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RELATIONSHIP OF CHITARWATA FORMATION PALEODRAINAGE AND PALEOENVIRONMENTS TO HIMALAYAN TECTONICS AND INDUS RIVER PALEOGEOGRAPHY

Kevin F. Downing and Everett H. Lindsay

ABSTRACT

During the late Oligocene and early Miocene paleodrainage and deposition in the western Himalayan foreland consisted of two distinct and dominant systems: 1) fluvio-deltaic sediments from the Indus River to the Katawaz Basin region near the Chaman Fault system and 2) marginal marine deposits in the western and northwestern portion of the foreland. The paleocurrent record of the Chitarwata Formation and overlying Vihowa Formation at Zinda Pir Dome developed in this study indicates an appreciable interval during the late Oligocene and early Miocene in which the northwest portion of the foreland basin included a coastline with drainage chiefly from the northwest towards the southeast. These results are consistent with the general pattern of south-eastern drainage in the western Himalayan foreland since the Eocene. The Chitarwata shoreline demarcated an edge of the ebbing Tethys-sea-marine foredeep and was structurally isolated from the main sediment flux of the Indus River to the Katawaz Basin further to the west. Conspicuous differences in character of lithostratigraphy, paleoenvironments, and vertebrate preservation between the Bugti Hills and Zinda Pir areas in the Chitarwata Formation advocate that the more southerly "Bugti member" of Chitarwata with its exceptional vertebrate faunas was actually a phase of fluvio-deltaic sedimentation related to the Shaigalu Fan of the Katawaz Basin.

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INTRODUCTION

The Chitarwata and overlying Vihowa Formations span an important interval of tectonic history recording the character of Himalayan foreland basin sedimentation during the obduction of the Indian and Asian plates in western Pakistan, with regional transition from marginal marine to fluvial environments, and the rise of the high Himalayas.

Previous investigation of the lithostratigraphy in the foothills of the Sulaiman Range at Dalana in Zinda Pir Dome (Downing et al. 1993) indicates the Chitarwata Formation is dominated by coastal paleoenvironments. In ascending order, the three units are associated with estuary, strandplain and tidal flat environments. The Vihowa Formation represents the prominent development of fluvio-deltaic sedimentation related to the southward progradation of the Indus River system.

On the basis of paleomagnetic data, the age span of the Chitarwata Formation in the Zinda Pir Dome has been evaluated as early Miocene from 22.3 –18.6 Ma (Friedman et al. 1992) more recently from 22–17.4 Ma (Lindsay and Downs 2000) and currently Oligocene at its base and earliest Miocene at the contact with the Vihowa Formation (Lindsay et al. this issue). In this age assessment, the Chitarwata Formation temporally overlaps with the Murree Formation exposed in northwest regions of the Potwar Plateau (Abassi and Friend 1989; Najman et al. 2003), the uppermost Shaigalu member of the Khojak Formation in the Katawaz Basin (Qayyum et al. 2001) as well as the Choksti Formation in the Indus suture zone (Clift et al. 2001a) and the Kasauli Formation in the Indian Himalayan foreland basin (Najman and Garzanti 2000).

To the southwest of Zinda Pir Dome in the Bugti Hills, the Chitarwata Formation also has been assigned a basal Bugti Member (Raza and Meyer 1984). The Bugti member has yielded possible early Oligocene vertebrate faunas (Welcomme and Ginsburg 1997, Marivaux et al. 2000; Welcomme et al. 2001), although an early Miocene radiometric date at 22.6 $\pm$ 2.9 Ma (Tabbutt et al. 1997) purportedly in its lower portion conflicts with this biostratigraphic assessment. A chronostratigraphic record has not yet been established for Bugti Hills so no direct comparison to Zinda Pir Dome sections can be made in this regard. Hence, the age correlation between the two regions relies on the biostratigraphy and homotaxis of mammals.

There has been an ostensible incongruence between the biostratigraphy and corresponding age assessments for lower parts of the Chitarwata Formation in Zinda Pir Dome and Bugti Hills (early Miocene versus ?early Oligocene). This disparity has been attributed to a time-transgressive facies in the Chitarwata Formation with older deposits preserved to the south (Raza et al. 2002) or an undetected but notable hiatus calling into question the previous chronostratigraphic assessment of the Chitarwata Formation at Zinda Pir Dome (see Welcomme et al. 2001). In this latter case, biostratigraphic succession may be interrupted by a significant hiatus between the Oligocene vertebrate faunas from the lower member (e.g., locality Z108 described by Flynn and Cheema 1994) and later faunas in the upper member. The latest biostratigraphic and chronostratigraphic findings by Lindsay et al. (this issue) suggest that the faunas from the classic Dera Bugti localities and lower member of the Chitarwata Formation at Zinda Pir Dome are probably both Oligocene and closer in age than previously recognized. Yet there are still consequential differences between the two faunas. Among these differences at Zinda Pir Dome are the absence of primitive muroids, a paucity of remains of large indricothere rhinos, and no demonstrated stratigraphic overlap of large indricotheres with early proboscideans (Lindsay et al. this issue).

An explanation for the observed biostratigraphic differences in each area is suggested by the consequential lithostratigraphic, taphonomic, and paleoenvironmental differences between the Chitarwata Formation in the Zinda Pir Dome and Bugti Hills. Most notably, the coastal marine facies at Bugti Hills are thin, only 30 m thick, and thereafter directly evolve into a fluvio-deltaic floodplain with coal beds and numerous paleosol horizons interpreted as tropical to subtropical densely forested environments (Welcomme et al. 2001, Antoine et al. 2003). In the Zinda Pir area coastal facies are over 300 m thick and evolve into a fluvio-deltaic system much higher in the section with the deposition of the Vihowa Formation (Downing et al. 1993). Vertebrates from Zinda Pir area are sparse through its marginal marine facies while the Bugti Member at Bugti Hills has for the past 150 years produced one of the richest fossil vertebrate faunas in Asia. While a notably attenuated coastal facies of the Chitarwata Formation at Bugti Hills is a possibility it is also soundly viable that the Bugti Member is geologically distinct and a direct lithostratigraphic correlation to the Chitarwata Formation is unwarranted. If so, the Bugti Member could be related to an entirely different depositional and drainage system and assignable to a different formation than the Chitarwata Formation.

Paleocurrents and Paleodrainage in the Western Himalayan Foreland

In order to characterize Himalayan foreland basin sedimentation and paleogeography in relation to the character and sequence of India-Asia tectonics, investigations of pre- and post-collisional paleocurrents and paleodrainage have been conducted in the Indian Himalaya, Potwar Plateau, Kohat Plateau, Katawaz Basin, Sulaiman Range (Zinda Pir Dome), and Balochistan (Figure 1). Pre-

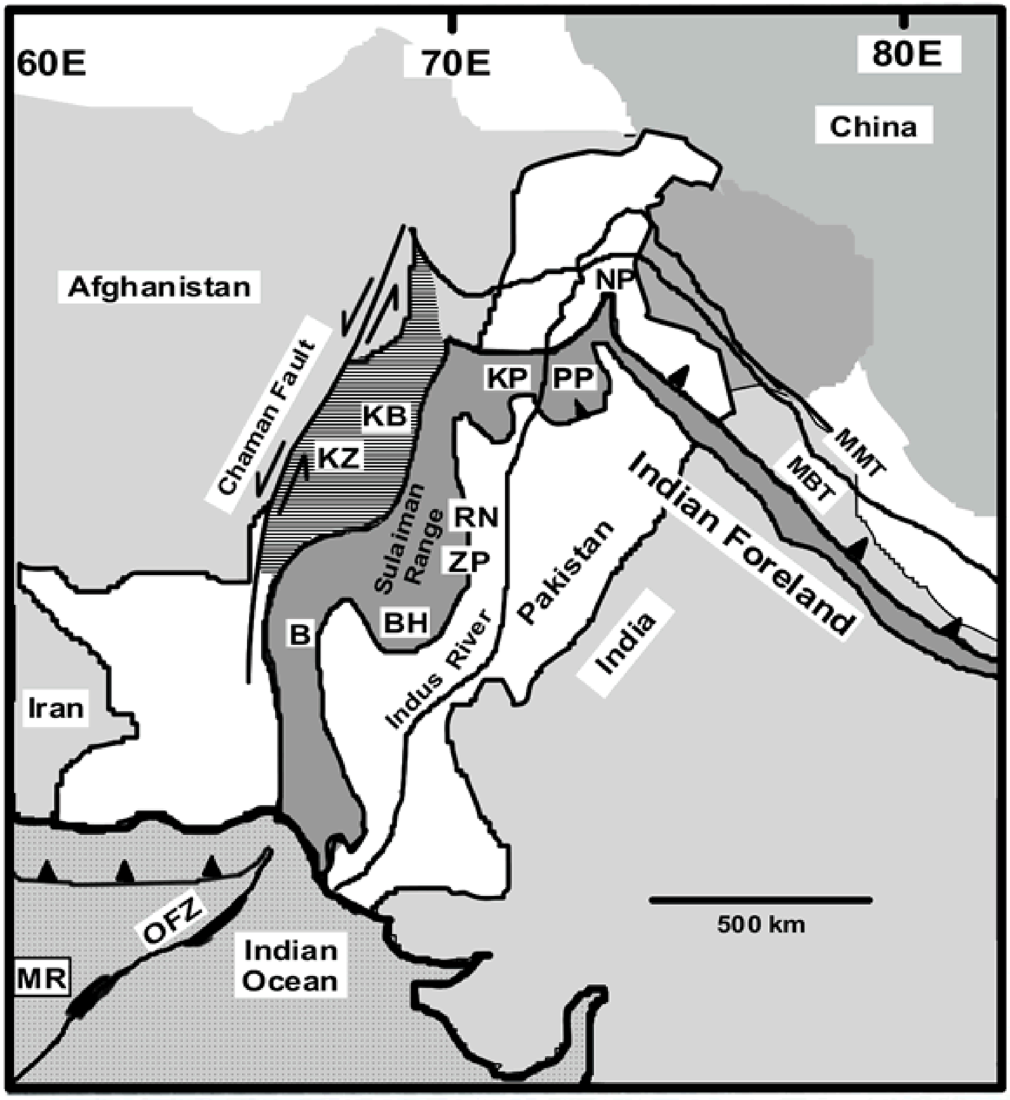


Figure 1. Locality map of major tectonic features and sedimentary basins in the Western Himalayan Foreland. Abbreviations are: B-Balochistan; BH-Bugti Hills; KB-Katawaz Block; KP-Kohat Plateau; KZ-Katawaz Basin; MBT-Main Boundary Thrust; MMT-Main Mantle Thrust; MR-Murrary Ridge; NP-Nanga Parbat Syntaxis; OFZ-Owen Fracture Zone; RN-Rakhi Nala and Chaudwan Zam; Zinda Pir Dome. Hatched shaded area represents the Katawaz Block and the shaded area is the deformed foreland region. Modified from Pivnik and Wells (1996).

collisional paleocurrent data is available from the late Cretaceous Pab Sandstone and supports northwest flow off of the Indian plate (Waheed and Wells 1990). Beginning in the early Eocene, paleocurrent indicators reflect post-collisional paleodrainage associated with the development of the Himalayan foreland and obduction along the western edge of the Indian plate (summarized in Table 1).

An early manifestation of the paleodrainage shift due to obduction and shelf reversal is recorded in the broadly distributed and marginal marine early Eocene Ghazij Formation in western Pakistan, where southeastward paleoflow from a northwestern highland is dominant (Waheed and Wells 1990; Clyde et al. 2003). A similar pattern is observed in the early Eocene Ganguri Sandstone of the Kohat Basin (Wells 1984; Pivnik and Wells 1996). Conversely in the Katawaz Basin, the early Eocene Khojak Formation indicates the Indus River system delta-fan complex is initiated with longitudinal and westward flow into the Katawaz remnant ocean (Qayyum et al. 1996; Qayyum et al. 2001).

Paleocurrent information in the western Himalayan foreland for the middle to late Eocene and the early Oligocene is sparse as this interval is marked by a return to open marine conditions rep-

Table 1. Eocene-Miocene Post-Collisional Paleocurrent Trends in the Himalayan Foreland.

Formation	Location	Age	Dominant paleocurrent trends	Drainage interpretation	Source
Kamlial Formation	Potwar Plateau	Middle Miocene	SE, E	Fluvial system indicating regional flow Flow from alluvial fans equivocal to regional flow	Johnson et al., 1985 Hutt, 1996 Willis, 1993
Upper units of the Choksti Formation (Indian Molasse)	Indian Himalaya	Oligocene-Early Miocene	SW	May represent the initiated Indus River with source from the Karakorum or Lhasa blocks (=Indian Plate)	Clift et al. 2001b
Chitarwata and Vihowa Formations	Zinda Pir Dome (Dalana)	Early Miocene (Oligocene?-Early Miocene)	SE	Coastal shelf system draining the Katawaz block highlands supplanted by the Indus river drainage	This Study
Chitarwata, Vihowa, Litra and Chaudhwan Formations	Zinda Pir Dome (Raki Nala and Chaudwan Zam)	Oligocene-Pliocene	SE, SW	Sequence of meandering river deposits to larger braided rivers to conglomerates, with drainage from W foothills and NW highland	Waheed and Wells, 1990
Khojak Formation	Katawaz Basin	Eocene-Early Miocene	SW	Delta-Fan complex which drained the Indus River system longitudinally into the Katawaz remnant ocean	Qayyum, 1996; Qayyum et al., 2001
Ganguri Sandstone	Kohat Basin	Early Eocene	SE	Nearshore environments with a NW source	Wells,1984; Pivnik and Wells, 1996
Ghazij Formation	Balochistan	Early Eocene	SE	From areas to the NW where uplift near initial zone of continent-continent contact and compression	Clyde et al., 2003
Ghazij Formation	Zinda Pir Dome Raki Nala and Chaudwan Zam	Early Eocene	SE	Post-collisional shelf slope reversal	Waheed and Wells, 1990

resented by the Kirthar Formation in the Sulaiman Range and the Kohat Formation in the Kohat Plateau (Hemphill and Kidwai 1973; Pivnik and Wells 1996). This marine deposition has been suggested to have occurred in a north-south oriented foredeep proximal to the south flank of a peripheral bulge with a southeast trending axis (Pivnik and Wells 1996). From the early Oligocene through the early Miocene and to the west of this foredeep in the Katawaz basin, the Shaigalu Member of the Khojak Formation, with its sandstone-rich subaqueous to subaerial facies, supports paleodrainage from the early Himalayan orogenic highlands to the Katawaz delta and Khojak fan (Qayyum et al. 2001). Hence, drainage of the Indus River into the Katawaz basin during the Oligocene-early Miocene is a key component to understanding regional terrestrial fluvio-deltaic sedimentation, including the interval encompassing the Bugti Member assigned to the Chitarwata Formation.

Paleodrainage trends spanning the Oligocene to Pliocene strata in the Himalayan foreland in the Sulaiman Range are provided in a study by Waheed and Wells (1990) at Rahki Nala and Chaudwan Zam in the Zinda Pir Dome. Although these authors did not correlate their data strictly to defined formations or to major lithological and paleoenvironmental shifts in their section through the Chitarwata Formation, such as the subunits observed at Dalana, their study indicated the general dominance of southeastward and southwestward-directed paleodrainage directions through their sections. On the Potwar Plateau, the fluvial system of the middle Miocene Kamlial Formation was dominated by southeastward and eastward-directed paleodrainage associated with a large river system (Johnson et al. 1985; Hutt 1996) or alluvial fans (Willis 1993), and was considered by Najman et al. (2003) to represent the first stratigraphic evidence of the Indus River diversion to its current position at about 18 Ma.

Paleodrainage has also been assessed through analysis of provenance data in many parts of the Himalayan Suture Zone. A broad analysis of detrital sandstone modes from the Himalayan suture belt by Garzanti et al. (1996, figure 6) suggested that during the earliest collisional stage (early Eocene) sediment dispersal was to both the eastern and western areas of the suture zone involving a roughly arcuate pattern of drainage about the Nanga Parbat syntaxis. In this scenario, southeastward and eastward drainage prevail on the western side of the syntaxis, and southwestward drainage prevails on the eastern side with components of northward and southward drainage expected as flow off a forebulge. During the subsequent early collisional stage (Oligocene-Miocene), these authors suggested a greater southwestwardly directed component of paleodrainage on the western side of the syntaxis possibly along the proto-Chaman fault zone. This westward drainage model is consistent with the subsequent findings for the Khojak Formation and Himalayan drainage in that region by Qayyum et al. (2001). Additional support for the early evolution of westward drainage is found in the paleocurrent directions in the Eocene Nurla and Oligocene to early Miocene Choksti formations (Clift et al. 2001a). These formations record a shift to a dominant southwestward paleocurrent trend from the dominant northward and northeastward directed flow expressed in the underlying Paleocene Chogdo Formation in the Indian Suture Zone. The corresponding provenance of K-feldspars within the Nurla and Choksti formations indicate a detritus source from the Lhasa block of the Asian plate and support structural control of Indus River paleodrainage by the suture zone since the early Eocene. Moreover, provenance of the siliciclastic Khojak Formation in the Katawaz Basin is consistent with the idea of east-west structural control of the Indus Drainage by the suture zone with a detrital source from the early Himalayan orogen to the east (Qayyum et al.1996; Qayyum et al. 2001).

Our study examined late Oligocene-early Miocene paleodrainage in the subunits of the Chitarwata Formation and lowermost sandstones of the Vihowa Formation at Dalana in the Zinda Pir Dome. This investigation was undertaken: 1) to provide a framework of paleodrainage for the Chitarwata Formation linked to biostratigraphy and chronstratigraphic control, 2) to better understand the relationship of the Chitawata Formation's marginal marine environments to the broader patterns of concurrent Himalayan tectonism, paleodrainage, and paleogeography, and 3) to investigate how age and preservation differences of vertebrate localities at Zinda Pir and Bugti Hills relate to paleodrainage and paleoenvironmental differences in the western Himalayan Foreland. In particular, the paleodrainage character indicated by the Chitarwata Formation provides an opportunity to investigate models of Indus River flow during the late Oligocene-early Miocene and evaluate whether the Zinda Pir Dome region was structurally and depositionally isolated from the main pulse of Indus River deposition (i.e., to the Katawaz Basin to the west).

METHODS

We collected paleocurrent information for the major sandstone units in the Chitarwata Formation and the lower portion of the Vihowa Formation at Dalana in the Zinda Pir Dome area. Our data were collected along measured sections with chronostratigraphic control and focused on mesoform features including large-scale planar crossbedding and trough crossbedding (Figure 2). Sedimentary structures evaluated in this study were $\geq$ 0.5 m in size. The Plate Tectonic Mapping System of the ODSN Plate Tectonic Reconstruction Service (Ocean Drilling Stratigraphic Network 2004) was used to evaluate plate configurations during deposition of the Chitarwata Formation. Paleocurrent measurements were structurally corrected for both the folding characteristics of the Zinda Pir Dome and the counterclockwise rotation of the Indian subcontinent since the late Oligocene following Dewey et al. (1989).

RESULTS

Over 250 paleocurrent measurements were taken for the three defined members of the Chitarwata Formation at Dalana (Downing et al. 1993) and the lowermost major sandstone units of the overlying Vihowa Formation. The stratigraphic placement of our sandstone reference units, the sedimentary structures evaluated, respective numbers of measurements, mean resultant directions and sense, 95% confidence intervals for directions, and maximum percentages are specified in Table 2. The corresponding Rose Diagrams for the sandstone units are presented in stratigraphic order in Figure 3.

Our paleocurrent results for lower Chitarwata Formation indicate a predominant southeastward mean resultant direction for the planar crossbedding evaluated in unit RS 7 (Figure 3.1). This is in general agreement with the more sparse data from trough axes in RS 7. An almost due-southward mean resultant direction is implied by unit RS 16, but it displays a notably high degree of directional variability. Results for planar crossbedding and trough axes in unit RS 24 in the middle unit of the Chitarwata Formation (Figure 3.2) are similar to those of unit RS 7, supporting a prevailing southeastward mean resultant direction.

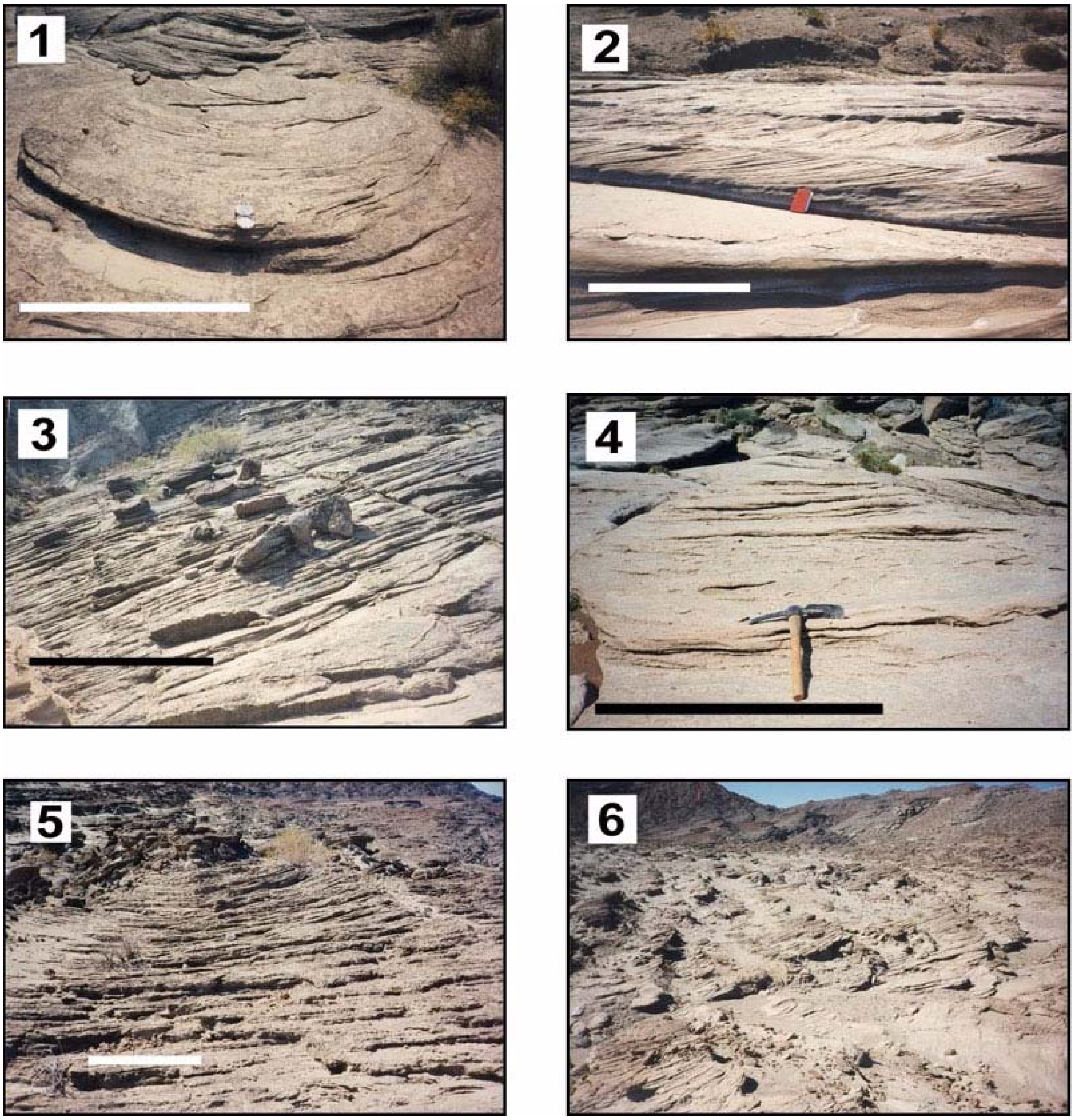
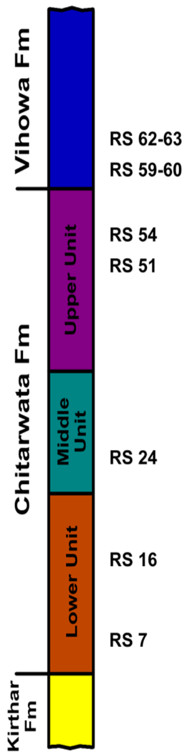


Figure 2. Examples of mesoform sedimentary structures evaluated for paleocurrent information in the Chitarwata and Vihowa Formations. 1: RS 7 trough crossbedding, 2: RS 7 planar crossbedding foresets, 3: RS 24 planar crossbedding, 4: RS 51 planar crossbedding, 5: RS 59-60 large trough crossbedding, 6: RS 59-60 planar crossbedding. All bars represent 1 meter.

Flow directions for the upper unit of the Chitarwata Formation were obtained from units RS 51 and RS 54 at Dalana and generally imply southward flow and drainage for the next interval of deposition (Figure 3.3). Directional flow to the south and to the southwest is supported by planar crossbedding in unit RS 51 and trough crossbedding axes in unit RS 54 L (lower), respectively. With moderate variance, trough crossbedding in RS 51 and RS 54 U (upper) in combination with sparse planar crossbedding data from RS 54 indicates southeastward flow. Southeastward drainage is supported by trough crossbedding and planar crossbedding data for the lowermost major sandstone units of the Vihowa Formation, RS 59-60 and RS 62-63 (Figure 3.4).

In aggregate, our paleocurrent data at Zinda Pir Dome for the Chitarwata and lower portion of the Vihowa Formation reflects a predominant southeastward mean resultant direction with some occasional deviation of current flow to the southwest and east. Our results are in general agreement with the previous results of Waheed and Wells (1990) at Chaudwan Zam through the Chitarwata Formation (their unit Ic). However, where they found a southwestward dominant drainage compo-

Table 2. Paleocurrent data and statistics for the Chitarwata and Vihowa Formations at Dalana.



Reference Unit	Sedimentary Structure	N (Number of Measurements)	Mean Resultant Direction and Sense	95% Confidence Interval	Maximum
RS 62-63	Planar Crossbeds	27	124°SE	±21°	22.2% [6 data]
RS 59-60	**Trough Crossbeds**	**5**	**103°SE**	**±28°**	**40% [2 data]**
RS 59-60	Planar Crossbeds	44	162°SE	+12°	25% [11 data]
RS 54 U	Trough Crossbeds	11	104°SE	+48°	18.2% [2 data]
RS 54 L	Trough Crossbeds	19	205° SW	+9°	31.6% [6 data]
RS 51	Trough Crossbeds	21	139°SE	+26°	23.8% [5 data]
RS 51	Planar Crossbeds	15	182°SE	+35°	20% [3 data]
RS 24	Trough Crossbeds	8	173°SE	+14°	37.5% [3 data]
RS 24	Planar Crossbeds	36	128°SE	+20°	19.4% [7 data]
RS 16	Planar Crossbeds	15	178°SE	+48°	20% [3 data]
RS 7	Trough Crossbeds	7	173°SE	+20°	42.9% [3 data]
RS 7	Planar Crossbeds	45	142°SE	+23°	15.6% [7 data]

nent at Raki Nala (their unit Ir), only the upper unit at Dalana has a distinct southwestward flow component. Altogether, exclusive of the distinctive cases for the suture zone and Katawaz Basin, the available paleocurrent information in the literature and this study support a dominant southeastward paleodrainage trend from the early Eocene through the Miocene in the Pakistan Himalayan foreland.

TECTONIC INTERPRETATION AND PALEOGEOGRAPHY

The paleogeographic setting of the Himalayan foreland during deposition of the Chitarwata Formation at Zinda Pir Dome was the product of both regional tectonic events related to India-Asia collision and eustatic sea level changes. The Indus Fan provides an aggregate record of sedimentation that must be addressed in discussions of paleodrainage of the Himalayas following the India-Asia collision. Analysis of multichannel seismic profiles and deep sea cores of the Indus Fan by Clift et al. (2001b) confirm that: 1) the Indus Fan and Indus River system are at least middle Eocene in age, 2) about 35% of the fan is comprised of Paleogene sediments signifying there was large topographic relief in southern Asia at that time, and 3) a rapid increase in sedimentation occurred during the middle Miocene. The Indus Fan also records a significant Oligocene-Early Miocene plate reorganization that impacted and influenced the uplift of the Owen Ridge (Mountain and Prell 1990) and Murray Ridge (at about 23 Ma) along the Owen Fracture Zone. This important tectonic event produced a southeastern deflection of sediments to the Indus Fan (Mountain and Prell 1990; Edwards et al. 2000; Clift et al. 2001b). It is also likely that this tectonic event had an as yet unascertained role in controlling the character of late Oligocene and early Miocene foreland drainage and sedimentation through its impact on plate interactions (e.g., Afghan Plate and Katawaz Block) along the Chaman fault zone.

The westward path of the Indus River during the Oligocene and Early Miocene was structurally controlled by the suture zone (Clift et al. 2001a). River capture leading to the Indus River's current configuration would happen later through the development of the Nanga Parbat syntaxis and its component structures: the Pamir indent, Karakorum fault and Nanga Parbat uplift (Brookfield 1998). The Katawaz Basin was the chief path for Indus river fluvio-deltaic deposition that also fed the Indus Fan from the early Eocene through roughly the early Miocene (Qayyum et al. 2001).

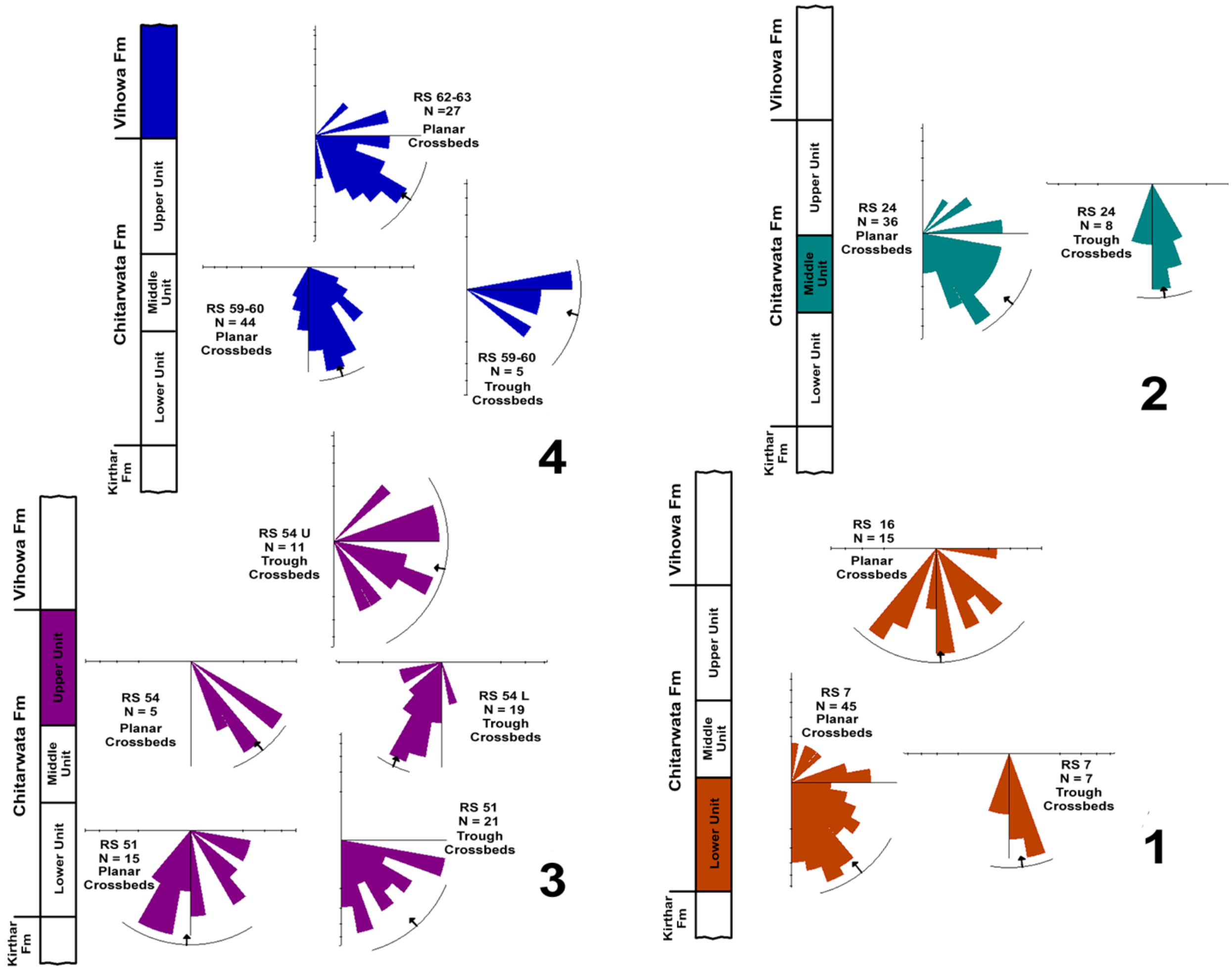


Figure 3. Rose Diagrams for the paleocurrent information in the Chitarwata and Vihowa Formations (see Table 2 for statistics, mean directions, and confidence intervals). Arrow indicates mean resultant direction and arc represents 95% confidence interval. 1: Lower Unit of the Chitarwata Formation (RS 7 and RS16), 2: Middle Unit of the Chitarwata Formation (RS 24), 3: Upper Unit of the Chitarwata Formation (RS 51 and RS 54), 4: Lower Vihowa Formation (RS 59-60 and RS 62-63).

We name and assign the Oligocene-early Miocene expression of the Katawaz Fan to the Shaigalu Fan, after the younger Shaigalu member in the Khojak Formation to distinguish it from the earlier phase of Eocene sedimentation expressed by Qayyum et al. (2001) as the Katawaz Delta and Khojak Fan system.

Northwest and west of the Zinda Pir area was a highland formed of the remnant Paleogene fore-arc complex comprised of melange and ophiolites (Brookfield 1998; Qayyum et al. 2001). Presumably the Katawaz Block to the east of the Chaman Fault Zone underlying the modern Sulaiman Range (Haq and Davis 1997) in combination with the Afghan Block to the west played an important structural role in both the character of these highlands and the style of Indus River sedimentation. To the north, a forebulge was implicitly present (Garzanti et al. 1996; Pivnik and Wells 1996) between the Zinda Pir area and the suture zone. Against this backdrop of plate interactions the Oligocene and early Miocene was characterized by marked shifts in eustatic sea level. The early Oligocene witnessed a rise to 200 m above current sea level at 34-30 Ma with a corresponding and precipitous drop of over 150 m at 30 Ma (Haq et al. 1987). During the remainder of the Oligocene and into the early Miocene, sea level generally trended higher with several oscillations including a cycle at the early Miocene (24 Ma) and then again at about 20 Ma (Haq et al. 1987). Although a direct correlation between these eustatic fluctuations and Chitarwata Formation facies is not yet possible, the sequence of paleoenvironments of the Chitarwata reflects the net effect of the trend towards higher sea level moderated by regional plate flexure and sediment influx.

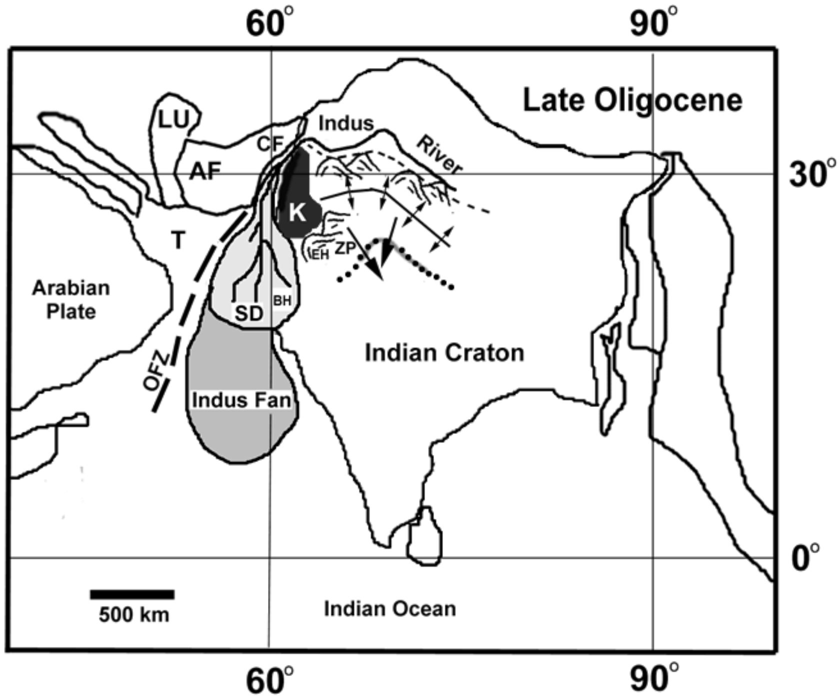


Figure 4. Schematic diagram showing the paleogeographic setting and drainage relationships between: (1) the coastline constituted by the Chitarwata Formation at Zinda Pir Dome, (2) Bugti Hills within the "Shaigalu" delta, (3) the Katawaz Block (as referred by Jadoon et al. 1994; Haq and Davis 1997), (4) the nascent Owen Fracture Zone, (5) the Chaman Fault Zone, (6) the highlands and forebulge adjacent to the Chitarwata Coast, and (7) the Indus Fan. Adapted from Qayyum et al. (2001) with plate configuration based on ODSN plate tectonic reconstruction model. Abbreviations are: BH-Bugti Hills; CF-Chaman Fault Zone; EH-Eastern Highlands; K-Katawaz Block; L-Lut Block; AF-Afghan Block; T- vestigal Tethys; OFZ-Owen Fracture Zone; SD-Shaigalu Delta; ZP-Zinda Pir Dome. Symbols used: large arrows denote the dominant paleocurrent trends in the Chitarwata Formation; dotted line depicts the Chitarwata coast; small arrows downslope to forebulge axis; small dashed line represents the suture zone; hills as indicated.

Our schematic paleogeographic reconstruction of the Chitarwata Formation is provided in Figure 4. With its dominant southeastward drainage, the coastal environments of the Chitarwata Formation received contributions from the highlands to the northwest and west as well as the forebulge to the north. Direct evidence of sediment contribution by proximal highlands is found in the upper member of the Chitarwata Formation where reworked and redeposited Eocene *Nummulites* are common in shell lags. If this scenario is accurate, there should be little if any contribution of recycled orogenic detritus from the suture zone since the Indus River is assumed restricted to the Katawaz Basin at that time. The Chitarwata coastal system would persist in this configuration for several million years only to be overrun by Indus River sediments at about 19.5 Ma (Lindsay et al. this issue) during a momentous shift to the current foreland basin marked stratigraphically by deposition of the Vihowa Formation.

IMPLICATIONS AND CONCLUSIONS

Our paleocurrent data suggest that there was an appreciable interval during the late Oligocene and early Miocene during which the Zinda Pir area was a stable coastline with paleodrainage chiefly from the northwest toward the southeast. This Chitarwata coast formed the northern and western edge of the Tethys-sea-marine foredeep, a structure recognized in sedimentary deposits in the Kohat Basin to the north by Pivnik and Wells (1996). The presence of marine invertebrates and oncolites in the early ?Miocene Murree Formation (Pivnik and Wells 1996) suggests that this marginal marine facies may have extended as far as the Kohat Plateau to the northwest. Moreover, this coastline was likely structurally isolated by a northern forebulge and regional highlands to the west from the main recycled orogenic detritus observed in the concurrent fluvio-deltaic deposits of the Katawaz Basin and the subsequent fluvial deposits of the Vihowa Formation. It is notable that Vihowa sedimentation predates deposition of the Kamlial Formation on the Potwar Plateau by at least a million years. This timing implies that initial Indus River deposition in the Himalayan foreland was asynchronous across the Himalayan front near the syntaxis.

In contrast to the Chitarwata Formation coastline, the Bugti Hills area of deposition is interpreted as a major fluvio-deltaic environment occupying a vast floodplain (Welcomme et al. 2001). It is difficult to reconcile the lithostratigraphic, paleoenvironmental, and taphonomic differences in the Chitarwata Formation between the Bugti Hills and Zinda Pir Dome areas as just a product of coeval or diachronous lateral variation in the same depositional system. Based upon the prevailing knowledge of regional deposition of the Indus River in the Oligocene and early Miocene summarized above, it is plausible that the more southerly Bugti Member of the Chitarwata Formation at Bugti Hills, with its exceptional Oligocene vertebrate faunas (Welcomme and Ginsburg 1997, Maivaux et al. 1999, Antoine et al. 2003, Metais et al. 2003), was a phase of fluvio-deltaic sedimentation related to distal deposition in the Katawaz drainage system as part of the Shaigalu Delta. In this scenario, the extensive Bugti Hills fluvio-deltaic environment would represent primary Indus River drainage from northern highlands rather than from western orogenic highlands as suggested by Welcomme et al. (2001). If correct, significant differences in fossil preservation and biostratigraphic relationships would be expected between the Zinda Pir and Bugti sediments. Moreover, vertebrates recovered in the Shaigalu member of the Khojak Formation might compare favorably in age to those at the Bugti Hills. Future comparison of provenance signals with respect to sandstones in the Chitarwata Formation from the Zinda Pir and the Bugti Hills areas should clarify whether they are indeed distinct in composition as well as clarify the timing and character of their signals and relationship to the concurrent Indus River drainage.

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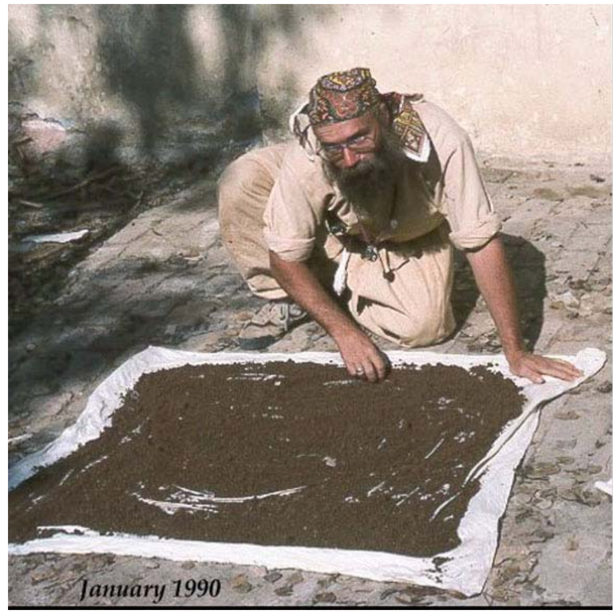

Figure 5. Tending to the concentrate, Dera Ghazi Khan, Pakistan, 1990.

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