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Fig. 5.4 Processed GPR radargrams (a) trace envelope based on magnitude draped over wiggle traces from 200 MHz antenna recorded across the KMF line at SE of Karanpur dome (site 1), location of site is shown in Fig. 3.1. The fault can be easily appreciated due to strong attenuation contrast and clear lateral discontinuity of the reflectors between 12 m to 16 m distance. The inferred highly steep reverse fault is placed at 14 m distance. Down arrows at the top of profile (marked as (b) and (c)) indicate the position of single scan in oscilloscope format. (b) and (c) shows the individual reflected waveform from Mesozoic rocks and Tertiary rocks respectively. (d) trace envelope based on magnitude draped over trace envelope based on phase acquired from 200 MHz antenna recorded across the KMF line between Ghuneri dome & Karanpur dome (site 2), location of site is shown in Fig. 3.1. The high amplitude reflectors at the top of profile represent 1.5 to 2 m thick Quaternary alluvial cover. The KMF is inferred to be a high angle reverse fault at ~ 20 m distance considering truncation of reflectors, change in dip and distortion of reflectors along the fault plane. Also note the strong attenuation contrast towards north for Tertiary rocks reflected by a pale red color of trace envelope based on magnitude. (e) and (f) shows the respective single scans for Mesozoic and Tertiary rocks. 77

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Fig. 5.6 Processed GPR radargrams (a) trace envelope based on magnitude draped over wiggle traces from 80 MHz antenna recorded across the KMF line at western flank of Ghuneri dome (site 3), location of site is shown in Fig. 3.1. The KMF can be easily appreciated at ~17 m

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Fig. 5.7 40 m long, north oriented GPR data recorded across the KMF, near Sahera village at site 5. See geological map of the study area in Fig. 3.1 for the location of GPR survey sites. Transect is taken over flat soil surface. Axis on left side shows penetration depth in meters and on right side two way travel time (TWTT) in ns is denoted. The upper axis shows section length in meters. Based on average subsurface radar wave velocity of 0.12 m ns^{-1} , radar arrivals have been translated to time-depth. Note that the direct air and ground waves have been muted in each of the plot formats. (a) Interpreted linescan plot. GPR amplitudes are represented by red (positive) and blue (negative) reflectors. Large arrows indicate the projected location of the KMF. Smaller arrows mark the interpreted position of secondary slip planes. Black dashed lines indicate conformable and non-conformable contacts between individual lithounits. (b) Interpreted sketch. From top to bottom, based on the reflectors response pattern, the cross-section is divided into radar facies RF1a – uppermost Late Quaternary valley-fill deposits, RF1b – Late Quaternary deposits, RF2 - Early Quaternary colluvium wedge-outs, RF3a - Mesozoic sandstone, RF3b – Mesozoic sandstone with chaotic reflections, RF4a and RF4b - Tertiary limestone deposits. Note the presence of Early Quaternary wedge-shaped deposits with onlapping and pinch over reflectors that

terminate against the disconformable sediment (RF2)-bedrock (RF3a and RF4a) interface. (c) Trace envelope based on magnitude draped over wiggle traces. The color scale reflects the energy continuum, with white contours representing the highest-energy regions, while the lowest-energy regions are represented by grey contours. The lateral energy changes of EM waves clearly marks the presence of fault planes. Black lines indicate fault planes and half-arrows denote movement direction of the upthrown block in Figs. (b) and (c). The hangingwall of the KMF is towards north and footwall is towards south. Note the presence of Early Quaternary channel-fill deposits (RF2) with tapering geometry and downlapping reflectors located in the footwall of the KMF. The steep northward dipping KMF with normal slip is interpreted to be located at ~29 m horizontal distance, which also extends upward into Quaternary deposits. The position of the KMF is inferred based on displacement, warping and truncation of continuous reflectors. Magnitude-based attribute in Fig. (c) supplements the presence of KMF as the high-energy contours of Mesozoic sandstone (RF3a) terminate against the KMF, which continue as low-energy contours of Tertiary limestone (RF4a and RF4b) in the hangingwall of KMF. The entire section is riddled with antithetic and synthetic slip planes with normal/reverse dip-slip motion.

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individual reflected waveform from Mesozoic rocks and Tertiary rocks respectively. (d) Wiggle traces acquired from 200 MHz antenna recorded across the KMF line at western flank of Mundhan anticline (site 6), location of site is shown in Fig. 3.1. The KMF is inferred to be a vertical fault at this site. (e) and (f) shows the respective single scans for Mesozoic and Tertiary rocks.

Fig. 5.9 32 m long, north oriented GPR data recorded across the KMF, north of Jumara dome at site 7. See geological map of the study area in Fig. 3.1 for the location of GPR survey sites. Axis on left side shows penetration depth in meters and on right side two way travel time (TWTT) in ns is denoted. The upper axis shows section length in meters. Based on average subsurface radar wave velocity of 0.12 m ns^{-1} , radar arrivals have been translated to time-depth. Note that the direct air and ground waves have been muted in each of the plot formats. (a) Interpreted linescan plot. GPR amplitudes are represented by red (positive) and blue (negative) reflectors. Large arrows indicate the projected location of the KMF. Smaller arrows mark the interpreted position of secondary slip planes. Black dashed lines indicate conformable and non-conformable contacts between individual lithounits. (b) Interpreted sketch with lithology represented by colored lines. From top to bottom, based on the reflectors response pattern, the cross-section is divided into radar facies RF1a – uppermost Late Quaternary valley-fill deposits, RF2 - Early Quaternary colluvium wedge-outs, RF3a - Mesozoic sandstone, RF3b – Mesozoic sandstone with chaotic reflections, RF4a and RF4b - Tertiary limestone deposits. Note the presence of Early Quaternary wedge-shaped deposits with onlapping and pinch over reflectors that terminate against the disconformable sediment (RF2)-bedrock (RF3a and RF4a) interface. (c) Trace envelope based on magnitude draped over wiggle traces. The color scale reflects the energy continuum, with white contours representing the highest-energy regions, while

the lowest-energy regions are represented by grey contours. The lateral energy changes of EM waves clearly marks the presence of fault planes. Black lines indicate fault planes and half-arrows denote movement direction of the upthrown block in Figs. (b) and (c).

Fig. 5.10 30 m long, north oriented GPR data recorded across the KMF, north of Jumara dome at site 8. See geological map of the study area in Fig. 3.1 for the location of GPR survey sites. At 20 m distance, the arrows (noise?) indicate steeply dipping diffraction tails affected by dispersion of EM waves. Axis on left side shows penetration depth in meters and on right side two way travel time (TWTT) in ns is denoted. The upper axis shows section length in meters. Based on average subsurface radar wave velocity of 0.12 m ns^{-1} , radar arrivals have been translated to time-depth. Note that the direct air and ground waves have been muted in each of the plot formats. (a) Interpreted linescan plot. GPR amplitudes are represented by red (positive) and blue (negative) reflectors. Large arrows indicate the projected location of the KMF. Smaller arrows mark the interpreted position of secondary slip planes. Black dashed lines indicate conformable and non-conformable contacts between individual lithounits. (b) Interpreted sketch with lithology represented by colored lines. From top to bottom, based on the reflectors response pattern, the cross-section is divided into radar facies RF1a – uppermost Late Quaternary valley-fill deposits, RF2 - Early Quaternary colluvium wedge-outs, RF3a - Mesozoic sandstone, RF4a and RF4b - Tertiary limestone deposits. Note the presence of Early Quaternary wedge-shaped deposits with onalpping and pinch over reflectors that terminate against the disconformable sediment (RF2)-bedrock (RF3a and RF4a) interface. (c) Trace envelope based on magnitude draped over wiggle traces. The color scale reflects the energy continuum, with white contours representing the highest-energy regions, while the lowest-energy regions are represented by grey contours. The lateral energy

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changes of EM waves clearly marks the presence of fault planes. Black lines indicate fault planes and half-arrows denote movement direction of the upthrown block in Figs. (b) and (c).

- Fig. 5.11** 24 m long, north oriented GPR data recorded across the KMF, north of Jumara scarp at site 9. See geological map of the study area in Fig. 3.1 for the location of GPR survey sites. (a) Interpreted linescan plot. GPR amplitudes are represented by red (positive) and blue (negative) reflectors. Large arrows indicate the projected location of the KMF. Smaller arrows mark the interpreted position of secondary slip planes. Black dashed lines indicate conformable and non-conformable contacts between individual lithounits. (b) Interpreted sketch with lithology represented by colored lines. (c) Trace envelope based on magnitude draped over wiggle traces. The color scale reflects the energy continuum, with white contours representing the highest-energy regions, while the lowest-energy regions are represented by grey contours. The lateral energy changes of EM waves clearly marks the presence of fault planes. Black lines indicate fault planes and half-arrows denote movement direction of the upthrown block in Figs. (b) and (c). 95
- Fig. 6.1** (a)-(d) 15 m long, SW oriented GPR profile acquired across the NNW striking WVF. Transect is taken in the riverbed of NE flowing Makdawali river. (e)-(h) 17 m long, SW oriented GPR profile recorded across the NW striking VF. See geological map of the study area in Fig. 3.1 for location of GPR survey sites. Axis on left side shows penetration depth in meters and on right side two way travel time (TWTT) in ns is denoted. The upper axis shows profile length in meters. Inset stereonet in Figs. (d) and (h) show the geometry of WVF and VF inferred from the radargram. 102
- Fig. 6.2** (a) to (d) show uninterpreted radargram, uninterpreted grayscale radargram, uninterpreted radargram processed with instantaneous 104

phase attribute and uninterpreted wiggle plot. Interpreted radar characteristics are shown in Figs (a1), (a2) and (a3). Axis on left side of the radargrams shows penetration depth in meters and on right side two-way travel-time (TWTT) in ns is denoted. The upper axis shows profile length (in meters) of the radargram. The presence of fault and deformation bands cluster are indicated by black arrows in Figs. (a) and (c), red arrows in Figs. (b) and (d).

Fig. 6.3 (a)-(c) the SW dipping VF is exposed with ~0.5 m positive relief from the surrounding flat soil surface. Inset stereonet: 14 fault-slip data recorded. (d) 17 m long, NE directed GPR profile acquired using 200 MHz antenna across the NNW striking VF near site 13 (see Fig. 3.1 for location of GPR survey site). Interpreted radargram is shown with the axis on left side denote penetration depth in meters and on right side two way travel time (TWTT) in ns. The upper axis shows profile length in meters. 107

Fig. 6.4 (a) Exposure of NW trending VF with reverse slip in Bhuj sandstone at site 14 formed under pure compressive stress regime. The red half-arrow indicates the upward motion of the missing block (hangingwall). Height of the person is 188 cm as scale. Inset paleostress tensor (lower hemisphere, equal-area projection) deduced by Right Dihedral Method (RDM) implemented in Win_Tensor (Delvaux and Sperner, 2003) software is shown. Black lines: fault planes with slip vectors (marked by open circles with arrows) ($n = 21$). Red arrows pointing inward: the orientation of maximum horizontal principal stress (S_{Hmax}). Green circle, triangle and square: orientation of maximum (σ_1), intermediate (σ_2) and minimum (σ_3) stress axes respectively ($\sigma_1 \geq \sigma_2 \geq \sigma_3$). (b) ~120 m SSE of site 14, person dragging the 200 MHz antenna with survey wheel attached to it in SW direction, perpendicular to approximate trend of the VF. (c)-(g) show uninterpreted radargram, interpreted radar facies, uninterpreted grayscale radargram, uninterpreted radargram 109

processed with instantaneous phase attribute and uninterpreted wiggle plot. Axis on left side of the radargrams shows penetration depth in meters and on right side two-way travel-time (TWTT) in ns is denoted. The upper axis shows profile length (in meters) of the radargram. At ~13 m horizontal distance, the VF can be identified due to sudden change in dip of the continuous reflectors. Both the faults are indicated by black arrows in Figs. (c) and (f), red arrows in Fig. (e) and white arrows in Fig. (g). The radargram processed with instantaneous phase attribute marks the clear offset and change in dip of the continuous reflectors along the VF as well as along the antithetic fault.

Fig. 6.5 (a) to (c) Regional-view of NNW trending GUF with reverse slip exposed in Bhuj sandstone. The red half-arrow indicates the upward motion of the missing block (hangingwall). Inset paleostress tensor (lower hemisphere, equal-area projection) deduced by Right Dihedral Method (RDM) implemented in Win-Tensor (Delvaux and Sperner, 2003) software is shown. Black lines: fault planes with slip vectors (marked by open circles with arrows) ($n = 14$). Red arrows pointing inward: the orientation of maximum horizontal principal stress (S_{Hmax}). Green circle, triangle and square: orientation of maximum (σ_1), intermediate (σ_2) and minimum (σ_3) stress axes respectively ($\sigma_1 \geq \sigma_2 \geq \sigma_3$). (d)-(h) show uninterpreted radargram, uninterpreted grayscale radargram, interpreted radar facies, uninterpreted radargram processed with instantaneous phase attribute and uninterpreted wiggle plot. Axis on left side of the radargrams shows penetration depth in meters and on right side two-way travel-time (TWTT) in ns is denoted. The upper axis shows profile length (in meters) of the radargram. The GUF can be located at ~10 m horizontal distance due to displacement along continuous, horizontal reflectors. Another subsidiary synthetic fault with reverse slip can also be located towards the footwall side of the GUF. Both the faults are

indicated by black arrows in Figs. (d) and (g), red arrows in Figs. (e) and (h).

Fig. 7.1 (a) Tectonic scheme of the VGKNFS as mapped in the present study, 117
after Shaikh et al. (2020). The structural contours with 1000 feet
(values are in negative) contour interval are drawn over the top of
Precambrian basement. The schematic cross-section A–A' below the
map is redrawn from Biswas (1993). VF: Vigodi Fault, WVF: West
Vigodi Fault, GUF: Gugriana Fault, KF: Khirasra Fault, NKHF:
North Khirasra Fault, NF: Netra Fault, KMF: Kachchh Mainland
Fault, NHRFZ: Northern Hill Range Fault Zone, VBA: Vigodi
Brachy-Anticline, KBA: Khirasra Brachy-Anticline, WMBA: Walka
Mota Brachy-Anticline, GD: Ghuneri dome, MA: Mundhan
Anticline, JD: Jara Dome, JUD: Jumara Dome and MD: Manjal
Dome. (b) Depth profile of upthrust fault modified and redrawn after
fig. 5 of Prucha et al. (1965). Red, inward-pointed double arrows
indicate depth-wise rotation in the orientation of maximum principal
stress axis (σ_1).

Fig. 7.2 Structural map of sector 1 (location shown in the geological map of 124
study area in Fig. 7.1). The sites of fault-slip measurements are
marked by green stars. The sites exposing non-striated faults are
marked by red stars and are not included in fault-slip analysis. Follow
Fig. 7.1 for interpretation of colors related to lithology shown in the
structural map. The stress tensors (lower hemisphere, equal-area
projection) deduced by Right Dihedral Method (RDM) implemented
in Win_Tensor (Delvaux and Sperner, 2003) for respective sites are
shown. Black lines: fault planes with slip vectors (marked by open
circles with arrows). Red inward-pointed and blue outward-pointed
double arrows: orientation of maximum (S_{Hmax}) and minimum (S_{Hmin})
horizontal principal stress respectively. Green circle, triangle and
square: orientation of maximum (σ_1), intermediate (σ_2) and minimum
(σ_3) stress axes respectively ($\sigma_1 \geq \sigma_2 \geq \sigma_3$). Black solid bars and open

bars at the periphery of paleostress tensors: orientation of S_{Hmax} and S_{hmin} axes respectively, for individual fault-slip data. For normal faults, $S_{hmin} = \sigma_3$ and for reverse faults, $S_{Hmax} = \sigma_1$. Site numbers are shown on upper left of stereoplots. n/nt: ratio of number of fault-slip data used in paleostress analysis relative to the total number of fault-slip data collected from the specific site. R' : stress index (Delvaux et al., 1997). Counting grid: the white and grey quadrants of the stereoplots corresponding to regions of compression and tension respectively. The colored panels on left of each stereoplots represent the inferred stress regime.

Fig. 7.3 (a)-(e) NW striking GUF with normal slip exposed at site 33 (sector 1) and (f)-(j) NNE striking cluster of deformation bands exposed along with the striated slip surfaces on both sides, at site 74 (sector 1). See the structural map in Fig. 7.2 for site location. (a) Panoramic-view of the GUF. d and e denote location of close-ups shown in Figs. (d) and (e). (b) NW looking outcrop-view of the GUF. Height of the person is 188 cm as a scale. (c) Close-view of the exposed footwall shows both the principal slip plane and synthetic, striated slip planes. Length of hammer: 30 cm as scale. (d) and (e) NE looking, close-ups of striated fault plane (attitude: 140° strike, 230° dip direction, 57° dip and lineations attitude: 113° and 110° rake, 48° and 55° plunge, 189° and 203° azimuth). (f) Outcrop-view of deformation bands cluster. h to j show location of close-ups of striated slip planes. (g) The block diagram shows cluster of deformation bands (variably dipping yellow planes) bounded on either sides by striated slip planes (grey colored striated planes). The green horizontal planes show level of topographic surfaces. (h)-(j) The striated fault plane (attitude: 210 - 230° strike, 300 - 320° dip direction, 60 - 70° dip amount and lineations attitude: 93 - 99° rake, 60 - 69° plunge, 313 - 339° azimuth). 13.5 cm long pen as scale in Figs. (e), (h)-(j). Inset sketches: block diagram (BD) of striated synthetic slip surfaces, sectional- (s-) view of

domino-type offsetting in tilted blocks in Fig. (c) – modified after fig. 1 of Doblasi (1998); BD of RM structures in Fig. (e), PO structures in Fig. (j) – modified after figs. 1e and 1f of Petit (1987). The white arrows indicate movement of the missing block.

Fig. 7.4 Structural map of sector 2 (location shown in the geological map of study area in Fig. 7.1). Follow Fig. 7.2 caption for interpretation of map and paleostress tensors deduced by Win_Tensor (Delvaux and Sperner, 2003). 127

Fig. 7.5 NNW striking VF with normal slip exposed (a)-(f) at site 44 (sector 2) and (g)-(i) at site 18 (sector 2). See the structural map in Fig. 7.4 for site location. (a) Multiple, synthetic, striated, secondary slip planes exposed in footwall along with the major slip surface. (b) East looking, close-view of striated fault plane (attitude: 175° strike, 265° dip direction, 64° dip and attitude of lineations: 83° rake, 63° plunge, 249° azimuth). Mineral steps consistently facing down-slope indicate down-slope movement of the missing block. (c) North looking, close-view of a portion of footwall shown as dotted circle in Fig. (a). Length of hammer is 30 cm as scale. (d)-(f) East looking, close-view of the striated fault plane (attitude: 155-168° strike, 245-258° dip direction, 48-71° dip and attitude of lineations: 88-94° rake, 48-71° plunge, 239-264° azimuth). (g) North looking, fault-parallel view of VF. (h) ENE looking, close-view of the striated fault plane (attitude: 161° strike, 251° dip direction, 82° dip and attitude of lineations: 94° rake, 81° plunge, 278° azimuth). The striated fault plane is intensely affected by sub-parallel tension gashes. (i) ENE looking, close-view of multiple striated slip planes (average attitude: 179° strike, 269° dip direction, 57° dip and average attitude of lineations: 80° rake, 56° plunge, 251° azimuth). Inset sketches: sectional- (s-) view of domino-type offsetting in tilted blocks, block diagram (BD) of (sub)-parallel striated, synthetic slip surfaces in Figs. (a), (g) and (i); s-view of mineral fibers in Fig. (b); s-view of knobby elevations in Figs. (d) and 130

(e); s-view of tension gashes and spurs in Fig. (h) – modified after fig. 1 of Doblas, (1998). S-view of synthetic fracture with normal drag in Fig. (c). BD of fractures with PT structures in Figs. (b) and (f) – modified after fig. 1 of Petit (1987). 13.5 cm long pen as scale in Figs. (b), (d)-(f) and (h). The white arrows indicate the downward motion of missing hangingwall.

Fig. 7.6 (a)-(f) NNW striking GUF with reverse slip exposed at site 19 (sector 2) and (g)-(j) NW striking GUF with reverse slip exposed in the cliff section of an alluvial river channel of the NE flowing Khari river, at site 7 (sector 2). See the structural map in Fig. 7.4 for site location. (a) Outcrop-view of the GUF. Height of the person is 178 cm as scale. (b)-(f) The fault plane (attitude: 155-172° strike, 245-262° dip direction, 59-78° dip) with striations (101-114° rake, 52-76° plunge and 267-288° azimuth). (g) Outcrop-view of the GUF. Height of the person is 188 cm as scale. i and j denote the location of close-ups shown in Figs. (i) and (j). (h) Close-view of the Jhuran shale lithology lying on the hangingwall of SW dipping GUF. 30 cm long hammer as scale. (i) and (j) Essentially dip-slip striations (96° and 97° rake, 66° and 60° plunge, 205° and 193° azimuth) developed on a fault plane (attitude: 130° and 110° strike, 220° and 200° dip direction, 67° and 66° dip). A 30 cm long hammer as scale in Figs. (c), (d), (h), and 13.5 cm long pen as a scale in Figs. (b), (e), (f), (i) and (j). Inset sketches: block diagram (BD) of asymmetric depressions in Fig. (d), BD of detached fragments marked by white asterisk in Fig. (i), sectional- (s-) view of tension gashes in Figs. (e) and (i) – reproduced from fig. 1 of Doblas (1998). BD of fractures with RO structures in Fig. (f) – reproduced from fig. 1 of Petit (1987). The white arrows indicate the upward motion of missing hangingwall.

Fig. 7.7 Structural map of sector 3 (location shown in the geological map of study area in Fig. 7.1). Follow Fig. 7.2 caption for interpretation of

map and paleostress tensors deduced by Win_Tensor (Delvaux and Sperner, 2003).

Fig. 7.8 (a)-(e) NW striking VF with reverse slip at site 27 (sector 3), (f) and 136
(g) NW striking VF with reverse slip cross-cutting NE flowing Makdawali river, at site 87 (sector 3). See the structural map in Fig. 7.7 for site location. (a) Outcrop-view of the VF. Height of the person is 188 cm as scale. (b) and (c) The striated fault plane (attitude: 130° and 124° strike, 220° and 214° dip direction, 64° and 66° dip, attitude of lineations: 120° and 127° rake, 51° plunge and 167° and 152° azimuth). In close-view, pipe-shaped linear grooves can be observed in Fig. (b). Carrot-shaped grooves can be observed due to dragging effect of grains. (d) Close-view of carrot-shaped markings shown in Fig. (c). (e) The striated fault plane (attitude: 150° strike, 240° dip direction, 71° dip, attitude of lineations: 20° rake, 19° plunge, 323° azimuth). Location of Figs. (b), (c) and (e) are shown in Fig. (a). (g) The fault plane (attitude: 110° strike, 200° dip direction, 72° dip) with striations (92° rake, 72° plunge, 194° azimuth). (h) Close-up of the fault plane (attitude: 350° strike, 260° dip direction, 53° dip) with two generations of striations (70° and 11° rake, 49° and 09° plunge, 291° and 343° azimuth). 13.8 cm long pen as scale in Figs. (b), (c), (e), (g) and (h). Inset sketches: plane- (p-) and sectional- (s-) view of pipe-shaped and carrot-shaped gouging-grain grooves in Figs. (b) and (c) respectively – modified after fig. 1 of Doblas (1998). Block diagram (BD) of PT type fractures in Fig. (g) – modified after fig. 1f of Petit (1987). The white arrows indicate the motion of missing hangingwall.

Fig. 7.9 (a)-(d) NNW striking WVF with reverse slip at sites 34 and 35 (sector 138
3), and (e)-(j) NW striking GUF with reverse slip exposed at site 67 (sector 3). See the structural map in Fig. 7.7 for site location. (a) WVF exposed at one of the cliff section of the NE flowing Makdawali river. (b) Close-view of the striated fault plane (attitude: 165° strike, 255° dip direction and 60° dip and attitude of lineations: 115° rake, 52°

plunge and 212° azimuth). (c) Fault-parallel view of WVF. Height of the person is 178 cm as scale. (d) Close-view of the two striated fault planes of the same generation. Plane (1) and (2): 158° and 155° strike, 248° and 245° dip direction, 72° and 60° dip, 110° and 97° rake, 63° and 59° plunge, 198° and 231° azimuth. Location of Figs. (b) and (d) are shown in Figs. (a) and (c) respectively. (e) Outcrop-view of the GUF. Height of the person is 188 cm as scale. (f)-(j) The striated fault plane (attitude: 290-320° strike, 25-50° dip direction, 28-55° dip and attitude of lineations: 77-93° rake, 49-55° plunge, 15-67° azimuth). Asymmetric cavity with congruous steps and asymmetric depression facing upslope marked by white asterisk in Figs. (f) and (g) respectively. Figs. (h) and (i) show cm long, linear, pipe-shaped gouging-grains leaving thick black grooves due to their upslope movement on the fault plane. P fractures generated almost perpendicular to striations orientation can be observed in Fig. (j). Inset sketches: sectional- (s-) view of mineral steps in Fig. (b), block diagram (BD) of striated synthetic slip surfaces in Fig. (d), BD of asymmetric cavities with congruous steps in Fig. (f), asymmetric depression in Fig. (g), plane- (p-) and s-view of pipe-shaped gouging-grain grooves in Figs. (h) and (i) – modified after fig. 1 of Doblas (1998). BD of P fractures in Fig. (f) – modified after fig. 1f of Petit (1987). 13.8 cm long pen as scale in Figs. (b), (d), (g)-(j). 30 cm long hammer as scale in Fig. (f). The white arrows indicate the upward motion of missing hangingwall.

Fig. 7.10 Structural map of sector 4 (location shown in the geological map of study area in Fig. 7.1). Follow Fig. 7.2 caption for interpretation of map and paleostress tensors deduced by Win_Tensor (Delvaux and Sperner, 2003). 139

Fig. 7.11 (a) Panoramic view of NNW striking GUF with reverse slip exposed at site 41 (sector 4, see the structural map in Fig. 7.10 for site location). (b) NNW looking, fault-parallel view of the GUF. Height 140

of the person is 178 cm as scale. Location of Fig. (b) is shown as white square in Fig. (a). (c)-(g) Close-view of striated fault plane (attitude: 146-185° strike, 250-275° dip direction, 63-72° dip and lineations attitude: 84-92° rake, 63-71° plunge, 246-286° azimuth). Inset sketches: plane- (p-) and sectional- (s-) view of carrot-shaped gouging-grain grooves in Figs. (c), (g) and pipe-shaped gouging-grain grooves in Figs. (e), (g) – modified after fig. 1 of Doblas (1998). Block Diagram (BD) of fractures with RO structures in Fig. (d) – reproduced from fig. 1 of Petit (1987). 13.5 cm long pen as scale in Figs. (c)-(g). The white arrows indicate the motion of missing block.

Fig. 8.1 Regional kinematics of the VGKNFS with reconstruction of the Late Mesozoic to Cenozoic paleostress orientations derived from fault-slip analysis. The biggest black inward-pointed double arrows (at the periphery of each sector) indicate the mean compressional directions derived for each of the four sectors. Inward-pointed and outward-pointed double arrows (within each sector): orientation of S_{Hmax} and S_{hmin} respectively. Colors given to arrows are according to the color scheme shown in vertical column of stress regime. Color scheme is based on the type of stress regime and stress index (R') (Delvaux et al., 1997). Rose plots show S_{Hmax} (red bars) and S_{hmin} (blue bars) orientation for each of the sector. On the right side of the map are sector-wise distribution of lower hemisphere, equal area projections for syn-rift extension and post-rift inversion phases representing principal stress axes (red circle: σ_1 , black triangle: σ_2 and blue square: σ_3) population calculated for each site with kamb contours. The biggest circle, triangle and square in stereonet represent mean σ_1 , σ_2 and σ_3 respectively. During syn-rift extension, sector 1: mean σ_1 at 052° \angle 82°, mean σ_2 at 165° \angle 25°, mean σ_3 at 270° \angle 33°; sector 2: mean σ_1 at 056° \angle 77°; mean σ_2 at 175° \angle 20°, mean σ_3 at 267° \angle 32°; sector 3: mean σ_1 at 086° \angle 75°, mean σ_2 at 161° \angle 29°, mean σ_3 at 283° \angle 26°; sector 4: mean σ_1 at 026° \angle 59°, mean σ_2 at 124° \angle 03°,

mean σ_3 at $216^\circ \angle 32^\circ$. During post-rift inversion, sector 1: mean σ_1 at $282^\circ \angle 34^\circ$, mean σ_2 at $264^\circ \angle 23^\circ$, mean σ_3 at $105^\circ \angle 60^\circ$; sector 2: mean σ_1 at $241^\circ \angle 22^\circ$, mean σ_2 at $326^\circ \angle 10^\circ$, mean σ_3 at $075^\circ \angle 70^\circ$; sector 3: mean σ_1 at $208^\circ \angle 45^\circ$, mean σ_2 at $254^\circ \angle 43^\circ$, mean σ_3 at $046^\circ \angle 80^\circ$; sector 4: mean σ_1 at $254^\circ \angle 48^\circ$, mean σ_2 at $330^\circ \angle 16^\circ$, mean σ_3 at $082^\circ \angle 77^\circ$. The average International Terrestrial Reference Frame (ITRF) velocity in the KRB is after Dumka et al. (2019). The colored overlay draped over shaded relief map represent S_{Hmax} orientation. Warm colors represent NNE–NE oriented S_{Hmax} .

Fig. 8.2 Conceptual kinematic models to explain the effect of changing stress fields in the Vigodi-Gugriana-Khirsra-Netra Fault System (VGKNFS). Red, inward-pointed and blue, outward-pointed double arrows indicate the orientation of S_{Hmax} and S_{hmin} respectively. (a) D1o deformation event – Initiation of the rift phase of the KRB during Late Triassic. ~NW directed extension prevailed in the VGKNFS. Activation of NNE–NE striking discontinuous cross-faults as normal faults occurred. The NW striking pre-existing weak planes remained non-responsive. (b) D1y deformation event – continued rift phase of the KRB till Late Cretaceous. The extension direction swung from ~NW to W-WSW. Normal slip along the major NNW–NW striking faults occurred which eventually truncated the earlier activated NNE–NE striking cross-faults. (c) D2 deformation event – post-rift inversion phase of the KRB from Late Cretaceous till now. The build-up of NNE–NE directed compressional stress field that continues till now. The compressional reactivation of NNW–NW striking major faults occurred. NNE–NE striking cross-faults with normal slip continue to exist but remained non-responsive. The convex upward plunge of major faults in Fig. (c) indicate their upthrust geometry. Curved topography near major faults indicate narrow deformation zone. Note that the outcrop-scale structural complexities are ignored. 147

Fig. 8.3 Plot showing sector-wise distribution of the mean S_{Hmax} orientation corresponding to major faults and unnamed cross-faults with reverse slip. The results of chi-square statistic are also shown. 152

Fig. 9.1 Schematic cross-sections (not to scale) showing major stages of tectonic evolution of the Kachchh Mainland Fault (KMF) damage zone since Post-Miocene. Thickness of colluvial wedge is highly exaggerated. 157

(a) Post-Miocene to Middle Pleistocene: reactivation of the KMF leading to deformation of Miocene marine sediments along the KMF. This time interval spans a long period of non-deposition and erosion of the pre-existing KMF scarp, which is comparable to the similar conditions in the Kachchh Mainland Uplift (KMU). Multiple phases of reactivation of the KMF during this period is indicated by uplift and southward tilting of Post-Miocene and Early Quaternary erosional surfaces in the KMU.

(b) Late Pleistocene: Erosion and retreat of paleo-KMF scarp. Deposition of coarse-grained sediments (colluvium) over the KMF, generated from degradation of the pre-existing KMF scarp. A thin colluvial wedge is formed by the colluvium fill over the KMF. Thickness of colluvial sediments shown is highly exaggerated. The sediments were deposited along a thin zone along the KMF forming wedge shape. The deposits may have been partially reworked as seen in the previously described analogous deposits exposed in the eastern part of the KMF zone. The phase of depositional wedge-shaped colluvial sediments was followed by erosion leading to formation of erosional surface over it.

(c) Upper part of Late Pleistocene: Offset of wedge shaped colluvial deposits due to reactivation of KMF. The scarp produced due to offsetting was flattened through erosion.

(d) Holocene: Submergence of KMF zone by shallow sea leading to deposition of saline sediments of the Great Rann. Marginal marine conditions prevailed until the last ~2000 years BP leaving a flat saline surface of the Great Rann abutting against the scarps.

Fig. 9.2 Schematic cross-sections showing long-term landscape evolution in response to periodic tectonic uplift along the western part of the Kachchh Mainland Fault (KMF). 165