

# STRUCTURAL SETTING AND PETROLEUM PROSPECTIVITY OF MARGALA HILLS, PAKISTAN

Muhammad Iqbal<sup>1</sup>, Tariq Baig<sup>1</sup> and Moin Raza Khan<sup>1</sup>

## ABSTRACT

Margala Hills are located in the north of Islamabad, the capital of Pakistan. The petroleum prospectivity of the Margala Hills is discussed through investigating its stratigraphy and structures style. Geological observations reveal that the contact between the molasse sediments and calcareous rocks is normal. Structures are although highly tectonised but the regional faults along the Margala Hills could not be confirmed. It is suggested that the prospective targets for petroleum occur in sedimentary sequences of the Margala Hills are probably also buried beneath regional Nathiagali Thrust. It enhances petroleum prospectivity of the area. Thick sediments with reasonable organic richness, reservoir horizons, top seal, and oil seepages are good indicators for existence of hydrocarbon system in the area.

## INTRODUCTION

The major structural elements of the region i.e. Margala Hills Range, Peshawar, Kohat, Potwar basins and Hazara Mountains have shown in Figure-1.

All rocks in the south of Kohistan Arc are regarded as part of the Indo-Pakistan Plate. The Hazara Mountain ranges comprised thick assemblages of low (Hazara Slate) to high grade metamorphic rocks. Peshawar Basin in the west of the Hazara Mountains, Margala Hills in the south and Potwar-Kohat basins further in the south and west, respectively, constitute the Mesozoic through Neogene sedimentary cover of the northwestern margin of the Indo-Pakistan Plate.

In Margala Hills and adjoining basins source, reservoir, seal and traps occur. Oil seepages at Golra and one from water well in the Balochistan House, Islamabad prove the existence of petroleum system. The first commercial discovery of oil at Khaur (1915) in Potwar and recent ones of oil, gas and condensate in Kohat Basin (Makori, Manzalai, Chanda, Mela and Mamikhel) show that Margala Hills are potential candidates for petroleum exploration.

This paper concludes that the stratigraphic contact between platform and overlying molasse sediments at places is normal and despite strongly tectonised structures, no persistent regional thrust-like the Main Boundary Thrust of the eastern and central Himalayas was recorded. Additionally, Margala Hills are formed as an overturned fold belt rather than any major fault. The impact of regional thrusts along which metamorphic rocks thrust on sedimentary sequences is discussed.

## PREVIOUS WORK

Waagen and Wynne (1872) wrote a report about the stratigraphy of Abbottabad and Hazara.

Middlemiss (1896) introduced the term Main Boundary Thrust.

Wadia (1931) used the term "syntaxis" for the sharply bending mountains around Muzaffarabad. He reported Panjal and Murree thrusts. The Panjal Thrust is an inner thrust and a regional sliding plane for a large Kashmir Nappe which brings southward Precambrian slates and schists (Purana Series) of the central mountains over Carboniferous-Eocene rocks. The outer Murree Thrust is a reverse fault which brings Carboniferous-Eocene rocks over Murree Formation.

Pascoe (1963) used the term Great Boundary Fault for Middlemiss's Main Boundary Fault. He considered Great Boundary thrust is the northern most limits of the molasse. But in 1963 he realized that the term Boundary Fault is a misnomer as molasse were then reported to the north of that fault.

Latif (1968) published a geological map and stratigraphic scheme for the entire southern Hazara. He divided the area into seven groups and twenty one formations. Each group was separated by an unconformity.

Calkins et al., (1975) divided the area into three structural blocks namely; Hazara-Kashmir Syntaxis, Western Arc, and Indus Re-entrant. The Panjal, Murree, and Darband faults separate these blocks. They suggested that the Murree and Panjal faults are steeply dipping reverse faults on the eastern limb and vertical on the western limb of the Hazara-Kashmir syntaxes north of Balakot.

McDouglas et al., (1993) suggested that the Main Boundary Thrust is a floor thrust along which a thrust system incorporating Precambrian and Phanerozoic rocks of the Kalachitta and Attock-Cherat ranges were placed over Cenozoic strata of the northern Kohat and Potwar Plateau. It means that a regional thrust i.e. the assumed Main Boundary Thrust along the Margala Hills Range, separates Margala Hills and adjoining basins.

Iqbal and Bannert (1998) after investigating the assumed trace of MBT near Islamabad concluded that there is no indication of any thrust and all contacts between Murree Formation and older rocks are concordant.

## STRATIGRAPHY

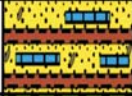

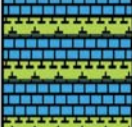

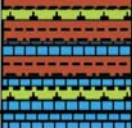
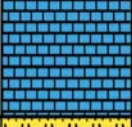
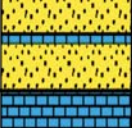

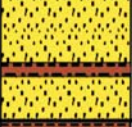


The stratigraphic succession encountered during the work starts with the Jurassic Samana Suk Limestone and ends with the Miocene Murree Formation (Table 1).

## GEOLOGICAL SETTING

The area has been formed due to collision of Indian and

<sup>1</sup>Pakistan Petroleum Limited, Exploration Department, PIDC House, Dr. Ziauddin Ahmed Road, Karachi, Pakistan.

Table 1- Generalized Stratigraphic succession of the Margala Hills.

AGE	FORMATION	LITHOLOGY	DESCRIPTION	PETROLEUM SYSTEM			REMARKS
				SOURCE	RES	SEAL	
Miocene	MURREE		Sandy shale, siltstone, sandstone, conglomerate, fossiliferous limestone at the base.				Detailed tectonic study is not carried-out.
Early - Middle Eocene	KULDANA		Variegated, multicoloured and maroon to magenta silt and shale, and yellowish to bluish grey, marly, well banked limestone and cellular limestone.				
Early Eocene	CHORGALI (LORA)		Alternating well banked limestone and brownish to greenish marl. The limestone has chert lenses in places.				Reacts with folding to tectonic pressure. Often recumbent folds.
Early Eocene	MARGALA HILL LIMESTONE		Well banked, usually dark grey but light grey weathering limestone, occasionally nodular, massive and cliff-forming.				Aheolina and Nummulites ataticus are the fossils to separate Margala Hill limestone from Lockhart limestone.
Late Paleocene	PATALA (KUZAGALI)		Medium to dark brown shale with marly limestone layers.				Under tectonic pressure the shale becomes phyllitic.
Middle Paleocene	LOCKHART (MARI LST.)		Well banked, usually dark grey and dark grey weathering limestone, occasionally nodular inliers; massive and cliff-forming; caves.				Small Nummulites and other fossils, no specific fossil for field identification can be observed.
Early Paleocene	HANGU		Oxidized sandstone, white clay, iron-crusts, rusty weathering limestone, pisolitic gossan.				Often tectonically reduced.
Early - Middle Cretaceous	DUBRAN KAWAGARH CHANALI		Well banked limestone with frequent layers of oyster, shallow water indications. Dark brown weathering limestone, partly dolomitic. Whitish-blue weathering, well banked limestone, rich in sea urchins, locally conglomerates, dolomitic in places.				
Early Cretaceous	LUMSHIWAL (GIMUL)		Dark brown weathering thickly banked sandstone of dark grey to black colour with an occasional greenish tint, glauconitic.				
Late Cretaceous	CHICALI (SPIT)		Black shale, thinly bedded, brown, often rusty weathering.				
Middle-Late Jurassic	SAMANA SUK (SIKHAR)		Well banked limestone, partly oolitic, often rich in fossils, yellowish tints, partly dolomitic.				Usually intensively folded.

Eurasian plates and is dominated by prominent regional structures all along the consuming plate boundaries. In the western Himalayas in Pakistan, the Indus Suture Zone (ISZ) is bifurcated into two structural zones, the Main Karakoram Thrust (MKT) and the Main Mantle Thrust (MMT) separated by obducted Kohistan Arc. The MKT, the northern suture, separates the intrusive and high grade metamorphic rocks of Eurasian Plate from the Kohistan Arc terrane.

The Kohistan Arc terrane has, on the northern edge, deformed gabbro, volcanics and greywacke (Rakaposhi Volcanics Complex) that are intruded by tonalite, diorites and pegmatites. To the south, the rocks are composed of a deformed, layered igneous complex metamorphosed to granulite facies. The southernmost rocks of the Kohistan Arc are metasediments, amphibolites, and granites. The MMT, the southern suture, separates the Kohistan Arc from the metasediments on the northern edge of the Indo-Pakistan Plate. It is the extension of the Indus-Tsangpo Suture. The northern edge of the MMT is marked by sporadic occurrences of ultramafic rocks. The Indo-Pakistan Plate rocks are late Precambrian to early Paleozoic schists, marbles, gneisses and granitic gneisses that have been thrust over the Tertiary molasse of the Rawalpindi and Siwalik Groups. Southward thrusting continues within the molasse sediments, which is the evidence of continued plates convergence.

Severe tectonic pulses resulted to discontinuities. Since Jurassic more than 670 m of marine sediments have been deposited below more than 7500 m thick molasse of coarse clastic continental sediments from Miocene onwards. It was followed by intense deformation, erosion and subsidence. During the uplift and deformation for the last 1.5 million years (Plio-Pleistocene), erosion in the Margala Hills Range remained more pronounced than deposition, so the preserved sediments are thin and discontinuous bodies of alluvium and eolian silts. Regional faults in the south of Kohistan Arc and their vergence are shown in Figure 2.

## STRUCTURAL GEOLOGY

### The Nathiagali Thrust

The Nathiagali Thrust is a shallow north dipping regional thrust which brings the metamorphic rocks (late Precambrian to early Paleozoic schists, marbles, gneisses and granitic gneisses) southward over the Tertiary sedimentary rocks. Rock packages on either sides of the thrust have different age and metamorphism.

In Pakistan Himalayas there was reworking of the early metamorphic pile, the reimbrication of cover and basement rocks and the final stacking of the metamorphic rocks into a pile of internally imbricated the south verging thrust nappes. Considerable Eocene over thrusting in the Himalayas produced major crustal scale basement cored nappes and the subsequent burial metamorphism (Coward 1994) so too much shortening occurred. South directed thrusts propagation occurred for large distance. This paper suggests that beneath the Nathiagali Thrust, the northern continuation of the prospective Margala Hills structures are buried (as assumed in Nepal, where oil shows occur in the Lesser Himalayas metamorphic rocks). It is a challenging tectonic concept but not a unique one, and would require state of art

seismic technology to resolve.

### The Main Boundary Thrust-MBT

The existence or absence of the Main Boundary Thrust (MBT) has great bearing on the hydrocarbon prospectivity. Generally it is believed that MBT which is an important fault in India & Nepal is extending to this area. In India and Nepal, Main Boundary Thrust is defined as a fault that delineates the frontal part of the doubled Indian crust or metamorphic Indian Plate basement rocks are underplated by the advancing and intact main body of the Indian Plate. Kaphle (1992) suggests that in western Nepal, the MBT separates the metamorphics of the Lesser Himalayas from Siwaliks. The uplift of the Himalaya is attributed to the buoyancy of the doubled sialic crust over the mantle material (Gupta & Narain, 1967; Kono, 1974; Choudhry, 1975; Le Fort, 1975; Mattauer, 1975; Powell and Conaghan, 1975).

In view of the role of MBT its nature was investigated through stratigraphic and structural study and traverses were made between Langrial (Karakki), Ghoragali and Islamabad (Figure 3).

Published geological maps show that MBT runs east-west in the east of the Jhelum Re-entrant and swings around to the west and then to the south roughly east of Balakot. Northeast of Islamabad, it gradually moves again to an east-west direction along the Murree Fault (Figure 1). In west of Jhelum Re-entrant MBT is absent and local faults demarcate the southern limit of Peshawar Basin and Margala Hills from Kohat and Potwar basins. Faults, associated with local anticlinal folds tectonically bring Mesozoic-Tertiary marine sequence of the Indo-Pakistan Plate over the molasse sediments. Iqbal and Bannert (1998) and Iqbal et al., (2007) have summarized the work of earlier workers as follows:

- I. Along the Murree Fault, only sedimentary rocks are in contact with the molasse sediments of the Murree Formation (Pascoe, 1963).
- II. There is no doubled crust of the Indian Plate under the Peshawar Basin (Davies & Lillie, 1994).
- III. The structure of northern Pakistan is not influenced by subduction and underplating below the Main Mantle Thrust (Indus-Tsangpo- Suture Zone). It is subducted under the Kohistan Island Arc Complex.
- IV. Metamorphic rocks north of the Margala Hills occur near Attock, roughly 75 km to the south of the Dargai ultrabasic rocks. The latter marks the Main Mantle Thrust (MMT). The Peshawar Basin occupies the area between Attock and Dargai and can't be considered as an indication of doubled sialic crust.
- V. Earthquake distribution to the north of the Jhelum Reentrant shows no indication of a bending and southwestward continuation of the MBT (Armbruster et al., 1978).
- VI. In the area under consideration, the Murree Fault is difficult to define.

The mentioned discussion reveals that instead of a regional fault the Margala Hills are formed by a regional overturned fold and the flanking synclines (basins) have acted as pathways for hydrocarbon migration. This interpretation is based on the following (see PJHR, 1998 for details).



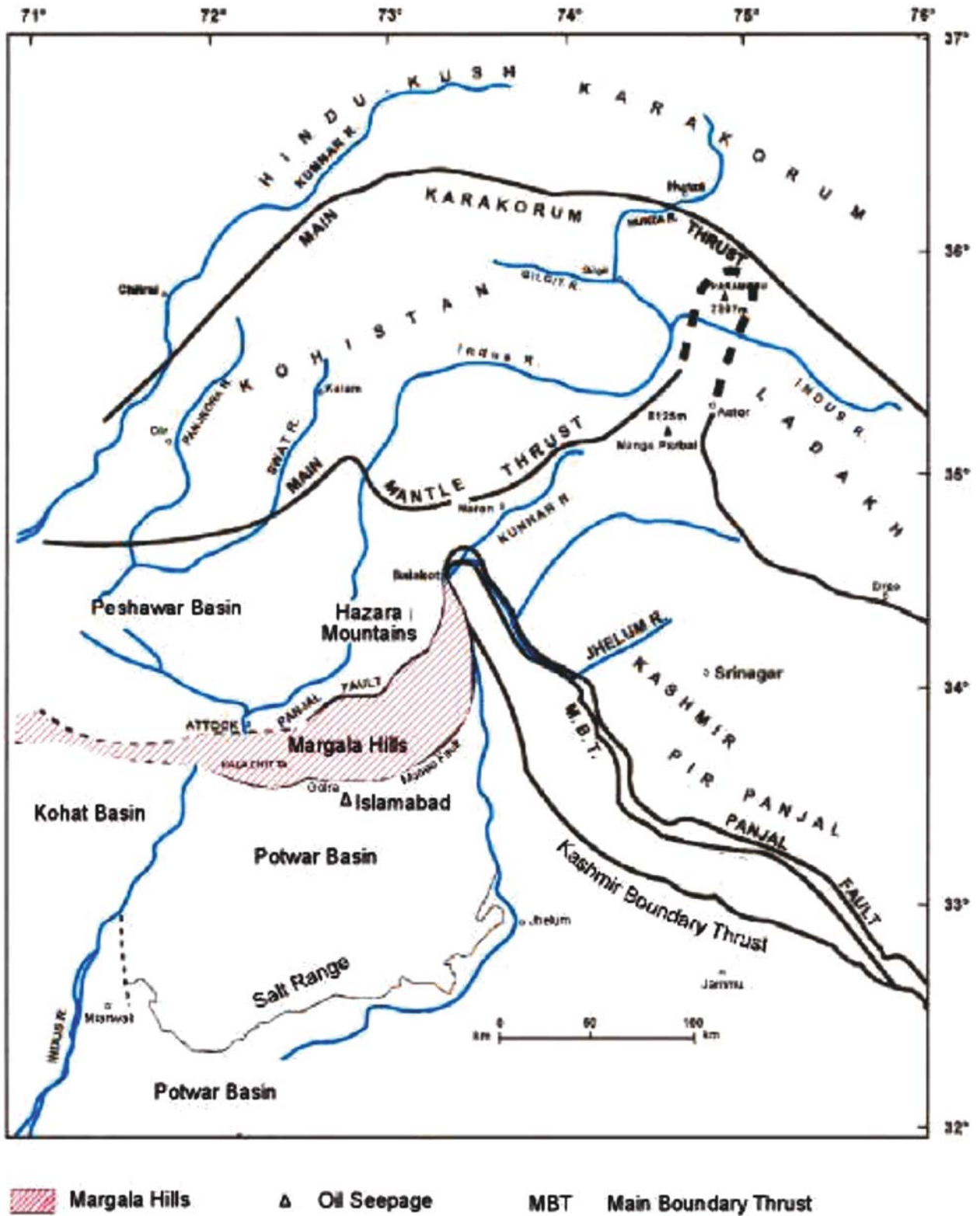


Figure 1-Major structures of the western Himalayas and location of the Margala Hills (modified after Ghazanfar et al., 1990).

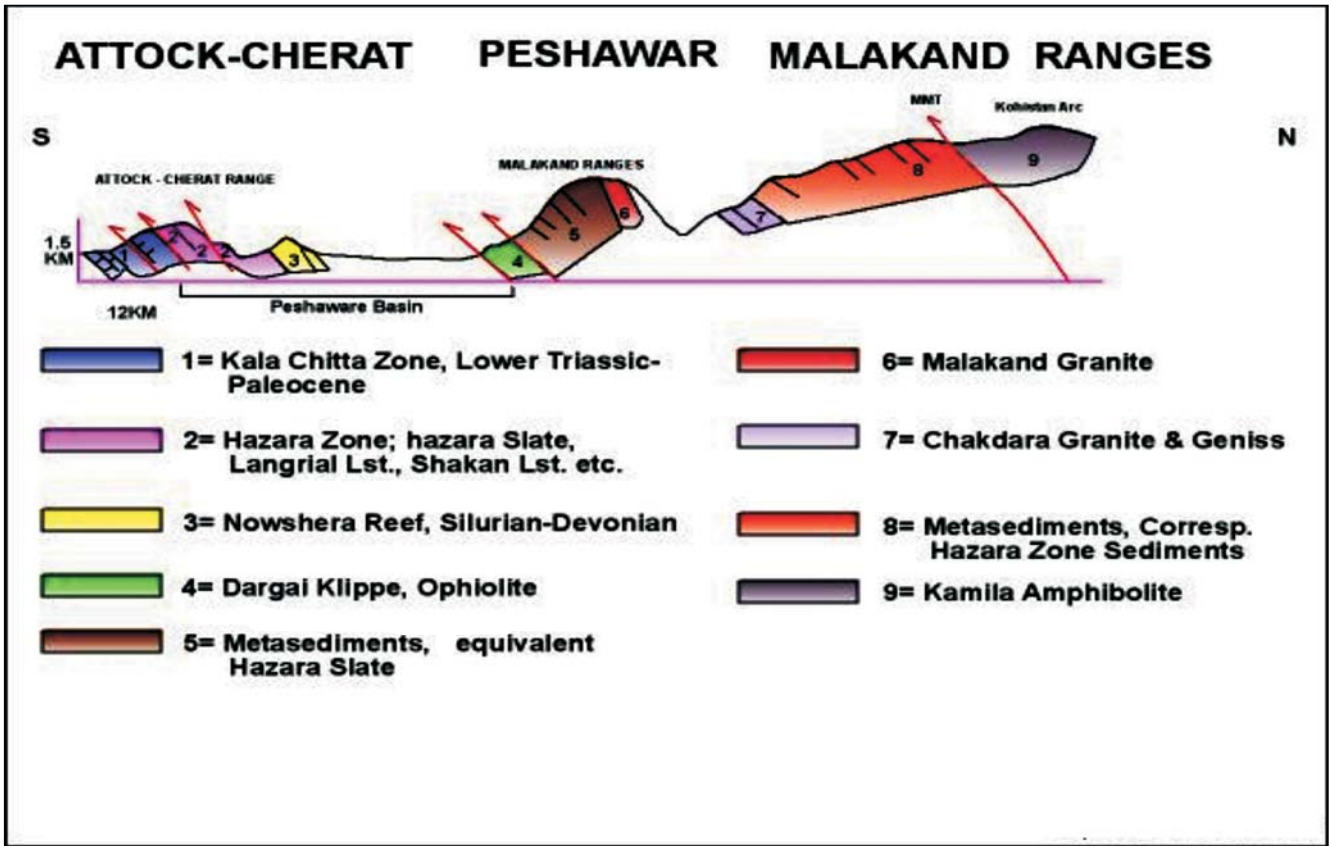


Figure 2- Section across Kalachitta-Attock-Cherrat (Peshawar-Hazara) and Malakand ranges (modified after Tahirkheli, 1982).

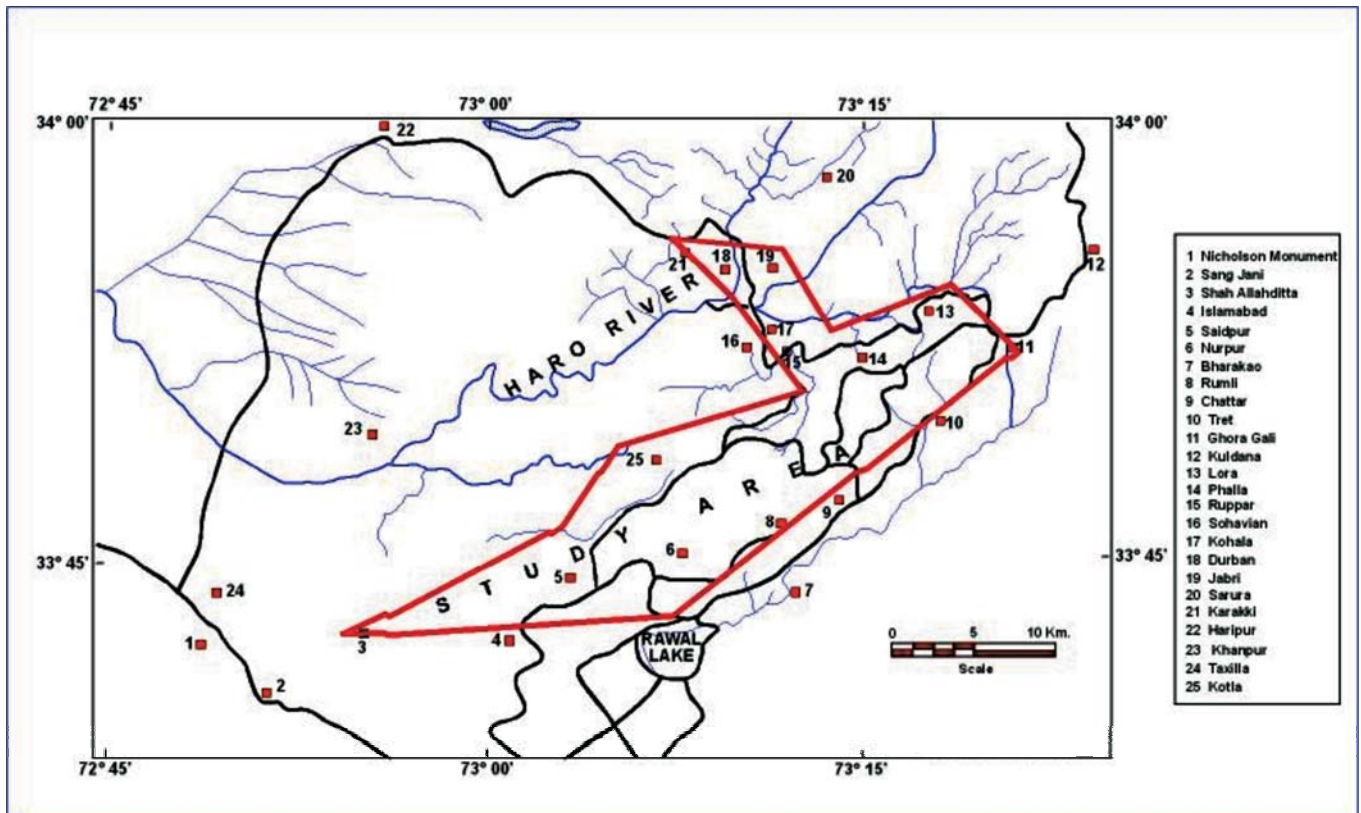


Figure 3- Sections visited in the Margala Hills.

## Major Structural Elements

The geological sketch maps (Figure 4 A and B) shows that sediments of Murree Fm. cover the south and southeastern part of the Margala Hills. Paleogene rocks are dominating the hills in the north of Islamabad with minor Jurassic rocks in the core of a few anticlines. Rocks have been folded during the Himalayan orogenesis. Following is a brief description of the major structures.

1. The Mandla - Tret Anticline
2. The Nurpur-Pithli Anticline
3. The Margala Hills Anticlinorium (MHA)
  - A. The Shah Allahditta Islamabad Segment
  - B. The Islamabad-Shahdara Segment
  - C. The Shahdara-Bashkoli Segment
4. The Dalhor-Gambhir Anticline
5. The area northwest of the Lora Synclinorium
6. The Mount Dubran fold and thrust structure

### 1. The Mandla - Tret Anticline

The core of Mandla-Tret Anticline is built by Chorgali Fm. but at Ghoragali, along the road to Langrial, tectonised Lockhart Limestone (3150/480 ) builds its core. At the southern flank of the anticline at Mandla, Kuldana Fms. concordantly overlain by Murree Fm. A syncline of folded Murree and Kuldana Fms. exist to the north of Mandla-Tret Anticline. From Tret to the northeast, Margala Limestone forms the core flanked by Kuldana Fm.

### 2. The Nurpur-Pithli Anticline

It appears in the north of Nurpur Shahan. There, Chorgali Limestone flanked by Kuldana Formation. emerges eastward under a south-facing thrust of the MHA. The anticline is continuously flanked by synclines of Kuldana Fm. At Baroha it is fully integrated into the mountain front of the first ridge of the Margala Hills. Further to the northeast, at Pithli, the anticline is flanked by a syncline with steeply south dipping Chorgali Limestone. It is verging towards the northwest (Figure 5, Section G G').

### 3. The Margala Hills Anticlinorium (MHA)

The MHA forms the first ridge of the Margala Hills north of Islamabad. It is built by multivergent folds of Margala Hill Limestone and Lockhart Limestone. Towards Nilan and Kharian valleys, it is flanked by a syncline with Kuldana Fm. in its core. The MHA continues beyond Shah Allahditta ( west of Islamabad outside the map). Its internal structure changes very rapidly along the strike and was investigated along the following traverses.

#### A. The Shah Allahditta -Islamabad Segment

Shah Allahditta village is located in the west of Islamabad, on Murree Fm. The Murree sandstone dips 3330/33° and is concordantly overlain by 20 m thick Kuldana Fm. thus indicating an overturned sequence(Figure 6). It is in turn

thrust by steeply folded Jurassic limestone. From the north it is overthrust by Margala Hill Limestone. They are bordered by an EW trending valley, filled with dark brown weathered shale of Patala Fm. Lockhart Limestone occurs in anticlinal position further in the north. Extending to the east, between Shah Allahditta and Islamabad the Mesozoic rocks are thrust over Tertiary Kuldana Fm.

#### B. The Islamabad-Shahdara Segment

In the north of Islamabad near Daman-e-Koh, on the road to Nilan valley, a triple crested anticline of

Jurassic oolitic limestone is exposed. Travelling by car from Islamabad at the first hairpin bend of the road, Hangu Fm. and Margala Hill Limestone are wedged in a synclinal position. The anticline is overturned to the south and the Mesozoic limestone crops out thrust upon Kuldana Fm. (Fig. 5, cross-section A-A'). The hanging wall towards the north is made of Lockhart Limestone with Hangu Fm. appearing in places. Usually, the contact is faulted, displaying disharmonic folding. Further to the N of Daman-e-Koh, the Lockhart Limestone is folded into a syncline with a small anticlinal fold in its core (Cross-section A-A'). To the north follows steeply south dipping 20 m thick discontinuous layer of Patala Shale. In this layer an important fault is running with a throw towards the north against south facing and folded Margala Hill Limestone. This Margala Hill Limestone is overturned towards the north in a disharmonic way above Chorgali Limestone, which in turn is folded in north facing recumbent folds. This leads to a widespread distribution of Chorgali Limestone along the north slope of the first ridge of the Margala Hills towards the Nilan valley and its further continuation to the east. These conditions remain unchanged for Islamabad and Shahdara segments (Fig. 5, cross-section C-C').

#### C. The Shahdara-Bashkoli Segment

About 1 Km northeast of Shahdara the southern flank of the MHA with Lockhart Limestone is in faulted contact with a syncline filled by Kuldana Fm. that separates it from the eastwards rising Nurpur-Pithli Anticline. The latter is incorporated into the mountain front of the Margala Hills east of 73010' E (west of Baroha) (Fig. 5, cross-section D-D'). The MHA develops into a single anticline of presumably Margala Hills Limestone and east of Pholira, (3 Km SE of Nilan Bhotu) a wide spread distribution of Chorgali Fm. can be observed. At Dheri Rakhala, the anticlinal core is composed of Margala Hills Limestone. To the south, Chorgali Fm. is found at the flank leading to the Kuldana Fm. of the syncline between Margala Hills Anticlinorium and the Nurpur-Pithli Anticline (Fig. 5, cross-section D-D'). To the north, a number of folds are added to the MHA. North of Dheri Rakhala, widespread folded Chorgali Fm. occurs serving as connecting structures. The Nilan valley hosts a syncline with Kuldana Fm. and extends to Kharian valley in the east.

#### 4. The Dalhor-Gambhir Anticline

The second ridge of the Margala Hills occurs in the north of Nilan valley is referred Dalhor-Gambhir Anticline. At Dalhor, Jurassic rocks are tectonically overlain by west dipping Tertiary limestone with abundant Nummulites. Southward, the



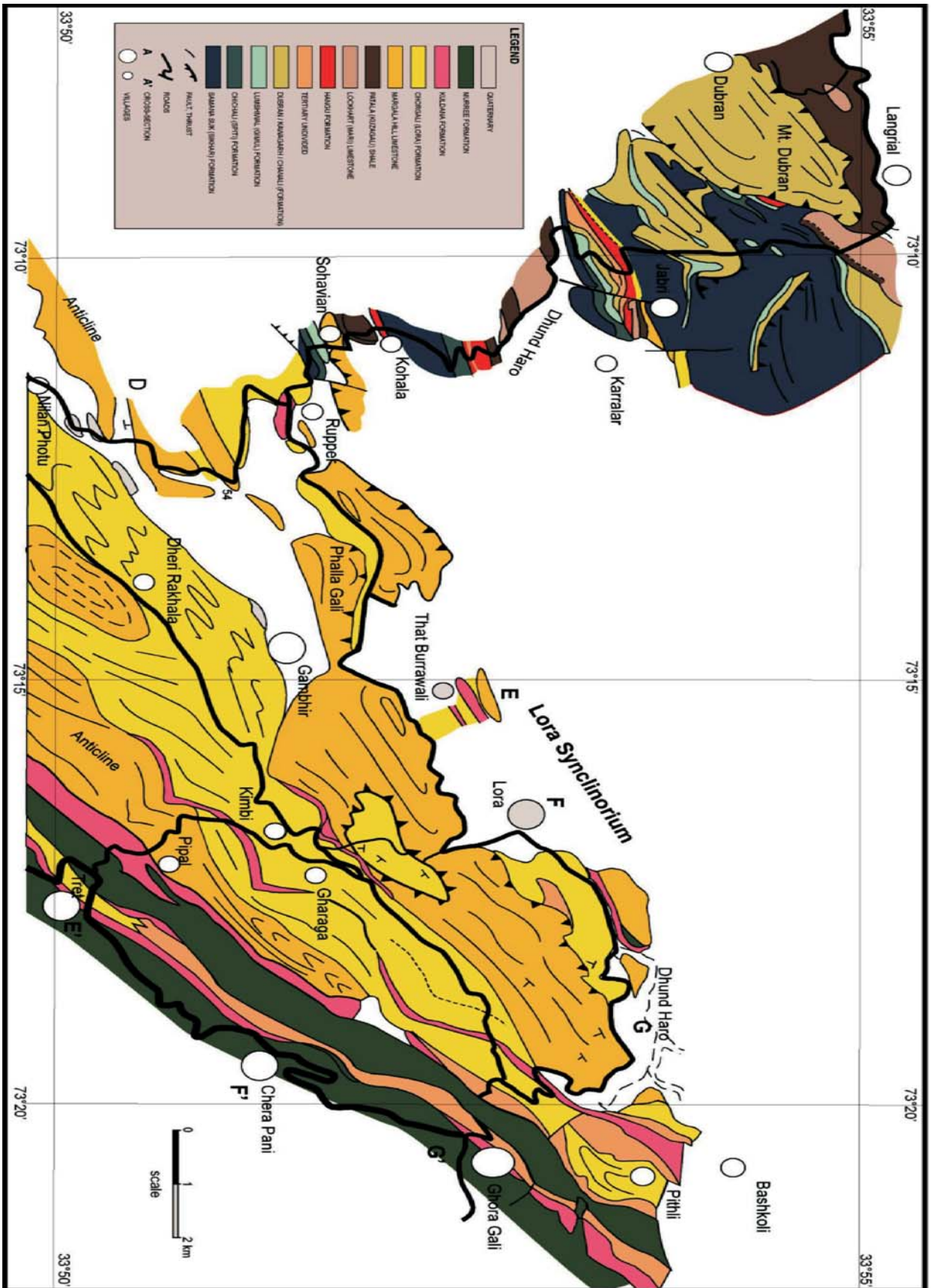
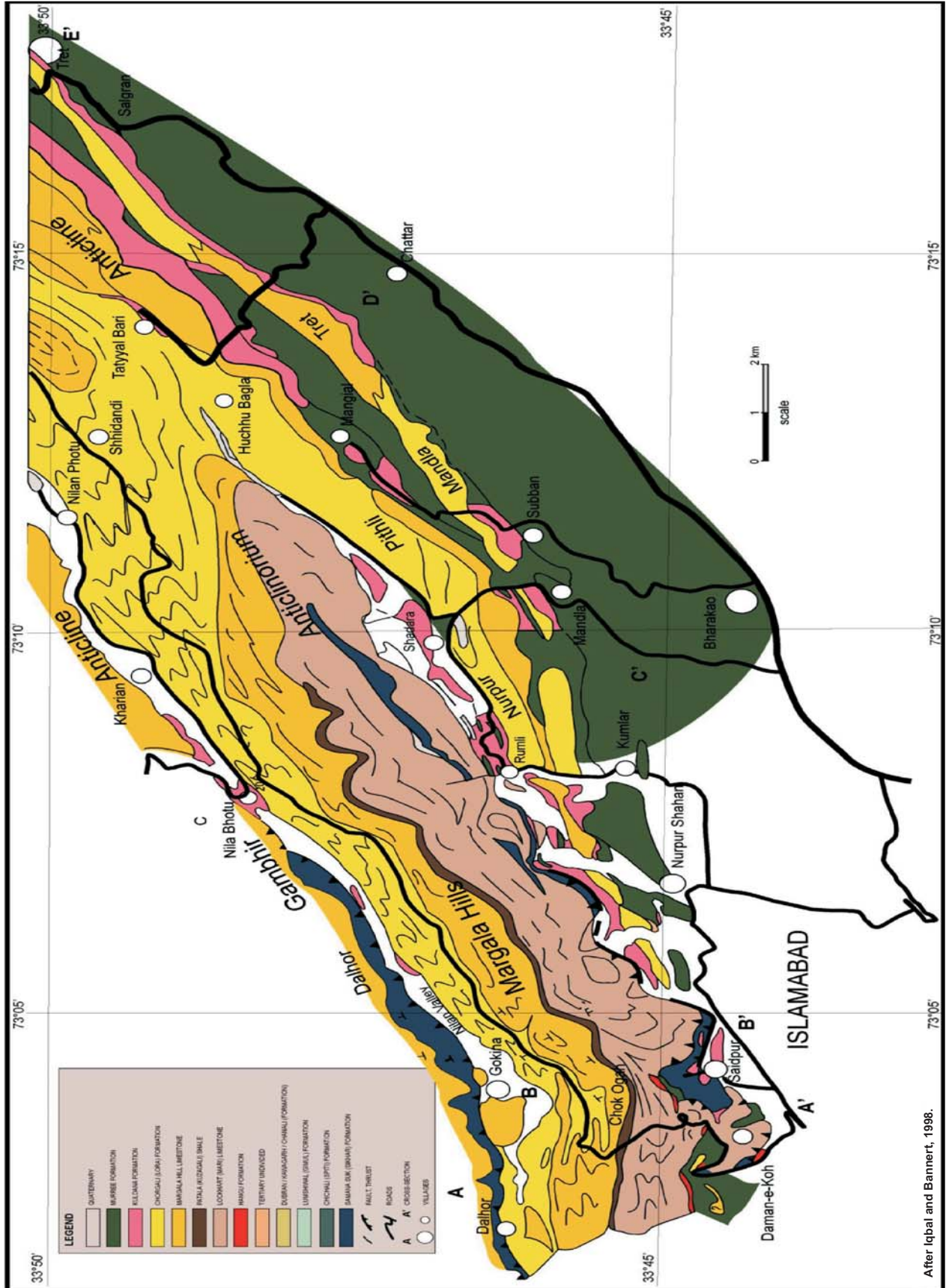


Figure 4A - Geological sketch map of the Islamabad-Ghoragali segment (northern part)



After Iqbal and Bannert, 1998.

Figure 4B - Geological sketch map of the Islamabad-Ghoragali segment (southern part).



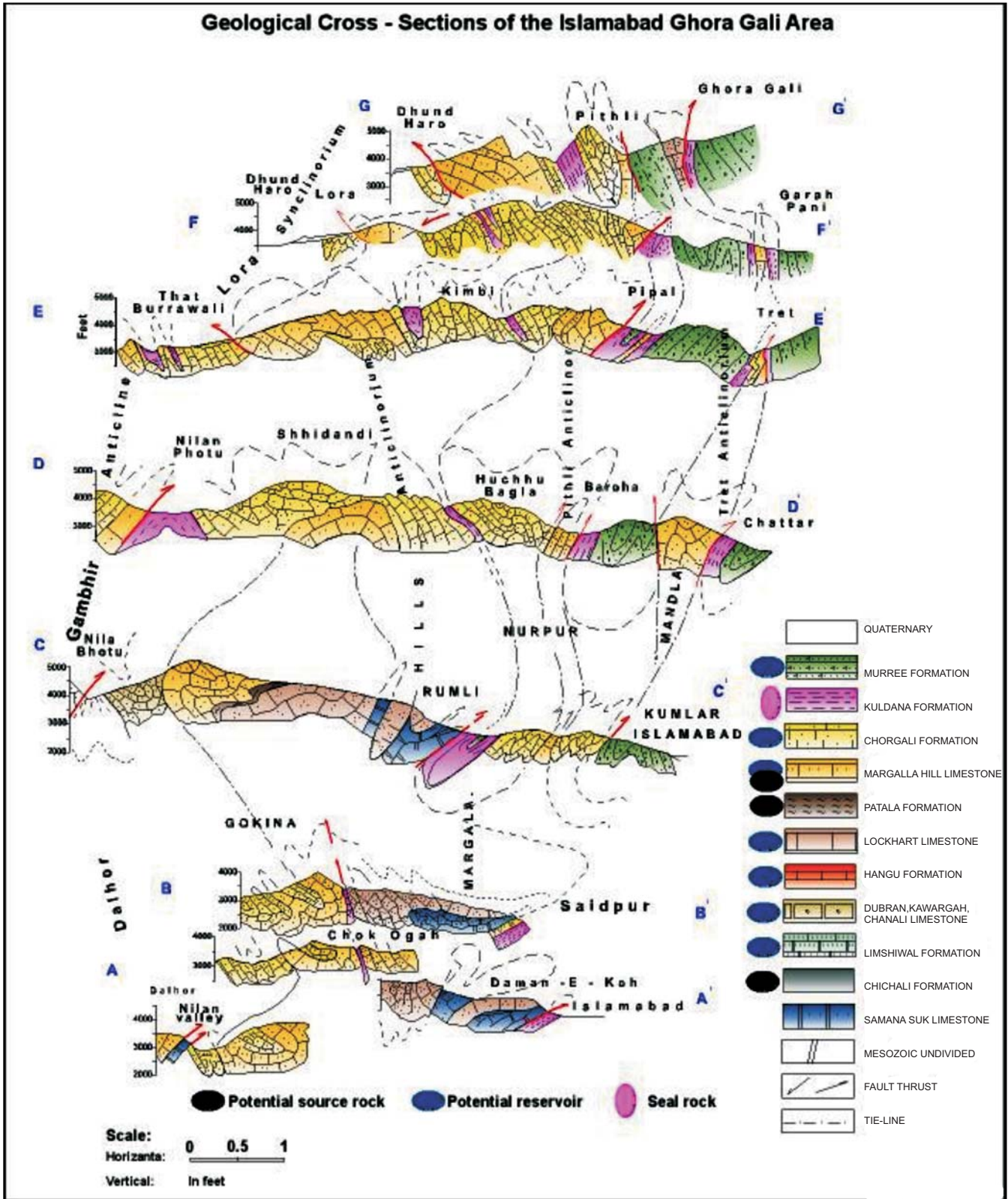


Figure 5 - Geological cross sections of the Islamabad-Ghorigali segment.

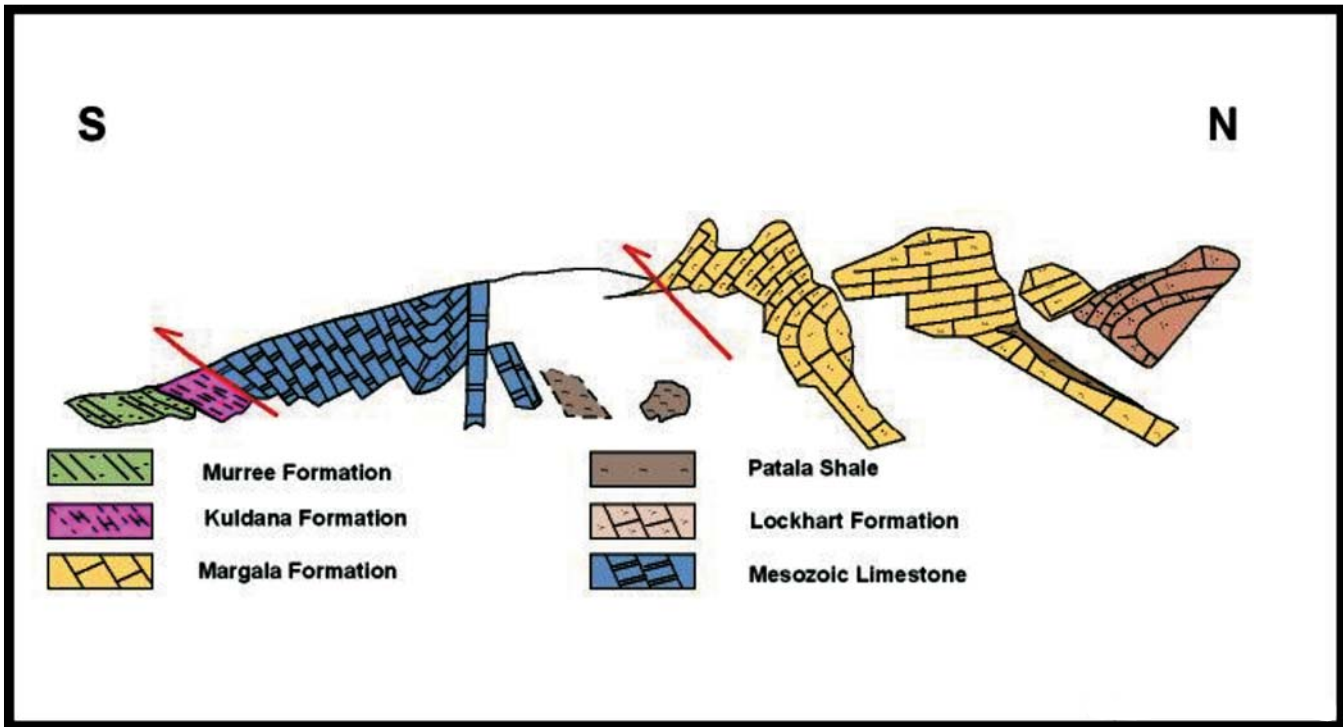


Figure 6 - Cross-section of the southern Margala Hills Anticlinorium north of Shah Allahditta - not to scale.

Jurassic rocks are in turn in steep tectonic contact with folded Chorgali Limestone of MHA, occupying the floor of Nilan valley. West of Gokina, outcrops of more resistant limestone force the Nilan River into a southward bend. From Gokina onwards to the east, Kuldana Fm. occupies the valley floor, indicating an eastward plunge of the syncline axis. Parallel towards the north, the Jurassic limestone continuously reduces its thickness below the thrust of Tertiary limestone until it disappears east of  $73^{\circ}08'30''$  E (approx. 1 Km W of Nila Bhotu). Near Nilan Bhotu Kuldana Fm. steeply dipping ( $3150/850$ ) and exposed along the road. To the north Tertiary limestone dipping northwest ( $3230/340$ ). To the south, strongly recumbent folded Chorgali Fm. occurs (Fig. 5, cross-section C-C').

Towards Gambhir valley, Dalhor-Gambhir Anticline yields a bundle of folds of Eocene rocks of Margala Hills Limestone and Chorgali Fm. At Phalla Galli, the northern front of this fold bundle appears as an overturned anticline of assumed Margala Hills Limestone.

##### 5. The area northwest of the Lora Synclinorium

The Lora Synclinorium is occupied by Chorgali Fm. with deeper synclines of Kuldana Fm. In its northwest, Jurassic rocks form a fold belt. Within this fold belt at least two anticlines occur. The core of the anticline is built by Jurassic limestone. One such anticline is at the bridge west of Rupper across the Katha Rupper and the second one north of Kohala. At Dhund Haro Lockhart Limestone and Patala Shale are folded in a synclinal position between the mentioned Jurassic anticlines at Kohala in the south. Jabri syncline with extremely thin Chorgali Fm. in its core and Margala Hills Limestone at its northern flank, which is in faulted contact to the recumbent

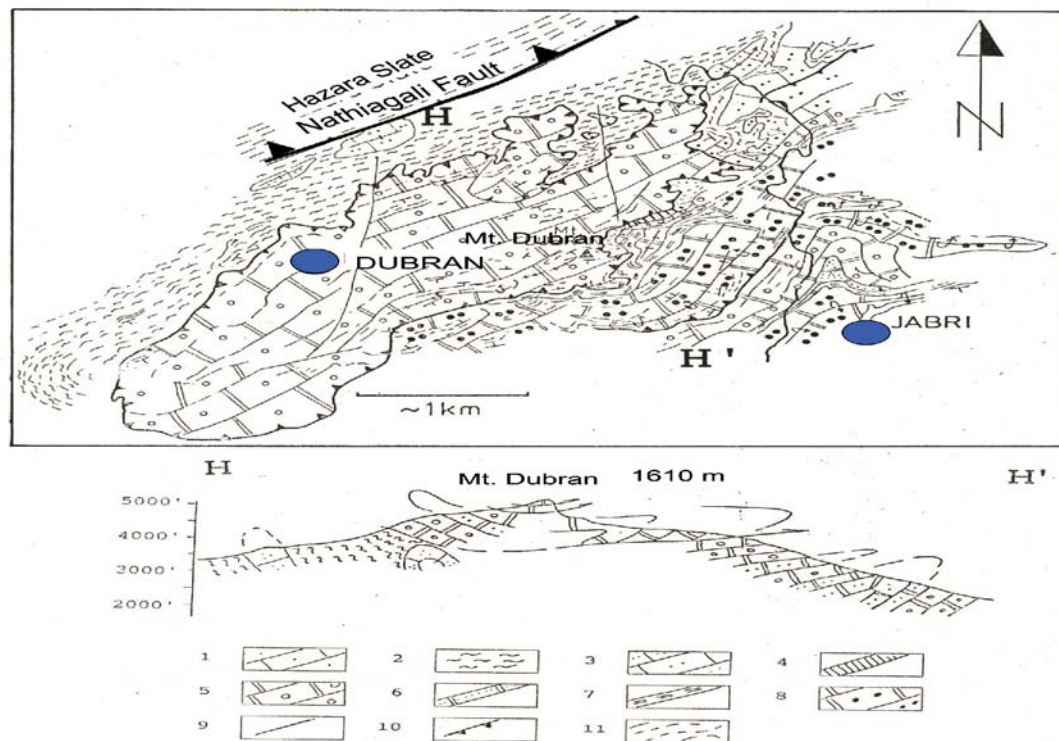
folds of Jurassic and Cretaceous limestone of Mount Dubran. The position of the entire syncline with respect to the Mount Dubran is of completely different structural pattern and it seems to be the result of a significant fault.

##### 6. The Mount Dubran fold and thrust structure

Dubran village occurs in the core of a north verging anticline with Jurassic limestone in its core. This anticline is overturned and its lower flank can be observed at the bridge north of Jabri, where Jurassic dolomite limestone is followed by a few meters of black Chichali shale and Lumshiwal sandstone. The youngest sediments are Lockhart limestone (Figure 7). This anticline is comprised of a number of south-facing recumbent folds, mostly of Jurassic limestone and dolomite, also including Lumshiwal sandstone and Chichali shale and possibly Kawagarh limestone. In the summit region, these folds are thrust by partly overturned Cretaceous limestone and Jurassic dolomite. The direction of the thrust is not yet clear but there are a number of indications that it comes from the north and can be seen in the context of the nearby Nathiagali Fault.

## DISCUSSION

The stratigraphic and structural investigation reveal that molasse sediments of Murree Fm. have been incorporated into the southern part of the Margala Hills, formed by calcareous sediments of the Indo-Pakistan Plate. These highly folded sediments have been dissected by Nathiagali and Murree faults. The Margala Hills Anticlinorium with Jurassic rocks in the core, is an important structure. The mentioned anticlinorium is overturned to the south. The core



1. Margala Hill Limestone 2. Patala Shale 3. Lockhart Limestone 4. Hangu Formation  
5. Kawagarh Limestone (Dubran limestone) 6. Lumshiwal Sandstone 7. Chichali Formation  
8. Samana Suk Limestone 9. Fault 10. Thrust 11. Strike of bedrock

**Figure 7 - Geological sketch map of the Mount Dubran.**

of the anticlinorium is generally thrust on Kuldana Fm. In the east of Huchhu Bagla, Chorgali Fm. of the Margala Hills Anticlinorium is in contact with Kuldana Fm. of the syncline. To the northeast, this Kuldana syncline is an integrated part of a system of folds that also includes the Nurpur-Pithli Anticline. This anticline in turn, develops out of the Kuldana Fm. east of Islamabad at Nurpur Shahan, and has to be regarded as an up-folded part of the Potwar Plateau.

Between Shah Allhiddita and Murree along the southern margin of the Margala Hills, no indication of a major fault like MBT was found. The Mandla-Tret anticline is a dominant south verging structure of the mountain front. Murree Fm. of the northern Potwar Plateau always is underlain by Kuldana Fm. of the southern Hazara. Thus this area is regarded as an autochthonous structural belt rooted at the northern fringe of the Potwar Plateau. It has been thrust in a piggy-back style very similar to the structures found in seismic sections by Lillie et al. (1987) and Baker et al., (1988).

The MBT west of Muzaffarabad is a transform fault, west of which the sediments overlying the basement of the Indian Plate are detached, folded, and thrust. It is assumed to be analogue to the transform faults bordering the re-entrants of the Western Fold belt (Bannert et al., 1992 a, 1992 b). The thrusts developed during the process of relative southward propagation of the detached sediments, in response to Eocene collision between the Indian Plate and Kohistan Arc at the site of Main Mantle Thrust (MMT). The speed and direction

of this northward movement is different from the southwestward movement of the Kashmir Himalaya to the east of the Jhelum Re-entrant.

Three detachment horizons have been identified. They occur within or at the base of Samana Suk Limestone and a higher one in the Kuldana Fm. Further to the north, a detachment horizon of regional importance is within or at the base of the Hazara slates. Its frontal thrust is the Nathiagali Thrust.

#### **This discussion led to the following:**

- A. Generally, there is consistency in the stratigraphic succession.
- B. Faults are generally reversed in nature.
- C. Multivergent folds are common.
- D. No regional thrust fault was observed.
- E. There is no persistent fault between the Mesozoic-Cenozoic rocks and the overlying molasse.

In view of the above at regional scale the contact between Mesozoic- Cenozoic and Miocene molasse sediments is concordant and the MBT does not occur at least in the area under investigation.

The Main Boundary Thrust extended from India and Nepal may lie further in the north.



### PETROLEUM PROSPECTIVITY

The Margala Hills is a hilly range, towering above the Potwar Basin is covered by Paleocene-Eocene rocks with Jurassic rocks in the core of a few anticlines. Cretaceous rocks so far, have been found south of Nathiagali Thrust at Mt. Dubran only. These rocks are hydrocarbon bearing in Kohat and Potwar basins. Thick molasse sediments form the southern folds of the hill ranges with local exposure of Eocene rocks along faults. The area is structurally complex and characterized by imbricate thrusts.

Indications of active petroleum system in the area exist. Outcrop samples show good organic richness which includes Chichali shales (Late Jurassic to early Cretaceous) with TOC 0.4-2.7% (Table-2). Paleocene rocks (Hangu Formation 0.5%, Lockhart Limestone 0.13-0.34% and in Patala Shale 0.2-0.4%), and Eocene Margala Hills Limestone and shale TOC of 0.2-0.6%. Extractable organic matter (EOM) in suggests good source rock potential. Since these values are from outcrops samples so is weathered version of the actual source potential. Reported oil seepages at Golra (Figure-8) and Balochistan House, Islamabad (Table-3) confirms the petroleum prospectivity of the area. The Prist/Phy ratio for oil seepages from Balochistan House suggests derivation of the sample from source rock deposited in anoxic marine environment. Nevertheless, one would tempt to interpret Balochistan House Seepage to be derived from more mature source rock than Golra Seepage sample, assuming derivation from the same source rock and similar level of biodegradation. The bulk composition data (Table-3),

however, can't help to understand source, maturity or post seepage influence on these seeps. Gas seepages have also been reported from Peshawar Basin.

Reservoir rocks are present in Lockhart Limestone and in Hangu Fm. Sands of Lumshiwal Fm. (Cretaceous) and Datta Sandstone (Jurassic) are proven reservoir rocks in the adjoining Kohat and Potwar basins. Intraformational shales are present in the Jurassic, Cretaceous and in Paleocene rocks, Eocene Jatta gypsum and Kuldana shale. These formations can act as seal for the underlying potential hydrocarbon reservoirs (Table-1).

Discoveries along the foothills of Margala Range and in the Kohat basin (Bhal Syedan, and Chanda, Mela, Makori, Manzalai, and Mamikhel, respectively) prove the generation, migration and accumulation of hydrocarbons.

The possibility of northern continuation of the mentioned rocks beneath the overriding thrust sheet of Nathiagali Thrust is a fascinating idea but structurally challenging.

Synthesis of data concludes that Margala Hills is not separated from the adjacent basins by a regional fault like MBT because the sedimentary contact is normal and no metamorphic rocks are in contact with the molasse sediments at the frontal part of the hills range. The Margala Hills Range appears to be a regional fold, characterized by southward overturned Margala Hills Anticlinorium that forms the mountain front of the south hill range. The Peshawar and Potwar and Kohat basins are situated on the fringes of the hills range and might serve as kitchen areas for the folded Margala Hills Range (Figure 9). Being structurally complex area so a comprehensive study involving modern exploration techniques (seismic, gravity, magnetic, satellite images, and geochemical) is needed to integrate surface and sub surface



Figure 8 - Golra Seepage west of Islamabad.

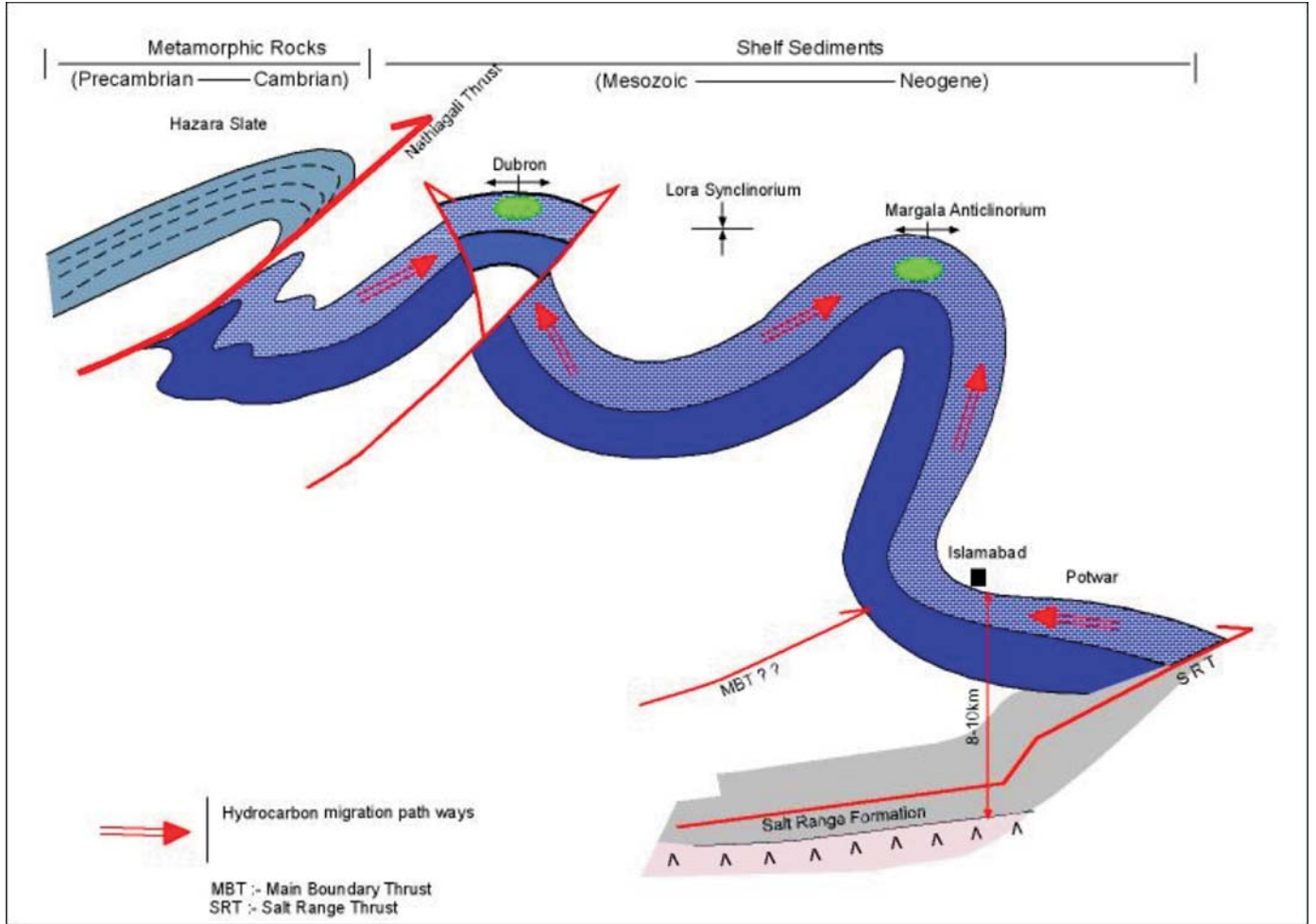


Figure 9 - A speculative model shows possible hydrocarbon migration mechanism in Margala Hills and adjoining Peshawar and Potwar basins .

Table 2 - Geochemical Data of Surface Rock Samples From Margala &amp; Kalachitta Ranges.

Formation	Lithology	TOC %	G.P.	HI	EOM	EXT /	SAT.	ARO	NSO.
Margalla Hills Lst.	Shale	0.49	0.2	41	-	-	-	-	-
Margalla Hills Lst.	Limestone	0.17	-	-	-	-	-	-	-
Margalla Hills Lst.	Limestone	0.26	-	-	-	-	-	-	-
Margalla Hills Lst.	Dark Limestone	0.34	-	-	-	-	-	-	-
Margalla Hills Lst.	Dark Limestone	0.57	-	-	312	55	39	36	25
Chichali Fm.	Shale	1.48	<0.1	7	15	1	-	-	-
Chichali Fm.	Black Shale	0.41	-	-	-	-	-	-	-
Chichali Fm.	Black Shale	2.68	<0.1	4	28	-	-	-	-
Chichali Fm.	Black Micaceous Sandy Shale	3.93	-	-	966	27	6	52	32
Hangu Fm.	Siltstone	0.48	<0.1	20	-	-	-	-	-
Hazara Fm.	Shale	0.4	-	-	-	-	-	-	-
Lockhart Lst.	Limestone	0.23	-	-	-	-	-	-	-
Lockhart Lst.	Dark Shale	0.34	-	-	-	-	-	-	-
Lockhart Lst.	Dark Limestone	0.13	-	-	-	-	-	-	-
Patala Fm.	Shale	0.25	-	-	-	-	-	-	-
Patala Fm.	Shale	0.25	-	-	-	-	-	-	-
Patala Fm.	Shale	0.4	<0.1	25	-	-	-	-	-
Upper Cretaceous	Dk. Grey to Black Mieritic Limestone	0.23	-	-	-	-	-	-	-

Table 3 - Geochemical Data Of Oil Seepages.

Name of Seepage	Depth (m)	Lithology	SAT.	ARO	NSO.	Prist/Phy	Phy/n	OEP-29
			HC %	BC%	%		C18	
Golra Seepage	Surface	Gypsum	52	40	8	-	-	-
Golra Seepage	Surface	Oil seepage	39	42	19	-	-	-
Golra Seepage	Surface	Oil seepage	32	46	22	-	-	-
Baluchistan House	100	Oil seepage	70	26	4	1.5	0.3	1.09



configuration of the region.

## REFERENCES

- Armbruster, J., K.H. Jacob and L. Seeber, 1978, Tectonics of the Lesser Himalayas in north Pakistan based on micro-earthquake observations -*Jour. Geophys. Res.*, 83, p.269-282.
- Baker D.M., R.J. Lillie, R.S. Yeats, G.D. Johnson, M. Yousuf and A. S. H. Zamin, 1988, Development of the Himalayan frontal thrust zone: Salt Range, Pakistan-*Geology*, v.16, p.3-7.
- Bannert, D. and H. A. Raza, 1992a, The segmentation of the Indo- Pakistan Plate *Pak. Jour. Hydroc. Resc.* v, no.2, p.5-18.
- Bannert, D., A. H. Cheema, A. Ahmed and Schaffer, U., 1992b, The development of the Western Fold Belt in Pakistan -*Geol. Jb.*, B 80, BGR Hannover, p.3-60.
- 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: US GS Professional Paper 716-C, 29p.
- Choudhry, S.K., 1975, Gravity and crustal thickness in the Indo- Gangetic Plains and Himalayan region, India - *Royal Astron. Soc. Geophys. Journ.*, v. 40, p. A41-452.
- Coward, M.P., 1994. Inversion Tectonics, Hancock, P.C., (eds) *Continental Deformation*. Pergamon Press, pp.421.
- Davies. D.M. and R J. Lillie, 1994, Changing mechanical response during continental collision: active examples from the foreland thrust belts of Pakistan - *Journ. Struct. Geol.*, v.16, no.1, p.21-34.
- Ghazanfar. M.. M. N. Chaudhry., K. P. M. Qayyum and R Ahmed, 1990, Geology and structure of Kuza Gali- Dunga Gali- Ayubia area, Hazara Potwar Basin with special reference to hydrocarbon prospects of Attock - Hazara fold and thrust belt, *Pak. Jour.f Hydroc. Resc.* vol.2, no.2, p.43-55.
- Gupta, H.K. and H. Narain, 1967, Crustal structure in the Himalayan and Tibetan plateau region from surface wave dispersion - *Seismol. Soc. America Bull.*, 57, .p.235-248.
- Iqbal, M. and D. Bannert, 1998, Structural Observations of the Margala Hills, Pakistan and the Nature of the Main Boundary Thrust. *Pak. Jour. Hydroc. Res.* vol.10, pp.41-53.
- Iqbal, M., Tariq Baig, Moin Raza Khan, 2007, Petroleum Potential of Kalachitta-Margalla Hills Range and adjoining Peshawar-Hazara-Basin, Pakistan in ATC 2007 proceedings p.121-138.
- Iqbal, M. Sheikh, M.K. Pasha and William V.S., 1993, Environmental Geology of Islamabad-Rawalpindi Area, Pakistan. *Record GSP* vol.111, p.1 7, issued May, 2000 by DG Geol. Surv. Pakistan.
- Kaple K.P. 1992, The Dadeldhura Granite, Far Western Nepal: Granites, in *Geology in South Asia*.-1. Proceedings of the First South Asia Geological Congress Islamabad, Pakistan, Feb. 23-27, 1992, pp. 8 1-92. Proceedings of the Southeast Asia.
- Kono, M., 1974, Gravity anomalies in east Nepal and their implications to the crustal structure of the Himalayas *Royal Astron. Soc. Geophys. Journ.*, 39, p.283-300.
- Latif, M.A., 1968, Explanatory notes on the Geology of South Eastern Hazara, to accompany the revised Geological Map. - *Jhb. Geol. Bundesanstalt, Sonderband 15*, Wien, p.5-20.
- 970a, Explanatory note on geology of southeastern Hazara to accompany the revised geological map.
- Le Fort, P., 1975, Himalayas: the collided range, present knowledge of the continental arc. - *Am. Jour. Sci.*, 275 A, New Haven, p.1-44.
- Lillie, R.J., G.D. Johnson, M.Yousuf, A. S. H. Zaman and R.S. Yeats. 1987, Structural development within the Himalayan foreland fold-and-thrust belt of Pakistan - *Can. Soc. of Petrol. Geol.*, Memoir 12, p.379-392.
- Mattauer, M., 1975, Sur le mecanisme deformation de la schistosite dans l'Himalaya. *Earth Planet. Sci. Let.*, p.28, 144- 154.
- McDouglas, W.J., Hussain.A, R.S.Yeats, Treloar P.J. And Searle M.P. 1993 Himalayan Tectonics, Geological Society of London Special Publication, No.74,pp. 58 1-588.
- Middlemiss, C.S., 1986, The Geology of Hazara and the Black Mountains, India *Geol. Surv. Mem.*, v.26, 302p.
- Pascoe, 1963, A manual of the Geology of Burma and India, v.3, 3 rd edition Calcutta, Govt.India press.
- Powell, Mc A. and P.J. Conaghan., 1975, Tectonic models of the Tibetan Plateau-*Geology*, 3, p.727-731.
- Shah, S.M.I.(ed.) 1977, Stratigraphy of Pakistan: Geological Survey of Pakistan.Mem. 12,Quetta.
- Tahirkheli, R.A.K. (1982), Geology of the Himalaya, Karakoram and Hindu Kush in Pakistan in *Geol.Bull.Peshawar* 13;p.40,fig.14.
- Wadia, D.N., 1931, The Syntaxis of the north-west Himalaya - its rocks, tectonics, and orogeny - *Ind. Geol. Surv.*, Records. 65, p. 189-220.
- Waagan, W. and Wynne, A.B., 1872, The Geology of Mount Sirban in the Upper Punjab-India *Geol. Surv.Mem.* 9, p.331-35.

**PJHR**

Received Nov. 20, 2009 , revised July 15, 2010 and accepted December 25, 2010. First the paper was presented in Annual Technical Conference of SPE-PAPG held in Islamabad, Pakistan, March 27-28, 2007 and published in its proceedings. Now the paper is being published after subjecting it to refereeing process outlined by Higher Education Commission , Islamabad, Pakistan.

