Pakistan Journal of Hydrocarbon Research
Vol. 24, (June 2014),p.01-17, 17 Figs. 01 Tables.

The Architecture of the Northwestern Indian Plate Collision Zone

Dietrich Bannert[1], Muhammad Iqbal[2] and Moin Raza Khan[2]

ABSTRACT

In recent years the geology of the area west of the Indus River became more and more unveiled by geological field work and satellite image interpretation. This paper presents the results of a geological satellite image interpretation controlled through published results of local and occasionally regional geological fieldwork. The results can help for a better understanding of the hydrocarbon potential and can lead to new target areas for future hydrocarbon and mineral prospecting.

Starting during Late Cretaceous the oblique collision of the Indian Plate with the Afghan Block resulted mainly in shear along N-S oriented strike-slip faults in the south which changed to obduction and thrusting along the northern part of the Indian Plate. The oblique collision finally buried the northern part of the Indian Plate beneath the Himalayan thrusts generally oriented in an E-W direction. The sea-floor of Tethys II underwent severe deformation during the collision and was segmented from south to north into the Bela, Muslimbagh and Zhob ophiolites and finally into Waziristan-Igneous Complex.

INTRODUCTION

The geology of larger parts of the Western Fold Belt of Pakistan west of the Indus River lacks a detailed knowledge due to its difficult accessibility. The area is built by late and post Paleozoic shelf and slope sediments and remains a prime target for further hydrocarbon prospecting. But it still lacks a detailed geological mapping, laboratory work and subsequent seismic surveying. Back in the late 50-ies Hunting Survey Ltd., did a modern geological reconnaissance mapping, based on aerial photograph interpretation and systematic ground surveys. The area covered stretched from the Makran coast in the south to the latitude of Zhob. The results provided a set of excellent geological maps in the scale of 1:250 000.

The area between Zhob and the Peshawar Basin in the north is geologically known only in small areas with the exemption of the Waziristan Volcanic Complex, Samana Ranges and the Kohat Plateau.

With the advent of earth-reconnaissance satellites a new tool became available to geologists. Satellite image interpretation by geologists opened a new window to a better understanding of larger structural features and facies developments. Gaps between published data from field visits can be connected by satellite image interpretation thus forming a comprehensive picture of the underlying geology. The possibilities of observation in three dimensions provided by Google Earth greatly enhance the quality of image interpretation, as will be demonstrated in this paper.

The result provides target areas for further fieldwork and follow-up geological prospecting for hydrocarbons and mineral deposits. However, we should always keep in mind that these results are only a further step towards a final picture and cannot substitute geological fieldwork.

The present paper attempts to improve our geological knowledge of the investigated area west of the Indus River and summarises previous systematic satellite image interpretation.

The collision zone between the Indian Plate and the Afghan Block of the Eurasian Plate margin provides deep insight into understand the mechanism of oblique plate collision. The collision zone in western Pakistan is little weathered, well exposed and largely void of vegetation. Accessibility is limited due to the remoteness of the area mainly along the Pakistan-Afghan border, but tremendous progress in satellite imagery, has generated a substantial data base that allows a closer look at the geology and morphology of the collision zone.

This paper synthesizes published information on sediment distribution, tectonics and the structure of the collision zone between the Indian Plate and the Afghanistan Block.

PREVIOUS WORK

The Western Fold Belt of Pakistan was called a festoon of folds by previous workers. The geological map of Pakistan (1:2 Million scale) by Bakr and Jackson (1964) summarized the geological knowledge of the collision zone, based on information provided by the Hunting Survey Corporation 1960 (HSC Colombo Plan Project, 1960). At that time plate tectonic concepts were in an early phase and HSC 1960 observations were mainly based on the interpretation of aerial photographs and field work. The Hunting Survey Corporation (1960) geological maps were partly controlled by field work and documentation is excellent. Abdel Gawad (1971) using hand-held astronaut photographs of the GEMINI Program discussed, for the first time, the nature of the Chaman Fault, which he identified as a left-lateral wrench-fault related to the collision of the Indian Plate with the Afghan Block. Meissner et al. (1975) mapped the Parachinar Quadrangle.

The publication “Geodynamics of Pakistan” (Farah and DeJong eds. 1979) included papers that were based on plate tectonic concepts. Bannert et al. (1992a and b) described the segmentation of the western Indian Plate along deep seated N-S aligned basement faults (Figure 1). A synoptic view of the geology of Pakistan was presented by Bender and Raza (eds. 1995), Kazmi and Jan (1997) and Kazmi and Abbasi (2008). Shah (1977 and 2009) systematically described the

[1] Moorstrasse 22, D-30916 ISERNHAGEN, Germany.
bannert.duh@t-online.de
[2] Pakistan Petroleum Ltd., Karachi, Pakistan.

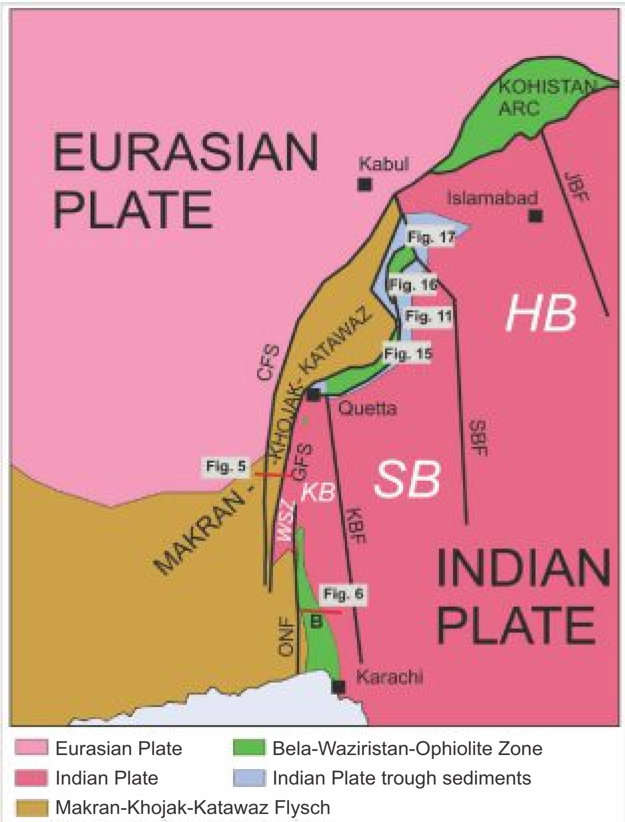


Figure 1 - The Indian-Eurasian plates collision zone with major fault systems and location of cross-sections.

B= Bela-Waziristan-Ophiolite Zone ***HB= Hazara Block***
SB= Sulaiman Block ***KB= Kirthar Block;***
WSZ= Western-Shear Zone
CFS= Chaman Fault System ***GFZ= Ghazaband Fault System***
Jhelum Basement Fault ***KBF= Kirthar Basement Fault;***
ONF= Ornach-Nal Fault ***SBF= Sulaiman Basement Fault***

stratigraphy of Pakistan. Banks and Warburton (1986) described the passive-roof duplex geometry in the frontal structures of the Kirthar and Sulaiman mountain belts. This concept is supported by Jadoon et al. (1992) in their studies of balanced seismic cross-sections.

Beck et al. (1995) identified the Mélange Boundary Zone separating the Indian shelf from the trench sediments of the Indian Plate slope and fore-deep sea-floor. This sea-floor towards the west is overlain by Jurassic to Lower Cretaceous Kurram Group rocks partly transgrading the peridotites and related ultrabasics near Khost (Afghanistan). At places they follow the Jurassic Tani Series (Kaever 1967). However, the facies appears to be different from the mélanges, which Beck et al. (1995) describe in the Pakistan Kurram region. Anwar et al. (1993) proposed the Khanozai Group for Triassic formations on the basis of newly discovered Triassic fossils in previously assumed Jurassic-Cretaceous series. Badshah et al. (2000) provided the geological map of the larger Waziristan area pointing out the Kurram Group and the subdivision of the Waziristan Igneous Complex. Shafique (2001) suggested that different rocks were sedimented in the Bela-Waziristan-Ophiolite Zone during Cretaceous times. He differentiated between rocks with volcanic intercalations and volcanic components and rocks of the slope and the adjacent Indo-Pakistan plate shelf.

RESULTS

This paper discusses the collision tectonics of the region. The description starts from the south to the north.

Figure1 shows major geological elements that include Makran-Khojak-Katawaz Flysch Zone, the Bela-Waziristan-Ophiolite Zone (BWZ), and Indian Plate with its shelf sediments between Karachi in the south and Islamabad in the north. The Afghan Block in the west with its own geological development arrived in several units not later than Kimmeridgian times at the southern margin of Eurasia Plate (Tapponier et al. 1981). Towards the south of Afghan Block and Eurasian Plate the Makran-Khojak-Katawaz flysch developed and was included in the collision with its eastern parts, now the Khojak and Katawaz segments. Flysch deposition started during Late Cretaceous. Although flysch is obducted to slope and shelf sediments of Indian Plate, it is part of the Afghan Block slope.

The Indian Plate was segmented during the collision into four blocks (Figure 1), namely

- Western-Shear Zone (WSZ) in the West
- Khuzdar Block (KB) in the southwest
- Sulaiman Block (SB), east of Quetta
- Hazara Block (HB) with Islamabad region

The segmentation occurred along left-lateral basement faults, namely

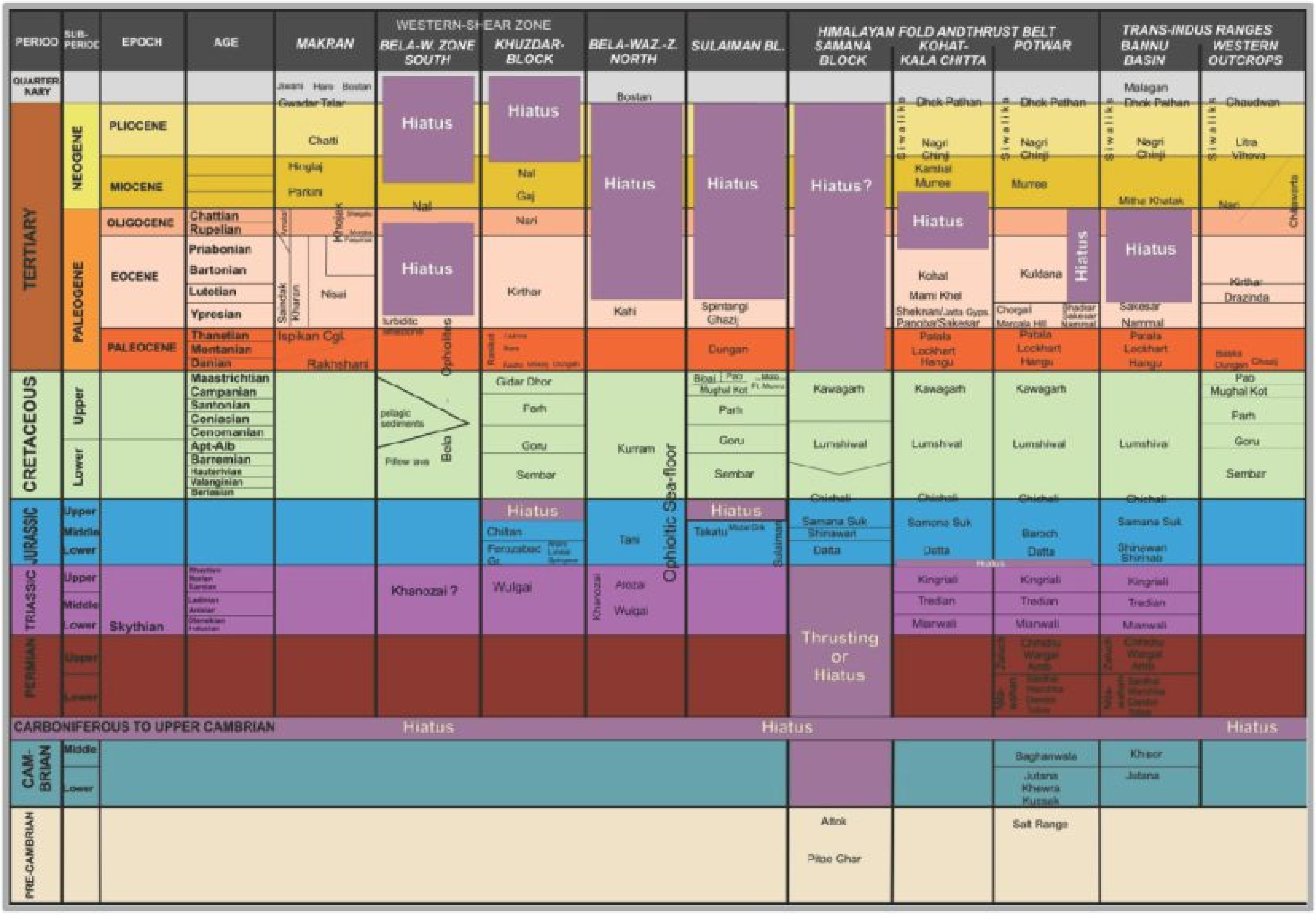
- Ghazaband Fault System
- Ornach-Nal Fault
- Kirthar Basement Fault
- Sulaiman Basement Fault and
- Jhelum Basement Fault.

Bakr and Jackson's (1964) correlation section shows the stratigraphic development of the Indus Basin which supports the concept of four tectonic blocks in Pakistan (Figure 2).

Originally the Makran-Khojak-Katawaz Flysch Zone was oriented E-W, whereas the Katawaz segment was situated south of the western Himalayan segment of the Eurasian Plate. No conclusive ages are available for the beginning of the flysch deposition. Quayyum et al. (1996) suggested a Middle Eocene to Early Miocene age for the Khojak Formation in the Katawaz segment. According to these authors, a proto-Indus delta received clastic sediments from the early Himalayan highlands. Turbidity currents fed the hemipelagic Khojak Fan, which formed a link to the large Makran Segment in the south. From the Khojak Segment to the south, off the Makran coast, the sea-floor undergoing northward subduction was covered by Neogene to recent flysch deposits. A Plio-Pleistocene submarine delta is exposed along and west of the Ornach-Nal Fault deposited by a Proto-Nal river (Bannert et al. 1992a). The delta sediments are the Hinglaj Formation (Talar Sandstone) and underlying Parkini Mudstone.

The Cretaceous / Palaeocene was the time during which the Indian Plate collided with the Afghan Block (Allemann 1979). This was followed by the indention of the Indian Plate into the southern margin of the Eurasian Plate, which generated left-lateral transcurrent faults, facilitating the northward movement of Indian Plate. The first left-lateral faults were the Chaman Fault System and Ghazaband Fault System. Both fault systems cut the Makran-Khojak-Katawaz

Table 1- Stratigraphy of the Western Fold Belt of Pakistan used in the present paper.



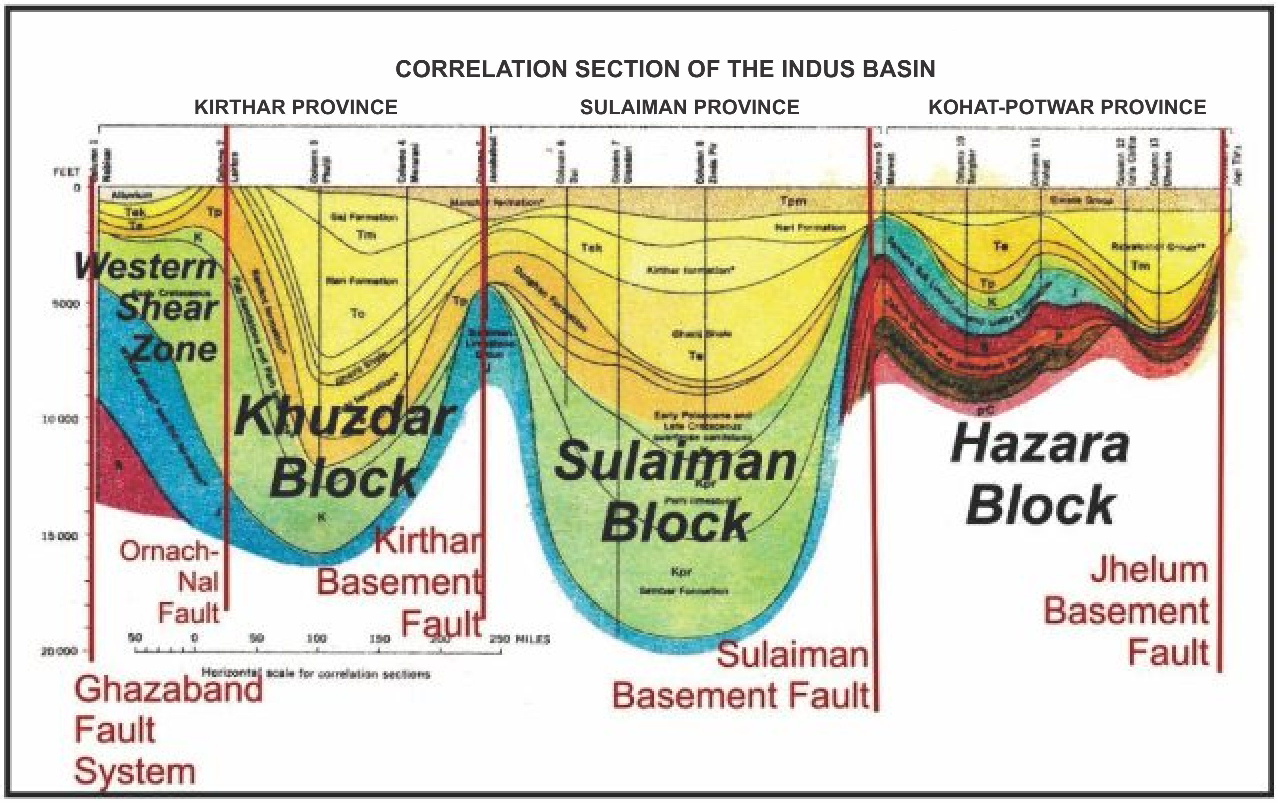


Figure 2 - Correlation section of the Indus Basin amended from Bakr and Jackson 1964. The faults shown in red are proposed by the authors.

Flysch trough and transported the Khojak-Katawaz Segment to the north. The Khojak Segment rotated anticlockwise and became elongated between the two fault systems. Along sinistral transcurrent faults, within the Khojak Segment, the earlier ± E-W folded flysch was dissected by sinistral N-S striking transcurrent faults (Figure 3), with the flysch zone reduced across strike to 40 km.

In the Makran area, the flysch occupies a 300 km wide zone oriented perpendicular to strike. Now, the Khojak Segment connects Makran Flysch with the Katawaz Basin, whereas towards the north flysch is replaced by molasse sediments from the Eurasian Plate proper (Quayyum et al. 1996). Finally, the Ornach-Nal Fault formed, which cuts across the frontal lobes of the accreted flysch west of Porali Plain. This resulted in mud intrusions west of Bela (Figure 4). In the Nushki area of the Khojak Segment, Pakistan Petroleum Ltd. carried out gravity surveys, geological mapping, and seismic data acquisition and constructed a hypothetical cross-section which resembles a large positive flower-structure between the Chaman Fault System and the Ghazaband Fault System in the west and east, respectively (Figure 5). The Khojak Segment absorbed the sinistral displacement created by the northward movement of the Indian Plate.

The **Bela-Waziristan-Ophiolite Zone** (BWZ) is characterized by the appearance of large ophiolitic bodies (Figure 6). DeJong and Subhani (1979) and Sarwar and DeJong (1984) described these large occurrences near Bela in the Porali Valley. The ophiolites are possibly of Cretaceous age similar to those of the Oman region to the SW across the Indian Ocean. Further to the north, in the Muslimbagh Segment, they are associated with the Triassic Khanozai Group.

Khuzdar Block

Bannert et. al., (1992 a and b) identified three tectonic elements in the Khuzdar Block between Karachi in the south and Quetta in the north. These tectonic elements are from west to east:

- Western-Shear-Zone with the Kalat Fold Belt
- Khuzdar Knot and Kalat Plateau
- Kirthar- Fold-Belt.

Sarwar and DeJong (1979) identified a Khuzdar-Karachi Block and considered an anti clock-wise rotation south of Kalat Plateau as being responsible for the opening of Porali Plain and convex-eastward arrangement folds of the Karachi Arc. The northern tip of Khuzdar Block is in the vicinity of Quetta, where Neogene rocks of the Sibi Re-entrant cover Mesozoic rocks of Khuzdar Block.

The **Western-Shear-Zone** tectonically alternates with parts of Makran flysch, especially in the area west of Bela (Figure 3 and 7). It is caused by subduction of the Indian Ocean sea-floor under the Afghan Block (White 1979, Dolan 1990). Coeval collision along the Ghazaband and Ornach-Nal Fault systems with a strong sinistral offset led to an alternating

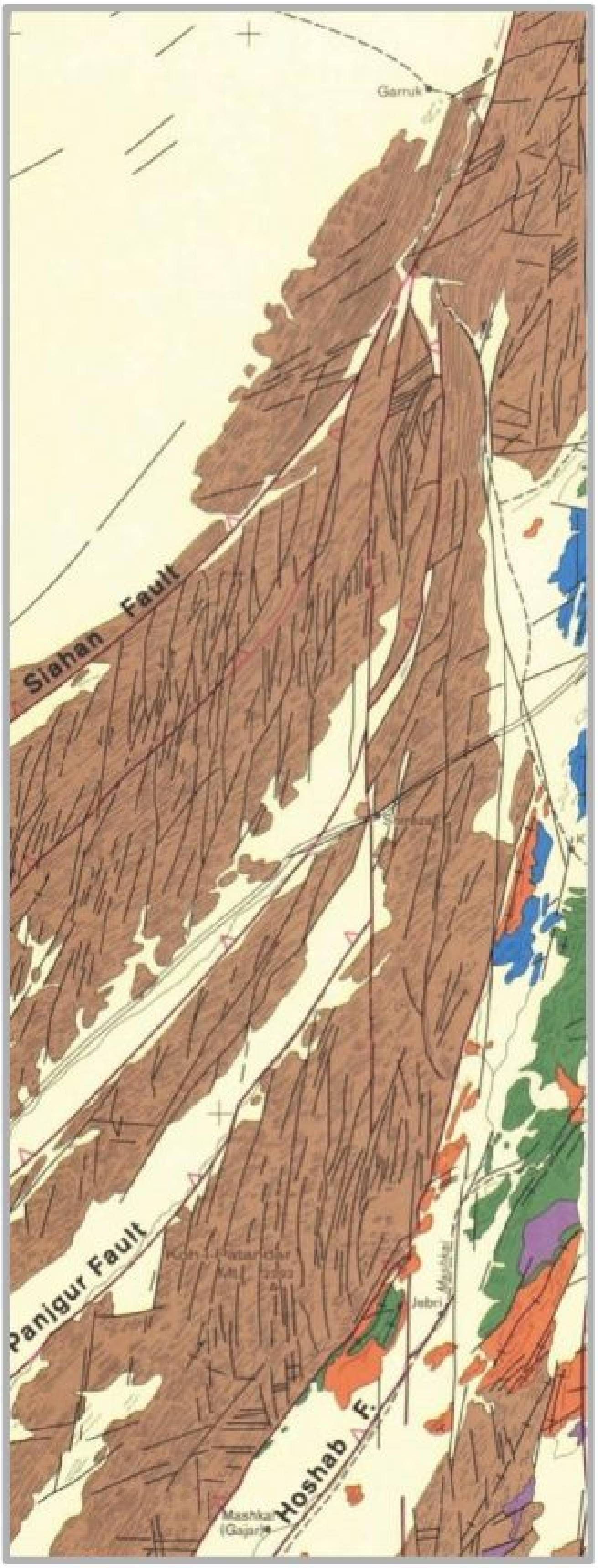


Figure 3 - Detail of Map 2 and 3 of Bannert et al. (1992a) of the southern part of Khojak Segment of the Makran-Khojak-Katawaz Basin showing the N-S faults related to the Chaman and Ghazaband fault systems. The map is 60 km wide in W-E direction. N is at the top.

assemblage of flysch and shelf sediments. They are forced into the N-S alignment of the Western-Shear-Zone. West of Khuzdar, the northern extension of the Bela ophiolites became involved into this tectonism, aswell. The Western-Shear-Zone is mainly built by Jurassic Chiltan and Shirinab formations, which is Triassic in parts and reported Permian limestone at Ghazaband Pass (Sokolov et al. 1965). The Perrmian limestone might be an olistolith embedded in Triassic rocks, which might be Khanozai Group rocks. Paleocene Dungan Formation and Eocene Kirthar Formation dominate the eastern parts of Western-Shear-Zone north of Kalat Fold Belt. Near Quetta it continues towards Zhob Valley (Figure 12). Anwar et al. **(**1993**)** proposed the Khanozai Group for Triassic formations on the basis of newly discovered Triassic fossils in previously classified Jurassic to Cretaceous rocks (Hunting Survey 1960). They might continue from Khanozai area southward into parts of the Western-Shear-Zone. However, detailed stratigraphic research and mapping still has to be carried out. Tectonically, Western-Shear-Zone and Bela-Waziristan-Ophiolite Zone seem to be in close relationship.

Khuzdar Knot

The Khuzdar Knot shows a peculiar deformation of the folds of southern and central Khuzdar Block (Figures 8 and 9). Sarwar and DeJong (1979) introduced the anti-clockwise rotational concept for the block, which resulted opening Porali Plain in the south above the Bela-Waziristan Ophiolite Zone leading to the Karachi and Hyderabad arcs adjacent to the east (Figure 7). The central part of the Khuzdar Block near Khuzdar shows NW-SE trending folds of Mesozoic sediments. However, north of 28°N the fold axes bend into a WSW-ENE.

This trend extends until Bulbul-Nur Gama Fault south east of Kalat Block.

Figure 4 - View across the massive and unbedded Hinglaj mud intrusion (H) into Pliocene Talar Sandstone (T). View goes to the east from 40 km west of Bela town.

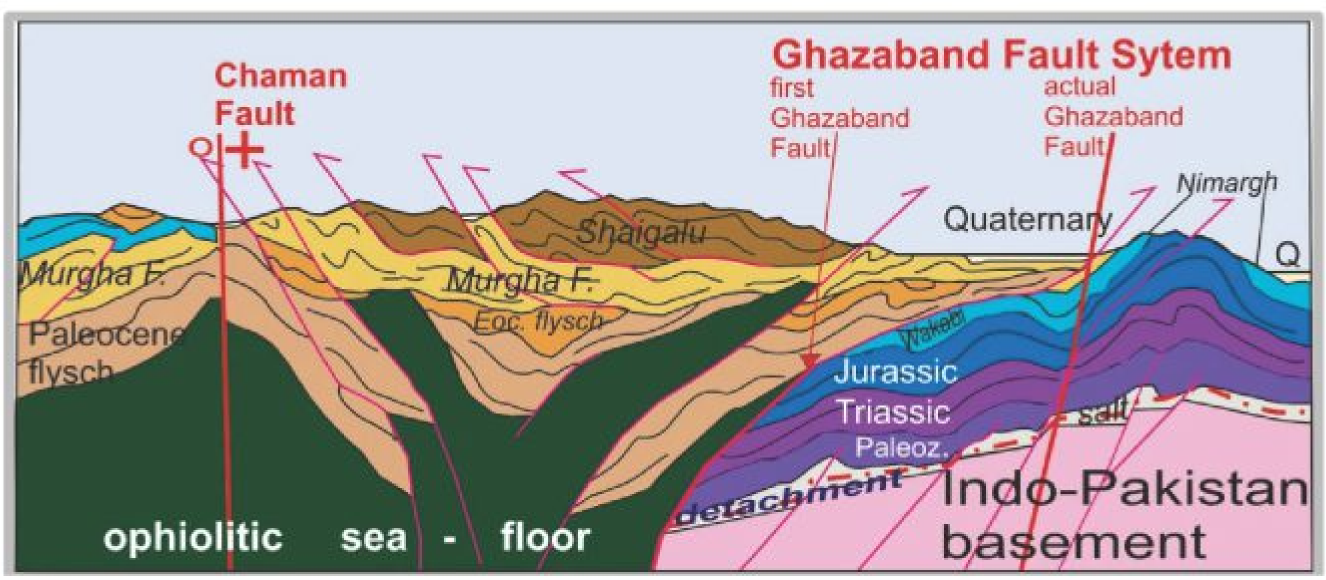


Figure 5 - Hypothetical cross-section approximately 29°30'N near Nushki through Khojak Segment of Makran-Khojak-Katawaz Flysch Trough and Western-Shear-Zone. Not to scale!

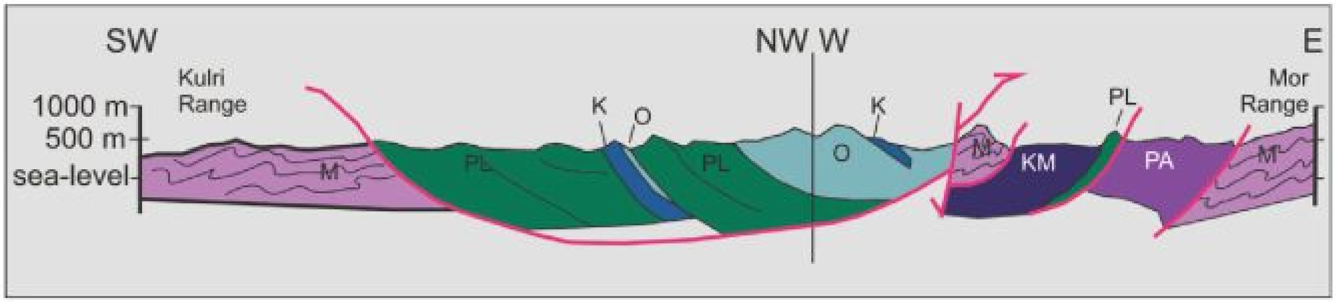


Figure 6 - Simplified cross-section through ophiolitic sea-floor between Kulri Range and Mor Range, Bela District (after DeJong and Subhani 1979, Figure 2)

K = Kuno Mélange ***KM = Kanar Mélange***
M = Mesozoic shelf of Indian Plate ***O = Bela Ophiolite*** ***PL = Pillow lava***

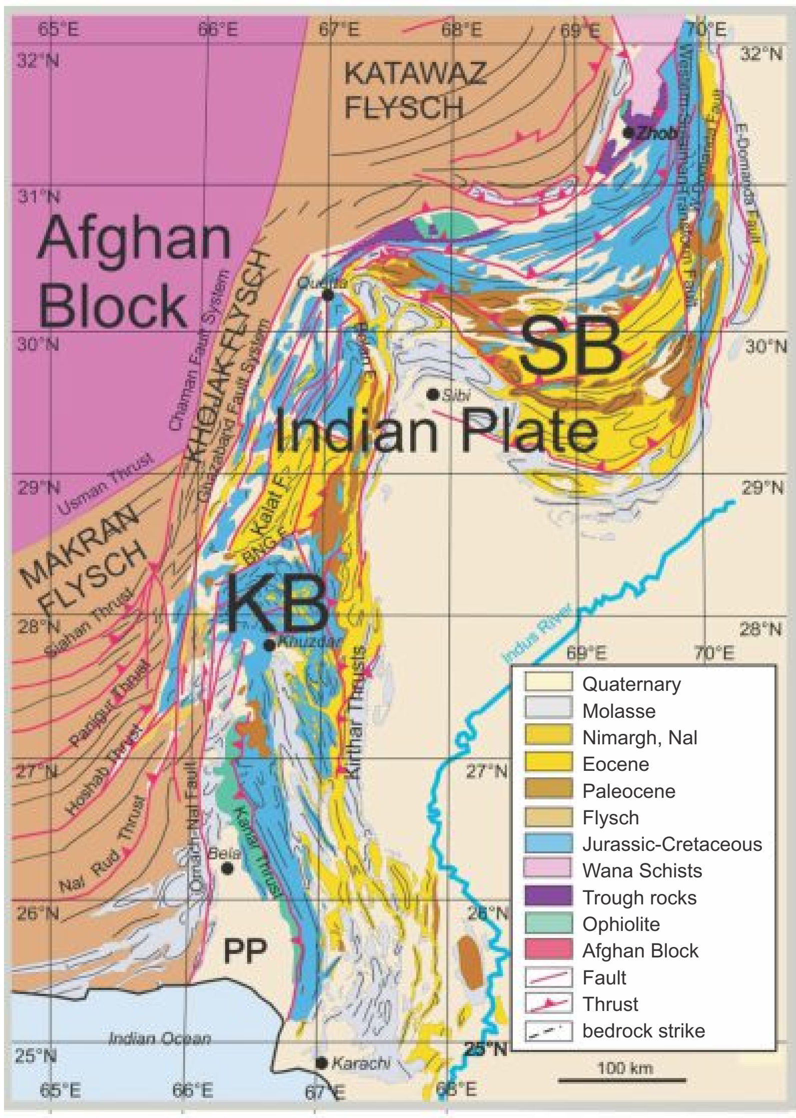


Figure 7 - The southern and central collision zone between Indian Plate and Afghan Block/Makran-Khojak-Katawaz Flysch Zone. Khuzdar Block is located N of Khuzdar town (below "KB"). The map is based on Hunting Survey Ltd. (1960), Bakr and Jackson (1964) and Bannert et al. (1992a).

KB = Khuzdar Block ***SB = Sulaiman Block*** ***PP = Porali Plain*** ***BNGF = Bulbul-Nur-Gama Fault***

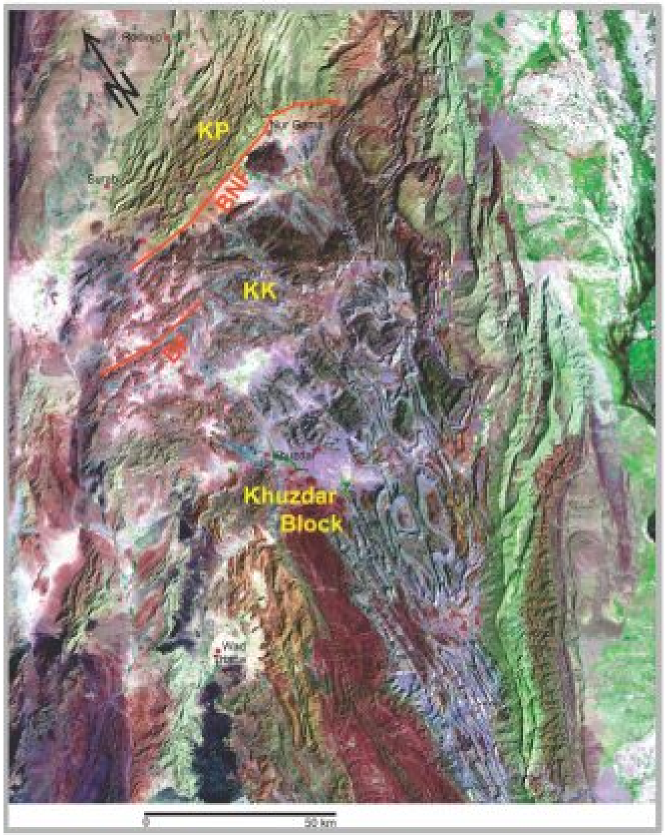
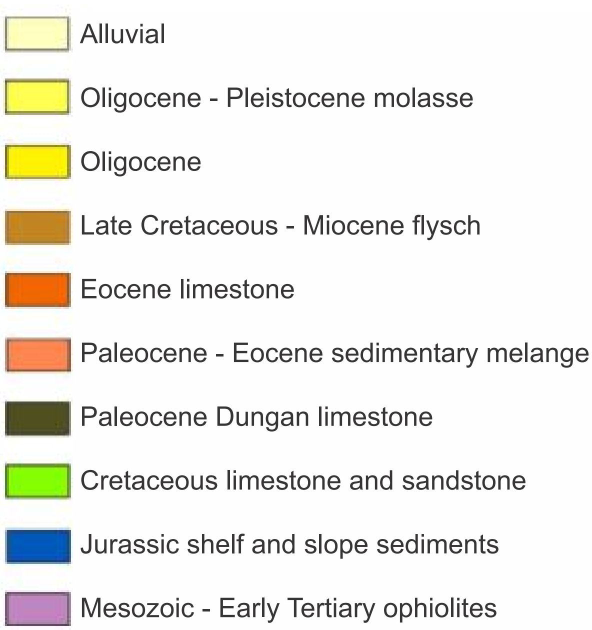


Figure 8 - LANDSAT-TM mosaic of Khuzdar Knot
BNF= Bulbul-Nur Gama Fault, DF= Diwani Fault, KB= Kalat Block, KK= Khuzdar Knot

Sarwar and DeJong (1979) named this fault Anjira-Gazan Fault and attributed a right-lateral sense of movement along this fault, which separates Kalat Fold Belt and Kalat Plateau from Khuzdar Knot. Parallel and south of Bulbul-Nur-Gama Fault Bannert et al. (1992a) identified Diwani Fault, with a sinistral sense of movement as indicated by the bend of fold axes convex to the NE between Zawa and Diwani. Khuzdar Knot is in a position where the pressure against the Ornach-Nal Fault is much higher than in the Porali Plain.

Kalat Plateau

The Kalat Plateau is located adjacent to and north of the Khuzdar Knot. The Eocene Kirthar Formation is the main rock exposed here. The western part is a fold belt and the eastern part is a plateau. Both are separated along a prominent fault, the Kirthar-Kalat- Boundary Zone (Figure 9). The position of the Kalat Fold Belt, and its deformation into anticlines and lack of intermittent synclines indicates a close relationship to the eastern part of the Western-Shear-Zone. The Kalat Plateau has a few gentle anticlines in its western part, but towards the east, the Kirthar Limestone is horizontal. Structurally the Kalat Plateau is more closely related to the Kirthar Fold-Belt, located to the east. It is a parautochtonous structure, originally belonging to the eastern part of the Western-Shear-Zone, pressed against the Khuzdar Block.



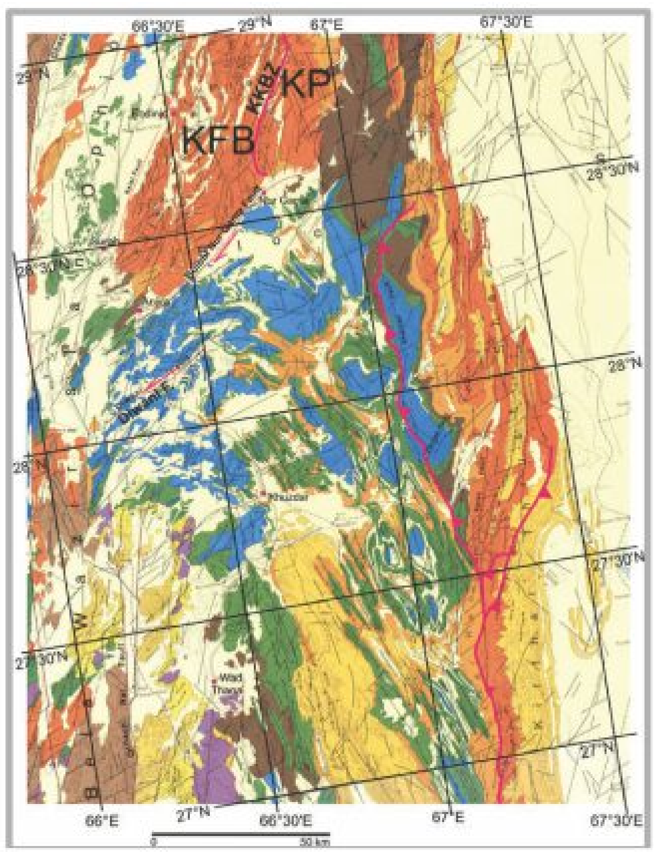


Figure 9 - Detail of Maps 2 and 3 of Bannert et al. (1992a) of the southern Kalat Plateau and Khuzdar Knot. In the E the west-vergent Kirthar Ranges are thrust to the W along the west-vergent Kirthar Thrusts, shown in dark red lines.
KFB = Kalat-Fold Belt, KP = Kalat Plateau, red lines = Kirthar-Kalat-Boundary Zone (KKBZ)

Kirthar Foldbelt

The Hunting Survey (1960) identified the west-vergent Kirthar thrusts (Figure 9), which originate from an “out-of-the-syncline” position and have their roots in the western part of Indus Fore-Deep. Below the Kirthar-Fold-Belt, Bannert et al. (1992a) assumed the presence of a N-S striking Kirthar-Basement Fault, with a sinistral displacement. The Kirthar-Basement Fault is the root for a large flower structure in the overlying sediments of Kirthar-Fold-Belt. The westward thrusts are generally located immediately to the east of the Khuzdar Knot. This is an indication of the strong W-E stress along the Ghazaband Fault System and the Sulaiman Block.

Sulaiman Block

The Sulaiman Block lies to the east of Khuzdar Block. Its eastern boundary is the Sulaiman Basement Fault (SBF in Figure 10). The N-S oriented structural pattern of the Khuzdar Block is replaced with an E-W oriented structural pattern in the Sulaiman Block. The Sulaiman Block is characterized by spectacular lobes, which have been described by Banks and Warburton (1986) as imbricate slices developed during southerly propagating piggy-back thrusting. A roof-thrust developed above the imbricate slices within the Ghazij and Goru Formations in the northern part. Jadoon et al. (1992, 1994 and 1996) provided further evidence for a thin-skinned tectonic model.

Bannert et al., (1992a) suggested that thrust sheets (KAT, KT, and PT in Figure 10) form the different lobes. These thrust sheets are generally present in the western-most part of the Sulaiman Block, east of Quetta, where Kazmi (1979) mapped the Bibai and Gogai nappes. They are overthrust by the higher Takatu and Ghundak nappes of Bannert et al. (1992a, Figure 29). Below the Bibai Nappe they identified the Kach Nappe. Bibai Nappe over-thrusts the westernmost part of the Loralai Nappe. In the Quetta area, the Khuzdar Block terminates against the Sulaiman Block. Molasse sediments of the Sibi Re-entrant (Figure 12) cover the contact zone. Sulaiman Block shelf sediments are thrust into convex-southwards lobes. The Kingri-Fault or Western Sulaiman-Transform-Fault (Bannert et al. 1992 a) forms their eastern boundary. East and north of this fault, thin-skinned tectonics is no longer present. Due to strong E-W compression a basement involved tectonic structure developed though still with remarkable nappes and klippen, which can be identified in Google Earth view (Figure 11).

BWZ	Bela-Waziristan-Ophiolite Zone
GF	Gardez Fault
GHF	Ghazaband Fault
HF	Harnai Fault
JBF	Jhelum Basement Fault
K	Kalat Plateau
KAT	Karahi Thrust
KB	Kabul Block
KBF	Kirthar Basement Fault
KF	Kumar Fault
KT	Karmari Thrust
M	Muslimbagh
MBT	Main Boundary Thrust
MMT	Main Mantle Thrust
MR	Mianwali Re-entrant
ONF	Ornach-Nal Fault
PCF	Panjshir Fault
PT	Pirkoh Thrust
Q	Quetta
SBF	Sulaiman Basement Fault
SaR	Salt Range
SF	Sarobi Fault
SR	Sibi Re-entrant
TR	Tank Re-entrant
WIC	Waziristan Igneous Complex
WSTF	Western Sulaiman Transform Fault
Z	Zhob

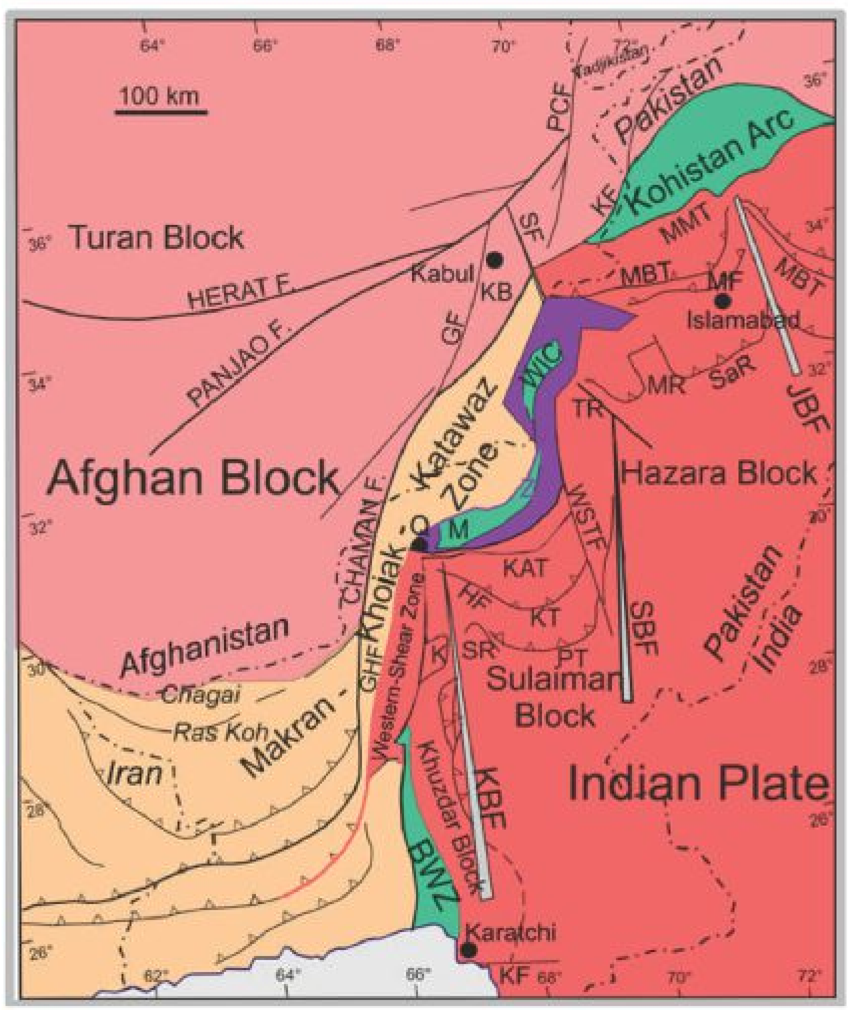


Figure 10 - Segmentation of the western India Plate in Pakistan (amended after BANNERT et al. 1992a, Figure1)

Figure 11a - Babar synform SE of Zhob (see Figure 14). Cretaceous shelf sediments with white Parh limestone as a marker bed.

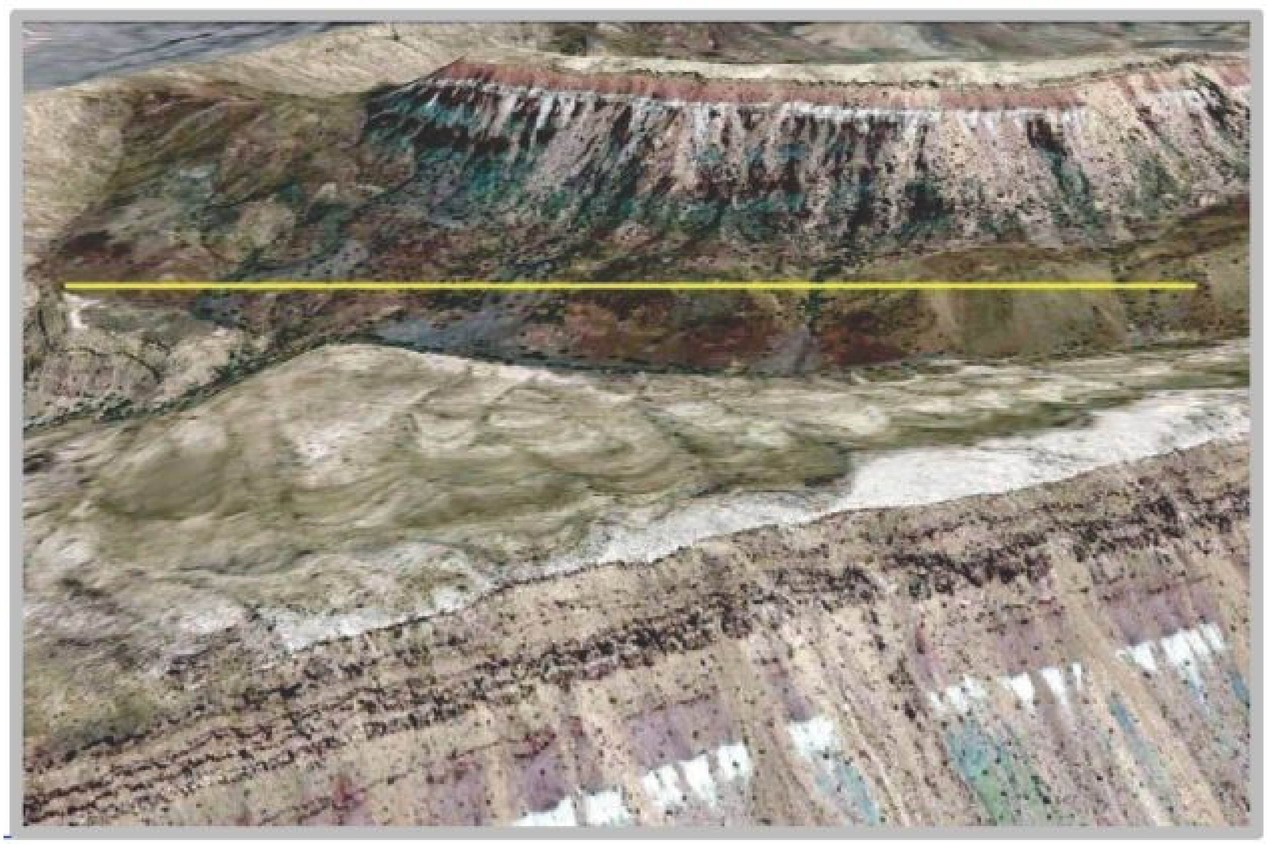


Figure 11b - Oblique view from the SW clearly showing a doubling of the sequence due to thrusting. Length of the bar = 2.5 km

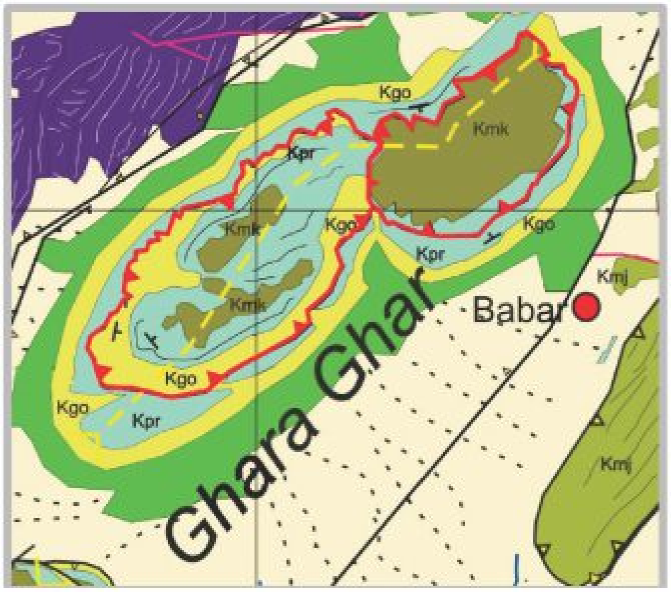


Figure 11 - Geological image interpretation map of Babar Synform.
The structure measures 18 km in SW-NE direction.
dark magenta: Khanozai Group:
dark green: Sembar Formation
Kmj: Mona Jhal Group
Kgo: Goru Formation
Kpr: Parh Formation
Kmk: Mughal Kot Formation
yellow dashed line marks the syncline axis

Bela-Waziristan-Ophiolite Zone north of 30°N

The "Quetta Syntaxis" vaguely describes the continuation of the "festoon of folds" of previous workers. In the meantime, new stratigraphic work has provided valuable information.

Anwar et al., (1993) proposed the Khanozai Group for Triassic formations on the basis of newly discovered Triassic fossils in those rocks, which were previously classified as Jurassic to Cretaceous (Hunting Survey 1960). The Khanozai Group rocks and Muslim Bagh Complex contain repeated volcanic agglomerates and conglomerates. Beck et al. 1995 described trough sediments associated with sea-floor rocks ranging in age from Triassic to Cretaceous. Near Gwal north of Quetta (Figure 12) the main part of the Bela-Waziristan Ophiolite Zone begins and can be followed along the Zhob Valley beyond the town of Zhob. Ghazaband Fault has an extension northwards named Zhob Valley Fault. It continues at least to Sur Kach (Figure 13). There, it probably follows at the base of the ophiolitic complex of Naweoba (Figure 14), which we consider to be a part of the Afghan Block fore-deep.The Katawaz Basin is thrust eastwards, including its base, the Nimargh Formation. However, this area needs a systematic field mapping in order to aive at a sound geological picture.

The Bela-Waziristan-Ophiolite Zone continues further to the east and swings northward to the south of Zhob (Figure 13). Ophiolites are apparently absent between Muslim bagh and Zhob. However, it cannot be ruled out that at least

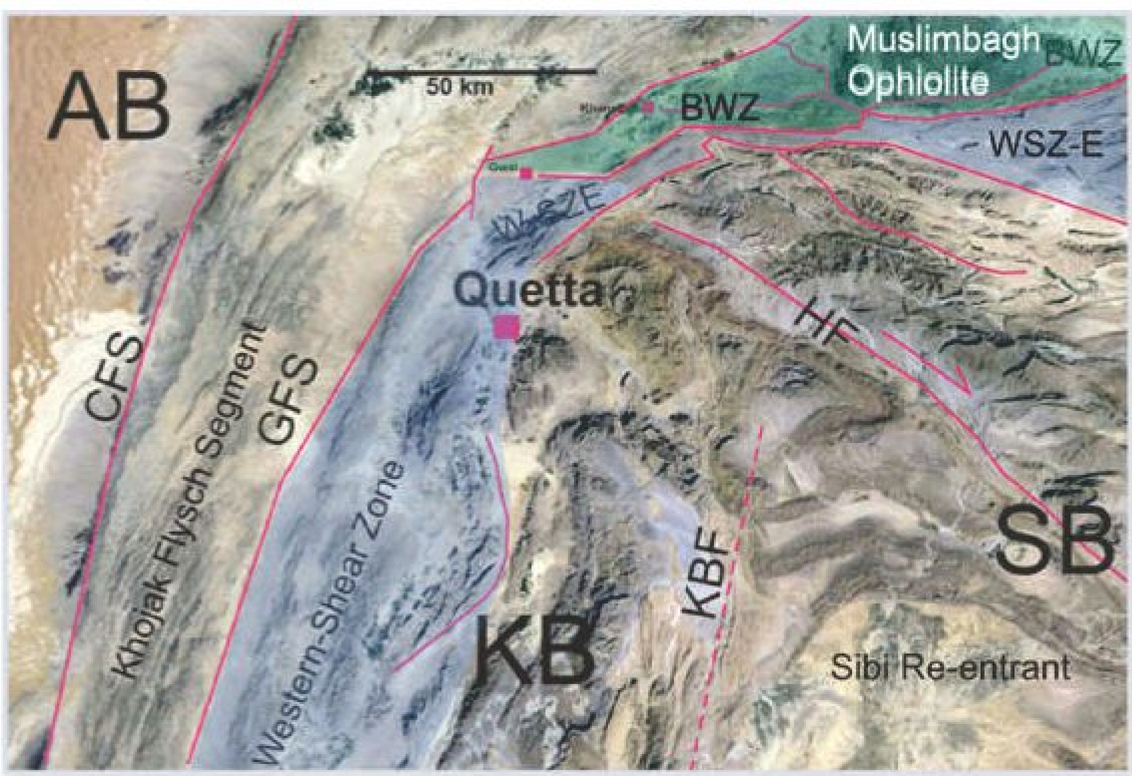


Figure 12 - GOOGLE Earth image of the Quetta area with the continuation of Western-Shear-Zone (WSZ-E) and western tip of Bela-Waziristan-Ophiolite Zone (BWZ).
AB = Afghanistan Block CFS = Chaman-Fault System GFS = Ghazaband-Fault System
HF = Harnai Fault KB = Khuzdar Block KBF = Kirthar Basement Fault
SB = Sulaiman Block WSZ-E = Western-Shear-Zone Extension.

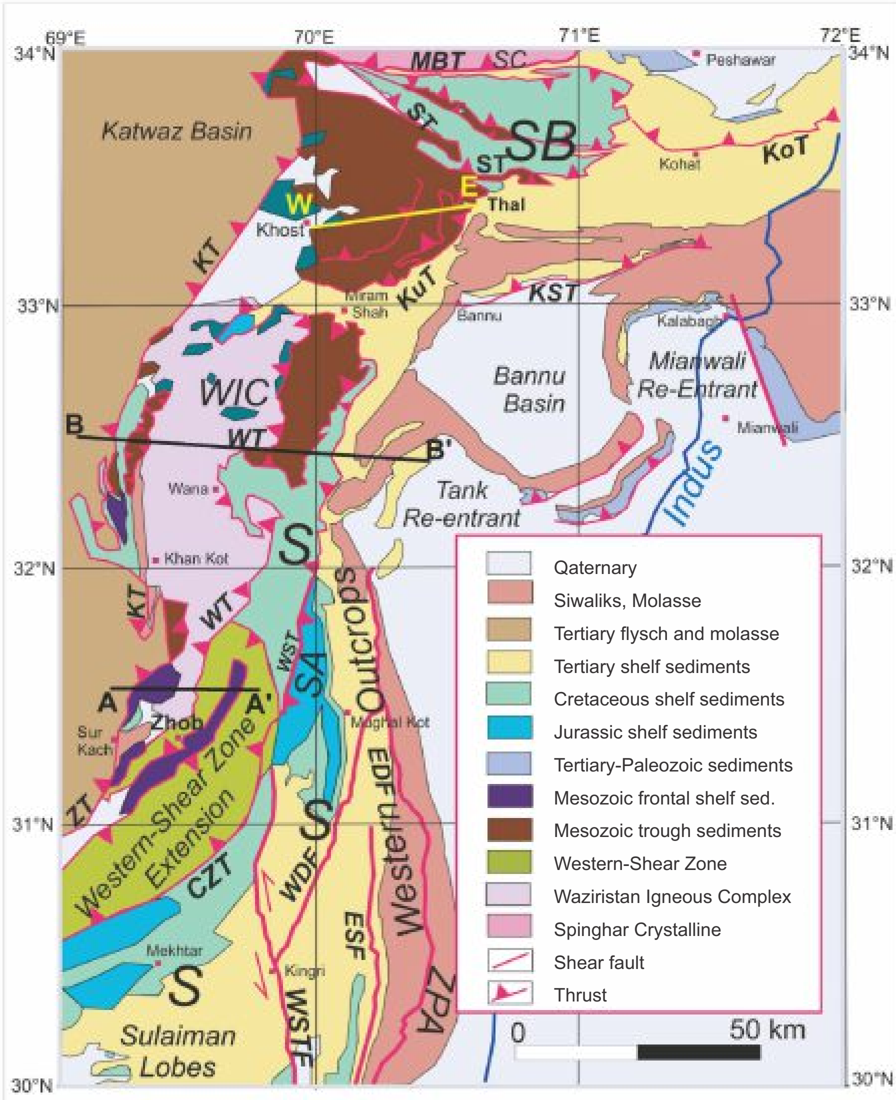


Figure 13 - Western Fold Belt, simplified structural map of the area between 34°N and 30°N west of Indus River.

Cross-sections: A-A' = Fig. 15; B-B' = Fig. 16 and W-E = Fig. 17

S = Sulaiman Block
CZT= Chinjan-Zakriazai Thrust
ESF= Eastern Sulaiman Fault
KT = Katawaz Thrust
KoT= Kohat Thrust
MBT = Main Boundary Thrust
SA = Sulaiman Anticlinorium
ST = Samana Thrust
WST = Western Sulaiman Thrust
WO = Western Outcrops
ZPA = Zindapir Anticlinorium
SB = Samana Block
EDF= Eastern Domanda Fault
KA = Khisor Anticline
KST= Basia-Khel-Surdagh Thrust
KuT = Kurram Thrust
MKA = Marwat-Kund Anticline
SC = Spinghar Crystalline
WIC = Waziristan-Igneous Complex
WT = Wana Thrust
WSTF = W-Sulaiman Transform Fault
ZVT = Zhob-Valley Thrust

volcanic inliers are present in the sediments. Definitely, this is the case south and NW of Zhob. Hunting Survey (1960) mapped vulcanite and serpentinite in the Zhob area.

Along the Zhob Valley a distinct thrust brings the Makran Flysch and its molasse sediments on top of the Bela-Waziristan-Ophiolite Zone. The Zhob-Valley Thrust (ZT in Figure 13) can be regarded by its function as the replacement of the Ghazaband-Fault System.

In the area west of Zhob, the Zhob-Valley Thrust swings to the north (Figure 13). North of Sur Kach (Figure 14), the Khanozai Group is thrust to the west over the Katawaz Murgha Faqirzai Formation. It buries the Zhob-Valley Thrust. Since the rocks of the Katawaz Flysch are of Upper Miocene to Pliocene age Helmcke et al., (1998), Quayyum et al., (1996), the present Zhob-Valley Thrust came into existence in Pliocene or more recent. Near Naweoba (1998) the same rocks are thrust to the east above the Wana Schists. It could

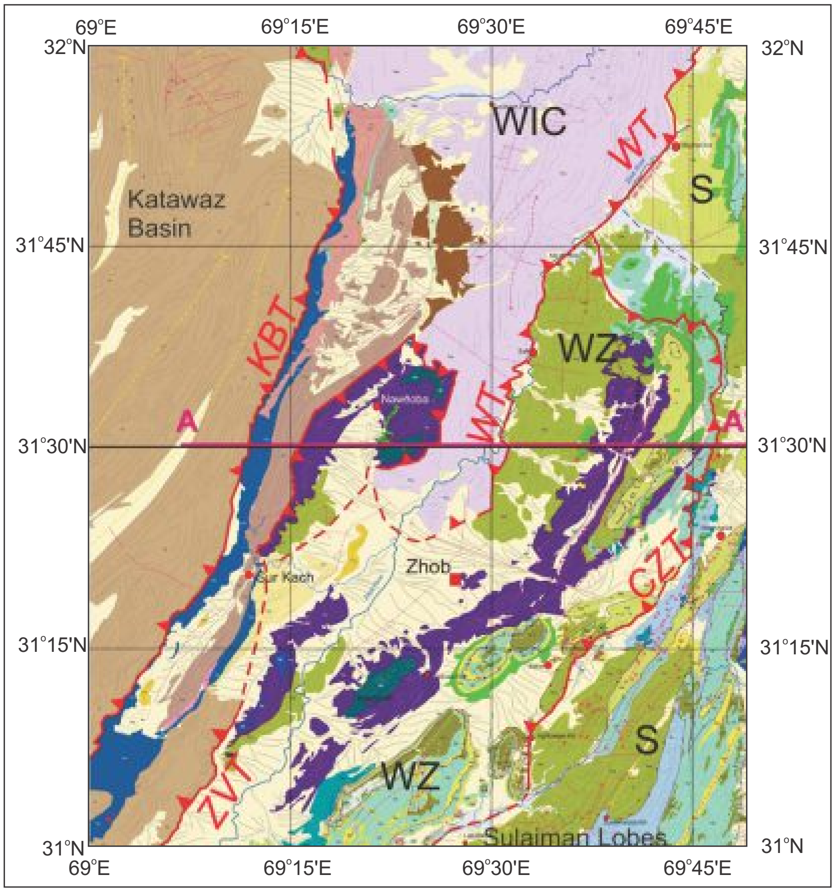


Figure 14 - Geological satellite image interpretation map of the Zhob area A - A' cross-section Figure15.

WT : Wana Thrust
KBT = Katawaz Basin Thrust
WZ = Western-Shear-Zone extension
CZT = Chinjan-Zakriazai Thrust
ZVT : Zhob Valley Thrust
WIC = Waziristan-Igneous Complex
S = Sulaiman Block

Tf: Katawaz Flysch
Qb: Bostan Formation
Tni: Nisai Formation
Kmj: Mona Jhal Group
Kmk: Mughal Kot Formation
Jlo: Loralai Formation
Trk: Khanozai Group
UB: Ultramafic rocks
Tmf: Murgha Faqirzai Formation
Tmu: Multana Formation
Ksm: Sembar Formation
Kgo: Goru Formation
Kpr: Parh Formation
Jsp: Spingwar Formation
Tk: Kurram Group
Pws: Wana Schists

be regarded as a flower structure with the Sembar Formation in the core and ophiolitic rocks along the thrust (Figure 15).

The Wana Schists are of epimetamorphic grade (Badshah et al. 2000) and are of Paleozoic age. Epimetamorphic schists are often associated with ophiolites. The Wana Schists have been included into the Tethys II sea-floor in this paper until further fieldwork and studies have been done to clarify their origin.

The Waziristan-Igneous Complex (WIC in Figure 14) splits the outer shelf sediments of the Khanozai Group rocks into two segments. The Waziristan-Igneous Complex is obducted from the west onto shelf sediments. It is embedded in trough sediments of the Kurram Group, Kahi and Tani mélange. The eastern thrust is the Wana Thrust (WT in Figure 14). The northern part of the Sulaiman Block becomes increasingly overwhelmed by the mélanges. The Sulaiman Anticlinorium is built by competent Jurassic limestone and reacts with a major west-vergent thrust along the western flank. Locally, along the eastern flank only smaller east-verging thrusts appear. However, along the eastern flank, a monocline of Tertiary shelf and molasse rocks of the Western Outcrops follows and finally disappears below the flood plain of Indus Fore-deep.

North of 32°N the geological situation between the Katawaz Basin Thrust (KBT in Figure 13) and Waziristan-Igneous Complex was mapped from satellite imagery. There is no ground control. Treloar and Izatt (1993) assumed the presence of a Katawaz Basin thrust above the trough rocks of the former Sulaiman Fore deep.

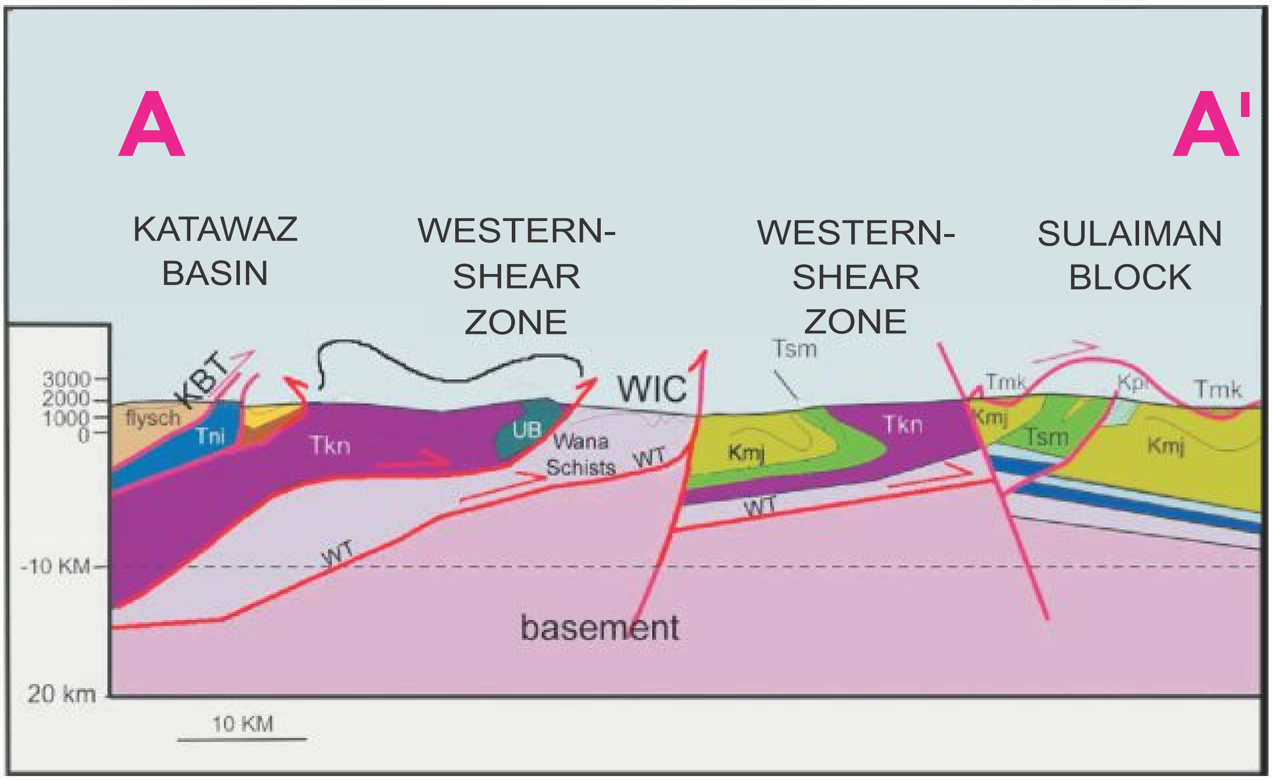


Figure 15 - Geological cross-section along line A A' of Figure 14 showing basement involved tectonics

Qbo = Bostan Formation ***Tn = Nisai Formation*** ***Kmj = Mona Jhal Group***
Tmf = Murgha Faqirzai ***Kmk = Mughal Kot Formation*** ***Ksm = Sembar Form.***
Jlo = Loralai Formation ***Jsp = Spingwar Form.*** ***Trk = Khanozai Group***
KBT = Katawaz Boundary Thrust ***WIC = Waziristan Igneous Complex*** ***UB = Ophiolite***

The Waziristan-Igneous Complex (Jan et al. 1985) is in tectonic contact with the underlying Wana Schists and Kurram Group units. On LANDSAT-ETM images the entire Waziristan-Igneous Complex is characterized by an east-west orientation of the rocks. In the central part ± west-east oriented anticlines can be observed. According to Jan et al. (1985) the Waziristan-Igneous Complex was tectonically emplaced during the Paleocene to early Eocene. It consists of ultramafic rocks, gabbros, sheeted dikes, pillow lavas, and pelagic sediments-a typical ophiolite suite. Beck et al. (1995) mentioned a high-pressure amphibole and pyroxene mineral composition. Other volcanic components include dacite, rhyodycite, andesite, tuff, volcanic breccias and agglomerate of typical arc composition comparable to the Kohistan Arc. The tuff in the upper part precludes a mid-ocean-ridge origin. Interbedded Albian carbonate indicate a post Early Cretaceous age.

Badshah et al., (2000) mentioned low-grade metamorphic rocks underlying the Waziristan-Igneous Complex. These rocks are considered metamorphosed rocks of shelf origin, such as the Chiltan Limestone and Pab Sandstone. We consider the epi-metamorphic Wana Schists to be part of the Tethys II sea-floor. The Waziristan-Igneous Complex documents a change in tectonic overprinting allowing the conclusion of its northern origin from a volcanic arc obducted from the trench of the Eurasian subduction zone. It signals the end of the strike-slip collision tectonics accompanying Western Pakistan from the shores of the Arabian Sea.

North of 32°30'N a large area is covered by the Tani and Kurram groups. Near Khost (Afghanistan) Kaever 1967 found Tani Group of Late Jurassic and Lower Cretaceous age transgressing ophiolitic sea-floor volcanics. The Kurram Formation overlies the Tani Formation near Khost.

The Tani and Kurram groups do not belong to the shelf sediments of the Indo-Pakistan Plate but belong to the Tethys II sea-floor sediment cover. (Badshah et al. 2000 and Tapponier et al. 1981), found Permian and Triassic fossils in the Kurram Group near Khost. Therefore, Badshah et al. 2000 suggested a Triassic to Late Cretaceous age for the Kurram Group. Still the problem persists, whether the Tani Group is part of the Kurram Group, or older, or younger. An exact location of future fossil evidence could help to solve the problem. From satellite images, the Tani Group and the overlying Kurram Group can be separately mapped based on Kaever's map.

The Tani Group consists of 1200 m of marine sediments. Shale and sandy limestone alternate form the base upwards. Towards the top, the amount of limestone is highly reduced and the group contains plant remnants of Gondwana affinity (Kaever 1967). Badshah et al.,(2000) reported the presence of Kurram thrust sheets with pillow lavas.

Several nappes or thrust sheets were identified on satellite imagery shown along a hypothetical cross-section (Figure 17). The Kurram Thrust (KuT on Figure 13) can be mapped from its intersection with SE-to-E striking Samana Thrust (ST on Figure 13).

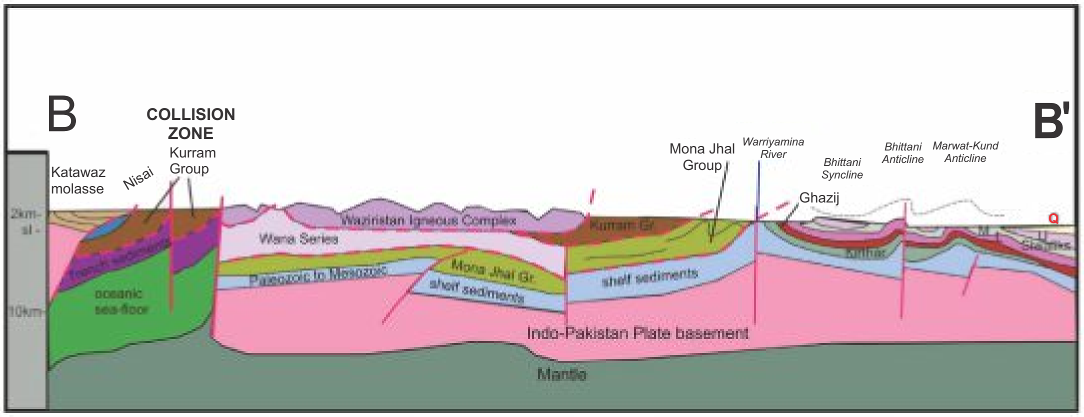


Figure 16 - Geological cross-section through the Waziristan-Igneous Complex and adjacent areas. Near A is the eastern edge of the Afghan Block assumed to underlie part of the Katawaz Basin. Cross-section along 32°30'N. A = 69°40'E; B = 70°28'E.

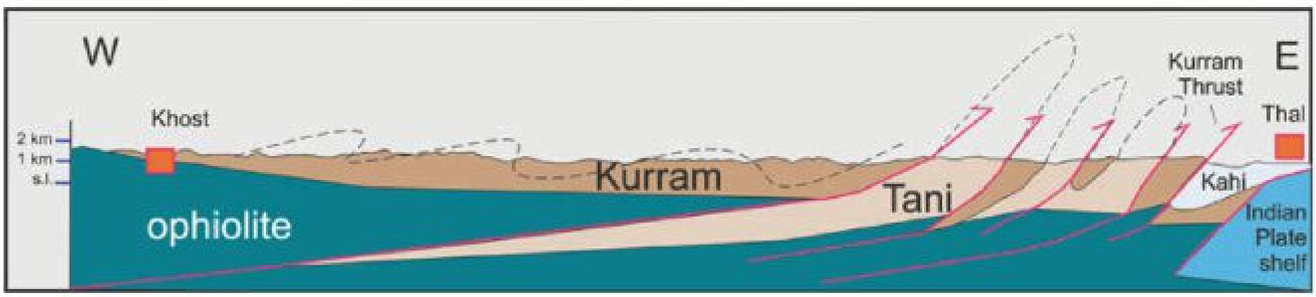


Figure 17 - Cross-section through the trough sediments of the Tethys II sea-floor along 33°30' N between Khost (Afghanistan) and Thal (Pakistan).

The Kurram Thrust is a transcurrent fault. It follows the Kurram River until Thal. There, it swings to the SW as a frontal thrust. It is, however, not the easternmost boundary, where Kurram Group rocks have been mapped. Meissner et al.,(1975) mapped further occurrences as tectonic windows or half-windows in the Samana Block. Samana Block consists mainly of Jurassic and Cretaceous shelf sediments south of Main Boundary Thrust (Figure 13)

The Northern end of Sulaiman Block

The Sulaiman Basement Fault is located below the Sulaiman Anticlinorium (SA in Figure 13) and west of the Zindapir Anticlinorium (ZPA in Figure 13). The major structures in the overlying shelf sediments have developed as flower-structures (Iqbal M. 2004). Quaternary sediments of the Tank Re-entrant obscure the northern termination of the Sulaiman Basement Fault. Most likely, it is cut or offset by a NW-striking dextral strike-slip fault below the Marwat-Kund Anticline, the western frame of Bannu Basin. This fault is in extension of the Sargodha High south of Potwar Plateau.

The Sulaiman Block east of the Western-Sulaiman-Transform Fault and its northern extension, the Western Sulaiman Thrust, becomes narrower. The Western Outcrops of the Middle Indus Basin thrust (Figure 13) have a mostly moderate, monoclinal dip to the east. They show deformation associated with the Waziristan-Igneous Complex and Kurram thrust sheets from the west. In the Miram Shah area, only Tertiary rocks are present, striking in a north easterly direction. The Tertiary rocks are of shallow water facies and molasse facies follows.

Samana Block

Jurassic to Cretaceous marine sediments dominate the thrust sheets of the Samana Block, west of Thal-Kohat line. Khan and Abbas (2011) called this unit the Samana Block and defined the Jurassic and Cretaceous rocks as belonging to the Outer Himalayas. They have been over-thrust onto the mainly Tertiary rocks of the Kohat Plateau. Meissner et al (1975) mapped several tectonic nappes of Jurassic and Cretaceous age rocks thrust upon each other. Intercalated are thrust sheets of Kurram Group rocks. Emplacement of the Samana thrust sheets is younger than emplacement of the Kurram thrust sheets and compare with the emplacement of the Waziristan-Igneous Complex north of Wana, which has an internal W-E orientation, pointing to a northern origin.

Spinghar Block

Khan and Abbas (2011) mentioned low grade metamorphic rocks similar to those of the Hazara area in the east (Spinghar Crystalline in Figure 13). The Block in the north is thrust along the Main Boundary Thrust (Iqbal and Bannert 1998) over Tertiary and Mesozoic rocks of the Samana Block. The Main Boundary Thrust dips rather steeply to the north.

CONCLUSIONS

The Western Indian Plate/Afghan Block collision zone has three segments with different tectonic styles. From the Indian Ocean to Quetta in the north the tectonics are determined by a zone with strong, left-lateral shearing in an N-S direction confined to the western part of Khuzdar Block. We call this the Western-Shear-Zone.

Between Quetta and Zhob, there are strong indications for the continuation of the Western-Shear-Zone rocks but with thrusting to the south and southeast in the Zhob area. It is a continuation of Khuzdar Block integrated into the tectonics of the northern Sulaiman Block Fold belt. Adjacent and to the north of the Western-Shear-Zone extension, widespread deeper slope sediments of the Khanozai Group are present. They overlie basic to ultrabasic volcanics and ophiolites of the Tethys II sea-floor.

North of Zhob epimetamorphic Wana Schists of unknown age are thrust to the east. We cannot rule out that they are part of the ophiolitic sea-floor of the Waziristan- Igneous Complex. The strike of the rocks is ± N-S. The Waziristan-Igneous Complex in most areas strikes W-E and might be thrust from the north over the Wana Schists. West and east of the Wana Schists and the Waziristan-Igneous Complex, a thick series of Mesozoic trench sediments appear which are thrust from the NW to the SE. They have their origin on the Afghan side, where they transgress over ophiolitic sea-floor in the vicinity of Khost.

West of Kohat, the structures described are thrust from the north and include Mesozoic hemipelagic limestone series of the south-vergent Samana Block. In the north, the Main Boundary Thrust originates from the north and includes Spinghar Crystalline rocks in its hanging wall. Tectonically, we are in the sub-Himalayan belt above the Eurasian subduction zone.

In many areas of Pakistan, the shelf sediments of the NW Indian Plate are hydrocarbon source rocks and reservoir rocks. A better understanding of the tectonic structures will open ways to determine further prospecting targets.

REFERENCES

Allemann, F. 1979: Time of emplacement of the Zhob Valley Ophiolites and Bela Ophiolites in Farah and DeJong (eds.): Geodynamics of Pakistan, 215-221, 1 fig. Geol Surv. Pakistan.

Anwar, M., A.N. Fatmi and I.H. Hyderi 1993: Stratigraphic analysis of the Permo-Triassic and lower-middle Jurassic rocks from the “Axial Belt” region of northern Balochistan region Geol. Bull. Punjab Univ., 28, 1-28.

Badshah,M.S., B. Gnos, M.Q. Jan, and M.I. Afridi , 2000: Stratigraphic and tectonic evolution of the northwestern Indian plate and Kabul block In: Tectonics of the Nanga Parbat Syntaxis and the western Himalaya (Khan, M.A., P.J. Treloar, M.P. Searle and M.J. Jan eds.) Geol. Soc. Spec. Publ. No. 170, 467-475.

Bakr, M.A. and R.O. Jackson 1964: Geological Map of Pakistan Geol. Surv. Pakistan.

Banks, C.J. and Warburton, J. 1986: Passive-roof” duplex geometry in the frontal structures of the Kirthar and Sulaiman mountain belts, Pakistan Journ. of Structural Geology, vol. 8, Nos. 3 and 4, 229-237, 9 figs.

Bannert, D., A. Cheema, A. Ahmed and U. Schäffer 1992a: The Structural Development of the Western Fold Belt, Pakistan Geol. Jahrbuch, Reihe B, Heft 80, 60 ps., 44 figs., 1 table, 1 map (3 sheets).

Bannert, D. and H.A. Raza 1992b: The Segmentation of the Indo-Pakistan Plate Pak. J. Hydroc. Res., vol. 4, 5-18, 7 figs.

Beck, R.A., D.W. Burbank, W.J. Sercombe, G.W. Riley, J.K. Barndt, J.R. Berry, J. Afzal, A.M. Khan, H. Jurgan, J. Mettje, A. Cheema, N. A. Shafique, R. D. Lawrence and M.A. Khan 1995: Stratigraphic evidence for an early collision between northwest India and Asia Nature, Vol. 373, 55-58, 3 figs.

Bender, F. and Raza, H. A. (eds.) 1995: Geology of Pakistan 414 pages, 3 geol. Maps Gebr. Borntraeger, Berlin, Stuttgart.

Dolan, P. 1990: Pakistan: a history of petroleum exploration and future potential in Brooks, J. (ed.) 1990: Classic Petroleum Provinces, Geol. Soc. Spec. Publ., 50, 503-524.

Kees A. And Ghulam Sarwar 1984: Composition and origin of the Kanar Melange, southern Pakistan Geol. Soc. Of America, Spec. Paper

Farah,A. and K.A. Dejong (eds.) 1979: Geodynamics of Pakistan Geol. Surv. of Pakistan, Quetta

Helmcke, D., Vollbrecht, A. and Kan Zaw 1998: Strukturelle Interpretation eines Abschnittes der Pishin Flysch Zone in West Pakistan nach LANDSAT-TM Daten Freiberger Forschungsheft, C 475, 163-172, 6 figs.

Hunting Survey Corporation Ltd. 1960: Reconnaissance Geology of Part of West Pakistan Maracle Press Ltd. Ottawa, Canada.

Iqbal, M. and D. Bannert 1998: Structural observations of the Margala Hills, Pakistan and the nature of the Main Boundary Thrust Pak. Journ. Hydroc. Research, vol. 10, p.41-53,5 figs., 2 tabs, 2 appends.

Iqbal, M. 2004: Structural Interpretation of Zindapir Anticlinorium Sulaiman Fold Belt, Pakistan and its Petroleum Prospects 190 pp., 86 figs., 3 tab., 1 geol. map - Diss. Univ. Punjab, Lahore, Pakistan.

Jadoon, I.A.K. 1990: The Style and Evolution of Foreland Structures: An Example from the Sulaiman Lobe, Pakistan Pak. J. H.R.,vol.3, 2, 1-17, 15 figs.

Jadoon, I.A.K., R.D. Lawrence and R.J. Lillie 1992: Balanced and retrodeformed geological cross-section from the frontal Sulaiman Lobe, Pakistan: Duplex development in thick strata along the western margin of the Indian Plate in: McClay (edit.): Thrust Tectonics.

Jadoon, I.A.K. and D. HELMCKE 1996: LANDSAT-TM and SPOT image interpretation of an active fault system in the central Sulaiman Lobe, Pakistan 11th Himalayan-Karakoram-Tibet Workshop 1996- Terra Nova, 8,4.

Jadoon, I.A.K., and A. Khurshid 1996: Gravity and tectonic model across the Sulaiman fold belt in western Pakistan and eastern Afghanistan Tectonophysics , 254, 1-2, 89-109, 9 figs.

Jadoon, I.A.K. and R.D. Lawrence 1994: Mari-Bugti pop-up zone in the central Sulaiman fold belt, Pakistan J. Struct. Geol., vol. 16, 2, 147-158, 9 figs.

Jadoon, I.A.K., R.D. Lawrence and S.H. Khan 1994: Mari-Bugti pop-up zone in the central Sulaiman fold belt, Pakistan J. of Structural Geol., 16, 2, 147-158, 5 figs.
Jadoon, I. A. K. , K. M. Bhatti , F. I. Siddiqui , S. K. Jadoon, S. R.H. Gilani , M. Afzal 2007: Subsurface Fracture Analysis In Carbonate Reservoirs: Kohat/Potwar Plateau, North Pakistan - Pakistan Journal of Hydrocarbon Research Vol. 17, (June 2007), p.73-93, 18 Figs., 1 Table.
Hemphill, W.R., Kidwai, A.H. and Sibghatullah 1973: Geological Map and sections of the Dera Ismail Khan Quadrangle, Pakistan USGS Prof. Paper, 716-B
Jan, M. Q., B. F. WINDLEY and A.KHAN 1985:The Waziristan ophiolite, Pakistan; general geology and chemistry of chromite and associated phases - Economic Geology, v. 80, no. 2, p. 294-306.
Kaever, M 1967a: Zur Geologie des Gebietes von Khost und Yakubi SE Afghanistan Neues Jb. Geol. Pal. Monatshefte, 6, 361-383.
Kazmi, A.H. 1979: The Bibai and Gogai Nappes in the Kach-Ziarat Area of Northeastern Baluchistan In: Farah and DeJong (eds.): Geodynamics of Pakistan, 333-339, 3 figs. Geol Surv. Pakistan.
Kazmi, A.H. and I. A. Abbasi 2008: Stratigraphy and historical Geology of Pakistan National Centre of Excellency in Geology, Peshawar - 524 pp.
Kazmi, A.H. and M. Quasim Jan 1997: Geology and Tectonics of Pakistan Graphic Publishers, Karachi 554 pp.
Kahn, M.A., And M. Abbas 2011: Interaction between the Himalayan and India-Afghan Collision Tectonics at the NW margin of the Indian Plate in the Kurram Region, NW Pakistan 26th Himalaya-Karakoram-Tibet Workshop, Canmore, Canada, July 12-13, 2011 Journ. of Himalayan Earth Siences, 44,1, p. 42-43 1 fig.
Meissner, C.R., M. Hussain, M.A. Rashid and U.B. Sethi 1975: Geology of the Parachinar Quadrangle, Pakistan USGS Prof Paper 716-F, 24 p.
Qayyum, M., A.R. Niem and R.D. Lawrence 1996: Newly discovered Paleogene deltaic sequence in Katawaz-basin, Pakistan, and its tectonic implications GEOLOGY, 24 (9), p. 835-838.
arwar, G. and K.A. Dejong 1984: Composition and origin of the Kanar Melange, southern Pakistan -. Geol. Soc. Of America, Special Papers v. 198, p. 127-138
Sarwar, G. and K.A. Dejong 1979: Arcs, Oroclines, Syntaxes: the Curvatures of Mountain Belts in Pakistan in Geodynamics of Pakistan FARAH,A. and K. A. DeJONG (eds.) 341-349 Geol. Surv. of Pakistan, Quetta
Shah, S.M.I. 2009: Stratigraphy of Pakistan Geol. S. Pakistan, Mem. 22, 381 pages.
Shah, S.M.I. 1977: Stratigraphy of Pakistan Geol. S. Pakistan, Mem. 12, 138 pages, 13 figs., 4 tbl.
Shafique, Naseer Ahmed 2001:Spatial Biostratigraphy of NW Pakistan- Dissertation Miami University, Oxford, Ohio, 137 pages.
Sokolov, B.A. and Shah, S.H.A. 1965: The occurrence of Permian sediments near the Ghazaband Pass, Quetta District, West Pakistan Punjab Univ. Geol. Bull. 5, 15-22, 2 figs. Lahore.
Tapponier, P.; M. Mattauer, F. Proust and C : Cassaigneau 1981 : Mesozoic ophiolites, sutures and large scale tectonic movements in Afghanistan Earth and Planetary Science Letters, 52, 355-371 Elsevier Sc. Publ. Amsterdam
Treloar, P. J. and Izatt, C. N. 1993: Tectonics of the Himalayan collision between the Indian Plate and the Afghan Block: a synthesis in TRELOAR and SEARLE Himalayan Tectonics, Geol. Soc., Spec. Publication No. 74, 69-87, 10 figs.
White, R.S. 1979: Deformation of the Makran Continental Margin - in Geodynamics of Pakistan Farah, A. and K. A. DeJong (eds.) 295-304 Geol. Surv. of Pakistan, Quetta.