Sedimentary Geology, 87 (1993) 25–37
Elsevier Science Publishers B.V., Amsterdam

Lithostratigraphy and vertebrate biostratigraphy of the early Miocene Himalayan Foreland, Zinda Pir Dome, Pakistan

Kevin F. Downing [a,*] , Everett H. Lindsay [a,**], William R. Downs [b] and Stephen E. Speyer [c]

[a] *Department of Geosciences, University of Arizona, Tucson, Ariz. 85721, USA*
[b] *Department of Geology, Northern Arizona University, Flagstaff, Ariz. 86011, USA*
[c] *Department of Geology, Arizona State University, Tempe, Ariz. 85287, USA*

Received May 27, 1992; revised version accepted January 11, 1993

ABSTRACT

Downing, K.F., Lindsay, E.H., Downs, W.R. and Speyer, S.E., 1993. Lithostratigraphy and vertebrate biostratigraphy of the early Miocene Himalayan Foreland, Zinda Pir Dome, Pakistan. Sediment. Geol., 87: 25–37.

Deposits in the Sulaiman foothills and Zinda Pir Dome in west-central Pakistan provide new insight into the critical early Miocene record of Himalayan Foreland sedimentation and paleobiology. The Chitarwata Formation, which underlies the Vihowa Formation in the Sulaiman foothills predates the Siwalik deposits on the Potwar Plateau of north-central Pakistan and provides a record of mammals spanning the interval between the early Miocene Bugti fauna and middle Miocene to Pleistocene Siwalik faunas. Siwalik deposits on the Potwar Plateau are no older than middle Miocene; they represent fluvial environments. In contrast, the Chitarwata and Lower Vihowa Formations in the Zinda Pir Dome represent coastal-delta plain and fluvial environments, respectively. Biostratigraphic information from the Chitarwata Formation, coupled with paleomagnetic data (reported by Friedman et al., 1992) from coincident strata, suggest that coastal environments persisted in the area of the Sulaiman foothills until about 18.6 Ma when they were replaced by fluvial environments, probably representing the ancestral Indus River system. Apparently, during the early Miocene when sediments of the Chitarwata Formation were accumulating on the western portion of the Himalayan Foreland Basin much of the area of the Potwar Plateau to the north was being eroded. The overlying Vihowa Formation, along with the relatively contemporaneous Kamlial Formation on the Potwar Plateau, represent the appearance of widespread terrestrial sedimentation in the Himalayan Foreland Basin.

Introduction

Collision of the Indo-Pakistan and Eurasian continental plates and concomitant development of the Himalayan Foreland has resulted in one of the most complete records of Neogene terrestrial sedimentation (Johnson et al., 1985) and vertebrate history (Barry et al., 1991). A wealth of knowledge about Himalayan Foreland sedimentation and paleobiology has been acquired through detailed examinations of Rawalpindi and Siwalik Group sediments of the Potwar Plateau of northern Pakistan that span the interval from 0.6 Ma to 18.6 Ma (Johnson et al., 1985, give the base of the section as 18.3 Ma because they used the Mankinen and Dalrymple polarity time scale). Absence of an earlier record on the Potwar Plateau has impeded understanding of both the sedimentological processes coincident with early unroofing of the Himalayas (i.e., Zeitler et al., 1982; Copeland et al., 1987; Richter et al., 1991) and the important Bugti–Siwalik faunal transition (Barry et al., 1991).

An important record of Himalayan Foreland sediments is present at Zinda Pir Dome on the eastern side of the Sulaiman Range of west-

* Present address: DePaul University, 243 South Wabash Ave., Chicago, Ill. 60604, USA.
** Corresponding author.

0037-0738/93/$06.00

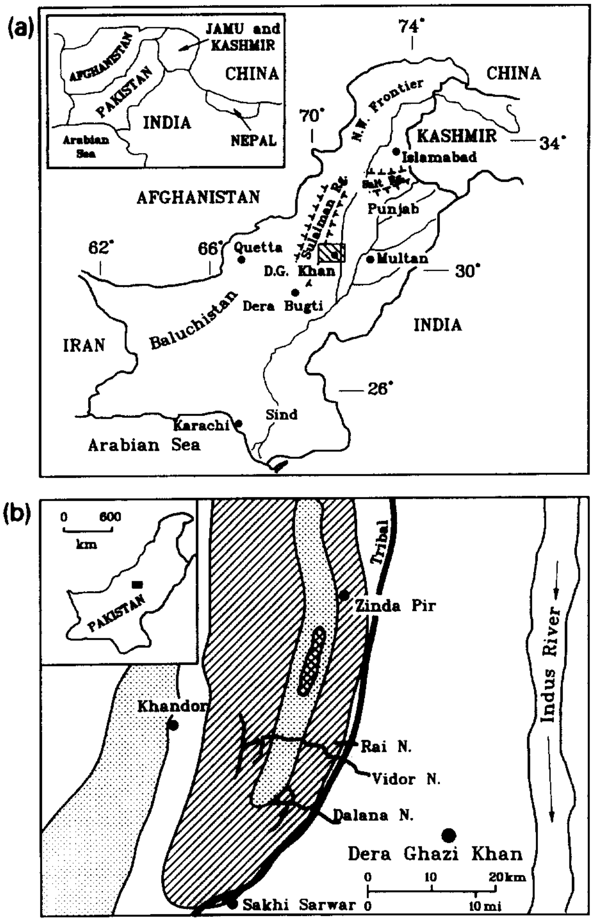

Fig. 1. (a) Map of study area in Pakistan. (b) Southern part of Zinda Pir Dome.

central Pakistan (Figs. 1a and 1b). More than 2500 m of Neogene sediments are represented in the Zinda Pir Dome (Eames, 1952), including more than 400 m of the Chitarwata Formation that predates deposition on the Potwar Plateau. Friedman et al. (1992) have recently presented the magnetic polarity sequence of the sections we report below. In the following study we address the lithostratigraphy and paleontology of the Chitarwata and Lower Vihowa Formations, exposed near the village of Dalana in the southern part of Zinda Pir Dome. These sediments are described and the depositional environments of the Chitarwata and Vihowa Formations are interpreted. Vertebrate fossil sites are placed in this stratigraphic framework and compared with the classic Siwalik and Bugti faunas.

Lithostratigraphy

Previous work

Sediments in the Sulaiman Range were initially described by Blanford (1883), who noted 2744 m of Eocene "Nummulitic Limestone" overlain by 610 m of sediments that he assigned to the Upper Nari Formation (Fig. 2). These deposits are overlain by 1524 m of Lower Siwalik sediments, overlain by 762 m of Upper Siwalik sediments. Blanford (1883, p. 34) questioned assignment of the Siwalik units to the Manchar Formation but discussed these only in the context of the Siwalik Formation or parts thereof. Blanford noted the presence of nummulitic forams in the Nari Fm. and considered that some if not all of the Nari sediments represent marine deposition; he considered the Lower Nari Formation absent.

Blanford (1883) Bugti Hills	Pilgrim (1908) Bugti Hills	Pilgrim (1912) Bugti Hills	Eames (1952) Rakhi Nala	Hemphill & Kidwai (1973) Chitarwata Post	Raza & Meyer (1984) Bugti Hills	Waheed & Wells (1990) Rakhi Nala		This Report Dalana	
Lower Siwaliks	Lower Siwaliks	Lower Siwaliks	Lower Siwaliks	Vihowa Formation	Lower Siwaliks	Subunit IIr	Unit X	Vihowa Formation	
Upper Nari Formation	Upper Nari Formation	Upper Gaj Formation	Upper Nari Formation	Chitarwata Formation	Chitarwata Formation	Subunit Ir	Unit X	Chitarwata Fm.	Upper Unit
								Chitarwata Fm.	Middle Unit
								Chitarwata Fm.	Lower Unit
Eocene "Nummulitic Limestone"	Eocene Limestone	Eocene Limestone	Eocene Kirthar Formation "Pellatispira Beds"	Eocene Kirthar Formation Drazinda Shale Member	Eocene Kirthar Formation Pirkoh Limestone Member	Eocene Kirthar Formation		Eocene Kirthar Formation Drazinda Shale Member	

Fig. 2. Chart showing terminology of stratigraphic units of Chitarwata and Vihowa Formations.

Blanford (1883, p. 57) also noted the presence of mammalian and reptilian bones, along with several species of freshwater molluscs, in the lower units of his "Lower Siwalik" division, especially near Dera Bugti. Vertebrate fossils had been reported from the Bugti Hills of Baluchistan by Vikary (1846), and preliminary description of those fossils were made by Lydekker (1883, 1884, 1886).

Dr. G.E. Pilgrim of the Geological Survey of India questioned Blanford's assignment of vertebrates from the Bugti area to Lower Siwalik strata. Pilgrim (1908) recognized a four-fold division of terrestrial sediments in the Bugti area, in ascending order (Fig. 2): Upper Nari (328 m), Lower Siwalik (328–457 m), Upper Siwalik (152 m) and Post-Tertiary (unspecified thickness). Pilgrim (1908) noted the occurrence of freshwater molluscs from 152 to 213 m above the base of the Upper Nari, and considered the abundant fossil remains in the Bugti Hills to be distributed throughout the Upper Nari, except for the uppermost 30 m, more or less. Pilgrim (1908, p. 143) mentioned but did not elaborate on a thin marine band of Lower Nari beneath the Upper Nari in the Sulaiman area, and implied that most of the Upper Nari represents terrestrial deposition. Pilgrim (1908, p. 145) also noted that the main exposures of the Upper Nari (and its contact with the Lower Siwalik strata) are continuous along the front of the Sulaiman Range between the Bugti Hills and the area north of Dera Ghazi Khan, which includes the Zinda Pir Dome.

Later, Pilgrim (1912) revised the stratigraphic assignments given above, considering that the deposit yielding the vertebrate fauna in the Bugti Hills should be assigned to the Gaj Formation, which is better developed in the Sind Province to the south. Pilgrim was influenced in his revision by the identification (by Mr. Vrendenburg) of the species of molluscs (*Ostrea gajensis, Ostrea vestita* and *Ostrea bicolor*) in the Bugti area that are well represented in the Gaj Formation and are absent from the overlying Nari Formation in Sind. Pilgrim (1912) argued that the age of the Bugti vertebrates should be assigned to the early Miocene, based on the (late Aquitanian or early Burdigalian) age of the molluscan species mentioned above, coupled with his comparison of the Bugti mammals with those from Siwalik deposits and from mammal faunas of Europe and North America.

Eames (1952) sampled and measured sections at Rakhi Nala, south of Zinda Pir Dome, and in the northern foothills of the Sulaiman Range. His purpose was to develop a stratigraphic framework, primarily for the correlation of Eocene deposits in those sections. Eames (1952) assigned the deposits between the Eocene limestone and "Lower Siwaliks" to the Upper Nari Formation (Fig. 2).

The Chitarwata Formation was named by Hemphill and Kidwai (1973) for sediments that had previously been referred to the Upper Nari or Upper Gaj Formation (Fig. 2). The work of Hemphill and Kidwai was focussed primarily in the northern foothills of the Sulaiman Range; they designated the type for both the Chitarwata and Vihowa Formations in that area. Hemphill and Kidwai (1973) measured the thickness of the Chitarwata Fm. (384 m) southwest of Domanda Post; they estimated a thickness (152 m) at Chitarwata Post (type section), and the nearby Litra (north of Chitarwata Post) and Kaura (south of Chitarwata Post) Nalas. Hemphill and Kidwai apparently did not visit the Bugti area or the southern part of the Zinda Pir Dome.

Strata in the Bugti area that produced the Bugti fauna were subsequently sampled for fossils by Raza and Meyer (1984). They accepted designation of fossiliferous units in the Bugti area as the Chitarwata Fm. but considered that the strata in that area may be older than the type area (northern Zinda Pir Dome), about 300 km to the north, and assigned the fossiliferous strata in the Bugti Hills to the "Bugti Member," implying that this represents the basal sequence of the Chitarwata Formation.

Waheed and Wells (1990) studied sandstones in two key reference sections (Chaudhwan Zam and Rakhi Nala) of the Sulaiman foothills, to identify provenance of major sediment sources. The Chaudhwan Zam section approximates the type area for the Chitarwata and Vihowa Fms., described by Hemphill and Kidwai (1973); the Rakhi Nala section approximates that described by Eames (1952) south of the Zinda Pir Dome. Waheed and Wells (1990) did not identify specific formations in their sections, giving numerals and letters to distinctive lithologies. We feel confident, however, that Subunit Ir (= Chitarwata) and Subunit IIr (= Vihowa) in Unit X of Waheed

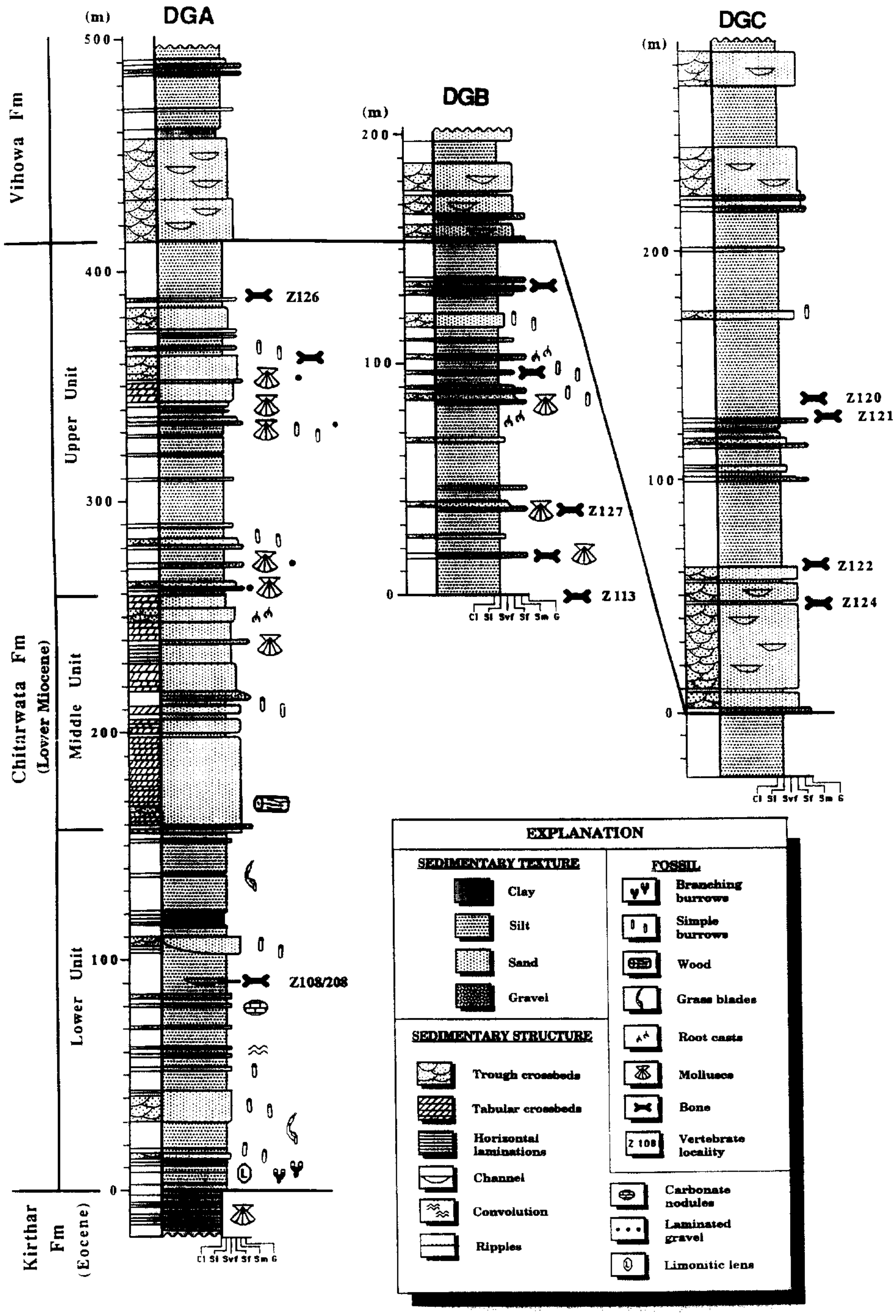

Fig. 3. Measured sections and lithologic correlations for the Chitarwata and Lower Vihowa Formations at Dalana (distance between sections DGA and DGB is 2 km, and between DGB and DGC is 1 km). The Chitarwata Formation is divided into three units corresponding to general facies associations (see text). Vertebrate localities span the transition from Bugti to Siwalik faunas (see text).

and Wells' Rakhi Nala section (only about 40 km from our sections in the Zinda Pir Dome) represent the Chitarwata and Vihowa Fms., as we recognize them in the Zinda Pir Dome (Fig. 2). One notable problem with the above correlation, however, is that Waheed and Wells did not recognize the presence of molluscs in any of their sections, which we found very distinctive for the upper unit of the Chitarwata Fm.

Chitarwata Formation

Type section

Hemphill and Kidwai (1973) characterized the Chitarwata Fm. along Vihowa Rud, east of Chitarwata Post, as "red, gray, and green claystone and subordinate amounts of siltstone and sandstone." They also noted "the siltstone is variegated, friable and ferruginous; the sandstone is white, friable, calcareous in places, and commonly ferruginous." The lithology is highly variable, with hard ferruginous sandstones and conglomerates located near the top of the formation in Litra and Kaura Nalas near the type section, and silty sandstone with thin carbonaceous beds, sulfur stains and root fragments in their measured section southwest of Domanda Post. Hemphill and Kidwai did not note the presence of mollusc shells (or vertebrate fossils) in the Chitarwata Fm. of sections they measured; they considered the Chitarwata represents terrestrial deposition of late Oligocene to late Miocene age, based on pollen collected in Toi Nala. Hemphill and Kidwai suggested that the Chitarwata Formation could be traced along strike through exposures in the Zinda Pir Dome and into the Bugti Hills where the well-known Bugti mammal fauna was collected; they noted, however, that continuity of these beds had not been established. Apparently, neither Eames, nor Hemphill and Kidwai had visited the Bugti area although aerial photographs of the Bugti area were surely available, at least to Hemphill and Kidwai.

Sections in the Zinda Pir Dome

Our stratigraphic sections (Fig. 3) are located near the village of Dalana in the southern portion of the Zinda Pir Dome, northwest of Dera Ghazi Khan (Fig. 1), approximately 30°5′N latitude, 70°22′E longitude. The area lies geographically between exposures at Chitarwata Post/Domanda Post (to the north) and the Bugti Hills (to the south). The measured thickness of the Chitarwata Fm. at Dalana Nala in the Zinda Pir Dome is 413 m.

We divide the Chitarwata Formation near Dalana into three superposed facies. These units are identified as facies because we recognize within each unit sedimentary features associated with a discrete depositional environment, and we have not had the opportunity to sample these units in other areas (e.g., Bugti Hills and Chitarwata Post) to ensure the geographic breadth of similar sedimentary features. We are reluctant to suggest that these same facies occur throughout the Chitarwata Formation, without having examined the sediments in other geographic areas. This would be especially hazardous when other published sections (e.g., Hemphill and Kidwai, 1973, plus Waheed and Wells, 1990) did not identify the molluscan and mammalian fossils we find in the deposits. We suspect that the facies we recognize in the Zinda Pir Dome are rather widespread and these units could readily be characterized as members of the Chitarwata Formation. We withhold that interpretation, however, until justified by examination and verification in other areas.

Lower unit

The base of the Chitarwata Formation at Dalana is identified at the bottom of the first well-indurated ferruginous siltstone ("ironstone"), that disconformably overlies shale and limestone beds with gastropods and forams, interpreted as the Drazinda Shale Member of the Kirthar Formation (Fig. 3).

Thickness of the lower unit is 156 m with the basal 19 m characterized by dense limonite-cemented siltstone and massive siltstones (as much as 10 m thick) heavily burrowed by *Thallasinoides*; density of burrows increases vertically within individual beds. Multicolored siltstones with minor burrowing and, to a lesser extent, fine-grained sandstones dominate the lithology of the remaining 139 m of the lower unit. The siltstone beds of the lower unit infrequently show nodular carbonate horizons, root casts and rarely grass blade impressions. Sandstones are usually thin, lenticular and weakly calcareous; a 12 m thick, fine-grain sandstone at 29 m and a 7 m thick, medium-grain sandstone at 101 m are crossbedded and incise underlying siltstones; they commonly show sparse *Skolithos* burrows. Very thinly laminated silts and shales sometimes underlie the sandstone beds; these fine-grain sediments occasionally show convolute bedding structures. Fossil molluscs were searched for but not observed within the lower unit of the Chitarwata Formation.

An important mammal fauna (locality Z108) is located in a thin, graded, gypsiferous channel fill near the middle of the lower unit. The channel is approximately 15 m wide and incises underlying green-gray clays and siltstone. A zone of iron oxidization outlines the channel bottom. The base of the channel fill is composed of a greenish-gray, mudstone pebble conglomerate (0.37 m thick), supported by a calcareous siltstone matrix. The channel fill fines upwards into a very pale orange, friable, weakly cross-stratified, gypsiferous, medium quartz sandstone.

Middle unit

The middle unit of the Chitarwata Formation is 104 m thick; the lower 74 m is dominated by massive, fairly well-sorted, yellowish-gray, medium to coarse sand with multistoried, tabular and trough crossbeds. Thin lenses of coarse sand with pebbles of siltstone and claystone occur a few meters above the basal sand of the middle unit; similar lenses occur at irregular intervals higher in the unit. Iron-rich concretions and abundant fragments of fossil wood are found on some exposed bedding planes of the sandstones. Lithologies are more varied in the upper third of the middle unit; thin orange to red siltstones and fine-grain sandstones alternate with coarse sands with tabular crossbeds in the upper third of the middle unit. Fine-grained beds of the middle unit commonly display sparse root casts and faint crossbedding. Poorly preserved molds of large bivalves and calcareous siltstone pebbles occur in a thin, calcareous, graded sand bed 84 m above the base of the middle unit. The upper part of the middle unit is characterized further by multicolored, slightly calcareous, fine-grain sandstones, some of which preserve ferruginous rootlets; the middle unit grades into the upper unit.

Upper unit

The upper unit is 153 m thick; it is dominantly a fine-grain sandstone or siltstone that is distinguished from the lower units by having poorly indurated, weakly calcareous, relatively thin (usually), graded sandstone beds that may contain abundant molluscs (as well as sporadic bone fragments and reworked Eocene *Nummulites*). These "shell beds" occur throughout the unit, alternating with finer-grained, poorly sorted sands and silts; individual "shell beds" are laterally continuous, having been traced for more than a kilometer. Rounded and poorly sorted gravels frequently line the base of individual "shell beds" and incise underlying siltstones. The larger intraformational clasts, composed of siltstones and sandstones, and molluscs often show thinly laminated calcareous coatings (< 5 mm thick) over their entire surface. Bedded sands are rare in these "shell beds"; when present, they show bidirectional stratification. The silts and fine-grain sands are poorly sorted, poorly bedded, slightly calcareous and usually unfossiliferous.

Mollusc accumulations in the "shell beds" are usually monospecific and are dominated by large trigonid (and exogyrid) bivalves, or less commonly, small turritellid gastropods. When observed on broad bedding planes, the majority of bivalve shells are disarticulated and oriented concave down, while the turritellids are randomly oriented. Shells are always poorly preserved, showing evidence of extensive recrystallization. A relatively thick, red and orange siltstone alternating with discontinuous sandstone lenses underlies the base of the Vihowa Formation.

Vertebrates from locality (Z113) near the base of the upper unit were recovered from a weakly calcareous sandstone at the top of a prominent "shell bed." Overlying thin, weakly bedded, trough cross-stratified, fine- to medium-grained sandstones yielded fossil bone scrap and show

TABLE 1

Fossil mammals from respective localities in the Chitarwata and Vihowa Formations near Dalana in the Zinda Pir Dome ("other" columns represent additional mammals collected from the lithologic units indicated)

	Lower Chitarwata (other)	Z108	Z113	Z126	Upper Chitarwata (other)	Z122	Z120	Lower Vihowa (other)
Chiroptera								
gen. indet.		X				X		
Scandentia								
gen. indet.						X		
Insectivora								
Erinaceidae								
gen. indet.						X		
Soricidae								
gen. indet.			X					
Rodentia								
?Chapattimyidae								
Fallomus		X	X					
Diatomys						X		
Baluchimyidae								
Baluchimys		X						
Lindsaya		X						
Lophibaluchia		X						
?Yuomyidae								
Hodsahibia		X						
Family incertae sedis								
Downsimys		X						
Ctenodactylidae								
Sayimys			X			X	X	
Sciuridae								
gen. indet.			X					
Cricetidae								
Eucricetodon			X	X				
Prokanisamys						X	X	
Primus			X					
Spanocricetodon			X	X		X		
Democricetodon						X	X	
Megacricetodon							X	
Myocricetodon						X		
Carnivora								
?Viverridae								
gen. indet.		X						
Proboscidea								
Gomphotheriidae								
Hemimastodon					X			
gomphothere				X	X			X
Deinotheriidae								
Deinotherium					X			X
Perissodactyla								
Rhinocerotidae								
gen. indet.	X	X			X	X	X	X
Chalicotheriidae								
gen. indet.					X			X

TABLE 1 (continued)

	Lower Chitarwata (other)	Z108	Z113	Z126	Upper Chitarwata (other)	Z122	Z120	Lower Vihowa (other)
Artiodactyla								
Suidae								
?Sanitherium			X				X	
Listriodon							X	X
Anthracotheriidae								
?Masritherium					X			
?Hyoboops								X
gen. indet.	X				X	X	X	X
Tragulidae								
gen. indet.					X		X	X
Bovidae								
gen. indet.							X	X

Skolithos burrows. Another vertebrate locality (Z135) occurs near the middle of the upper unit, in a compact, very fine sandstone that underlies a prominent, very calcareous "shell bed". It appears that the upper unit of the Chitarwata Fm. thickens toward the southern nose of the Zinda Pir Dome.

Lower Vihowa Formation

Type section

Hemphill and Kidwai (1973) designated the type area of the Vihowa Fm. in Vihowa Rud, east of Chitarwata Post, where the thickness of the Vihowa Fm. was estimated about 700 m; they noted a thickness of 430 m for the Vihowa Fm. at Chaudhwan Zam and about 700 m at Litra Nala.

Hemphill and Kidwai characterized the Vihowa Fm. as "gray and brown sandstone and subordinate amounts of red and brownish-red sandy siltstone. The sandstone consists of subangular, medium, and coarse grains and is massive, thick bedded, and crossbedded." They noted "abundant scattered pebbles in the upper part, clay material and ferromagnesian mineral grains in the middle part, and abundant secondary calcite in the middle and lower parts." They also noted abundant fossil fragments, mostly foraminifera, in coarse sands and pebble conglomerates near the base. Mammal bone and tooth fragments were reported from several areas (e.g., Baddha village and between Parwara and Landai villages).

Section in the Zinda Pir Dome

We place the contact between the Chitarwata Formation and overlying Vihowa Formation at the base of a thick, poorly sorted, laterally continuous, light olive-gray sandstone that overlies the siltstone at the top of the Chitarwata Formation. The contact is sharp, with minor scalloping along the contact and no perceptible truncation of underlying beds. Our section near Dalana is not complete; we have measured only 290 m of the lower part of the Vihowa Fm.

The basal gray sandstone is about 60 m thick; it has complex multistory channeling with frequent basal conglomerate lenses. The upper part of the basal sandstone intertongues with and is replaced by red siltstone. Channels of coarse sediment occur infrequently in the red siltstone but they are thinner than the channels in the basal gray sandstone.

Vertebrate fossils were recovered from several localities (Z120, Z122 and Z124) in the red siltstone that intertongues with and overlies the basal gray sandstone. A general increase in the quantity and quality of vertebrate remains characterizes this portion of the section. Thick, massive sandstones and thick siltstones dominate the overlying section.

Vertebrate paleontology

Chitarwata fauna

Vertebrates are rare in the lower unit of the Chitarwata Formation near Dalana. Localities Z108 and Z208 are the exception; they have produced several rodents, plus bat, ?viverrid, rhino and anthracothere fossils (Table 1). Rodents in the lower unit of the Chitarwata are dominated by Baluchimyinae, similar to those reported from the Bugti area by Flynn et al. (1986). Near the base of the upper unit of the Chitarwata Formation, locality Z113 has produced a diverse small mammal assemblage, including primitive cricetid rodents, and a shrew. Similar rodents have been collected at locality Z135 in the middle of the upper unit. Near the top of the Chitarwata Formation, at locality Z126, more advanced cricetid rodents were recovered. Rhino and anthracothere fossils are the common large mammals in the upper unit of the Chitarwata Formation, along with rare proboscidean, small bovid and tragulid remains.

Gingerich et al. (1990) noted the record of *Anthracobune* from the Eocene Subathu Fm. in Kashmir, and pointed to the probable Eocene radiation of mammal Tethytheria, including Proboscidea, in southern Asia. The fossil record of proboscideans and other tethytheres is better established in Africa (e.g., Maglio and Cooke, 1978; Tassy and Shoshani, 1988), however, and virtually nothing is known of proboscideans in southern Asia until the early Miocene Bugti fauna. Both primitive (e.g., *Hemimastodon crepusculi*; Tassy, 1988) and advanced (e.g., *Gomphotherium angustidens* and *Deinotherium pentapotamiae*; Raza et al., 1984) species of proboscideans are recorded from the Bugti fauna, which has led vertebrate paleontologists to suggest a "proboscidean datum" for the presumed dispersal of proboscideans from Africa during the early Miocene. According to this scenario, proboscideans dispersed to Asia and Europe in the early Miocene, and the Bugti proboscideans are considered more primitive than those recorded from Orleanian MN 4 faunas of Europe (Tassy, 1989). The "out of Africa" dispersal scenario needs to be tested; it is the best scenario, currently, for the early evolution of proboscideans. A critical tie-point in this scenario is timing of the dispersal, or more precisely, the appearance of advanced proboscideans in Pakistan. We have recorded proboscideans from several levels in the upper unit of the Chitarwata Fm. near Dalana, and would place a "proboscidean datum" near the base of the upper unit. This would mark the Pakistan "proboscidean datum" as about 20.5 Ma, based on the poorly constrained paleomagnetic data from the Zinda Pir Dome, presented by Friedman et al. (1992), which should be slightly earlier than the European "proboscidean datum." At the present time we are unable to establish whether the appearance of proboscideans in the Zinda Pir Dome is earlier than their appearance in the Bugti area.

Vihowa fauna

Sites in the Lower Vihowa Formation (e.g., localities Z120, Z122) have produced advanced cricetids, rhizomyids, a ctenodactylid, the enigmatic rodent *Diatomys*, possibly a hedgehog (erinaceid), plus tree shrew (tupaiid) and a bat. Large mammals from the same sites include gomphothere, deinothere, chalicothere, rhino, suid, anthracothere, tragulid and bovid fossils. The cricetids and bovid from the Vihowa Fm. appear similar to cricetids and bovid from the lower part of the Kamlial Fm. in the Potwar Plateau. However, the genus *Potwarmus*, which appears near the base of the Kamlial Fm. but is not common until the middle of the Kamlial Fm., has not been recovered from the Vihowa Fm.

Discussion

Depositional environments

Our sections at Dalana suggest that deposits of the Chitarwata Formation at Dalana represent a coastal system. Composite sedimentary features of the three facies of the Chitarwata Formation and Lower Vihowa Formation suggest the sequential shift, in ascending order, of estuary,

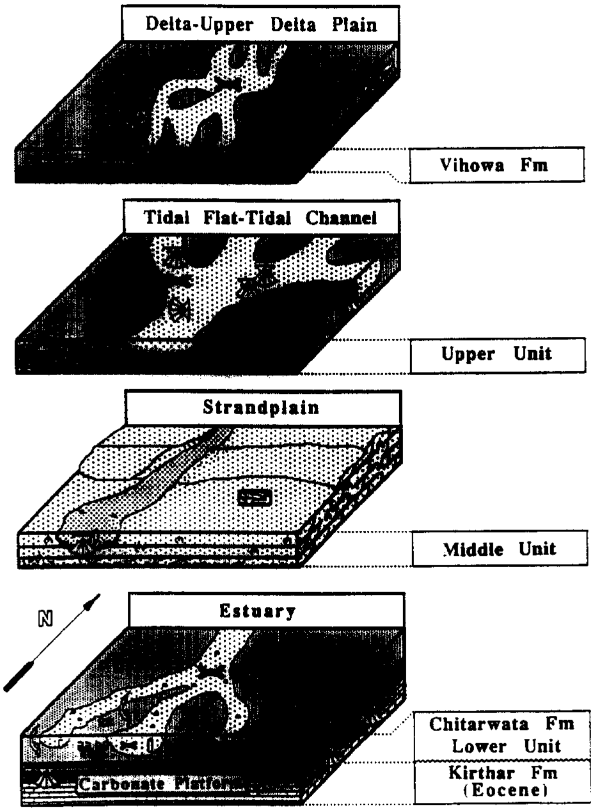

Fig. 4. Schematic block diagrams showing provisional interpretations of the depositional environments of the Chitarwata and Lower Vihowa Formations at Dalana. Units of the Chitarwata Formation correspond to coastal subenvironments. The Lower Vihowa Formation marks a shift to terrestrial sedimentation in delta plain environments.

strandplain, tidal flat/tidal channel, and fluvial paleoenvironments (Fig. 4).

Estuary affinity for the lower unit of the Chitarwata Formation is supported by: (1) *Thallassinoides* and *Skolithos*, common ichnogenera in marginal marine environments (Seilacher, 1967); (2) repetitive beds of ironstone and iron-oxide associated with *Thallassinoides* burrows, suggesting alternating subaerial exposure and surface weathering phenomena (Ekdale et al., 1984); (3) carbonate nodule horizons of possible pedogenic origin; (4) rare grasses and convolute bedding, prominent features in coastal marsh areas (Frey and Basan, 1985); and (5) faunal mixing of sharks and mammals, similar to modern estuary settings (e.g., Georgia estuaries; Frey et al., 1975).

Strandplain affinity for the middle unit is supported by the thick, well-sorted, relatively coarse sandstones with tabular and trough crossbeds. Main bounding surfaces are well defined in these crossbeds but second-order and third-order surfaces are poorly developed. Also, the unit was not sampled well enough to derive meaningful data on grain size, skewness or kurtosis of crossbeds. We consider that these beds are eolian, based primarily on better sorting than we see in the massive, crossbedded sands at the base of the Vihowa Fm., which we interpret as fluvial. Presence of fossil wood and root casts, along with the absence of marine fossils, suggest that the middle unit is subaerial rather than subaqueous. The upper part of the middle unit grades into the upper unit, which we interpret as a tidal flat/tidal channel environment. Thus, the middle unit shifts from subaerial to tidal deposition (according to our interpretation), and we believe that the best interpretation for this unit is a strandplain deposit. These features are comparable to wave-dominated strandplain and barrier-island coastline environments described by Fraser (1989).

Tidal flat/tidal channel affinity for the upper unit is supported by the repetition of thin, discontinuous sandstones with local concentrations of shells, the "shell beds." The repetition and lateral displacement of discontinuous, thin "shell beds," coupled with concentrations of near-monotypic, poorly preserved molluscs in the sands suggests channels on a tidal flat. This interpretation is strengthened by the abundance of disarticulated bivalve shells in hydrodynamically stable positions, along with algal-mud overgrowths on many of the clasts, that suggest intermittent but persistent tumbling. In addition, bi-directional, small-scale cross-stratification of sands near the top of some "shell beds" suggests tidal currents. Taken together, these data suggest intermittent, medium- to high-energy regimes for the "shell beds" that are characteristic of tidal channels. The repetitive character of the shell beds and interbedded silts, along with the general lack of characters typical of sandy intertidal tidal flats, is similar to muddy tidal flat sequences described by Alexander et al. (1991) for the modern Korean coast. All of the molluscs observed in the upper unit (e.g., *Trigonia, Exogyra* and *Turritella*) are marine organisms, characteristic of littoral or sublittoral environments; no terrestrial molluscs were observed in the upper unit.

A fluvial paleoenvironmental interpretation for the Lower Vihowa Fm. is supported by the poor sorting of sands plus the abundance, scale (e.g., 2 m thick foresets) and complexity of channels in the basal sandstone. The Lower Vihowa Fm. could also be interpreted as a delta plain paleoenvironment; sedimentological features observed in the Lower Vihowa Fm. are comparable to those described for the modern Indus River-dominated delta plain of Pakistan (Kazmi, 1984), although of much smaller scale. Total absence of marine affinity within sediments of the Lower Vihowa Fm., along with increasing abundance of vertebrate fossil remains in these sediments, support the fluvial interpretation. Also, we recognize no distinctive difference between sediments of the Lower Vihowa Fm. and those of the Kamlial Fm. on the Potwar Plateau, which is considered a fluvial deposit. Further study of the Vihowa Fm. will help to identify its depositional environment more securely.

Biostratigraphy

The small mammals from the lower unit (e.g., locality Z108) of the Chitarwata Fm. are most similar to the small mammal fauna from Bugti (Flynn et al., 1986); cricetid small mammals from the upper unit (e.g., locality Z113) of the Chitarwata Formation are most like the cricetids reported from the Murree Formation in the Trans-Indus area (de Bruijn et al., 1981). Rhinos and anthracotheres are the dominant large mammals from the Chitarwata Formation, both near Bugti and near Dalana. Tragulids and bovids are not known from the Bugti fauna but are present in the upper unit of the Chitarwata Formation near Dalana. The Bugti fauna includes the earliest known record of proboscideans outside of Africa (Tassy, 1988); proboscideans are well represented in the upper unit of the Chitarwata Fm. but are presently unknown from the lower unit. Most of the mammals that occur in the Lower Vihowa Formation (e.g., localities Z120 and Z122) are also known from the Kamlial Formation (or higher strata) of the Siwalik sequence on the Potwar Plateau (Barry et al., 1990). The distinctive cricetid rodent *Potwarmus* appears near the base of the Kamlial Formation in the Siwalik sequence. We consider that absence of the rodent *Potwarmus* in the Lower Vihowa Formation indicates that the Vihowa Fm. may be slightly older than the lower strata of the Kamlial Formation. We have sampled only the lower 150 m of the Vihowa Formation in the Zinda Pir Dome, and would expect to find *Potwarmus* in higher stratigraphic levels, if our interpretation is correct.

Kazmi (1984, p. 82) suggested that the basal part of the Chitarwata Fm. (Gaj Fm. of Pilgrim) in the Bugti area, with a mixed fauna of oysters and mammals is the earliest indication of the Indus River delta. Based on our data from the Chitarwata Fm. near Dalana, the entire Chitarwata Fm. is near-shore, with variable and intermittent influx of terrestrial sediments. Moreover, the Chitarwata Fm. lacks the sedimentary thickness expected of a major deltaic sedimentary body. The overlying Vihowa Fm., however, with fluvial sediments is a more reasonable candidate for the early Indus delta. Our preliminary results (we have sampled neither the Chitarwata nor the Vihowa Fms. over any sizable geographic area) suggest that the Vihowa Fm., rather than the Chitarwata Fm., represents the early prograding Indus delta. If this proves accurate, it infers that the Indus delta developed much later (e.g., about 18 Ma) than the docking of the Indo-Pakistan Plate with Eurasia. Moreover, our data and that from the Potwar Plateau (e.g., Johnson et al., 1985) indicate that sediment contribution from the rising Himalaya Mountains were rather meager until about 18 Ma. This is the most intriguing result of our study.

Summary

Two distinct phases of sedimentation are recorded by the Chitarwata and Lower Vihowa Formations at Dalana. An initial coastal phase corresponds to the three units of the Chitarwata Formation, representing estuary, strandplain and tidal flat/tidal channel environments. Biostratigraphic information coupled with paleomagnetic data from coincident strata (Friedman and Tauxe,

1991) imply that coastal environments persisted in this area until about 18.6 Ma, followed by a second phase of sedimentation representing fluvial deposits of the Lower Vihowa Formation. Vertebrate fossils from the Chitarwata Formation are concentrated in estuary channel fills and tidal "shell bed" sequences; in contrast, vertebrates from the Lower Vihowa Formation occur in fluvial deposits. The Vihowa Fm. represents the first-known expression of the ancestral Indus River.

This preliminary analysis of the mammals from the Chitarwata and Vihowa Formations in the Zinda Pir Dome suggests that these deposits will provide ample paleontologic data to clarify the temporal and environmental relationship between the Bugti and Siwalik faunas. Further collection and study should also clarify the appearance of several mammal groups (e.g., proboscideans, bovids and tragulids) in southern Asia.

Acknowledgements

We appreciate the help of Mohamid Anwar, Qasim Baluch, Jessica Harrison, Kevin Moodie, Mike Cassiliano, David Clark and Jeff Gee for their help in the field, especially collecting and processing the small mammal fossils by screen washing. We are especially indebted to Dr. S. Mahmood Raza and the Pakistan Geological Survey and to Mr. I.U. Cheema and the Pakistan Museum of Natural History for logistic support of the field work, along with general counsel for organization and execution of the field work. This project grew out of collaboration with the Harvard–Geological Survey of Pakistan research project, administered by David Pilbeam and John Barry. It was supported by the Smithsonian Foreign Currency Program, administered by Ms. Francine Berkowitz.

References

Alexander, C.R., Nittrouer, C.A., Demaster, D.J., Park, Y.A. and Park, S.C., 1991. Macrotidal mudflats of the southwestern Korean coast: a model for interpretation of intertidal deposits. J. Sediment. Petrol., 61: 805–824.

Badgley, C.E., 1986. The taphonomy of mammalian fossil remains from Siwalik rocks of Pakistan. Paleobiology, 12: 119–142.

Barry, J.C., Pilbeam, D. and Flynn, L.J., 1990. Key biostratigraphic events in the Siwalik sequence. In: E.H. Lindsay, V. Fahlbusch and P. Mein (Editors), European Neogene Mammal Chronology, NATO ASI Ser. A, Vol. 180, Plenum Press, New York, pp. 557–572.

Barry, J.C., Morgan, M.E., Winkler, A.J., Flynn, L.J., Lindsay, E.H., Jacobs, L.L. and Pilbeam, D., 1991. Faunal interchange and Miocene terrestrial vertebrates of southern Asia. Paleobiology, 17: 231–245.

Blanford, W.T., 1883. Geological notes on the hills in the neighborhood of the Sind and Punjab Frontier between Quetta and Dera Ghazi Khan. India Geol. Surv. Mem., 20, 136 pp.

Brusca, R.M., 1979. Common Intertidal Invertebrates of the Gulf of California. University of Arizona Press, Tucson, Ariz., 513 pp.

Copeland, P., Harrison, T.M., Kidd, W.S.F., Ronghua, X. and Yuquan, Z., 1987. Rapid early Miocene acceleration of uplift in the Gangdese Belt, Xizang (southern Tibet), and its bearing on accommodation mechanisms of the India–Asia collision. Earth Planet. Sci. Lett., 86: 240–252.

De Bruijn, H., Hussain, S.T. and Leinders, J.J.M., 1981. Fossil rodents from the Murree formation near Banda Daud Shah, Pakistan. K. Ned. Akad. Wet. Proc. Ser. B, 84: 71–99.

Downing, K.F. and Goebel, K.A., 1991. Relationship of India–Asia convergence to sandstone depositional environments and detrital modes in early Miocene deposits of Zinda Pir Dome, Pakistan. Geol. Soc. Am., Abstr. Prog., 23: A466.

Eames, F.E., 1952. A contribution to the study of the Eocene in standard sections in the western Punjab and in the Kohat District. Q.J. Geol. Soc. London, 107: 159–171.

Ekdale, A.A., Bromley, R.G. and Pemberton, S.G., 1984. Ichnology: the use of trace fossils in sedimentology and stratigraphy. Soc. Econ. Paleontol. Mineral., Short Course, 15, 317 pp.

Flynn, L.J., Jacobs, L.L. and Cheema, I.Q., 1986. Baluchimyinae, a new Ctenodactyloid rodent subfamily from the Miocene of Baluchistan. Am. Mus. Novit., 2841: 1–58.

Fraser, G.S., 1989. Clastic Depositional Sequences. Prentice-Hall, Englewood Cliffs, N.J., 459 pp.

Frey, R.W. and Basan, P.B., 1985. Coastal salt marshes. In: R.A. Davis (Editor), Coastal Sedimentary Environments. Springer, New York, N.Y., pp. 225–302.

Frey, R.W., Voorhies, M.R. and Howard, J.D., 1975. Estuaries of the Georgia coast, U.S.A.: sedimentology and biology, VIII. Fossil and recent skeletal remains in Georgia estuaries. Senckenbergiana Marit., 7: 257–295.

Friedman, R. and Tauxe, L., 1991. The magnetostratigraphy of the Chitarwata and Lower Vihowa Formations of the Dera Ghazi Khan area, Pakistan. Geol. Soc. Am., Abstr. Prog., 23: A419.

Friedman, R., Gee, J., Tauxe, L., Downing, K. and Lindsay, E., 1992. The magnetostratigraphy of the Chitarwata and lower Vihowa formations of the Dera Ghazi Khan area, Pakistan. Sediment. Geol., 81: 253–268.

Gingerich, P.D., Russell, D.E. and Wells, N.A., 1990. Astragalus of *Anthracobune* (Mammalia, Proboscidea) from the early-middle Eocene of Kashmir. Univ. Michigan, Contrib. Mus. Paleontol., 28: 71–77.

Hemphill, W.R. and Kidwai, A.H., 1973. Stratigraphy of the Bannu and Dera Ismail Khan areas, Pakistan. U.S. Geol. Surv., Prof. Pap., 716-B, 36 pp.

Johnson, N.M., Stix, J., Tauxe, L., Cerveny, P.F. and Tahirkheli, R.A.K., 1985. Paleomagnetic chronology, fluvial processes and tectonic implications of the Siwalik deposits near Chinji Village, Pakistan. J. Geol., 93: 27–40.

Kazmi, A.H., 1984. Geology of the Indus delta. In: B.U. Haq and J.D. Milliman (Editors), Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan. Van Nostrand Reinhold, New York, N.Y., pp. 71–84.

Klootwijk, C.T., Conaghan, P.J. and Powell, C.McA., 1985. The Himalayan Arc: large-scale continental subduction, oroclinal bending and back-arc spreading. Earth Planet. Sci. Lett., 75: 167–183.

Lydekker, R., 1883. Indian Tertiary and post-Tertiary vertebrata. Siwalik selenodont suina, etc. India Geol. Surv. Mem., Palaeontol. Indica, Ser. 10, 2 (5): 142–176.

Lydekker, R., 1884. Indian Tertiary and post-Tertiary vertebrata. India Geol. Surv. Mem., Palaeontol. Indica, Ser. 10, 2 (1–2): 1–66.

Lydekker, R., 1886. Indian Tertiary and post-Tertiary vertebrata. India Geol. Surv. Mem., Palaeontol. Indica, Ser. 10, 4 (1): 1–22.

Maglio, V.J. and Cooke, H.B.S. (Editors), 1978. Evolution of African Mammals. Harvard University Press, Cambridge, Mass., 641 pp.

Pilgrim, G.E., 1908. The Tertiary and post-Tertiary freshwater deposits of Baluchistan and Sind, with notes of new vertebrates. India Geol. Surv. Rec., 37 (2): 139–166.

Pilgrim, G.E., 1912. The vertebrate fauna of the Gaj series in the Bugti Hills and the Punjab. India Geol. Surv. Mem., 2, Palaeontol. Indica, 4 (2), 83 pp.

Raza, S.M. and Meyer, G.E., 1984. Early Miocene geology and paleontology of the Bugti Hills, Pakistan. Geol. Surv. Pak., Mem., 11: 43–63.

Raza, S.M., Barry, J.C., Meyer, G.E. and Martin, L., 1984. Preliminary report on the geology and vertebrate fauna of the Miocene Manchar Formation, Sind, Pakistan. J. Vertebrate Paleontol., 4: 584–599.

Richter, F.M., Lovera, O.M., Harrison, T.M. and Copeland, P., 1991. Tibetan tectonics from $^{40}Ar/^{39}Ar$ analysis of a single K-feldspar sample. Earth Planet. Sci. Lett., 105: 266–278.

Seilacher, A., 1967. Bathymetry of trace fossils. Mar. Geol., 5: 413–428.

Tassy, P., 1988. Le statut systématique de l'espèce Hemimastodon crepusculi (Pilgrim): L'éternel problème de l'homologie et de la convergence. Ann. Paleontol. (Vertebr.–Invertebr.), 74: 115–127.

Tassy, P., 1989. The "Proboscidean datum events": how many proboscideans and how many events. In: E.H. Lindsay, V. Fahlbusch and P. Mein (Editors), European Neogene Mammal Chronology. NATO ASI Ser. A, Plenum Press, New York, 180: 237–252.

Tassy, P. and Shoshani, J., 1988. The Tethytheria: elephants and their relatives. In: M.J. Benton (Editor), The Phylogeny and Classification of the Tetrapods, Vol. 2. Mammals. Syst. Assoc. Spec. Vol., 35B: 283–325.

Vikary, N., 1846. Geological report on a portion of the Baluchistan Hills. Q.J. Geol. Soc. London, 2: 260–265.

Waheed, A. and Wells, N.A., 1990. Changes in paleocurrents during the development of an obliquely convergent plate boundary (Sulaiman fold-belt, southwestern Himalaya, west-central Pakistan). Sediment. Geol., 67: 237–261.

Zeitler, P.K., Johnson, N.M., Naeser, C.W. and Tahirkheli, R.A.K., 1982. Fission-track evidence for Quaternary uplift of the Nanga Parbat region, Pakistan. Nature, 298: 255–257.