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Determination of rifting vectors in Eastern continental margin of India: A combined study of Paleostress analyses and Remote Sensing data

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Summary

Rifting vectors in the Eastern continental margin of India have been ambivalent and are important for understanding the tectonics of the related basins. A combined study of paleostress analyses and remote sensing data has been employed to determine the rifting vectors. The results show the major rifting trend is NW-SE basement onwards, the basement shows a NE-SW extension in addition to the above.

Introduction

The rifting vector is essential to determine tectonic segmentation along any passive margins. A combined study of methodical field based paleostress analysis along with satellite images interpretation is useful to determine the rifting vectors. The same also helps to understand the basin evolution. Mesoscopic structures are used to derive orientations of stresses in rocks. Lineament analysis has also been used together with field studies to gain enhanced confidence on paleostress analysis for an improved understanding of the tectonics of a basin.

Tectonic studies in Indian sedimentary basins have been studied on satellite images or geophysical data but a combined field and remote sensing study has not been carried out. This study aims to analyse the tectonics of the Eastern continental margin of India from field and remote sensing data.

Objectives and Study area

The breakup of India and Antarctica during Early Cretaceous formed the basins along the Eastern Continental Margin of India (ECMI). The paleostress orientations of this rifting episode have remained ambivalent and a field study to analyse brittle deformation structures (fractures and striated faults) to obtain the rift-vectors was initiated.

Synrift sediments are exposed in certain locations in the basins of the ECMI viz. the Cauvery Basin, the Krishna-Godavari Basin and the Mahanadi Basin. The study area with the basins are shown in Fig. 1.The basement, prerift (wherever present) and synrift sediments were studied for analysis of brittle structures. The rift vectors derived from this study were then correlated with lineament analysis from ETM+ images for an enhanced control.

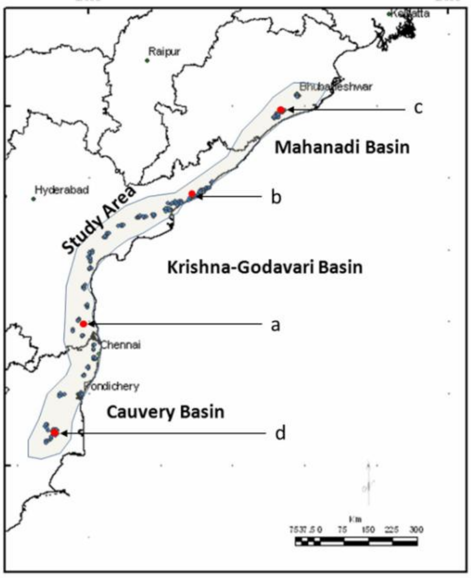

Fig. 1: Map of the study area with the basins of the Eastern continental margin of India. The blue dots represent the field locations. a, b, c, d refer to locations on field for corresponding field photographs in Fig. 2.

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Methodology

Fractures and striated faults are most commonly used for estimation of the paleostress orientations (Shah et al., 2007 and references therein). Extension fractures develop parallel to each other and are perpendicular to the minimum principal stress ($\sigma 3$) and their orientations were collected from the field. Movement of adjoining fault blocks cause striae to develop on fault planes. These striae can be used to determine the sense of movement of the fault.

Rift related faults reactivate, more often along pre-existing anisotropies or pre-existing faults and the orientation of faults in the sediments indicate the structural grain and structural grain in the basement provide a comprehensive idea about the rifting vectors in the sediments.

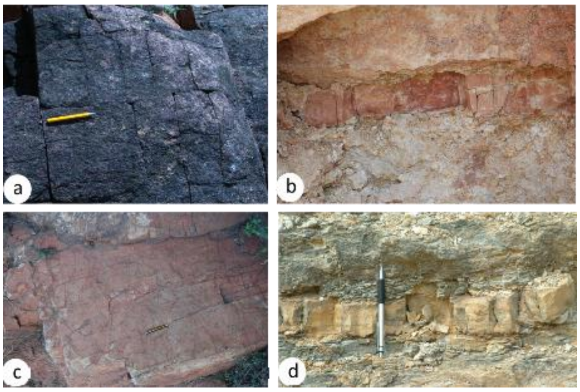

Fig. 2: (a) Parallel sets of extensional joints oriented N-S and E-W in garnet gneiss. The E-W joints are older than the N-S joints at this outcrop. The pencil points due E. (b) Ectension fractures in a sandstone bed sandwiched between thick clay beds. Termination of the fractures indicated clearly the extension nature of the joints. Photograph is 2m wide. (c) NNW and NNE striking, closely spaced extensional joints in the Khondalite gneiss near Chilka Lake. (d) Extension fractures in calcareous sandstone. The fractures strike in random orientations, dip consistently at very steep angles, terminate against the lithological boundaries, and show consistent spacing. Refer to Fig. 1 for locations of the field photos.

Field data (Fig. 2 shows the different structures in the field) in the form of orientations of the fractures and faults (poles to planes) are plotted on stereonets (lower hemisphere projections) with stratigraphic control. The poles are contoured and the highest concentrations of the pole plots indicate the directions of maximum extension (Fig. 3). In this figure, fracture data from one stratigraphic horizon is plotted on each of the stereoplots. The direction of maximum extension is NW-SE in all cases except in the Khondalite gneiss (Basement). There are two directions of extension in the basement and denotes an older extension, which is not manifested in the sediments. The size of the data is mentioned in each of the stereoplots in the figure. The data set has to be very large (preferably >30, excellent >100) to obtain improved control through this analysis. Most of these stereoplots were prepared from data size >100 points.

In the presence of striated faults (Fig. 4), the fault slip data were collected accurately in the form of orientation of the fault plane and pitch of the striae (slickensides) on the fault plane with the sense of movement. The biggest hurdle was that striated faults are either poorly developed or not developed in sedimentary rocks and naturally, in this study, the largest concentration was found in basement rocks. The large set of fault slip data were analyzed statistically to derive clusters of faults, which are likely to be similar in terms of deformation and different episodes of deformations were singled out from this statistical analysis. Graphical (dihedra and trihedra method, Ramsay and Lisle, 2000) and numerical inversion (direct inversion method, Angelier, 1990 & 1994) was done on the faults belonging to the different clusters to obtain the stress orientation and the shape factor respectively, for each of the clusters (Fig. 5). This analysis provides the principle stress orientations, as seen on the plots.

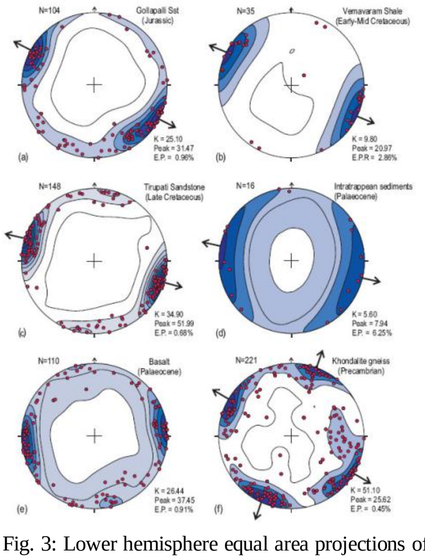

Fig. 3: Lower hemisphere equal area projections of the fracture data. Contours at s = 1.00. E. P.-% of each point. Arrows mark direction of maximum extension.

Lineaments (Fig. 6) were mapped on ETM+ satellite images (spatial resolution: 30 m) with utmost care to leave out anthropogenic features (e.g. roads, railways, boundaries, etc) and to preferentially pick large scale fractures and discontinuities. Rose diagrams (frequency- azimuth) were prepared from the lineament data (Fig. 7). The rose diagrams were correlated with the stress orientations derived from the paleostress analyses. The arrows on Fig. 7 mark the direction of maximum extension. There was ground truth already present in the form of extensive field data and the extension vectors were derived from the lineament analysis.

The complete process can be summarised in a workflow chart as in Fig. 8.

Fig. 4: Striated fault surface in outcrop. The steps point towards the right side of this photograph and that indicates the direction in which the missing block moved past the block that is present

Results and Discussion

The results of this analysis show that there is a NW-SE extension in the Krishna-Godavari basin sedimentary rocks, basalts, intra-trappeans and basement gneisses, which can be attributed to the rifting of India and Antarctica. The stress inversion results (done only on the basement gneisses) show that there are multiple basement reactivations in the form of thrust, oblique slip, strike-slip modes of deformation, where some of the structural grains can be attributed to the East Coast rifting episode. This analysis would not have a stratigraphic control i.e. the absolute ages for the corresponding deformations would not be available nevertheless the relative ages can be indicated.

The remote sensing analysis further strengthens the inference on the rift vectors. In the field study only small parts of a much larger area are covered, invariably due to obvious reasons. Remote sensing data provides the bridge to the gap for the entire area and since there is considerable agreement among the analyses, the remote sensing analysis supports the evidence from field.

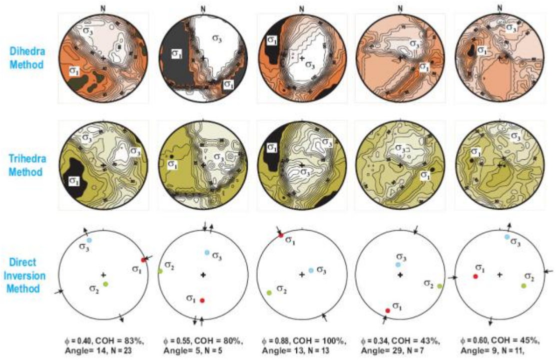

Fig. 5: Result of palaeostress analyses on five sets of fault obtained from cluster analysis. F – shape parameter, COH-%, of faults that agree with the solution, Angle- average misfit angle, N – number of faults.

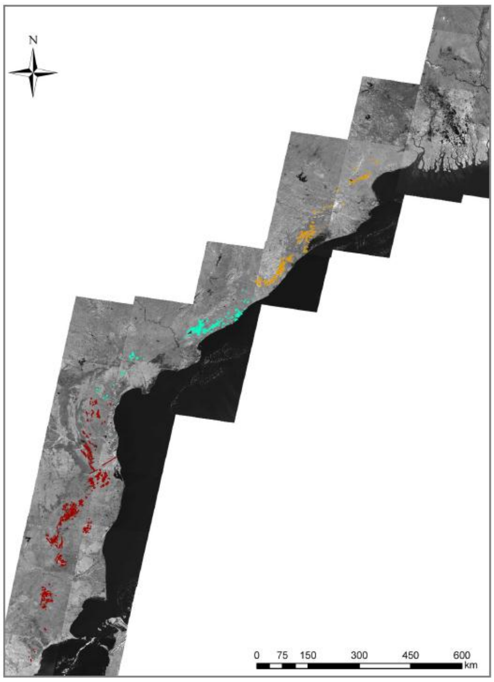

Fig. 6: Lineaments mapped on ETM+ images (Band 4) along the Eastern Continental Margin of India. The lineaments are colour coded; lineaments in the Cauvery Basin are coded in red, Krishna-Godavari Basin in Blue and Mahanadi in Yellow.

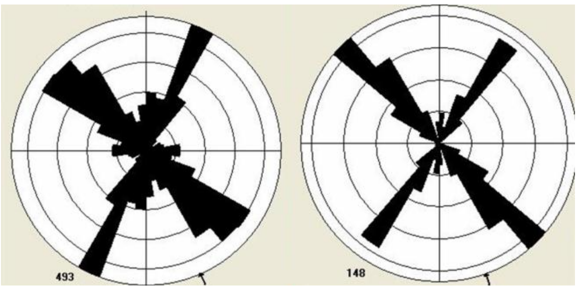

Fig. 7: Rose diagrams (frequency-azimuth) prepared from the mapped lineaments from ETM+ images. There is a strong alignment, one towards NW-SE and the other towards NE-SW. These lineaments when correlated with the ground data suggest a NW-SW extension for the passive margin. Sample size mentioned lower left of the plots. Arrows mark the direction of extension, which corresponds with those in Fig. 3 and 5.

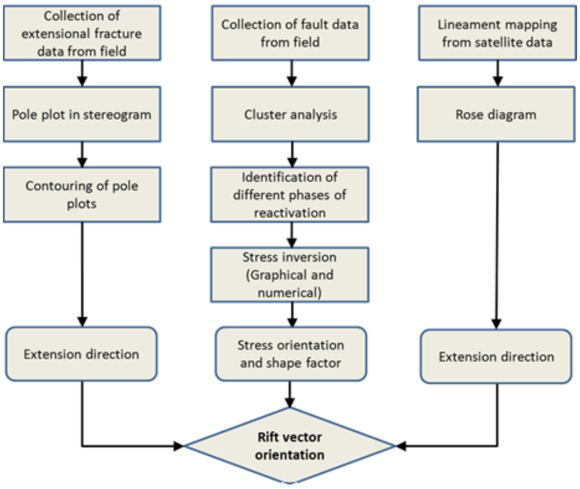

Fig. 8: Workflow chart for determination of rifting vectors from field data and lineament analysis from satellite images.

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