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Role of Chaman transform boundary fault in the deformation of Eastern Kharan Fore–Arc Basin

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Abstract

The eastern part of Kharan Fore-Arc Basin has been evaluated for its subsurface structural style and its relation to plate boundary conditions. This part of Kharan Fore-Arc Basin resides on the eastern margin of Eurasian Plate south of Raskoh Range where the Indo-Pakistani Plate to the east has a transpressional boundary relation along Chaman Fault. A local area was the subject of an integrated 2D seismic, gravity, magnetic and remote sensing data evaluation, primarily for the purposes of hydrocarbon exploration. Conclusions on the tectonic character of the local area near the Chaman Fault have been extended into the broader region. The Raskoh Range and the North Makran Range confine the area to the north and south respectively. Jurassic to Oligocene igneous and sedimentary rocks have been documented in the outcrops along Raskoh Range. The sedimentary fill in the Fore Arc south of Raskoh ranges from 5000-7000 m in thickness based on gravity and magnetic data sets. The seismic reflection data also reveal a similar sedimentary fill. The Chaman Fault Zone is characterized by sinistral strike-slip movement with a minimum offset of 15 km (Lawrence and Yeats, 1979). Seismic reflection data suggest that the structural style in the eastern Kharan Fore- Arc Basin is dominantly associated with a transpressional regime. The structural features that appear on seismic data are dominantly positive flowers, bounded by high angle reverse faults that branch-off upward from steep fault zones at depth. A few of these steep fault zones at depth seem to link with the Chaman Fault and its splays such as Usman-Chaman Fault which dips steeply to the north and changes its motion from strike-slip to transpressional in the southwest direction, away from the Chaman Fault. The Cretaceous to Eocene sedimentary package is considered to contain a potential petroleum system.Potential reservoir targets include the carbonates of the Eocene Kharan Formation and the sandstone of the Cretaceous to Paleocene Rakhshani Formation. An effective sealing mechanism is likely to have been provided by thick shale sequences ranging in age from Cretaceous to Paleocene.

Keywords: Chaman transform boundary fault; Eastern Kharan; Fore–Arc Basin; Indo Pakistani plate.

1. Introduction

The area which is the focus for this present work lies in the Kharan and Chagai districts of Balochistan Province where access is by means of the Quetta – Zahidan rail track and link roads. This place is primarily an arid zone and occupies eastern part of the Kharan desert where it is dominantly covered by alluvial fans and sand dunes to the south of low lying hills of Chagai and Raskoh ranges. The south of alluvial plain is bounded by the Siahan Range (northern Makran Range). The Kharan Alluvial Plain, Raskoh and Siahan ranges culminate to the east by N-S trending Chaman Fault (Fig.1). The Kharan Desert is a structural low (also known as Maskhel Depression in the literature available). To the east it lies at about 650m AMSL while the topographic elevation in the surrounding hills varies from 2000 to 3000m AMSL.

2. History of geological and geophysical activities

Geological studies and exploration activities in this region date back to 1960 when the Hunting Survey Corporation (HSC) conducted mapping of this area as part of the project with Geological Survey of Pakistan, GSP. Subsequently this work was published in the Geological map of Pakistan in 1964 by Baker and Jackson.

An aeromagnetic and gravity survey was conducted in Balochistan for exploration of minerals in 1981 and the report was compiled by Allan Spectors and Associates. The GSP also conducted a gravity survey in 1986 and map was compiled by Khadim and Sakhawat.

Fig. 1. Location Map of the study area.

Exploration focused on the hydrocarbon potential of this part of Kharan Fore-arc began when OGDCL during 1993- 96 acquired 507 km of 2D seismic and conducted geological mapping to establish source, reservoir and seal potential in the area.

In the west of the study area hydrocarbon exploration activities were conducted by Union Texas in 1998-99. Murphy Oil held acreage in the Kharan Desert area for a longer period and only managed to acquire gravity and magnetic surveys in 1999. In 2003, PPL conducted Geological field work which was followed by seismic data acquisition and SFD (stress field detection) survey in 2012 to evaluate the potential of the area.

3. Data set

The geological mapping, aeromagnetic, gravity and seismic data sets were evaluated and integrated to understand the structural geometry and sedimentary fill in the study area, in which 2D seismic coverage was restricted to only the eastern part of the Kharan Fore-Arc Basin. The evaluation of this dataset has been used to improve our understanding of the regional tectonic evolution.

4. Stratigraphy

Information on the stratigraphy of the study area is drawn from outcrops of Raskoh range in north, Chagai Arc in northwest, Siahan Range in the south and Chaman fault zone in the east as shown in the HSC map 1960 (Fig. 2), published reports and articles. The generalized stratigraphic column is shown in figure 3.

4.1. Sinjrani Group

The oldest known rocks in the study area are the Sinjrani Group which mainly consist of andesitic and basaltic lava flows. The group is exposed in the Chagai and RasKoh areas where it attains a thickness of up to 1200m. The Sinjrani Group is assigned a Cenomanian to Santonian age by Raza et al. (2001) and is correlatable to the lower part of the Kuchakki Group.

4.2. Humai Formation

The overlying Humai Formation mainly consists of shale, sandstone, siltstone and thin-bedded limestone with subordinate layers of volcanic rocks in the lower part. Limestone becomes dominant in the upper part. The limestone is fossiliferous on the basis of which Campanian to Lower Maastrichtian age has been assigned to the Humai Formation (Raza et al., 2001). The increase in limestone in the upper part suggests shallowing upward sequence indicating a transition from mid and outer shelf to inner shelf carbonates during a period of global fall in sea level.

4.3. Rakhshani Formation

The Rakhshani Formation is mainly represented by shale and sandstone, conglomerates with occasional lava flows and with thin limestone beds in the lower part. The sandstones are medium to coarse grained, cross bedded and represent a fluvial depositional environment. The conglomerates contain boulders and pebbles of lava flows which seem to have been derived from the older rocks due to uplift in parts of the Raskoh Range.

The limestones are fossiliferous and, on the basis of fauna contained in the limestone, a Danian to Thanetian age has been assigned to the Rakhshani Formation (Raza et al, 2001). According to Aziz et al, (2005), the Rakshani Formation represents accretionary sediments of the Makran Arc–Trench system.

4.4. Kharan Limestone Formation

The Kharan Limestone Formation is represented by medium to dark grey, thin- to

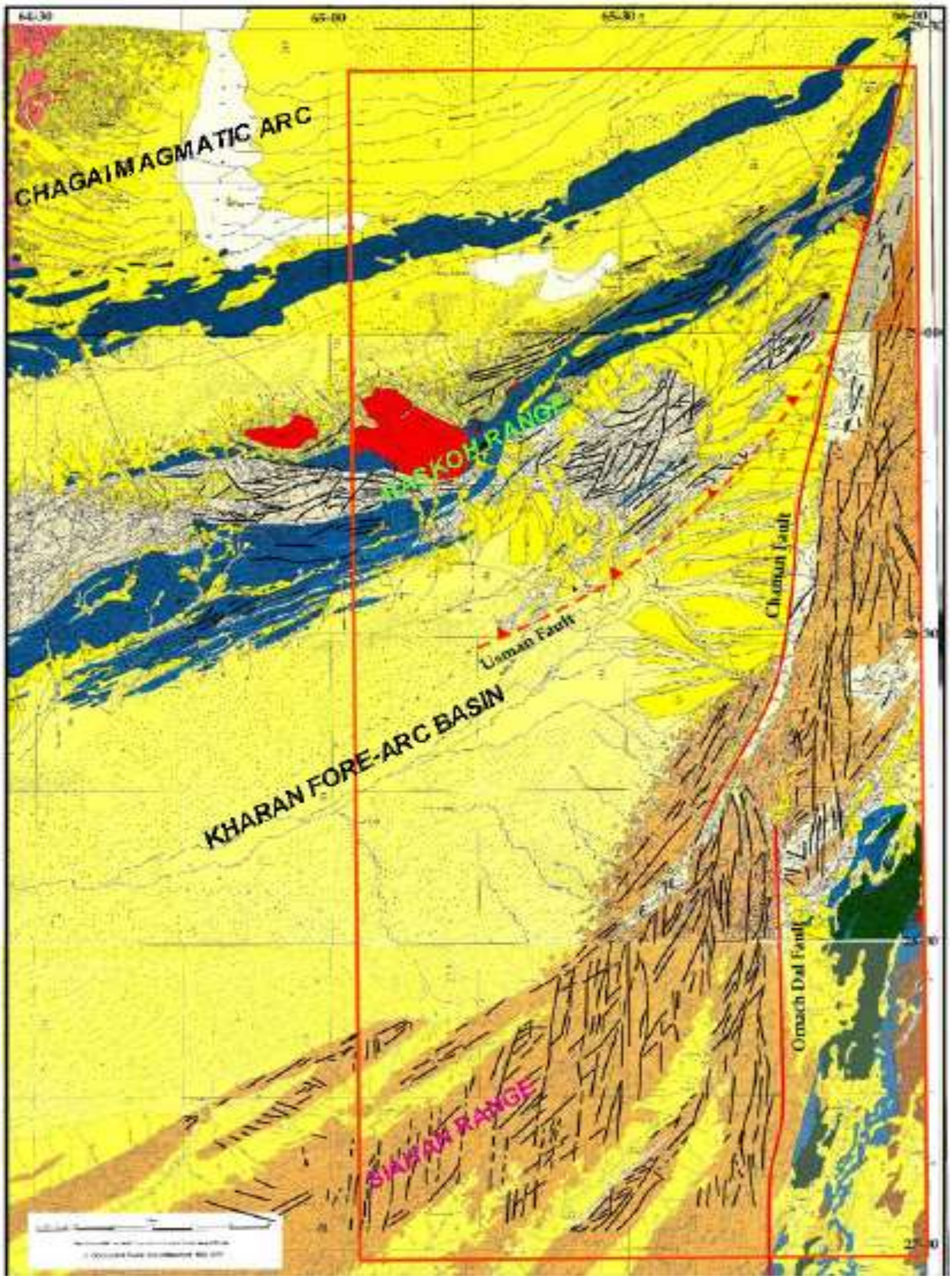


Fig. 2. Geological map of the study area modified after Hunting Survey Corporation 1960.

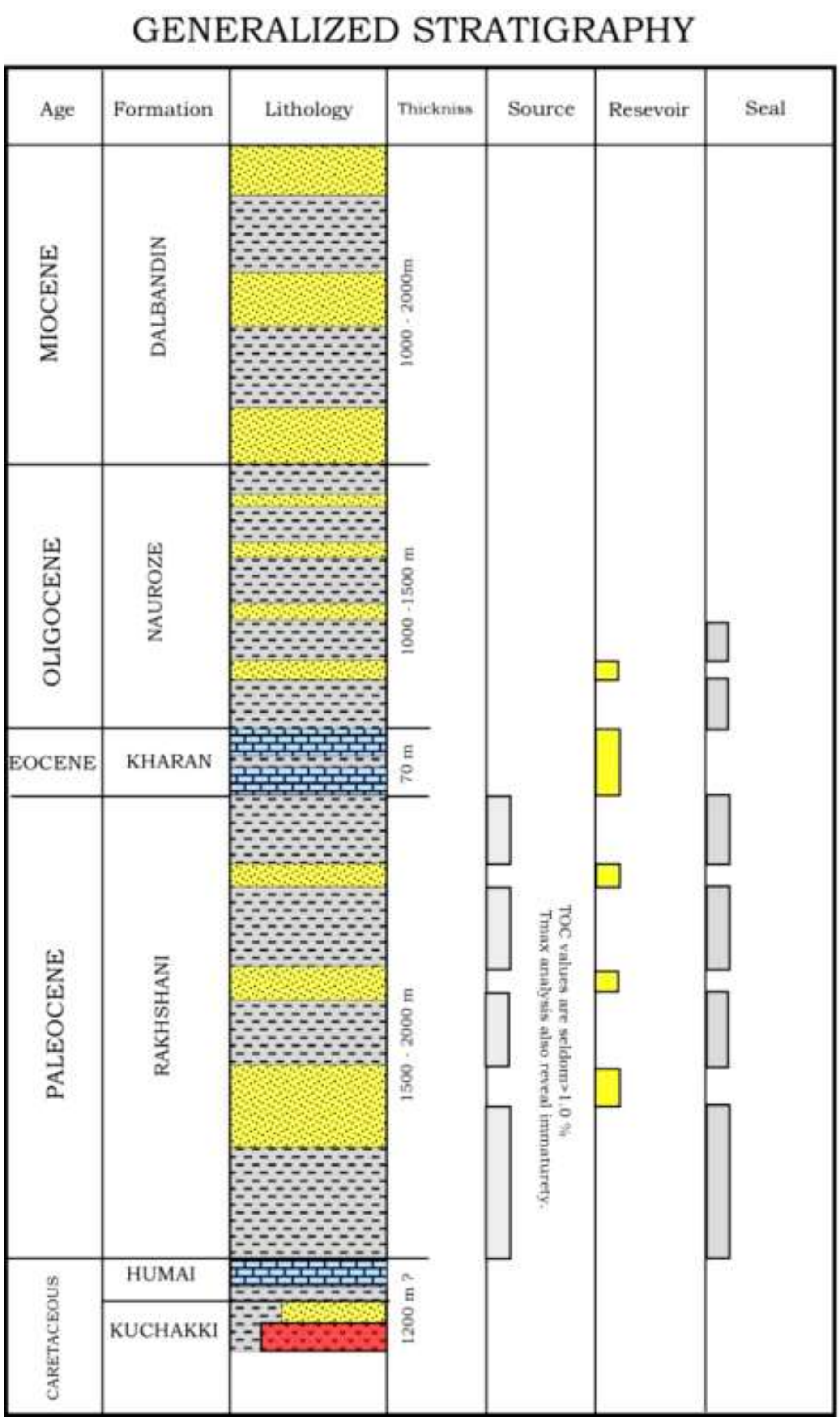


Fig. 3. Generalized Stratigraphy of the study area.

massive-bedded lime mudstone and subordinate shale. The formation was first described by the Hunting Survey (1960) and according to Raza et al. (2001), it ranges in age from uppermost Thanetian to Lutetian based on its fossil assemblage. The presence of allochthonous blocks of nummulitic limestone (Kharan Formation) along the northern flank of the Siahan Range suggest proximity to the Kharan Shelf edge and the formation of debris flows produced by gravity sliding which occurred along the slope in deeper waters.

4.5. Nauroz Formation

The Nauroz Formation mainly consists of shale and sandstone with occasional limestone and conglomerates (Hunting Survey, 1960). On the basis of fossil evidence, Shah and Tahir (1995) assigned an Oligocene age to the formation. The predominance of sand in the upper part suggests an extensive network of fluvial channels which in turn suggests a considerable fall in sea level during the Oligocene.

4.6. Dalbandin Formation

The Dalbandin Formation of Miocene age mainly consists of continental sandstone, siltstone and conglomerates. It is considered age-equivalent to the Shigalu Formation of the Pishin Fold Belt.

4.7. Bostan Formation

The Bostan Formation is Pleistocene in age and ranges in thickness from a few meters to several hundred meters. It represents valley infill in the Kharan and Dalbandin troughs. The sediments are dominated by a succession of continental cobbles and boulders of sandstone, limestone and volcanics. The formation is characterized by an angular unconformity at the base.

5. Geophysical data interpretation and validation of structural style

5.1. Aeromagnetic data

The area of study was covered by aeromagnetic survey and a map was compiled by Allan Specter and Associates (1981) for the Geological Survey of Pakistan (Fig. 4). The qualitative and quantitative evaluation of the anomalies of the map reveals the broader structural configuration. The total magnetic intensity map shows increase in magnetic intensity from the Kharan Fore-Arc Depression (45800 gamma) to the Raskoh Uplift (47750 gamma) in north. The contouring and shape of the anomalies coincide with the location of structural lows and highs present in the Depression and to the north. The increase in the magnetic intensity field and the shape of the high was also reported by HSC (1960). The anomaly in the north of the study area also suggests the presence of a structural barrier which may be related to the Usman Fault. The depth anomalies suggest that magnetized rocks of igneous nature are present; calculation for depth to magnetic basement ranges from 3500 to 4000 m below ground level (Allan Specter and Associate, 1981). However, near the Chaman Fault it varies from 3850 to 6300 m below ground level. This localized increase in range probably reflects juxtaposition near the structure of complex blocks in a positive flower structure configuration that is likely to have a transpressional setting.

5.2. Gravity data

GSP (1986) conducted a gravity survey in the Kharan Fore-Arc and parts of the Raskoh Range. The Bouguer gravity map compiled after this survey by Khadim and Sakhawat (1986) provides useful information for understanding the structural setting of the study area (Fig. 5). Quantitative analyses of this map suggests the presence of three structural lows, the deepest in the middle and shallowest in north. The presence of structural

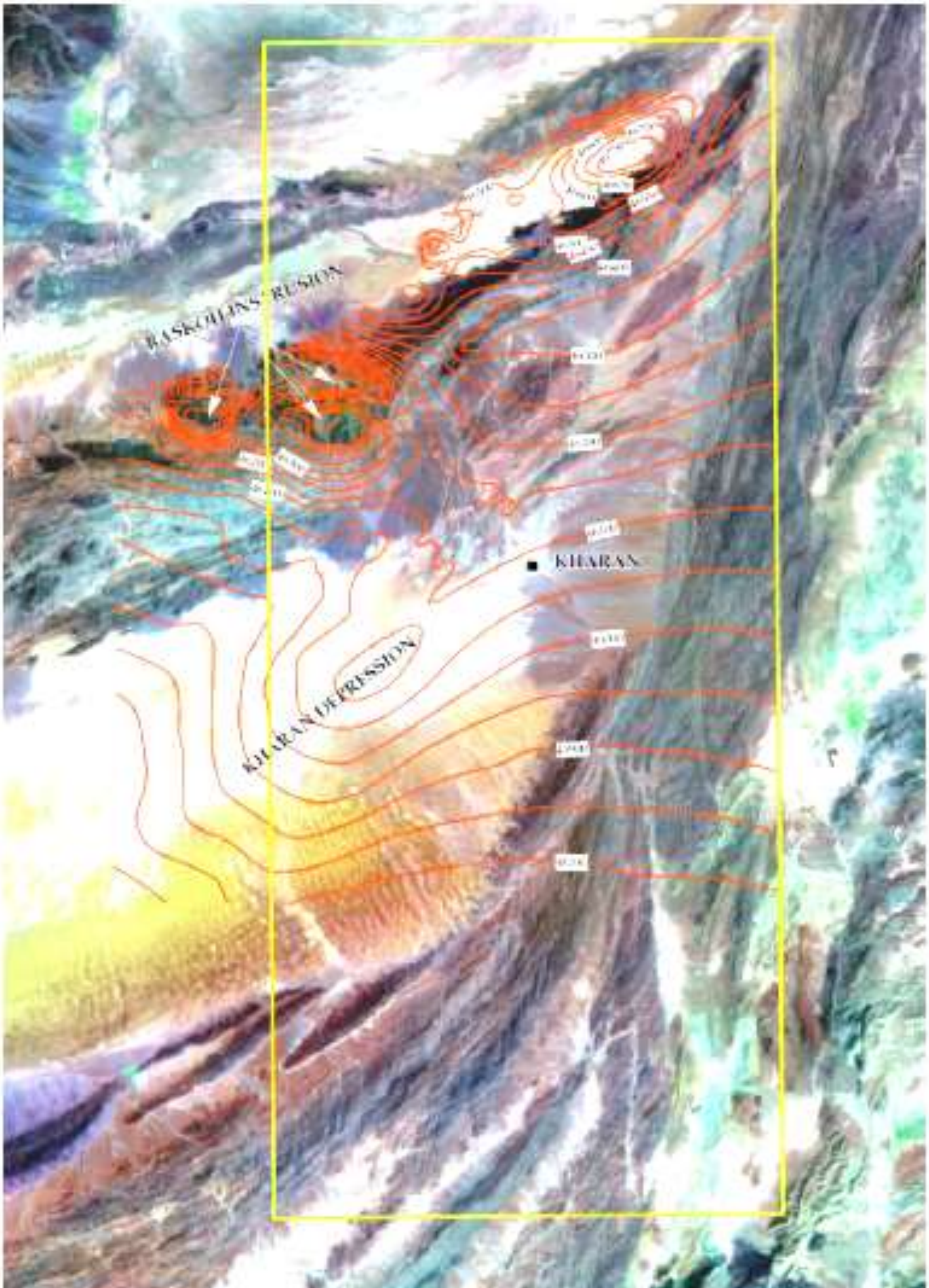


Fig. 4. Overlay of Aeromagnetic map on Landsat data to establish relationship of key structural features; modified after Allan Specter and Associate, 1981.

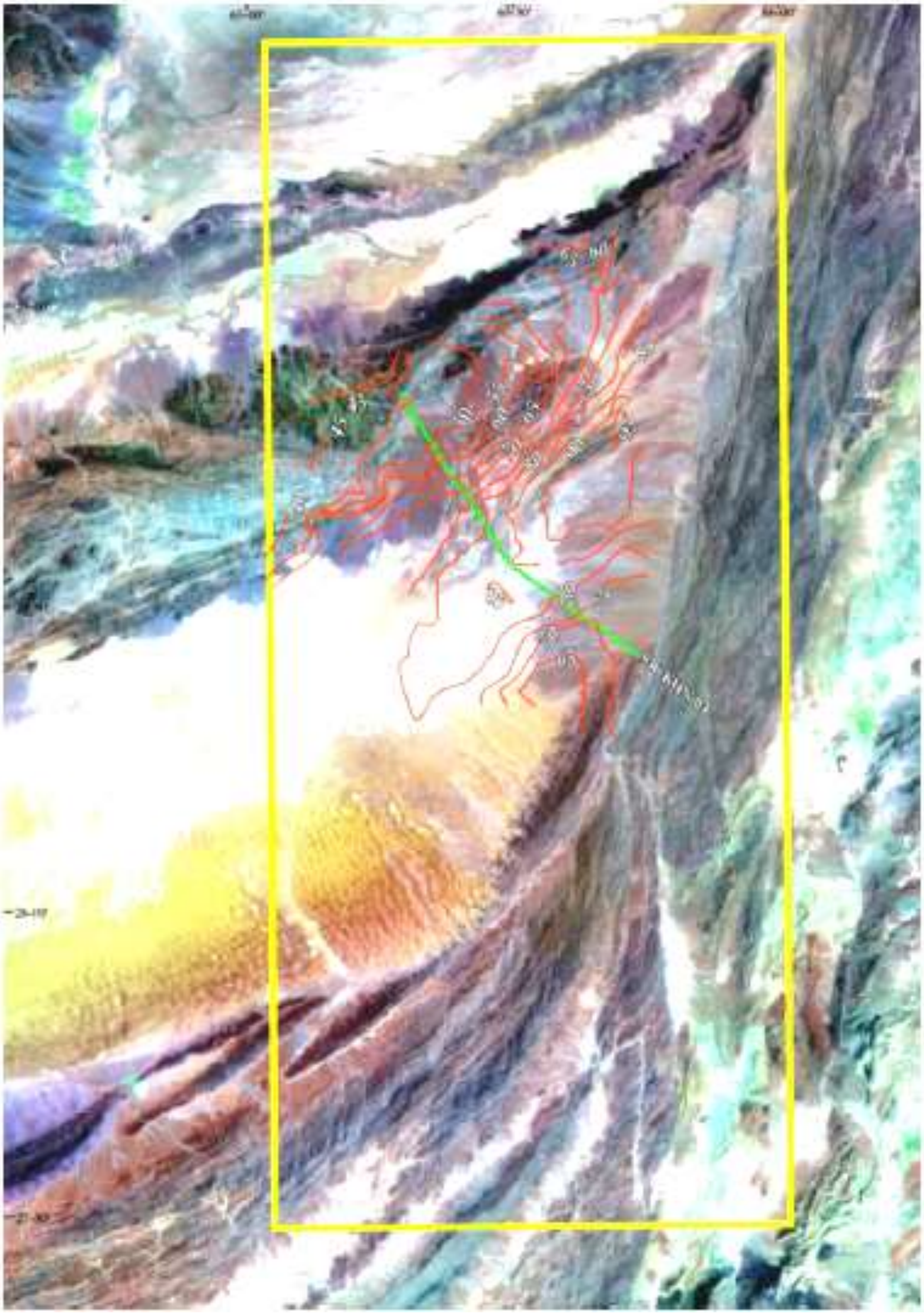


Fig. 5. Overlay of Bouguer gravity map on Landsat data to establish relationship of key structural features; modified after GSP (1986).

barriers (structural highs or faults) aligned NE-SW is one of the more likely interpretations of this data. The structural lows also coincide with the synclines shown by seismic data. Generally the contour trend of the map is aligned parallel NE-SW, parallel to the major trend of the Raskoh Range and the Kharan Fore-Arc Basin. The southern anomaly indicates a shallower depth than the central which supports the idea of the uplift of southern part of Kharan Fore-Arc Basin near the Siahan Range. The location of the Usman Fault can be placed between central and northern anomalies while the structural axis of Kharan Fore Deep is fits with the central anomaly. The structural barrier between the middle and southern anomaly could be a splay of Chaman Fault, dipping at a high angle through sedimentary cover.

5.3.Seismic data

The 2D seismic line, 93-KHN-03, migrated version (Fig. 6) from the 1993 survey of OGDCL has been interpreted and used as an example to validate the structural configuration of the Kharan Fore-Arc Basin and its relationship with the Chaman Fault. This line is aligned across the trend of the structural features of the Kharan Fore-Arc Basin, (location plotted on figure 5, green line). The quality of seismic data is reasonable and allows an understanding that the reflection geometries correspond directly to structural features and stratigraphic boundaries. The first higher amplitude marker is suggestive of a strong acoustic impedance as at the boundary of the Eocene carbonate (Kharan Limestone) and overlying clastics of the Oligocene Nauroz Formation. Discontinuities in the reflection packages are indicative of high angle faults linking at deeper level to form positive flower structures.

This interpretation suggests deformation of fore-arc sedimentary cover by transpressional movements which relate to development of the Chaman Fault at the time of collision of the Indo-Pakistani and Eurasian Plates. The fault system of flower structures present in the middle of the study area may be related to splays of the Usman Fault which links with the Chaman Fault in the NE as suggested by Lawrence and Yeats (1979).

Interpretation at deeper levels on the seismic is not very reliable due to the quality of reflectivity. The correlation of the magnetic basement of Allen and Spectors (1979) with the seismic data is also tentative.

5.4. Integration of geophysical data

The magnetic, gravity and seismic data was integrated to generate a greater understanding of the structural deformation in this area, (Fig. 6). This integration suggests:

1. The thickness of sedimentary cover ranges from 5000 to 7000 m in the study area of the Kharan Fore-Arc Basin. The variation in depth of Magnetic basement as suggested by Allen Specter and Associates (1981) leads one to infer the presence of structural lows and highs bounded by high angle faults of transpressional origin.

2. The gravity anomalies, magnetic maps and structural highs on 2D seismic data are in agreement in the north of the study area around the Raskoh Uplift but magnetic data toward south is not consistent with gravity and seismic. This discrepancy could be due to scale and magnitude of resolution (Fig. 6). However gravity trends do coincide with the structural highs and lows delineated by seismic data.

3. The interpretation of seismic data leads to suggest the presence of a potential source rock of Paleocene and older buried deeply in the Kharan Fore- Arc which may lie in an oil/gas window.

6. Tectonic evolution

The study area is located close to the junction of southeastern margin of the Afghan Block which is in contact with Indo-Pakistani Plate via a transform boundary defined by the Chaman Fault (Fig. 7). Along this margin Jacob and Quittmeyer 1979 also recognized the presence of the Arabian Plate margin subducting just south of Kharan Fore Arc Basin.

The plate tectonic history which deformed the area can be tracked back to Permo-Triassic rifting of different continental blocks from the northern Gondwana margin which was geographically located along the southern part of the Paleo-Tethys. These blocks include Iran, Afghan, Lutand Indo-Pakistani Plate (Fig. 8).At the same time, the Paleo-Tethys began to subduct beneath southern Eurasia and this event resulted in the formation of an active continental margin with associated magmatism. The Neogenesubduction of Arabian plate along the coastal Makran region is still an ongoing phenomenon causing continued deformation of the MakranAccretionary Wedge.

The history of events documented by Russell, Sarwar et al. (1979), suggested deformation from the Cretaceous to the Quaternary age rocks, development of a volcanic arc and deposition of sediments on the southern margin of Afghan and Lut blocks (Fig. 9). Volcanism is associated with subduction of the Arabian Plate either just south of KharanForearc Basin (as suggested by Jacob and Quittmeyer 1979) or along coastal Makran region as depicted by earthquake seismology data (Jacob and Quittmeyer 1979 (Fig. 10). The igneous rocks exposed along the Raskoh Range are also related to such tectonic activity; however this has been geographically separated from the Chagai Magmatic Arc by the intervening Dalbandin Trough.

The sedimentary depositional phases include accumulation of both clastic and nonclasticfacies which commenced to accumulate on the trailing margin of the Afghan Block when it became the active margin of the Eurasian Block with a change of basin geometries evolving though time. Geographically the area underwent various modification through subsidence, uplift, lateral detachment and erosion. The phases of such sedimentary cycles are marked by representative sequence boundaries with typical onlapping surfaces and unconformities. During this span of time (Triassic rifting to recent suturing) the area was subjected to a succession of extensional, compressional and transpressional stress regimes by the movement of crustal blocks (fragmented continental and oceanic).

During the Late Triassic- Early Jurassic, the Paleo-Tethys closed gradually and this closure was followed by suturing of the Afghan block with other micro continents to increase the southern extent of the Eurasian Plate (Fig. 8). Part of the study area lies on this detached micro-continental plate and thus has gone through a stage of passive margin development in south and active margin deformation in north close to suturing. Evidence of such deformation in Triassic-Jurassic depositional history is not well known. Subsidence of the Neo Tethys (Tethys-3) south of Eurasian Block continued during the Cretaceous and the Chagai and Raskoh magmatic activity on the southern margin of Afghan Block probably relates to this subsidence (Fig. 8). Besides magmatic activity, the deformation of the area has taken place to a compressional structural setting. During the Cretaceous the northward movement of Indo-Pakistani Plate resulted in obduction of ophiolitic crust of the Neo Tethys along its north and western margin (Tethys-3). The Paleogene Collision of the Indo-Pakistani Plate with Eurasia created a transform boundary with Afghan Block producing transpressional deformation in the study area. The Chaman Fault is one of the structural features originating at this stage. The Neogene subduction of Arabian Plate set up complex structural geometries like arc

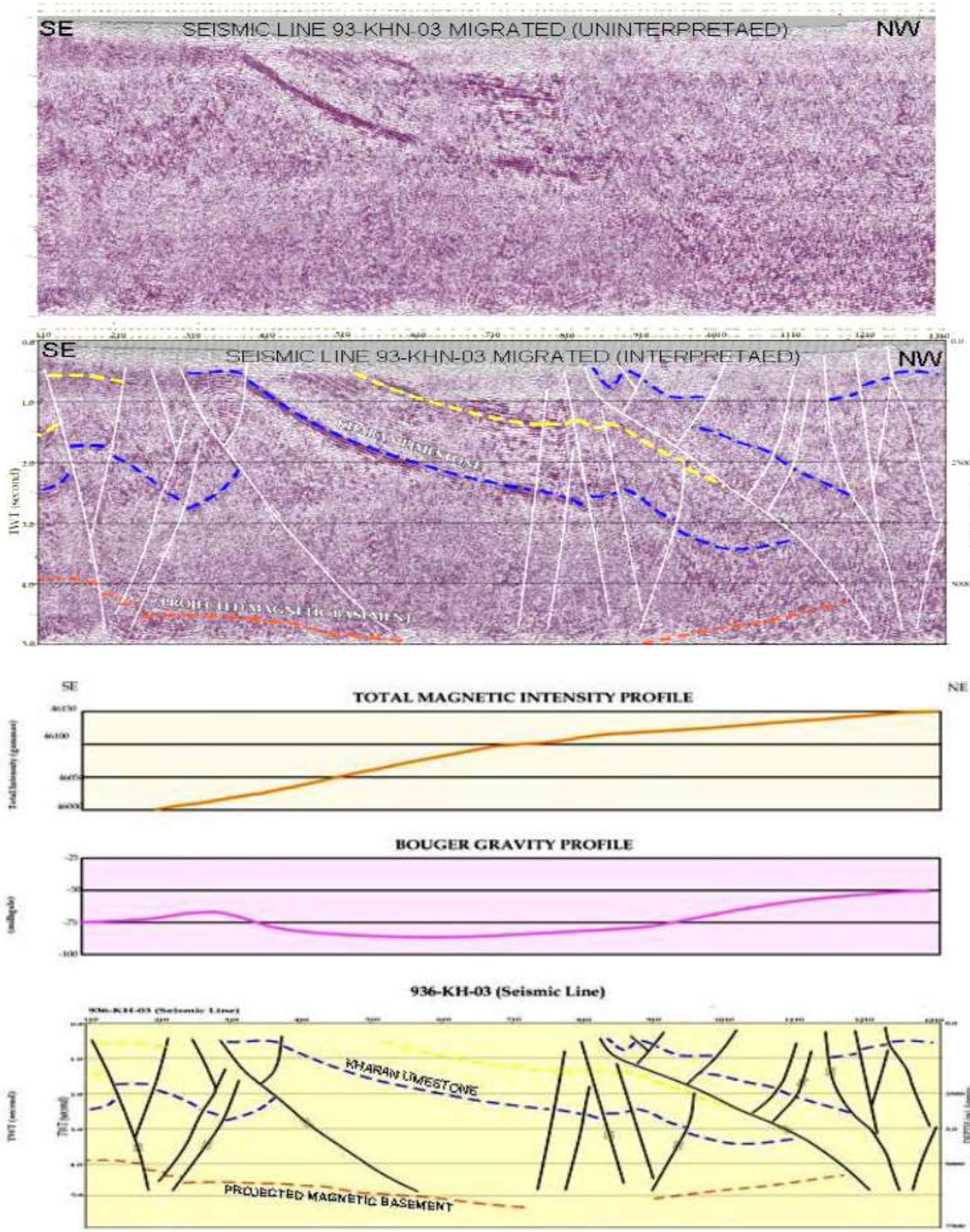


Fig. 6. Interpretation of 2D seismic line 93_KHN-03 (migrated version) across Kharan Fore-Arc Basin and integration with magnetic and Gravity data.

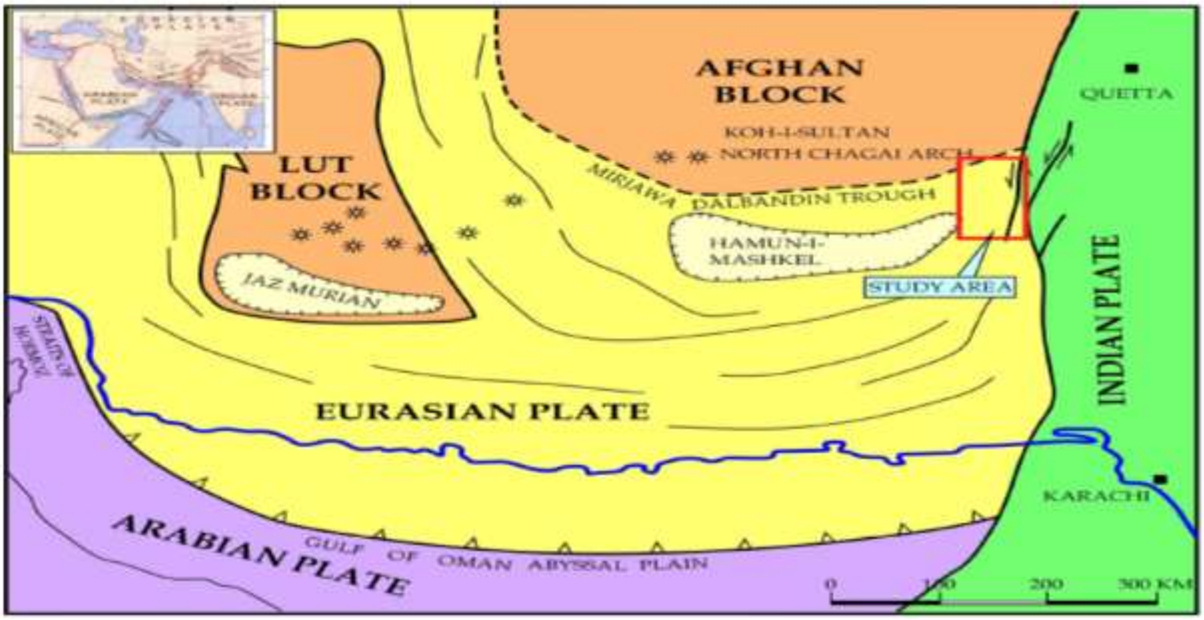


Fig. 7. Tectonic setting of the study area, modified after Russell et al., 1979.

trench features, rotation of central Iran Block (Lutvs Afghan) and the development of an accretionary wedge. From the Paleogene to Recent, the Chaman Transform Fault and its splays have deformed the sediments of Kharan Fore-Arc into positive flower features in the area of study. The seismic data interpretation of line 93-KH-03 clearly suggest presence of these structural features as a splay of Chaman fault in SE. (Fig. 6).

7. Structural style and deformation

7.1. Extensional features Phase

Extensional faulting during Triassic rifting stage; subsidence and transtensional movement along major fault zones during Jurassic:

Evidence

There is no any direct structural evidence available to validate this speculative deformation in the area of study but manifestations of extensional conditions (such as extension faulting, horst, graben, negative flower, gravity faulting and presence of sedimentary wedges) may be preserved in other parts of Kharan Fore-Arc basin and along the southern margin of Afghan block. As Triassic rifting is not known as failed rift therefore peripheral bulge and density collapse features may not have been preserved, while the extensional tilted fault blocks, horst and graben structures preserved on trailing margin (which includes also the study area) may have been inverted by later stages of deformation. The most likely interpretation of gravity and magnetic data sets may lead to conclude such features do exist.

7.2. Compressional and transpressional features

Phase:

a. Compressional and transpressional deformation (inversion of paleo trend) during Late Jurassic–Mid Cretaceous and Paleogene:

b. Compressional and transpressional deformation of Neogene stage:

Evidence

Features related to this deformation have been preserved but have been modified by later transpressional stages of deformation. The northern margin of Afghan and Lut blocks may have gone through folding and thrusting while the southern margin at this time remained passive until the subduction of Neo Tethys floor below the Afghan block. The history of events documented by Sarwar et al. (1979), suggest uplifting and folding from Cretaceous to Quaternary age rocks along with development of the volcanic arc along southern margin of Afghan Block. (Fig. 9). The volcanic arc in south is partitioned by an intra-arc basin (Dalbandin Trough) which also developed during this deformation stage. The post Paleocene compressional and transpressional deformation overprinted the geometry of earlier structures.

7.3. **Raskohuplift**

Also known as the Raskoh Range; a topographically elevated feature at surface in the north, this feature is structurally controlled by thrusting and folding of Cretaceous to Oligocene strata to form a hanging wall bounded by the Usman/Kukab transpressional fault, which dips to the northwest. The movement of this fault is also believed to be modified from compressional in the west to transpressional (left lateral) in the north as it swings to form a segment of the Chaman Fault of Lawrence and Yeats (1979). The Hunting Survey Corporation (HSC, 1960) mapped this area of the Raskoh Range using satellite photographs and managed to pick folding (anticlinal & synclinal) with intervening thrust or back thrust transpressional faults exposures on surface (Fig. 2). This structural trend as shown on the HSC map and Landsat lineation map (Fig. 2&12) is aligned east-west with a change to northeast at the culmination near the Chaman Fault. The compressional structural trends also appear to be intersected by N-S faults and sheared lineations which can be picked by the structural offsets that can be seen along the ridges (Figs. 13&15). The type of folding varies from plunging to doubly plunging, symmetrical to gently asymmetrical, south-facing with the frontal thrust dipping north. Near the Chaman Fault trace, these fold and faults appear to align at an angle setting up an en-echelon pattern which is a common feature of strike-slip faulting. Kamran and Moin (2003) have also mapped compressional folding and a thrust fault system in the north of the fore-arc basin to the west of the study area (Fig. 14). The geometry of these folds show structural symmetry and tight cores.

The Raskoh range is structurally separated from the Chagai Arc by an intervening low (Dalbandin Trough). Lawrence and Yeats (1979) suggested the presence of a sole thrust which emplaced the ultramafic rocks (Bunap Intrusions of granitic origin) as a tectonic slice along Kharan uplift.

7.4. **Kharan Fore-Arc Trough**

The study area covers the eastern part of this feature where it is juxtaposed with Chaman Fault Zone. The name Kharan Fore-Arc is also referred to this feature which is broadly a structural low in the arc-trench gap system of the present tectonic setting of Eurasian Plate with Arabian Plate. This structural low is bordered by the Usman Fault and Raskoh Uplift in the north while to the south it is juxtaposed by the northern margin of the Makran Range also known as Sihahan Range (Fig. 12). Here, the stratigraphy is masked by Quaternary alluvial fans and patches of sand dunes. The studies of Lawrence and Yeats (1979) suggested the uplifting of the northern edge of basin even during recent times.

The subsurface geophysical data (gravity, magnetic and seismic) has been evaluated to understand the structural geometry which suggests the presence of a 5000 to 7000m thick sedimentary section above basement. The seismic data shows high angle reverse faults and flower structures. The faulting appears to cut basement and deeper levels and may have a link as a splay of Chaman Fault originating from deeper levels of Moho (Fig. 6).

7.5. **Northern Makran Range (Siahan Range)**

This feature is the northernmost exposure of Oligocene and Miocene clastic sediments which originated as part of an accretionary prism (Fig. 12&16). Structurally the Siahan Range has been uplifted against the fore-arc basin and it culminates in the east at the Chaman Fault. The clastic sediments exposed in this uplift show tight folding which is aligned NE-SW direction. The folding is more dominant and complex in the west while to the east the bedding is intersected by N-S trending shear faults which are aligned parallel to the Chaman and OrnachNal Fault Zone (Fig. 16). The displacement along conjugate lineaments can also be seen from a Google image. Jacob and Quittmeyer 1979 suggested that the subduction of Paleo-Tethys south of the Kharan Fore-Arc Basin along its trend occurred prior to the existence and uplift of Siahan Range. The presence of folding and shearing across the fold trend reflects the Neogene deformation stage caused by transpressional movement and activity of southeastern margin along Chaman Transform Fault.

7.6. **Chaman Fault Zone**

This feature is present to the west of study area and is a major fracture zone which separates the Indo-Pakistani Plate to the east from Eurasian Plate in the west. The Chaman Fault establishes a transform boundary relation between both the plates with a left lateral movement. The transform relationship of both the plates started to develop in the Late Paleocene with the northwest collision of Indo-Pakistani Plate with the Afghan Block. This oblique collision set up a transpressional deformation which resulted in an eastward termination of many structural features that lay on the Afghan Block (Dast-i-Margo, Chagai Magmatic Arc, Dalbandin Trough, Raskoh Magmatic Arc, Kharan Fore Arc Basin) and folded features of the MakranAccretionary Prism (Siahan Range). Lawrence and Yeats (1979) managed to establish a minimum left lateral displacement of 155km on the fault which is supported by exotic blocks of Bunap intrusions, Kharan Limestone and facies resemblance with Raskoh Range. In places, structurally folded and faulted features of Afghan Block are aligned at an angle with the Chaman Fault to form en-echelon geometries.

The structural style identified from surface geological data and subsurface seismic interpretation in the Kharan Fore-Arc Basin show transpressional deformation which is represented by the high angle fault system of flower features. These faults can be linked to the Chaman Fault as splays forming en-echelon patterns (Fig. 17).

8. **Hydrocarbon potential**

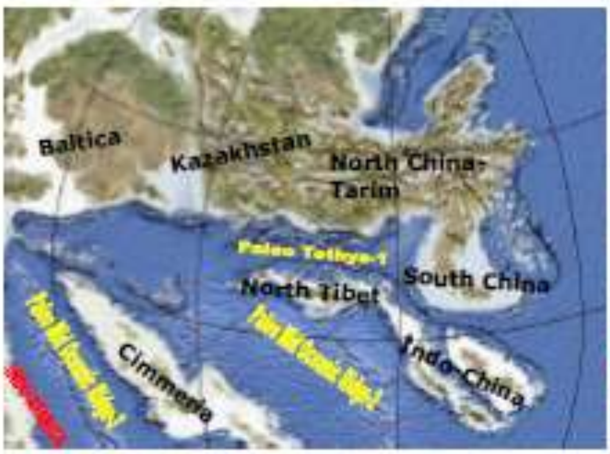
8.1. Source rock potential

The Paleocene Rakhshani Formation has been identified as a potential source rock in the Balochistan Fold Belt Basin. Geochemical analysis on two outcrop samples from the Rakhshani Formation reveal TOC contents ranging from 0.5 to 1.98 % with genetic potential of 0.07 kg/tone (Aziz et al., 2005). These authors claim that the geochemical values are not representative due to a thick weathering zone which caused oxidation of the organic matter. In the Kharan Basin, the Rakhshani Formation is expected to be mature for oil and gas at a maximum depth of 5500 meters (Aziz et al., 2005). These source rocks appear to be deeply buried, here based on our seismic interpretation (Fig. 17).

In addition to the Rakhshani Formation, the Eocene Kharan Limestone may also act as a source rock in the area (Aziz et al., 2005). According to Aziz et al. 2005 the basal part of the Kharan Limestone is composed of wackestone which may host organic matter of good quality. The reported low TOC values of

320-285 M.Y Late Carboniferous
Paleo Tethys Ocean & Paleo Mid Oceanic Ridge
Present between India-Africa and Eurasia

280-250 M.Y Middle Permian
Closing of palo Tethys phase-1
Separation between north Tibet and Cimmeria by
Tethys-2:Separation of Cimmeria form Gondwana



240 MY Early Triassic
Closing of palo Tethys phase-1
Collision of North Tibet and IndoChina
Separation of Cimmeria form Gondwana

230-210 M.Y Late Triassic
Separation between north Tibet and Cimmeria by Tethys -2
Separation of Cimmeria, NW Iran And Lut form Gondwana
by Tethys -3 and origin of mid oceanic ridge.

188-157 M.Y Mid Jurassic
Closing of palo Tethys phase-2 and
Suturing of Lut, Helmand and Lhasa With Laurasia

160-145 M.Y Late Jurassic
Closing of palo Tethys phase-2 and
Suturing of Lut, Helmand and Lhasa With Laurasia

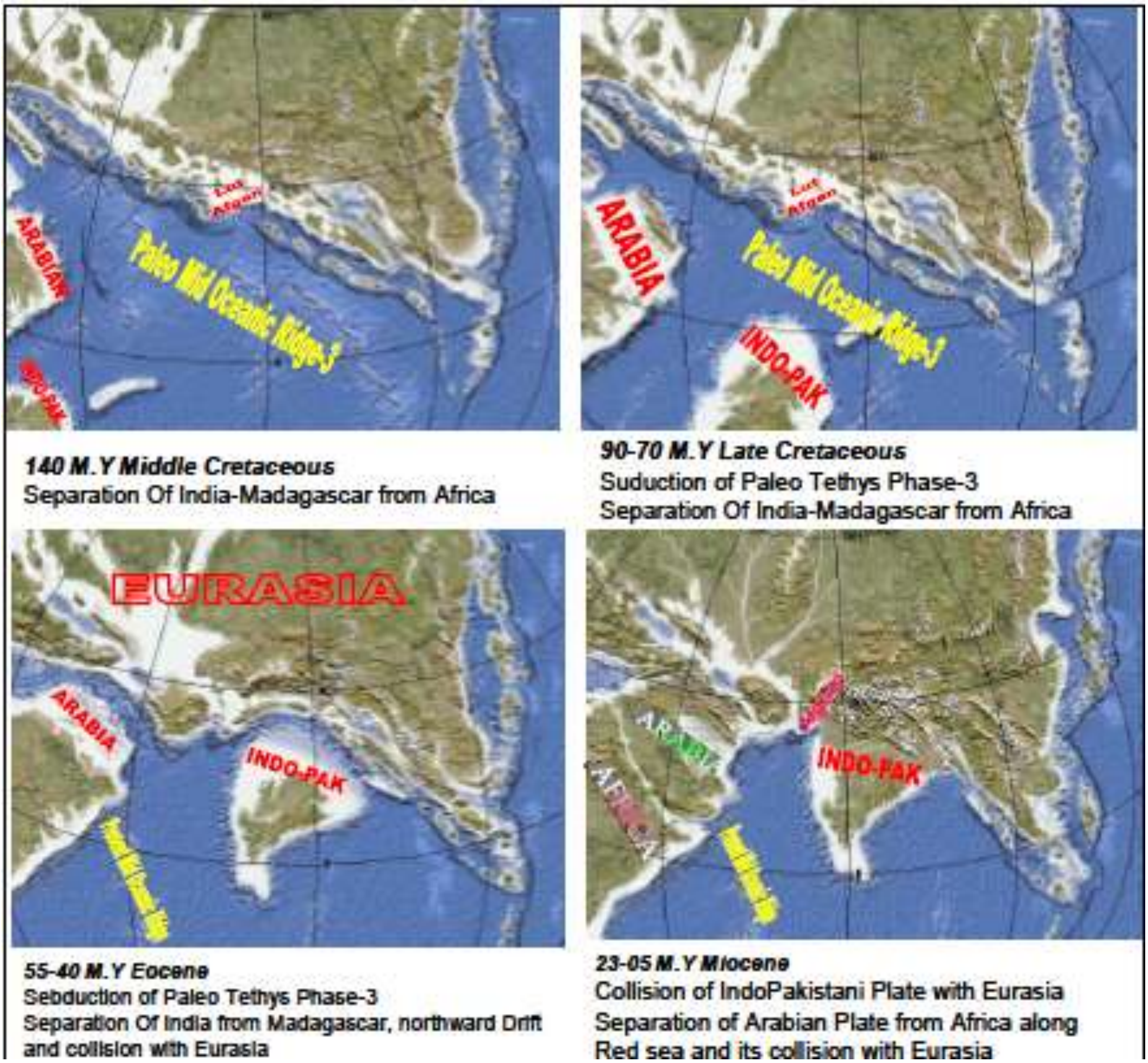


Fig. 8. Plate tectonic evolution of Gondwanaland and Eurasia showing rifting and suturing of Afghan micro-continent and Indo-Pakistani Plate.

up to 0.22% could be due to intense weathering and oxidation of the surface samples. The Kwash oil seep of the Siahan range and gas associated with mud volcanoes along the Makran coast are evidence of source rocks mature enough for oil and gas generation in the Balochistan basin.

8.2. *Reservoir rock*

Carbonate buildups and shelf margin carbonates of the Kharan Formation are expected to provide potential exploration targets (Aziz et al., 2005). These authors noticed development of grainstone with some intergranular porosity in the upper part of the formation as well as a number of dolomitized zones leading to the development of vuggy porosity in the Kharan Limestone. Besides, fracture porosity in the limestone will improve the reservoir characteristics of this unit as a result of deformation related to transpression (Fig.17).

The upper part of the Rakhshani Formation is characterized by a gritty sandstone, conglomerate and fine to coarse grained sandstone interbedded with shale.

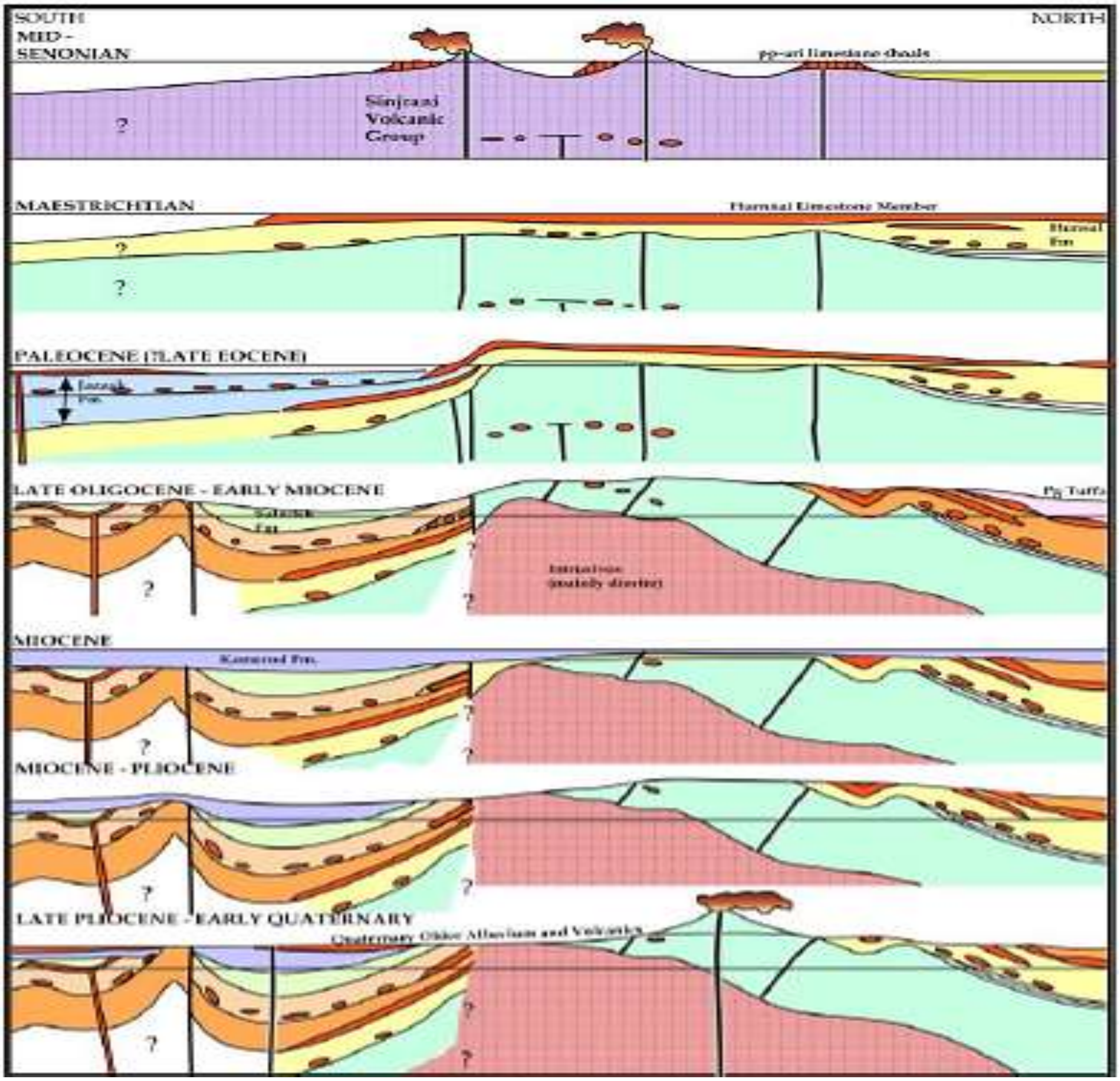


Fig. 9.Geological History modified after Russell et.al 1979.

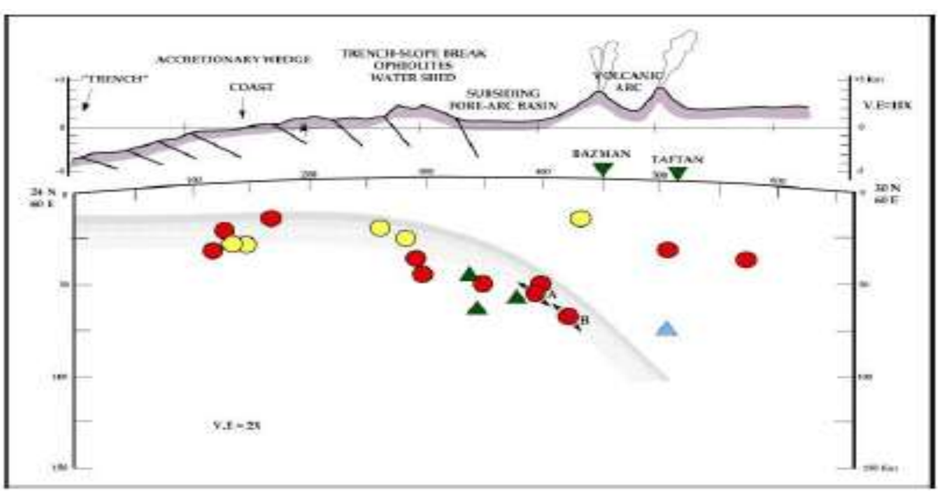


Fig.10. Deformation style of Makran and fore Arc basin, modified after Jacob and Quittmeyer, 1979.

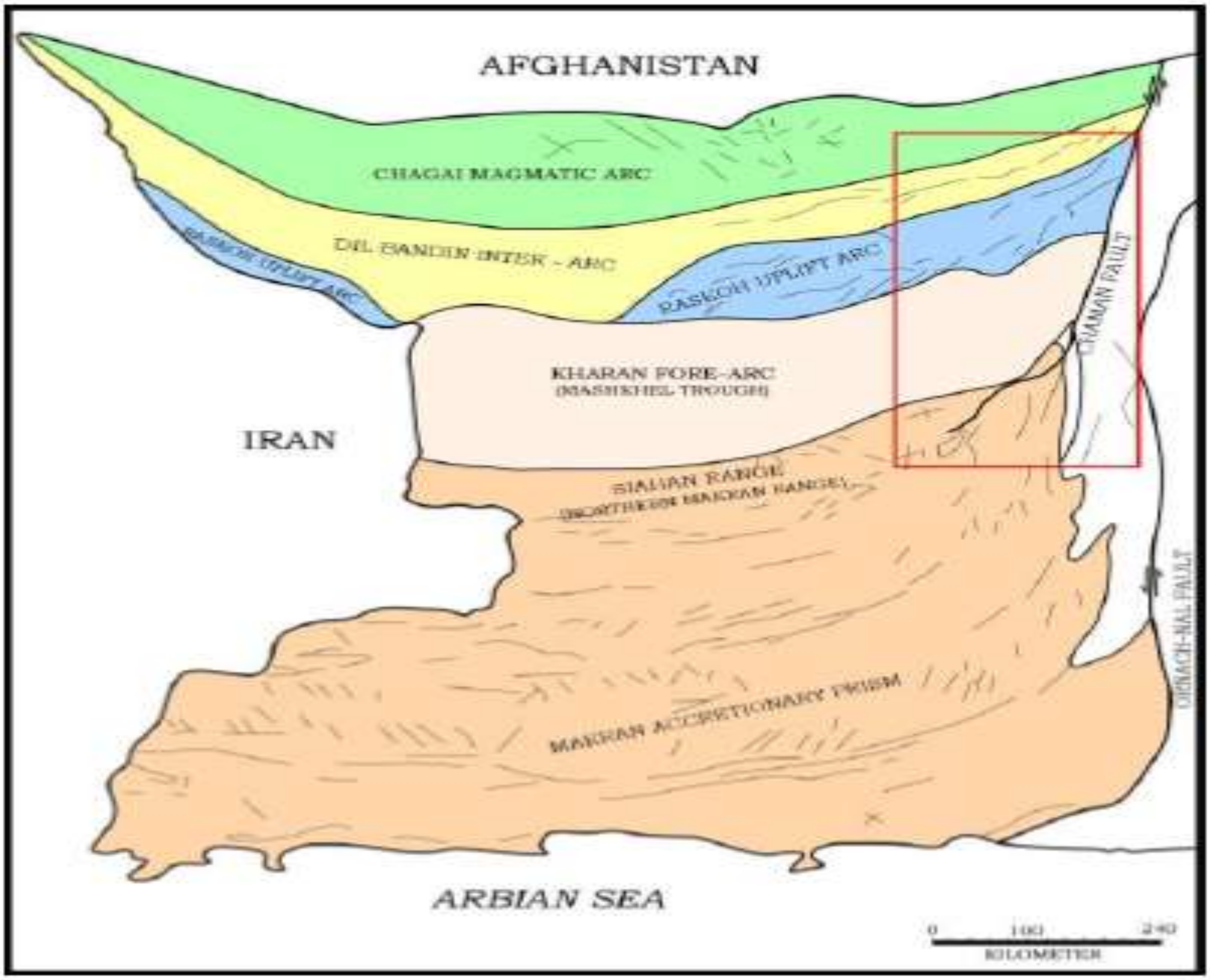


Fig. 11. Major Tectonic zones of Baluchistan Basin.

Fig. 12. Landsat image showing structural features at Indo-Pakistani and Eurasian Plate margin.

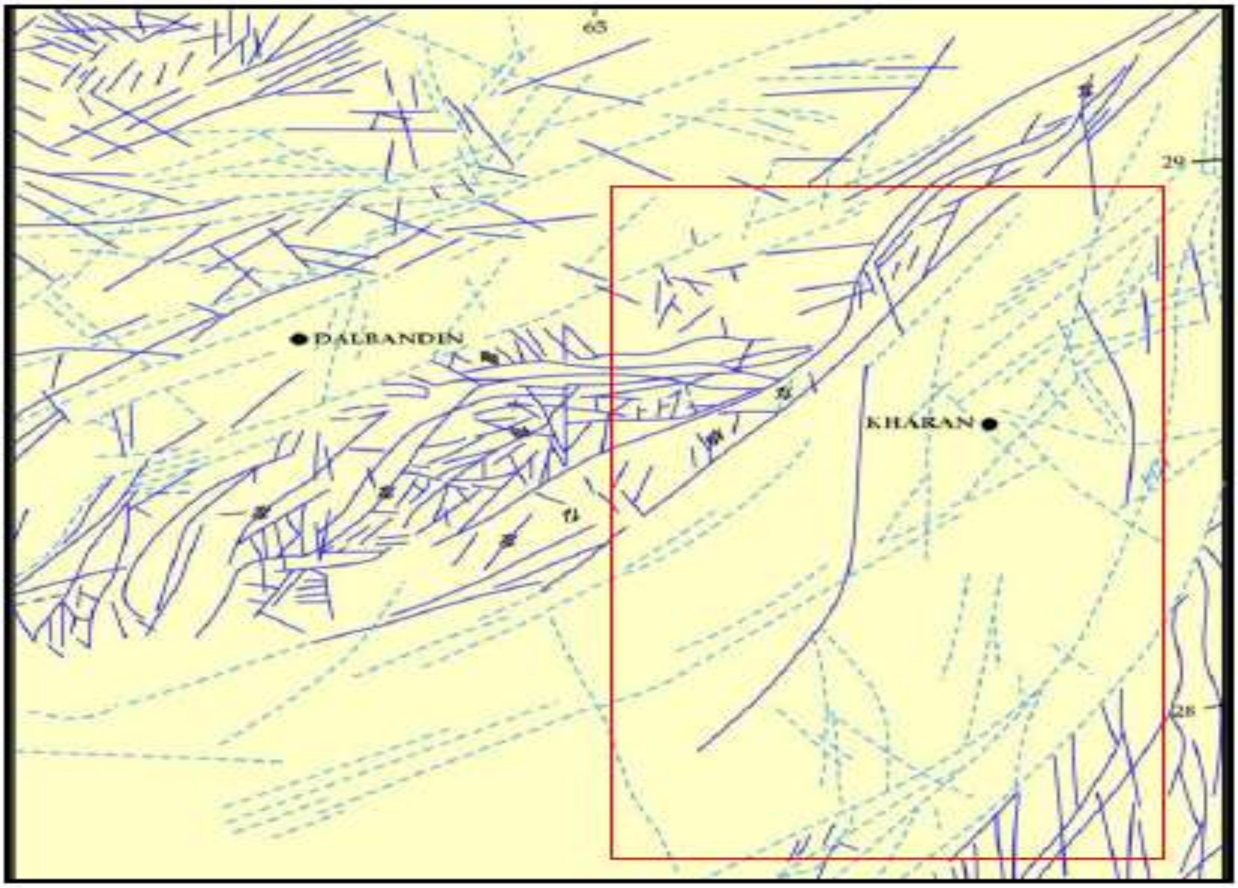


Fig.13. Landsat lineation map of study area (modified after Kazmi et al., 1979).

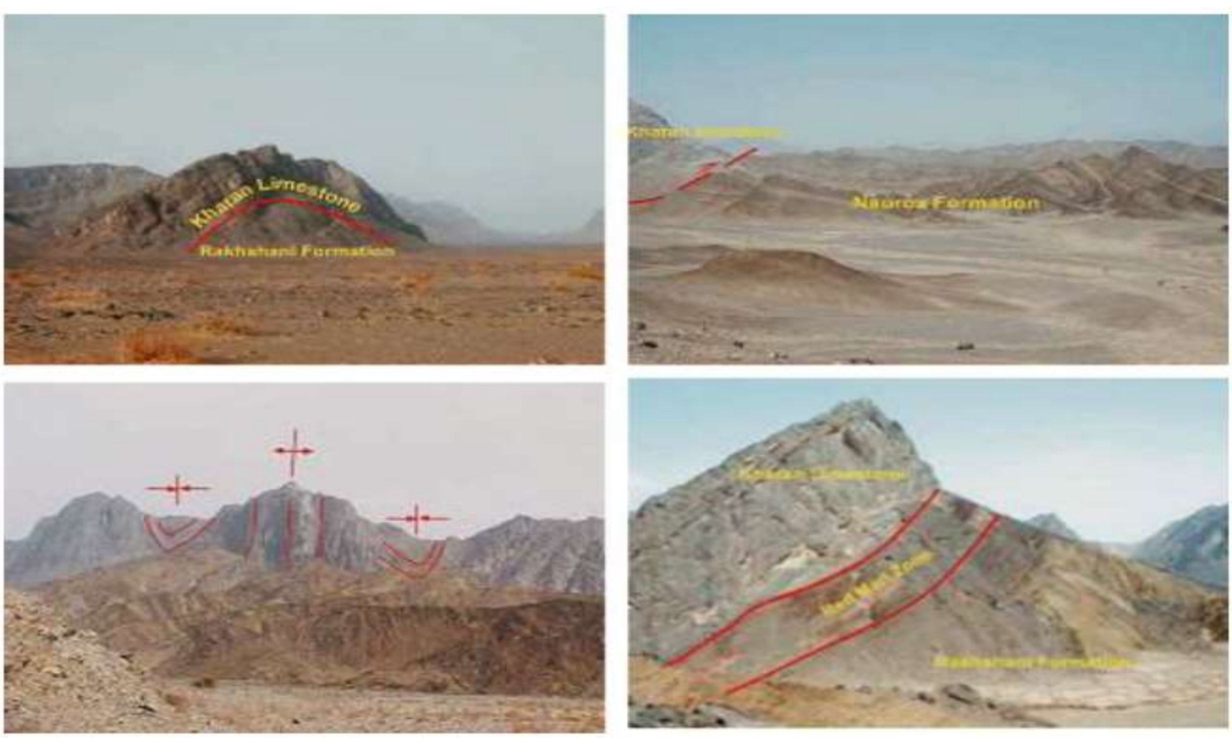


Fig. 14. Folding and thrusting of sedimentary strata west of study area along Raskoh Range, after Kamran and Moin (2003).

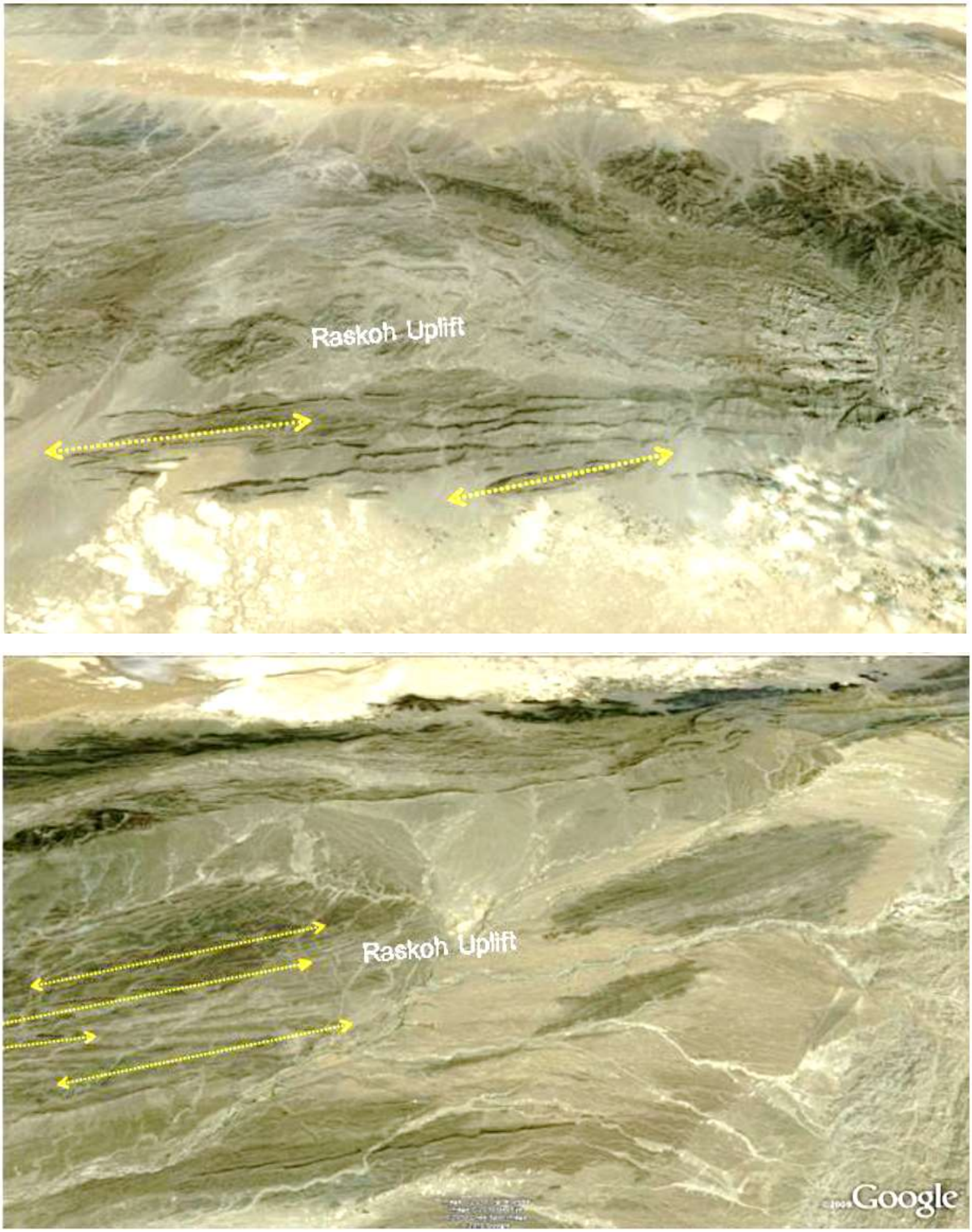


Fig.15a. Folding and shear deformation along Raskoh Range.

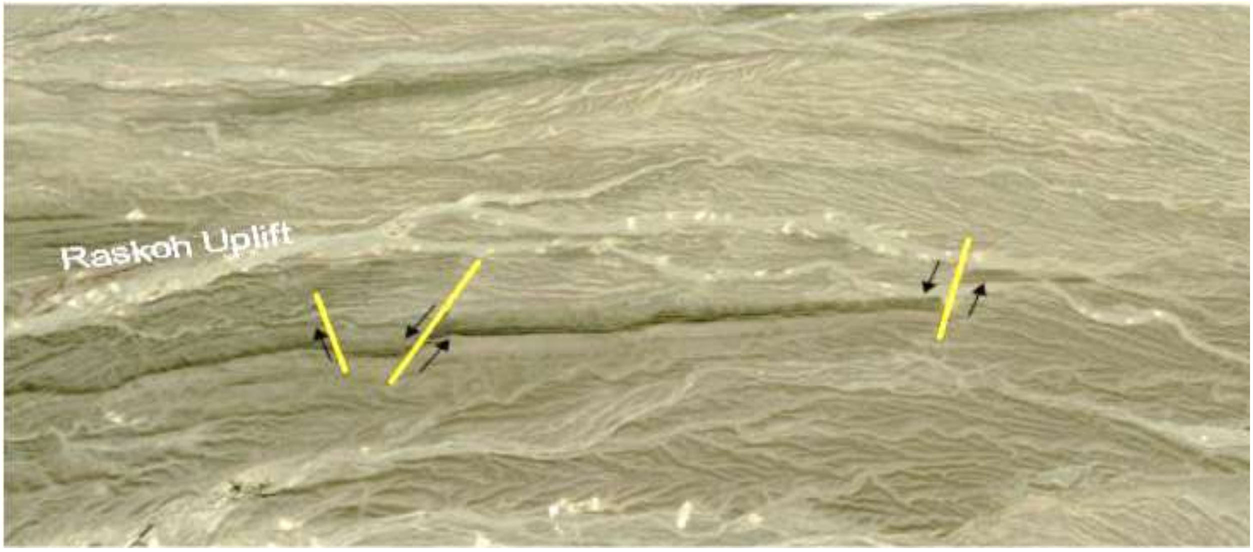


Fig.15b. Folding and shear deformation along Raskoh Range.

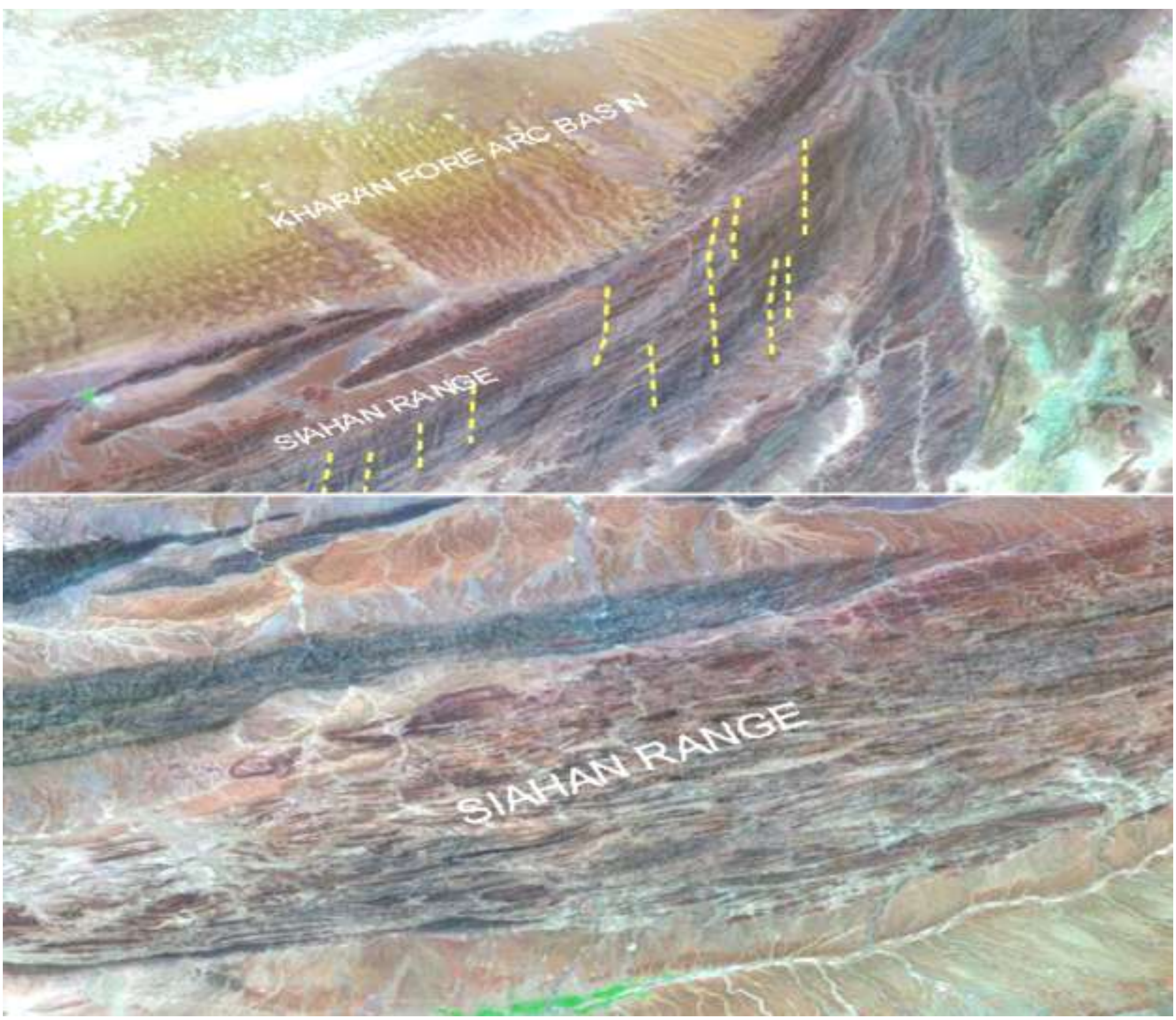


Fig. 16. Landsat image showing Folding and shear deformation along Northern Makran Range during Neogene.

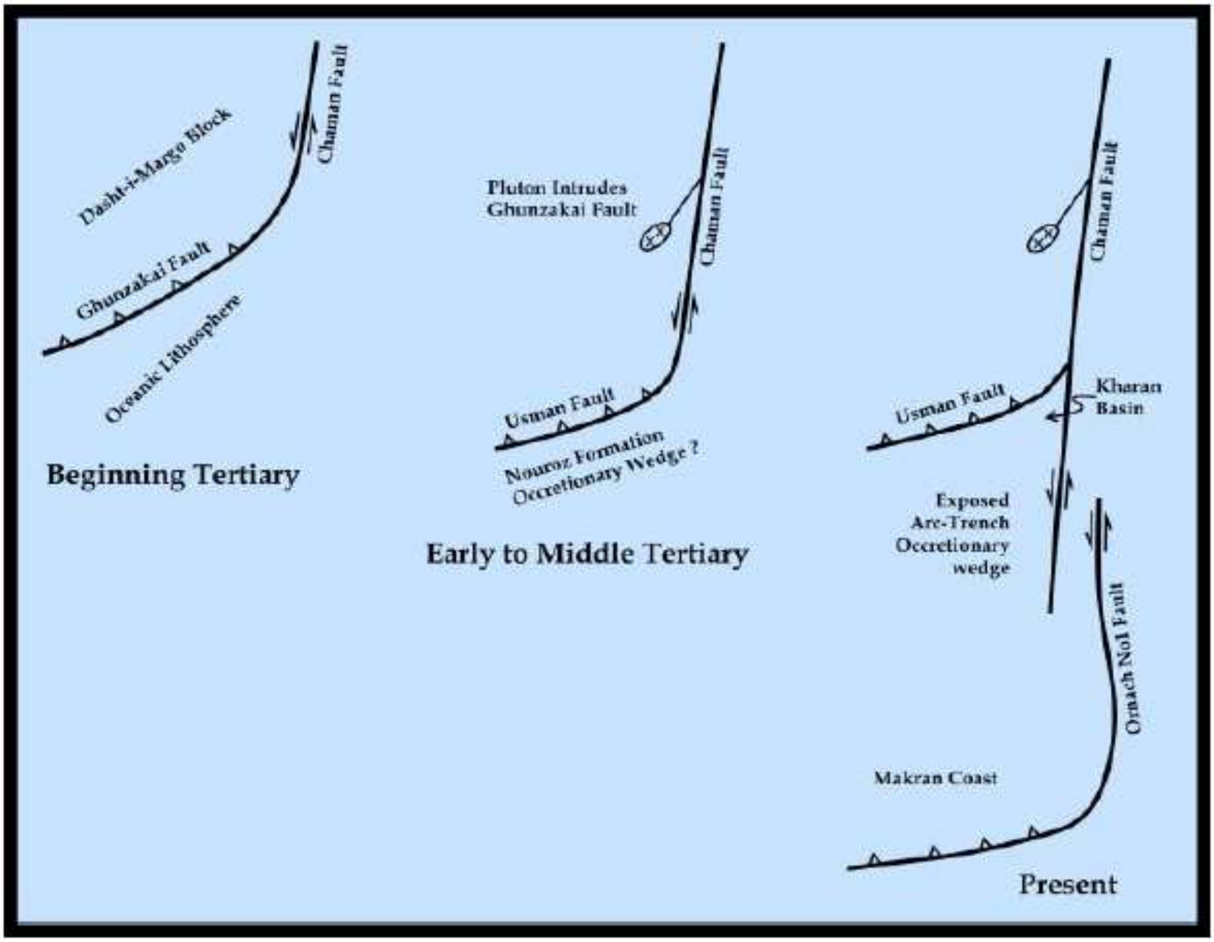


Fig. 17. Usman Fault and Kharan Fore Arc Basin and its relation with Chaman Fault; after Lawrence and Yeats (1979).

These zones may provide potential reservoirs (Aziz et al., 2005). The upper part of the Nauroz Formation is dominantly composed of quartz arenite of considerable thickness. The sandstones are medium to coarse grained and well sorted. These sandstones could also serve as potential reservoirs (Aziz et al., 2005)

8.3. Seal

The thick sequences of intraformational shale within the Rakhshani and Nauroz formations can provide an effective sealing mechanism for the Rakhshani and Nauroz sandstone reservoirs. Whereas, the shale of the Nauroz Formation is expected to provide a top seal for the Kharan Limestone reservoir.

9. Conclusions

The structural style in the study area which lies in the eastern Kharan Fore- Arc Basin is mainly associated with transpressional tectonics as a result of sinistral strike slip movement along the Chaman Transform Boundary Fault.

The structural features that appear on seismic data are dominantly positive flowers, bounded by high angle reverse faults that branch-off upward from steep fault zones, which at depth seem to link with the Chaman Fault and its splays such as Usman-Chaman Fault which dips steeply to the north and changes its characteristics from strike-slip to transpressional in the southwest direction, away from the Chaman Fault.

The aeromagnetic and gravity maps revealed depth of sedimentary basin in the study area, its structural trend and relationship of structural geometries with certain anomalies.

The Cretaceous to Eocene sedimentary package is considered to contain a potential petroleum system. The likelihood of potential Paleocene source rocks in the area cannot be ruled out. Potential reservoir targets include the carbonates of the Eocene Kharan Formation as well as the sandstones of the Cretaceous to Eocene Rakhshani Formation. Effective sealing mechanism is likely to be provided by the thick shale sequences.

The Neogene strata close to the Chaman Fault show a very low grade dynamo thermal metamorphism which may lead to establish a localized kitchen area.

The complex multiphase deformation of this area has resulted in the development of fracture systems which is appropriate for any reservoir rocks suitable for hydrocarbon exploration.

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Authors' Contribution

Sajjad Ahmad (Sr.) performed regional tectonic and history of collision. Saeed Hasan did evolution of outcrop data and surface structural Geometry. Khalid Mehmood Contributed for evaluation of igneous rocks (Chagahi Arc and other facts of fore-arc subductions). Tahir Maqsood performed gravity, magnetic and seismic data interpretation. Ramsha Tahir did Location access and data base review and cross section study

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