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# The Segmentation of the Indo-Pakistan Plate

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## ABSTRACT

**The Kirthar and Sulaiman ranges of western Pakistan and the Kohat and Potwar area adjacent to the northeast have been structurally analyzed using Landsat-MSS colour and black and white images at a scale of 1:250,000, literature studies, and a limited field survey. The pattern of tectonic deformation caused by the collision of the Indo-Pakistan Plate with the Eurasian Plate have been analyzed. Tethyan oceanic crust covered by Triassic through Early Tertiary sediments, are preserved between the Eurasian Plate and the Indo-Pakistan Plate and called the Bela-Waziristan Ophiolite Zone.**

**The oblique collision of the Indo-Pakistan Plate with the Eurasian Plate forced the Indo-Pakistan Plate to rotate in an anticlockwise mode. The collision further opened a number of basement faults that segmented the western part of the Indo- Pakistan Plate - mostly on Pakistan territory - into several basement blocks, which were involved en-echelon in the collision. They are the Kirthar Basement Fault in the southwest, the Sulaiman Basement Fault, and the Jhelum Basement Fault in the northeast. The deformation of the sediments of the Indo-Pakistan Plate during the collision resulted in different tectonic patterns on the individual basement blocks.**


## INTRODUCTION

In the area W of the Indus river in Pakistan (here referred to as West Pakistan Fold Belt) is the collision zone between the Indo- Pakistan Plate arriving from the S and the Eurasian Plate in the W and N (Figure 1). The Afghanistan Block, in pre-Mesozoic times a part of Gondwana collided during the Late Jurassic/Early Cretaceous with the southern Eurasian Plate (Tapponnier et al., 1981). Remnants of the Neo-Tethyan sea-floor form a conspicuous ophiolitic zone between the Eurasian Plate (Afghanistan Block and Kabul Block) and the Indo-Pakistan Plate.

The geological literature of Pakistan referring to the Western Fold Belt and the Kohat-Potwar area (Figure 1) only recently provided information necessary to arrive at a better analysis of the mechanics of the continent-to-continent collision of the Indo-Pakistan Plate with the Eurasian Plate. Hunting Survey Corp. (1961) provided an excellent geological map, as well, as a wealth of geological observations. Wilson (1965) and Abdel-Gawad (1971) described the long N-S transcurrent Chaman Fault in the western part of the area under discussion. Sarwar and DeJong (1984) related the deformation of the area between the converging Eurasian Plate in the N and the Indo-Pakistan Plate in the S to the development of strike-slip faults and associated detachment tectonics in the segments inbetween. They all, however, followed the concept of a continuous fold belt, the Kirthar-Sulaiman mountain belt of Stoecklin (1977). This mountain belt extends from the southern Khuzdar Block northwards for approximately 600 km, bends towards the SE in the Quetta Syntaxis, continues in the Loralai Lobe (Hunting Survey Corp. 1961), and finally coalesces in the NE with the Trans-Indus Ranges and the Salt Range of Kohat and Potwar (Sarwar and DeJong, 1984).

The Neo-Tethys is represented in the ophiolitic rocks E of the Afghanistan Block. In western Pakistan, the Neo-Tethys consists of two ophiolitic zones. The first is the Bela-Waziristan Ophiolite Zone in eastern Balochistan and Waziristan. Tapponnier et al. (1981) connect it in Afghanistan with the Khost Ophiolite Complex. Further to the N in Pakistan, the Bela-Waziristan Ophiolite Zone is left-laterally off-set to the N by the Sulaiman Basement Fault and might continue along the southern margin of the Kohistan Arc. The second ophiolitic zone which represents the former Neo-Tethyan subduction zone of the southern margin of the Eurasian Plate, is along the Chaman Fault (Wilson, 1965). In the N, the Chaman Fault separates the Afghanistan Block in the W from the Kabul Block in the E (Tapponnier et al., 1981). These authors assume a pre-Late Paleocene emplacement of the ophiolitic melange which contain exotic blocks of Maastrichtian limestone . This is also the time of emplacement of the ophiolites of the Bela-Waziristan Ophiolite Zone (Allemann, 1979).

Three distinct zones have been identified in the West Pakistan Fold Belt (Vredenburg, 1901; Stoecklin, 1977; and Hunting Survey Corp., 1961):

- the Arenaceous Zone, stretching from the Makran in the W along the Khojak Segment and Pishin Basin in the NW.

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**LEGEND**

horizontal hatching: Indo-Pakistan Plate
vertical hatching: Afghanistan Block
light grey: Makran-Khojak-Pishin Flysch Zone
dark grey: Bela-Waziristan Ophiolite Zone
oblique hatching: concealed basement faults
black triangles: Neogene volcanism
black dots: towns
solid line: fault trace
solid line with open triangles: thrust

Faults:
GF = Ghazaband Fault
GF. = Gardez Fault
HF = Harnai Fault
JBF = Jhelum Basement Fault
KAT = Karahi Thrust
KBF = Kirthar Basement Fault
KF = Kutch Fault (S of Karachi)
KF = Kumar Fault (E of Kabul)
KT = Karmai Thrust
MBT = Main Boundary Thrust
MMT = Main Mantle Thrust
ONF = Ornach-Nal Fault
PCF = Panjshir Fault
SBF = Sulaiman Basement Fault
SF = Sarobi Fault
WSTF = Western Sulaiman Transform Fault

Tectonic units:
BWZ = Bela-Waziristan Ophiolite Zone
K = Kalat Plateau
KH.B. = Khuzdar Block
M.B.H. = Marri-Bugti Hills
KA B = Kabul Block
KOH.A. = Kohistan Arc
KTS = Kirthar Thrust Sheets
MR = Mianwali Re-entrant
SR = Sibi Re-entrant
S.R. = Sulaiman Ranges
TR = Tank Re-entrant

Towns: Black dots
I = Islamabad
K = Karachi
KA = Kabul
Q = Quetta

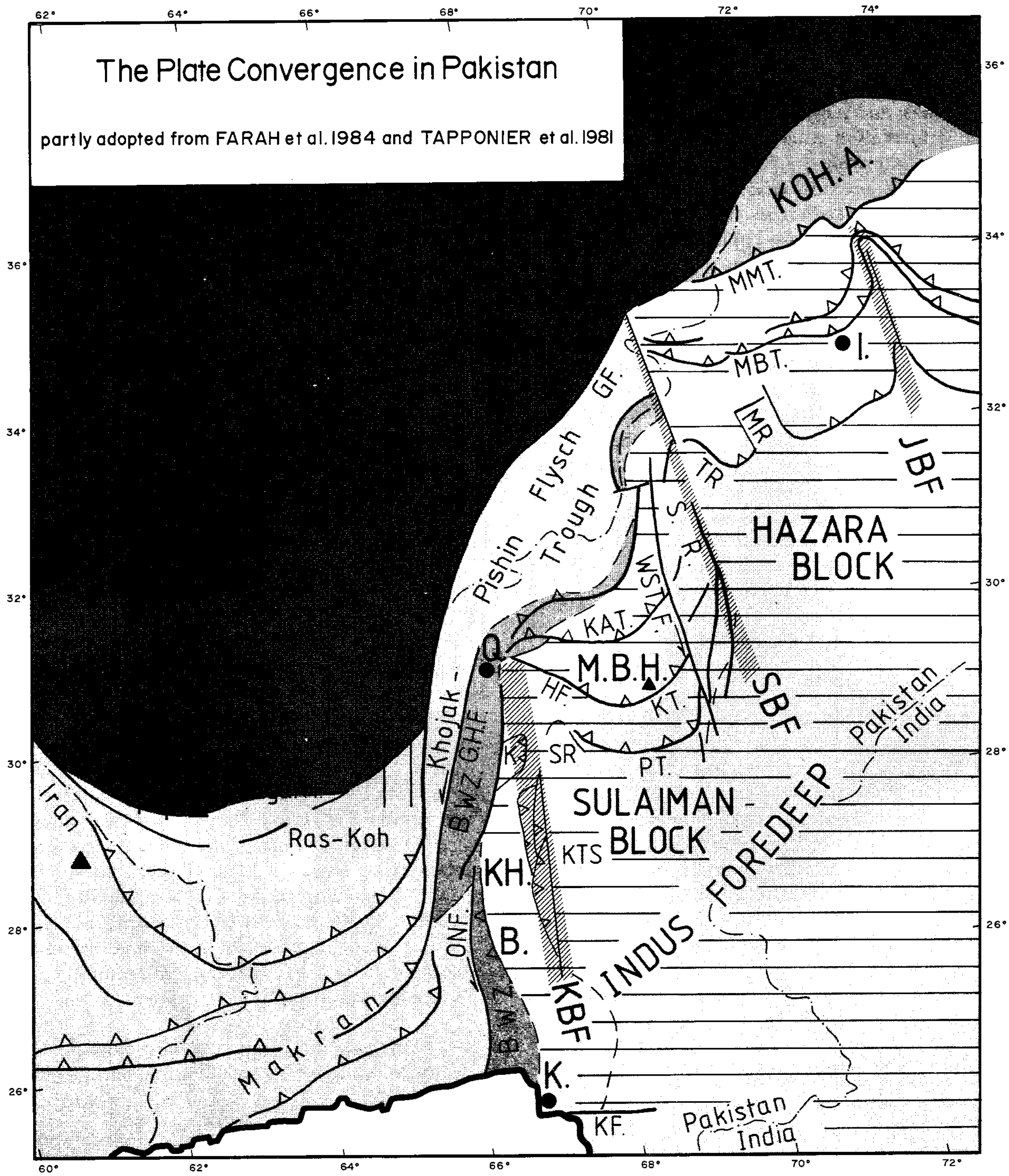



Figure 1— The plate convergence in Pakistan (after Bannert et al., 1989).

- the Axial Zone, appearing W of Karachi near Bela, trending N along the Zhob valley and further on to Waziristan, characterized by the abundance of ophiolitic rocks.
- the Calcareous Zone, forming the area of Khuzdar and the Kirthar ranges E of the Axial Zone, the fold lobes of the Marri- Bugti Hills (Loralai Lobes of Hunting Survey Corp., 1961) and the Sulaiman ranges and their equivalents in the Kohat and Potwar area.

The Arenaceous Zone represents the Late Mesozoic through Late Tertiary flysch trough which developed in the W 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 (Farhoudi and Karig, 1977).

The Axial Zone is the remnant of the young Mesozoic Tethys with ophiolitic ocean floor and its Mesozoic through Early Tertiary sedimentary cover (Allemann, 1979).

The Calcareous Zone is composed mainly of geosynclinal and shelf sediments laid down on the northward advancing Indo-Pakistan Plate.

The area under consideration is affected by numerous N-S oriented transcurrent faults, which have been described by WilsoN (1965) and Abdel-Gawad (1971) and more recently by Lawrence and Yeats (1979) and Lawrence et al. (1981) among others.

Hunting Survey Corp. (1961) mapped the larger part of the West Pakistan Fold Belt and described the general tectonic picture as that of a continuous fold belt deformed in a festoon-like manner around the northwestern Indo-Pakistan Shield. Nappe tectonics in the area NE of Quetta have been identified by Hunting Survey Corp. (1961) and Kazmi (1979) with Gogai and Bibai nappes. Banks and Warburton (1986) were the first to consider duplex structures in the Marri-Bugti Hills.

For the Makran area, the tectonic style of deformation was described as a sedimentary accretionary prism (Farhoudi and Karig, 1977; Arthurton et al., 1982; Jacob and Quittmeyer, 1979.

Lillie et al. (1978) identified detachment tectonics and southward thrusting in the Salt Range of the Potwar Plateau.

This paper is based on a tectonic analysis of 16 Landsat-MSS scenes and presents a synthesis of various tectonic concepts published. It exploits the synoptic overview provided by the imagery and is based on a thorough analysis of the tectonic structures encountered.

## GEOLOGY

The following description will start in the E with the sedimentary cover of the Indo-Pakistan Plate and then continues with the Neo-Tethyan Bela-Waziristan Ophiolite Zone further W and finally includes the Makran-Khojak-Pishin Flysch Trough in front of the Afghanistan Block of the Eurasian Plate.

### The Indo-Pakistan Plate

The sediments deposited on the shelf and frontal eugeosyncline of the Indo-Pakistan Plate were strongly deformed by the continent-to-continent collision of the two converging plates. In the process of this collision, the sedimentary overburden detached from its crystalline basement of the Indian Shield and from the possibly adjacent Neo-Tethyan ophiolitic sea-floor adjacent to the N. This sea-floor is considered here to be part of the Indo-Pakistan Plate.

The area can be divided into three different blocks distinguished from each other by different styles of tectonic deformation.

*The Khuzdar Block.*— The Khuzdar Block is the area between the Bolan Pass to the N, the Arabian Sea to the S, the Kalat and Ornach-Nal faults in the W, and the Kirthar ranges in the E (Figure 2).

The southern and central part of the Khuzdar Block consists of folded Mesozoic through Oligocene rocks. The fold axes strike NW-SE (Figure 2). During Jurassic and Cretaceous times geosynclinal sediments, ammonite bearing limestone and marly limestone as well as *Globotruncana* bearing limestone, were deposited. During Cretaceous times, clastic weathering products of the Indian Shield were transported as delta sediments into the area, forming the terrigene Pab Formation (White, 1981). Paleocene Gidar Dhor Formation, Paleocene through Oligocene Jamburo Formation, and Eocene shelf sediments of the Indo-Pakistan Plate are the youngest marine sediments deposited. They were deposited during the initial folding of the Khuzdar Block. Jamburo and Gidar Dhor formations contain layers with exotic blocks, especially in the W. Both formations contain the erosional debris of the Late Cretaceous Kanar Melange (Sarwar, 1982; Sarwar and DeJong, 1984) and the Bela Ophiolites, which were obducted during the Paleocene (Allemann, 1979, Sarwar and DeJong 1984). Finally, the whole complex of the Bela ophiolites was thrusted eastwards onto the Mesozoic sediments of the Indo-Pakistan shelf. The folding of the sediments continued and included the Early Tertiary sediments as well.

There is the possibility that the Khuzdar Block underwent an anticlockwise rotation, totalling 90° from an originally SW-NE orientation of the fold-trend to the final NW-SE trend of today. This rotation according to Sarwar and DeJong (1984) resulted in the opening of the conspicuous wedge of the Porali plain at the SW end of the Khuzdar Block, as well as in the eastvergent folding and

**LEGEND**

| | |
|---|---|
| light grey: | Makran-Khojak-Pishin Flysch Zone |
| medium grey: | Bela-Waziristan Ophiolite Zone |
| dark grey: | ophiolite of the Bela-Waziristan Ophiolite Zone |

Abbreviations:

| | |
|---|---|
| BF | = Bolan Fault |
| BWZ | = Bela-Waziristan Ophiolite Zone |
| SF | = Sanni Fault |
| SS | = Sangan Syncline |
| TGA | = Tor Ghar Anticline |
| TS | = Timur Syncline |
| WSTF | = Western Sulaiman Transform Fault |
| ZS | = Zarghun Syncline |

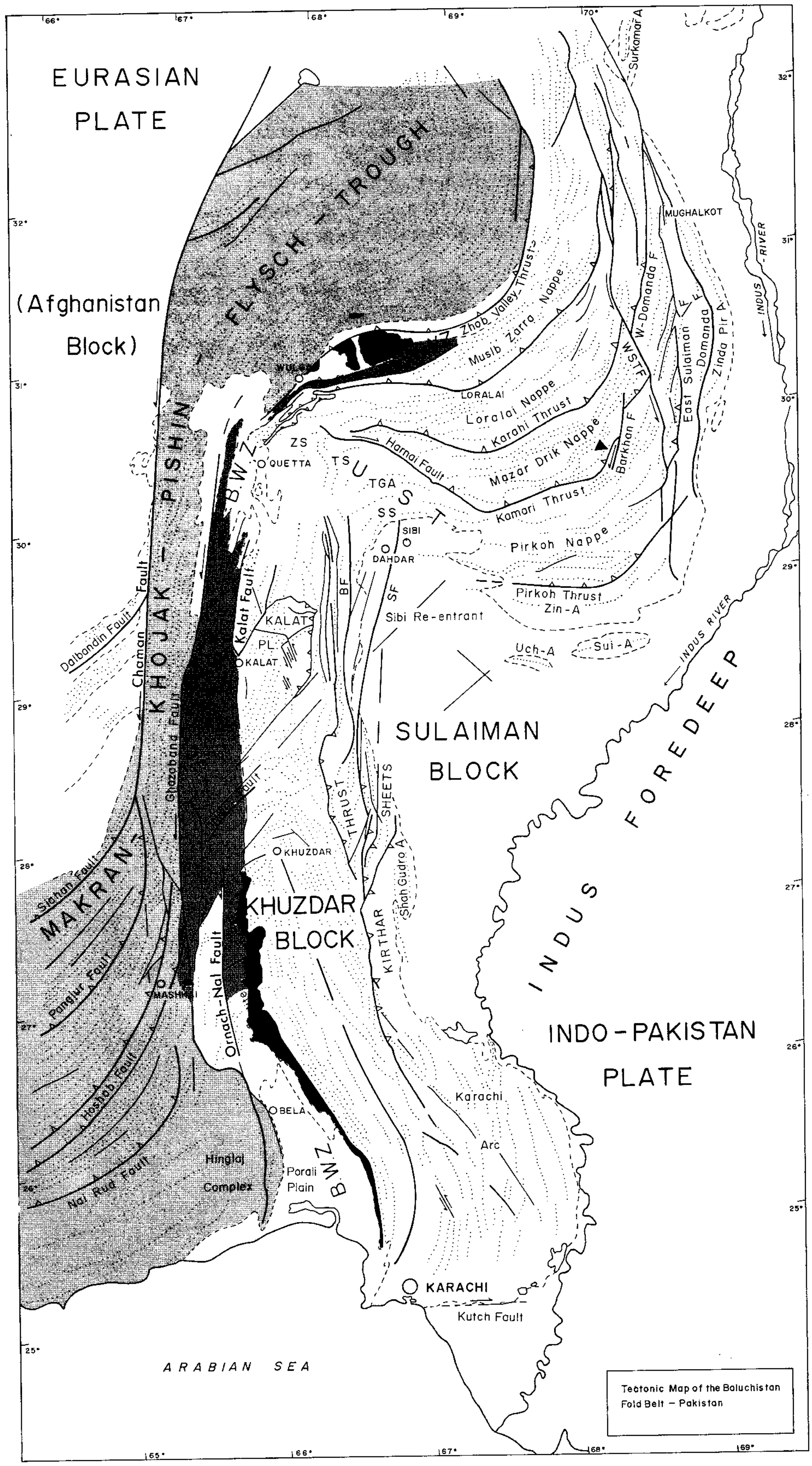



**Figure 2— Tectonic map of the West Pakistan Foldbelt in W Pakistan (after Bannert et al., 1989).**

detachment of the Karachi Arc N of Karachi. Two more thrust complexes connected with the latest phase of rotation have been identified. One is the Kalat Plateau N of Khuzdar where Early Eocene Ghazij Formation as well as the overlying Late Eocene Spintangi Formation apparently have been thrust eastward over the already folded Mesozoic sediments and their cover of Early Tertiary Jamburo Formation. A second pile of thrust sheets, whose nature is better established (Hunting Survey Corp. 1961) is found along the eastern margin of the Khuzdar Block in the Kirthar Ranges, built by the tectonically competent Late Eocene Kirthar Limestone. The well bedded Kirthar Limestone is of completely different facies than the boulderlike massive Spintangi Limestone. The Kirthar Thrust Sheets have been identified as "out-of-the-syncline" structures thrusted westward in the last act of deformation (Figures 3 and 4). Towards the N, the Kirthar Thrust Sheets continue as anticlines. The thrusts mostly occupy the positions of synclines. These faults can be followed for more than 100 km and a slide-slip motion could be observed in the area W of Dadhar. Westward thrusting fits a model in which a frontal roof thrust overlies the frontal horses of an E-facing duplex structure. Apparently, Ghazij Shale of Early Eocene age was the upper detachment horizon for the roof-thrust fault. Deeper detachment horizons are the Parh Series sediments W of Kharzan (Figure 3) and horizons below the Jurassic sediments.

The eastern limitation of the Khuzdar Block towards the monoclinal Indus Foredeep is below and E of the Kirthar Thrust Sheets. Below the thrust we have to assume the continuation of the Mesozoic sediments striking SE in large anticlines or duplex structures. They terminate along a N-S trending basement fault, for which the name Kirthar Basement Fault is proposed. It separates the tightly folded Khuzdar Block from the more or less monoclinal dipping Indus Foredeep situated on the next segment of the Indo-Pakistan Plate, the Sulaiman Block.

There are numerous indications, that the Khuzdar Block also is affected by northward directed compression at its western parts (along the road from Khuzdar to Bela in the south, expressed in E-W trending folds and approximately N-S directed strike-slip faults.

*The Sulaiman Block.*— To the NE of the Khuzdar Block the geo-morphological expression of the country rock changes completely. The conspicuously southward directed anticlinal fold lobes of the Marri-Bugti Hills (Loralai Lobes of Hunting Survey Corp., 1961), of which the Sulaiman ranges (Sulaiman Anticlinorium of this paper) are the easternmost part, dominate the area.

The Marri-Bugti Nappes have been described by Banks and Warburton (1986) as duplex structures above a detachment horizon of presumed Precambrian salt. The rocks involved are marine deposits of Mesozoic through Tertiary age deposited on the shelf of the northwestern Indo-Pakistan Plate folded during the continent-to-continent collision. In the N, parts of the Bela-Waziristan Ophiolite Zone are involved in the Marri-Bugti Nappes. The Marri-Bugti Nappes are bounded in the W by the right-lateral Harnai Fault (Figure 1) which runs within the incompetent Ghazij Shale and continues as the Karmari Thrust further to the SE (Figure 5).

A number of major nappe complexes and thrusts have been identified between the Zhob valley in the N and the Indus Foredeep in the S (Figure 5). They are from N to S:

- the Pishin Flysch Nappe
- the Zhob Valley Thrust
- the Muslimbagh Zarra Nappe
- the Chinjan-Zakriazi Thrust
- the Loralai Nappe
- the Karahi Thrust
- the Mazar-Drik Nappe
- the Karmari Thrust
- the Pirkoh Nappe
- the Pirkoh Thrust.

Internally, the large nappe complexes most likely are divided in several smaller nappe units

In the S, the Pirkoh Nappe include molasse sediments of the Urak-Sibi Trough which are of Oligocene to Recent age. This indicates that the age of the thrust becomes younger southwards. Within the Mazar-Drik Nappes, near the town of Kohlu, the interpretation of Landsat images revealed a group of three volcanoes (Figure 6). Aerial photographs taken over the area confirmed this observation.

The Muslimbagh-Zarra Nappes extend westward into the area of Quetta. There, Hunting Survey Corp. (1961) and Kazmi (1979) established the Gogai and Bibai nappes which can be clearly identified on Landsat imagery. A total of 8 thin-skinned nappes could have been outlined on the imagery (Figure 7). Field observations revealed, that the nappes in the N, adjacent to the Zhob valley are steeply thrust from the valley and shallow upwards to form isolated klippen (e.g. Takatu Mt. and Gundak Mt.). For most of the nappes, the Ghazij Shale acted as the lubricant and detachment horizon.

Between the Sulaiman Block and the Khuzdar Block to the SW, the triangular Urak-Sibi Trough with its polyvergent Zarghun Syncline and Tamur Syncline form a passive-roof-duplex above the collision of the structures of both blocks, which are directed obliquely against each other. It is worth to notice, that the molasse sediments of the Zarghun Syncline built the highest mountain of the West Pakistan Fold Belt, the Zarghun Mt.(3.562 m).

In the E, the southward propagation of the Marri-Bugti Nappes apparently was controlled by a N-S striking underground step-fault for which the name Sulaiman Basement Fault is proposed, acting as a barrier that prevented a further extension of the nappes to the E. The step down of the Sulaiman Basement Fault was caused by

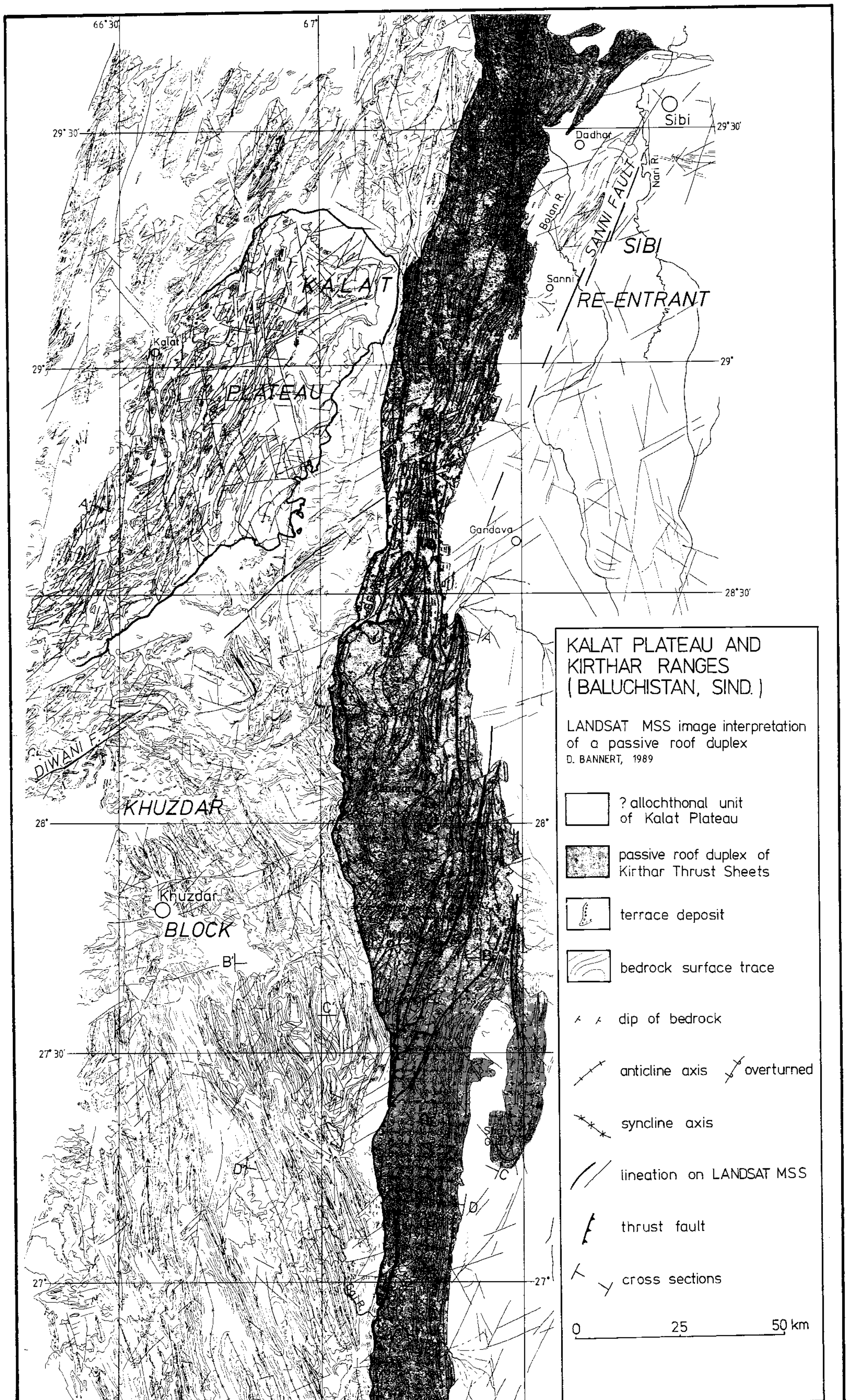



**Figure 3— Landsat image interpretation of Kalat Plateau and Kirthar Ranges (after Bannerrt et al., 1989).**

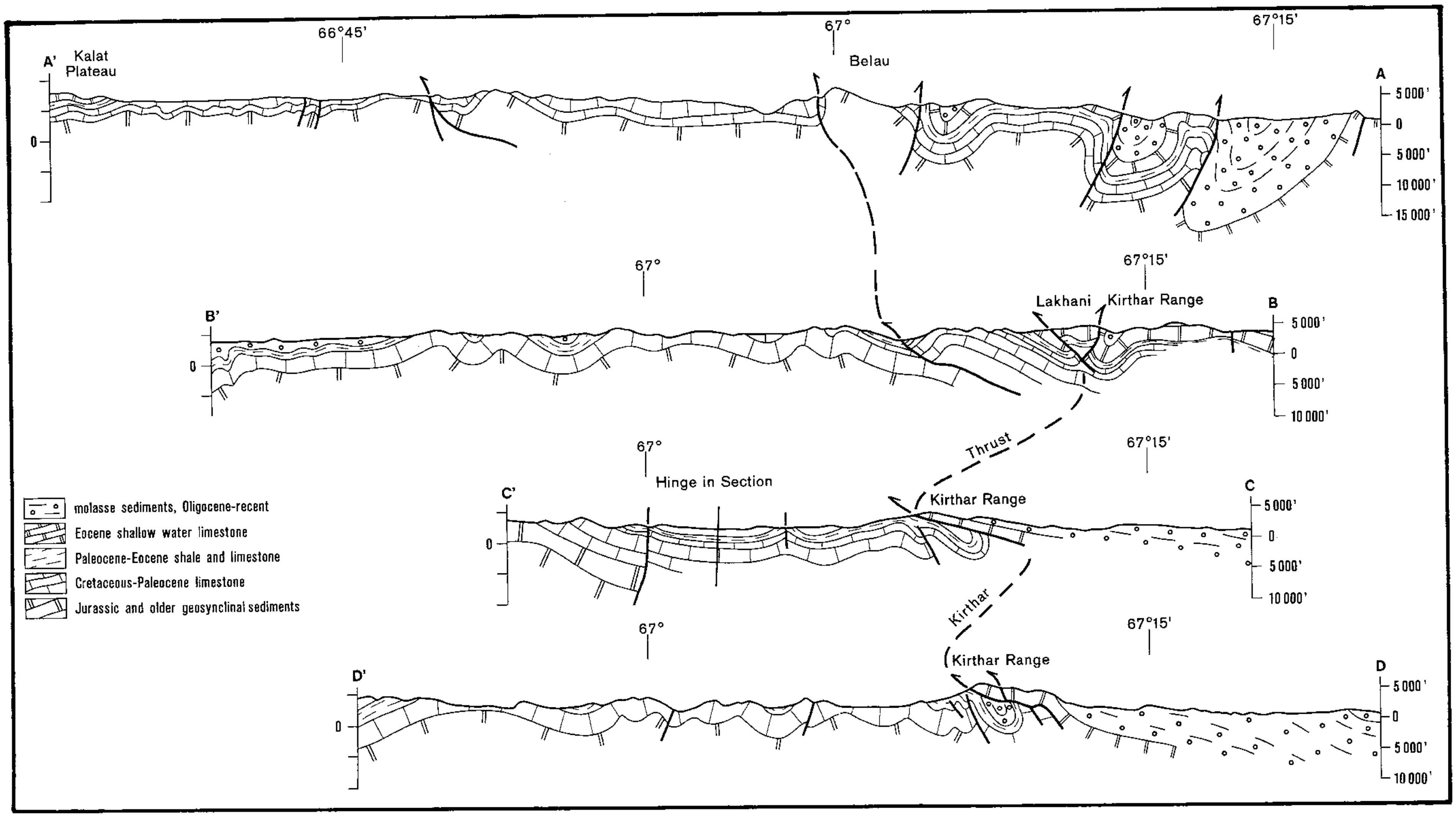



Figure 4— Tectonic cross-sections through the Kirthar Ranges, adapted from Hunting Survey Corp. (1961). Westward directed back-thrusting is evident. For location, see Figure 3.

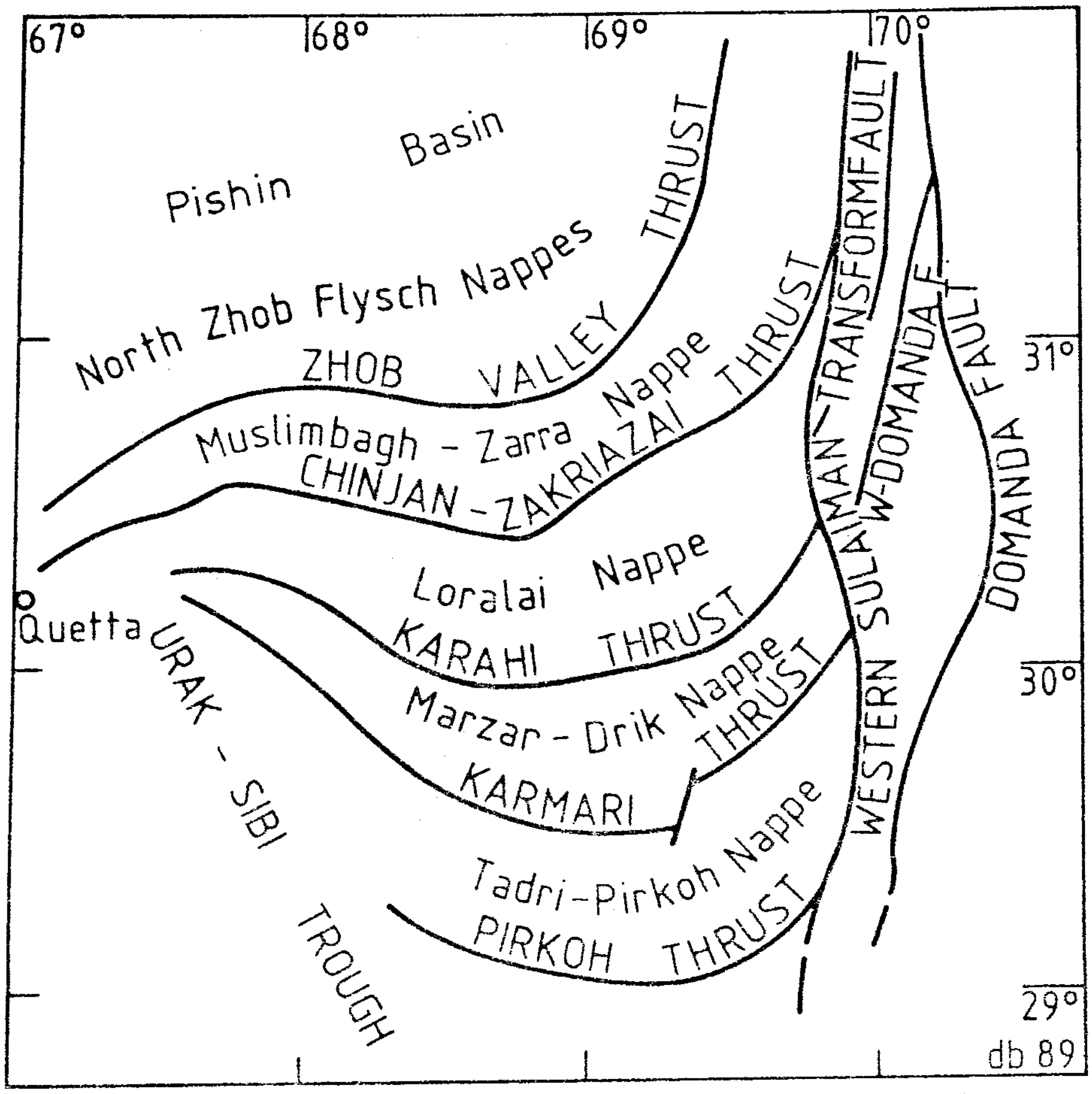



Figure 5— Main faults of the Marri-Bugti Hills and the Sulaiman Ranges (after Bannert et al., 1989).

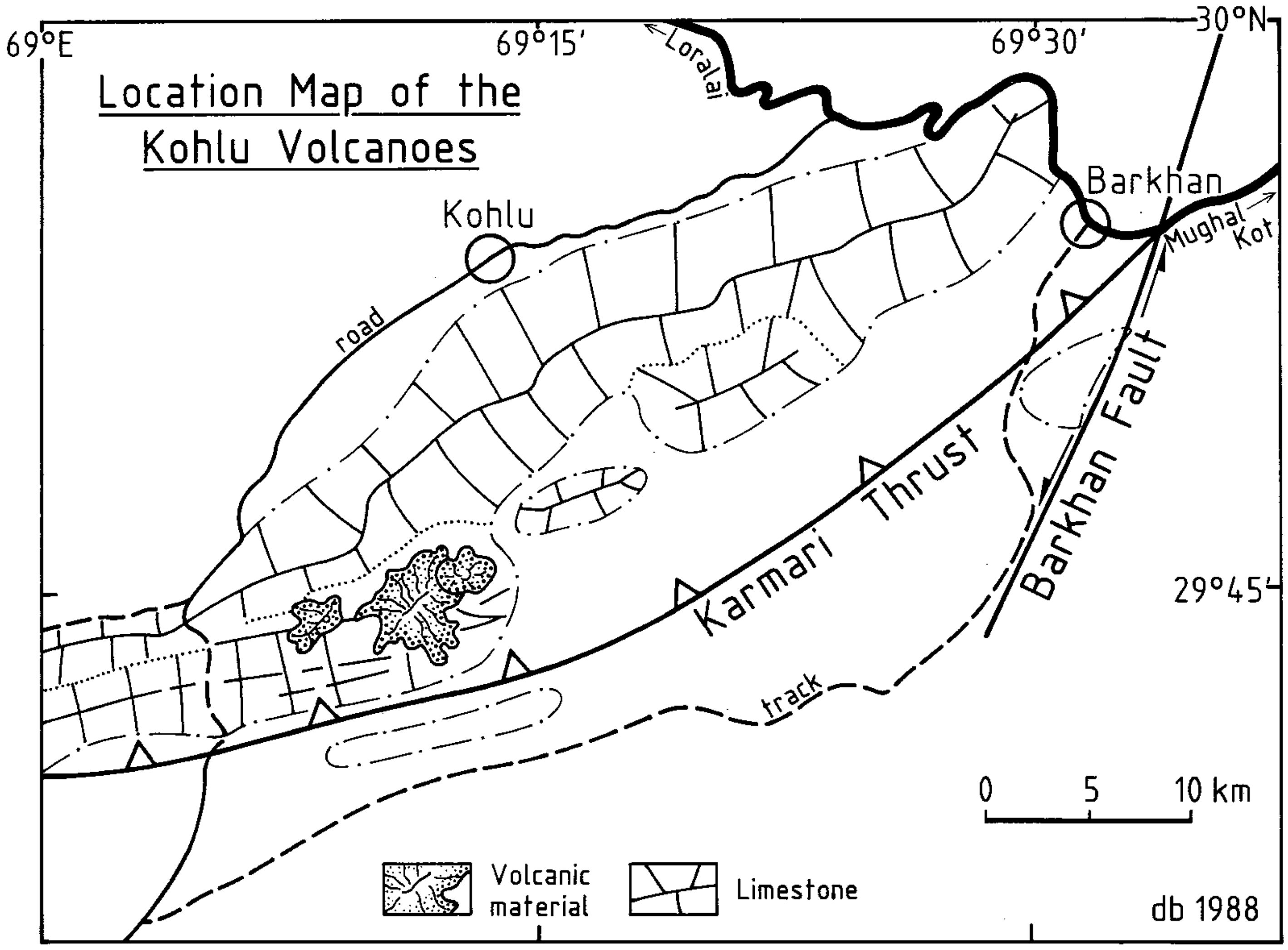



**Figure 6— Location map of the newly detected Kohlu Volcanoes in the Marri-Bugti Hills (after Bannert et al., 1989).**

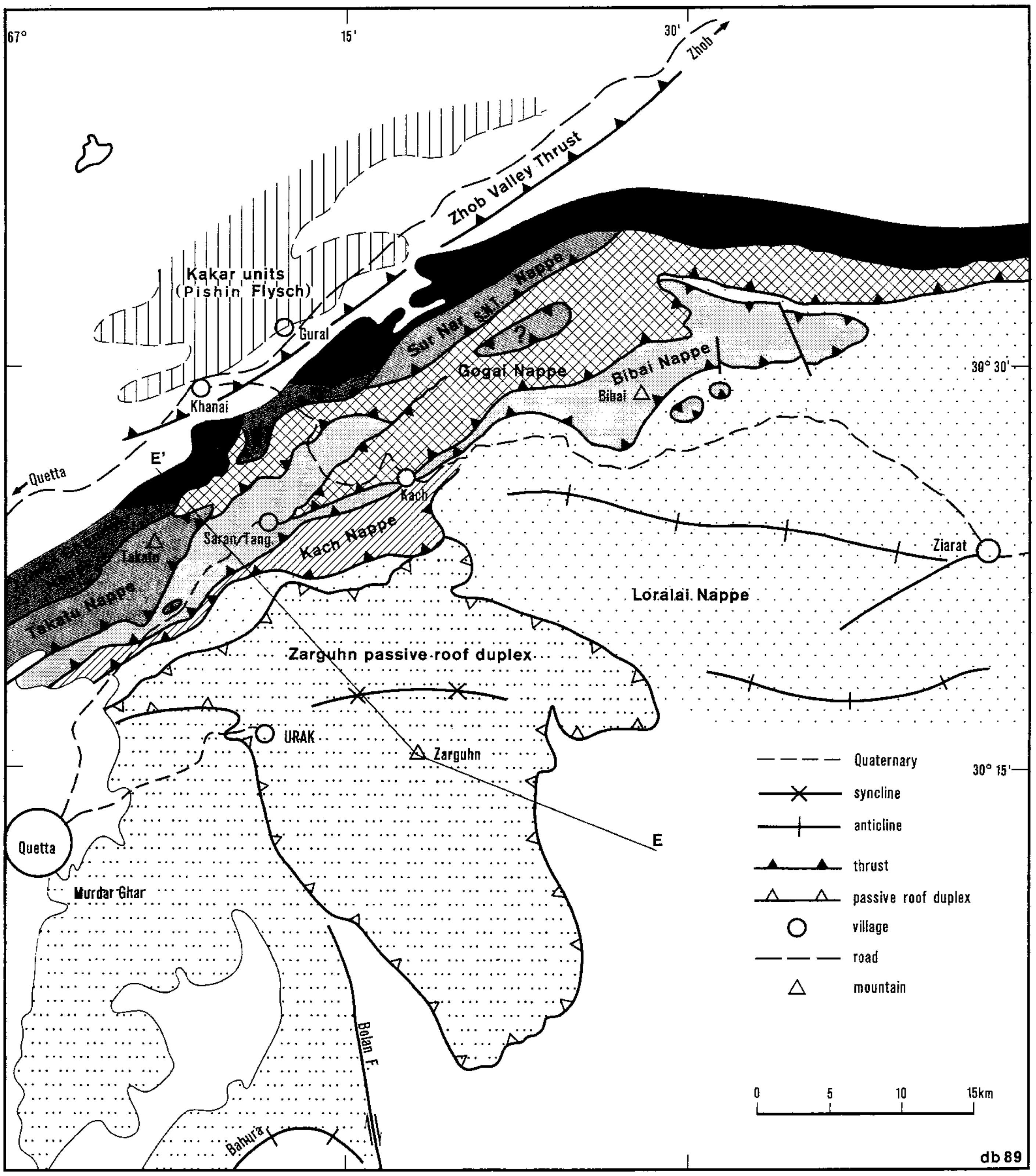
the northward dip of the Sulaiman Block at the beginning of the collision. The Sulaiman Basement Fault caused a conspicuous N-S alignment of the individual anticlines of the Sulaiman Anticlinorium, as well as the compressional upwarp of the Sulaiman ranges against the central part of the Marri-Bugti Hills. The "pressing" of the eastern Marri-Bugti Nappes against the Sulaiman Basement Fault apparently caused a considerable friction, resulting in the suppression of intermittend synclines and finally in the appearance of the Western Sulaiman Transform Fault. This fault has been in part already identified by Farah et al. (1984). It has a left-lateral displacement of 27 km, according to observations on Landsat imagery. This fault took over the southward movement of the Marri-Bugti Nappes.

The northward dip of the Sulaiman Block during the underthrusting below the Bela-Waziristan Ophiolite Zone resulted in the Urak-Sibi Trough which took the increasing amount of molasse sediments resulting from the orogenic uplift of the neighbouring areas.

The Sulaiman Basement Fault continues N along the westside of Tank Re-entrant, W of the Kohat Fold Belt, dissecting the eastward extension of the Zhob Valley Fault E of the Waziristan Ophiolite and finally links with the Sarobi Fault E of Kabul. Seeber and Armbruster (1979), after interpreting earthquake data of NW Pakistan found evidence for a deep-seated fault separating Sulaiman Block in the W from the Hazara Block in the E.

*The Hazara Block*.— E of the Sulaiman Block a further basement segment of the underlying Indo-Pakistan Plate has been identified for which the name Hazara Block is proposed. The Hazara Block moved northward independently from the Sulaiman Block. Its eastern margin lies under the Jhelum Re-entrant. There, a further basement fault, the Jhelum Basement Fault, has to be assumed. Seeber and Armbruster (1979, Figure 3) located an accumulation of deep-seated earthquakes trending NW for 100 km from the northern tip of the Jhelum Re-entrant. They eventually link with the SW-striking Kunar Fault Zone which is the NW flank of the Kohistan Arc (Figure 1).

Towards the N, the Hazara Block underthrusts the various sedimentary and partly metamorphic rocks of the Western Himalaya along the Main Mantle Thrust. These rocks form southward advancing nappes (Treloar et al., 1991). Their lowest thrust is the Main Boundary Thrust of the central and western Himalaya. This thrust splits into several thrusts W of the Jhelum Re- entrant, all thrusting towards the S. The shelf sediments of the Indo-Pakistan Plate S of the metamorphic Himalayan nappes and below the Main Boundary Thrust decoupled during the underthrusting from the basement of the Indo-Pakistan Plate.




**Thin skinned detachment tectonics NE of Quetta and Zarghun passive roof duplex. -Baluchistan, Pakistan.**

**Figure 7— Thin skinned detachment tectonics NE of Quetta (after Bannert et al., 1989).**

The non-metamorphic cover of the Hazara Block consists of Precambrian, Paleozoic, Mesozoic, and Cenozoic strata. They were not deformed during pre-Himalayan orogenetic events, but large-scale uplifts from time to time resulted in the erosion or non-deposition of formations (Shah, 1977). These sediments decoupled S of the Main Boundary Thrust after the deposition of the molasse sediments of the Kohat-Potwar area in the Precambrian Salt Range Formation (Lillie et al., 1987; Baker et al., 1988). The areas affected are the Potwar Plateau in the E, the Kohat Fold Belt across the Indus river, and the Mianwali Re- entrant in the W (Trans-Indus Ranges).

The Hazara Block is bordered in the W by the Sulaiman Basement Fault and in the E by the Jhelum Basement Fault. Above the Jhelum (Figures 1 and 8) Basement Fault a system of surface faults can be delineated on Landsat imagery which control the course of Jhelum river in the area W of the Potwar Plateau. The folded and possibly detached Siwalik sediments E of the Jhelum Basement Fault built the eastern side of the Jhelum Re-entrant. There, their trend is NW-SE, gradually assuming an eastern direction towards the central Himalayan foreland. The same sediments overlying the Potwar Plateau strike SW-NE at the western side of the Jhelum Re-entrant. Where both fold systems meet, the Jhelum Fault System offsets both en-echelon in a zig-zag mode. The eastern Potwar Plateau in this area is subjected to some backthrusting as shown by Johnson et al. (1986) and Leathers (1987). In the northern Jhelum Re-entrant, the Tertiary molasse sediments are thrust by the Main Boundary Thrust and its overriding sediments and metamorphic rocks of the Hazara Syntaxis. Bossart et al. (1988) attributed the syntaxis to a dome of the molasse sediments in the underground and its overriding thrust sheets, thus enabling the Hazara units to move southwards along the Main Boundary Thrust along the western flank of the dome.

W of the Potwar Plateau, there is a further re-entrant, the Mianwali Re-entrant. It is flanked in the E by the southward advancing Potwar Plateau and the right-lateral Kalabagh Fault. In the N the S-verging Surghar Anticline which bends sharply to the S north of Malla Khel village, thus forming the western margin of the Mianwali Re-entrant. According to Khan et al. (1986) and drilling results, the Mianwali Re-entrant is underlain by autochtonuous unfolded sediments of the Indo-Pakistan Plate. The Mianwali Re-entrant is the northwestward extension of the Sargodha High, an area that received only a reduced amount of Paleozoic platform sediments. This situation changed during the Tertiary with the deposition of 1400 m of Siwalik molasse sediments.

W of the Mianwali Re-entrant is the conspicuous Bannu Basin. Together with the Surghar Anticline the frame of the Bannu Basin is often referred to as Trans-Indus Ranges in the literature. The Bannu Basin is in the S, the W, and the E surrounded by elongated anticlines verging outwards from the center of the basin. In the S, the Marwat Anticline has in its front the Kisor Range, a monocline dipping to the NW towards the Bannu Basin. The Bannu Basin itself represents a completely unfolded rectangular syncline. In the center of the syncline, only 500 m of Siwaliks have been drilled. It is assumed here, that the cores of the anticlines surrounding Bannu Basin and Mianwali Re-entrant are filled with evaporites, accumulated before in the areas of the modern anticlines. In the underlying basement, step faults with a downthrow towards the Bannu Basin are assumed, very much like the step fault that caused the upwarping and southward advancement of the Salt Range thrust sheet. The northern part of the Trans-Indus Ranges, the Kohat region has a different style of deformation. The sediments are thrust in imbricate thrusts southwards similar in the way that Lillie et al. (1987) described for the northern Potwar Plateau.

## The Neo-Tethys

The Neo-Tethys originally covered the ocean N of the Gondwana continent and S of the Eurasian Plate. The Tethys covered 4000 km of ocean which was the site of the northwards movement of the Indo-Pakistan Plate during the Mesozoic and Cenozoic. In this paper, the geodynamic development of the Neo-Tethys is described in two chapters. One refers to the remaining ophiolitic sea-floor and the second chapter refers to the adjacent flysch-trough that developed in front of the Afghanistan Block.

*The Bela-Waziristan Ophiolite Zone.*— The elongated Bela-Waziristan Ophiolite Zone parallels the sediments of the Indo-Pakistan Plate just described in the W and N, and the chain of flysch sediments surrounding the Afghanistan Block further in the W. It is characterized by the frequent occurrence of ophiolitic rocks and their sedimentary cover. It is regarded as the remnant of the Tethys sea-floor that was not completely consumed during the continent-to-continent collision. There are a number of major ophiolite occurrences from the S near the shores of the Arabian Sea to Waziristan in the N: the Bela Ophiolites (DeJong and Subhani, 1979), the Muslimbagh Ophiolite (Ahmad and Abbas, 1979), and Waziristan (Asrarullah et al., 1979). Wittekind and Weippert (1973) connect these ophiolites with the Khost Ophiolite further in the N in Afghanistan.

The age of the ophiolites is Mesozoic. Late Cretaceous *Globotruncana* bearing limestones overly the ophiolites at many places (Gansser, 1979). Kazmi (1979) described the Bibai Volcanics of Late Cretaceous age from the area W of Quetta. It contains tuffaceous rocks, agglomerates and isolated layers of Late Cretaceous limestone. The volcanic rocks of the agglomerates indicate an intra-plate origin according to own observations. The sequence is followed by the Paleocene Dungan Limestone. It cannot be ruled out that also older Mesozoic rocks occur between the Cretaceous and the ophiolites. The emplacement of the ophiolites on the sediments of the Indo-Pakistan Plate occurred during the Paleocene with the subsequent development of the Kanar Melange (DeJong and Subhani 1979). Transgressive reefal limestone is followed in places by Oligocene nummulitic limestone (Allemann, 1979, Figures 12-14). Hunting Survey Corp. (1961) called this limestone of Oligocene through Miocene age the Nal Limestone.

There are indications of an pre-Late Cretaceous folding of the Tethys sea-floor according to Hunting Survey Corp. (1961; Map 14-Mashkai). The Late Cretaceous sediments of the Bela-Waziristan Ophiolite Zone are folded in elongated shallow folds. It is noteworthy that the synclines contain no younger rocks than Late Cretaceous. Remnants of Tertiary geosynclinal rocks are absent.

At the beginning of the continent-to-continent collision, the Bela-Waziristan Ophiolite Zone was thrust upon the sediments of the Indo-Pakistan Plate, causing the first folding of the sediments of the Khuzdar Block. During that time, the collision zone was most likely arranged in an E-W manner S of the Eurasian Plate.

The eastern boundary of the Bela-Waziristan Ophiolite Zone is not very distinct. Although it is thrust in the S on the Khuzdar Block, further N this thrust is lacking, and ophiolitic melange has been found underlying Late Cretaceous globotruncana bearing Parh limestones in the area W of Khuzdar. There it is folded together with Jurassic sediments. Topographically, the Kalat Fault separates the Bela-Waziristan Ophiolite Zone in the W from the Khuzdar Block in the E.

*The Makran-Khojak-Pishin Flysch Trough.*— The Makran-Khojak-Pishin Flysch Trough of Pakistan and Afghanistan is part of the continental margin of the southern Eurasian Plate. It is a continuous zone of sediments, to a larger part of geosynclinal flysch nature, later transitioning upwards and sidewards into orogenic molasse sediments in places. It can be divided into three segments characterised by different tectonic styles, the Makran, Khojak, and Pishin Flysch segments.

Since the Maastrichtian, S of the Afghanistan Block a flysch trough developed (Arthurton et al., 1982). The sediments were derived from the N. It is underlain in its southern part by Mesozoic Tethys sea-floor and its sedimentary cover. In the N it is underlain by the volcanics of the Chagai-Ras Koh Arc and the Kandahar Volcanic Arc. In the Khojak Segment, the flysch is of Eocene, Oligocene and Miocene age (Wittekindt and Weippert, 1973; Hunting Survey Corp. 1961). The Pishin Segment developed between Late Paleocene and Miocene times (Wittekindt and Weippert, 1973). The area may have been occupied previously by shallow water sediments (Nisai Group and Nimargh Limestone of Hunting Survey Corp. 1961) and by Tethys sea-floor prior to the flysch sedimentation derived from the Afghanistan Block. During Oligocene times a shallowing of the flysch trough lead to the deposition of molasse sediments (Wittekindt and Weippert 1973).

The Makran-Khojak-Pishin Flysch Trough underwent a differentiated geological history during the collision of the Indo-Pakistan Plate with the Eurasian Plate.

The Makran Segment developed continuously an accretionary wedge of flysch sediments above the subduction zone, where since the Late Cretaceous the oceanic part of the Arabian Plate is subducted under the Afghanistan- and Lut blocks of the southern Eurasian Plate. Most of the sediments are of Oligocene and Miocene age. During the Miocene, the deep water sediments of the Parkini Mudstone Formation were deposited followed by the Pliocene shallow water Talar Sandstone (Crame, 1984). In the Hinglaj area of the eastern Makran, the Talar Sandstone could be identified as the delta of the Pliocene Proto-Nal River, which is now elevated during the latest stage of accretion.

The foremost eastern extension of the subduction zone, however, was choked during the collision and flysch sedimentation ceased. The Makran-Khojak-Pishin Flysch Trough was dissected by the left-lateral Chaman Fault which assumed the position of the former subduction zone (Lawrence and Yeats, 1979; Lawrence et al., 1981; Tapponnier et al., 1981) and separated the Makran segment from its continuation in the E. 30 km E of the Chaman Fault and parallel to it the left-lateral Ghazaband Fault developed which is younger in age. Between the two faults, the Khojak segment of the formerly continuous flysch trough was severely affected. It became extremely stretched in N-S direction between the two faults and took the main impact of the collision. There are indications on Landsat images for numerous left-lateral longitudinal strike-slip faults that dissect the entire Khojak Segment. Along these faults, the separation of the Makran Segment from the Pishin Segment took place.

At the beginning of this process, the Makran-Khojak-Pishin Flysch Trough had still an approximate SW-NE orientation. When, during the Paleocene, the continent-to-continent collision began, the southern margin of the Eurasian Plate indented (Sarwar and DeJong, 1984), and the left-lateral Chaman Fault developed. The collision led to the anticlockwise rotation of the Khojak segment, the Bela-Waziristan Ophiolite Zone to the E of it, and the Indo-Pakistan Plate. The offset along the Chaman Fault is estimated to be at least 200 km (Lawrence and Yeats, 1979). Due to the extreme stretching of the flysch in the Khojak Segment, a considerable E-W compression resulted. Off the Makran coast, the accretionary flysch wedge continued to grow and oceanic sea-floor was consumed leading to the development of the accretionary wedge of first folded and later thrusted flysch sediments. The Chaman Fault continued southward as well and linked with the newly developed S-directed thrusts, continuously growing in length to the S as new thrust piles developed. Later, this process was taken over by the younger Ghazaband Fault 30 km to the E. This fault begins in the N 30 km W of Quetta and extends southward as far as $27^{o}$ N, where it connects with the NE-SW striking thrusts in the Makran flysch sediments.

Following the emplacement of the ophiolites, uppermost Early Eocene through Middle Eocene clastic flyschoid rocks were deposited in the Pishin Segment. Later, it has been thrusted SE-wards over the Bela-Waziristan Ophiolite Zone. The structure of these nappes have not been studied in detail in Pakistan, however, it can be observed on Landsat imagery that they consist of long, open and broad synclines separated by narrow anticlines. In Afghanistan, Wittekindt and Weippert (1973) showed, that the cores of the synclines are generally occupied by Eo-Oligocene molasse sediments.

## DISCUSSION.

The area under consideration belongs to the suture zone between the approaching Indo-Pakistan Plate in the S and the Afghanistan Block and Eurasian Plate in the N. Four rock successions are involved in the tectonic deformation:

- the geosynclinal and marine platform sediments of the Indo-Pakistan Plate,

- the orogenic molasse sediments of the Indus Foredeep,
- the ophiolitic suites in the Bela-Waziristan Ophiolite Zone, and
- the Neogene flysch of the Makran-Khojak-Pishin Flysch Trough.

Following the final break-up of Gondwana during the Early Cretaceous, crustal unrest is documented during the Late Cretaceous by the occurrence of a volcanic arc (Bibai Formation, Kazmi, 1979) in the Bela-Waziristan Ophiolite Zone, assumed to be the oceanic part of the Indo-Pakistan Plate. Also, on the southern rim of the Afghanistan Block a volcanic arc developed (Chagai-Ras Koh and Kandahar Arc, Arthurton et al., 1982; Wittekindt and Weippert, 1973). It appears, that tectonic events S of the Afghanistan Block and outside of the subduction zone are responsible for the folding of the sedimentary cover of the Bela-Waziristan Ophiolite Zone. Did this folding occur near oceanic transform faults?

The final collision began with the emplacement of the Bela-, Muslimbagh-, Zhob-, Waziristan-, and Khost ophiolites, as well as the closure of the subduction zone along the southern margin of the Eurasian Plate during the end of Cretaceous and during the Paleocene. The continent-to-continent collision that followed resulted in the segmentation of the Indo-Pakistan Plate along N-S trending basement faults.

The early Tertiary folding established for the Khuzdar Block followed the relative quiet Eocene with prevailing shallow-water sedimentation on the Indo-Pakistan shelf E of the Khuzdar Block. Flysch sedimentation between the Bela-Waziristan Ophiolite Zone and the Chagai-Ras Koh/Kandahar Arc commenced. The flysch was deposited on magmatic ocean floor rocks and the overlying geosynclinal sediments of the remaining Tethys, as well as on shelf sediments belonging to the Afghanistan and Kabul blocks.

Following the Late Eocene, the relative quietness on the Indo-Pakistan shelf was again interrupted, when the second phase of the collision began. At this time, the already folded Khuzdar Block in the W, the leading edge of the Indo-Pakistan Plate, rotated anticlockwise into its current position. If we assume that the southern margin of the Eurasian Plate had a SW-NE trend shortly before the collision, the initial folding of the sediments of the Khuzdar Block would have resulted in fold trends of the same direction. At the end of the rotation of the Khuzdar Block the general fold trend is NW-SE. The amount of rotation would be in the vicinity of 90°.

The already folded Khuzdar Block reacted as a consolidated block when the backthrusted Kirthar Thrust Sheets and the Kalat Plateau Thrust developed as the final thrusts in Miocene/Pliocene times during the rotation. This explains the change in the strike of the tectonic pattern between the Mesozoic sediments of the Khuzdar Block and the sediments of its eastern part, the Kirthar Ranges. The Kirthar Thrust Sheets are out-of-the-syncline thrusts. They reacted as a passive-roof duplex above the underthrusting Khuzdar Block, very much the way described by Banks and Warburton (1986, Figure 7) for the Marri-Bugti area. It is obvious that the westward thrusts die out towards the S where the Karachi Arc commences its eastward motion, also a result of the anticlockwise rotation. The Karachi Arc is terminated in the S by the right-lateral W-E trending Kutch Fault (Sarwar and DeJong, 1984). Toward the N the Kirthar Thrust Sheets become narrow anticlines, separated by vertical faults with a N-S strike-slip movement.

The Indo-Pakistan Plate to the E separated from the Khuzdar Block along the Kirthar Basement Fault and continued to move northward, also rotating anticlockwise into the Eurasian Plate (Powell, 1979) at the same time. The Kirthar Basement Fault assumed an important function: it enabled the northward movement of the bulk of the Indo-Pakistan Plate after the increased friction caused by the collision of the Khuzdar Block with the Afghanistan Block slowed down the Khuzdar Block. The indention of the Indo-Pakistan Plate was enabled by the development of further N-S strike-slip faults between the two plates: Chaman, Ghazaband, and Ornach-Nal faults. In the Indo-Pakistan Plate the Sulaiman Block E of the Kirthar Basement Fault continued to move northward. The leading edge of the Indo-Pakistan Plate was now the northern part of the Sulaiman Block, below the Marri-Bugti Hills.

During the second phase of the collision the sediments of the Sulaiman Block decoupled from the basement. This was favoured by a northward dip of the Sulaiman Block beneath the Marri-Bugti Hills and the Pishin Basin as a result of the subduction. It enabled a southward thrusting of the piles of Marri-Bugti Nappes, with the northernmost Muslimbagh-Zarra Nappe already belonging to the Bela-Waziristan Ophiolite Zone. They, in turn, were overridden by the flysch nappes of the Pishin Basin. Because the collision of the Indo-Pakistan Plate with the Afghanistan Block was oblique (Sarwar and DeJong 1984), the new leading edge - the Sulaiman Block - collided sometime after the Paleocene, in Eocene/Oligocene times. A second basement fault opened, the Sulaiman Basement Fault.

The block E of the Sulaiman Basement Fault continued northward into the Himalayan collision zone. This block is the Hazara Block, which has its eastern boundary along the third of the large basement faults, the Jhelum Basement Fault.

The collision continued further E in the Hazara Block which assumed the new leading edge of the Indo-Pakistan Plate after the Sulaiman Block slowed down. It was now a head-on collision which resulted in a more severe deformation of the overlying sediments (Tahirkheli et al., 1979). The time of the collision can be concluded from the appearance of Oligocene Siwalik molasse in the southern foredeep. The metasediments of the Hazara Block which are generally regarded to belong to the shelf of the Indo-Pakistan Plate have been thrusted southward in a similar way as the sediments of the Sulaiman Block, this occurred before Miocene times.

The eastern boundary is the assumed Jhelum Basement Fault which is represented at the surface by the Jhelum Fault System, along which the Salt Range Thrust Sheet and the molasse thrust sheets of the western Himalaya collide. According to Seeber and Armbruster (1979), strong seismicity occurs along a line from the NW Jhelum Re-entrant to the NW for a distance of 100 km, crossing the Kohistan Arc and linking with the Kunar Fault.

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