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Structural Features Of The Area Around Lanja, Distric Ratnagiri, Maharashtra, India

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Abstract: *The Konkan Coastal Belt (KCB) region is an excellent example of a tectonically controlled landscape whose physiographic features are the manifestation of the earth movements along theconfiguration of tectonic lineaments, joint, fracture patterns that was produced by the primordial fault pattern in the Precambrian basement. Fracture and joint patterns in the brittle crust of the Earth contain information on the stress and strain field during deformation. Faults, Fracture and joint patterns of the Lanja region of southern KCB have been studied to understand the (neo)tectonic setting of the study area.*

The major structural trend in the study area is nearly N-S that is NNW-SSE. This derived trend is in good agreement with the regional trend proposed by Powar (1993) and Michel and Widdowson (1991). The westward dipping listric fault is inferred from the field studies. This derived trend has played a pivotal role in its geo-morphotectonic evolution.

Key words: neo-Joints, fractures, Maximum principal stress (σ1) directions.

INTRODUCTION:

The continental scale passive west coast margin of India representing one of the rifted margins of world has attracted many researchers because to its unique spatial position and its major role in shaping the tectonic characteristics of India. Still there is ample of scope to dive in the research in tectonics of west coast margin of India. Northern part of this west coast margin of India is covered by voluminous Deccan basaltic lava flows, covering an area about half a million square kilometres erupted 65Ma representing K-T boundary, marked by mass extinction on a global scale. Coast parallel precipitous escarpment (Western Ghat Scarp) trending nearly about N-S direction recedes eastward due to intense weathering and generates a narrow lowland at its west and a plateau at its east forms three distinct morphotectonic units from west to east are Konkan lowland(Konkan Coastal Belt), Western Ghat Scarp (called Sahyadri in local Indian language) and Deccan plateau. Formation of these morphotectonic units, their evolution, seismic events, view of mantle plume theory in its formation as well as recent trends in remote sensing are source of this research.

Fig.1: Location map of the study area

Natural examples of fracture and joint patternscan have complex geometries including combinations of extension and conjugate shear fractures.Example of conjugate joint systems that are oriented with a small angle to the principalstress axis. The study suggests that fracture patterns can record complexdeformation histories that include primary uniaxial loading due to an overlying rocksequence followed by tectonic strain.

Fractures in rocks are surfaces or narrow zones of structural discontinuity (loss of cohesion) that are the product of mechanical rupture. This mode of deformation is defined as brittle failure; at higher temperatures and higher pressures, ductile failure (permanent deformation due to flow, but without loss of cohesion) may occur before the point of brittle failure is reached. Fractures may be dilational, i.e., joints (mode I fractures), or may exhibit shearing with components parallel (mode II) or perpendicular (mode III) to the direction of propagation of the fracture front. Shear fractures are also known as faults.

Elementary fracture mechanics:

Changes in hydrostatic stress cause volume change, but the existence of non-hydrostatic stress (i.e. the deviatoricstress tensor with non-zero elements) is necessary for deformation. The application of a small differential stress produces an instantaneous, recoverable deformation in an elastic solid. However, if the brittle failure criterion is satisfied, fracturing will result.

•EXTENSION FRACTURES (Mode I) form perpendicular to the minimum stress, and parallel to the maximum stress.
•TENSION FRACTURES are extensional, mode I fractures produced in response to a minimum stress that is tensile.
•SHEAR FRACTURES formed under triaxial compression, (the most common stress state in nature; see Twiss and Moores, 1992, page 172), may occur alone, or form a conjugate pair. Their planes form parallel to sigma 2, and form angles with sigma 1 that are less than 45 degrees. The planes of maximum shear stress lie at ± 45 degrees; however, at about ± 30 degrees, a balance is struck between a high shear stress, and a low normal stress, and failure usually occurs within a few degrees of a ± 30 degree angle with σ_1.
•tensile fractures can form at depth in an environment of compressive stress if the pore fluid pressure is high enough.
•The age relationship of truncating joints is unambiguous; truncated joints belong to a later episode (Pollard and Aydin, 1988, page 1190).

DATA USEDAND METHODOLOGY

In the present study, LANDSAT – 7 Enhanced Thematic Mapper (ETM+) digital data was used to locate the structurally interested locations to visit during field studies. Survey of India topographic maps (No. 47 H/5, 6, 9 and 10) of the study region of the scale 1:50000 and published District Resource Map – Ratnagiri District, Maharashtra (G.S.I., 2001) were used for geo-information and geo-referencing. During fieldwork 200 Ground Control Points (GCPs) were collected with attributes using a handheld Global Positioning System (GPS) receiver with an expected error of 3-4m. Most of the GCPs are the intersections of rivers and roads, bridges etc. This data was used for georeferencing and ground truthing of joint and fracture sets.

RESULTS AND DISCUSSION:

Joints observed across the coastal cliffs, along bedrocks of rivers and tributaries controlled by lineaments, and in Ghat region indicate that these are well coincide with N-S, NW-SE and ENE-WSW, the major lineaments. Figure 1 represents the structural map showing lineaments and joints recorded in the field. These joints occur either in the form of closely or widely spaced fracture cleavages, conjugate sets of fractures or in association with more than one trend. N-S joints are vertical to steeply dipping towards west, except those observed along the curvilinear lineaments. Strike variations of N-S joints along the linear N-S lineaments are in the range of N18^{0}W to N14^{0}E, while those along curvilinear lineaments (Agav- Mandavkar and Palu) are widely varying from N47^{0}W through N-S to N40^{0}E. NW-SE and ENE-WSW joints occur with N-S joints in the eastern region of the study area. Conjugate sets of fractures were observed in the plan view in the bedrocks of Dhokachi and Sakharpa streams as well as in the coastal cliffs and wave cut terraces. Details of the attitudes of joints and their morphological characters are described lineament and subzone-wise locations.

Joints along Coastal Lineaments (L5) and DTL Subzone:

The areas of observations include steep to vertical sea cliffs, Google earth images of wave cut terraces and bedrocks of stream segments in the DTL subzone. Very closely spaced joints were observed along the E-W face of the cliff. The most prominent fracture cleavages are seen in the cliff, near Kasop, Agargula and Adivre villages.

The cliff (Plate 1) near Kasop exhibits two types of vertical joints; 1) curvilinear N-S and 2) vertical conjugate. The conjugate sets of joints are vertical and smooth which terminate at curvilinear N-S joints, reveals that they are younger. The trend of a conjugate set of joints (Plate 2) is N12^{0}E and N70^{0}E. The dihedral angle between conjugate sets varies from 550 to 580. The bisecting axis of dihedral angle is N41^{0}E, which is the inferred maximum principal stress (σ_1) direction. Some of the vertical joints are trending N360E (Plate 3) and exhibit plumose marks which represent extensional joints indicating maximum principle stress (σ_1) direction. The maximum principle stress (σ_1) directions derived from a conjugate set of joints and plumose marks coincide well and nearly same.

Plate: 1: Costal rocks exhibiting vertical and curvilinear joint sets near Kasop.

Selected Google Earth images near the Adivre coast (Plates 4 and 5) exhibit wave cut terraces, cliffs and joints. The trends of exposed mega joints in the wave cut terraces are N23^{0}W and N33^{0}E. The dihedral angle between them is 560. Hence, the maximum stress direction determined is N40E. Map (Fig. 1) shows dominance of N-S lineaments controlling major coastal segments; however, both the Google images exhibit two cliff orientations. Major and minor cliffs are controlled by N-S and a conjugate set of joints trending N23^{0}W and N33^{0}E respectively.

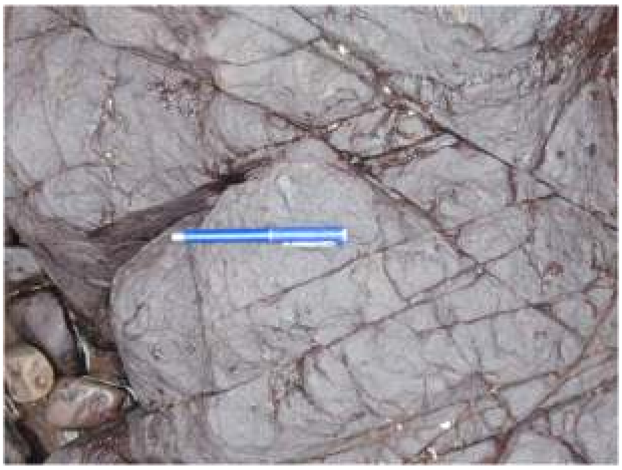

Plate 2: Plan view of conjugate set of joints, near kasop.

The observations made in the DTL near, a) Hatis village, located at the sharp bend of Kajali river, b) Kalthe, in the deep valley of the Dhokachi river in the north and 3) Solgaon, west of Rajapur in the south. The vertical widely spaced joints in the cliff of Hatis are trending N20^{0}E nearly to coincide with one of the conjugate set observed near Kasop. The potholes and small waterfalls in the bedrock of the deeply dissected Dhokachi stream near Kalthe exhibits joints trending N100E and vertical conjugate set of joints. The conjugate sets of joints (Plate 6) oriented in N18^{0}W and N42^{0}E, with dihedral angle 600. Thus the maximum principal stress axis (σ_1) inferred is N28^{0}E. The first order stream in the lateritic terrain, near Solgaon located west of Rajapur, is controlled by N-S trending joints.

Joints along N-S Trending L4 Lineament:

Vertical N-S trending joints and significant structures were observed in linear bedrock stream channels at three locations from north to south namely Jhapre, Rajapur and Shembavane (Fig. 1). Jhapre channel exhibit N-S vertical joints and potholes (Plate 4.13) on either banks indicating active deepening as a result of rejuvenation. The deep 'V' shaped tributary stream of Rajapur, near Bhatwadi, has 7 waterfalls of different heights and a group of widely spaced vertical joints are exposed in bedrock trending in the N12^{0}W direction. Similarly, a sinus mega-joint of length more than 69m was recorded in the Rajapur stream. This stream also exhibits cascades, number of N-S and NNW-SSE trending joints. A hot-spring is located near Rajapur, on the left bank of Kodavliriver. The road cut exposure near Shembavne displays few structures, namely, widely spaced vertical joint set and wavy jointing pattern in the form of antiform and synform associated with brittle fractures indicating signs of compressive stress, whose axes orients in N-S direction, revealing E-W palaeo-stress.

Plate 4.9: A cliff of vertical face of extensional joint showing plumose marks near Kasop

Joints in EFH subzone:

The Joints of various characters were observed in the northern Khorninko and southern EFH subzone. The Khorninko block exhibit widely spaced fracture cleavages and conjugate set of joints. The joint data is presented in the map (Fig. 1) suggest that widely spaced fracture cleavages coincide with the trend of Agav – Mandavkar (L1) and Palu (L2) stream channels. These joints are trending in the N430W in the northernmost channel segments and their strikes are gradually changing to N-S in the middle segments of the channels, whereas, southern segments show strikes trending in the N45^{0}E. These joints are steeply dipping in the range of 790 to vertical. In the northernmost area they are dipping towards southwest, in the middle towards the west while in the southern channel joints exhibit dip towards northwest.

Conjugate sets of joints trending in NNW-SSE and ENE-WSW are observed only in this block. These are observed mainly in the bedrocks of, i) Sakharpa stream near Kirbet, ii) Salpe stream, iii) 4th order Vilavade stream near Argaon and iv) Machkundi river near Vaghangaon and Belkanwadi. In general, the trends of these vertical joints are N30^{0}W to N47^{0}W, coinciding NW-SE lineaments and N720E to N80^{0}E, coinciding ENE-WSW lineaments while N6^{0}W to N18^{0}W coinciding N-S lineament. The closely spaced vertical fracture cleavages (Plate 4.17) trending N140W and dipping 840W in the bedrock of a stream along with waterfall are exposed near Argaon. One of the fracture surface exhibit slickenside (Plate 8) associated with comb fractures, orthogonal joints and gutters. These fracture sets and associated kinematic indicators are strong evidence of normal fault which coincide with the trend of NNW-SSE, the major lineament (N-S) in the study area.

Plate 4: Google image showing cliffs, wave-cut terrace and conjugate joint set of joints., near Adivre village.

Plate 5: Google image exhibiting N30^{0}W and N-S mega joints as well as beach deposits controlled by them. Location: near Adivre village

Joints in southern EFH block were studied in the bedrock of streams, along the curvilinear N-S lineament (L6) namely, Ojharti (Patelwadi) and Phuphere streams, also along Sukh river (L8), namely, Panhala, Bhatwadi, Kharepatan and Gaulwadi. These channels exhibit both bedrock and alluvium channels with numerous ponds and hence shows a poor exposure of bedrocks. The joints in the former streams are mainly trending in N-S direction, while those along Sukhriver exhibit trends from N39^{0}W to N43^{0}W. Last but not least, the Ghat section also shows the N8^{0}W trending closely spaced joint sets.

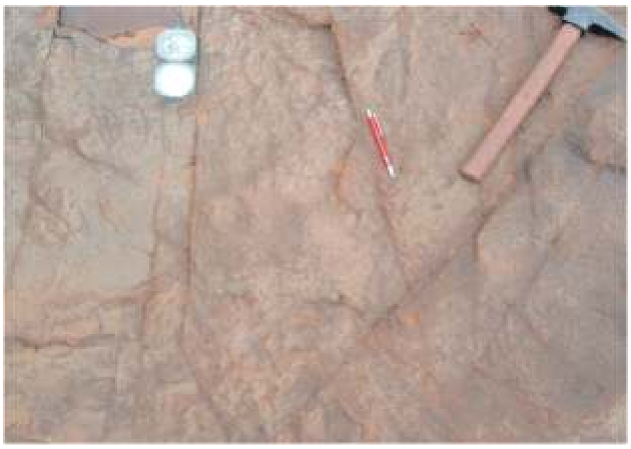

Fig. 6: Conjugate set and N-S joints observed in Dhokachi bedrock, near kalthe village.

CONCLUSION:

The study region is traversed by N-S, NW-SE, ENE-WSW and NE-SW trending lineaments. N-S lineaments are most dominating and control the landscape. Deep N-S curvilinear valleys controlled L1, L2 and L6 lineaments are inferred as normal listric faults. Fault planes of L1 and L2 are dipping towards west while that of L6 towards east. L1 and L6 listric faults separate the EFH and LRL subzones, whose foot walls and hanging walls are on opposite sides. Foot wall of L1 is towards east and that of L6 towards west. The NW-SE trending L7 lineament separates these listric fault system and represent the linkage between them and can be used to divide northern and southern EFH as Khorninko and Sukh blocks respectively. Thus this pattern of faults is responsible for the landscape development in the northern and southern EFH and LRL subzones. The trace of N-S linear lineament abutted at the curvilinear L2 lineament also indicates its younger age. Thus the traces of N-S lineaments recorded east of L2 lineament are relatively younger than curvilinear lineaments.

Plate 7: Vertical N8^{0}W trending fracture cleavages in bedrocks of tributary of Vilavade stream, near Argaon

The trend of fresh fault exposed near Argaon (Plate 4.18) coincides with the N-S linear lineaments. The kinematic indicators along this fault plane exhibits suggest the normal type of fault whose hanging wall is towards west. The fault plane of this fault is parallel to the closely spaced joint set recorded at its footwall. According to Stewart and Hancock, 1990, the locally developed and closely spaced joint set associated with small scale steep fault restricted to either or both the hanging wall and foot wall are shallow formed shatter zone accompanying subsurface neotectonic normal fault. Thus the small scale fresh fault and associated closely spaced joints, near Argaon, is the shatter zone lying in subsurface, above the neotectonic normal fault. The closely spaced joints are also recorded in the channel of khorninko (L3 lineament), which are oriented parallel to the Argaon fault suggesting L3 lineament is subsurface fault. L4 lineament coincides with the line of hot-springs indicating the presence of fault while L5 lineaments coincide with the West Coast Fault.

Analysis of neo-joint sets with respect to their orientation, style, geometry and architecture (Hancock and Barka, 1987; Stewart and Hancock, 1994) show that, these joints in most of the outcrops are systematic and belongs to well defined extensional sets and conjugate system.

Extensional joints:

The closely spaced vertical fractures associated with normal faults are extensional joints those orientations coincide mainly with the inferred N-S normal faults and neotectonic fault (L3). The trends of these joints vary along inferred listric faults lineaments in the range of NW-SE through NE-SW. In general, these are restricted to N-S linear lineaments in the range of NNW-SSE to N-S. The planar vertical joints abuts at the curvilinear joints in the coastal cliff (Plate 1) express their younger age. The planar vertical joints in plan view are conjugate.

Plate 8: Fresh fault plane showing slikenslide associated slickenline (S), comb fractures (C), orthogonal joints (O) and gutters (G) in bedrocks of Vilavade stream, near Argaon.

Conjugate sets of lineaments and joints:

Image analysis and DTA results brought out the trends of a conjugate set of NW-SE and ENE-WSW lineaments. Similarly, the mega joints appeared in the wave-cut terraces and in the coastal plains exhibit conjugate set of joints trending mainly in; 1) NNW-SSE and NW-SE, (N23^{0}W and N33^{0}E), 2) NNE-SSW and ENE-WSW, (N12^{0}E and N70^{0}E) and 3) NW-SE and ENE-WSW, (N45^{0}W and N74^{0}E). The former two conjugate sets are observed along the coastline and in the coastal plateau region respectively. The last conjugate set of joints mostly observed in EFH subzone.

The spectrum of a conjugate set of joints encloses dihedral angle close to 600 suggesting these are shear fractures. The maximum principal stress (σ_1) directions for first two conjugate sets are N5^{0}E and N41^{0}E, its mean comes to N23^{0}E, which coincides with the compressive stress direction of the 'mid-continent' regime imposed by the collision of the Indian subcontinent with Eurasian at the Himalayan boundary (Gowd et al, 1992). The maximum compressive palaeostress (σ_1) direction derived from third conjugate joint sets and the lineaments is in the WSW-ENE direction. This stress direction appears to be nearly similar to the intraplate stress field originating in the Central Indian Ocean, which is dominating in the South Indian Shield (Gowd et al, 1992).

Neotectonic Setting and Environment:

The lineament analysis and autocorrelation analysis of aspect (Fig. 3.22 and 3.24) have pointed out that the major structural trend is nearly N-S that is NNW-SSE. This derived trend is in good agreement with the regional trend proposed by Powar (1993) and Michel and Widdowson (1991). The N-S trending curvilinear deep valleys of Agav-Mandavkar and Palu (L1 and L2) are inferred as westward dipping listric fault while fault along L6 curvilinear lineament is eastward dipping. Likewise, the fresh normal fault observed near Argaon is parallel to the N-S structural trend / lineaments. Hence, L3 and L5 and other N-S trending lineaments are possibly normal faults. These fault lies in the EFH subzone that is in non-lateritic corridor of the coastal plain of post mid-Tertiary age. The presence of a number of normal faults in the region supports extensional tectonics.

The neo-joints in the inferred listric faults and observed fresh fault near Argaon are steep, closely spaced and represent the extension fractures. The fresh fault exhibit comb fractures perpendicular to fault plane and closely spaced orthogonal joint set. According to Stewart and Hancock, 1994, such association in fresh fault are accompanying subsurface neotectonic normal fault. According to Hancock and Engelder, 1989, the neotectonic joints are a special category of unloading joints formed close to the earth's surface caused by tectonic / residual stresses after uplift. Such neotectonic joints are much more abundant and wide spread than faults which occur in the uppermost 1-2km at the earth's crustal level and uniformly oriented throughout the intra-plate region (Stewart and Hancock, 1994). The NNW-SSE structural anisotropy derived from autocorrelation analysis of aspects reveals dominating structures in the study area are neotectonic.

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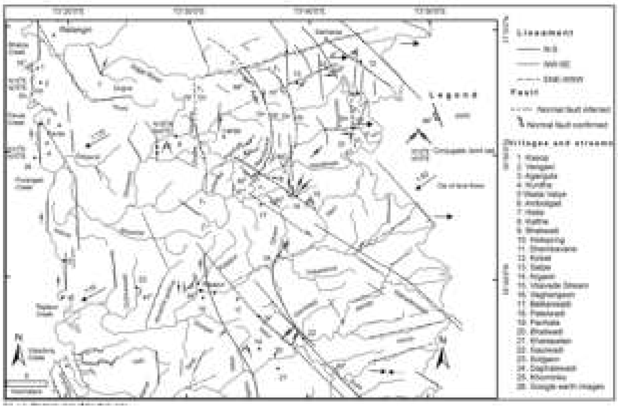

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