AN ABSTRACT FOR THE THESIS OF

Kevin R. Pogue for the degree of Doctor of Philosophy in Geology presented on December 3, 1993.

Title: Stratigraphic and structural framework of Himalayan Foothills, Northern Pakistan

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Abstract approved: ____________________

Dr. Robert S. Yeats

The oldest sedimentary and metasedimentary rocks exposed in the Himalayan foothills of Pakistan record a gradual transition seaward from the evaporites of the Salt Range Formation to pelitic sediments deposited in deeper water to the north. The Upper Proterozoic Tanawal Formation was derived from erosion of a northern highland produced during the early stages of Late Proterozoic to early Ordovician tectonism. Early Paleozoic tectonism is indicated by an angular unconformity at the base of the Paleozoic section, the intrusion of the Mansehra Granite, and the local removal of Cambrian strata. Paleozoic shallow-marine strata are preserved in half-grabens created during extensional tectonism that began during the Carboniferous and climaxed with rifting during the Permian. Paleozoic rocks were largely or completely eroded from northwest-trending highlands on the landward side of the rift shoulder. Thermal subsidence of the rifted margin resulted in transgression of the highlands and deposition of a Mesozoic section dominated by carbonates. Compressional tectonism related

to the impending collision with Asia commenced in the Late Cretaceous. Rocks north of the Panjal-Khairabad fault were deformed and metamorphosed during Eocene subduction of northern India beneath the Kohistan arc terrane. Following their uplift and exhumation, rocks metamorphosed beneath Kohistan were thrust southward over unmetamorphosed rocks along the Panjal and Khairabad faults which are inferred to be connected beneath alluvium of the Haripur basin. Contrasts in stratigraphy and metamorphism on either side of the Panjal-Khairabad fault indicate that shortening on this structure exceeds that of any other fault in the foothills region. The migration of deformation towards the foreland produced south- or southeast-vergent folds and thrust faults in strata south of the Panjal-Khairabad fault and reactivated Late Cretaceous structures such as the Hissartang fault. The Hissartang fault is the westward continuation of the Nathia Gali fault, a major structure that thrusts Proterozoic rocks in the axis of a Late Paleozoic rift highland southward over Mesozoic strata. Fundamental differences in stratigraphy, metamorphism, and relative displacement preclude straightforward correlation of faults and tectonic subdivisions of the central Himalaya of India and Nepal with the northwestern Himalaya of Pakistan.

Stratigraphic and Structural Framework of Himalayan Foothills, Northern Pakistan

by

Kevin R. Pogue

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Elisa Weinman Pogue, whose loving presence sustained me during this endeavor.

On first examining a new district, nothing can appear more hopeless than the chaos of rocks; but by recording the stratification and nature of the rocks and fossils at many points, always reasoning and predicting what will be found elsewhere, light soon begins to dawn on the district, and the structure of the whole becomes more or less intelligible.

CHARLES DARWIN

TABLE OF CONTENTS

STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF HIMALAYAN FOOTHILLS, NORTHERN PAKISTAN

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (cont.)

LIST OF TABLES

CONTRIBUTIONS OF AUTHORS

Chapter one of this thesis was published in the Geological Society of America Bulletin in August of 1992 with Bruce Wardlaw, Anita Harris, and Ahmad Hussain as co-authors. Bruce Wardlaw and Anita Harris identified the conodonts that form the basis for most of the age determinations (Table I.1). Ahmad Hussain was the first to discover many of the stratigraphic inconsistencies addressed in the study and his guidance in the field was invaluable.

Chapter two was published in Tectonics in August of 1992 with Joe DiPietro, Said Rahim Khan, Scott Hughes, John Dilles, and Robert D. Lawrence as co-authors. Joe DiPietro's stratigraphic observations from Swat were critical in constructing correlations with the Paleozoic and Mesozoic stratigraphy of the Peshawar basin. Said Rahim Khan was the only geologist with previous field experience in the region investigated, and his guidance and recognition of critical localities greatly facilitated the study. Scott Hughes provided the geochemical analyses of diabases and amphibolites (Table II.1a) and plotted and interpreted the results (Figures II.4, II.5, and II.6). John Dilles collected many of the samples that were analyzed and provided petrographic descriptions (Table II.1b). Discussions and field excursions with Robert D. Lawrence were enlightening and contributed to many of the ideas presented in this paper.

Chapter three is unpublished but will eventually be submitted with Michael Hylland and Robert S. Yeats as co-authors.

Mike Hylland mapped relationships in the southern Gandghar Range and Hasan Abdal area that are important in working out correlations between Proterozoic units and locating the Panjal-Khairabad fault. Bob Yeat's interpretations of the structural geometry and deformational history of the Attock-Cherat Range facilitated correlations with structures and events in other parts of the foothills region.

STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF HIMALAYAN FOOTHILLS, NORTHERN PAKISTAN

Introduction

The primary emphasis of this dissertation is the description and interpretation of the stratigraphic and structural transition between the Himalayan foreland fold and thrust belt south of the Peshawar basin and the metamorphic and igneous terrane in the footwall of the Main Mantle Thrust (MMT). The location of the area studied in detail is outlined on Figure I.1 and is shown enlarged on Figure I.2. The dissertation is presented as three manuscripts. The first manuscript (Pogue and others, 1992a) describes the Paleozoic and Mesozoic stratigraphy of the Peshawar basin and revises the stratigraphic nomenclature for these rocks based on field relationships and new paleontological data. The data presented in the first manuscript imply that the Peshawar basin was affected by rifting during the late Paleozoic. The second manuscript (Pogue and others, 1992b) examines this rifting event in greater detail through the integration of stratigraphic, structural, paleontological, radiometric, and geochemical information.

The limits of the study area are expanded in the third manuscript to include the entire region between the MMT and the Main Boundary Thrust (MBT). This region (termed the "Himalayan foothills") is subdivided into three tectonic blocks and the stratigraphy and structure of the individual blocks is detailed independently. In the disscussion sections, evidence is presented that permits correlation of the stratigraphy between the three blocks, the tectonic history of the region is outlined, and the proposed tectonic subdivisions are compared to their counterparts in the central Himalaya of northern India.

PALEOZOIC AND MESOZOIC STRATIGRAPHY OF THE PESHAWAR BASIN, PAKISTAN: CORRELATIONS AND IMPLICATIONS

Abstract

The most complete Paleozoic sequence described from Pakistan is exposed in bedrock inliers and in ranges fringing the eastern Peshawar basin. Interbedded quartzite and argillite of the Precambrian and Cambrian Tanawal Formation is overlain unconformably by the Cambrian(?) Ambar Formation. The Misri Banda Quartzite unconformably overlies the Ambar and contains Ordovician *Cruziana* ichnofossils. New conodont discoveries restrict the ages of overlying formations as follows: Panjpir Formation, Llandoverian to Pridolian; Nowshera Formation, Lochkovian to Frasnian; and Jafar Kandao Formation, Kinderhookian to Westphalian. The Karapa Greenschist, consisting of metamorphosed lava flows, separates the Jafar Kandao from Upper Triassic (Carnian) marbles of the Kashala Formation. The Upper Triassic and Jurassic(?) Nikanai Ghar Formation forms the top of the section.

Correlatives to the Peshawar basin stratigraphy are present locally in the Sherwan synclinorium of Hazara and in the Khyber Pass region. The sequence contrasts markedly with the Paleozoic and Mesozoic section exposed south of the Khairabad thrust in the Attock-Cherat Range. This thrust and its northeastern continuation in Hazara north of Abbottabad thus form the boundary in Pakistan between the Lesser Himalayan and Tethyan Himalayan sections, a

function performed by the Main Central thrust (MCT) in the central Himalaya of India and Nepal.

The newly-dated Carboniferous to Triassic horizons provide the first firm age constraints on the protoliths of the high-grade Swat metasediments. The dating of the metasediments has, in turn, provided age constraints on pre-Himalayan tectonism and associated intrusions. Two major tectonic episodes during the Late(?) Cambrian and Carboniferous produced positive areas north of the Peshawar basin that provided coarse detritus to the Misri Banda Quartzite and Jafar Kandao Formation.

Introduction

The sedimentary and metasedimentary rocks of the Himalayan foothills of northern Pakistan have not received as much attention as their counterparts in northern India. Early stratigraphic studies of the Indian rocks (e.g. Hayden, 1904) were aided by relatively fossiliferous and accessible sections, far from the frontier. The rocks of the Northwestern Frontier Province (now part of Pakistan) were by comparison, devoid of fossils and logistically hazardous. Therefore, when Gansser (1964) proposed tectono-stratigraphic subdivisions of the Himalaya they were logically based on the relatively well-documented successions exposed in the central Himalaya of northern India. Efforts to extend Gansser's central Himalayan subdivisions westward to Kashmir and Pakistan have been impeded by the apparent absence in Pakistan of a Tethyan Himalyan succession and a fault analogous to the Main Central Thrust (MCT)(Yeats and Lawrence, 1984). This study is the first to systematically sample the sedimentary and metasedimentary rocks of the Peshawar basin for fossils, and the results indicate the presence in Pakistan of a well-developed Paleozoic and Mesozoic section comparable to the classic Tethyan sections of northern India.

The Peshawar intermontane basin lies 150 km north of the active front of Himalayan deformation at the Salt Range and 50 km south of the Main Mantle thrust, the suture between the Indian plate and the Kohistan island arc terrane (Figure I.1). The tectonic setting is transitional between a sedimentary fold-and-thrust belt

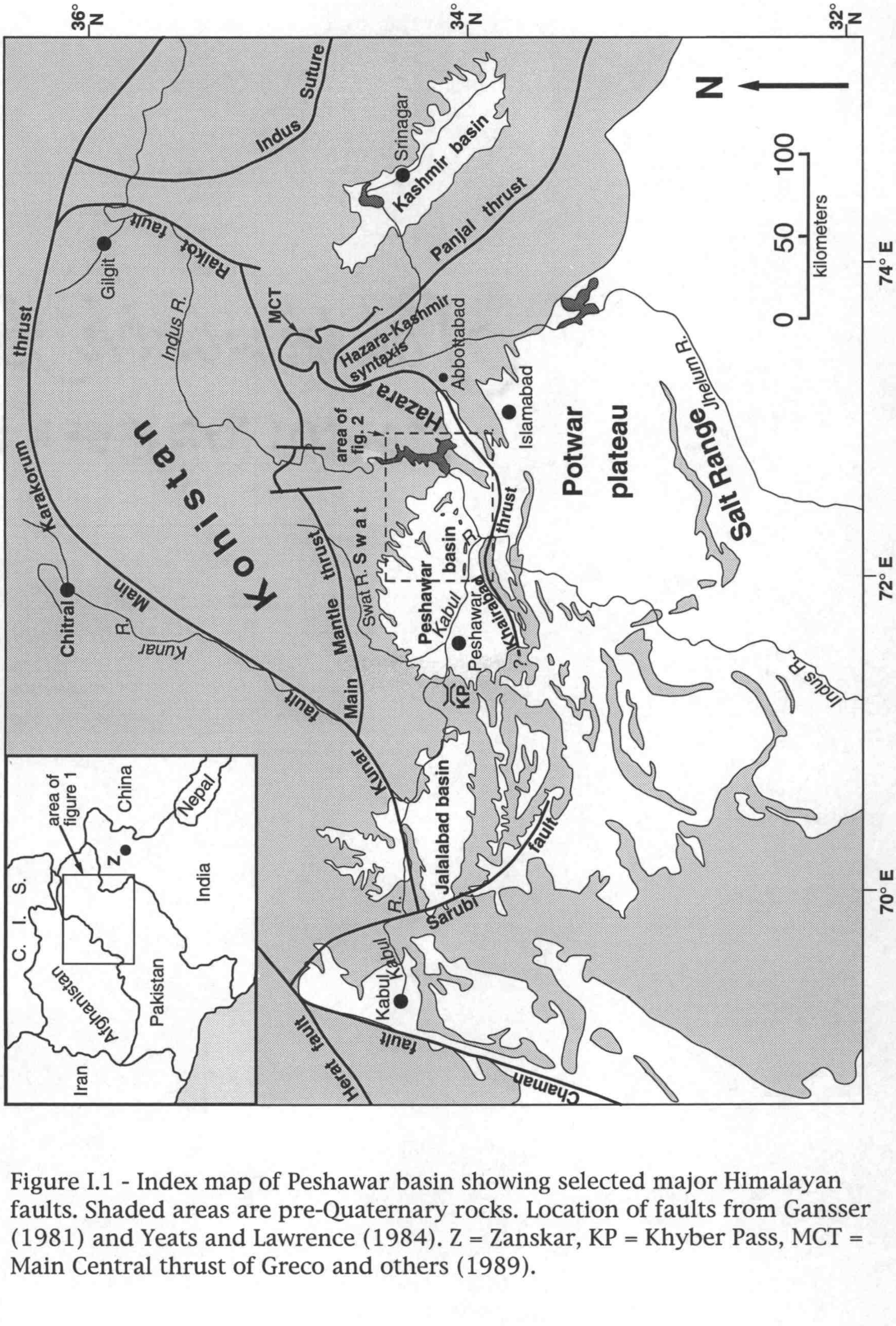

Figure I.1 - Index map of Peshawar basin showing selected major Himalayan faults. Shaded areas are pre-Quaternary rocks. Location of faults from Gansser (1981) and Yeats and Lawrence (1984). Z = Zanskar, KP = Khyber Pass, MCT = Main Central thrust of Greco and others (1989).

to the south and a metamorphic terrane to the north, in Swat. Exposures of Mesozoic and older strata are limited to small inliers of bedrock within the basin, and to ranges north and east of the Peshawar basin fill (Figure I.2). In the first comprehensive stratigraphic study of the area, Martin and others (1962) subdivided the rocks in the northeastern part of the Peshawar basin into the Swabi-Chamla Sedimentary Group and the Lower Swat-Buner Schistose Group. Davies and Ahmad (1963) described orthoconic nautiloids from the hills south of Swabi, indicating a Paleozoic age (Figure I.2). The presence of Paleozoic rocks was confirmed by Teichert and Stauffer (1965) who discovered a fossil assemblage indicative of a Devonian reef complex near Nowshera. Stauffer (1964; 1968a) compiled data on probable Paleozoic localities throughout northern Pakistan. Fuchs (1975) described the stratigraphy of several bedrock inliers near Swabi and Nowshera in an attempt to integrate the area into a Himalayan stratigraphic framework. A study of the conodont fauna of the carbonate rocks north of Nowshera by Molloy (1979) has so far provided the most detailed biostratigraphic information on Peshawar basin strata.

The need for stratigraphic revision became apparent during the remapping of the eastern Peshawar basin, when major inconsistencies were discovered in the earlier work (Figure I.3). In order to provide a coherent and regionally applicable stratigraphy, major outcrops were examined and described, and fossiliferous horizons were sampled. Bulk samples of macrofossil-bearing horizons were processed for conodonts. Bedrock exposures of the eastern Peshawar basin were subdivided into six areas for which

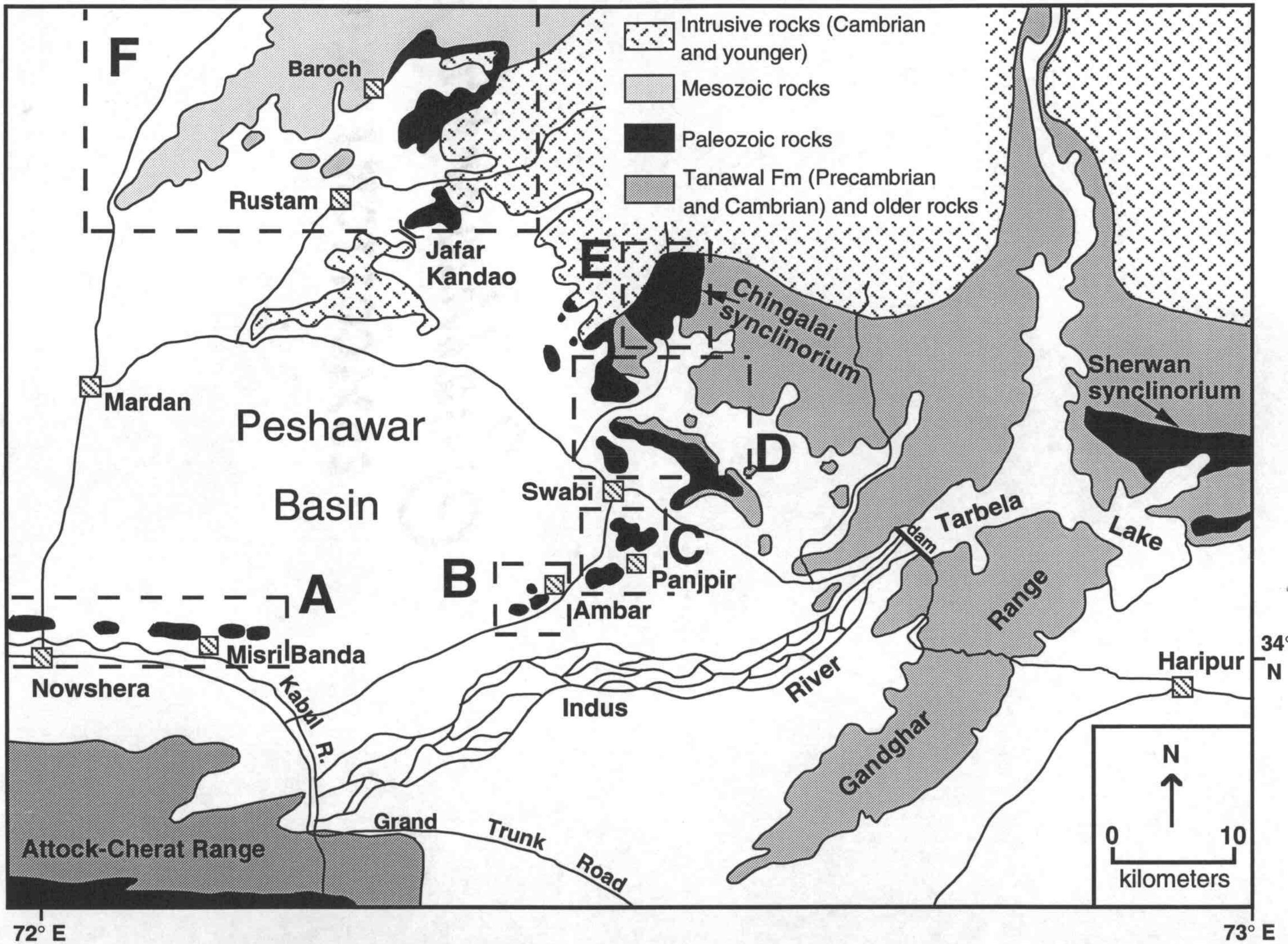

Figure I.2 - Generalized geologic map of the eastern Peshawar basin showing areas for composite stratigraphic columns (figure I.4).

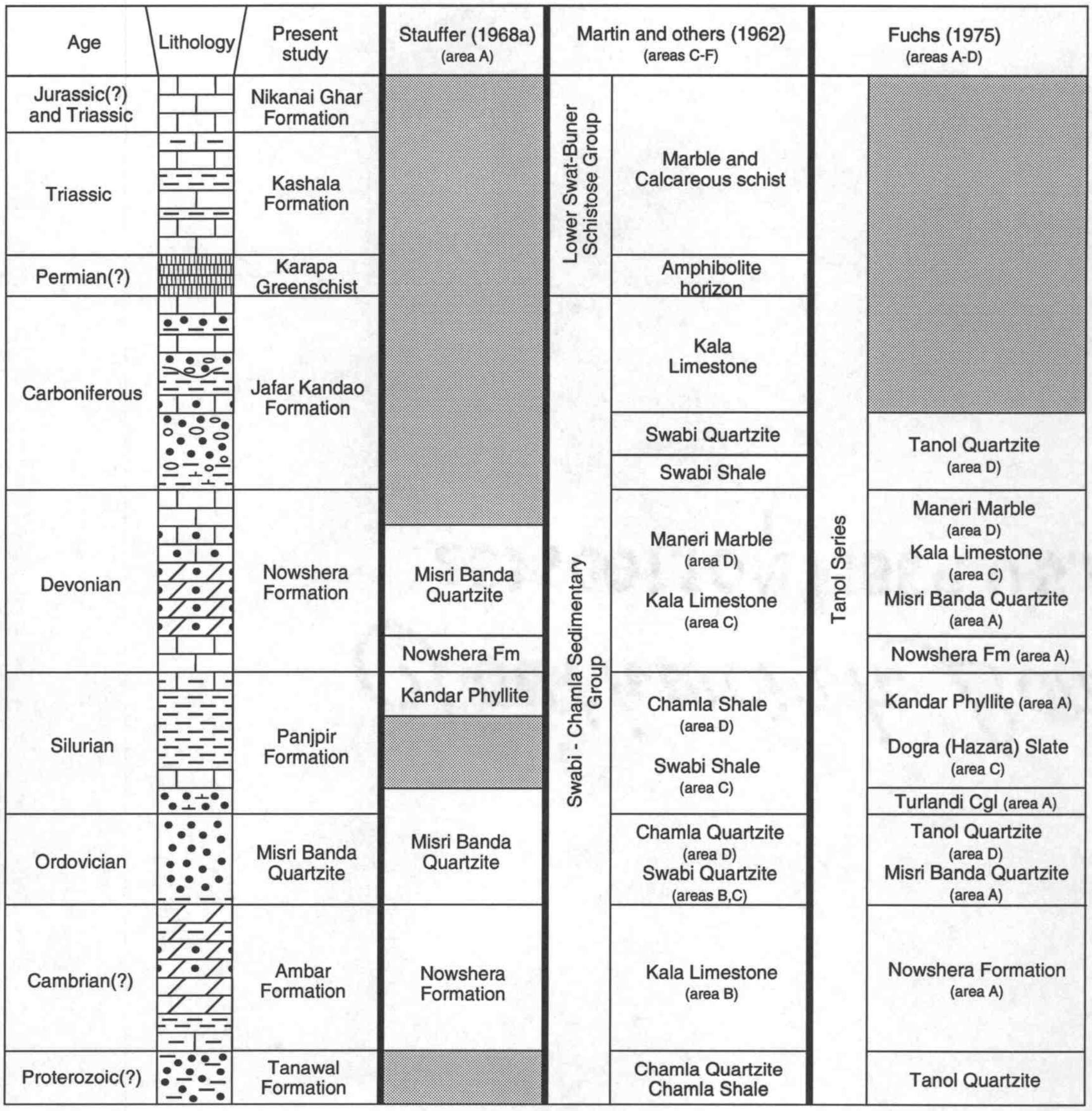

Figure I.3 - History of stratigraphic nomenclature for the eastern Peshawar basin, northern Pakistan. Refer to figure I.2 for area designations. See figure I.4 for explanation of lithologic symbols.

composite stratigraphic columns were constructed (Figure I.2, Figure I.4). Area A consists of the hills north of Nowshera where Teichert and Stauffer (1965) first described Lower Devonian reef deposits. Areas B, C, D, E, and F were included on the reconnaissance map of Martin and others (1962), and subsequent workers (Davies and Ahmad, 1963; Fuchs, 1975) have used their informal stratigraphy (Figure I.3). In Pakistan, the only Paleozoic units formally recognized by the Stratigraphic Committee of Pakistan are those of the Salt Range (Shah, 1977).

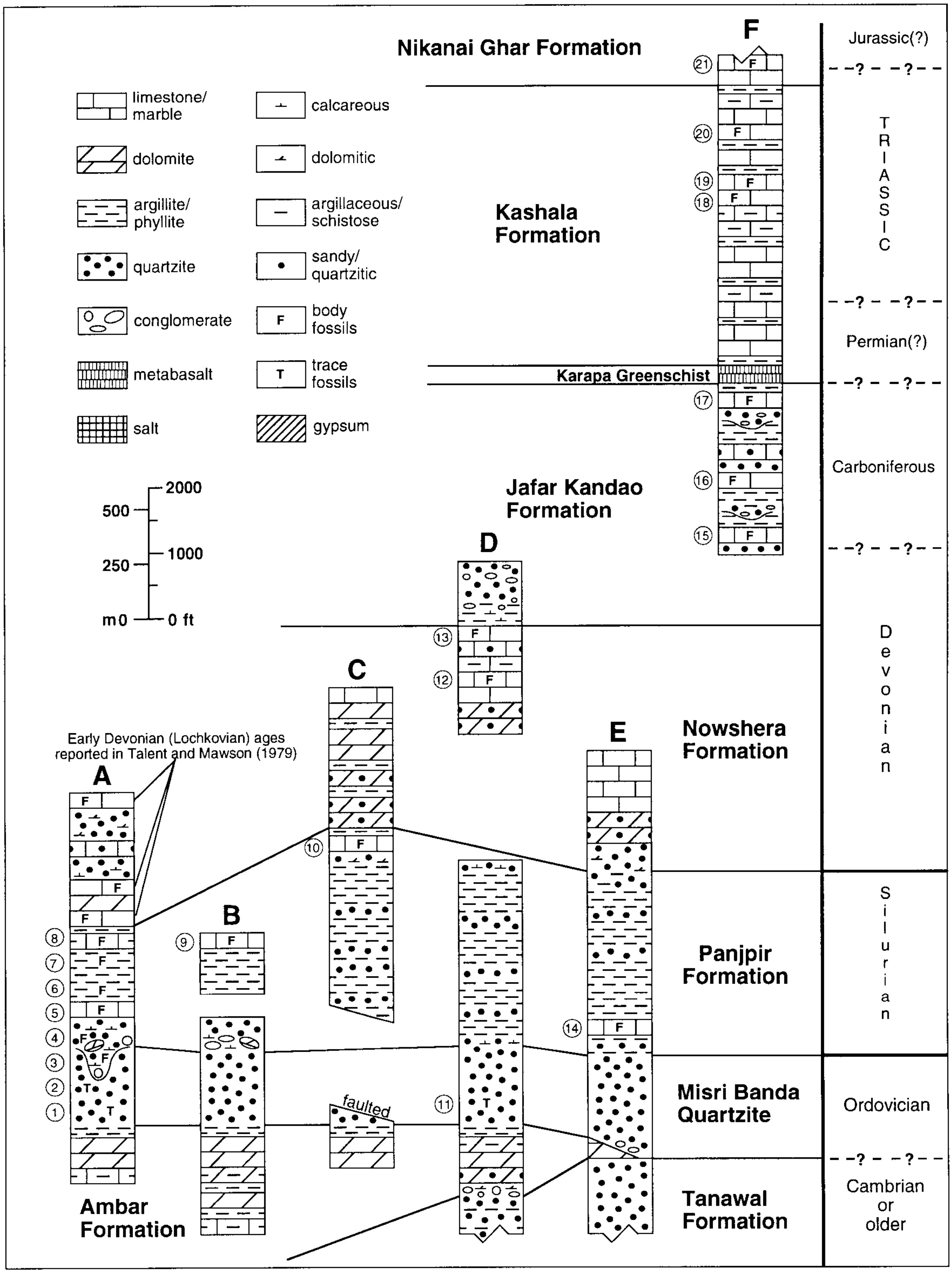

Figure I.4 - Correlation of composite stratigraphic columns for selected areas of the eastern Peshawar basin. Numbers indicate approximate stratigraphic levels for fossil collections listed in table I.1.

Stratigraphy

Tanawal Formation

In the eastern Peshawar basin, the Tanawal Formation unconformably overlies graphitic phyllite and marble that were lithologically correlated by Calkins and others (1975) with the Proterozoic(?) Salkhala Formation of northern Kashmir. The contact is marked locally by a pebble or cobble conglomerate. The Tanawal Formation consists of interbedded quartzite and argillite and rare limestone lenses. The quartzite is commonly cross-bedded, and the interfaces between quartzitic and argillaceous beds are commonly ripple-marked. In the large bedrock inliers east of Swabi, the upper contact is defined by an abrupt transition from argillite or quartzite to dolomite or conglomerate of the overlying Cambrian(?) Ambar Formation. Northward from Swabi, the Ambar lenses out so that the Misri Banda Quartzite overlies the Tanawal Formation in the Chingalai synclinorium.

The Tanawal Formation is intruded by Mansehra Granite, which yielded a whole rock Rb/Sr age of 516 ± 16 Ma (Le Fort and others, 1980), thus restricting the Tanawal to Cambrian or older. In Hazara, north of the Khairabad thrust (Panjal fault of Calkins and others, 1975), the Tanawal is overlain by strata similar to parts of the Abbottabad Group, which overlies the Proterozoic Hazara Group south of the thrust. The Hazira Member of the Tarnawai Formation, which overlies the Abbottabad Group, yielded an Early Cambrian fauna (Fuchs and Mostler, 1972; Rushton, 1973; Latif, 1974; Talent and Mawson, 1979). A Proterozoic age for the Tanawal could be inferred if the overlying strata are indeed correlative with the Abbottabad Group.

Ambar Formation

Carbonate rocks exposed in the isolated hills between Nowshera and Swabi (Figure I.2; areas A-C) were named the Ambar Formation for the village of Ambar by Pogue and Hussain (1986). The Ambar Formation overlies the Tanawal Formation north and east of Swabi (area D; Figure I.2 and Figure I.4). South of Swabi, these rocks were mapped by Martin and others (1962) as Kala limestones and dolomites (Figure I.3). Stauffer (1968a) considered the carbonate rocks that form the base of the section near Misri Banda (area A; Figure I.2 and Figure I.4) to represent a dolomitized part of the Lower Devonian Nowshera Formation (Figure I.3).

North and east of Swabi, the Ambar Formation unconformably overlies the Tanawal Formation. The contact is locally marked by a cobble or pebble conglomerate consisting of well-rounded quartzite clasts in a matrix that grades upward from quartzite or argillite to sandy dolomite. In the Peshawar basin south of Swabi, the lower contact is concealed beneath Peshawar basin alluvium. Five to ten meters of argillite underlie the unconformable contact with the overlying Misri Banda Quartzite. Massive sandy dolomite with characteristic "butcher-block" weathering is the dominant lithology of the Ambar Formation. The Ambar Formation thins dramatically north of Swabi and is absent in the northern half of the Chingalai synclinorium.

The age of the Ambar Formation is restricted to Late Proterozoic to Early Ordovician by underlying and overlying formations. Two pieces of evidence argue for a Cambrian age, however. Basal pisolitic beds at Ambar have microscopic shell debris in the interstices of the pisoliths, arguing against a Late Proterozoic age. East of Tarbela Lake, in the Sherwan synclinorium, a thick-bedded dolomite with butcher-block weathering is exposed above the Tanawal Formation and below feldspathic quartzite containing worm burrows. Some sections of the dolomite in the Sherwan synclinorium containing phosphatic intervals are lithologically identical to parts of the Sirban Formation of the Lower Cambrian Abbottabad Group (Ghaznavi and others, 1983).

Misri Banda Quartzite

The Misri Banda Quartzite was named by Stauffer (1968a) for calcareous and dolomitic quartzite overlying the Lower Devonian reef-bearing limestones of the Nowshera Formation. The formation was named for the village of Misri Banda and a type section was established along the stream valley immediately northeast of the village. South of Swabi (areas B and C; Figure I.2), Martin and others (1962) mapped these rocks as Swabi Quartzite; north of Swabi they were mapped as Chamla Quartzite (Figure I.3). Detailed mapping by Pogue and Hussain (1986) revealed that the quartzite at the type section near Misri Banda village is lithologically distinct from the calcareous and dolomitic quartzite that overlies the reef-bearing limestone near Nowshera. Furthermore, the quartzite near Misri

Banda is overlain by argillite and phyllite that are identical to rocks mapped by Stauffer (1968a) as Kandar Phyllite, which underlies the Nowshera reef limestones. The stratigraphic inference that the quartzite at Misri Banda is an older formation was confirmed by the discovery of the Ordovician ichnofossil *Cruziana rugosa* in the upper beds of the formation east of Misri Banda village (Table I.1, no. 2). Based on this discovery, Pogue and Hussain (1986) restricted the Misri Banda Quartzite to the unconformity-bounded arenaceous sequence between the Ambar Dolomite and the Panjpir Formation (Kandar Phyllite of Stauffer (1968a)). The calcareous and dolomitic quartzite stratigraphically above the Nowshera reef-bearing limestones was reassigned to the Nowshera Formation.

Throughout the eastern Peshawar basin, the basal unconformity of the Misri Banda Quartzite is marked by a sharp contact between medium- to coarse-grained, locally dolomitic quartzite and underlying argillite of the Ambar Formation. In the Chingalai synclinorium, however, the unconformity is marked by up to 10 m of conglomerate consisting of cobbles and pebbles of quartzite and argillite in a coarse-grained quartzite matrix. The upper bounding unconformity lies at the base of a conglomerate, calcareous quartzite, or argillite of the Panjpir Formation. The Misri Banda Quartzite is primarily a well-sorted medium- to fine-grained feldspathic quartzite with 10-20% feldspar. Thin intervals of interbedded argillite are particularly common in the southern exposures where argillite may account for 50% of the upper part of the Misri Banda Quartzite. Vertically oriented tube-shaped burrows from 0.5 to 1.5 cm in diameter (*Skolithos*) occur within the

Table I.1 - New fossil data for Paleozoic and Mesozoic rocks in the Peshawar Basin

Sample number*	Latitude N. / Longitude E. (Survey of Pakistan topographic sheet)	Stratigraphic unit	Fossil group and Key taxa	Age
1	34°01'00"/72°06'48" (43 B/4)	Misri Banda Quartzite	Trace fossils: *Skolithos*	Paleozoic
2	34°01'29"/72°09'13" (43 B/4)	Misri Banda Quartzite	Trace fossils: *Cruziana rugosa*	Early and Middle Ordovician
3 (11980-SD)	34°01'05"/72°06'33" (43 B/4)	Panjpir Formation	Conodonts: *Ozarkodina excavata, O. remscheid-ensis;* CAI = 5	Silurian (late middle Ludlovian and Pridolian)
4 (11983-SD)	34°01'12"/72°09'07" (43 B/4)	Panjpir Formation	Conodonts: *Distomodus* sp. indet.; CAI = 5.5-6.5	Silurian (Llandoverian and early Wenlockian)
5 (11775-SD)	34°01'22"/72°09'13" (43 B/4)	Panjpir Formation (Sample is stratigraph-ically below sample 6.)	Conodonts: *Ozarkodina excavata, O. remscheid-ensis remscheidensis, Walliserodus* sp.; CAI = 5-5.5	Silurian (late middle and early late Ludlovian) *siluricus* Zone
6 (11774-SD)	34°01'15"/72°09'14" (43 B/4)	Panjpir Formation	Conodonts: *Kockelella variabilis, Oulodus* sp. indet., *Ozarkodina excavata, O. remscheidensis remscheidensis, Panderodus* sp., *Polygnathoides siluricus, Walliserodus* sp.; CAI = 5-5.5	Silurian (late middle and early late Ludlovian) *siluricus* Zone
7 (11975-SD)	34°01'15"/72°08'13" (43 B/4)	Panjpir Formation	Conodonts: *Oulodus elegans, Ozarkodina crispa, O. excavata, O. remscheidensis, Panderodus unicostatus;* CAI = 5.5-6.5	Silurian (latest Ludlovian) lower *eosteinhornensis* Zone
8 (11981-SD)	34°01'50"/71°59'55" (43 B/4)	Panjpir Formation	Conodonts: *Oulodus* sp. indet., *Ozarkodina excavata, O. remscheidensis;* CAI = 5-5.5	Late Silurian and Early Devonian (middle Ludlovian to early Pragian)
9 (11974-SD)	34°04'55"/72°24'50" (43 B/8)	Panjpir Formation	Conodonts: *Kockelella*? sp. indet., *Ozarkodina confluens, O. excavata, O. remscheidensis* or *Kockelella variabilis;* CAI = 5-6	Silurian (late Wenlockian to early Pridolian) *crassa* Zone into *eosteinhorn-ensis* Zone
10 (11772-SD)	34°05'40"/72°29'05" (43 B/8)	Panjpir Formation	Conodonts: *Oulodus*? sp. indet., *Ozarkodina* aff. *O. confluens, O. excavata, O. remscheidensis;* CAI = 5-7	Late Silurian and early Early Devonian
11	34°08'20"/72°37'08" (43 B/12)	Misri Banda Quartzite	Trace fossils: *Skolithos*	Paleozoic
12 (11978-SD)	34°09'36"/72°28'00" (43 B/8)	Nowshera Formation	Conodonts: *Belodella devonica, Dvorakia* sp., indet., *Icriodus corniger/struvei* plexus, *Poly-gnathus* sp. indet.; CAI = 5-6.5	Devonian (latest Emsian and Eifelian)
13 (11982-SD)	34°03'07"/72°25'00" (43 B/8)	Nowshera Formation	Conodonts: *Ancyrodella* cf. *A. buckeyensis, Poly-gnathus* cf. *P. webbi;* CAI = 7	Devonian (Frasnian) Middle *asymmetricus* Zone to Upper *gigas* Zone
14 (11977-SD)	34°16'37"/72°35'22" (43 B/11)	Panjpir Formation	Conodonts: *Carniodus* sp. indet., *Icriodella* sp. indet.; CAI = 8	Silurian (Llandoverian and early Wenlockian)
15 (31036-PC & 31038-PC)	34°18'37"/72°17'53" (43 B/7)	Jafar Kandao Formation	Conodonts: *Protognathodus* sp. indet.; CAI = 5.5	Late Devonian and Early Carboniferous (late Famennian and Tournaisian)
16 (30660-PC & 31035-PC)	34°20'05"/72°19'10" (43 B/7)	Jafar Kandao Formation	Conodonts: *Eotaphrus* sp. indet., *Gnathodus pseudosemiglaber, G. semiglaber;* CAI = 5.5-8	Early Carboniferous (late Tournaisian)
17 (31039-PC)	34°26'03"/72°21'56" (43 B/7)	Jafar Kandao Formation	Conodonts: *Neogondolella* cf. *N. donbasica, Rhachistognathus* sp. indet.; CAI = 5.5-6	Middle Carboniferous (Westphalian B)
18 (33337-Mes.) & 19 (33336-Mes.)	34°25'21"/72°16'40" (43 B/7)	Kashala Formation	Conodonts: *Neogondolella polygnathiformis augusta* (*Epigondolella augusta* of Kozur); CAI = 5.5-6 (18); CAI = 6.5-7.0 (19)	Triassic (late Carnian)
20 (33338-Mes.)	34°23'21"/72°14'41" (43 B/7)	Kashala Formation	Conodonts: *Neogondolella polygnathiformis augusta* (*Epigondolella augusta* of Kozur); CAI = 6.5-7. Fish tooth	Triassic (late Carnian)
21	34°32'00"/72°20'00" (43 B/7)	Nikanai Ghar Formation	Palaeoniscoid? fish tooth	Late Devonian to Jurassic
22 (11979-SD)	34°03'57"/71°21'35" (38 N/8)	Ali Masjid Formation	Conodonts: *Icriodus* sp. indet., *Palmatolepis* aff. *Pa. gracilis* plexus, *Pa.* aff. *Pa. perlobata* plexus, *Polygnathus extralobatus, Po. perplexus, Po.* n. sp.; CAI = 5-7	Devonian (late Famennian) *expansa* Zone

Note: sample 22 from Khyber area; sample numbers keyed to Figures 3 and 4. CAI = conodont color alteration index.

* U. S. Geological Survey collection number.

quartzite throughout the area (Table I.1, nos. 1, 11). The presence of *Cruziana rugosa* in the interbedded argillite and quartzite of the upper part of the Misri Banda Quartzite limits the age of these rocks to Early and Middle Ordovician (Tremadocian to Llandeilian).

Panjpir Formation

The dominantly argillaceous sequence below the Nowshera Formation and above the Misri Banda Quartzite was named the Panjpir Formation by Pogue and Hussain (1986). The uppermost 60 m of the Panjpir Formation exposed beneath the reef-bearing limestone north of Nowshera was first mapped as Kandar Phyllite by Stauffer (1968a). Pogue and Hussain (1986) renamed the formation to reflect the presence of lithologies other than phyllite and established a type section at Panjpir village, south of Swabi (Figure I.2, area C), where over 600 m of the formation crops out. Rocks in the area of the type section were mapped as Swabi Shale by Martin and others (1962)(Figure I.3).

The basal unconformity of the Panjpir Formation in several outcrops between Nowshera and Ambar is marked by a discontinuous conglomerate composed of subrounded to rounded cobbles and pebbles of quartzite and angular to rounded boulders and cobbles of dolomite in a coarse-grained calcareous quartzite matrix. A bulk sample of calcareous quartzite from the basal Panjpir conglomerate near Misri Banda yielded *Ozarkodina excavata* and *Ozarkodina remscheidensis*, conodont species also found in the basal Panjpir at other localities (Table I.1, no. 3). In areas where the conglomerate is absent, the unconformity lies at the base of brown-weathering calcareous quartzites. On the small hill northeast of Misri Banda that produced *Cruziana* ichnofossils, a crinoidal limestone lens within the calcareous quartzite of the basal Panjpir yielded a Silurian (Llandoverian and early Wenlockian) conodont (Table I.1, no. 4).

The dominant lithology of the Panjpir Formation is dark-gray to olive-gray argillite, phyllite, and meta-siltstone. Near Swabi (areas C and D) and in the Chingalai synclinorium (area E), these lithologies are interbedded with argillaceous quartzite. The upper Panjpir Formation throughout the Peshawar basin is characterized by interbedded argillite and fossiliferous limestone. The upper Panjpir limestone exposed north of Nowshera (area A) has yielded Late Silurian (Pridolian) conodonts (Talent and Mawson, 1979). Stratigraphically equivalent limestone intervals exposed northeast of Misri Banda (area A), northwest of Ambar (area B), and north of Panjpir (area C) have also yielded Late Silurian conodonts making this horizon the most widely exposed fossiliferous interval in the Peshawar basin.

Nowshera Formation

Stauffer (1968a) named the Nowshera Formation for fossiliferous carbonates above the Kandar Phyllite (now called Panjpir Formation) and below the Misri Banda Quartzite (Figure I.3). In the vicinity of Swabi (areas D and E), these rocks were mapped by Martin and others (1962) as either Kala Limestone or

Maneri Marble (Figure I.3). Pogue and Hussain (1986) redefined the Nowshera Formation to include calcareous and dolomitic quartzites mapped by Stauffer (1968a) as Misri Banda Quartzite. The inclusion of the quartzites within the Nowshera was based primarily on the presence of Lower Devonian (Lochkovian) limestones stratigraphically above and below the quartzites. The Nowshera Formation consists of sandy dolomite, calcareous and dolomitic quartzite, calcareous argillite, and fossiliferous limestone. The lower contact is placed at the base of the first thick interval of massive limestone overlying the interbedded argillite and limestone of the Panjpir Formation. Limestone in the lower part of the formation north of Nowshera (area A) yielded macrofossils and conodonts that confirm an Early Devonian (Lochkovian) age for these horizons (Talent and Mawson, 1979). North of Swabi, fossiliferous limestone 5 m below the upper contact with the Jafar Kandao Formation yielded conodonts indicating an early Late Devonian (Frasnian) age (Table I.1, no. 13). The Nowshera Formation thus ranges in age from Early to early Late Devonian.

Jafar Kandao Formation

Pogue and Hussain (1986) named the Jafar Kandao Formation for exposures on either side of Jafar Kandao (pass) 5 km southeast of Rustam. The rocks at the type section were mapped by Martin and others (1962) as Swabi Quartzite, Swabi Shale, and Kala Limestone. Previous workers (Martin and others, 1962; Fuchs, 1975) assigned exposures of the Jafar Kandao 1 km north of Swabi to formations below their Maneri Marble (now called the Nowshera Formation). However, inverted cross-bedding reveals that these outcrops are in the overturned limb of a syncline, so the strata are younger than the Nowshera Formation.

The basal unconformity of the Jafar Kandao Formation is marked by a discontinuous conglomerate composed of pebbles and cobbles of quartzite, argillite, or limestone in an argillite or quartzite matrix. The lower one-third of the formation consists of argillite with lenses of limestone, conglomerate, and argillaceous quartzite. Conodonts from the limestone lenses restrict the age of these beds to latest Late Devonian and Early Carboniferous (early Tournaisian) (Table I.1, no. 15). The quartzite and conglomerate occur in channels and are locally up to 50 m thick. Most conglomerate clasts are quartzite, but well-rounded granitic cobbles constitute the majority of clasts in a conglomerate lens exposed 1 km north of Jafar Kandao. The middle one-third is dominated by interbedded argillite, calcareous quartzite, and sandy limestone that yielded Early Carboniferous (late Tournasian) conodonts (Table I.1, no. 16). The upper one-third is primarily argillite with lenses of argillaceous quartzite and conglomerate. Conodonts from thin-bedded limestone immediately below the upper contact indicate a Late Carboniferous (Westphalian B) age (Table I.1, no. 17).

Karapa Greenschist

The Jafar Kandao Formation is overlain with sharp contact by a greenschist which was interpreted as metamorphosed tholeiitic basalt by Ahmad and others (1987) based on geochemical analyses. These rocks are here named Karapa Greenschist for the village of Karapa, 20 km northeast of Baroch where the unit is well-exposed and accessible. The type section crops out along the south-facing slope of Gumbat Sar between the villages of Karapa and Sonigram (Survey of Pakistan topographic sheet 43 B/7). The Karapa Greenschist is restricted to Late Carboniferous (Westphalian B) to Late Triassic (Carnian) by conodonts in the underlying and overlying formations.

Kashala Formation

Above the Karapa Greenschist, over 1500 m of interbedded marble and phyllite are exposed in a large bedrock promontory north of Rustam. These rocks were mapped by Martin and others (1962) as marbles and calcareous schists of the Lower Swat - Buner Schistose Group (Figure I.3). The rocks of the Lower Swat - Buner Schistose group of Martin and others (1962) were reassigned by Kazmi and others (1984) to the Manglaur schist, Alpurai schist, and Saidu schist. DiPietro (1990) renamed the Manglaur schist the "Manglaur Formation" and the Saidu schist the "Saidu Formation". DiPietro (1990) also revised the Alpurai schist as the Alpurai Group which includes the Marghazar, Kashala, Nikanai Ghar, and Saidu Formations (Figure I.5). The Kashala Formation overlies an amphibolite at the top of the Marghazar Formation that is the higher grade equivalent of the Karapa Greenschist. We therefore

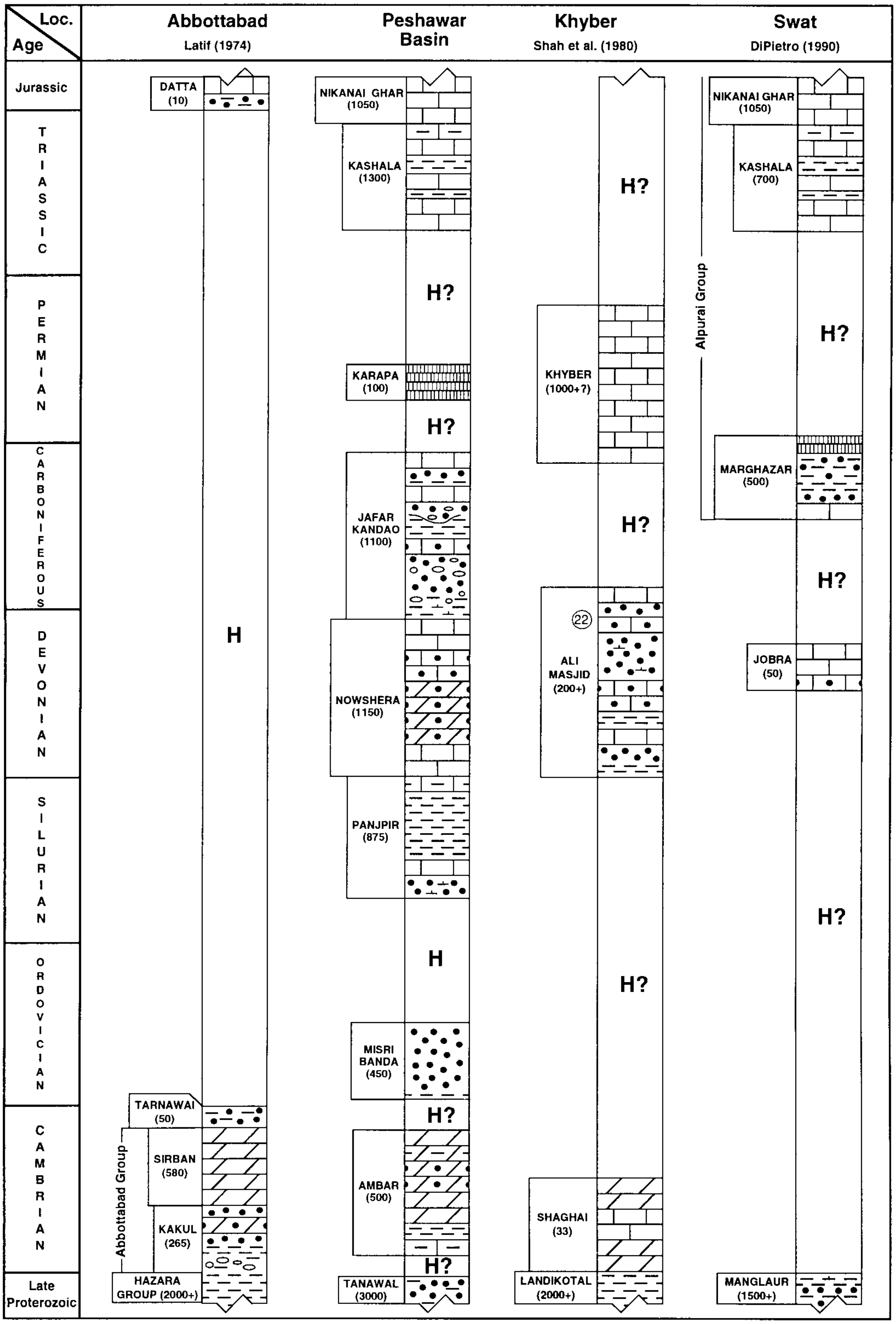

Figure I.5 - Correlation of Peshawar basin stratigraphy with adjacent areas in Pakistan. All stratigraphic units are formation rank unless otherwise noted; numbers in parentheses indicate approximate thickness, in meters. H = major hiatus. Lithologic symbols same as figure I.4.

assign rocks north and west of Rustam with similar stratigraphic position and lithology to the Kashala Formation.

In exposures bordering the Peshawar basin, the Kashala Formation is composed of thick (>100 m) intervals of massive resistant brown-weathering marble and dolomitic marble alternating with less resistant intervals of interbedded marble and calcareous phyllite. Marble sampled from three horizons near the middle of the Kashala Formation yielded Late Triassic (Carnian) conodonts (Table I.1, nos. 18-20).

Nikanai Ghar Formation

Palmer-Rosenberg (1985) and Ahmad (1986) used the informal name Nikanai Ghar marble to refer to massive marble and dolomitic marble exposed on Nikanai Ghar mountain in southern Swat. These rocks compose the upper one-third of what were formerly the marbles and calcareous schists of the Lower Swat-Buner schistose group of Martin and others (1962). The Nikanai Ghar was given formation status by Ahmad and others (1987) who recognized it as the youngest metasedimentary unit exposed in southern Swat.

The Nikanai Ghar Formation consists primarily of white to dark-gray, thick-bedded to massive, finely to coarsely crystalline marble and dolomitic marble. Minor constituents include thin beds of calcareous schist, schistose marble, and calcareous quartzite. The Nikanai Ghar Formation weathers to form distinctive white cliffs and is thus readily distinguishable from the orange-brown-weathering marble of the underlying Kashala Formation. The only exposures near the Peshawar basin are 5 km north of Baroch where the basal 200 m crop out on the crest of a large bedrock promontory. The age of the Nikanai Ghar Formation is tentatively restricted to Late Triassic and Jurassic by the age of the underlying Kashala Formation and the presence of questionable palaeoniscoid fish teeth (Table I.1, no. 21).

Local Correlations

Abbottabad Area

The stratigraphy of the area between Abbottabad and Islamabad, south of the Khairabad thrust, differs dramatically from areas north of the thrust. South of the thrust, the Tanawal Formation is absent, and an abbreviated Paleozoic section consisting of the Lower Cambrian Abbottabad Group and Tarnawai Formation lies unconformably on the Proterozoic Hazara Group (Latif, 1974; Baig and others, 1988). The Tarnawai Formation is unconformably overlain by Jurassic strata (Figure I.5). Age constraints on the Sirban Formation, the upper formation of the Abbottabad Group, as well as lithologic similarities, suggest a correlation with the Ambar Formation.

Attock-Cherat Range

Yeats and Hussain (1987) considered the Darwaza and Hissartang Formations and Inzari Limestone exposed on the southern flank of the Attock-Cherat Range to be correlative with the Paleozoic section near Misri Banda. As no fossils have been discovered, the correlation is based on lithologic similarities, primarily of quartzites and argillites of the Hissartang with the Misri Banda Quartzite and Panjpir Formation. Diabase dikes intrude the Proterozoic and Paleozoic of the Peshawar basin up to the level of the Karapa Greenschist. In the Attock-Cherat Range, strata of Proterozoic age and the presumed Paleozoic formations are intruded by diabase dikes, whereas Mesozoic strata are not. If the dikes belong to the same intrusive event as the Karapa Greenschist, then all rocks bearing them are older than the Mesozoic.

Khyber Area

The mountains of the Khyber Agency, a semi-autonomous tribal area 20 km west of Peshawar, expose sedimentary and meta-sedimentary rocks that have correlatives in the eastern Peshawar basin. Due to difficult access, type sections for the area were assigned along the main paved highway connecting Peshawar with the Khyber Pass (Stauffer, 1968b). Because these roadside sections are unfossiliferous, later workers were forced to correlate solely on the basis of lithology. The result has been general confusion as lithologically similar sequences reoccur at several different horizons.

Khan (1969) described lithologies of the Ghundai Sar "reef complex" 17 km west-northwest of Peshawar that strongly resemble the reef deposits near Nowshera and contain a similar, although poorly preserved, fauna (Talent and Mawson, 1979). A sample collected by Ahmad Hussain of thin-bedded crinoidal limestone overlying the reef complex yielded late Famennian conodonts (Table I.1, no. 22). Talent and Mawson (1979) reported an assortment of Late Devonian and Early Carboniferous brachiopods in samples collected by S.M.I. Shah near Gandah Gallah 30 km west-southwest of Peshawar. Early Carboniferous conodonts have also been reported from the Gandah Gallah area (Molloy, 1979). The fossiliferous horizons and stratigraphic information outlined in these studies indicate that correlatives to much of the Peshawar basin stratigraphy are exposed in the Khyber area (Figure I.5). Attempts at establishing firm correlations and a coherent stratigraphy must await an easing of political tensions in the area so that precise field relationships can be established.

Swat

Northeast of Baroch, in southern Swat, high-grade metamorphic equivalents of the Jafar Kandao Formation and Karapa Greenschist are included in the Marghazar Formation, the oldest unit of the Alpurai Group (DiPietro, 1990). The Karapa Greenschist occurs as an amphibolite horizon that is an important marker bed throughout Swat (Martin and others, 1962). The Kashala Formation and Nikanai Ghar Marble have type sections in Swat where they crop out extensively. Correlations of units older than the Jafar Kandao with high-grade equivalents in Swat are difficult because the belt of outcrop is interrupted by the Ambela Intrusive Complex. Based on its stratigraphic position below the Marghazar and its calc-silicate mineralogy, DiPietro (1990) considers the Jobra Formation as possibly correlative to the Nowshera Formation. The Manglaur Formation, the oldest metasedimentary unit in Swat, is predominantly quartzite and quartz-mica schist that is the probable high-grade counterpart of the Tanawal Formation.

Regional Correlations

India

In the central Himalaya of India and Nepal, Paleozoic and Mesozoic sedimentary rocks are exposed within the tectonic subdivisions known as the "Tethyan Himalaya" and "Lesser Himalaya". The dramatic contrasts in Paleozoic facies between these blocks have been cited as evidence for large displacements on the intervening Main Central thrust (MCT)(Gansser, 1964). The Lesser Himalayan facies crops out south of the MCT and is characterized by the absence of Ordovician through Devonian strata, a general lack of fossils, and Permian strata containing tillites and flora with Gondwana affinities. In contrast, a relatively complete and fossiliferous Paleozoic section with a subtle Gondwana influence characterizes the Tethyan facies.

The tectonic subdivisions applied in the central Himalaya have not been employed west of the Hazara-Kashmir syntaxis due to the apparent absence in this region of a basement-involved thrust comparable to the MCT. However, the relatively complete and fossiliferous nature of the Paleozoic rocks of the Peshawar basin implies close ties with Tethyan rather than Lesser Himalayan stratigraphy. A comparison of the stratigraphies of the Peshawar basin and the Zanskar Tethys Himalaya of northern India (Figure I.1), reveals many similarities (Gaetani and others, 1986; 1990) (Figure I.6). Though more closely related geographically, the Paleozoic of the Kashmir basin contains elements of both the Tethyan and Lesser Himalayan facies and thus displays marked differences (Shah, 1978). The Panjal Traps, a thick interval of basaltic flows that are a probable counterpart to the Karapa Greenschist, are an important similarity, however.

Salt Range

The Paleozoic stratigraphy of the Salt Range, with an Ordovician to Carboniferous hiatus and well-developed Permian Gondwana sequence, correlates more closely with the Lesser Himalayan facies of northern India than with most other sections in northern Pakistan. However, tentative correlations have been established with Proterozoic and Cambrian formations in the Hazara region south of Abbottabad. Latif (1984) and Stocklin (1986) consider gypsum beds in the Hazara Group in southeastern Hazara to be representative of a transition between the evaporite-dominated Late Proterozoic Salt Range Formation and Hazara Group argillite. Based on similarities in lithology and sequence, Latif (1984) correlated the Sangargali, Mohmdagali, and Mirpur Members of the Kakul Formation with the Khewra Sandstone, Kussak Formation, and Baghanwala Formation, respectively, of the Salt Range. Salt Range counterparts to the upper two Cambrian formations of Hazara, the Sirban and Tarnawai, are interpreted as eroded at an unconformity at the top of the Baghanwala. As we correlate the Ambar Formation with the Sirban Formation, Latif's interpretation implies that no correlations exist between the Paleozoic sections of the Peshawar basin and the Salt Range. However, Stocklin's (1986) correlation of the Sirban Formation with

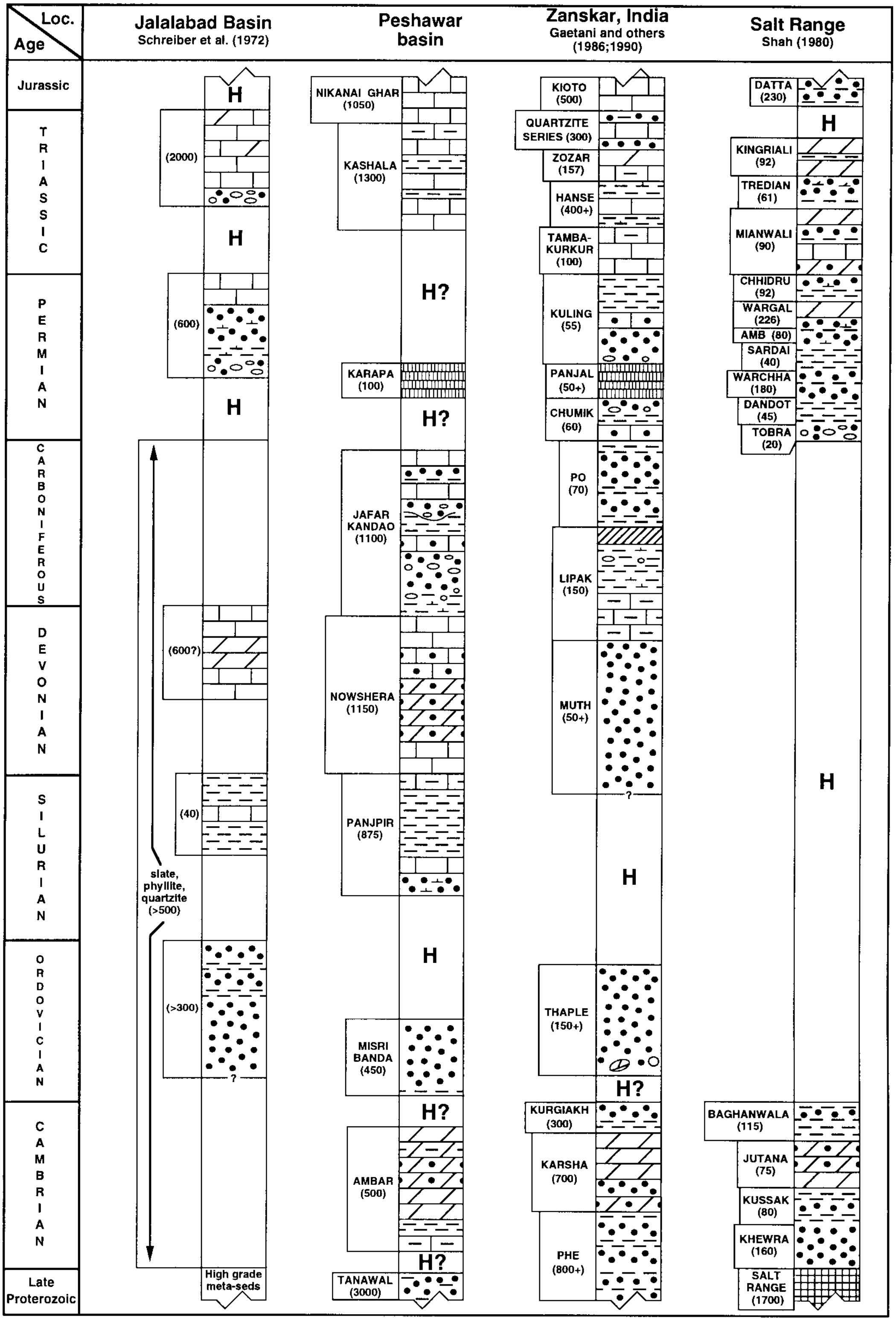

Figure I.6 - Regional correlations of Peshawar basin stratigraphy. Named stratigraphic units (where available) are of formation rank unless otherwise noted; numbers in parentheses indicate approximate thickness, in meters. H = major hiatus. Lithologic symbols same as figure I.4.

similar dolomites of the Lower and Middle Cambrian Jutana Formation implies a Cambrian link between the Salt Range and the Peshawar basin. The fossiliferous portions of the Kashala Formation are correlative with the upper part of the Middle and Upper Triassic (Ladinian and Carnian) Kingriali Formation (Zaninetti and Bronnimann, 1975).

Afghanistan

Paleozoic and Triassic rocks exposed in the Jalalabad basin of eastern Afghanistan represent a westward continuation of the discontinuous outcrop belt that stretches from the eastern Peshawar basin to the Khyber Pass region. Close correlation between the stratigraphy of the Peshawar and Jalalabad basins is indicated by the presence in both areas of Ordovician quartzites, Upper Silurian argillites with interbedded orthoceratid limestones, and thick Devonian carbonates (fig 6). Both sections are intruded by diabase dikes up to a prominent Late Carboniferous unconformity (Schreiber and others, 1972).

Chitral

Thick sequences of Ordovician, Devonian, Permian, and Mesozoic strata in the high mountains of Chitral in extreme northern Pakistan lie north of the Main Karakorum thrust and are therefore part of Eurasia (Reed, 1911; Desio, 1966; Talent and others, 1982). There is speculation, however, that Chitral is part of one of many fragments of Gondwana which preceded India in northward drift across the Tethys (Talent and others, 1986). The timing of the rift and drift of the Chitral fragment is poorly constrained, but a comparison of the Early Devonian faunas of Chitral with those from Nowshera led Talent and Mawson (1979) to conclude that the two areas were on different and isolated continental blocks. The stratigraphy of Chitral has yet to be fully deciphered due to intense tectonic shuffling; more detailed studies could reveal pre-Devonian affinities between the two regions.

Implications

The Paleozoic stratigraphy of the Peshawar basin, outlined above, is the most complete and detailed yet discovered in Pakistan. The existence of a fairly complete Paleozoic section in northern Pakistan bridges one of the biggest gaps in the belt of Paleozoic rocks extending from Saudia Arabia to Burma. Ordovician ichnofossils in the Misri Banda and late Early and Middle Devonian conodonts in the Nowshera Formation are the first evidence for rocks of these ages from Pakistan south of the Main Karakorum thrust. Conodonts from the Panjpir Formation have provided the first evidence for rocks of Early and Middle Silurian age from Pakistan. Recent revelations concerning the apparently falsified Silurian and Devonian biostratigraphy of the Indian Himalaya (Talent and others, 1988; Talent, 1989) accent the importance of these new finds. The unfortunate but necessary rejection of virtually all Indian Silurian and Devonian fossil identifications renders the Panjpir and Nowshera Formations the most complete and most accessible Silurian and Devonian section in the Himalaya.

The dating of the Peshawar basin stratigraphy has provided protolith ages for the Swat metasediments, rocks previously considered as entirely Silurian and Devonian (Stauffer, 1968a) or even Precambrian basement (Searle and others, 1987). The ages of the Swat metasediments have in turn provided new constraints on the ages of the intrusive rocks of the region. Mafic dikes that intrude the Mansehra Granite in Hazara yielded $^{39}Ar/^{40}Ar$ dates of 284±4 Ma and 262±1 Ma (Baig, 1990). These radiometric ages support our observations that diabase dikes and sills, ubiquitous in the Paleozoic rocks of the Peshawar basin, are conspicuously absent in units younger than the Karapa Greenschist. In Swat, mafic dikes are similarly restricted to stratigraphic horizons below the Karapa Greenschist-equivalent amphibolite horizon. We have therefore interpreted the lava flows that constitute the protolith for the Karapa Greenschist as the extrusive equivalent of the mafic dikes. Any rock intruded by the Karapa-related diabase is thus certainly older than Late Triassic and probably older than middle Permian. Most of the Ambela Granitic Complex, a suite of alkaline granite, syenite, and minor carbonatite, is intruded by these dikes, thus supporting radiometric ages of syenite in the Ambela of 297±4 and 315±15 Ma obtained by Le Bas and others (1987). However, northeast of Baroch, the Ambela Granitic Complex intrudes the Kashala Formation, indicating that parts of the Ambela Complex are younger than Carboniferous.

The stratigraphic contrast between Paleozoic sections on either side of the Khairabad thrust supports the notion of large horizontal displacement along this fault. The Khairabad thrust forms the boundary in Pakistan between typical Lesser and Tethyan Himalayan sections and thus serves as an analog to the MCT of the central Himalaya. North of Abbottabad, Greco and others (1989) mapped a prominent mylonite zone considered to be a western extension of the MCT to within a few kilometers of the Khairabad thrust (Mansehra thrust of Greco and others (1989)) (Figure I.1). Additional mapping may reveal that the two faults merge in this region. The continuity of the stratigraphy within the structural block bounded by the Khairabad and Main Mantle thrusts argues against the presence of intervening Himalayan faults of large displacement.

The Peshawar basin section provides evidence for at least two major episodes of tectonism. A Late Cambrian event is indicated by the removal of the Ambar Formation and the deposition in the basal Misri Banda Quartzite of conglomerate with clasts derived from the underlying Tanawal Formation. The feldspathic sands of the Misri Banda Quartzite may represent the erosional products of a granitic highland produced during this episode. This Late Cambrian event coincides with the intrusion of a belt of cordierite granites found throughout the Himalaya which includes the Mansehra Granite of Hazara (Le Fort and others, 1980; Baig and others, 1988). Evidence for Late Cambrian tectonism is also recorded in the sedimentary rocks of Spiti, northern India (Hayden, 1904; Jain and others, 1980) and in the Zanskar Tethys Himalaya (Garzanti and others, 1986).

A second major period of tectonism, initiated during the Early Carboniferous, is denoted by granitic-clast cobble conglomerate in the Jafar Kandao Formation. The provenance of the granitic clasts could be either the Cambrian(?) Swat Granite, which crops out 40 km to the northwest, or Indian-plate granitic basement, which is exposed 100 km to the northeast in the gorge of the Indus River (Baig and Snee, 1989; Baig, 1990). The intrusion of the bulk of the Ambela Granitic Complex during the Carboniferous is a further manifestation of this event, which culminated in the widespread intrusion of diabase dikes and eruption of the basalt that is the protolith of the Karapa Greenschist (Pogue and others, 1992b). Baud and others (1989) interpreted Upper Permian rocks of the Potwar Plateau and Salt Range as rift highland erosional products that accumulated in a "rim basin" landward of the rift. Stratigraphic characteristics of the Peshawar basin Paleozoic section indicate that a northern positive area existed prior to the Permian, shedding detritus as early as the Early Carboniferous. The absence of Permian rocks correlative to the Salt Range sequence may indicate that the Peshawar basin area was subaerial during the climax of the rifting event.

LATE PALEOZOIC RIFTING IN NORTHERN PAKISTAN

Abstract

Metasedimentary rocks exposed in the eastern Peshawar basin and the southern Swat region of northern Pakistan provide evidence for late Paleozoic continental rifting. The onset of extensional tectonics in the Early Carboniferous is indicated by north derived clasts in the Jafar Kandao Formation eroded from thermally induced uplifts of parts of the formerly passive margin of Gondwana. Rift highlands were eroded until they were inundated during the Middle Carboniferous. Renewed uplift accompanied the eruption of basaltic lava flows during the Early Permian. Uplift along south dipping, northeast striking normal faults during the Carboniferous was accompanied by alkaline magmatism represented by the Shewa-Shahbazgarhi and Warsak porphyries and Koga syenite. Geochemistry of basaltic flows (now amphibolites) and intrusions associated with Permian uplift is similar to the coeval Panjal volcanics of northwestern India and indicates rift zone magmatism. Postrifting thermal subsidence led to the deposition of Upper Triassic marine carbonate rocks which unconformably overlie the rift basalts. A similar tectonic history in central Afghanistan suggests continuity between the two regions prior to the opening of the Neo-Tethys.

Introduction

The Cenozoic compressional structures created by the collision of India with Eurasia have been the focus of many geological investigations of the Himalaya. By comparison, the earlier tectonic history of the Himalayan region has been poorly documented. The detailed stratigraphy and paleontology of sedimentary and metasedimentary rocks and radiometric dates and geochemical analyses of igneous rocks that are necessary to decipher this earlier history are only now becoming available. One area where the supply of new information has been especially rich is the Himalaya of northern Pakistan, where a relatively complete Paleozoic and early Mesozoic stratigraphy has been described (Pogue and others, 1992a). The excellent exposures, accessibility, and paleontological control of the Pakistan section provide an unparalleled view of pre-Himalayan sedimentation on the northern margin of Gondwana. This stratigraphic information, when combined with new geochemical analyses and radiometric dates on the igneous rocks of the region, permits the recognition of a major phase of late Paleozoic rifting.

Previous investigations

In Pakistan, Indian plate exposures of middle Paleozoic metasediments are confined to the region north of the Khairabad thrust and south of the Main Mantle thrust (MMT), the suture between the Indian continent and the Kohistan island arc (Figure II.1). These rocks crop out extensively in the mountains surrounding the eastern Peshawar basin and in the Himalayan foothills of Swat district to the north (Figure II.2). The metamorphic grade ranges from lower greenschist facies in the southern Peshawar basin to middle amphibolite facies in central Swat.

The initial reconnaissance study of the area covered in Figure II.2, performed by Martin and others (1962), outlined the stratigraphy and made important observations concerning intrusive relationships. However, the higher-grade metamorphism and more extensive deformation largely erased the macrofossil record of the northern rocks, thereby limiting Martin and others (1962) to a description of the rock units. The first firm paleontological control in the Peshawar basin was provided by Stauffer (1968a), who described a Devonian reef in the southern basin and documented the presence of poorly preserved fossils in the more northern localities. Talent and Mawson (1979) added to the paleontological data set as did Pogue and Hussain (1986), who revised the stratigraphy of Stauffer (1968a) and extended its application as far north as Swabi. Bulk samples of carbonate rocks from the northern Peshawar basin and southern Swat yielded conodonts, enabling

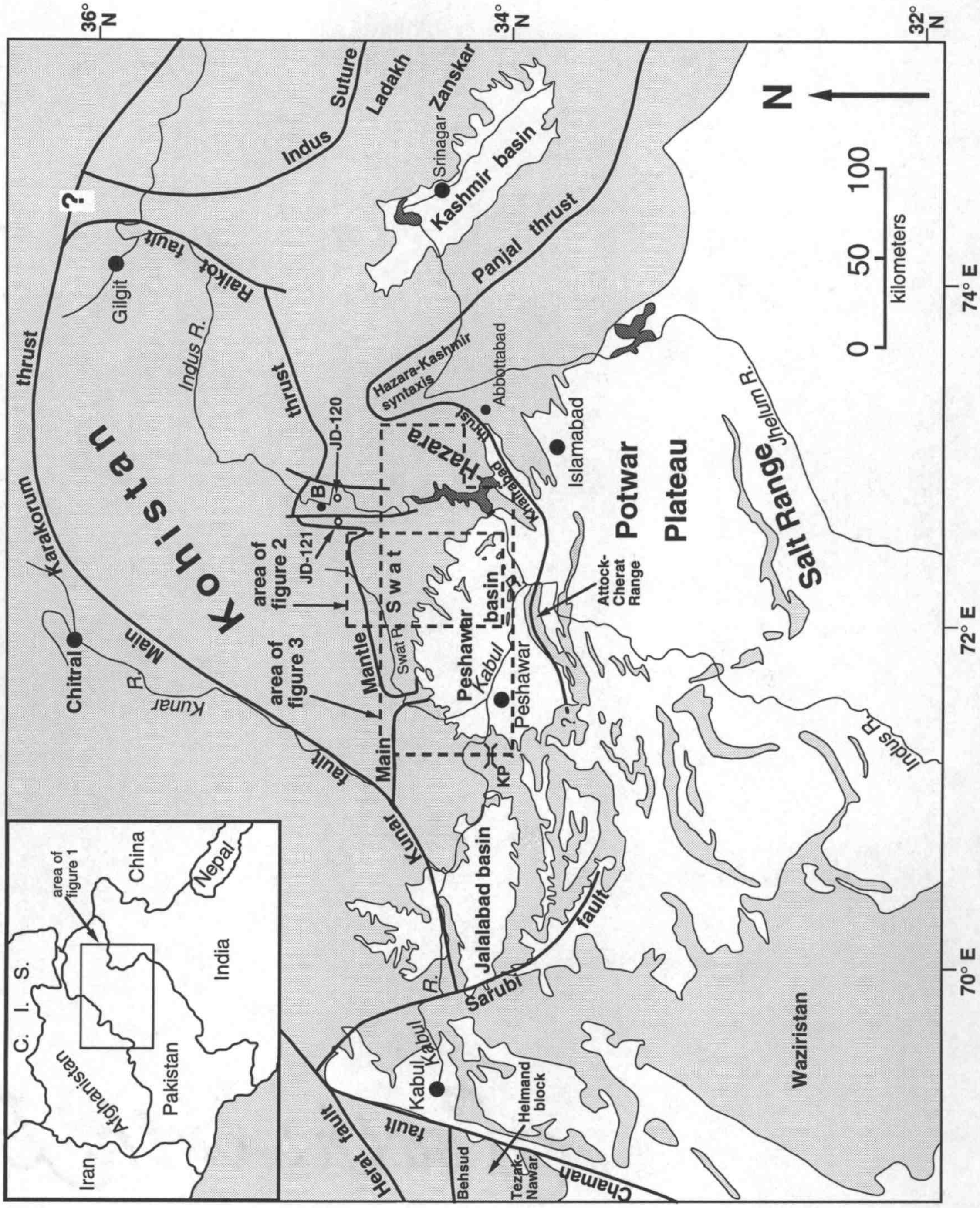

Figure II.1 - Location map of the Peshawar basin and vicinity showing selected major faults. B is Besham; KP is Khyber Pass. Small open circles are geochemical sample localities. Locations of faults are from Gansser (1981), Yeats and Lawrence (1984), Lawrence and others (1989), and Baig (1990).

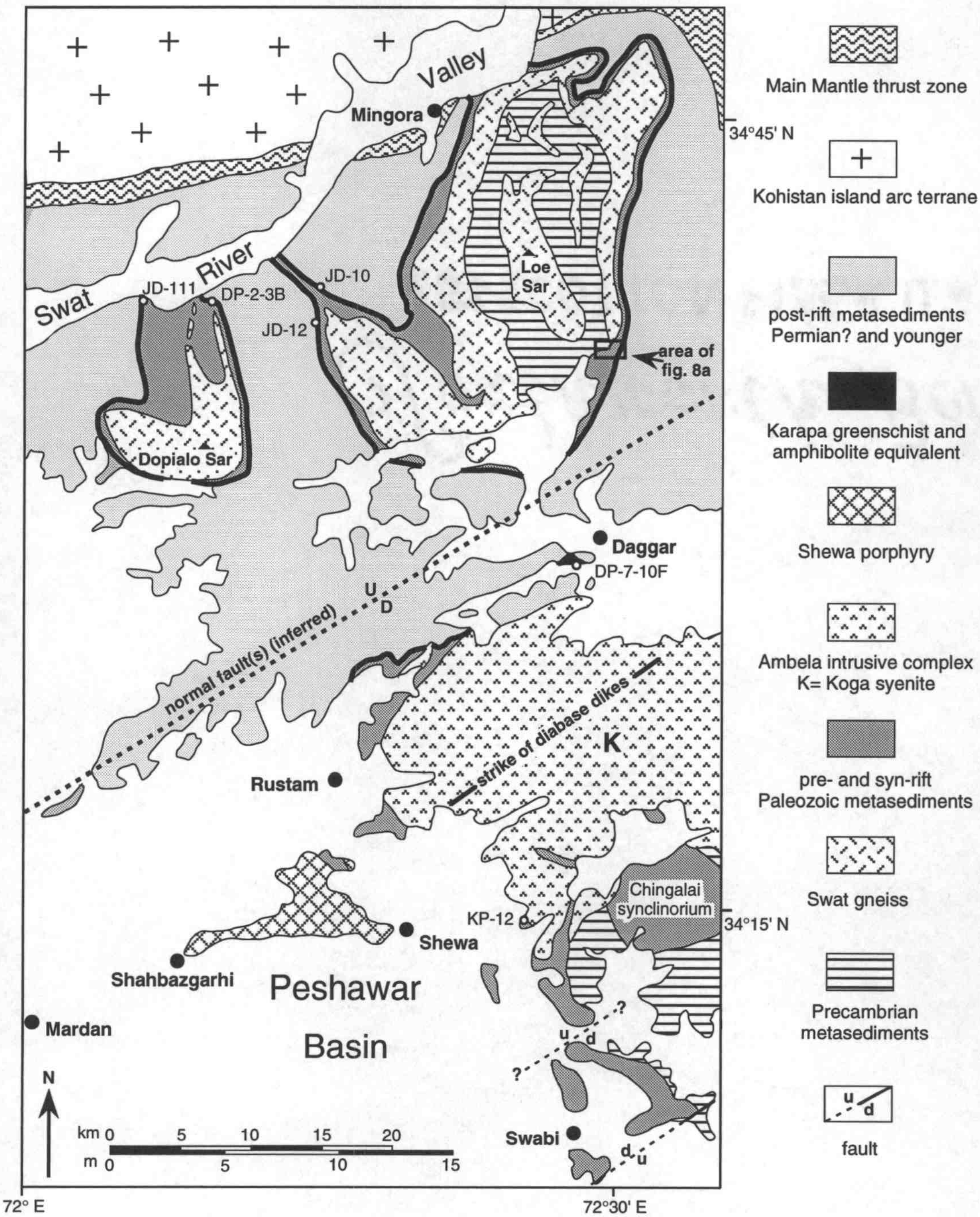

Figure II.2 - Tectonic map of the northeastern Peshawar basin and south-central Swat. Small open circles are geochemical sample localities.

Pogue and others (1992a) to revise the stratigraphy of Martin and others (1962) and construct local and regional correlations. Pogue and others (1992a) described several conodont-bearing horizons critical to the present study from outcrops near Rustam, where Peshawar basin stratigraphy can be traced around the western end of the Ambela intrusive complex (Figure II.2). Conodonts recoveredfrom the most northerly of these outcrops (10 km NNW of Rustam) are strained by ductile flow and have a conodont color alteration index of 7 indicating host rock temperatures of approximately 400°C (Pogue and others, 1992a).

The first study of the igneous rocks of the area by Coulson (1936a), included chemical analyses on "soda-granite" from the Khyber area near Warsak and on "porphyries" from near Shahbazgarhi (Figure II.3). Coulson (1936a) concluded that the rocks from the two areas were geochemically very similar and possibly consanguineous. In a separate study, Coulson (1936b, p. 340, 1937), noted the presence of numerous "epidiorite" dikes and sills that were "similar and possibly of Panjal Trap age" intruding marble north of Swabi (Figure II.2). The metamorphism of marble midway between Swabi and Rustam was attributed to dikes of "epidioritic and amphibolitic" rock. Coulson (1937, p. 228) also invoked the proximity of the "Buner granite," described as a "biotite-granite with 74.30% silica," as a contributing factor in the metamorphism.

The igneous rocks of Swat and the eastern Peshawar basin were re-examined by Martin and others (1962) who named and described the Swat granites and granite gneisses, the Ambela

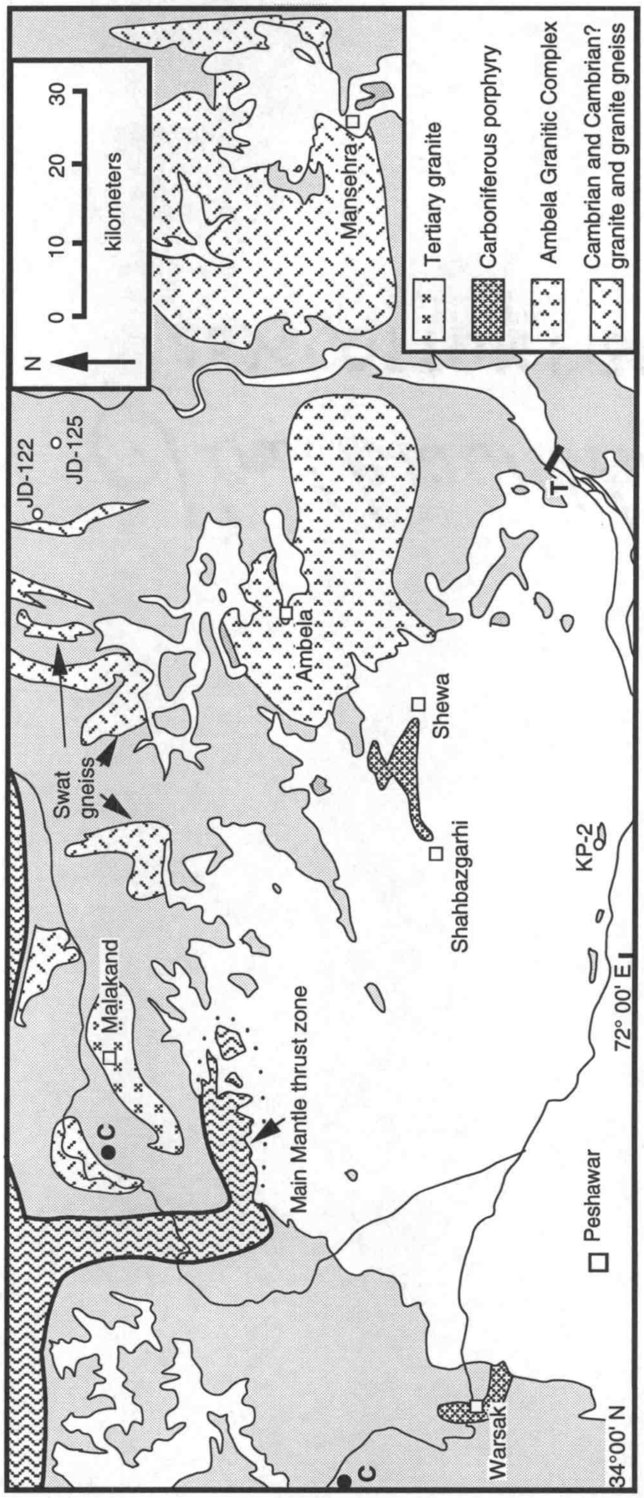

Figure II.3 - Major igneous intrusions in the vicinity of the Peshawar basin. C is Carbonatite; T is Tarbela intrusions. Small open circles are geochemical sample localities.

Granite (Buner granite of Coulson (1937)), and the Shewa Formation. Martin and others (1962) also first noted the presence, in Swat, of a stratigraphically persistent amphibolite horizon that was interpreted by King (1964) as a metamorphosed sill. The Ambela Granite of Martin and others (1962) was the subject of a petrographic analysis by Siddiqui (1965, 1967) who recognized avariety of intrusive rocks, including syenite and the Naranji Kandao Carbonatite. The Babaji Syenite, Koga Syenite, and Chingalai Granodiorite Gneiss were named as constituents of the "Ambela Granitic Complex" in a further study by Siddiqui and others (1968) which included petrologic and geochemical analyses of feldspathoidal syenites and associated rocks.

The similarity between the intrusive rocks at Warsak and Shewa-Shahbazgarhi first noted by Coulson (1936a, 1936b), together with a new locality of similar "alkaline microgranites" near the Tarbela damsite (Figure II.3), led Kempe and Jan (1970) to propose an extensive alkaline igneous province encompassing the northern Peshawar basin. They suggested that the alkaline rocks were intruded in two stages during the Tertiary. On the basis of petrographic and geochemical analyses of alkaline intrusives from Warsak and Shewa-Shahbazgarhi compared with the Koga syenite analyzed by Siddiqui and others (1968), Kempe (1973, p. 399) concluded, "there can be little doubt that the Warsak-Shewa groups of granite and the rocks at Koga are petrogenetically related." K/Ar dates, interpreted as age of emplacement, were also reported for the Warsak alkaline granite (41 Ma) and the Koga nephaline syenite (50 Ma) (Kempe, 1973). The mafic rocks associated with the porphyritic microgranites at Warsak were the subject of a petrographic and geochemical investigation by Kempe (1978, p. M35), who concluded that amphibolitic metagabbro and metadiabase previously interpreted as intrusive (Ahmad and others, 1969; Kempe, 1973) were metamorphosed mafic tuffs or lava flows interlayered with Paleozoic metasediments. It was suggested that the associated porphyritic microgranites might also have an extrusive origin and represent "metamorphosed highly porphyritic alkaline rhyolitic lavas."

A detailed study by Jan and others (1981a) of the geology and petrography of the "alkaline complex" near Tarbela dam revealed a wide variety of rocks including diabase, albitite, sodic granite, and carbonatite within a fault zone in Precambrian metasediments. Jan and others (1981a, p. 3) cited the "close petrographic resemblance" of the Tarbela alkaline granites with those of Shewa-Shahbazgarhi and Warsak as evidence for including these rocks in a "Late Cretaceous-Early Tertiary alkaline igneous province". The petrography and geochemistry of all igneous rocks interpreted as part of a "Peshawar Plain igneous province" was summarized by Kempe and Jan (1980) and again by Kempe (1983). In addition to the alkaline rocks from the Warsak, Shewa-Shahbazgarhi, Ambela, and Tarbela outcrops, carbonatite from the Khyber area (Jan and others, 1981b) and granite and carbonatite exposed near Malakand (Chaudhry and others, 1974, 1976; Ashraf and Chaudhry, 1977) were cited as possible further manifestations of the alkaline igneous province. The common association of alkaline igneous rocks with extensional tectonics led Kempe and Jan

(1980) to propose a rift origin for the province. They further concluded that the Peshawar basin is the eroded remnant of a Tertiary rift valley. Kempe and Jan (1980, p. 76) invoked "rebound relief tension" or "compression release following the initial plate collision" as a tectonic environment.

The first large-scale application of $^{39}Ar/^{40}Ar$ dating techniques to the metamorphic and igneous rocks of northern Pakistan by Maluski and Matte (1984) provided a new set of radiometric ages on the intrusions of the Peshawar plain alkaline igneous province. Determinations on amphibole (two samples) and biotite (one sample) from the Warsak "alkaline granite gneiss" yielded ages of 43.5, 40, and 42 Ma, respectively. These ages, as well as the 41 Ma K/Ar date of Kempe (1973), were interpreted as metamorphic rather than emplacement ages. An age of 23 Ma on muscovite from the Malakand Granite was viewed as an emplacement age, since the rocks sampled showed no effects of Himalayan metamorphism and intrusive contacts crosscut foliations of Himalayan (Tertiary) age. Syenitic gneiss of the Ambela Granitic Complex yielded a 47.5 Ma age which was interpreted, along with the 50 Ma K/Ar date of Kempe (1973), as "the minimum age of the climax of the metamorphism" (Maluski and Matte, 1984, p. 12). The $^{39}Ar/^{40}Ar$ ages of Maluski and Matte (1984), together with K/Ar and Rb/Sr ages later published by Le Bas and others (1987) plus two additional K/Ar dates, led Kempe (1986) to a reassessment of the emplacement chronology of the Peshawar plain alkaline igneous province. Kempe (1986) accepted the Maluski and Matte (1984) interpretation of the $^{39}Ar/^{40}Ar$ ages as representing a metamorphic event; however, he speculated that emplacement immediately preceded the metamorphism.

The Rb/Sr ages of 297 ± 4 and 315 ± 15 Ma on the Koga Syenite by Le Bas and others (1987) and a K/Ar age from the Tarbela intrusive complex of 350 ± 15 Ma (Kempe, 1986) forced Kempe (1986) to abandon the concept of coeval magmatism related to a single rifting event for the Peshawar plain alkaline igneous province and to suggest repetition of alkaline magmatism over very long periods instead. Tertiary rifting was retained by Kempe (1986) as the tectonic environment of the alkaline intrusions at Warsak and for the bulk of the Ambela intrusive complex. On the basis of K/Ar ages on biotite, Le Bas and others (1987) interpreted isolated carbonatites exposed 50 km NW and 60 km north of Peshawar (Figure II.3) to have been intruded along thrust faults at 31 ± 2 Ma and later deformed by the thrusts at 24 ± 2 Ma. While Kempe (1986) considered these carbonatites to represent the final stages of rift-related magmatism, the association of the intrusions with faults interpreted as thrusts prompted Le Bas and others (1987) to reject the Tertiary rifting hypothesis.

Rafiq's (1987) investigation of the Ambela Granitic Complex yielded the most comprehensive geochemical and petrological data set yet obtained from these rocks. On the basis of their geochemical similarities with granites of the east African rift, Rafiq (1987) suggested a within-plate rift setting for the bulk of the intrusions near Ambela.

Magmatism

Due to the dearth of paleontological control, the metasedimentary country rock has, until recently, provided few constraints on the timing of Peshawar basin magmatism. This situation was largely remedied by conodont zonation of the metasediments of the eastern Peshawar basin by Pogue and others (1992a). Conodonts recovered from metasediments north of Rustam bracketed the age of the Swat amphibolite horizon first mapped by Martin and others (1962). Westphalian B conodonts from phyllitic limestones 10 m below the amphibolite and Carnian conodonts from marbles 500 m above restrict the emplacement of the amphibolite protolith to Middle Carboniferous to Late Triassic, a time span that coincides with the range of ages deduced for the Panjal volcanics of the Kashmir basin (Gansser, 1964). The Panjal volcanics consist of basaltic and felsic pyroclastics (the "agglomeratic slates") overlain by up to 2500 m of basaltic rocks (the Panjal "traps") which were interpreted by Bhat and others (1981), on the basis of their geochemistry, to have been erupted during continental rifting that climaxed in the Permian. Geochemical analyses of the Swat amphibolite by Ahmad (1986) also suggested a protolith of continental basalt. The amphibolite horizon was mapped throughout Swat by Lawrence and others (1989) as an intrusion within the Alpurai Group. On the basis of contact relationships and its consistent position within the stratigraphic sequence, the protolith of the Swat amphibolite was reinterpreted by DiPietro (1990) to be basaltic flows rather than the sill first proposed by King (1964).

An equally important discovery made during recent mapping in Swat (DiPietro, 1990) and the Peshawar basin (Pogue and others, 1992a) is that the diabase dikes and sills first noted by Coulson (1937) are restricted to rocks stratigraphically underlying the amphibolite horizon. These intrusions are widespread in the pre-Permian section between the Main Mantle and Khairabad thrusts but have not been observed in Mesozoic or younger rocks. The relationships suggest that the diabase was intruded in one episode of Permian magmatism, and further observations of dikes terminating in the Swat amphibolite horizon (DiPietro, 1990) support the notion that the intrusions served as feeders for basaltic volcanism. An investigation of similar mafic intrusions and amphibolite exposed in the Hazara-Kashmir syntaxis midway between the Peshawar and Kashmir basins by Papritz and Rey (1989) revealed that the intrusions and amphibolite resemble one another geochemically and are geochemically similar to the Panjal volcanics. Papritz and Rey (1989) also observed that mafic intrusions in the syntaxis region were absent in rocks younger than a stratigraphically persistent amphibolite horizon. Mafic dikes intruding Mansehra Granite in Hazara yielded $^{39}Ar/^{40}Ar$ plateau dates of 284 ± 4 Ma and 262 ± 1 Ma confirming a Permian age for basaltic magmatism in this area (Baig, 1990). The 262 ± 1 Ma date is especially noteworthy as it falls within a 10 Ma "window" for Panjal volcanism as bracketed by fossils in the Zanskar area of northern India (Figure II.1)(Gaetani and others, 1990).

The geochemistry of Swat amphibolites, amphibolites from the Hazara-Kashmir syntaxis, and Panjal volcanics supports their derivation from coeval or at least equivalent protoliths produced by rift zone magmatism. The major element chemistry, obtained by wavelength dispersive X ray fluorescence (XRF) analysis, of eight amphibolites and two diabases was provided by the U.S. Geological Survey at Denver, Colorado (Table II.1). Trace element analyses (Table II.1) were obtained by instrumental neutron activation analysis (INAA) at Oregon State University. Covariations in P_2O_5 and TiO_2 (Figure II.4) exhibit 6X ranges in both elements without significant distinction between the three types.

Overall elemental variations in Swat amphibolites are more suitable for assessment of the tectonomagmatic regime. These are depicted as multielement (spidergram) plots (figures II.5 and II.6), shown normalized to primordial mantle values (Taylor and McClennan, 1985). A wide range exists among incompatible elements (e.g. Th = 0.4-17 ppm, La = 4.4-72 ppm, and Ba = 43-640 ppm), which coincides with the variation observed in major element and transition metal abundances. The overall uniformity among pattern shapes, especially among the less mobile elements (Ta to Yb), reflects a similar magmatic origin. An exception to this uniformity is displayed by a contrast in Th/Ta ratios, which forms the basis for separating the compositions into two types. Relatively high Th/Ta and especially depleted Ta (and Nb) abundances are typical of volcanic rocks derived by subduction zone processes (e.g., Pearce, 1982). However, such compositions also exhibit depleted P and Ti values, and their patterns typically yield negative anomalies of Ta (Nb), P, and Ti. Relatively high Th and U values in the Swat units are likely derived from crustal contamination by Th-rich

Table II.1a Geochemical Analyses of Amphibolites and Diabase Dikes from the Eastern Peshawar Basin, Swat, and the Besham Area, Northern Pakistan

	Sample									
	DP-2-3B	DP-7-10F	KP-2	KP-12	JD-10	JD-12	JD-120	JD-121	JD-122	JD-125
East Longitude	72°10.8'	72°27.8'	72°02.8'	72°26.0'	72°17.0'	72°16.3'	72°49.6'	72°39.5'	72°41.0	72°43.7'
North Latitude	34°39.3'	34°29.4'	34°01.8'	34°15.4'	34°39.3'	34°38.2'	34°48.2'	34°48.1'	34°42.6'	34°40.5'
Location figure	2	2	3	2	2	2	1	1	3	3
XRF (wt. %)										
SiO2	47.70	49.60	43.00	49.90	48.40	48.00	46.10	49.00	49.10	49.90
TiO2	1.81	1.83	5.37	5.09	2.68	1.49	1.67	3.10	1.20	1.42
Al2O3	13.70	13.80	12.50	7.36	13.50	14.20	13.60	12.60	14.20	13.70
Fe2O3 total	14.50	13.60	15.70	12.60	14.50	12.40	11.20	17.40	13.60	14.80
MnO	0.22	0.21	0.21	0.15	0.21	0.20	0.11	0.25	0.21	0.24
MgO	6.70	6.31	6.76	8.52	6.57	7.33	6.81	5.55	7.59	7.06
CaO	10.80	8.78	10.90	12.80	11.00	11.90	13.90	9.75	11.30	10.00
Na2O	2.66	3.86	2.35	1.17	2.15	2.38	2.03	1.53	1.45	2.04
K2O	0.24	0.19	0.51	1.68	0.54	0.37	0.58	0.54	0.60	0.21
P2O5	0.16	0.19	0.57	0.48	0.24	0.15	0.15	0.35	0.09	0.13
LOI	0.59	3.07	2.40	0.59	0.56	1.96	3.70	0.51	0.88	0.81
Sum	99.08	101.44	100.27	100.34	100.35	100.38	99.85	100.58	100.22	100.31
INAA (ppm)										
Sc	47.60	46.50	29.10	65.10	34.80	45.50	29.60	45.10	52.50	50.10
Cr	130.00	110.00	140.00	210.00	220.00	240.00	130.00	86.00	200.00	85.00
Co	51.40	48.10	50.50	37.40	46.90	46.10	41.00	46.10	47.00	48.10
Ni	96.00	55.00	110.00	18.00	88.00	120.00	79.00	58.00	70.00	67.00
Zn	90.00	74.00	85.00	63.00	----	----	----	----	180.00	----
Rb	3.60	2.50	12.00	39.00	3.10	7.50	23.30	8.40	16.00	5.20
Sr	130.00	460.00	550.00	160.00	120.00	110.00	160.00	150.00	98.00	150.00
Cs	0.11	0.32	0.55	0.64	0.06	0.22	0.57	0.10	0.18	0.04
Ba	75.00	64.00	480.00	200.00	110.00	90.00	74.00	240.00	87.00	43.00
La	7.84	10.50	26.00	25.90	12.80	7.50	12.50	20.40	4.12	4.40
Ce	16.20	22.30	54.60	58.10	31.90	17.50	28.30	46.00	10.40	11.50
Nd	14.00	15.00	39.00	38.00	20.00	12.00	15.00	27.00	6.00	10.00
Sm	4.31	4.37	9.32	9.36	5.84	3.56	4.50	7.70	2.68	3.16
Eu	1.55	1.57	3.30	1.73	1.94	1.19	1.33	2.19	1.04	1.11
Tb	1.06	1.05	1.20	1.44	1.04	0.79	0.75	1.34	0.83	0.73
Yb	2.83	3.00	1.76	2.71	2.43	2.30	2.24	3.84	2.43	3.09
Lu	0.42	0.42	0.26	0.40	0.34	0.40	0.33	0.57	0.39	0.46
Zr	78.00	24.00	170.00	200.00	83.00	10.00	101.00	163.00	31.00	52.00
Hf	3.51	3.39	5.48	4.81	4.32	2.34	3.30	5.52	1.61	2.15
Ta	0.40	0.57	2.05	1.82	0.78	0.31	0.47	1.07	0.40	0.26
Th	1.88	2.20	2.38	6.84	0.95	1.61	3.48	3.41	0.75	0.42
U	0.28	0.10	0.41	1.20	0.36	0.24	0.96	1.28	0.05	0.28

XRF is X ray fluorescence, LOI is loss on ignition, and INAA is instrumental neutron activation analysis.

Table II.1b Descriptions and Petrology of Amphibolites and Diabase Dikes From the Eastern Peshawar Basin, Swat, and the Besham Area, Northern Pakistan

Sample	Description	Petrology
DP-2-3B	foliated and lineated epidote amphibolite horizon in Marghazar Formation	Hb + Ep + Qtz + Olig + Sph + Ap
DP-7-10F	foliated and lineated epidote amphibolite horizon in Marghazar Formation	Actinolitic Hbl + Qtz + Alb(?) + Ep + Sph + Ap
KP-2	vesicular diabase sill intruding Ordovician Misri Banda Quartzite	Hbl + Chl + Alb + Ep + Calc + Augite + Mag + Qtz + Sph + Ap
KP-12	diabase dike cutting Ambela granite	Hbl + Alb(?) + Ep + Clz + Sph + Ksp + Hem + Ap
JD-10	foliated and lineated epidote amphibolite horizon in Marghazar Formation	(detailed petrology unavailable)
JD-12	foliated and lineated epidote amphibolite horizon in Marghazar Formation	(detailed petrology unavailable)
JD-120	foliated epidote amphibolite sill in feldspathic quartzite	Hbl + Qtz + Olig + Biot + Ep + Clz + Sph + Py
JD-121	weakly foliated garnet amphibolite within Gar-Musc schist, Marghazar Formation(?)	Hbl + Olig(?) + Gar + Qtz + Sph + Ilm
JD-122	foliated and lineated garnet amphibolite within quartzite, feldspathic quartzite, and marble of Marghazar Formation(?)	Hbl + Olig(?) + Qtz + Clz + Gar + Sph + Ap
JD-125	foliated and lineated amphibolite within Gar-Musc-Biot schist of Marghazar Formation(?)	Hbl + Qtz + Andesine + Ilm(?) + Sph + Clz + Ap

Abbreviations are actinolite (Act), albite (Alb), apatite (Ap), biotite (Biot), clacite (Calc), chlorite (Chl), clinozoisite (Clz), epidote (Ep), garnet (Gar), hematite (Hem), hornblende (Hbl), ilmenite (Ilm), K-feldspar (Ksp), magnetite (Mag), muscovite (Musc), oligoclase (Olig), pyrite (Py), quartz (Qtz), and sphene (Sph).

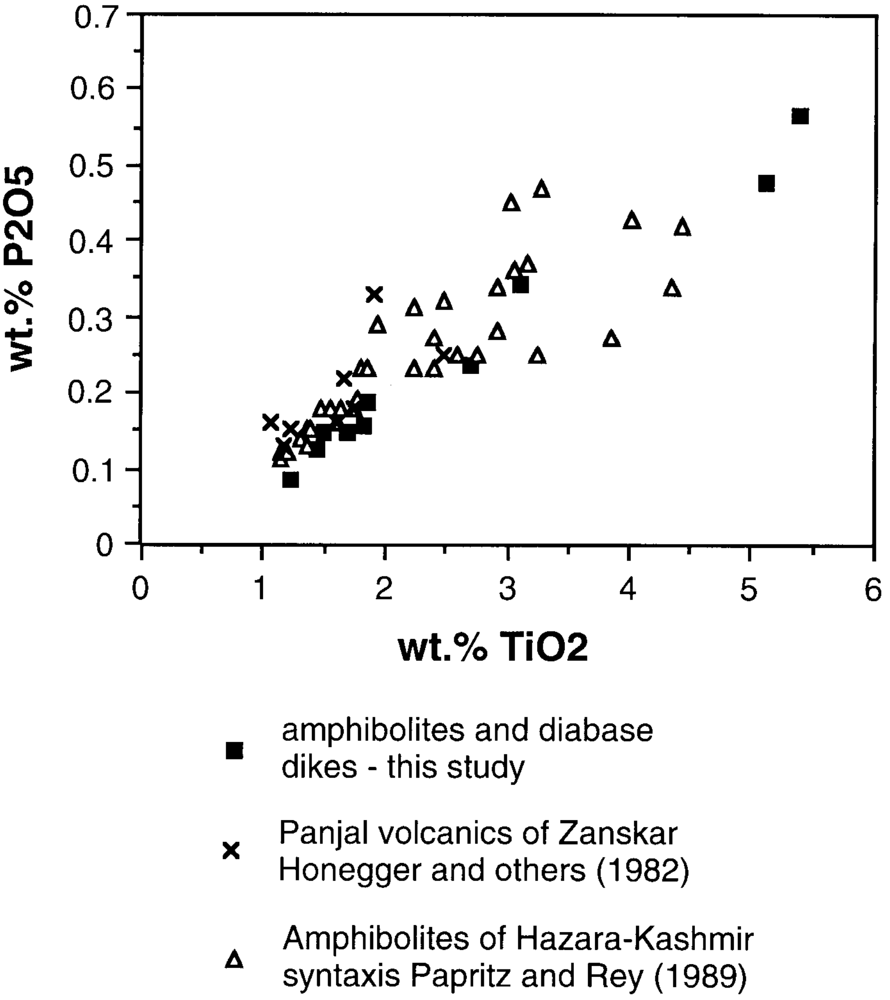

Figure II.4 - Covariation of P_2O_5 and TiO_2 illustrating the range from subalkalic (low P and Ti) to alkalic compositions (high P and Ti) of mafic units from the Peshawar basin, Swat, Hazara-Kashmir syntaxis, and Ladakh.

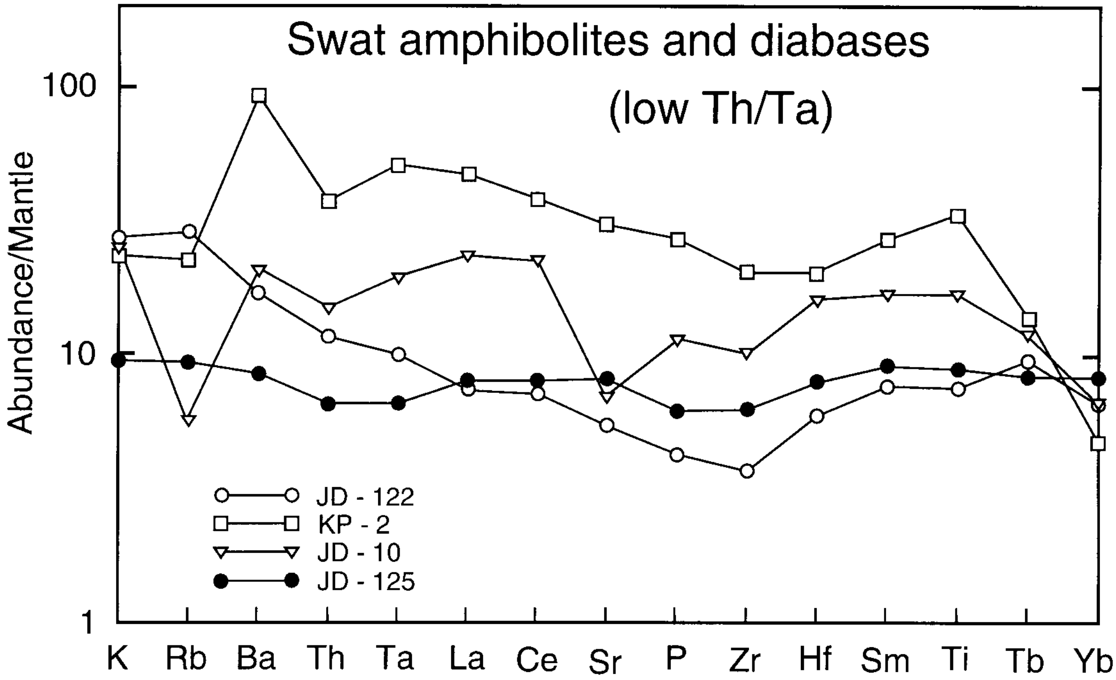

Figure II.5 - Multielement plots of Swat and Peshawar basin amphibolites and diabases having low Th/Ta ratios, shown normalized to Earth mantle abundances (Taylor and McClennan, 1985).

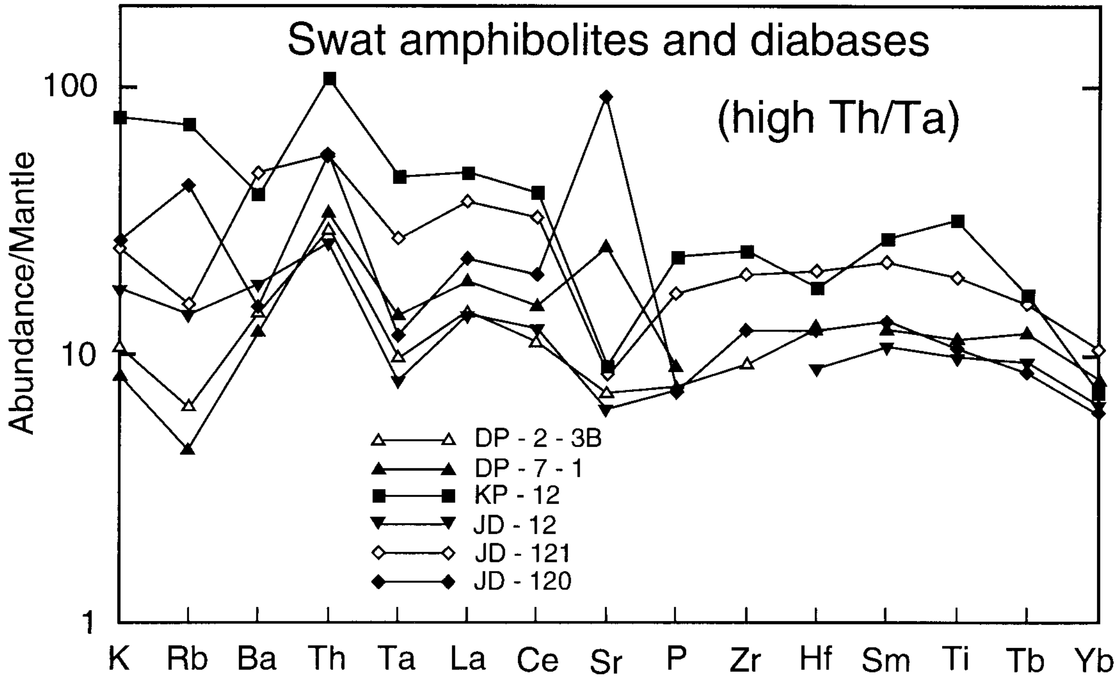

Figure II.6 - Multielement plots of Swat and Peshawar basin amphibolites and diabases having high Th/Ta ratios, shown normalized to Earth mantle abundances (Taylor and McClennan, 1985).

granitic rocks or possible alteration during the magmatic stage. This is also reflected in the mobile elements K to Th in all patterns although the observed variation is more likely related to metamorphism and the ensuing effects of water-induced mobility (Pearce, 1982). Swat/Peshawar basin compositions yielding low Th/Ta ratios (Figure II.5) are more appropriate for defining source regions as well as the tectonomagmatic regime. The nearly flat pattern and low alkali element abundances of JD-125 suggest derivation from nonenriched or depleted (MORB-like) mantle, possibly obtained by larger degrees of melting in a rift environment to produce a tholeiitic component of the series. By contrast, the high Ti diabase, KP-2, yields a pattern (which compares well with KP-12) probably derived from lower degrees of melting and typifying the alkalic members of the sequence. Although some mobility is expected in alkali elements (K and Rb), these relations are supported by the P_2O_5 versus TiO_2 relations exemplified by subalkalic (JD-125 and JD-122) and alkalic (KP-2 and KP-12) signatures. The presence of thoeliitic members that display somewhat primitive, normal MORB-like, patterns of trace elements (JD-122 and JD-125, Figure II.5) argues for an extensional system that produced magmas that erupted without significant crystal fractionation.

If the mafic dikes and amphibolites of the Peshawar basin and Swat are the product of Permian rifting, as suggested by their geochemistry as outlined above, then alkaline igneous rocks of the Peshawar basin intruded by these dikes are pre-Permian. The alkaline porphyry of Shewa-Shahbazgarhi contains unusually large diabase dikes and intrudes Upper Devonian-Lower Carboniferous metasediments (lower part of the Jafar Kandao Formation of Pogue and others, (1992a)) 5 km southeast of Rustam. A Carboniferous emplacement age is therefore suggested for the Shewa-Shahbazgarhi rocks. This chronology is supported by Carboniferous Rb/Sr ages on the Koga Syenite (Le Bas and others, 1987) which shares a close petrogenetic relationship with the Shewa-Shahbazgarhi porphyry (Kempe, 1973). The interpretation of Kempe (1978), that the porphyritic microgranites and hornblende schists at Warsak are metamorphosed volcanics interlayered with Paleozoic metasediments, supports both the emplacement chronology deduced to the east and the close relationship between the alkaline porphyry and mafic igneous rocks. The hornblende schists exposed at Warsak are almost certainly the equivalent of the Swat amphibolite. A similar association of metamorphosed porphyry and mafic volcanics has been described from the Kashmir basin, where sheared porphyritic rhyolite, lithologically identical to cataclastic porphyry from the Shewa-Shahbazgarhi area, underlies the basalt flows of the Panjal volcanics (Davies, 1956). The relationships between the alkaline igneous rocks and the metasedimentary country rock outlined above support Maluski and Matte's (1984) interpretation of Eocene radiometric ages as representative of metamorphism rather than emplacement. Alkaline magmatism in the Peshawar basin is thus viewed as a Carboniferous event, which preceded the Permian emplacement of diabase intrusions and eruption of basalt flows.

The presence of numerous diabase dikes indicates that much of the Ambela Granitic Complex was emplaced prior to the Permian. Rafiq (1987) concluded that the entire complex was emplaced during the middle to late Paleozoic; his conclusion was based on the Late Carboniferous Rb-Sr age determined by Le Bas and others (1987) for the Koga Syenite, which was interpreted to have intruded during the waning phases of Ambela magmatism. However, the eastern half of the Ambela Complex is largely megacrystic granite that strongly resembles the Mansehra Granite of Hazara, as well as parts of the Swat granite to the north. The eastern edge of the Ambela megacrystic granite is separated from similar Mansehra Granite by less than 20 km across the gorge of the Indus River (Figure II.3). In the walls of the gorge, basal intrusive contacts of both the Ambela and Mansehra granites are concordant with quartzite and phyllite of the Tanawal Formation suggesting that erosion by the river has breached a formerly continuous sheet-like intrusion. An emplacement age of Late Cambrian and/or Early Ordovician for the Mansehra Granite is based on a 516 ± 16 Ma Rb/Sr isochron (Le Fort and others, 1980), a 500 Ma U/Pb zircon date (R. Zartman and P. Zeitler, personal communication, 1986) and an $^{39}Ar/^{40}Ar$ date of 493 ± 1 Ma (Baig, 1990). A similar age for Ambela megacrystic granite is in agreement with Rafiq's (1987) conclusion that these rocks constitute the oldest suite in the complex. The Swat Granite Gneiss, exposed 15 km north of the Ambela Granitic Complex (figures II.2 and II.3), was considered by DiPietro (1990) to be another

Mansehra-correlative pluton based on textural similarities and intrusive relationships.

The western half of the Ambela complex consists primarily of syenite and alkaline granite (Rafiq, 1987) that intrude metasedimentary country rock as young as Carboniferous. Most of these rocks are petrogenetically related to the Koga Syenite (Rafiq, 1987). However, south of Daggar, part of the Ambela intrudes metasedimentary rocks of the basal Kashala Formation, whose middle horizons have yielded early Late Triassic conodonts (Pogue and others, 1992a). The granitic rocks in this area are tourmaline bearing and devoid of diabase intrusions, suggesting a correlation with tourmaline granite gneiss described by DiPietro (1990) as intruding the Swat amphibolite 25 km northwest of Daggar. The presence of post-Permian, Carboniferous, and probable Cambrian intrusives indicate that the Ambela Granitic Complex was emplaced during at least three distinct episodes of magmatism.

The interpretations of contact and intrusive relationships and radiometric ages described above contradict the association of Peshawar basin magmatism with Himalayan collisional tectonics first proposed by Kempe and Jan (1970). However, the absence of deformation and diabase dikes support the Tertiary (23 Ma) age derived by Maluski and Matte (1984) for the Malakand Granite.

Stratigraphy

Eastern Peshawar Basin

Lithologies and facies relations of late Precambrian-Devonian metasediments exposed in the eastern Peshawar basin indicate deposition in a northward deepening, epicontinental, shallow marine environment (Figure II.7). Late Cambrian to Early Ordovician tectonism, coincidental with intrusion of the Mansehra and related granites, created highlands north of the depositional basin from which Cambrian strata were eroded (Pogue and others, 1992a). Shallow marine sedimentation resumed in the Ordovicianand continued relatively uninterrupted until near the close of the Devonian. An abrupt change from carbonate- to clastic-dominated sedimentation at the contact between the Nowshera and Jafar Kandao formations heralds the demise of passive epicontinental sedimentation. The basal 30 cm of the Jafar Kandao Formation, exposed 3 km north of Swabi, is calcareous sandstone containing carbonate pebbles derived from the underlying Nowshera Formation. Limestones from the upper Nowshera Formation 7 m below this contact yielded Upper Devonian (Frasnian) conodonts. The carbonate pebble beds are overlain by 50+ m of pebbly argillite and conglomerate with clast lithologies indicative of derivation from the pre-Nowshera Paleozoic section. Similar lithologies are exposed 4 km southeast of Rustam, where a limestone lens within argillite yielded uppermost Devonian (late Famennian) to Lower Carboniferous (Tournaisian) conodonts. A

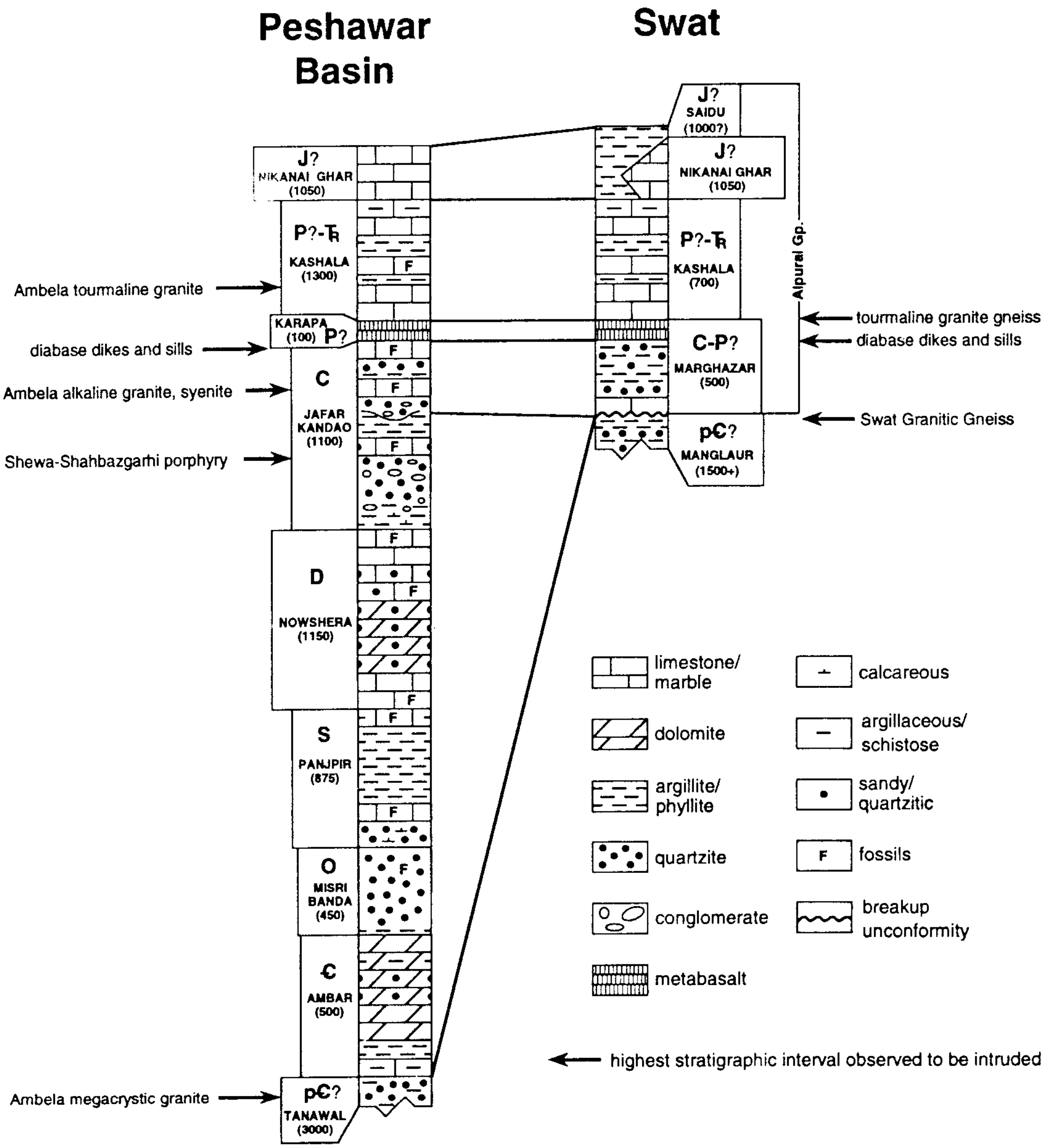

Figure II.7. - Correlation of generalized stratigraphic columns for Swat (DiPietro, 1990) and the eastern Peshawar basin (Pogue and others, 1992a). Numbers in parentheses give approximate formation thicknesses in meters.

300+ m interval of argillite overlying the conodont horizon contains several channel-filling cobble conglomerates with well-rounded clasts, up to 40 cm in diameter, of quartzite and granitic rock. The clast lithologies indicate northward derivation, because granitic rocks of a suitable provenance are absent to the south. Lithologies of the granitic clasts closely resemble Indian plate Precambrian granitic basement described by Baig (1990) in the gorge of the Indus River 100 km to the northeast. The upper one half of the Jafar Kandao Formation displays great horizontal variability. Pogue and others (1992a) recovered Lower Carboniferous (Visean) conodonts from one of several discontinuous intervals of quartzitic limestone that are interbedded with the dominant argillite and quartzite, and minor conglomerate. A thin interval of argillaceous limestone 20 m below the contact with metamorphosed basalts of the Karapa Greenschist yielded Middle Carboniferous (Westphalian B) conodonts (Pogue and others, 1992a). The Karapa Greenschist, with a mineral assemblage of chlorite-quartz-ilmenite-albite-sphene, has a sharp contact with the uppermost argillite bed of the Jafar Kandao Formation. No relict flow structures or jointing have been observed that would indicate subaerial or subaqueous eruption. However, the majority of the basalt flows of the correlative Panjal volcanics were erupted subaerially (Bhat and Zainuddin, 1978). The Karapa Greenschist is overlain by 50 m of argillite and thin-bedded limestone that form the base of the Kashala Formation. The remainder of the Kashala Formation consists of thin intervals of phyllite interbedded with thick-bedded brown marble that contains Late Triassic (Carnian) conodonts (Pogue and others, 1992a). No Permian strata have been recognized, but the Triassic fossiliferous horizons are separated from the Karapa Greenschist by over 500 m of strata that could be, in part, Permian. Massive white marble of the Nikanai Ghar Formation forms the top of the Peshawar basin section.

Swat

The oldest unit exposed in Swat is the Manglaur Formation, a probable correlative to the Precambrian and Cambrian? Tanawal Formation which forms the base of the Paleozoic section in the Peshawar basin (Kazmi and others, 1984; Lawrence and others, 1989). The Manglaur Formation is intruded by several large sheet-like bodies of Upper Cambrian Swat Granitic Gneiss and is overlain by the Marghazar Formation, the oldest unit of the Alpurai Group of DiPietro (1990) (Figure II.7). An unconformity at the Manglaur/Marghazar contact is indicated by the presence of pebbles and K-feldspar clasts, derived from the Swat Granitic Gneiss, in Marghazar psammitic schist. The Marghazar Formation varies from <50 m to >1000 m in thickness and consists of pelitic schist, hornblende schist, psammitic schist, and schistose marble. A 20- 50-m-thick interval of amphibolite forms the top at all exposures in central Swat, and other discontinuous amphibolite bodies occur throughout the unit. In areas where the Marghazar Formation is thin, it is composed almost entirely of the upper amphibolite horizon. The metasedimentary part of the Marghazar Formation is correlative with the upper Jafar Kandao Formation based on lithologic similarities and the stratigraphic position below the Karapa Greenschist-correlative amphibolite horizon. The Kashala Formation overlies the Marghazar Formation and is the oldest unit common to Swat and the Peshawar basin. The principal lithologies in the two areas are similar, although the unit gradually thins and becomes more schistose to the north. In Swat, the Kashala Formation is overlain by marble of the Nikanai Ghar Formation in the region south of the Loe Sar gneiss dome, and by graphitic phyllite of the Saidu Formation elsewhere.

Interpretation

The conglomerate intervals in the lower Jafar Kandao Formation record the progressive denudation of a tectonic highland north of the depositional basin. The uplift of this highland climaxed during the Early Carboniferous when granitic cobbles derived from subaerially exposed Precambrian basement were deposited in fluvial channels. The lateral variability and conglomerate intervals of the upper Jafar Kandao indicate that tectonic instability continued into the Middle Carboniferous.

The absence of strata in Swat correlative with the thick (3000 m) lower Paleozoic section of the Peshawar basin suggests Swat as a source for the clastic intervals of the lower Jafar Kandao Formation. The sediments of the basal Marghazar were deposited on eroded Precambrian rocks as the Middle Carboniferous seas partially inundated Swat. Much of Swat remained exposed until buried by the Permian(?) basalt flows which form the protolith of the upper

Marghazar amphibolite horizon and Karapa Greenschist. The absence of relict pillow structures in the amphibolite/greenschist, apparent lack of Permian strata, and the presence of reworked lower Paleozoic *Panderodus* conodonts in the Lower Permian Amb Formation of the Salt Range (B. Wardlaw, personal communication, 1989) suggest that renewed uplift and erosion accompanied subaerial extrusion of the basalt. A major transgression, initiated by thermal subsidence of the rifted margin, reestablished shallow marine sedimentation by the late Triassic, when the fossiliferous carbonate rocks of the Kashala Formation were deposited.

Structure

Over 2000 m of Cambrian through Devonian metasedimentary rocks are exposed in the Chingalai synclinorium, whereas only 30 km to the north, on the southern margin of the Loe Sar dome, lower Paleozoic rocks are absent (Figure II.2). The intervening distance increases to 50-60 km when the shortening effects of Himalayan folding are removed. The proximity of these contrasting sections precludes a gradual transition and implies instead the existence of an intervening fault or series of faults along which uplift of the northern block occurred relative to the southern block during the Carboniferous. The precise location of the principal inferred fault(s) bounding the uplifted Swat block is unknown because exposed bedrock in the critical area is entirely post-Lower Carboniferous in age. However, smaller-scale faults in pre-Carboniferous rocks in Swat and the Peshawar basin are interpreted as representative of the deformational style in general. One such fault is suggested by contact relationships on the eastern flank of the Loe Sar dome, 13 km north of Daggar, where the thickness of the Marghazar Formation is abruptly quadrupled by the addition of an older section (Figure II.2). A detailed map of the area, oriented to facilitate down-structure viewing, is presented in Figure II.8a. Lithologic layering, which parallels the contact with older formations in the younger section, is truncated against the contact with the Manglaur Formation and Swat Gneiss in the older section. Figure II.8b is an interpretation of the contact relationships in cross section, prior to intrusion of tourmaline granite (tg) and prior to

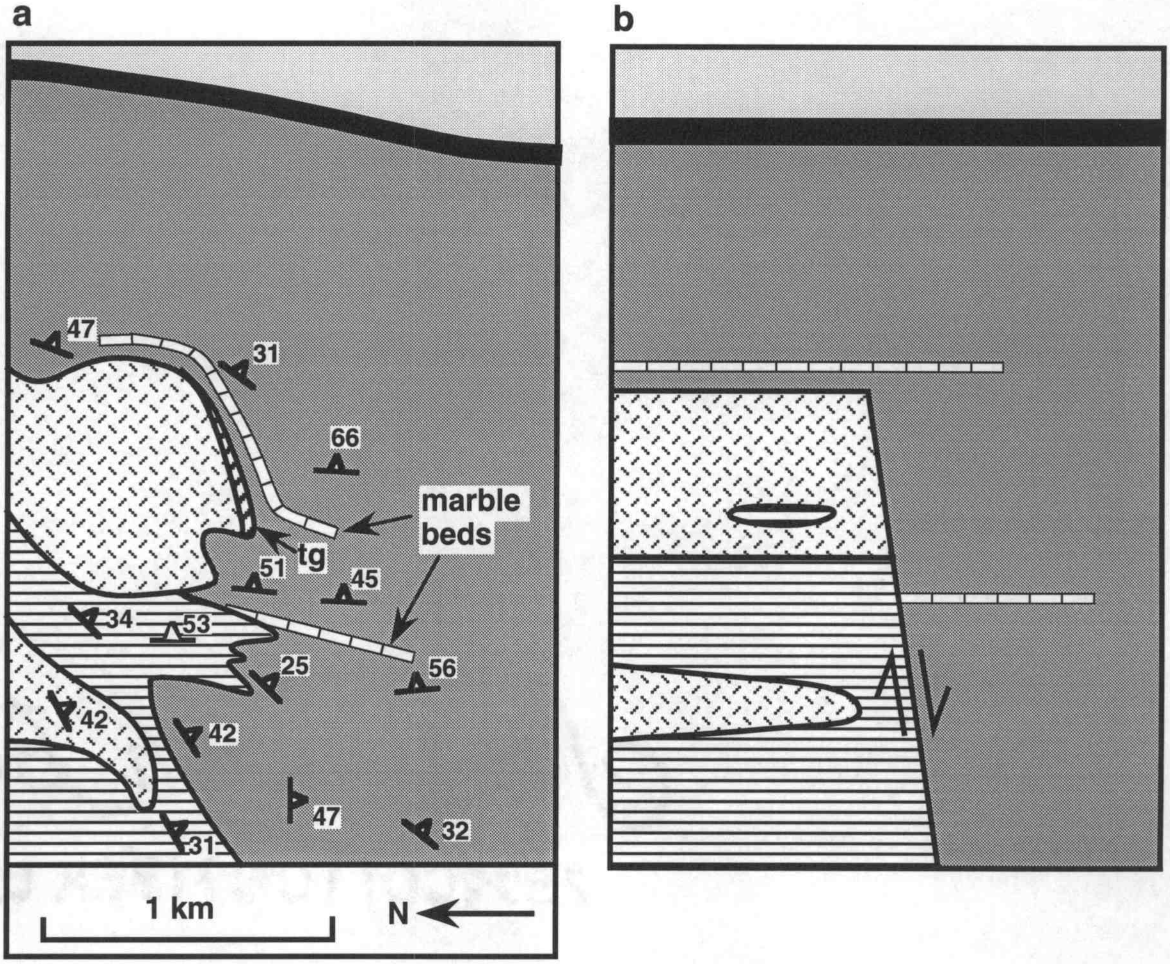

Figure II.8 - (a) Geologic map of the Lewanai Ghar area of southern Swat orientated to facilitate down-structure viewing. Patterns are the same as for figure II.2; tg is tourmaline granite (Tertiary). (b) Interpretation of pre-Himalayan structure of the Lewanai Ghar area.

Himalayan folding and metamorphism. The truncation of layering in the older Marghazar is interpreted to have resulted from syndepositional normal faulting.

Two subparallel high-angle faults which offset Precambrian-Silurian formations north and east of Swabi (Figure II.2) may define a minor Carboniferous graben. The northeast strike of these faults is oblique to the Himalayan structural trends but is parallel to the strike of diabase dikes in the Ambela Granitic Complex to the north (Rafiq, 1987). These dikes, as well as the contacts between individual granitic intrusions that comprise the Ambela Complex, have a northeastern strike (Rafiq, 1987), indicating a northwest-southeast orientation of maximum extension during emplacement.

Another suspected Paleozoic normal fault hosts the "alkaline" igneous complex exposed near Tarbela Dam (Figure II.3)(Jan and others, 1981a). This fault, expressed as a 300 m wide shear zone in Precambrian metasediments, was interpreted by Calkins and others (1975) as a segment of the dominantly left-lateral Darband fault, of Himalayan age. The association of mafic intrusions with this fault, which are elsewhere restricted to pre-Permian rocks, suggests that it originated as an older Paleozoic structure. If the 350 ± 15 Ma K/Ar date (Kempe, 1986) on an amphibole albitite from the Tarbela complex is accepted as an emplacement age, then initial motion must have occurred during, or prior to, the Late Devonian.

Summary and Conclusions

Stratigraphic, radiometric, structural, and geochemical evidence indicates major rifting in northern Pakistan during the late Paleozoic. Pre-rift sedimentary rocks were deposited as late as the Late Devonian (Frasnian) in a northward deepening epicontinental sea (Figure II.9a). Thermally induced uplift and emergence of the northern part of the epicontinental basin began prior to the Early Carboniferous and was accompanied by the development of major northeast striking normal faults and the inception of alkaline magmatism (Figure II.9b). Alkaline magmatism continued into the Middle Carboniferous, while erosion led to the eventual submergence of the Early Carboniferous highlands (Figure II.9c). Renewed uplift accompanied the emplacement of porphyritic alkaline rhyolite flows, diabase dikes and sills, and basalt flows during the Late Carboniferous-Permian climax of rifting (Figure II.9d). Thermal subsidence subsequent to rifting reestablished marine sedimentation by the Late Triassic (Figure II.9e).

The rift sequence outlined above provides the first direct evidence from Pakistan for the late Paleozoic fragmentation of northern Gondwana. Stratigraphic evidence for late Paleozoic rifting has been documented in Zanskar and the adjacent Lahul-Spiti area of northern India where Permian marine sediments unconformably overlie eroded normal fault bounded highlands (Baud and others, 1989; Gaetani and others, 1990). The timing and geochemistry of Panjal volcanism in Kashmir and Zanskar also support an

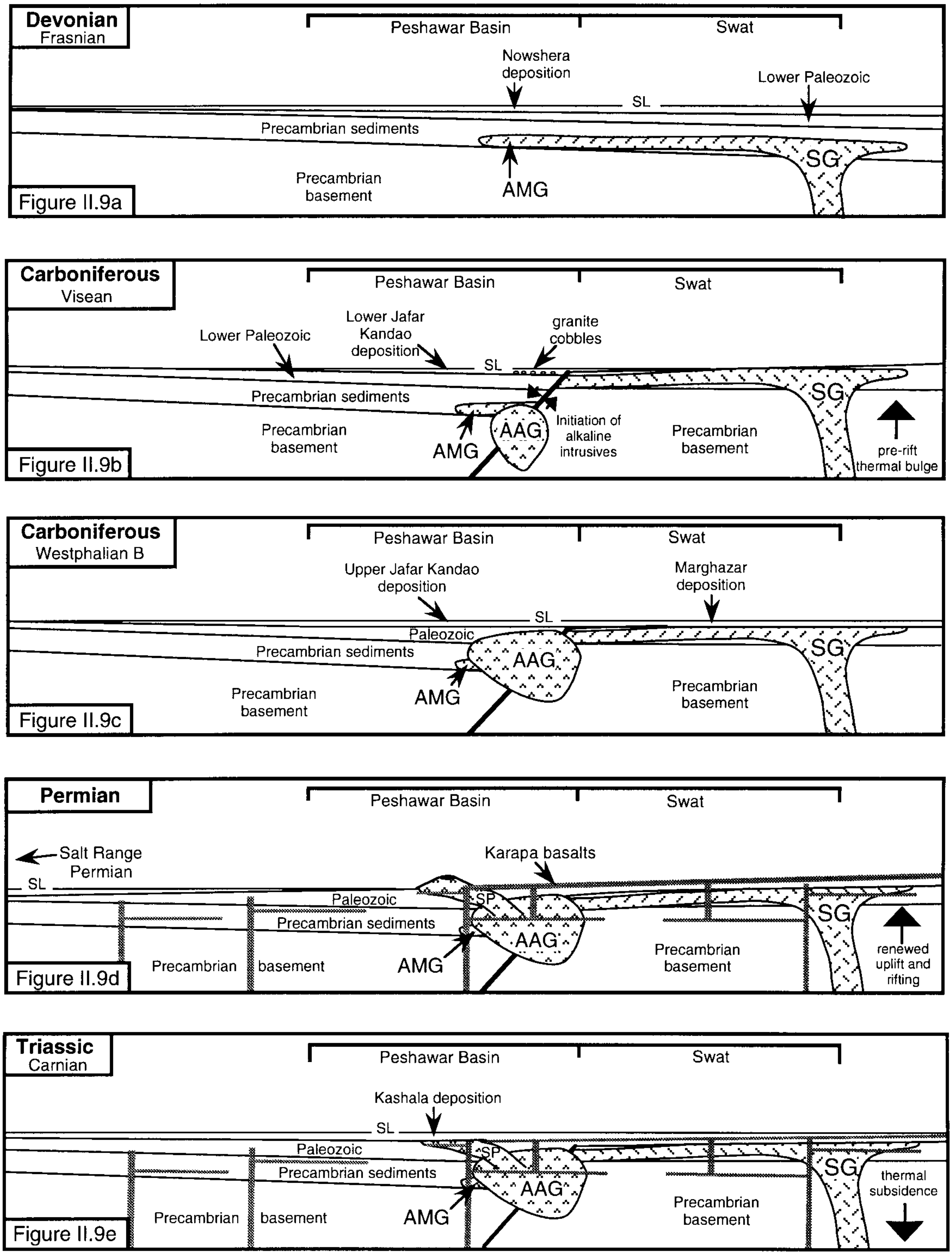

Figure II.9 - Sequential schematic cross-sections illustrating the late Paleozoic to early Mesozoic tectonic evolution of part of the Gondwanan margin of northern Pakistan. SG is Swat granite gneiss, AMG is Ambela megacrystic granite, AAG is Ambela alkaline granite, and SP is Shewa porphyry. SL is approximate sea level.

association with late Paleozoic rifting (Bhat and others, 1981; Sengör, 1984; Baud and others, 1989; Gaetani and others, 1990). Sengör (1984) proposed that the Panjal "traps" were genetically related to rifting of the Cimmerian microcontinent (I, T, and A in Figure II.10), a strip of the northern margin of Gondwana which detached from India during the late Paleozoic and drifted northward, closing the Paleo-Tethys and opening the Neo-Tethys in its wake (Figure II.10). Gaetani and others (1990) similarly ascribe sedimentary evidence for rifting to the opening of the Neo-Tethys. The selection of Cimmeria as the rifted fragment is supported by the similar style and timing of extensional tectonics in continental fragments in Iran and Afghanistan (I and A in Figure II.10) (Sengör, 1990; Sengör and others, 1988). The opening of the Neo-Tethys is indicated in Iran by a widespread unconformity at the base of the Permian section which has been attributed to uplift along normal faults prior to rifting (Stöcklin, 1984). Evidence of late Paleozoic rifting is also preserved in the Helmand block (zone) of central Afghanistan, another Cimmerian fragment (Figure II.1). The northern part of the Helmand block (Behsud subzone of Boulin, (1988)) consists of Proterozoic basement intruded by 496 ± 11 Ma granodiorites overlain by upper Paleozoic and Triassic strata. A relatively complete and greatly thickened Paleozoic section with shallow-water epicratonic affinities characterizes the southern part (Tezak-Nawar subzone of Boulin, (1988)). Boulin (1988) interpreted the abbreviated Paleozoic section of the Behsud subzone to have resulted from Late Devonian to Late Carboniferous uplift accompanying extension along south-dipping normal faults. The

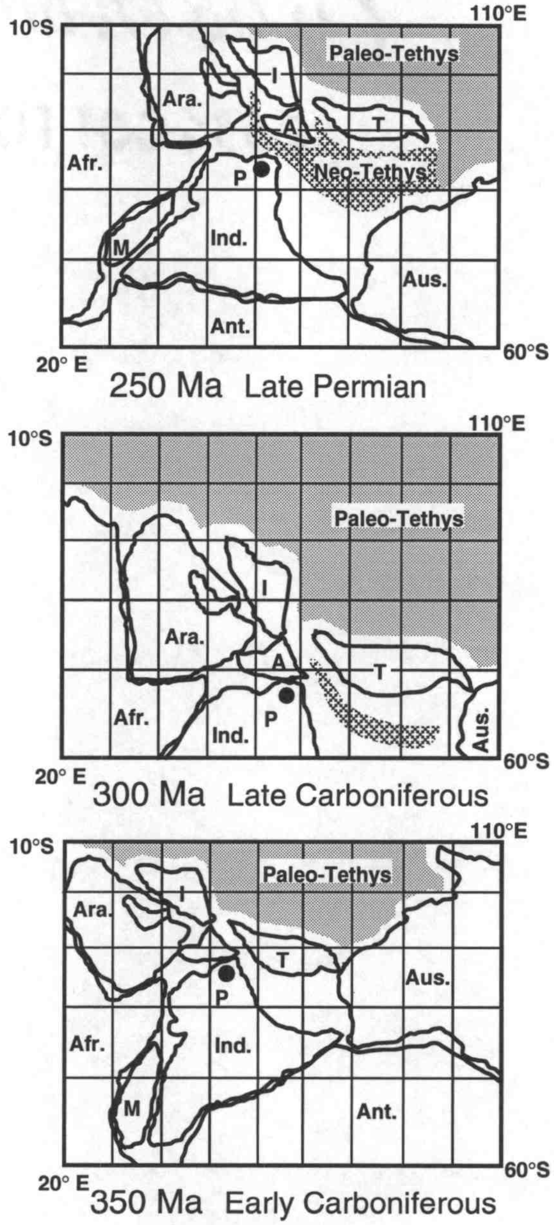

Figure II.10 - Generalized late Paleozoic tectonic evolution of northern Pakistan and surrounding regions (Mercator projection; modified from Scotese and Denham, (1988)). Shaded areas represent oceanic crust, non-shaded areas, continental crust. Abbreviations are A, Afghanistan (Helmand block); Afr, Africa; Ant, Antarctica; Ara, Arabia; Aus, Austrailia; Ind, India; I, Iran; M, Madagascar; P, Peshawar basin; T, Tibet (Lhasa block). See Sengor (1990, figure 6A) for a detailed interpretation of Early Triassic tectonics.

obvious similarity of the Behsud and Tezak-Nawar subzones with Swat and the Peshawar basin suggests continuity between the two areas (Figure II.10, 350 and 300 Ma) prior to opening of the Neo-Tethyan ocean basin represented today by the Waziristan ophiolites (Figure II.10, 250 Ma).

STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF HIMALAYAN FOOTHILLS, NORTHERN PAKISTAN

Abstract

Pre-Cenozoic sedimentary rocks and the protoliths for metasedimentary rocks exposed between the Main Boundary thrust and Main Mantle thrust were originally deposited in a shallow epicontinental marine environment near the north or northwest-facing passive margin of continental India. A formerly continuous sequence of Proterozoic rocks represented by the Hazara (Dakhner) Formation, Manki Formation, and Gandaf Formation forms the base of the sedimentary section and records a gradual transition seaward from the evaporites of the Salt Range Formation to pelitic sediments deposited in deeper water to the north. Limestones of the Shahkot and Utch Khattak formations are essentially carbonate interbeds within the upper part of the pelite-dominated basal Proterozoic section. Quartzite and argillite of the Tanawal Formation were derived from erosion of a northern highland produced during the early stages of a Late Proterozoic-early Ordovician phase of tectonism. The Tanawal Formation thins dramatically southward to be replaced by carbonates of the Shekhai Formation. Early Paleozoic tectonism is indicated by an angular unconformity at the base of the Paleozoic section, the intrusion of the Mansehra Granite, and the local removal of Cambrian strata. Paleozoic shallow-marine strata are preserved in half-grabens created during extensional tectonism that began during the Carboniferous and climaxed with rifting

during the Permian. Paleozoic rocks were largely or completely eroded from northwest-trending highlands on the landward side of the rift shoulder. Thermal subsidence of the rifted margin resulted in a gradual transgression of the highlands and deposition of a Mesozoic section dominated by shallow-water carbonates. Compressional tectonism related to the impending collision with Asia commenced in the Late Cretaceous with initial motion on thrust faults in the Attock-Cherat Range. Reverse motion on the Cherat fault during this time may represent reactivation of a normal fault formed during Late Paleozoic rifting. Rocks north of the Panjal-Khairabad fault were deformed and metamorphosed during subduction of northern India beneath the Kohistan arc terrane during the Eocene. Following subduction and uplift, metamorphic rocks east of the Indus syntaxis were imbricated along a series of thrust faults that place higher-grade rocks to the north over lower grade rocks to the south. Unlike their counterparts east of the Indus syntaxis, metamorphic rocks in Swat are unfaulted and record early folding along north-trending axes. The Indus syntaxis appears to represent a major tectonic boundary between areas that have been subjected to contrasting styles of deformation or have been differentially uplifted so that different structural levels are exposed to the east and west. Following their uplift and exhumation, rocks metamorphosed beneath Kohistan were thrust southward over unmetamorphosed rocks along the Panjal and Khairabad faults which are inferred to be connected beneath alluvium of the Haripur basin. Significant contrasts in stratigraphy and metamorphism on either side of the Panjal-

Khairabad fault indicate that shortening on this structure exceeds that of any other single fault in the foothills region. The migration of the deformation front towards the foreland produced south- or southeast-vergent folds and thrust faults in unmetamorphosed strata south of the Panjal-Khairabad fault and reactivated Late Cretaceous structures such as the Hissartang fault. The Hissartang fault is the westward continuation of the Nathia Gali fault, a major structure that thrusts Proterozoic rocks in the axis of a Late Paleozoic rift highland southward over Mesozoic strata. North-vergent folds and south-dipping overturned thrust faults in the hanging wall of the MBT resulted from an episode of backfolding that followed Late Miocene south-direct thrusting along the MBT. Evidence of continuing Himalayan deformation in the foothills include Quaternary faults and microearthquake seismicity in the southern Peshawar basin. Fundamental differences in stratigraphy, metamorphism, and relative displacement preclude straightforward correlation of faults and tectonic subdivisions of the central Himalaya of India and Nepal with the northwestern Himalaya of Pakistan.

Introduction

The Himalaya of northern Pakistan consists of three major tectonic provinces. North of the front of Himalayan deformation at the Salt Range thrust and south of the Main Boundary thrust (MBT; Figure III.1) the Kohat and Potwar plateaus expose unmetamorphosed Mesozoic and Tertiary sedimentary rocks and Neogene foredeep sediments deformed by folds and thrust faults typical of a foreland thrust belt. The stratigraphy and structure of the Salt Range and foreland plateaus is relatively well-documented (e.g. Khan and others, 1986; Lillie and others, 1987; Baker and others, 1988; Pennock and others, 1989; McDougall and Khan, 1990; Gee, 1989) due to the integration of detailed surface mapping with borehole and seismic data obtained in the search for petroleum. North of the MBT, the Main Mantle thrust (MMT) separates rocks of the Indian plate on the south from the Kohistan terrane, a Jurassic to Late Cretaceous island arc which was accreted to Asia at about 100 Ma (Treloar and others, 1992). The region between these major faults displays a transition from the unmetamorphosed fold and thrust belt to the south to high-grade metamorphic rocks in the hanging wall of the MMT. This region will be referred to herein as the Himalayan foothills since the topography between the MBT and the MMT gradually rises in elevation northward toward the high Himalayan peaks. The foothills region is bounded on the south and east by the MBT or Murree thrust, and on the north by the MMT. The studied area is limited on the west by the politically

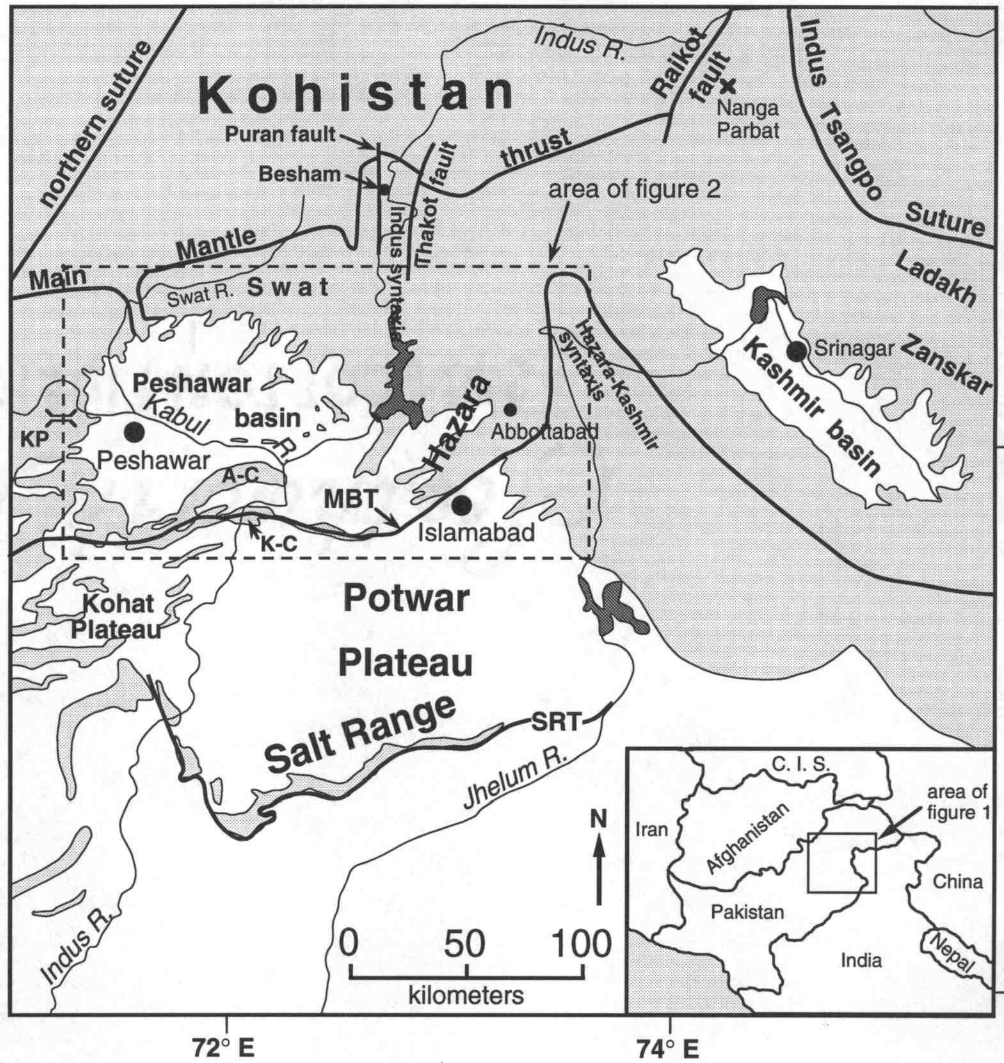

Figure III.1 - Location map of the Himalaya of northern Pakistan and northwestern India showing selected major faults. KP is Khyber pass; A-C is Attock-Cherat Range; K-C is Kala Chitta Range; MBT is Main Boundary thrust; SRT is Salt Range thrust. Locations of faults are from Gansser (1981), Yeats and Lawrence (1984), Baker and others (1988), Lawrence and others (1989), and Baig (1990).

inaccessible and poorly mapped mountains of the Khyber area which form the border with Afghanistan (Figure III.2).

Individual detailed geological investigations in the Himalayan foothills of Pakistan have generally concentrated on restricted geographical areas with each new study proposing new names for similar or identical stratigraphic units and structures. This is an unfortunate tendency throughout much of the Himalaya, and later workers attempts at regional syntheses have been impeded by the confusion of terminology. The stratigraphic and structural synthesis presented here was prompted by the recent availability of geologic maps (Bossart and others, 1988; Lawrence and others, 1989; Baig, 1990; Hylland, 1990; Hussain and others, 1990; DiPietro and Lawrence, 1991; Greco, 1991; this study) and the discovery in the newly-mapped areas of stratigraphic and structural relationships that facilitate correlations with adjacent areas mapped previously by Latif (1970), Meissner and others (1974), and Calkins and others (1975) (Figure III.3). Additional information has been provided by reconnaissance geologic maps of the area north of Mansehra by Coward and others (1988) and Treloar and others (1989a; 1989b). Stratigraphic interpretations are based on the generalized stratigraphic columns displayed in Figure III.4 which were derived from the new maps presented herein and stratigraphic information contained within Latif (1974), Meissner and others (1974), Calkins and others, (1975), Hussain and others (1990), DiPietro and Lawrence (1991), and Pogue and others (1992a).

As shown in Figure III.2, the foothills region can be divided into three tectonic regions or blocks, bounded by major Himalayan

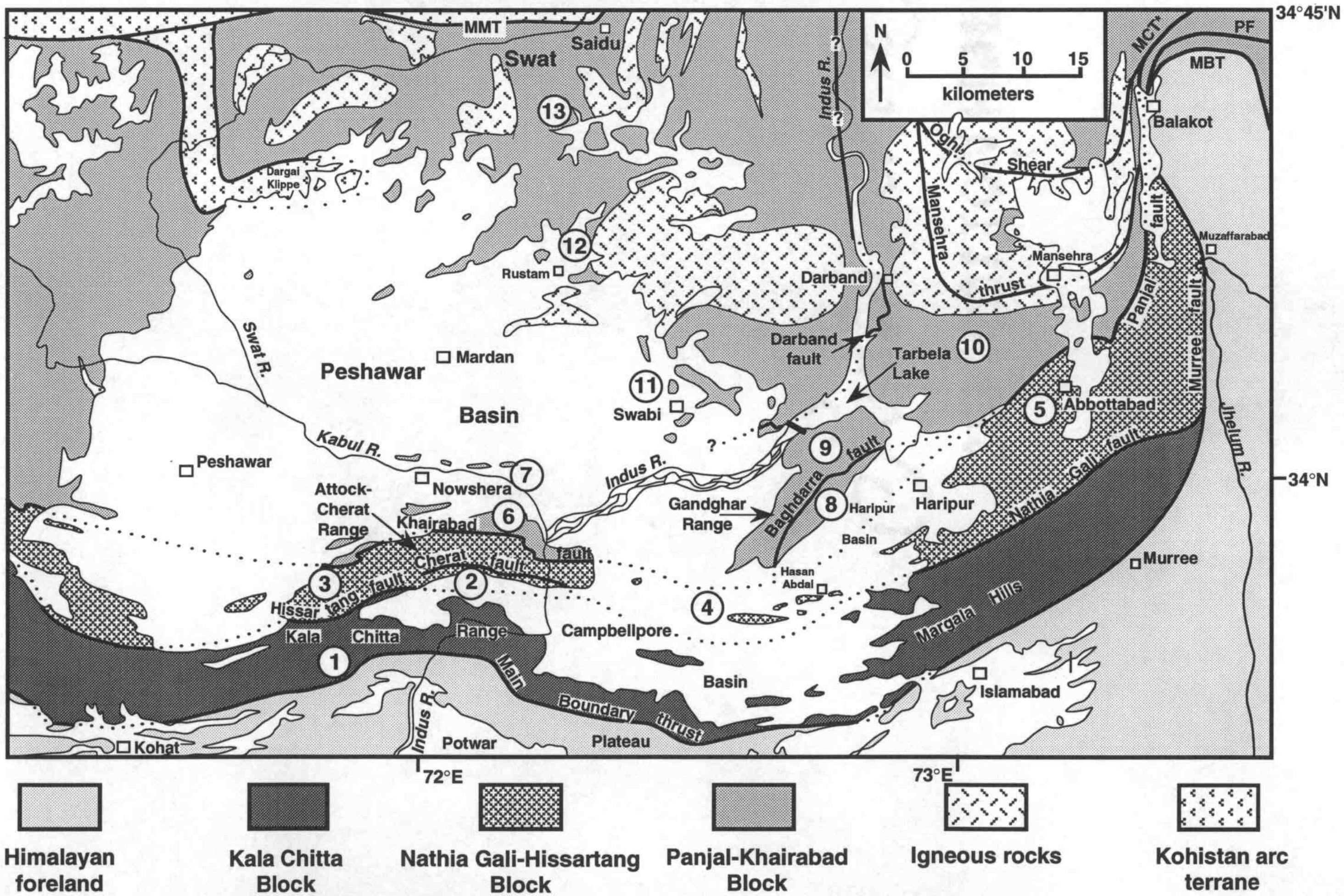

Figure III.2 - Tectonic map of the Himalayan foothills of northern Pakistan. MCT* is Main Central Thrust of Bossart and others (1988); PF is Panjal fault, MMT is Main Mantle thrust. Circled numbers refer to column locations on figure III.4.

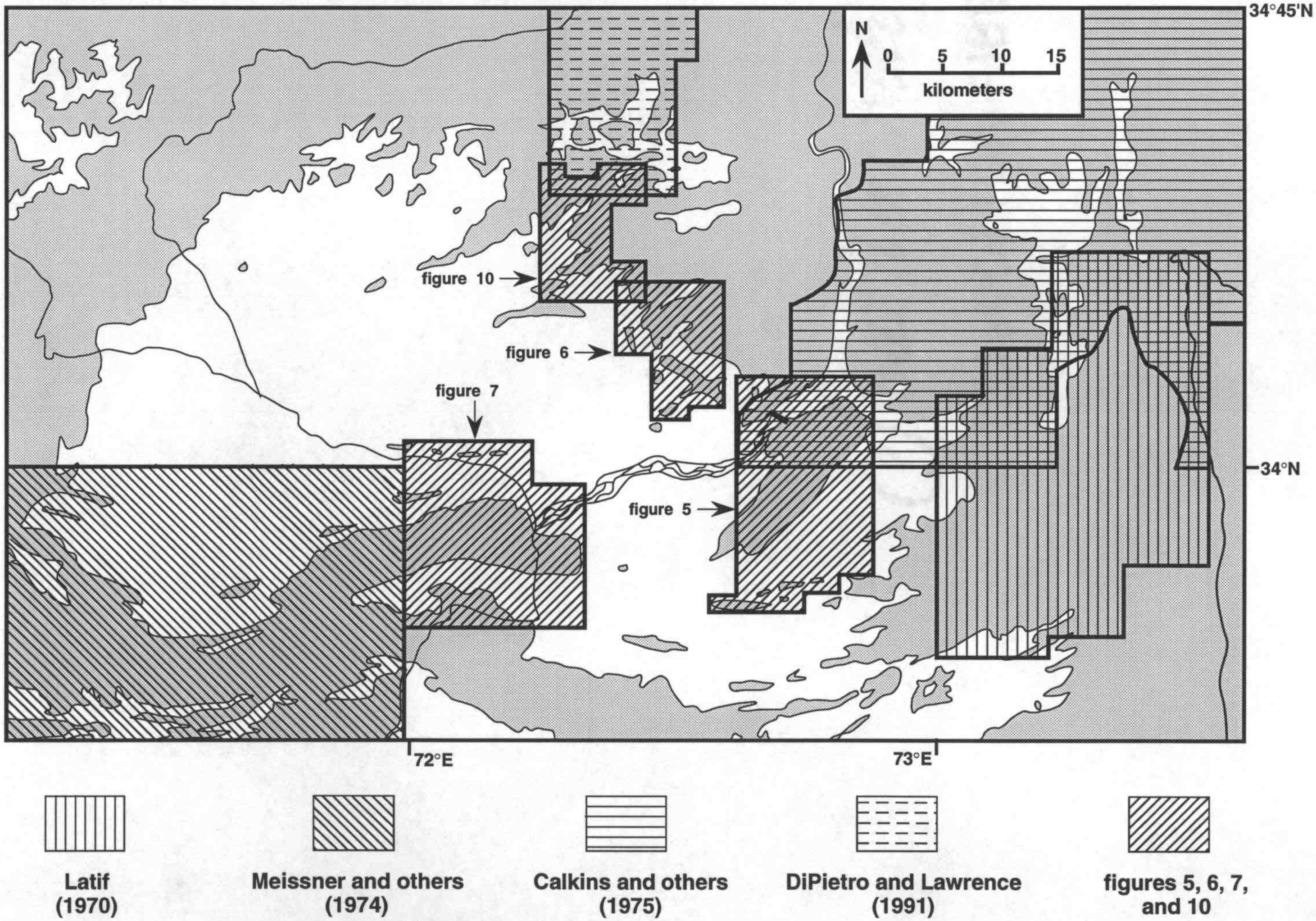

Figure III.3 - Map showing location of geologic maps presented in this study and the location of other maps that were used as the primary source of geologic information for their respective areas.

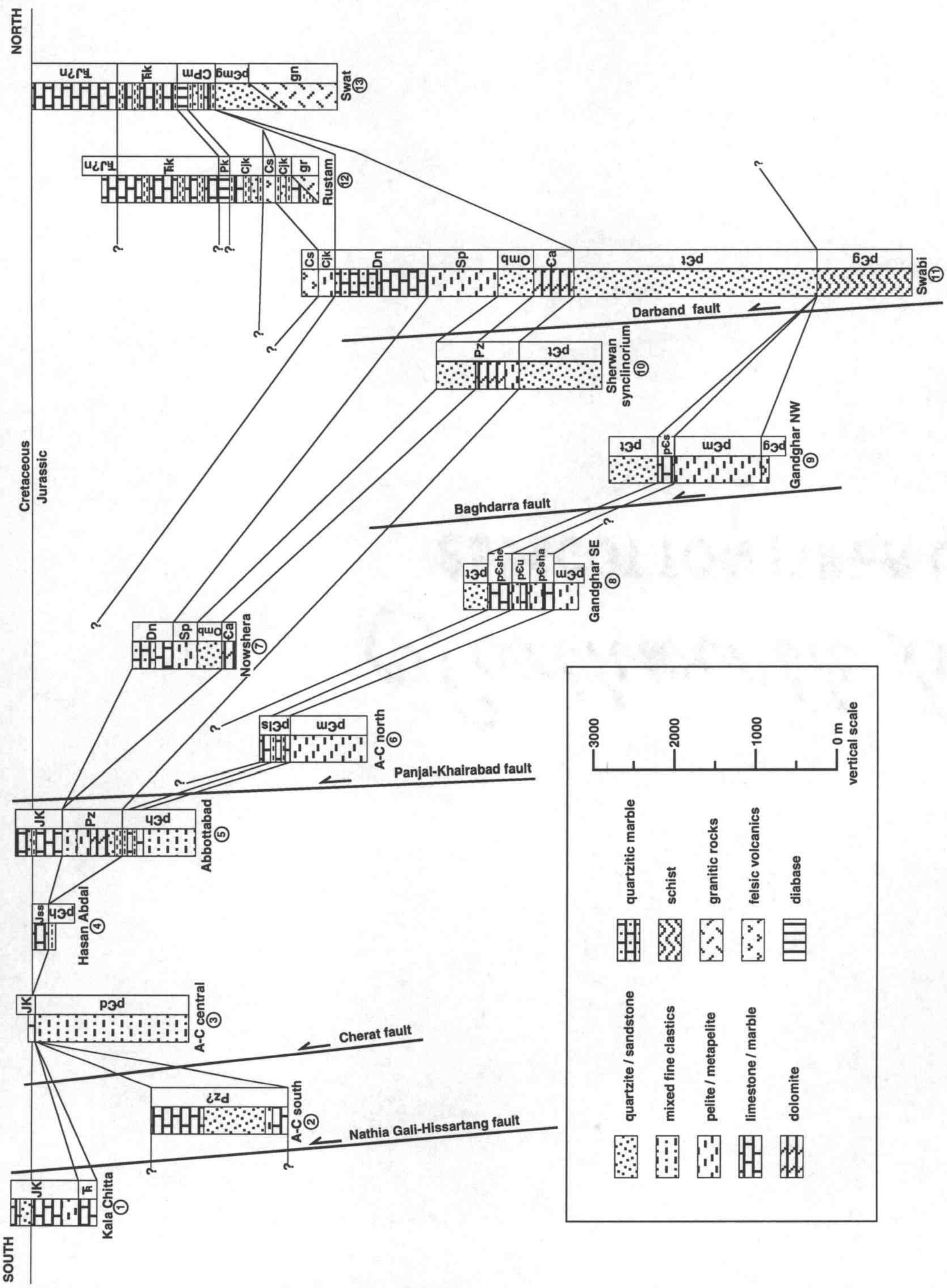

Figure III.4 - Correlation of stratigraphic columns for Himalyan foothills of northern Pakistan. Unit abbreviations are the same as in figures III.5, III.6, III.7, and III.10. For location of columns see figure III.2. CPm is Marghazar Formation of DiPietro and Lawrence (1991). p€mg is Manglaur Formation of Dipietro and Lawrence (1991). p€ls is undifferentiated Precambrian limestone of the Shahkot, Utch Khattak, and Shekhai Formations.

faults. The southern block is referred to as the Kala Chitta-Margala block after the Kala Chitta Range and Margala Hills which form prominent escarpments along the southern boundary of the block. The central block is referred to as the Nathia Gali-Hissartang block after the two names given to the major fault that is the first fault north of the Salt Range thrust to bring Proterozoic rocks to the surface. The northern Panjal-Khairabad block is named after the two faults, presumed to be continuous beneath alluvium, that form the southern boundary of the block. The Panjal-Khairabad block extends north to the MMT and thus contains the northernmost Indian plate rocks in the foothills.

Stratigraphy

Panjal-Khairabad block

Gandaf Formation

Except for outcrops of Early Proterozoic Indian-plate crystalline basement in the Besham area (Baig, 1990), the oldest exposed rocks in the Panjal-Khairabad block are carbonaceous phyllite and graphitic schist and marble that Calkins and others (1975) mapped as Salkhala Formation based on similarities to rocks in Indian Kashmir referred to as the Salkhala "series" by D. N. Wadia (Pascoe, 1929). The type locality of Wadia's Salkhala "series" in the gorge of the Kishenganga River (Neelum River in Pakistan) was later mapped by Ghazanfar and others (1983) who concluded that rocks near Salkhala village more closely resembled metamorphosed Tanawal Formation than the lithologies described by Wadia (Pascoe, 1929). They therefore proposed that rocks previously designated as Salkhala "series" be reassigned to the Gamot and Sharda Formations of the Sharda Group. Despite the work of Ghazanfar and others (1983), the term "Salkhala" has persisted in geological literature, even in the regional journal in which their work was published (Bossart and others, 1984, 1988; Greco, 1986). The Salkhala "unit" of Bossart and others (1988) is a fault-bounded tectonostratigraphic subdivision that includes a significant percentage of granitic gneiss, amphibolite, and quartzite as well as the typical carbonaceous metapelite and marble. While

Calkins and others (1975) correlation of the oldest rocks of the southern Panjal-Khairabad block with part of Wadia's Salkhala "series" (Pascoe, 1929) or Bossart and others (1988) Salkhala "unit" is probably valid, the ambiguity of the term with regard to stratigraphic type locality, lithologic content, and unit boundaries limits its applicability outside of Kashmir. For these reasons, the rocks mapped by Calkins and others (1975) in the vicinity of Tarbela Lake are referred to as the Gandaf Formation.

The Gandaf Formation is here named for the village of Gandaf located 3 km north of Tarbela dam (Figure III.5). The type section is designated along the hillsides south and east of the village where the formation consists of carbonaceous and calcareous phyllite and schist and carbonaceous marble with interbedded muscovite-chlorite-quartz schist. These outcrops are in the hanging wall of the Darband fault and are part of a belt of Gandaf exposures that parallels the west shore of Tarbela Lake (Figure III.5). Their northward extent in the gorge of the Indus River has not been mapped, but lithologies typical of the Gandaf Formation were reported by Middlemiss (1896) along the great S-shaped bend in the Indus 10 km north of Darband (Figure III.1). The Gandaf Formation is also exposed in a 100-m- to 1-km-wide belt in the hanging wall of the Baghdarra fault in the Gandghar Range (Figure III.5) where it has a transitional contact with overlying Manki

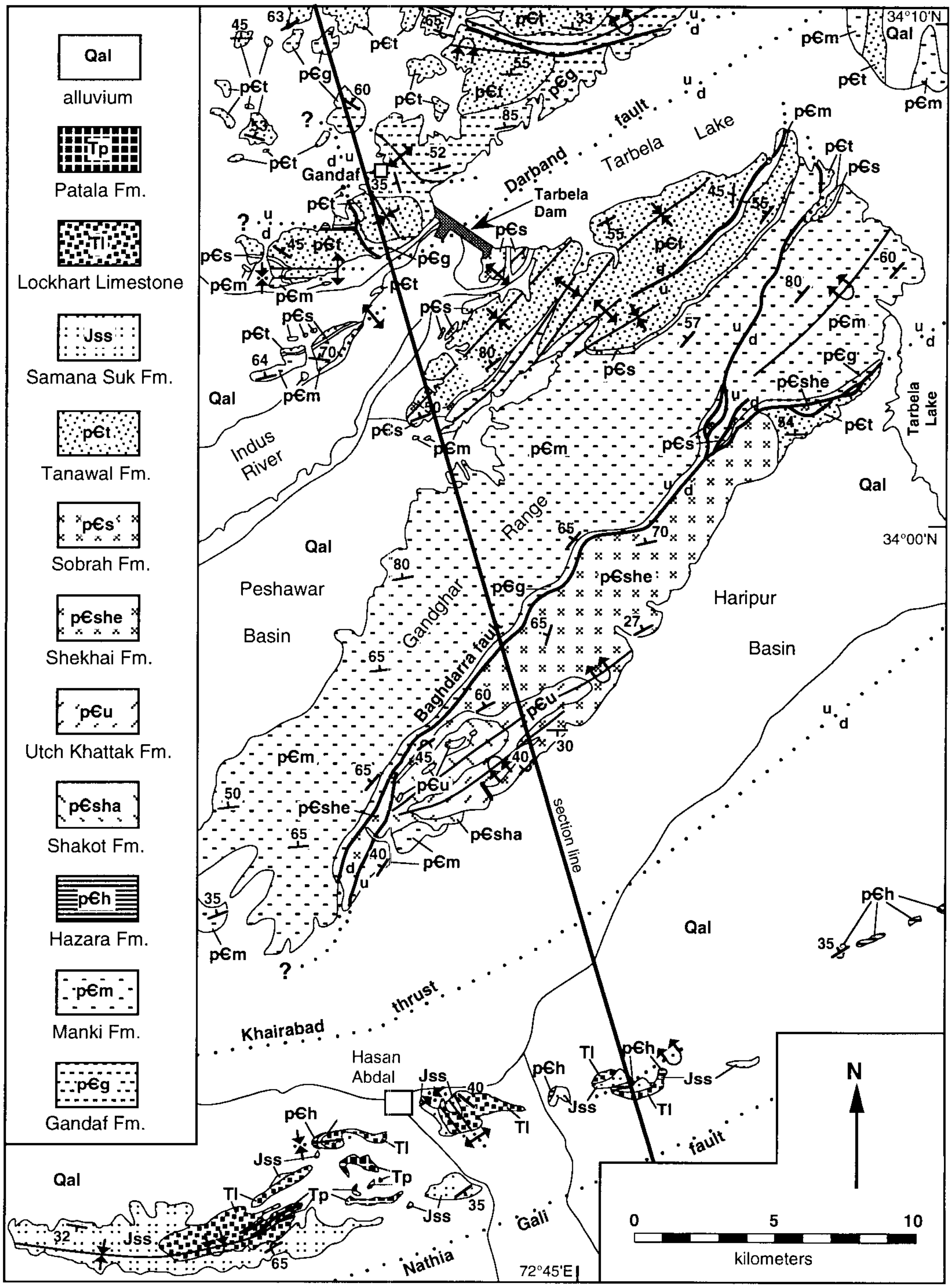

Figure III.5 - Geologic map of the Gandghar Range and vicinity. See figure III.3 for location.

Formation slate and argillite. As with all units in the Panjal-Khairabad block, the metamorphic grade of the Gandaf Formation increases from south to north. The Gandghar Range exposures are primarily carbonaceous slate and graphitic phyllite with thin lenses of marble. In the Tarbela Dam area, the Gandaf Formation is schistose whereas on the north end of Tarbela Lake, quartzo-feldspathic gneiss predominates (Calkins and others, 1975). A Late Proterozoic age is inferred for the Gandaf Formation based on its stratigraphic position below the Tanawal and Manki Formations (Baig and others, 1988).

Manki Formation

Dark, low-grade metapelite over 1000 m thick overlies the Gandaf Formation in the Gandghar Range and forms the oldest exposures in the Attock-Cherat Range. These rocks were previously assigned to a variety of formations including the "Attock Slates" (Waagen and Wynne, 1872), "slate series" (Middlemiss, 1896), "Dogra Slates" (Wadia, 1931), "Hazara Slate Formation" (Marks and Ali, 1961), and "Manki Slate" (Tahirkheli, 1970). The comprehensive study of Calkins and others (1975) mapped these rocks throughout the foothills as Hazara Formation. However, rocks north of the Panjal-Khairabad fault mapped as Hazara Formation by Calkins and others (1975) are lithologically distinct from typical Hazara Formation exposed south of Abbottabad (Latif, 1970). The contrast between basal Proterozoic lithologies north and south of the Panjal-Khairabad fault in the Attock-Cherat Range was noted by

Yeats and Hussain (1987) and Hussain and others (1990) who mapped the northern section as Manki Formation and the southern section as Dakhner Formation. The Manki Formation of Yeats and Hussain (1987) is composed almost exclusively of argillite, slate, and phyllite, and outcrops are restricted to the Panjal-Khairabad block. Exposures of interbedded shale, siltstone, and sandstone of the Dakhner Formation are limited to the Nathia Gali-Hissartang block.

The Manki Formation is composed primarily of dark gray to black or brown argillite, slate, phyllite, and argillaceous meta-siltstones. Minor constituents include graywacke and marble with associated calcareous phyllite. Slaty cleavage is well-developed in thick sequences of homogenous argillite. In the hanging wall of the Baghdarra fault, the Manki Formation displays a gradational contact with the underlying Gandaf Formation (Figure III.4, column 9), a relationship analogous to the gradational contact between the Dogra slates and Salkhala series described by Wadia (1934) in Indian Kashmir. The Manki Formation is Late Proterozoic in age based on correlations with the Hazara Formation.

Proterozoic Carbonates

In the northern Attock-Cherat Range (Figure III.4, column 6) and in the footwall of the Baghdarra fault in the Gandghar Range (Figure III.4, column 8), the Manki Formation is overlain by over 500 m of limestone with interbedded argillite. Tahirkheli (1970) subdivided these rocks into the Shahkotbala Formation, Khattak

Limestone, and Shekhai Limestone. Hussain (1984) and Yeats and Hussain (1987) renamed the units as the Shahkot Formation, Utch Khattak Formation, and Shekhai Formation, respectively, to reflect the presence of lithologies other than limestone and/or to denote a more precise type locality. Calkins and others (1975) mapped Gandghar Range carbonates as Triassic Kingriali Formation.

The basal cherty limestone of the Shahkot Formation has a gradational contact with the underlying Manki Formation. The limestone is overlain by 100-150 m of shale and argillite that is identical to the Manki Formation. A distinctive 10-70 m interval of resistant carbonate composed of lenticular blocks of stromatolitic limestone in a matrix of calcareous mudstone forms the base of the overlying Utch Khattak Formation in The Gandghar Range. The basal Utch Khattak in the Attock-Cherat Range is a conglomerate consisting of clasts of the Manki and Shahkot formations in a limestone matrix. The upper Utch Khattak Formation is shale and argillite similar to the upper Shahkot Formation. The Shekhai Formation is comprised of a basal 1 m-thick bed of quartzite overlain by a thick sequence of light to dark gray, brown, or pink thin-bedded to massive dolomitic and arenaceous limestone and marble.

On the northwestern flanks of the Gandghar Range, in the hanging wall of the Baghdarra fault, a carbonate interval of highly variable thickness intervenes between the Manki and Tanawal Formations (Figure III.4, column 9; Figure III.5). These rocks are here named the Sobrah Formation for exposures southwest of Tarbela dam near Sobrah village. The type locality is 1 km southeast of Sobrah on the southern slopes of a hill with summit elevation 1930 ft. on Survey of Pakistan topographic sheet 43 B/12 (72°41' E long.; 34°02' N lat.). The Sobrah Formation consists of light gray to pink, thin-bedded to massive arenaceous and dolomitic marbles. Calcareous and dolomitic quartzites are minor constituents except near Tarbela dam where they account for one-third of the exposures. Where the unit is thick, thick-bedded to massive marbles, identical to the Shekhai Formation, predominate. The thinner intervals consist of thinly interbedded marble and calcareous argillite. The Sobrah Formation has a maximum thickness of over 200 m at the Tarbela dam spillways but thins abruptly and is locally absent in adjacent areas to the east and west. The Shahkot, Utch Khattak, Shekhai, and Sobrah formations are considered to be Late Proterozoic in age based on their stratigraphic relationships with the Manki Formation and Tanawal Formation and the relative abundance of stromatolites.

Tanawal Formation

Interbedded quartzite and metapelite exposed widely throughout the region between Mansehra and the Indus River (Tarbela Lake) was originally named the Tanol group by Wynne (1879), and has since been referred to as the Tanawal Series (Wadia, 1931), Tanol Formation (Ali, 1962), or Tanawal Formation (Calkins and others, 1975). The Geological Survey of Pakistan lists the unit as Tanawal Formation (Shah, 1977). West of the Indus, in the hanging wall of the Darband fault, lithologies identical to the

Tanawal Formation and in similar stratigraphic position were mapped as Chamla Quartzite or Chamla Shale by Martin and others (1962). Calkins and others (1975) and Pogue and others (1992a) included these rocks in the Tanawal Formation.

The Tanawal Formation is a metaclastic unit with a protolith of quartzose sandstone, siltstone, and shale. Conglomeratic intervals are common at the base of the unit and occur locally in the overlying beds. The quartzite beds commonly display assymetric ripple-marks and crossbedding. Common lithologies range from quartzite and argillite near Tarbela dam to schistose quartzite and quartz-mica schist near Mansehra. Calkins and others (1975) proposed a granitic source area for the quartzites based on the ubiquitous occurrence of accessory tourmaline and feldspar. The thickness of the Tanawal Formation north of Swabi (Figure III.6) exceeds 3000 m (Figure III.4, column 11). The Tanawal Formation unconformably overlies the Gandaf Formation west of the Darband fault, the Sobrah or Manki Formation between the Darband and Baghdarra faults, and the Shekhai Formation east of the Baghdarra fault (figures III.4 and III.5). A 516 ± 16 Ma Rb/Sr isochron on the Mansehra granite (Le Fort and others, 1980), which intrudes the Tanawal Formation in Hazara, restricts the age of the Tanawal Formation to Late Proterozoic to Cambrian.

Paleozoic and Mesozoic Formations

Over 3500 m of Paleozoic strata crop out extensively north and west of the Darband fault along the northeastern margin of the

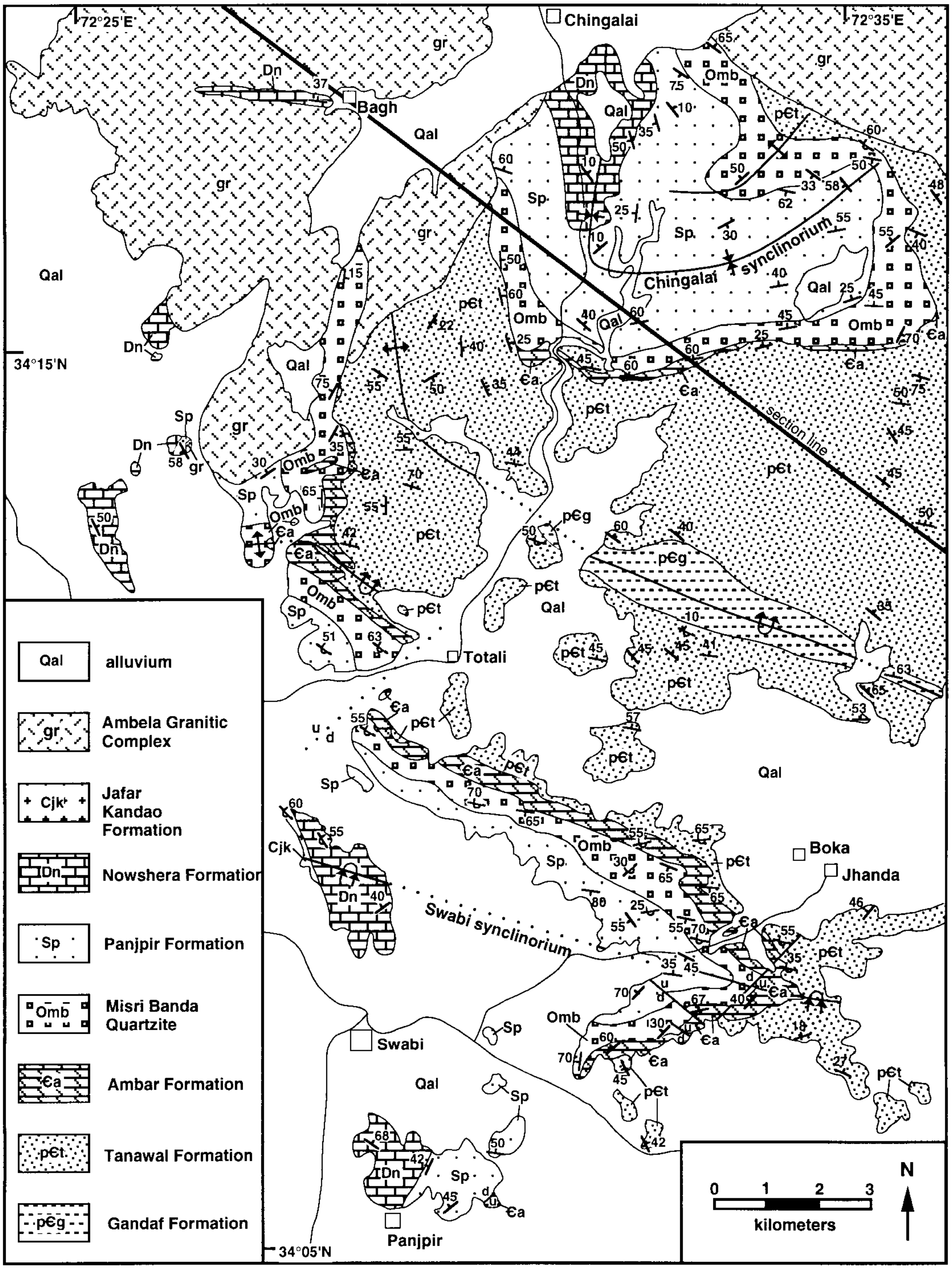

Figure III.6 - Geologic map of the Swabi area, northeastern Peshawar basin. See figure III.3 for location.

Peshawar basin (Figure III.4, column 11). Pogue and others (1992a) revised the Peshawar basin stratigraphy of Martin and others (1962) and Stauffer (1968a) based on extensive mapping and new paleontologic information. The Ambar Formation, a dolomite-dominated carbonate sequence unconformably overlying the Tanawal Formation, is the probable base of the Paleozoic section. Although the Ambar is unfossiliferous, an Early Cambrian age can be inferred from its stratigraphic position and lithologic similarity with the Sirban Formation of the Lower Cambrian Abbottabad Group. The overlying fossiliferous Ordovician through Carboniferous section is dominated by lithologies typical of shallow-water epicontinental sedimentation (Pogue and others, 1992a). Lower Paleozoic rocks correlative with the Peshawar basin section are also exposed in the region between Abbottabad and Tarbela Lake in the cores of the Sherwan synclinorium and two smaller synclinal structures (Figure III.4, column 10). Calkins and others (1975) mapped these rocks as Upper Triassic Kingriali Formation. The only rocks of confirmed Permian age are mafic dikes and sills that intrude the Mansehra Granite in Hazara for which Baig (1990) reported $^{39}Ar/^{40}Ar$ plateau dates of 284 ± 4 Ma and 262 ± 1 Ma. Based on geochemical similarities to mafic intrusives dated by Baig (1990) and on stratigraphic position, Pogue and others (1992b) consider the Karapa Greenschist of the northern Peshawar basin to be metamorphosed Permian basalt.

The only confirmed Mesozoic rocks in the Panjal-Khairabad block are the Upper Triassic carbonates of the Kashala Formation exposed in bedrock promontories within the northern Peshawar basin (Pogue and others, 1992a). The absence of a major unconformity at the top of the Kashala Formation implies that the overlying Nikanai Ghar Formation and its lateral equivalent, the Saidu Formation, are also Mesozoic in age (DiPietro and others, 1993).

Nathia Gali-Hissartang block

Hazara and Dakhner Formations

The oldest rocks exposed in the region between the Panjal and Nathia Gali faults belong to the Hazara Formation. Near the southern limit of exposure of the Hazara Formation, sandstone and shale displaying ripple marks and mud cracks are the dominant lithology. Northward, the relative percentage of shale gradually increases as does the grade of metamorphism. In the vicinity of the Panjal fault, the unit consists of weakly metamorphosed pelitic rocks and greywackes. East of Haripur, the upper part of the Hazara Formation contains two laterally persistent algal limestone horizons that Latif (1969) referred to as the Langrial limestone and Miranjani limestone (Figure III.4, column 5). Latif (1969) also noted discontinuous beds of gypsum in the Hazara Formation southeast of Abbottabad. The Hazara Formation is Late Proterozoic in age based on its position unconformably below the Lower Cambrian Abbottabad Group and on Late Proterozoic whole-rock Rb/Sr dates that indicate the age of provenance of Hazara Formation clastic material (Crawford and Davies, 1975; Baig and others, 1988). Yeats and Hussain (1987) assigned the oldest rocks in the region between the Khairabad and Hissartang faults in the central Attock-Cherat Range to the Dakhner Formation. The Dakhner Formation is lithologically identical to the southern, shallow-water facies of the Hazara Formation. The exposed thickness of both the Hazara and Dakhner Formations exceeds 1000 m.

Cambrian

Throughout most of the Nathia Gali-Hissartang block, fossiliferous Jurassic, Cretaceous, or Paleocene strata overlie the Upper Proterozoic Hazara or Dakhner Formation on a major regional unconformity. In southeastern Hazara, near Abbottabad, however, an unconformity-bounded sequence dominated by dolomite and shale intervenes (Figure III.4, column 5). The first reference to these rocks was by Middlemiss (1896) who referred to them as the "Infra Trias". Marks and Ali (1961) introduced the name "Abbottabad Formation" for the same sequence. The Abbottabad Formation was subsequently subdivided into four formations comprising the Abbottabad Group by Latif (1970) who suggested a possible Silurian or Devonian age. Latif (1974) redesignated the Galdanian Formation and Hazira Formation as members of a new and separate Tarnawai Formation thereby reducing the constituent formations of the Abbottabad Group to two. Calkins and others (1975) mapped Abbottabad Group rocks as Triassic Kingriali Formation. The oldest unit of the Abbottabad Group is the Tanakki Conglomerate which Latif (1974) designated as the basal member of the Kakul Formation. The Tanakki Conglomerate consists of angular or subangular pebble- to boulder-sized clasts derived primarily from the underlying Hazara Formation in a purple siltstone matrix. Baig and others (1988) consider weakly metamorphosed Hazara pelite clasts within the unmetamorphosed siltstone matrix as evidence for a Late Proterozoic "Hazaran orogeny". The remainder of the Kakul Formation consists of purple sandstone and shale interbedded with cherty carbonates. The resistant cherty and phosphatic dolomite of the overlying Sirban Formation forms the most conspicuous outcrops of the Abbottabad Group. The Tarnawai Formation consists of a lower Galdanian Member composed of manganese-rich siltstones and hematitic mudtones and an upper Hazira Member which is primarily glauconitic and phosphatic shale and siltstone (Latif, 1974). The Tarnawai Formation is Early Cambrian in age based on hyolithids and sponge spicules recovered from the Hazira Member (Latif, 1972). Unfortunately, the journal reporting these fossils confused the stratigraphic interval by substituting "Hazara" for "Hazira" throughout the article. Latif (1974) considered the Abbottabad Group to be Early Cambrian based on its unconformable contact with the underlying Upper Proterozoic Hazara Formation and conformable contact with the overlying Lower Cambrian Tarnawai Formation.

Paleozoic(?) Rocks of the Attock-Cherat Range

On the southern flank of the Attock-Cherat Range an enigmatic sequence of rock is exposed in the structural block bounded on the north by the Cherat fault and on the south by the Hissartang fault (Figure III.7; Figure III.4, column 2). The oldest of the units, The Darwaza Formation, consists of lower thin-bedded carbonates overlain by maroon argillite. Unconformably overlying the Darwaza Formation are interbedded ferruginous quartzite and dark-gray argillite of the Hissartang Formation which are in turn overlain by light gray fine-grained bioturbated limestone of the Inzari Formation. Similarities of quartzite and argillite of the Hissartang Formation with the upper Misri Banda Quartzite and argillite of the lower Panjpir Formation prompted Yeats and Hussain (1987) to suggest a correlation with Paleozoic rocks near Nowshera (Figure III.4, column 7). Carbonates of the Darwaza Formation and Inzari Formation, however, are lithologically dissimilar to the Ambar Formation and Nowshera Formation, their proposed Peshawar basin counterparts. In addition, despite repeated searches, fossils have not been found in the Paleozoic(?) rocks of the Attock-Cherat Range. The suggested correlatives in the Nowshera area are abundantly fossiliferous. Despite the difficulty of lithologic correlation and lack of fossils, structural and intrusive relationships imply that this problematic section is indeed Paleozoic. The Paleozoic(?) rocks of the southern Attock-Cherat Range are overthrust by the Upper Proterozoic Dakhner Formation along the Cherat fault (Figure III.7). Elsewhere in the foothills

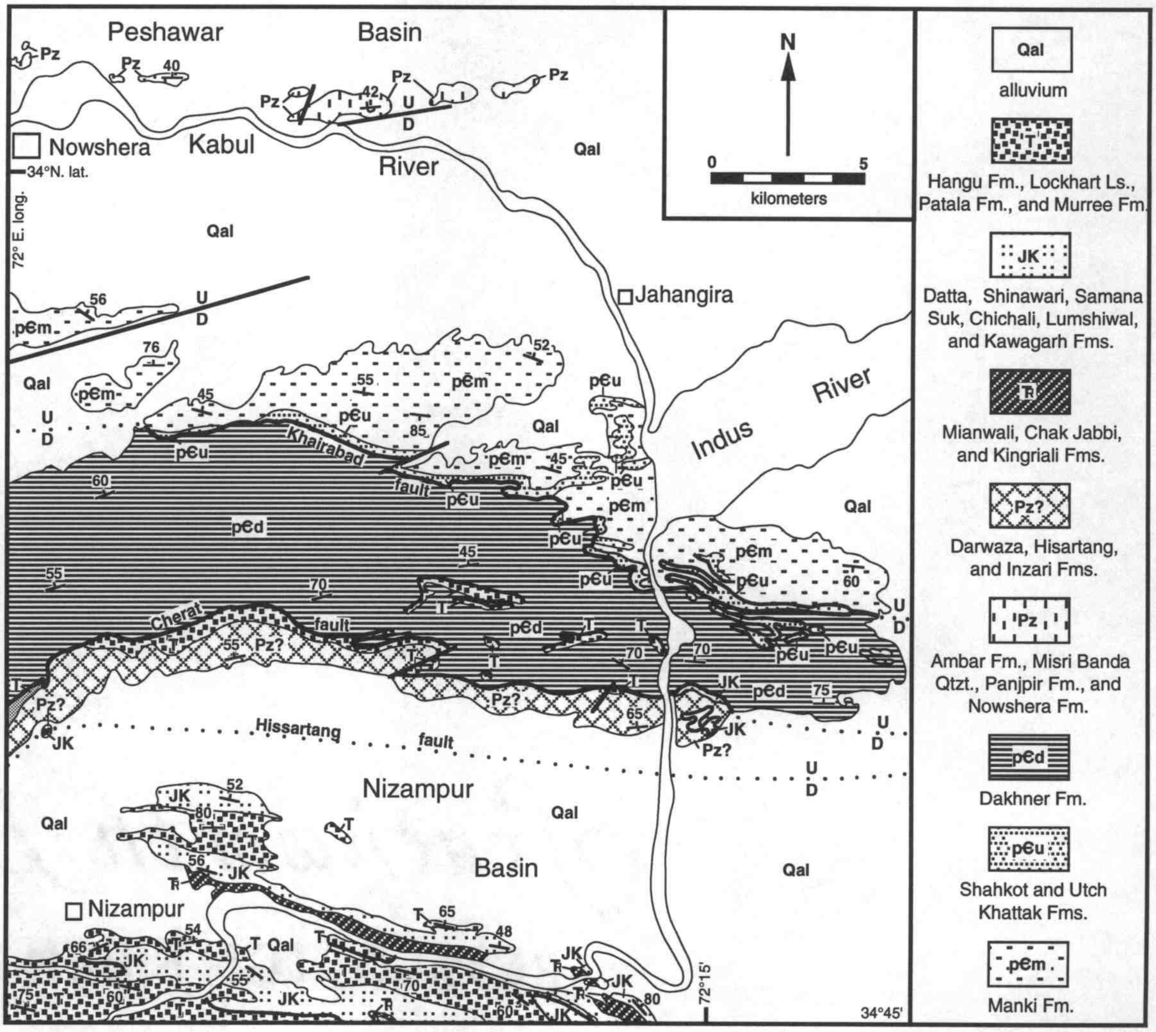

Figure III.7 - Geologic map of portions of the Nowshera hills, Attock-Cherat Range, and Kala Chitta Range, simplified From Hussain and others (1990). See figure III.3 for location.

region, faults of similar style and displacement invariably place older rocks in the northern block over younger rocks in the southern block, implying that rocks on the south side of the Cherat fault are younger than the Dakhner Formation. Pogue and others (1992b) observed that rocks younger than Permian are devoid of the diabase dikes and sills that are otherwise ubiquitous in the foothills region. Diabase dikes intrude the Paleozic(?) section of the Attock-Cherat Range suggesting a pre-Permian age for these rocks.

Mesozoic

In Hazara, Upper Proterozoic or Lower Cambrian strata in the Nathia Gali-Hissartang block are overlain by Jurassic strata (Figure III.4, columns 4, 5). Latif (1970; 1974) subdivided these rocks into the Thandiani Group composed of the Maira Formation and the Sikhar Limestone. Later workers (Shah, 1977; Calkins and others, 1975) noted a close correlation of the Hazara Jurassic section with the Datta, Shinawari, and Samana Suk Formations of the Kohat area and chose to extend the Kohat nomenclature to Hazara rather than use the new names proposed by Latif (1970). Latif (1980) later abandoned his Jurassic formation names in favor of the Kohat terminology. The Datta Formation and Shinawari Formation are very thin (25 m combined; Latif, 1969) compared to their type sections (235 m combined; Danilchik and Ibrahim Shah, 1987). In typical outcrops northeast of Abbottabad interbedded red shale and sandstone make up the majority of the Datta Formation. The overlying Shinawari Formation consists of shale interbedded with thin-bedded limestone. The Middle Jurassic Samana Suk Formation is relatively well-developed throughout most of Hazara where it consists of as much as 300 m of light to dark gray thick-bedded locally pelloidal and oolitic limestone (Calkins and others, 1975). The Jurassic section thins dramatically southwest of Abbottabad and the Datta Formation and Shinawari Formation are absent in the Hasan Abdal and Kherimar Hills (Figure III.5; Figure III.4, column 4). In the Attock-Cherat Range, the only rocks of Jurassic age are discontinuous outcrops of Samana Suk Formation in fault-bounded blocks along the Cherat fault east of the Indus River (Hussain and others, 1990).

In Hazara, strata of purely Jurassic age are overlain by Upper Jurassic to Lower Cretaceous black shale and calcareous sandstone (Figure III.4, column 5) that was mapped by Middlemiss (1896) and Latif (1970) as Spiti Shale and Giumal Sandstone based on correlations with rocks of similar age and lithology in the Spiti valley of northern India. More recent workers (Calkins and others, 1975; Shah, 1977) chose to correlate with formations with type sections in the southern Potwar plateau, substituting Chichali Formation and Lumshiwal Sandstone for Spiti Shale and Giumal Sandstone, respectively. These units form a thin but persistent marker horizon in northeastern Hazara but are absent southwest of Abbottabad where the Samana Suk Formation is overlain by Paleocene Lockhart Limestone. In Hazara, the Lumshiwal Sandstone is overlain by 100 m of light gray fine-grained Upper Cretaceous limestone first mapped by Middlemiss (1896) as the basal part of the "Nummulitic series" and later by Latif (1970) as Chanali

Limestone. Calkins and others (1975) mapped Upper Cretaceous limestone as Kawagarh Limestone based on correlations with the Kawagarh Formation of the Kala Chitta Range. Cretaceous rocks are absent in the Hasan Abdal and Kherimar Hills sections (Figure III.4, column 4) but 6 m of highly sheared Upper Cretaceous limestone unconformably overlies the Dakhner Formation at one locality in the central Attock-Cherat Range (Yeats and Hussain, 1987; Figure III.4, column 3).

Tertiary

An unconformity marked by a 1- to 2-m-thick laterite forms the base of the Paleocene section throughout the Nathia Gali-Hissartang block. This laterite, together with the overlying sandstone, shale, coal and nodular thick-bedded to massive limestone has been variously assigned to the Nummulitic series (Middlemiss, 1896), the Mari Limestone (Latif, 1970), the Cherat Limestone (Tahirkheli, 1970), and the Kala Chitta Group (Calkins and others, 1975). Meissner and others (1974) separated the Paleocene in the Kohat plateau into a lower Hangu Formation dominated by coal-bearing clastic sediments and an upper Lockhart Limestone. Hangu Formation and Lockhart Limestone are the names recognized by the Stratigraphic Committee of Pakistan (Shah, 1977) for Paleocene rocks exposed in the Potwar and Kohat plateaus and in Hazara. Paleocene rocks unconformably overlie Upper Cretaceous limestone north and east of Abbottabad, Jurassic Samana Suk Formation in the Kherimar Hills, and Proterozoic Dakhner Formation and Paleozoic(?) Inzari Limestone in the Attock-Cherat Range. Interbedded greenish gray fissile shale and thin-bedded dark gray limestone of the Upper Paleocene-Lower Eocene Patala Formation overlie the Lockhart Limestone throughout the Nathia Gali-Hissartang block. The Patala Formation was mapped as part of the Nummulitic series by Middlemiss (1896), the Kuzgali Shale by Latif (1970), the Bakhtai Formation by Tahirkheli (1970), and the Kala Chitta Group by Calkins and others (1975). Shale of the Patala Formation is the youngest bedrock in the Hasan Abdal area (Figure III.5). A thin interval of nodular gray limestone of Early Eocene age mapped by Latif (1970) as Margala Hill Limestone conformably overlies the Patala Formation in Hazara. The Margala Hill Limestone is the youngest bedrock exposed in the Nathia Gali-Hissartang block south and east of Abbottabad. In the Attock-Cherat Range, the Margala Hill Limestone is missing and the Patala Formation is overlain unconformably by red and gray shales and sandstones that are presumed to be correlative with the Miocene Murree Formation.

Kala Chitta-Margala Block

The oldest exposed rocks in the Kala Chitta-Margala block are thin-bedded limestone and marl of the Lower Triassic Mianwali Formation which crop out in the northern Kala Chitta Range (Figure III.7; Figure III.4, column 1; Hussain and others, 1990). Overlying the Mianwali Formation are Middle to Upper Triassic limestone and dolomite of the Chak Jabbi and Kingriali Formations. Triassic rocks are not exposed in the Kala Chitta-Margala block east of the Kala

Chitta Range where the oldest outcrops consist of limestone of the Middle Jurassic Samana Suk Formation. The stratigraphic succession of Jurassic, Cretaceous, and Paleocene strata of the Kala Chitta-Margala block is similar to that outlined above for the Nathia Gali-Hissartang block except that the section is generally thicker. In the Kala Chitta-Margala block in southern Hazara, Paleocene strata are overlain by a great thickness of Lower Eocene Margala Hills Limestone followed by thin-bedded marl and limestone mapped by Latif (1970) as Lower Eocene Lora Formation. In the Kala Chitta Range, similar Lower Eocene carbonates were divided by Meissner (1974) into a lower Sakesar Limestone and an upper Shekhan Limestone. Lower to Middle Eocene variegated gypsiferous mudstone and clay interbedded with sandstone, conglomerate, and marl are the youngest rocks in the Kala Chitta-Margala block. These rocks are mapped as Kuldana Formation in southern Hazara (Latif, 1970) and as Mami Khel Clay in the Kala Chitta Range (Meissner and others, 1974).

Correlation and stratigraphic framework of pre-Tertiary strata

Figure III.8a is an interpretation of the Cretaceous configuration of stratigraphic units of the foothills region in the Cretaceous, prior to Himalayan deformation. The figure is diagrammatic and is not intended to represent a pre-Cretaceous cross-section at any particular location. The columns superimposed on the diagram are the same as in Figure III.4 and are located on

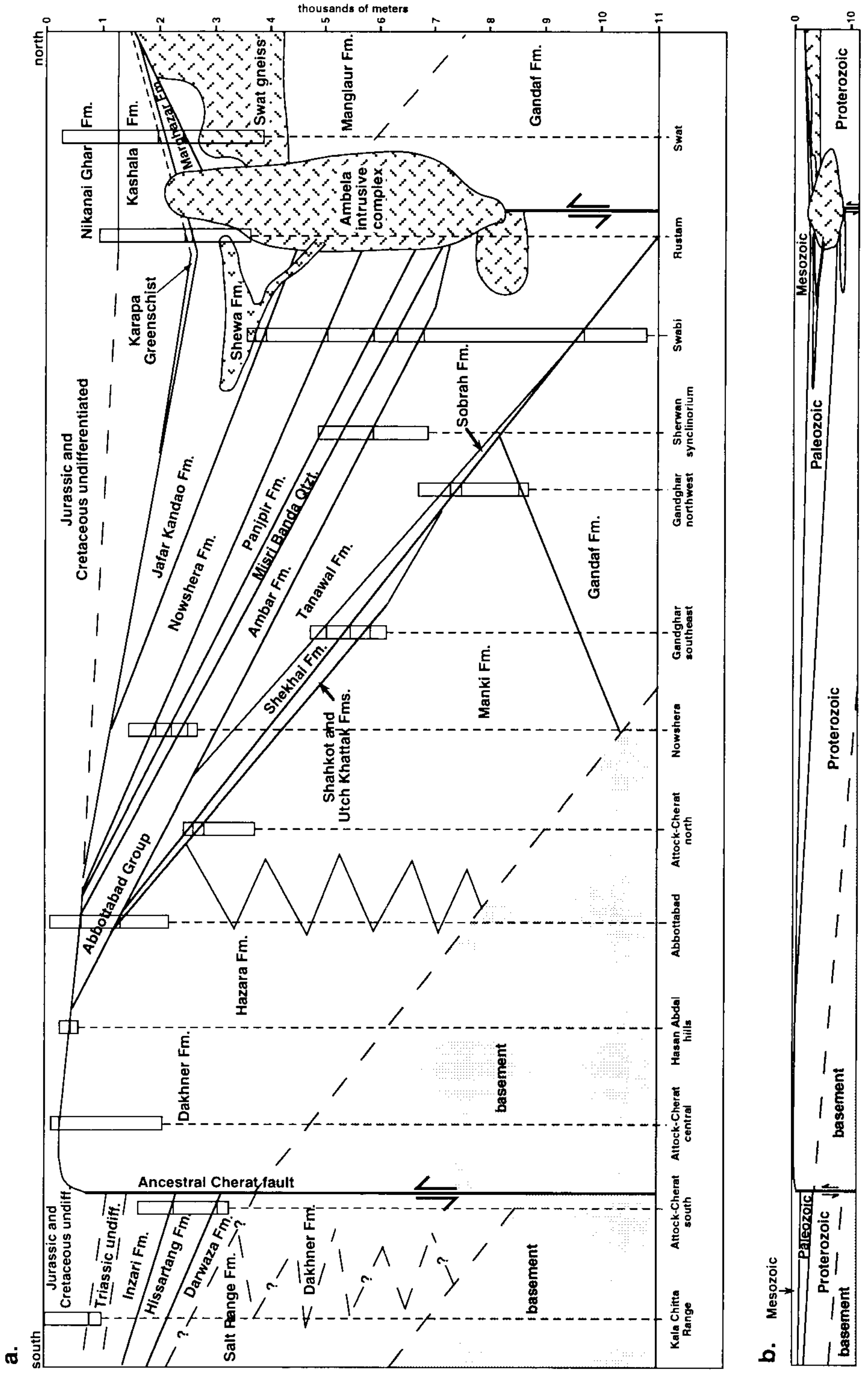

Figure III.8a - Interpretation of pre-Late Cretaceous stratigraphic framework of Himalayan foothills of northern Pakistan. Superimposed columns are the same as in figure III.4. Patterned areas are igneous rocks, shaded area is Precambrian crystalline basement. Figure III.8b - Simplified version of figure III.8a with no vertical exaggeration.

Figure III.2. The horizontal positions of the columns have been adjusted to compensate for the effects of Himalayan shortening and therefore do not reflect present-day distances or relative positions. Columns north of the Panjal-Khairabad fault, such as the Attock-Cherat Range north column, are therefore positioned to the north of those that lie south of the fault, such as the Abbottabad column, regardless of current geographic locations (Figure III.2). A rough estimate of the vertical exaggeration of Figure III.8a can be made by measuring the current north-south distance between two locations within one block and then doubling this distance to remove the effects of Himalayan shortening. Using this technique vertical exaggeration is approximately 10X. Figure III.8b is a simplified and unexaggerated version of Figure III.8a.

Proterozoic

Stratigraphic relationships between the Hazara (Dakhner) Formation, Manki Formation, and Gandaf Formation in the foothills region indicate that these units were originally deposited as a laterally continuous section, presumably on crystalline basement in a northward-deepening marine environment. Lithologies and sedimentary stuctures indicative of shallow marine deposition are common in the Dakhner Formation and in the Hazara Formation south of Haripur. Gypsum beds in the Hazara Formation documented by Latif (1969) represent a facies that is transitional with the evaporite-dominated Salt Range Formation which occupies a similar stratigraphic position south of the MBT. On Figure III.8, Upper Proterozoic rocks beneath the Kala Chitta Range are similarly inferred to be transitional between evaporites of the Salt Range Formation and shallow water marine clastics of the Dakhner Formation. Exposures of the northern pelitic facies of the Hazara Formation north of Abbottabad have endured low-grade metamorphism and are virtually identical to the Manki Formation. This similarity prompted Calkins and others (1975) to map extensive exposures of low-grade metapelite north of the Panjal-Khairabad fault (Manki Formation) as Hazara Formation. The contrasts in lithology and metamorphic grade between the formations are obvious, however, south of Haripur where the Panjal-Khairabad fault has juxtaposed the Manki Formation and the shallow water facies of the Hazara (Dakhner) Formation (figures III.5 and III.7). The northward progression of facies of the Hazara Formation thus record a transition from evaporites of the Salt Range Formation to low grade metapelite of the Manki Formation.

In the central Gandghar Range, Manki Formation slate and argillite is thrust over Proterozoic limestone along the Baghdarra fault (Figure III.5). Both Wynne (1879) and Middlemiss (1896) recognized that the slate in the hanging wall grades into graphitic phyllite within one kilometer of the fault. Middlemiss (1896) also noted the strong similarity of the graphitic phyllite to rock exposed in the gorge of the Indus River north of Darband (Figure III.2). Similar lithologies also form the western abutment of Tarbela dam (Figure III.5). The gradual transition of Manki Formation slate to graphitic phyllite near the Baghdarra fault indicates increased metamorphism of intervals of the Manki Formation exposed along the fault. In the northwestern Gandghar Range, the Manki Formation is overlain by a discontinuous interval of limestone of the Shekhai Formation followed by Tanawal Formation quartzite. Across the Indus River, on the northwest side of the Darband fault, the Shekhai Formation is absent, and graphitic phyllite, schist, and marble of the Gandaf Formation is overlain directly by quartzite of the Tanawal Formation. The lithologic contrast between the Manki Formation and Gandaf Formation on either side of the Indus River is thus interpreted to result primarily from an abrupt increase in metamorphic grade across the Darband fault. The strip of graphitic phyllite adjacent to the Baghdarra fault in the Gandghar Range has been mapped as Gandaf Formation on Figure III.5 since it is indistinguishable from typical Gandaf Formation exposed northwest of the Indus River. A belt of Gandaf Formation exposures extends northward along the Indus River toward Besham (Figure III.1) where Baig (1990) described graphitic phyllite of the Karora Group unconformably overlying Precambrian basement. Additional mapping may reveal that the Gandaf Formation and Karora Group are lateral equivalents. On Figure III.8 the contact between the Manki and Gandaf Formations is a metamorphic facies boundary drawn at the transition of slate or argillite to graphitic phyllite. Marble intervals included in the upper Gandaf Formation near Tarbela dam may represent higher-grade equivalents of the Shahkot or Utch Khattak formations.

The Shahkot and Utch Khattak Formations are locally thick carbonate interbeds within the upper part of the Manki Formation (Figure III.8). In the southeastern Gandghar Range (Figure III.5), both formations include an upper argillite or slate identical to the underlying Manki Formation. The only major unconformity in the section is marked by a thin quartzite interval at the base of the overlying Shekhai Formation. Southwest of Abbottabad, thin limestone intervals in the upper part of the Hazara Formation identical in lithology and position to the Shahkot and Utch Khattak Formations were mapped by Latif (1970) as Miranjani and Langrial Limestone, respectively and included in the Hazara "Group".

The Shekhai and Sobrah Formation are interpreted as a generally southward-thickening limestone lens at the base of the Tanawal Formation. These formations lack the algal laminations common to the Shahkot and Utch Khattak Formations and are more arenaceous. They are separated from the underlying Utch Khattak or Manki Formations by an unconformity marked locally by a thin quartzite interval. In the Gandghar Range, both formations are overlain by quartzite of the Tanawal Formation. The southward thickening of the Shekhai Formation at the apparent expense of the Tanawal Formation suggests that the two formations may be separate facies of the same stratigraphic interval.

The Tanawal Formation is interpreted as a clastic wedge derived from the erosion of a granitic highland to the north. The absence of the Tanawal Formation in all sections south of the Panjal-Khairabad fault indicates relatively rapid southward thinning of the 1000-m-thick sections exposed north of Swabi (Figure III.6) and northwest of Abbottabad (Calkins and others, 1975). The southward thinning of the Tanawal Formation is difficult to document since a complete section is not exposed south of Swabi.

For reasons outlined above, the Sobrah and Shekhai Formations are interpreted to partially substitute for the Tanawal Formation in the Gandghar Range and southern Peshawar basin.

Paleozoic

The base of the Paleozoic section throughout the foothills region is an angular unconformity marked by a conglomerate. A Late Proterozoic or Early Cambrian tectonic event uplifted, tilted, and weakly metamorphosed the Tanawal, Manki, and northernmost Hazara Formations prior to deposition of the overlying Ambar Formation or Abbottabad Group. Calkins and others (1975) and Baig and others (1988) suggest that this period of uplift was responsible for the removal of the Tanawal Formation from the Nathia Gali-Hissartang block in Hazara. However, there is no direct evidence that the Tanawal Formation was ever deposited south of the Panjal-Khairabad fault. The southward thinning of the Tanawal Formation may therefore be the result of Late Proterozoic-Early Cambrian erosion or non-deposition or both.

Thick sections of Paleozoic rocks exposed within the Panjal-Khairabad block are interpreted to have been preserved in a large half-graben created during late Paleozoic rifting of the northern margin of Gondwana (Figure III.8). Pogue and others (1992b) proposed a concealed northeast-striking normal fault or series of normal faults near the northern margin of the Peshawar basin to account for late Paleozoic uplift and removal of Cambrian through Devonian strata in Swat. A similar structure is proposed in Figure

III.8 to account for the absence of the entire Paleozoic section from much of the Nathia Gali-Hissartang block. The axis of the uplift, where all Paleozoic formations have been removed, and Jurassic or Cretaceous strata rest on eroded Proterozoic Dahkner or Hazara Formation, can be traced from the central Attock-Cherat Range eastward and northward through Hasan Abdal to southern Hazara. In Hazara, Latif (1980) documented progressive southward removal of Cambrian strata beneath the unconformity at the base of the Jurassic. Rift-associated uplift in southern Swat can be constrained as Late Carboniferous to Permian based on the onlap of eroded Proterozoic rocks by the Marghazar Formation and Karapa Greenschist (Pogue and others, 1992b). Uplift of the southern fault block can be constrained as being younger than the Lower Cambrian Tarnawai Formation which is the youngest unit beneath the unconformity and older than the Jurassic strata which overlie the unconformity. There is no evidence to support major tectonism within this time interval other than the late Paleozoic rifting event responsible for the similar uplift in southern Swat. A Late Cambrian event was responsible for the emplacement of granite in the Mansehra and central Swat areas (Swat Gneiss) and the removal of the Ambar Formation in the Chingalai and Sherwan synclinoria (LeFort and others, 1980; Pogue and others, 1992a). However, no evidence of this episode is recorded in rocks farther south. The late Paleozoic event resulted in the intrusion of diabase dikes throughout the Nathia Gali-Hissartang block. Reworked lower Paleozoic conodonts in the Permian Amb Formation of the Salt Range testify to the removal of lower Paleozoic rocks from late

Paleozoic rift highlands (Pogue and others 1992b). The eruption of the silicic volcanics of the Shewa Formation and the emplacement of alkaline granite of the Ambela intrusive complex are further manifestations of Late Paleozoic rifting (Figure III.8; Pogue and others, 1992b). The absence of Paleozoic strata throughout most of the Nathia Gali-Hissartang block is therefore interpreted to be the result of uplift on a fault or series of faults on the southern flank or "shoulder" of a late Paleozoic rift. Throughout most of its length, the fault responsible for the uplift has been concealed by younger thrusting along the Nathia Gali fault (Figure III.9). In the Attock-Cherat Range, however, a thick fault-bounded interval of rocks of probable Paleozoic age is preserved in the hanging wall of the Hissartang fault (Figures III.4 and III.7). These rocks, represented by the Darwaza, Hissartang, and Inzari Formations, are interpreted in Figure III.8 as a former southward continuation of Paleozoic strata exposed in the southern Peshawar basin. The Cherat fault separates the Attock-Cherat Paleozoic(?) section on the south from Proterozoic Dahkner Formation overlain by Cretaceous strata on the north (Figure III.7; Yeats and Hussain, 1987; Hussain and others, 1990). The position of the Cherat fault is consistent with that proposed to account for late Paleozoic uplift. Latest Cretaceous motion of the Cherat fault documented by Yeats and Hussain (1987) may represent the reactivation of an older rift-related structure. On Figure III.8, retrodeformation of late Paleozoic displacement on the Cherat fault implies that the Cambrian stratigraphy in the Abbottabad area is transitional between the Ambar Formation and part of the Paleozoic(?) section of the Attock-Cherat Range. This is

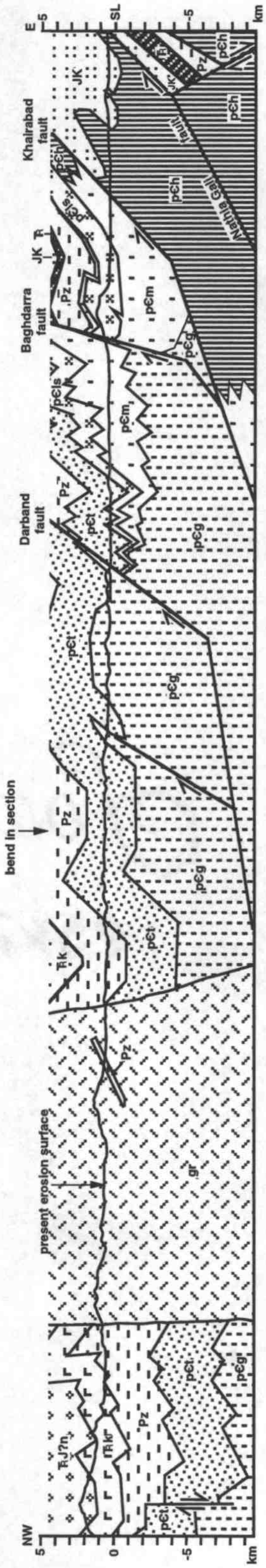

Figure III.9 - Balanced geologic cross-section of the central Himalayan foothills of northern Pakistan. Patterns and unit abbreviations are the same as in figures III.5, III.6, III.7, and III.10. For location see figures III.2, III.6, III.7, and III.10.

not the case, however. In Hazara, due to the northeasterly strike of Cambrian facies, the Abbottabad Group, which has been correlated with Cambrian strata of the Salt Range (Latif, 1984; Stocklin, 1986), is preserved on the north side of the Late Paleozoic uplift. Cambrian rocks similar to those of the Salt Range would be expected in the subsurface south of the concealed eastward continuation of the Cherat fault in southern Hazara. The Kala Chitta block is inferred to be underlain by Paleozoic rocks transitional between the Paleozoic(?) section of the Attock-Cherat Range and the Salt Range Paleozoic section (Figure III.8).

Mesozoic

The oldest Mesozoic rocks exposed north of the Cherat fault are Upper Triassic (Carnian) marbles of the Kashala Formation which were deposited on the eroded surface of the Karapa Greenschist following thermal subsidence of the late Paleozoic rift highlands of southern Swat (Pogue and others, 1992b). The southern uplift, associated with the Cherat fault, apparently remained subaerial throughout the Triassic as no rocks of this period have been observed overlying eroded upper Proterozoic or Cambrian strata along the entire length of the uplift. Transgression of the southern highland commenced in the Early Jurassic when the Datta Formation was deposited on the Abbottabad Group and Tarnawai Formation in Hazara. The highland was mostly inundated by the Middle Jurassic when limestones of the Samana Suk Formation were deposited on the Upper Proterozoic Hazara

Formation throughout southern Hazara and in the Hasan Abdal area. Unnamed late Cretaceous limestone overlying Upper Proterozic Dakhner Formation in the central Attock-Cherat Range (Yeats and Hussain, 1987) indicates that some parts of the uplift remained subaerial into the Cretaceous. Mesozoic formations exposed in the Kala Chitta block were deposited on the south side of the Late Paleozoic uplifts and reflect deposition in a deeper water environment than their type sections to the south in the Salt and Surghar Ranges (Fatmi, 1973; Yeats and Hussain, 1987).

Structure

Structural framework of the foothills

Panjal-Khairabad block

The Panjal-Khairabad fault was first mapped by Middlemiss (1896), who recognized it as an important structure forming the boundary between the "crystalline and metamorphic zone" northwest of Abbottabad and the "slate" zone to the southeast. The fault was named the Sobrah fault by Latif (1969) for the excellent exposures near Sobrah Gali, 7 km WNW of Abbottabad. Calkins and others (1975) considered the fault to be a western continuation of the Panjal fault mapped by Wadia (1957) at the front of the Pir Panjal Range in Indian Kashmir. The fault has appeared on more recent maps as the Tarbela thrust (Coward and others, 1982) or Mansehra thrust (Coward and Butler, 1985; Greco and others, 1989; Greco, 1991). However, the majority of recent workers have followed Calkins and others (1975) in referring to the fault as the Panjal fault or Panjal thrust. The Panjal fault diverges from the Murree fault 10 km south of Balakot and strikes generally southwestward between Mansehra and Abbottabad before it is buried by Haripur basin alluvium (Figure III.2). Coward and others (1988) turn the fault sharply northwards at this point so that it runs along the east side of Tarbela Lake before turning west to merge with the "MCT" in southern Swat. Stratigraphic evidence is strongly against this interpretation, however. The Gandghar Range exposes a large thickness of Tanawal Formation, a unit which is elsewhere restricted to areas north of the Panjal fault. In fact, Gandghar Range structure and stratigraphy can be readily traced across the eastern arm of Tarbela Lake (Figure III.5) into rocks on the north side of the Panjal fault. Calkins and others (1975) mapped the southwestern continuation of the Panjal fault along a prominent shear zone exposed along the southeastern escarpment of the Gandghar Range. This interpretation was based on the presence of similar stratigraphic offset across the structure. However, rocks on the southeastern side of the fault, mapped by Calkins and others (1975) as Triassic Kingriali Formation, belong instead to the Upper Proterozoic Shekhai Formation and Tanawal Formation. In the southern part of the Gandghar Range, in areas not mapped by Calkins and others (1975) the Shekhai Formation is underlain by other Proterozoic limestones which are in turn underlain by Manki Formation (Figure III.5) a unit elsewhere restricted to regions north of the Panjal fault. Isolated hills near Hasan Abdal, 8 km southeast of the Gandghar Range, expose argillite and sandstone of the Upper Proterozoic Hazara Formation overlain by limestone of the Jurassic Samana Suk Formation. This stratigraphy is identical to that exposed in much of southern Hazara in the region south of the Panjal fault. For this reason, the Panjal fault is inferred to be concealed beneath Quaternary alluvium in a position between the Gandghar Range and the Hasan Abdal hills (Figure III.5). The fault on the southeastern flank of the Gandghar Range mapped by Calkins and others (1975) as the Panjal fault is mapped on Figure

III.5 as the Baghdarra fault and is interpreted on III.9 to be an imbricate of the Panjal fault.

Stratigraphic throw along the Khairabad fault of the northern Attock-Cherat range as mapped by Yeats and Hussain (1987) and Hussain and others (1990) is virtually identical to that along the Panjal fault to the northeast. North of the fault, weakly metamorphosed argillite and slate of the Manki Formation are overlain by a thick interval of Proterozoic limestone. South of the fault, unmetamorphosed Upper Proterozoic Dakhner Formation is overlain by Upper Cretaceous limestone (Figure III.7). The Khairabad fault is concealed beneath alluvium of the southern Peshawar basin west of the Attock-Cherat Range until it emerges in the hills south of the Khyber Pass (Figure III.2; Ahmad Hussain, personal communication). The Khairabad fault is interpreted to be the westward continuation of the Panjal fault of southern Hazara, and the fault system therefore is collectively referred to as the Panjal-Khairabad fault.

All pre-Cenozoic rocks north of the Panjal-Khairabad fault have been metamorphosed. The original slaty cleavage of the Manki Formation and schistosity of the Gandaf Formation were imparted during the Late Proterozoic Hazaran orogeny (Baig and others, 1988). Pre-Cenozoic rocks younger than these formations remained unmetamorphosed until the Himalayan collision during the early Tertiary. In general, the grade of metamorphism increases from south to north in the Panjal-Khairabad block. Paleozoic carbonates near Nowshera (Figure III.7) are recrystallized but show little or no evidence of ductile flow. Conodonts recovered from these rocks have a color alteration index (CAI) value of 5 indicating peak metamorphic temperatures of 300° C (Pogue and others, 1992a). Triassic carbonates exposed on the northern edge of the Peshawar basin near Baroch (Figure III.10) contain ductilely deformed conodonts with a CAI value of 7, indicating peak metamorphic temperatures of 400° C (Pogue and others, 1992a). Between the Peshawar basin and the MMT, the metamorphic grade increases gradually but dramatically. DiPietro and Lawrence (1991) describe a northward progression of metamorphic facies from lower greenschist 5 km north of Rustam to kyanite grade in the core of the Loe Sar gneiss dome 5 km southeast of Saidu (Figure III.2). Metamorphic rocks of lower greenschist facies are exposed in the Indus gorge in the Besham area, north of areas in Swat that display kyanite-grade metamorphism. These rocks belong to the Upper Proterozoic Karora Group and are confined to a tectonic window bounded by the Thakot fault, the Puran fault, and the MMT (Figure III.1; Baig, 1990). The relationship of these rocks and the structures that bound them to areas farther south are unclear, since the Indus gorge between Darband and Besham is unmapped. Between the Indus River and the Hazara-Kashmir syntaxis, metamorphism in the Panjal-Khairabad block increases northward from lower greenschist to sillimanite grade in abrupt steps at thrust faults that imbricate a stratigraphy dominated by Tanawal Formation quartzites intruded by Mansehra Granite (Calkins and others, 1975; Coward and others, 1988; Treloar and others, 1989a).

The structure of the southern part of the Panjal-Khairabad block is dominated by south- or southeast-vergent folds that

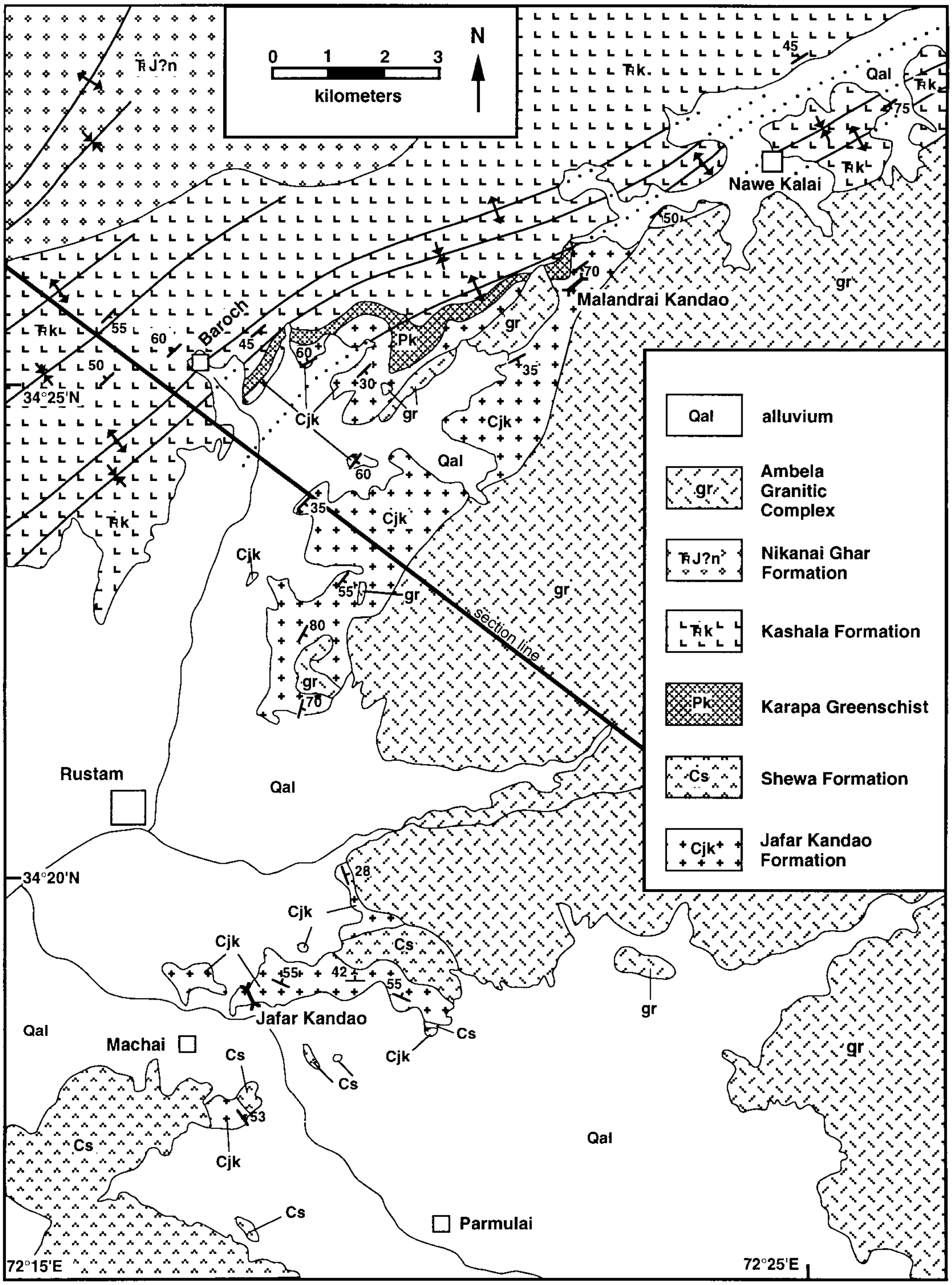

Figure III.10 - Geologic map of the Rustam area, northern Peshawar basin. See figure III.3 for location.

deform bedding and bedding-parallel foliation in the low-grade metamorphic rocks. Bedding and foliation strike generally north-northeast east of Mansehra on the western limb of the Hazara-Kashmir syntaxis and northeastward north of Abbottabad (Calkins and others, 1975). In the southern Gandghar Range, the Indus syntaxis accounts for a gradual 45° rotation of strike to a general east-west orientation that is maintained farther west in outcrops in the northern Attock-Cherat Range and Nowshera area (figures III.5 and III.7; Hussain and others, 1990). Rocks on the northern margin of the Peshawar basin display complicated map patterns indicative of multiple folding episodes. The structure of the Chingalai synclinorium (Figure III.6) suggests that early northwest-trending folds were refolded along northeast-trending axes. The folded Proterozoic and Paleozoic strata in Figure III.6 are truncated by the Ambela Granitic Complex, suggesting that the intrusive rocks in this area postdate folding. However, the granite is intruded by diabase dikes which are elsewhere restricted to rocks that are Permian and older (Pogue and others, 1992b). Hence, the possibility exists that some of the folding is pre-Himalayan. A resolution of this problem must await detailed mapping and radiometric dating of the constituent plutons of the Ambela Granitic Complex.

In the vicinity of Rustam (Figure III.10), alkaline volcanics of the late Paleozoic Shewa Formation are clearly folded, and associated alkaline granite of the Ambela Granitic Complex acts as a buttress to Himalayan folds that wrap around and are locally backfolded against the northwestern margin of the intrusive rocks (figures III.9 and III.10). North of the Ambela Granitic Complex, in

Swat, DiPietro and Lawrence (1991) recognized four distinct folding episodes. The first three episodes with north-trending fold axes have been refolded along east-trending axes producing the gneiss-cored dome structures of central Swat. The north-trending folds die out south of the garnet isograd and the major folds all trend to the east and are south-vergent except where deflected by buttressing of the Ambela Granitic Complex (DiPietro and Lawrence, 1991). The east- and east-southeast-trending folds in the northern Peshawar basin near Swabi (Figure III.6) abruptly rotate to a northeasterly trend along the west shore of Tarbela lake as they approach the Indus syntaxis (Figure III.5). On either side of the Indus river valley, from Tarbela dam to at least as far north as Darband, bedding and foliation similarly swing northward to become parallel with the axis of the syntaxis and the strike of the associated Darband fault (Calkins and others, 1975). In the area east of the Indus river between Darband and Mansehra, tight to isoclinal south-vergent folds are associated with an imbricate thrust stack of Tanawal Formation and Mansehra Granite (Calkins and others, 1975; Treloar and others, 1989b). Fold axes abruptly swing northward between Mansehra and Balakot on the western flank of the Hazara-Kashmir syntaxis (Calkins and others, 1975; Bossart and others, 1988).

The Panjal-Khairabad block west of the Indus river is notable for the absence of internal imbrication. The Paleozoic stratigraphy and metamorphic grade of the Nowshera and Swabi areas are very similar, precluding a Himalayan fault of large displacement beneath the intervening alluvium (Pogue and others, 1992a). Recent geologic mapping of the area between Swabi and the MMT (figures III.6 and III.10; DiPietro and Lawrence, 1991) revealed no evidence for the "MCT" of Coward and others (1988), the Alpurai thrust of Treloar and others (1989a), or any other major Himalayan fault. The only faults of consequence between the Khairabad fault and the MMT are a series of left-stepping en echelon active faults that bound the south side of bedrock islands in the southern Peshawar basin (Yeats and Hussain, 1989). In contrast to the region west of the Indus syntaxis, the Panjal-Khairabad block north of Mansehra is extensively imbricated by a series of thrust faults that include the Oghi shear and Mansehra thrust (Figure III.2; Treloar and others, 1989a). These faults diverge from the north-striking Thakot fault on the eastern side of the Indus syntaxis, swing eastward north of Mansehra and then bend northward once again before merging with a mylonite zone along the western side of the Hazara-Kashmir sytaxis (Treloar and others, 1989a). The faulted terrane north of Mansehra is separated from the unfaulted region of Swat by the Indus syntaxis and the associated Darband fault (Figure III.2). The Darband fault may represent the southern continuation of the Puran or Thakot fault which bounds the Besham block to the north (Baig, 1990). The Darband fault appears to die out to the southwest near Tarbela dam where it splits into several imbricate splays that thrust graphitic metapelite of the Gandaf Formation over quartzite of the Tanawal Formation (Figure III.5).

Nathia Gali-Hissartang block

The first fault north of the Salt Range to bring Precambrian rocks to the surface was named the Nathia Gali fault by Latif (1984) for exposures just north of the village of Nathia Gali on the main road between Abbottabad and Murree. Throughout southern Hazara, the Nathia Gali fault places fine-grained clastic rocks of the Proterozoic Hazara Formation over Mesozoic and Tertiary limestone (Latif, 1970). The Nathia Gali fault splits from the Murree fault 5 km south of Muzaffarabad and then closely parallels the Murree fault before turning abruptly westward 10 km farther south (Figure III.2; Greco, 1991). The fault strikes generally southwestward through southern Hazara before it is concealed beneath alluvium in the southern Haripur basin (Figure III.2; Latif, 1970). The fault must extend westward beneath the alluvium of the Campbellpore basin south of outcrops of Hazara Formation in the hills near Hasan Abdal (figures III.2 and III.5) before emerging from the alluvium in the southern Attock-Cherat range as the Hissartang fault where it thrusts lower Paleozoic(?) Darwaza Formation over the Jurassic Samana Suk Formation (figures III.2 and III.7; Yeats and Hussain, 1987; Hussain and others, 1990). The correlation of the Nathia Gali fault with the Hissartang fault is based on the similarities between the stratigraphy of footwall rocks exposed in the Margala Hills and Kala Chitta Range and on the restriction of outcrops of Proterozoic strata to areas north of the faults. Normal motion along the ancestral Cherat fault (Figure III.8) during the late Paleozoic is probably responsible for the preservation of Paleozoic(?) rocks in the hanging wall of the Hissartang fault in the Attock-Cherat Range. The displacement of Tertiary strata across the Hissartang fault at the western end of the Attock-Cherat Range is small compared to the displacement of pre-Tertiary strata observed in outcrops to the east. This relationship led Yeats and Hussain (1987) to conclude that the majority of the displacement on the fault occurred during the Cretaceous. West of the Attock-Cherat Range, the fault is concealed by alluvium of the southern Peshawar basin before it emerges within Tertiary strata north of Kohat (Figure III.2; Meissner and others, 1974).

With the exception of the northern exposures of the Hazara Formation northwest of Muzaffarabad, the rocks of the Nathia Gali-Hissartang block are unmetamorphosed. North of Abbottabad, pelitic rocks of the Hazara Formation were gently folded and metamorphosed to slate and argillite by the Hazaran orogeny prior to deposition of the overlying Tanakki Conglomerate (Baig and Lawrence, 1987; Baig and others, 1988). The effects of the Hazaran orogeny are subtle or absent in exposures of the Hazara Formation south of Abbottabad and in the Dakhner Formation of the Attock-Cherat Range.

The strike of fold axial planes and thrust faults within the Nathia Gali-Hissartang block generally parallels the strike of the nearest segment of the Nathia Gali or Hissartang faults (Latif, 1970; Hussain and others, 1990). In Hazara, the folds have been generated by at least two distinct phases of northwest-southeast oriented compression. The first southeast-vergent phase was associated with southeast-directed thrusting of the Nathia Gali fault and its hanging wall imbricates. The second phase produced north-vergent backfolds that locally fold the Nathia Gali fault and its imbricates so that they dip to the south and appear as normal faults in outcrop (Latif, 1970; Calkins and others, 1975). Folds with northwest-trending axes such as in the hills east of Hasan Abdal (Figure III.5) occur rarely and are interpreted to have been produced in areas of high shear strain between south-vergent and north-vergent structures. Evidence for a backfolding episode is lacking in the hanging wall of the Hissartang fault in the Attock-Cherat Range where faults and folds are consistently south-vergent.

Kala Chitta-Margala block

In southern Hazara, north of Islamabad, Mesozoic and Tertiary strata of the Margala Hills are thrust to the southeast over Miocene Murree Formation redbeds along the MBT. In this area, displacement on the MBT (also known as the Murree fault) is distributed along a zone of thrust faults that gradually merge toward the the northeast to form a single north-striking fault along the western flank of the Hazara-Kashmir syntaxis (Latif, 1970; Yeats and Lawrence, 1984; Greco, 1991). West of the Margala hills, the MBT zone strikes east-west along the southern flank of the Kala Chitta Range and the northern boundary of the Kohat Plateau (Figure III.2; Meissner and others, 1974). The unmetamorphosed Mesozoic and Tertiary strata exposed between the MBT and the Nathia Gali-Hissartang fault have been deformed by multiple episodes of north-south compression that have produced both south- and north-vergent coaxial folds and associated thrust faults. Backfolding of formerly south-vergent structures has produced moderate to steep southward dips on the constituent faults of the MBT zone in the Margala and Kohat hills (Latif, 1970; Coward and others, 1988).

Structure discussion

Deformational history of the foothills

Pelitic rocks of the Gandaf Formation, Manki Formation and northern Hazara Formation were deformed, metamorphosed to lower greenschist facies, uplifted, and eroded prior to deposition of the lower Cambrian Abbottabad Group. Baig and others (1988) refer to this event as the Hazaran orogeny and speculate that it may be related to the assembly of Gondwana during the Late Proterozoic. The intrusion of the Mansehra and Swat granites into the Tanawal and Manglaur Formations in the northern part of the Panjal-Khairabad block during the Cambrian (LeFort and others, 1980) could either have occurred during the late stages of the Hazaran orogeny or be part of an unrelated episode of tectonism. The thick intervals of tourmaline-bearing feldspathic quartzite that comprise much of the Tanawal Formation were probably derived from a northern granitic highland produced during Late Proterozoic or Early Cambrian tectonism. The Tanawal Formation may have originally accumulated in an intracontinental epirogenic basin well inland of the orogenic highland that was the source of the sediments. This orogeny could have resulted from the accretion of Precambrian crystalline basement rocks now exposed in the Besham and Nanga Parbat regions to the northern formerly passive margin of India.

Removal of the Cambrian Ambar Formation and deposition of Lower Ordovician conglomerates and feldspathic sandstones in the northern Peshawar basin provides evidence for Late Cambrian tectonism (Pogue and others, 1992a). Beginning in the Carboniferous, the foothills region was affected by extensional tectonics that eventually climaxed in rifting during the Permian. This extensional phase was reponsible for the alkaline granite, syenite, and carbonatite of the Ambela Granitic Complex and alkaline porphyry of the Shewa Formation (Pogue and others, 1992b). The diabase dikes and sills that are ubiquitous in the pre-Triassic rocks and their extrusive equivalent, the Karapa Greenschist, were also emplaced at this time. Normal faulting on the landward side of the rift shoulder produced elongate northeast-trending highlands in central Swat, the central Attock-Cherat Range, and southern Hazara. It was at this time that early folds may have been produced in pre-Carboniferous strata in the Chingalai synclinorium as the rocks moved past curves or steps on the surfaces of normal faults. Erosion of the uplifted fault blocks produced major unconformities in Swat where Carboniferous or Permian rocks overlie Proterozoic metaclastic strata (Pogue and others, 1992b) and in the Attock-Cherat Range and southern Hazara where Jurassic and Cretaceous limestone overlie Proterozoic clastic rocks.

Renewed tectonism commenced during the Late Cretaceous with initial motion along the Cherat and Hissartang faults in the Attock-Cherat Range (Yeats and Hussain, 1987). Widespread compressional tectonics related to the obduction of the Kohistan island arc may have begun as early as 62 Ma (Klootwijk and others, 1985) and was certainly underway by 50 Ma (Patriat and Achache, 1984). According to DiPietro and Lawrence (1991), early west-vergent folds in the northern Panjal-Khairabad block in Swat were produced during initial oblique convergence of the western margin of the Indian plate with Kohistan. Kyanite grade metamorphism in Swat is attributed by DiPietro and Lawrence (1988) and DiPietro (1991) to Eocene subduction of the Swat sequence to depths of 35-45 km beneath MMT suture melange. Lower grade rocks exposed as far south as the northern Attock-Cherat Range were probably metamorphosed at the same time by the same mechanism but at substantially shallower depths. Although the timing and style of metamorphism are similar to Swat, Treloar and others (1989a) find no evidence for early west-vergent folds in the northern Panjal-Khairabad block east of the Indus River. DiPietro and Lawrence (1991) and Treloar and others (1989a) agree that the eventual southward accretion of the Kohistan arc is responsible for the large-scale south-vergent folds in Swat and south-vergent folds and thrust faults north of Mansehra. After the emplacement of Kohistan, the deformation front migrated southward and rocks previously subducted and metamorphosed beneath Kohistan were thrust over unmetamorphosed rocks along the Panjal-Khairabad fault. This chronology is supported by Treloar and others (1992) who suggest that motion of the Panjal-Khairabad fault prior to 20 Ma was largely responsible for uplift and exhumation of the high-grade metamorphic rocks south of the MMT. The deformation front continued to migrate southward during the Miocene, producing south-vergent folds and thrust faults in the region between the MBT and the Panjal-Khairabad fault. The Hissartang and Nathia Gali faults were reactivated during this time, although displacement was small compared to pre-Paleocene displacement, based on offsets in the Murree Formation in the western Attock-Cherat Range (Yeats and Hussain, 1987). Major displacement along the MBT zone began between 10 Ma and 5 Ma based on stratigraphic and structural relationships outlined by Treloar and others (1992). The major south- or southeast-vergent structures of the foothills were subsequently folded about north-trending axes during the development of the Hazara-Kashmir and Indus syntaxes. Bossart and others (1988) attribute the formation of the Hazara-Kashmir syntaxis to a progressive rotation of the principal axis of compression from northeast to northwest during the Himalayan collision. Offset river gravels, tilted terraces, and air-photo lineaments suggest recent motion along north-striking faults associated with the Indus syntaxis (Yeat and Hussain, 1989; Baig, 1990). Left-stepping pressure ridges adjacent to Quaternary faults (Yeats and Hussain, 1989) and an east-trending zone of seismicity in the southern Peshawar basin (Seeber and others, 1981) attest to continuing tectonism in the foothills region.

Correlation with tectonic subdivisions of the central Himalaya

Much effort has been expended in attempts to extrapolate the tectonic subdivisions proposed by Gansser (1964) for the central Himalaya to the northwestern Himalaya in Indian Kashmir and Pakistan. The problems involved with such attempts were summarized by Yeats and Lawrence (1984), who proposed a unique set of subdivisions for the Himalaya of northern Pakistan. Despite the efforts of Yeats and Lawrence (1984), recent workers have continued to apply central Himalayan tectonic nomenclature to northern Pakistan. A primary concern of some studies has been to locate the Pakistani equivalent of the MCT. The MCT of Gansser (1964; 1981) lies at the base of a thick slab of Precambrian crystalline basement that has been transported a large distance to the south over unmetamorphosed or very low-grade metamorphic rock. The amount of shortening on the MCT is such that it has proved very difficult to correlate the sedimentary cover of the hanging wall (the Tethyan Himalaya) with sedimentary rocks of the footwall (the Lesser Himalaya). Greco and others (1989) consider a prominent mylonite zone exposed in the Kaghan valley north of the Hazara-Kashmir syntaxis to be a northwestern extension of the MCT. As mapped by Bossart and others (1988) and Greco and others (1989) the MCT-correlative mylonite zone strikes northward on the west side of the syntaxis near Balakot (Figure III.2) where it is interpreted to turn to the west and merge with the Oghi shear of Coward and others (1986). Greco and others (1989) therefore consider the Oghi shear as the tectonic equivalent of the MCT of the central Himalaya. Coward and others (1988) consider the Mansehra thrust, which also converges with the mylonite zone of Bossart and others (1988) and Greco and others (1989), to be the Pakistani MCT. Both Coward and others (1988) and Greco and others (1989) base their correlations on the sharp increases in metamorphic grade across the faults. However, neither the jump from chlorite to biotite grade at the Mansehra thrust nor the jump from garnet to kyanite grade at the Oghi shear is comparable to the dramatic increase in metamorphism across the MCT in the central Himalaya. Furthermore, the presence of Tanawal Formation intruded by Mansehra granite in the hanging wall and footwall of both the Mansehra thrust and Oghi shear precludes the dramatic shortening that would be expected across the MCT. Rather than being major tectonic boundaries, the Oghi shear, Mansehra thrust, and other similar faults north of Mansehra appear to imbricate a portion of the Indian plate that was formerly subducted beneath Kohistan along the MMT such that formerly deeper higher grade rocks to the north are thrust southward over equivalent lower grade rocks. The entire metamorphic terrane was then thrust to the south over unmetamorphosed rocks along the Panjal-Khairabad thrust. The contrast in stratigraphy and grade of metamorphism across the Panjal-Khairabad fault implies dramatic shortening, leading Pogue and others (1992a) to suggest that the Panjal-Khairabad fault is the Pakistani analog to the MCT. However, while the stratigraphic relationships across the two faults are analogous, the Panjal-Khairabad fault does not appear to involve basement nor does it mark the base of a topographic step in the manner of the MCT.

Thus, while the Panjal-Khairabad fault shares some characteristics with the MCT, it is not the western continuation of that structure. The absence of a major crustal-scale thrust fault in northern Pakistan similar to the MCT of the central Himalaya may be related to decreased shortening due to oblique convergence of the Pakistani Himalaya near the western edge of the Indian plate.

Pogue and others (1992a) consider the thick section of Paleozoic and Mesozoic strata exposed in the Peshawar basin north of the Panjal-Khairabad fault to be the western Himalayan equivalent to the Tethys Himalaya of the central Himalaya. However, central Himalayan Tethyan sections are unmetamorphosed and unconformably overlie or are faulted against crystalline basement of the High Himalaya while the "Tethyan" rocks of the Peshawar basin consist of greenschist-facies metamorphic rocks that unconformably overlie a thick section of Proterozoic metasediments that are more typical of Gansser's (1964) Lesser Himalaya. The foothills region therefore contains no terrane comparable to the High Himalaya and the metasedimentary rocks exposed north of the Panjal-Khairabad fault constitute a metamorphosed hybrid of Gansser's (1964) Tethyan and Lesser Himalaya.

Pogue and others (1992a) and Treloar and others (1992) correlate rocks in the footwall of the Panjal-Khairabad fault with the Lesser Himalaya of northern India and Nepal based on the presence of thick intervals of Proterozoic sedimentary rocks, the absence of Ordovician through Carboniferous strata, and the structural position of the rocks north of the apparent westward continuation of the

MBT. However, upper Paleozoic rocks of Gondwana affinity typical of the Lesser Himalaya are not present in northern Pakistan except south of the MBT in the Salt Range. Furthermore, exposures of Proterozoic sedimentary rocks in the foothills are bounded on the south not by the MBT, but by the Nathia Gali-Hissartang fault, a major structure which has no counterpart in the Lesser Himalaya. The foothills region is bounded on the south by the MBT, which like its namesake in the central Himalaya thrusts older rocks southward over deformed foredeep strata. However, Tertiary molasse of the Murree Formation crops out extensively to the north of the MBT south of Peshawar and exposures of pre-Murree rocks in the Pakistan Himalaya are not limited to regions north of the MBT as they are in the Himalaya of northern India. The observations outlined above make it apparent that the central Himalayan tectonic subdivisions of Gansser (1964) and their bounding structures cannot be extrapolated to northern Pakistan.

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