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Late Cenozoic tectonics and sedimentation in the north-western Himalayan foredeep: II. Eastern limb of the Northwest Syntaxis and regional synthesis

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ABSTRACT

In order to help delineate the succession of late Cenozoic tectonic and stratigraphic events in the north-western Himalayan foredeep and adjacent ranges, a geological transect is described which extends from the north-eastern margin of the Kashmir Basin to the axis of the Jhelum Re-entrant along the eastern boundary of the Potwar Plateau. When combined with previous bedrock mapping, chronologic and stratigraphic studies of nine sections in the intermontane basin and the bounding foredeep define three primary pulses of late Cenozoic uplift affecting the Pir Panjal Range (5–4, 1·9–1·5, and 0·4–0 Myr ago). Many of the changes in facies, provenance, and palaeocurrents observed in the sedimentary rocks along the transect can be related to these deformational episodes.

When these data are combined with those from the Potwar Plateau and adjacent intermontane basins in Pakistan (Johnson *et al.*, this volume), a synthesis emerges illustrating a complex evolution of the foredeep during the past 5 Myr. Early episodes of uplift and rotation in the vicinity of the Salt Range are shown to be synchronous with initial uplift of the Pir Panjal Range. Extensive deformation between 2·1 and 1·6 Myr ago across much of the Potwar Plateau and, perhaps, along the bounding thrusts of the Pir Panjal appears causally related to a thrust ramping event in the Salt Range. In addition to providing a history of sedimentation and deformation that is more temporally constrained than has previously been possible, this study suggests a synchrony of several sets of structural events across a broad portion of the foredeep. This widespread synchrony may represent diverse responses to a common cause: stress accumulation and release due to interactions between irregular basement topography on the underthrusting Indian plate and the basal detachment of the overriding foredeep.

INTRODUCTION

As a consequence of the past and continuing collision of the Indian subcontinent with Eurasia, propagating faults and folds have disrupted the proximal margin of the Himalayan foredeep. Although previous geological studies have served to delineate the structural style of this disruption, the timing and tempo of these deformational events have been only loosely constrained. During the past decade, numerous chronologies based on magnetic polarity stratigraphy and fission-track dating have been developed for the terrestrial sediments of the Himalayan foredeep and the adjacent intermontane basins in the vicinity of the Northwest Syntaxis (Fig. 1). This spectacular bend in the collisional ranges bordering peninsular India occurs at a plexus of mountains where the Pamirs, Hindu Kush and Himalaya meet. These latter two ranges lie on the west and east flanks, respectively, of the Northwest Syntaxis, and it is the deformation along their southern margins that has disrupted molasse deposition in the adjoining Indo-Gangetic foredeep and has created the Peshawar, Campbellpore and Kashmir intermontane basins. A detailed transect of the western limb of the Northwest Syntaxis from the Peshawar Basin to the Jhelum River (Fig. 1) has been described in an accompanying paper (Johnson *et al.*, this volume). The objectives of this paper are two-fold: first, to describe a similar transect through the eastern arm of the Syntaxis from Kashmir

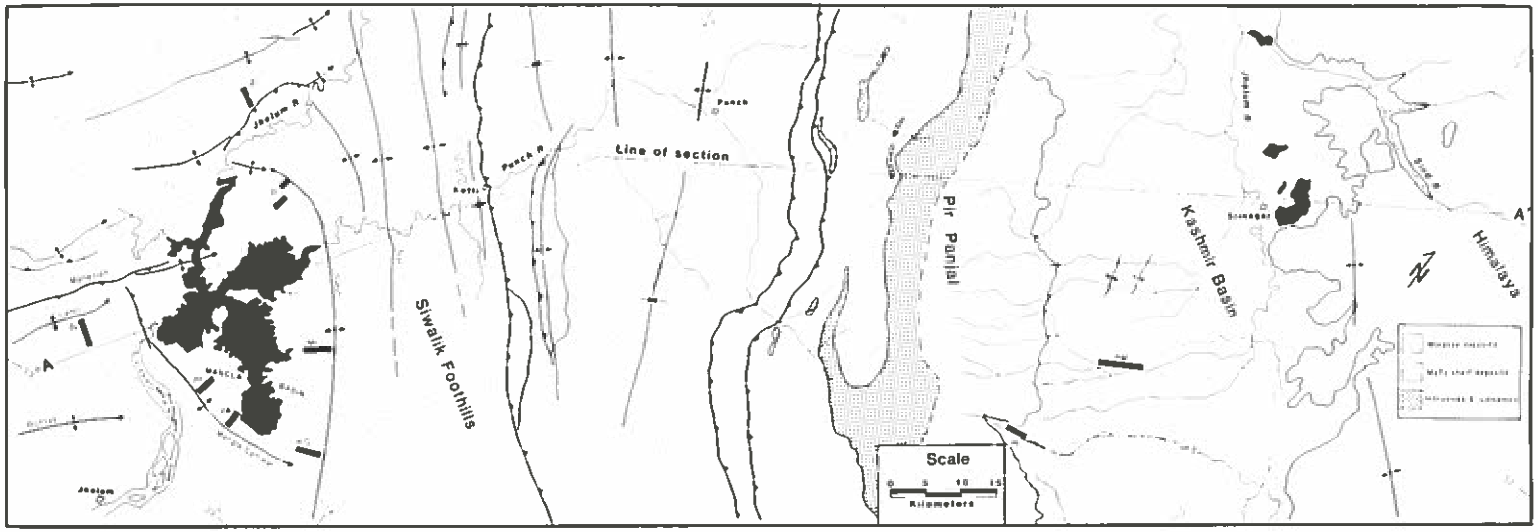

Fig. 2. Geologic map extending from the Jhelum River to the north-eastern margin of the Kashmir Basin. The Cenozoic molasse sediments of the Himalaya are shown by the stippled pattern. The Siwaliks (Neogene) and the Murrees (mid-to late Palaeogene) are not differentiated, because they represent a depositional continuum. The molasse is overthrusted along its north-eastern margin by an imbricated stack of bedrock slices composed of Eocene limestones and pre-Cenozoic bedrock. The Panjal Traps and associated gabbroic intrusions form much of the crestal area of the Pir Panjal Range. The gentle north flank of the range is mantled with glacial deposits which obscure most of the bedrock. The Kashmir Basin is filled with 1·3 km of Plio–Pleistocene Karewa sediments and is bounded on its north-eastern margin by folded and faulted Palaeozoic and Mesozoic bedrock. Geology is based in part on previous mapping by Middlemiss (1919), Wadia (1928, 1931, 1934), Shah (1968, 1978, 1980) and Fuchs (1975). Locations of measured and dated stratigraphical sections are shown by black boxes: Dina (DI); Hirpur (H); Jari (JA); Jhel Kas (JK); Kas Guma (KG); Mawa Kaneli (MK); Rata-Dadial (RD); Romushi (RM); Sakrana (S). Line AA' indicates the position of the cross-section (Fig. 3).

gressed by a shallow Eocene-aged sea from which the 'nummulitic' limestone (Godwin-Austin, 1959; Wadia, 1928) was deposited. Remnants of this limestone are found both in Ladakh and the Greater Himalaya to the north and in the south flank of the Pir Panjal Range. However, within the basin itself, uplift has caused complete erosion of these limestones and any additional pre-Pliocene sediments which may have overlain these strata.

Above this extensive unconformity, the intermontane sediments of the Karewa Formation (Lydekker, 1876, 1883) were deposited (Fig. 2). The depositional contact of the Karewas with the underlying bedrock is only rarely exposed within the Kashmir basin. Where it does crop out, however, such as in the river valleys at the southern end of the basin, deeply weathered palaeosols 10 m or more thick attest to a long interval of non-deposition and soil development that preceded initiation of intermontane sedimentation.

The asymmetry of uplift along the margins of the Kashmir basin and the continuing deposition in its northern portions have restricted extensive exposures of the Karewa Formation to eroded valleys along the north-western flank of the Pir Panjal Range (Fig. 2). Exposures here indicate that, in sharp contrast to the fluvial deposition that characterizes the Indo-Gangetic external molasse basin, the approximately 1300 m thick Karewa succession (Karunakaram & Rao, 1976; Burbank, 1982) is dominated by lacustrine mudstones, lignites, and deltaic siltstones and sandstones (Bhatt, 1975; Singh, 1982; Burbank & Johnson, 1983). These low-energy deposits occur immediately above the exposed basal unconformity and suggest that an early pulse of uplift of the ancestral Pir Panjal Range caused extensive ponding of the pre-existing fluvial systems within the newly defined Kashmir basin. Lacustrine sedimentation persisted throughout the interval of intermontane sedimentation and continues today in the shallow lakes along the northern basin margin (Fig. 2).

Within this predominantly mudstone Karewa sequence, coarse conglomerates punctuate the record of quiet-water deposition. Palaeocurrent measurements taken from imbricated and cross-bedded conglomerates (Fig. 5) in the lower two-thirds of the Karewas exposed on the flanks of the Pir Panjal Range indicate derivation from a north-easterly source, presumably the Great Himalaya. We infer that pulses of uplift along the northern basin margin caused thick wedges of conglomerates to be shed south-westwards across nearly the entire low-relief basin. In the upper third

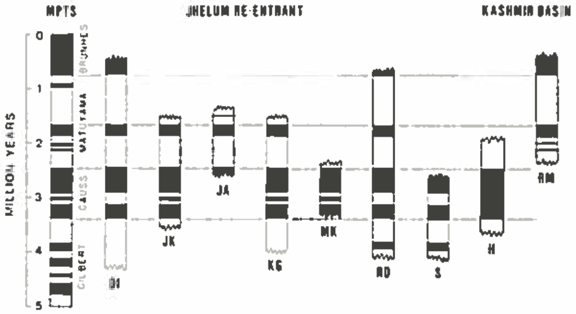

Fig. 4. Correlation of local magnetic polarity stratigraphy with the magnetic polarity time-scale (Mankinen & Dalrymple, 1979). Both fossil occurrences and the frequent presence of prominent ashes associated with the Gauss–Matuyama boundary assist in the recognition of identifiable chrons and subchrons at the local scale. Volcanic ashes in Kashmir and further west in northern Pakistan have been fission-track dated (Burbank, 1982; Johnson *et al.*, 1982) and serve to reinforce the correlations shown here. For a more detailed discussion of the sections shown here, see Johnson *et al.* (1979), Raynolds (1980) and Burbank (1982). The sections are arranged in the spatial sequence in which they would be encountered on a traverse starting from the Jhelum River and ending in Kashmir. Dina (DI); Hirpur (H); Jari (JA); Jhel Kas (JK); Kas Guma (KG); Mawa Kaneli (MK); Rata-Dadial (RD); Romushi (RM); Sakrana (S).

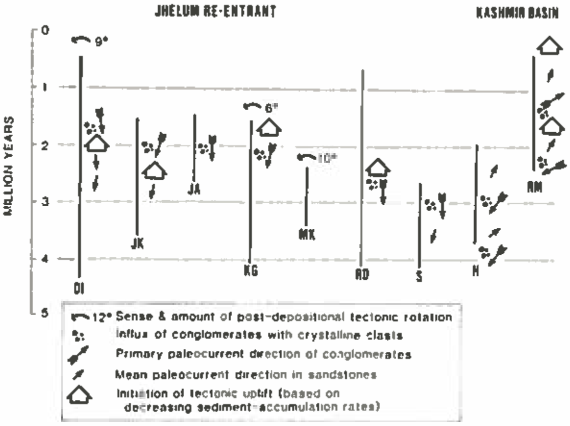

Fig. 5. Schematic representation of tectonic and sedimentologic events for the local sequences aligned along the cross-sectional traverse. The vertical line represents the temporal duration of each section as interpreted from the magnetostratigraphic data. The amount of post-depositional rotation is determined from the magnetostratigraphic data from each section. Those sections showing no rotation are those whose mean magnetic orientation is not significantly different from geographical north and south. Each of the events (influx of conglomerates, initiation of tectonic uplift, or palaeocurrent direction) is shown in its proper temporal position in the local sequence. Section abbreviations are the same as those for the previous figure.

occurred prior to the last 4 Myr of active tectonism and deposition.

Pir Panjal Range

On the NE slopes of the Pir Panjal Range, glacial deposits and the extensive 'Karewa' surfaces obscure most of the bedrock. However, from the range crest for nearly 25 km to the SW, surficial outcrops are abundant and reveal a complex sequence of folded and faulted Palaeozoic to early Tertiary rocks that lie to the north of the deformed sediments of the foredeep (Figs 2 and 3). Because political considerations have led to restricted access to this region, most of our interpretations are based on previous mapping by Middlemiss (1919), Wadia (1928, 1931, 1934), Shah (1968, 1972, 1978, 1980) and Fuchs (1975).

The bedrock units in the Pir Panjal generally strike NNW to SSE, and, although there is lateral variation along the range, the structure depicted along the transect (Figs 2 and 3) is largely representative of the style of deformation in the remainder of the range. Along the transect, four major stratigraphic and structural units are apparent (Wadia, 1928). Upper Carboniferous 'Agglomeritic Slates', Carboniferous to early Triassic Panjal Traps, and associated gabbroic intrusives form the crestal region of the Pir Panjal Range. These are overlain by, but may be in fault contact with, the largely terrestrial Gondwana strata. Both of these units have been tightly folded and moderately overturned to the SW (Fig. 3). They, in turn, rest unconformably above the early Palaeozoic (?) Dogra slates (Wadia, 1928; Shah, 1968; Fuchs, 1975) which are also overturned and verging to the SW. This entire sequence has been thrusted along the Panjal Thrust and over the fourth stratigraphic/structural unit which is dominated by Eocene limestones and shales. This thrust may be structurally equivalent to the 'Main Central Thrust' of the central and eastern Himalaya (Seeber, Armbruster & Quittmeyer, 1981). Additional north-dipping thrusts are present within this zone (Shah, 1980), in each case bringing Palaeozoic rocks on to overturned Eocene strata. The southern margin of the Pir Panjal zone is delineated by the 'Main Boundary Thrust' (MBT) or 'Murree Thrust' which carries the Eocene and older rocks above the proximal molasse sediments of the Murree Formation.

The timing of deformation within this Pir Panjal sequence is not well constrained, although at least the outermost zone was deformed in post-Eocene times. The singularity of south-westward vergence throughout the range suggests that, despite evidence of multiple cleavages resulting from earlier deformations (Wadia, 1928), the Cenozoic Himalayan compression has overprinted the entire sequence. Our chronologic data from Kashmir for the initiation of intermontane sedimentation, as well as palaeocurrent and provenance data from the molasse to the south (described in the next section), suggest to us that much of the thrusting commenced in the early Pliocene (Burbank, 1983). On the other hand, the absence of external molasse strata north of the MBT and the presence of thick palaeosols below the Karewa beds suggest that the region of the present Pir Panjal may have represented an area of positive, but low relief that stood slightly above the molasse basin during the late Miocene.

Data from the Murree molasse strata to the SE of the transect indicate that these rocks, like those in the Kashmir basin, have undergone ~45° of clockwise rotation (Klootwijk *et al.*, 1983). In the Punjab Re-entrant 200 km farther SE, Siwalik strata as young as 7 Myr have been clockwise rotated 7–10° (Johnson *et al.*, 1983). Because the Plio–Pleistocene Karewa beds are unrotated (Burbank, 1982), the interval of rotation is most likely to have occurred between post-middle Miocene and pre-middle Pliocene (~10–4·5 Myr) and perhaps can be constrained to an even narrower time slice between 7 and 5 Myr. Because of the regional nature of this late Tertiary rotation, it is unlikely to be due to movement along a specific thrust. We interpret it as resulting from a broad-scale rotation related to the initial structural development of the Jhelum Re-entrant (Fig. 1). Apparently once the thrusts bounding the Pir Panjal Range developed around 4–5 Myr, differential rotation of the allochthonous rocks of the thrust sheets ceased, despite continued motion along the thrusts and continuing Indo-Asian convergence.

The deformed foredeep

A 30 km wide zone dominated by the Oligocene–Miocene molasse strata of the Murree Formation extends south from the MBT (Wadia, 1928; Rao & Rao, 1976; Shah, 1980). Near the southern margin of this zone in the vicinity of the transect (Figs 2 and 3), a major thrust fault brings both Eocene limestones and Permo–Triassic marine sediments to the surface. Near Kotli, 5 km farther south, a second thrust (Middlemiss, 1919) carries the Murrees above the Middle Siwalik strata of late Miocene age. Broad, open folds characterize most of the 'Murree Zone', and within one gentle syncline just south of the

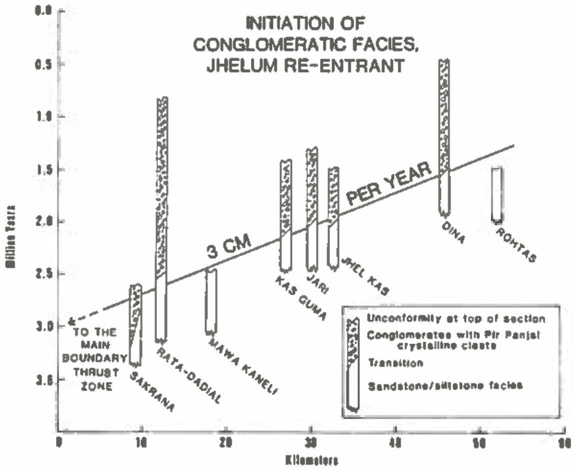

Fig. 7. Initiation of conglomeratic facies in the Pir Panjal foothills and the easternmost Potwar Plateau. The relative position of each section is derived from an orthogonal projection of the geographical location of the section on to the line of the cross-section (see Fig. 2). The age of the facies boundary represents the onset of conglomeratic sedimentation at each location. The magnetostratigraphic age of this stratigraphic horizon and a regression through these facies boundaries indicates that the south-westward onslaught on conglomerates proceeded at a mean rate of about 3 cm yr^{-1}. If this mean rate is extrapolated back in time and space towards the Main Boundary Thrust zone, it suggests that these conglomerates would first have appeared between 4 and 5 Myr ago in response to thrusting and early uplift of the Pir Panjal Range.

sandstones preserve south-directed palaeocurrents. We interpret the white sandstones to represent the ancestral Indus River flowing longitudinally along the axis of the foredeep and draining into the Ganges River (Raynolds, 1982). The brown sandstones, which are also the dominant sandstone type found east of the Jhelum River along the transect described here, are interpreted to reflect the ancestral Jhelum River and to be a response to the structural development of the Jhelum Re-entrant and uplift of the Pir Panjal Range. This fundamental re-arrangement of the drainage systems occurs in several dated sequences between 4 and 5 Myr. Thus, the timing of the initiation of Karewa sedimentation in Kashmir, the onslaught of conglomerates, and the re-arrangement of drainage patterns converge on a date of 4–5 Myr ago for initial uplift of the Pir Panjal and concurrent development of the Jhelum Re-entrant.

SYNTHESIS AND SUMMARY

When the chronologic, stratigraphic, and structural data from both west (Johnson *et al.*, this volume) and east of the Jhelum River are considered, it is possible to develop a tectonic history for the north-western Himalayan foredeep that is well constrained in time and space over the past 5 Myr (Fig. 8). Clearly, there are many limitations to such a synthesis. Although data from over 18 dated locations are considered in this reconstruction, there are many faults and folded structures that have not been studied. This makes it necessary to interpolate between dated structures. The techniques used in this study do not permit us to date certain structures due to the absence of syndeformation strata in outcrop. For example, although the onset of sedimentation in the Peshawar Basin provides an upper age limit for the time of deformation, the long history of deformation of foredeep strata in the vicinity of the Peshawar basin (Burbank, 1983; Burbank & Tahirkheli, 1985) and the thick alluvial cover south of the Attock Range seem to preclude the direct determination of a reliable date for the onset of major movement along the Attock thrust. Similar restrictions apply to the thrusts bordering the south-western margin of the Pir Panjal Range. In addition, within the Potwar Plateau (Figs 1 and 3), there are a number of undated thrusts that are considered to be of only secondary importance to the overall deformational pattern, but which may, in fact, have played a more intrinsic role. Despite these caveats, the reconstruction presented here provides one of the most tightly constrained syntheses of foredeep deformation that is presently available. This synthesis builds upon an earlier analysis (Burbank & Raynolds, 1984) and incorporates additional data from stratigraphic, chronologic, and geophysical studies.

In this north-western portion of the Himalayan foredeep, we can delineate three discrete regions that are discriminated on the basis of the style and causes of the deformation experienced by each. One region lies to the east of the Jhelum River and encompasses the structures along the transect described here, all of which are oriented subparallel to the strike of the Himalaya and appear to reflect a NE–SW oriented compressional regime. The second region comprises the eastern Potwar Plateau west of the Jhelum River and extends north-westwards to the Peshawar basin (Figs 3 and 4, Johnson *et al.*, this volume). Here, the major structural features trend NE–SW, subparallel to the strike of Attock–Cherat, Margala, and Hindu Kush Ranges. The western margin of this region is transitional to the third area (Fig. 4, Johnson *et al.*, this volume) which encompasses the remainder of the Potwar Plateau extending from the Salt Range to the Kala Chitta Range.

Deformation in the easternmost area is quite clearly related to tectonic history of the NW–SE trending Pir Panjal and Great Himalayan Ranges. The Potwar Plateau to the west appears to be underlain by a very efficient, salt-lubricated detachment (Seeber *et al.*, 1981; Burbank, 1983; Lillie *et al.*, 1985; Johnson *et al.*, this volume). Much of the latest Cenozoic Indo-Asian convergence in this area appears to be accommodated along this detachment with a resultant decrease in the magnitude of deformation in the strata north of the Salt Range. The intermediate region between these two areas contains structures similar to those of the central and western Potwar Plateau inasmuch as they are parallel to the structural trends of the crystalline ranges to the north. However, rather than passively rafting the entire Phanerozoic section above a detachment as occurs to the west, the distal thrusts cut up section, and the structural deformation is considerably more intense. We interpret these changes as reflecting palaeogeographic control, whereby the Eocambrian salt deposits are attenuated or absent to the east, and, consequently, no single widespread detachment developed in this region.

Within the window of time (0–5 Myr) under consideration, the earliest major phase of deformation between 4 and 5 Myr ago is related to initial uplift of the Pir Panjal Range along its bounding thrusts and structural definition of the Kashmir intermontane basin (Fig. 8). The re-arrangement of pre-existing drainage patterns as the south-flowing ancestral Jhelum River supplanted the east-flowing ancestral Indus River is viewed as a response to this uplift and to the incipient development of the Jhelum Re-entrant. The clockwise rotation of the region east of the syntaxial axis, at least within the newly formed Kashmir basin, ceased at this time. From the newly uplifted fault front of the Pir Panjal, a conglomeratic wedge bearing volcanic clasts prograded to the south and transgressed sequentially across the dated localities in the eastern Potwar Plateau (Figs 7 and 8).

The folding, erosion, and rotation that occurred in both the Baun and the Kotal Kund /Tatrot/Andar area between ~4·5 and 3·5 Myr ago (Johnson *et al.*, this volume) suggests that the Salt Range detachment may have become active at this time and that, as a result, the 'Potwar allochthon' was structurally defined for the first time (Fig. 8). The coincidence in time (Fig. 8) of this initial deformational episode near the Salt Range with the first interval of major uplift of the Pir Panjal Range suggests these events may be causally linked. Whether or not this deformation resulted from encounters between irregular basement topography with existing thrust ramps (Burbank, 1983) is a matter of speculation. It is interesting to note that, if these events are indeed related, stress release occurred synchronously at localities more than 100 km apart with little or no apparent deformation in the intervening area where molasse sedimentation continued unabated (Fig. 8).

Within the Kashmir basin itself, the predominantly lacustrine Karewa sediments began to aggrade by 4 Myr ago. Sporadic, thrust-modulated pulses of uplift along the north-western margin of the basin shed coarse conglomerates south-westward across the basin

3) have continued to accumulate coarse sediments until the present time. The large dashed box on the left panel labelled 'Potwar Allochthon' depicts that area riding above the eastern edge of the Salt Range detachment surface. On the right panel, three intervals of uplift in the vicinity of the Pir Panjal Range have defined the Kashmir Basin, controlled palaeocurrent patterns, and deformed the adjacent foredeep to the SW. The Kotli Thrust (KT) is likely to have been active in the early to middle Pleistocene, but it is not well dated. The earliest interval of deformation along the Panjal (PT) and Murree (MT) Thrusts in the Pir Panjal (4–5 Myr ago) is contemporaneous with the deformation inferred from the records at Baun and Kotal Kund (Johnson *et al.*, this volume). Although these latter sites lie to the south of the left panel, the 'Potwar Allochthon' is inferred to have become structurally defined at this time. Early Pleistocene deformation in the Attock–Cherat Range along the Attock Thrust (AT) is succeeded by younger deformation to the south and east. Out-of-sequence thrusting is indicated by movement along the Riwat Thrust (RT) between 3·0 and 2·5 Myr ago and by later, major movement on the MBT between 2·1 and 1·9 Myr ago. This rapid motion on the MBT, the strong deformation of the Soan Syncline (SS), and related deformation that rippled across the proximal foredeep are all interpreted as responses to a major thrust ramping event in the vicinity of the Salt Range (Johnson *et al.*, this volume). Following this event, counter-clockwise rotation of portions of the Potwar Allochthon and adjacent regions occurred. The surface of the block illustrates active present-day processes. Deposition is largely restricted to the axial portions of the intermontane basins and narrow floodplains. Regions of high seismicity within 10–15 km of the surface (Seeber *et al.*, 1981) are shown by stars. Presently or recently active faults that break the surface seem to be associated with shallow seismicity.

is correct (Johnson *et al.*, this volume), out-of-sequence deformation also occurs, such that initial buttressing and uplift of the Salt Range ultimately results in severe deformation 100 km farther north in a more proximal position within the Himalayan foredeep. Similarly, the initial deformation episodes 4–5 Myr ago in the Pir Panjal and Kotal Kund suggest a causal linkage between two widely separated areas.

Finally, the style of Plio–Pleistocene structural disruption in the north-western Indo–Gangetic foredeep appears strongly dependent on the distribution of the incompetent (particularly evaporitic) horizons in the Phanerozoic succession. Although the orientation of the bedrock ranges, bounding thrusts, and fold axes strike nearly perpendicular to each other in the eastern Potwar Plateau on either side of the Jhelum Re-entrant, the style of deformation appears very similar in both areas. Deformation is limited to a narrow zone and is seen to have spread sequentially across these areas. In contrast, in the central Potwar Plateau above the salt-lubricated detachment, deformation occurred in widely separated areas with minimal involvement of the intervening strata. Moreover, except for brief pulses of stress release along the trailing edge of the detached mass, nearly all subsequent convergence in this portion of the foredeep appears to be accommodated along the efficient, largely aseismic Salt Range detachment.

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