AN ABSTRACT OF THE THESIS OF

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Title: Geology of the Southern Gandghar Range and Kherimar Hills, Northern Pakistan

Abstract approved: Robert S. Yeats
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The Gandghar Range and Kherimar Hills, located in the Hill Ranges of northern Pakistan, contain rocks that are transitional between unmetamorphosed foreland-basin strata to the south and high-grade metamorphic and plutonic rocks to the north. The southern Gandghar Range is composed of a succession of marine strata of probable Proterozoic age, consisting of a thick basal argillaceous sequence (Manki Formation) overlain by algal limestone and shale (Shahkot, Utch Khattak, and Shekhai formations). These strata are intruded by diabase dikes and sills that may correlate with the Panjal Volcanics. Southern Gandghar Range strata occur in two structural blocks juxtaposed along the Baghdarra fault. The hanging wall consists entirely of isoclinally-folded Manki Formation, whereas the footwall consists of the complete Manki-Shekhai succession which has been deformed into tight, northeast-plunging, generally southeast (foreland) verging disharmonic folds. Phyllite near the Baghdarra fault displays kink bands, a poorly-developed S-C fabric, and asymmetric deformation of foliation around garnet porphyroblasts. These features are consistent with conditions of dextral shear, indicating reverse-slip displacement along the fault.

South of the Gandghar Range, the Panjal fault brings the Gandghar Range succession over the Kherimar Hills succession, which is composed of a basal Precambrian arenaceous sequence (Hazara Formation) unconformably overlain by Jurassic limestone (Samana Suk Formation) which in turn is unconformably overlain by Paleogene marine strata (Lockhart Limestone and Patala Formation). The Hazara and Manki formations, considered to be stratigraphically equivalent, show an increase in metamorphic grade to the north. In the Kherimar Hills, the Hazara Formation is unmetamorphosed, whereas in the Gandghar Range, the Manki Formation is

metamorphosed to the greenschist-lower epidote-amphibolite grade. Younger strata in both areas show little to no evidence of metamorphism.

The Gandghar Range succession is identical to the succession in the hanging wall of the Khairabad fault in the Attock-Cherat Range, and the Kherimar Hills succession resembles the succession in the footwall of the Khairabad fault. These relationships indicate that the Panjal and Khairabad faults are continuous and juxtapose two major, laterally continuous structural blocks. South of the Kherimar Hills, the Nathia Gali fault brings the Kherimar Hills succession, in which rocks as old as Precambrian are exposed, over the Margala Hills succession, in which the oldest rocks exposed are Mesozoic. To the west, the Cherat and Hissartang faults are considered to be bifurcations of the Nathia Gali fault. The Paleocene Lockhart Limestone is common to the stratigraphic successions on both sides of the Hissartang, Cherat, and Nathia Gali faults. Pre-Paleocene successions differ across the Hissartang and Cherat faults, indicating large amounts of displacement and juxtaposition of the successions in Late Cretaceous time. Pre-Paleocene successions juxtaposed along the Nathia Gali fault indicate that most of the displacement along the fault occurred prior to deposition of the Jurassic Samana Suk Formation. Tertiary faulting has occurred on the Hissartang, Cherat, and Nathia Gali faults, although this displacement is small relative to the pre-Paleocene displacement. Pre-Paleocene displacement along the Khairabad-Panjal fault cannot be demonstrated due to the absence of Tertiary strata to the north.

The Hill Ranges fault system, composed of the Main Boundary thrust and Murree, Nathia Gali, Cherat, Hissartang, Khairabad, Panjal, and Baghdarra faults, forms a hinterland-dipping duplex. The estimated minimum total horizontal separation on the Hill Ranges fault system is 85 km, based on the restoration of projected Paleozoic hanging-wall and footwall cutoffs on a balanced cross section. Crystalline basement is not involved in the Hill Ranges fault system. The sedimentary cover is decoupled from the basement along a detachment that corresponds to the Salt Range thrust.

Geology of the Southern Gandghar Range and Kherimar Hills,
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INTRODUCTION

BACKGROUND AND PURPOSE

The Himalayan mountain chain is the product of continuing convergence between the Indian subcontinent and Eurasia. Prior to the early Tertiary, the two landmasses were separated by the Tethys seaway. Oceanic crust of the northern Indian plate was consumed until continental collision commenced in the Eocene, resulting in a decrease in convergence rate from 10 cm/yr to 5 cm/yr (Molnar and Tapponier, 1975; Valdiya, 1984; Yeats and Lawrence, 1984). Convergence has continued to the present at a rate of 5-6 cm/yr (Minster and Jordan, 1978), which implies that approximately 2000 km of closure between the Indian and Eurasian plates has taken place since initial collision. For the Indian Himalaya, Molnar and Tapponnier (1975) suggested that 300-700 km of shortening was accommodated by underthrusting of the Indian plate beneath Eurasia, 500-1000 km was accommodated by generally east-trending strike-slip faulting in China and Mongolia, and 200-300 km was accommodated by crustal thickening in mountain belts north of the Himalayan collision zone. For the Pakistan Himalaya, the amount of shortening has been estimated at approximately 500-700 km on the basis of restored balanced cross sections (Coward and Butler, 1985; Butler, 1986) and approximately 600-1,100 km on the basis of crustal thickness estimates from observed gravity profiles (Malinconico, 1989). However, it remains unclear as to precisely how the shortening in Pakistan is being accommodated.

The purpose of this study is to provide a better understanding of the style and amount of crustal shortening across the Hill Ranges of northern Pakistan. The Hill Ranges (Attock-Cherat Range, Gandghar Range, Kala Chitta Range, and Margala Hills) are located approximately 125 km north of the active Himalayan deformational front at the foot of the Salt Range (Figures 1 and 2). These low, discontinuous mountain chains, separated from each other by alluvial plains, extend from the Hazara-Kashmir syntaxis westward to the Safed Koh. Faults associated with the Hill Ranges are considered to be the western equivalent of the Main Boundary thrust of

Figure 1. Map of the Indian subcontinent, showing political subdivisions and selected Himalayan mountains. NP = Nanga Parbat (8125 m); K2 = K2 (8611 m); E = Everest (8848 m). Area of Figure 2 shown by rectangle.

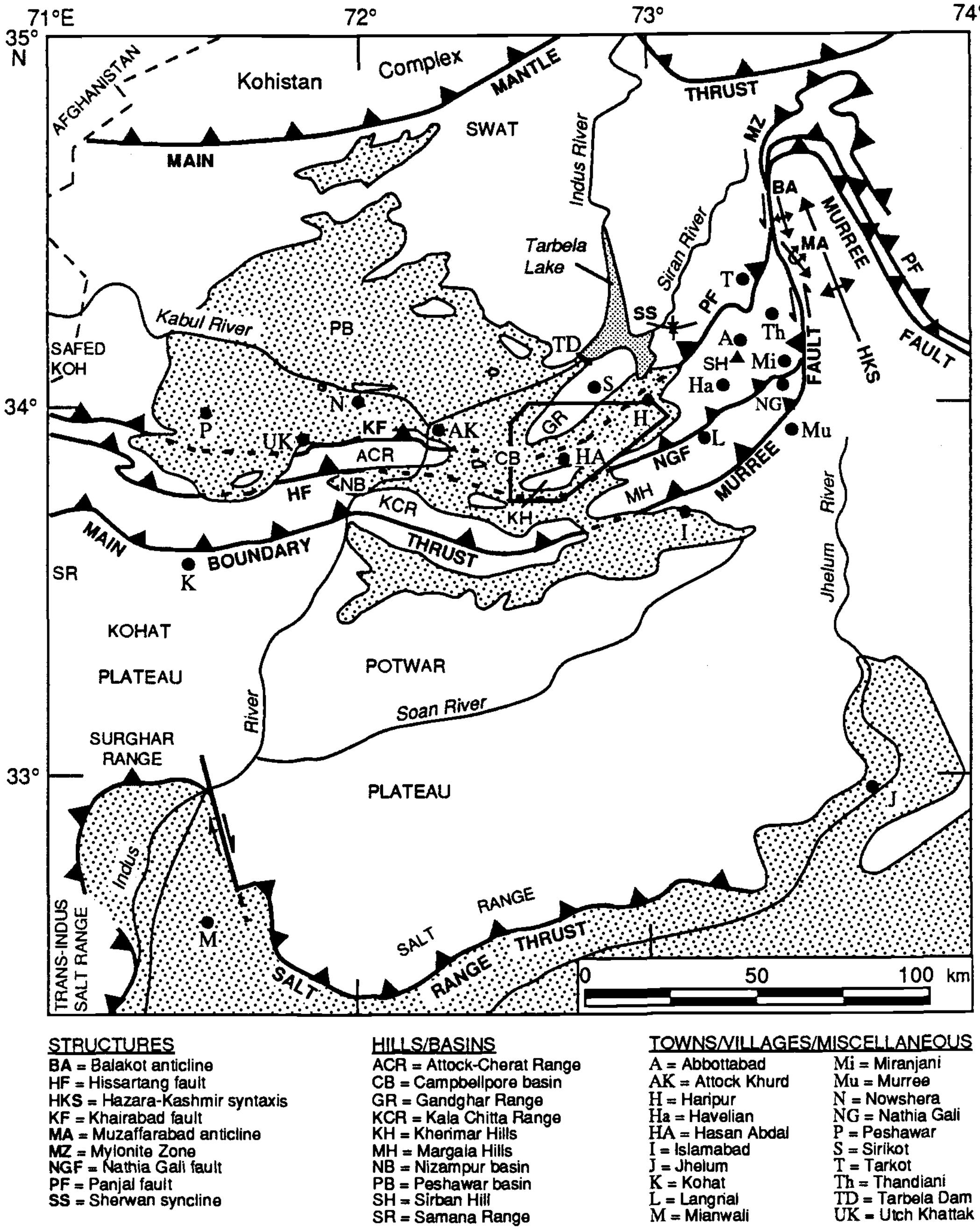

Figure 2. Generalized tectonic map of northern Pakistan, showing regionally significant structural boundaries, geographic localities discussed in text, and location of study area (outlined area in middle of figure). Lowlands shown by stippled pattern. Compiled from Calkins and others (1975), Yeats and Hussain (1987), Greco and others (1989), and this report.

the Indian Himalaya (Yeats and Lawrence, 1984). Coeval strata of Mesozoic and early Tertiary age can be correlated across the Hill Ranges from the Potwar Plateau to Hazara, and Eocene strata found in deep wells in the Potwar Plateau are similar to those of the Kala Chitta Range and Margala Hills.

The stratigraphic and structural relationships among the Hill Ranges themselves are problematic due to facies and thickness changes, structural complications, and extensive Quaternary fluvial and lacustrine deposits. At the heart of the problem is an enigmatic sequence of unfossiliferous clastic and metaclastic strata that comprise the oldest rocks exposed in the Hill Ranges. In the fall of 1987, geological mapping was carried out in the southern Gandghar Range and Kherimar Hills. This relatively little-studied area contains excellent exposures of the basal sequence of the Hill Ranges. Also, it is located in the central part of the Hill Ranges and is therefore a critical link between the rocks of southeast Hazara to the east and the Attock-Cherat Range to the west. This paper summarizes and interprets the data collected in the field, suggests stratigraphic and structural correlations across the northern Hill Ranges from southeast Hazara to the Attock-Cherat Range, and estimates the minimum horizontal separation on the major faults associated with the Hill Ranges.

LOCATION AND ACCESSIBILITY

The study area is located in the North-West Frontier Province of northern Pakistan. It lies between 33°45' N and 34°00' N latitude and between 72°30' E and 73°00' E longitude, and is covered by Survey of Pakistan topographic sheets 43 C/9 and 43 C/13 (Figure 2; Plate 1). While the entire area encompasses 923 km^2 (360 mi^2), the area of exposed bedrock is 160 km^2 (62 mi^2), or 17% of the total area. The remainder of the area is covered by fill of the Campbellpore and Peshawar basins. As shown in Figure 3, bedrock exposures occur in three general locations: 1) the Gandghar Range; 2) the Kherimar Hills, and; 3) a northeast-trending belt of low hills south of Haripur, hereafter referred to as the "Haripur hills." It should be noted that the Kherimar Hills proper consist of the east-trending ridge that extends from near Garshin in the west to Rathargarh in the east. For the purposes of this report, however, the Kherimar Hills are considered to include all of the low hills that extend approximately 26 km between Garshin and Bhui.

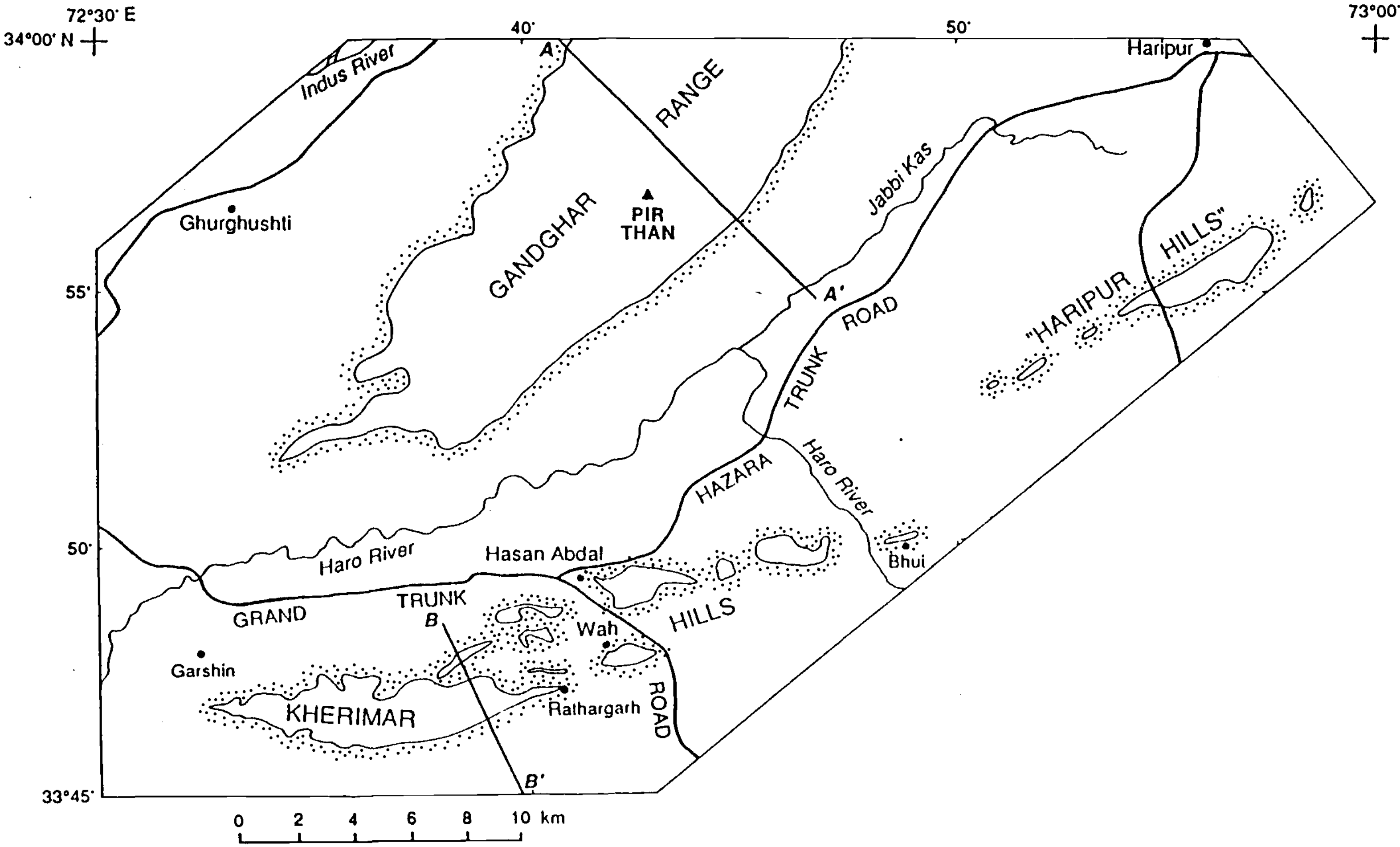

Figure 3. Map of the study area, showing outcrop locations (surrounded by stippled pattern), major roads (heavy lines), and selected towns and villages. A-A' and B-B' are locations of cross sections shown in Figures 12 and 13, respectively.

Towns and villages are scattered throughout the area, with major population centers being located at Ghurghushti, Hasan Abdal, Wah, and Haripur. These towns are connected by paved roads, including the Hazara Trunk Road and the Grand Trunk Road, the latter being the major east-west highway across northern Pakistan which passes through Hasan Abdal (Figure 3). Secondary roads provide vehicle access to most of the smaller villages, and many of the dry washes on the west flank of the Gandghar Range are negotiable by four-wheel-drive vehicles. Footpaths lead to the most remote villages in the area.

TOPOGRAPHY, CLIMATE, AND DRAINAGE

Total relief within the study area is 1022 m (3351 ft), with elevations ranging from a minimum of 320 m (1050 ft) above sea level on the south bank of the Indus River near Hasanpur to a maximum of 1342 m (4401 ft) above sea level in the Gandghar Range at Pir Than (Figure 4). The most extreme relief occurs on the southeast flank of the Gandghar Range, where the range rises 976 m (3200 ft) from its base to the summit of Pir Than in 2.5 km (1.5 mi). Other notable elevations in the area are the 740 m (2427 ft) summit of the Kherimar Hills proper and the 715 m (2344 ft) summit of the hill adjacent to Hasan Abdal.

The climate of the area is semiarid, with over half of the total precipitation falling as monsoon rains during July and August. As a result, vegetation tends to be thin and scattered. Numerous low-growing species dominate the countryside below 1200 m, while stately pines cover the summit crest of the Gandghar Range.

The Gandghar Range serves as the drainage divide between the two major river systems in the area, the Indus and the Haro (Figure 5). The Indus River crosses the extreme northwest corner of the study area, while the Haro River crosses the middle of the area. Other important streams include Jhablat Nala, Jabbi Kas, and Kahal Kas. Secondary drainage is characterized by a dendritic pattern.

PREVIOUS WORK

The earliest published references to the geology of the study area were made by Verchere (1866-67) during his geological reconnaissance of the greater northwest

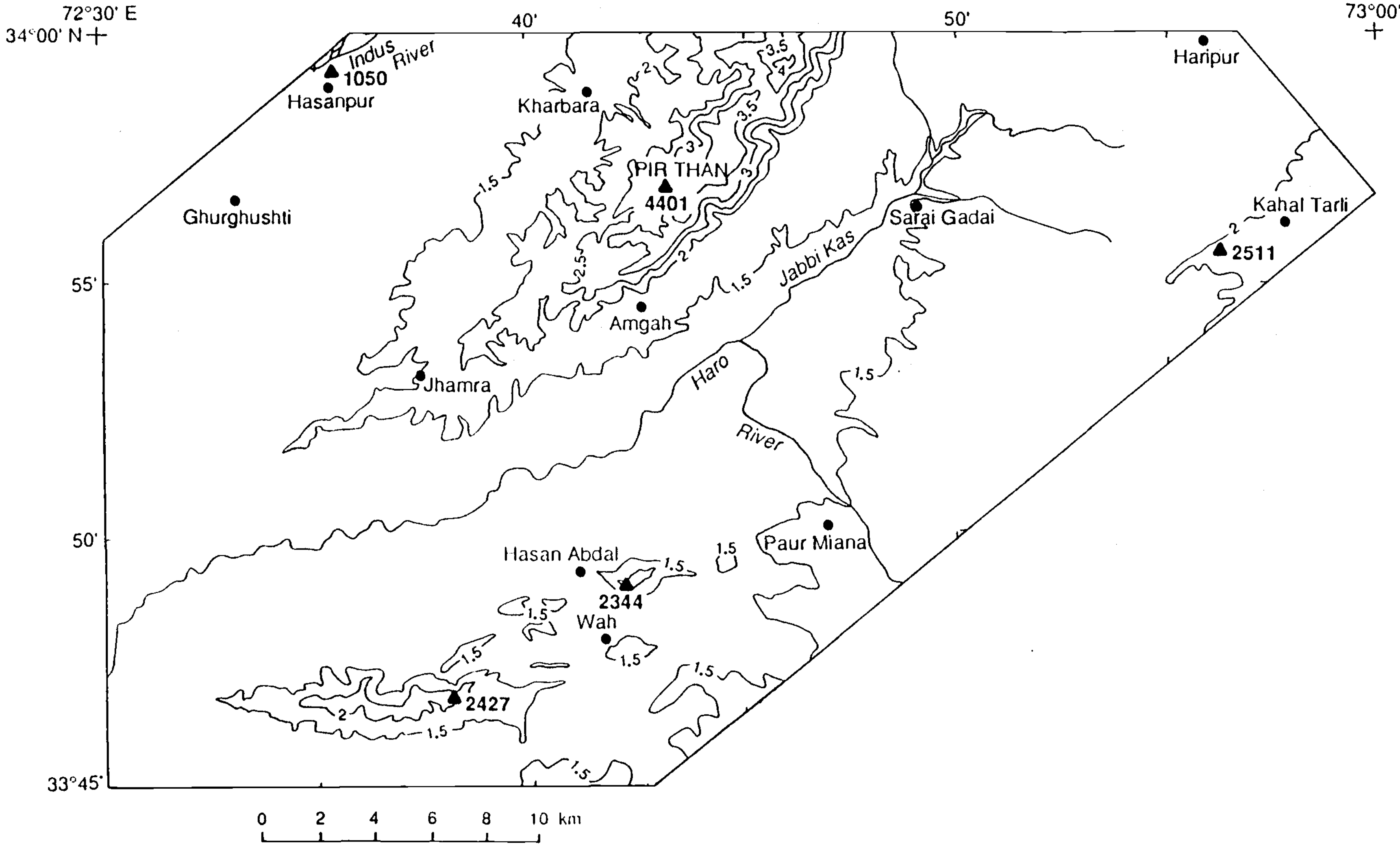

Figure 4. Topographic map of the study area, simplified from Survey of Pakistan topographic sheets 43 C/9 (1959) and 43 C/13 (1964). Spot elevations (triangles) in feet; contour elevations in feet x 1000. Contour interval = 500 ft.

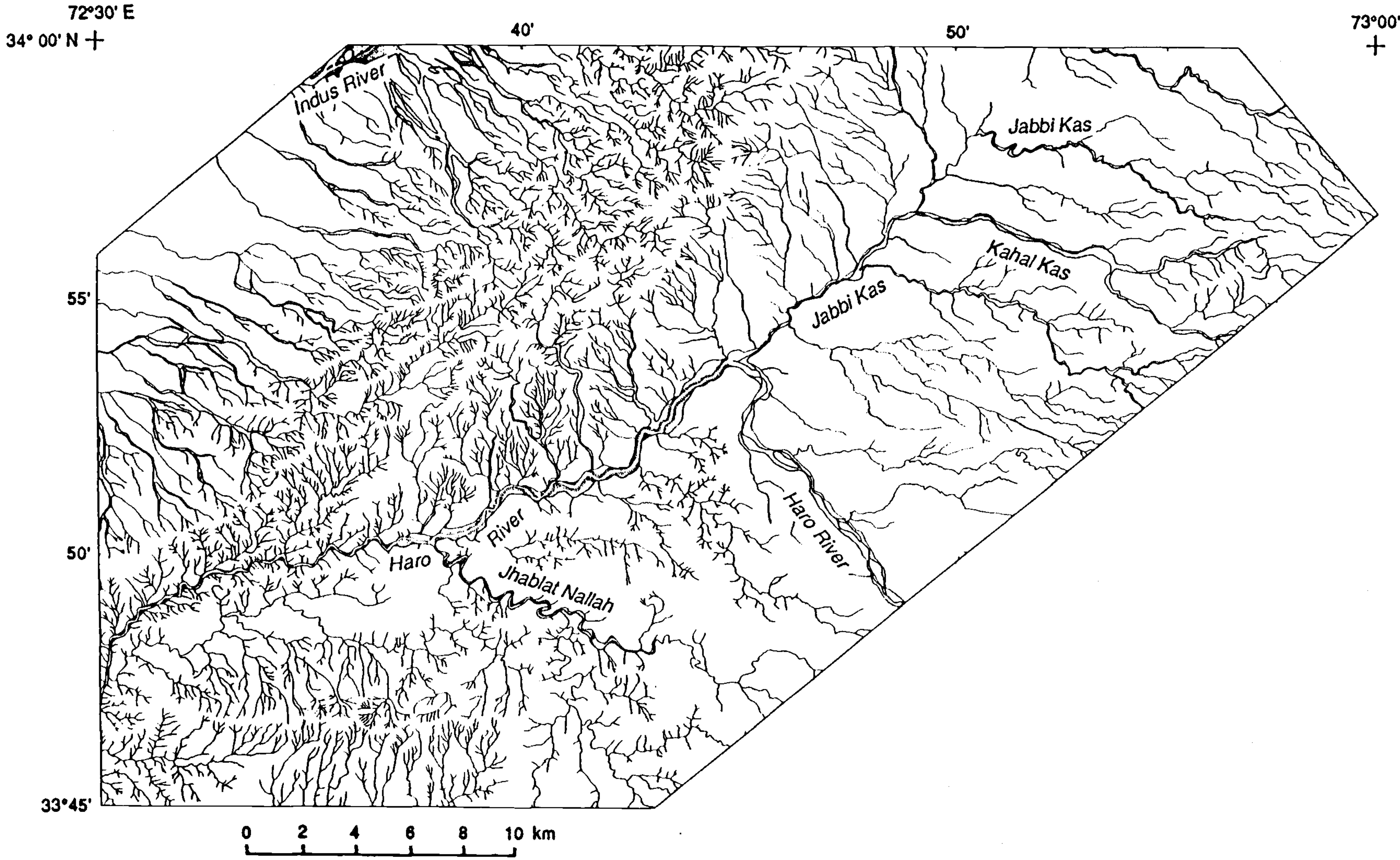

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Figure 5. Drainage map of the study area. Gandghar Range forms drainage divide between the Indus and Haro rivers.

Himalayan region. Waagen and Wynne (1872) established the broad stratigraphic relationships of the area based on their mapping at Sirban Hill near Abbottabad. Wynne (1879) provided the first relatively detailed account of the geology of the study area, including a geological sketch map of Hazara at a scale of 1 in = 8 mi and three cross sections through the Gandghar Range. Wynne, who considered the Attock Slates to be Paleozoic, was the first to recognize the unconformity between those rocks and the overlying Mesozoic strata near Hasan Abdal. Middlemiss (1896) published a geological map of Hazara at a scale of 1/2 in = 1 mi. Both Wynne and Middlemiss made reference to the limestones in the Gandghar Range, but were uncertain of their age and relative stratigraphic positions. In his paper on the geology of the Attock district, Cotter (1933) assigned a pre-Late Carboniferous, possibly Cambrian or Precambrian, age to the Attock Slates and discussed the hills in the vicinity of Hasan Abdal in some detail. The northern part of the Gandghar Range was mapped during a detailed geological study of Hazara from 1961 to 1965 by the Geological Survey of Pakistan and the U. S. Geological Survey (Calkins and others, 1975). The Gandghar Range was mapped in its entirety by Tahirkheli (1971), who suggested that the Gandghar Range comprises a lateral extension of the Attock-Cherat Range. Tahirkheli considered all rock units in the Gandghar Range to be Paleozoic, correlative with lithologically similar units in the Attock-Cherat Range and southeastern Hazara.

REGIONAL GEOLOGIC SETTING

The study area is located in the fold-thrust belt near the southern margin of the Pakistan Himalaya (Figure 2). In the Kala Chitta Hills-northern Potwar Plateau area to the south, Mesozoic and lower Tertiary marine strata are thrust over molasse along the Main Boundary thrust. The molasse is composed of the Rawalpindi and Siwalik Groups, with facies transgressing time southward in response to the advance of Himalayan thrust sheets. The Murree Formation of the Rawalpindi Group, for instance, ranges in age from Late Paleocene in the apex region of the Hazara-Kashmir syntaxis (Bossart and Ottiger, 1989) to early Miocene in the Kohat region (Meissner and others, 1973). In the Potwar Plateau, the molasse overlies Eocambrian evaporites (Salt Range Formation) and Phanerozoic strata that are thrust southward over the Indian craton (Lillie and others, 1987). Seismic reflection profiles show that in contrast to the northern Potwar Plateau, the central and southern parts are relatively undeformed (Khan and others, 1986; Lillie and others, 1987). At the southern edge of the Potwar Plateau, the Salt Range has been interpreted as a fault-bend fold (Baker and others, 1988) produced by southward thrusting of the Salt Range Formation and overlying strata over a down-to-the-north basement fault. The Salt Range overrides synorogenic fan material and alluvium along the Salt Range thrust (Yeats and others, 1984), marking the active deformational front of the Pakistan Himalaya.

The region north of the study area to the Main Mantle thrust is composed of shelf strata of the northern margin of the Indian plate, exhibiting varying degrees of metamorphism and intruded by granitic rocks ranging in age from Paleozoic to Miocene (Maluski and Matte, 1984). In northern Hazara, the area north of the Panjal fault is dominated by the clastic, late Precambrian(?) Tanawal Formation and the Mansehra granite (516 $\pm$ 16 Ma Rb/Sr isochron age, Le Fort and others, 1980), which intrudes the Tanawal Formation (Calkins and others, 1975). The Mansehra granite is in part a gneissic, sheet-like body that may be in thrust contact with adjacent rocks (Shams, 1969; LeFort and others, 1980; Yeats and Lawrence, 1984). In the vicinity of Swat, Precambrian and Paleozoic schists and gneisses are intruded by the Early Paleozoic(?) Swat granite gneiss, Himalayan syntectonic tourmaline granite, and post-tectonic biotite granite/granodiorite (Lawrence and others, 1989). Some of the rocks are interpreted as probable high-grade metamorphic equivalents of Precambrian and Paleozoic strata exposed in the Peshawar basin (DiPietro, 1990;

Pogue and others, in review). Farther north, the Main Mantle thrust marks the suture between the Indian plate and the Kohistan arc (Tahirkheli and others, 1979; Coward and others, 1982). The Main Mantle thrust is a composite of remnants of Tethys Ocean lithosphere that once intervened between the Indian subcontinent and the Kohistan arc, and is the host rock for most of the emerald deposits of Pakistan (Lawrence and others, 1989). The Kohistan arc, which developed as a composite island-arc complex near the southern margin of the Asian continent (Tahirkheli and others, 1979; Bard and others, 1980), is sutured to Asia along the Main Karakoram thrust (Tahirkheli, 1979).

East of the study area, Late Precambrian to Holocene strata are well exposed in the fold-thrust belt of southeast Hazara (Latif, 1969, 1970), comprising most of the western limb of the Hazara-Kashmir syntaxis. Here, after following a gently curving arc across northern India and Kashmir, the Himalayan mountains turn back on themselves in a tight reentrant (Wadia, 1931; Calkins and others, 1975). The syntaxis consists of a series of overlapping nappe units composed of Precambrian to Cretaceous rocks that are thrust over the Tertiary Murree Formation along the Murree fault. A change in overthrust direction from southwest to southeast followed by the formation of a large sinistral ductile shear zone (Jhelum fault of Ghazanfar and others, 1986) has resulted in the present geometry of the syntaxis (Bossart and others, 1988). In the eastern part of the syntaxis, the mylonitic shear zone shows strong similarities to the rocks of the Main Central Thrust Zone in other parts of the Himalayas, and may be correlative with the Main Central thrust (Greco and others, 1989).

The Attock-Cherat Range and Plio-Pleistocene Peshawar basin lie to the west of the study area. The Peshawar basin fill is composed predominantly of lacustrine silt with interbedded fluvial sand and gravel containing clasts of Kohistan provenance, indicating deposition by the ancestral Kabul and Indus rivers (Burbank, 1982). Paleozoic strata exposed in bedrock inliers and in the mountains fringing the eastern Peshawar basin represent the most complete Tethyan stratigraphy described from northern Pakistan (Pogue and others, in review). South of the Peshawar basin, the Attock-Cherat Range consists of three fault-bounded structural blocks. Metaclastic rocks and limestone of probable Late Precambrian age in the northern block are thrust southward over unfossiliferous flysch of Precambrian age overlain by Cretaceous and Tertiary strata of the middle block (Yeats and Hussain, 1987). These are in turn thrust southward over the southern block, which is composed of an unfossiliferous Paleozoic(?) sequence of limestone, argillite, and quartzite overlain by a Tertiary sequence resembling that of the central block (Yeats and Hussain, 1987). The Paleozoic(?) sequence is tentatively correlated, on the basis of lithology, with the Paleozoic sequence exposed near Nowshera in the southern Peshawar basin (Yeats and Hussain, 1987). The southern block is thrust over the Triassic to Eocene foreland sequence of the Kala Chitta Range and Margala Hills (Yeats and Hussain, 1987). Late Quaternary deformation is indicated by pressure ridges near the northern margin of the Attock-Cherat Range, and Jurassic limestone in the south-facing front of the range is thrust over alluvial-fan gravels at the western end of the Nizampur basin (Yeats and Hussain, 1989).

The rocks of the Hill Ranges, transitional between unmetamorphosed foreland-basin strata to the south and high-grade metamorphic and plutonic rocks to the north, have been brought to the surface along major ramp faults (Yeats and Lawrence, 1984) rising from a single detachment surface that, based on seismicity, extends beneath the entire area from the Salt Range to the Main Mantle thrust (Seeber and others, 1981). Uplift of the Hill Ranges associated with south-directed thrusting was initiated after deposition of the Murree Formation 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). Magnetostratigraphic dates in the Campbellpore basin indicate that sedimentation there began by at least 1.8 Ma (Burbank, 1982). Similar but undated sediments are widely distributed throughout the Peshawar basin (Said and Majid, 1977). The Peshawar basin sediments may have been ponded by uplift of the Attock-Cherat Range along the Hissartang fault and subsequently the Main Boundary thrust, which also ponded sediments in the Campbellpore basin (D. W. Burbank and R. G. H. Raynolds, written communication, 1986, to Yeats and Hussain, 1989). Deposition of Peshawar and Campbellpore basin fill ended about 0.6 Ma (Burbank and Tahirkheli, 1985).

STRATIGRAPHY

Bedrock within the study area consists of eight sedimentary and metasedimentary formations ranging in age from Precambrian to Paleocene. These lithostratigraphic units are overlain by Pliocene to Recent sediments of fluvial and lacustrine origin. Figure 6 shows the stratigraphic succession exposed in the southern Gandghar Range, which consists of a thick, basal argillaceous sequence (Manki Formation) overlain by algal limestone and shale (Shahkot, Utch Khattak, and Shekhai formations). A Proterozoic age for this succession, as suggested by Talent and Mawson (1979), is supported by the lack of fossils, a correlation of the Manki Formation with the Hazara Formation, which is of Proterozoic age, and the commonly gradational nature of the contacts throughout the succession. The entire succession contains basic igneous intrusions of probable Late Pennsylvanian - Early Permian age. Figure 7 shows the stratigraphic succession exposed in the Kherimar Hills, which consists of a basal arenaceous sequence (Hazara Formation) unconformably overlain by Jurassic limestone (Samana Suk Formation) which in turn is unconformably overlain by Paleogene marine strata (Lockhart Limestone and Patala Formation). The unconformities provide evidence for important tectonic events prior to Himalayan orogeny, although not necessarily involving penetrative deformation or metamorphism. Igneous rocks do not occur in this succession.

Two important differences exist between the stratigraphic succession of the southern Gandghar Range as given above and that given by Tahirkheli (1971). First, different bedrock unit names are used. Originally, Tahirkheli (1970) applied the names "Manki Slate," "Shahkotbala Formation," "Khattak Limestone," and "Shakhai [*sic*] Limestone" to lithostratigraphic units in the Attock-Cherat Range. Later, Tahirkheli (1971) applied the names "Sirikot Slate," "Mohat Nawan Limestone," "Baghdarra Limestone," and "Pir Than Limestone" to lithostratigraphic units in the Gandghar Range and correlated them, respectively, with the units in the Attock-Cherat Range listed above. In the Attock-Cherat Range, the names "Manki Formation," "Shahkot Formation," "Utch Khattak Formation," and "Shekhai Formation" are modified from the names applied by Tahirkheli (1970) and are currently used by the Geological Survey of Pakistan. Based on the correlations made by Tahirkheli (1971), these modified names are applied to the Gandghar Range in

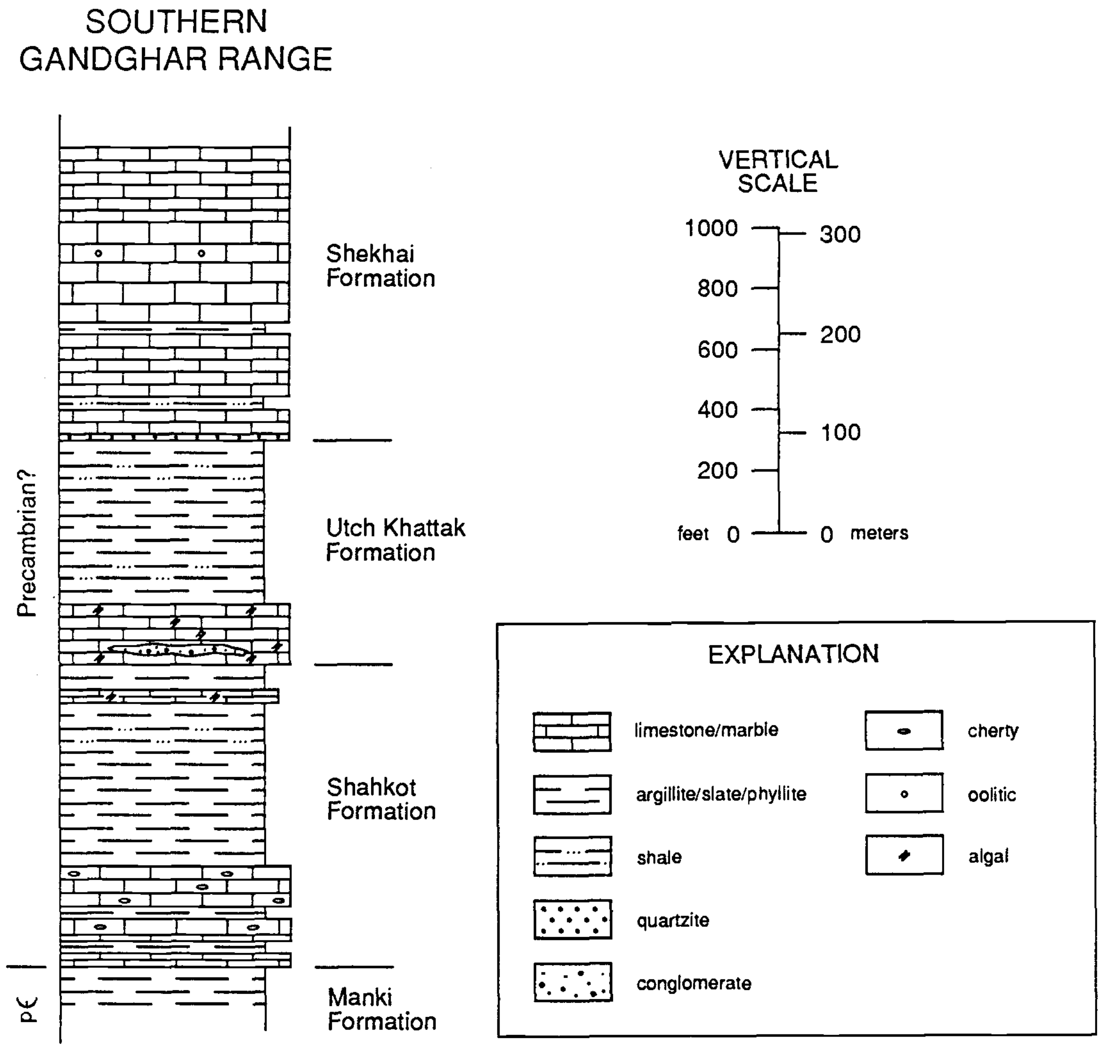

Figure 6. Schematic stratigraphic column for the southern Gandghar Range. Thickness of limestone "brick" pattern (not drawn to scale) indicates relative bedding thickness; e.g. thinnest "bricks" indicate thin-bedded limestone, thickest "bricks" indicate thick-bedded/massive limestone. Intraformational conglomerate in Utch Khattak Formation is exposed at the mouth of the canyon near Amgah.

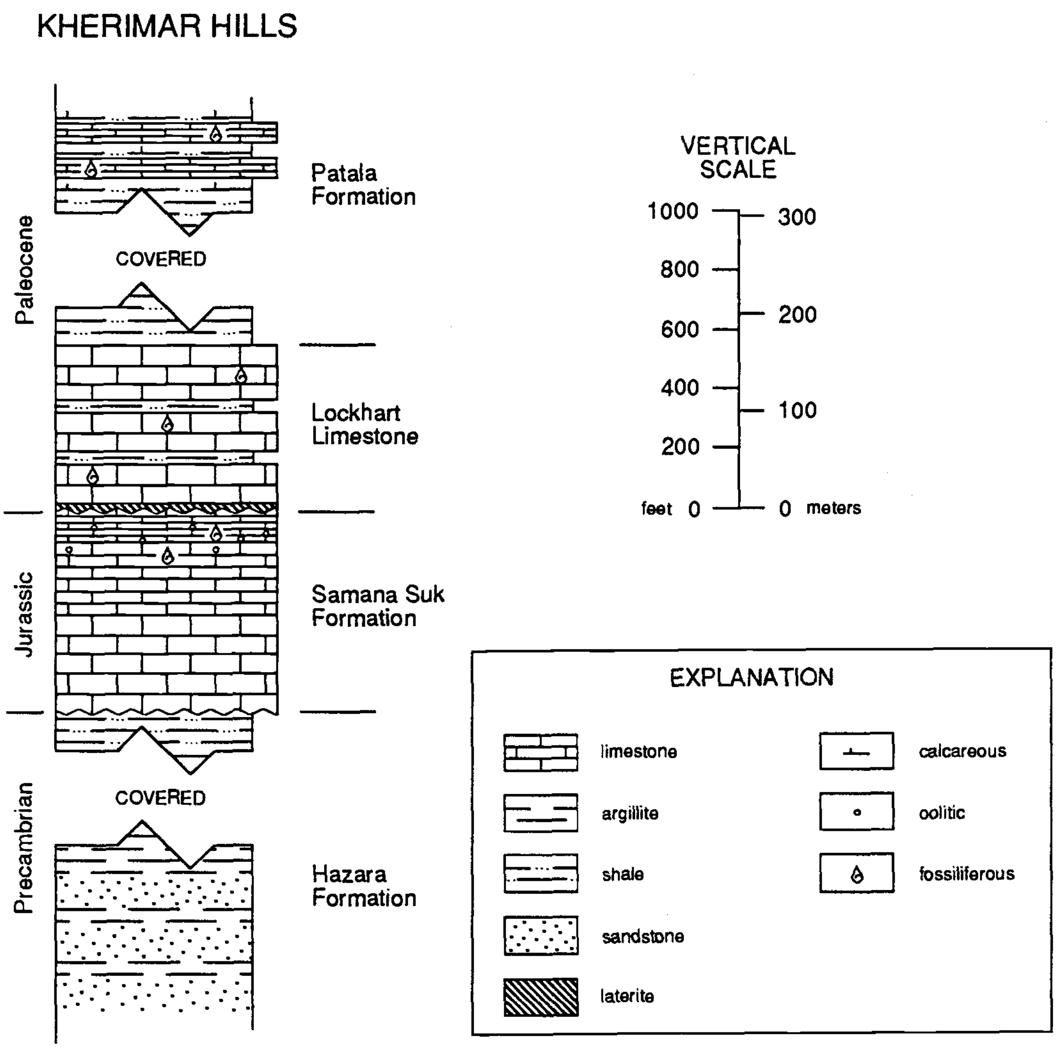

Figure 7. Schematic stratigraphic column for the Kherimar Hills. Thickness of limestone "brick" pattern (not drawn to scale) indicates relative bedding thickness as described in Figure 6.

preference to the local names of Tahirkheli (1971) to create a more regionally consistent stratigraphic nomenclature.

The second difference between the stratigraphic succession of the southern Gandghar Range given above and that given by Tahirkheli (1971) is that the relative stratigraphic positions of the two oldest bedrock units are reversed. In both the Attock-Cherat Range and Gandghar Range, Tahirkheli (1970, 1971) considered the Shahkot Formation (Shahkotbala Formation/Mohat Nawan Limestone) to be the oldest unit, overlain by the Manki Formation (Manki Slate/Sirikot Slate). However, recent work in the Attock-Cherat Range (Hussain, 1984; Yeats and Hussain, 1987) and this study in the Gandghar Range shows that the oldest bedrock unit in both areas is the Manki Formation.

STRATIGRAPHY OF THE SOUTHERN GANDGHAR RANGE

Manki Formation

As indicated in Table 1, the Manki Formation has a long and complicated history of nomenclature. This widespread argillaceous unit comprising the oldest bedrock outcrops within the study area was originally named "Attock Slates" by Waagen and Wynne (1872) after exposures at Attock (now "Attock Khurd") near the confluence of the Kabul and Indus rivers. Waagen and Wynne extended the term "Attock Slates" to the argillaceous rocks at the base of the sedimentary sequence exposed at Sirban Hill near Abbottabad. Middlemiss (1896) referred to the basal argillaceous and arenaceous sequence exposed throughout Hazara as the "Slate series." The same rocks were called "Dogra Slates" by Wadia (1931) after a similar argillaceous sequence in Kashmir with which he correlated the Hazara sequence. Marks and Ali (1961) retained the "slate" designation in their term "Hazara Slate Formation," although they pointed out that slate was only one of several lithologies present. Latif (1970) dropped the "slate" designation and elevated the sequence to group status, giving the names "Lower Formation," "Miranjani Limestone," "Middle Formation," "Langrial Limestone," and "Upper Formation" to the distinct lithological units exposed in southeastern Hazara. Calkins and others (1975) referred to the sequence as the "Hazara Formation."

Table 1. History of nomenclature of the Manki Formation and correlative units.

AUTHOR(S)	AREA	NAME
Waagen and Wynne (1872)	Abbottabad	Attock Slates
Middlemiss (1896)	Hazara	Slate series
Wadia (1931)	Kashmir	Dogra Slates
Marks and Ali (1961)	Abbottabad	Hazara Slate Formation
Latif (1969)	Southeast Hazara	Hazara Group
Tahirkheli (1970)	Attock-Cherat Range	Manki Slate
Tahirkheli (1971)	Gandghar Range	Sirikot Slate
Calkins and others (1975)	Hazara	Hazara Formation
Shah (1977)	Attock-Cherat Range	Attock Formation
Hussain (1984)	Attock-Cherat Range	Manki Formation
Present study	Gandghar Range	Manki Formation

In the Attock-Cherat Range, Tahirkheli (1970) renamed the "Attock Slates" of Waagen and Wynne as the "Manki Slate," with the type section at Manki Ghar, an isolated hillock approximately six miles south of Nowshera. The listing "Attock Formation" is given in the Geological Survey of Pakistan publication "Stratigraphy of Pakistan" (Shah, 1977) for a formation restricted to the Attock-Cherat Range that includes the Manki Slate as well as the Shahkotbala Formation and Khattak Limestone. Hussain (1984) renamed the "Manki Slate" of the Attock-Cherat Range as the "Manki Formation" to reflect the presence of lithologies other than slate. In the Gandghar Range, Tahirkheli (1971) used the local designation "Sirikot Slate" for lithologies previously referred to as "Attock Slates" by Wynne (1879) and Cotter (1933) and "Slate series" by Middlemiss (1896).

The Manki Formation is continuously exposed over the entire western slope of the southern Gandghar Range in the hanging wall of the Baghdarra fault (Plate 1). It is also exposed in the footwall of the Baghdarra fault in the vicinity of Kala Katha in the southeastern part of the range. The top of the Manki is gradational into the overlying Shahkot Formation (Figure 6). The relationship of the base of the Manki with underlying rocks is less clear. The base may be exposed adjacent to a 100 m- to 1 km-wide belt of carbonaceous slate and graphitic phyllite in the hanging wall of the Baghdarra fault. Similar lithologies exposed along the Indus River north of the Gandghar Range were assigned by Calkins and others (1975) to the Salkhala Formation, the type section being a thick sequence of carbonaceous slate, graphitic phyllite, and marble that underlies the Dogra Slates in Kashmir (Wadia, 1934). If the carbonaceous slate and graphitic phyllite of the Gandghar Range are true Salkhala Formation, then the base of the Manki is gradational with the underlying rocks in a relationship analogous to the contact between the Dogra Slates and Salkhala Formation in Kashmir. However, the Salkhala lithologies exposed in the Gandghar Range may be Manki Formation that has been locally metamorphosed by movement along the Baghdarra fault. If the latter is true, then the base of the Manki is not exposed. The thickness of the Manki Formation is uncertain due to isoclinal folding. However, outcrop width in the Gandghar Range implies a structural thickness in excess of 1000 m.

The Manki Formation is composed of argillite, slate, and phyllite. The rocks are dark greenish gray or dark gray on fresh surfaces and olive gray, dark gray, or reddish brown on weathered surfaces. An increase in metamorphic grade to the north is indicated by a petrological change from argillite and slate in the southern Gandghar

Range to phyllite with extensive quartz veining in the vicinity of Sirikot. Phyllite in the northern part of the study area is characterized by a mineral assemblage consisting of microcrystalline quartz, feldspar, chlorite, sericite, and biotite, with minor epidote and graphite. Garnet is present in rocks adjacent to the Baghdarra fault, and zeolite occurs as fracture-filling material. These minerals indicate greenschist- to lower epidote-amphibolite-facies metamorphism of a pelitic protolith. Argillite and slate commonly display two sets of cleavage that impart a splintery texture to the rock. A bedding-parallel set of cleavage may represent bedding fissility, as suggested by Latif (1969). The other set is axial-plane cleavage. Perfect slaty cleavage, such as at the exposure of Manki near Kala Katha, is rare. Graded bedding was the only sedimentary structure observed in the Manki.

The Manki Formation is of probable Proterozoic age, based on the lack of fossils and a correlation with the Hazara Formation. This correlation is addressed in the "Discussion" section of this paper, and age constraints for the Hazara Formation are given below in the discussion of that unit.

Shahkot Formation

The Shahkot Formation was originally mapped by Tahirkheli (1970) as the "Shahkotbala Formation," a shale, slate and limestone unit in the Attock-Cherat Range. Shah (1977) grouped the Shahkotbala Formation with the Manki Slate and Khattak Limestone under the heading "Attock Formation." Tahirkheli (1971) referred to one of the limestone units in the Gandghar Range as the "Mohat Nawan Limestone" and correlated it with the Shahkotbala Formation of the Attock-Cherat Range. On his map of part of the Attock-Cherat Range, Hussain (1984) refers to the unit as the "Shahkot Formation." The various names given the Shahkot Formation are summarized in Table 2.

Within the study area, exposures of Shahkot Formation are restricted to the southeastern Gandghar Range in the footwall of the Baghdarra fault (Plate 1; Figure 8). In the vicinity of Dhar Chitti, argillite of the upper part of the Shahkot is exposed in the core of a north-plunging anticline, and limestone of the lower part of the Shahkot caps the rounded hill (elevation 2137') approximately 500 m northeast of Kuldarra. The Shahkot is approximately 300 m thick, and both the lower and upper

Table 2. History of nomenclature of the Shahkot Formation and correlative units.

AUTHOR	AREA	NAME
Tahirkheli (1970)	Attock-Cherat Range	Shahkotbala Formation
Tahirkheli (1971)	Gandghar Range	Mohat Nawan Limestone
Shah (1977)	Attock-Cherat Range	Attock Formation
Hussain (1984)	Attock-Cherat Range	Shahkot Formation
Present study	Gandghar Range	Shahkot Formation

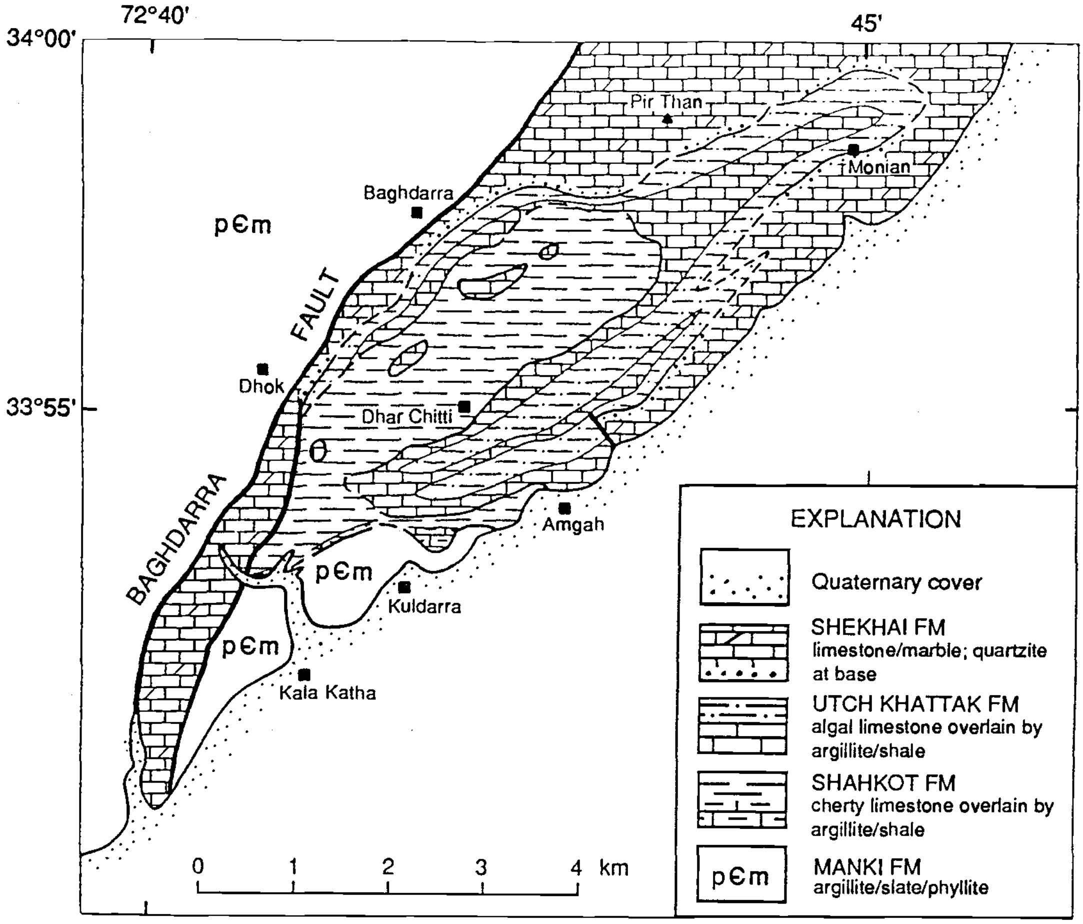

Figure 8. Lithologic map of the southern Gandghar Range in the vicinity of Dhar Chitti, showing basal Shekhai quartzite and distribution of limestone versus argillite and shale in Shahkot and Utch Khattak formations. Lithologic contacts represented by thin lines; formation contacts (dashed where approximately located) represented by medium lines; faults represented by thick lines.

contacts are conformable with the underlying Manki Formation and overlying Utch Khattak Formation, respectively (Figure 6).

The Shahkot Formation consists of limestone, argillite, and shale. A fine- to medium-grained, thin- to medium-bedded limestone unit approximately 100 m thick occurs at the base of the formation. It is yellowish gray on fresh surfaces and brownish gray on weathered surfaces, contains patches of white chert, is extremely hard, and has subordinate interbeds of dark greenish gray argillite and shale. In thin section, the limestone consists of approximately equal proportions of micritic and sparry calcite with subordinate microcrystalline quartz and is classified as a dismicrite (after Folk, 1959, 1962). Deformed calcite crystals and minor amounts of metamorphic epidote indicate low-grade metamorphism. Overlying this limestone bed is dark greenish gray, thinly-laminated argillite. The argillite is similar in appearance to argillite of the Manki Formation and has the same splintery texture due to two sets of cleavage. Enclosed within the argillite near the top of the formation is a thin, discontinuous bed of algal limestone.

Tahirkheli (1970) reported fossils from the Shahkot Formation in the Attock-Cherat Range which were tentatively identified as bryozoans of early Paleozoic age, probably late Ordovician to early Silurian. However, during the course of subsequent detailed studies in the Attock-Cherat Range by Hussain (1984) and Yeats and Hussain (1987), and during the present study in the Gandghar Range, no fossils were found in the Shahkot. Given that the Shahkot has a gradational contact with the underlying Manki Formation and occurs stratigraphically below other unfossiliferous strata, the Shahkot is probably of late Precambrian age, as suggested by Hussain (1984).

Utch Khattak Formation

This unit of shale, argillite, and distinctive limestone was first mapped in the Attock-Cherat Range by Tahirkheli (1970) as the "Khattak Limestone." Shah (1977) grouped the Khattak Limestone with the Manki Slate and Shahkotbala Formation under the heading "Attock Formation." Tahirkheli (1971) referred to one of the limestone units in the Gandghar Range as the "Baghdarra Limestone" and correlated it with the Khattak Limestone of the Attock-Cherat Range. Hussain (1984) renamed the Khattak Limestone as the "Utch Khattak Formation" from exposures near Utch

Khattak village, reflecting the presence of lithologies other than limestone. The various names given the Utch Khattak Formation are summarized in Table 3.

Within the study area, exposures of Utch Khattak Formation are restricted to the southeastern Gandghar Range in the footwall of the Baghdarra fault (Plate 1; Figure 8). The Utch Khattak has conformable contacts with the underlying Shahkot Formation and overlying Shekhai Formation, and is 200-250 m thick (Figure 6).

The Utch Khattak Formation is composed of limestone, argillite, and shale. Limestone occurs at the base of the formation and is quite distinctive. It is fine to medium grained, thin bedded, and bluish gray to dark gray. In thin section, the limestone is characterized by micritic calcite with a vaguely pelleted structure occurring within laminoid fenestrae, and is classified as a micrite (after Folk, 1959, 1962). The limestone, which occurs in lenticular blocks up to 15 cm thick and 1 m long enclosed in a matrix of brown, resistant, calcareous mudstone, represents reworked pieces of algal mat. Stromatolites are well developed in places, but are ambiguous as to original orientation. The limestone varies in thickness from approximately 10 m to 70 m and is overlain by dark greenish gray, thinly-laminated argillite with subordinate interbeds of light gray to light brown thin-bedded shale.

No fossils have been found in the Utch Khattak Formation. An intraformational conglomerate within the Utch Khattak contains clasts of Manki Formation and Shahkot Formation, indicating that the Utch Khattak is younger than both. This conglomerate is exposed both in the Attock-Cherat Range (Tahirkheli, 1970; Yeats and Hussain, 1987) and in the Gandghar Range, at the mouth of the canyon near Amgah. Given that the Utch Khattak is unfossiliferous, has a normal, locally gradational contact with the underlying Shahkot Formation, and occurs stratigraphically below other unfossiliferous strata, it is probably of late Precambrian age, as suggested by Hussain (1984).

Shekhai Formation

The Shekhai Formation was originally mapped in the Attock-Cherat Range by Tahirkheli (1970) as the "Shakhai [*sic*] Limestone." Tahirkheli (1971) referred to one of the limestone units in the Gandghar Range as the "Pir Than Limestone" and correlated it with his Shakhai Limestone of the Attock-Cherat Range. Yeats and Hussain (1987) applied the term "Shekhai Formation" to reflect the presence of

Table 3. History of nomenclature of the Utch Khattak Formation and correlative units.

AUTHOR	AREA	NAME
Tahirkheli (1970)	Attock-Cherat Range	Khattak Limestone
Tahirkheli (1971)	Gandghar Range	Baghdarra Limestone
Shah (1977)	Attock-Cherat Range	Attock Formation
Hussain (1984)	Attock-Cherat Range	Utch Khattak Formation
Present study	Gandghar Range	Utch Khattak Formation

Table 4. History of nomenclature of the Shekhai Formation and correlative units.

AUTHOR	AREA	NAME
Tahirkheli (1970)	Attock-Cherat Range	Shakhai Limestone
Tahirkheli (1971)	Gandghar Range	Pir Than Limestone
Yeats and Hussain (1987)	Attock-Cherat Range	Shekhai Formation
Present study	Gandghar Range	Shekhai Formation

lithologies other than limestone. The various names given the Shekhai Formation are summarized in Table 4.

Within the study area, the Shekhai Formation is exposed in the footwall of the Baghdarra fault (Plate 1; Figure 8). North of Pir Than, the Shekhai forms virtually the entire eastern half of the range up to latitude 34° N. Here, the trace of the Baghdarra fault is closer to the range front, resulting in a narrower outcrop width of the Shekhai. The thickness of the Shekhai is uncertain since the top is truncated by the Baghdarra fault. Also, the massive nature of much of the limestone precludes good structural control, so that the intensity of folding is not known. However, outcrop width implies a thickness of at least 300 m. The Shekhai conformably overlies the Utch Khattak Formation (Figure 6).

The Shekhai Formation is composed of limestone and marble with subordinate argillite, shale, and quartzite. Limestone is fine to medium grained, thin bedded to massive, and occurs in a variety of colors, including light gray, dark gray, light brown, and pink. The weathered surface is typically light gray or light brown and relatively smooth. Locally, the limestone is oolitic. In thin section, the limestone consists of micrite, laminated in places, and ranges in classification from a micrite to an oomicrite (after Folk, 1959, 1962). Small areas of white marble are associated with igneous dikes, suggesting local thermal metamorphism of the limestone. A bed of pink and white quartzite up to 1 m thick occurs at the base of the Shekhai, and intercalations of dark greenish gray, thinly-laminated argillite and light gray shale occur throughout the formation.

No fossils have been found in the Shekhai Formation. Yeats and Hussain (1987) considered the Shekhai to be probably Precambrian based on the absence of fossils and the conformable basal contact with the Utch Khattak Formation. Several lines of indirect evidence point to a Proterozoic or possibly early Cambrian age for the Shekhai Formation, and a Proterozoic age for the Shahkot and Utch Khattak formations. First, the only organic features preserved in these rocks are stromatolites and other algal features commonly found in Precambrian rocks. Second, a thin limestone unit (Sobrah Formation) overlies the Manki Formation near Tarbela Dam and is considered to be correlative with the Shekhai Formation, based on lithologic similarities (K R. Pogue, personal communication, 1989). The Sobrah Formation is unconformably overlain by the Tanawal Formation which, in turn, is intruded by the 516-Ma Mansehra granite. It follows that the Tanawal Formation is Middle Cambrian or older and the Shekhai and Sobrah formations could be as young as Cambrian.

Third, the quartzite at the base of the Shekhai Formation may represent a disconformity, indicating that a significant amount of time elapsed between deposition of the Utch Khattak and Shekhai formations.

Intrusive Rocks

The only igneous rocks that occur *in situ* within the study area are basic dikes and sills that intrude all of the strata exposed in the Gandghar Range. The intrusive bodies are generally less than 2 m thick and are structurally deformed along with the country rock. The rocks display an ophitic texture, characterized by labradorite laths enclosed in augite, and are therefore diabase. In the adjacent Peshawar basin, diabase dikes intrude Precambrian and Paleozoic strata up to the level of the Late Pennsylvanian - Early Permian Karapa Greenschist (Pogue and others, in review). Pogue and others (in review) interpret the lava flows that constitute the protolith for the Karapa Greenschist as the extrusive equivalent of the diabase dikes. Assuming that the igneous rocks in the Gandghar Range and Peshawar basin are related, the age of the Gandghar Range intrusions is Late Pennsylvanian - Early Permian. Pogue and others (in review) suggested the Karapa Greenschist is a probable counterpart to the Panjal Volcanics, intermediate to basic schistose rocks that occur along the eastern limb of the Hazara-Kashmir syntaxis and which are conformably overlain by Triassic marine strata (Bossart and others, 1988).

STRATIGRAPHY OF THE KHERIMAR HILLS

Hazara Formation

A comparison of the history of nomenclature of the Hazara Formation (Table 5) with that of the Manki Formation (Table 1) shows that the two bedrock units were long considered to be the same. The two formations, undifferentiated, have been referred to as the "Attock Slates" (Waagen and Wynne, 1872), "Slate series" (Middlemiss, 1896), "Dogra Slates" (Wadia, 1931), "Hazara Slate Formation" (Marks and Ali, 1961), "Hazara Group" (Latif, 1970), and "Hazara Formation" (Calkins and others, 1975; Shah, 1977), as outlined above for the Manki Formation.

Table 5. History of nomenclature of the Hazara Formation and correlative units.

AUTHOR(S)	AREA	NAME
Waagen and Wynne (1872)	Abbottabad	Attock Slates
Middlemiss (1896)	Hazara	Slate series
Wadia (1931)	Kashmir	Dogra Slates
Marks and Ali (1961)	Abbottabad	Hazara Slate Formation
Latif (1970)	Southeast Hazara	Hazara Group
Tahirkheli (1970)	Attock-Cherat Range	Attock Shale
Calkins and others (1975)	Hazara	Hazara Formation
Shah (1977)	Hazara	Hazara Formation
Hussain (1984)	Attock-Cherat Range	DakhnerFormation
Present study	Kherimar Hills	Hazara Formation

In the Attock-Cherat Range, Tahirkheli (1970) introduced the term "Attock Shale" for lithologies similar to the Manki Formation but more arenaceous and lacking the cleavage typical of the Manki. Hussain (1984) renamed the "Attock Shale" as the "Dakhner Formation" to avoid confusion with the earlier term "Attock Slates." Yeats and Hussain (1987) suggested that the Dakhner and Manki may be stratigraphically equivalent, differing only in degree of metamorphism. Lithologies virtually identical to the Dakhner Formation are present in the Kherimar and Haripur hills. These rocks are also lithologically identical to the Hazara Formation south of Abbottabad near Havelian and, given their proximity to the latter, are referred to as "Hazara Formation" and considered to be correlative with the Dakhner Formation.

Within the study area, the Hazara Formation is unconformably overlain by the Samana Suk Formation (Plate 1; Figure 7). Due to poor exposures and strong folding of Tertiary age, it is unclear whether this contact is an angular unconformity or a disconformity. The base of the Hazara Formation is not exposed. The most extensive outcrops occur in the Haripur hills where outcrop width implies a thickness of at least 800 m.

The Hazara Formation is composed of shale, argillite, and sandstone. The sequence is typically dark greenish gray on fresh surfaces and weathers to a lighter shade of greenish gray, but shale and sandstone in some localities weather to light brown or red. Shale is laminated and fissile whereas argillite and sandstone are very thinly to thickly bedded. The sandstone is a subgraywacke on the basis of well-sorted, subangular to subrounded quartz and subordinate feldspar in a matrix of clay minerals and chlorite. In the Haripur hills, alternating beds of sandstone and argillite have oscillation-ripple marks and flute casts preserved on bedding surfaces. These features are well displayed in the road cut along the Haripur-Taxila road. Hazara lithologies exposed outside of the study area include slate, quartzite, gypsum, and limestone (Latif, 1969; Calkins and others, 1975). Two limestone interbeds, first mentioned by Middlemiss (1896), are quite distinct and can be traced over a relatively large area. They are exposed northeast of Haripur at Miranjani and Langrial, respectively. The Miranjani limestone is characterized by cherty patches and algal pisoliths and contains a well-developed stromatolitic zone (Latif, 1969). The Langrial limestone is characterized by bluish gray nodules enclosed in a brown, highly resistant clayey matrix that gives the limestone a distinctive meshwork appearance (Latif, 1969). Marks and Ali (1961) suggested that the limestone within the Hazara represents infolded Paleozoic or Triassic limestone, whereas other workers have observed gradational contacts between the limestone and enclosing rocks (Latif, 1969; Cheema, 1970; Calkins and others, 1975).

The age of the Hazara Formation is Precambrian on the basis of radiometric dating of rocks sampled in the vicinity of Abbottabad. Rb/Sr whole-rock model ages of 765 $\pm$ 20 Ma and 950 $\pm$ 20 Ma were obtained by Crawford and Davies (1975). These ages have subsequently been recalculated to be 739 $\pm$ 9 Ma and 951 $\pm$ 8 Ma, respectively (Baig and Lawrence, 1987; Baig and others, 1988). In the vicinity of Abbottabad, the basal Tanakki conglomerate of the Abbottabad Group, which is Cambrian based on the presence of hyolithids and *Chancelloria* sponge spicules in the overlying Hazira Shale (Latif, 1972; Rushton, 1973), contains clasts of Hazara (Latif, 1974). No definitive fossils have ever been found in the Hazara Formation. "Fossil-like objects" resembling inarticulate brachiopods have been reported in the Hazara by Davies and Ahmad (1963), but these and similarly cryptic objects in the Hazara reported by Latif (1969) remain to be positively identified and may simply be algal remains (A. J. Rowell, *in* Davies and Ahmad, 1963). Pelecypod and gastropod shells found in a limestone lens within the Attock Shale (Dakhner Formation) by Tahirkheli (1970) are interpreted to occur in Cretaceous or Paleocene limestone that overlies the Dakhner unconformably or is in thrust contact with the Dakhner (Yeats and Hussain, 1987).

Samana Suk Formation

This widely distributed unit was originally referred to as the "Triassic Series" by Waagen and Wynne (1872), who considered the rocks to be Triassic based on the occurrence of gastropod and bivalve shells, especially *Megalodon* and *Dicerocardium*. Middlemiss (1896) retained the general term "Triassic Series," but added the designation "upper limestones." Cotter (1933) applied the term "Kioto limestone" when he correlated the "Triassic limestone" of the Kala Chitta Range and Hazara with the Kioto limestone of the Spiti region of northern India. Cotter also considered the Kioto limestone of the Kala Chitta Range and Hazara to be as young as middle Jurassic, based on the fossil assemblage and stratigraphic position of the Kioto limestone below the Upper Jurassic Spiti Shale. Latif (1970) referred to the Jurassic limestone of Hazara as the "Sikhar Limestone." Davies (1930) first applied the term "Samana Suk Limestone" to the Jurassic limestone of the Samana Range. The term

"Samana Suk Formation" was first used by Shah (1977), reflecting the presence of lithologies other than limestone. Shah also extended the term to include correlative units in the Samana Range, Kohat region, western Salt Range, Trans-Indus ranges, Kala Chitta Range, and Hazara. The various names given the Samana Suk Formation are summarized in Table 6.

Within the study area, the Samana Suk Formation is exposed throughout the Kherimar Hills (Plate 1). As shown in Figure 7, the Samana Suk unconformably overlies the Hazara Formation, although the exact nature of this unconformity is unclear due to poor exposure and strong folding of Tertiary age. The Samana Suk is disconformably overlain by the Paleocene Lockhart Limestone (Figure 7). The thickness of the Samana Suk varies greatly, ranging from a minimum of 1 m near Paur Miana to a maximum of 200 m in the Kherimar Hills proper.

The Samana Suk Formation is composed of limestone with subordinate shale. The limestone is fine grained, thin to thick bedded, and is typically dark gray or pale yellowish brown on fresh surfaces, although light brown and pink colors are not uncommon. Weathered surfaces are light gray to light brown and generally smooth. Discontinuous interbeds of light brown shale up to 1 m thick occur near the base of the formation. Oscillation-ripple marks and stylolites occur near the top of the formation, and the uppermost beds contain variable amounts of comminuted shell debris and are locally pelloidal and oolitic. Petrographically, the limestone ranges in classification from a micrite to a biopelmicrite (after Folk, 1959, 1962).

The fossil fauna of the Samana Suk Formation consists of brachiopods, ammonoids, bivalves, gastropods, crinoids, and foraminifers (Fatmi, 1973; Meissner and others, 1973). As a whole, the fauna indicates an essentially Middle Jurassic age for the Samana Suk (Fatmi, 1973). In Hazara, however, the Samana Suk may be as young as Oxfordian (Latif, 1969).

Lockhart Limestone

This Paleocene limestone formation was originally named the "Nummulitic Formation" by Waagen and Wynne (1872) in reference to the family of Foraminifera that comprises a significant part of the fossil fauna of the limestone in Hazara. The same rocks were named the "well-bedded massive limestone" member of the "Nummulitic Series" by Middlemiss (1896) and the "Mari Limestone" by Latif

Table 6. History of nomenclature of the Samana Suk Formation and correlative units.

AUTHOR(S)	AREA	NAME
Waagen and Wynne (1872)	Abbottabad	Triassic Series
Middlemiss (1896)	Hazara	Triassic Series (upper limestones)
Davies (1930)	Samana Range	Samana Suk Limestone
Cotter (1933)	Kala Chitta Range and Hazara	Kioto Limestone
Latif (1970)	Southeast Hazara	Sikhar Limestone
Shah (1977)	Northern Pakistan	Samana Suk Formation
Present study	Kherimar hills	Samana Suk Formation

(1970). Correlative rocks were referred to as the "Hill Limestone" in the Kala Chitta Range and southern Hazara (Cotter, 1933), "Cherat Limestone" in the Attock-Cherat Range by Tahirkheli (1970), "Khairabad Limestone" by Gee in the western Salt Range (Fermor, 1935), and "Tarkhobi Limestone" in the Kohat region (Eames, 1952). The name "Lockhart Limestone" was introduced by Davies (1930) for exposures near Fort Lockhart in western Kohat and was extended to include all of the correlative units listed above in the Kohat-Potwar-Hazara region (Shah, 1977). The various names given the Lockhart Limestone are summarized in Table 7.

Within the study area, exposures of Lockhart Limestone occur throughout the Kherimar Hills (Plate 1). The Lockhart disconformably overlies the Samana Suk Formation and is conformably overlain by the Patala Formation (Figure 7). The Lockhart-Patala contact is only exposed in the eastern part of the Kherimar Hills proper, on the overturned southern limb of the Kherimar syncline. The thickness of the Lockhart Limestone ranges from 100 m to 180 m.

The Lockhart Limestone is fine to medium grained, locally nodular, and medium bedded to massive. Fresh surfaces are light gray to dark gray and often produce a strong fetid odor. Weathered surfaces are light gray and typically rough. Petrographically, the limestone is classified as a biomicrite (after Folk, 1959, 1962). Minor intercalations of dark gray to black thinly-laminated shale occur throughout the formation. The base of the Lockhart is marked by laterite, 1-2 m thick, which is overlain by up to 20 m of soft, nodular, pale yellowish orange limestone. Cotter (1933) considered this basal sequence to be a calcareous facies of the "Variegated Sandstone" of Middlemiss (1896), who first described the sequence exposed at the hill adjacent to Hasan Abdal.

On the basis of a fossil fauna consisting of algae, foraminifers, corals, molluscs, and echinoids, the Lockhart Limestone is Paleocene in age (Fatmi, 1973).

Patala Formation

The youngest bedrock unit exposed within the study area was included in the "Nummulitic Formation" of Waagen and Wynne (1872). Middlemiss (1896) discussed the unit under the heading "shales, marls, and concretionary and nodular limestone" of the "Nummulitic Series," and Cotter (1933) considered the unit to be part of the "Hill Limestone." Correlative rocks have been referred to as "Tarkhobi

Table 7. History of nomenclature of the Lockhart Limestone and correlative units.

AUTHOR(S)	AREA	NAME
Waagen and Wynne (1872)	Abbottabad	Nummulitic Formation
Middlemiss (1896)	Hazara	Nummulitic Series (well-bedded massive limestone)
Davies (1930)	Kohat	Lockhart Limestone
Cotter (1933)	Kala Chitta Range and S. Hazara	Hill Limestone
Gee, *in* Fermor (1935)	Western Salt Range	Khairabad Limestone
Eames (1952)	Kohat	Tarkhobi Limestone
Latif (1970)	Southeast Hazara	Mari Limestone
Tahirkheli (1970)	Attock-Cherat Range	Cherat Limestone
Shah (1977)	Kohat, Potwar, Hazara	Lockhart Limestone
Present study	Kherimar hills	Lockhart Limestone

Shales" in the Kohat region (Eames, 1952), "Bakhtai Formation" in the Attock-Cherat Range (Tahirkheli, 1970), and "Kuzagali Shale" in Hazara (Latif, 1970). The term "Patala shale" was introduced by Davies and Pinfold (1937) for exposures in Patala Nala in the Surghar Range. Shah (1977) used the term "Patala Formation," reflecting lithologies other than shale and extended to include correlative units in the Kohat-Hazara region. The various names given the Patala Formation are summarized in Table 8.

Within the study area, the Patala Formation is exposed in the core of the Kherimar syncline, forming the low hills in the vicinity of Qandharipur and Babraki (Plate 1). The base of the Patala, exposed in the overturned southern limb of the Kherimar syncline, is conformable with the underlying Lockhart Limestone (Figure 7). The top of the Patala is not exposed, and the thickness is uncertain due to intense folding and faulting. However, outcrop width implies a thickness of at least 200 m.

The Patala Formation is composed of interbedded limestone and shale. Dark greenish gray fissile shale at the base of the formation is overlain by interbedded limestone and shale. The limestone is medium grained, thin to medium bedded, dark gray on fresh surfaces and light gray on weathered surfaces. Petrographically, the limestone is classified as a biomicrite (after Folk, 1959, 1962). Dark greenish gray, thin-bedded to fissile, locally calcareous shale generally 10 m thick occurs between the limestone beds. From a distance, the formation has a distinctive corrugated appearance due to the contrast in resistance to weathering between the limestone and shale.

The fossil fauna of the Patala Formation is composed of foraminifers, molluscs, and ostracods, and indicates a Late Paleocene age (Fatmi, 1973).

Pliocene to Recent Sediments

The broad, low-lying plains of the study area are covered by a thick sequence of unconsolidated to semiconsolidated alluvial and lacustrine deposits of clay, silt, sand, and gravel. These deposits were briefly alluded to by Wynne (1879), Middlemiss (1896), and Cotter (1933). Latif (1970) proposed the name "Havelian Group" for the sequence of unconsolidated materials of fluvial and lacustrine origin exposed in southeast Hazara, but no formalized name for these deposits exists at the present time.

Table 8. History of nomenclature of the Patala Formation and correlative units.

AUTHOR(S)	AREA	NAME
Waagen and Wynne (1872)	Abbottabad	Nummulitic Formation
Middlemiss (1896)	Hazara	Nummulitic Series (shales, marls, concretionary and nodular limestone)
Cotter (1933)	Kala Chitta Range and S. Hazara	Hill Limestone
Davies and Pinfold (1937)	Surghar Range	Patala shale
Eames (1952)	Kohat	Tarkhobi Shales
Latif (1970)	Southeast Hazara	Kuzagali Shale
Tahirkheli (1970)	Attock-Cherat Range	Bakhtai Formation
Shah (1977)	Kohat and Hazara	Patala Formation
Present study	Kherimar hills	Patala Formation

A detailed study of the evolution of the Kashmir and Peshawar basins by Burbank (1982) included a history of the Campbellpore basin, the eastern end of which is occupied by the Haro River drainage. The presence of numerous preserved rootlets within the lacustrine strata and the lack of vertical and lateral persistence of the strata indicate that the sediments were deposited in shallow, ephemeral lakes, and frequent interbedding of thin sands and silts with the laminated, rootlet-bearing muds is suggestive of conditions in oxbow lakes that receive sporadic input of coarser sediments during flood events (Burbank, 1982). Based on the above observations, Burbank interpreted the depositional environment of the Campbellpore basin sediments as a meandering river system. Paleocurrent measurements derived from crossbedded sandstones indicate that the river(s) flowed in a westerly direction (Burbank, 1982).

On the basis of magnetic polarity stratigraphy, sedimentation in the Campbellpore basin began at least 1.8 m.y. ago (Burbank, 1982). Termination of sedimentation is marked by a heterolithic conglomerate overlain by a thin sequence of normally magnetized lacustrine sediments (Burbank, 1982). The conglomerate, exposed in a section along the Haro River west of the present study area, contains clasts of limestone, quartzite, granite, and diorite; whereas the limestone clasts could have originated in the nearby Kala Chitta Range, the quartzite and igneous lithologies represent source areas well to the north (Burbank, 1982). Other northerly-derived heterolithic conglomerates interfinger with limestone conglomerates that have a source in the Kala Chitta Range, leading Burbank to suggest that ongoing aggradation of the basin fill was punctuated by input of clastic material produced by sporadic faulting and uplift of the Kala Chitta Range. The sequence of lacustrine sediments is widespread in the Campbellpore basin and is probably the result of uplift of the Kala Chitta Range at the western end of the basin, causing ponding of the drainage by raising the local base level (Burbank, 1982). Continued uplift is causing dissection of the lacustrine deposits by small, intermittent streams, producing local badland topography which is especially well-developed in the areas between Burhan and Lawrencepur and north of Hasan Abdal (Plate 1).

Some important constituents of the Quaternary deposits of the study area and surrounding region are large blocks of exotic lithologies perched upon bedrock or apparently embedded in the surrounding alluvium. The depositional history of these blocks was the subject of considerable debate during the latter half of the nineteenth century (a complete bibliography of the pertinent literature published during that time is given in Cotter (1929)). For example, Wynne (1879) reported boulders of granite or granitic gneiss, one of which measured 7 x 7 x 11 m, at a site at the north end of the Gandghar Range now covered by the waters of Tarbela Lake. The scenario Wynne proposed for the emplacement of these boulders, which he considered to have been transported from a source area somewhere to the north, involved a greater volume of flow on the Indus River than at present, flow of the Indus River down the east side of the Gandghar Range, lakes occupying the low-lying basins, and transportation of the boulders on ice rafts. After observing the same rocks, Middlemiss (1896) considered them to be outcrop of granitic gneiss rather than boulders. During his study of the "erratic blocks" of the Attock district, Cotter (1929) observed blocks of granite, syenite, gneiss, schist, and slate that definitely were not outcrop, and proposed an alternative to the ice raft mechanism of emplacement. He stated that the blocks could have been transported from the north down the Indus River following a catastrophic glacial outburst flood event. Recently, Shroder and others (1989) have suggested that a boulder of Nanga Parbat gneiss, located near the west abutment of the Haro River Bridge on the Grand Trunk Road, was emplaced after a 1-1.5 km-thick ice dam in the Indus gorge near Nanga Parbat failed. Other catastrophic floods on the Indus have been attributed to failure of dams formed by landslides. For example, a major flood that occurred on the Indus in 1841 was the result of failure of a dam created by an earthquake-generated slide near Nanga Parbat (Shroder and others, 1989). Given the depositional environment of the Campbellpore basin sediments proposed by Burbank (1982), it would seem likely that the exotic blocks there were deposited during flood events, or possibly by much larger ancestral rivers, rather than by ice rafts on lakes.

STRUCTURE

Within the study area, bedrock occurs in four structural blocks separated by generally northeast-trending reverse faults (Figure 9). From north to south these faults are the Baghdarra (named in this report), the Panjal (Wadia, 1931; Calkins and others, 1975), and the Nathia Gali (Coward and Butler, 1985; "Kalabagh fault" of Latif, 1969). The Baghdarra fault is well exposed in the Gandghar Range, but the Panjal and Nathia Gali faults are buried beneath Campbellpore basin fill. However, the presence of these latter two faults is strongly suggested by the contrasting facies and different groups of formations exposed in the Gandghar Range, Kherimar Hills, and farther south in the Kala Chitta Range. Figures 9 and 10 summarize the structural and stratigraphic relationships between the different structural blocks.

The Baghdarra fault, named after the village located approximately 3 km southwest of Pir Than, brings the Manki Formation and younger rocks of the eastern Peshawar basin over the Shekhai Formation. In the southern Gandghar Range, the hanging wall of the Baghdarra fault is composed entirely of isoclinally-folded Manki Formation. Axial-plane cleavage is generally northeast-trending, although an east-northeast trend becomes prevalent at the southernmost tip of the range. Chevron folds and kink bands are present in the rocks adjacent to the fault, indicating compression roughly parallel to foliation.

Oriented phyllite samples collected from the narrow zone of carbonaceous slate and graphitic phyllite adjacent to the Baghdarra fault near Baghdarra village contain small (0.5-1 mm diameter) subhedral to euhedral garnet porphyroblasts. As shown in Figure 11, the primary foliation is deformed asymmetrically around the porphyroblasts. Also, kink bands and a poorly-developed S-C fabric are present. These features are consistent with conditions of dextral shear, indicating reverse-slip displacement along the Baghdarra fault. Despite the absence of pinwheel garnets and other indicators of internal deformation in the porphyroblasts, the asymmetry of the deformed foliation suggests that the porphyroblasts may be syntectonic, possibly forming at the same time as the kink bands and S-C fabric in response to movement along the fault.

In the footwall of the Baghdarra fault, the complete Manki-Shekhai succession has been deformed into a series of tight, northeast-plunging folds. The intensity of folding has produced significant shearing at virtually every lithologic contact. These folds are illustrated in Figure 12, which is a structural cross section through the

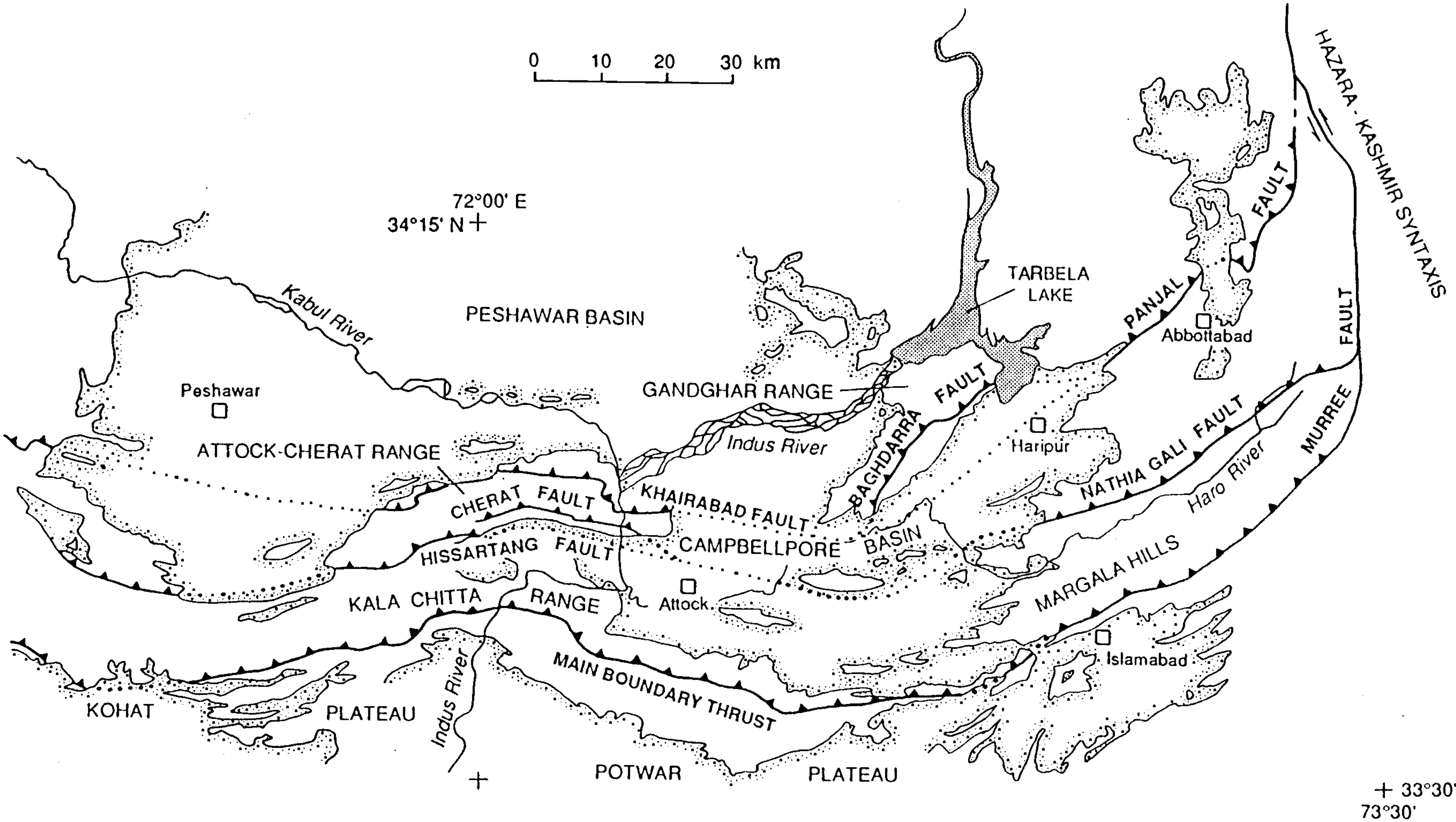

Figure 9. Tectonic map of the Hill Ranges, showing suggested correlations of the Panjal, Nathia Gali, and Murree faults in the east with the Khairabad, Cherat, and Hissartang faults and Main Boundary thrust in the west. Lowlands shown by stippled pattern. Adapted from Burbank and Tahirkheli (1985) and Yeats and Hussain (1987).

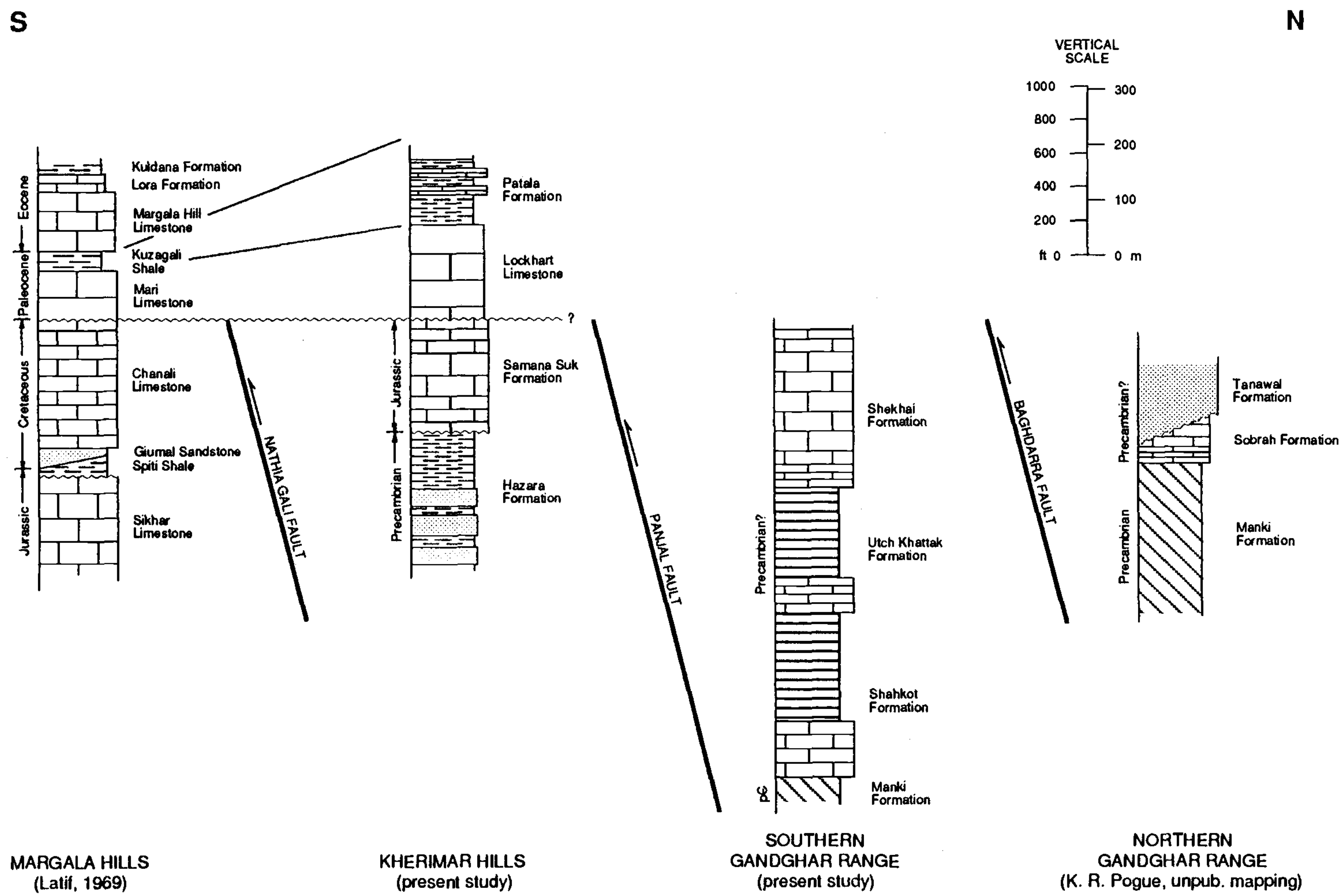

Figure 10. Stratigraphic successions of the Gandghar Range, Kherimar Hills, and Margala Hills juxtaposed along the Baghdarra, Panjal, and Nathia Gali faults. Lockhart Limestone and Patala Formation common to Kherimar Hills and Margala Hills, suggesting juxtaposition of pre-Lockhart strata along Nathia Gali fault prior to Lockhart deposition. Younger strata not preserved in Gandghar Range.

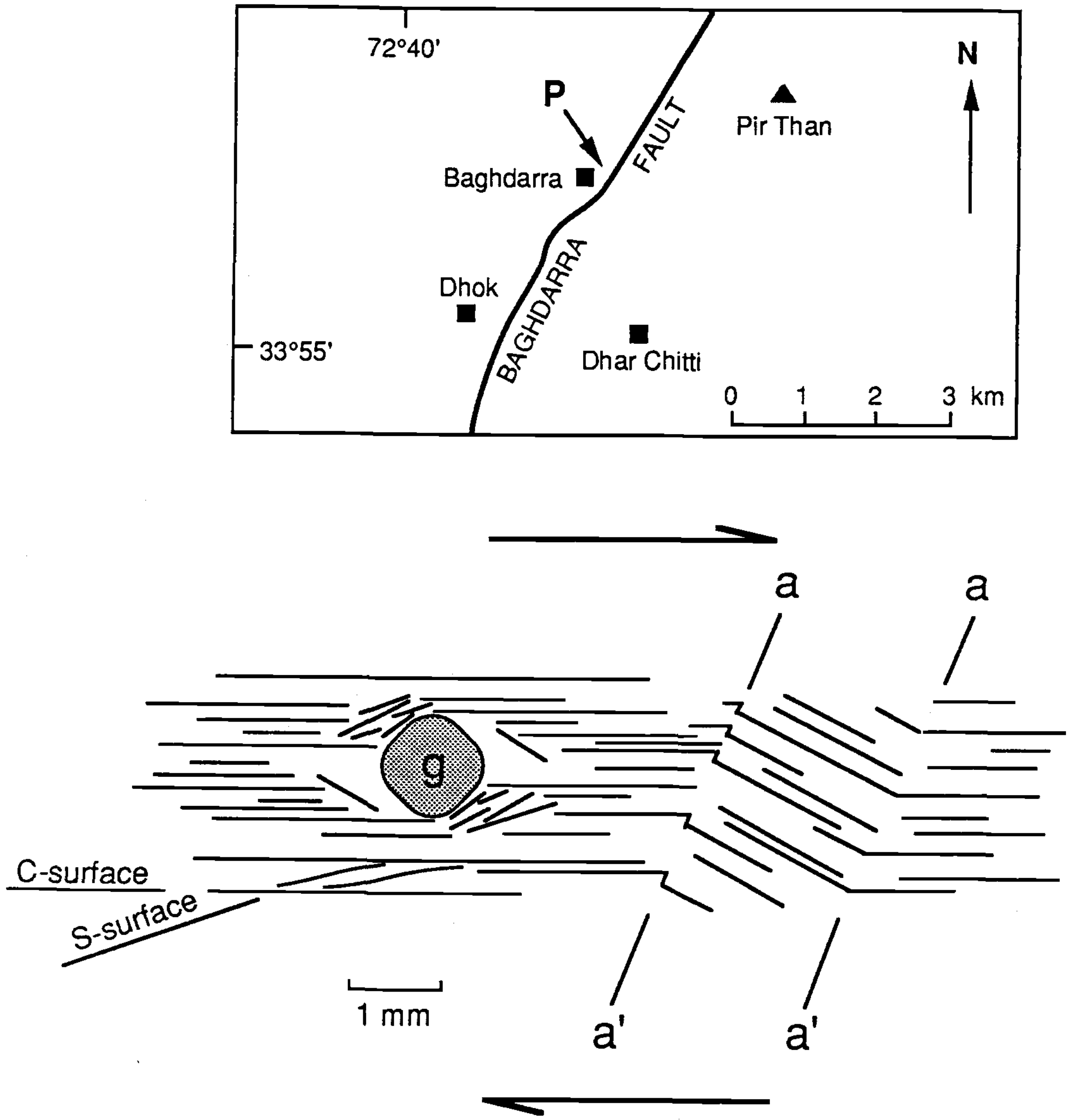

Figure 11. Simplified composite line drawing of photomicrograph of oriented (top = west, right = up) phyllite sample from near Baghdarra fault. Sample locality (P) shown above and in Figure 12. Shear-sense indicators include asymmetric deformation of primary foliation around garnet porphyroblasts (g), kink bands (between boundaries a-a'), and rotation of foliation (S) between shear planes parallel to C, resulting in a poorly-developed S-C fabric. Features are consistent with conditions of dextral shear, indicating reverse slip displacement along the Baghdarra fault.

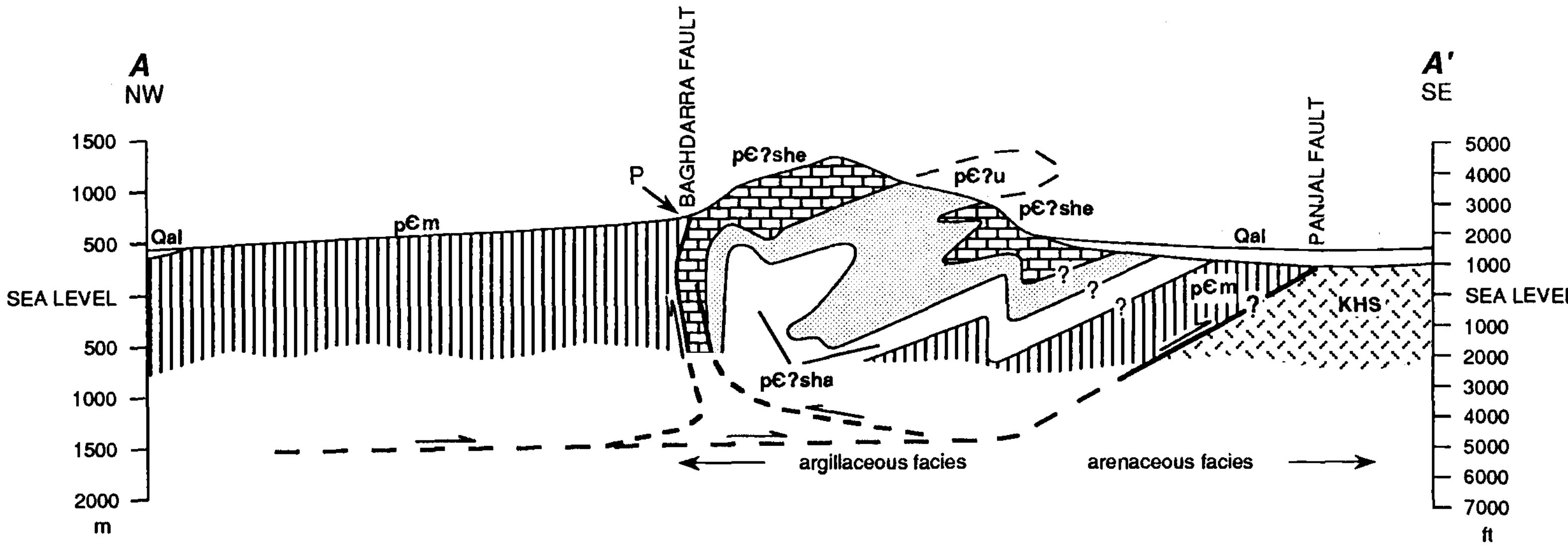

Figure 12. Structural cross section of the southern Gandghar Range, with structures projected into section from up-plunge direction. No vertical exaggeration. Ramp-and-flat geometry of Panjal fault shown diagrammatically. Location of ramp based on mechanical strength difference between argillaceous and arenaceous strata as discussed in text. pЄm = Manki Formation; pЄ?sha = Shahkot Formation; pЄ?u = Utch Khattak Formation; pЄ?she = Shekhai Formation; Qal = alluvium. KHS = Kherimar Hills succession; P = oriented phyllite sample locality (see Figure 11). See Figure 3 for location of cross section.

southern Gandghar Range with structures projected into the section from the up-plunge direction (after Mackin, 1950). In general, the folds are disharmonic and southeast (foreland) verging. The disharmonic nature of the folds is due to the significant volume of ductile argillite and shale within the Shahkot and Utch Khattak formations, which has resulted in attenuation of overturned fold limbs and accumulation of material in fold hinges. The orientation of the folds suggests a southeasterly transport direction along the Panjal fault. A northwest-vergent anticline adjacent to the Baghdarra fault is interpreted as a fault propagation fold related to a backthrust, movement along which has resulted in overturning of the northwest limb of the anticline. Although no definitive indications of fault dip could be found, the Baghdarra fault must also be overturned if it is assumed that it cuts consistently up dip. Deformation of the Baghdarra fault along with footwall strata suggests that the Baghdarra fault is older than the Panjal fault and is being carried piggy-back style by the Panjal fault.

Aside from minor outcrop-scale faulting, the fold limbs in the southern Gandghar Range are relatively intact. Two exceptions to this situation are the backthrust discussed above and a vertical, northwest-trending fault located at the base of the southeastern Gandghar Range front near Amgah (Plate 1). Given that the latter structure is perpendicular to the prevailing structural trend, it is interpreted as a tear fault accommodating differential movement in the hanging wall of the Panjal fault.

The Panjal fault likely has a ramp-and-flat geometry beneath the southern Gandghar Range, as shown diagrammatically in Figure 12. If the detachment surface is located near or at the base of the Manki Formation, which is suggested by the absence of rocks older than Manki exposed at the surface, then a flat or very gently dipping segment beneath the eastern part of the range is necessary to hold the Manki structurally high and prevent post-Manki strata from being preserved. Assuming the Manki and Hazara formations are correlative, a ramp would be likely to occur somewhere near the boundary between argillaceous Manki-type rocks and arenaceous Hazara/Dakhner-type rocks, associated with a change in the mechanical strength of the rocks.

As shown in Figures 9 and 10, the Kherimar and Haripur hills occur in the hanging wall of the Nathia Gali fault. In southeast Hazara, the Precambrian Hazara Formation is not exposed south of the Nathia Gali fault in the Margala Hills. Likewise, Precambrian rocks are not exposed in the Kala Chitta Range. This suggests that the Nathia Gali fault is present beneath basin fill south of, and probably close to, the Kherimar Hills, as shown in Figure 9. In general, structures in the Kherimar Hills trend roughly parallel to the presumed trace of the fault, suggesting that they are related to movement along the fault. However, different parts of the hanging wall have responded to this movement in different ways, resulting in three distinct types of structures: 1) south- or foreland-verging folds; 2) north- or hinterland-verging folds and faults, and; 3) northwest-trending folds.

An example of south-verging folds is the overturned anticline that forms the hill near Paur Miana (Plate 1). Also, bedding-plane slip observed in the Hazara Formation in the Haripur hills is consistent with south-vergent structures. In contrast, north-verging folds and faults occur in the eastern part of the Kherimar syncline. The east-plunging Kherimar syncline is the dominant structure of the Kherimar Hills, trending parallel to and extending the length of the Kherimar Hills from near Garshin to Wah. In the vicinity of Rathargarh, the Samana Suk Formation overlies the Lockhart Limestone in the south limb of the syncline, indicating that the south limb is overturned (Figure 13). Given the apparent proximity to the Nathia Gali fault, the overturning is possibly due to a blind backthrust related to the Nathia Gali fault. Several small-displacement, imbricate reverse faults appear to be related to the backthrusting/overturning, and the Patala Formation is strongly deformed in the core of the syncline due to intense squeezing.

The structural configuration of this part of the Kherimar Hills is strikingly similar to that near Nicholson Monument in the Margala Hills. There, overturning of the south limb of a syncline in the hanging wall of the Main Boundary thrust, with the Samana Suk Formation overlying younger strata, has been produced by movement along a backthrust related to the Main Boundary thrust (Hussain and Lawrence, 1987).

An anomalous set of northwest-trending folds comprise the hill adjacent to Hasan Abdal (Plate 1). These folds involve the Lockhart Limestone, and since no other folds of similar orientation occur in Lockhart or younger strata elsewhere in the Kherimar Hills, it is doubtful that they represent northeast-southwest-directed compressive stress. Rather, the present orientation of the folds is most likely due to their location between south-vergent structures to the east and north-vergent structures to the west. Differential movement between these two areas would result in an intervening zone of relatively high shear stress. The present orientation of the folds could be the result of drag of pre-existing east-trending structures along a dextral strike-slip fault or simply reflect bending strain in the high shear stress area.

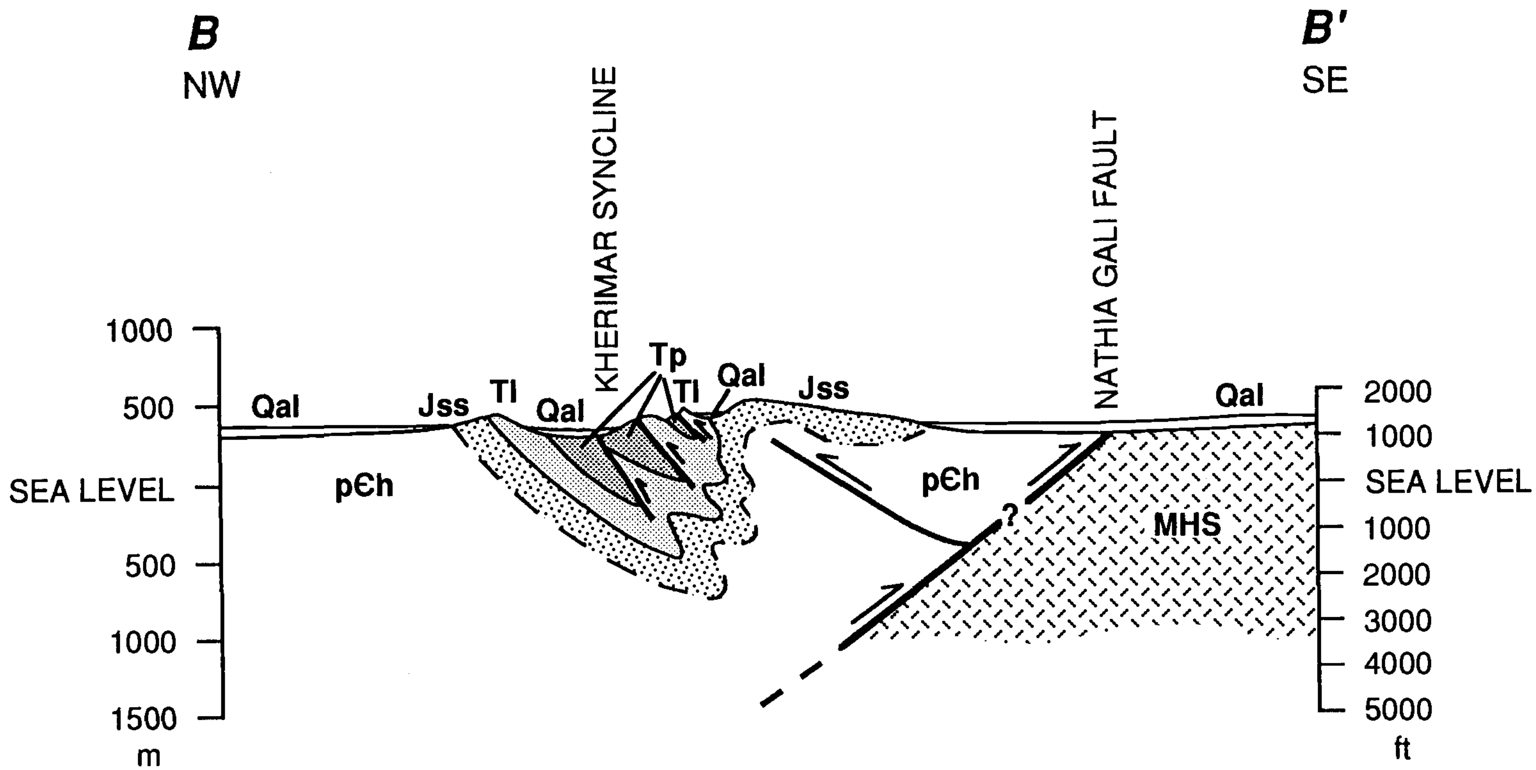

Figure 13. Structural cross section of the Kherimar Hills, showing overturned southern limb of the Kherimar syncline and postulated blind backthrust. No vertical exaggeration. pЄh = Hazara Formation; Jss = Samana Suk Formation; Tl = Lockhart Limestone; Tp = Patala Formation; Qal = alluvium. MHS = Margala Hills succession. See Figure 3 for location of cross section.

DISCUSSION

CORRELATIONS AND DEPOSITIONAL HISTORY OF THE ROCKS IN THE HANGING WALL OF THE PANJAL FAULT

Previously, the basal sequences on both sides of the Panjal fault were considered to be the same unit. For example, Calkins and others (1975) mapped both as "Hazara Formation." However, the two sequences differ markedly in lithology and degree of metamorphism. The sequence in the hanging wall of the Panjal fault in the Gandghar Range is argillaceous, has well-developed cleavage, and has undergone greenschist- to lower epidote-amphibolite-facies metamorphism. In contrast, the sequence in the footwall of the Panjal fault in the vicinity of Hasan Abdal and Haripur is arenaceous, lacks cleavage, and contains no metamorphic minerals. The basal sequence of the Gandghar Range is identical to the Manki Formation of the northern Attock-Cherat Range, whereas the basal sequence of the Hasan Abdal-Haripur area is identical to the Dakhner Formation of the central Attock-Cherat Range. Therefore, the basal sequence exposed on the north (hanging wall) side of the Panjal fault should be referred to as "Manki Formation," restricting the term "Hazara Formation" to the basal sequence exposed on the south (footwall) side of the Panjal fault. As suggested by Yeats and Hussain (1987), the Hazara Formation is correlative with the Dakhner, as one can be traced into the other.

Marks and Ali (1961) likened the Hazara to the Alpine flysch, suggesting that the Hazara was formed under marine geosynclinal conditions with rapid subsidence and sedimentation. Calkins and others (1975) suggested that the Hazara was probably a shallow-water deposit, noting the presence of limestone, graphite, and gypsum. Davies (1963) and Latif (1969) divided the Hazara Formation in the Haripur-Abbottabad area into two separate facies. The southern facies, dominated by arenaceous strata with subordinate algal limestone and gypsum, exhibits cross bedding, interference- and oscillation-ripple marks, and desiccation cracks, and is probably a shallow-water deposit (Latif, 1969). In contrast, the northern facies is dominated by argillaceous strata, exhibits graded bedding, flute casts, flow casts and fucoids, is devoid of cross bedding, ripple marks, desiccation cracks, algal limestone or gypsum, and is probably a deep-water deposit (Latif, 1969). This suggests that the Manki and Hazara formations were deposited on the north-facing slope of a passive continental margin, or possibly an epicontinental sea. To the south, in the

Potwar Plateau and Salt Range, Precambrian strata are continental and include a thick sequence of evaporites (Salt Range Formation). Tahirkheli (1982) suggested that the Manki Formation of the Attock-Cherat Range is correlative with the Hazara Slate (Hazara Formation) of the Hazara district, and Yeats and Hussain (1987) suggested that the Manki and Dakhner formations may be stratigraphically equivalent. The strong similarities between the Hazara Formation and the protolith of the Manki Formation support both of these suggestions.

As discussed above, two distinctive limestone beds are enclosed within the Hazara Formation near Miranjani and Langrial in southeast Hazara. The lithologic characteristics of the Miranjani and Langrial limestones, as described by Latif (1969), are strikingly similar to the limestones of the Shahkot and Utch Khattak formations, respectively. Additionally, a limestone bed within the Dakhner Formation in the Attock-Cherat Range is similar to the Utch Khattak limestone, based on lithology and the presence of poorly preserved stromatolites (A. Hussain, written communication, 1989). Given the apparent stratigraphic equivalence of the Manki and Hazara-Dakhner formations, it is suggested that the Miranjani and Langrial limestones are directly correlative with the limestones of the Shahkot and Utch Khattak formations, respectively. Figure 14 shows a possible pre-thrust configuration of the Precambrian rocks on either side of the Panjal fault. If these relationships prove to be correct, then the limestones serve as excellent marker beds and may be useful in determining the amount of stratigraphic separation along the Panjal fault.

As shown in Figure 15, the Shahkot, Utch Khattak, and Shekhai formations are easily correlated between the northern Attock-Cherat Range and the southern Gandghar Range. These formations, however, are not present in the hanging wall of the Panjal fault northeast of the Gandghar Range. The oldest rocks exposed east of Tarbela Lake in the vicinity of Sherwan belong to the Precambrian(?) Tanawal Formation (Calkins and others, 1975). Quartzite in the northern Gandghar Range, which presumably overlies the Shekhai Formation, has been correlated with the Tanawal Formation (Tahirkheli and Majid, 1977). Therefore, the absence of pre-Tanawal strata in the Sherwan area can be attributed to the northeast plunge of the Gandghar Range structures. The Manki Formation is exposed in the hanging wall of the Panjal fault northeast of Abbottabad. In this area, the Manki is conformably overlain by the Tanawal Formation, the contact being marked only by a lithologic change from slate to quartzite; in several places the contact is gradational (Calkins and others, 1975). Therefore, the Shahkot, Utch Khattak, and Shekhai formations were

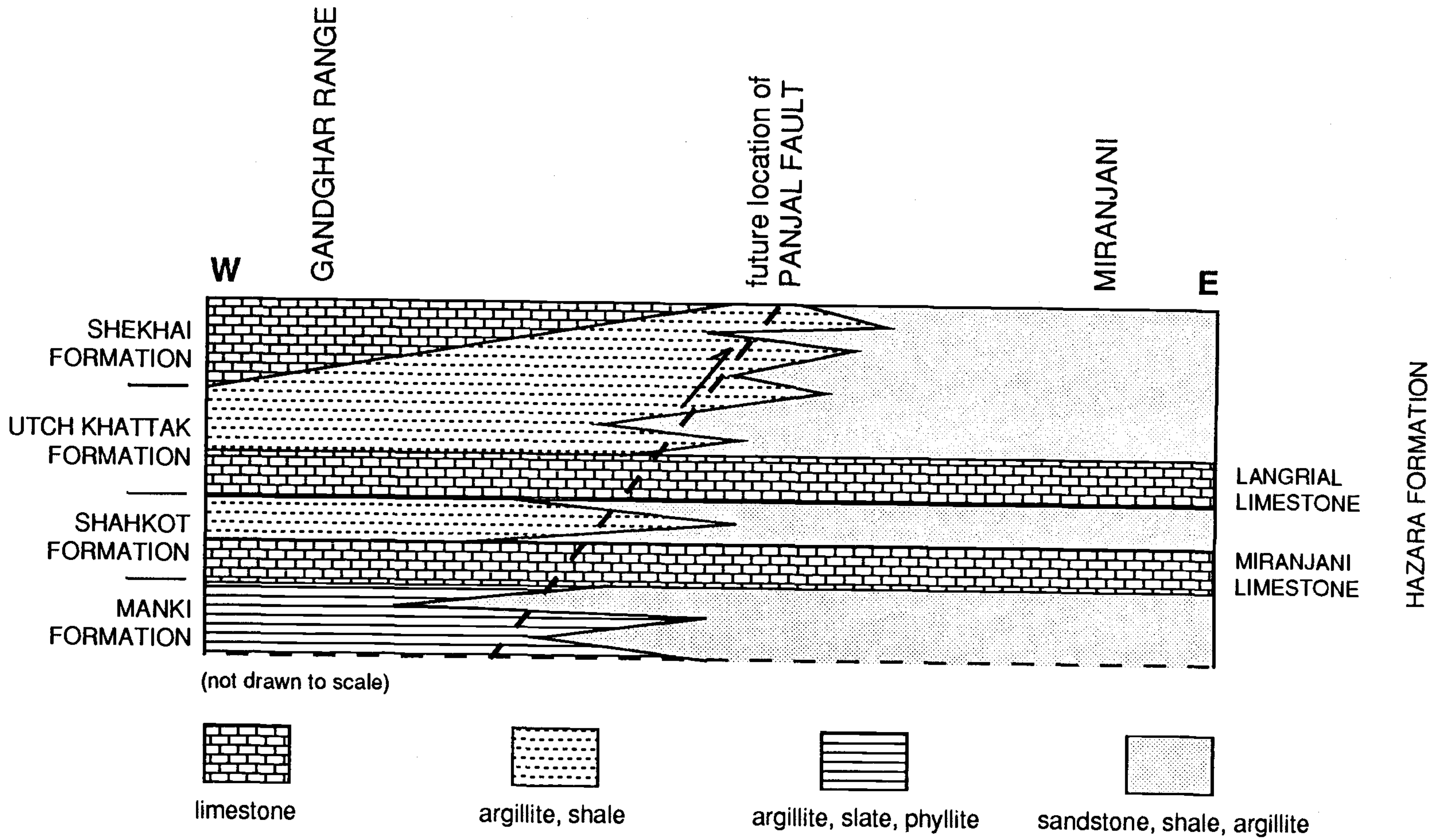

Figure 14. Proposed pre-thrust stratigraphic relationships of Precambrian rocks on either side of the Panjal fault. Miranjani and Langrial limestones are considered to be correlative with the limestones of the Shahkot and Utch Khattak formations, respectively.

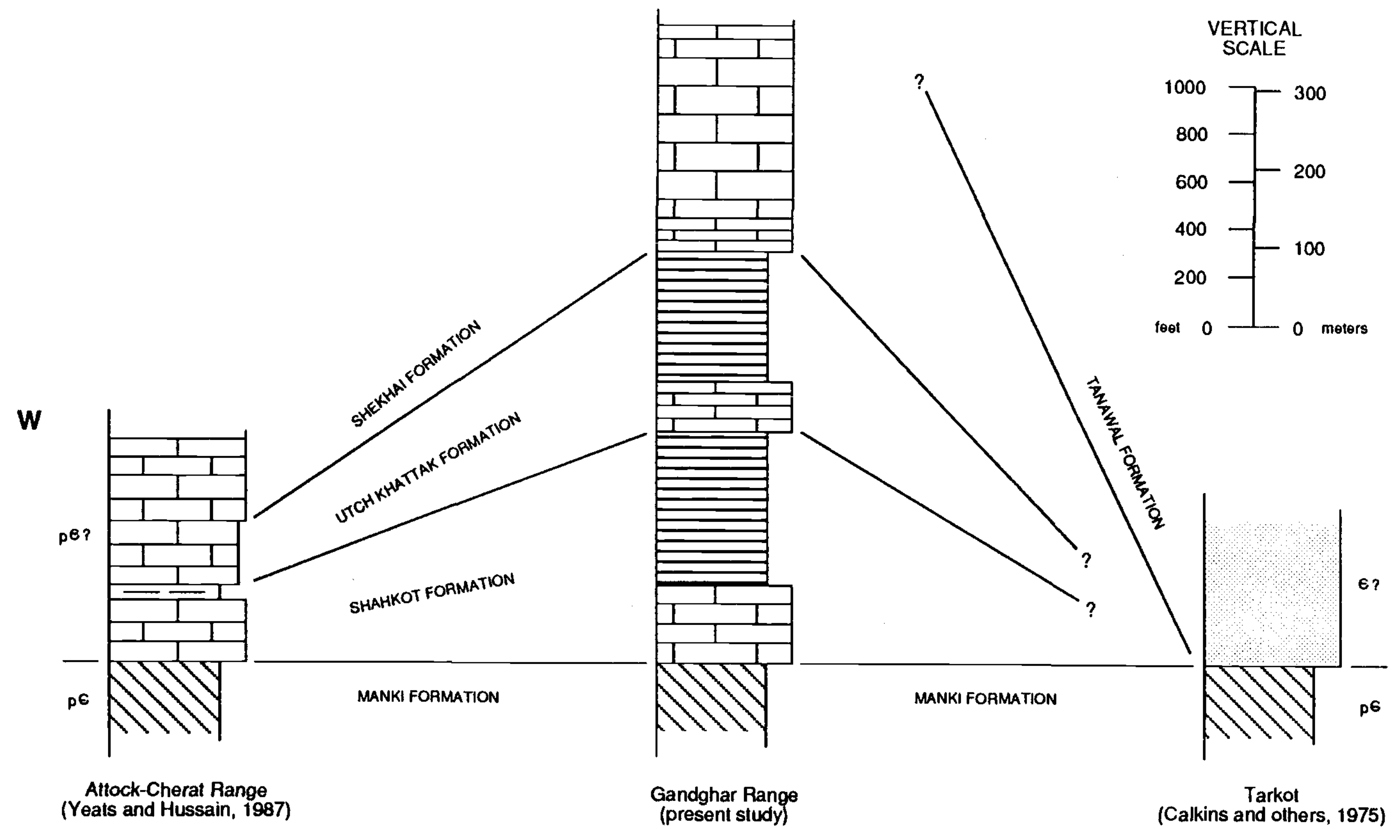

Figure 15. Correlation of stratigraphic successions in the northern Attock-Cherat Range, southern Gandghar Range, and Tarkot area. All successions occur in hanging wall of Khairabad-Panjal fault.

either not deposited in this area or were completely removed by erosion prior to deposition of the Tanawal Formation.

The Shahkot-Shekhai succession is a product of shallow marine deposition. The algal nature of the limestone in the Shahkot and Utch Khattak formations, the presence of quartzite and oolitic limestone in the Shekhai Formation, and the significant volume of shale in all three formations suggest that they were deposited in an intertidal-flat environment. Since the Manki Formation appears to be a deep-water deposit, the complete succession records a general shallowing of the depositional basin. The basal contact of the Tanawal Formation, which in some places is an unconformity marked by a boulder conglomerate and in others is a gradational contact marked only by a lithologic change from slate to quartzite (Calkins and others, 1975), indicates local cessation of marine deposition.

CORRELATIONS AND DEPOSITIONAL HISTORY OF THE ROCKS IN THE FOOTWALL OF THE PANJAL FAULT

At Sirban Hill near Abbottabad, the Hazara Formation is unconformably overlain by the Cambrian Abbottabad Group (Latif, 1970). Across most of southeast Hazara, however, Paleozoic rocks are absent, the Hazara Formation being directly overlain by Jurassic strata (Latif, 1970, 1980). As shown in Figure 16, bedrock formations from a representative stratigraphic section at Thandiani are easily correlated with the rocks of the Kherimar Hills. A slightly different succession occurs in the central block of the Attock-Cherat Range, where the Dakhner Formation is unconformably overlain by either Cretaceous strata or the Lockhart Limestone, and the Patala Formation is overlain by Murree redbeds (Yeats and Hussain, 1987). The presence of the Murree Formation in the Attock-Cherat Range is unusual, since these rocks are not preserved north of the Murree fault in southeast Hazara or north of the Main Boundary thrust in the Kala Chitta Range. One possibility is that the Murrees of the Attock-Cherat Range, like those of the Hazara-Kashmir syntaxis, are Paleocene in age. The present distribution of the Murree Formation is most likely a function of a complicated series of events, including deposition of the rocks at different times in different places and preservation or erosion due to differential uplift along one or several thrust faults.

As discussed above, the Hazara Formation is composed of both deep- and shallow-water facies, and the entire formation is unconformably overlain by younger

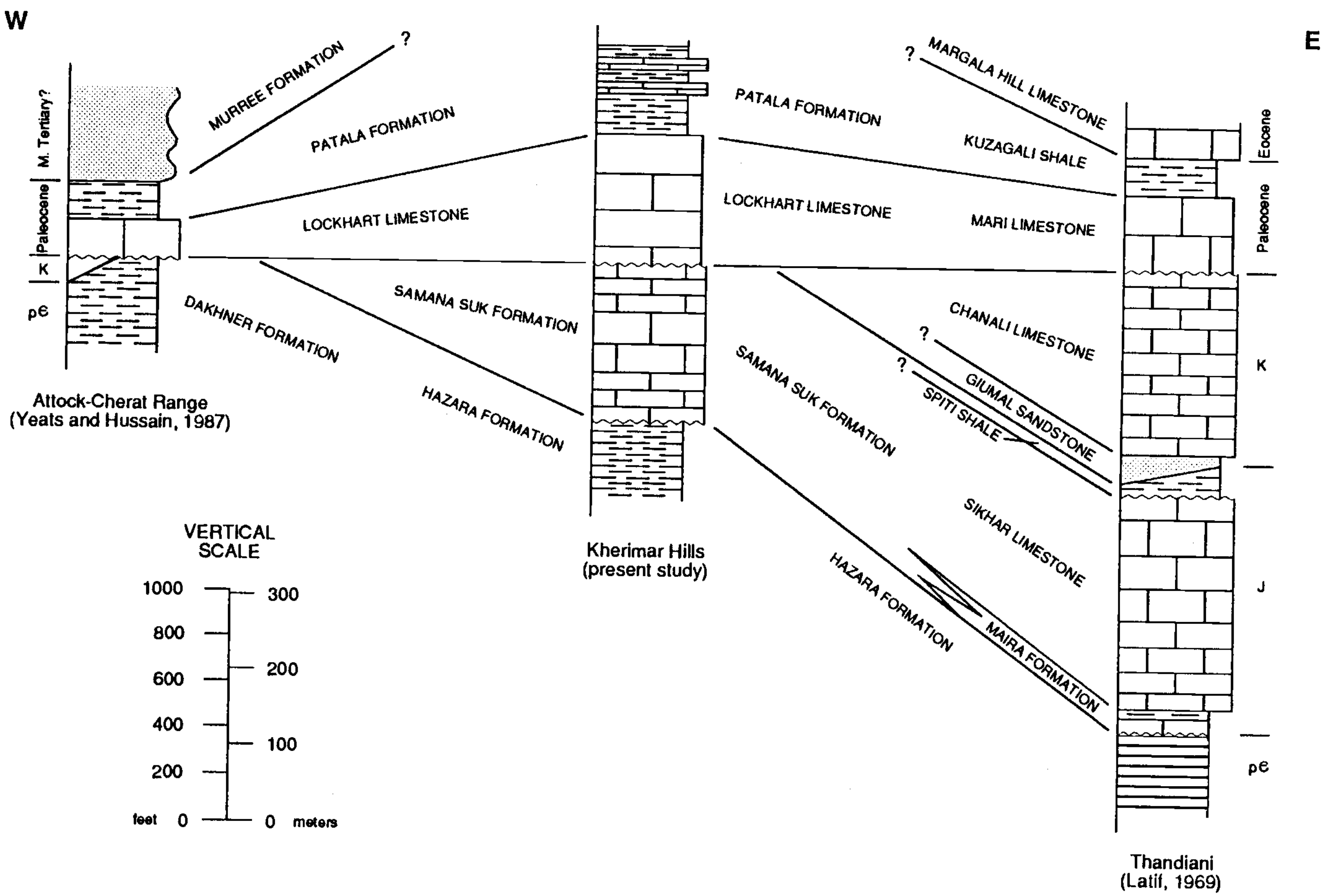

Figure 16. Correlation of stratigraphic successions in the central Attock-Cherat Range, Kherimar Hills, and Thandiani area. All successions occur in footwall of Khairabad-Panjal fault.

rocks. According to Latif (1969), both the unconformity below the Cambrian Abbottabad Group and below Jurassic strata are angular. This relationship and the absence of the entire Paleozoic section in most of southeast Hazara indicate significant regional tectonism prior to deposition of Jurassic strata. The extended period of non-deposition and/or erosion resulted in a landscape of considerable relief upon which Jurassic marine strata were deposited. The fossil fauna and sedimentary structures of the Samana Suk Formation indicate deposition under shallow marine conditions.

The well-developed laterite at the base of the Lockhart Limestone indicates a period of weathering in warm climatic conditions. In addition to laterite at the base of the Mari Limestone, Latif (1969) observed bituminous shale and coal, oolitic hematite, sandy and oolitic shale, and limonite in the lower Paleocene of southeast Hazara. This led him to suggest that deposition of the lower part of the Mari Limestone occurred in deltaic or near-shore environments, and that the bulk of Mari-Lockhart deposition occurred after a marine transgression. The fauna and abundance of shale in the Patala Formation indicate that these rocks were deposited under relatively shallow marine conditions, suggesting that a marine regression occurred after deposition of the Lockhart Limestone (Latif, 1969).

IMPLICATIONS OF STRUCTURE AND METAMORPHISM

Tahirkheli (1971) correlated the rocks of the Gandghar Range with lithologically similar units in the Attock-Cherat Range and also implied that the two ranges were related structurally. More recently, detailed mapping in the Attock-Cherat Range led Hussain (1984) to reverse the relative stratigraphic positions of the Manki Slate (Manki Formation) and Shahkotbala Formation (Shahkot Formation) established by Tahirkheli (1970), and Yeats and Hussain (1987) provided a structural framework with which to compare the Attock-Cherat Range and the Gandghar Range. It is now apparent that the stratigraphic successions of the Gandghar Range and the northern block of the Attock-Cherat Range are identical. Furthermore, the central block of the Attock-Cherat Range, separated from the northern block by the Khairabad fault, contains a stratigraphic succession similar to that of the Kherimar Hills. This supports the suggestion by Yeats and Hussain (1987) that the Khairabad fault is the western continuation of the Panjal fault, and indicates that the Khairabad-Panjal fault juxtaposes two major, laterally continuous structural blocks along its combined length. Similarly, the stratigraphic successions exposed in the footwalls of the Nathia Gali and Hissartang faults are virtually identical (Figure 17), indicating that another laterally continuous structural block exists south of these faults in the Margala Hills and Kala Chitta Range.

The Paleocene Lockhart Limestone is common to the structural blocks on either side of the Hissartang, Cherat, and Nathia Gali faults, and the overlying successions in these blocks are similar. Across the Hissartang and Cherat faults, pre-Lockhart successions vary considerably, indicating large amounts of pre-Paleocene displacement along the faults with juxtaposition of the successions after deposition of Upper Cretaceous strata but prior to Lockhart deposition (Yeats and Hussain, 1987). The pre-Paleocene tectonic event may have been the obduction of Kohistan island-arc crust over the west-northwest-facing Mesozoic passive margin of the Indian plate. This event has been dated at 75-80 Ma based on ages of blueschist metamorphism at the Main Mantle thrust (Maluski and Matte, 1984). Alternatively, Yeats and Hussain (1987) have suggested that the tectonic event was younger than Kohistan island-arc obduction and may have been a collision between the Indian plate and microcontinents. Across the Nathia Gali fault, pre-Paleocene successions are similar at least to the level of the Jurassic Samana Suk Formation. This suggests that most of the displacement along the Nathia Gali fault is pre-Samana Suk. If displacement occurred along the Nathia Gali fault in conjunction with the Late Cretaceous collision event, it was small compared to that which occurred along the Hissartang and Cherat faults.

Although an angular unconformity at the base of the Paleocene is not demonstrated within the present study area, the unconformity is undeniably angular on a regional scale. Yeats and Hussain (1987) documented an angular unconformity at the base of Paleocene strata in the Attock-Cherat Range, Potwar Plateau and Salt Range. The Paleocene overlaps Cretaceous to Permian strata in an east-southeasterly direction across the Potwar Plateau and directly overlies Cambrian strata in the easternmost Salt Range, indicating a west dip of pre-Paleocene strata (Yeats and Hussain, 1987). In contrast, the Paleocene north of the Main Boundary thrust and Murree fault rests on Cretaceous strata in both the Margala Hills and Kala Chitta Range (Figure 17). The Lockhart locally rests on older strata in the Kala Chitta Range close to the Hissartang fault, indicating a south dip of pre-Paleocene strata near the Hissartang fault (Yeats and Hussain, 1987). North of the Hissartang and Nathia Gali faults, the Paleocene overlaps Cretaceous and Jurassic strata in a westerly

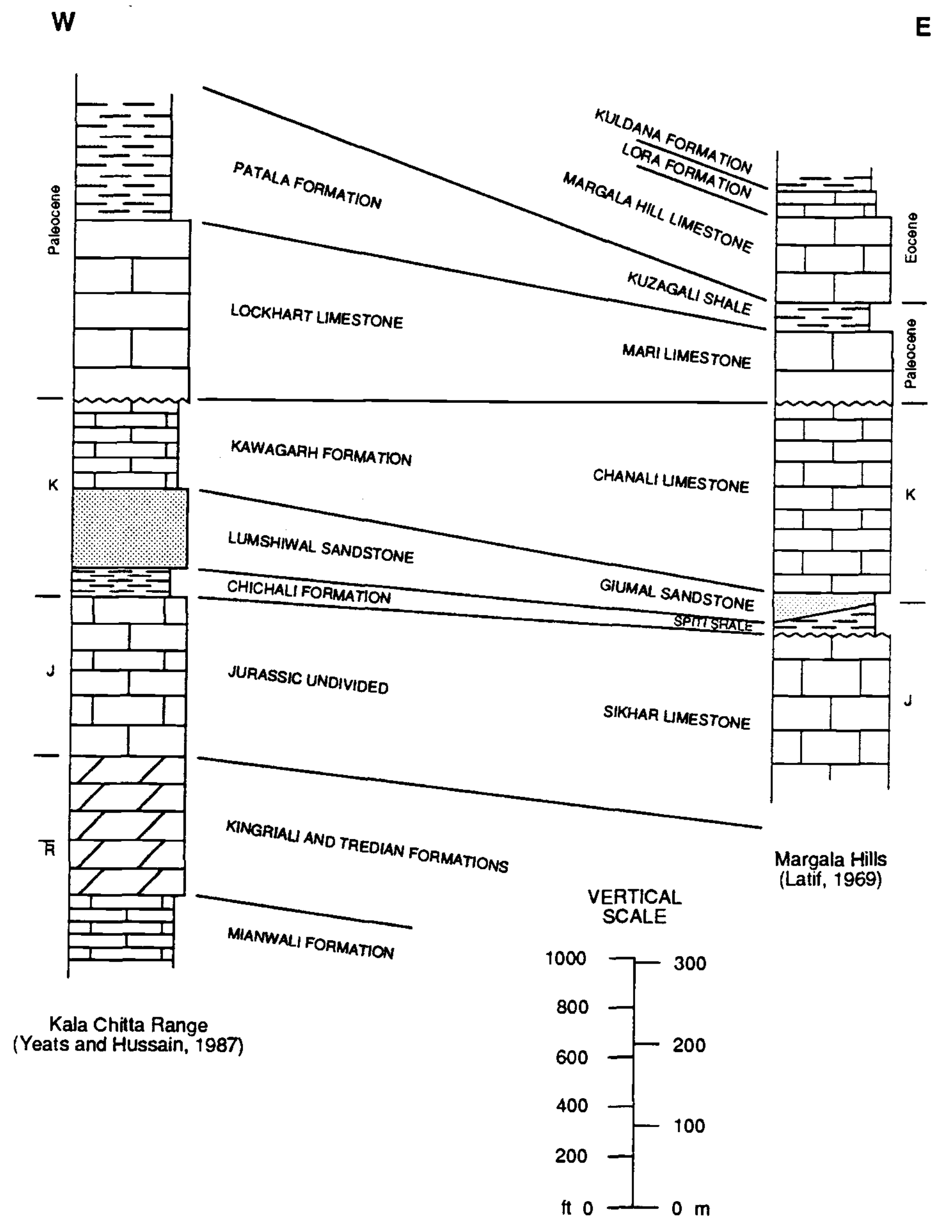

Figure 17. Correlation of stratigraphic successions in the Kala Chitta Range and Margala Hills. Kala Chitta Range succession occurs in footwall of Hissartang fault, and Margala Hills succession occurs in footwall of Nathia Gali fault.

direction across southeast Hazara and directly overlies Precambrian strata in the Attock-Cherat Range, indicating an east dip of pre-Paleocene strata (Figure 16). These relationships, which are summarized in Figure 18a, suggest that the individual structural blocks juxtaposed along the Main Boundary thrust and Murree, Hissartang, and Nathia Gali faults responded differently to the Late Cretaceous collision event. Apparently, the southern block underwent westward tilting, whereas the northern block underwent eastward tilting.

A possible mechanism by which opposite senses of dip are produced in nearby thrust sheets during the same tectonic event is illustrated in Figure 18b. In this "pivotal stacking" model, a thick, rectangular sheet of flexible material has two parallel slits, representing incipient faults, that extend from one end of the sheet to near the other end. Semi-horizontal compressive stress is applied to the slit end of the sheet, normal to the slits, so that the ends of the three "arms" of the sheet become stacked upon each other. In this configuration, the top surface of the upper "arm" dips in one direction, the middle "arm" is horizontal, and the top surface of the lower "arm" dips in the opposite direction as that of the upper "arm." Also, since horizontal compressive stress is applied only to the slit end of the sheet, the displacement along the faults is rotational about a vertical pivot; the amount of displacement decreases toward the pivot. The "arms" of the sheet are directly analogous to the crustal blocks bounded by the Main Boundary thrust and Murree, Hissartang, and Nathia Gali faults, both in terms of the dip of pre-Paleocene strata and the relative amounts of displacement along the faults. The larger amount of post-Samana Suk, pre-Paleocene displacement along the Hissartang and Cherat faults as compared with the Nathia Gali fault suggests that horizontal compressive stress was concentrated to the west.

The Hissartang and Cherat faults were reactivated after deposition of the Murree Formation, but this displacement is small (Yeats and Hussain, 1987). Presumably, the Nathia Gali fault was reactivated at about the same time, although the absence of the Murree Formation in southeast Hazara precludes the precise timing of Tertiary faulting. The similarity in facies of Tertiary strata on either side of the Nathia Gali fault indicates that, like the Hissartang and Cherat faults, Tertiary displacement is small relative to the pre-Paleocene displacement.

Figure 19 shows a possible reconstruction of a hinterland-dipping duplex composed of the Hill Ranges fault system. This reconstruction is based on the interpretation of the Hazara-Kashmir syntaxis as a north-plunging anticlinorium folding the Murree and Panjal faults (Coward and others, 1982; Bossart and others,

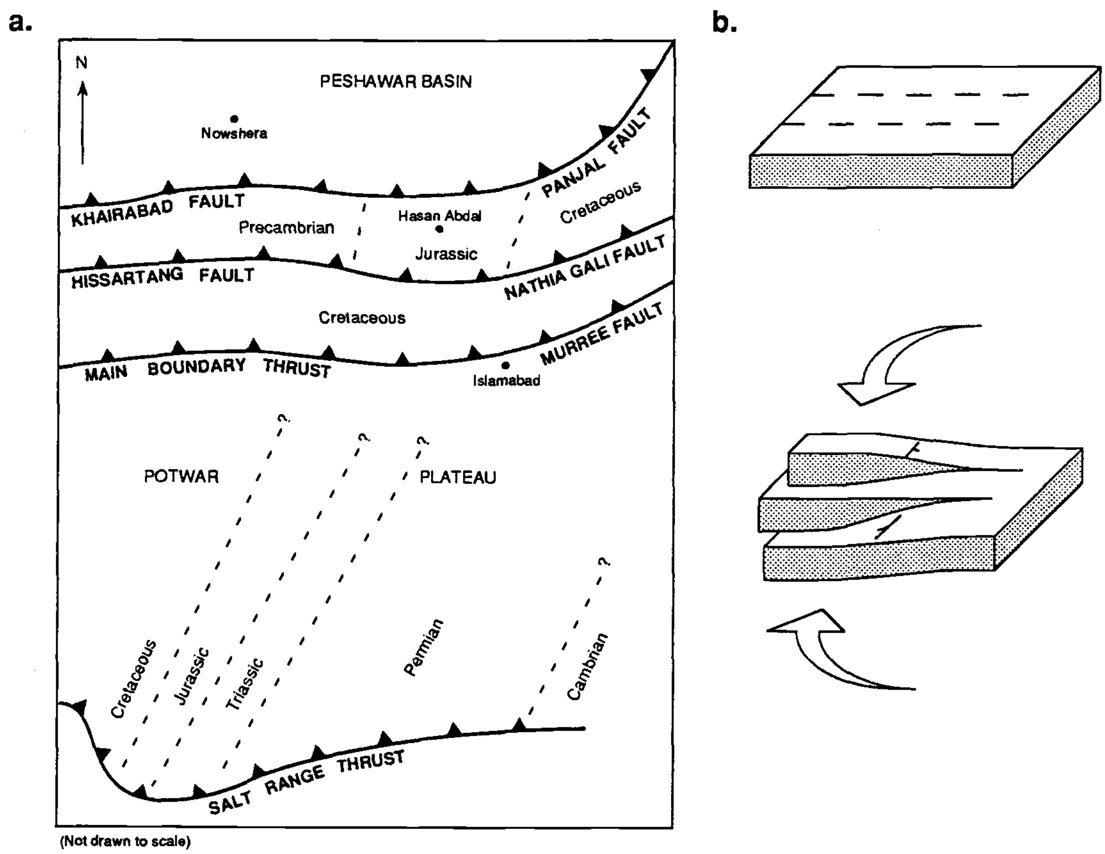

Figure 18. (a) Sketch map showing subcrop boundaries of strata beneath Paleocene. Pre-Paleocene strata south of Main Boundary thrust - Murree fault dip west; pre-Paleocene strata north of Hissartang and Nathia Gali faults dip east. Potwar Plateau data from Yeats and Hussain (1987). (b) Block diagram illustrating how "pivotal stacking" produces opposite sense of dip in nearby thrust sheets. Note that amount of displacement along thrusts decreases toward pivot.

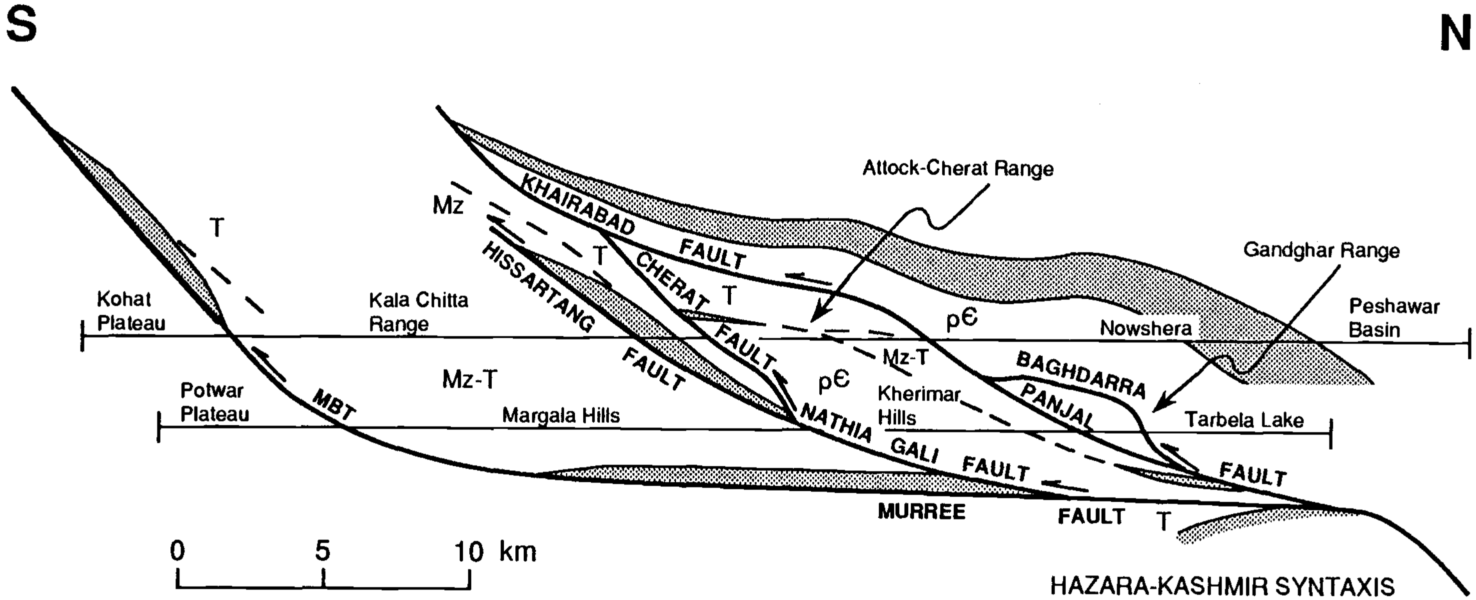

Figure 19. Possible configuration of hinterland-dipping duplex in the Hill Ranges. pЄ = undifferentiated Precambrian rocks, including the Manki, Hazara, Dakhner, Shahkot, Utch Khattak, and Shekhai formations; Mz-T = Mesozoic to Tertiary strata (not including Murree Formation); T = Tertiary strata (including Murree Formation); shaded areas represent Paleozoic strata. MBT = Main Boundary thrust. Upper horizontal line represents line of section extending from Kohat Plateau to Peshawar basin. Lower horizontal line represents line of section extending from Potwar Plateau to Tarbela Lake. Sequential restoration of duplex illustrated in Figure 20. Modified from Yeats and Hussain (1987).

1988). A down-structure view of the west flank of this anticlinorium shows the Panjal and Nathia Gali faults to merge with the younger Murree fault, which comprises the floor thrust of the imbricate stack. Map relations farther west can be seen as structurally higher features in cross section. The lower horizontal line in Figure 19 represents a line of cross section from the Potwar Plateau to Tarbela Lake, and the upper horizontal line represents a line of cross section from the Kohat Plateau to the Peshawar basin. Map patterns suggest that syntaxis-related folding does not affect rocks west of the Attock-Cherat Range. Therefore, structures above the upper horizontal line in Figure 19 are projected above the present ground surface and represent rocks that have been removed by erosion.

Using the Paleozoic section for control, the minimum horizontal separation on the Hill Ranges fault system can be estimated if three assumptions are made. First, the Paleozoic succession in the Peshawar basin near Nowshera is assumed to be correlative with the unfossiliferous Paleozoic(?) succession in the hanging wall of the Hissartang fault and correlative at least in part with the Cambrian Abbottabad Group, as suggested by Pogue and Hussain (1986). Second, Paleozoic rocks are assumed to be present in the subsurface in the hanging wall of the Main Boundary thrust - Murree fault. This condition is suggested by the presence of rocks as old as Triassic exposed in the Kala Chitta Range. Third, Paleozoic rocks are assumed to have been present in the hanging wall of the Main Boundary thrust but were subsequently removed by erosion. The basis for this assumption is discussed below. These rocks are shown in Figure 19 as the Paleozoic strata in the hanging wall of the Main Boundary thrust above the upper horizontal line.

Figure 20 illustrates the sequential restoration of the Hill Ranges duplex. Based on the projected Paleozoic hanging-wall and footwall cutoffs, the calculated minimum horizontal separations are 40 km on the Main Boundary thrust - Murree fault, 19 km total on the Hissartang, Cherat, and Nathia Gali faults, and 26 km on the Khairabad-Panjal fault. The estimated total minimum horizontal separation of 85 km on the Hill Ranges fault system may be considerably less than the actual total separation, since the intersection of the Cherat and Khairabad faults and the locations of Paleozoic cutoffs above the upper horizontal line on Figure 19 are highly speculative. Also, since internal deformation of the various crustal blocks was not considered, the total horizontal separation is probably considerably less than the total amount of shortening across the Hill Ranges.

Figure 20. Sequential restoration of Hill Ranges duplex shown in Figure 19. (a) Restoration of Main Boundary thrust (MBT) - Murree fault involves matching postulated Paleozoic in the hanging wall (see discussion in text) with Muzaffarabad Paleozoic in the footwall. Horizontal separation = 40 km. (b) Restoration of Hissartang, Cherat, and Nathia Gali faults involves matching unfossiliferous Paleozoic(?) in the hanging wall of the Hissartang fault with Paleozoic presumed to be in the subsurface above the Murree fault, and matching postulated Paleozoic in the hanging wall of the Cherat fault with Paleozoic(?) above the Hissartang fault. Total horizontal separation = 19 km. (c) Restoration of Khairabad-Panjal fault involves matching Nowshera Paleozoic in the hanging wall with Abbottabad Paleozoic in the footwall. Horizontal separation = 26 km. Total minimum horizontal separation on Hill Ranges fault system is 85 km. Horizontal separation on Baghdarra fault is not calculated due to lack of control.

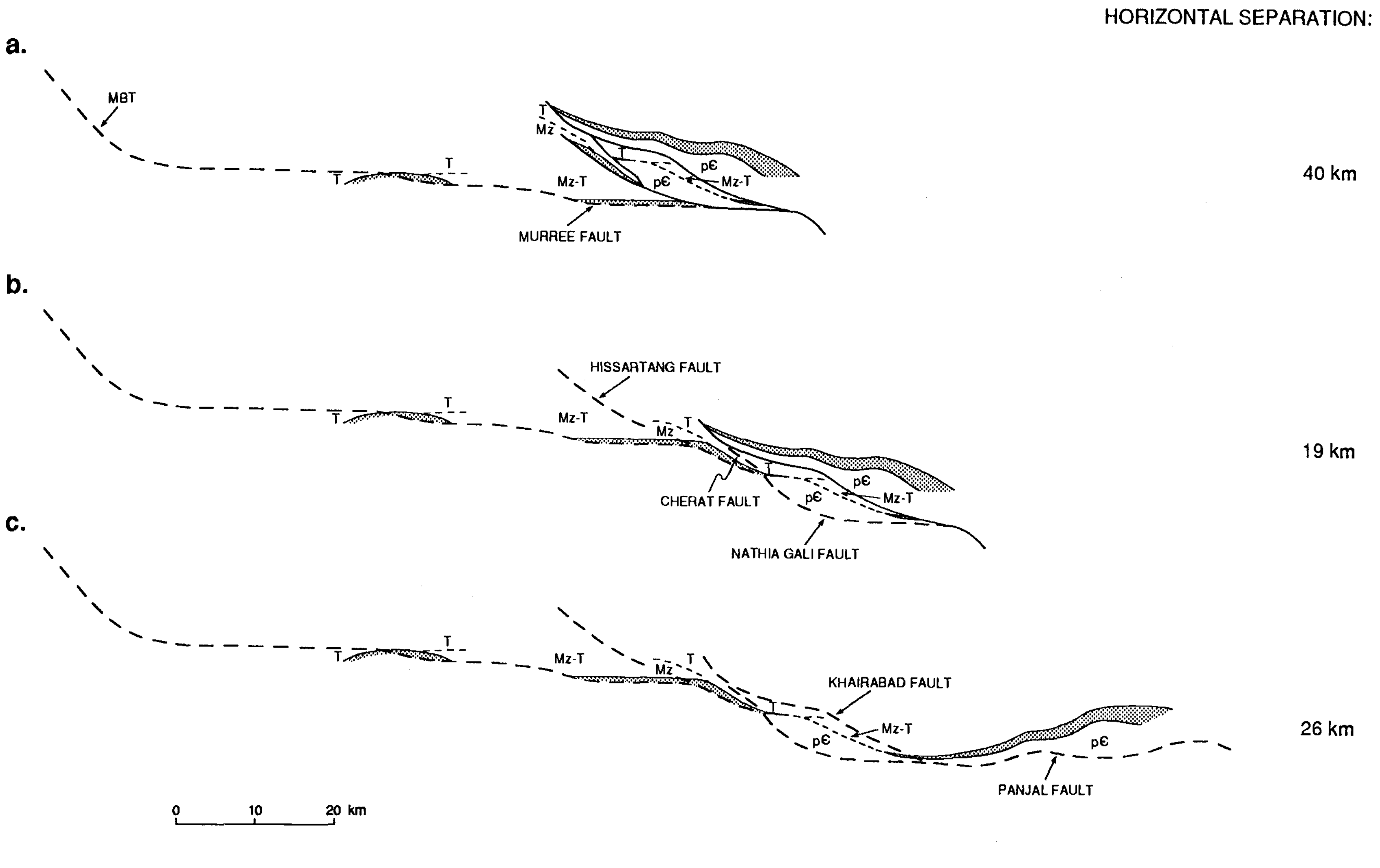

Figure 20. See caption on page 59.

The horizontal separation on the Hill Ranges fault system calculated above is similar to that calculated by Yeats and Hussain (1987). However, there are two important differences between the balanced cross section shown in Figure 19 and that of Yeats and Hussain (1987, their Figure 10). First, the geometric configuration of the imbricate stack is different. Rather than being separate splays off of the Panjal fault, the Cherat and Hissartang faults are interpreted as bifurcations of the Nathia Gali fault. Second, Yeats and Hussain (1987) do not consider Paleozoic strata that occurs in the footwall of the Murree fault. The Cambrian Abbottabad Group is exposed in the western part of the apex region of the Hazara-Kashmir syntaxis, in the cores of the Muzaffarabad and Balakot anticlines (Calkins and others, 1975; Ghazanfar and others, 1986). Here, the Abbottabad Group is directly overlain by Paleocene strata which in turn are overlain by the Murree Formation, which is of Late Paleocene - Middle Eocene age in this area (Ghazanfar and others, 1986; Bossart and Ottiger, 1989). To successfully restore movement along the Main Boundary thrust - Murree fault, the Abbottabad Group must be matched with a sequence of Cambrian rocks directly overlain by Tertiary strata in the hanging wall of the fault. Since the postulated Paleozoic in the subsurface beneath the Margala Hills and Kala Chitta Range successions is overlain by Mesozoic strata, it cannot be used for a successful restoration. Therefore, it is suggested that Cambrian rocks, at least in part directly overlain by Tertiary strata, existed in the hanging wall of the fault and have subsequently been removed by erosion. These postulated Paleozoic strata would satisfy the stratigraphic constraints for successful restoration of the Main Boundary thrust - Murree fault, as shown in Figure 20.

In the northern Gandghar Range, the continuation of the Baghdarra fault has been interpreted in different ways. Tahirkheli (1971) interpreted it as a reverse fault, bringing Manki Formation over younger quartzite, whereas Calkins and others (1975) interpreted it as a normal fault. Additionally, Calkins and others (1975) considered the structure to be a continuation of the Panjal fault. Evidence from the southern Gandghar Range, which includes field relationships and kinematic indicators, supports a reverse sense of motion along the fault and indicates that it is not a continuation of the Panjal fault. Northeast of the Gandghar Range, the trend of the Baghdarra fault is unknown. It may cross the southeast arm of Tarbela Lake and merge with the Panjal fault beneath basin fill north of Haripur, as illustrated in Figure 9, or it may have a more northerly trend, being present but unrecognized in the vicinity of the Sherwan syncline. South of the Gandghar Range, the Baghdarra fault disappears beneath Campbellpore basin fill and presumably rejoins the Panjal fault. These relationships suggest that the Baghdarra and Panjal faults form a horse, as shown in Figure 19.

The amount of displacement along the Baghdarra fault is uncertain, since footwall cutoffs are obscured by basin fill. The Sobrah Formation near Tarbela Dam, considered to be stratigraphically equivalent to the Shekhai Formation (K. R. Pogue, personal communication), occurs in the hanging wall of the fault and is considerably thinner than the Shekhai Formation in the footwall of the fault. Northeast of the Gandghar Range, it is likely that the Baghdarra fault juxtaposes Tanawal Formation against Tanawal Formation, assuming the Baghdarra fault crosses the southeast arm of Tarbela Lake south of the Sherwan syncline. Whereas both of these conditions argue against large amounts of stratigraphic separation, they do not preclude large amounts of horizontal separation. A strike-slip component of movement may also be present, but probably is not significant relative to the dip-slip component.

Burbank (1982) has implied that uplift of the Gandghar Range occurred in relatively recent times. A heterolithic conglomerate bed within a section of the Campbellpore basin fill along the Haro River contains boulders of diorite and granite up to 3 m in diameter and is directly overlain by normally-magnetized lacustrine sediments (Burbank, 1982). This conglomerate, representing an extra-basinal source area somewhere to the north, was apparently deposited by a fluvial agent more powerful than the modern Haro River. Burbank (1982) suggests that the ancestral Indus River flowed through the eastern Campbellpore basin, as originally suggested by Wynne (1879), and was diverted by uplift of the Gandghar Range sometime during the Brunhes chron. With this in mind, it is interesting to note that uplift of the Attock-Cherat Range apparently occurred in the Pleistocene, as indicated by Jurassic bedrock thrust over fan gravels at the western end of the Nizampur basin (Yeats and Hussain, 1989). Yeats and Hussain (1989) suggested that the Indus River, which cuts across the eastern end of the Attock-Cherat Range, is antecedent to uplift of the range. If the Indus had originally flowed through the eastern Campbellpore basin, it seems likely that it would have cut across the uplifting Gandghar Range in a similar manner. The topography of the northern end of the Gandghar Range, as viewed on maps made prior to the formation of Tarbela Lake, does suggest a river channel cutting across the range. Perhaps this channel was formed by the Siran River, a former tributary of the Indus that now flows into Tarbela Lake. Large floods on the

Indus could easily have travelled the short distance up this channel and then washed down the Campbellpore basin drainage, depositing exotic material along the way.

In terms of regional metamorphism, the biotite-garnet isograd is located considerably north of the Gandghar Range (Calkins and others, 1975), with the majority of Gandghar Range rocks occurring in the chlorite zone of the greenschist facies. Since garnet-bearing rocks in the southern Gandghar Range occur only within the narrow zone adjacent to the Baghdarra fault, it is possible that they are the result of frictional shear heating associated with movement along the fault. Shear heating has been considered to be at least partly responsible for garnet growth in rocks adjacent to the Main Central thrust in Nepal (Arita, 1983) and Alpine fault in New Zealand (Johnston and White, 1983). However, while not precluding local shear heating, recent fission track data indicate that the metamorphic zonation near the Alpine fault is due to differential uplift rates, with maximum uplift occurring adjacent to the fault (Kamp and others, 1989). More work is needed to determine whether the garnet-bearing rocks adjacent to the Baghdarra fault are the result of shear heating or simply represent higher grade rocks from a deeper structural level.

Baig and Lawrence (1987) and Baig and others (1988) have presented evidence for a late Precambrian to Early Cambrian metamorphic episode in Hazara. The Tanakki conglomerate at the base of the Abbottabad Group contains clasts of the underlying Hazara Formation (Latif, 1974). Baig and Lawrence (1987) and Baig and others (1988) report that whereas the clasts of Hazara Formation display cleavage and new metamorphic mica, the matrix does not, indicating that regional metamorphism affected the Hazara Formation prior to deposition of the Abbottabad Group in Cambrian time. In the Haripur and Kherimar hills, however, the Hazara Formation contains no metamorphic minerals and is uncleaved. In the Kherimar Hills, the overlying Samana Suk Formation contains small amounts of detrital epidote, but no metamorphic minerals. Likewise, the Paleocene Lockhart Limestone and Patala Formation are unmetamorphosed. Therefore, there is no evidence that the Kherimar Hills succession, including the Hazara Formation, has been affected by a metamorphic episode of any age. This indicates that the late Precambrian-Early Cambrian metamorphic episode that affected the Hazara Formation near Abbottabad had little or no effect on the Hazara farther south in the Kherimar Hills.

The Kherimar Hills are presently located approximately 65 km southwest of Abbottabad, and restoration of the intervening structures would increase that distance. Coward and Butler (1985) have restored the crustal block bounded by the Panjal fault (their Abbottabad thrust) and Nathia Gali fault to an undeformed width of approximately 160 km. The amount of separation along the major block-bounding faults estimated in this study, however, argues against such a large amount of shortening within a single block. Nevertheless, restoration of the strongly-deformed crustal block would certainly increase its width significantly. Therefore, the occurrence of low-grade metamorphism in the Hazara Formation near Abbottabad and the absence of related metamorphism in the Hazara of the Kherimar Hills can be attributed to the distance that originally separated the two areas.

SUMMARY AND CONCLUSIONS

Meaningful estimates of crustal shortening can only be made with an understanding of the geologic and tectonic history of the area in question. Furthermore, the stratigraphic and structural relationships as determined in the field provide the necessary constraints for a meaningful estimate. In this study, geologic mapping of the southern Gandghar Range and Kherimar Hills served to bridge the gap between the relatively well-understood areas of southeast Hazara to the east and the Attock-Cherat Range to the west. Consequently, the estimated minimum horizontal separation of 85 km on the Hill Ranges fault system is based on a more complete understanding of the geologic and tectonic history of the Hill Ranges as a whole. The geology of the study area, the proposed regional stratigraphic and structural correlations, and the present tectonic setting of the Hill Ranges are summarized in the following paragraphs.

The rocks of the southern Gandghar Range and Kherimar Hills comprise deep- to shallow-marine, Precambrian, Jurassic and Paleogene strata that are transitional between unmetamorphosed foreland-basin strata to the south and high-grade metamorphic and plutonic rocks to the north. The Precambrian Hazara and Manki formations, considered to be stratigraphically equivalent, show an increase in metamorphic grade to the north. In the Kherimar Hills, the Hazara Formation is unmetamorphosed, whereas in the Gandghar Range, the Manki Formation is metamorphosed to the greenschist-lower epidote-amphibolite grade. Younger strata in both areas show little to no evidence of metamorphism.

Three major reverse faults, the Baghdarra, Panjal, and Nathia Gali, can be identified in the study area. In the Gandghar Range, the Baghdarra fault brings Proterozoic and Paleozoic strata of the eastern Peshawar basin over a succession composed of the Precambrian Manki Formation and Proterozoic(?) limestone. The amount of separation on the Baghdarra fault is uncertain due to obscured footwall cutoffs. However, the contrast in thickness between the Proterozoic(?) limestones in the hanging wall and footwall of the Baghdarra fault indicates a large amount of displacement along the fault. The garnet-bearing rocks adjacent to the Baghdarra fault are S-C tectonites, using the classification of Lister and Snoke (1984). The occurrence of these rocks is significant in that they indicate a zone of non-coaxial laminar flow, suggesting that displacement along the Baghdarra fault has been characterized by both brittle and plastic deformation.

South of the Gandghar Range, the Panjal fault brings the Gandghar Range succession over the Kherimar Hills succession, which is composed of Precambrian flysch overlain by Jurassic and Paleogene carbonates. The Panjal fault is significant in that the Precambrian(?) Tanawal Formation is a dominant constituent of the hanging wall, but is not present in the footwall. Also, the Panjal fault, which is correlative with the Khairabad fault in the Attock-Cherat Range, marks the boundary between the Precambrian Manki and Hazara formations, with Manki occurring in the hanging wall and Hazara occurring in the footwall. South of the Kherimar Hills, the Nathia Gali fault brings the Kherimar Hills succession over the Margala Hills succession. The Nathia Gali fault is significant in that the Hazara Formation is widespread in outcrop in the hanging wall, but is not exposed in the footwall. To the west, the Cherat and Hissartang faults are considered to be bifurcations of the Nathia Gali fault. The Paleocene Lockhart Limestone is common to the stratigraphic successions on both sides of the Hissartang, Cherat, and Nathia Gali faults. Pre-Paleocene sequences differ across the Hissartang and Cherat faults, indicating large amounts of displacement and juxtaposition of the successions in Late Cretaceous time. Across the Nathia Gali fault, pre-Paleocene sequences are similar at least to the level of the Jurassic Samana Suk Formation. This suggests that most of the displacement along the Nathia Gali fault is pre-Samana Suk. Pre-Paleocene displacement on the Khairabad-Panjal fault cannot be demonstrated due to the absence of Tertiary strata to the north.

The present tectonic setting of the study area is thin-skinned thrusting involving both seismic and aseismic deformation. In contrast to the northeast trend of surface structures, deep-crustal seismicity defines two major northwest-trending fault zones, interpreted as buried northwest extensions of the Himalayan frontal faults beyond the Hazara-Kashmir syntaxis (Seeber and Armbruster, 1979; Seeber and others, 1981). The lack of correlation between deep and shallow structures indicates the presence of a detachment surface beneath the Hill Ranges that separates basement from the overlying sedimentary wedge (Seeber and others, 1981). The detachment, which is well constrained by microearthquake data at a depth of about 12 km in Hazara (Seeber and others, 1981), coincides with a low-velocity layer (A. Marussi, personal communication, to Seeber and others, 1981). The presence of gypsum in the Hazara Formation near Muzaffarabad (Latif, 1969; Calkins and others, 1975) strongly suggests that the Eocambrian evaporites of the Salt Range extend north to Hazara (Latif, 1970) and coincide with the detachment beneath the Hill Ranges (Seeber and others, 1981).

A summary of the stratigraphic relationships within the sedimentary wedge is shown in Figure 21, which is based on the restoration of the balanced cross section presented in Figure 19. Cambrian and Permian strata of the central and eastern Salt Range, which are directly overlain by Tertiary strata (Gee, 1989), extend northward in the subsurface of the Potwar Plateau (Lillie and others, 1987; Baker and others, 1988; Pennock and others, 1989). The Cambrian Jhelum Group is considered to be correlative with the Cambrian Abbottabad Group exposed in the Muzaffarabad area; the Salt Range Permian was evidently removed by the unconformity at the base of the Tertiary. North of Muzaffarabad, a fairly complete Mesozoic section has been preserved in the Margala Hills and Kala Chitta Range in a wedge that pinches out to the north in the Attock-Cherat Range. The future Murree fault will develop within the Paleozoic section and propagate through this Mesozoic wedge. The Paleozoic section pinches out in the Attock-Cherat Range north of the future Cherat fault, so that Tertiary strata locally rest on Precambrian rocks (Yeats and Hussain, 1987). Farther north at Abbottabad, the Cambrian Abbottabad Group is overlain by Mesozoic strata (Latif, 1974). At Nowshera, a Lower to Middle Paleozoic sequence is exposed, and Upper Paleozoic to Triassic strata occur in the northern Peshawar basin (Pogue and others, in review). These relationships suggest that Mesozoic strata were continuous across what is now the Peshawar basin, and were subsequently removed by uplift and erosion.

South of the future location of the Khairabad-Panjal fault, Precambrian strata comprise a shallow marine arenaceous facies. These rocks interfinger with Eocambrian evaporites to the south and grade into a deeper water argillaceous facies to the north, which is overlain by shallow water carbonates and clastics. These Precambrian deposits may have formed the floor of a shallow epicontinental sea in which the Paleozoic section was deposited, as suggested by Pogue and others (in review). The true Tethyan passive continental margin probably developed during the early Mesozoic, after rifting and eruption of the Permian Panjal Volcanics (Searle and others, 1987). Mesozoic rocks in the Surghar Range and western Salt Range are typically terrigenous, whereas equivalent rocks in the Kala Chitta succession are mainly carbonates (Meissner and others, 1973; Yeats and Hussain, 1987). Also, the Permian-Eocene succession in the Salt Range becomes thicker and more complete

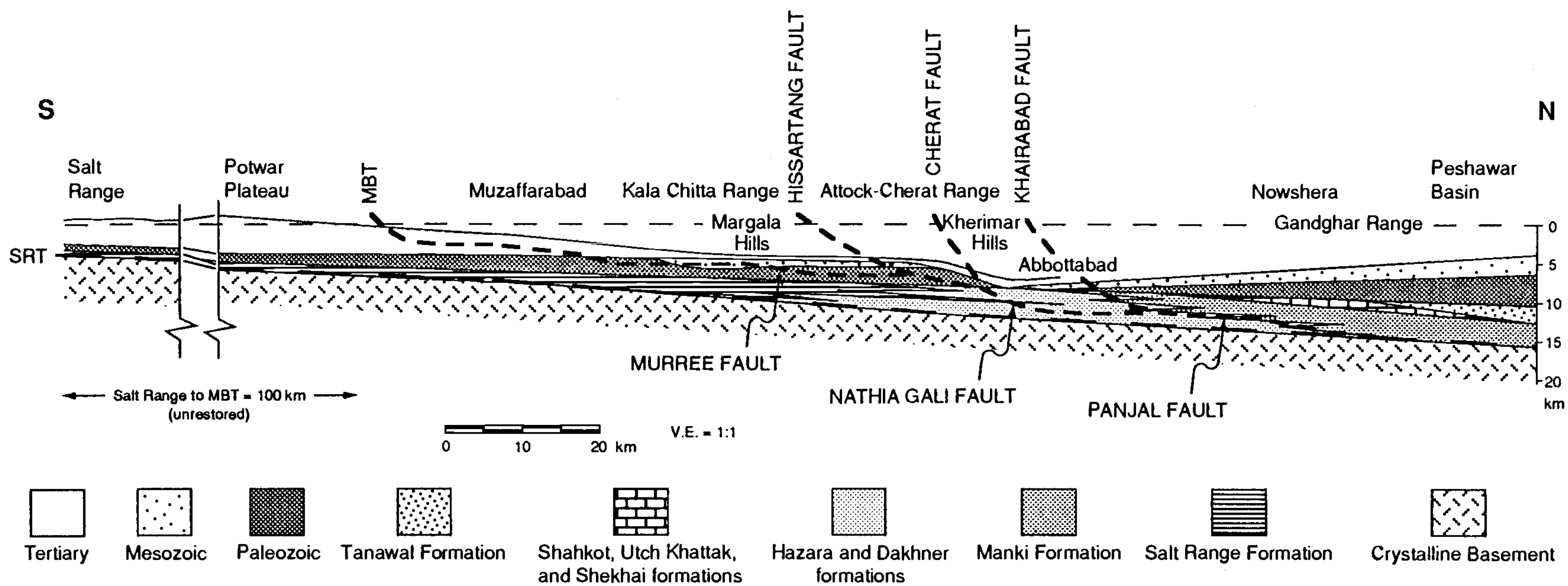

Figure 21. Stratigraphic relationships of Hill Ranges strata above detachment surface at base of sedimentary wedge, based on restoration of the balanced cross section shown in Figure 19. Future locations of faults shown by heavy dashed lines. MBT = Main Boundary thrust; SRT = Salt Range thrust . Section is telescoped between Salt Range and northern Potwar Plateau. Paleozoic rocks at Muzaffarabad are considered correlative with Salt Range Paleozoic. Salt Range and Potwar Plateau stratigraphy compiled from Lillie and others (1987), Baker and others (1988), Gee (1989), and Pennock and others (1989).

from east to west (Fatmi and others, 1984; Yeats and Hussain, 1987). These relationships suggest a west-northwest-facing passive continental margin during the Mesozoic (Yeats and Hussain, 1987). Tertiary rocks were deposited in an asymmetric foreland basin with a gentle south flank and steep north flank (Meissner and Rahman, 1973; Wells, 1984). The Murree Formation, representing the molasse facies of early-formed thrust sheets, prograded onto progressively younger shallow marine deposits as the thrust front and foreland basin migrated to the southwest (Bossart and Ottiger, 1989).

The change in mechanical strength associated with the transition between the arenaceous- and argillaceous-facies Precambrian rocks may have localized the position of the future Khairabad-Panjal fault. The occurrence of gypsum in the hanging wall of the Nathia Gali fault indicates that the Panjal fault ramped up from a position corresponding to the detachment at the base of the sedimentary wedge. Ramping of the detachment may have been due to a very thin, possibly discontinuous evaporite layer that did not necessarily favor decoupling of the sedimentary cover from the basement. Ramping may also have been produced by a down-to-the-north basement fault, as it was at the Salt Range. Continued horizontal compressive stress ultimately led to decoupling of the sedimentary cover from the basement south of the Panjal ramp, forming the Salt Range thrust.

In the vicinity of the Hill Ranges, seismicity indicates a complex pattern of active faulting that generally reflects north-south shortening (Armbruster and others, 1978) and is characterized by reverse and strike-slip displacements (Seeber and others, 1981). Yeats and Hussain (1989) described four left-stepping pressure ridges near the southern margin of the Peshawar basin that involve late Quaternary deposits. The en echelon distribution of the east-northeast-trending faults, which are high-angle and accompanied by instrumental seismicity, may indicate a left-slip component (Yeats and Hussain, 1989). In 1977, a magnitude 5.2 (USGS) earthquake occurred near Islamabad, and the slip-vector from the fault-plane solution of the main shock indicated left-lateral strike-slip motion (Seeber and Armbruster, 1979). The 1977 earthquake did not involve surface rupture (Seeber and Armbruster, 1979), and there is no evidence of surface rupture in the zone of late Quaternary deformation in the southern Peshawar basin (Yeats and Hussain, 1989). Likewise, no evidence of Holocene faulting was observed during the present study. However, the seismic risk associated with the growing number of major population, administrative, and industrial centers in this area clearly warrants continued analysis of geologic and earthquake data.

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