Pakistan Journal of Hydrocarbon Research
Vol.2, No.2(July 1990), P.43-55, 5 Figs., 1 Table

Geology and Structure of Kuza Gali–Dunga Gali–Ayubia Area, Hazara-Potwar Basin with a Reference to Hydrocarbon Prospects of Attock–Hazara Fold and Thrust Belt

Munir Ghazanfar[1], Mohammad Nawaz Chaudhry[1], Khalid Pervaiz[2], Mazhar Qayyum[3] and Riaz Ahmed[4]

ABSTRACT

The Attock-Hazara fold and thrust belt of Pakistan forming the northern rim of oil producing Kohat-Potwar depression is a slab of folded platform sediments which were thrust southward. The thrusting accompanied by rotation and decollement produced stacks of stratigraphic sections. This foldbelt, especially its southern front, is of some interest for hydrocarbon exploration because of its continuation with the oil producing Potwar area and presence of a number of oil seepages.

Detailed geological mapping of a part of the fold and thrust belt (Kuza Gali-Dunga Gali-Ayubia area) has been carried out at a scale 1:9560 in order to understand lithostratigraphy, structure and regional geology in relation to the larger tectonic framework. Stratigraphically, the area shows exposures of rock units from Middle Jurassic to Eocene and belongs to the so-called Kohat-Potwar basin. The overall structure of the mapped area is an anticlinorium bounded by the two synclinoria to its north and south.

INTRODUCTION

The Dunga Gali-Kuza Gali area (Figure 1) lies in a relatively accessible part of northwestern Himalaya and represents a region with a well developed stratigraphic column and interesting structure. Reconnaissance geological work was carried out in this area by Middlemiss (1896) as part of a much larger project of reconnaissance mapping. It was followed by a relatively detailed mapping by Latif (1970). This later work, too, however, was preliminary in nature. The present work covers a much smaller area but is intended to provide a better understanding of the stratigraphy as well as the structure based on a detailed and more precise geological mapping at a relatively large scale (1:9560).

[1]Institute of Geology, Punjab University, Lahore
[2]Atomic Energy Minerals Centre, Lahore
[3]Water & Power Development Authority, Lahore
[4]Hydrocarbon Development Institute of Pakistan, Islamabad.

PREVIOUS WORK

A summary of the previous work in the study and adjoining areas is given below:

Waagan (1872) worked in the vicinity of Changla Gali, an area adjacent to the presently investigated area. He differentiated the stratigraphic units by describing a simplified section starting from Khaira Gali Bazar to Changla Gali through Chumbi Peak (8746'). He split the stratigraphic succession into broad groups : Spiti Shales, Sandstone Series and Nummulitic Limestone Series, generally separated by faults dipping in several directions.

Mention here may also be made of work by Waagan and Wynne (1872) in the area of Mount Sirban near Abbottabad. The Abbottabad area about 15 miles to the southeast is in the same broad stratigraphic groups namely, Semi-Cretaceous and Nummulitic Formation. They also geologically mapped these units, described their fauna and correlated the sequence with that of Spiti district.

C.S. Middlemiss (1896) in his detailed work on the geology of Hazara and Black Mountains for the first time presented a preliminary and reconnaissance geological map of a large part of Hazara, described the rock units and gave an account of the stratigraphy and major structure. He divided the geology of the area into four zones of disturbance: Crystalline and metamorphic zone, Slate or Abbottabad zone, Nummulitic zone and the Upper Tertiary zone. He separated these zones on the basis of metamorphism, faults and stratigraphy. The presently mapped Kuza Gali-Dunga Gali-Ayubia area falls under his Nummulitic zone. He broadly classified the rocks present in this section into Trias limestone, Spiti shales, Grey limestone, Giumal sandstone and Nummulitic limestone. However, he did not make any attempt to separate the different limestone, shale and marl units as we know them today within the Nummulitic series. He found the area structurally much disturbed to make these subdivisions possible. Latif (1970) gave a brief account of the stratigraphy of southeastern Hazara, supported by a geological map on a scale of one inch to a mile. He classified the lithostratigraphic units into 7 groups separated by unconformities and further subdivided them into 21 formations, correlating them with the adjoining areas. He distinguished different formations within the loose and broad grouping of Tertiary "Nummulitic limestone series" of Middlemiss (1896). He renamed most of the units in accordance with the stratigraphic code. Some of these nomenclatures were later accepted by the Stratigraphic Committee of Pakistan.

In 1913-1914, Indolex Petroleum Syndicate drilled a well in the vicinity of oil seepages near Golra encountering an oil show at 91.5m depth. Pascoe (1920) described a number of seepages from near the foldbelt front (Figure 1).

Attock oil company drilled Bokra-1 in 1936 and Bokra-2 between 1945-1947, oil shows were found in Bokra-2. In 1963 three bore holes were drilled by OGDC at Chharat, oil shows were recorded in these wells.

Calkins et al (1975) gave an account and a map of the geology of Hazara-Kashmir syntaxis and the adjacent regions including those occuring to the north of presently mapped area. Structurally, they called the mapped area of southern Hazara as the Garhi Habibullah syncline. According to them, southwards the rocks of Garhi Habibullah syncline have been deformed into a series of doubly plunging northeast trending asymmetric folds with one limb generally faulted. They described the ruptures as a system of anastomosing faults which run parallel to the strike of the beds for a considerable distance.

REGIONAL GEOLOGY

The mapped area represents a small section through part of a much larger tectonic feature, the Attock-Hazara folded belt (Sokolov and Shah, 1966) or the Fold and thrust belt (Yeats and Lawrence, 1984). It would not be inappropriate to combine the two captions mentioned above and call it the Attock-Hazara fold and thrust belt (Figure 1). Structurally, this area represents a megasynclinorium. The northern tip of this megasynclinorium was called the Garhi Habibullah syncline by Calkins et al (1975) who mapped that part. Part of the Attock-Hazara fold and thrust belt was mapped by Latif (1970) who described the stratigraphy of this area in the explanatory notes accompanying the geological map.

Stratigraphically the area of southeastern Hazara forms a part of the much larger so-called Kohat-Potwar sedimentary basin. It shows a fairly complete stratigraphic succession from Precambrian to Miocene with the notable absence of Middle and Upper Palaeozoic sequence in addition to a number of other smaller disconformities.

The Attock-Hazara fold and thrust belt, of which the Kuza Gali- Dunga Gali-Ayubia area stratigraphically as well as tectonically forms the northeastern part, runs in the form of an E-W elongated linear belt which turns northwards in the east to merge into the Hazara-Kashmir syntaxis. To the north and south the Attock-Hazara fold and thrust belt is bounded by the Panjal Fault (the Abbottabad fault of Baig & Lawrence, 1987) and the Murree fault (Calkins et al, 1975) respectively and their lateral equivalents. To the east and then north the two faults come closer and finally coalesce for a time near Hassa, north of Garhi Habibullah.

A look at the geological map of southeast Hazara (Latif 1970) shows that the megasynclinorium of the Attock-Hazara fold and thrust belt along the Murree-Abbottabad road is divisible into at least two synclinoria (Figure 2): the Nawashahr synclinorial complex towards Abbottabad and the much larger the Kuza Gali synclinorial complex towards Murree. The two synclinorial complexes comprise a large number of NE-SW trending smaller structures.

The Kuza Gali synclinorial complex is the larger of the two synclinorial complexes and progressively enlarges and complicates towards the southwest. Further west it continues as the main megasynclinorium or the Attock-Hazara fold and thrust belt. On the Murree-Abbottabad road the Kuza Gali synclinorial complex is bounded in the northwest by the Nathia Gali fault or the Hazara fault of Baig & Lawrence (1987) against the Hazara Slates near Kalabagh. Rocks older than Mesozoic, however, are not exposed in the southeast, suggesting that the depositional axis of the basin was systematically shifting towards the southeast and south consequent upon the Himalayan uplift.

STRATIGRAPHY

The exposed rocks within the mapped area of Kuza Gali-Dunga Gali range in age from Jurassic to Eocene. The stratigraphic sequence of these rocks is shown below (after Shah, 1977):

Formation	Age
Kuldana Formation	Middle Eocene
Chorgali Formation	Early to Middle Eocene
Margala Hill Limestone	Early Eocene
Patala Formation	Late Paleocene
Lockhart Limestone	Middle Paleocene
Hangu Formation	Early Paleocene
Kawagarh Formation	Late Cretaceous
Lumshiwal Formation	Early Cretaceous
Chichali Formation	Late Jurassic to Early Cretaceous
Samana Suk Formation	Middle Jurassic

A brief description of lithostratigraphic characteristics of these formations in the area follows. For location the reader should refer to geologic map, Figure 3.

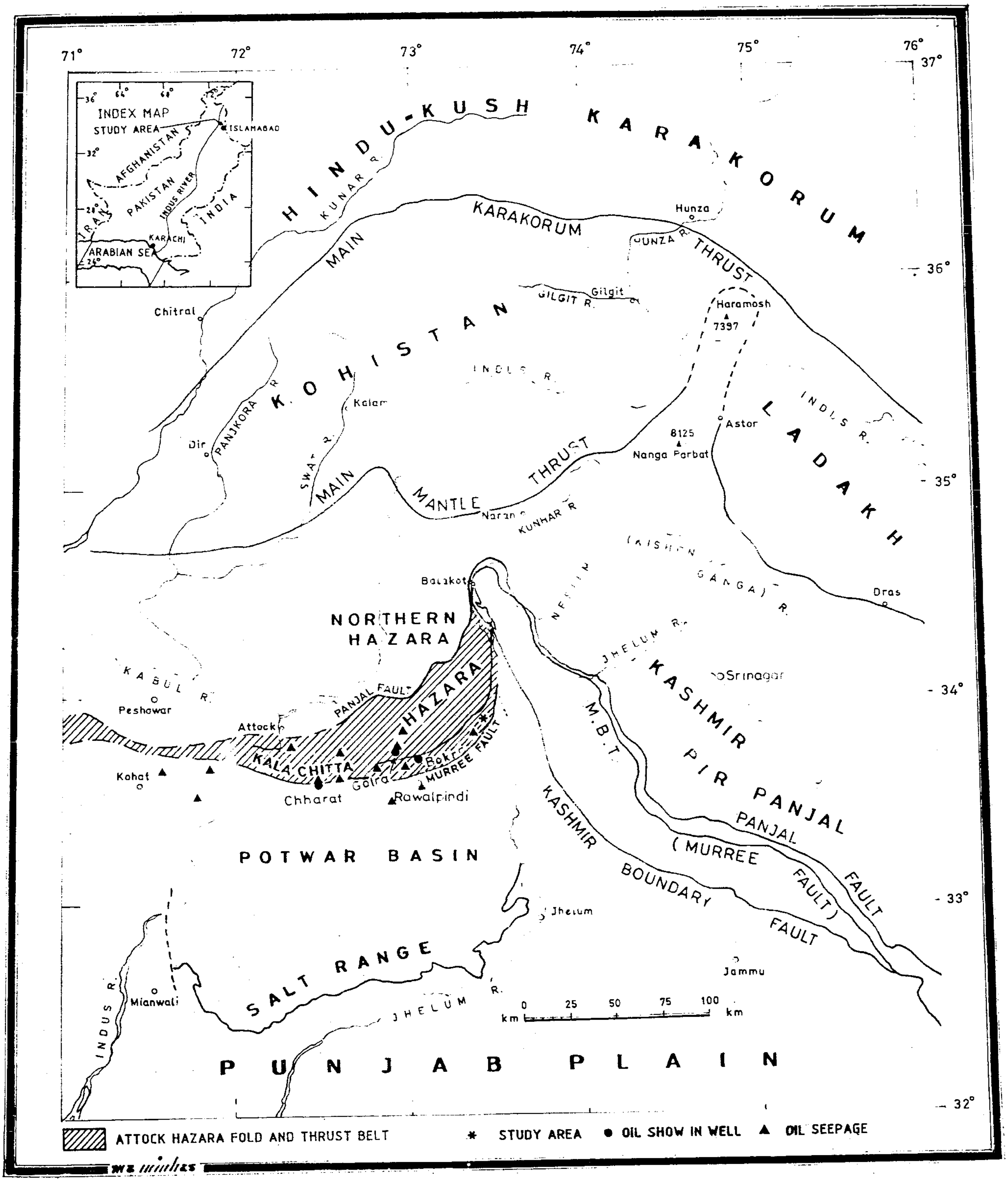


Figure 1— Regional tectonic setting showing location of Attock Hazara Fold and Thrust belt and study area.

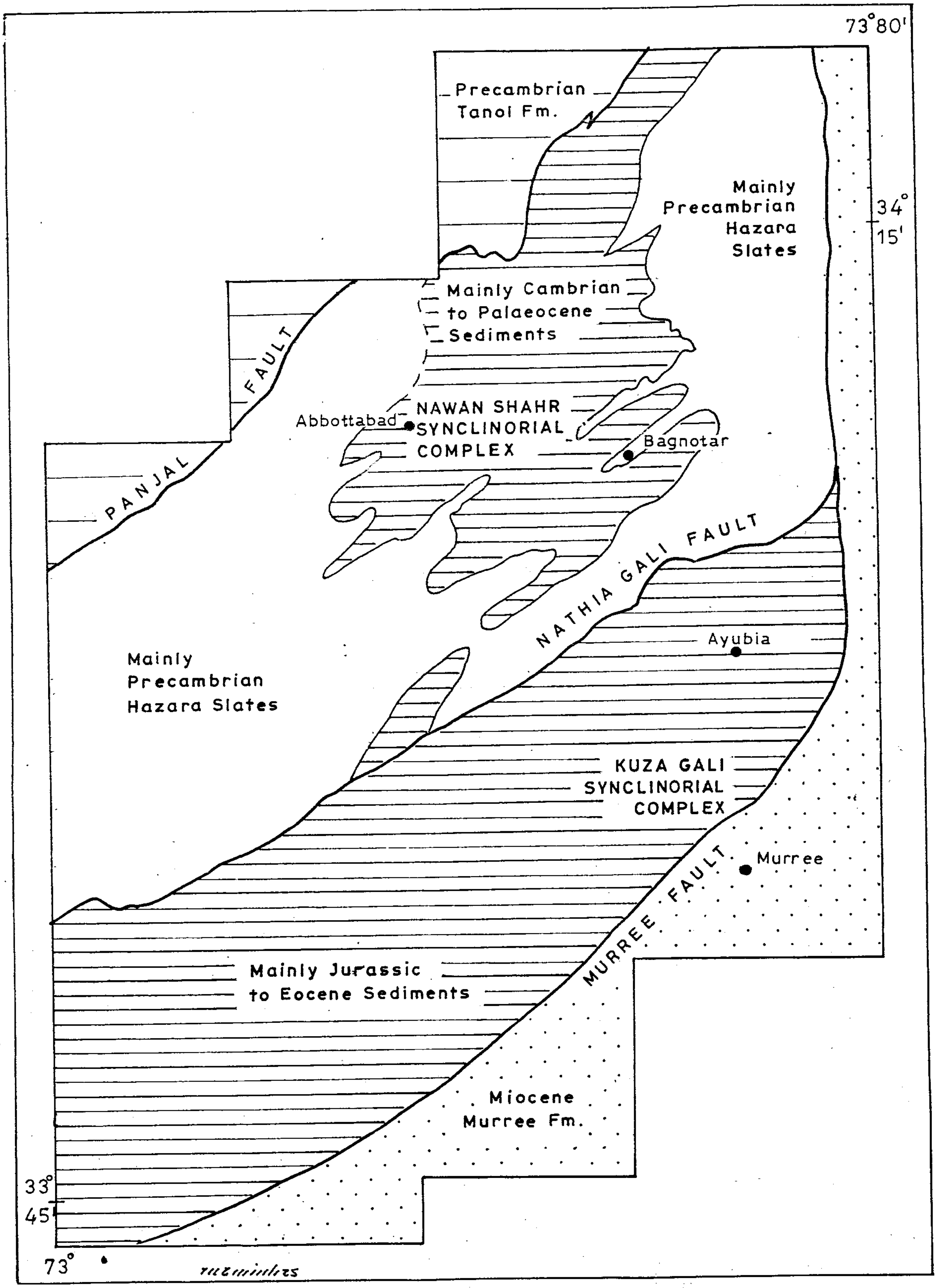


Figure 2— Major tectonic subdivision of the northeastern part of the Thrust belt (after Latif, 1970).

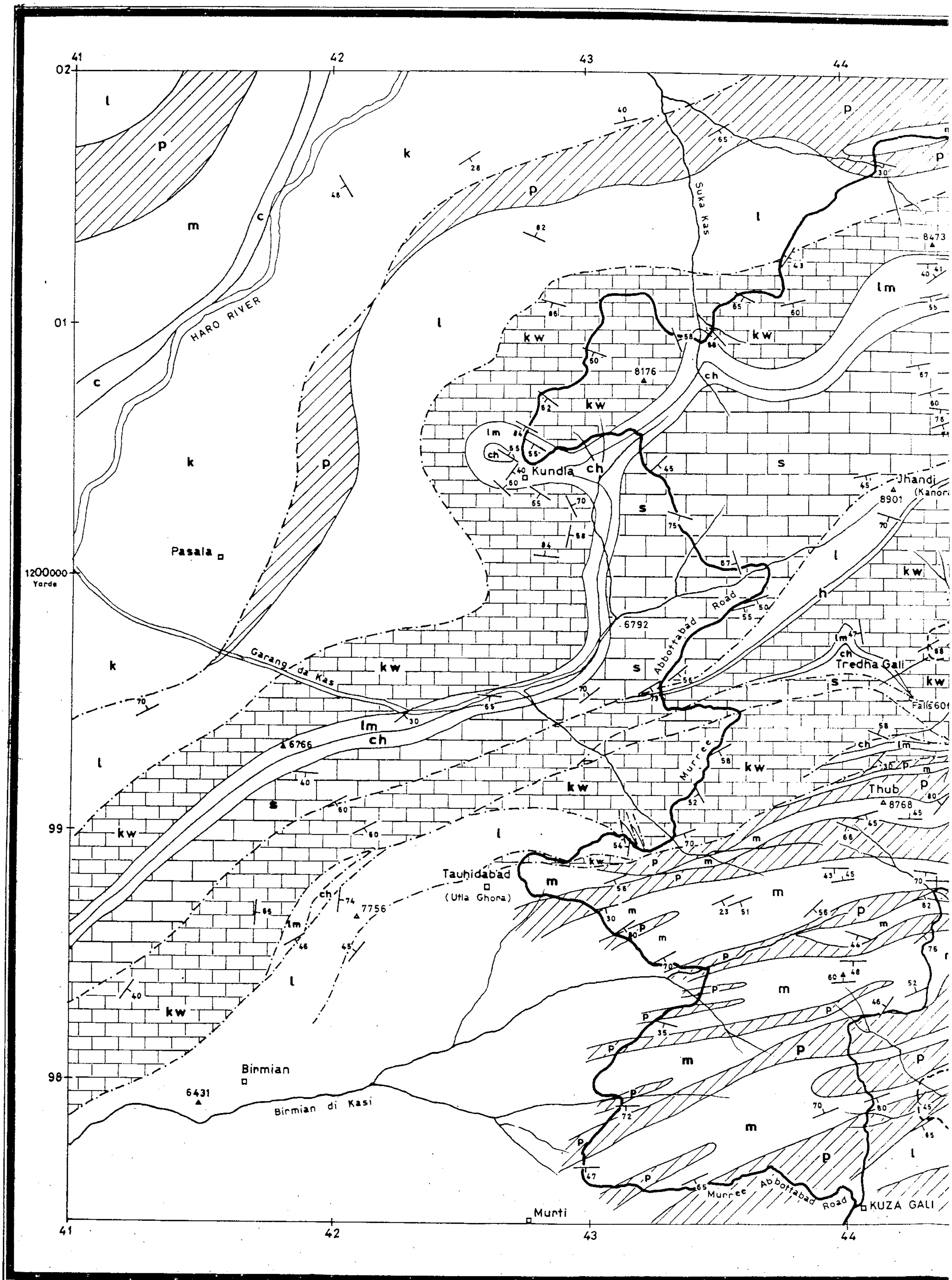
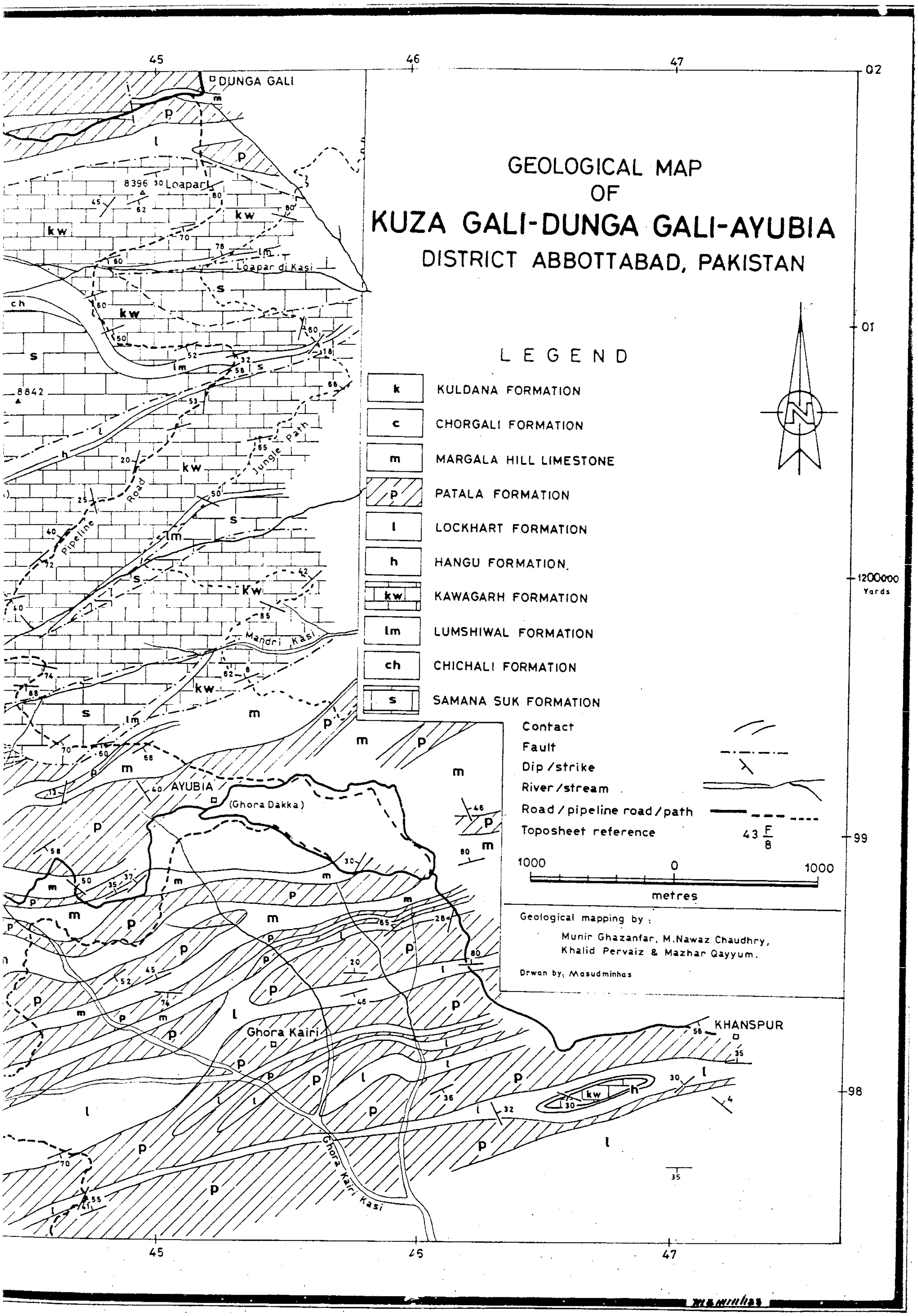


Figure 3— Geological map of Kuza Gali-Dunga G



ali-Ayubia, Dis trict Abbottabad, Pakistan.

Samana Suk Formation

The main outcrop of the Samana Suk Formation, which is the oldest stratigraphic unit in the area, is exposed in the core of an anticlinorium towards the north of the mapped area. On the roadside this exposure occurs between Tauhidabad and Kundla and on the ridge top north of Kanora peak (8901').

The Samana Suk Formation comprises mainly limestone which is medium to dark grey on fresh surface and brownish grey to dark brownish grey on the weathered surface. At places, especially on cliff faces, the weathered surface shows large patches of dark grey or yellowish grey. It is well bedded, the individual beds being 1 to 3 feet in thickness. Some parts show few inches thick intercalations of marl or shale between massive beds. The bedding planes of some massive beds are particularly irregular with pits and protuberances, where marly intercalations are present. At most places the rock is medium grained. Yellow dolomitic patches, streaks and bands are present especially towards the lower and middle portions. These patches are generally deep yellow on weathered surface but are also yellowish grey or yellowish brown on weathered as on fresh surface. In the latter case they appear to be somewhat sandy. The patches are irregular but show a rough alignment parallel to bedding. The dolomitization from its shape and irregularity appears to have taken place subsequent to deposition. Oolites are either not developed or are difficult to distinguish at most places. Some horizons however, have particularly well developed oolites. One such horizon is found towards the top, near the contact with Chichali shales. Some arenaceous beds are also found. A quartzitic bed is found just south of Kundla besides milestone Nathia Gali 6 km. It is light brownish grey on the weathered surface and light brownish grey with yellow limonitic specks on the fresh surface. The Samana Suk limestone exhibits a variety of lithofacies which differ from each other in composition, grain size, inclusions and sedimentary structures. The distinguishing characteristics of the formation can, therefore, only be used in a broad sense. There are places where Samana Suk Limestone is fine grained, light grey or without dolomitic patches. In the Bagnotar area to the west, at places, the limestone is seen to comprise a patchy, coarse and fine grained texture in the same specimen.

Shallow water sedimentary structures especially ripple marks are found at places. However, it must be mentioned that shallow water features in this area are rather sparse compared to certain other areas. This and the presence of a fair amount of fine grained facies indicate relatively deeper water conditions of deposition for this area.

The Samana Suk limestone is the thickest unit but does not show its full development as the lower contact is not exposed anywhere within the area. At places e.g. near Kundla (towards Tauhidabad) the quartzite mentioned above is exposed in its lower part which, in some ways, resembles the Datta Formation occuring at the base of Samana Suk elsewhere in this area.

Chichali Formation

The Chichali Formation outcrops only at two places in the study area, one at Tredha Gali where it makes a small triangular patch and the other at Kundla. This latter outcrop is fairly extensive and runs in the form of bands. On the east over and across the Dunga Gali-Kuza Gali ridge and to the south and west below the roadside into the drainage of Garang da Kas. This outcrop is throughout in sequence with Lumshiwal to the northwest and Samana Suk to the southeast. The outcrop is especially wide at Kundla because of folding.

The Chichali Formation consists of dark grey to black splintery shales. At places the shales show rusty brown, khaki or greenish grey colour. Subordinate beds of sandstone are present. Ferruginous concretions and veins of quartz and calcite are present. The lower contact with Samana Suk shows a small disconformity while the upper contact with Lumshiwal sandstone is gradational. Parts of Chichali Formation are fossiliferous and contain a fauna of ammonoids and molluscs.

Lumshiwal Formation

Within the mapped area five distinct outcrops of Lumshiwal Formation occur in contact with Kawagarh Formation. The best section is developed near Kundla although the sequence is not straight and right at Kundla bazar there is a fold within the Lumshiwal repeating the sequence in part.

The Lumshiwal Formation comprises four principal lithologies, marl, shale, sandstone/quartzite and haematitic sandstone. Some impure glauconitic sandstones, brownish grey on fresh surface and yellowish brown on weathered surface alongwith some shales occur towards the base where the formation has a gradational contact with Chichali Formation. Close to the top of this glauconitic horizon there is a thin richly fossiliferous horizon containing many ammonoids, belemnites and brachiopods. Other fairly pure quartzite bands, dark grey with light grey patches on fresh surface and yellowish brown on weathered surface occur towards the middle of the formation. Some of these are very resistant and are the only parts seen where the exposures are poor or concealed under vegetation. In its uppermost part this quartzitic lithology contains intraformational breccias and conglomerates with angular grains and pieces of quartzite few mm to 30 cm or even more in size embedded in sandstone.

Between the sandstone, shales and impure quartzites of the base and the quartzites of the middle part there is a 10 to 20 feet thick haematitic zone which is much limonitized now. The quartzites and the conglomeratic zone of the middle is followed towards the top by siltstones and shales. The siltstones and shales are dark grey on fresh surface and yellowish brown on the weathered surface. The shales are splintery while the siltstones occur as relatively massive beds, some of which are lenticular grading into shales.

Kawagarh Formation

Three main outcrops of the Kawagarh Formation occur in the area. Two are exposed on the roadside from Tauhidabad to some distance short of Kundla and the third from north of Kundla to some distance short of Dunga Gali. These extensive exposures cross the Ayubia-Dunga Gali ridge to appear on the pipeline road for most of the distance between the 60 feet waterfall mark and Dunga Gali. West of and below the roadside the two main outcrops continue in the vicinity of Barian, Keri Sarafeli.

In General the Kawagarh Formation consists of medium grey to light brownish grey limestone which is whitish grey, light grey, creamish grey and light brownish grey on the weathered surface. The texture is commonly fine grained but there are marked variations. It is interesting to note that the whitish grey weathering part nearly always comes out fine grained. More significant is the close association of textural variation. Within the same sample there may be patches of fine grained and medium grained texture. At places medium grained brownish grey limestone encloses dark grey cores of fine grained material. Some parts contain yellow dolomitic patches and dolomitic streaks and even bands. The presence of yellow dolomitic streaks etc., gives a creamish white colour to the weathered surface. A few coarser beds of sandy limestone are also present. These have a chopboard weathering style. Such beds are also found in the Samana Suk Formation. Graded bedding was observed in the Kawagarh limestone at least at one point near Kundla.

A part of Kawagarh is marly and intercalations of marl and calcareous shales are also present. This part is especially well developed on the pipeline road as also near Changla Gali (outside the mapped area). The marly part is dark grey to yellowish grey on fresh surface and relatively more yellowish on the weathered surface. It exhibits well developed fracture cleavage. The marly part on the pipeline road as at some other places the limestone, too, has a dark grey colour on the fresh surface. The sedimentary structure of some parts especially near the top, is such that it gives an appearance of nodularity.

The base of Kawagarh Formation is well exposed near Kundla. Here the basal part can be seen to be a slightly irregular surface with some pebbles and few inches to about one foot long now filled linear grooves commonly taken as worm tracks. These features indicate at least a short break in deposition. Some intraformational conglomerates containing pebbles also occur a few feet above the base.

The Kawagarh Formation is known to contain Upper Cretaceous planktonic foraminifera (Latif, 1970). However, apart from a few beds containing pelecypods, fossils are generally not seen in the field.

Hangu Formation

The Hangu Formation is exposed in the form of very thin bands wherever the base of Lockhart Limestone is exposed. Because of its red colour, it acts as a marker horizon. The best exposures in the area are near Kuza Gali-Dunga Gali ridge top at Kanora peak (8901').

The Hangu Formation is very poorly developed and is mainly residual in nature in the area. The thickness is small and only two main lithologies are present, laterite, and fireclay. Subordinate carbonaceous shales and sandstone are also present at places.

The lateritic lithology is reddish brown to reddish black or reddish grey or even greyish on fresh surface and reddish brown, dark grey and rusty brown on the weathered surface. At places, well developed oolites are present. The laterite and other haematitic beds were measured 13 feet thick on pipeline road and 20 feet on the Kanora peak.

The fireclay is pale white and earthy grey on the fresh surface and yellowish brown to rusty brown on the weathered surface. It is fine grained and at some places (near Kuza Gali) pisolites have developed. Near Changla Gali (outside the mapped area) on the roadside both the laterite and fireclay are missing and only a carbonaceous shale horizon remains. The fireclay is 6 feet thick on the pipeline road, 10 feet on Kanora peak and 5 feet on roadside near Kuza Gali.

Lockhart Limestone

The Lockhart Limestone is present in the area at four different localities in the form of single or multiple whitish bands. A number of bands alternating with Patala Formation occur at Khanspur and extend southeast crossing the Darwaza Kas towards Kuza Gali. Another exposure occurs near Tauhidabad on the roadside and crosses the Ayubia-Dunga Gali ridge at Kanora peak. A third exposure occurs with a faulted contact against Kawagarh Formation in the south of Dunga Gali. Southwestwards it extends towards Pasala. A fourth exposure occurs below the roadside north and west of Tauhidabad.

The Lockhart Limestone is generally medium grained, hard and gives foeted smell on breaking. It is dark grey on fresh surface and its weathered colour varies, being generally dirty grey with dark grey patches but pale grey and rusty grey patches are also seen. The limestone is nodular. The size of the nodules generally varies between 5 to 8 inches.

The limestone has a fair amount of marly intercalations. These marly intercalations are generally upto six inches in thickness and weather pale grey. In the section between Kuza Gali and Changla Gali, the limestone is found frequently intercalated with marls/shales. In this case the weathering colour of limestone ranges from dark grey to earthy grey with sometimes creamish appearance while the fresh colour is dark grey. Here the deformed nodules have been streched parallel to the bedding planes. On the other hand where the limestone is massive the nodules appear subrounded in shape.

Foraminiferal fossils can be seen with the naked eye. Generally, the formation is less fossiliferous as compared to the Margala Hill Limestone. Occasional richly fossiliferous beds are also seen. Species of *Lockhartia, Assilina* and *Nummulites* are common.

Calcite veins ranging in thickness from 1 mm to 2 cm are fairly abundant.

Patala Formation

The Patala shales, which stratigraphically occur between the Lockhart and Margala Hill Limestone, have the most often repeated outcrops in the area. These repetitive bands extend from the Khanspur-Ayubia spur across the southern part of Kuza Gali-Dunga Gali ridge top, into the drainage of Barmian di Kasi between Kuza Gali and Tauhidabad. The exposures are again repeated in the north of the area between Dunga Gali and Nathia Gali (outside the mapped area). Since most of the exposures are in the form of alternating bands of Patala and Margala Hill Limestone, the Patala shales are nearly everywhere folded as cores of anticlines. They are found in sequence only where Lockhart Limestone starts outcropping. One such outcrop is near Kuza Gali after which Latif (1970) had named the unit as Kuza Gali Shales. The Patala shales are yellowish brown to yellowish grey on weathered surface and also on the fresh surface. At other places the shales are greenish brown or greenish grey on fresh surface and brown to dark brown on the weathered surface. They have been called Khaki Shales also after their colour. Occasionally some patches are grey on the fresh surface. At one place near Tauhidabad the upper part of Patala shales is dark grey in colour.

The shales are splintery but at times the splinters take on the shape of small brittle flakes.

Within the body of the shales subordinate lithologies, both arenaceous and calcareous, occur in the form of thin bands. The calcareous bands are also prominent in the dark grey part of shales near Tauhidabad. The arenaceous bands can be seen at Kuza Gali.

Small foraminifers are common in the shales but not clearly seen. They are, however, very prominent in some marly bands within shales. One marly band which extends from the roadside near chair lift base to Thub top (Chair lift top) has very large upto 1 cm size forams and resembles parts of Chorgali Formation.

Topographically, the Patala Shales play a very significant role. They are the site of many valleys and saddles (galies) and generally make gentle slopes.

The lower contact with Lockhart Limestone is gradational but the upper contact of Patala Formation with the Margala Hill Limestone is sharp.

Margala Hill Limestone

The Margala Hill Limestone is exposed in the form of thin to well developed outcrop bands in the mapped area. Its best exposures can be seen between Tauhidabad and Kuza Gali on Murree-Nathia Gali road and between Kuza Gali and Ayubia (Ghora Dakka) on the roadside. The outcrops in the synclinal structures alternate with bands of Patala Formation. The Margala Hill Limestone has faulted contact against Kawagarh Formation at Tauhidabad and on the pipeline road.

The Margala Hill Limestone is mainly a fossiliferous, medium grained, nodular limestone with subordinate marls/shales. On the weathered surface it is bluish grey, yellowish grey, pale grey and on the fresh surface it is generally dark grey. The unit is relatively pure limestone towards its upper part with less marls/shales. Below this there is a sequence of marl/shale and limestone. Here the nodules are embedded in the marls. The lower part is again medium to thickly bedded with less marls.

Generally, the limestone is medium grained, however, at places, as near Ayubia, fine grained limestone with conchoidal fracture is also observed. Fine calcite veins upto 4 mm are common but less frequent than in the Lockhart Limestone showing its massive nature. Some pyritic nodules are also observed which have weathered to limonitic powder leaving hollow cavities. The limestone, at most places, is rich in larger foraminiferal fossils (3-8 mm size). The fossils in marls appear like black specks and discs. In the limestone nodules the fossils appear in white outlined cross sections and are easy to identify.

Choragli Formation

The only exposure of the formation in the mapped area is in the form of a NE-SW band on the right bank of Haro river.

The formation comprises limestones, marls and shales and is distinguished by its marly nature and large size of microfossils. The general colour on the weathered surface is pale to light yellowish grey. On the fresh surface the limestone is grey while the marl is cream coloured. The typical strong nodularity of Lockhart and Margala Hill limestones is missing and the formation is generally thin bedded. The formation is rich in larger foraminifers and molluscs.

Kuldana Formation

The only exposure of Kuldana Formation is present in the northwestern corner of the mapped area in the form of a wide band mainly running on the left bank of Haro river. The southeastern margin of the outcrop is faulted against the Patala Formation.

The colour of the formation is generally crimson to brick red. The shales are varicoloured mostly reddish, crimson, buff, pale grey and greenish grey. The shales and marls have subordinate gypsiferous and arenaceous lithologies and beds of limestone. Occasional beds of conglomerates are also found. The limestone is yellowish grey on the fresh surface, while the sandstone is greenish grey and red. The gypsiferous bands are light grey to white. The formation on the whole is fine grained and thin bedded. It is fossiliferous and contains both macro and microfossils.

MAIN STRUCTURAL FEATURES

The Kuza Gali synclinorial complex comprises three main structures in the Dunga Gali - Kuza Gali area (Figure 2). These can be described as a NE-SW trending anticlinorium, the Kundla anticlinorium bounded on the north and south by two synclinoria, the Nathia Gali synclinorium and the Ayubia synclinorium, respectively.

Kundla Anticlinorium

The Kundla anticlinorium covers a fair distance on the roadside from Tauhidabad to north of Kundla and on the pipeline road between sixty feet water fall to close to Dunga Gali (Loapar). Structurally it consists of two anticlines with Samana Suk Formation in the core and Kawagarh Formation or younger rocks with strike faults on the limbs. The major folds which we may term as the Kanora anticline and Tredha Gali anticline are both refolded and faulted at most places on the limbs. Faults have eliminated a variable amount of sequence from the limbs of these folds. In fact the whole of the southeastern limb of Kanora anticline has been faulted away.

Ayubia Synclinorium

The Ayubia synclinorium trends ENE-WSW and covers the areas of Khanspur, Ayubia, Kuza Gali and Tauhidabad (Figure 4 b). In the central part it consists of repetitive folds of Margala Hill Limestone and Patala Formation. The southeastern flank which extends from Khanspur towards Kuza Gali shows repetitive folding in slightly older units, Lockhart Limestone and Patala Formation. The northwestern flank is in main faulted by the Tauhidabad Fault. Here the Lockhart Limestone is generally missing. The Patala and Margala Hill Limestone, in general, have been brought in direct contact with Kawagarh or older formations. Some faulted exposures of Lockhart Limestone are, however, found near Tauhidabad.

Nathia Gali Synclinorium

The southern flank of this synclinorium has a faulted contact between the Kawagarh Formation and Lockhart Limestone. However, as we move towards the core of southwest plunging structure successively younger rocks upto Kuldana Formation are exposed at Malachh and Pasala. This structure covers the northwestern part of the mapped area and extends further north and northwest through Nathia Gali upto the Nathia Gali Fault.

FOLDING

The anticlines are generally sharp and tight as compared to the synclines. Intraformational folding is seen especially in Kawagarh and Samana Suk outcrops where they are thick and well exposed. For example, such folding can be seen in the Kawagarh Formation north of the Sixty Feet Water Fall on the pipeline road. Here the intraformational folds are nearly isoclinal and with almost vertical axial planes. Similar folds in Kawagarh Formation can also be seen on roadside between Kuza Gali and Changla Gali. Here the fold axial planes can be seen to be curved. Intraformational folding in Samana Suk Limestone is less common and where present is more open. Some of this can be seen in the Samana Suk outcrop southeast of Kundla.

Close to some major faults the Kawagarh and Samana Suk limestones also show parasitic folds like the tight symmetrical folds in Samana Suk at the Sixty Feet Water Fall on the pipeline road and the folding in Kawagarh Limestone along the Tauhidabad fault, near Tauhidabad on the roadside. Numerous parasitic folds are also seen in the Kuldana Formation along the Malachh fault. They are made more prominent by the crenulations in the gypsiferous bands.

Two clear phases of folding in the area can be differentiated. The main folds trend ENE-WSW and in many cases are doubly plunging. A second phase of folding has flexed the limbs of the first main phase folds. These folds plunge down the limbs of main folds and are generally less tight.

FAULTS

As pointed out above the Attock Hazara Fold and Thrust Belt (AHFTB) is bounded on the north and the south by the Panjal and the Murree faults respectively. Inside, the AHFTB is traversed by numerous anastomosing strike faults of variable throw and significance, including the Murree fault (Figure 1) (Margala fault of Baig and Lawrence, 1987). These strike faults collectively have been called the Punjabi equivalent of the Main Boundary Thrust of Kashmir and India (Yeats and Lawrence, 1984). As will be shown later under discussion of deformation, these parallel strike faults do not all belong to the same phase and therefore cannot be treated as the collective equivalent of the MBT in Kashmir and India. A brief description of the significant strike faults between Dunga Gali and Kuza Gali is given below.

Malachh Fault

This important fault runs between Pasala and Malachh. (Malachh is located just outside north of the mapped area). For most of the length this fault brings Patala shales in direct contact with Kuldana, however, southwest of Garang da Kas, Kuldana is brought in contact with Lockhart Limestone. The outcrop of this fault shows open flexures more or less parallel to the folding.

Dunga Gali Fault

This fault occurs to the south of Dunga Gali where it trends NE-SW. It crosses the pipeline road as well as the main road. It then takes a broad turn around Kundla and bends again to continue southwest across Garang da Kas. This fault separates the Lockhart Limestone in the north from the Kawagarh Formation in the south (Figure 4a). It extends over a long dis tance but the stratigraphic throw is not very large. On the roadside it dips 30° to the southeast where the outcrop shows some brecciation especially in the Lockhart Limestone. It is a reverse fault, at least near the surface.

Water Fall Fault

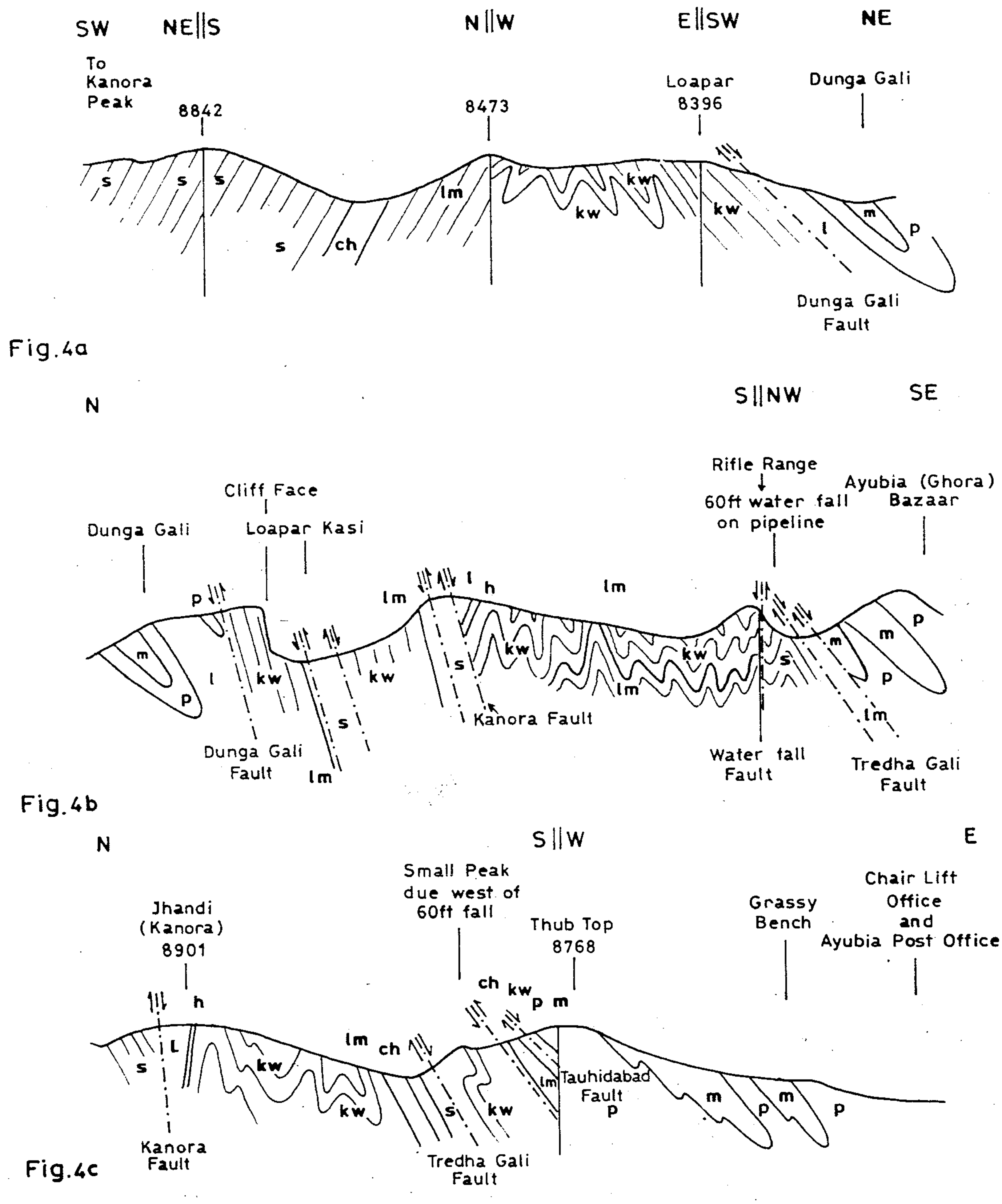
This fault appears on the pipeline road, just north of the Sixty Feet Water Fall (Figures 3, 4b) where it separates the Kawagarh Formation from the Samana-Suk Formation. Westwards it crosses the ridge at Tredha Gali. Here a small outcrop of Chichali and Lumshiwal appears to the north of this fault. Further west, however this outcrop is eliminated again, before the fault appears on the roadside and then merges into Tredha Gali Fault see below after crossing the Grang da Kas. On the pipeline road this fault is very steep to near vertical. In the Tredha Gali, however, it dips steeply to the south. It is a normal fault. Crushing can be seen along the fault zone on the pipeline road. Parasitic folds are also seen in Samana Suk close to the fault plane. A fault related escarpment is also present above the pipeline road.

Kanora Fault

This NE-SW trending fault extends across the Kuza Gali-Dunga Gali ridge passing the ridge at Kanora peak (Figure 4c). It appears on the roadside between Tauhidabad and Kundla. This fault brings Lockhart Limestone in contact with Samana Suk Formation on Kuza Gali-Dunga Gali ridge. However, towards the roadside and further southwest the Lockhart Limestone and Hangu Formation are missing and Samana Suk Formation is in faulted contact with Kawagarh Formation. Crushing resulting from this fault can be seen both on the roadside as well as on the pipeline road. On the Kanora peak (8901') it is a high angle normal fault dipping to the southeast.

Tredha Gali Fault

This fault more or less parallels the Water Fall Fault and runs close to the south of it. On the pipeline road it has brought Lumshiwal Formation in contact with the Samana Suk Formation near the Sixty Feet Water Fall and the Rifle Range mark on the map (Figures 3, 4b). It crosses the Kuza Gali- Dunga Gali ridge just south of Tredha Gali and appears on the roadside in a valley, marking a major bend of road between Tauhidabad and Kundla. Both south of Tredha Gali and on the roadside it separates Kawagarh Formation from Samana Suk Formation. Further southwest it separates two slices of Kawagarh and then Kawagarh from Lockhart. On the western side a slice of Lumshiwal Formation and Chichali Shales appears for



s = Samana Suk Fm., ch = Chichali Fm., lm = Lumshiwal Fm.,
kw = Kawagarh Fm., h = Hangu Fm., l = Lockhart Fm., p = Patala Fm.,
m = Margala Hill Lst., S||NW = Bend in section.

Figure 4— Sketch sections: (a) along Dunga Gali-Ayubia ridge upto Jhandi (Kanora) peak, (b) along the pipeline road, (c) from Jhandi (Kanora) peak to Thub (chair lift top) to Ayubia post office.

some distance to the north of this fault. On the pipeline road where it is more or less concealed under the debris it appears to dip 55° to the southeast, while on the roadside it is nearly vertical.

This fault has been named the Tredha Gali Fault although it passes south of it and it is the Water Fall Fault that really passes through Tredha Gali.

Tauhidabad Fault

At Tauhidabad road bend this NE-SW trending fault separates the Kawagarh Formation and the Margala Hill Limestone (Figure 5a). Further to the east this fault continues across the Kuza Gali-Dunga Gali ridge, crossing the ridge just north of Thub chair-lift top where it separates Kawagarh and Patala formations (Figure 5b). Still further east it merges with the Tredha Gali fault. On the road-side, where a lot of crushing and parasitic folds associated with this fault can be seen, this fault dips 40° to the south. Near Thub top also the fault dips to the south.

CONCLUSIONS

Deformation

It is interesting to note that contrary to the major faults and folds in the Himalaya to the north and in Kashmir many of the faults are dipping to the south and southeast in this area and the fold axial planes are overturned to the northwest.

The faults are either high angle reverse type or high angle normal type. In fact, in this small investigated area there are nearly equal numbers of both.

The numerous normal faults in the investigated area have also been explained as pseudonormal faults i.e. northwards dipping deep thrusts which are overturned near the surface to become high angle normal faults. They have also been shown as highly warped thrusts (Coward et al, 1986). Although, no substantial evidence of rotation, overturning or warpping is seen in the fairly deep sections exposed in this high relief area later overturning to the northwest is more likely. The reverse faults would then also be later, possibly formed during overturning.

We may, therefore, conclude that the area mapped has suffered through at least four phases of deformation. The first phase, D_1, involved the deformation and metamorphism of the Precambrian sequence that now underlies the sedimentaries a short distance to the north of the mapped area. On the metamorphosed Hazara Slate sequence the sedimentaries were then deposited. The second phase, D_2) led to south and southeast directed major thrusting and folding. These structures were then overturned to the northwest during the third phase, D_3, when the southeast dipping faults were generated. Most of the reverse faults seen today in the area belong to the D_3 phase. The fourth phase, D_4 involved NE-SW directed compression during which NW-SE trending folds at an angle to the previous ones were superimposed on the earlier D_2 and D_3 structures which were rotated anticlockwise in general.

It may be interesting to compare the structural trends of the Ayubia area with that of the Balakot area to the north. It would be noted that an opposing dip relationship is found west and east of River Kunhar in the Balakot area (Ghazanfar et al, 1986). The sedimentary rocks of the Balakot-Muzaffarabad anticline (east of river Kunhar) are dipping to the northeast with the folds overturned to the southwest as against the opposite dips in the nearby metamorphic and related thrusts within them on the western bank of river Kunhar. Now if the Balakot-Muzaffarabad anticline were to be rotated clockwise and the syntaxial bend unfolded to bring the Balakot-Muzaffarabad anticline in parallelism with the Attock-Hazara fold belt, the consonance between the structural style of Balakot-Muzaffarabad anticline and that of the presently mapped Dunga Gali-Kuza Gali-Ayubia area becomes apparent. The anticlockwise rotation of the Ayubia section of the Attock-Hazara fold and thrust belt is a southward continuation of the much stronger anticlockwise rotation which gave rise to the Hazara-Kashmir syntaxis of the Himalayas further north. There is thus a deformational continuity between the D_4 structures of Ayubia section and the formation of Hazara-Kashmir syntaxis.

Some Field Problems Regarding Limestones

In many ways the Kawagarh limestone resembles the Samana Suk limestone and the traditional distinguishing characteristics of Samana Suk limestone being medium grey, coarse grained, arenaceous, oolitic, with yellow dolomitic patches and being tougher and relatively thick bedded are not found everywhere. These must be taken only as a general and overall guide. There are parts of Samana Suk limestone which are fine grained, light grey, nonoolitic, pure, and without dolomitic patches. These resemble the Kawagarh Limestone and at places, it is not possible to say which is which in the field. Conversely, parts of Kawagarh limestone are medium to dark grey, coarse grained, arenaceous, medium to thick bedded and with yellow dolomitic patches. The character of the exposure as a whole and its stratigraphic position, therefore remains an important means of distinction between the two limestones in an area which is much folded, faulted and inverted at many places. Furthermore, in an overall sense, Samana Suk weathers dark brown compared to the light grey weathering of Kawagarh.

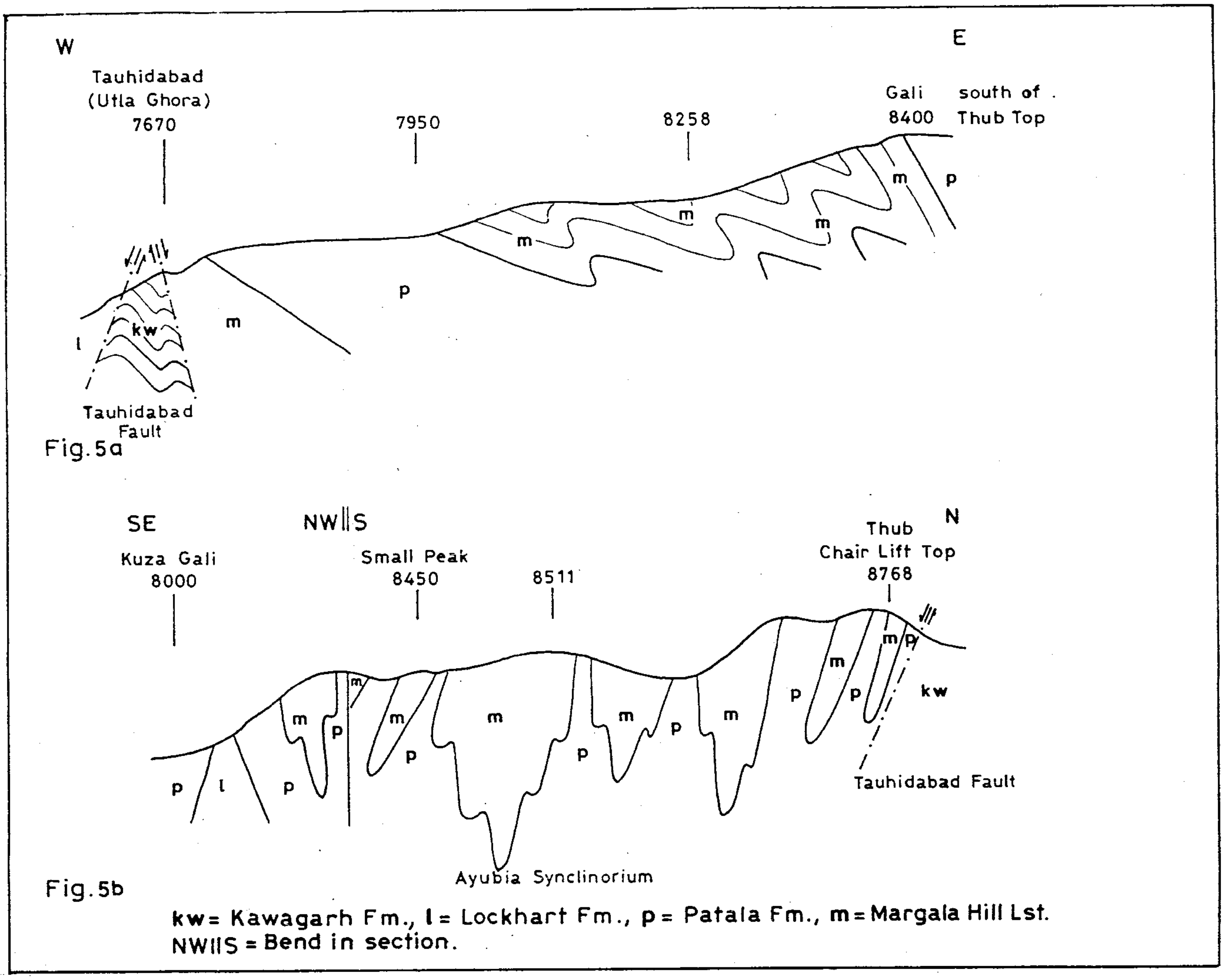


Figure 5— Sketch sections: (a) between a gali (south of Thub top) and Tauhidabad (Utla Ghora), (b) along ridge top between Kuza Gali and Thub (chair lift top).

Some horizons of Lockhart Limestone are very confusing with Margala Hill Limestone particularly where they are massive. Here it becomes very difficult to distinguish Lockhart Limestone from Margala Hill Limestone. The size of the fossils and of the nodules have previously been described as the distinguishing criteria in the field. These features, however, help only in a broader sense. The Lockhart Limestone is poorly fossiliferous with fossils generally upto 2 mm in size, though sometimes upto 3 or 4 mm. On the other hand in Margala Hill Limestone the fossil size ranges from 3-5 mm but occasionally upto 8 mm in some horizons associated especially with marls, as was seen at Chora Keri. The nodule size which is generally upto 5 inches in Lockhart Limestone (occasionally upto 8 inches) in Margala Hill Limestone varies between 4 to 12 inches and can occasionally be one and a half foot or so. The marly intercalations are also a criterian. They are fewer and minor in the case of Margala Hill Limestone as against the Lockhart Limestone which has marls in relatively greater proportion. The weathering colour, too, at times, may serve as a criterion for distinguishing the two formations. The weathering colour of Lockhart Limestone is more earthy grey and relatively darker grey compared to Margala Hill Limestone which generally shows a light to medium grey colour on the weathered surface. The grey weathering colour of Margala Hill Limestone looks fresh unlike that of Lockhart Limestone which looks dirty in most cases. Calcite veins are yet another criterion. The calcite veins are much abundant and relatively well developed in the Lockhart Limestone. The veins in the Lockhart Limestone are generally 1 mm to 1 cm in thickness (occasionally 2 to 2.5 cm). On the other hand in the Margala Hill Limestone the veins are fewer except in the middle part.

Hyrocarbon Potential of the Attock Hazara Fold and Thrust Belt

Potential source rocks have been identified by Hydrocarbon Development Institute of Pakistan (HDIP) and German Advisory Group geochemical studies (1987) in the Attock Hazara Fold and Thrust belt. These studies indicate that Margalla Hill Limestone (TOC: 0.50%); Patala Formation (TOC: 0.40%); Lockhart Limestone (TOC: 0.57%); Hangu Formation (TOC: 0.49%); and Chichali Formation (TOC: 3.39%) may act as source rocks. Vitrinite reflectance studies of HDIP-BGR (1987), however, show that in general the pre-Miocene section in Hazara Area is rather over- mature for oil (VR: 1.7%, Patala Formation to 2.3%, Chichali Formation) but is within gas window, whereas in Kala Chitta Range, section upto Chichali Formation is within oil window (VR:1.01%, Chichali Formation).

Geochemical analysis of samples for the present study indicate that Margala Hill Limestone (TOC: 1.57%), Patala Formation (TOC: 1.58%), Hangu Formation (TOC: 0.56%) and Chichali Formation (TOC: 0.89-2.14%) may be the potential source rocks in the area (Table 1).

Potential hydrocarbon reservoirs can be found in Samana Suk Formation, Lumshiwal Formation, Hangu Formation, Lockhart Limestone, Margalla Hill Limestone, Chorgali Formation, Kuldana Formation and Murree Formation.

Table 1. Geochemical analyses of samples from study area.

Sample Lab. No.	Formation	Lithology	TOC (%)
4049	Margala Hill Limestone	Limestone	1.57
4048	Margala Hill Limestone	Limestone	0.54
4039	Patala	Shale	1.58
4045	Lumshiwal	Sandstone	0.46
4042	Hangu	Shale	0.56
4043	Chichali	Shale	1.03
4047	Chichali	Shale	0.89
4040	Chichali	Shale	2.14

Seals are no problem as impervious beds mainly shales and some dense carbonates are abundantly present in the stratigraphic column of the area.

Structural traps related to thrusting and buried in the mountain front in the south, the backthrust structures, and juxtaposition of Mesozoic-Tertiary source rocks and various reservoirs of Jurassic to Tertiary ages are likely targets for furture exploration. However, like exploration in other overthrust belts of the world, locating traps in attock Hazara fold and thrust belt also is a problem which can only be resolved through expensive seismic surveys.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Mr. H.A. Raza, Director General HDIP and Wasim Ahmed, Manager HDIP Islamabad Operations, for Geochemical analyses of field samples at HDIP Islamabad Labs.

REFERENCES

Baig, M.S., and R.D. Lawrence, 1987, Precambrian to Early Paleo zoic Orogenesis in the Himalaya: Kashmir Jour. Geol., v.5, p.1-22.

HDIP-BGR Technical Cooperation, 1987, Preliminary results of organic geochemical analysis on surface rock samples: HDIP's internal report.

Calkins, J.A., T.W. Offield, S.K.M. Abdullah, and S.T. Ali, 1975, Geology of the Southern Himalayas in Hazara, Pakistan and adjacent areas: United States Geological Survey Profession al Paper 716-C, 29p.

Coward, M.P., B.F. Windley, R.D. Broughton, I.W. Luff, M.G. Petterson, C.J. Pudsey, D.C. Rex, and M.A. Khan, 1986, Collision tectonics in the NW Himalayas, in: M.P. Coward and C.R. Alison, eds., Collision Tectonics: Blackwell Scientific Publications, Oxford, p.203-219.

Ghazanfar, M., M.N. Chaudhry, K.J. Zaka, and M.S., Baig, 1986, The geology and structure of Balakot Area, District Manseh ra, Pakistan: Geological Bulletin of the Punjab University, v.21, p.30-49.

Kazmi, A.H., and R.A. Rana, 1982, Tectonic map of Pakistan: Geological Survey of Pakistan, Quetta.

Latif, M.A., 1970, Explanatory notes on the geology of South Eastern Hazara to accompany the revised geological map: Wein Jb. Geol. B.A. Sonderban, v.15, p.5-20.

Middlemiss, C.S., 1896, The geology of Hazara and the Black Mountains: Geol. Surv. Ind. Mem., v.26, p.88-177.

Pascoe, E.H., 1920, Petroleum in the Punjab and Northwest Fron tier Province: Geol. Surv. Ind. Mem., v.40, p.330-489.

Shah, S.M.I., 1977, Stratigraphy of Pakistan: Memoirs of the Geological Survey of Pakistan, v.12, 138p.

Sokolov, B.A. and Shah, S.H.A., 1966, Major tectonic features of Pakistan, part I - Western Province: Journal of Scientific and Industrial Research, v.4, p.175-199.

Waagen, W., 1872, Rough section showing the relation of the rocks near Mari (Murree) Punjab: Mem. Geol. Surv. India, v.5(part I), p.15-18.

----- and A.B. Wynne, 1872, The geology of Mount Sirban in upper Punjab: Memoirs of the Geological Survey of India, v.9, p.331-350.

Yeats, R.S., and R.D. Lawrence, 1984, Tectonics of the Himalayan thrust belt in northern Pakistan, in B.U. Haq, & J.D. Milliman, eds., Marine geology and oceanography of Arabian Sea and coastal Pakistan, p.177-198.