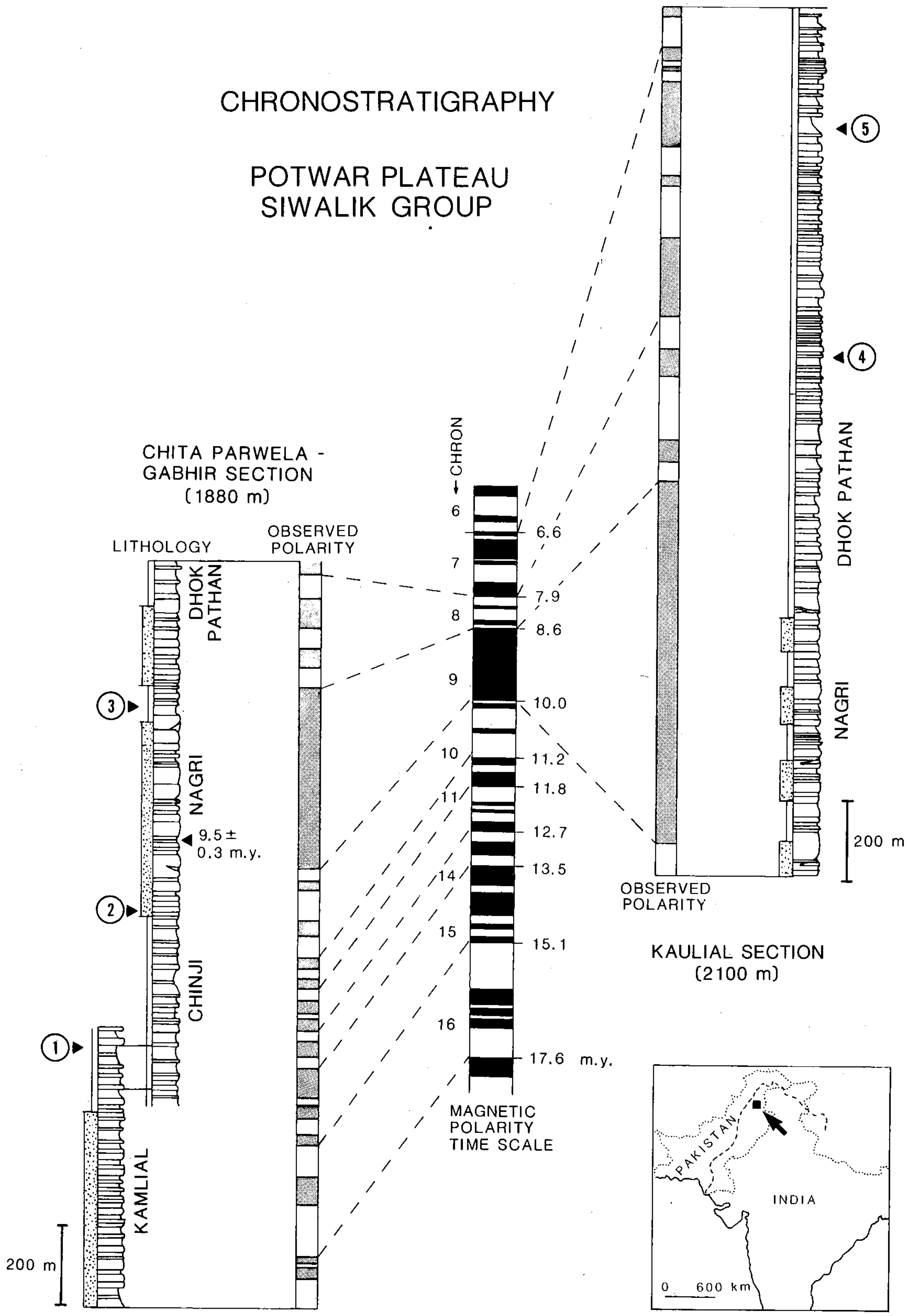

FIG. 1.—Chronostratigraphic framework for the Potwar Plateau Miocene deposits, showing positions of the five levels used for the lateral facies study (circled numbers). Left column represents the section on the southern limb of the Soan Synclinorium, right column the section on the northern limb (distance approximately 50 km). (Compiled from Tauxe and Opdyke, 1982 and Johnson and others, 1985.) Stippled bars to left of the lithologic columns indicate parts of the section with greater than 50 percent sandstone. Inset map shows location of the Potwar Plateau (Box) in northern Pakistan.

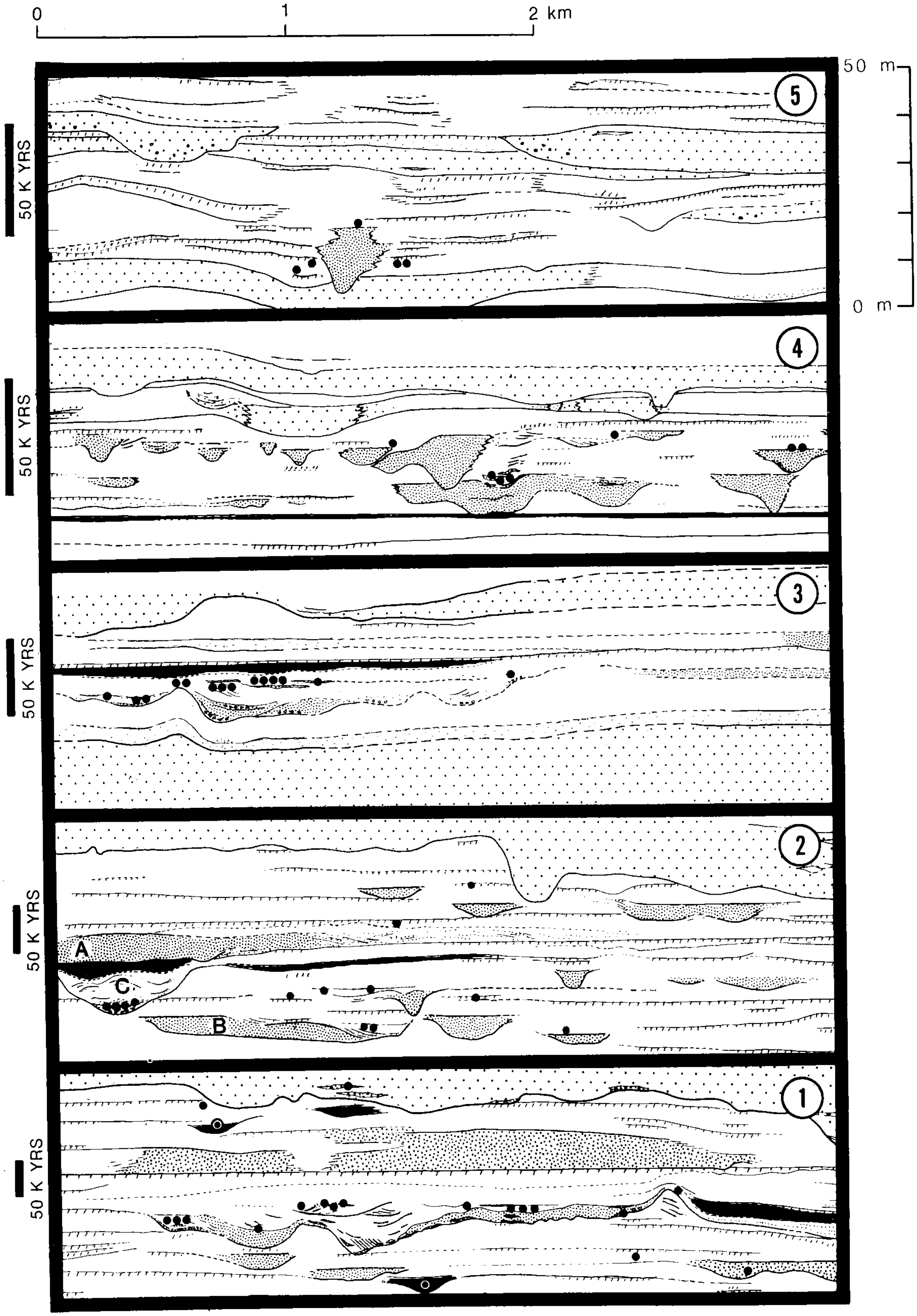

FIG. 2.—The five lateral facies sections, drawn to the same scale with 20× vertical exaggeration. For ease of comparison, only similar-width portions of the overall sections are shown. Vertical bars to the left show the thickness equivalent to 50,000 years, as calculated from data on Figure 1 for 300-m segments centered on each study level. Symbol key: coarse stippling = major channel belt sandstones, fine stippling = secondary channel sands within the floodplain deposits, dark shading = silty clay, blank = silts and marls, hatched lines = pedogenic horizons. The black dots show vertebrate localities, with 1 dot = 1–10 fossils, 2 dots = 11–100, 3 dots = 101–1000, 4 dots = 1000. The three-dimensional outcrop pattern was abstracted somewhat to make the two-dimensional diagrams. Laterally continuous pedogenic horizons were used as horizontal datums.

ages of fine-grained sediment between major sand bodies are "major floodplain deposits" and the distinct siltstones, sand bodies, marls, and clays within them are "secondary floodplain facies."

LITHOFACIES PATTERNS AND TAPHONOMY

Level 1.—The lower Chinji (13.1 my) section covers 3.3 km with nine logs documenting as much as 65 m in thickness. The major floodplain unit lies below a sheet sand 10–15 m thick and contains numerous sand bodies representing channels of varying geometries and sizes. There are also erosional troughs with fine-grained channel fill. Paleosol horizons occur throughout the overbank facies, in some cases directly lateral to channel margins.

The section includes a continuous irregular erosional feature with discontinuous sand lenses along its base. The deposits above the erosion surface fine upward to an extensive clayey-silt paleosol that was used as a horizontal datum. The deepest point relative to this datum is filled with silt/fine sand couplets with large-scale foreset bedding that dips steeply into the erosional contact. Above these inclined couplets are interbedded fine sands, intraformational conglomerates and silts with variable dips showing multiple cross-cutting stages of channel fill that fine upward to the capping paleosol. The lower units above the basal erosion surface have little sign of bioturbation, but middle to upper parts of the fill are root-mottled and locally burrowed.

The erosional feature is interpreted as an abandoned channel, cut by the same river system that laid down the major sheet sands. This feature is so large (1.5 km across normal to current direction) that it might be termed a "failed avulsion," where erosion took place during one or more major flood events, and subsequent fill occurred during sporadic (and waning) flow when the active channel failed to occupy this position on the floodplain. Sedimentary features of the fine-grained channel fill indicate rapid (perhaps 1.5–15 m/1000 yrs) deposition relative to the average overall rate of 0.14/1000 yrs (Table 1). The abandoned channel is regarded as distinct from "paleogully systems" of Kraus and Middleton (1984) and Kraus and others (1985) because the lower part of the fill indicates rapid sedimention in deep (5 m) water, because of the uniqueness of the feature (there are no signs of other erosional features lateral to it), and because laterally associated paleosols do not indicate prolonged periods of land surface stability. Further discussion of this and other sedimentary features will be given elsewhere (Behrensmeyer, in prep.).

TABLE 1.—RELATIONSHIP OF TIME COMPONENTS IN THE LATERAL FACIES SECTIONS TO VERTEBRATE FOSSIL ABUNDANCE

Facies Level:	Older → 1	2	3	4	→ Younger 5
SEDIMENT ACCUM. RATE: m/1000 YRS	0.14	0.19	0.32	0.48	0.46
# DISTINCT PALEOSOLS (IN 20 m)	6.4	8.0	2.6	5.2	7.6
AVERAGE MAXIMUM YRS PER SOIL	22,300	13,200	24,000	8,000	5,700
# FLOODPLAIN CHANNELS (IN 20 m × 1 km)	1.1	2.4	0.6	7.0	0.8
# VERTEBRATE LOCALITIES (IN 20 m × 1 km)	2.3	2.0	1.7	1.4	.9

Note: Numbers are based on chronostratigraphic data in Figure 1 and lithologic data shown in Figure 2, with average rates of accumulation calculated from Figure 1 for a 300-m interval bracketing each level. Numbers of soil horizons are standardized for 20 m of thickness; maximum years per soil = time represented in 20 m/# paleosols in this interval. Numbers of floodplain channels and vertebrate localities are standardized for a 20 m × 1 km portion of each lateral facies section.

The highest density of vertebrate occurrences lies within the middle to upper part of the abandoned channel fill in the crosscutting lenses of silts, conglomerates, and fine sands. The vertebrate remains include associated and articulated body parts, and most are unabraded. A wide range of body sizes and taxa are represented. Bones are fragmentary and whole, and many show evidence of carnivore activity. They occur as dense local patches dispersed through the silt/sand lenses but not as a continuous "bonebed." The evidence points to autochthonous, attritional accumulation and burial, with some local effects of water transport and sorting as sporadic flow filled the abandoned channel.

Low density occurrences of vertebrate remains are associated with some of the other, small-scale channel fills and with levee and overbank facies. A few very abraded fossils were also documented in a conglomerate lens within the major channel sand body.

Level 2.—The upper Chinji (10.5 my) section covers 2.5 km with 9 logs measuring as much as 80 m in thickness. A major sand body caps floodplain deposits which include a number of secondary sand units. Many of these appear to be sheetlike but are actually broad channel sand bodies occupying shallow depressions eroded into the mudstone facies (Fig. 2:2). One (A) passes laterally into well developed levee facies that can be followed more than 1.3 km normal to the channel edge. Another (B) passes from left to right into lateral aggradation surfaces and a fine-grained channel fill over a distance of 225 m normal to current direction.

The largest feature in this section is an erosional trough (Fig. 2:2, C) 10 m in depth which is floored by a conglomerate of algal oncolites and soil glaebules. This is overlain by a thick deposit of interbedded silt and silt/sand couplets with highly variable depositional dips, followed by a clay with deep, sandfilled desiccation cracks. This sequence is interpreted as a channel fill in which active flow was abruptly reduced after deposition of the basal conglomerate.

The richest vertebrate locality occurs in this abandoned channel fill, with thousands of bones concentrated immediately above the basal oncolitic conglomerate in the fine-sand/silt facies. The taphonomic nature of the bone assemblage is much the same as in the major abandoned channel in Level 1, with somewhat more variability in abrasion and fewer associated remains. A second channel in Level 2 has approximately 30 identifiable specimens associated with fine-grained sediments in an abandoned channel lateral to a point-bar deposit.

Other isolated or low density bone occurrences are found in the levee facies and in pedogenic horizons formed on the mudstone facies.

Level 3.—The Nagri (8.8 my) level includes approximately 25 m of floodplain deposits which rest upon a 76-m-thick multistoried sandstone in the sand-dominated Nagri Fm. Exposures are somewhat poorer than at other levels, and six logs document 4.2 km in this section. Secondary sand bodies include sheets with conformable basal contacts and a complex of lenses associated with a major erosional feature within the mudstone facies (left half, Fig. 2:3).

This erosional feature has an irregular lower contact overlain by highly variable units of sand, inclined silt/sand couplets, *in situ* stromatolites as much as 0.6 m in diameter, oncolitic conglomerates, carbonate and iron oxide glaebule conglomerates, and bioturbated silty to sandy clays. These deposits are a maximum of 12 m thick and fine upward to a capping paleosol. The erosional feature and its overlying deposits represent a large-scale channel which bears many similarities to the abandoned channel at Level 1. The channel fill of Level 3 is more complex and indicates highly variable flow before abandonment. The large stromatolites in growth positions also indicate extended periods of relatively quiet (non-turbid) water within the channel.

Fossil vertebrates occur in great abundance within the middle to upper levels of the abandoned channel fill. A number of different taphonomic histories are evident, and assemblages include weathered, abraded bones mixed with fresh, associated elements. Low numbers of vertebrae indicate winnowing, and surface scratches, breakage and vertical orientations of bones in excavated samples document trampling prior to burial (Behrensmeyer and others, 1986). Carnivore activity is also evident from tooth marks and breakage patterns. The unabraded components of the assemblages probably represent attritional accumulation around waterholes within the abandoned channel, with minor redistribution due to sporadic flow events. The fauna represents the entire spectrum of Nagri taxa including the hominoid *Sivapithecus*.

Other fossil occurrences have not been found outside of the context of the abandoned channel. The floodplain facies appear to be more homogeneous than at other levels, lacking small-scale channels and laterally variable paleosol horizons.

Level 4.—The "Sub-U" level (8.2 my) in the Dhok Pathan Formation is characterized by 4- to 10-m-thick sheet sandstones with associated gray silts overlying 15- to 20-m-thick floodplain deposits. Thirteen vertical logs document approximately 3.2 km of nearly continuous exposures. The floodplain deposits include numerous small-scale ribbon sand bodies of a buff sand. A previous study of facies relationships at this level (Behrensmeyer and Tauxe, 1982) demonstrated that the sheet sand bodies and gray silts represent the "blue-gray" fluvial system, which is distinct from the "buff system" that deposited ribbon sands and associated red-brown floodplain deposits. The buff sands are attributed to one or more tributary systems that fed the major river represented by the blue-gray sheet sands (Behrensmeyer and Tauxe, 1982).

The buff sand bodies are more laterally restricted, with lower width/depth ratios, than ribbon sands in Levels 1 and 2. They are also more complex internally, with evidence of mutistory deposition. Fine-grained fills are uncommon and restricted to the uppermost portions of these channels. In their overall geometry and lateral associations with fine-grained facies and other sand bodies, they resemble ribbon sands in Oligocene-Miocene fluvial deposits in the Spanish Ebro Basin (Friend and others, 1979).

Abundant vertebrate fossils occur at the top of one of the larger buff channels. They are associated with dipping lenses of carbonate glaebule and mudclast conglomerate which alternate with fine sands and silts. These fill a small depression cut into the top of the underlying sand body and represent deposition during temporary reactivation of flow in a nearly abandoned channel. The fossils include a mixture of fresh and abraded material representing both local and distant sources of vertebrate remains.

Other vertebrate occurrences are associated with the tops and margins of the buff channels, as is typical of this part of the Dhok Pathan Formation (Badgley and Behrensmeyer, 1980; Badgley, 1982). None were found in the fine grained floodplain sediments or paleosol horizons at this level.

Level 5.—The upper part of the Dhok Pathan Formation is markedly different from the other levels, as shown in the fifth section (6.9 my). Twelve logs document as much as 70 m of thickness over a distance of 3.1 km. The major channel belt sands are as much as 8 m thick and can be traced laterally into well bedded levee facies and paleosols developed on overbank facies.

The floodplain deposits are homogeneous with evenly bedded fine sands and silts and thick silty clays with pedogenic features. There are very few secondary sand bodies. One ribbon sand more than 10 m thick shows evidence of vertical aggradation without lateral migration after the initial erosional event. In contrast to Level 4, there is no difference in lithology between the major sheet sands and the ribbon sand, and they appear to belong to the same ("buff") fluvial system.

Intensive searching for fossils at this level resulted in a cluster of low to moderate density localities in the levee and floodplain paleosols developed on mudstone facies lateral to and above the ribbon sand body.

DISCUSSION

Sixty percent of the 45 vertebrate localities in the five study levels are associated with secondary channels in the major floodplain deposits (Fig. 3), and those with more than 100 specimens occur only in this context. Fossils also tend to occur in the middle to top of relatively fine-grained fills of these channels, although they may be associated with thin beds of coarser sediment. This is true over a wide range of channel widths from 50 m to 1.5 km and is a recurring pattern throughout the vertical sequence of Siwalik formations, even though the overall nature of the fluvial systems changed significantly through time. The richest fossil-bearing units are associated with the large-scale abandoned channels in the Chinji and Nagri Formations (Levels 1–3).

Fossils that are present in other contexts, such as paleosols and levees, are typically few in number, and portions of the Siwalik sequence which have few secondary channels (e.g., Level 5) have relatively poor fossil records.

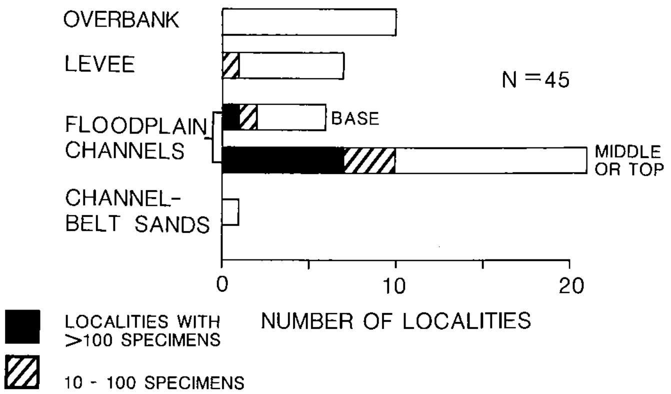

FIG. 3.—Summary of the sedimentary context of the 45 vertebrate localities documented in the five lateral facies studies. (Note: not all localities are shown in the representative portions of the sections in Fig. 2.)

Documentation of patterns of extinction, immigration, evolution, and overall faunal change therefore depend to a considerable degree on the record preserved in secondary channels on the Miocene floodplains.

Some of these channels probably were caused by crevassing events in which various scales of erosion and deposition took place during periods of overbank flow from a major active channel. In avulsion-dominated systems, such as the lower Indus River of recent times, major channel-switching events are well documented (Holmes, 1968) and provide a realistic model for the large-scale abandoned channels in Levels 1 and 3. Smaller scale ribbon sand bodies in floodplain deposits in other fluvial sequences have been attributed to anastamosed channels in rapidly aggrading systems (e.g., Smith and Putnam, 1980; Smith, 1986) and to the evolution of splay channels following major avulsion (Smith and Cross, 1985). Similar causes may account for some of the secondary channels in the Siwalik floodplain deposits. Tributaries that drained the floodplain or local uplands provide an alternative mechanism for these channels, and further work will be needed to distinguish between the two possible causes in the absence of obvious lithologic differences, such as in the buff versus blue-gray sands in Level 4.

From the standpoint of the vertebrate record, distinguishing the cause of floodplain channels is less important at this stage of analysis than establishing the pattern of association of fossils with such channels, particularly with various types of abandoned channel fill. An abandoned channel context for vertebrate fossil concentrations has been recognized by many workers, notable recent examples being bone concentrations in the Cretaceous Wealden Group of Great Britain (Stewart, 1981), the Permian Cutler Formation of New Mexico (Berman and others, 1985), and Carboniferous channels in Ohio (Hook and Ferm, 1985). Such occurrences have been recorded as typical of particular localities or formations rather than as a recurring pattern through a long stratigraphic interval which is documented here for the Siwalik sequence.

Given the litho- and chronostratigraphic framework available for the Siwalik formations, we can address the larger question of possible controls on the frequency of secondary channels and their associated vertebrate record. In Table 1, sediment accumulation rate is shown in relation to some of the measurable characteristics of the five study levels. Paleosol horizons are taken as rough indicators of hiatuses in the section, and these appear to reflect generally shorter time breaks as the rate of accumulation increases upward. The number of secondary channels is highly variable through time, reflecting different styles of floodplain aggradation, but the frequency of abandoned channels with fine-grained fill decreases in the upper two levels.

If rates of floodplain channel formation were constant through time, then we might expect that slower sediment accumulation and longer hiatuses would result in a higher probability of floodplain channel sands occurring in any given outcrop section (particularly if they were tributary channels). With more time represented in any given hiatus, there might also be a greater chance of recording a "rare event" such as a large-scale crevasse channel or "failed avulsion." Thus, one control on the frequency of floodplain channels may be rate of sediment accumulation.

Another control on the number and size of floodplain channels is obviously the nature of the fluvial systems themselves. In the lower three study levels, secondary channels and particularly the large-scale abandoned channels may reflect an avulsion-dominated fluvial regimen enhanced by relatively low average rates of accumulation. A different fluvial system (the "buff" system) was responsible for most of the floodplain facies in the Dhok Pathan Formation on the north side of the Soan Synclinorium. This system was characterized by a different style of floodplain deposition, operating in the context of more rapid average accumulation rates, and it generated fewer secondary channels conducive to vertebrate preservation in the upper two study levels.

Other factors that might have influenced floodplain channel frequency in the study levels include local climate (i.e., as a control on the amount of vegetation on the floodplain) and the proximity of a major channel (e.g., more levee facies with fewer channels proximal to the channel belt) (Behrensmeyer, in prep.).

Since relatively rapid permanent burial is a prerequisite for bone preservation (Behrensmeyer, 1978), the inverse relationship between number of localities and average rate of sediment accumulation in Table 1 is initially puzzling. This can be attributed, however, to the combination of fluvial regimen and a low overall accumulation rate which led to numbers of abandoned channels in the lower study levels. The rate and mode of filling of these channels was optimal for vertebrate preservation, in contrast to sedimentation patterns in other subenvironments on the floodplains. In the upper two study levels, fossils still tend to occur in the tops of margins of secondary channels, but a change in fluvial regimen resulted in fewer opportunities for vertebrate preservation in this context. Other favorable environments for preservation apparently were also uncommon in this fluvial setting.

Floodplain channels represent a complex of processes that could work together to promote bone preservation. The presence of the topographic lows and relatively rapid in-filling of the channel troughs are undoubtedly two of the critical factors. Abandoned channels are also places where surface and ground water are concentrated, and they provide favorable habitats for plant growths, animal activity and predation (such as at waterholes) which would contribute attritional vertebrate remains. Faunas from this context should represent localized, time-averaged samples of the original vertebrate communities inhabiting areas proximal to the floodplain channels. Such channels would have important effects on the ecology of the floodplain floras and faunas as well as on their preservation.

CONCLUSION

The taphonomic pattern of fossil preservation in association with abandoned channels in the Siwalik sequence is supported by other studies of the Chinji and Dhok Pathan Formations (Badgley and Behrensmeyer, 1980; Badgley, 1982; Raza, 1983). The pattern seems to hold regardless of the scale of channel or the major fluvial system to which it belongs. Thus, the quality of the vertebrate record is linked to the frequency and scale of abandoned channels in the Siwalik sequence. The occurrence of such channels in fluvial systems should relate to climatic and tectonic controls on the fluvial regimen, as expressed in discharge, flood periodicity, sediment type, net rate of sediment accumulation, and floodplain vegetation. It seems likely that fluvial systems characterized by a greater number and variety of abandoned channel segments may preserve a larger proportion of vertebrate remains than many other types of systems throughout the stratigraphic record. This would be an example of a "taphonomic megabias" (Behrensmeyer and Kidwell, 1985) in which the large-scale tectonic and climatic controls could be approached through study of the causes of abandoned floodplain channels.

The presence of vertebrate fossils in such contexts may hold important information concerning rates and mode of channel fill which would be of value to sedimentologists. Finally, comparative taphonomic studies of preservational modes in the Siwalik Group and other fluvial sequences, such as the Willwood Formation of Wyoming, where vertebrate fossils are most comon in paleosols (Bown and Kraus, 1981), could provide new insights on the relationships between large-scale controls on fluvial sedimentation and different contexts for vertebrate preservation.

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