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ACKNOWLEDGEMENTS. We thank the Director, IICB, for his kind interest; Mrs B. Das and Mr R. Bera for technical help and the unknown reviewer for his/her active interest. S.K.M. thanks DST and NES, Govt. of West Bengal and S.M. thanks DBT, Govt. of India for financial support.

Received 24 January 2000; revised accepted 11 April 2000

Identification of probable faults in the vicinity of Harnai–Ratnagiri region of the Konkan coast, Maharashtra, India

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The Konkan coastline from Harnai to Guhagar consists of many straight line segments being arranged in an en-echelon manner. The false color composite (FCC) reveals the coincidence of these segments with NW–SE trending lineaments that conspicuously cut across the Deccan Basalt Province adjoining the seacoast. Furthermore, another less prominent lineament set has been noticed in ENE–WSW direction offsetting the former. These lineaments are occupied by major rivers which originate from the Western Ghats escarpment and flow westerly into the Arabian Sea. Trellis and barbed type of drainage pattern are observed due to strong influence of these sets of lineaments. One of the NNW–SSE lineaments extending from Harnai to Kajurli has been studied, which reveals the presence of narrow and straight course of river flowing along it. While the western bank of the river is steep with a number of waterfalls, the eastern side carries flat terraces. The riverbed exposes highly fractured basalt criss-crossed by NNW–SSE and ENE–WSW sets of fractures. The NNW–SSE set which is sympathetic to the main lineament, hosts quartz veins that show pinch-and-swell and boudinage structure. The boudins are sigmoidal and are arranged in en-echelon pattern indicating shear origin. Hence it is believed that the NNW–SSE lineaments are probable faults in the area. Rare slickensides are observed on the quartz vein wall, which are mostly subvertical, suggesting a dip slip nature of faulting. The faulting is post-Deccan Basalt and could be Quaternary in age.

THE Deccan Trap forms one of the major fissure eruption provinces of Upper Cretaceous–Eocene age, covering an area of about 500,000 km^2 of the Indian Peninsula. It extends from central and western to the Arabian Sea and probably to Seychelles. The coastal geomorphology of West Coast of India is greatly controlled by the tectonics of the Deccan Volcanic Province (DVP). The structural framework of the DVP, along the West Coast, has been studied in great detail by many researchers. The important structural features include (1) The NW–SE trending West Coast fault[1–5], (2) N–S trending West Coast anticline[6–10], (3) Western Ghats escarpment[1,11–16], (4) Panvel flexure[18–24] and many NW–SE and E–W trending lineaments. The south-western DVP is dominated by NW–SE lineaments which are considered to be the transmission of the northwesterly structure of Dharwar-craton which presumably underlies the basaltic province[15,10]. These megastructures have probably originated due to uplift and rifting of the Western Passive Continental Margin[26]. Though these lineaments are considered to be faults, convincing field criteria to support such conclusion are, however, lacking. In this paper an attempt has been made to evaluate these lineaments on the basis of detailed structural analysis. The study area lies to the west of the Western Ghats escarpment between Harnai and Guhagar (Toposheet No. 47 G/1–4 and 8, 7) in the Ratnagiri district of Maharashtra (Figure 1).

The study area is marked by undulating hills. The hills are made up of horizontal basaltic lava flows with flat lateritic capping. The coastal line is remarkably straight with a few land protrusions into the sea. The beaches are very narrow and are characterized by vertical cliffs with flat rock beds. Vashishti and Shastri are two major rivers in the area, which originate from the Western Ghats escarpment and flow westerly into the Arabian Sea. The rivers are marked by right angle bends. Many tributaries meet these rivers at right angle, sometimes forming barbed joins.

The study of the IRS 1C LISS III FCC(532) reveals that the NNW–SSE trending coastline is the major linear feature in the area (Figure 2). Detailed analysis reveals that the coastline consists of many long northwesterly

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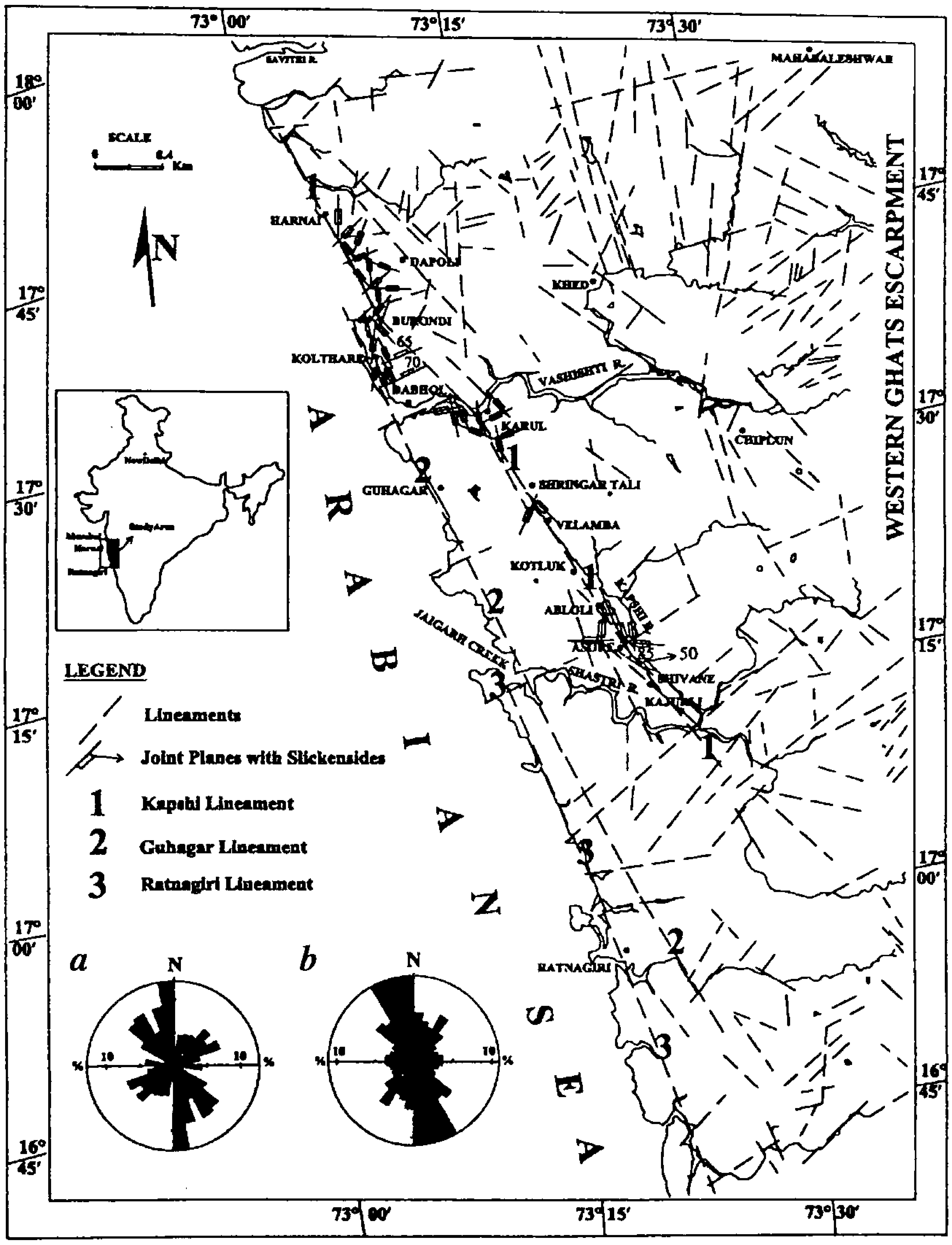

Figure 1. Lineament map of part of Konkan Coast, prepared from IRS 1C LISS III FCC (RGB 532). *Inset:* Location map of the study area. *a*, Length percent–azimuth rose diagram for lineament data; *b*, Frequency-Azimuth Rose diagram for joint data from field.

trending straight segments arranged in a right handed en-echelon pattern (Figure 1). These are connected by E–W trending short segments. As a result, an overall 'Z' pattern is discernible. The E–W offsets have become the site of confluence of the major rivers. Small islands occur invariably with narrow land connections immediately south of the confluence point (e.g. 1. North of Harnai, 2. Jaigarh creek, 3. South of Dabhol and 4. North of Ratnagiri). Further, the northwesterly straight segment of the coast is found to be in alignment with a northwesterly lineament which runs straight across the DVP for quite long distance. Three such lineaments have been picked up in FCC following the northwesterly straight coastline segment (Figure 1).

Similarly, the E–W trending segments follow into the land by the ENE–WSW trending lineaments which are, however, short compared to the NNW–SSE lineaments. The drainage pattern is strongly controlled by these two sets of lineaments. Though the major rivers flow westerly following the ENE–WSW lineaments, the river course is studded with a number of box meanders whose arms coincide with the NNW–SSE lineaments. Most of the smaller tributaries flow with straight courses coinciding with the above said lineaments and join the main river at right angle producing trellis pattern. Examples of barbed drainage pattern where the tributary join the main river in the opposite direction to the flow of the major river are also present. The coincidence of river channels with the lineaments underlines the structural control on the drainage pattern in the area.

A length percent-azimuth rose diagram (Figure 1 *a*) was plotted using the lineament map prepared from the

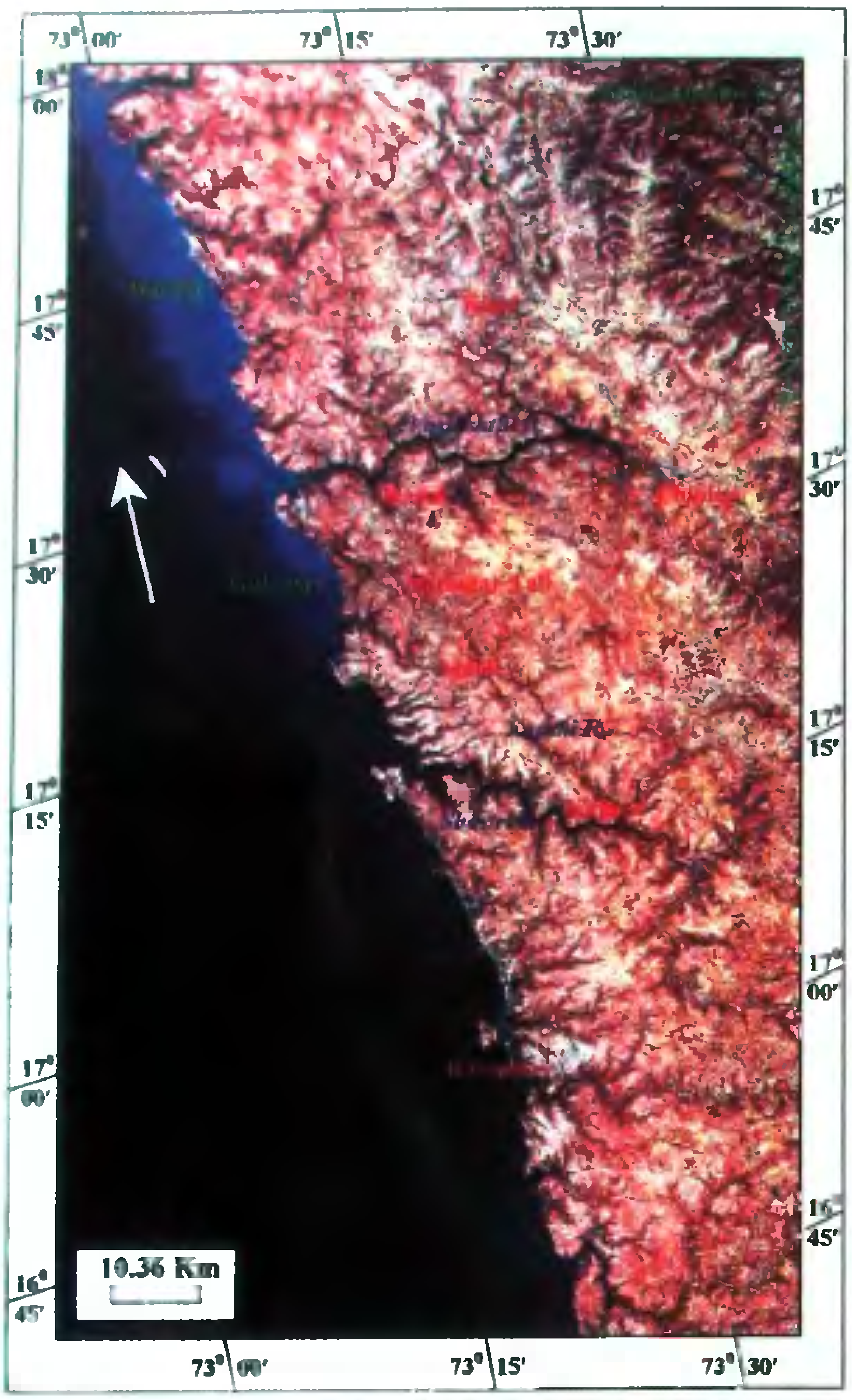

Figure 2. IRS 1C LISS III false color composite (RGB 532) of a part of Konkan coast.

FCC. In this, the length of each lineament class was plotted as percentage of the total length of all the lineaments taken together against the azimuth. The Rose Diagram shows the predominance of NNW–SSE to N–S lineaments over the ENE–WSW lineaments. The lineaments in the NNW–SSE direction are invariably larger compared to their counterparts.

In the field the Kapshi lineament was targeted to study. Mapping of this lineament was done right from Harnai to Kajurli. It was found that a narrow stream occupies the lineament with deep gorges in most parts. However, it passes over a water divide at Shringar Tali (Figure 1) from where the rivers flow in opposite directions. Along the main course of the river there are a number of natural ponding created by E–W blockades. The western bank of the stream is steeper than the eastern bank. The smaller streams meeting the river from west pass through many waterfalls (Figure 3 *a*) while the rivers flowing from east are gentle with open terraces. The basalt on either side comprises three flows such as the lower most vesicular basalt overlain by two jointed massive basalt flows. The contacts are almost horizontal showing a negligible dip (4°) towards SW. It has been observed that the contacts in the western bank however occur at higher elevation than that of the eastern bank, suggesting probable displacement along the river course. However, this difference is very less and of the order of about 10–15 meters. Further, the laterite cappings (and also the plateau surfaces) on either side of the river occur at different heights.

The fracture pattern along the lineament is studied in great detail. Nearly 200 joint/fracture data have been collected and plotted in Frequency-Azimuth rose diagram (Figure 1 *b*). The rose diagram obtained by this method was also observed to correlate well with the length–azimuth rose diagram (Figure 1 *a*) obtained from the lineament map. The fractures can be classified into two sets, of which the NNW–SSE set is more penetrative (Figure 3 *b*). The spacing between the fractures varies from 15 cm to ½ m. The rocks along the fractures are crushed. At places distinct breccia is produced. Quartz veins occupy the fractures (Figure 3 *c*). The width of the vein varies from few mm to 2 cm. The veins show pinch and swell structure and boudinage structure. The boudins are asymmetrical and are arranged in en-echelon manner (Figure 3 *c*). This is a clear evidence of shear origin of the boudins and fractures. At places the wall of the quartz veins and the faulted surfaces on basalt are exposed where slickenside striations are visible (Figure 3 *d*). These striations are mostly vertical to steeply plunging. This is a further evidence of faulted nature of the lineament. The nature of faulting is dip slip. Since the fractures are more or less vertical with gentle swing either to SW or NE, it is not possible to say at this stage the direction of faulting. Occurrence of a particular flow at a lower elevation on the eastern side with respect to the western side indicates a vertical down-throw of the eastern block. However, in view of the change in the dip direction from SW to NE, it is not possible to say about the normal or a reverse nature of faulting.

Oriented samples of the fractured basalt have been collected and studied under microscope. Sections were prepared perpendicular to the NNW–SSE planes. It was found that the rock consists of plagioclase phenocrysts floating in fine grained plagioclase + pyroxene matrix. The laths are extremely fractured (Figure 3 *e*) with fractures oriented primarily along NNW–SSE direction. The plagioclase laths show displacement along these fractures (Figure 3 *f*). Correlation with mesoscopic

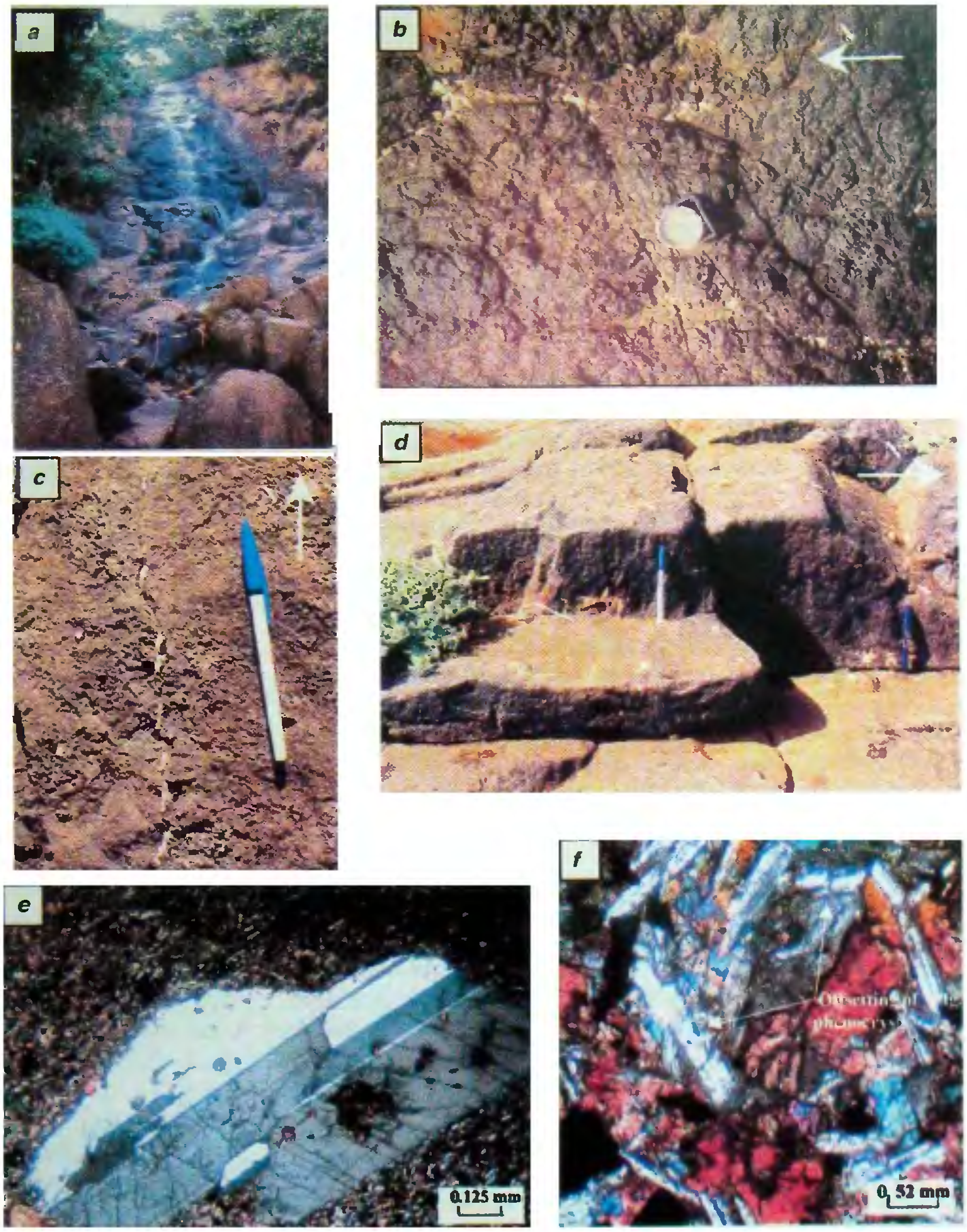

Figure 3. Structural and geomorphic evidences of faulting. ***a***, Water Falls across NNW–SSE trending fracture plane; ***b***, Shear fractures along NNW–SSE and E–W directions; ***c***, en-echelon quartz veins along NNW–SSE fracture plane; ***d***, Slickensides on NNW–SSE fracture surface; ***e***, Profuse fracturing of Plagioclase phenocryst showing preferred orientation of fracture planes along NNW-SSE direction; ***f***, Offsetting of Plagioclase lathes along NNW–SSE fracture plane.

structure reveals that these fractures are parallel to the NNW–SSE set.

Through correlation of large-scale structures with mesoscopic and microfabric framework it is certain that the NNW–SSE sets of fractures show characters of a fault. However the intensity of faulting may not be more. These sets of fractures are sympathetic to the NNW–SSE lineaments that are prominently observed in large scale. Hence it is believed that the lineaments have been activated resulting in dipslip faulting.

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ACKNOWLEDGEMENTS. We thank Prof. T. K. Biswal for his valuable guidance during the field and in the laboratory. We are also grateful to Prof. V. Subramanyan, Prof. K. V. Subbarao, and Prof. D. Chandrasekharam for their valuable discussions and suggestions. We are also thankful to DST for funding the project.

Received 26 July 1999; revised accepted 21 October 1999