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Integration of Satellite Data and Field Observations in Pishin Basin, Balochistan

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ABSTRACT

Pishin Basin, Balochistan remained unexplored due to reasons, such as, poor geological database, remoteness, and lack of infrastructure.

However, widespread distribution of thick sedimentary sequences with organic rich intervals, interbedded sand bodies, reefal build ups, intra-formational shale, conglomeratic layers, occurrence of mud volcanoes, gas seepages and structurally undisturbed configuration of the surface rocks are fascinating leads. Therefore, un-explored basins like Pishin Basin merit geological / petroleum exploration.

INTRODUCTION

Pishin Basin is located on the western corner of Indo-Pakistan Plate. It is bounded in the east by ophiolite suites and Zhob Valley Thrust (ZVT) whereas sinistral Chaman Fault occurs in its west. In the north it extends to the Main Boundary Thrust (MBT) and in the southwest becomes narrow and merges to Makran area (Figure 1). It is shaped and compressed generally in east west direction, stretched from north to south, shortened and inverted during Late Tertiary collision between Indian Plate and Afghan Block.

The basin fill depicts carbonate and thick flysch type sediments of interbedded sandstone, shale and subordinate limestone, ranging in age from Eocene through Miocene with potential source, reservoir and cap rocks. The sedimentary succession hosts multiple horizons of organic rich dark grey shale, fine grained, and laminated- thin bedded limestone in the basal part. Algal-coral reefs, thick sand bodies and conglomeratic layers are common in the middle part of the sedimentary pile, which may act as reservoir horizons, whereas, intra-formational shale beds may act as cap rocks

The structural style of the area is dominated by broad synclinoria, flanked by tight and steeply dipping anticlines, generally more than 100 km long. Imbricate duplexes, propagating southward along basal planes are common. The basin is analogous in several structural aspects to various orogenic mountain fold and thrust belts of the world with proven hydrocarbon bearing record. Mud volcanoes and associated oil and gas seepages are encouraging petroleum explorationists.

Being a huge un-explored basin of the country, Hydrocarbon Development Institute of Pakistan (HDIP) in 1999, formulated a project of exploring it.

This paper is based on a field trip to sections in the northeast of Pishin Basin (Murgha Faqirzai Concession) under the said project to promote exploration in un-explored areas. Modern satellite images were interpreted and results were cross-checked in the field. The area is currently being explored by Paige Limited.

PREVIOUS WORK

Pishin Basin is named as Pishin Trough (Zuberi and Dubois, 1962), Kakarkhorasan Flysch Basin, (Kazmi and Rana 1982), Pishin Flysch belt (Farah et al., 1984), Pishin Median Basin (Ahmed, 1991, 1998), Pishin Flysch Segment (Bannert et al., 1992), Pishin Katawaz Flysch Trough (Bannert and Raza, 1992, Bender and Raza, 1995) and Katawaz Flysch basin (Jadoon, 1992). Thick sequence of flysch type sediments, runs for more than 800 km in a north-south strip, is presumably responsible for such type of diversified nomenclature. The emplacement of widespread ophiolitic suites in the area is addressed by most of the previous investigators. Review of the available literature reveals the contribution of the following:

Hunting Survey Corporation (HSC, 1961) divided the western fold belt (the area in the west of Indus River) from east to west into three main divisions; namely the Calcareous Zone (Indus Basin), Axial Belt and the Arenaceous Zone (Balochistan Basin). The Calcareous Zone is composed mainly of shale and limestone ranging in age from late Triassic to Neogene (Otuski et al; 1989). The Axial Zone is characterized by a complex sequence of ultramafic rock, pillow lavas, and deep-sea sediments. Thick assemblage of sandstone, shale, siltstones, conglomerate and carbonates characterize the Arenaceous Zone. The Arenaceous Zone represents the Late Mesozoic through Late Tertiary flysch trough which developed in the west in front of the southern Eurasian Plate and its terrains of Gondwana origin sutured during the Mesozoic. In the frontal Makran area the flysch deposition continues until today (Bannert & Raza, 1992 quote Farhoudi and Karig, 1977). Pishin Basin (Eocene to Miocene) is a part of the Arenaceous Zone. HSC, 1961 described the general tectonic picture of the western fold belt, as a continuous fold belt deformed in a festoon–like manner around the northwestern Indo- Pakistan Shield.

Zuberi and Dubois (1962) suggest that the Axial Belt is related to the worldwide system of oceanic ridges. They correlate the sinistral Chaman Fault with the African Rift Valley, both as continental features, and the extension of the Indian Oceanic Rift. They had also reported gas seepages on the tectonic map of the Pishin area.

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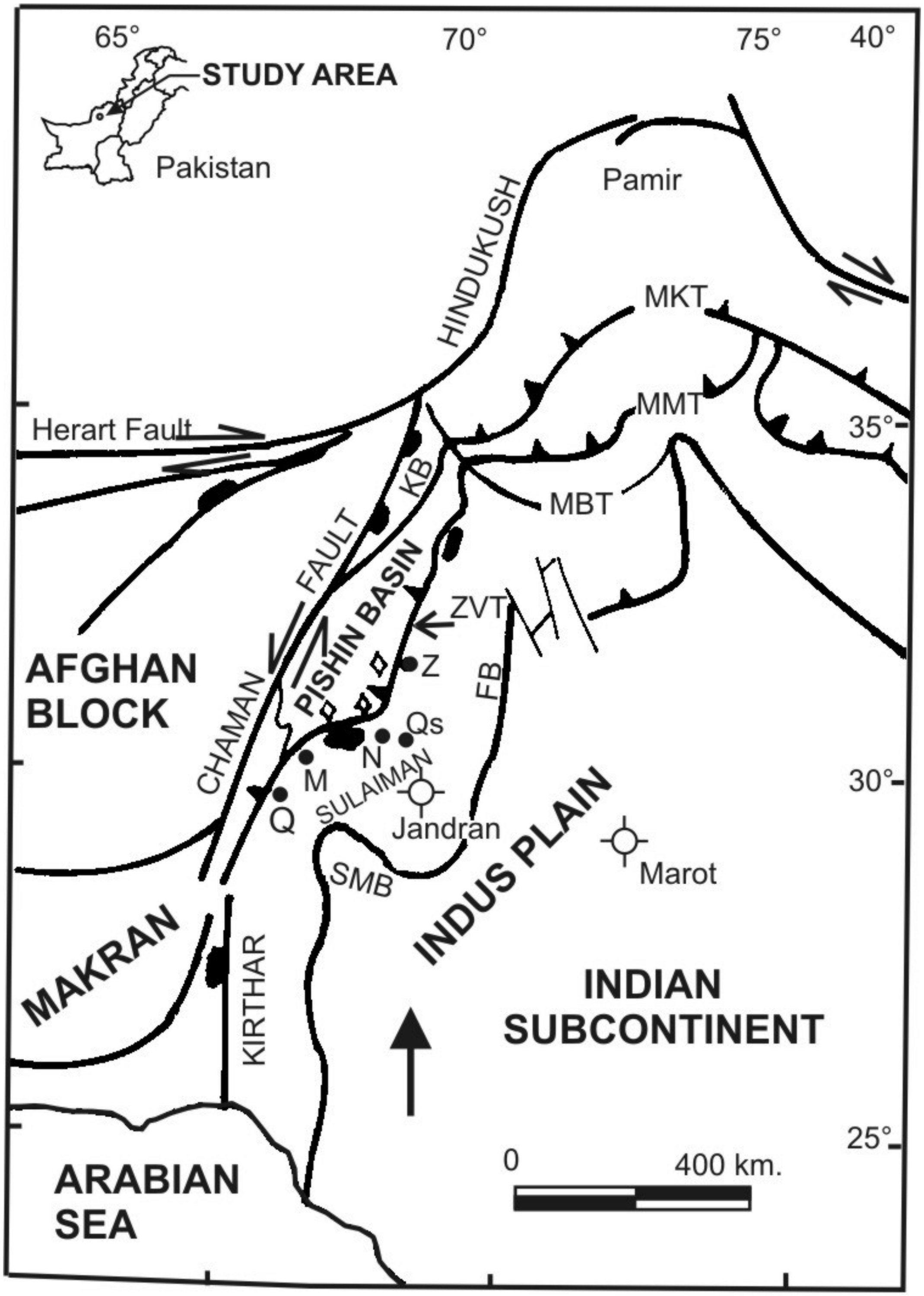

Figure 1- Location Map of the Pishin Basin. Arrow indicates relative drift of the Indian Plate with respect to Afghan Block (modified after Jadoon & Khurshid, 1996).

Abbreviations show MKT= Main Karakoram Thrust, MMT= Main Mantle Thrust, MBT= Main Boundary Thrust, KB= Kabul Block, ZVT= Zhob Valley Thrust (after Bannert et al; 1992), QS= Qila Saifullah, N= Nisai, M= Muslim Bagh, Q= Quetta, SMB= Sibi Molasse Basin.

Ahmed (1991, 1998) gives detail account of the petroleum prospectivity of Pishin Basin. The author determines conservatively 20,000 barrel per cubic mile as recoverable oil and 800 million barrel of oil or gas equivalent as potential reserves and 2.4 TCF gas for Pishin Basin. Ahmed and Jamil (2002) carried out outcrops based facies analyses of the sequences exposed in the area.

Bannert and Raza (1992) are of the opinion that the basin evolved as a remnant of Neo-Tethys before the collision of the western passive margin of the India Plate with Afghan Block. According to these researchers, basement faults are responsible for the segmentation of the Indo-Pakistan Plate and its present geometry (Figure 2).

Treloar and Izatt, (1993) consider the basement of the sequence in Pishin Basin as a transitional continental crust of the Indian Plate.

Qayyum et al; (1994) suggest that flysch to deltaic type sediments of the Khojak – Pishin Flysch zone deposited by south-to-south west paleoflows of the ancestral Indus River, which gave rise to Murgha Faqirzai and Shaigalu delta. This deltaic sequence was subsequently folded and resulted the present structural style. After the formation of the Kirthar-Sulaiman Ranges the Indus River system shifted to its present position.

Beck, (1995) is of the opinion that Kabul Block is a corner of India, which was broken away during the latest Paleocene and early Eocene. The oblique convergence of the irregular Indian and Asian margins resulting in the formation of the Katawaz (Pishin) basin as well as counter clockwise rotation of sutures to the north of the Jalalabad Basin. A deep marine transitional basin formed west of Waziristan-Khost Ophiolites during the late Paleocene and early Eocene. This basin, Katawaz Basin subsided rapidly during early Eocene and was closed during the Oligocene-Pliocene by NW-SE compression

Jadoon and Khurshid (1996), consider that the crystalline basement (34 km below the Marot well, Figure 1) abruptly steepened along the Chaman Fault system and the resulting crystalline crust in eastern Afghanistan thickens to 57 km due to: i) structural thickening within the Afghanistan Block, and ii) underplating by crust of the Indian subcontinent. Their geological model suggests that the western Mesozoic passive NNE trending and NW dipping margin of the Indian subcontinent is under thrusting the Afghan Block along a decollement at about 15 km depth in the hinterland of the Sulaiman Foldbelt.

Iqbal (1999 unpublished report) discusses the structural geology of the northeastern part of Pishin Basin.

STRATIGRAPHY

In reconnaissance visits to Nisai Section in the lower reaches of Murgha Faqirzai Rud (northwest of Muslim Bagh) and Surkach-Shaigalu Road Section (west of Zhob) the exposed stratigraphy and structures were studied (Figure 3).

Stratigraphic succession reveals that sedimentation in the basin started on a magmatic basement with the deposition of carbonates of Nisai Formation (Early Eocene) and ends with Multana Formation (Pleistocene-Pliocene age). The oldest sedimentary sequence of Nisai Formation is divided into Basal-slope forming (Plate-1A) and the Top-ridge forming (Plate-1B) parts (Table 1). The Basal Part consists predominantly of greenish-grey shale with alternation of thin-bedded limestone, marl and calcareous sandstone.

The beginning of thin-bedded limestone in the upper portion of the Basal Part is considered as the base of the proposed Top Part of Nisai Formation, which in Nisai Section, comprises of thin to medium bedded (15-50 cm each) limestone with minor intercalation of shale. Limestone beds are dark grey, fine grained and laminated with hydrocarbon smell. Samples collected for source rock potential from this part, give encouraging total organic content (TOC), in some samples, even better than published results of TOC such as > 0.5 % for shale of Murgha Faqirzai and Nisai Formation mentioned by Ahmed, (1998).

The upper Top Part of Nisai Formation comprises of thin to medium bedded cliff forming limestone. Beds of limestone are medium to thick, dark grey on fresh surface and cream colour on weathered surface.

The carbonate sediments are overlain by thick siliciclastic sequence of Murgha Faqirzai Formation (Oligocene). It is mainly shale sequence with minor beds (20-60 cm) of sandstone (Plate-1C). The Murgha Faqirzai Formation passes up into the Shaigalu Sandstone, which consists of intercalated cross-bedded and ripple marked (Plate-2A) sandstone and shale often red in colour with conglomerate horizons. This sequence shows both an upward and northward transition from shallow marine to estuarine or fluviatile deposition condition (HSC, 1961). The overall thickness of the exposed sequence in the area is more than 3500 m.

Field based observations suggest two types of deformation i.e. detachment and duplication (table-1). Detachment is taking place in incompetent sequence where duplication is manifested by competent limestone and sandstone units. The shortening due to intensive folding and faulting has been accommodated by these deformational events.

GEOLOGY OF THE AREA

Continental sediments cover the eastern fringe of Pishin Basin, whereas carbonate and predominantly flysch sediments occur respectively in the central and extreme western parts. Shaigalu Sandstone covers a major part of the Pishin Basin both in Pakistan and its western extension into Afghanistan.

The sedimentation in this narrow elongated trough started by Eocene time with repeated eustatic rises and falls as interpreted by the occurrence of carbonates and clastic sedimenets. These sediments as a whole termed as Nisai Formation (Table-1). This trough at the terminal Eocene-Oligocene time was broadened due to the northward shift of Kabul Block, and presently occupies a position between the Chaman Fault in the west and Zhob Valley Thrust in the east-southeast (Bannert and Raza, 1992).

Around this time the rising Himalayas started to feed this trough. Consequently, the carbonate system was overwhelmed by the flysch type sediments comprising of shale and interbedded sandstone known as Murgha Faqirzai Shale (Khojak Formation). At the later stage the wide spread fluvial activities deposited Multana / Bostan formations.

The Dynamics and Geometry of the India Eurasia Plate Collision in Pakistan

The Indian Plate during the oblique continent-to-continent collision ruptured along basement faults below todays re-entrants causing individual block movement (after Bannert and H.A. Raza, 1992).

LEGEND

GF	= Ghazaband Fault	**Tectonic units**	
GF	= Gardez Fault	BWZ	= Bela-Waziristan Ophiolite Zone
HF	= Harnai Fault	K	= Kalat Plateau
JBF	= Jhelum Basement Fault	KH.B	= Khuzdar Block
KAT	= Karahi Thrust	M.B.H	= Marri-Bugti Hills
KBF	= Kirthar Basement Fault	KA.B	= Kabul Block
KF	= Kuch Fault (S of Karachi)	KOH.A	= Kohistan Arc
KF	= Kunar Fault (E of Kabul)	KTS	= Kirthar Thrust Sheet
KT	= Karmai Thrust	MR	= Mianwali Re-entrant
MBT	= Main Boundary Thrust	SR	= Sibi Re-entrant
MMT	= Main Mantle Thrust	TR	= Tank Re-entrant
ONF	= Ornach Nal Fault	**Towns: Block dots**	
PCF	= Panjsher Fault	I	= Islamabad
SBF	= Sulaiman Basement Fault	K	= Karachi
SF	= Sarobi Fault	KA	= Kabul
WSTF	= Western Sulaiman Transform Fault	Q	= Quetta

Figure 2- Showing the segmentation of Indo-Pakistan Plate due to basement faults (after Bannert and Raza, 1989).

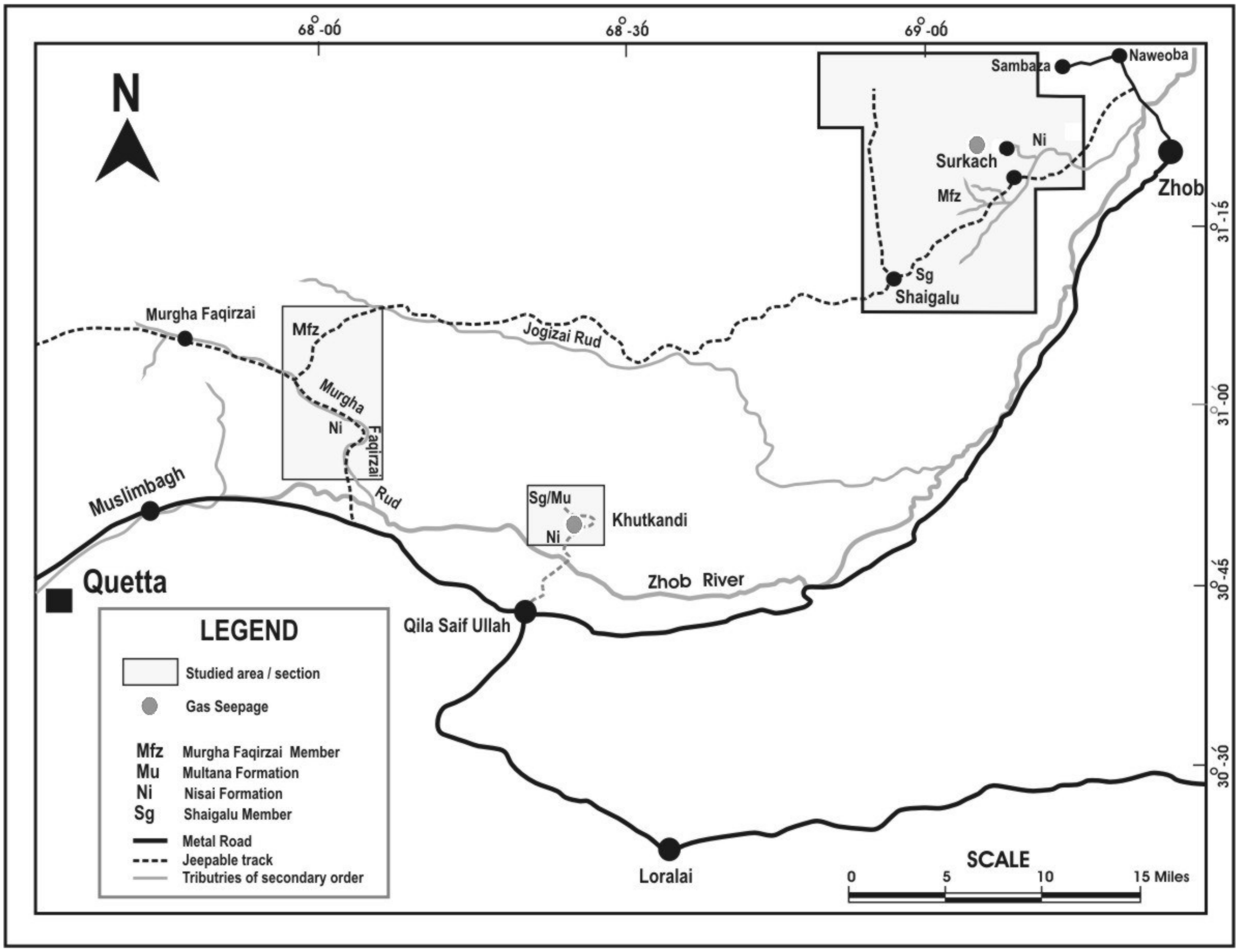

Figure 3- Location map of the study area, Pishin Basin, Pakistan.

According to Treloar and Izatt, (1993), the Katawaz Basin (Pishin Basin) is a part of one large flexural basin, located on the western margin of the Indian Plate, which has developed as a result of subsidence; synchronous with sedimentation of the shelf margin in the early Eocene is indicated by the deposition of clay rich sediments on nummulites bearing limestone. These researchers quote Sengor et al. (1988) that the dominance of shallow marine to fluviatile sediments in the upper half of the succession is indicative that, although subsidence continued as the basin filled during the Oligo- Pliocene, sedimentation was not in a trench environment as the word "flysch" has generated the view that they are trench deposits.

INTERPRETATION OF SATELLITE DATA

Satellite images due to its synoptic view provide substantial information about the surface configuration of rocks. That is why R&D institutes and exploration & production companies incorporate interpretation of satellite images as an integral part of any geological study.

Prior of visiting Pishin Basin, LANDSAT TM-5 images (coloured) with 30 meters resolution were analyzed in HDIP. These images are supposed to be the best option for lithological discrimination.

Different combinations of the TM bands can be displayed to create different composite effects. The order of the bands corresponds to the Red, Green, and Blue (RGB) colour guns of the monitor. The colour combination of the image (TM) interpreted reflect to pseudo colour (Bands 7,4,1 create pseudo colour composite, In pseudo colour, the colours do not reflect the feature in natural colours. For instance, roads may be red, water yellow, and vegetation blue).

Interpretation of images is generally based on some geological criteria such as tone, texture, shape, pattern; drainage etc. These criteria accompanied by the geological background of the interpreter in field geology enable one to derive information of interest. For example any offset of a road or creek is generally associated with structural disturbance. Similarly linear features on images usually reflect to subsurface faults (for further details reader may like to see the previous article in PJHR vol.13, 2003).

Table 1. A generalized stratigraphic column shown on the left and the structural-stratigraphic units and their dominant characteristics on the right. Thickness are not to scale. Detachment horizons are shown by a wavy line which extends only partly across column for minor detachment horizons (adopted from Wallance and Hanks,1990 for Brooks Range, Alaska).

AGE	STRATIGRAPHIC UNITS	SYMBOL	LITHOLOGY	STRUCTURAL-STRATIGRAPHIC UNITS		REMARKS
PLIOCENE / PLEISTOCEN	Bostan Multana		Conglomerate sandstone &shale	Regional southward directed thrust	Du8	Its tectonic deformation is not included
MIOCENE	Shaigalu		Sandstone with minor shale	Intensive folding & overthrusting	DU7	
OLIGOCENE	Murgha Faqirzai		Shale with shelly beds △ (reefs) ○ (Source rock)	Thrust duplication	DU6 Su4 DU5	Detachment in shale Shelly beds react to tectonic pressure
EOCENE	*Nisai* Ridge forming Top part Slope forming Basal part		(Fault?) Limestone ○ (Source rock) Shale with sandy l imestone Calcareous sandstone ○ (Source rock)	Multiple horse in Zhob area, with large thrust sheets, minor duplexes in Muslim Bagh area, squeezes synclines southward verging thrust Dishormonic microfolds Listric faults Detachment Nisai/Surkach Thrust	SU3 DU4 Su2 Du3 SU1 Du2	Normal fault
	Basement		Zhob Valley Thrust		DU1	

SU Structural Units; DU Detachment Horizan

Interpretation of the images of the northeastern part of the Pishin Basin reveals several antiformal and synformal structures. These folds are highly interesting as generally they are more than 100 kilometers long. The trend of the folds is in the northeast-southwest direction. The folds are generally broad synclines and highly reduced and faulted anticlines. Beds in the core of the antiforms, located in the vicinity of the frontal deformed zone, are sub-vertical to vertical. Faults generally cut steeply dipping and overturned eastern flanks of the anticlines (Figure 4). In overall the faults run parallel to the strike, however, some lineaments are also dissecting the older rocks in northwest-southeast direction. In the field recent deformation is envisaged as the sub recent sediments are involved in folding, thrusting and dipping towards the hinterland at places.

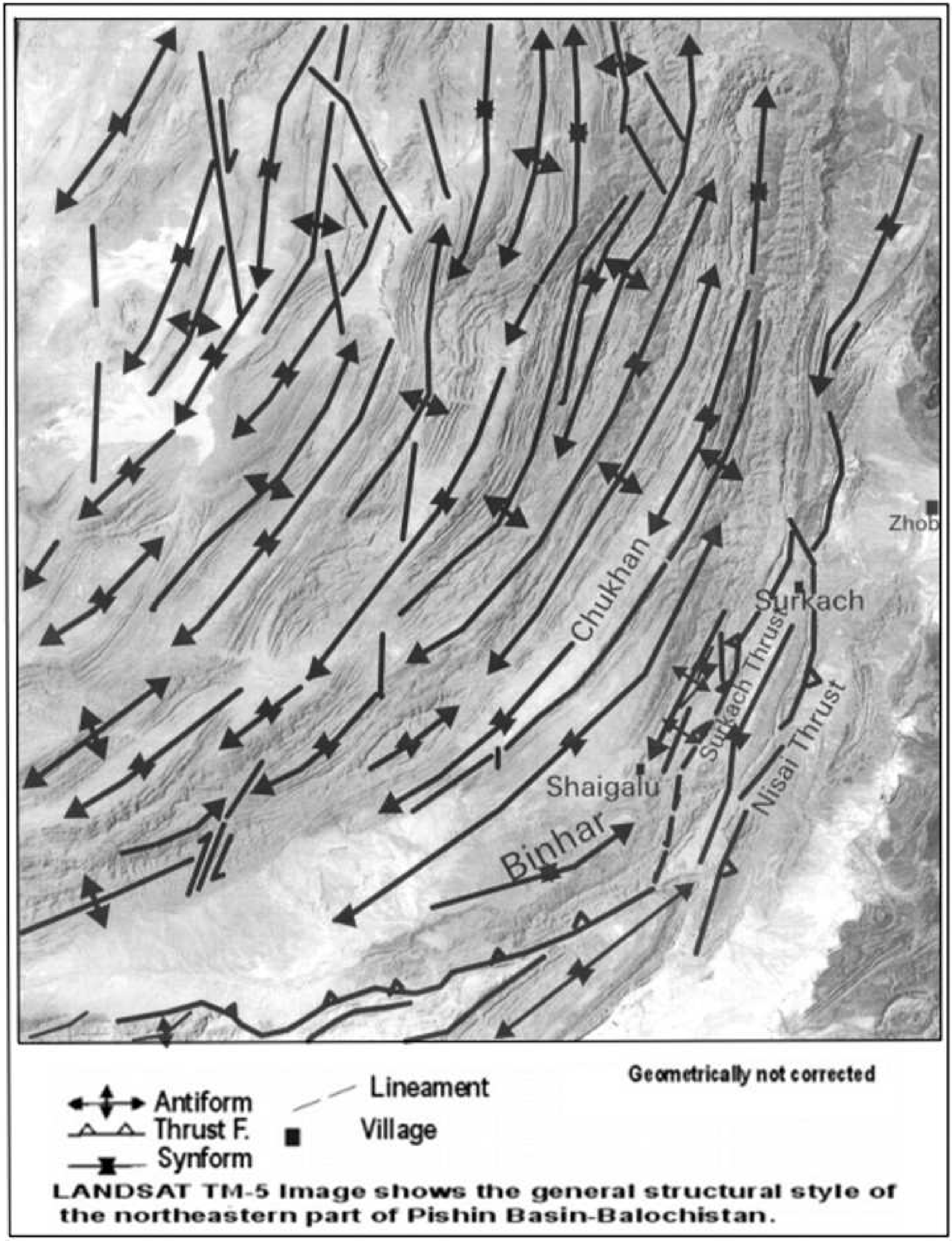

Figure 4- Interpretation of LANDSAT TM-5 images showing the surface anticlines of the Pishin Basin, Balochistan.

Nisai Anticline is a fault bounded structure that is thinner towards the foreland and thicker towards the hinterland. The axes of the folds are trending in east west direction in Nisai Section. A fault runs parallel to the main axis.Thrusts and normal faults were recorded in the field. The normal faults show hanging wall with northwards down throw in Nisai limestone near Nika Akhtar Ziarat (Figure 5A). The faults observed in the area generally show ramp-flat geometry in competent and incompetent sequences. The structural style at the Nisai area reflects that the rocks have been shortened along dominantly south verging duplex fans and disharmonic folds. Southward verging packages of fault bounded folds (horse) were investigated at places in Nisai Section.

In the Surkach area west of Zhob, the exposed thickness of the Tertiary rocks is relatively increasing. The general trend of the axis of the basin is in north south direction contrary to the east west trend of the fold axis of the Nisai Section. There is variation in the attitude of beds along and across the strike. The area is characterized by large wavelength broad folds mainly synclinoria with highly squeezed anticlines, generally faulted on both flanks. In the internal part of the Surkach – Shaigalu area, high angle reverse faults also occur. The deformation front in the west of Zhob Valley is intensely deformed as compared to the area around Shaigalu Fort. Therefore, structures away from the deformation front are less disturbed and are supposed to be potential candidates in subsurface for hydrocarbon subject to presence of source, reservoir rocks, tectonic understanding and other optimum conditions.

GEOLOGICAL OBSERVATION ALONG THE TRAVERSES

The area under investigation is well mapped by HSC (1961) on 1:253,000 scales, therefore, these maps and stratigraphic nomenclature were adopted. The new findings were incorporated into these maps and schematic cross sections were drawn. Following is a brief description for the surface structural configuration of rocks exposed in the northeastern part of Pishin Basin.

Nisai Section

Nisai Section is named by HSC (1961) after the name of Nisai Village. Actual section is located in Murgha Faqirzai Rud and accessible via an un-metalled mugha Faqirzai – Nisai Road (Figure 3).

The broad Zhob River valley between Qila Saifullah-Muslim Bagh and the Murgha Faqirzai Rud, hosts Zhob-Muslim Bagh Ophiolites, is transected by Zhob Valley Thrust (Figure 1). Near Tangi Ziarat in the lower reaches of Murgha Faqirzai Rud, the sub recent sediments encountered are overlain by a thick conglomeratic sequence with subordinate sandstone and orange-brown shale at the top (Figure 5). The pebbles are up to 25 cm in diameter and consist of sandstone, limestone, marl, abundance of ultramafic fragments and red jasper. This sequence is presumably Multana Formation. Tectonics of the Multana Formation could not be investigated in detail; however the mentioned sequence is dissected by several faults. Since Multana Formation shows gentle north dipping and underlying the sub-recent sediments therefore, it indicates Multana Formation is involved in recent deformation events and the tectonic impact of continent-to-continent collision has arrived here quite late.

Nisai Anticline (Figure 5) presents complex structural geology. Faults are multivergent. The contact between Multana and Nisai formations is faulted. On the right bank of Murgha Faqirzai Rud, at the contact of the last yellow shale sequence of the Multana Formation, there is a 2 m thick brownish to maroon color limestone bed, consists sub-angular to angular clasts, with minor fragments of ultramafic rocks and forams. HSC (1961) considers it as the base of Nisai Formation. The mentioned limestone bed thrusts upon the orange color shale of Multana Formation with low angle ($320^o/20^o$), which facilitates the southward advancement of the basin. Analysis of LANDSAT TM imagery (Figure 4) of the area and subsequent field investigation revealed that the mentioned fault is a regional fault and runs along the strike in east - west direction for a long distance which follows irregular topography of the area and swings towards north further in the east of Nisai Section. Therefore, the mentioned fault (Plate-1A) is named Nisai Thrust (Iqbal, 1999-unpublished report).

About 500 meters in the north of Nisai Thrust, on the left bank of the Murgha Faqirzai Rud, south verging disharmonic folds occur in thin bedded sandy limestone in the Basal Part of Nisai Formation. In the west of Akhtar Nika Ziarat, normal fault could be seen in Nisai Limestone, with down thrown block to the north.

At the contact of Nisai and Murgha Faqirzai formations a conglomeratic bed occurs, which has been considered as the contact between Nisai and the overlying Murgha Faqirzai formations. It indicates an uplift period. The conglomeratic bed is followed by interbedded sequences of shale, sandstone and coral reef (2m thick) of the Murgha Faqirzai Formation. This situation remains consistent for about 100 meters till there is sudden increase both in number and thickness of shale layers. In addition several faults have been identified and incorporated into figures 5 and 5A. In the top left part of figure 5, sub vertical to vertical beds occur in Nisai Formation. Here the sense of movement could not be ascertained. Detail structural study and understanding the tectonic kinematics of the area is required.

Surkach – Shaigalu Section

Surkach and Shaigalu villages are approximately 34 km and 54 km, respectively in the southwest of Zhob (Fort Sandeman). These localities are accessible via an un-metalled Zhob-Shaigalu road. Surkach has a population of about 50 houses. Shaigalu Fort was built in British time. The mentioned villages (Figure 2) are located on topographic sheets No. 39E/3 and 39A/16 of the Survey of Pakistan and HSC (1961) map No. 29.

The structural style of the Surkach-Shaigalu Section is complex. Two north south trending outcrops of Nisai Formation are exposed in the east and west of the Surkach village. The mentioned village is located in a syncline, bounded on both flanks by out crops of Nisai Formation.

Nisai Formation exposed in the east of the Surkach village is gently thrust upon Multana Formation (Figure 6). But at places the thrust is high angle ($320^o/60^o$-80^o). Figure 6A is a schematic cross-section along Surkach-Shaigalu road.

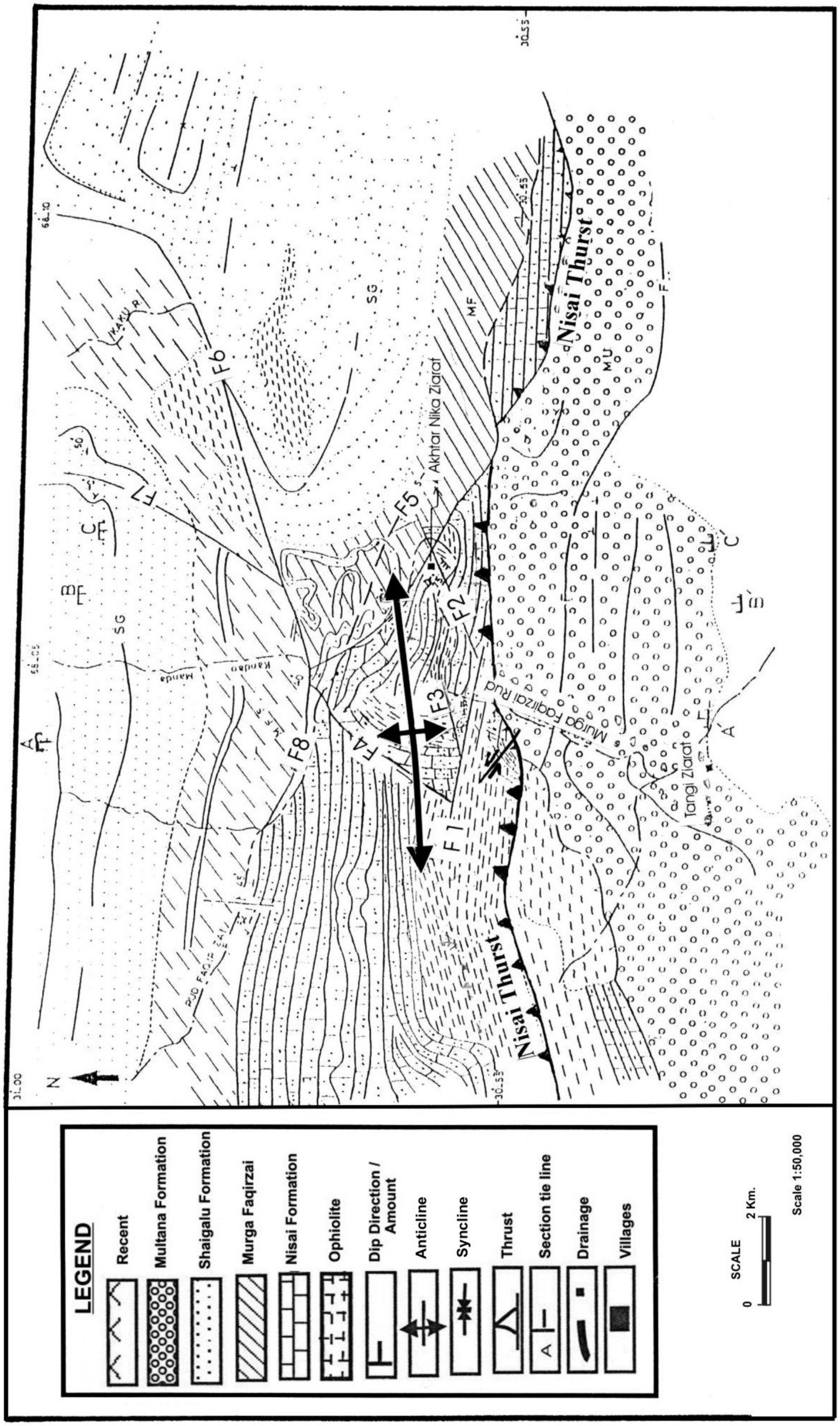

Figure 5- Geological map of Nisai Section (Murgha Faqirzai Rud). Modified after Hunting Survey Corporation, (1961), Map # 27.

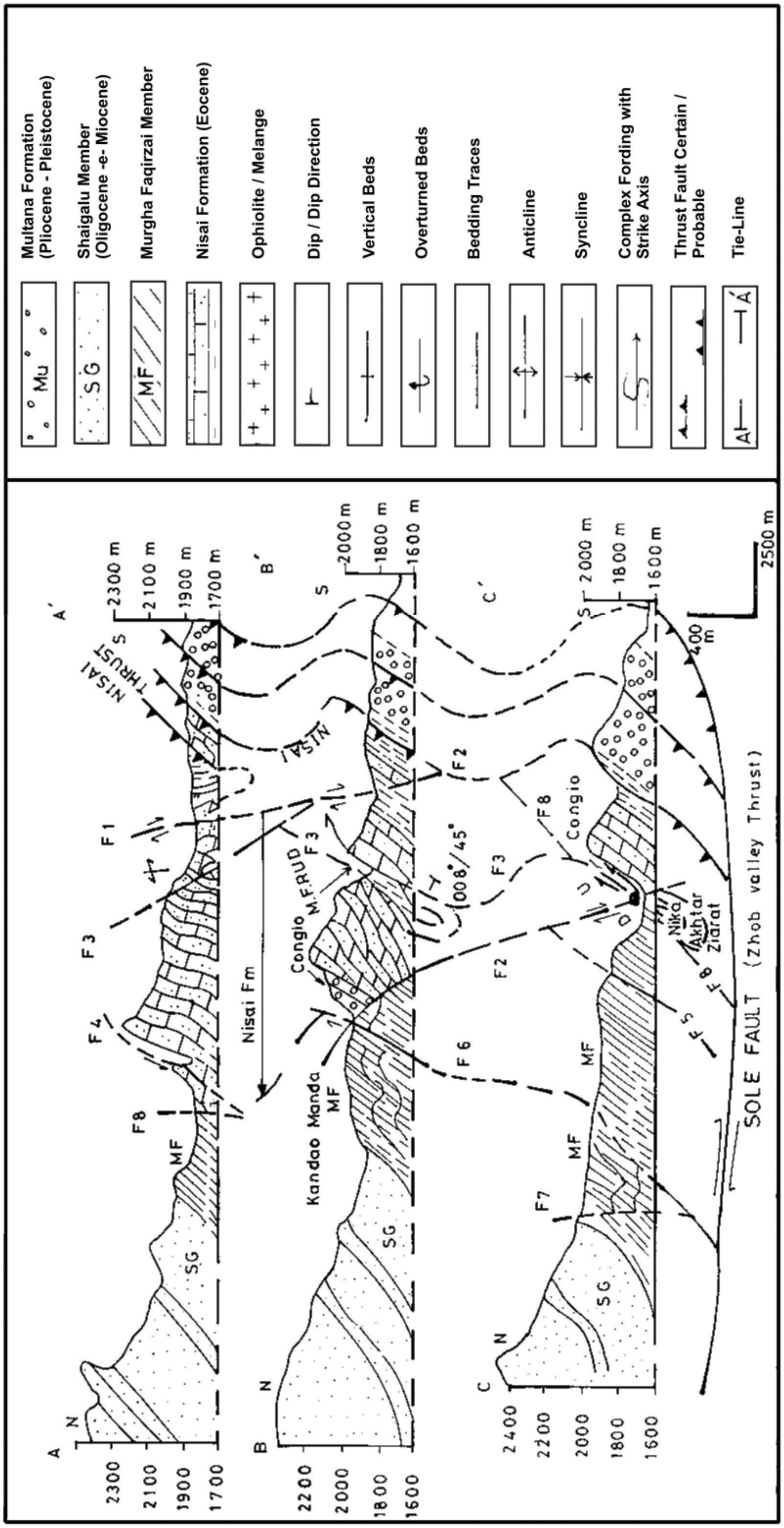

Figure 5A- A schematic cross-section along Nisai Section, Abbreviations stand for Nisai Formation (Ni), Murgha Faqirzai Formation (MF), Shaigalu Sandstone (Sg) and Multana Formation (Mu), F1, F2, etc. are faults encountered in the area.

In the west of the Surkach village, at Sharan Tangi, another anticline occurs in Nisai limestone. At Sharan Tangi, Nisai Formation exhibits its maximum thickness and dominantly consists dark-grey shale, chert layers with coquina beds in the basal part. Beds of Nisai limestone are highly deformed and occur as package of thrust sheets forming an imbricate zone with east vergence. Here the contact between Nisai Formation and Multana Formation is also faulted and the former formation thrusts on the latter. (Plate -1B). The mentioned thrust is named Surkach Thrust (Iqbal, 1999 unpublished report).

At Sharan Tangi, it was noted that in the basal part of Nisai limestone the beds are steeply dipping ($310^o/55^o$) northwest where at stragiraphically high-level, beds are gently northwest dipping ($310^o/30^o$). The eastern limb of the mentioned anticline is overturned to the west and truncated by a regional fault. It forms a system of thrust duplexes i.e. a series of imbricate thrust faults which arising from a sole thrust below and curved upward to join a roof thrust. Nisai limestone and shale occurs as stacks bounded by thrusts.

Another southwest verging fault in the Multana Formation occurs in the western part of the syncline i.e. the western beds dip ($320^o/45^o$) northwest and the eastern beds dip ($190^o/55^o$) southwestwards. As a result the reddish sequence of the Multana Formation is squeezing out towards the southwest in the north west of the Surkach. Sudden decrease in the limestone beds and increase in shale about 4 km in south of Surkach is probably due to the said fault, which has juxtaposed the shale of Murgha Faqirzai Formation in the southwest against Nisai limestone. The Surkach gas seepage occurs in the north of the mentioned village is also supposed to be along the regional fault. Therefore, regional faults may be investigated for such seepages in the rest part of the Pishin Basin.

The general vergence of the thrusts in the area of Surkach is towards east. It indicates that the tectonic transportation is from west to east contrary to the north-south trend in Nisai Section. The southwestward swing in the trend of transport direction may be due to south-west rotation associated with the collision tectonics.

In the south west of Surkach, on Surkach-Shaigalu road, there is a massive outcrop of coral reefs, parallel to latitude 31^o.15'. The coral reef is overlain by Murgha Faqirzai Formation.

Shaigalu Section

Shaigalu village (31^o 09' 57" - 68^o 56' 20") is situated about 2058 meters above mean sea-level, on the western limb of Shaigalu Main Anticline. The core of the Shaigalu Main Anticline is incised by small tributaries due to axial dip of the fold ($030^o/05^o$) towards northeast. A soft shaly sequence of greenish-earthy colour shale of the upper transitional part of Murgha Faqirzai Formation occurs in the core of the anticline. This anticline is flanked by syncline both in east and west. The syncline in the east is very tight, squeezed and faulted.

Shaigalu Sandstone form the limbs of Shaigalu Anticline. The beds of Shaigalu Sandstone are cross-bedded and ripple marked (Plate-2A) sandstone and shale often red in colour, with conglomerate horizons.

The eastern flank of Shaigalu Anticline is dipping $170^o/25^o$-50^o where the western limb is gently west dipping $300^o/10^o$-20^o. The attitude of beds remains nearly persistent for several kilometers.

Towards northeast of Shaigalu Fort, on the road to Surkach, overturning of beds occurs, causing doubling in thickness of Murgha Faqirzai Formation, and makes its measurement difficult.

The fold axis of the Shaigalu Main Anticline strikes 196^o and dips 10^o southwest. The plunge of the fold can be seen on the road in the east of the Shaigalu Malatia Post where the plunge is $190^o/5^o$. Towards the southwest in the front of the Shaigalu Fort, the axis of the fold is buried in alluvium for a few hundred meters and re-appears further in the south, where the plunge of the Shaigalu Main anticline can be observed.

In the east of Shaigalu Main Anticline another anticline occurs which is named Shaigalu East Anticline by this researcher (Iqbal 1999). The axial plane of the mentioned anticline is dipping towards northeast ($030^o/05^o$). There is thick exposure of shale of Murgha Faqirzai Formation between Shaigalu and Surkach. Some interbedded competent layers within the mentioned formation are steeply west dipping (Plate-1C). The shale is generally dark grey in color.

Chukhan Anticline runs for several kilometers in the west of Shaigalu Main Anticline. Sediments of the upper part of Murgha Faqirzai Formation cored the anticline. There is consistency in attitude of beds for several kilometers. Chukhan Anticline is flanked by a broad syncline in the east. Nearly 16 antiforms have been inferred from satellite image of the area.

MUD VOLCANOES AND ASSOCIATED GAS SEEPAGES

The gas seepages in the Pishin Basin were first indicated on Zuberi and Dubois (1962) maps. During the current geological investigation, mud volcanoes and associated gas seeps were visited and sampled. They are located in:

1. North west of Surkach (31^o 22` 67" N - $69^o$ 11` 55" E)
2. West of Qila Saifullah at Khutkandi (31^o 53` 24" N - $68^o$ 28` 12" E)

Additionally the local inhabitants disclosed about oil and gas seepage i.e. Loogai (smoke) but the mentioned locality could not be visited due to logistic problems and time constraint.

Gas Seeps at Surkach

The location of the mud volcanoes and associated gas seeps (Figure 3, Plate-2B, 31^o 22` 67" N - 69o 11` 55" E) is approximately 2.5 km in the north west of the Surkach with a bearing of 330^o from the mentioned village. At this locality a cluster of mud volcanoes is spread over an area of 1 kilometers radius. The mud volcanoes and associated seepages occur in the greenish-grey shale sediments of the Basal part of the Nisai Formation. The mud volcanoes can easily be identified as they stand relatively high than the topography of the surrounding. Mud slurry from the craters with peculiar light blue to ash-grey color of the mud volcanoes can be observed from a long distance. The slurry of the mud volcanoes contains thin layers of oil. At this locality a group of three mud volcanoes occur very

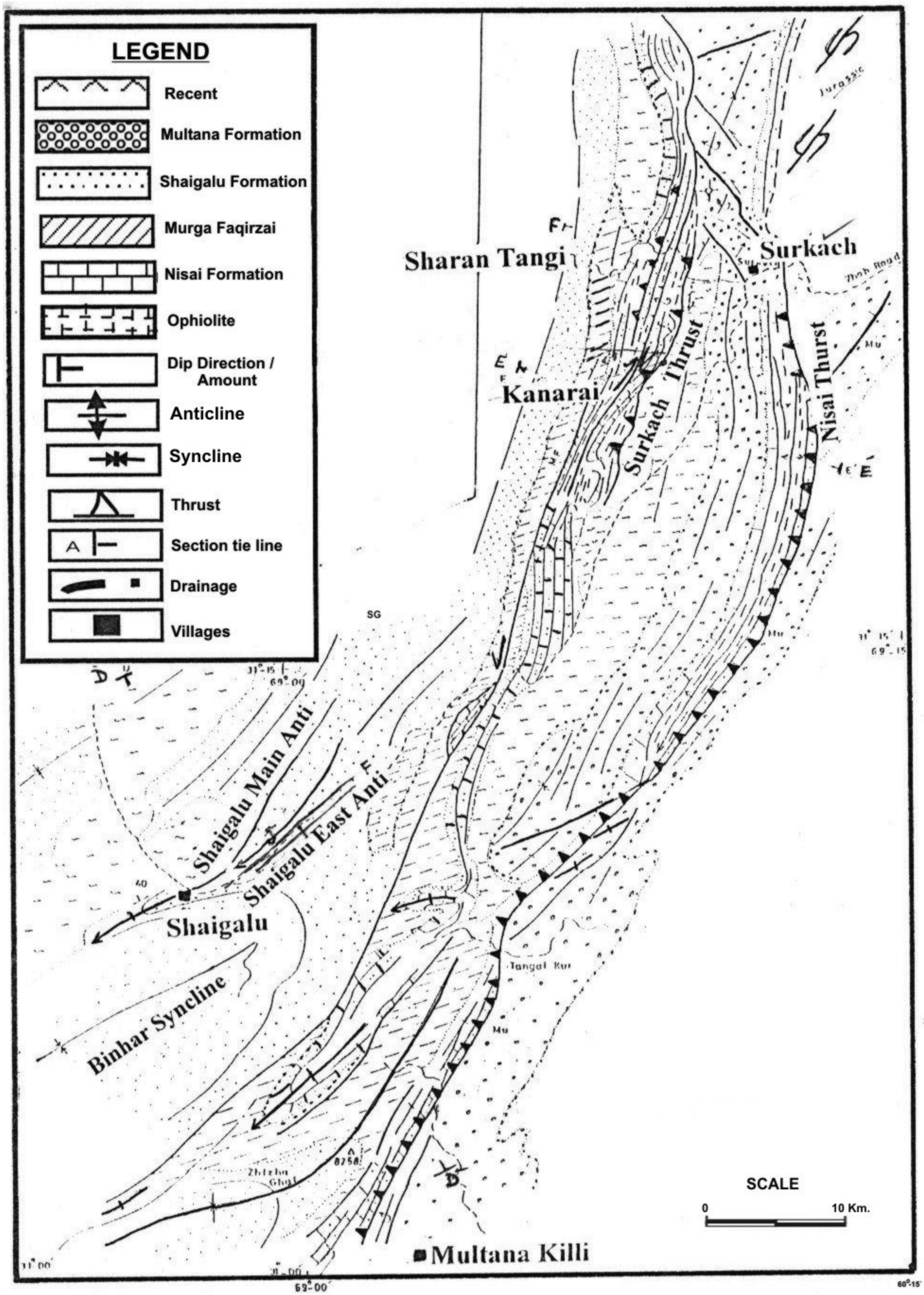

Figure 6 - Surkach-Shaigalu Section (Modified after HSC, 1961, Map # 29).

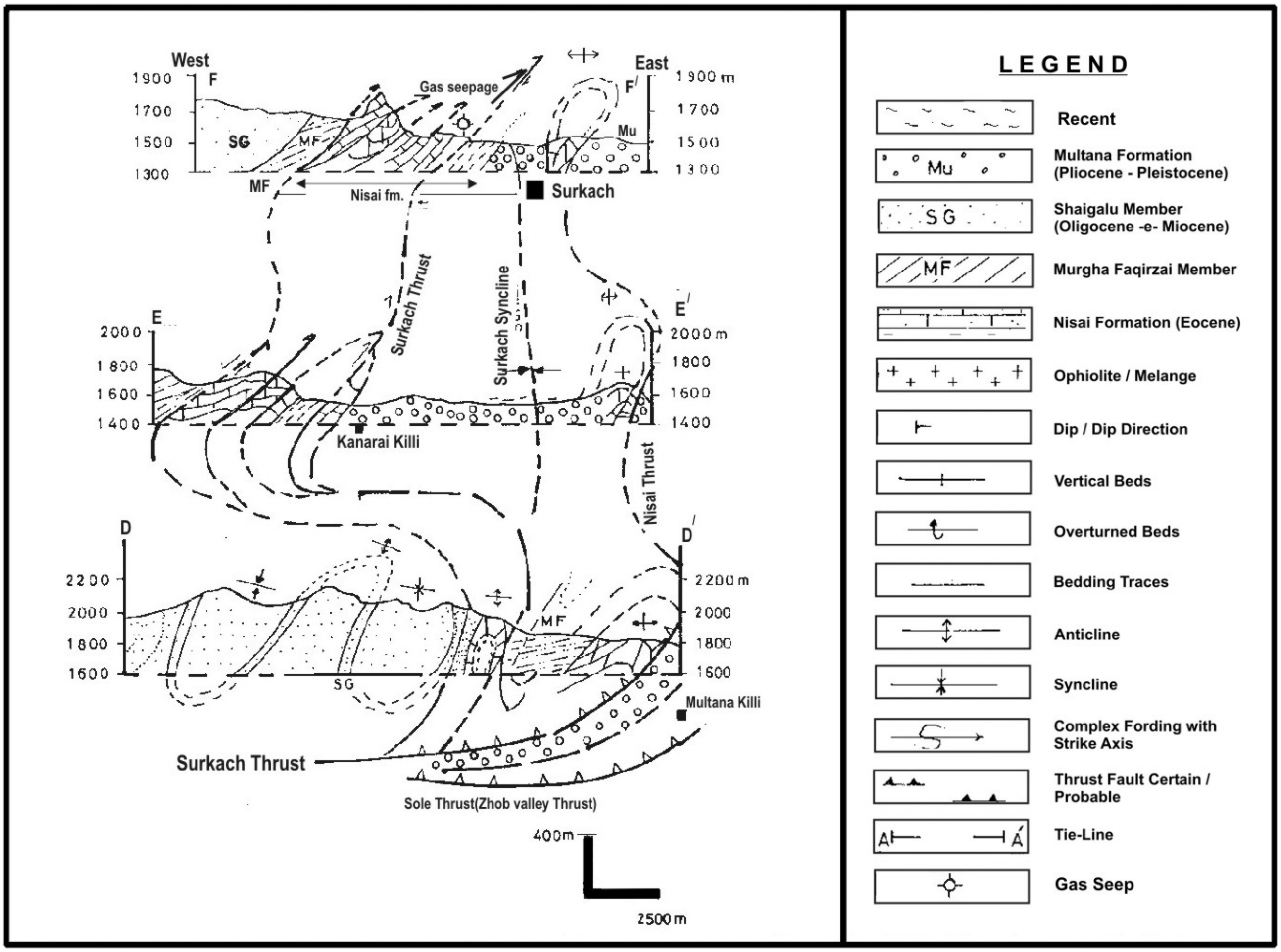

Figure 6A- A schematic diagram showing the structural style of the Surkach-Shaigalu Section.

prominent against the soft and eroded shale sequence of the background. The slope in its front is built by mud stuff emitted with mud volcanoes. It is considered that the mud volcanoes and the gas seepages have been brought to the surface along the Surkach Thrust.

Mud Volcanoes and Gas Seeps at Khutkandi West of Qila Saifullah

These mud volcanoes and associated gas seeps (Figure 3, 31^o 53\` 24" N - 68$^o$ 28\` 12" E) are located in the west of Qila Saifullah. The locality is accessible via Gardab Nala. They are located in Spera Manda and the location is called Khutkandai (boiling spring). The mud volcanoes occur in the light blue to silver ash colour sandy beds of the Multana Formation (?). The beds are gently northeast dipping (015^o/22^o). The mud volcanoes are active and violently gushing out muddy water and highly inflammable gas after short intervals. The crater of a dormant volcano was also observed. It is about 3 meters in diameter and 1.5 meters deep.

Structural observations reveal that the mud volcanoes and gas seepages are located in a synclinal position and have brought to the surface with a northeast-southwest fault. These mud volcanoes with highly inflammable gas and oil layers indicate mature source rocks in the area.

DISCUSSION

Pishin Basin is covered by strata of Eocene and younger rocks. The succession comprises of thin nummulitic limestone in the basal part and thick shale and sandstone sequence in the upper portion. Sediments of Shaigalu Sandstone cover major part of the Pishin Basin and its western extension into Afghanistan.

The general structural style of the basin is characterized by broad synclines and highly squeezed and faulted anticlines. Folds are trending in southwest direction in the south and northeast in the northern portion. But locally east-west and north- south trending folds also occur. The eastern flank of the basin is faulted. Faults are generally low angle thrust faults with minor duplexes and contractional fans, link and normal faults in the area of Nisai whereas in the west of Zhob, around Shaigalu, high angle reverse faults also occur. In overall structural style at the deformation front is typical of thin-skinned tectonics associated with oblique convergence of the Indo-Pakistan Plate. The persistent southeast facing folds and faults indicate the tectonic transportation was from northwest. Several lineaments have been derived from satellite images running in the direction opposite to the folds and cut the sequences, indicate to recent tectonic episodes.

Generally the anticlinoria exposed at surface are relatively narrow, compressed and eastern flank is highly dipping or even overturned to west at places. The overturned flank is also cut by strike parallel fault. Based on a reconnaissance field visit, presently a structural model without subsurface information is premature. However, we are optimistic to have seismic data soon, which may greatly facilitate our tectonic understanding of the area.

PETROLEUM PROSPECTIVITY

Geological investigation suggests that Pishin Basin has organic rich sediments, thick beds of sandstone, reefal build-ups, intra-formational conglomerates, interbedded thick shale, mud volcanoes, associated seepages with highly inflammable gas and thin layers of oil. The organic richness of the outcrop and gas samples is satisfactory. These findings establish a source-reservoir-seal trilogy of the area.

The kinematics of the structural style at surface infers characteristics of orogenic fold and thrust belts. Such structures are considered to be highly hydrocarbon bearing in the subsurface with relatively more thermal maturity than the overlying riding thrusts (Bannert et al; 1989).

Based on the study of the surface geology, especially more structural complexity in the subsurface is expected in the frontal part, whereas towards the inner part of the basin, relatively undisturbed structures may occur which might be good candidates for occurrence of hydrocarbon subject to precise subsurface information through geophysical data and especially existence of source rocks.

RECOMMENDATIONS

1. Pishin Basin, Balochistan has relatively poor geological database. Therefore, due to its marvelous outcrops it merits geoscientific investigations.
2. To establish a data base, geochemical sampling in a systematic order is suggested for precisely knowing the organic richness of the rocks and most importantly determining migration and correlation of hydrocarbons in regional perspective.
3. Basin infill history and facies identification, its extent and environment of deposition is very important. If supported by seismic data it give a clue about the existence, and depth of a facies in the subsurface, or grading of the source / reservoir rocks in the deeper part of the basin.
4. Information about the reservoir characteristics of potential reservoir levels is at rudimentary stage. Therefore, detail catalogue of porosity and permeability at various reservoir levels should be established. That is why several selected samples are under process for the said job in Reservoir Engineering Lab HDIP to narrow down the reservoir horizons.
5. Interpretation of structural geology of the area is required. It must be supplemented by interpretation of satellite images and extensive fieldwork to understand the tectonics of the region.
6. Data with particular reference to subsurface geology, with national / international organizations and E&P companies should be publish or placed in public domain to enhance further research on their working materials.

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PLATE 1


Nisai Section (Murgha Faqirzai Rud)
North
South
Nisai Thrust
Part of Nisai limestone
Multana (?) formation
Murgha Faqirzai Rud

(A)

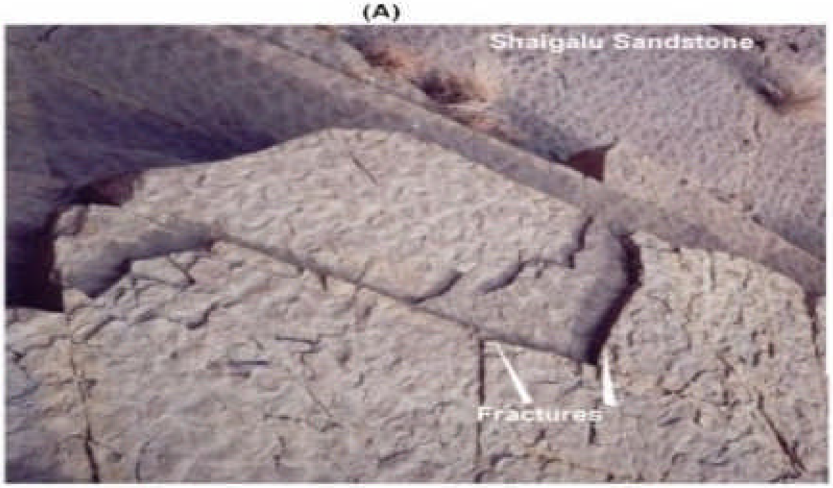

Sharan Tangi (Surkach Section)
South
North
Nisai limestone
F
Nisai limestone
Surkach Thrust
Multana (?) formation

(B)

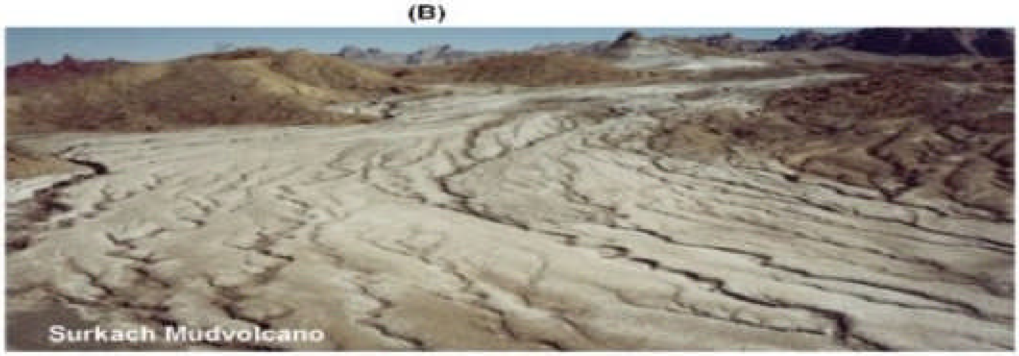

Surkach-Shaigalu Road
West
East
Murgha Faqirzai Shale
70°

PLATE 2

(A)



(B)



(C)