Active faulting in the southern Peshawar basin, Pakistan

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ABSTRACT: *Evidence for active faulting is found in the Peshawar basin parallel to its southern margin. The faults run along four left stepping ridges that diagonally cut across imbricate thrust structures of the Attock-Cherat Range. The unlithified sediments of the Peshawar basin comprising of lacustrine, fluvial, and alluvial-fan deposits dated at 2.8 to 0.6 Ma and the younger alluvial-fan gravels are strongly folded, faulted, and are cut by east-northeast-trending faults with their north sides up thrown. The faults postdate some of the fan drainage but defects other drainage. The en-echelon distribution of the ridges and low-angle slickensides in some faults indicate that the faults may be strike-slip. The faults extend 40 km in east-northeast direction to the Tarbela Dam area where the base of Indus River gravels is apparently displaced by a reverse faults with northwest side up. Additional lineations and south facing scarps occur at the southern side of the Attock-Cherat Range where Jurassic limestone is faulted over gravels material.*

INTRODUCTION

The deposition of the Peshawar basin fill sediments, including lacustrine and fluvial deposits continued between 2.8-0.6 Ma (Burbank and Tahirkheli, 1985). During the time of deposition of the Peshawar basin deposition continued in the Siwalik foredeep basin to the south in the Surghar Range and Trans-Indus Salt Range (Khan, 1983) and to the southeast in the Potwar Plateau (Raynolds and Johnson, 1985). Thrusting occurred in the northern Potwar Plateau south of Rawalpindi between 1.8 and 2.1 Ma (Raynolds and Johnson, 1985) and in the eastern Salt Range and in the Trans-Indus Salt Range more recently than 0.6 Ma (Khan, 1983; Yeats and others, 1984). After termination of deposition of Peshawar basin fill at 0.6 Ma, four *en echelon,* left-stepping pressure ridges formed within the Peshawar basin, close to and parallel to the front of the Attock-Cherat Range (Fig. 1).

The Peshawar basin fill, including the Jallozai Formation of Tahirkheli (1970), began with low-energy floodplain deposits containing soil zones succeeded by northward-prograding alluvial fans with a source in the Attock-Cherat Range, including that the range ponded the basin at that time (Burbank and Tahirkheli, 1985). The axis of the Peshawar basin may have been close to its southern margin, which cuts diagonally across the northern, central, and southern blocks of the Attock-Cherat Range (Fig. 1). The Kabul River and Swat River cut deep gorges through the ranges bounding the Peshawar basin on the northwest, and they may be antecedent to uplift of those ranges.

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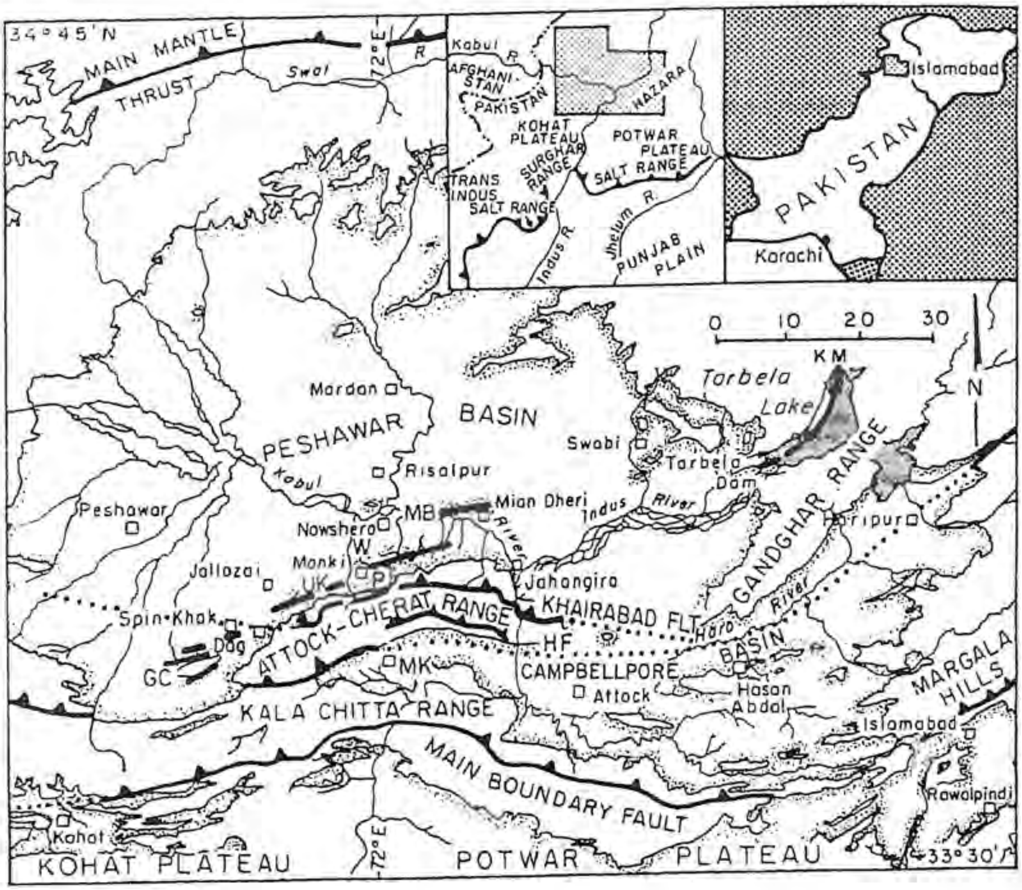

Fig. 1. Map of the Peshawar basin showing late Quaternary fault traces (heavy solid lines) and older regional thrust faults (heavy lines with teeth): Main Mantle thrust, Khairabad-Panjal thrust, and Main Boundary thrust. H.F. = Hissartang fault. Pressure ridges: GC = Garhi Chandan; UK = Uch Khattak; W = Walai; MB = Misri Banda. Villages: P = Pallosai, MK = Mir Kalan.

The sediments of Peshawar basin are predominantly lacustrine silts with interbedded fluvial sands and gravels containing clasts of Kohistan provenance, indicating deposition by the ancestral Kabul and Indus rivers. Burbank and Raynolds (1988) have suggested that the Peshawar basin sediments may have been ponded by uplift of the Attock-Cherat Range related to movement on their Attock thrust (Hissartang fault of Yeats and Hussain, 1987) and subsequently the Main Boundary thrust, which also ponded sediments in the Campbellpore basin. Deposition of Peshawar basin and Campbellpore basin fill, including lake beds north of the Peshawar basin alluvial fans, ended about 0.6 Ma (Burbank and Tahirkheli, 1985), about the same time that deposition of the Siwalik foredeep basin strata ended in the Surghar Range and Trans-Indus Salt Range (Khan and others, 1988) and in the eastern Salt Range (Raynolds and Johnson, 1985). Younger sediments in the Peshawar basin include catastrophic-flood deposits (Burbank and Tahirkheli, 1985) and alluvial-fan and fluvial deposits. These younger deposits, along with older rocks, are faulted and folded during the Quaternary time.

LATE QUATERNARY DEFORMATION

Active faulting occurs to the north of the MBT along ENE trending high angle faults in the Peshawar Basin. The faulting is associated with four left stepping, en echelon pressure ridges formed within the Peshawar basin parallel to its southern margin (Fig. 1). Additional evidence is found 40 km farther east at Tarbela Dam, although this area is off trend, being right-stepping rather than left-stepping. The pressure ridges are, from west to east, the Garhi Chandan, Uch Khattak, Walai, and Misri Banda ridges, each named for villages located in the vicinity (these are labeled GC, UK, W, and MB in Fig. 1).

Peshawar basin fill, dated as 2.8 to 0.6 Ma by Burbank and Tahirkheli (1985), is directly correlated only to the westernmost ridge; however, the fill is more or less contemporary with lacustrine deposits, with fanglomerate that has an Attock-Cherat Range provenance, with loosely consolidated river gravel that has rounded clasts of granitic rock, and with miceaceous gray sand, also fluvial. The fluvial deposits have a northern provenance and were probably deposited by the ancestral Kabul River, flowing parallel to the Attock-Cherat Range but closer to it than present. Similar deposits were reported by Said and Majid (1977) in the southwestern Peshawar basin. These sediments are widespread in the Peshawar basin, and at most localities, they are flat lying. At the easternmost ridge, a normally magnetized sequence of repeated graded beds may have been deposited as catastrophic-flood deposits by the Indus River (Burbank, 1983; Burbank and Tahirkheli, 1985). An angular unconformity within this sequence is evidence of deformation during deposition.

Local steep dips in the Quaternary sediments adjacent to ridge-front faults indicate that part of the deformation way by folding. The straight trace of some of the ridge-front faults are in contrast to the lobate trace of late Quaternary thrusts at the foot of the Salt Range and suggest that these faults are relatively high angle, involving the basement. The left-stepping pattern of the three ridges suggests that they were formed by oblique-slip faulting with a component of left-lateral strike slip and reverse slip. A brief description of each ridge follows.

Garhi Chandan Ridge

The Garhi Chandan Ridge defines a broad fold plunging east and west with Murree Formation in the core (Fig. 2). The ridge is covered on both sides by sediments of Pliocene-Pleistocene age, including the ash-bearing sediments dated by Burbank and Tahirkheli (1985). Gravel in this sequence consists predominantly of pre-Murree clasts from the Kala Chitta Range, with Murree clasts increasing in percentage upsection. These sediments dip southeast off the eastern end of the ridge at Walai China; the strike ridge extends 8 km northeast to Spin Khak with dips as much as 40°SE. North of the ridge, adjacent to the Murree exposures, sediments dip as high as 60°N. Farther north, the sediments are folded into a syncline and anticline; the northern anticline is asymmetric, with dips ranging from 40°S to 10°N. These folds die out westward. The sediments are overlain with angular unconformity by fan gravels having a southern provenance.

The Garhi Chandan ridge is faulted both to the northern and southern sides against the basin fill sediments. A north-northwest-south-southeast profile across the Garhi Chandan ridge and adjacent fan surfaces to the north and south (Fig. 2) shows a vertical separation of 100 m of the base of the fan gravels north and south of Garhi Chandan ridge. A fault on the south side of the ridge accounts for most of the separation; Murrees on the north must be faulted against fan gravels to the south to account for the lack of Murree clasts in the continuation of this ridge farther north. The Irish Bridge fault on the north side of the ridge forms and most pronounced photo lineation in the area, but it, too, has its north side up, faulting fan gravels dipping 20°N on the south against older, more deformed sediments on the north. The gravels at Irish Bridge are only displaced about 60 m vertically relative to the gravel flatiron north of the ridge (although their depositional top is not pre-

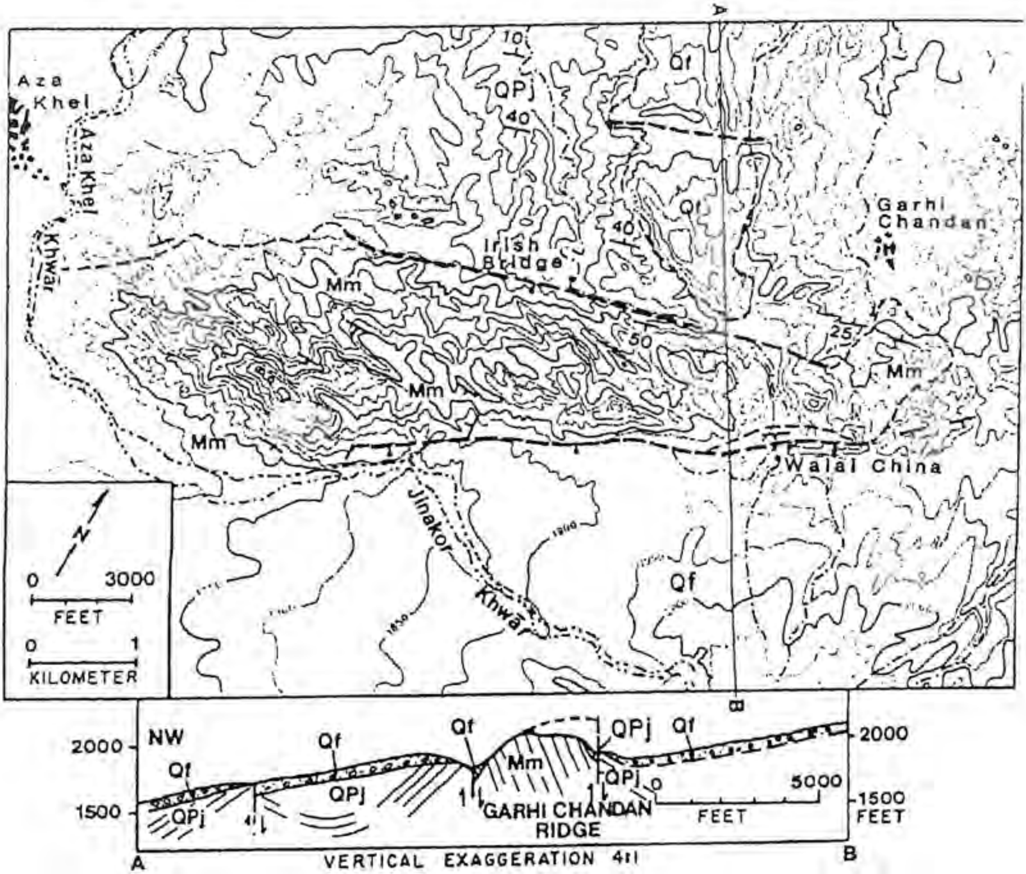

Fig. 2. Topographic map and cross section of Garhi Chandan ridge and vicinity; contour interval 50 ft. Ridge itself underlain by Murree Formation, adjacent area underlain by Pliocene-Pleistocene sediments covered by younger alluvial fan gravels. Heavy dashed lines indicate faults; bar and ball on downthrown side. A-B locates cross section; vertical exaggeration 4:1. Steeply dipping gravels south of fault at Irish Bridge are projected into cross section, but they occupy an area too small to show on map. Mm = Murree Formation; QPj = Jallozai Formation of Tahirkheli (1970); Qf = late Quaternary alluvial fan gravels.

served at Irish Bridge). The map shows that the Garhi Chandan ridge has a steep south flank and gentle north flank; the north flank may have been overlain originally by gravels subsequently removed by erosion except for the remnants at Irish Bridge. If so, the original gravel surface must have been tilted northward more than the present slope of the gravel surfaces farther north and south.

At the western end of the Garhi Chandan ridge the Jinakor Khwar flows down the southernmost fan surface and is deflected westward to Aza Khel Khwar (Fig. 2). On the other hand, a very small stream is not deflected by the ridge at Walai China but cuts a gorge through the Murrees, suggesting antecedence to ridge growth. The deflection by the ridge of some but not all of the drainage, and the dominance locally to Murree clasts in gravels close to the ridge, suggest that the ridge grew during fan-gravel deposition and continued to grow afterward. The modern alluvium is not faulted, and scarps on the northernmost fault are low and degraded, suggesting that latest deformation is Pleistocene rather than Holocene.

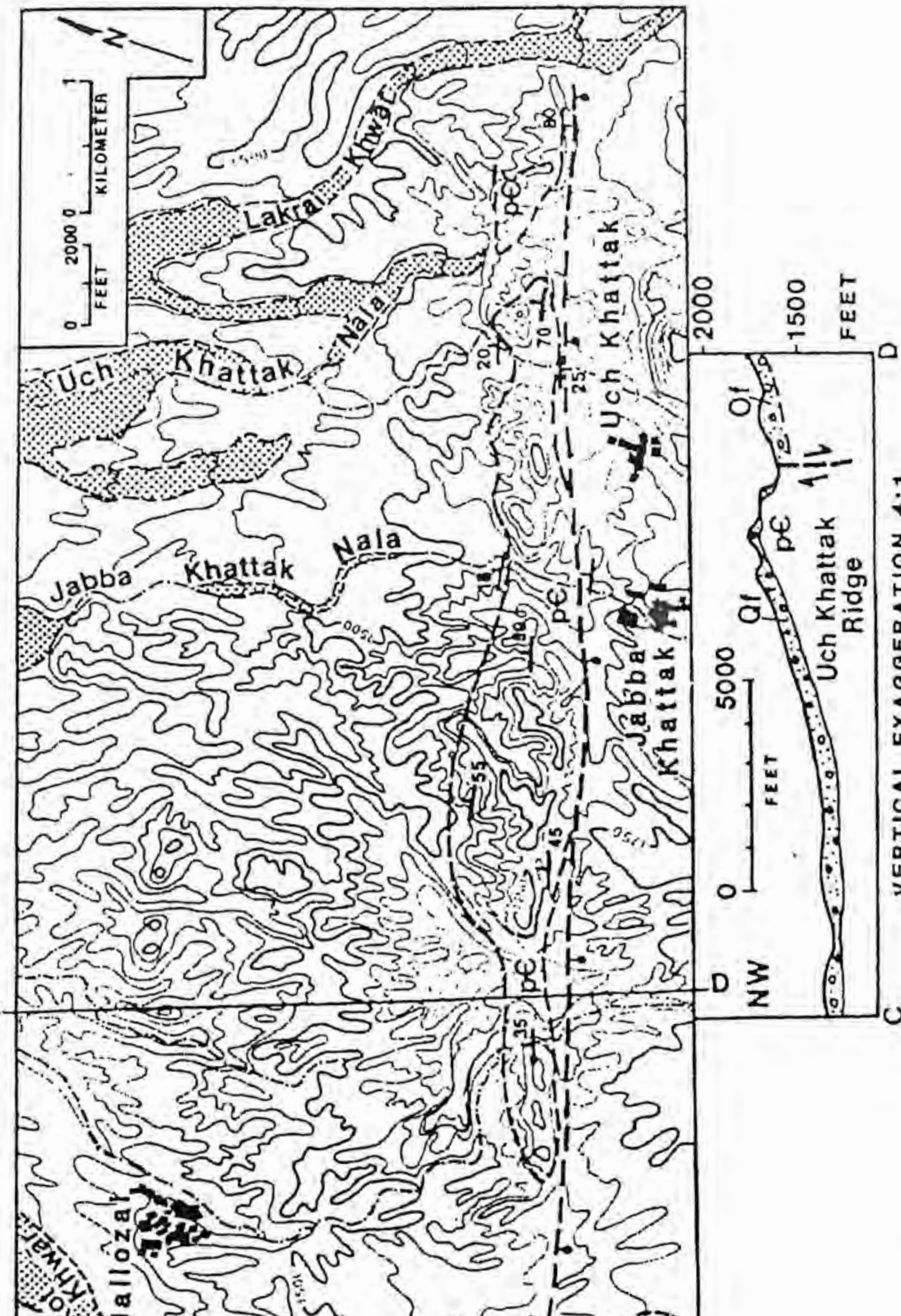

Fig. 3. Topographic map and cross section of Uch Khattak ridge. Symbols same as Figure 3; pC = Precambrian metaclastic rocks and limestone.

Uch Khattak Ridge

The Uch Khattak ridge is comprised of Precambrian metaclastic rocks (Manki Slate) succeeded by Precambrian limestone in an overturned, southward-verging syncline. In Uch Khattak Nala, bedrock is overlain on the north by fanglomerate containing locally derived Manki Slate clasts. The fanglomerate is itself overlain by river gravel with a northern provenance. This sequence dips 20°N. On the south side of the ridge fanglomerate dipping 25°S was exposed in a trench near Uch Khattak village. Farther west, in Jabba Khattak Nala, which, like Uch Khattak Nala, cuts through the ridge (Fig. 3), lake beds of the Jallozai Formation of Tahirkheli (1970) dip 16°N on the north side of the ridge. South of the ridge similar lake beds also dip north toward the ridge, indicating the fault has north-side-up separation.

The tilted and deformed sediments are overlain with angular unconformity by fan gravels derived from the Attock-Cherat Range to the south. These gravels are displaced by the fault with a down-to-the-south vertical separation of *50* m at Jabba Khattak Nala (Fig. 3). Vertical separation diminishes west and east of the bedrock exposures, and the fault has not been traced west of Shahkot Khwar or east of Lakrai Khwar. None of the streams crossing that fault is deflected, and slickensides in tilted lake beds in Jabba Khattak Nala are dip-slip, suggesting dip-slip displacement on the fault.

Walai Ridge

The Walai ridge is located between Walai and Manki villages (Figs. 1, 4) and contains Manki Formation dipping steeply to the north-northeast. The ridge has a gentle north slope and steep, linear south-southeast-facing ridge has a gentle north slope and steep, linear south-southeast-facing ridge front that truncates foliation at a low angle (Hussain, 1984). Two streams, the Tangi Khwar and the Pirano Khwar, cut through the bedrock ridge and appear to be antecedent to it. Near the village of Piran, Burbank and Tahirkheli *(1985)* reported a normally magnetized sequence consisting of repeated graded beds that they interpreted as catastrophic flood deposits, probably from the Indus River, deposited during the past *0.7* m.y. (Burbank, *1983*). These deposits rest directly on Manki Formation. As reported by Burbank and Tahirkheli *(1985)*, the catastrophic-flood deposits are separated by a colluvial zone, below which the beds dip 10°N, and above which they dip at only 20°N, indicating uplift and northward tilting of the Walai ridge during the time of deposition of the colluvium. We observed numerous sand dikes in these deposits, suggesting seismic shaking.

A more complete stratigraphic section is found at Walai at the eastern, down plunge end of the ridge. The Manki Formation is overlain by loosely consolidated river gravel containing rounded clasts of granitic rock and by micaceous gray sand, also fluvial. These sediments have a northern provenance and were probably deposited by the ancestral Kabul or Indus River. West of Walai, the micaceous sand is overlain by silt, which is interbedded with fanglomerate dominated by clasts of Dakhner Formation (Precambrian? shale and argillite of the central block of the Attock-Cherat Range) and less common limestone. East of Walai, the silt is overlain with angular unconformity by Dakhner clast fanglomerate that locally has a flat-topped constructional surface (Fig. 4) on which a soil has developed.

These sediments define an asymmetric anticline having gentle dips on the north and steep dips on the south. Sediments in the southern limb consistently dip *25°* to *35°S* between Walai and Manki and as much as *80°S* in a stream cut east of Walai. They steeply dipping sediments are succeeded southward by clay gouge marking the Manki fault, then by flat-lying fanglomerate on the south side of the fault. The constructional surface is displaced by the Manki fault, with vertical separation about 30 m at Pirano Khwar. From Walai eastward, the young alluvial fans are apparently offset right-laterally across the fault, but it has not been demonstrated that this is due to right slip on the Manki fault.

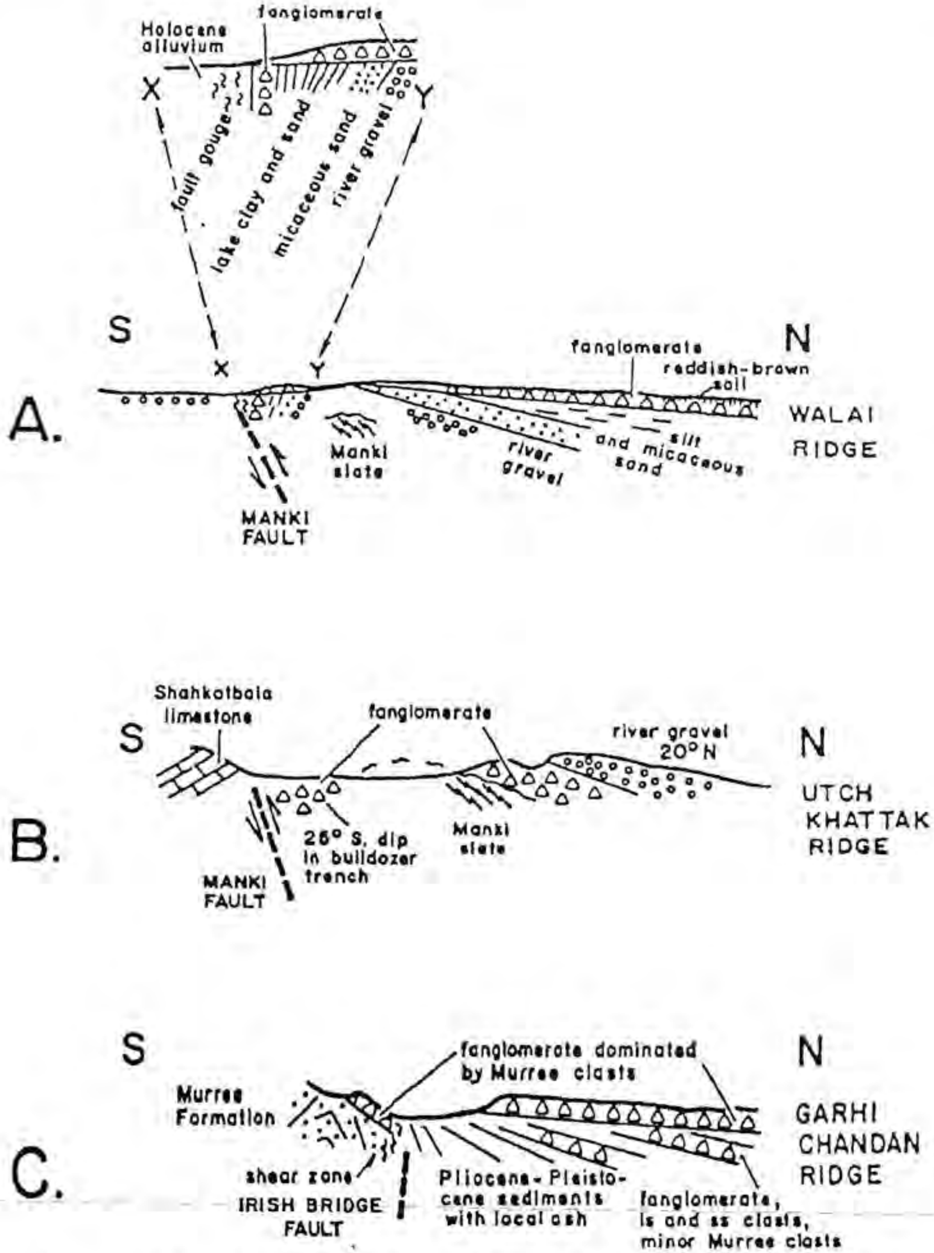

Fig. 4. Diagrammatic Cross Sections of three Pressure Ridges North of the Attock-Cherat Range, Pakistan.

Misri Banda Ridge

The Misri Banda is located north of the Kabul River in an east-trending series of linear bedrock ridges underlain by Paleozoic strata. In the Misri Banda-Mian Dheri area, the bedrock is overlain unconformably by flat-lying lacustrine sediments on the north and by gently to strongly folded lacustrine and fluvial sediments on the south. The lacustrine sediments on the south side are cut by a fault that strikes N60° to 68°E, dip 80°N, and is exposed for a strike distance of 3 km. The fault zone is about 50 cm wide and is marked by slickenside-bounded lenses of clay and silt. Slicken-sides plunge 30°E, suggesting a large component of strike-slip. The general dip of the lacustrine sediment varies from 5° to 10°S, but close to the fault, the dip is steeper. Sediments adjacent to the fault on its northern side dip 40°S, whereas those on its southern side dip 85°S. The extension of the fault farther east or west is covered by modern flood-plain deposits. The area between the Misri Banda ridge and the Kabul River to the southeast is also underlain by flood-plain deposits. The folded lacustrine sediments at Misri Banda are overlain unconformably by loess, and the base of the loess is not displaced by the fault.

Flat-lying lacustrine sediments overlie the north side of the bedrock ridge between Nowshera and Risalpur and in the low hills between Mian Dheri and Jahangira. The absence of young sediments west of Misri Banda precludes the identification of the entire bedrock ridge as the uplifted north side of a Quaternary fault. The structural trends of deformed sediments at Misri Banda are parallel to those at Walai and other ridges to the west-southwest, and Misri Banda may be simply another left-stepping pressure ridge of that system. If so, the presence of the bedrock ridge west of Misri Banda is unexplained. In addition, the absence of a sequence coeval with the fan gravels deformed at the other ridges precludes the determination of the age of faulting more accurately than younger than about 0.6 Ma.

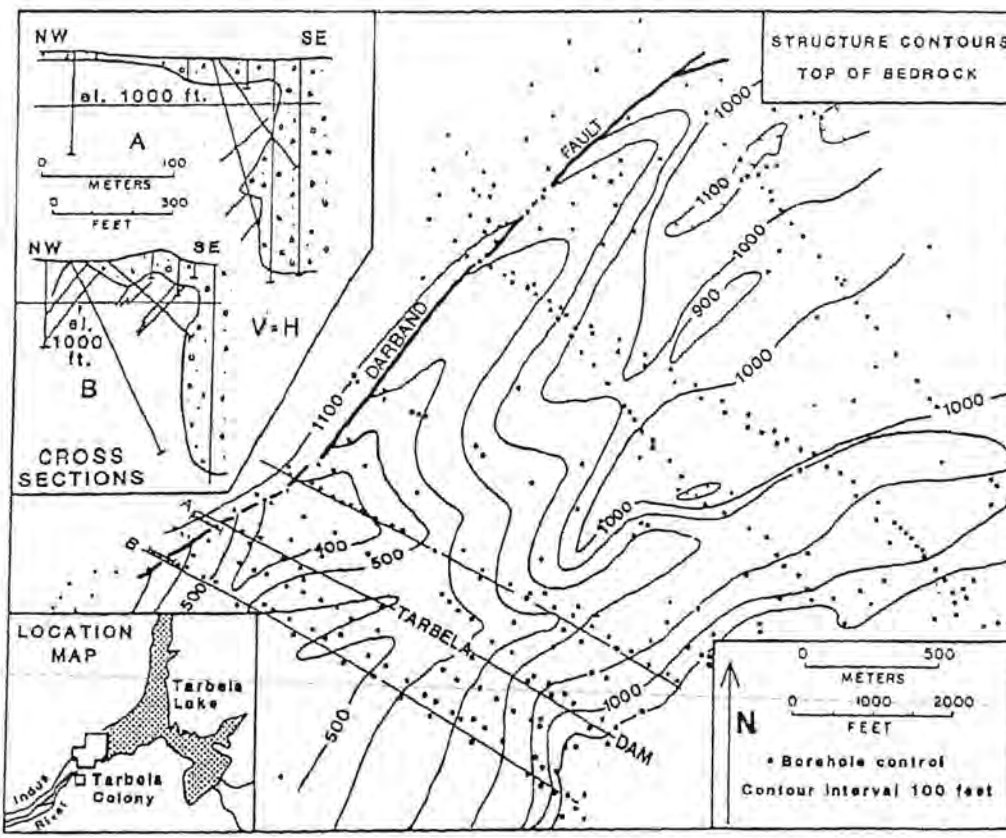

Fig. 5. Structure contours in feet of top of bedrock at Tarbela Dam. Darband fault marked by vertical to overhanging escarpment in bedrock, as noted in two cross sections. No vertical exaggeration in cross sections; scale of cross sections in larger than that of map.

Tarbela Area

At Tarbela, the Darband fault runs northeast parallel to the Indus River and has formed an overhanging escarpment at the base of Indus River gravels with an escarpment with 140 to 210 m of vertical separation (Fig. 5). This escarpment is presumed to represent a reverse-separation fault dipping 65° NW to vertical, based on the dip of the overhang as constrained by boreholes (cross sections A and B, Fig. 5). In addition, a borehole 1,750 m northeast of the dam on the northwest side of the Indus flood plain, on trend with the escarpment, contained gravels dipping more than 70°. The low rolling hills of Tarbela Colony, mapped as Quaternary terrace deposits by Calkins and others (1975), are underlain by lacustrine, fluvial, and alluvial-fan deposits having dips varying from 20's to 40°N and strikes N20° to 70°E. These are cut by faults having a few centimeters of displacement, striking N75°E to N70°W, dipping 50°N to vertical; most have reverse separation, but some are normal. These sediments are cut by a more or less level erosion surface of moderate relief that may have originated as a high-level Indus River terrace, but if so, there are no Indus River gravels preserved on this surface. The attitudes of bedding and minor faults strike more easterly than the Darband fault and the present straight course of the Indus River at Tarbela Dam.

Farther north, air photographs taken prior to the filling of Tarbela Lake show a fault cutting bedrock on the west side of the Indus Valley. This fault is characterized by aligned shutter ridges, scarps facing alternately uphill and downhill, and left-lateral stream offsets of 200 to 350 m. This fault may connect on the south with the Darband fault at the dam.

DISCUSSIONS

The active faulting extends for nearly 60 km within the Peshawar basin, parallel and close to its southern margin. The linear, south-facing front of the Attock-Cherat Range at the western end of the Nizampur basin at Mir Kalan (MK of Fig. 1) also marks a north-dipping reverse fault between Jurassic limestone and alluvial-fan gravels of the Nizampur basin. A gap of 40 km separates the Misri Banda ridge from Tarbela, and the Tarbela deformed zone may represent a separate structure. If it is part of the same structure, it is off trend, stepped right rather than left. On the other hand, additional photo lineaments in the Attock-Cherat Range have the same east northeast trend as individual faults on the pressure ridges. These lineations are discordant to the low-angle, generally east trending thrust structures of the Attock-Cherat Range (Fig. 1; Yeats and Hussain, 1987; Hussain and others, 1988) and clearly are younger.

An intermontane basin near Pallosai is blocked by a ridge of bedrock to the north, but deformed Quaternary sediments are not exposed in this basin to document whether the ridge marks the up thrown side of a fault. If the deformation zone includes the entire Attock-Cherat Range, then the Tarbela exposure could well represent part of the same zone, and the gap in exposures may be caused by the shifting course of the Indus braided stream between Tarbela and the Attock-Cherat Range. Furthermore, the straight southwest trend of the Indus in this area may be influenced by the deformation zone, which would have the same trend.

The Attock-Cherat Range itself may represent a large-scale version of the pressure ridges to the north, faulted on the south against the sediments of the Nizampur basin (Fig. 6). Like the smaller ridges, the Attock-Cherat Range is asymmetric in profile with a steeper south slope. The Indus River may be antecedent to uplift of the range, analogous to the small streams cutting gorges through the pressure ridges. It is otherwise hard to explain why the Indus River cuts a gorge across the eastern end of the range and does not flow farther east around its eastern end though the Campbellpore basin. Uplift of the Attock-Cherat Range and ponding of Peshawar and Campbellpore basin sediments may be related to thrusting on the Main Boundary fault to the south

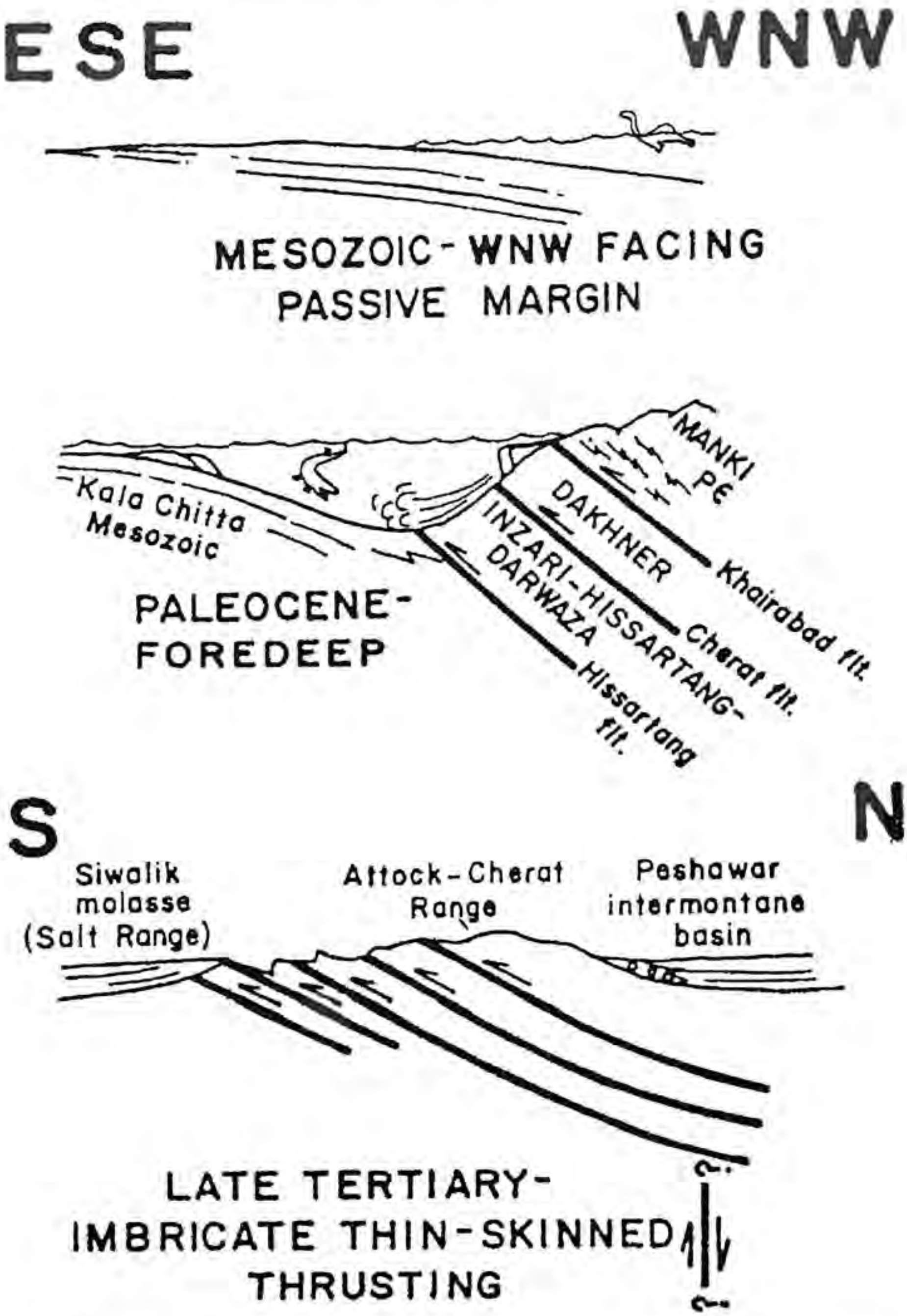

Fig. 6. Evolution of the Attock-Cherat Range. Top: west-northwest-facing Mesozoic sequence, now preserved only in Kala Chitta Range. Centre: juxtaposition of major fault-bounded blocks of Attock-Cherat Range with Kala Chitta sequence, followed by creation of Paleogene foredeep. Bottom: post-Murree, pre-Pliocene imbricate thrusting, uplifting Attock-Cherat Range and forming Peshawar basin. Thrusts may ramp over north-facing basement faults that later could propagate to surface as active tectonic zone in southern Peshawar basin.

beginning about 2.1 Ma (Burbank and others, 1988). If so, this uplift and entrenchment of the Indus River would be coeval with early uplift on at least the Garhi Chandan ridge (as dated by flanking sediments) and possibly the others as well.

The evidence for strike-slip is limited to low-angle slicken-sides on the fault at Misri Banda. A left-slip component is suggested by the en echelon, left-stepping pattern of the ridges, but the ridges are discontinuous, and total left slip in subjacent bed-rock must be too small for the ridge-bounding faults to coalesce into a single fault zone. Evidence for left-lateral displacement is present only on the north-trending fault at Tarbela Lake, suggesting that the strike of this fault is closest to that of the slip vector between the main Peshawar Basin block and the Attock-Cherat and Gandghar Ranges. Except for the Tarbela Lake fault, all faults have north side up, like the older thrusts, but these faults have linear map traces and are not lobate as is the Salt Range thrust (Yeats and others, 1984). In contrast to the Salt Range thrust, on which instrumental seismicity is low, the southern Peshawar basin active fault zone is marked by a zone of instrumental seismicity (Seeber and others, 1981). The instrumental seismicity and linear fault traces suggest that the faults cut downward to basement rocks and thus constitute a potential seismic hazard.

The Peshawar basin sequence, as young as 0.6 Ma, was strongly deformed and eroded before deposition of north-sloping alluvial fans from the Attock-Cherat Range. These fans were further cut by faults, none of which have large displacement; the largest documented vertical separation is 100 m on the faults bounding the Garhi Chandan ridge on the north and sough. Even if the Attock-Cherat Range were considered as a large tilted fault block the Quaternary displacement on this fault adjacent to the Nizampur basin must be small, because the range-front fault cannot be traced west into the Kala Chitta Rage or east into the Campbellpore basin. The alluvial fans are dissected by younger fans and fluvial deposits, and these deposits show no evidence of faulting. The subdued nature of south-facing fault scarps suggests that faulting last occurred in the Pleistocene; the elapsed time since the most recent surface rupture is on the order of 10^5 yr. The southward migration of the thrusting reached the Main Boundary fault during the time of deposition of Peshawar and Campbellpore basin sediments. The faulting described here began at the same time that thrusting occurred on the Main Boundary fault and continued as thrusting migrated still farther south to the Salt Range.

CONCLUSIONS

The Peshawar Basin was formed as the Attock-Cherat and Kala Chitta ranges were elevated as a result of south-verging imbricate thrusting during Middle Tertiary Period on the back of the Main Boundary Thrust (Fig. 6). This was followed by deep erosion, and deposition of lacustrine, fluvial, and alluvial-fan deposits in the Peshawar and Campbellpore basins. Active faulting zone best documented on four east-northeast-trending, en echelon, left-stepping pressure ridges began to form during deposition of these sediments and continued after deposition ceased and after deposition of alluvial fans unconformably on these sediments. All documented faults have north side up, and none appear to cut Holocene deposits. The deformation zone may continue east to Tarbela Dam, where similar deposits are folded and faulted, and a fault appears to displace the base of Indus River gravels at the dam. The active faulting is also documented in the Nizampur basin to the south across the Attock-Cherat Range, where bedrock is faulted against fan gravels.

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