Proterozoic wrench footprints in Bouguer anomaly map of the Outer Himalayas- (Jammu-Dehradun sector), India

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ABSTRACT

While manifestation of wrench tectonics is typically common in seismic data and simple to interpret, it is seldom so in gravity data. A rare classical example of wrench footprints captured distinctly in a composite Bouguer anomaly map is showcased here. The map reconstructed from several pieces of earlier piecemeal maps in the Jammu-Dehradun sector of the outer Himalayas reveals footprints of Proterozoic transtensional wrench tectonics and the basement morphology in the area. Typical wrench associated features such as the *en echelon* folds, structural highs and lows tending to merge and/or face each other, west-ward lateral shift of structural lineaments suggesting strike-slip faults and steep normal faults manifest the left-handed (sinistral) divergent wrench. The different nature of the gravity anomalies in the Jammu Sub-Himalayas and Kangra recess also suggests dissimilar basements in the two areas, being older (Meso) Proterozoic and relatively more fragmented in the former than the less disturbed, younger (Neo) Proterozoic Vindhyan basement in the latter.

Significant differences are also observed between the Bouguer, and the geology maps of the area and are attributed to their response to diverse geologic objects. While the gravity depicts primarily the architecture of the basement, deformed by the Proterozoic wrench, the geology map in contrast, charts the younger Neogene and Quaternary outcrops, deformed by the post-Eocene compressional '*thin skin-tectonics*' without any involvement of the basement.

The composite gravity map and its comprehensive interpretation allow revealing the regional tectonics and the type, nature, and configuration of the basement in the Outer Himalayas.

KEYWORDS

Proterozoic sinistral wrench, composite Bouguer map, skin tectonics, Jammu Sub-Himalayas, Kangra recess, Vindhyan basement.

INTRODUCTION

The Outer Himalayas is bounded by the Main Boundary Thrust (MBT) in the north and the Himalayan Frontal Thrust (HFT) in the south (Figure 1). The present study area is focused mainly on the Jammu Sub-Himalayas (Riasi-Jammu) and the Kangra Recess (Nurpur-Sarahan) geologic units of the Outer Himalayas and is limited by the Kalakot Precambrian ridge in the north and Dehradun in the south (Figure 1).The belt, more than 400 kms long and with widths varying from 30 - 80 kms was covered by several gravity campaigns by Oil and Natural gas Corporation (ONGC) over a period of several years. The Bouguer gravity maps prepared and interpreted piecemeal from time to time were included in the joint study report prepared by the Directorate General of Hydrocarbons (DGH), India, ONGC, and Oil India Ltd. (OIL), (DGH-ONGC-OIL, 2000).

The piecemeal gravity maps portraying mainly the basement showed little correspondence with the geology maps of the surface structures. The seismic, due to its imaging limitations portrayed essentially the shallower Neogene structures and were also of little help to provide information on configuration of the deeper features including the basement. It thus prompted us to construct a comprehensive composite Bouguer anomaly map in an endeavor to understand the regional tectonics and structural style of the subsurface in the area. The composite map is reconstructed from the old legacy Bouguer anomaly maps available for the areas, namely, i) the Rajouri-Riasi, ii) the Riasi-Surinsar, iii) the Jammu-Sarahan and iv) the Dehradun-Mohand. The piecemeal analogue maps were in diverse scales and contour intervals that made compositing arduous involving meticulous adjustments and modifications. The interpretation is based solely on this reconstructed analogue map with no other data available for processing that could support the conclusions.

BRIEF GEOLOGY

The Outer Himalayas (Sub-Himalayas) is defined by the Main boundary thrust (MBT) in the north and the Himalayan frontal thrust (HFT), also called the Main frontal thrust (MFT), in the south. The northwestern part of the Outer Himalayas in India comprises of five geologic units, namely, i) the Jammu Sub-Himalayas, ii)

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the Kangra Recess, iii) the Nahan salient, iv) the Doon Recess, and v) the Rishikesh – Tanakpur (Sharma, 2015), shown in Figure 1. The stratigraphy mostly comprises the Quaternary and the Neogene sediments with the Siwaliks and the Dharamsalas thrusted along the HFT over the Quaternary alluvium of the Indo-Gangetic Plains. Neogene fluvial molasses of about 5-8 kms thickness rest unconformably on the Proterozoic Vindhyan basement (Thakur et al., 2014; Sharma, 2015) and were subjected to compression consequent to post Eocene subduction of the Indian plate under the Euro-Asian plate. The younger sediments were folded and thrusted by *'thin skin tectonics'* without involving the basement. The bounding thrusts, the HFT and the MBT are recognized as listric faults restricted to the Sub-Himalayan *decollement,* called the MHT (Prasad et al., 2011). Below the MHT occur the Meso-to Neoproterozic Vindhyan Supergroup rocks which in turn overlie the crystalline basement (Srivastava et al., 1983). HFT, the youngest and the last of the series of major thrusts propagating southwards that separates the Siwalik Hill Range of Himalayas from the Indo-Gangetic plain is reported discontinuous and blind at places (Sharma, 2015; Jagtap et al., 2022).

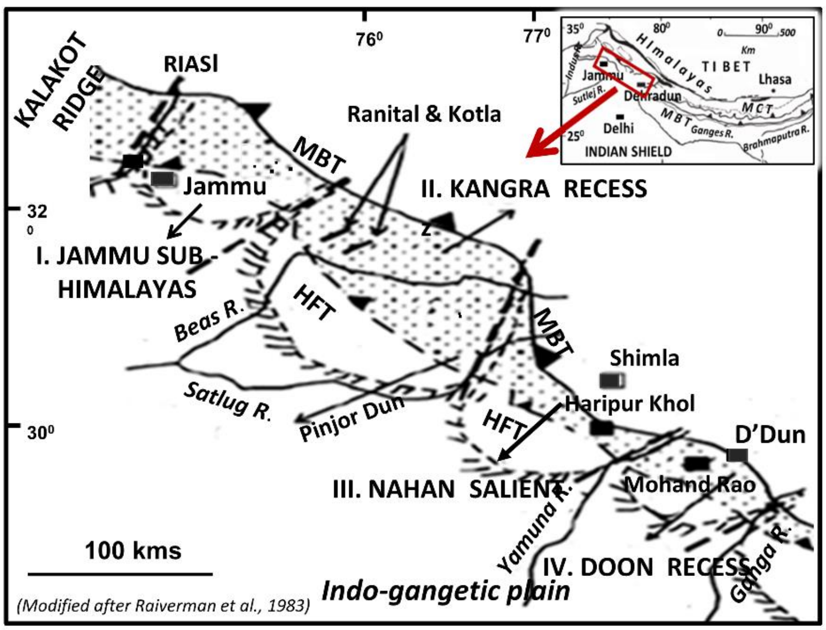

Figure 1. *Index map showing the study area, spanning the Jammu-Dehradun sector of the Outer Himalayas with the geologic units.*

INTERPRETATION OF GRAVITY DATA

A. Composite Bouguer map of the Outer Himalayas (Riasi-Dehradun)

The reconstructed composite Bouguer map of the Outer Himalayas with approximate outline of the defining major thrusts, the MBT and the HFT, marked for easy reference, is shown in Figure 2. Gravity contours beyond the MBT are scattered haphazardly, posing problems for integration and were excluded from the composite map. The map portrays essentially the dominant regional northwest- southeast trending structural features flanked by a number of down-to-basin, northeast-hading normal faults. The long and linear natures of the contours of generally near-uniform gradients spreading over a large area in the central part (the Kangra Recess) suggest the basement (Proterozoic) as the main causative of the gravity anomaly. Bouguer anomalies of sizable dimensions and amplitude in the Jammu sub-Himalayas (Riasi-Sarinsar) in Figure 3 also support that the response is mainly due to the deeper causative, due to the density contrast between the Proterozoic basement and the overlying Neogene and Quaternary sediments.

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Interestingly, the gravity data show little correspondence with the two major defining northeastward verging thrusts, the MBT and the HFT. While the MBT is conspicuous by its complete lack of expression in the entire area, the HFT is discernible mostly in the central part, but as a normal fault characterized by a bunch of closely-spaced contours with steep gradient. However, based coarsely on surface positioning, a reasonable correspondence of the HFT seen in the Bouguer and the geology map (Figure 2) suggests the HFT, as a pre-existing normal fault in the basement which was reactivated to a thrust fault during later compression. Further north, however, the HFT is marked by its absence in the gravity map in the Surinsar-Mastgarh area (Figure 3), indicating that the basement normal fault does not extend to this area. This is consistent with reported geology, the HFT being discontinuous and blind at places (Sharma, 2015) and remains non-emergent in the north for a continuous stretch of ~200 km beneath the Surinsar - Mastgarh Anticline (Jagtap et al., 2022). The MBT, on the other hand, having no gravity expression in the entire area signifies the thrust resulted due to compression and is a listric fault limited to the decollement, the Himalayan thrust (MHT). The Bouguer map thus provides information about the genesis of the major bounding thrusts, the HFT and the MBT and more importantly provides the corroborative evidence of '*skin tectonics*' in the Himalayan geology. However, by far the most significant takeaway from the reconstructed composite map (Figure 2) is the revelation of footprints of Proterozoic wrench captured in gravity data. The remarkable abrupt swing of the dominant regional north-west trending contours in the central part to west-northwest trend near Surinsar in the north and the conjugate swing to east-southeast in the south near Sarahan, symbolize left-handed (sinistral) wrench couple with the stress direction oriented westnorthwest-eastsoutheast. Remarkably, the contour trend recurves to the regional northwest trend further north of Jammu (Figure 3), marking the extent of the wrench corridor, from Riasi to Dehradun. More evidence of the Proterozoic transtensional wrench and associated structures are discussed later in detail.

B. Bouguer Map of Jammu Sub-Himalayas (Riasi-Surinsar)

The enlarged portion of the composite map for the sector Jammu Sub Himalayas displays more clearly the Proterozoic wrench and the resultant structural features (Figure 3). The total absence and the patchy Bouguer response of the bounding thrusts, the MBT and the HFT and the reasons thereof are discussed earlier. The main noticeable features in the map are the conspicuous structural closures, the Riasi low, the Surinsar high and the Udhampur low and the 'comet tail' shaped long linear low nose at the bottom (shown by red arrow in the ellipse). The prominent northwest-southeast trending Surinsar high broadly corresponds with the well-known geologically mapped Surinsar-Mastgarh anticline (SMA), described as northwest trending anticline and the complementary Udhampur syncline with a thrust contact (Basu, 2004). However, there are two differences noticeable in the gravity map, namely, i) the Surinsar high and the Udhampur low appear as two independent structural closures separated by tight low and high nose features, and ii) instead of the 'contact thrust', an east-hading normal fault marks the eastern flank of the Surinsar high. Considering the size and amplitude of the Bouguer anomaly, it is inferred SMA was a Paleo-basement high at the roots of the younger Neogenes that got the present structural expressions during Himalayan compressional tectonics. Similarly, the Udhampur and the Riasi lows are interpreted as basement Paleo-troughs with northeast hading normal gravity faults at their western and eastern flanks respectively.

The most fascinating feature in the map (Figure 3), however, is the elongated 'comet tailed' nosal feature, the northwestward continuation of the prominent low nose near Nurpur (NL) in Figure 4. The NL appears sheared and morphed to an elongated nosal feature with trend changed to west-northwest (marked solid red arrows in Figure 4) and extending further ends up against the fault at the eastern flank of the prominent Surinsar high. The Surinsar high in the north also shows its split limb morphed to a constricted north-northwest trending narrow nosal feature, similar to NL shear, and culminating against the well-defined Riasi low (marked red dotted arrows in Figure 3). The changes in the morphology and dominant strikes of the structural

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highs, terminating against lows and *vice-versa* are considered typically associated with wrench tectonics. The reported geology of the northwest trending active sinistral strike-slip fault with oblique slip component parallel to the Surinsar-Mastgarh anticline (Sharma and Chaudhri, 2020) further suggests a probable imprint of the Tertiary compressional tectonics superimposed on Proterozoic transtensional wrench. Nonetheless, from the complicated nature of the anomalies in this part, the basement in the Jammu sub-Himalayas is inferred to be severely deformed and fragmented and is probably due to obstruction to the wrench offered by the orthogonal trending Archean Kalakot ridge.

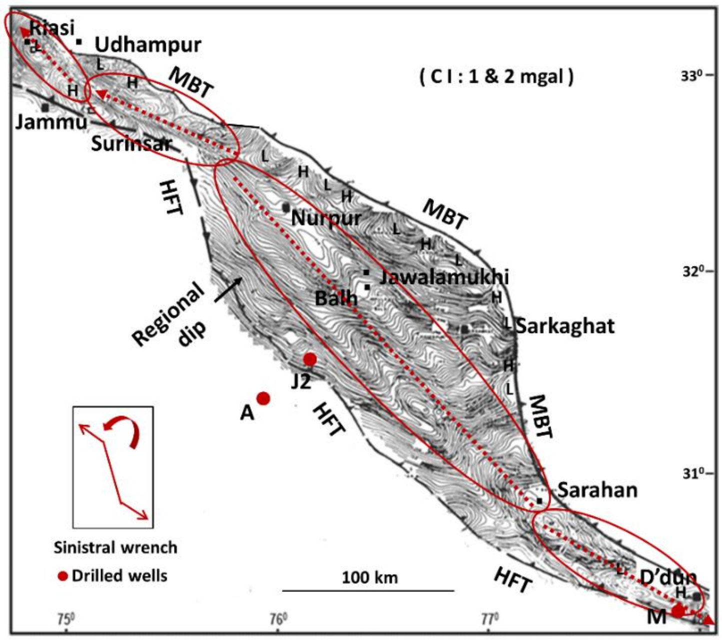

Figure 2. *The composite Bouguer map depicting the Precambrian (Proterozoic) basement configuration. Notice the abrupt swing of the dominant northwest-southeast trending contours in the central part to west northwest near Surinsar and the conjugate swing to east southeast near Sarahan symbolizing left-handed (sinistral) wrench and its stress direction (west northwest-east southeast). The major thrust, MBT, has no gravity expression, whereas the HFT, conspicuous only in the central part, is seen as a normal fault characterized by a bunch of contours with steep gradient.*

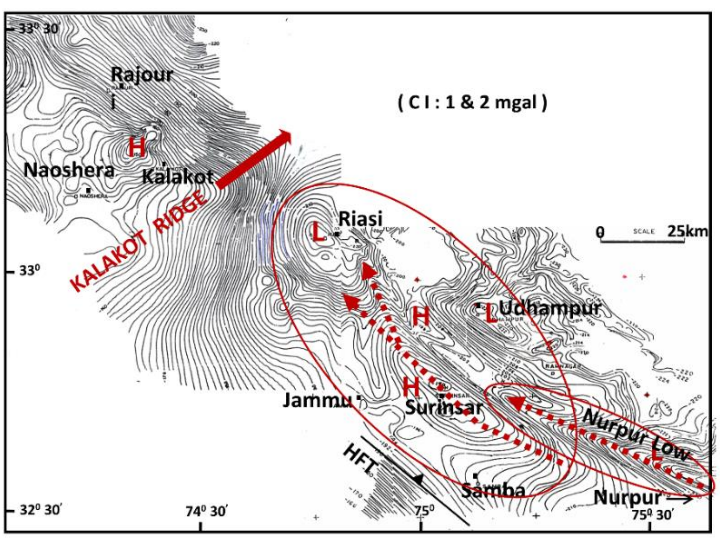

Figure 3. *Zoomed gravity map of Jammu Sub-Himalayas (Riasi-Surinsar) distinctly displaying the structural features associated with wrench. Note the prominent low, north of Nurpur (Figure 2), sheared as a nasal feature with abrupt trend change to west northwest (shown by red dotted arrows) and terminating against the Surinsar high. Mark the Surinsar high branching northwards and terminating against the prominent Riasi low. The complicated pattern of anomalies suggests the basement severely deformed and fragmented. 'H' and 'L' represent highs and lows.*

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C. Bouguer Map of the Central part, the Kangra Recess (Nurpur-Sarahan)

The Bouguer anomaly map of the Kangra recess showing a drastic change in structural styles from that in the Jammu Sub-Himalayas offers more evidence of wrench associated features (Figure 4). It is distinguished by a chain of elongated, near-parallel *en echelon* nosal folds striking northwest-southeast with normal faults at the flanks. The long parallel trends of the nosal highs and lows, however, after a distance, show lateral shift and appear to merge with/or face each other, a phenomenon considered typically associated with wrench. A striking example is the pair of noses, the low near Balh (BL) and the high near Jawalamukhi (JH), displaying an unmistakable lateral shift to the left (westward) before continuing as the conjugate pair (marked dotted red arrows in Figure 4). The shift results in the Balh low facing squarely the Jawalamukhi high, presenting a unique 'rectangle' shaped contour (marked red star). This and another similar starred feature to the west (Figures 4, 5a) clearly indicate left-handed (sinistral) strike-slip faults. More evidence of strike-slip fault is evident in shifting of the northward plunging Sarahan high (SH) to the left before continuing as a nosal feature to merge with Balh low (marked red dotted arrows in Figure 4). The northwest-southeast striking folds, the abrupt swing in dominant strike in the northern and southern ends, the lateral shift of structural lineaments signifying strike-slip faults, highs and lows merging/facing each other and the steep normal faults (Figures 3 and 4), all strongly suggest episode of Proterozoic transtensional sinistral wrench with the stress direction oriented west northwest-east southeast.

Another interesting feature in the map is the change in the nature of the long and linear smooth anomalies in the central part to anomalies of alternating lows separated by highs (ridges) bordering the MBT. Some of the notable structural lows are the Nurpur (NL), the Dharmsala (DL), the Palampur (PL) and the Sarkaghat (SL) separated by intervening highs (ridges), named the Nurpur (NR), the Palampur (PR) and the Sarkaghat (SR) with northeast-southwest strike (highlighted in Figure 4). The intensity of the Bouguer anomalies indicate these as paleo basement features trending orthogonal to the dominant regional strike which raises doubt about the continuity of the Vindhyan basement into this peripheral part near the MBT. The narrow ridges separating the lows distinctly show the Aravalli trend and may plausibly represent older Precambrian basement ridges. However, in view of inadequate data along the margin of the MBT and lack of data beyond, the inferences may be considered tentative.

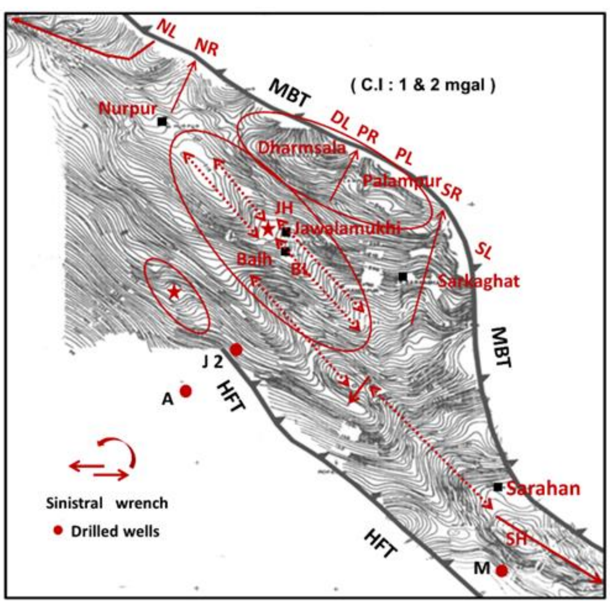

Figure 4. Zoomed map in the Kangra recess shows notably the wrench associated structures. The northwest-southeast trending elongated, near-parallel conjugate pair of features the Balh low (BL) and the Jawalamukhi high (JH), and another similar couple, north of Sarahan high (SH), showing distinct lateral shift to left (westward) and continuing northwards. The lateral shift makes the Balh low face the Jawalamukhi high (marked red star). The strike of the fold axes, the abrupt swing in contour trend, lows/highs facing/merging each other, and the strike-slip faults strongly indicate wrench. note the significant contrast in the nature of the anomalies at the MBT border from those in the central part.

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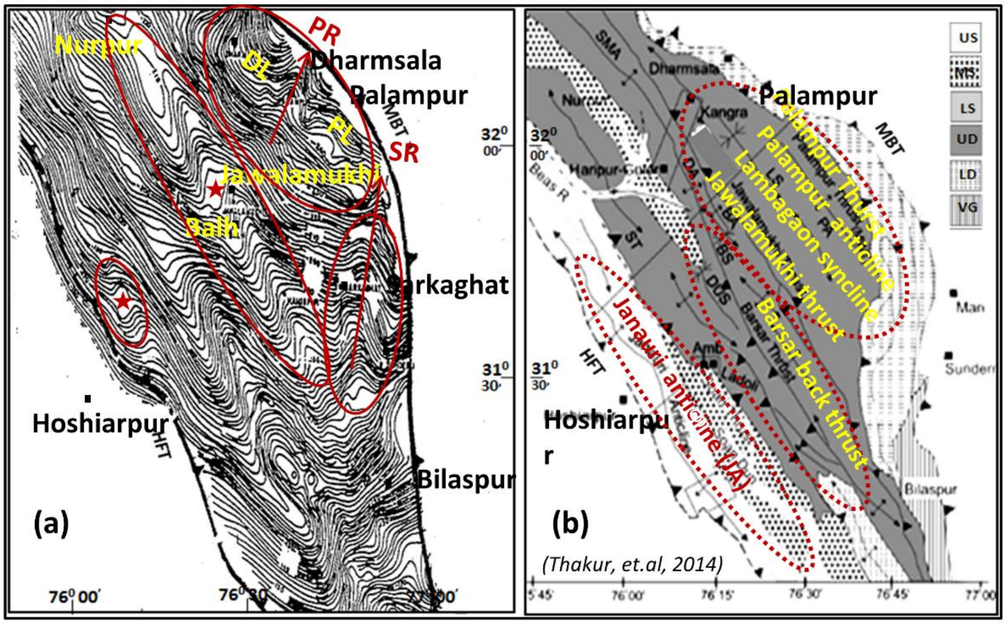

Figure 5. *Comparison of the (a) gravity and (b) the geology map of the Kangra recess displaying areas of major discordances (marked with dotted ellipses). Note the Janaury and Palampur anticlines, the Lambagaon syncline and the thrusts, Palampur, Jawalamukhi and the Barsar (Figure 5b) are not seen in the gravity map (5a). On the other hand, the lows, the Dharamsala (DL) and Palampur (PL) and the north-south trending ridges, the Palampur (PR) and the Sarkaghat (SR) in gravity (Figure 5a) are not mapped in geology.*

D. Comparison of the Bouguer and the geology map in the Kangra Recess (Nurpur – Sarahan)

Comparison of the gravity and the geology map of the Kangra recess (Thakur et al., 2014), based on ground positioning of the structural features provides interesting studies (Figure 5). For instance, the prominent features mapped in geology, the Janauri anticline (JA), the Palampur anticline (PA), the Lambagaon syncline (LS) and the thrusts, the Palampur , the Jawalamukhi and the (back thrust) Barsar (yellow/red annotations, Figure 5b) do not correspond, one to one, to the Bouguer anomalies (Figure 5a). The large Lambagaon syncline (LS) mapped in geology broadly corresponds to the gravity lows bordering the MBT, the Dharamsala low (DL) and the Palampur low (PL) but apparently with diverse strikes. While all geologic features mapped are oriented northwest-southeast, these Bouguer anomalies seem to have an orthogonal cross trend. Also noticeably, the prominent paleo ridge near Sarkaghat (SR) is not seen in the geology map (Figure 5b).

Further, the gravity data do not show evidence of thrust faults mapped in geology, as all the faults are indicated as normal faults. However, the HFT and the Jawalamukhi thrusts broadly corresponding with the normal basement faults in the Bouguer map, suggest reactivation of the Precambrian (Proterozoic) faults to thrust faults during the Himalayan compressive tectonics. The significant incompatibility in the maps, on the whole, underscores the fact that the maps portray two entirely different geologic objects. While the gravity essentially depicts the deep Proterozoic basement morphology affected by divergent wrench tectonics, the geology map charts the surface folds and thrusts within the Neogene sediments, deformed by post-Eocene '*thin skin tectonics*' without involving the basement.

E. Thematic tectonic sketch map of Proterozoic basement in the Kangra Recess

As stated earlier, the Bouguer map in the Kangra recess shows the structural anomalies in the central part distinctly dissimilar from those in the area bordering the MBT. The outlines of the features (Figure 4) with their structural attitude and orientation are thematically sketched for convenient display and understanding of the regional tectonics (Figure 6). The westward shift of the conjugate pair of features, the Jawalamukhi high and

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the Balh low in the central part and a similar shift of the couple marked 'H' and 'L', north of Sarahan high (SH), described earlier, is now evident with more clarity, signifying left-handed (sinistral) strike-slip fault. Similarly, the dissimilar nature of Bouguer anomalies bordering the MBT (Figure 4), with a pattern of alternating lows and highs (indicated by arrows in Figure 6) and dipping northeast are more distinctly visible. The conspicuous mega change observed in the dominant strike of the MBT to north-south trend for a considerable distance along 77^0 E longitudes is intriguing. The happenstance of the change in nature and orientation of the structural anomalies bordering the MBT and its conspicuous shift in orientation may possibly be linked to neotectonics, post MBT.

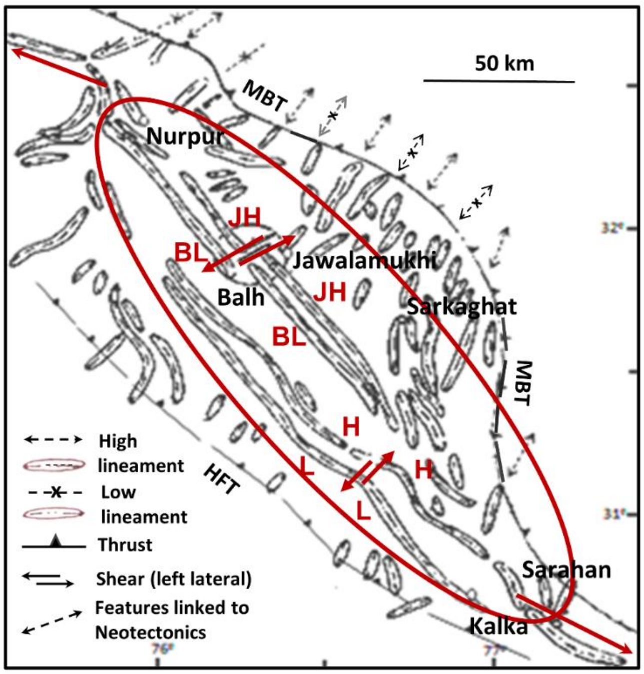

Figure 6. *Shows the thematic tectonic sketch map of Proterozoic basement in the Kangra recess based on outlines of the anomalies and their alignment (Figures 2 and 4). The change in dominant northwest-southeast trend of contours in northern and southern end (marked by arrows) symbolizes the wrench and stress direction. The westward shift of pairs of high and low features near Jawalamukhi and Sarahan (highlighted by solid red arrows) further indicates left-handed strike-slip fault. Notice the plotted outlines of the Bouguer anomalies bordering the MBT (marked by arrows) showing a pattern of alternating highs and lows with orientation orthogonal in contrast to the dominant trend.*

F. Basement morphology in the Jammu Sub-Himalayas and the Kangra Recess

A remarkable utility of the composite Bouguer map is the convenient display of the contrasting nature of the anomalies in the Jammu Sub-Himalayas and the Kangra recess (Figures 3 and 4). The distinct high-amplitude structural closures in the Jammu Sub Himalayas, in contrast to the long and linear nature of *en echelon* nosal features in the Kangra recess, strongly indicate dissimilar nature of the basements in the two areas. While the basement topography in Jammu sub-Himalayas appears highly uneven and fragmented with paleohighs and lows, it is relatively even and less disturbed in the Kangra recess where the younger (Neo)Proterozoic Vindhyans are believed to comprise the basement floor. This is also supported by the drilled well data. The Janaury well (J2) drilled on the Janaury anticline in the Kangra recess close to and east of the HFT met Proterozoic metamorphic basement rocks directly below the Siwaliks (Sastri, 1979).However, the well Mohand (M) drilled near DehraDun in the same tectonic setting but farther away to the southeast along the strike, bottomed in 70m of Vindhyans (Neoproterozic) indicating the Vindhyan sedimentary formation thickening significantly to southeast of the Kangra recess (Prasad et al., 2011). The approximate locations of the wells Adampur (A), J2 and M are shown in Figures 2 and 5 and the conceptual geologic section through the well J2 in the Kangra recess (Prasad et al., 2011) shown in Figure 7. Based on the above, it is reasonable to infer that the (Neo) Proterozoic Vindhyans have thinned out to the north and are absent in the Jammu Sub Himalaya (Riasi-Surinser area) where older Precambrian (Meso) Proterozoic may constitute the basement. However,

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continuity of the (Neo) Proterozoic basement in central part of the Kangra recess seems to be doubtful towards the east in the peripheral part, bordering the MBT.

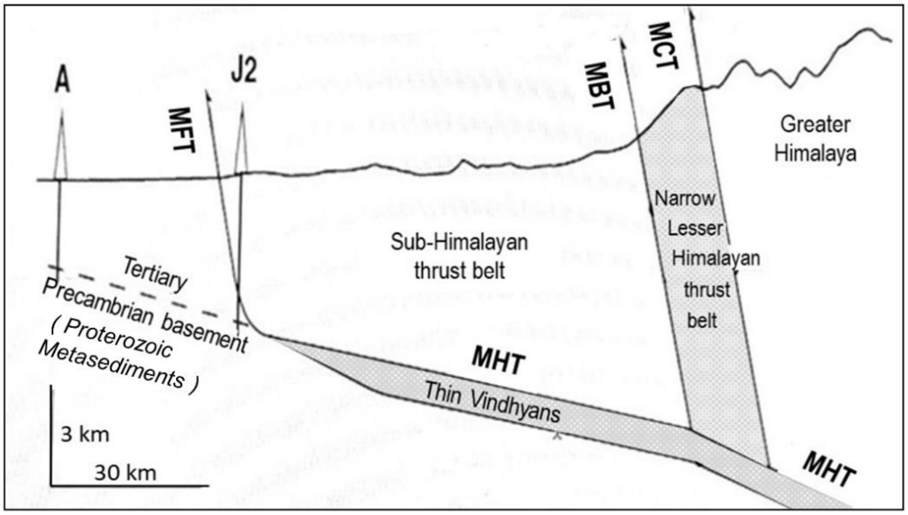

__Figure 7.__ The conceptual geological cross section through Adampur (A) and Janauri (J2) wells across the Kangra recess (after Prasad et al., 2011) showing the wells bottoming in Precambrian basement. It also illustrates the thin skin tectonics with the Himalayan decolloma MHT, underlain by a thin layer of Vindhyans. The Precambrian basement is qualified by the author as Proterozoic metasediments based on reports of J2 well (Sastri, 1979).

CONCLUSIONS

1. The composite Bouguer map captures distinctly the footprints of Proterozoic transtensional sinistral wrench in the Jammu-Dehradun sector of the Outer Himalayas with the stress direction oriented west northwest-east southeast.

2. The type of basement and its configuration is different in the Jammu Sub-Himalayas and in the Kangra recess. The basement in the Jammu area seems to be older Precambrian (Mesoproterozoic), uneven and fragmented whereas in the Kangra recess it is younger Neoproterozic Vindhyans, being even and less disturbed.

3. Gravity data provides supportive evidence to *thin skin tectonics* theory in Himalayan geology as evinced by significant incompatibility between the gravity and the geology map. While gravity portrays the basement configuration, the geology maps the Neogene surface folds and thrusts.

4. Normal basement faults in Bouguer map showing correspondence with mapped surface thrusts indicate reactivation of Proterozoic transtensional faults during compressional Himalayan tectonics.

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REFERENCES

Basu, P. K., 2004, Siwalik mammals of the Jammu Sub-Himalaya, India: an appraisal of their diversity and habitats**,** Quaternary International**, 117**(1), 105-118. https://doi.org/10.1016/S1040-6182(03)00120-4

DGH-ONGC-OIL Joint study, 2000, Recompilation and reinterpretation of geoscientific data of Punjab Basin, Unpublished report (Part-I and Part-2).

Jagtap, S., A. Pandey, R. Jayangondaperumal, A. K. Sharma, A. Anilkumar, I. Singh and A. Kumar et al., 2022, Active uplift along uncommon bending moment fault in the northern limb of Surin Mastgarh Anticline, Jammu Sub- Himalaya, Himalayan Geology, **43**(2),442-456.

Prasad, B. R., V. V. Rao, H. C. Tewari and S. L. Klemperer, 2011 Crustal structure beneath the Sub-Himalayan fold–thrust belt, Kangra recess, northwest India, from seismic reflection profiling: Implications for Late Paleoproterozoic orogenesis and modern earthquake hazard, Earth and Planetary Sciences Letters **308**(1), 218-228. https:/doi/org/10.1016/j.epsl.2011.05.052

Raiverman, V., S. V. Kunte and A. Mukherjee, 1983, Basin geometry, Cenozoic sedimentation and hydrocarbon prospects in north-western Himalaya and Indo-Gangetic plains, Petroleum Asia Journal, **6**, 67–92.

Sastri, V. V, 1979. An overview of petroleum geotectonics of the region to the north and south of the Himalaya, In "Himalayan Geology Seminar New Delhi 1976, Section III, "Oil and Natural Gas resources". Geol. Surv. India Misc. Publ., part 5, **41**, 247–274.

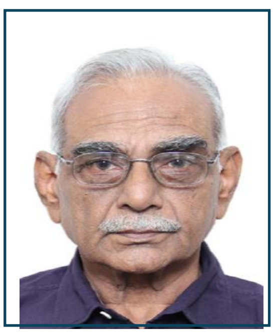
Sharma, R., 2015, Exploration in thrust-fold belt of NW Himalayas: Insights into subsurface stratigraphy, tectonics, and hydrocarbon potential, ONGC Bulletin, **50**, 9-74.

Sharma, V and A. R. Chaudhri, 2020, Active tectonic strike-slip fault development near Goran, Samba and Kathua Districts, Jammu and Kashmir, Open Journal of Geology, **10**, 4. https:/doi/org/10.4236/ojg.2020.104016

Srivastava, B. N., M. S. Rana and N. K. Verma, 1983, Geology and hydrocarbon prospects of the Vindhyan Basin, Pet. Asia, J., **6**, 179–189.

Thakur, V.C., M. Joshi, D. Sahoo, N. Suresh, R. Jayangondaperumal, and A. Singh, 2014, Participating of convergence in Northwest Sub-Himalaya: estimation of late Quaternary uplift and convergence rates in Kangra reentrant, North India, Int. J. Earth Sci., **103**, 1037-1056. https:/doi/org/10.1007/s00531-014-1016-7

BIOGRAPHY



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In 1987, he was honoured with the National Mineral Award by the Government of India for his pioneering contribution in the field of reservoir seismic. He received an Honorary Life Membership from SPG, India, in 2006 and an outstanding geophysicist award from GEOINDIA in 2008. In 2013, he was awarded the B. S. Negi gold medal for lifetime contribution in petroleum geophysics by SPG, India. He has published several papers and authored a book entitled "*Interpretation and evaluation of seismic data for hydrocarbon exploration and production-a practitioner's guide*", published by Springer in March 2016. A second edition of this book containing additional topics, including "*Exploration and exploitation of unconventional reservoirs – role of seismic*" was published by Springer in April 2021.

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