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# The impact of incipient uplift on patterns of fluvial deposition: an example from the Salt Range, Northwest Himalayan Foreland, Pakistan

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## ABSTRACT

During much of the middle and late Miocene, the Northwest Himalayan foreland basin was dominated by a large, eastward flowing, axial fluvial system analogous to the modern Ganges drainage. As structural deformation encroached on the foreland during latest Miocene to Pleistocene, the foreland became increasingly partitioned. One of the earliest defined deformational events was the incipient uplift of the Salt Range along the southern margin of the Potwar Plateau. Initial deformation of the Salt Range at 5.7–5.8 Ma is manifest in the depositional record by the appearance of N–NE-flowing fan deposits that initially interfinger with and eventually replace large-scale sheet sandstone bodies of the east-flowing axial draining system. Detailed stratigraphic investigations serve to delineate the contrast between these two systems. Distinctive upward fining trends occur during this transition, and channel-belt width and depth dimensions decrease significantly as the local, smaller rivers begin to dominate the proximal depositional record. Within the temporal context defined by magnetostratigraphic data, a gradual northwards displacement of the ancestral, axial, Indus-like system in response to the initial stage of uplift can be delineated. Continuing deformation appears to have shunted the ancestral Indus system to the west and off the Potwar Plateau slightly after 5 Ma.

## INTRODUCTION

Erosion of syntectonic strata, inadequate temporal control and incomplete exposures often preclude unambiguous analyses of the impact of structural events on an ancient depositional system. Recent studies in the Himalayan foreland basin of northern Pakistan have successfully dated episodes of movement along individual faults and well-defined fault zones (Burbank *et al.*, 1986; G. Johnson *et al.*, 1986; Burbank & Beck, 1989a). This success results from both the excellent exposures and the extensive suite of magnetostratigraphies (e.g. N. Johnson *et al.*, 1982; Raynolds & Johnson, 1985) that exist in the Potwar Plateau region (Fig. 1). The combination of stratigraphic indicators of deformation, such as tectonic rotations, unconformities and changes in provenance, palaeocurrents and subsidence rates (Burbank & Raynolds, 1988), with precise chronologies from previous palaeomagnetic studies, has served to delineate a detailed history of thrusting within the northwestern Himalayan foreland during the past 6 m.y. (Fig. 2).

Most of the structural events described in these previous studies have been defined through a synthesis of well-dated deformational indicators derived from numerous stratigraphic sections. Given this history of compressional deformation during the late Cenozoic in the Potwar Plateau region, it is now possible to examine in considerably more detail the sedimentological changes associated with individual thrusting events. This paper focuses on changes in patterns of fluvial deposition that were a result of initial deformation and uplift of the Salt Range. Sedimentological investigations have been carried out at four localities north and east of the present day Salt Range (Fig. 3). The results reveal distinct changes in the fluvial systems, unique to

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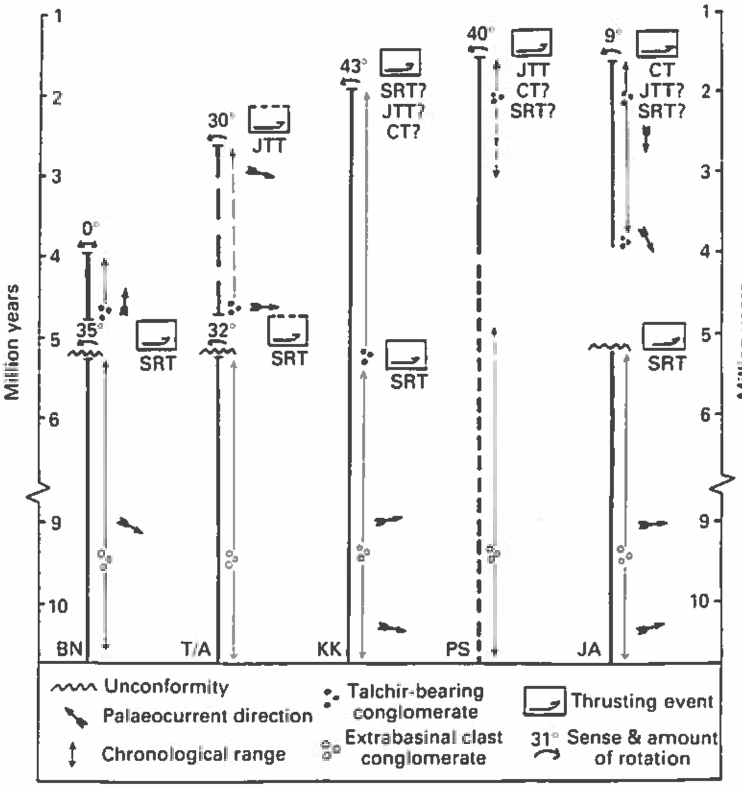
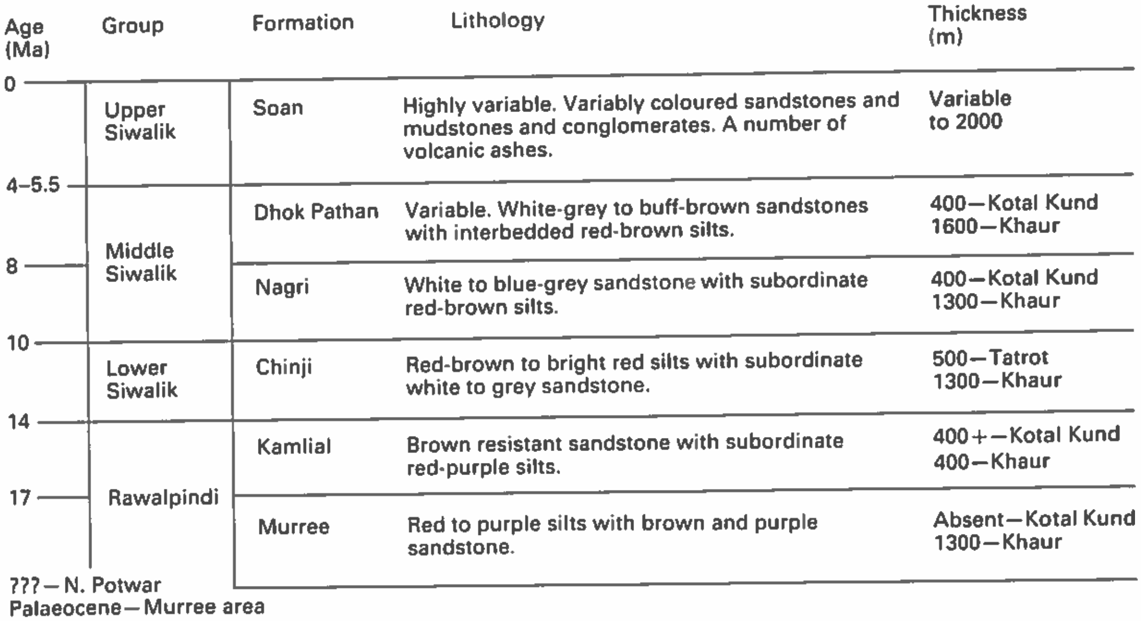


**Fig. 2.** Time–event diagram for five sections adjacent to the Salt Range. BN, Baun; T/A, Tatrot/Andar; KK, Kotal Kund; PS, Pind Savikka; JA, Jamarghal. The solid vertical lines represent the chronological range of each stratigraphical section and are dashed where chronological data are uncertain. Clast compositions, unconformities and palaeocurrents are plotted at their observed chronological level in each section. The rotational symbols indicate that the underlying strata have been rotated by the indicated amount. Inferred events of thrusting are depicted by thrust symbols within boxes at the appropriate chronological level. Thrust abbreviations: CT, Chambal Thrust; JTT, Jogi Tilla Thrust; SRT, Salt Range Thrust. (Modified from Burbank & Beck (1989).)

the late Cenozoic molasse strata helps to define a Salt Range source area for the enclosing beds. Third, following deposition of a varied Palaeozoic and Mesozoic sequence and an early Cenozoic carbonate sequence, the thick fluvial molasse strata of the Rawalpindi and Siwalik Groups (Fatmi, 1974) were deposited (Fig. 4). Strata of the Middle Siwalik Dhok Pathan Formation were deposited ~8–5 Ma, whereas the Upper Siwalik Soan Formation was deposited mostly during the Plio-Pleistocene. This study focuses on these two formations in the vicinity of the Salt Range. In general, strata of the Dhok Pathan Formation, like those of the underlying Chinji and Nagri Formations are thought to have been deposited by a large easterly flowing river analogous to the modern Indus River (Raynolds, 1980, 1981; Behrensmeyer & Tauxe, 1982; G. Johnson *et al*, 1986; Burbank & Beck, 1989a). The depositional setting of the Soan Formation is considerably more diverse. Physical disruption of the proximal foreland by progressive encroachment of structural deformation caused a partitioning of the previously monolithic basin (Raynolds & Johnson, 1985; Burbank & Raynolds, 1988). Consequently, smaller scale, locally sourced fluvial systems supplanted the previously axial system.

Structurally, the Potwar Plateau is an allochthonous sheet that has moved southward, with little internal deformation, on a low angle detachment (Seeber & Armbruster, 1979; Leathers, 1987; Baker *et al.*, 1988; Lillie *et al.*, 1987). The detachment ramps toward the surface near the northern margin of the Salt Range. The abnormally large width (60–100 km) of the detached, but little deformed, Potwar area is attributed to the regional extent of the underlying evaporite sequence. Total displacement (18–24 km) along the tip line of the Salt Range detachment decreases toward the east. Concomitantly, however, internal deformation of the thrust sheet increases in an eastwards direction (Fig. 3), being accommodated by closely spaced folds, thrust-cored anticlines, and both fore- and back-thrusts (Baker, 1987; Leathers, 1987; Pennock, 1988).

The temporal control for this study comes from



| Age (Ma) | Group | Formation | Lithology | Thickness (m) |
|---|---|---|---|---|
| 0 | Upper Siwalik | Soan | Highly variable. Variably coloured sandstones and mudstones and conglomerates. A number of volcanic ashes. | Variable to 2000 |
| 4–5.5 | Middle Siwalik | Dhok Pathan | Variable. White-grey to buff-brown sandstones with interbedded red-brown silts. | 400—Kotal Kund<br>1600—Khaur |
| 8 | | Nagri | White to blue-grey sandstone with subordinate red-brown silts. | 400—Kotal Kund<br>1300—Khaur |
| 10 | Lower Siwalik | Chinji | Red-brown to bright red silts with subordinate white to grey sandstone. | 500—Tatrot<br>1300—Khaur |
| 14 | Rawalpindi | Kamlial | Brown resistant sandstone with subordinate red-purple silts. | 400+—Kotal Kund<br>400—Khaur |
| 17 | | Murree | Red to purple silts with brown and purple sandstone. | Absent—Kotal Kund<br>1300—Khaur |
| ???—N. Potwar<br>Palaeocene—Murree area | | | | |

**Fig. 4.** Siwalik stratigraphic nomenclature. Age and thickness estimates: Upper Siwaliks, Opdyke *et al.* (1979), Raynolds (1980); Middle Siwaliks and Chinji Formation, N. Johnson *et al.* (1982), Tauxe & Opdyke (1982); Kamlial Formation, Raza (1983), Fatmi (1974), our estimates; Murree Formation, Fatmi (1974), Bossart & Ottigar (1989). Age estimates for formational boundaries are approximate, and have been documented as being regionally time transgressive on the order of $10^5$–$10^6$ years.

the Gauss chron, as evidenced by their magnetozonations and by the presence of radiometrically dated ashes (fission track method: G. Johnson *et al.*, 1982). The two sections at Tatrot-Andar Kas and Kotal Kund have been linked through tracing laterally extensive sheet sandstones between the two localities (N. Johnson *et al.*, 1982). Correlations of these MPSs with the MPTS are of high quality and allow for confidence in dating initial uplift of the Salt Range based on stratigraphic evidence. The correlations of the magnetostratigraphies used in this study with the MPTS (Fig. 5) are largely those of the original workers (N. Johnson *et al.*, 1982), with the exception of portions of the Baun and Jamarghal Kas sections. These latter correlations are tenuous in portions due to complex reversal patterns. However, the correlations presented here (Fig. 5) are most consistent with what is known of lithofacies ages in other parts of the Potwar Plateau. These chronological data have been used to constrain the timing of initiation of uplift of the Salt Range (Burbank & Raynolds, 1988; Burbank & Beck, 1989a, b).

Near Baun (Fig. 3), previous workers (N. Johnson *et al.*, 1982; Burbank & Beck, 1989a) have noted a 10° shallowing in dip and distinct sedimentological changes across the Dhok Pathan/Soan Formation boundary, which may be an unconformity. Sedimentological changes include the sudden appearance of coarse, immature sands, poorly rounded gravels with a Salt Range provenance, and a palaeocurrent change from easterly directed flow to more northerly directed flow. Magnetic data from Opdyke *et al.* (1982) define a differential tectonic rotation across this boundary, such that the stratigraphically higher Soan Formation is unrotated. The changes occurring at the Dhok Pathan/Soan boundary have been interpreted as a drainage reorganization resulting from incipient uplift of the Salt Range south of the study area (Burbank & Beck, 1989).

Although our suggested correlation of the Baun MPS with the MPTS would place this initial uplift event at ~5.4 Ma, the uncertainties in the correlation itself indicate that better constrained sections need to be used to date this event more unambiguously. The first appearance of distinctive sedimentological changes occurs at Kotal Kund at ~5.7 Ma. These distinctive changes are followed shortly by the first appearance of Talchir clasts at ~5.4 Ma.

been used to differentiate and compare the different fluvial systems present in the foredeep and to document the interactions of the fluvial systems within the basin, prior to and during disruption of the foreland.

## RESULTS

Four sections are reported on here that provide insights into depositional changes resulting from initial uplift along the Salt Range décollement. The Baun, Kotal Kund and Andar Kas sections chronicle sedimentological changes north and east of the present day Salt Range. The Jamarghal Kas section is notable in that it records effects of uplift southeast of where incipient structures were growing. The Kotal Kund section provides the most detailed and well-correlated magnetostratigraphy, enabling a determination that initial Salt Range deformation began as early as 5.7 Ma (after MPTS of Berggren *et al.*, 1985).

### Lithofacies

Two groups of sandstone are readily differentiated in strata deposited between 7 and 4.5 Ma in the Salt Range area: white to light grey sheet sandstones and pale brown sandstones having comparatively reduced channel-belt dimensions of width and depth. White sandstones are distinctive from brown sandstones because of their greater bedform size, distinctive internal bedding structures, greater channel belt width, larger macroform size, higher degree of grain sorting, and distinctive pebble component.

White sandstones are a uniform colour throughout the study area, varying between light grey and white. White sandstones have relatively uniform grain size, dominantly medium grain in beds containing metre-scale cross-stratification and fine grain in planar stratified beds. Pebble conglomerates occur infrequently as thin (<20 cm) lags at the bases of erosional scours (particularly the bases of stories) and are of two types: those dominated by extraformational clasts and those dominated by intraformational clasts. Soil concretions and mudstone rip-ups constitute more than 95% of the intraformational conglomerates. Soil concretions are generally poorly rounded, and mudstone rip-ups are subangular with rounded edges. Extraformational conglomerates typically contain less than 10% intraformational clasts and are characterized by rounded to well-rounded intrusive, volcanic, metamorphic, quartzite and limestone clasts (Fig. 6). Heavy-mineral analyses of the white sandstones in the Potwar Plateau and Jhelum Re-entrant area (Raynolds, 1981; Cerveny, 1986) show these sandstones to be characterized by abundant blue-green hornblende (generally >30%). Two rivers draining the Kohistan arc terrain of the Himalaya, the modern Indus and Swat Rivers, are the only rivers flowing into the Himalayan foreland today that have similar high blue-green hornblende contents (Cerveny, 1986). This similarity, along with the scale of fluvial channels and channel belts and palaeocurrent indicators of easterly directed flow, has led to the conclusion that a large fluvial system draining the high Himalaya, the palaeo-Indus River, formerly flowed eastward across the Potwar Plateau region before entering the Ganges River drainage (Raynolds, 1981; G. Johnson *et al.*, 1982).

White sandstones display well-developed bedding structures with large-scale (50–75 cm laminae sets) trough cross-stratification the dominant structure. Planar cross-stratification occurs less frequently and is also typically found in laminae sets of 50–75 cm height. Planar stratification is found frequently in the upper one-half of stories (after Friend, 1983).

Sandstone bodies always display sharp erosional lower contacts. Over lateral distances of 30+ m, channelling of sandstone bases more than 5 m is common. The erosional channels of some sandstone bodies are infrequently as deep as 15 m. Sandstone bodies are generally multistoreyed, with individual storeys of the order of 2–3 m thick and lateral dimensions often in excess of 50 m. Storeys are generally distinguished by their sharp erosive contacts with underlying units. Some storeys viewed in outcrops oriented perpendicular to palaeoflow can be clearly identified as channel-scour fill units. In exceptional outcrops, lateral accretion bed-sets are distinguishable. Within some storeys, sandstone- and siltstone-filled channels exhibit dimensions of the order of 3–5 m depth and 30–75 m width. Storeys observed in exceptional outcrops oriented parallel to palaeoflow directions can often be traced for distances of 50–100 m. Upper contacts of storeys or sandstone bodies with overlying silt and clay units are typically gradational. In most cases, bedding structures within the transition from sandstone to silt and clay floodplain deposits is obscured by disruption, particularly bioturbation of bedding.

Plateau (Tatrot-Andar Kas, Kotal Kund and Jamarghal Kas). The magnetic polarity stratigraphy has been interpreted as spanning ~10–4 Ma.

The upper 10 m of Dhok Pathan section (Fig. 7A) at Baun consists of massive and stratified red-brown mudstone horizons interspersed with two 2 m thick palaeosols, all typical of the underlying section. The stratigraphically highest 'white sandstone' complex occurs immediately below this palaeosol complex. Directly overlying the 'white sandstone' and palae-

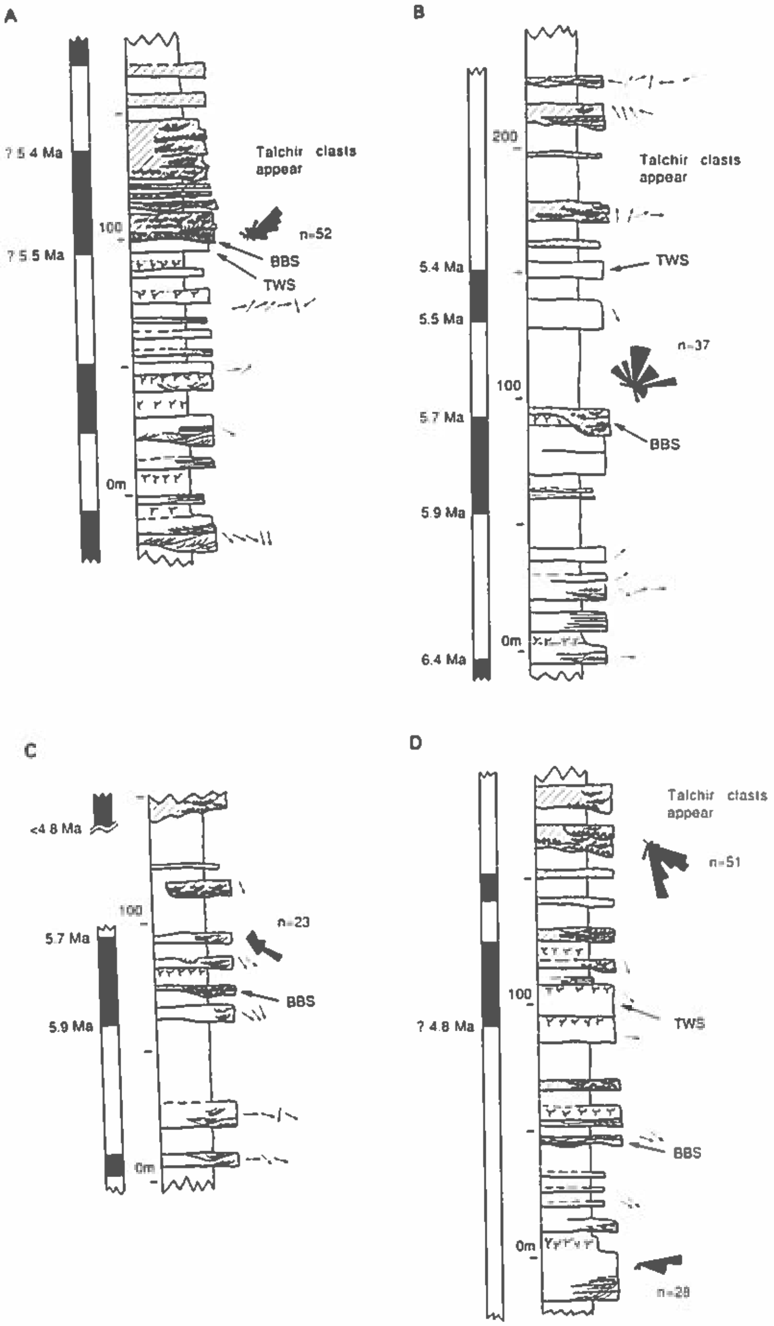


**Fig. 7.** Vertical stratigraphic sections from (A) Baun, (B) Kotal Kund, (C) Andar Kas and (D) Jamarghal Kas. Brown and beige coloured sands having a Salt Range source are stippled with grey pattern. First occurrences of sands having a Salt Range source (basal brown sandstone, BBS) and last occurrences of white, 'palaeo-Indus' sands (top white sandstone, TWS) are indicated. Palaeocurrents collected during measurement of the sections are presented as both individual measurements (small arrows) and summary rose diagrams.

horizons and well-stratified silt, interbedded with thin (3–5 m) fluvial bodies. The thin brown sandstones have relatively uniform grain size, ranging from medium to fine. Internal structures are difficult to distinguish due to poor exposures, but it can be discerned that grain size is relatively constant throughout outcrops and displays none of the rapid lateral and vertical changes described above. Poor exposures of this sequence have prevented the collection of palaeocurrent data from this interval.

### *Interpretation*

The changes occurring at the Dhok Pathan/Soan boundary have previously been interpreted as an angular unconformity and drainage reorganization resulting from incipient uplift of the Salt Range south of the study area (N. Johnson *et al.*, 1982; Burbank & Beck, 1989a, b). Field observations of the boundary imply that the observed change in dip is an artefact of a shallowing in dip that occurs through that portion of the section and not an angular unconformity. The boundary is considered to be a disconformity that represents a short, but indeterminate, period. Changes (provenance, sandbody characteristics and palaeocurrents) that occur across the boundary represent a geologically instantaneous change from sedimentation by the axially oriented palaeo-Indus River to proximal fan sedimentation from fluvial systems that flowed transverse to the juvenile Salt Range. Strata that lie greater than 30 m above the boundary display higher proportions of silt relative to sand, as well as sandstones that are relatively less coarse. Strata above the proximal fan deposits appear to represent deposition within low-energy, low-gradient systems characterized by small, sluggish channels. These strata appear to represent ponded or relatively more distal facies.

## Kotal Kund

### *Observations*

The Kotal Kund section lies at the eastern termination of the Salt Range within the western limb of the Kotal Kund syncline and ~5 km from the tipline of the Salt Range thrust (Fig. 3). At Kotal Kund, a continuous section exists from the Chinji Formation through the Nagri, Dhok Pathan and Soan Formations. The MPS at Kotal Kund has been interpreted as spanning an interval from ~11 to 2 Ma. (Fig. 5). Unlike the section at Baun, the Dhok Pathan/Soan Formation boundary is indistinct and occurs over a 150 m thick interval. This zone is marked by interfingering of white sandbodies with brown-sand channel-belts of smaller dimensions that contain conglomeratic clast populations indicating a Salt Range source area. Palaeocurrent data document a change from southeasterly directed flow below the boundary to northeasterly directed flow above the boundary (Figs 7B & 8).

A panel diagram (Fig. 9) showing lateral and vertical facies variability and encompassing the interval marking the Dhok Pathan/Soan Formation boundary serves to illustrate the large-scale character of changes in fluvial style that occurred at this locality. The lowermost 120 m are marked by extensive sheets of poorly cemented white-grey sandbodies alternating with overbank silt and soil units. Channel belts, 5–15 m thick, typically consist of stacked units of individual channels with storey thicknesses of 3–5 m. Though exposure is greater than 80%, the poorly cemented sandstones create inadequate outcrops, preventing determination of lateral dimensions for individual channels. The widths of the channel belts are also poorly constrained, but are usually larger than the lateral scale of observation, i.e. >4 km.

The basal brown sandstone described here (Figs 7B & 9) lies above a well-developed soil, is laterally discontinuous, and is erosionally scoured as deeply as 10 m into the underlying strata. The well-developed soil horizon is only present where it has not been removed by channelling of the overlying sand, i.e. erosion followed soil development. Within this predominantly medium grain sandbody, there are numerous conglomeratic lags of pebble size material that are exclusively intraformational, comprising soil nodules, mudstone rip-ups and angular Siwalik sandstone clasts. Within the overlying brown sandstone, there are also extensive pebbly conglomeratic lags dominated by intraformational material, but they also contain a subordinate population (<5% of the total) of extraformational material. This extraformational material primarily contains assorted limestone, Eocene Nummulitic limestone, quartzite and pink Talchir clasts. As seen at Baun, the Talchir clasts indicate a clear Salt Range provenance.

Above the top white sandstone (Figs 7B & 9), macroforms in brown sandstones display rapid lateral and vertical facies changes, from gravels to pebbly sands, to exclusively sands. Sandbodies are laterally discontinuous, occurring as thin channelized sheets, indicating comparatively small channel-belt proportions. The basal brown sandstone does not show closely spaced and rapid facies changes as the overlying brown sandstones do.

### *Interpretation*

The bottom brown sandstone, though lacking extraformational clasts indicating a Salt Range provenance, is best explained as being the first expression of a new fluvial regime within the area, because (i) all other occurrences of anomalous coloured sandstones within Dhok Pathan strata on the Potwar Plateau can be attributed to fluvial systems different from the palaeo-Indus, (ii) sandstones with a definite Salt Range source make their first appearance only slightly above the bottom brown sandstone and (iii) the bottom brown sandstone and later brown sandstones have northeast-directed palaeocurrents, whereas earlier deposited white sandstones have clear east-southeast palaeocurrents. The displacement of the white sand system and the appearance of the new system is best explained as a manifestation of topographic expression of the Salt Range to the southwest. The sandstone's location straddling the reversal boundary between what is identified as magnetic chrons 5.1r and 5.2 (Berggren *et al.*, 1985) suggests that initiation of uplift within the Salt Range had occurred by ~5.7 Ma. Talchir clasts first appear 150 m above the basal brown sand. The delayed appearance of Talchir clasts corresponds well with the expected unroofing sequence of the Salt Range. The unroofing of Permian Tobra Formation strata (the source of Talchir clasts) would have required the stripping of 2–3 km of overlying strata (primarily Murree and Siwalik strata) (Leathers, 1987).

The basal brown sand is of significantly larger dimensions than later brown sands. The basal brown sand is apparently an amalgamated channel-belt, while the later brown sandstones are reduced in size and represent small channel belts or individual channelling events. Several explanations may be proposed for the difference. One explanation is that the basal brown sand is a contaminated palaeo-Indus deposit. This suggests that the white sands of the palaeo-Indus were diluted by locally high input of detritus from the juvenile Salt Range. Alternatively, the anomalously large dimensions of the basal brown sand may simply reflect a reduced subsidence rate acting during deposition of sands that are entirely derived from the juvenile Salt Range. A third explanation would be to consider the basal brown sand as representative of a depositional environment intermediate between an alluvial fan environment (e.g. the latter, smaller scale brown sands) and the large axial system north of the Salt Range.

## **Tatrot-Andar Kas**

### *Observations*

The Tatrot-Andar Kas section is situated 1–3 km north of the Jogi Tilla thrusts in the southeastern limb of the Kotal Kund syncline (Fig. 3). The section consists of two parts, separated by a distance of 5 km along strike. The two sections have been connected by means of tracing between the two sections a continuous sandstone bed and a specific normal polarity zone (McMurtry, 1980; N. Johnson *et al.*, 1982). Only the Andar Kas sequence was examined in detail during this study.

The Dhok Pathan Formation at Kotal Kund and Andar Kas are similar in many respects. Some channel sandstone units are traceable between the two sections (N. Johnson *et al.*, 1982). Within exposures of the Kotal Kund syncline, individual sandbodies of the Dhok Pathan lithofacies can in exceptional cases be traced laterally for 10 km.

Figure 9A is a panel diagram constructed on a sequence of outcrops oriented approximately perpendicular to palaeoflow directions for the white sand system of the Dhok Pathan. Notable in the diagram is an upward fining trend. Below the strata shown in the panel there is a thick Dhok Pathan section containing laterally extensive white sandstone channel belts. Throughout the Dhok Pathan interval, the white sandstones are characterized by channel belts ranging from 5 to 15 m in thickness and having a lateral extent of 2 to >10 km. The top of the Dhok Pathan Formation is marked by a slight unconformity at Tatrot village (Opdyke *et al.*, 1979; N. Johnson *et al.*, 1982). This unconformity appears considerably more pronounced at Andar Kas, where it cuts stratigraphically downwards across the top of the panel (Fig. 9). The strata overlying the unconformity have an apparent Salt Range source as evidenced by the presence of minor quantities of Talchir clasts near Tatrot village (Burbank & Beck, 1989a). The strata above the unconformity are normally magnetized (N. Johnson *et al.*, 1982) and at 5.5 Ma show an east flow direction (Figs 7D & 8). Palaeocurrents collected from brown sandbodies above the last white sandstone document a southeast flow direction.

### *Interpretation*

Two reasonable correlations of the magnetic reversal pattern may be made for the age of the white/brown sandstone correlation. First, the two normal magnetozones (100–150 m level: Fig. 7D) may be correlated with magnetic chron 5. This correlation is not preferable, because it places the first occurrence of brown sands at ~6.0 Ma. If the displacement of the white sands and appearance of the brown sands is considered to be linked with changes at either Kotal Kund or Rhotas, a date of ~6.0 Ma is inconsistent with what is known at these other areas. Alternatively, the two normal magnetozones within the transition may be correlated with the two lowest normal polarity magnetozones in the lower half of the Gilbert (Fig. 5). This correlation is preferred, because it places the first brown sand appearance at ~5.2 Ma, a date in concordance with sedimentological changes observed at Kotal Kund, Andar Kas and Rhotas (discussed below), and because the dimensions of the brown sandbodies above the last white sandstone are considerably larger than in the other studied sections. This suggests that the brown sandstones at Jamarghal Kas may represent a younger fluvial system that has integrated flow from the Salt Range with the ancestral Jhelum River (Raynolds, 1980).

Relative to other studied sites, the reduced channel-sandstone frequency in the Jamarghal Kas section may result from its location farther to the south and, consequently, farther from the flexure-inducing load of the Himalaya, such that subsidence rates were lower (Burbank & Beck, 1989c). As a result, there may have been a lower frequency of palaeo-Indus channel migration across the Jamarghal Kas region. Such a situation has been predicted by depositional models for asymmetrically subsiding basins (Leeder & Gawthorpe, 1987). Additionally, the difficulty in matching the Jamarghal MPS with the MPTS may reflect lower subsidence rates. With slower subsidence, strata remain closer to the depositional surface for longer intervals, and as a result they are more likely to be removed by subsequent erosional events or to be magnetically overprinted due to complex pedogenic processes.

Beige sandbodies that are interfingered with white palaeo-Indus River sandbodies are attributed to fluvial systems that drained from the juvenile Salt Range, and larger brown sandbodies that occur above the last white sand are attributed to a larger fluvial system, probably the palaeo-Jhelum River. The last appearance of the white palaeo-Indus sands on the Potwar Plateau occurs in the lower Gilbert chron (Rhotas, Ganda Paik) (Raynolds, 1981). Large-scale brown channel sands, equivalent in scale to the preceding white sandstones, are present throughout the Gilbert at Jamarghal Kas and on the Rhotas and Mahesian structures (Raynolds, 1980, 1981; Burbank *et al.*, 1986). In consideration of this last observation, thick, laterally extensive brown sands at Jamarghal Kas are most likely the deposits of a palaeo-Jhelum system, such as that seen on the Rhotas and Mahesian structures. After the palaeo-Indus was displaced to its present course west of the Potwar Plateau, the palaeo-Jhelum system of N–S drainages flowed freely across the as yet relatively undeformed eastern Potwar Plateau.

## SUMMARY AND CONCLUSIONS

Along the northern flank of the Salt Range, distinct sedimentological changes have been interpreted in the past as representing incipient uplift of the Salt Range at ~5 Ma (Opdyke *et al.*, 1979; N. Johnson *et al.*, 1982; G. Johnson *et al.*, 1986; Burbank & Beck, 1989). Burbank & Beck (1989a) combined data on conglomerate compositions, palaeocurrents and palaeomagnetically defined tectonic rotations in order to date and describe initial uplift of the Salt Range. Results presented here more precisely date the initiation of uplift and provide a more detailed picture of fluvial system responses to uplift.

Two distinct phases of sedimentation are observed at each of the studied localities. The older phase is characterized by white sandstones deposited by a very large, easterly flowing, axial fluvial system. Channel-belt sandstones are often >10 m thick and have lateral dimensions exceeding several kilometres (Fig. 9). Some channel-belt sandbodies can be traced laterally for 10 km or more. The predominance of blue-green hornblende in the heavy-mineral suite and the 'Himalayan' lithologies found in conglomerates suggests deposition from an ancestral Indus River system, because this is the only *major* river system in the Himalaya today that carries similar abundances of blue-green hornblende (Cerveny, 1986). The dimensions of the white sandstone system in the southern Potwar region during Dhok Pathan deposition are compa-

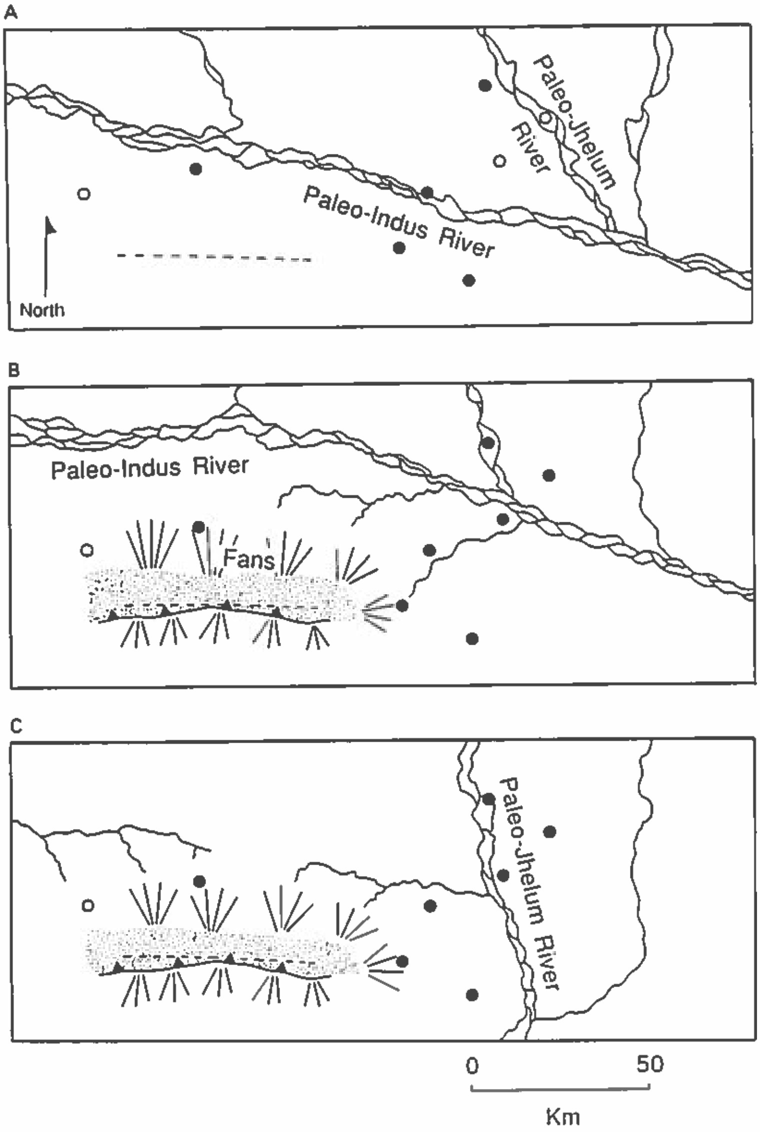


**Fig. 10.** Palaeogeographical reconstructions for (A) 6.0, (B) 5.2 and (C) 4.8 Ma. (---) Position of the basement normal fault used as a reference frame. (A) Prior to initiation of deformation in the Salt Range, the palaeo-Indus system migrated (north–south) freely across the Potwar Plateau region while flowing ESE across the region to the Ganges River system. (B) Subsequent to initial uplift in the vicinity of the normal fault that apparently localized ramping of the Salt Range décollement, small drainages developed and shed sediments onto fan systems which developed along the flanks of the range. The palaeo-Indus River was confined between transverse drainages to the north and the Salt Range to the south. Data from the MPS sections on the Rhotas anticline indicate that white sands of the 'palaeo-Indus' were deposited throughout the period of fluvial system interfingering along the flanks of the Salt Range. Deposits at Andar Kas and Jamarghal Kas are interpreted as being distal equivalents to fan systems observed at Kotal Kund and Baun. (C) Continued deformation of the Potwar allochthon shunted the palaeo-Indus River off the Potwar Plateau to its present southerly flowing course west of the study area. The palaeo-Jhelum River subsequently flowed freely across the eastern Potwar Plateau.

three more proximal sites. This suggests that the displacement of the ancestral Indus system to the north was accomplished through a gradual shifting of the drainage axis to the north prior to the eventual permanent shunting of the palaeo-Indus system off the Potwar Plateau. This interpretation is reinforced by the stratigraphy at Kotal Kund, where white and brown sandbodies interfinger for ~0.3 m.y. (Figs 7B & 9) before the white sand system is finally displaced.

Lithofacies relationships in sections (Raynolds, 1980) on the Rhotas and Mahesian structures suggest that the palaeo-Indus system (as represented by the white sand system) persisted in the Potwar Plateau region, north of the present day Salt Range, as late as the early (4.8–5.3 Ma) Gilbert magnetic chron (Fig. 5). If the palaeo-Indus debouched into the foredeep in the vicinity of the Kohat Plateau to the west, as suggested by Johnson *et al.* (1985), then the implication is that deformation and uplift within the Potwar allochthon, during its initial existence from ~5.8–5.0 Ma, was insufficient to

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