

Structural Geometry and Tectonics of Southern Part of Karachi Arc - A Case Study of Pirmangho and Lalji Area*

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Abstract

The south-western end of the Kirthar fold belt is underlain by Nari and Gaj Formation of Oligocene-Miocene ages respectively deposited on the northwestern edge of the Indian continental shelf. Structures are northeast-southwest oriented with folds plunging mainly towards southwest. Pir Mangho Anticline and Lalji Syncline are the major structures of the region. Both are fault induced folds indicated by their double hinges and kink geometries. Thrust is blind and not exposed in the region; however several sinistral strike slip faults transect the areas which are antithetic to the tectonic transport of the Karachi arc. The upper detachment lies in the Metan clays at the base of the Gaj Formation while the lower detachment lies probably within the Eocene shale.

Major folding of the strata has taken place on frontal ramps while at places oblique ramps are also the cause of some folding. Pir Mangho Dome is a consequence of thrusting on such a pair of ramps. Structural vergence indicates tectonic transport towards southeast. However, structures of the region may have been initially north south oriented and may have been rotated clockwise, evidenced by the presence of some extensional structures to the south of the area. However, partly structural geometry of the Karachi arc is original, evidenced by the presence of en-echelon folds. Eastward tectonic transport of the Karachi arc is post Miocene in a thin skinned fashion as a result of India -Arabia convergence.

These structural geometries extend towards north and northeast all along the Karachi arc and the Kirthar fold belt. Pir Mangho-Lalji area studied can be used as an analogue to interpret and explore the region.

Introduction

A major proportion of up to date discovered hydrocarbons are found in structural traps. Efforts made so far to target such traps have resulted in discoveries as well as dry holes. Better understanding is a key towards success. It is therefore, imperative to understand regional tectonics and structural geometries at local scale. Many efforts have already been made towards this direction. It is also worth to mention here that in other parts of the world many oil and gas fields were abandoned considering that they have been depleted; nevertheless, renewed exploration in those abandoned fields, in the light of modern understanding of structure and tectonics, brought them to the re-exploited stage and new discoveries were made (Boyer and Elliot, 1982). We think that there is still an ample potential which lies in the fold belt areas where fault induced folds are the common structural styles which have been discussed by many researchers all over the world. The references worth mentioning, for instance, are (Dahlstrom, 1969; Boyer and Elliot, 1982; Suppe 1985, Ramsay and Huber 1987). Their findings are considered as most relevant to the fold and thrust belts where thin skinned tectonic is a pronounced deformational style.

In Kirthar and Sulaiman fold belts, right from Salsabil to Bhit gas fields, all hydrocarbon accumulations are found in structural traps. These fold belt areas exhibit similar fault induced folds as major structural styles which have already been mapped and published by various authors such as (Banks and Warburton, 1986; Jadoon et al., 1991; Jadoon et al., 1994; Niamatullah et al., 2000).

The Kirthar fold belt was initially mapped on reconnaissance bases by the Hunting Survey Corporation, 1960. Later in 2001, the Karachi area.

Mapped on a scale of 1:100,000 and subsequently published (Qureshi et al., 2001), however, its tectonic and structural style was never addressed under modern understanding of thrust tectonics. The area located in the southern part of the Kirthar Fold Belt near Karachi is therefore selected to understand regional tectonics and local structural styles to facilitate future exploration in this area.

Study Area

The Pir Mangho-Lalji area is located to the northwest of Karachi ([Figure 1](#)) in the southern part of the Kirthar fold belt (Hunting Survey Corporation, 1960; Kazmi and Rana, 1982) ([Figure 2](#)). All the structures are north-south oriented north of Pir Mangho and swing southwest as they are followed towards the coast. This swing of structures is because the study area is located at the southern end of the Karachi Arc which is of arcuate nature convex eastward ([Figure 3](#)). The area is underlain by Nari and Gaj Formations of Oligocene and Miocene ages respectively. These rocks were deposited in Karachi Trough which is a triangular depositional basin opening southwards towards Arabian Sea. This depositional basin was formed by uplifted of the surrounding area in the southern part of Kirthar Fold Belt during Himalayan Orogeny.

Lithostratigraphy

Stratigraphically the Pir Mangho-Lalji area is covered by the Nari and Gaj Formations belonging to Oligocene and Miocene age respectively (Figure 4). The Nari Formation consists mainly of sandstone and shale with subordinate limestone while the Gaj Formation consists of shale with subordinate sandstone and limestone. Both of these Nari and Gaj Formations were deposited in shallow marine environments in the former Karachi trough. The shallow marine depositional condition is evidenced in the study area by the presence of reefal limestone in Ghora Laki and Jhill members of the Nari and Gaj Formations and the presence of the well developed cross bedding and ripple marks in the Halkani and Orangi members of the Nari Formation and Talawa member of Gaj Formation. The provenance of these Nari and Gaj Formations are considered to be the Pab range in the Kirthar present north of the Karachi trough. The Nari and Gaj Formations exhibit a thickness of at least 800 and 1000 meters respectively in the study area. Structurally the shale of these Nari and Gaj Formations are acting as detachments for the movement of the thrust sheet.

Regional Tectonics

The Kirthar Fold Belt which is north-south oriented between Quetta and Karachi, is more than 800 km long and about 200 km wide. It is bounded by the Chaman Transform Fault System to the west and the Kirthar or Kachhi Foredeep in the east. The fold belt has formed by folding and thrusting of shelf sediments at the northwestern edge of the Indian Plate. The fold belt has originated as a result of India-Eurasia convergence to the north and India-Arabia to the south (Sarwar, 1992; Niamatullah, 1998). Many of the workers demonstrated the thin skinned as the most plausible deformation style all along the belt. However, some thick skinned deformation has also been reported in the southern part of it (Smewing et al., 2002).

The Karachi Arc is located in the southern part of the Kirthar fold belt (Hunting Survey Corporation, 1960; Kazmi et al., 1982) (Figure 3). This is an eastward arcuate structural feature is bounded by east-west oriented sinistral and dextral faults near Mancher Lake in north and near Karachi in south respectively (Sarwar and DeJong, 1979). The east verging structures in the Karachi Arc indicate an eastward tectonic transport in a thin skinned fashion as a result of India - Arabia convergence (Sarwar, 1992; Niamatullah, 1998).

Two detachment horizons, the older one lies in the Middle Jurassic to Early Cretaceous Sembar Formation while the younger one lies within Early Eocene Ghazij Formation where flats are located in flat-ramp geometry, which in turn is evident by the presence of fault induced folds in the belt (Banks and Warburton, 1986; Niamatullah et al., 2000). A possibility of a third detachment horizon of Eo-Cambrian salt formation cannot be ruled out.

Structural Geometries

The major structures of the area are the Pir Mangho Anticline (PMA) and the Lalji Syncline (LS) (Figure 5). The structural trend is northeast-southwest in the area, while to the north of Pir Mangho Anticline, structural trend changes sharply to the north. A number of sinistral strike slip faults displace the strata. The most important is the Pir Mangho Fault (PMF), which is a northwest southeast trending sinistral strike slip fault (Figure 6). This fault has partitioned the strain in the area. No thrust fault is exposed, however the structural style in the area indicate presence of a blind thrust in the area.

Pir Mangho Anticline (PMA)

It is an asymmetric southeast facing anticline, which has acquired somewhat domal shape. It is a double hinge anticline in which fold hinges diverge towards southwest in the plunge direction. The forelimb anticline is plunging towards southwest but its hinge swings westward at its northern extremity close to the PMF (Figure 5). To the north of Pir Mangho Dome across PMF strata acquired a sub horizontal attitude. Farther north structure is nearly a non-plunging anticline.

The fold exhibit kink geometry which is very prominent in the fore limb (Figure 7). The interlimb angle of the forelimb anticline is 128-154 degrees as compared to the back limb anticline, where there is a slight change of attitude (Figure 8) having an interlimb angle of about 160 degrees. This back limb anticline disappears towards southwest. This kink geometry may lead to the presence of a blind thrust having staircase pattern in subsurface. It is generally considered that emplacement of thrust sheet produced folds having kink geometry (Ramsay and Huber, 1987; Suppe, 1985; Boyer and Elliot, 1982). Moreover, kink is quite sharp on the Pir Mangho Hill whose sharpness gradually decreases towards southwest in Orangi area. A pair of kinks is present across the PMA at a high angle (Figure 5) running in southeast and northwest direction from the Pir Mangho Hill forming cross folds. To the southeast of PMA a third anticlinal kink is present running parallel to the PMF where forelimb of the cross fold is present (Figure 5 and Figure 9). While towards northwest a synclinal kink is present running parallel to the PMF where its back limb is better developed (Figure 10). If not fully but partly the Pir Mangho Fault is partitioning strain. Towards north of the fault, both style and trend change sharply and it extends a non-plunging anticline having horizontal strata in between.

Lalji Syncline (LS)

This is located to the southwest of the Pir Mangho Anticline. It is also a double hinge syncline having kink geometry where hinges plunging towards southwest (Figure 11). The two synclinal hinges are separate in the northeast but converge towards southwest where they join together and form a single hinge asymmetric fold facing southeast in Orangi area. Where fold is double hinged, its eastern limb is dipping at a low angle towards west, while its northwestern limb is dipping at a higher angle towards southeast.

Faults

Several strike slip faults transect through the area ([Figure 5](#)). Pir Mangho Fault (PMF) is the most important fault of the area which is a northwest southeast trending vertical fault with subhorizontal striation and having sinistral displacement. There is a swing of about 30 degrees at two places in the strike of the fault. The sense of displacement and the geometry of swing produces restraining bend along the fault. Towards its northwestern end synthetic riedel shears are also present having strike slip displacement ([Figure 12](#)). The PMA suddenly ends up against this fault. However, part of Lalji Syncline in its northeastern part has been displaced along this fault. The fault is partly partitioning strain in the area. Moreover, there is a change of structural trend across this fault ([Figure 13](#)).

Two types of strike slip faults are observed in the areas which are sub-parallel to each other. One type of fault cuts across bedding at a high angle, but display slickenside striations which are oriented parallel to the bedding plane. These strike slip faults developed on the lateral sides of thrusting slab while the slab was moving on a flat. These faults indicate the presence of flats and hence the fault induced folding style of the area. These faults cannot produce offsets in strata. The second types are tear faults in which striation is not parallel to the bedding and they have displaced the strata, when strata were inclined. These faults are northwest-southeast oriented ([Figure 14](#)). These tear faults displaced the strata in a sinistral sense and are antithetic to the main tectonic transport direction of Karachi Arc. However, field evidences indicate that some of the strikes slip faults initially developed as the former type. Later on these faults provide the weak zone and developed into latter type.

No thrust fault is exposed in the area. However, folding style indicate the presence of at least one major blind thrust in this area. The strike of the frontal foot wall ramp can be predicted with the help of surface structures and is supposed to be parallel to the back limb of the PMA.

Discussion

The kink geometry of folds at Pir Mangho and cross fold suggests that they are fault bend folds ([Figure 15](#) and [Figure 16a](#)). These folds indicate the presence of a blind thrust in subsurface having stair-case pattern. The major Pir Mangho Anticline (PMA) is formed by climbing of thrust sheet on a frontal ramp as the tectonic transport is towards southeast in this part of Kirthar fold belt. While the folds crossing it at a high angle have developed by partial climbing of thrust sheet on an oblique ramp, the northeast-southwest orientation of the back limb of the Pir Mangho Anticline indicates an orientation of the frontal ramp present in subsurface. Although the anticline of the frontal ramp of the PMA has a sharp kink, the back limb is a gentle anticline. This may be due to circular hinge sectors (Tavani et al., 2005) or due to tectonic erosion of the upper end of footwall ramp. The back limb syncline is very gentle suggesting a very low footwall cut off angle.

The kinks developed oblique to the PMA probably by movement of thrust sheet on oblique ramp. The particular geometry and the orientation of the cross folds suggests the presence of an oblique ramp in subsurface. This oblique ramp terminates at its intersection with frontal ramp (Figure 16b). The back limb of the crossed kink is present on the rear side of this intersection to the northwest of the PMA. To the southeast of PMA in foreground the back limb is missing while the forelimb is developed. This intersection of forelimb of the frontal fold and the lateral fold can be seen on the ridge of the Ghoralaki Limestone south of Pir Mangho Ziarat. This kind of geometry is predicted when a thrust sheet climbs on an intersecting frontal and oblique ramp. The presence of intersecting frontal and oblique ramp in subsurface is also evidenced by the presence of swing in the fore limb of the PMA (Figure 5). At the surface the presence of another small fault striking parallel to the PMF but dipping parallel to the back limb and cross fold (Figure 17) and probably parallel to the oblique ramp in subsurface having sub horizontal striation also support the interpretation of an oblique ramp in the subsurface. The fault plane data indicate such faults as having oblique slip displacement with components of strike slip and thrust movement (Figure 14).

It was a blind thrust on which movement of hanging wall has produced fault bend fold at Pir Mangho as well as the cross fold present at a high angle to it (Figure 16b). However, later the oblique ramp above which the cross fold was developed turned out as an emergent fault, named as "Pir Mangho Fault". It is a southwest dipping fault at moderate angle parallel to the back limb of cross fold in the subsurface. However, it dips at a steep angle at the surface. Moreover, it also propagated at a deeper level where it transects the footwall ramp of the PMA and displaced it. This is suggested by the transected and displaced back limb syncline (Figure 5). Because in such type of folds the back limb syncline is always fixed at the lower end of footwall ramp (Suppe, 1985; Ramsay and Huber, 1987; Boyer and Elliot, 1982). Moreover, the conversion of blind fault at oblique ramp into an emergent fault is also evidenced by the faulted anticline of cross fold where this strike slip fault (PMF) dissected it and runs parallel to it (Figure 18). The upper detachment for this fault bend fold lies in the Metan clays at the base of the Gaj Formation. While the lower detachment lies somewhere below the Nari Formation, probably in Eocene shales.

Application

Before better understanding of the fault induced fold geometry many of the structures tested in other parts of the world were dry in the early stage of the exploration and produced the hydrocarbons in the later exploration stages with the modern structural geological concepts applied (Banks and Warburton, 1986). Fault related anticlines are the main producing structure in many fields of the Kirthar Fold Belt and Potwar areas. The study area also exhibit the fault related domal structure, developed as a result of climbing of thrust sheet on a frontal ramp and an oblique ramp. This area can be used as an analogue to understand the structural styles of thin skinned tectonic areas like the Sulaiman Lobe which is a southeast vergent arcuate structural feature. In the central part of the fold belt thrust sheets are climbing on the frontal ramp with the possibility of some oblique ramp on the sides of the lobe.

To work on the structure in the thin skinned affective areas the position of the main detachments and frontal, oblique, and lateral ramps need to be evaluated in more detail. Because many of the lateral ramps can breach the main structure of interest if the faults are non-sealing and crossing through the crest of the structure.

Conclusion

Structural geometries indicate the presence of fault bend folds in the study area. Absence of any emergent and exhumed thrust in the area suggests the presence of a blind thrust in subsurface. The Pir Mangho domal structure is formed by the climbing of hanging wall mainly on the frontal ramp which is present in subsurface parallel to the northeast southwest structural trend and partly climbing an oblique ramp oriented at a high angle to it. The structural vergence indicates an east-southeast tectonic transport of the cover rocks. The involvement of Miocene rocks in deformation indicates that the tectonic activity is post Miocene.

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Figure 1. Satellite imagery of north of Karachi. Inset is the area mapped.



Figure 2. Satellite imagery showing the Kirthar Fold Belt.



Figure 3. Satellite imagery of the Karachi Arc. Inset is the study area.










Stratigraphic Column of the Study Area						
Age		Formations	Members Acc to New Literature	Members Acc to Current Study	Lithology	Description
Period	Epoch					
QUAT	Pleist-Pliocene	Recent	Recent	Recent		Consist of Sandstone, Shale & Conglomerate
TERTIARY	MIOCENE	GAJ	Mol	Talawa		Consist of limestone & Shale
				Jhil		Consist of Reefal limestone
			Mundro	Metan		Consist of Shale & Limestone
	OLIGOCENE	NARI	Orangi	Orangi		Consist of Sandstone & Shale
				Gora laki		Consist of Reefal limestone
				Halkani		Consist of Siltstone & Shale
			Pir Mangho	Pir Mangho		Consist of limestone, Shale & Sandstone
			Hub	Tobo		Consist of Sandstone, Shale & Limestone

Figure 4. Stratigraphic Column of the area mapped.

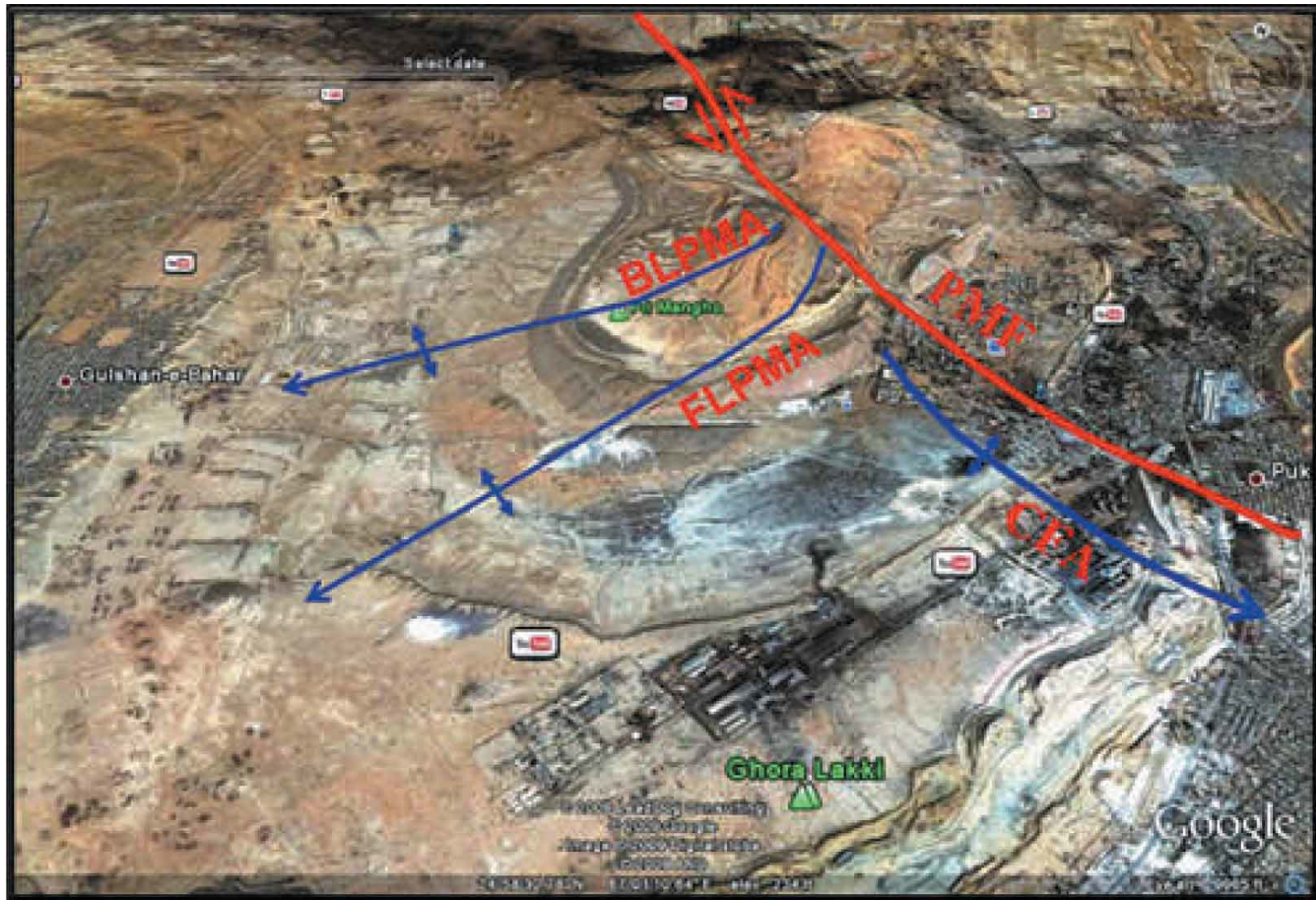


Figure 6. Satellite imagery of the area mapped looking north. Abbreviations are: PMF for the Pir Mangho Fault, FLPMA for Fore Limb Pir Mangho Anticline and BLPMA for the Back Limb Pir Mangho Anticline, CFA for the Cross Fold Anticline.



Figure 7. Photograph showing the kink geometry of the fore limb of the Pir Mangho Anticline. Abbreviations are: PMA for the Pir Mangho Anticline, FLAAT for the Fore Limb Anticlinal Axial Trace. View is looking south.

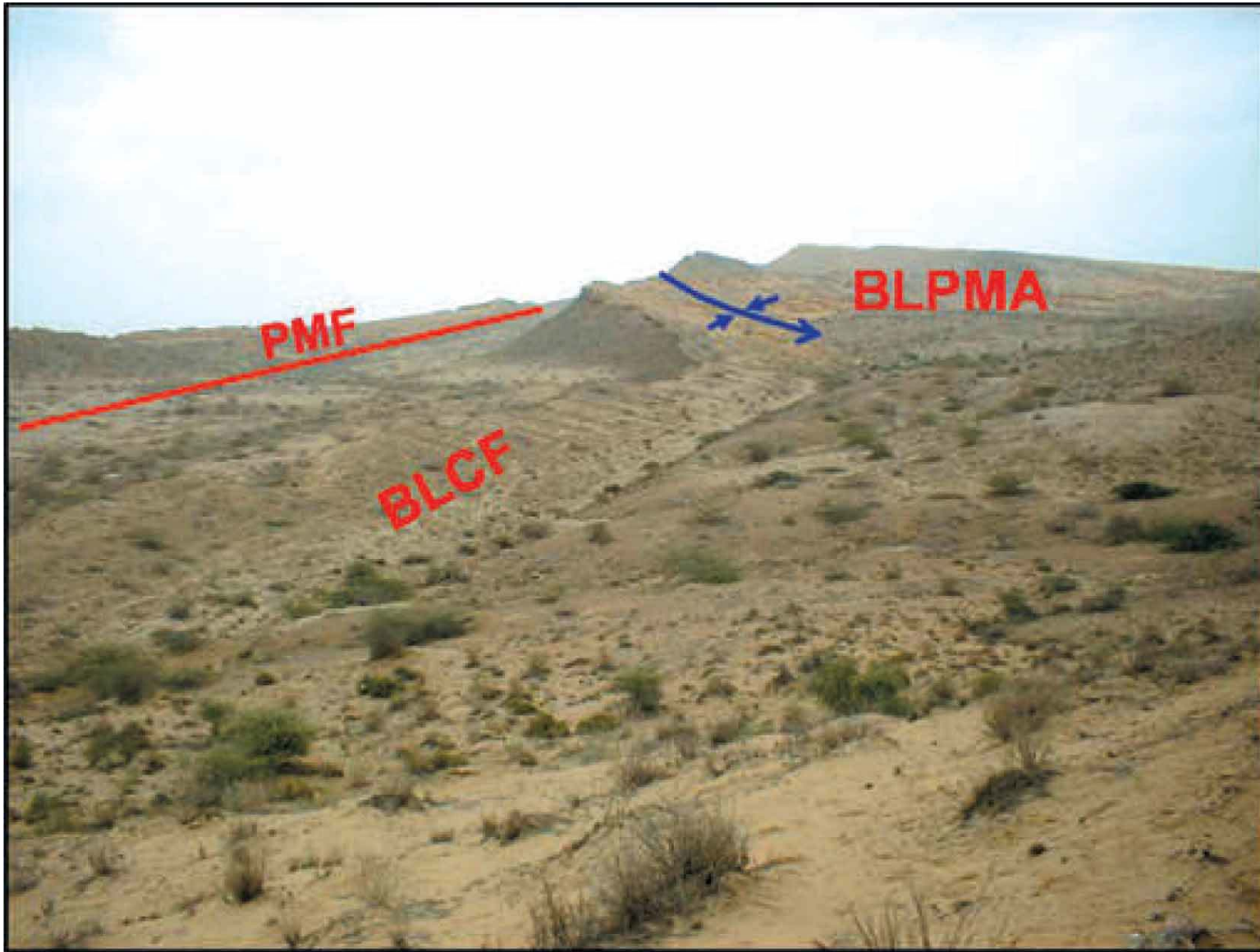


Figure 8. Photograph showing the Synclinal Cross Fold at high angle to the Pir Mangho Anticline. Abbreviations are: BLPMA for the Back Limb Pir Mangho Anticline, BLCF for the Back Limb Cross Fold and PMF for the Pir Mangho Fault. View is looking east.

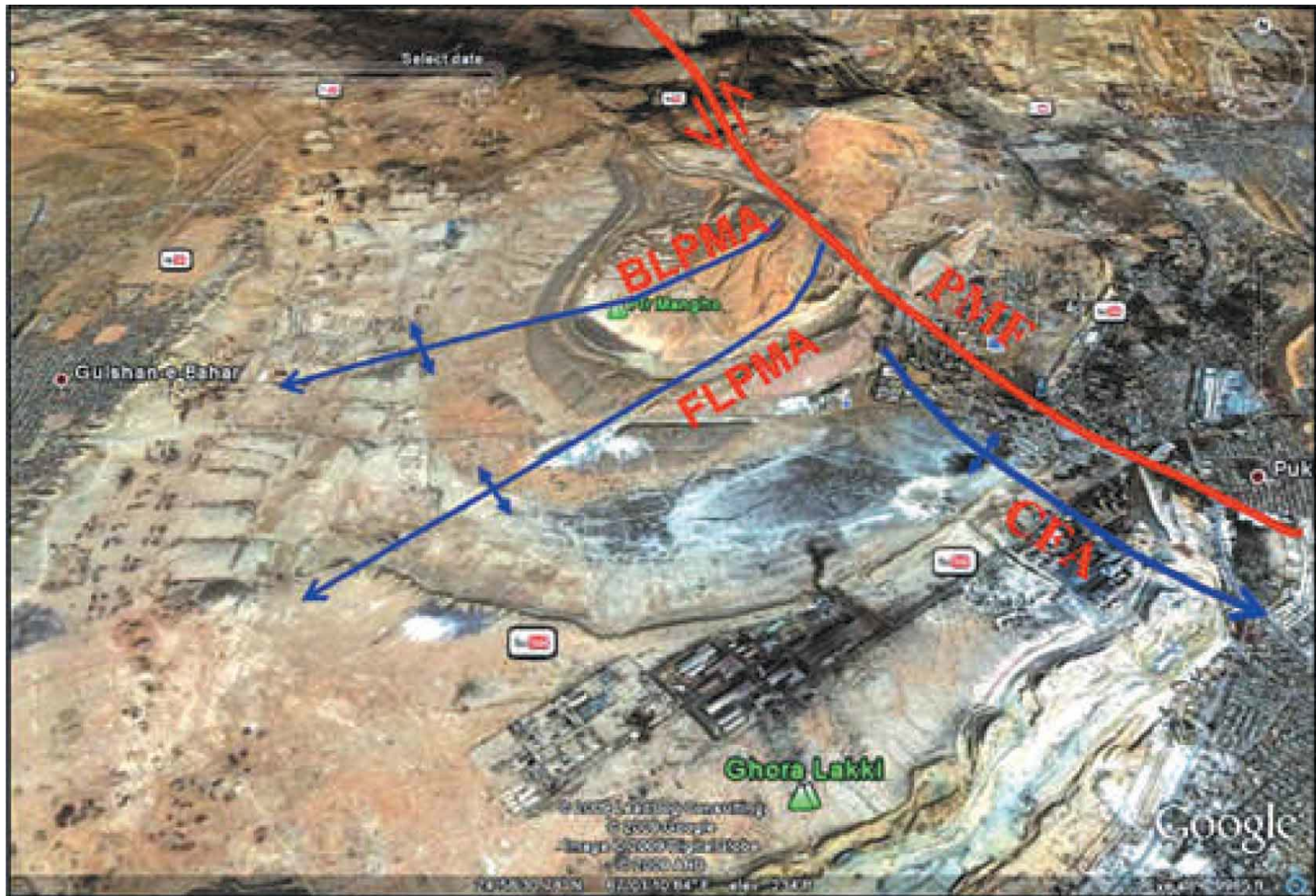


Figure 9. Satellite imagery showing Anticlinal Cross Fold present parallel to the Pir Mangho Fault. Abbreviations are: CFA for Cross Fold Anticline. Other abbreviations are same as in Figure 6. View is looking north.



Figure 10. Photograph showing the gentle Pir Mangho Anticline. Abbreviations are PMA for the Pir Mangho Anticline and CF for the Cross Fold. View is looking southeast.

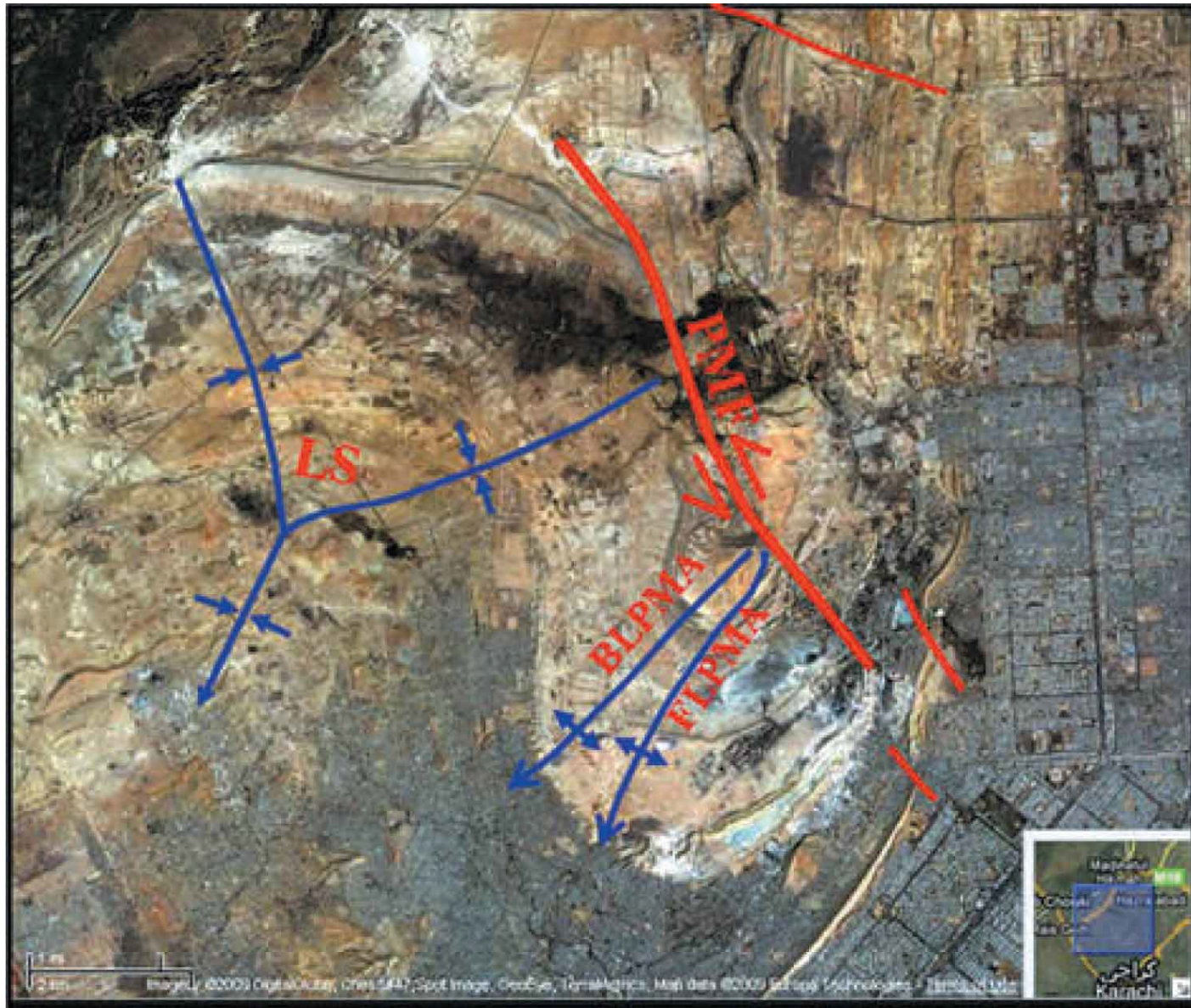


Figure 11. Satellite imagery showing the kink geometry and two hinges of the Lalji Syncline which join together southwest and become one synclinal hinge. LS for Lalji Syncline, other abbreviations are same as in Figure 6. View looking towards north.



Figure 12. The northern part of the Pir Mangho Fault where synthetic riedel shears are present. Abbreviations are: PMF for the Pir Mangho Fault and RS for Riedel Shears.

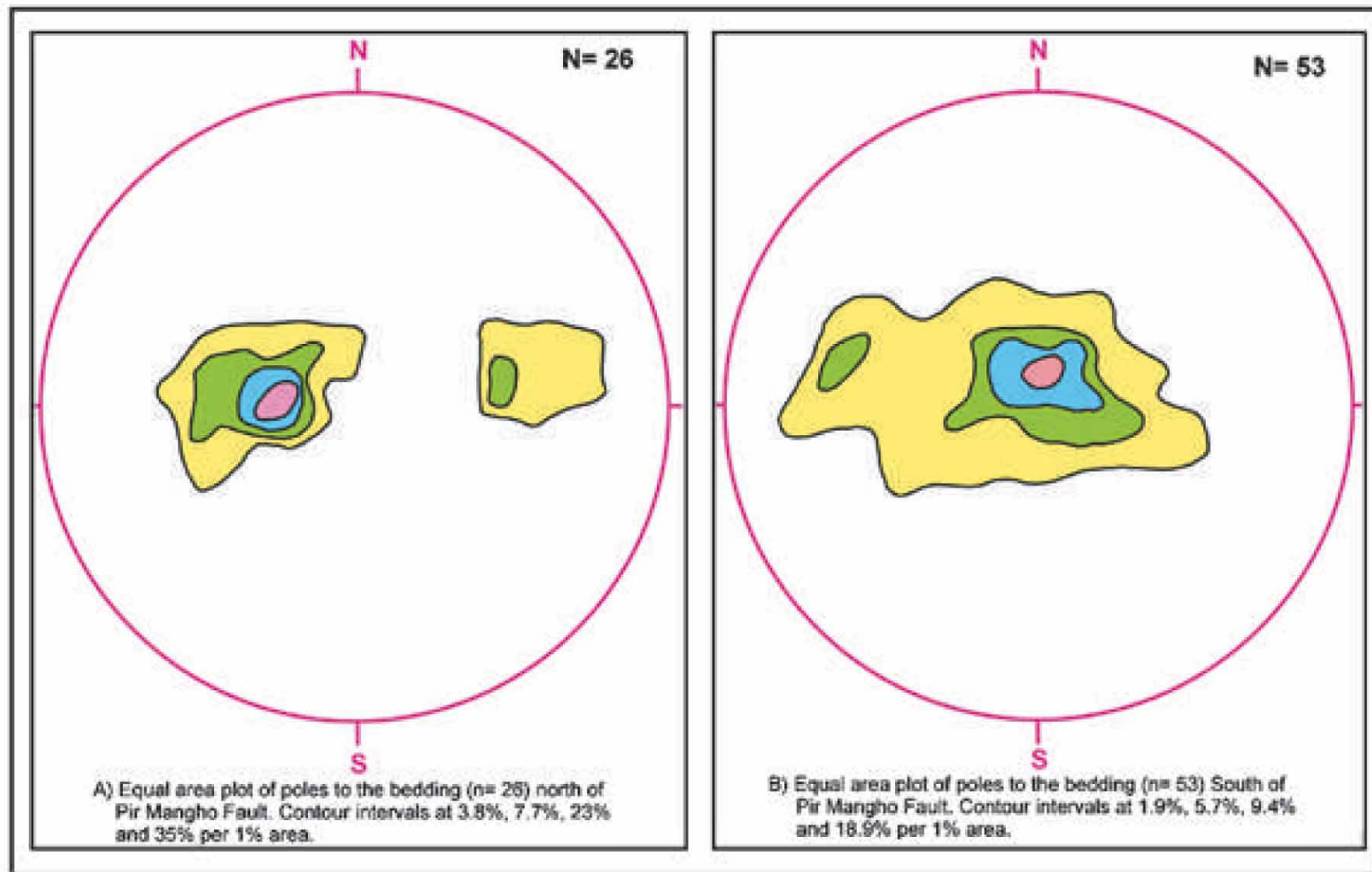


Figure 13. Equal area plot of poles to bedding showing different structural trends in two areas across the Pir Mangho Fault.

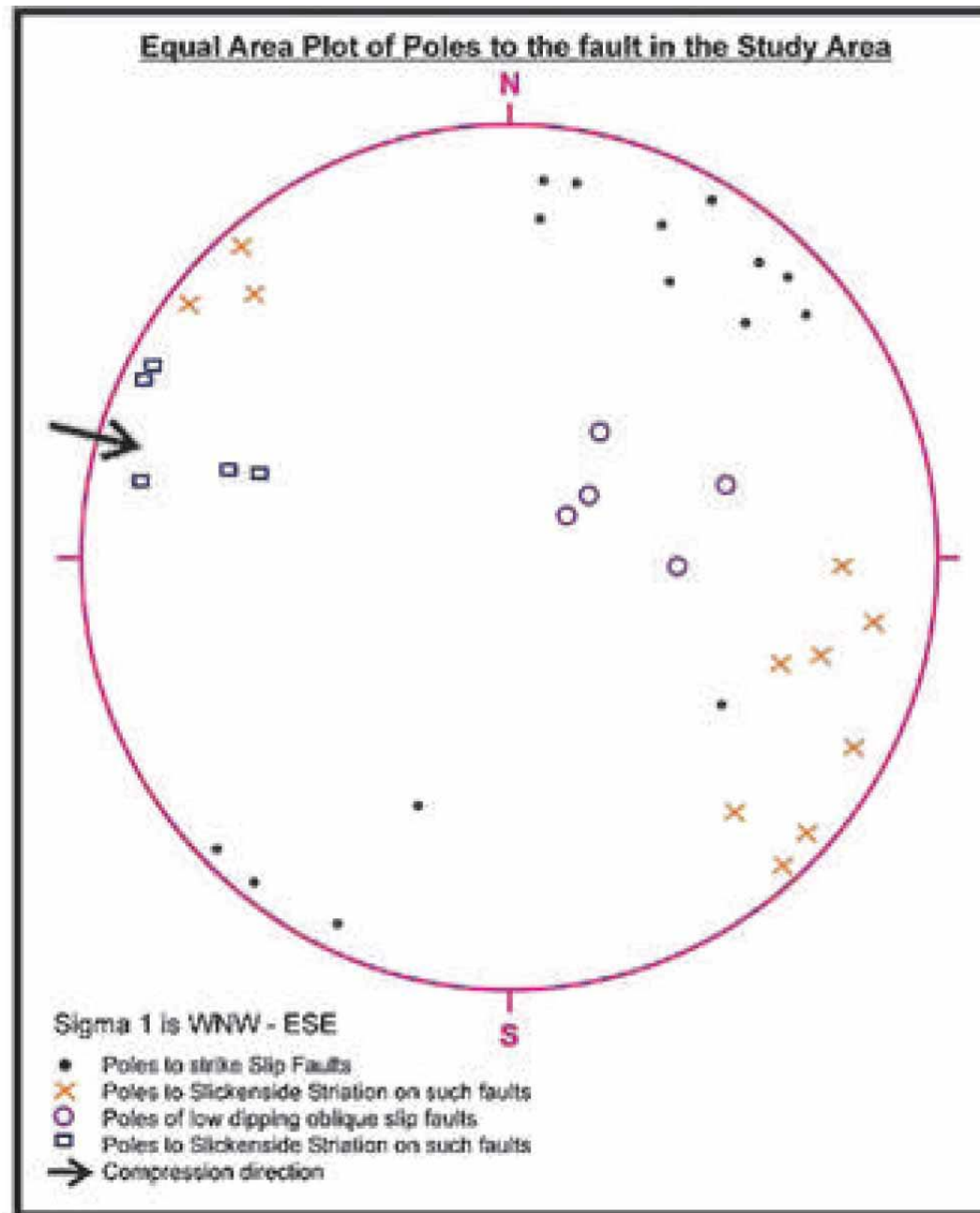


Figure 14. Equal area plot of poles to fault planes and slickenside striation on them.



Figure 15. A distant view of the Pir Mangho Fold. Abbreviations are PMA for the Pir Mangho Anticline and BLCF for the Back Limb Cross Fold. View is looking east.

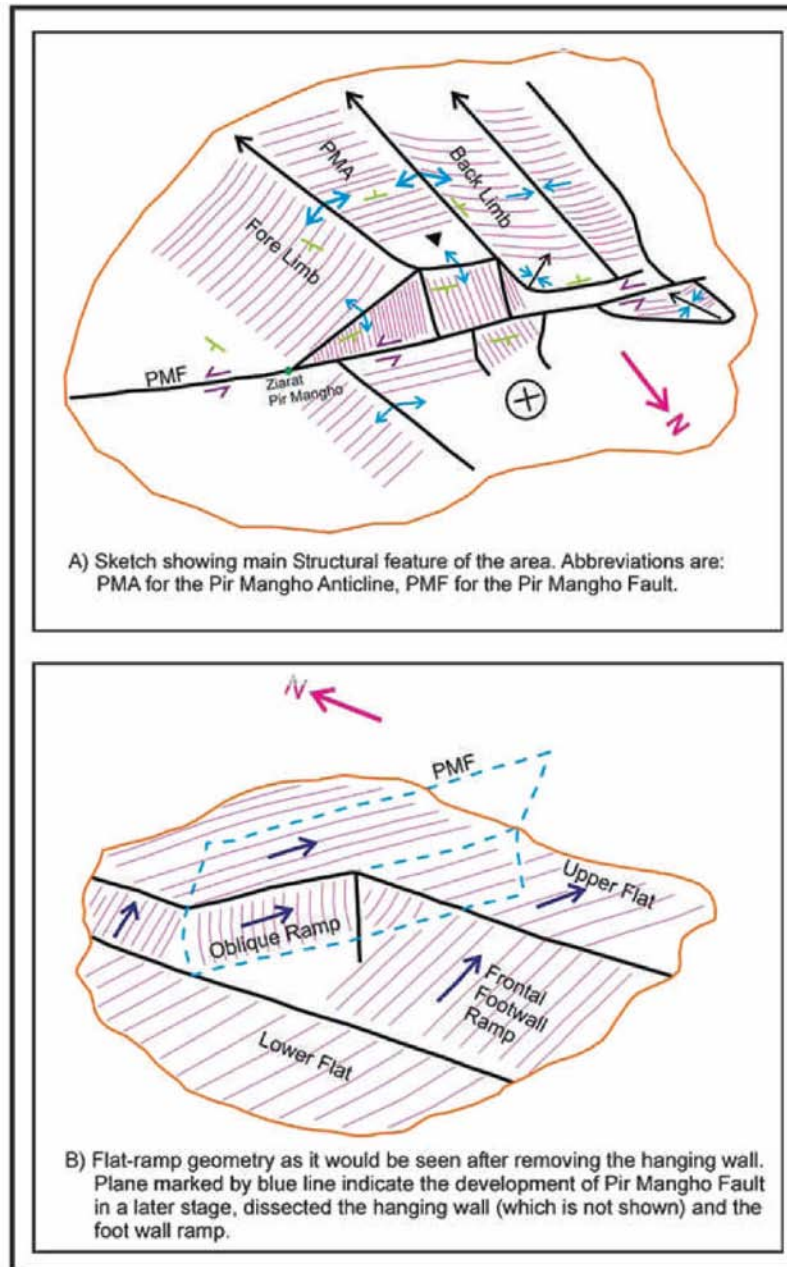


Figure 16. A, B Structural Models of the area.



Figure17. An oblique slip fault in the Pir Mangho Member. View is looking toward south. Height of the escarpment is 10 meters

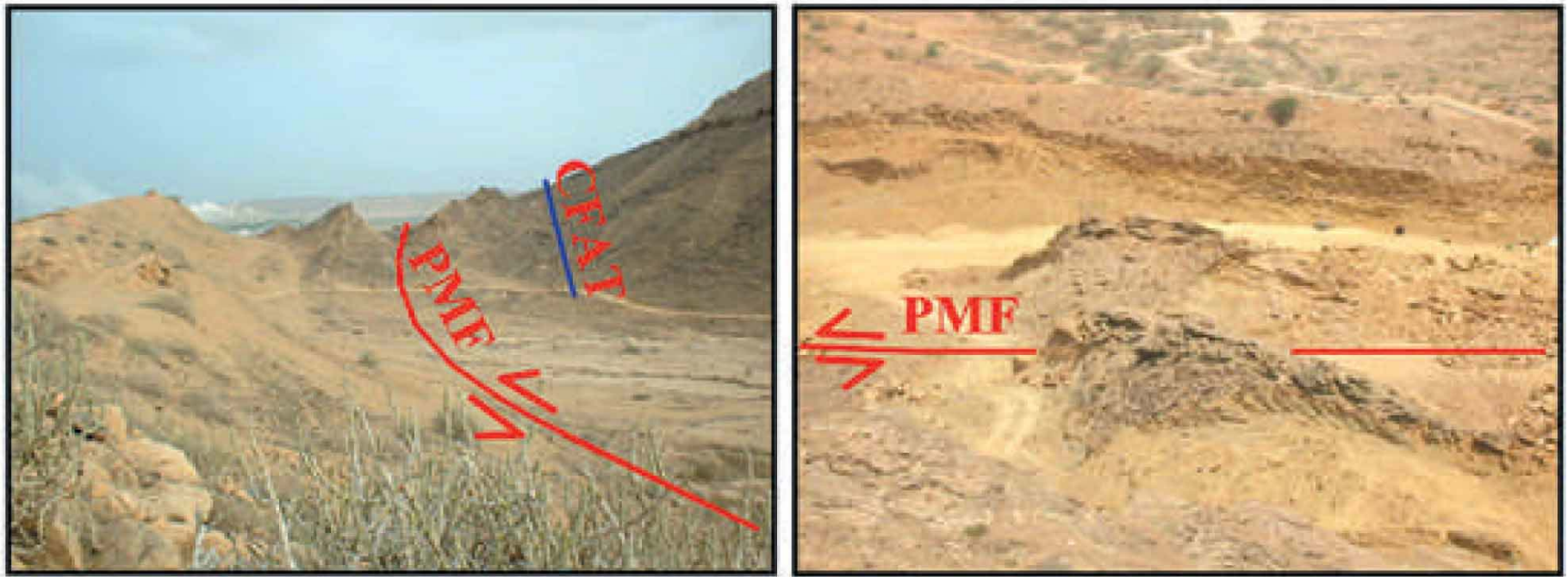


Figure18. The Pir Mangho Fault is cutting across the fore limb of the cross fold in vicinity of the Pir Mangho hill. a) A view of the dissected forelimb looking east. PMF is for the Pir Mangho Fault and CFAT for the Cross Fold Axial Trace. b) Same feature and same place as in a), but view is looking north from the Pir Mangho Hill.