Pakistan Journal of Hydrocarbon Research
Vol. 8, No. 1 (January 1996). p. 31-42. 13 Figs

Mari-Bugti Fold-and-Thrust System and Rotation in the Sulaiman Lobe of Pakistan: Interpretation of the Satellite Data (1:50,000)

Ishtiaq A. K. Jadoon[1] and D. Helmcke[2]

ABSTRACT

The Mari-Bugti fold-and-thrust system in the Sulaiman fold belt is an active tectonic feature of the Himalayan collision zone. Satellite data (LANDSAT and SPOT) combined with surface and subsurface studies show a general EW in the central and NW structural trends in the western part of the thrust system. The central part is dominated by a series of paired foreland and hinterland vergent reverse faults and related folds. These faults of variable map length show minor displacement (km) and generally sole out at a shallow depth of 4-5 km in an upper detachment of the Cretaceous strata above a duplex. Some faults penetrate to a depth of about 9-15 km and sole out in lower detachment of the Paleozoic strata. As a result Cretaceous and younger strata is exposed in the cores of tight anticlines as pop-ups, or fault-related anticlines at the tip of a blind or emergent thrust. Variation of structures from tight fault-related anticlines (i.e. Fazal Chal, Kalabuha) to relatively broad folds and synclinal flats (i.e. Sund Thal) is observed due to lateral transfer of displacement and structures.

In the western Sulaiman, NW structural trends can be related to drag at the lateral termination of the fold belt. Besides, a series of EW trending anticlines of left-stepping and en-echelon arrangement are interpreted to develop between the dextral Harnai and Khalifat faults.

LANDSAT and SPOT data shows a system of EW trending dextral faults with significant strike-slip displacement (as much as 5 km). These are recognized to obliterate former structural features and geometries. In conclusion, active deformation of the Mari-Bugti fold-and-thrust system can be explained in terms of out-of-sequence faulting and anti clockwise rotation due to transpression near the western sinistral boundary of the Indian subcontinent.

INTRODUCTION

The Sulaiman fold belt with more than 60,000 km2 of the exposed Paleogene to Triassic platform strata is one of the main petroleum zones of Pakistan (Figure 1). It has produced over 69% of the total 402.5 billion cubic feet of gas produced in the country during 1986-1987 (Kemal and Malik, 1987), and is generally considered as a gas prone area. However, sizable amount of oil may be present (Raza et al., 1989a). This can be supported by the occurrence of gas condensate in wells (Dhodak) and seepages of oil from the western (Destangi, Khattan, Samach, Spintangi), central (Khatikkani), and eastern (Mughal Kot, Burzam, Raghasar) Sulaiman fold belt (Raza et. al., 1989a and 1989b).

Despite of its petroleum potential and over 100 years of history of exploration, the Sulaiman fold belt remains relatively unexplored. It is mainly due to poor accessibility in this security sensitive area. Mapping of the Sulaiman/Kirthar and Makran Ranges so far is based on aerial photographs and LANDSAT DATA interpretations (Hunting Survey Corporation, 1961; Bannert et al. 1992). These studies along with tectonic map of Pakistan (Kazmi and Rana, 1982) are useful for the general structural trends along the western boundary of the Indian subcontinent.

Kazmi and Rana (1982) mapped folds in the frontal part of the Sulaiman fold belt and an extensive system of faults in the more internal part of the thrust system (Figure 1). Bannert et al. (1992) proposed a series of imbricates, foreland-verging nappes which break the surface for the evolution of the Sulaiman fold belt (Figure 2a). Jadoon (1994a) observed that faults in the central part of the Sulaiman fold belt, herein called as Mari-Bugti fold-and-thrust system (MBFTS), exhibit minor displacement and are generally restricted to the roof sequence of a passive-roof duplex. The minor displacement is incompatible with the long map traces of the faults. Therefore, long map traces of some thrust/reverse faults may be a result of more than one faults at concurrent stratigraphic position as shown in figure 3, similar to the Appalachians Valley and Ridge Province (Diegel and Wojtal, 1985). In this article, satellite data combined with previous geological and geophysical studies is used to resolve lateral structural variation and style of the MBFTS to provide a framework for hydrocarbon exploration.

SATELLITE DATA, OBSERVATIONS, AND INTERPRETATIONS

The satellite data available for this study consist of 3 LANDSAT TM and 12 SPOT (black and white) photographs provided by Tullow Oil on a scale of 1:50,000 (Figure 4). In addition, cut up left and right look images of SPOT scenes were available for a stereoscopic view and extrapolation of dip data. The satellite data combined with geological and geophysical observations have been used to produce a structural map of the MBFTS (Figure 5). The main observations are:

---

[1] Department of Earth Sciences, Quaid-i-Azam University, Islamabad, Pakistan.

[2] Institute of Geology and Dynamic of the Lithosphere, Georg-August University, Goettingen, Germany

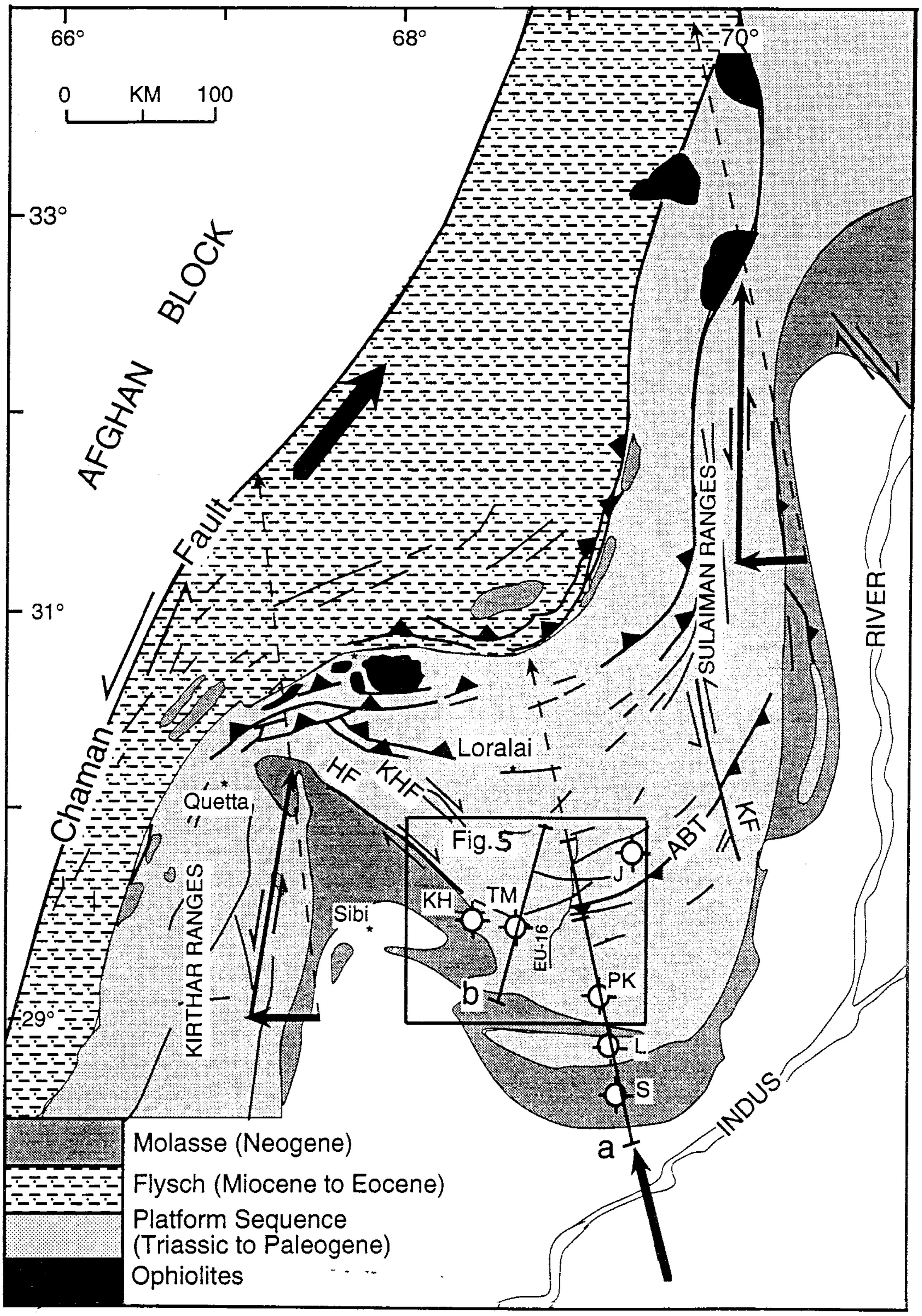

Figure 1- Simplified tectonic map of the Sulaiman fold belt at the western boundary of the Indian subcontinent (modified from Kazmi and Rana, 1982). Thick crooked NS line shows the location of a seismic profile interpreted by Jadoon (1994a) and discussed in text. Box shows the location of Figure 5. Dashed lines with arrows show plate convergence vector (Minister and Jordan, 1978; Nakata et al. 1990). Full lines with arrows show distributed strike-slip and thrust related deformation east of the Chaman fault. Abbreviations: ABT, Andari backthrust; HF, Harnai Fault; KF, Kingri Fault; KHF, Khakifat Fault. Well abbreviations: J, Jandran; KH, Khattan; L, Loti; Pk, Pirkoh; S, Sui; TM, Tadri Main.

1) A general arcuate convex to the south structural trend is the most prominent feature of the MBFTS. The arcute structural trend is typical of foreland directed thrusting above a decollement, observed in natural cases (Elliot 1976), and by experimental modelling (Dixon and Liu, 1992). This can be related to the decreasing amount of lateral displacement at the lateral margin of the fold belts, similar to as observed by Bannert et al. (1992) shown in figure 2a. Decreasing displacement toward margin of the thrust sheets imposes an increasing amount of rotation and strike-slip deformation (Figure 2b). The paleomagnetic studies show about 50° of clockwise rotation of bedding in the western Sulaiman (Klootwijk et al., 1981, 1985), consistent with its arcute geometry.

2) Nearly 7 km thick section of molasse strata is reported to exist in the Sibi trough (Banks and Warburton, 1986; Ahmed et al., 1992) that can be seen on seismic reflection line BP-212 located in figure 5. The platform sequence is deeper than 7 km in the Sibi trough. However, an uplifted sequence of Eocene to Jurassic platform strata is progressively exposed in the core zones of anticlines towards north and NE in the fold belt. The Eocene Ghazij and Kirthar Formations are mostly exposed in the hinge zones of broad synclines. Older strata are mostly exposed in the cores of tight fault-bounded anticlines towards east and north, and in the cores of relatively broad and gentle anticlines (Gidari, Miri, Dungan) towards west. The distribution of exposed strata is related to the geometry of subsurface structures and style of deformation. For example, presence of Jurassic strata in the core zones of broad and gentle Gidari, Miri, and Dungan anticlines in the western part of the MBFTS involves several kilometer of uplift along faults. Any exposed thrusts of large magnitude dip displacement, however, is not recognized. This implies blind nature of thrusts below above anticlines.

3) Faults are recognized as reverse, oblique, and strike-slip faults. Reverse faults of foreland and hinterland vergence juxtapose Cretaceous and Paleocene strata in the cores of tight, symmetrical anticlines against Eocene strata (Figure 6a). As a result Cretaceous rocks bounded between faults in the cores of tight anticlines are exposed as pop-ups (Fazal Chal, Kalabuha, Andari). In other cases, fault break the surface as emergent thrusts, such as Goradand-1 fault (Figure 7). Maximum dip displacement along these faults is 3.5 km (along Tadri backthrust; Figure 6b). Lateral structural variation by transfer of displacement from fold to fault or from fault to fault is observed, similar to as described by Dahlstrom (1969) for the Canadian Rockies (Figure 8).

4) A systematic pattern of left steeped en-echelon fold axes between NW trending Khalifat and Hamai faults is a peculiar feature of the western part of the MBFTS (Figure 1). The Hamai and Khalifat are oblique faults with apparent dominant dextral strike-slip displacement evidenced by clockwise vergence of drag folds in the Kirthar and molasse strata, and offset and drag of anticlinal axes. En-echelon arrangement of the above anticlines can be related to dextral strike-slip deformation along Khalifat and Hamai faults (Figure 9).

5) Strike/oblique-slip faults show an EW (Ningir), ENE-WSW (Goradand, Jandran), and NW (Hamai) trend. Strike-slip faults show a consistent dextral slip approaching 4-5 km (Figures 10 and 11) and displace former structural features such as fold axes and bedding.

6) Several kind of fault-related structural geometries, important for hydrocarbon traps, can be predicted: including emergent faults, fault-bend folds, fault-propagation folds, pop-ups, and strike-slip duplex (Figure 12).

7) Kinematics of deformation can be explained in terms of secondary out-of-sequence thrusting (Figure 13a), strike-slip deformation due to rotation along margin of thrust sheets, and anti clockwise block rotation in the Sulaiman fold belt (Figure 13b).

8) Active seismicity (Quittmeyer et al. 1979), structurally controlled physiographic features, flow of the drainage system parallel to the structural trends, and its disruption against the structures (folds, faults) suggests acute uplift and active deformation of the MBFTS.

9) Oil seepages at Khattan, Somach, and Spintangi are located along/or near the faults. This suggests that exposed faults may be providing conduits for the lateral and updip migration of the hydrocarbons, rather than acting as seals.

FAULTS AND RELATED FEATURES

Jandran Backthrust

This ENE-WSW trending fault south of Kohlu was previously mapped by Kazmi (1979) as an active fault termed as Kohlu. It is, herein, called as Jandran backthrust due to its hinterland vergence (Kemal and Malik, 1987; Jadoon et al., 1994a) below the Jandran Range. Thus, Jandran Range can be interpreted as a fault-propagation fold that has developed at the tip of a propagating fault (Figure 12a), which penetrates to a depth of about 7 km (Jadoon et al. 1994a). The fault presently breaks the surface along most of its length of about 44 km as an emergent thrust (Figure 12b) and emplaces Paleocene Dungan limestone against overturned upper Eocene Kirthar limestone (Figure 5). Lower Eocene Ghazij is mapped along the surface termination of the fault.

Miran Shah Fault

It is apparently an ENE-WSW trending dextral strike-slip fault south of the Jandran Range, based on satellite data. Bannert et al. (1992) reported three Neogene andesitic or mud volcanoes based on the interpretation of LANDSAT data in this vicinity. Our interpretation shows steep to overturned outcrops of Ghazij shale parallel to the trend of the above fault and southward dispersion of alluvium fans. A field check is important to resolve the complexity.

Fazal Chal Pass (Kunal), Kalabuha, and Andari Range Faults

A set of foreland and hinterland verging reverse faults of general EW trend bounds tight anticlines such as Fazal Chal Pass, Kalabuha, and Andari (Figure 5). Cretaceous and Paleocene strata in the cores of these tight anticlines is thrust

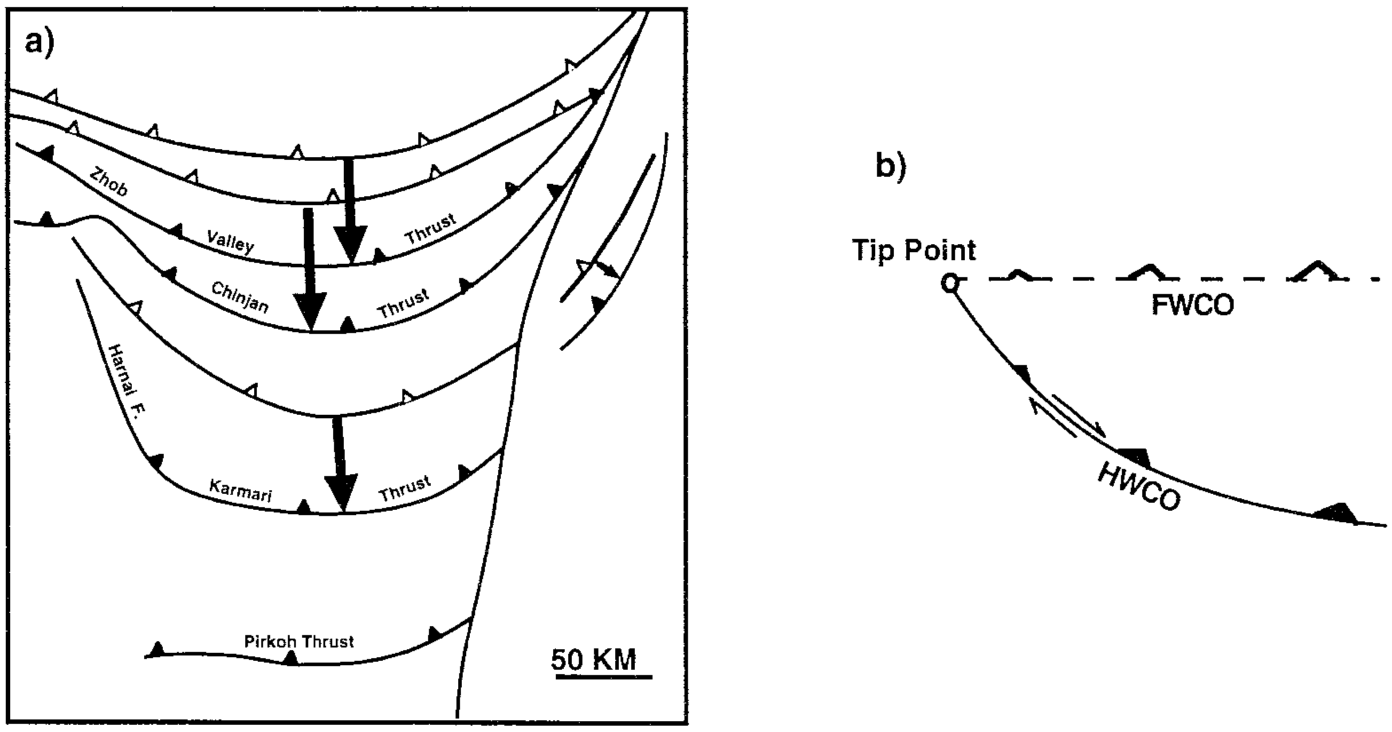

Figure 2- a) Evolution of the Sulaiman fold belt as south vergent nappes (from Bannert et al. 1992). b) Conceptual model to illustrate maximum displacement in the center of an arcuate thrust sheet, decrease of dip displacement towards tip points, and induced strike-slip due to rotation.

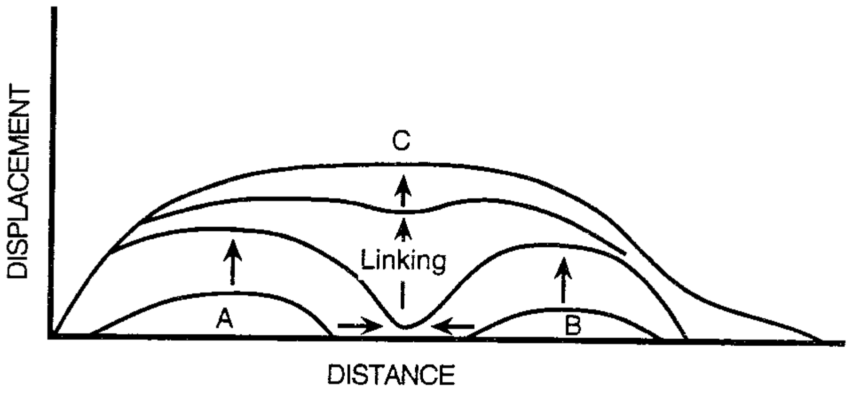

Figure 3- Fault displacement plotted against length (from Davison, 1994). Notice, long thrust faults must show greater amount of displacement. Alternately small faults at similar positions may be linked to form an apparent long map trace of a fault.

over mostly Eocene Ghazij shale in the adjacent synclines. Their map length varies between 9 to 40 km (excluding Andari set of Faults), maximum to be observed with Kunal/Fazal Chal backthrust that shows along strike dextral offset of the Ghazij shale (Figure 5). Jadoon et al. (1994a) recognized these faults and tight anticlines as reverse faults of minor displacement (about 1-2 km) penetrating to a depth of about 4-5 km and associated pop-ups (Figure 12c).

The Andari backthrust is mapped to extend eastward as a continuous fault (Figure 1). However, it shows minor displacement (Jadoon et al., 1994a). Its long map trace may be a result of more than one faults that link together at concurrent stratigraphic positions (Diegal and Wojtal, 1985; Davison, 1994) as illustrated in figure 3.

The Fazal Chal set of faults die out westwards. This is reflected by broadening and final termination of Kunal anticline into flat strata of Eocene limestone in the Sund Thal (plateau). Similarly, westward termination of Kalabuha set of faults is reflected by broadening of synclinal area between Goradand and Kunal anticlines and development of the Goradand-1 fault towards west (Figures 5 and 6). The change in structural and geomorphic expression from tight fault-related anticlines to folds and broad synclinal flats can be visualized in terms of transfer of structures (Figure 8), discussed by Dahlstrom (1969) and Dixon and Liu (1992).

Figure 8 illustrates the concept of transfer of structures. It shows that shortening in a unit area may remain constant, however, it should not necessarily remain constant along one structure. For example a fault may show decreasing degree of shortening and development of a fold towards tip points, but another fault may show increasing degree of shortening near the termination of the former one, reflecting transfer of displacement from first to the second fault. Thus, total shortening in a unit area may remain constant, systematically distributed over a system of fold-and-faults in a thrust system.

Ningir Fault

Ningir is an EW trending oblique fault with dominant dextral slip of about 5 km along its surface trace of about 15 km (Figures 5 and 10). It is termed as Ningir after the development of Ningir anticline along the western tip of the fault which may primarily be similar to a detachment fold during its present stage of evolution (Figure 12d). The dextral strike-slip along this fault is observed by the offset of Ghazij and Kirthar strata, synclinal axis of the Goradand anticline, and associated drag fold on the satellite data (Figure 10). It is the most spectacular feature on the satellite data that manifests itself topographically by an offsetted drag fold of competent Kirthar strata, and provides a clear evidence of dextral displacement along EW faults in the MBFTS.

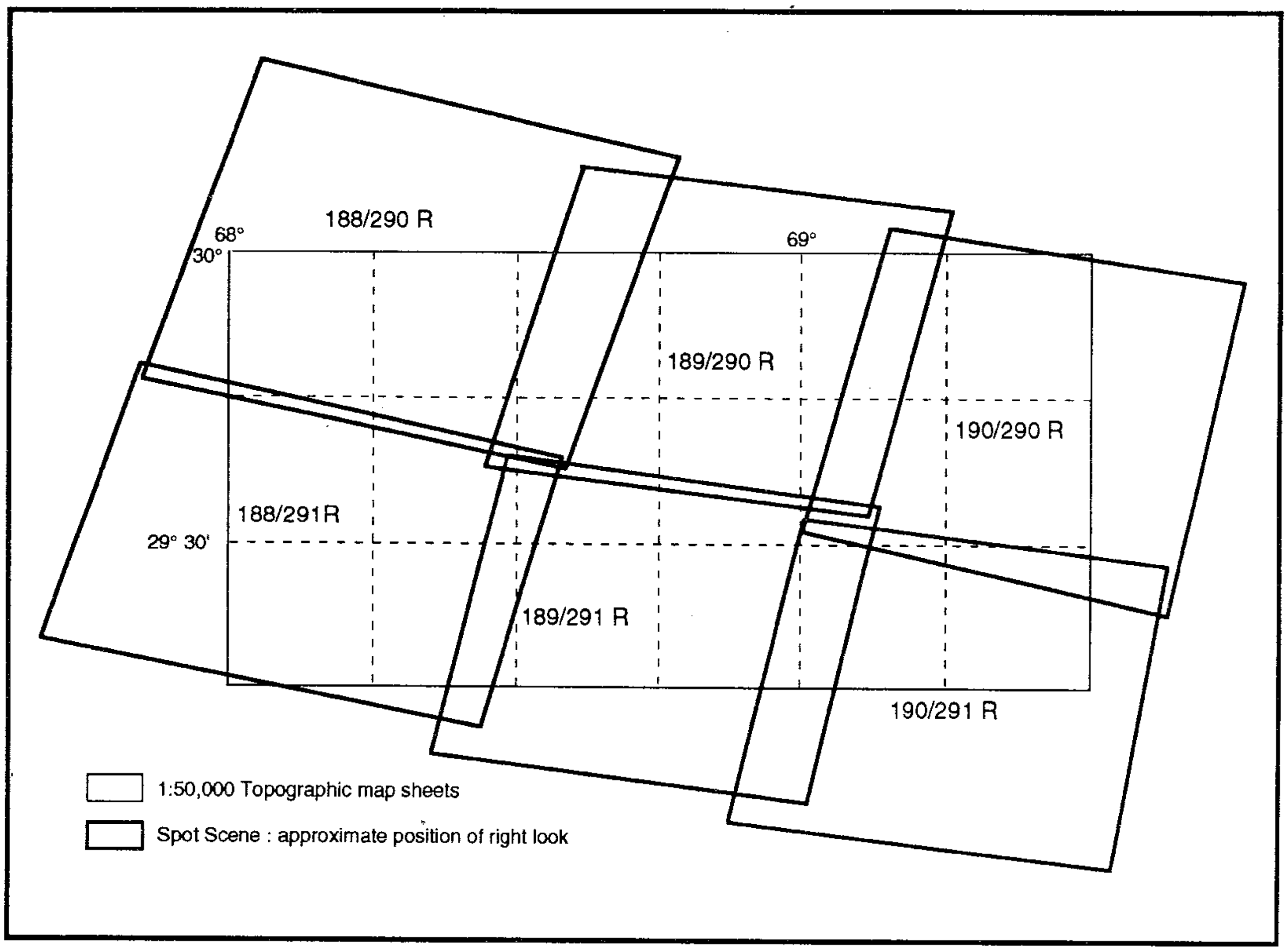

Figure 4- Map of the SPOT scenes (1:50,000).

Goradand-1 Fault

Surface expression of the Goradand-1 (Figures 5 and 10) can be seen on the satellite data by a pronounced ENE-WSW trending lineament. The fault continues along the southern edge of the Goradand Range and appears to terminate in the Tadri backthrust towards west. This implies that it may be older than the latter. Map trace of the fault is about 45 km (Figure 5).

The Goradand Range (anticline) represents hanging wall block of the above thrust. The thrust juxtaposes a sequence of Paleocene to Cretaceous strata against Eocene Kirthar/Ghazij strata (Figures 10). A seismic reflection profile allows to constrain the minor dip displacement of less than 2 km (1 second on two way travel time data) near the eastern termination of this emergent thrust (Figures 7). However, a minimum displacement of about 3 km can be predicted along the fault (Figure 6b).

In the Sulaiman fold belt an upper detachment (roof thrust) can preferably be located in the Cretaceous or Eocene strata (Banks and Warburton, 1986; Jadoon et al, 1994a, 1994b). However, its recognition is critical for correct interpretation of the subsurface structural geometries. Seismic reflection profile (Figure 7) shows that the Goradand-1 fault of shallow penetration (Ismail fault of Jadoon et al. 1994a) involves post Eocene strata in deformation of an upper structural unit above the Jurassic. Subsurface expression of the SE verging hanging wall block of Cretaceous and younger strata above Goradand thrust against almost horizontal footwall block can be seen in the seismic reflection line shown in figure 7. This clear example showing post Eocene (Paleocene to Cretaceous) strata as part of a single upper structural unit is critical to locate the upper detachment in the Cretaceous, and not in the Eocene in most of the Sulaiman fold belt.

Goradand-2 Fault

This fault south of the Goradand-1 is located in the Kirthar limestone. Its general EW trend changes to NE near eastward termination of the Goradand-1 fault. It is recognized as a dextral strike-slip fault based on offset of bedding (Kirthar Formation), associated drag, and offset of a synclinal axis (Figure 10). About 4 km of apparent dextral strike-slip displacement can be measured along fault based on the satellite data. NE trend of the Goradand Range, discordant to the general EW structural trends in the MBFTS may be related to the anti clockwise rotation of a block between Ningir and Goradand-2 faults.

Kahar Nala Set of Faults

This is a set of EW and NE trending faults of relatively smaller length. They show a clear dextral displacement (200 m to 800 m) north of Sian Koh anticline (Figures 5 and 11). The drag folds (strike-slip duplex?) of variable half-wavelength (about 1 km to 0 km) depending upon the displacement along each fault are mapped (Figure 11). They are important, similar

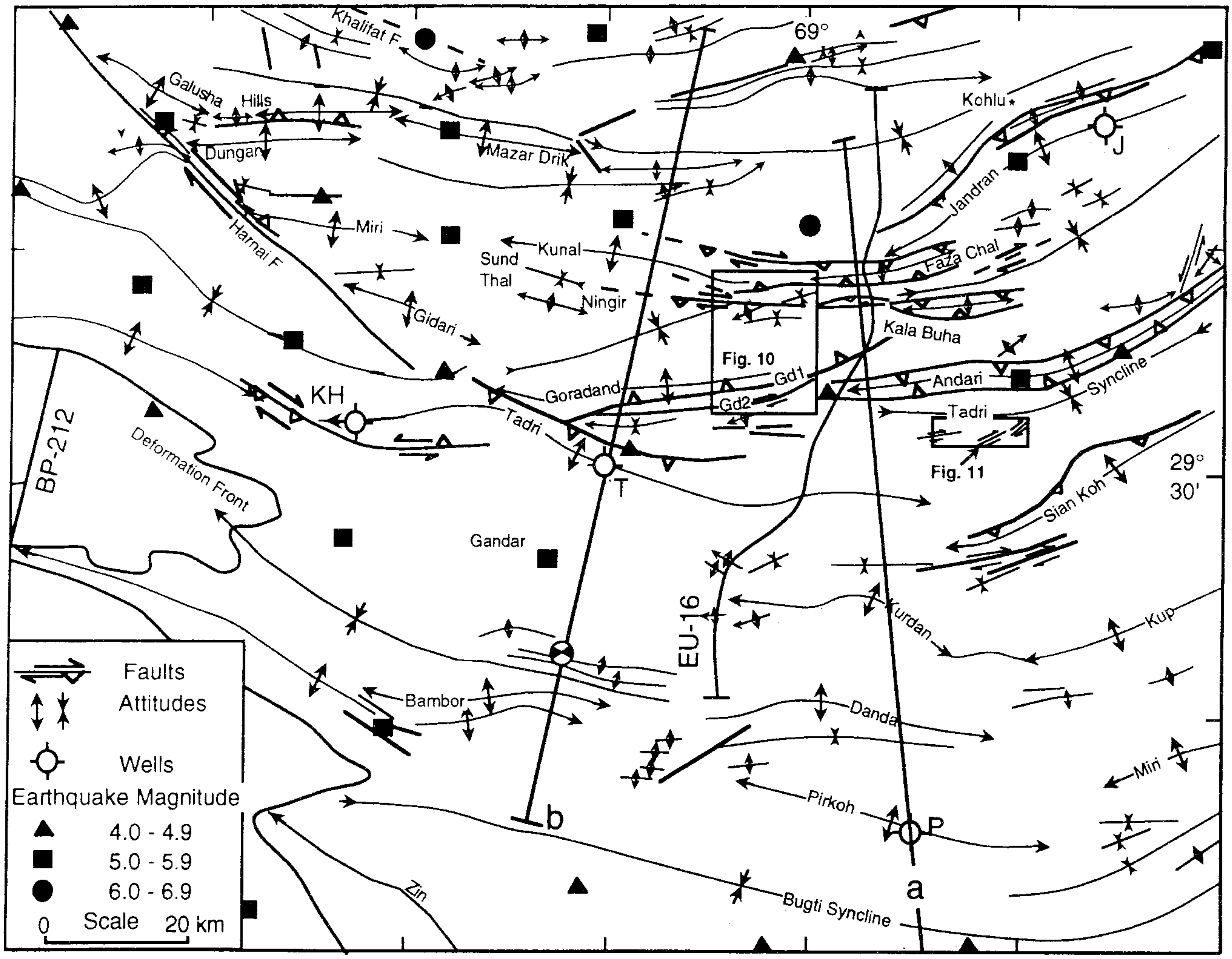

Figure 5- Structural map of the MBFTS (See Figure 1 for location of the map). Mapping is compiled interpreting LANDSAT and SPOT scenes (1:50,000) supplied by Tullow Oil modifying the geological map based on air photo interpretation by Jones (1961) on a scale of 1:2,53,400, and Jadoon et al.(1994a); published 3 sheets (1:50,000) and unpublished (1: 2,50,000) maps of the Geological Survey of Pakistan. See location of seismic reflection profiles (EU-16 and BP-212). EU-16 provides critical control for the structural interpretation, and depth penetration of some exposed faults (Jadoon et al., 1994a), whereas BP-212 shows more than 7 s thickness of layered stratigraphy in the Sibi trough on two way travel time data. A segment of EU-16 between Andari and Kala Buha is shown in figure 5. Lines a and b are shown in figure 6.

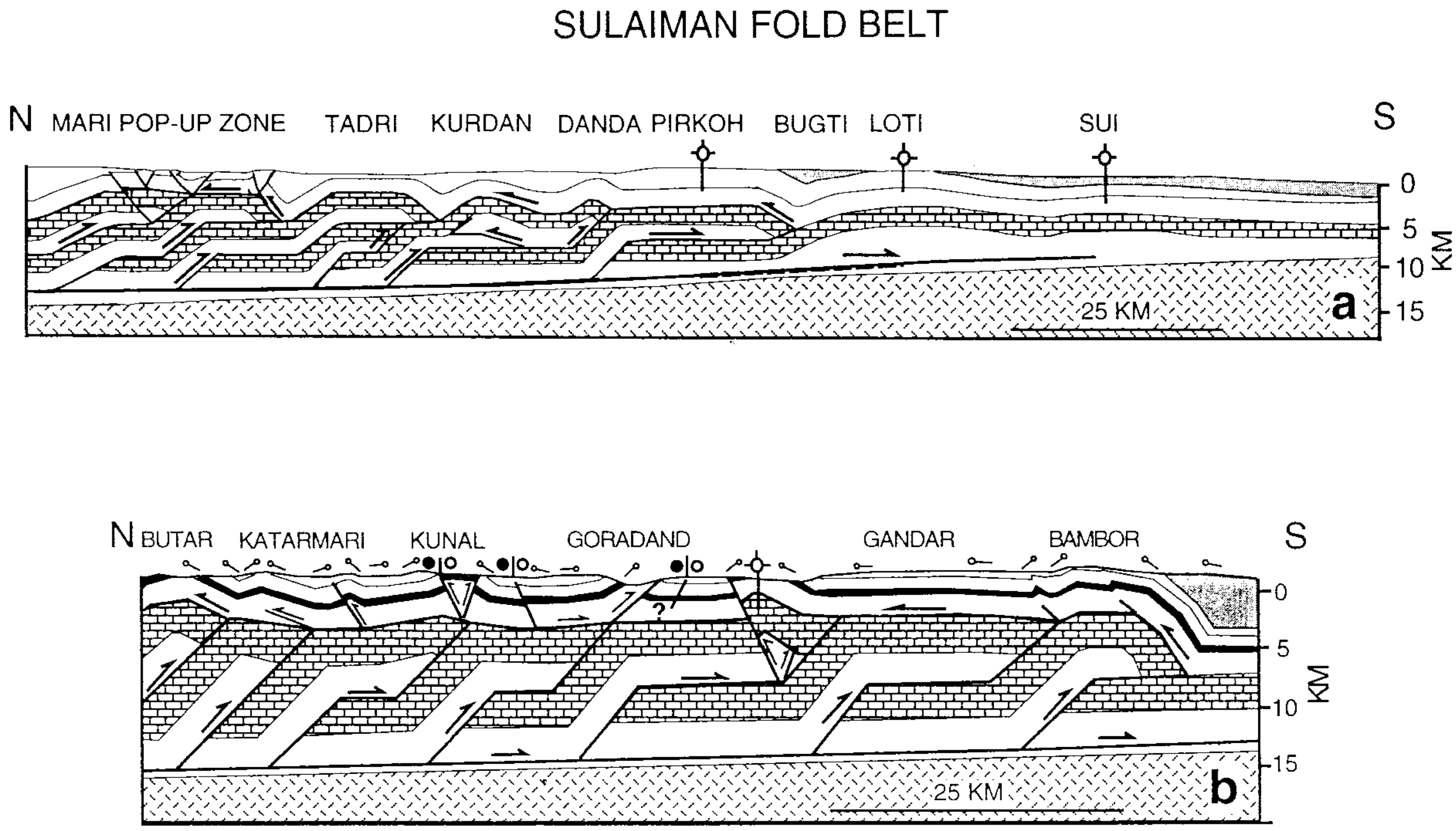

Figure 6. Geological cross-sections: a) from Jadoon et al., (1994a) and b) from Jadoon (1995), across the foreland of the Sulaiman fold belt. See figure 4 for the location of cross-sections. The cross-sections show a passive-roof duplex geometry with most of the exposed structures restricted to the roof sequence. Filled circles in figure 6b show movement of blocks away from reader. Patterns: sand, molasse; bricks, Jurassic; random dashes, crystalline basement; white from top to bottom, Eocene, Cretaceous, and Triassic to Paleozoic. Black pattern in figure 6b shows Paleocene.

to Ningir and Goradand-2, to show dextral strike-slip displacement along EW trending faults in the MBFTS.

Khattan Fault

This fault is named after the Khattan river south of the Tadri anticline. Its trend is WNW-ESE. The fault can be traced for about 35 km on the satellite data and is a complex feature with along strike variation of vergence and opposite sense of strike-slip (dextral and sinistral) displacement (Figure 5). It may primarily be a strike-slip fault or more favorably 2 faults of opposite vergence at similar positions (see figure 12f). A passive-backthrust whose geometry is being obliterated by a secondary foreland vergent oblique fault, shown as a blind fault in figure 6.

Oil seepages in the Khattan river may be related to this fault. It is possible that oil first migrates updip along a passive-backthrust from the adjacent Sibi trough from a Cretaceous or younger source and then follows updip along foreland vergent thrust (Figure 12f). Alternately, oil may be migrating updip, along foreland vergent secondary fault, from a deeper breached reservoir of older strata (Jurassic?).

Tadri Backthrust

It is a WNW-ESE trending reverse fault of hinterland vergence located near the western part of the Tadri anticline. The fault was previously mapped by Hunting Survey Corporation (1961). Along 27 km length of the fault, mostly Paleocene Dungan limestone is thrust over upper Eocene Kirthar strata. Dip displacement of about 3.5 km and a depth penetration of about 9 km can be predicted along the fault (Figure 6). Crystalline basement is deeper than this depth.

Tadri backthrust and the Khattan fault may be modifying plane-roofed duplex geometry of Tadri anticline into a fault-propagation fold and a pop-up (Figures 6, 12g)

Harnai Fault

Harnai is a south vergent oblique fault of NW-SE trend with dominant dextral strike-slip. The fault, mostly located in the Ghazij Shale, at the surface is predicted to offset older strata and structures at depth (Figure 12f). It is interpreted to merge in the lower detachment at a depth of about 15 km (Jadoon, 1995).

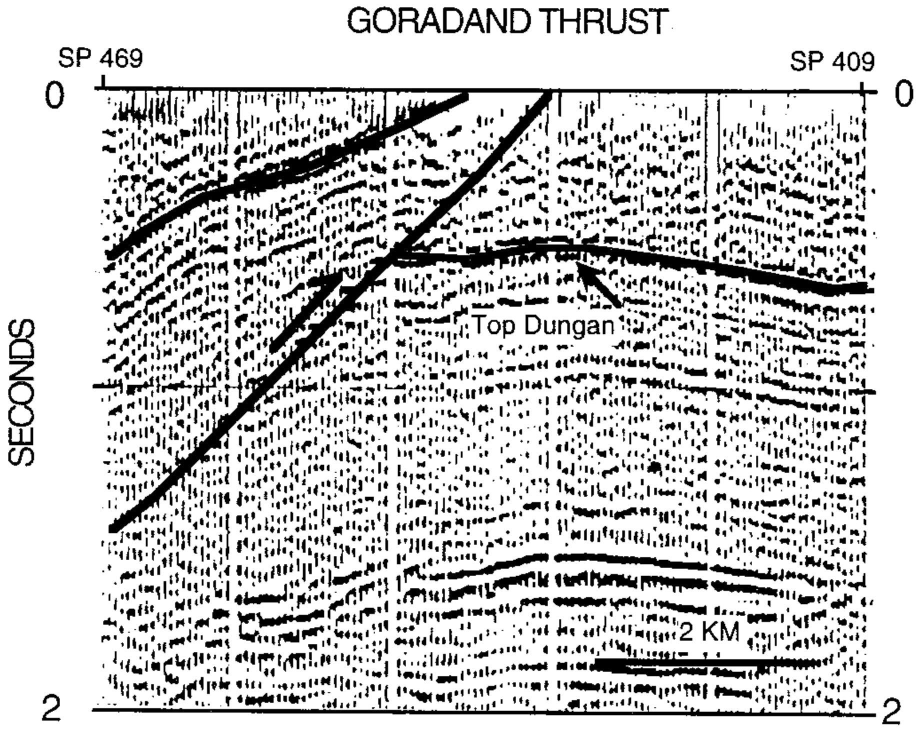

Figure 7- A part of seismic reflection line EU-16 between the Andari and Kalabuha Ranges located in figure 5. The figure show seismic expression of the Goradand thrust (Goradand-1 fault in the text) and related minor displacement.

Dextral strike- slip along Hamai fault is evidenced by the drag folds reflecting clockwise rotation and drag of the fold axes (Figure 6). However, its NW trend and kinematic evolution may be related to the rotation of thrust sheets due to drag at the lateral termination of the Sulaiman fold belt. Concentrated seismicity along the fault suggests it to be active similar to most of the other exposed faults. This fault was previously recognized by several workers (Hunting Survey Corporation, 1961; Kazmi, 1979; Bannert et al., 1992). Overall structural expression of the mountain front in the vicinity of Hamai fault is of a foreland dipping monocline, similar to as described previously by Banks and Warburton (1986).

STRUCTURAL STYLE AND KINEMATICS

The central Sulaiman fold belt consists of a complex system of hidden and exposed faults and folds. Simplest fault-related fold geometries can be defined as detachment, fault-bend folds, fault-propagation folds or pop-ups, depending upon if they develop over a detachment, bending of a fault or at the tip of a hidden or an emergent fault (Figure 12).

The emergent fault system of the Mari-Bugti can generally be divided into three groups. 1) Reverse faults of shallow penetration (4-9 km) such as Jandran, Andari, and Tadri (Jadoon, 1995); 2) Oblique-slip faults of deeper penetration (15 km) such as Hamai (Jadoon, 1995); and 3) young strike-slip faults of consistent dextral offset such as Goradand-2 and Kahar Nala. Shallow depth of the exposed, probably active, faults is consistent with the shallow depth of the earthquakes (Quittmeyer et al., 1984).

The reverse faults are interpreted to mostly sole out in an upper detachment at the base of the Cretaceous strata and may represent out-of-sequence deformation to create required taper for foreland translation of the thrust wedge (Davis et al. 1983) and to produce a mechanically stable backthrust wedge configuration in the low-angle triangle zone geometry of a passive-roof duplex in the Sulaiman fold belt (Jadoon, 1995; Figure 13a).

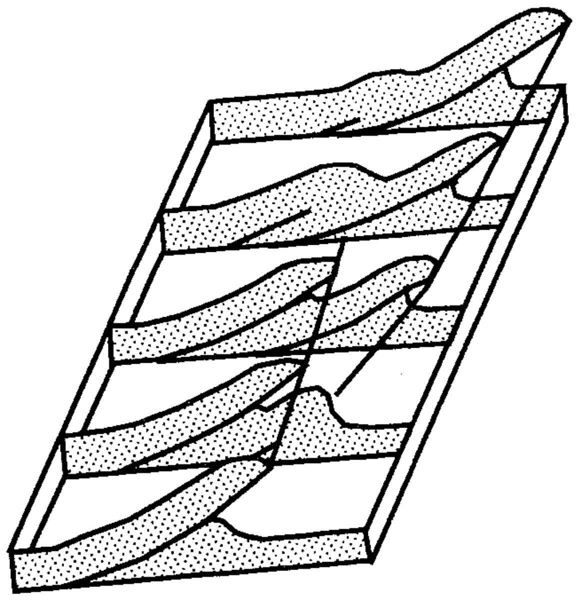

Figure 8- Transfer of structures in a fold-thrust system (from Dahlstrom, 1969).

Younger set of EW trending faults obliterate former structural trends. They show a consistent dextral strike-slip displacement (as much as 4-5 km), and related drag folds and strike-slip duplexes. Their recognition suggests onset of dominant transpressive deformation involving block rotation in the Sulaiman fold belt between the NS trending Sulaiman/Kirthar Ranges near the western boundary of the Indian subcontinent (Figures 1 and 13b). EW trending strike-slip faults are also recognized in the Kohat fold belt towards north (Pivnic and Sarcombe, 1993). It suggests that such features may be present in other parts of the Himalayan fold belt in Pakistan.

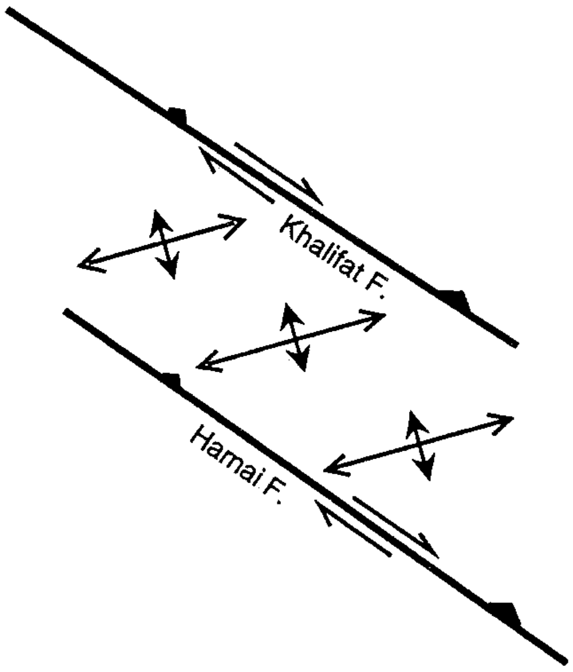

Figure 9- Kinematics and evolution of en-echelon folds (Gidari, Miri, Dungan) between Hamai and Khalifat faults.

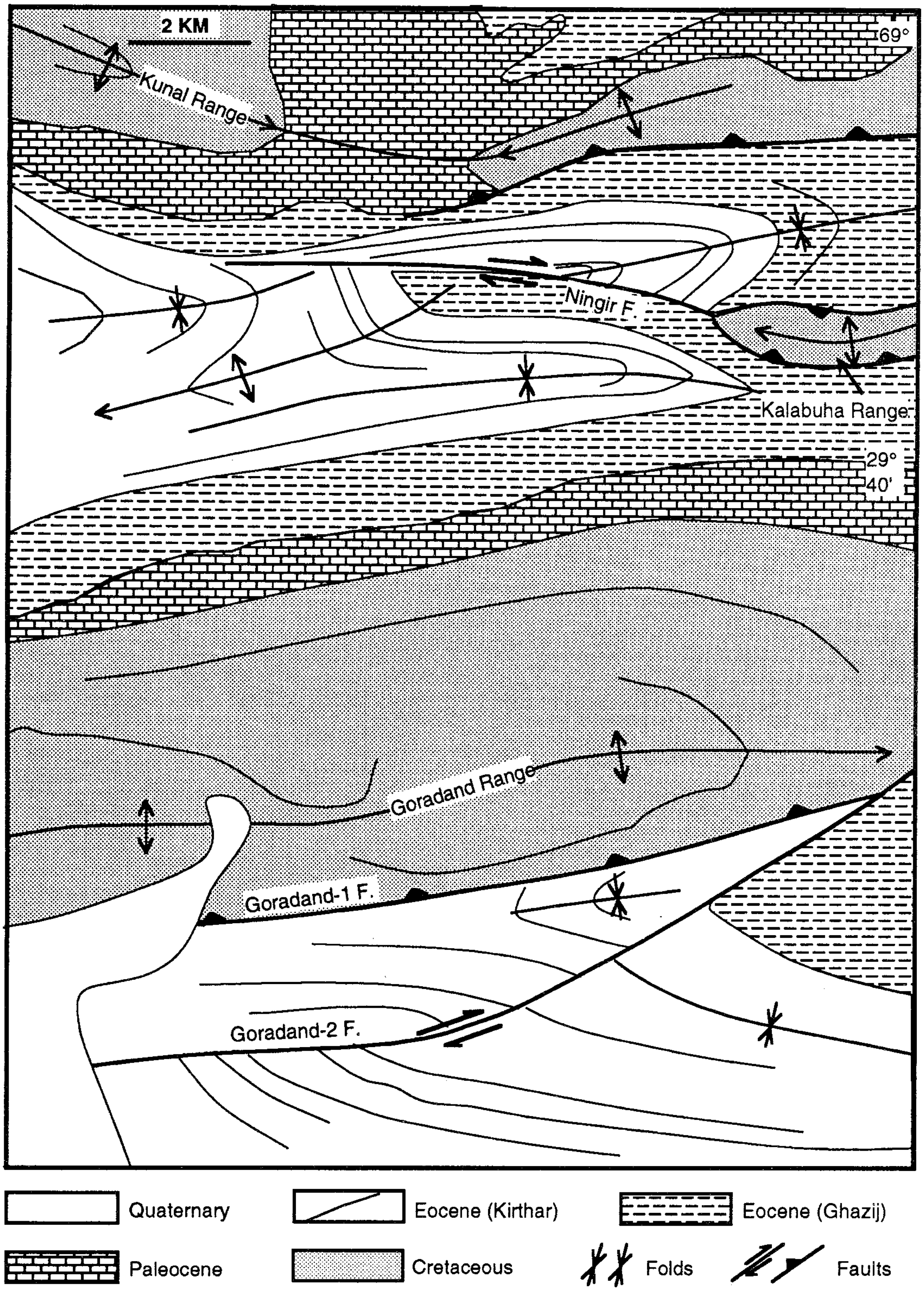

Figure 10- Structural map of a part of the Mari-Bugti based on LANDSAT TM interpretation to show dextral strike-slip and reverse faults. See figure 5 for location and figure 7 for the seismic expression of the Goradand-1 fault.

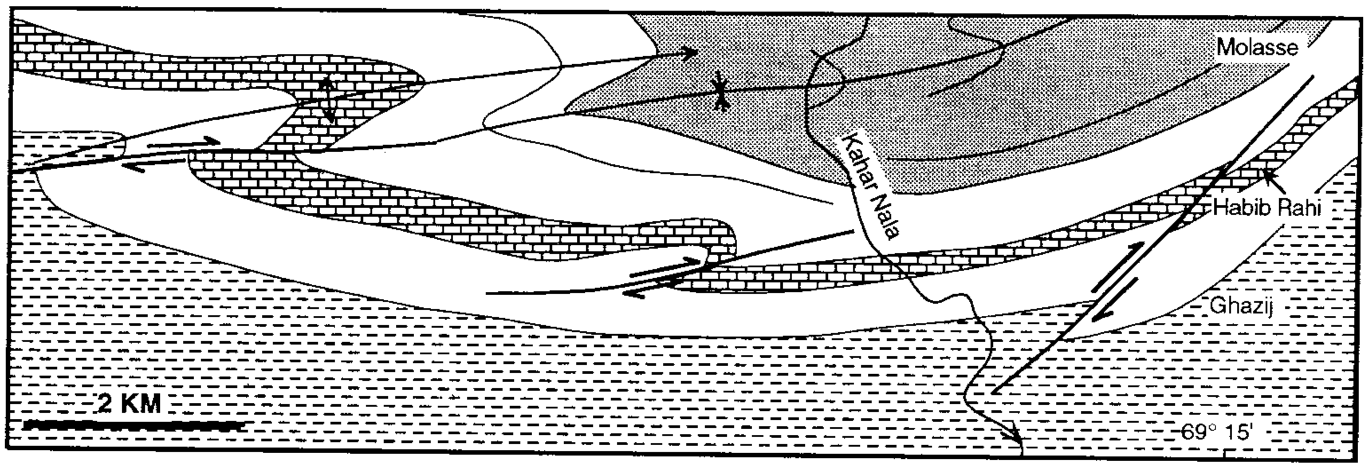

Figure 11- Structural map of a part of the Mari-Bugti based on LANDSAT TM interpretation to show a set of dextral strike-slip faults north of Sian Koh and associated strike-slip duplexes. See figure 5 for location.

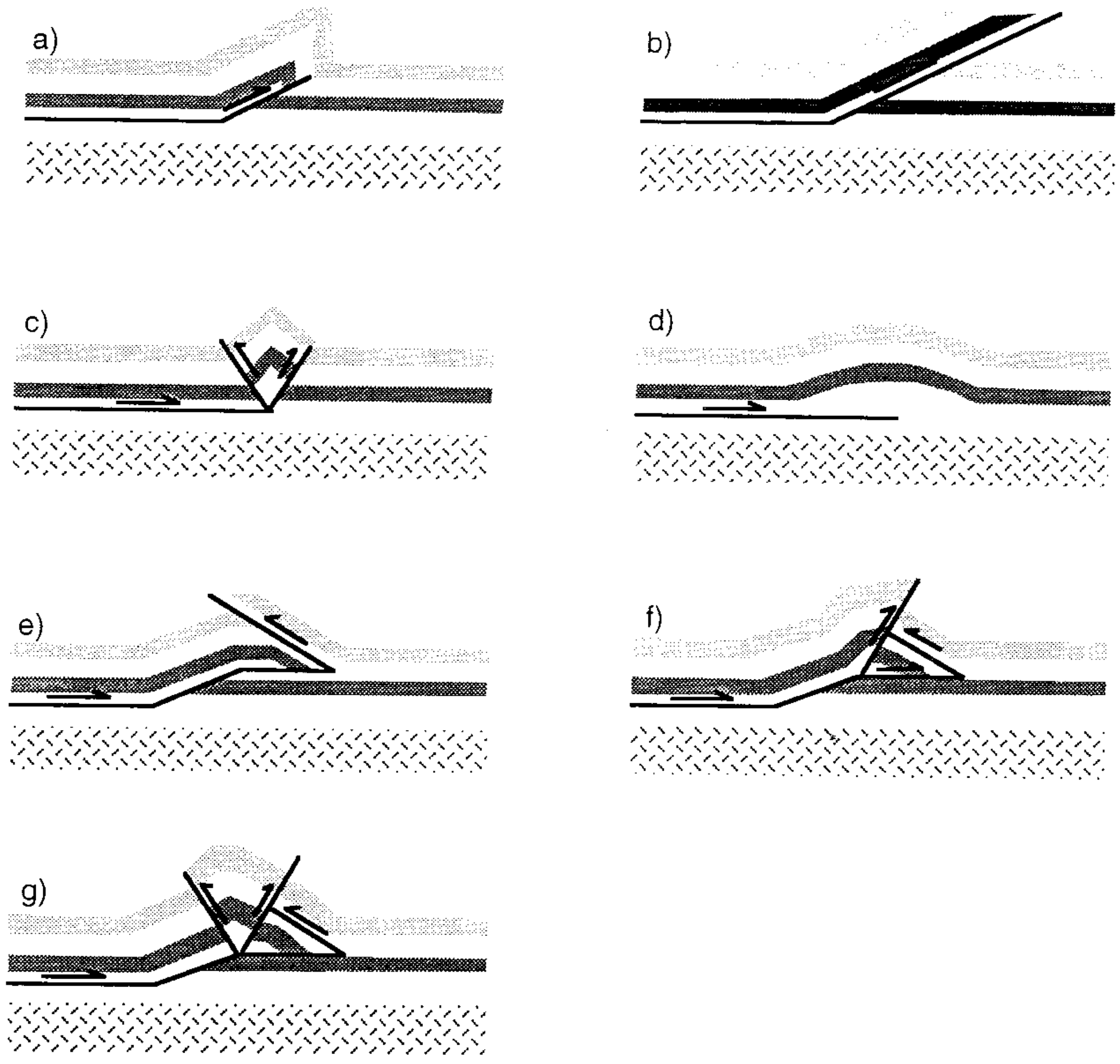

Figure 12- Interpretation of the fault-related folds in the MBFTS: a, fault-propagation folds; b, emergent thrusts; c, pop-ups; d, detachment folds; e, fault-bend folds; f and g compound ramp anticlines.

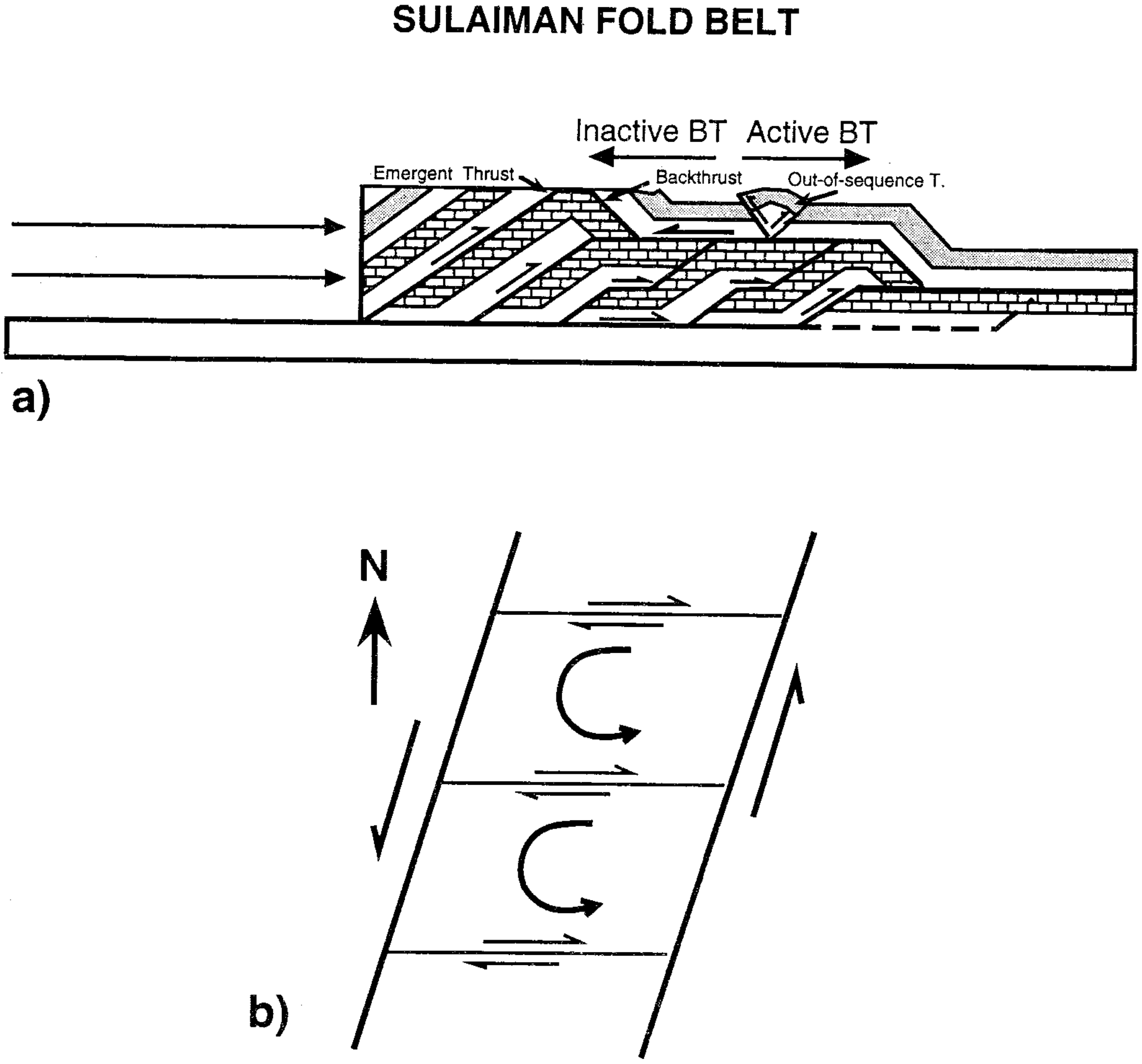

Figure. 13- Simplified model of the Sulaiman fold belt. a) MBFTS is analogous to out-of-sequence deformation in a mechanically instable backthrust wedge configuration (Jadoon et al., 1994a; Jadoon, 1995), which is under an influence of dominant strike-slip deformation between NS trending Sulaiman and Kirthar Ranges (b). See figure 1 for distribution of strike-slip and thrust related deformation east of the Chaman fault.

CONCLUSIONS

The Mari-Bugti fold-and-fault system consists of a peculiar system of hidden and exposed faults and folds. Simplest fault-related fold geometries are defined as detachment, fault-bend folds, fault-propagation fold, or pop-ups depending upon if they develop over a detachment, bending of a fault, and at the tip of a hidden or an emergent fault. Transfer of displacement, such as faults to folds, due to along strike variation in the amount of displacement is observed.

The faults can be divided into three general groups:

1) Reverse faults of shallow penetration (4-9 km), such as Jandran, Andari, and Tadri. These faults generally sole out in an upper detachment of the Cretaceous strata and involve minor dip-slip displacement. They represent out-of-sequence deformation of a thrust wedge.

2) Oblique-slip faults of deeper penetration (15 km), such as Hamai. These faults sole out in lower detachment of the Paleozoic strata and involve dominant dextral strike-slip deformation due to rotation of the thrust sheets at the lateral termination of the thrust system. In the western Sulaiman fold belt, left-stepped anticlines of en-echelon arrangement (Gidari , Miri, Dungan) can also be related to dextral displacement along Hamai and Khalifat fault.

3) Strike-slip faults, such as Goradand-2 and Kahar Nala set of faults. Persistent dextral strike-slip as much as about 4-5 km and related drag folds and strike-slip duplex are a peculiar feature of such structures on the Landsat data. Their evolution can be related to the onset of dominant Quaternary transpression involving anti clockwise block rotation between NS trending Sulaiman and Kirthar Ranges near the western boundary of the Indian subcontinent.

The Sulaiman fold belt is one of the main petroleum zones of Pakistan. This study provides an overview of the structural style and lateral structural variation in the MBFTS. Structural analyses show in-sequence and out-of-sequence deformation. The out-of-sequence faults may provide conduits or seals for the accumulation and/or migration of hydrocarbons. Surface oil seepages of Samach, Spintangi, and Khattan located along/or near the faults suggests that out-of-sequence faults may provide conduits for lateral migration into adjacent structures or updip migration of hydrocarbons to produce surface seepages. Detailed structural studies are critical for successful exploration and exploitation of the hydrocarbons.

ACKNOWLEDGEMENT

This work is carried out at Goettingen University during a post-doctoral fellowship (1994-1995) to the first author by Alexander von Humboldt Stiftung. We gratefully acknowledge Dr. J. McCann of Tullow Oil for providing LANDSAT/ SPOT scenes and other geophysical data for this study. A reconnaissance field check of structures and stratigraphy between Kohlu and Andari Range was made possible (for the first author) by Assistant Commissioner Kohlu, M. Ilyas in the winter of 1990, for which he is gratefully acknowledged. Friendship of M. Kollmann and access to his personal computer made this project an enjoyable experience. Finally, the first author wishes to acknowledge his colleague Dr. A. A. Khawaja for his cooperation, without which it was not possible to conduct this research.

REFERENCES

Ahmed, R., S.M. Ali, and J. Ahmad, 1992, Structural styles and hydrocarbon prospects of Sibi foreland basin, Pakistan: Pakistan J. Hydrocarbon Research, v. 4, no.1, p. 31-40.

Banks, C.J., and J. Warburton, 1986, 'Passive roof duplex' geometry in the frontal structure of the Kirthar and Sulaiman mountain belt, Pakistan: J. of Structural Geology, v. 8, p. 229-237.

Bannert, D., A. Cheema, and A. Ahmad, 1992, The geology of the western fold belt: structural interpretation of the LANDSAT-MSS Satellite Imagery (1:500,000): Hannover, Germany, Federal Institute of Geosciences and Natural Resources, 3 Sheets.

Dahlstrom, C.D.A. 1969, Balanced cross-sections: Canadian J. of Earth Science, v. 6, p. 743-757.

Davis, D., J. Suppe, and F.A. Dahlen, 1983, Mechanics of fold-and-thrust belts and accretionary wedges: J. of Geophysical Research, v. 88, p. 1153-1172.

Davison, I., 1994: Linked fault systems; Extensional, strike-slip and contractional: in P.L. Hancock, eds., Continental Tectonics: University of Bristal, p. 121-142.

Diegel, F.A., and S.F. Wojtal, 1985, Field trip in SW Virginia and NE Tennessee, southern Appalachians: University of Tennessee, Department of Geological Sciences, Studies in Geology v. 9, p. 70-118.

Dixon, J.M., and S. Liu, 1992, Centrifuge modelling of the propagation of thrust faults: in K. McClay, eds., Thrust Tectonics: Chapman and Hall, p. 53-69.

Elliot, D., 1976, The energy balance and deformation mechanisms of thrust sheets: Philosophical Transactions of Royal Society of London A 283, p. 289-312.

Hunting Survey Corporation. 1961, Reconnaissance geology of part of West Pakistan: a Columbo plan cooperative project: Hunting Survey Corporation, Toronto, Canada.

Jadoon, I.A.K., R.D. Lawrence, and S.H. Khan, 1994a: Mari-Bugti pop-up zone in the central Sulaiman fold belt, Pakistan: J. of Structural Geology, v. 16, p. 147-158.

__, R.D. Lawrence, R.D. and R.J. Lillie, 1994b, Seismic data, geometry, evolution, and shortening in the active Sulaiman fold-and-thrust belt of Pakistan: AAPG Bulletin, v. 78, p. 758-774.

__, 1995, Three dimensional geometry of passive-roof duplex, Quaternary transpression, and hydrocarbon traps in the Sulaiman foreland, Pakistan: Pakistan J. Hydrocarbon Research, (submitted).

Kazmi, A.H., 1979, Active fault system in Pakistan, in A. Farah and K.A. DeJong, eds., Geodynamics of Pakistan: Geological Survey of Pakistan, p. 285-294.

__,1981, Stratigraphy and sedimentation of the Jurassic in north-eastern Baluchistan: Geological Bulletin, University of Peshawar, v. 14, p. 193-198.

__, and R.A. Rana, 1982, Tectonic map of Pakistan (1:2,000,000), Geological Survey of Pakistan.

Kemal, A., and M.A. Malik, 1987, Geology and gas resources of Mari-Bugti agency, Pakistan: Acta Mineralogica Pakistanica, v. 3, p. 72-81.

Klootwijk, C.T., R. Nazirullah, K.A. DeJong, and A. Ahmad, 1981, A paleomagnetic reconnaissance of northern Baluchistan, Pakistan: J. of Geophysical Research, v. 86, p. 289-305.

__, P.J. Conghan, and C.M. Powell, 1985, The Himalayan arc, large scale continental subduction, oroclinal bending, and back-arc spreading: Geologische Rundshau, v. 67, p. 37-48.

Minister, J.B., and T.H. Jordan, 1978, Present day plate motion: J. of Geophysical Research, v. 83, p. 5331-5354.

Nakata, T., K. Otsuki, and S.H. Khan, 1990, Active faults, stress field, and plate motion along the Indo-Eurasian plate boundary: Tectonophysics, v. 181, p. 83-95.

Pivnik, D.A., and W.J. Sercombe, 1993, Compression and transpression related deformation in the Kohat Plateau, NW Himalaya, in P.J. Treloar and M.P. Searle, eds., Himalayan Tectonics: Geological Society London, Special Publication 74, v. 559-580.

Quittmeyer, R.C., A. Fąrah, and K.H. Jacob, 1979, The seismicity of Pakistan and its relation to surface faults, in A. Farah and K.A. DeJong, eds., Geodynamic of Pakistan: Geological Survey of Pakistan, p. 271-284.

__, A.A. Kaffa, J.G. Armbruster, J.G. 1984, Focal mechanisms and depths of earthquakes in central Pakistan: a tectonic interpretation: J. of Geophysical Research, v. 89, p. 2459-2470.

Raza, H.A., R. Ahmed, S.M. Ali, J. Ahmad, 1989a, Petroleum prospects: Sulaiman sub-basin, Pakistan: Pakistan J. Hydrocarbon Research, v. 1, no. 2, p. 21-56.

__, R. Ahmed, S. Alam, and S.M. Ali, 1989b, Petroleum zones of Pakistan: Pakistan J. Hydrocarbon Research, v. 1, no. 2, p. 1-20.