ID No. 2004921

Indo–Eurasian Plate Collision and the Evolution of Pak–Iran Makran Microplate, Pishin–Katawaz Fault Block, Porali Trough and the Western Belt (Ex-Axial Belt)

Abstract

Interpretation of tectonics of Indian and the Eurasian Plate reveal presence of a microplate west of the northward drifting Indian Plate (IP) by Early Eocene, which was subsequently accreted to the Eurasian Plate (EP). This microplate is designated as Pak–Iran Makran Microplate (P–IMM). The P–IMM is situated between the Zendan Fault in Iran and the Ornach-Nal Fault in Pakistan. The eastern part of P–IMM is represented by the Makran Accretionary Prism (MAP) in Pakistan. The northern border of P–IMM coincides with the Jiroft Fault in Iran, which is interpreted to extend eastward along the northern margin of the MAP and most likely joins/truncates along the Chaman Fault.

By Oligocene, the converging IP and the Afghan microplate bordered a NE-SW oriented sea, with P–IMM in the SW. This 'Remnant Closing Sea' (Neo-Tethys) received Oligocene-Miocene flysch mainly from the NE, and is now represented by the Pishin-Katawaz Fault Block (P–KFB). This entire set-up was exposed to a synchronized dynamic environment. The plates were converging, the Oligocene–Miocene depositional trough was shrinking, the IP's western collisional zone was subducting/evolving, Porali Trough was opening as the IP was rotating anti-clockwise, followed by the post-Miocene E–W compression in a transgressional setting. The left-lateral Chaman–Moqur Fault and the Ornach–Nal Fault mark the boundary between Afghan microplate and the P–IMM (Eurasian Plate) to the west and the Pishin–Katawaz Fault Block (subduction zone of Indian Plate) in the east. The eastern margin of P–KFB is faulted, along the Quetta Fault System (QFS), against the collisional margin of the IP (Fig.1). The collisional margin is traditionally described as the Axial Belt. It constitutes a mix of sedimentary rocks where ophiolite obducted across the K–T Boundary and it is also interbedded with volcanics and colored mélanges, which are imbricated as a result of Himalayan orogeny. This linear zone most likely represents the detached sedimentary cover of the Indian Shield during collision. It is proposed to designate the collisional zone as 'Western Belt' (Ex-Axial Belt), which represents the western most part of the Indus Basin (IB), and to be considered a Geological Province of the IB. This entire kinematic and dynamic history is spread over a period of approximately 55 Ma.

Introduction

The initiation of collision of the Indian Plate (IP) with the Eurasian Plate (EP) is a late Cretaceous (Maastrichtian) event. However, the continent-to-continent collision, which raised the Himalayan Ranges, is considered to be initiated in the Middle Eocene (1 and 2). Prior to the main collision with Asia, the Kohistan–Ladakh Island Arc (K–LIA) evolved on the northern extremity of the IP, wherein its calc-alkaline volcanic arc igneous activity ended by 61 Ma (3). Although IP is not in direct contact on surface, with the EP in Pakistan, but its leading edge may be in contact and in a state of collision with the EP along a subduction zone resulting in duplication of the crust.

The western margin of the IP is considered to be in an early stage of oblique collision with the EP. The oblique collision and/or transpression resulted in the development of Chaman–Ornach-Nal Fault and the QFS with the presence of sporadic outcrops of ophiolite mainly along the latter and a zone of sedimentation in between the two, which is dominated by the presence of marine clastics termed as Khojak flysch (Oligo–Mio). This zone of sedimentation and deformation is recognized as the Pishin–Katawaz Fault Block (P–KFB). It is presented that the Porali Trough (PT) in the south is a continuation of the P-KFB, and in combination represent zone of subduction filled by the flysch deposits. The western boundary of this subduction zone is marked by the Chaman–Moqur and the Ornach–Nal faults system; whereas the eastern boundary is marked by the QFS (Fig.1). However, the leading edge of the passive margin of the IP is considered to extend as far to the west as the Afghan Block and the P–IMM below the over-thrusted P–KFB with the presence of about 57 km thick duplicated crust of the Afghan Block (4). The source of Khojak flysch was from the north-east, and these sediments overlie Mesozoic stratigraphy of the Indus Basin with obducted ophiolite in between. The depositional trough is considered to extend southward along the Porali Trough, which is interpreted to be elongated in an E–W orientation due to the anti-clockwise rotation of the IP.

Pak–Iran Makran Microplate (P–IMM)

Evolution

An animation of drifting plates by Shell International shows presence of a new microplate, besides Iran/Lut/Afghan blocks, close to the western margin of the IP during Early Cenozoic. This microplate eventually accreted with the Iranian/Lut/Afghan microplates. A mosaic of four time-lapsed snapshots, from the animation, shows the drifting of the microplates, and its accretion to the EP during Cenozoic time (Fig.2). The new microplate, as inferred by the Shell Animation, is hereby named as Pak–Iran Makran Microplate (P–IMM). Its accretion with the northern plates may be evidenced by the presence of a conspicuous east–west zone of ophiolite in between, marked by the Jiroft Fault (5). This boundary is extended further to the east as a plate boundary in Pakistan (2); though the ophiolite is absent eastwards in Pakistan, which may be related to the absence of their sub-aerial exposure (Fig.3).

Extent

The P–IMM is a fault-bounded microplate of inferred oceanic lithosphere with surface exposures of Eocene to Miocene and younger sedimentary rocks that accreted to the Eurasian Plate. These entirely marine flysch deposits were folded and faulted in the Early Pleistocene (6). Deposition and deformation of these deposits is attributed to the development of Makran Accretionary wedge/prism (7) along a subduction zone which marks the southern boundary of the P–IMM in the offshore (Oman Trench). Its E–W limits stretch from NS oriented Zendan Fault in Iran (5) to the Ornach–Nal Fault in Pakistan. Whereas, its northern limit is represented by the E–W oriented Jiroft Fault in Iran, which is marked by the presence of ophiolite along the southern margin of Iranian/Lut Block in Iran, and along an inferred plate boundary (Panjgur fault?) in Pakistan between Chagai calc-alkaline volcanic belt (including the Kharan Fore-arc Province) and the Makran Flysch Province (2 and 6), (Fig.3).

Pishin-Katawaz Fault Block (P-KFB)

The P–KFB is a fault-bounded block of inferred oceanic/transitional lithosphere, which possibly represents fragmented part of the Neo–Tethys and the Indian Plate (IP) with surface exposures of dominantly Eocene to Miocene sedimentary rocks. The strata has been folded and faulted during Neogene as a result of the collision. It is bounded towards east by the Chaman–Moqur and the Ornach–Nal faults system and to the southeast by the Quetta Fault System (8 as in 9). This mega fault block, which overlies the subduction zone between Indian Plate and the Eurasian Plate, wedges out towards north; and in the south it is linked with the Porali Trough (Fig.1).

Stratigraphically, the fault block (subduction zone) is filled with 4–6km thick sequence of flysch, deltaic and molasse type of sediments (10), which is represented by the Khojak Formation (Oligocene–Miocene) that overlies the Nisai limestone (Eocene). An exploratory well drilled to more than 4000 m in the Pishin Fault Block (the southern part of P-KFB in Pakistan) (Fig.1) remained within the Khojak Formation, without encountering the targeted Nisai limestone (11).

Evolution and Kinematic Model

Evolution of the P–KFB was initiated with the mid-Cretaceous calc-alkaline volcanism of the Kandhar arc (Fig. 4A and 4B). This was followed-up with the shift of subduction system and emplacement of Muslimbagh ophiolites in Paleocene along the southern margin of the block (Fig. 4C). By Eocene the converging IP and the Afghan microplate were interpreted to be separated by a NE–SW oriented sea with presence of an oblique subduction system along the Quetta Fault System. This 'Remnant closing Sea' (Neo–Tethys) have received Late Oligocene–Miocene flysch mainly from a northeasterly source, which is now represented by the Pishin–Katawaz Fault Block (Fig. 4D). This entire set-up has been exposed to a synchronized dynamic environment of a convergent system that lasted from Eocene–Miocene till today. The plates were converging, with the deposition of Oligocene–Miocene flysch in a shrinking trough and the development of a collisional margin of the IP, while the Porali Trough was opening as the IP was rotating anti-clockwise, followed by the post-Miocene E–W compression in a transpressional setting. This onward collision further closed and narrowed the trough (Fig. 4E) (12). In this setting, the initially NE–SW oriented Pishin–Katawaz trough was compressed and closed, sandwiched between the IP and the EP. The northward drift of the IP caused the deformation of P–KFB resulting in the NNE-SSW structural trend as we see it today. The southern part of this fault block (Porali Trough) is interpreted to be in continuation with the P–KFB along a narrowed zone (Fig.1 and Fig. 5). The crust underneath the P–KFB is interpreted as segmented oceanic / transitional crust related to the NW margin of the IP.

Porali Trough

The NS oriented Porali Trough is considered as a product of the anti–clockwise rotation of the Indian Plate. The deposition of Eocene–Miocene marine deposits may have occurred in a tongue of sea with extension towards NE between the converging plates. The convergence has led to the obduction of Bela ophiolites, which are now exposed along the eastern margin of the trough (Fig.1). Porali Trough is considered to be analogous to the P-KFB based on similar type of sedimentary rocks and presence of ophiolites over NW margin of the IP. Porali Trough is interpreted to be elongated in an E–W orientation due to the anti-clockwise rotation of the IP.

Western Belt

Extent and Location

Hunting Survey Corporation (13) identified a long, narrow sinuate-shaped zone, with distinct lithological characteristics, which runs from Arabian Sea through Bela, Khuzdar, Quetta, Zhob and Waziristan up to the Kurram Agency, where it extends into Afghanistan. The belt was developed from Eocene onwards. The zone was named as the ‘Axial Belt’. The belt is generally considered to separate Indus Basin from the Balochistan Basin in a broader context. However, the present authors consider that it represents the marginal province of the detached sedimentary cover of the Indian Shield and hence, is part of the Indus Basin. It is recommended to be called as ‘Western Belt’ (WB) instead of the ‘Axial Belt’ (14).

Geological Limits

The western limit of the belt is clearly marked by the Quetta Fault System (QFS) of Schreiber *et.al* (9). Southwards, QFS cannot be joined with Ornach–Nal fault because the latter is a plate boundary. QFS is, hence, interpreted to follow the western limit of the Bela ophiolite exposures. The eastern limit of the belt exhibits series of faults with the Kirthar Range and the Sulaiman Range. It is interpreted that through the Porali Trough the Western Belt is restricted to the Bela ophiolite belt and most likely extends in the offshore (Fig.5). At the northern extremity, the Kurram Thrust marks the eastern boundary (Fig.1).

Stratigraphy

The Western Belt is a 10-50 km wide zone with unique geological characteristics that constitute a typical mix of the Cenozoic sedimentary rocks containing igneous rock components, and the obducted ophiolite across the K–T Boundary. Sporadic outcrops of ophiolite are present throughout the length of the belt and they are associated with the pelagic sediments, which contain gabbroic and dolomitic components. It is postulated that the shrinking ‘Neo-Tethys’ covered the western margin of the detached sedimentary strata of the Indian Shield where the unique sequences of the trough (Nisai and Khojak flysch) were deposited on top of the Mesozoic stratigraphy of the Indus Basin. Similarly, in Kurram Agency, the characteristics of Triassic–Cretaceous stratigraphic units are similar to the chrono-equivalent units of the Indus Basin (14).

Western Belt – A Geological Province of the Indus Basin

As discussed, the Western Belt represents the leading edge of the detached sedimentary cover, which reflects hinterland part of the Kirthar–Sulaiman ranges that served as a linear shifting zone. It forced the geosynclinal sediments towards the east. Due to this dynamic setting a unique stratigraphic assemblage, dominated by the rocks of Indus Basin, constitutes the proposed Western Belt (WB). As per the above discussion, WB is proposed to be considered as a marginal Geological Province of the Indus Basin by the name of 'Western Belt Geological Province' (14).

Conclusions

1. The P–IMM is inferred to represent a microplate of the Eurasian Plate, which is bounded towards north by the Jiroft Fault in Iran with presence of ophiolite and an inferred boundary on strike in Pakistan. Its southern margin is marked by the Makran convergence zone.
2. Zendan Fault in Iran and the Ornach–Nal Fault in Pakistan mark the western and the eastern limits of the P–IMM, respectively.
3. Pishin–Katawaz Fault Block (P–KFB) is interpreted to represent segmented oceanic/transitional crust related to the NW margin of the Indian Plate.
4. The Chaman–Moqur and the Ornach–Nal transform faults System and the Quetta Fault System (QFS) are interpreted to represent the western and the eastern limits of the P–KFB.
5. Tectonic modeling across P–KFB shows its evolution with shift of a subduction zone from Chaman – Ornach-Nal Faults in the west to the QFS towards east.
6. The P–KFB and the Porali Trough are analogues, which in combination are inferred to represent marginal zone of Indus Basin overlying the subducting Indian Shield.
7. The Western Belt (Ex-Axial Belt), through the Porali Trough, is probably restricted to the Bela ophiolite belt. The QFS is thus inferred to follow the western margin of the Bela ophiolite belt.
8. The Western Belt is considered to represent the leading edge of the Indus Basin (IB), and is proposed to be considered a Geological Province of IB.

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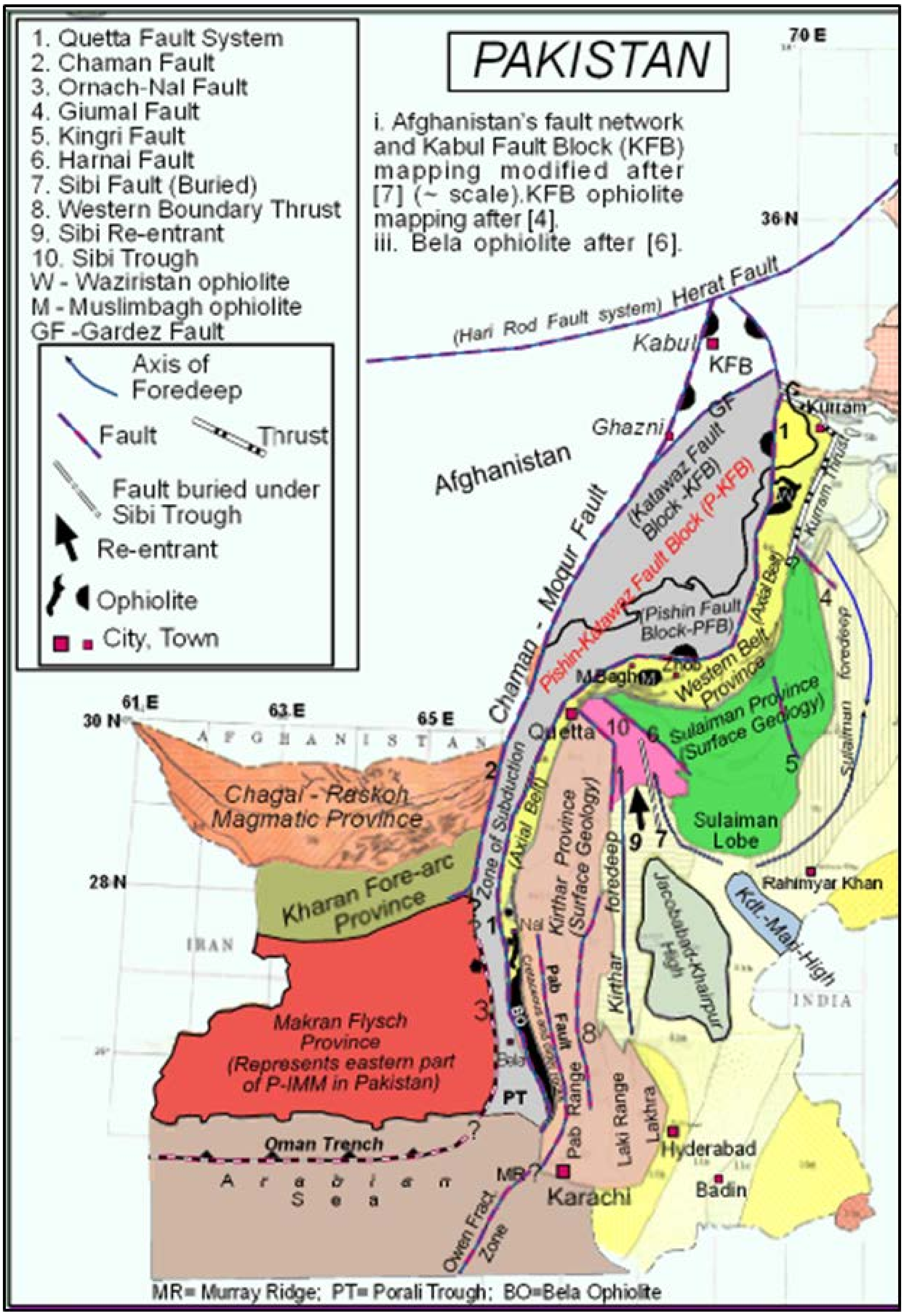

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Fig. 1. The Basin Architecture and the Geological Provinces (GPs) of western part of Pakistan. Chaman and the Ornach-Nal Faults System mark the border between Balochistan Basin to its west and the Indus Basin to the east. The Quetta Fault System (QFS) represents the limit of the western margin of the continental crust of the Indian Plate - the Indus Basin. Western Belt Province (WBP) belongs to the Indus Basin. The Porali Trough (PT), a product of anti-clockwise rotation of Indian Plate, and P–KFB a product of converging microplates are interpreted to be analogues, where similar Eocene-Miocene sediments were deposited on the subducting oceanic / transitional crust of the Indian Shield. The P–KFB and the Porali Trough are interpreted to be in continuation along a narrowed zone of subduction and are considered to represent marginal zone of the Indian Shield. [Modified after (12)].
Tectonic Map of Pakistan [6] is used as a base for delineating the GPs.

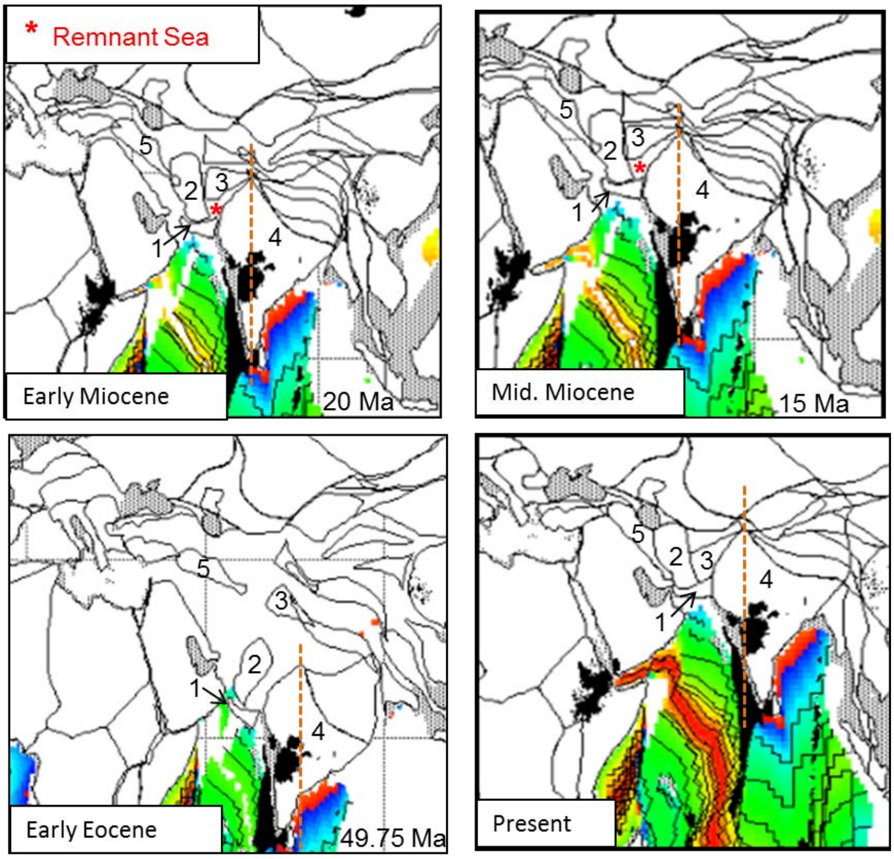


Fig. 2. A combination of sequential snap-shots from an animation of the drifting tectonic plates. The proposed Pak-Iran Makran microplate (P–IMM), the eastern part of which represents the Makran Accretionary Prism in Pakistan, independently kept pace with the northward drift of the Indian Plate, and the other microplates. The Remnant Sea that was initiated around 40 Ma provided a depositional trough for the future Pishin–Katawaz Fault Block (P–KFB). The dashed line highlights the anti-clockwise rotation of the Indian Plate. Microplates 1, 2, 3 and 5 are part of the Eurasian Plate. [Modified after (14,12)]. (1. Pak–Iran Makran microplate; 2. Central Iranian/Lut microplates;
3. Afghan microplate; 4. Indian Plate; 5. Zagros)
(Snap-shots reproduced, with thanks, after obtaining permission of Shell

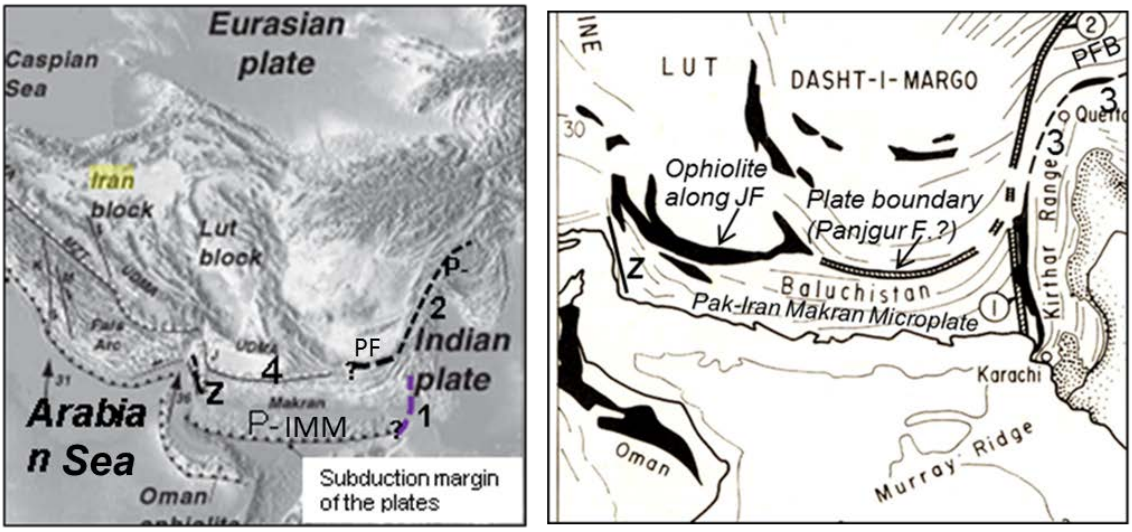
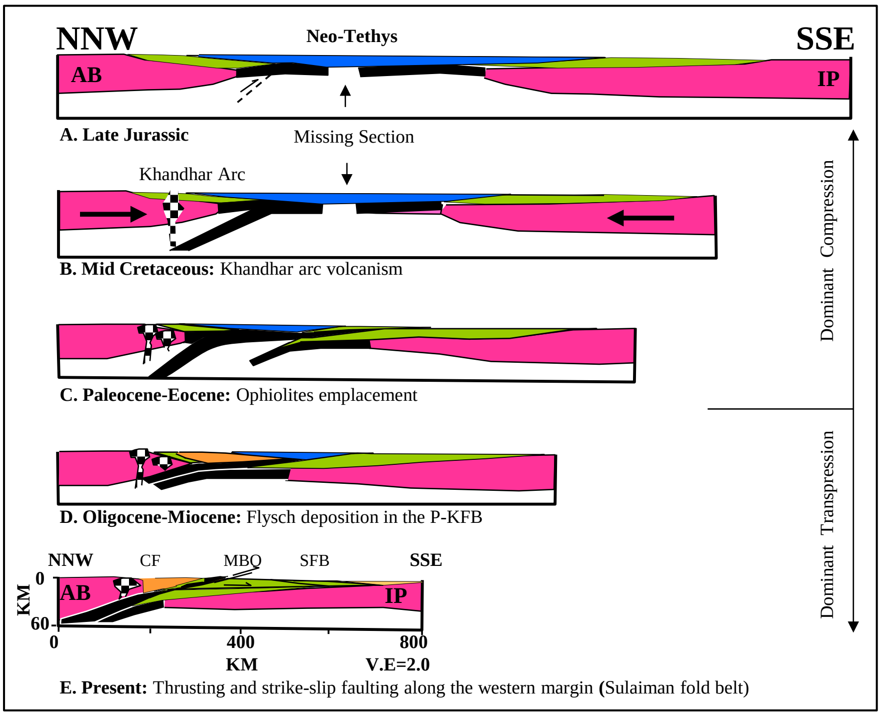


Fig. 3. An interpretation of Pak-Iran Balochistan region by Aubourg *et al.* [5] on left, and by Powell [2] on the right. Both interpretations show the westward turning of the Chaman Fault in line with the Panjgur Fault in Pakistan and the Jiroft Fault in Iran. Powell considers the Panjgur Fault to be a plate boundary and shows ophiolite along Jiroft Fault in Iran. The system marks the northern boundary and justifies the presence of the proposed Pak-Iran Makran microplate (P-IMM). The Oman subbduction margin marks the southern boundary [Modified after (14)].1- Ornach-Nal Fault, 2- Chaman-Moqur Fault, 3- Quetta Fault System, 4 –Jiroft Fault (JF), Z – Zendan Fault, PFB -- Pishin Fault Block, PF – Panjgur Fault

Fig 4. A Kinematic Model inferring the tectonic development across the western margin of the Indian Plate (IP) and the Afghan Block (AB). Please see text for detail.



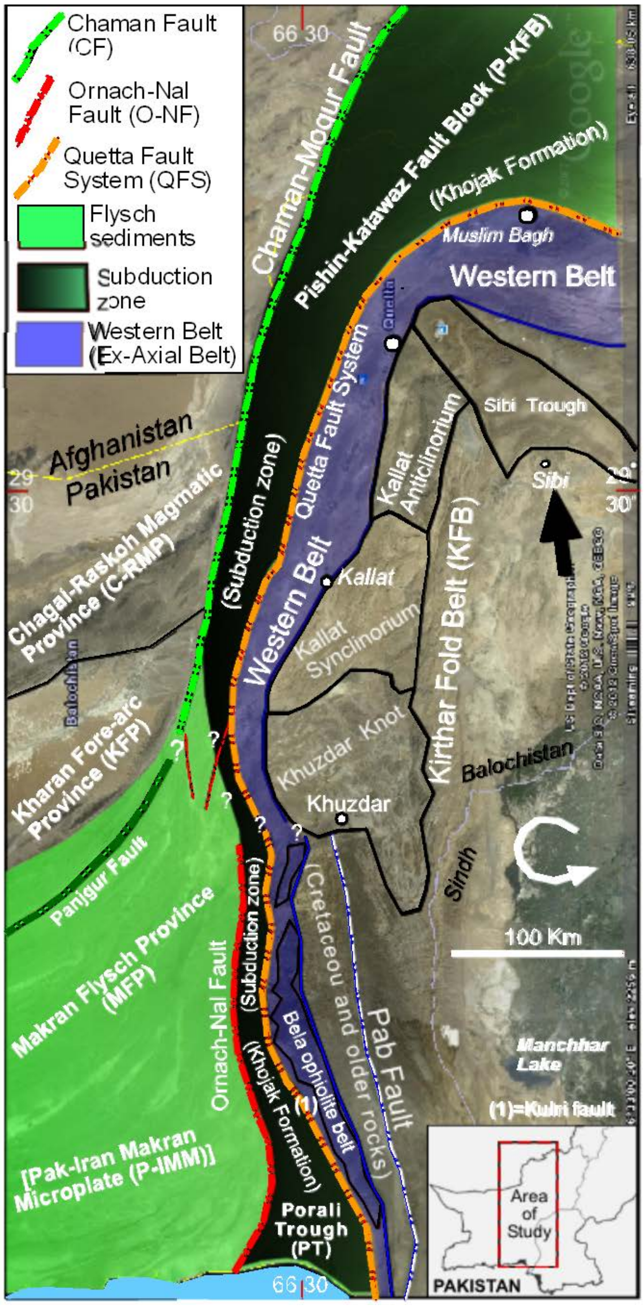


Fig.5. An interpreted Google earth image showing relationship of Chaman Fault, Ornach-Nal Fault, Quetta Fault System (QFS), Western Belt (Axial Belt) and the continuity of the Porali Trough sediments with those of the Pishin-Katawaz Fault Block (P-KFB). The continuation of sediments of P–KFB and the P–IMM as seen on surface is inferred to be late deposition that covered the fauts. The subduction zone between Indian and the Eurasian Plate falls between QFS and the Ornach-Nal/Chaman faults combined (14). In this setting the Porali Trough and the P-KFB are considered analogues. Western Belt (WB), through Porali Trough is inferred to be restricted to the Bela ophiolite belt. QFS marks the exposed eastern limit of the detached sedimentary cover of the Indian Plate - The Indus Basin. Western Belt is considered a Geological Province of the Indus Basin. The curved arrow indicates the anti-clockwise rotation of Indian Plate; the black arrow shows the northward convergence.
[KFB zones after (6)].