

CONCLUSIONS

The various E-W trending faults of the KRB including the KMF were active during the rift sedimentation in Mid-Late Mesozoic time (Biswas, 1999). The sedimentation was followed by an extensive phase of pre-Deccan Trap intrusive activity (Biswas and Deshpande, 1973). Maurya et al. (2017a) demonstrated the complex interaction between magmatism and faulting that led to the formation of flexure along the fault zone. The main Deccan Trap effusive activity did not affect the northern mainland as all the lava flows are confined to southern KMU (Biswas, 1993). According to the model proposed by Maurya et al. (2017a), the pre-Deccan Trap intrusive activity along the fault zone led to the doming of the overlying Mesozoic sequence. The Ukra intrusive, the largest of the intrusive also occurred during this time (Santonian to pre-Deccan Trap). The major conclusions of the present study with regard to the long long-term landscape evolution of the western Kachchh are as follows.

1. The landscape of the study area shows overwhelming control of the uplift bounding KMF and the intra-uplift VGKNFS. The geomorphological and structural characteristics of both fault systems were investigated in the present study to work out the long-term evolution of the landscape.
2. The shallow subsurface geophysical studies using GPR, carried out at the western KMF in the western part of the KRB in general points to vertical to north-dipping normal fault. It is inferred that the KMF is mostly a vertical fault at Mundhan anticline, Ghuneri dome and Sahera which becomes steep north-dipping normal fault near Karanpur dome and Jumara dome. The GPR studies along the western part of the KMF are in good agreement with the field geological studies.
3. Segmented nature of the western part of the KMF is supported by NW/NE striking transverse faults with oblique-slip motion. It also points to crucial role of various transverse faults responsible for the change in strike of the KMF and variation in seismicity along the KMF. It is hypothesized that these transverse faults play a

key role in stress transfer between uplift-bounding KMF and intra-uplift VGKNFS.

4. From the KRB, the present work is the first attempt at imaging and identifying the potential existence of sub-seismic colluvial wedges. Most colluvial wedges, like low-velocity seismic tomogram findings, are associated with the low-amplitude velocity EM waves zone with semi-continuous to chaotic reflections. On the other hand, stacked, high-amplitude cone-shaped reflections of the potential colluvial wedge are also observed.
5. Multiple secondary antithetic and synthetic slip planes with normal/reverse slip were imaged from the damage zone of the KMF. None of the slip planes were having surficial occurrence due to continuous sedimentation record towards the downthrown block of the KMF. These secondary slip planes may be the branch faults splaying from the primary KMF at depth. Upon reaching up the surface, they displace, warp etc. the Quaternary sediments suggesting Holocene deformation. The evidence of drainage deflection/termination along the KMF are also reported. Such evidence along with the presence of potential colluvial wedges, observed in the GPR cross-sections, suggest that the western part of the KMF is neotectonically active.
6. GPR surveys reveal – (i) normal slip in the middle segment of the VF, (ii) reverse slip in the southeastern segment along the VF and, (iii) reverse slip of the WVF along with the presence of deformation bands cluster. The fault geometry and slip-sense inferred through GPR profiles comply with the structural observations.
7. Regional paleostress field and the polyphase tectonic history of the VGKNFS was done through analysis of fault slip data. Since the faults are exposed in uniform lithology, slip-sense is inferred by observing various slickenside kinematic indicators. Carrot-shaped and pipe-shaped gouging grain grooves, mineral steps, fractures with different morphologies, domino-type offsetting in footwall/hangingwall, drag folding etc. are found useful in deciphering normal/reverse slip-sense.
8. The paleostress tensors obtained through Win_Tensor, T-Tecto, FaultKin and SG2PS are in good agreement with each other. Although, some show discrepancy in terms of the orientation of three principal stress axes. The results suggest that the VGKNFS encompasses non-Andersonian faulting with the temporally changing stress-fields.

9. The statistical analysis using chi-square goodness-of-fit test was performed on the derived paleostress analysis results. The test implies the probability of fault reactivation in VGKNFS. The VF ($\chi^2 = 0.86$) and unnamed faults ($\chi^2 = 1.10$) with reverse slip show good fit while the GUF ($\chi^2 = 4.67$) shows poor fit with the contemporary compressional stress field with NE-NNE oriented S_{Hmax} .
10. Two major deformation events – older D1 and younger D2 are defined based on the paleostress analysis results. The D1 event is associated with extensional kinematics, governing from Late Triassic to Late Cretaceous. It is further divided into two sub-groups – older D1o and younger D1y. The D1y event shows W-WSW oriented S_{hmin} attributed to NNW striking GUF and VF. The D1o event shows NNW-NW oriented S_{hmin} , near-perpendicular to the NE, ENE strike of unnamed cross-faults. The break-up of the Gondwanaland led to the rifting of KRB. This caused the build-up of extensional stresses in the KRB and formed normal faults during D1 event. After India-Africa separation, counter-clockwise drift of the Indian plate began from Mid-Jurassic time onward. This caused the strike-slip motion of earlier activated normal faults in the KRB. However, none of the major faults in the VGKNFS preserve any significant evidences of strike-slip motion.
11. The D2 event, governing from Late Cretaceous to the present times, is related to positive inversion of the KRB and is characterized by NNE-NE oriented S_{Hmax} . It is mainly expressed by compressional reactivation of NW-NNW striking VF, WVF, GUF, KF, NKHF and NF. A large part of the compressive stresses are accommodated in the intra-uplift fault zones (e.g., in the VGKNFS) as evidenced by the reverse nature of major faults (e.g., VF and GUF), than the uplift-bounding faults (e.g., KMF). The far-field compressional stress field is generated by: (i) back-thrust from the Indian-Eurasian plate collision at the convergent margin during Late Paleocene-Eocene and, (ii) the spreading Carlsberg ridge at the divergent margin in the Indian Ocean that exerts horizontal ridge push force to the KRB.
12. Compressional reactivation of faults in the VGKNFS is highly selective. The entire length of NW striking VF did not reactivate, though, it is optimally oriented to the current NNE directed S_{Hmax} . The NW (in sector 1) and SE (in sectors 3, 4) segments of the VF show reverse slip. While, only ~5 km lateral stretch (in sector 2) in the middle segment show normal slip and thus, it remained silent during D2

event. The NW striking GUF acts as a scissor fault. At its NW extremity (in sector 1), the GUF remained non-responsive during D2 event while in rest other parts, the GUF has witnessed reverse slip (in sectors 2, 3, 4). NNE, NE striking unnamed cross-faults exposed in all the four sectors did not undergo compressional reactivation due to their unfavorable orientation. The nature of preferential reactivation of faults is due to the uneven distribution of compressive stresses during D2 event within the intra-uplift VGKNFS.

13. Continued tectonic uplift of the area under compression and further along the KMF through Tertiary and Quaternary times led to the formation of the present structurally controlled landscape. The tectonic uplift relates to the inversion of the basin in response to compressive stresses induced by the collision of the Indian plate further to the north. The hyper-arid climatic regime also points to dominant role of tectonic uplift in the formation of rugged erosional landscape.
14. Down faulting along the KMF ensured that the northern limb of the flexure attained far greater inclination than the southern limb in the NHRFZ. Increasing compressive stresses and continued faulting caused the northern limb to become sub-vertical to vertical. The uplifting movements led to the formation of NHRFZ and the initiation of large-scale erosion of the landscape. A north facing fault scarp in the steeper northern limb was produced as a consequence of faulting. The extensive tectonically controlled erosion induced by uplift led to the retreat of the KMF scarps. By Mid-Miocene, the retreated scarp was more imposing than the scarp along the fault line. This phase marks the initiation and the formation of the Jaramara scarp.
15. The Mid-Miocene was a period of the largest transgression when the sea encroached a large part of the Kachchh basin. However, the uplifted flexure zones and related uplifts remained exposed. The post-Miocene uplift of these zones under compression is evidenced by the faulted contact of the Mesozoic rocks and Miocene sediments that mark the surface trace of the KMF exposed in patches along its length. Erosion of the study area resulted in further northward retreat of the Jaramara scarp and the upliftment of the KMF scarp to its present height.
16. The Jaramara scarp attained its current position during Middle Pleistocene as evidenced by the aeolian miliolite deposited in front of the scarp and on the back slopes of the scarp. The miliolite deposits in the Jara river gorge striding the Jaramara scarp face are incised by ~25 m which is a reflection of the amount of

uplift of the area along the KMF in the post-miliolitic time. This is well supported by the ~25 m high knickpoint along the Gandi river that is formed over the Ukra intrusive. The deeply incised courses of the stream and several knickpoints and the Jara river gorge testify to the neotectonic component of uplift induced erosion of the landscape.

17. The precipitous Jaramara scarp is the remnant of a retreated KMF scarp and currently occurs ~4 km away from the actual KMF fault line. The ~4 km distance of the Jaramara scarp from the KMF is the cumulative amount of retreat that has occurred during the Cenozoic. Since then the inversion of the basin began in the post Deccan Trap time. The scarp appears to have been preserved till present mainly because of the wide Ukra intrusive which comprises a more resistant lithology than the Mesozoic rocks. However, the preservation of the scarp is also attributed to the hard and compact arenaceous lithology of the upper part of the Jhuran Formation that makes up almost half of the scarp height. The relatively softer lithologies of the lower part of Jhuran Formation and the underlying Jumara Formation suffered more erosion and formed low dissected structurally controlled topography developed over the Jumara and Jara domes. The present KMF scarp, which is of considerably lower height than the Jaramara scarp, attained most of its present elevation due to post-Miocene uplift along the KMF.