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Zone of Late Quaternary deformation in the southern Peshawar Basin, Pakistan

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ABSTRACT

Four left-stepping pressure ridges extend for nearly 60 km parallel and close to the southern margin of the Peshawar basin, cutting diagonally across older imbricate thrust structures of the Attock-Cherat Range. Lacustrine, fluvial, and alluvial-fan deposits dated at 2.8 to 0.6 Ma are strongly folded, faulted, and eroded prior to deposition of alluvial-fan gravels, which are themselves cut by east-northeast–trending faults with their north sides upthrown. The pressure ridges postdate some of the fan drainage but deflect other drainage. The east-northeast–trending faults are high-angle and accompanied by instrumental seismicity; there is no evidence for strike-slip except for the en echelon distribution of the ridges and low-angle slickensides on one of the faults. Alluvial-fan and fluvial sediments are folded and faulted at Tarbela Dam, 40 km east-northeast of the easternmost pressure ridge, and the base of Indus River gravels is apparently displaced by a reverse fault with the northwest side up. Farther north, a fault adjacent to Tarbela Lake has left-lateral displacement. Additional lineations and south-facing scarps occur throughout the Attock-Cherat Range, and Jurassic limestone is faulted over gravels at the western end of the Nizampur basin. We interpret these features as part of a broad zone of deformation involving seismogenic crust; direction of slip is south-southwest. There is no evidence of surface rupture in this zone during Holocene time.

INTRODUCTION

A previously undescribed zone of late Quaternary deformation extends across the southern Peshawar basin east to the Indus River in the Himalayan foothills of Pakistan. In contrast to the recent faulting at the foot of the Salt Range (Yeats and others, 1984), the Peshawar basin deformed zone is accompanied by seismicity (Seeber and others, 1981). We describe this zone and interpret the timing of late Quaternary deformation with respect to the formation of the Peshawar intermontane basin and the southward migration of foreland thrusting.

REGIONAL SETTING

The Peshawar intermontane basin is superimposed on a fold-thrust belt at the southern margin of the Pakistan Himalaya (Fig. 1). North of the Peshawar basin, the northern edge of the Indian plate includes strata of Precambrian and Paleozoic age intruded by granitic rocks varying in age from Paleozoic to Miocene (Maluski and Matte, 1984). On the north is the suture zone marked by the Main Mantle thrust separating Indian plate rocks from the Kohistan island-arc sequence farther north. The Peshawar basin is bounded on the south by the Attock-Cherat Range and on the east by the Gandghar Range, both of which contain rocks transitional between metasediments of the Lesser Himalaya and foreland-basin strata of the Kala Chitta Range (Tahirkheli, 1970, 1971). Precambrian metaclastic rocks are overlain by unfossiliferous, probably Precambrian limestone in the Attock-Cherat Range and by Paleozoic strata east of Swabi (Pogue and Hussain, 1986). In the Attock-Cherat Range, the Precambrian metaclastic rocks and Precambrian(?) limestone are thrust over unfossiliferous Precambrian(?) flysch overlain by Cretaceous limestone, Paleocene and early Eocene marine strata, and Murree red beds that may be as young as early Miocene. This sequence is

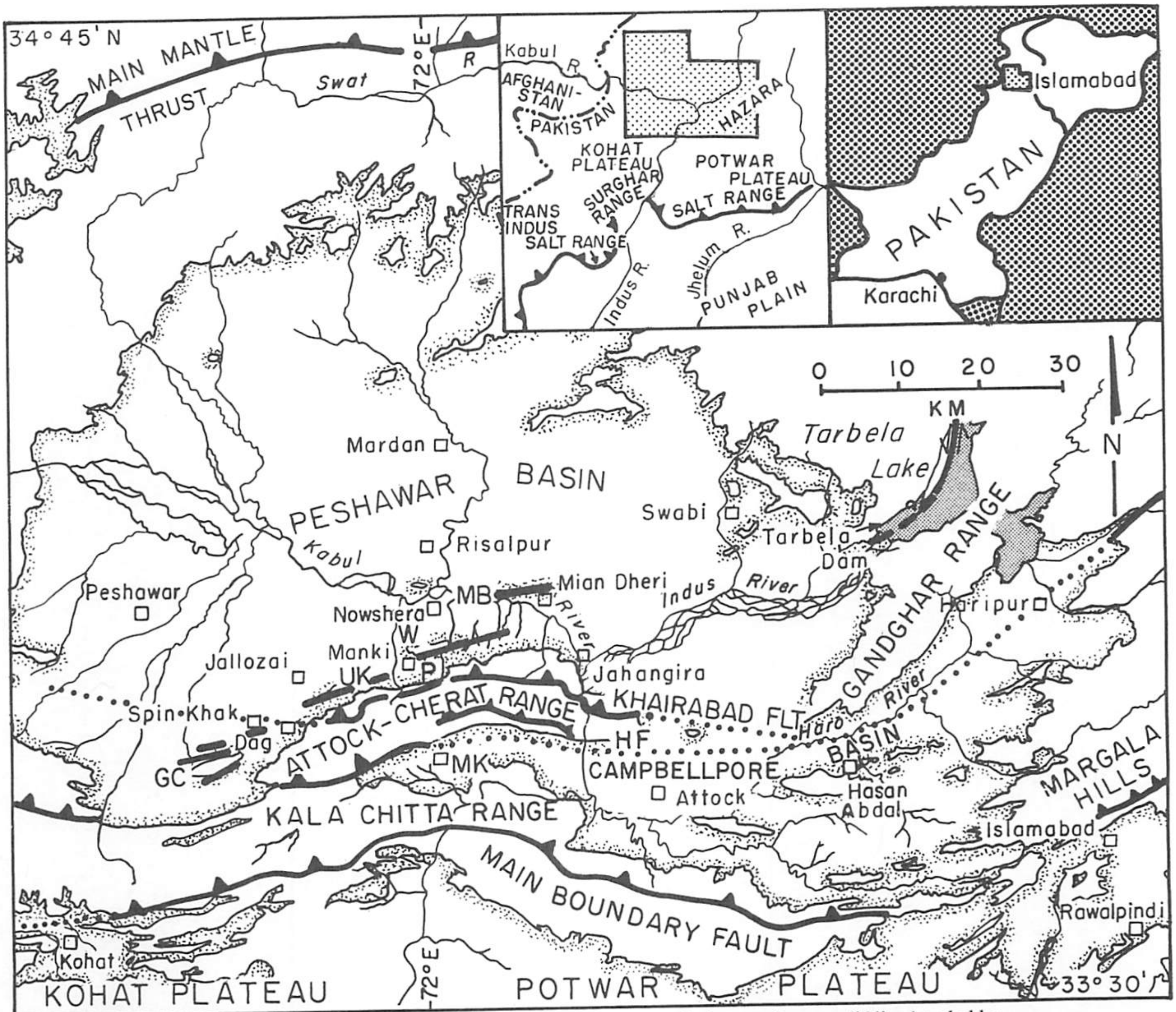

Figure 1. Map of the Peshawar basin showing late Quaternary fault traces (heavy solid lines) and older regional thrust faults (heavy lines with teeth): Main Mantle thrust, Khairabad-Panjal thrust, and Main Boundary thrust. H.F. = Hissartang fault. Pressure ridges: GC = Garhi Chandan; UK = Uch Khattak;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

itself thrust over unfossiliferous limestone, argillite, and quartzite that are overlain by Tertiary strata similar to the Tertiary sequence in the adjacent block to the north (Yeats and Hussain, 1987). These rocks are thrust over an unmetamorphosed foreland sequence of Triassic to Eocene age, part of the Kala Chitta Range and Margala Hills. The southern margin of the Peshawar basin cuts across the Attock-Cherat thrust structures, as shown in Figure 1, such that on the main road from Peshawar south to Kohat, the basin is bounded on the south directly by rocks of the Kala Chitta Range (Meissner and others, 1974).

Southward-verging thrusting took place after deposition of Murree red beds, but prior to 2.8 Ma, the oldest magnetostratigraphic dates of the base of the Peshawar basin fill at the western end of the Attock-Cherat Range (Burbank and Tahirkheli, 1985). At the western end of the range, flood-plain deposits are overlain by conglomerate from northward-prograding alluvial fans dominated by limestone clasts that indicate a southern source (Burbank and Tahirkheli, 1985). Sedimentation in the Campbellpore basin began 2.0 Ma, based on magnetostratigraphy (Burbank, 1982). Similar but undated sediments are widely distributed throughout the Peshawar (Said and Majid, 1977) and Campbellpore basins, as well as the Nizampur basin and the Indus River valley west of the Gandghar Range. The sediments 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

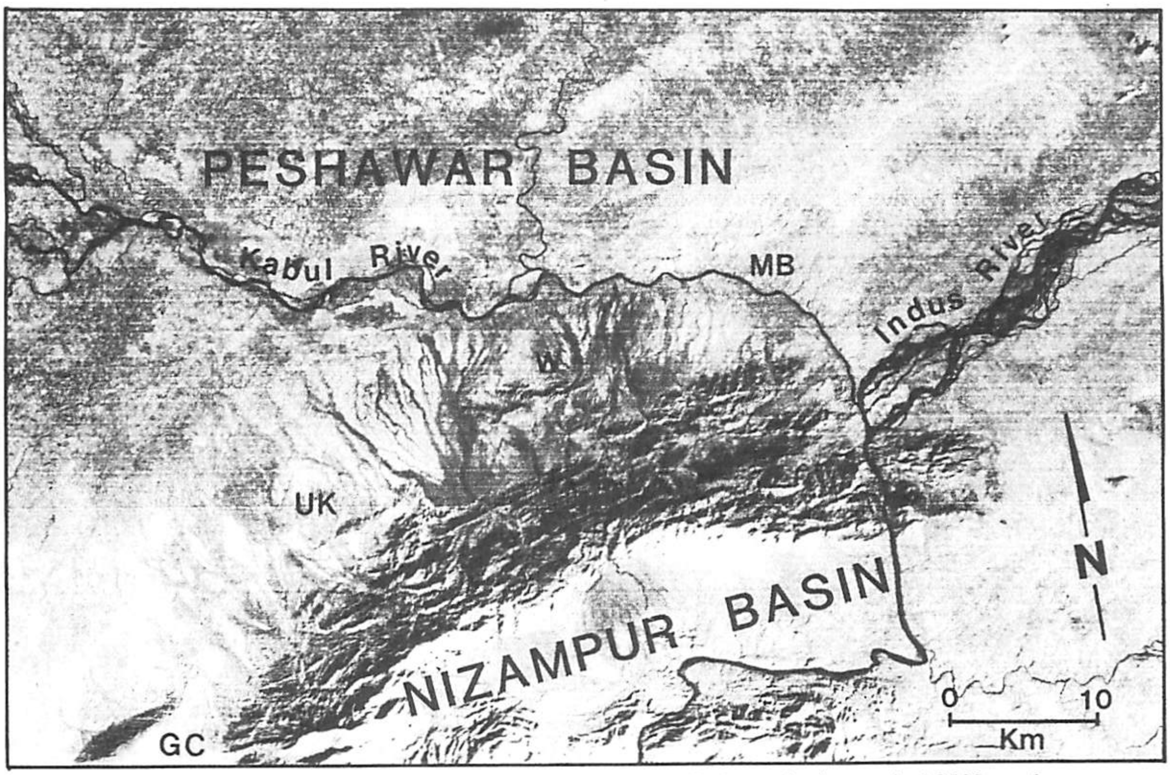

Figure 2. Part of Landsat image 2673-04552-7 of the southern Peshawar basin, acquired 25 November 1976. Note four pressure ridges north of Attock-Cherat Range (GC, UK, W, MB; see Fig. 1), linear fault pattern within the Attock-Cherat Range parallel to faults in these ridges, and absence of linear pattern in Quaternary sediments east of MB.

(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.

Late Quaternary deformation

Evidence for late Quaternary tectonics is found in four left-stepping, en echelon pressure ridges formed within the Peshawar basin parallel to its southern margin (Figs. 1, 2). Additional evidence is found 50 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 Figs. 1 and 2). A brief description of each ridge follows.

Garhi Chandan ridge. The Garhi Chandan ridge (Fig. 3) is underlain by south-dipping Murree red beds that underwent strong folding, thrusting, and development of slaty cleavage in pre-Pliocene time. Murree strata strike easterly and are truncated by the east-northeast trend of the ridge itself. Flanking the ridge on both sides are sediments of Pliocene-Pleistocene age, including the ash-bearing sediments near Garhi Chandan village 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, especially in the Dag section of Burbank and Tahirkheli (1985) east of the ridge. 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 Garhi Chandan structure defines a broad fold plunging east and west with Murree Formation in the core. (Southeast dips of Pliocene-Pleistocene sediments south of the ridge are based on photo interpretation; the area is tribally owned and could not be visited.)

The deformed sediments are extensively eroded such that no remnant of their original depositional surface has been preserved. The sediments are overlain with angular unconformity by fan gravels having a southern provenance. The high, north-northwest–sloping flatiron north of the ridge is held up by gravels containing limestone clasts from the Kala Chitta Range and only subordinate Murree clasts, indicating that the Garhi Chandan ridge was not a source of these gravels. Conversely, gravels at Irish Bridge, close to their basal contact with the Murree Formation, are dominated by Murree clasts.

A north-northwest–south-southeast profile across the Garhi Chandan ridge and adjacent fan surfaces to the north and south (Fig. 3) 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 the most pronounced photo lineation in the

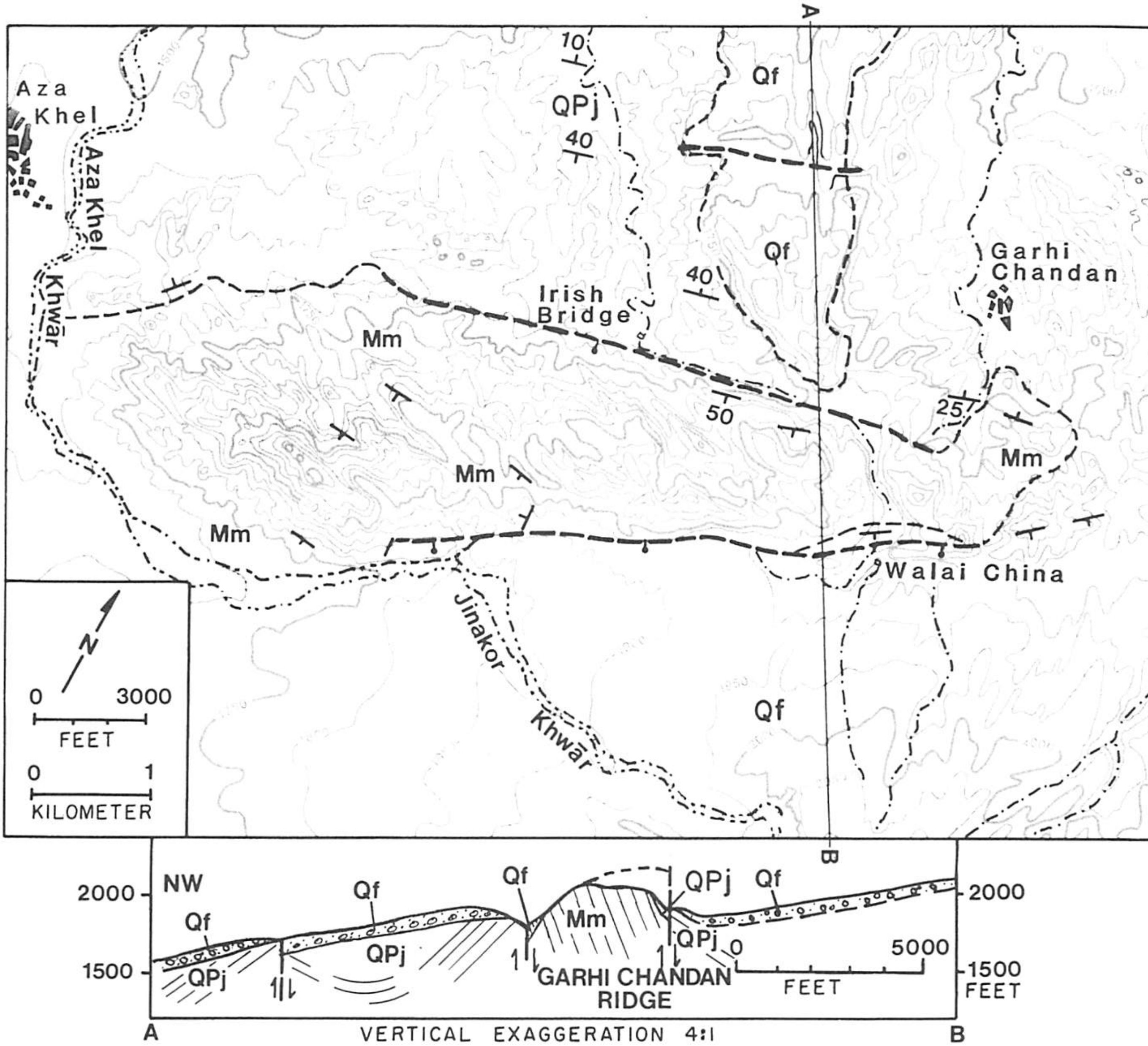

Figure 3. Topographic map and cross section of Garhi Chandan ridge and vicinity; contour interval 50 ft. Ridge itself underlain by Murree Formation, adjacent area underlain by Pliocene-Pleistocene sediments covered by younger alluvial fan gravels. Heavy dashed lines indicate faults; bar and ball on downthrown 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.

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 preserved 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.

The gravel surface 1.7 km north of the Irish Bridge fault is cut by another fault having a north-side-up vertical separation of 20 to 25 m. This fault is traced discontinuously about 7.5 km east-northeast to the vicinity of Spin Khak, where separation is less than 10 m. A north-trending fault mapped by Burbank and Tahirkheli (1985) south of Garhi Chandan village is a depositional contact between Murrees and deformed sediments, rather than a fault.

Jinakor Khwar (khwar = intermittent stream) flows down the southernmost fan surface and is deflected westward to Aza Khel Khwar at the west end of Garhi Chandan ridge (Fig. 3). 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 of 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.

Uch Khattak ridge. The Uch Khattak ridge is underlain by Precambrian metaclastic rocks (Manki Slate) overlain by Precambrian(?) limestone in an overturned, southward-verging syncline. In Uch Khattak Nala (nala = small stream), 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. 4), lake beds of the Jallozai Formation of Tahirkheli (1970) dip 16°N on the north side of the ridge. South of the ridge and south of a prominent photo lineation marking the Uch Khattak fault, similar lake beds also dip north toward the ridge, indicating the fault has north-side-up separation.

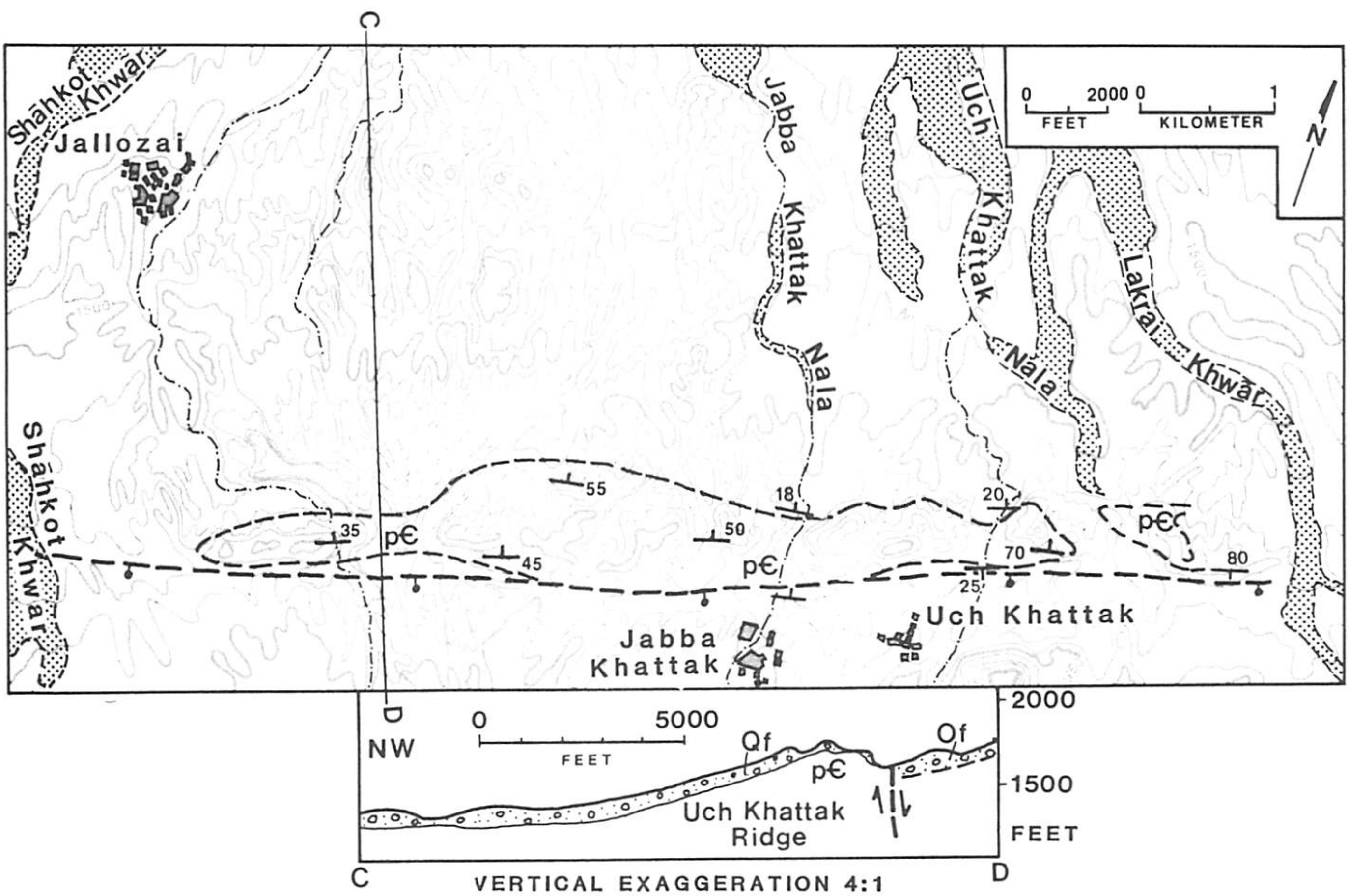

Figure 4. Topographic map and cross section of Uch Khattak ridge. Symbols same as Figure 3; pЄ = Precambrian metaclastic rocks and limestone.

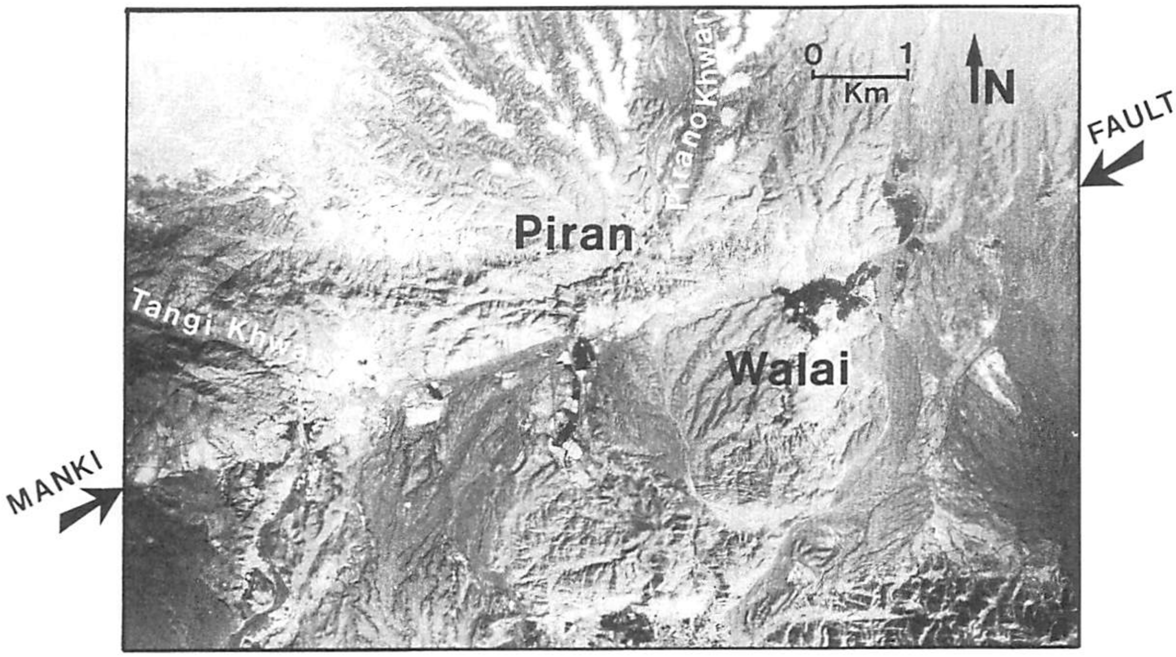

Figure 5. Air photo of western part of Walai ridge west of Walai. Tangi Khwar and Pirano Khwar are north-flowing streams antecedent to Walai ridge.

The 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. 4). 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 the 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 between the villages of Walai and Manki (Figs. 2, 5, 6) is underlain by Manki Formation dipping steeply north-northeast. The 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 (Fig. 5). 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 2°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, downplunge 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. 6) 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. The 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 (Fig. 6), but it has not been demonstrated that this is due to right slip on the Manki fault. The apparent right-lateral offset could be explained by eastward diversion of the streams by uplift of the east-plunging Walai ridge, a suggestion that is supported by the absence of right-lateral offsets of streams more than 11 km east of Walai (right side of Fig. 6). This diversion is analogous to the postulated westward diversion of Jinakor Khwar by the west-plunging Garhi Chandan ridge (Fig. 3).

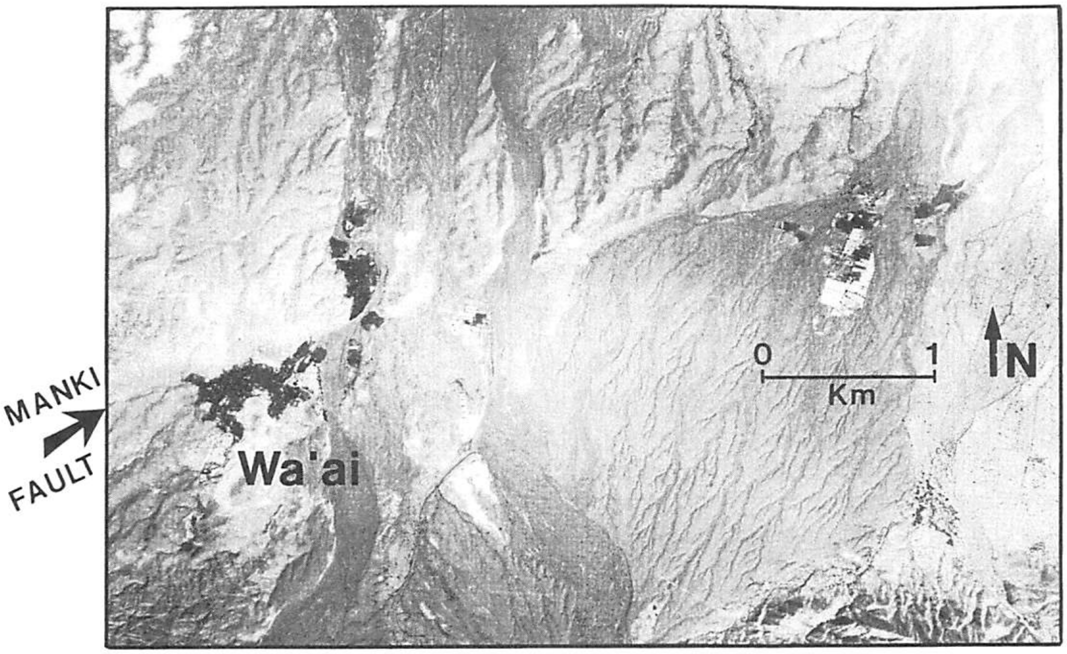

Figure 6. Air photo of Manki fault (arrow) showing apparent offset of alluvial fans east of Walai. Right-lateral deflection of streams is probably due to eastward diversion of these streams by the rising Walai ridge rather than right-slip on the Manki fault. Fault cannot be traced to eastern edge of photo.

Misri Banda ridge

Immediately north of the Kabul River, an east-trending series of linear bedrock ridges underlain by Paleozoic strata extends from Nowshera to the east of Misri Banda for a strike distance of nearly 20 km (Stauffer, 1968; Pogue and Hussain, 1986) (Fig. 1). 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, dips 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. Slickensides 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.

Tarbela

At Tarbela Dam, Calkins and others (1975) mapped the Darband fault trending northeast, parallel to the Indus River. The principal evidence for this fault is an overhanging escarpment at the base of Indus River gravels, an escarpment with 140 to 210 m of vertical separation (Fig. 7). 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. 7). 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.

DISCUSSION

The four left-stepping pressure ridges extend for nearly 60 km within the Peshawar basin, parallel and close to its southern margin. 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 (Fig. 2). 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 upthrown side of a fault. However, 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) marks a

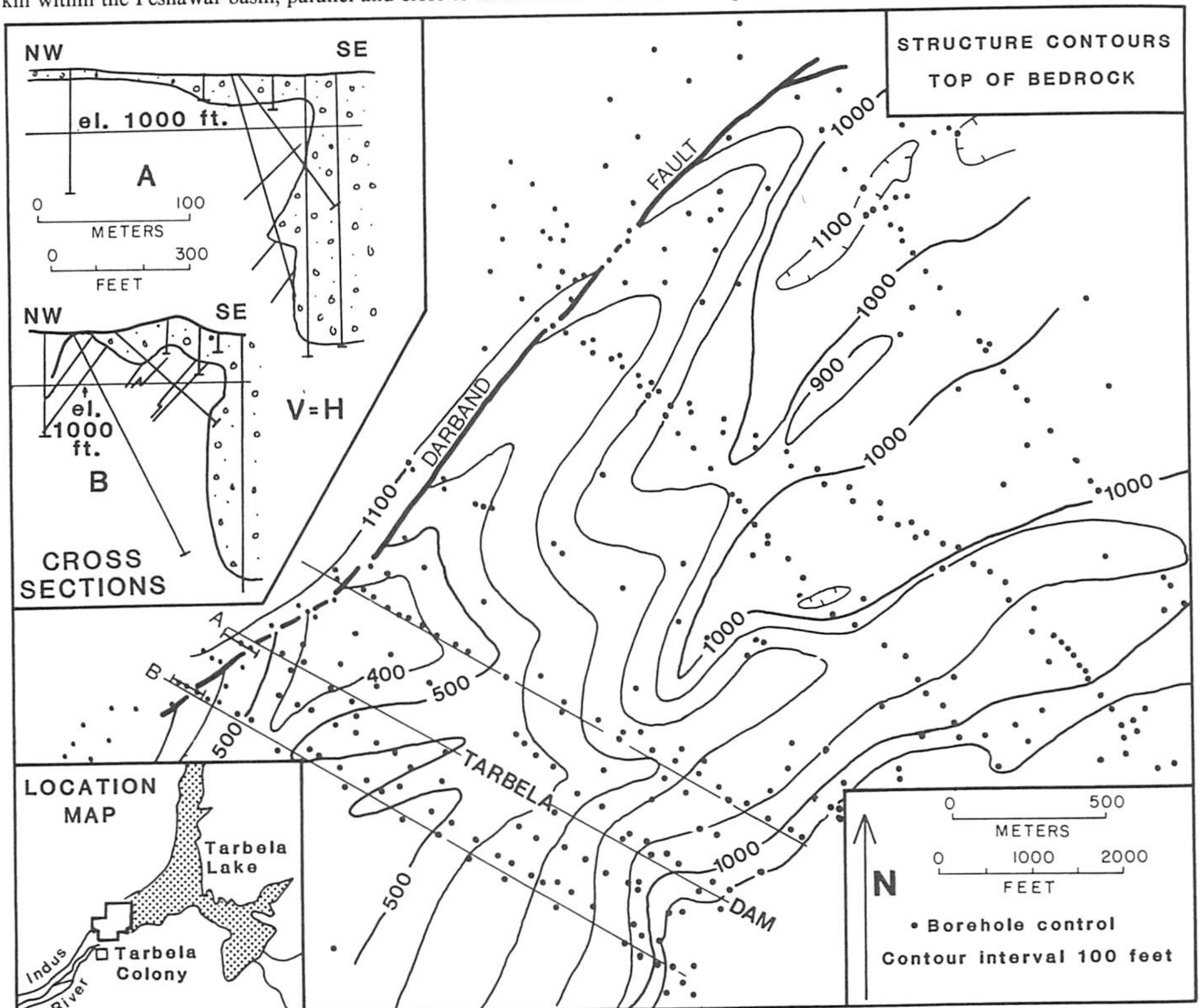

Figure 7. Structure contours in feet of top of bedrock at Tarbela Dam. Darband fault marked by vertical to overhanging escarpment in bedrock, as noted in two cross sections. No vertical exaggeration in cross sections; scale of cross sections is larger than that of map.

north-dipping reverse fault between Jurassic limestone and alluvial-fan gravels of the Nizampur basin. 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.

It is possible that the Attock-Cherat Range itself is a large-scale version of the pressure ridges to the north, faulted on the south against the sediments of the Nizampur basin. 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 through 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 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.

Except for the Tarbela Lake fault, evidence for strike-slip on this zone of deformation is limited to low-angle slickensides 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 bedrock 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 addition, the southern Peshawar basin is marked by a zone of instrumental seismicity (Seeber and others, 1981), in contrast to the Salt Range thrust, on which instrumental seismicity is low. The linear fault traces and the instrumental seismicity suggest that the faults cut downward to basement rocks and thus constitute a seismic hazard.

Yet slip rates on these faults must be low, because individual faults have not coalesced into a single displacement zone. 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 south. 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 Range 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-migrating wave of 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. Therefore, this faulting may represent an incipient phase of high-angle faulting analogous to the strike-slip faults of Afghanistan and western China. A similar change to high-angle faulting may be occurring in central Nepal, where the older Main Central thrust is reactivated by faults that are largely south-side-up with evidence for right-lateral strike-slip (Nakata and others, 1984; Nakata, this volume).

CONCLUSIONS

South-verging imbricate thrusting involving the Murree Formation, as young as Middle Tertiary, was followed by deep erosion, then deposition of lacustrine, fluvial, and alluvial-fan deposits in the Peshawar and Campbellpore basins as the Attock-Cherat and Kala Chitta ranges were elevated on the back of the Main Boundary fault. A zone of deformation 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 zone may also extend south across the Attock-Cherat Range, where bedrock is faulted against Nizampur basin fan gravels, and east-northeast–trending photo lineations in the Attock-Cherat Range may represent additional north-side-up faults discordant to older thrust structures.

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