Structural Analyses of the Lunavada–Santrampur Area (Gujarat, India) Using Remote Sensing Images

Geetika H. Chauhan, G. S. Rao, and Soumyajit Mukherjee

Abstract The Lunavada Group of rocks occupies parts of Sabarkantha and Panchmahal districts in Gujarat (India) and have undergone polyphase deformation in the Kadana Formation at NE Gujarat. This study analyzes folds and lineaments to visualize the tectonics using remote sensing images of Santrampur and the surrounding areas. The DEM data was obtained from ASTER and satellite images from Sentinel-2. Analytical technique such as Topographic openness is used to visualize the openness and closeness of the topography. Various hill shades were generated to understand the area from different sun angles, and the best two directions were merged to interpret the lineaments and were latter plotted on a rose diagram. The study uses Google Earth for identifying various fold geometries. With this chapter, we draw attention to structural geologists, the area Santrampur as an excellent place for fieldwork, training and tectonic research.

1 Introduction

We introduce to the reader a hitherto unknown area to structural geologists-Santrampur (Gujarat, India). Google Earth image reveals spectacular mega-scale structures (folds and faults) from field and interpreted for tectonics. We hope this chapter will give the first impetus to structural geologists to undertake detail works on this terrain. Santrampur is one such area that the instructor can display on a large screen to even the beginners on structural geology and encourage to interpret structures. In this way, the instructor can develop a very interactive session with students.

G. H. Chauhan (✉)
Department of Geology, K. J. Somaiya College of Science and Commerce, Vidyanagar, Vidyavihar, Mumbai, Maharashtra 400077, India
e-mail: geetikamacs@gmail.com

G. S. Rao
Prithvi Geospatial, A-9, Arjun Center, Govandi (E), Mumbai, Maharashtra 400088, India

S. Mukherjee
Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, Mahatrashtra 400076, India

S. Mukherjee (ed.), *Structural Geology and Tectonics Field Guidebook—Volume 1*, Springer Geology, https://doi.org/10.1007/978-3-030-60143-0_21

The structures are so obvious in the image that even the shy students would start interpreting, right or wrong!

The southernmost part of Aravalli Mountain belt is known as Southern Aravalli Mountains Belt (SAMB). This area is at the junction between the Aravalli Craton in the north and the Dharwar Craton to the south. It is also a part of the Narmada–Son belt. The Lunavada Group occupies parts of Sabarkantha and Panchmahal districts in Gujarat (Fig. 1a). Gupta and Mukherjee (1938) first mapped the area. The study area extends from 23° 01′ 25.51″ N to 73° 37′ 50.3″ E and from 23° 23′ 11.62″ N to 73° 45′ 36.4″ E. It comes within the Survey of India's topo-sheet No. 46 E/12. The best way to reach the study area is by the Highway NH 48 that connects Delhi and Mumbai. Another way to reach the study area is by train, first from Vadodara to Godhra, and then from Godhra to Lunavada.

Mahi and Panam are the two major rivers in the study area. The area comprises peneplains to the north of Lunavada and toward the south and east is an intensely folded and faulted terrain. The peneplains consist of softer rocks such as chlorite schists and mica schists, which are easily eroded and covered by soil; whereas hard resistant quartzites associated with these metapelites forms the fold limbs (Fig. 1b, also see Fig. 2). Structural geology and tectonics of the area have been worked out by a few workers so far, e.g., Gupta and Mukherjee (1938), Iqbaluddin (1997), Mamtani (1999) and Joshi (2013). Recently, Mukherjee et al. (2020) published numerous structural field photographs from the Lunavada area.

This entire sequence is complexly folded at least thrice and was subsequently intruded by the Godhra Granite (Mamtani et al. 2000). There are very well-defined complex deformation events, which can be seen regionally in the satellite image (Fig. 3). The southern part of the study area around Lunavada, Santrampur and further south is characterized by regional-scale superposed folds. The northern part of the study area shows tight folds and close-spaced axial planar fractures (Fig. 4). A sinistral shear zone (Mamtani et al 1999) exists in the northern part of the study area with a mean trend of N50° E–S 230° W (Fig. 5).

2 Structural Detail Deduced from Google Earth Image

Polyclinal fold: These folds show axial surfaces with variable or contrasting closure directions (Fig. 6).

Second-order folds: M-shaped (Fig. 7a) and Z-shaped folds (Fig. 7b) are documented easily after zooming in the Google Earth image.

Curved axial trace of the fold: This is interpreted from the image (Fig. 8). Curved axial trace of the fold would mean that the folded rock underwent at least two generations of compression.

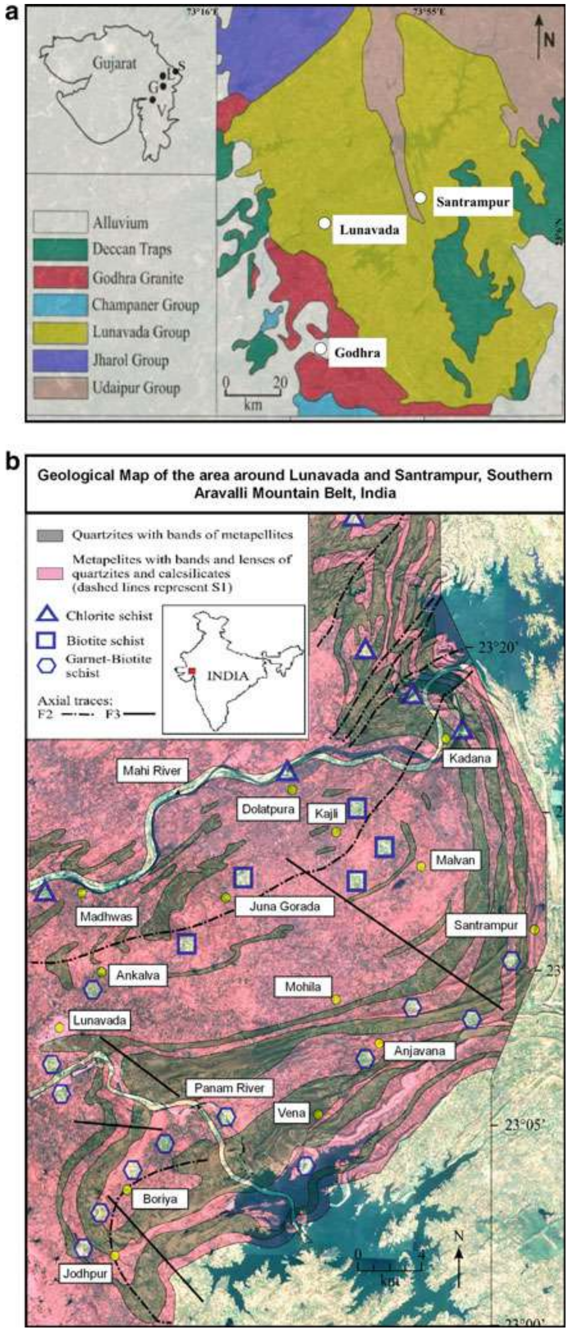


Fig. 1 **a** Part of the lithostratigraphic map of the SAMB around Lunavada (after Gupta et al. 1980). L = Lunavada, G = Godra, V = Vadodara and S = Santrampur. **b** Geological map of the study area. Schists of different metamorphic grades (chlorite, biotite and garnet biotite schists) are shown by different symbols (after Mamtani et al. 2001)

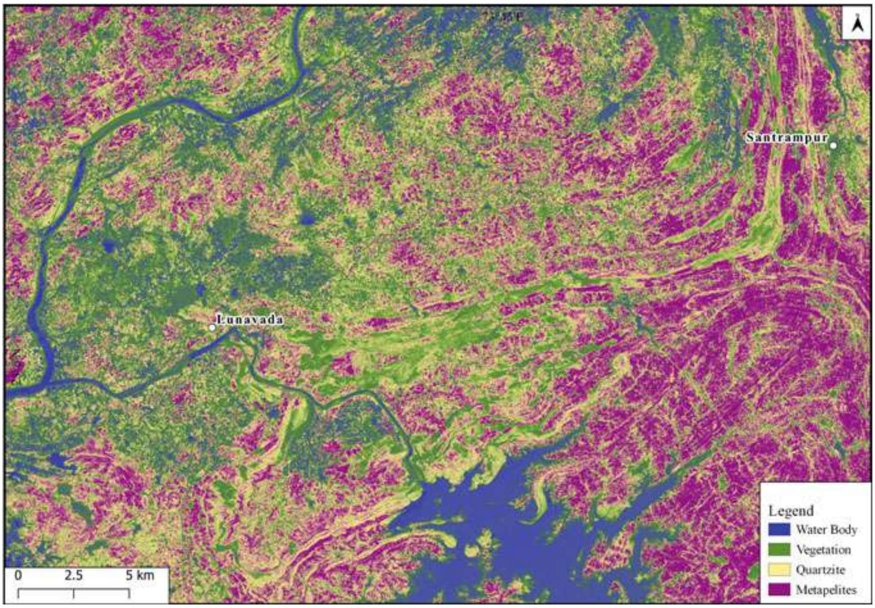


Fig. 2 Sentinel-2 image displaying intercalation of quartzite with metapelites generated using band ratio of band 4(red) by band 2(blue) after applying ATCOR

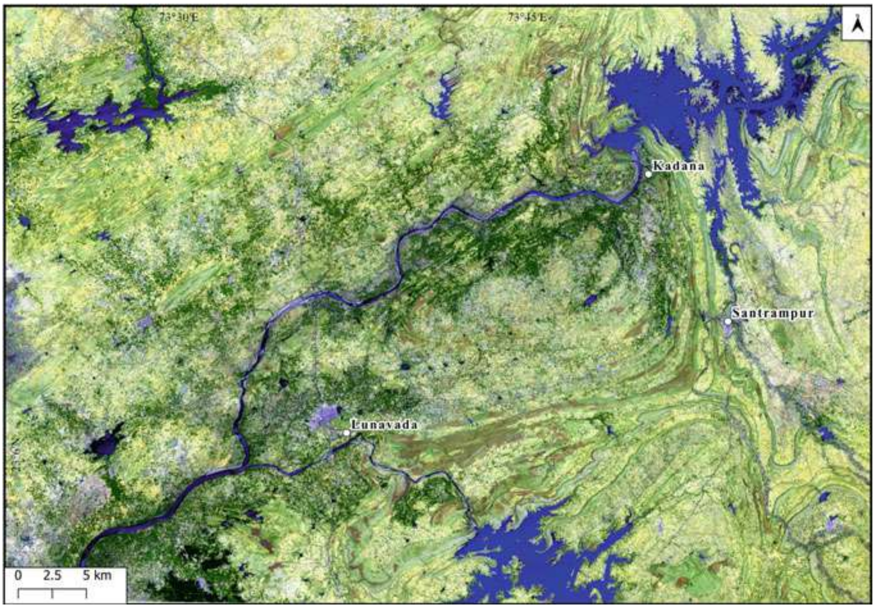


Fig. 3 Sentinel-2 band combination (12-11-2) displaying the study area

Fig. 4 Google Earth Image of the study area

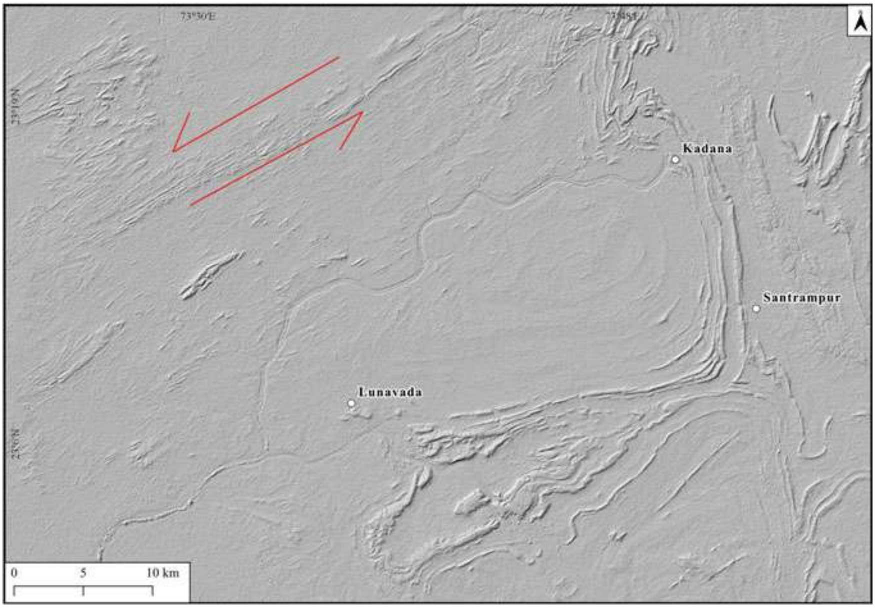


Fig. 5 ASTER GDEM (90m) Hillshade azimuth of 315° and solar elevation of 30° showing sinistral shear zone

Fig. 6 Google Earth image of polyclinal fold (inside box)

3 Data Analyses Using Remote Sensing Images

Use of remote sensing images in structural geological data is a well-established procedure (e.g., Misra et al. 2014; Babar et al. 2017; Misra and Mukherjee 2017; Vanik et al. 2018; Dasgupta and Mukherjee 2019). Meer et al. (2014) presented the potential of Sentinel-2 imagery (10 m resolution) in structural interpretation. Such an imagery with ASTER GDEM (90 m resolution) was used for structural trendlines and lineaments interpretation. QGIS (V.2.18.24) was the open-source software used for processing and mapping the data during the analysis. Image processing techniques like atmospheric correction and band rationing were used. Fill-nodata algorithm was used for processing of DEMs to make it error free. Geoprocessing tool, Topographic openness, was used to understand the surface concavities and convexities.

The Sentinel-2 images were atmospherically corrected by applying the Dark Object Subtraction-1(DOS-1) method. A bandset containing the blue band (band 2) with a 10-m resolution, and two short wave infrared bands (band 11 and 12) with resolution of 20 m were created to visualize the area (Fig. 3). To differentiate the quartzite from metapelites, a band ratio was created by ratioing the red band (band 4) with the blue (band 2). Quartzites appeared creamish whereas the metapelites purple (Fig. 4).

Hillshades of ASTER DEM were generated with azimuth to highlight all the smaller linear features. In order to identify linear topographic features from the DEM, seven shaded relief images were generated. The first shaded relief image

Fig. 7 **a** Google Earth image of the second-order M-type fold. **b** Google Earth image of the second-order Z-type fold

Fig. 8 Google Earth image of curved axial trace

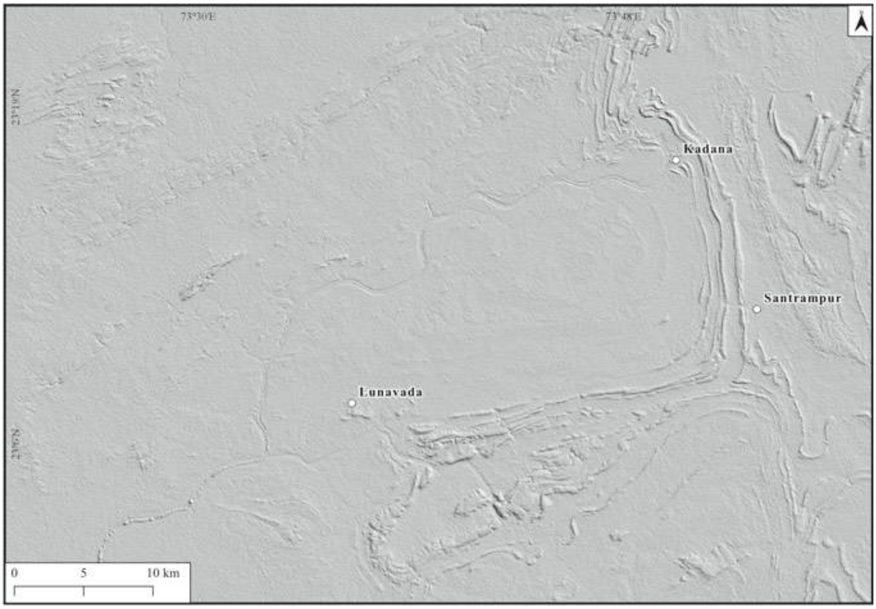


Fig. 9 Hillshade derived from ASTER GDEM with azimuth of 45° and solar elevation of 45°

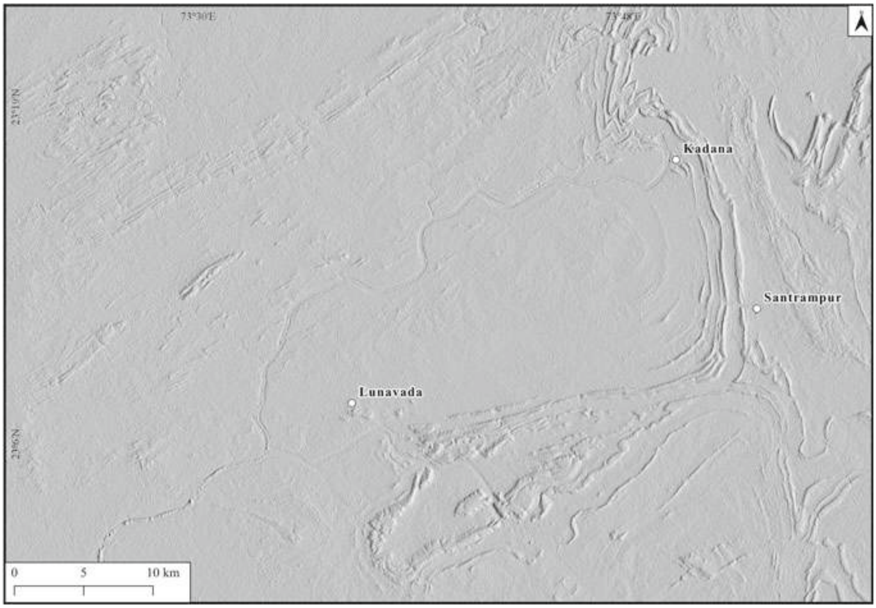


Fig. 10 Hillshade derived from ASTER GDEM with azimuth of 90° and solar elevation of 45°

created had a solar azimuth (sun angle) of 45° (Fig. 9) and a solar elevation of 45°. The other six shaded relief images were created with six contrasting illumination directions 90° (Fig. 10), 135° (Fig. 11), 180° (Fig. 12), 225° (Fig. 13), 270° (Fig. 14) and 315° (Fig. 15). The second step is to merge the two DEMs which best represents the surface, i.e., 135° and 45° (Fig. 16).

Topographic openness is a tool used to understand the openness of the topography (Elmahdy 2010). It describes the degree of dominance or enclosure of a point relative to the surrounding terrain, in eight different directions within a given radial distance. Measured above the surface, a positive openness emphasizes convex features in the landscape. Measured below the surface, a negative openness emphasizes concave features in the landscape. Positive openness (Fig. 17) reflects the surface upward and/or ridge (footwall of fault). On the other hand, a negative openness (Fig. 18) reflects surface downward and/or channel (fault zone).

The topography which looked more or less even was better visualized after using the Topographic Openness algorithm. The Positive openness map highlighted the concave up features like the fold, it's deformed limbs and other elevated parts present in the area; however, the Negative openness map emphasized the convex landform present below the concave up features and its surrounding. A depression is seen to pop-up in the negative openness map between the Mahi river channel and the northern limb of the fold in the northwest direction indicating deeper crust.

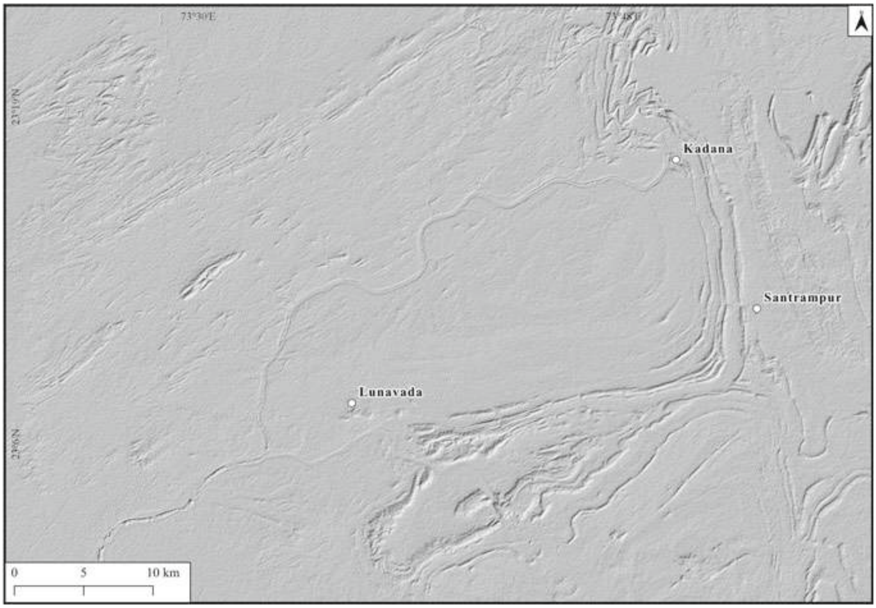


Fig. 11 Hillshade derived from ASTER GDEM with azimuth of 135° and solar elevation of 45°

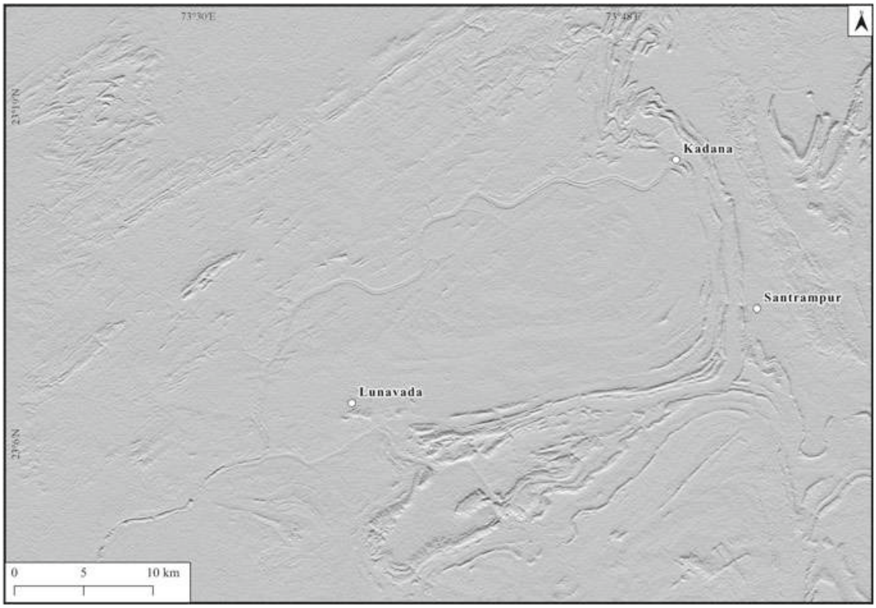


Fig. 12 Hillshade derived from ASTER GDEM with azimuth of 180° and solar elevation of 45°

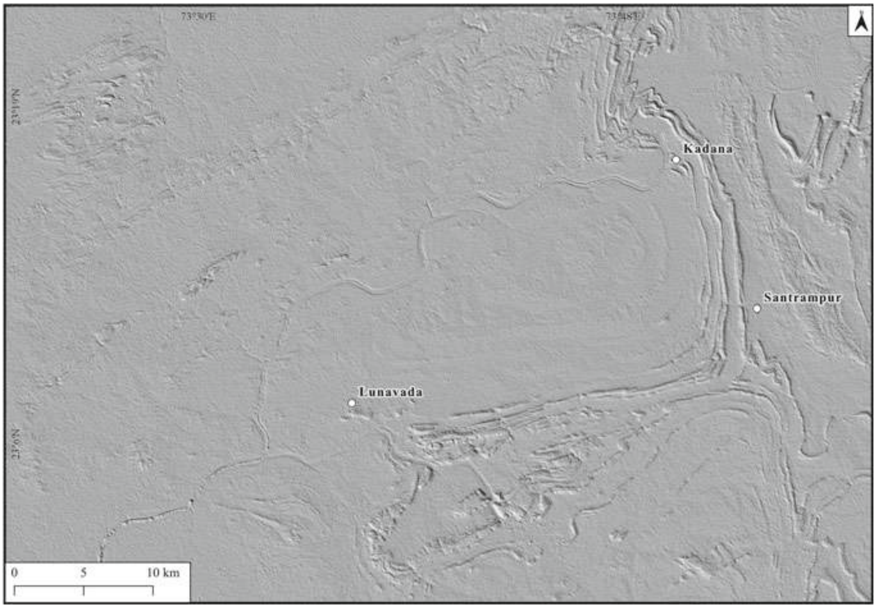


Fig. 13 Hillshade derived from ASTER GDEM with azimuth of 225° and solar elevation of 45°

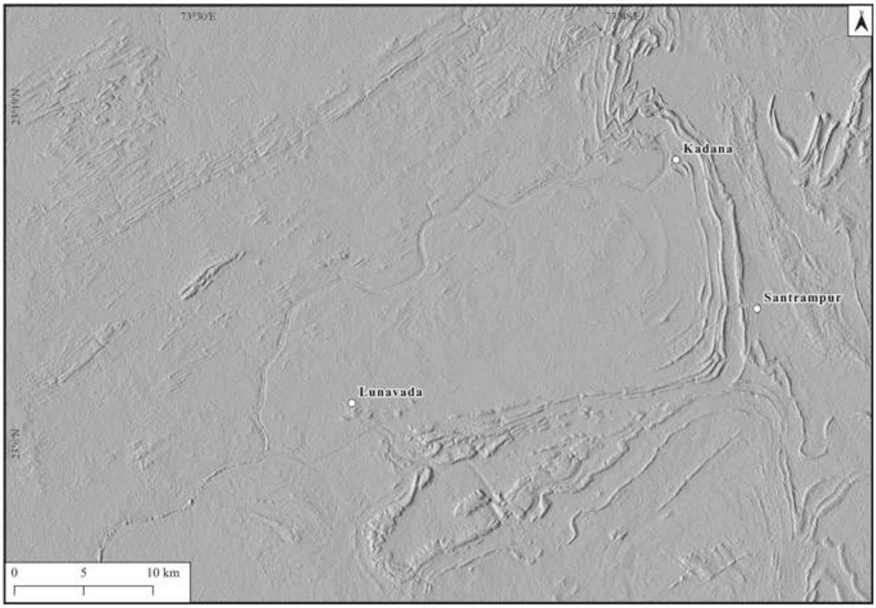


Fig. 14 Hillshade derived from ASTER GDEM with azimuth of 270° and solar elevation of 45°

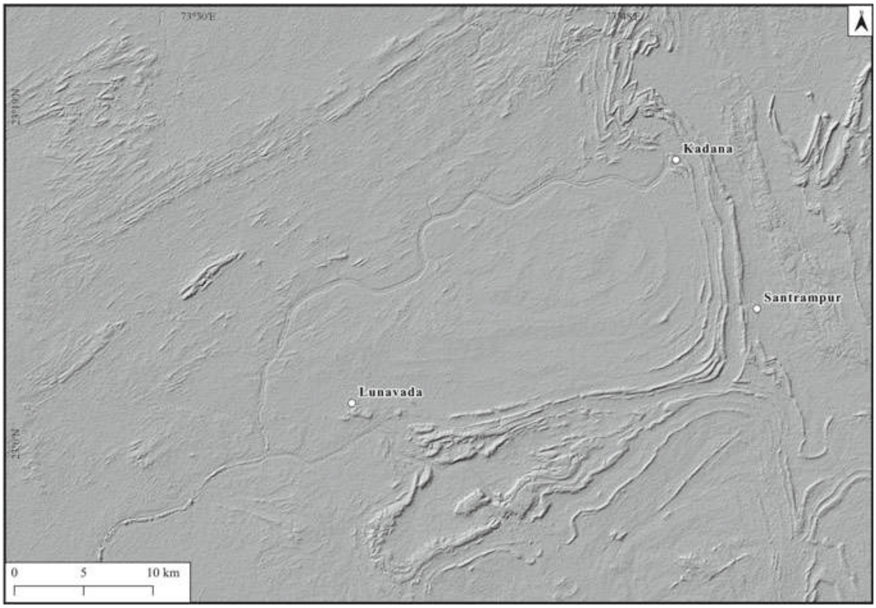


Fig. 15 Hillshade derived from ASTER GDEM with azimuth of 315° and solar elevation of 45°

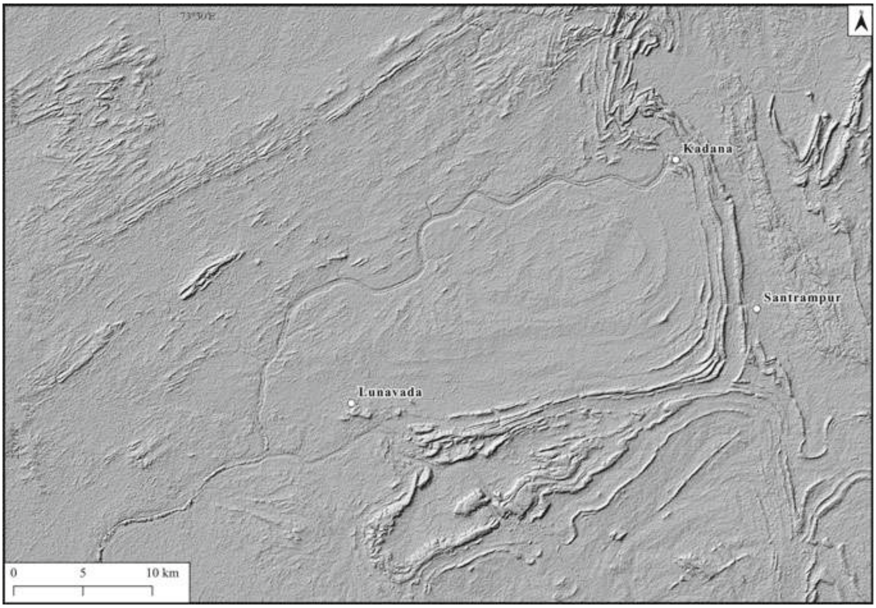


Fig. 16 Merging of two hillshades with azimuth 315° and 45° and solar elevation of 45°

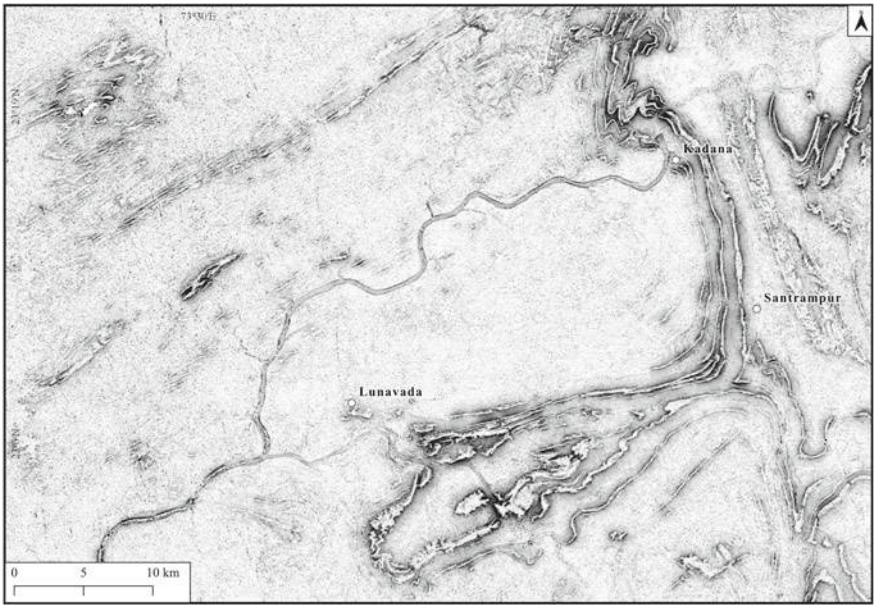


Fig. 17 Positive openness map (enhancing surface upward)

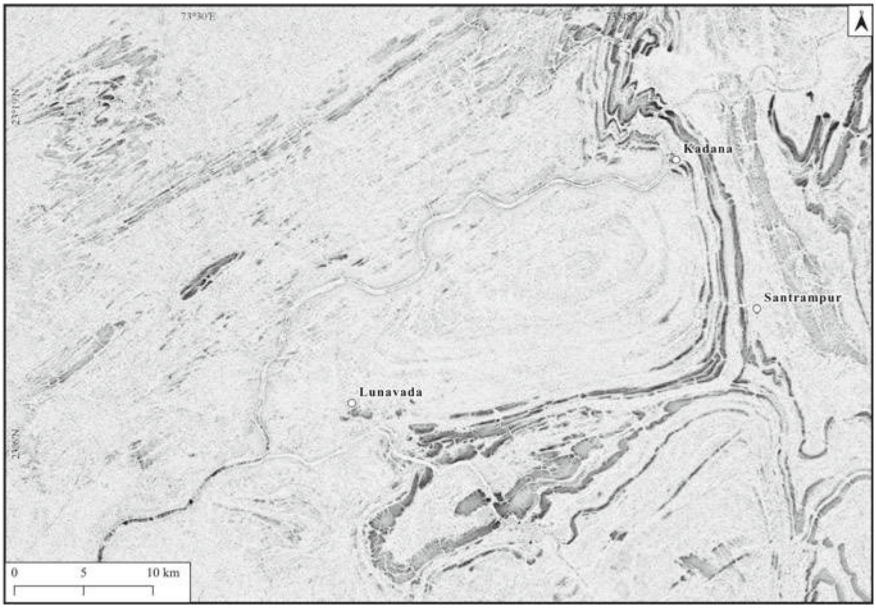


Fig. 18 Negative openness map (enhancing surface downward)

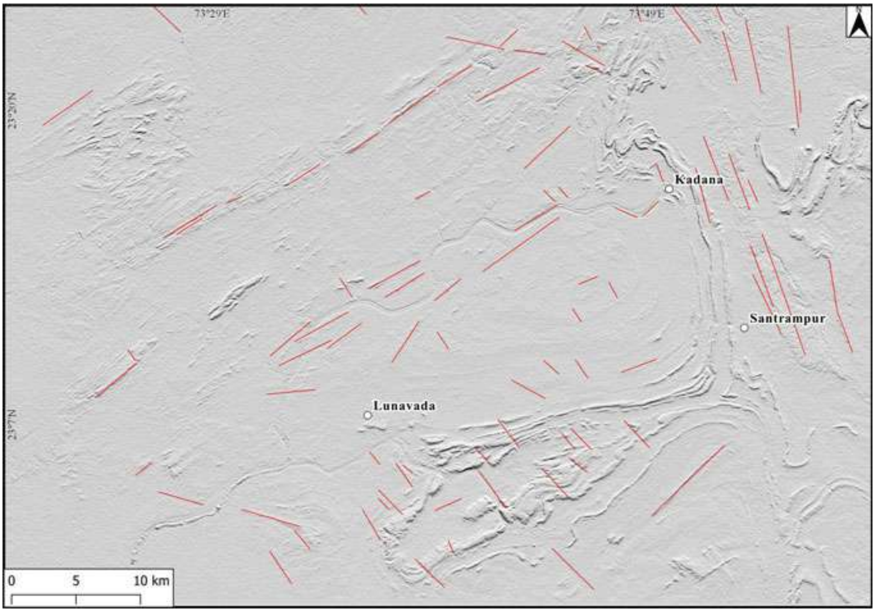


Fig. 19 Lineaments extracted by merging two hillshades with azimuth of 315° and 45° and solar elevation of 45°

4 Analysis of Lineaments

Automatic technique of lineament identification was avoided as many non-meaningful linear may crop-up due to illumination, topography, shadow, etc. Two DEMs (Figs. 9 and 15), with azimuths 315° and 45° and a solar elevation of 45°, were merged to trace the lineaments. A total of 92 lineaments were identified (Figs. 19 and 20) and plotted on the rose diagram (Fig. 21) with the help of Rose.net (V.0.10.0.0, year: 2012) software. The Rose diagram clearly shows that NW and NE are the two dominant trends.

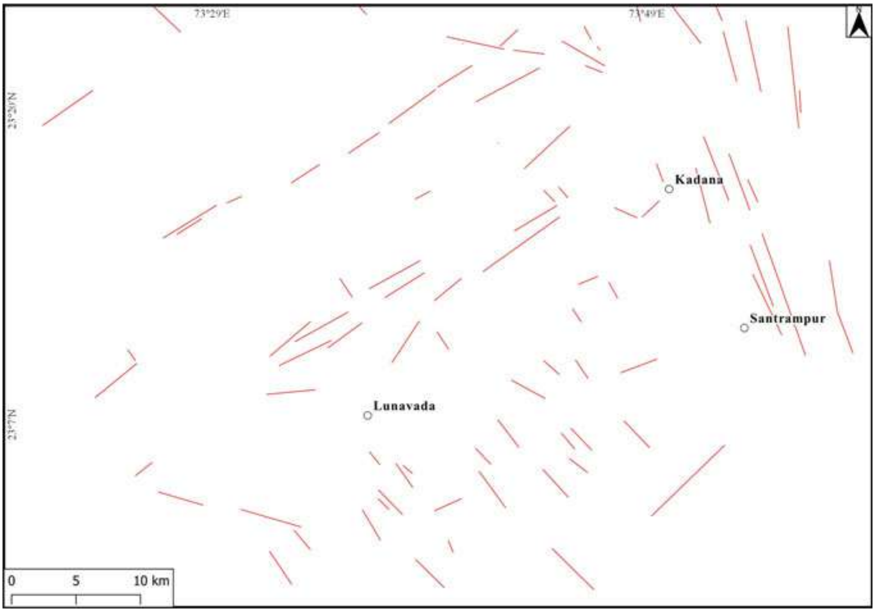
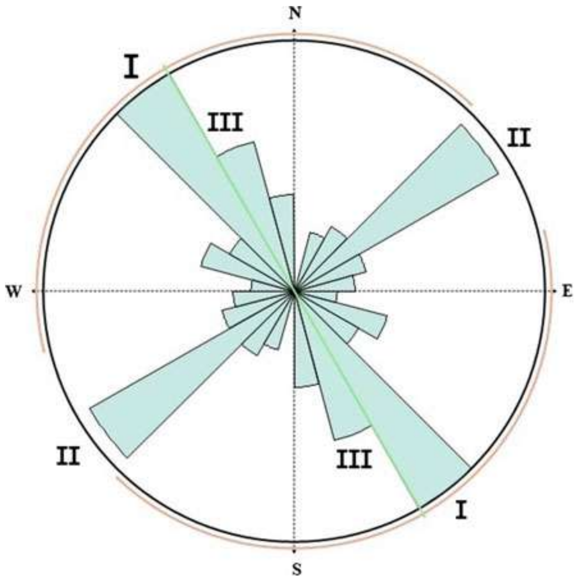


Fig. 20 Map displaying lineaments extracted from ASTER GDEM

Fig. 21 Rose diagram showing distribution of lineaments in the study area



5 Conclusions

Study of Google Earth images reveals eye-catching polyclinal folds, second-order folds and superposed folds from Santarampur area (Gujarat, India). Image analyses gives us improved idea about the topography as well as the dominant trend of natural lineaments in the area.

Acknowledgements The amazing detail of structures in remote sensing images from Santarampur was pointed out by Satardu Bhattacharya (Space Application Center) to SM. Thanks to Springer (Marion Schneider, Alexis Vizcainoand the proofreading team) for assistance and Aditya Joshi (MS University Baroda) for interaction. Subhobroto Mazumder (ONGC Dehradun) provided detail useful comments on this article. Thanks to Marion Schneider, Annett Buettener, Boopalan Renu, Alexis Vizcaino, Doerthe Mennecke-Buehler and the proofreading team (Springer). Dutta and Mukherjee (2021) summarize this work.

References

Babar, Md., Kaplay, R. D., Mukherjee, S., & Kulkarni, P. S. (2017). Evidences of deformation of dykes from Central Deccan Volcanic Province, Aurangabad, Maharashtra, India. In S. Mukherjee, A. A. Misra, G. Calvès, & M. Nemčok (Eds.), *Tectonics of the Deccan Large Igneous Province* (Vol. 445, pp. 337–353). London: Geological Society of London Special Publications.

Dasgupta, S., & Mukherjee, S. (2019). Remote sensing in lineament identification: Examples from western India. In A. Billi & A. Fagereng (Eds.), *Problems and solutions in structural geology and tectonics. Developments in Structural Geology and Tectonics Book Series* (Vol. 5, pp. 205–221). Amsterdam: Elsevier. ISSN: 2542-9000. ISBN: 9780128140482.

Dutta, D., & Mukherjee, S. (2021). Introduction to Structural Geology and Tectonics Field Guidebook—Volume 1. In S. Mukherjee (Ed.), *Structural Geology and Tectonics Field Guidebook—Volume 1*. Switzerland: Springer Nature Switzerland AG. Cham. pp. xi-xvi. ISBN: 978-3-030-60142-3.

Elmahdy, S. (2010). Topographic openness algorithm for characterizing geologic fractures of Kuala Lumpur limestone bedrock using DEM. *Journal of Geomatics, 4,* 63–65.

Gupta, B. C., & Mukherjee, P. N. (1938). Geology of Gujarat and southern Rajputana. *Recruitment of the Geological Survey of India, 73*(2), 103–208.

Iqbaluddin, S. U. D., & Javed, A. (1997). Geomorphology and landscape evolution of bharatpur district, rajasthan. *Journal of the Indian Society of Remote Sensing, 25*(3), 177–186.

Joshi, A., Limaye, M. A., & Deota, B. S. (2013). A model representing successive deformational events of Ankalwasynform, Lunavada Group, Gujarat. *Gondwana Geological Magazine, 28*, 1–4.

Mamtani, M. A., Greiling, R. O., Karanth, R. V., & Merh, S. S. (1999). Orogenic deformation and its relationship to AMS fabric—An example from the Southern Margin of the Aravalli Mountain Belt, India. *Memoir Geological Society of India, 44*, 9–24.

Mamtani, M. A., Karanth, R. V., Merh, S. S., & Greiling, R. O. (2000). Tectonic evolution of the southern part of Aravalli Mountain Belt and its Environs: possible causes and time constraints. *Gondwana Research, 3*, 175–187.

Mamtani et al. (2001). Time relationship between metamorphism and deformation in Proterozoic rocks of the Lunavada region, Southern Aravalli Mountain Belt (India) - a microstructural study. *Journal of Asian Earth Sciences, 19*(1), 195–205.

Meer, F. D., Werff, H. M. A., & Ruitenbeek, F. J. A. (2014). Potential of ESA's Sentinel-2 for geological applications. *Remote Sensing Environment, 148*, 124–133.

Misra, A. A., Bhattacharya, G., Mukherjee, S., & Bose, N. (2014). Near N-S paleo-extension in the western Deccan region in India: Does it link strike-slip tectonics with India-Seychelles rifting? *International Journal of Earth Sciences, 103,* 1645–1680.

Misra, A. A., & Mukherjee, S. (2017). Dyke-brittle shear relationships in the Western Deccan Strike Slip Zone around Mumbai (Maharashtra, India). In S. Mukherjee, A. A. Misra, G. Calvès, M. Nemčok (Eds.), *Tectonics of the Deccan Large Igneous Province* (Vol. 445, pp. 269–295). London: Geological Society of London Special Publications.

Mukherjee, S., Bose, N., Ghosh, R., Dutta, D., Misra, A. A., Kumar, M., Dasgupta, S., et al. (2020). *Structural geological atlas.* Berlin: Springer. ISBN: 978-981-13-9825-4.

Vanik, N., Shaikh, H., Mukherjee, S., Maurya, D. M., & Chamyal, L. S. (2018). Post-Deccan trap stress reorientation under transpression: Evidence from fault slip analyses from SW Saurashtra, western India. *Journal of Geodynamics, 121,* 9–19.