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Fluvial history of late Cenozoic molasse, Sulaiman Range, Pakistan

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ABSTRACT: *Two measured sections show that Himalayan molasse in west-central Pakistan is 3850m thick at the northern end of the Sulaiman Range and 3150m thick at the southern end. The basal units in both sections are made up principally of channel lags, in-channel megaripples, point bars, floodplain, and crevasse-splays. These represent clayey to sandy meandering rivers that flowed SE in the north and SSW in the south. A sandstone-dominated middle unit in the south is made up of channel lag and fill, in-channel megaripples and large transverse bars, and some overbank material. These are thought to have been large sandy braided rivers that flowed SW. The conglomeratic uppermost units in both sections are channel lag & coarse longitudinal bars, fine longitudinal bars, megaripples, and some overbank material. These were deposited by gravelly to cobbly braided rivers that flowed SW in the south and SE to ENE in the north.*

These changes in facies, drainage, and fluvial style can be related to the uplift and eastward advance of the orogenic front of the Sulaiman Range. In the south, the gradual transition from meandering through sandy braided to cobbly braided rivers and a consistent SW flow obliquely into the modern Sulaiman Range indicate little or no uplift of the immediately adjacent orogen. In the north, clayey and sandy meandering rivers change abruptly to cobbly braided rivers and flow simultaneously changes from SE (longitudinal) to E (transverse). The onset of boulder conglomerates occur about 700m lower in the north than in the south, which suggests that the northern end of the Sulaiman Range was uplifted slightly earlier.

INTRODUCTION

In this paper, we wish to describe the overall history of fluvial deposition in the Sulaiman Range in west-central Pakistan. This area is of interest because it is a virtually unstudied part of the western Himalayan orogen. The Sulaiman Range is a N-S fold-belt range that rises abruptly from the plains west of the Indus River (Fig. 1). It is the front of the southwestern arm of the Himalayas, which is more or less the boundary area with Afghanistan and which incorporates the Indo-Eurasian plate boundary. We studied one long section at each end of the Sulaiman Range (Fig. 1). Due to the climate and the tectonism, exposures are exceptional.

Previous work

The last decade has seen a considerable increase in research on the Himalayan molasse, both in terms of modern and ancient depositional environments, lithostratigraphy, paleontology, and especially much extremely interesting work using detailed magnetostratigraphy to tie depositional rates and facies to tectonic history. Representative examples of important works in these areas include Parkash and others (1983) and Bristow (1987) for modern environments; Behrensmeyer and Tauxe (1982) for ancient environments; Barry (1984) and Barry et al. (1980) in litho- and biostratigraphy; Hussain et al. (1979) and Badgley and Behrensmeyer (1980) in paleontology; and Burbank and Raynolds (1988) for applications of magnetostratigraphy. Most of the work on the Siwalik molasse has concentrated on the Potwar Plateau and adjacent areas on the other side of the Salt Range, the main Himalayan foreland basin. Their relationships with the Sulaiman Range have never exactly been determined, although they are generally taken to be part of a coeval blanket of molasse linked through the little-studied Kohat District and, prior to the rise of the Salt Range at ca. 5 m.y. (Beck and Burbank, 1990), through the subsurface of the Indus plain.

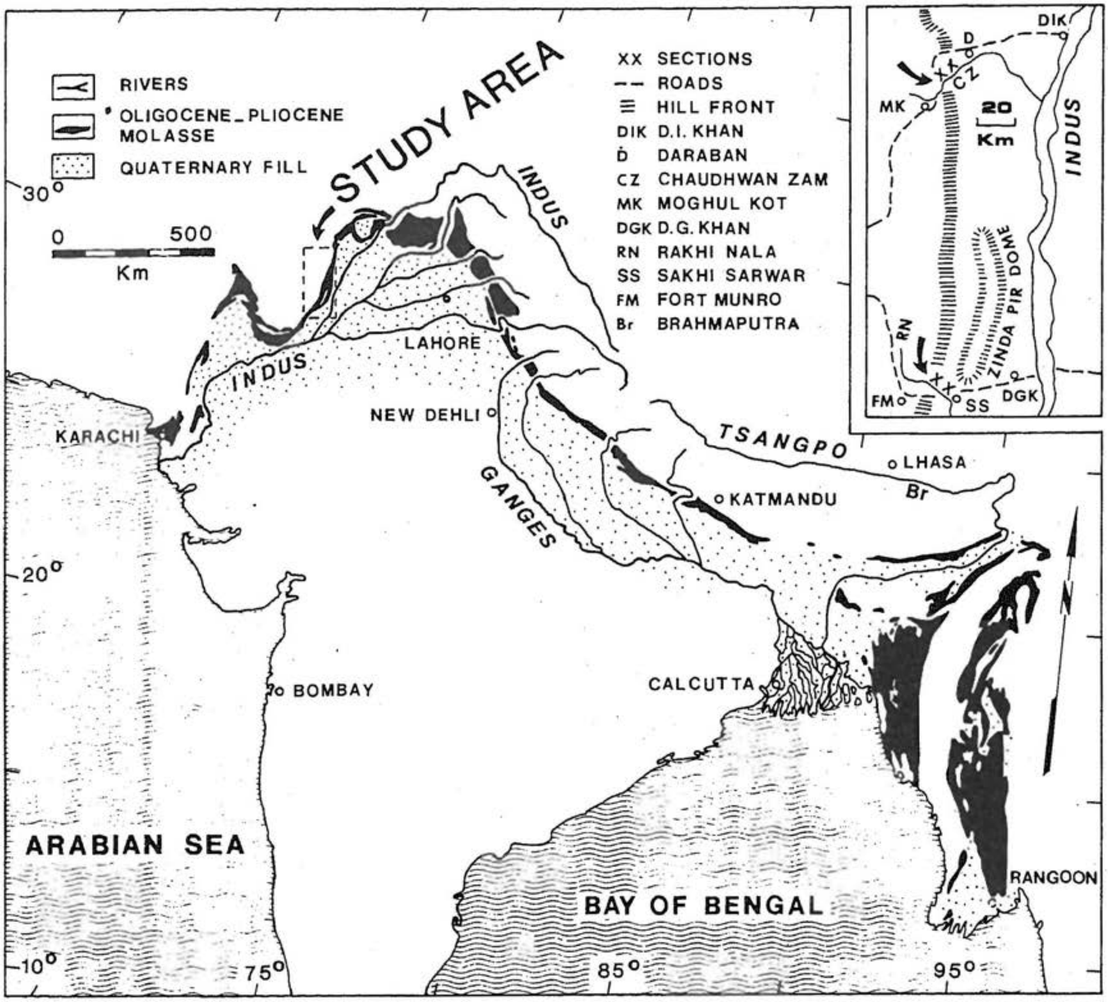

Fig. 1. The study area, and its relationship to outcrops of Himalayan molasse around Indo-Pakistan.

Recent work in the Kohat District by Beck and Burbank (1990) has shown a several-million year mismatch in lithostratigraphy between it and the Potwar district. They show that from 13.5-11.5 m.y.B.P. an Indus-like river flowed south through the Kohat area, but became diverted eastward, through the Potwar into the Ganges, until being diverted back again by 4.5 m.y.B.P. This suggests caution in correlating the Sulaiman Range molasse without good paleomagnetic controls.

The most intensive previous study of the molasse in our study area was a mapping and lithostratigraphy project by Hemphill and Kidwai (1973). Our area was also on the fringes of a large scale reconnaissance by the Hunting Survey (1960). Earlier reports, although fascinating, do not bear directly on fluvial interpretations: for information about them, the reader is referred to the two works just mentioned.

Waheed and Wells (1990) have analyzed paleocurrent changes through the two Sulaiman Range sections with regard to their tectonic setting and orogenic significance. Figure 5 of that paper presents the measured sections to be discussed here.

Methods

We investigated two very long sections because we were interested in changes in molasse deposition during the Himalayan orogeny. We chose not to measure a large number of laterally equivalent sections (as, for example, Behrensmeyer, 1987, and Behrensmeyer & Tauxe, 1982, were able to do). We did this because we lack magnetostratigraphic control and because the principal lesson of recent research on the Siwaliks is that traditional lithostratigraphy is inadequate for correlation (Pilbeam et al., 1977; Barry et al., 1980; Barry, 1984; Krishnaswamy, 1981; Beck and Burbank, 1990). To emphasize this point, we have not used standard Siwalik nomenclature or even the local nomenclature of Hemphill and Kidwai (1973). Instead we have divided the molasse into informal local units, A and B in the north, and X, Y, and Z in the south.

Just as we avoid correlating the Sulaiman Range molasse to better known Siwalik sections, we are likewise not drawing any correlations between our two sections, except in the most general fashion between their bases (both bury the same Late Eocene-Oligocene unconformity in a similar fashion), and between their tops, and in that we consider that conglomerate first appears "significantly" lower (i.e., earlier) in the north than in the south. For our purposes and given current knowledge of Sulaiman Range stratigraphy, it suffices to observe changes over relative stratigraphic time in single, isolated, very long stratigraphic sections. Paleocurrents were assessed using the methods in Wells (1988).

The southern section is located where Rakhi Nala (Rakhi River) leaves the Sulaiman Range, below the road from Dera Ghazi Khan to Quetta. The northern section crops out along the Chaudhwan Zam gorge, which is accessible to the east of the road to Mughal Kot from Dera Ismail Khan via Daraban.

RESULTS

Our sections have been detailed in Waheed and Wells (1990, fig. 5) and will not be repeated here, but they are summarized in general terms in Figure 2. Table 1 describes the main facies present in each of the major divisions, and gives them general, first-order, interpretations. Table 2 summarizes Markov chain analyses using the program by Wells (1989). We will discuss the units from the base up, and for ease of discussion we will combine unit B with unit Z and unit A with unit X.

Basal beds, both sections

The very bases of both the northern and southern sections consist of highly colored shales (somewhat irregular bands of white, purple, orange, lavender, brown, etc.) and thin and relatively fine-grained but massive sandstones. Hemphill and Kidwai (1973) called the northern strata the Chitarwata Formation, whereas Eames (1954) referred the southern beds to the Nari Series. We included them in units A and X because they are comparable to the finer facies above, because the sections are more or less gradational, and because they contain so few features that nothing definitive can be said about them.

In both sections, the basal contact with the underlying late Eocene shales (the Drazinda Shale) seems conformable, and in a way is repeated several times in the overlying beds. In the north, Hemphill and Kidwai (1973) record both a local coaly sulfurous horizon and local oxidation in the uppermost Drazinda. In our northern section, the contact is not obvious or well exposed. Green and brown Drazinda shales with abundant marine invertebrates pass up into a complex of thin fine brown sandstones, green and brown gypsiferous clays, and red, white and brown clays (possibly pedogenized?). In the south, the basal brown sandstone lies abruptly on green shale, not far above a coal mine. In both sections, the overlying massively bioturbated and brightly colored shales and thin massive sandstones are distinctively different from underlying strata, but they appear to repeat hiati that are no less intense than the one culminating the Drazinda.

Some of the "Chitarwata" sandstones contain rare hints of original lamination, ripple and megaripple crossbeds, and grain-size alternations. One set of mudcracks was seen, and intraformational clasts including flat clay pebbles, and small flecks of plant debris are relatively common. Most of the sandstones, however, have been completely homogenized, and have been further overprinted by any of several secondary fabrics. These include root/burrow mottles, nodules, and casts, some hematitic; breakage of the bed into vertical columns, possibly by tap root action; iron induration in the forms of massive impregnation, joint linings, nodules, concretions around intraformational clay pebbles, encasements and mottles around roots/burrows, and ir-

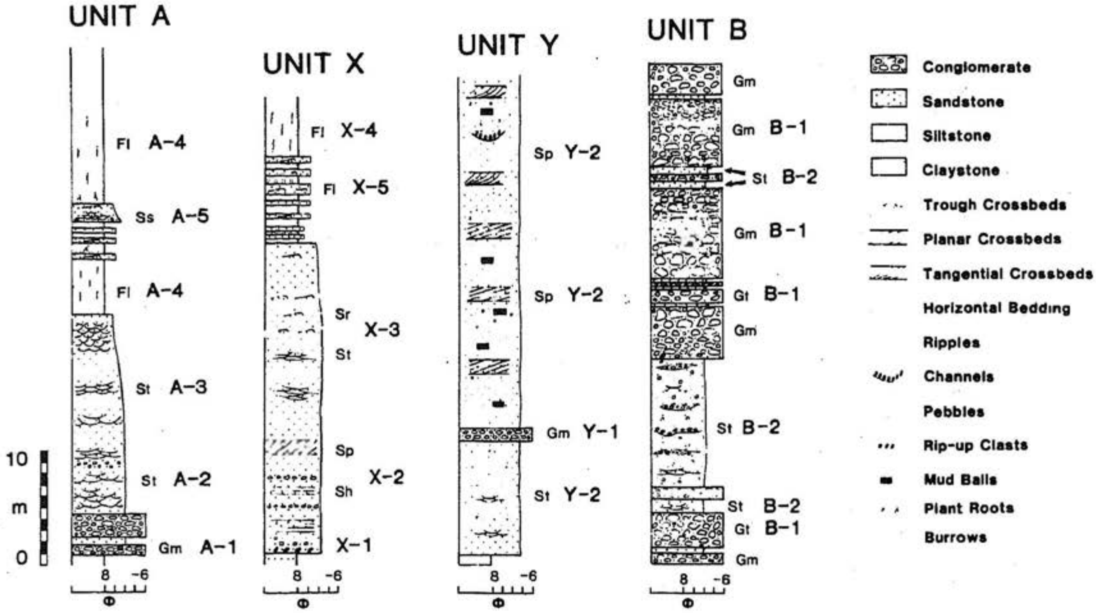

Fig. 2. The measured sections: Chaudhwan Zam represents the northern end of the Sulaiman Range, and Rakhi Nala the southern end.

regular mottles. The sandstones seem to be tabular and mostly less than 1m thick. In terms of geometry and likely original fabric, they are reasonably similar to the splay and floodplain facies seen in the overlying molasse.

Lower units, both sections

As described in Table 1 and in contrast to the upper units, the bulk of units A and X show classical meandering features, such as channels with epsilon crossbedding. The channel sands typically show strong upward fining and classic point-bar crossbedding (Figs. 3A & C), and there is abundant overbank clay with exceptionally fine examples of crevasse-splay deposits (Fig. 3B). According to Markov Chain analyses (Table 2), both sections show strongly asymmetrical (unidirectional or non-reversing) successions from channel lags through coarse channel fills and point bars to floodplain fines, which enclose crevasse splays. There are also many intraformational clay clasts (pebbles to boulders), which were presumably formed by bank collapse (Figs. 4B, C, D). The largest clay boulders, now preserved as casts in an exceptional northern sandstone, exceed several meters in length, and were rounded, molded, and potholed by river water moving over them and around them (Fig. 4C).

Middle unit, southern section

The middle part of the southern section, unit Y, comprises multistory, large, and somewhat irregular sand sheets with few floodplain clays (Fig. 3D). No deep channeling is seen, and in general channels are not readily distinguished. Mini-sequences show both fining and coarsening upward, and complex vertical and lateral accretion, although there are few clearly channel-margin epsilon crossbeds. Most crossbedding is characterized by marked changes in grain size from one foreset to the next. All of this suggests braided streams. On the other hand, the lack of clays probably results as much from erosion as from nondeposition. There are some clayey floodplain-paleosol sequences, and mudballs, clay pellets, and lenses of clay are common - in particular, one bed in the sandiest part of the section contains layers of clay cobbles and 90cm diameter clay balls, and another contains one of 1.5 by 0.8m. Also, many of the sandstones seem best interpreted as overbank, proximal, crevasse-splays (Fig. 3F). The coarser facies tend to alternate with each other, as do the floodplain and splay facies, so overall transitions are quite symmetrical

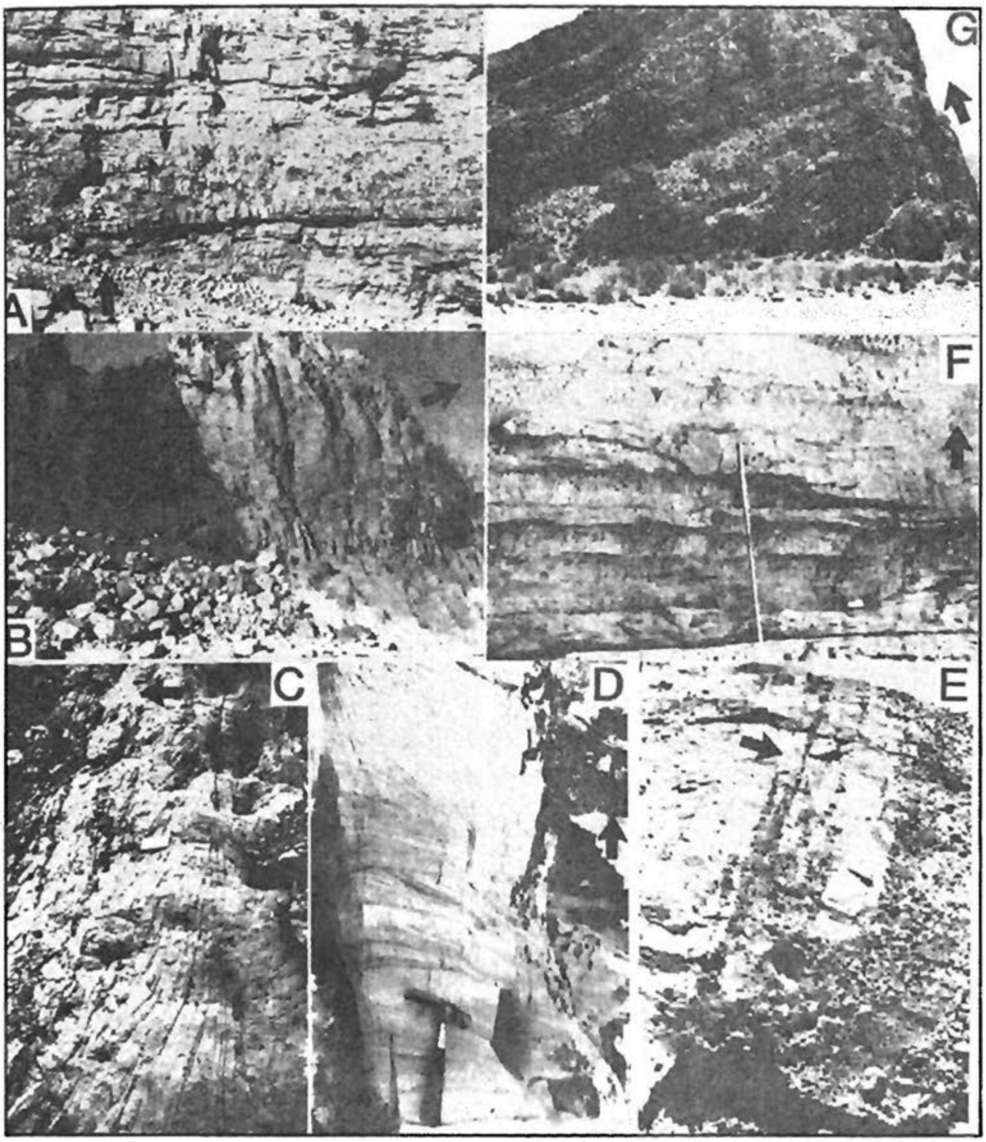

Fig. 3. All large arrows point stratigraphically upward.

A: From meandering-stream part of Chaudhwan Zam section (unit A). Note the asymmetrical, winged, 15.5 by 1.25m channel (AC) and the lateral accretion sets in a lower fining-upward unit (small arrows). The field of view is ca. 20m wide.

B: Thick crevasse splay, spreading non-erosively over floodplain clays. The width of field of view is ca. 5m. Unit X, Rakhi Nala.

C: Slightly irregular lateral accretion bedding (dipping away from photographer), in point-bar facies, Chaudhwan Zam unit A.

D: Stacked megaripples, in channel deposit of braided-stream, Rakhi Nala unit Y.

E: Coarse channel fill/longitudinal bar sandstone with pebble layers and lenses, cut into at base of photo by a cobble-filled channel, whose conglomerates eventually spread over the old sand-bar surface. The length of arrow is 40cm. From base of unit B, Chaudhwan Zam.

F: Overbank facies, resembling sandy splays, floodplain muds and a small and shallow, upward-fining, pebbly sandstone channel. The base of the picture is the top of a relatively large, pebbly sandstone braid-channel. Unit Y, Rakhi Nala.

G: The core of the base-of-B conglomeratic lithosome, unit B, Chaudhwan Zam. Smaller arrower points to person for scale.

TABLE 1. DESCRIPTIONS OF FACIES ASSOCIATIONS

Facies. INTERPRETATION (characteristic lithologies)

PRT=Predominantrocktype, SRT=Secondary rock type,MRT=Minor rock type; Order of description: Grain size, Fabric,Bedding type & thickness, Basal contacts, Upper contacts, Clast lithology.

Units B & Z

BZ-1. FACIES ASSOCIATION OF CHANNEL LAGS, VERY COARSE CHANNEL FILL, & VERY COARSE LONGITUDINAL BARS (massive to crudely stratified cobble-boulder conglomerates); PRT: Conglomerates, pebbles-boulders. Poorly sorted, randonm fabrics, no stratification except rare imbrication & normal grading; Clasts (subangular-subrounded)=sandstone, siltstone, claystone, limestone, chert; SRT: Sandstone, coarse, as massive to crossbedded lenses.

BZ-2. LONGITUDINAL BAR (massive to stratified pebble sandstone with minor interbedded conglomerate); PRT: Sandstone, coarse-medium. Massive to trough-bedded. Thick bedded, locally fining upward. BC= sharp, flat to irregular; SRT: Interbedded conglomerate, finer than BZ-1. Lenticular, normally graded, crudely stratified; MRT: Very common lenses of clayey to silty sandstone.

BZ-3. IN-CHANNEL MEGARIPPLES (massive to crossbedded sandstone); PRT: Sandstone, much like AX-2 & Y-3, medium-fine, locally pebbly. BC sharp, UC gradational into overlying claystone; SRT: Sporadic lenses of conglomerates and of sandy claystone.

BZ-4. OVERBANK & ABANDONED-CHANNEL FILL (red sandy siltstone & claystone); PRT: Red sandy siltstone & claystone. Overbank and abandoned-channel clays differ only in geometry; SRT: Common thin interbeds of pebbly sandstone & conglomerates, some microchannels; SRT: Megaripple sandstone, in cyclic alternation with finer beds, especially in northern section; Comments: Channels here seem shallower & less well defined, & overbank deposits are uncommon & indistinct.

BZ-5. FACIES AT THE EDGES OF THE CONGLOMERATE LITHOSOME; PRT: Thickly interbedded, flat, coarse and fine beds; Coarse: Either largely tabular conglomerates with crude horizontal organization or largely tabular megaripple sandstones; Fine: Floodplain clay, if coarse is sand, or thinly bedded sandy clays or clays and sands if coarse is conglomeratic.

Unit Y

Y-1. CHANNEL LAG & FILL (massive to crossbedded conglomerates, with interbedded sandstones); PRT: Conglomerate, pebbles & cobbles of sandstone, siltstone, limestone & chert. Planar, tangential & trough crossbeds, 0.9-2.0m. BC= sharp, erosional, and occasionally undulatory; SRT: Sandstones, coarse-medium, in crossbedded lenses.(Comments: Some granulestones are made up almost entirely of well imbricated, reworked, large benthic foraminifera.)

Y-2. LARGE COARSE BARS (pebbly sandstone, notably with large straight-crested transverse bedforms); PRT: Sandstone, coarse-medium. Many clay pellets, clay lenses, & intraformational pebbles to boulders of sand & clay; Large planar, tangential & trough crossbeds, with dips $<25°$. Many scour & fills & small channels; Upper & lower contacts are gradational; both fining & coarsening upward.

Y-3. IN-CHANNEL MEGARIPPLES (crossbedded to massive sandstone); PRT: Sandstone, mostly like Facies AX-2, medium-very fine, with many intraformational pebbles & granules of silt & sand along foresets and within ss. Lower parts flat- to trough-bedded or massive. Upper part finer & more bioturbated; Local upward-fining sequences.

Y-4. OVERBANK (channel, splay, and floodplain); PRT: Crevasse-channel sands, like AX-5, more bioturbation, in channelform lenses that can grade up and out into floodplain beds; SRT: Floodplain facies: brown silty to sandy claystones; MRT: Splay sands, like AX-5. Alternating sandstone & claystone, flat- to cross-bedded, with climbing ripples.

Units A & X

AX-1. CHANNEL LAG (pebble conglomerate & interbedded sandstone); PRT: Congl., pebbles with sand matrix. Crude imbrication & normal grading. BC= sharp, erosional, channelform; UC= flat, gradational. CL= Flat clay pebble, claystone, siltstone, sandstone, limestone; SRT: Sandstone, medium GS. Massive to crossbedded, in discrete lenses.(Comments: S. section has thinner conglomerates, more flat clay pebbles. Coarse clasts increase up-section.)

AX-2. IN-CHANNEL MEGARIPPLES (massive crossbedded sandstone & subordinate claystone); PRT: Ss, medium-fine, with some pebbles. Tabular, trough, & tangential crossbeds with 3-30°

dips. Troughs upto 5m across; In erosively bounded 10-50cm thick single sets and multiple cosets. Local upward fining.MRT: Some intraformational pebbles of red clay (flat-pebble rip-up congls. are especially common in S.) & sandstone, & large irregular cobbles of clay (from bank collapse).(Comments: Some pebbles of extraformational sandstone & limestone. One northern ss has clay blocks longer than 3 meters.)

AX-3. POINT BAR (fining-upward sandstone with interbedded claystone); PRT: Ss, fine - very fine. Epsilon; small-scale planar, tangential, & trough; climbing ripples. Thick to thin bedded, locally laminated, with slumps, ball & pillow, and bioturbation; SRT: Red claystone, as interbeds, in upper half of this facies.

AX-4. FLOODPLAIN (varicolored claystone & interbedded very fine sandstone); PRT: Claystone (red, brown, maroon, lavender, etc.), clayey to silty, nodular, variably bioturbated, with plant fragments, roots, and rare pieces of bone. Some horizons of calcareous concretions & grit bands; SRT: Interbedded sandstone, very fine. Crossbedded, ripple-laminated, bioturbated. Very thin-bedded to laminated & lenticular.

AX-5. CREVASSE SPLAY/CREVASSE CHANNEL (rippled to crossbedded sandstone with interbedded claystone); PRT: Sandstone, medium-very fine.Low angle trough & planar crossbeds, ripple lamination. Thin bedded to laminated; Crevasses show complex channelling & filling, erosive bases with abundant basal rip-up clasts, & gradational tops; Splays=thin sheets, sharp to gradational bases, gradational tops, coarsening-upward or alternating coarse & fine ss.

(Table 2).

Paleocurrents show flow to the SSW, intermediate between the directions for units X and Z, and the directional variances are likewise slightly less than for X and slightly more than for Z (Fig. 5: see Waheed and Wells, 1990). It is also noteworthy that Y contains the largest crossbeds seen in the entire molasse sequence at either site. The largest, seen in exceptional flat-iron exposures, was a single, straight-crested bedform, with a preserved height of 2m and a partial crest length, oriented transversely across the channel, of 32m. Neither end was seen, and the bedform had migrated unchanged along the length of the outcrop, ca. 50m. Several exposures suggested other transverse bedforms about as large, and trough crossbeds were also larger than elsewhere (fig. 7A in Waheed & Wells, 1990). We interpret the large size of the bedforms, the abundance of sand, and the southward flow as indicating a relatively large, non-proximal, longitudinal trunk river.

Upper units, both sections

The upper parts of the sections (units Z and B) are principally conglomeratic. Our measured section through unit B in Chaudhwan Zam is shown as being somewhat conglomeratic at top and bottom and having a thick central sandy zone (Fig. 2 here, fig. 5 in Waheed & Wells, 1990). However, unit B actually consists of large packages of nearly pure conglomerate, on the order of a few thousands of meters wide and a few hundreds of meters thick. These are enclosed and separated by thinner bedded, sandier and clayier units. Because our section follows the river gorge, it tends to side-step the cores of the conglomerate lithosomes. Paleocurrents indicate eastward flow in the conglomerate of the northern section, indicating drainage away from the orogen (Fig. 6), but SSW in the southern conglomerate, which is *into* the orogen. Neither section contains clasts of the local distinctive Cretaceous to Eocene strata until their tops, which also indicates that the nearest edge of the Sulaiman Range was not uplifted until very recently (Fig. 4G).

Bedding in units Z and B show large, irregular, shallow, and ill-formed channels of coarse gravel and sand (Fig. 3G). These show a lot of crosscutting and much flat or gently sloping organization (beds, graded zones, lenses, etc.), which suggests many complex longitudinal gravel bars. There are some apparently out-of-channel deposits, including thin but complex gravel sheets, small channels, and some siltstone and claystone, which together suggest poorly developed and generally coarse braid-plain facies. According to the Markov chain analyses in Table 2, the southern section shows random alternation of facies, but northern section tends to have alternations between either the coarser two facies or the finer two facies. Overall, the upper beds

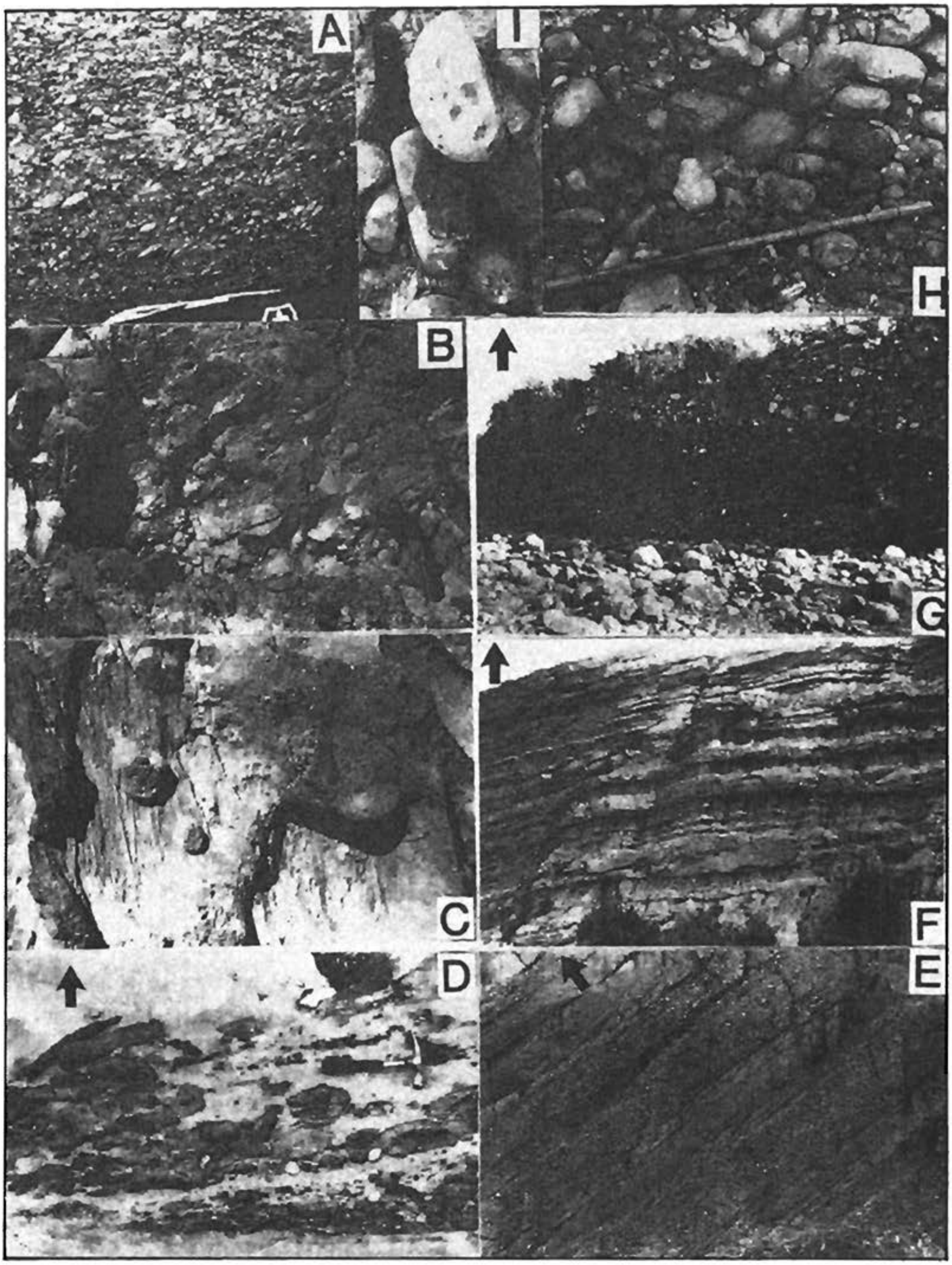

Fig. 4. A: Sandstone composed mostly of reworked Eocene benthic forams, which show good imbrication; unit X, Rakhi Nala. Top of penknife for scale at bottom of picture.

B & C: Distant and close-up views of the base of sandstone bed, which is the cast of a huge clay boulder (from the shadow at left to the right of the person is the cast of just one clast), unit A, Chaudhwan Zam. Field of view of C is about 1m across.

D: Intraformational clasts of iron-encrusted shale, from low in unit X, Rakhi Nala.

E & F: Facies BZ-5: flat to irregular beds of alternating, relatively coarse and fine clastics.

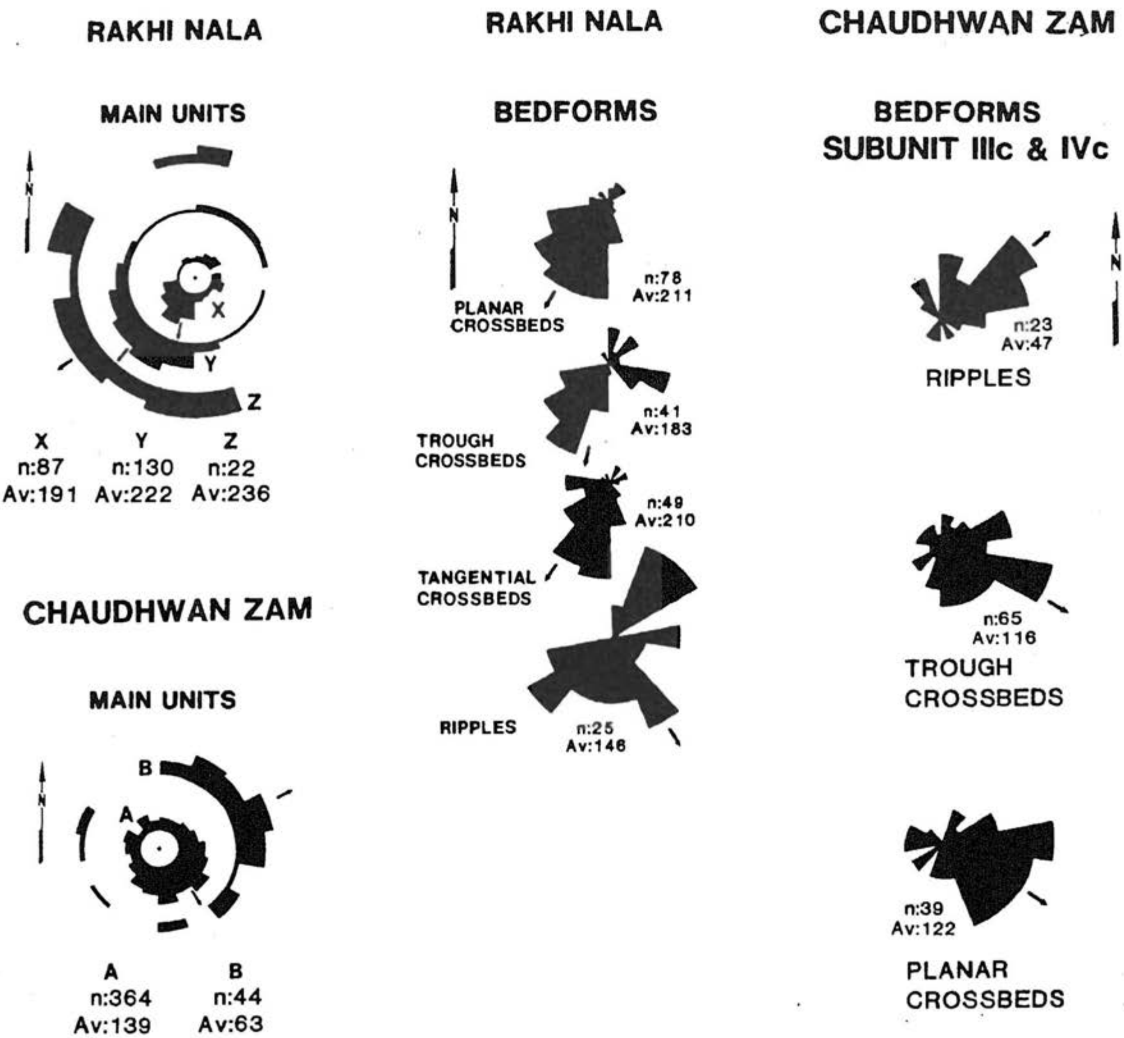

Fig. 5. Summary of paleocurrent measurements. Chaudhwan Zam diagrams show further stratigraphic subdivision (see Fig. 2; done for all units), and Rakhi Nala diagrams illustrate separation by bedforms in stratigraphic subdivisions whose paleocurrent means and distributions are statistically similar.

E shows conglomerate and sandstone; F shows coarse to pebbly sandstone alternating with clayey sand to sandy clay. This facies typically occurs at the edge of the conglomerate facies typified by Fig. 3G. Note that the finer facies is also interbedded. The arrow in E represents slightly less than 1 m, and in F slightly more. Both photos from Chaudhwan Zam, unit B.

G: Top of Rakhi Nala section. Compare abundance of light-coloured boulders of locally derived Cretaceous Pab Sandstone in modern river bed, with smaller numbers on top of terrace and even smaller numbers below. The length of arrow is 80cm.

H & I: Shearing and crushing/solution pits in coarse and matrix-poor conglomerates, unit B, Chaudhwan Zam.

TABLE 2. MARKOV ANALYSES FOR GROUPED FACIES ASSOCIATIONS: Facies numbersrefer to Table 1; Transition diagrams show all transitions with confidence > .95 & binomial probability <.10

CHAUDHWAN ZAM UNIT B - pebbly braided rivers

	Raw data matrix					Difference matrix				
	#1	#2	#3	#4			#1	#2	#3	#4
1. Very coarse fill	--	80	24	13	117	#1		15.1	-2.7	-12.4
2. Coarse bars	112	--	4	11	127	#2	28.1		-18.0	-10.0
3. Megaripple ss	21	6	--	30	57	#3	-9.2	-13.3		22.5
4. Overbank etc.	9	1	28	--	53	#4	-18.9	-1.8	20.7	
	142	102	56	54	354					

Sequence chi square = 188.9 /5 df (NON-RANDOM):
Asymmetry chi square = 7.7 /6 df (SYMMETRICAL)

3.5 66.7
Very coarse <—-> coarse ss <—-> overbank
9.4 58.5

RAKHI NALA UNIT Z - pebbly braided rivers

	#1	#2	#3	#4			#1	#2	#2	#4
1. Very coarse fill	--	22	27	3	52	#1		0.3	0.0	0.1
2. Coarse bars	22	--	9	0	31	#2	0.0		0.1	0.7
3. Megaripple ss	25	8	--	1	34	#3	-0.6	0.5		0.0
4. Overbank etc.	3	0	1	--	4	#4	0.6	-0.7	0.0	
	50	30	37	4	121					

Sequence chi square = 1.9 /5 df (RANDOM):
Asymmetry chi square = 0.1 /5 df (SYMMETRICAL);No favored transitions

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RAKHI NALA UNIT Y - sandy braided-mixed rivers

	#1	#2	#3	#4	#5			#1	#2	#3	#4	#5
1. Channel lag	--	30	0	3	0	33	#1		12.9	-1.2	-6.6	-5.2
2. Large coarse bars	27	--	7	20	5	59	#2	10.2		3.9	-5.3	-8.8
3. Megaripple ss	2	5	-	1	0	8	#3	0.7	1.4		-1.0	-1.1
4. Floodplain	1	21	0	-	23	45	#4	-8.6	-4.8	-1.8		15.1
5. Crevasse-splay	3	5	0	21	--	29	#5	-2.4	-9.5	-1.0	12.9	
	33	61	7	45	28	174						

Sequence chi square = 109.2 /11 df (NON-RANDOM):
Asymmetry chi square = 7.6 /9 df (SYMMETRICAL)

9.8 5 .0 29
Channel lag <—-> coarse bars —–> ss floodplain <—-> splay
6.3 20.4

RAKHI NALA UNIT X - meandering rivers

	#1	#2	#3	#4	#5			#1	#2	#3	#4	#5
	--	--	--	--	--	--		--	--	--	--	--
1. Channel lag	--	11	2	0	0	13	#1		7.7	-0.1	-5.1	-2.6
2. Coarse fill	5	--	19	5	1	30	#2	1.7		13.3	-9.0	-6.0
3. Point bar	4	4	--	12	1	21	#3	1.9	-1.7		3.2	-3.4
4. Floodplain	4	12	0	--	23	39	#4	-1.1	-2.1	-8.9		12.0
5. Crevasse-splay	0	3	0	22	--	25	#5	-2.6	-4.0	-4.4	11.0	
	13	30	21	39	25	128						

Sequence chi square = 118.2 /11 df (NON-RANDOM):
Asymmetry chi square = 33.6 /9 df (ASYMMETRICAL)

18.3 31.4 13.1
Channel lag —> coarse fill ——> point bar floodplain <—-> splay
11.0

CHAUDHWAN ZAM UNIT A - meandering rivers

	#1	#2	#3	#4	#5			#1	#2	#3	#4	#5
	--	--	--	--	--	--		--	--	--	--	--
1. Channel lag	--	76	3	1	0	80	#1		46.7	-4.1	-28.8	-13.9
2. Coarse fill	75	--	34	20	0	129	#2	36.6		21.3	-33.2	-24.8
3. Point bar	0	2	--	34	2	38	#3	-8.7	-9.8		22.0	-3.6
4. Floodplain	21	32	0	--	65	118	#4	-14.3	-16.2	-11.7		42.2
5. Crevasse-splay	3	2	0	63	--	68	#5	-13.7	-20.7	-5.5	39.9	
	99	112	37	118	67	433						

Sequence chi square = 499.9 /11 df (NON-RANDOM):
Asymmetry chi square = 93.4 /10 df (ASYMMETRICAL)

74.5 35.8 40.7 78.1
Channel lag <—-> coarse fill—-> point bar—-> floodplain <—-> splay
35.0 69.0

---

suggest stony plains and even stonier braided channels.

Boulders and cobbles in the conglomerates show abundant effects of tectonism. The carbonate clasts show abundant pressure-fitting at grain-grain contacts (pits caused by pressure solution and/or pulverization), whereas clasts of sandstone are shattered or sheared (Fig. 4H & I). Both effects are greatest where the clasts are largest and where cement and matrix are least (typically, these are all associated). It seems that uplift and tilting of the conglomerates has added great stress to clast-clast contacts, and dissolution has further shifted and augmented stress fields until many clasts have simply been crushed in nutcracker-like movements between other clasts. Identical features have been discussed by Wiltschko and Sutton (1982), although they attributed them to overburden pressure alone.

The modern situation

The modern rivers and the tops of the dissected alluvial fans under which our sections end contain abundant boulders, etc., of Eocene to Jurassic sedimentary rocks. Many of these are derived from the very distinctive Cretaceous Pab Sandstone, Paleocene clastics and carbonates, and the Eocene Habib Rahi and Pir Koh Limestone, which form the present eastern edge of the Sulaiman Range a few kilometers to the west (Fig. 4G).

DISCUSSION

The base

This basal "Chitarwata" zone is not easily interpreted. Wells in particular explains its features as the result of intense pedogenesis, and interprets the sandstones as being equiva-

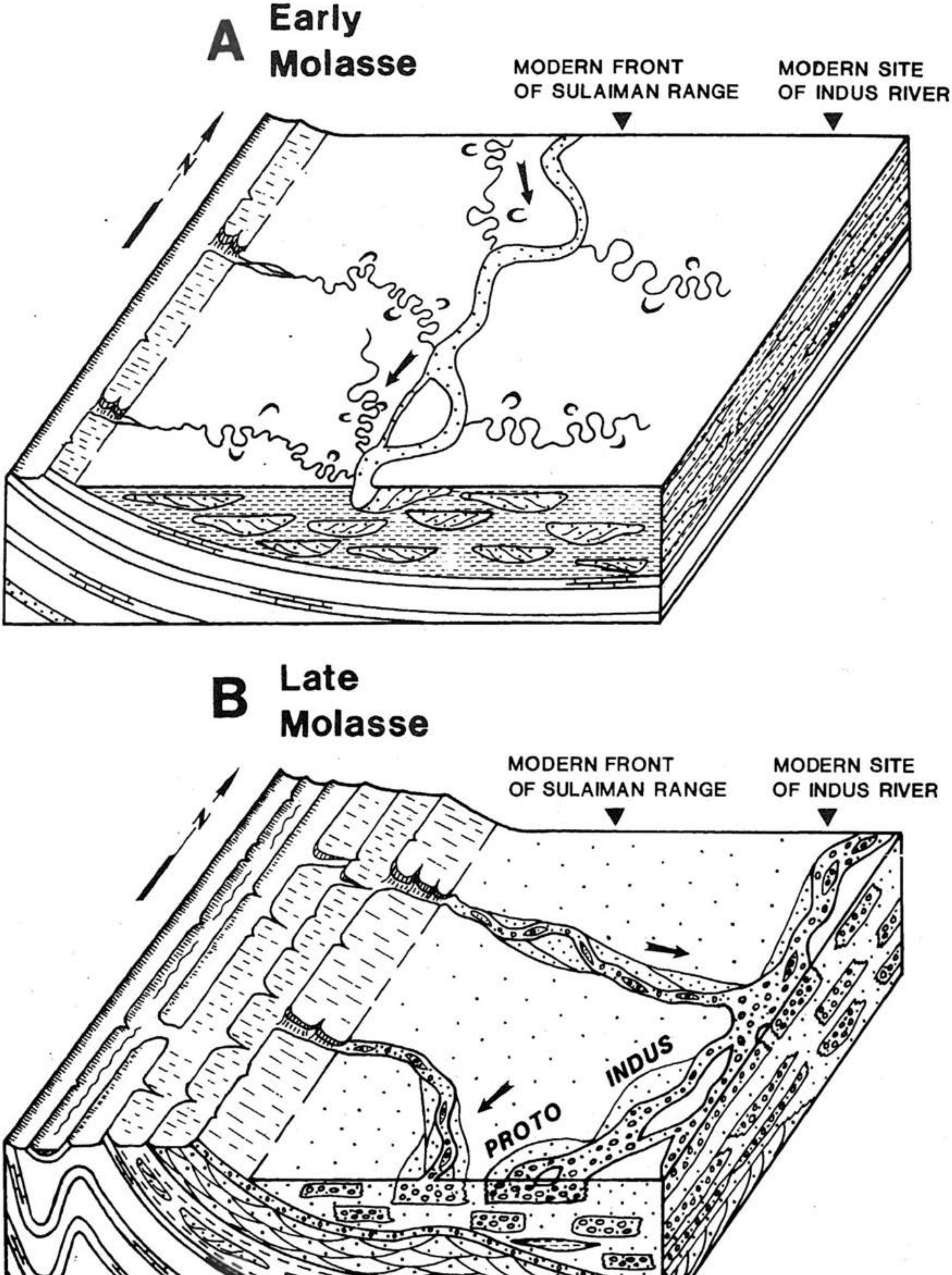

Fig. 6. General interpretations of paleogeography. A: during early deposition of molasse from the north; B) after eastward influx of conglomerates in the northern section.

lent to the splay-and-floodplain facies seen in the overlying molasse. Waheed had earlier suggested that these beds might be deltaic, on the basis of their geometry and clay content (Waheed &Wells, 1987). Downing et al. (1990) have recently investigated the same strata in Zinda Pir dome (slightly east of a point between our two sections), where they found a marine shell bed and some vertebrate fossils, which were absent in our sections. They interpreted burrows like our root/burrow mottles and nodules as marine *Thalassinoides*. They interpret this part of the section as estuarine. Both models might be correct: the shell beds could be local estuaries, while the multicolored bioturbated shales and sandstones could be the low interfleuves separating or alternating with estuaries and bays, and both the marine and nonmarine facies might be similarly bioturbated. Regardless, these beds represent the first molasse to be deposited over the underlying disconformity, and they apparently accumulated so slowly that none of the beds escape thorough pedogenesis and/or bioturbation. Therefore, this would seem to have been a time when the base level changed but little, reflecting general equilibrium or stability in terms of uplift, subsidence, or eustasy. They may represent part or all of the Oligocene, in which case the Oligocene is likely to be marked more by hiati than by deposition.

Unit Y

Unit Y sandstones seem to combine indicators of in-channel braiding with overbank deposition more typical of meandering rivers. Several writers have noted that many rivers do not fall nicely into classical braided and meandering categories (e.g., Jackson, 1978): on the one hand, it is possible to have very sandy and very coarse-grained meandering rivers (Jackson, 1978; Forbes, 1983), whereas on the other hand considerable levees and overbank splay, significant lateral accretion, and wide expanses of overbank mud can be associated with braided rivers (Coleman, 1969; Bristow, 1987; Wells & Dorr, 1987a). Rivers on the Indian subcontinent in particular tend to mix braided and meandering behaviors, due to extremely seasonal fluctuations in discharge. The Brahmaputra comprises large-scale braiding and giant bedforms with huge overbank wet-season splays (Coleman, 1969; Bristow, 1987). The Kosi shows two sets of bedforms and terraces relating to wet- and dry-season discharges (Gohain & Parkash, 1985), as does the Auranga, although in the latter the low-flow braid-bars are completely reworked by higher discharges (Gupta, 1989). The Ganges is both braided and organized into giant meanders, depending on the season and scale of inspection, and this is also seen in much smaller rivers (see figs. 1, 3, & 5D in Wells & Dorr, 1987a). Although the details, controls, and influences concerning these mixed-character rivers are not known, we suggest that unit Y may have included this sort of river.

Other minor noteworthy findings

First, the tectonic crushing seen in the boulder and cobble conglomerates could well be significant in the overall reduction of grain size into late and distal molasse. This seems especially true in Himalayan-style orogenic belts because they have proximal conglomerates and because their orogenic fronts typically prograde over time and cause the uplift and reworking of earlier coarse molasse, as is occurring here.

Another feature of note is the facies around the edges of the conglomerate lithosomes. As has already been explained, our northern section followed a river gorge and thus tended to flow around the coarsest and purest packages of conglomerate. In three principal instances, we found ourselves lateral to thick and nearly pure bodies of conglomerate, on the order of a few kilometers across and a few hundred meters thick, whereas our section cut through distinctive sequences of thickly interbedded, flat, coarse and fine facies Figs. 4E & F). Grain sizes in the alternating beds were proportional: where the coarse facies was sandy, the fine facies was floodplain clay, but where the coarse beds were conglomerate, the fine beds were sand or clayey sands. Bedding surfaces are slightly irregular, and flat bedding dominates within each facies, although some of the sands are crossbedded sheets. These façies are not channeled and in geometry at least are reminiscent of overbank splays.

Assuming a climate that permits vegetation, sedimentation generally appears to have been fairly rapid, because the deposits are not thoroughly pedogenized (unlike the completely bioturbated terrace sands around the head of Tista River fan in Assam, as shown in fig. 4A of Wells & Dorr, 1987a). Our best guess is that these beds might represent rare sheetfloods off the edges of the principal conglomerate belts, but we admit that this interpretation is not entirely satisfactory.

A third feature of note is the abundance of reworked large benthic Paleogene foraminifera in the sandstones (Fig. 4A). Pre-Himalayan Eocene strata in particular have voluminous "Nummulitic shales," which are actually uncemented or poorly cemented grainstones of flat, coin-sized forams like Nummulites and Assilina. These are abundant in the Tethyan and post-Tethyan sediments (e.g., Wells, 1984; Kaever, 1970), and are highly erosible. Some of the granulestones, in both sections, consist almost entirely of reworked foraminifera. Because of their flat and discoidal shapes, they are typically extremely well imbricated.

CONCLUSIONS

Two long sections through the molasse beside the western arm of the Himalayas show overall coarsening to the present, from an initial phase of slow and pedogenically dominated deposition, through classic meandering rivers, ultimately to conglomeratic braided rivers. In the southern section in particular, the meandering and braided rivers are separated by a very sandy zone of rivers of mixed characteristics, dominated by braided features, but nevertheless showing some overbank deposits more typical of meandering rivers. We suggest that these are similar to some modern Indian rivers, whose monsoonal fluctuations give them distinct split personalities. The delayed appearance of clast lithologies now exposed locally and the continual flow of the molasse-bearing rivers obliquely *into* the modern orogen (until the onset of east-going conglomerates in the northern section), suggests that the orogenic belt has only recently prograded to its present eastern front.

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