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Neogene deformation of Siwaliks affected by the Delhi–Hardwar ridge as seen in satellite data, India

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The Siwalik ranges east of Hardwar exhibit deformation pattern not akin to the general deformation trend of the Siwaliks elsewhere in the western Himalaya. Satellite image (IRS-LISS-II) of the region displays remarkably deformed Siwalik in this region. The deformation pattern reveals that these structures might have been primarily caused by the Delhi–Hardwar ridge. There has been compressional tectonics which were generated due to westward thrusting movement of rocks across the N–S trending Mithawali thrust and obstruction by the shallow buried NNE trending Delhi–Hardwar ridge.

LOWEST topography in the Himalayan orogen is represented by the Siwalik ranges occupying the depression in front of the higher Himalayan mountain belt. Prior to the formation of mountain belt, Siwalik sediments piled up resting on the Indian plate having a northward slope. Subsurface ridge like structural features as an integral part of the Indian plate might have played an important role in generating distinct deformational structures in the overriding rock mass. The Delhi–Hardwar ridge has been identified as shallow buried structural feature on the basis of geological, geophysical and aeromagnetic investigations in the western Indo-Gangetic plains[1].

The youngest tectonic unit, the Siwalik range, extends all along the foothills of the Himalayan mountain belt comprising mollasse sediments subjected to folding and thrusting under compressional tectonism. However, these rocks escaped the vigour of tectonic activity that suffered by the higher Himalayan ranges. In fact, Siwalik rocks in the Dehra Dun valley show less deformation and are mostly represented by the inclined beds (one limb of fold) in the foothills region. But on satellite image, intense folding in Siwalik rocks east of the Hardwar may be observed. It appears that the deformation has been affected due to interaction of other structures as well, which needs proper attention. Figure 1 shows the study area and generalized tectonic setup.

On the structural aspect of the Siwalik range of Dehra Dun region[2–9], considerable information has been published and the Siwalik ranges recently have been mapped in detail[10] (Figure 2). But, the remarkable Siwalik structures between Hardwar and Laldhang escaped the attention of many.

With the advent of satellite images having synoptic view, higher spatial and better spectral resolution, it has become possible to recognize deformation structures having tectonic significance in a better and more reliable way. Hitherto, the minor structural changes could not be realized on ground mapping which has always a limited coverage. This limitation acted as a hindrance to recognize tectonic significance of the structural features.

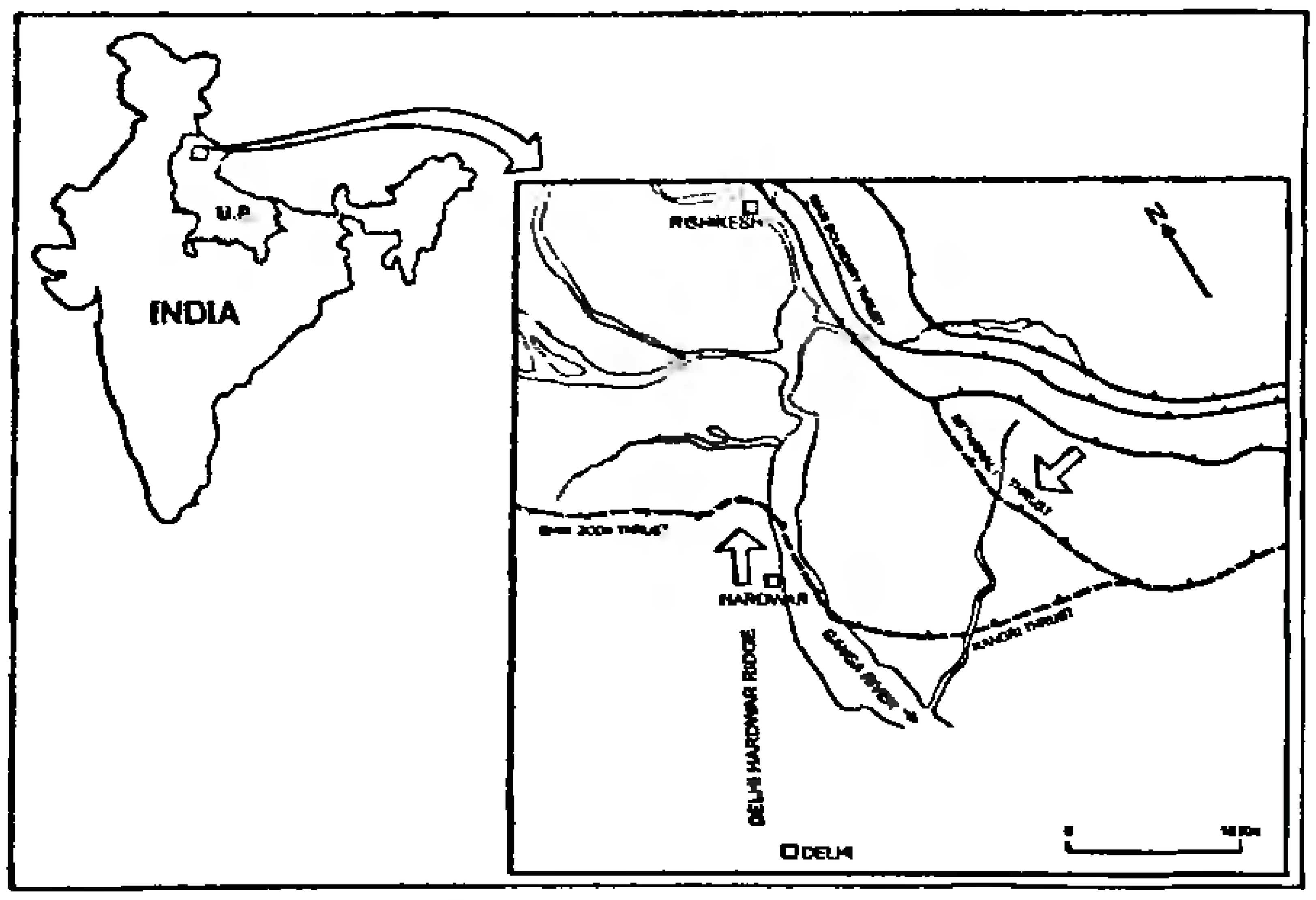

Figure 1. Study area and regional tectonic setup. Large arrows indicate orientation of compressional stresses.

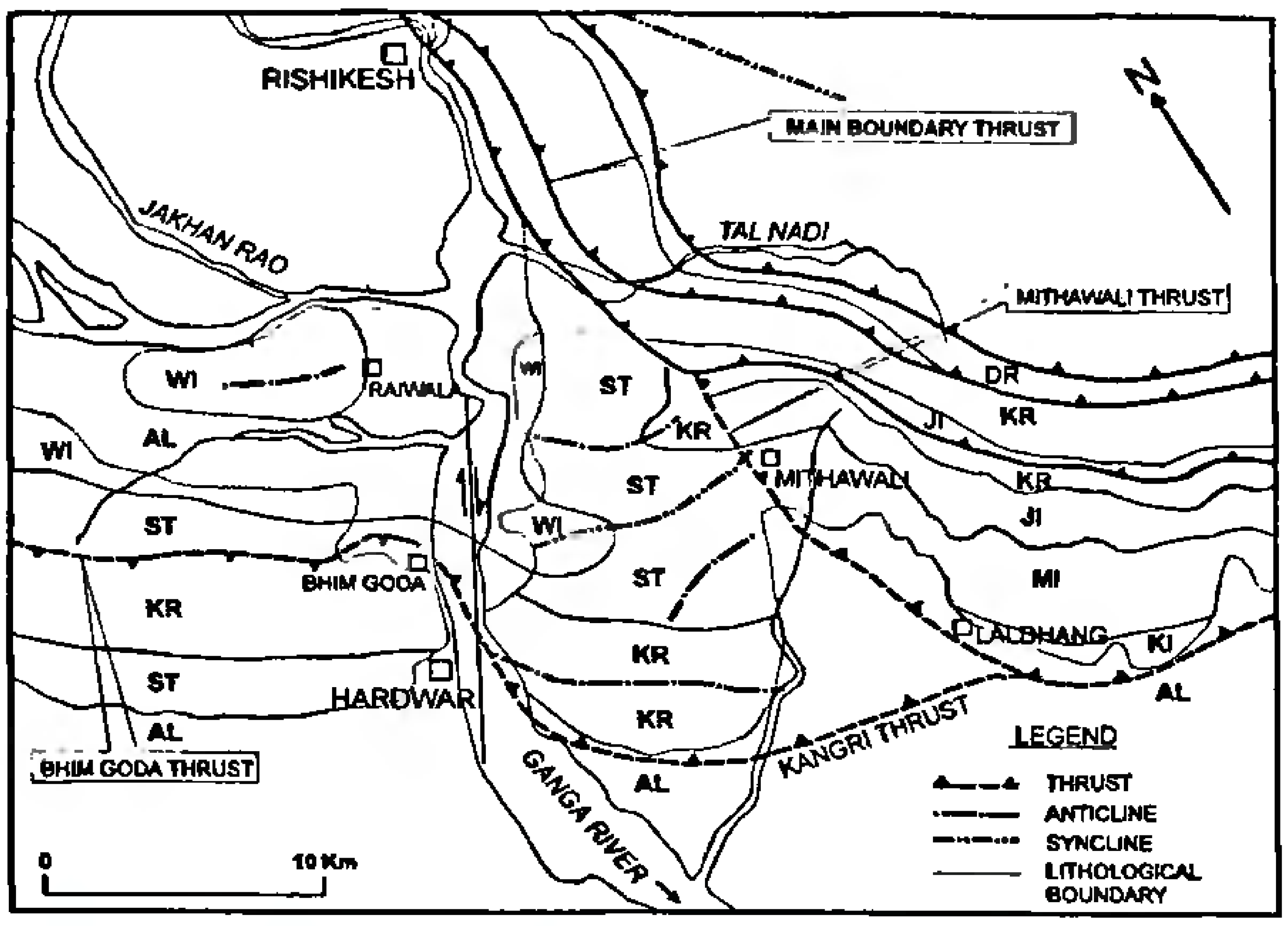

Figure 2. Geotectonic map of the study area and surroundings. AL, Alluvium; WI, Wahdevi and ST, Sadhot (below to Upper Siwalik group); KR, Kalidhar (belong to Middle Siwalik group); JI, Jawalamukhi; MI, Makreri; KI, Kumarhatti and DR; Dharmpur (below to Lower Siwalik group).

Figure 3. IRS-LISS-II FCC (432 in RGB scheme) image of the study area depicting Siwalik deformations.

Structurally, Siwalik rocks in the area west of the Ganga river folded into anticlines and synclines along the foothills region. In fact, between the Yamuna and Ganga rivers, the Siwaliks are less disturbed structurally and thick zones of the middle and upper Siwaliks are exposed[10]. In this region, Siwaliks are separated by the wide Dehra Dun valley and are exposed at a considerable distance from the Main Boundary Thrust. Whereas, the tectonic scenario east of the Ganga river is different altogether. Siwalik rocks east of the Ganga river have been intensely folded and the middle and upper Siwaliks are exposed in quite thin zones. Structural features of the study area and surroundings are shown in Figure 2.

It is evident that the Siwaliks are bounded by the Mithawali and Kangri thrusts (Frontal Thrust) in the east and south-west respectively[10] (Figure 2). Folding intricacy of the rocks in this region is not reflected on the published map. But the satellite image (Figure 3) clearly displays intensely-deformed rocks having a tectonic significance.

Siwalik rocks east of the Ganga river have suffered a different type of deformation as revealed by the satellite image. In this region, Siwaliks show multiple folding. Prominent fold ridges have developed with N–S axes and curved NW–SE and NE–SW limbs. Fold morphology suggests that this region has been affected by E–W oriented compression as well (Figures 3 and 4). Further, rocks close to the Ganga river show southward dragging effect, indicating right lateral faulting along the Ganga river.

It may be noted that a subsurface feature Delhi–Hardwar ridge extends up till foothills of the Himalaya. The Delhi–Hardwar ridge is buried shallow and represents a north–north-eastward extension of the Delhi fold belt[1,11] which delimit the Ganga basin to west. This ridge hits Siwaliks striking normal between the Yamuna and Ganga rivers. Under compressional tectonic regime, the Delhi–Hardwar ridge acted as an obstruction to the southward-migrating Siwalik folds. Consequently, the Siwalik ranges have been severely folded and faulted. Southward-dipping Bhim Goda thrust is a deviation from normal northward dipping Mohand and Kangri thrusts on the either side of the former thrust. This might have some relation to the Delhi–Hardwar ridge.

It is suggested that intense deformation of Siwalik rocks in the Hardwar–Laldhang region has been affected due to interaction between NNE aligned Delhi–Hardwar ridge and westward thrusting movement of the rocks across the Mithawali thrust resulting in oblique movement.

Siwaliks and other Himalayan rocks have been affected by lateral faulting dislocating geological formations caused by prevailing compressional tectonism. Different structures have formed due to interaction of various tectonic features such as Delhi–Hardwar ridge.

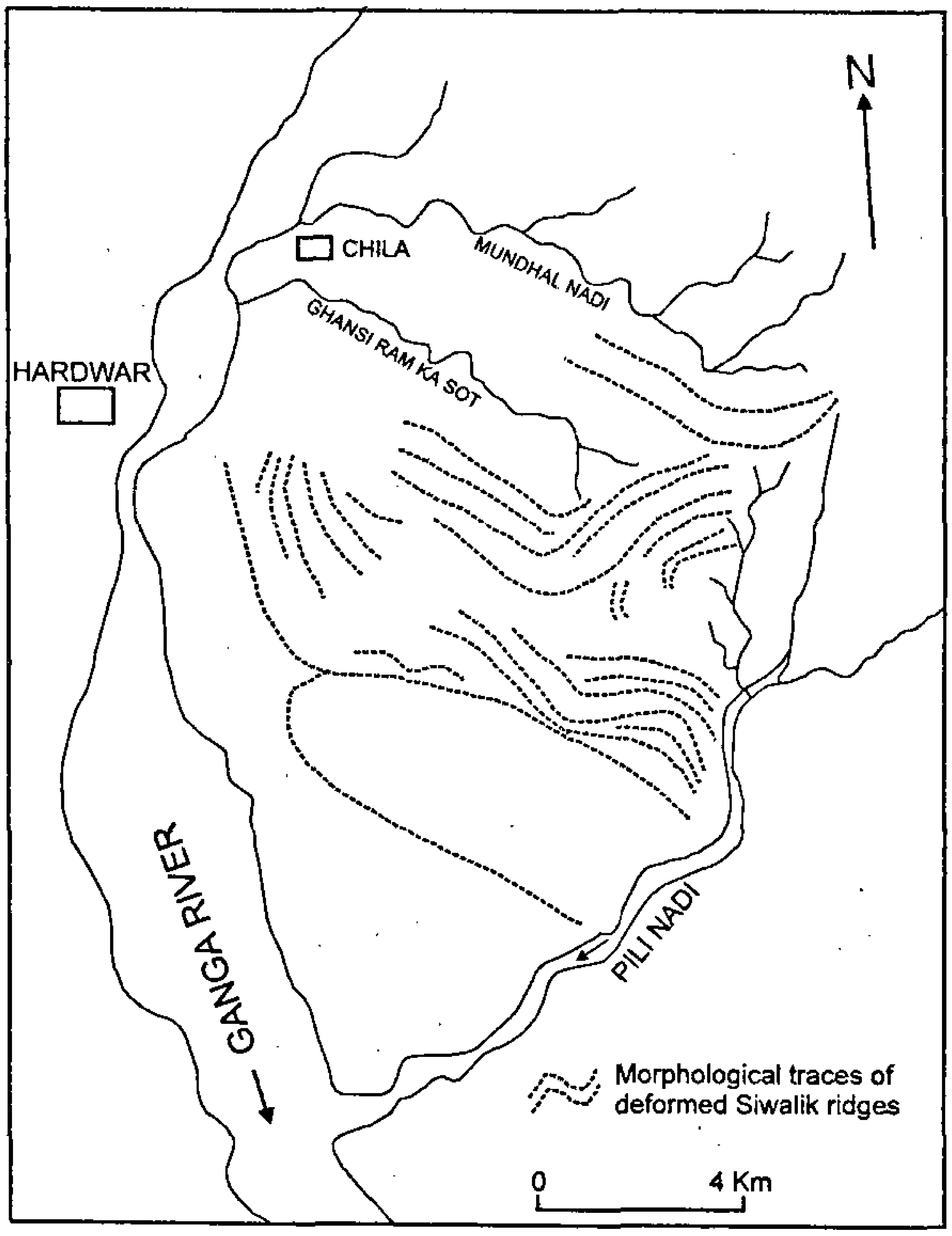

Figure 4. Map showing morphological traces of deformed ridges as interpreted on satellite image (Figure 3).

Similar to the Delhi–Hardwar ridge, there are other north-east trending transverse ridges in Ganga basin facing the Himalayan foothills. These are Meerut–Nazibabad[12], Faizabad and Monghyr–Saharsa ridges[1,3]. Basement depth contour map of the Gangetic basin[3] reveals that the Delhi–Hardwar ridge has a gentler dip than the other ridges. Further, the Delhi–Hardwar ridge is probably extended for considerable distance below the Himalayan belt[13]. Therefore, in Hardwar region greater interaction of Delhi–Hardwar ridge on Siwaliks is expected. And findings of this study are purely based on satellite image of the Hardwar region. Further studies of other areas where transverse ridges face the Siwaliks may reveal new information in future for later correlation.

It is believed that the thrusting sequences in the Himalaya orogeny have migrated southward as the collisional tectonism grew[14–16] and the Himalayan Frontal Thrust (HFT) is the latest development. Earthquake activity in and around Delhi–Hardwar ridge and Siwalik range[17] warrants active tectonic status of the region. Moreover, there had been active interaction between the Delhi–Hardwar subsurface ridge and overlying geological formations in generation of Uttarkashi earthquake of October, 1991 (ref. 13). Therefore, it appears that the Delhi–Hardwar ridge has played an active role in framing up of present tectonic set up of the region. Hence, further modification in folding and faulting may be anticipated under continued compressional tectonism in this region.

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Thorium-rich monazites from the beach sands of Kalingapatnam–Baruva Coast, Andhra Pradesh, East Coast of India

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Of the five microprobe analyses of monazites, one shows a very high concentration of ThO_2 (30.81%) and relatively high Ca and low LREE (Ce, Nd, La, Pr, Sm) indicating that it is a cheralite variety of monazite. The other four monazites also show high concentration of ThO_2 ranging from 12.30 to 15.89. Charnockites and pegmatites occurring in the drainage basin of the hinterland are the source rocks for the monazites. The monazites have an obvious bearing on the economic potential of these sands in exploring them along with the other associated heavy minerals like ilmenite, garnet, sillimanite and zircon.

THE east coast beaches of India are known for the occurrence of heavy minerals like monazite, zircon, rutile, ilmenite, magnetite, garnet and sillimanite. The monazite is a principal economic source of rare earths and thorium. The occurrence of monazite in the beach sands of Visakhapatnam[1,2], Visakhapatnam–Bhimunipatnam[3], Kalingapatnam-Baruva[4,5] and in the deltas of Andhra Pradesh[6] along the east coast has been reported. The earlier studies were oriented towards the quantification of individual heavy minerals in the beach sands including the monazites. However, a few attempts were made to know the chemical composition of the monazites from the beach sands along the east coast of India. The occurrence of cheralite, a thorium-rich variety of monazite in the beach sands of Visakhapatnam–Bhimunipatnam area has been reported[7]. This paper presents the geochemistry of the monazites from the beach sands between Kalingapatnam and Baruva (Figure 1), based on the microprobe analysis.

The beaches between Vamsadhara and Mahendratanaya rivers are enriched in heavy minerals like ilmenite, garnet, sillimanite, orthopyroxenes, monazite, zircon, rutile, etc. and the concentration of heavies ranges from 11 to 53 (wt%) in dunes, 4 to 33 in backshore, 2 to 48 in upper foreshore and 2 to 33 in lower foreshore. The heavy minerals are concentrated more in the finer fractions (–0.25 to +0.125 and –0.125 to 0.062 mm) than in the coarser fraction (> 0.25 mm) and also the concentration of heavy minerals is high nearer to the mouths of streams and small creeks[5].

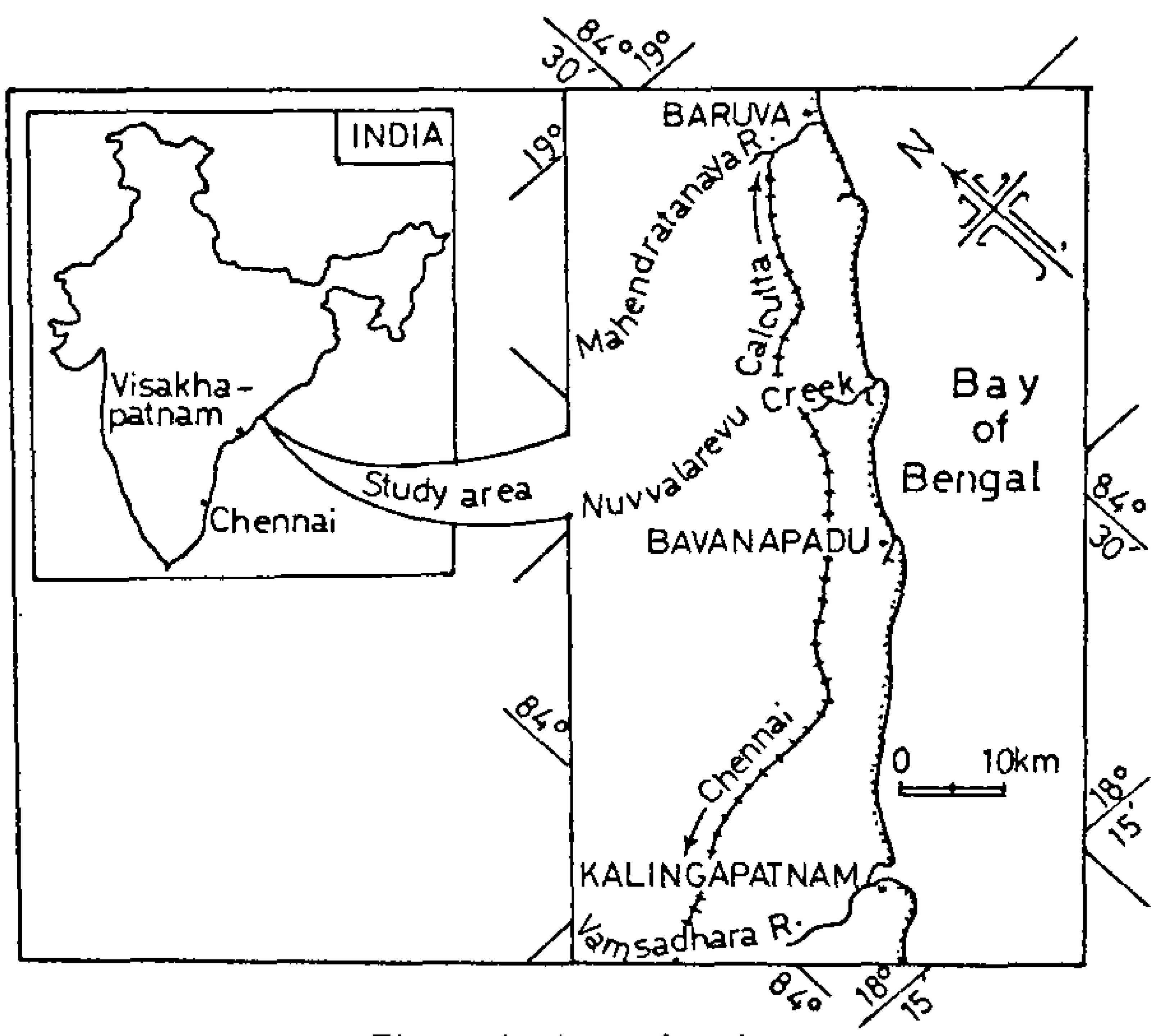

Figure 1. Area of study.