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SEISMIC AND BATHYMETRIC STUDIES OF AREA AROUND LANJA, DISTRICT RATNAGIRI, INDIA.

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Abstract:-The western part of India is one of the seismotectonic provinces. West coast of India has experienced number of shallow to moderate scale seismic events. These seismic events have proved that the west coast of India is tectonically active regime. To understand its tectonic activity, an attempt has been made to correlate the seismic events with the major lineaments formed in the study area as well as its impact on offshore region with the help of bathymetric data. The results show the continuity of onshore structures, lineaments and seismic events with that of the offshore structures and lineaments.

Keywords: Bathymetric data, seismic zones and events and correlation.

I.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.

Major aspects of morphotectonic studies are lineaments, river valleys, basins, coastlines, isolated hills etc. The processes, structures and landforms associated with tectonic deformation of the earth's crust modify the relief and rate of erosion of the affected regions. Study of topography gives a first hand and indispensable indication of the distribution and arrangement of morphological features within a region. Remote sensing is the useful tool to identify geomorphic and tectonic features and therefore it helps to understand morphotectonics of the study area. In this paper, remote sensing data of LANDSAT ETM+ were used to recognize geomorphic features, lineaments and prepared maps of lithology and lineaments of the area around Lanja, District Ratnagiri, Maharashtra state, India (Fig.1)

Fig.1: Location map of the study area

The Indian shield is believed to be Stable Continental Region (SCR). According to Mahadevan (2004) the western continental margin of India is one of the seismotectonic provinces. West coast of India is a passive margin and has experienced few numbers of shallow earthquakes in the last 200 years whose magnitude was in the range of 2.0M to 6.0M. The morphotectonic features, the Arabian Sea, KCB and the Western Ghats are paralleling the west coast. Post magmatic tectonism is responsible for down faulting and submergence of the western part of DVP under the Arabian Sea. The continental shelf of Arabian Sea, west of the west coast fault has a series of Horst and Graben.

There are a number of views regarding major structures and seismicity along the west coast margin of India. According to the Raja Rao et al, (1978) the thermal springs along the coast and seismic events in the west coast region are manifestation of thermal and tectonics activities. Intra-plate seismicity has been attributed to the reactivation of basement faults (Gowd et al, 1996) especially in the rifted passive margins (Stein et al, 1989) and to the intersection of faults (Talwani, 1989). According to Chandra (1977), Gaur (1994) and Khatri (1999) the earthquakes in the shield areas are generally attributed to the Himalayan collision tectonics. The seismicity of the Indian shield operates in this compression field generated by the plate boundaries as; i) backthrust from Himalaya and ii) ridge push forces from expanding Carlsberg ridge (Gowd et al, 1992). According to Widdowson and Mitchell (1999), the continued isostatic adjustment in response to denudational unloading and offshore sediment loading of the Indian passive margin through the retreat of the Western Ghat escarpment, augmented by extensive removal of basaltic cover east of the Ghat, are major contributory causes of a continued seismic activity in the southwestern Deccan region. Geomorphological evidence also supports the theory that the Ghats are a consequence of Cenozoic uplift, rifting and down faulting (Radhakrishna 1993). Presence of numerous linear hot-springs in the KCB represents the openness of the fracture system and can be ascribed as high heat flow regime and might have played a role in the thermal amplification of compression stresses. The geothermal province in West Coast coincides with the extensional regime and developed N-S trending fault system during the Quaternary period, due to unequal uplift of the western margin. These faults proved to be sources of stress accumulation and sites of normal faulting resulting in E-W extension due to block adjustment along the N-S plane (Reddy et al, 2000). The west coast is characterized by high uplift and/or subsidence due to relatively large deformation, magmatism, high heat flow and hot springs (Raval, 1995 and Gowd et al, 1996). In this context seismic and bathymetric data of the study area were analyzed to understand the relationship between recent seismicity and tectonic features.

DATA USED AND METHODOLOGY:

Seismic data and 1 min. bathymetric grided data were used for seismic and bathymetric analyses. The seismic data were acquired from India Meteorological Department (IMD) in the form of; location of epicenters (latitude, longitude), magnitude, depth of focus and date of event. Seismic data were used for plot of frequency versus magnitude and to superimpose the locations of epicenters on a lineament map of the study area. The magnitude and depth of epicenters were compared with individual lineament and with the interactive online geophysical map published by the Geological Survey of India (GSI).

General Bathymetric Chart of the Oceans (GEBCO) provides global bathymetry gridded datasets for the world's oceans in 30 arc sec (roughly 1 km at the equator) and 1 min grids available for download from British Oceanographic Data Centre (BODC; http://www.bodc.ac.uk). The bathymetry of the study region was obtained. The resolution of the data was found to be ideal for detection of submarine channels which are of a larger dimension compared to onland river systems. The GEBCO is in the form of digital elevation model (DEM) compatible for processing, analysis and interpretation within a geographical information system (GIS). The GEBCO DEM was processed for the derivatives in a GIS environment and submarine channels were extracted using a workflow model given by Kundu and pattanaik (2011). The GEBCO DEM was also used to generate a digital profile and slope aspect map (Fig. 6.6C). Offshore lineaments were recognized and extracted by visual interpretation with the help of submarine channels and dominance of aspect orientations (Fig. 6.6D).

REGIONAL OFFSHORE STRUCTURES:

India's continental margin is characterized by features such as 1) a wide continental shelf extending NW-SE, 2) a noteworthy straight shelf edge bordered by 200m isobaths, 3) a narrow continental slope bounded between 200m and 2000m isobaths and 4) the oceanic basin of the Arabian Sea (Fig.6.1). The shelf is 3000km wide in the Kutch-Saurashtra area but gradually narrows down southward to 50km in Kerala offshore, complemented to this, the continental slope is narrow in the north but widened towards south. As a consequence of rifting and seafloor spreading between India, Madagascar and Seychelles several structural features have evolved in the eastern Arabian Sea and the adjoining West Coast of India (Naini and Talwani, 1982; Biswas, 1988). Biswas (1988) suggests that many of the structural trends and basement features in the region have been inherited from the Precambrian structural grain of the western Indian shield. Ghosh and Zutshi (1989) observed that the structural trends seen in the offshore areas have become complicated by later shearing movements along the shelf edge. They have also reported the presence of listric faults around the Mumbai region. Laxmi-Laccadive ridge and depression close to the slope are the prominent features in the Arabian Sea. These ridges and depressions are characterized by a number of narrow Horst and Graben features created by extension. The west coast is marked by NNW-SSE trending horst and graben structures. Malod et al. (1997) inferred that the oceanic crust north of Laxmi ridge has been formed before 64 Ma due to spreading around a triple junction connecting the oceanic Laxmi basin, Narmada Son lineament and the Cambay rift. Talwani and Reif (1998) also proposed that the opening of Laxmi basin predates the emplacement of Deccan volcanism and the ocean-continent transition is located below the eastern margin of the Laxmi basin. They further suggest that the seismic velocities greater than 7.0 km/sec in the region represent the initial oceanic crust. On the other hand, Miles et al. (1998) proposed thinned continental crust in the Laxmi basin and noted the existence of underplated crust below the Laxmi ridge and Laxmi basin. They further suggest that the basement features in the Laxmi basin may be due to large scale intrusions. According to Todal and Eldholm (1998) formation of Deccan Continental Flood Basalts (CFB) is related to syn-rift-to-break up volcanism during separation of Seychelles from India and suggested a three stage tectonic model comprising of continental extension and fan-shaped spreading between India and Seychelles.

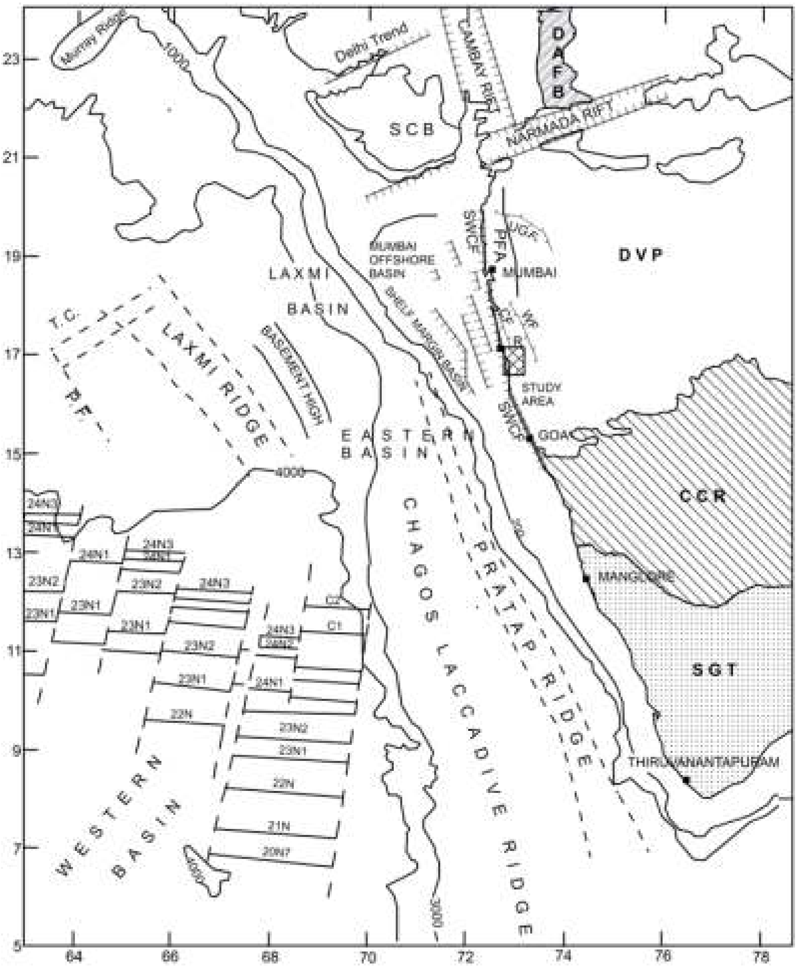

Fig. 2: Tectonic and structural trend map of the eastern Arabian Sea and the adjoining West Coast of India. Tectonic and structural details of the western Indian shield and the offshore areas are adopted from Biswas (1982, 1987) and Subrahmanyam et al. (1995). Lines with numbers in the Arabian Sea are magnetic anomaly identifications from Chaubey et al. (1995) and Miles et al. (1998). Dashed lines indicate fracture zones. P.F – Pseudo fault; T.C. – Transferred crust; DVP – Deccan Volcanic Province, CCR – Central Cratonic Region; SGT – Southern Granulite Terrain; SCB – Saurashtra Continental Block; GH – Girnar Horst; FL – Fermor Line; DAFB – Delhi Aravalli Fold Belt, PFA – Panvel Flexure Axis, SWCF – Segmented West Coast Fault (Campanile, 2007), CF – Chiplun Fault, WF – Warna Fault (Seismotectonic atlas of India, GSI, 2000) (Modified after Radhakrishna, et al., 2002).

REGIONAL SEISMIC AND GEOPHYSICAL DATA:

Mahadevan and Subbarao, 1999, classified the DVP into five major crustal provinces on the basis of tectono-magmatism. Five crustal provinces are as follows;

1.The western pericontinental Belt of Active Rifts (BARS),
2.The Sourashtra Continental Blocks (SCB),
3.The Horst-Graben Narmada – Tapti – Son belt (SONATA),
4.The platformal region, south of the SONATA belt and east of BARS, referred as the SE Platform Block (SEPB) and
5.The North-Eastern Platformal Block (NEPB) north of SONATA belt, comprising Malwa plateau and surroundings.

Mahadevan and Subbarao, 1999, further divided BARS into three parts, such as:

a.The offshore faulted region, seaward of the present coast of which Cambay rift is a continental vestige and along which sedimentation exemplified by the oil-producing “Bombay High” has led to considerable loading and flexuring of the crust.
b.The coastal plains (KCB) characterized by rift cushions (as at Cambay and Ankaleshwar), thinned lithosphere and

asthenosphere upwelling, and
c.The geomorphologically high Western Ghats with a west looking scarp that was possibly the shoulder zone of the western pericratonic rift.

As per the above classification, the study area belongs to the coastal plains from the BARS province of DVP. The seismotectonic characters of five provinces are given in the table 6.1, which indicates that no large scale recorded earthquakes have occurred in the KCB.

The number of earthquakes occurred in the BARS are more than those occur in other provinces, however, the cumulative moment release and strain rate per year are relatively medium in comparison with other provinces. This indicates that the Konkan coastal zone and adjacent Ghat are of moderate to low seismicity <6.0M. The earthquakes generated in the BARS province are mostly shallow focus, whose depth varies from 0 to 8km, but some registered hypocenters are ~ 30 km deep and the intensities of these earthquakes fall in the range of < IV to VI.

Drainage patterns in the northern KCB (West coast) are controlled by lineaments and there are evidences of faulting and some of which are likely to be seismogenic (Subramanyan, 1981).

Mahadevan and Subbarao (1999) opined the regions of BARS are experiencing differential uplift. Nair (1990) has correlated the neotectonic activity along the Western Ghats to transform faults of the Carlsberg Ridge. According to Subrahmanyan et al. (1995), the seafloor spreading related to the Carlsberg Ridge is responsible for the reactivation of ENE-WSW and NE-SW trending Precambrian lineaments on the Western continental margin.

Table 1: Comparative seismic characters of five provinces (After Radha Krishna and Mahadevan, 2000).

Region	No. of earthquakes	Maximum Magnitude	Cumulative moment release X 10^{24} dyne cm	Strain rate Yr^{-1}
SCB	07	5.5	6.8	4.2 x 10-11
BARS	70	6.0	29.62	1.49 x 10-10
SONATA	12	6.3	57.7	1.2 x 10-10
Godavari Graben	06	5.7	1.52	1.7 x 10-11
Kutch seismic domain	26	7.8	4233.4	3.5x 10-8

Seismicity in this region opens up weak planes in the form of deep-seated fractures and joints and triggers the land-sliding events (Valdiya, 2004). Figure 3 Vulnerability Atlas of India based on the Seismo-tectonic map of India, corroborates the seismotectonic structures.

According to Balakrishna (2001) a zone of high gravity gradient between negative anomalies on the continents and positive anomalies in the sea infers the West Coast Fault. It has several sections separated from each other by horizontal shear. The Mohorovicic discontinuity below the Deccan Plateau is at a depth of 37-42km (Narain et al, 1987) about 30km along the west coast (Kaila et al., 1987) and 13-14km below the continental shelf at the Arabian Sea (Babenko et al, 1981) (Fig. 6). This coastal thinning along the coast and continental shelf and thickening in the plateau region indicate the isostatic uplift (Crough, 1978), involving the crust.

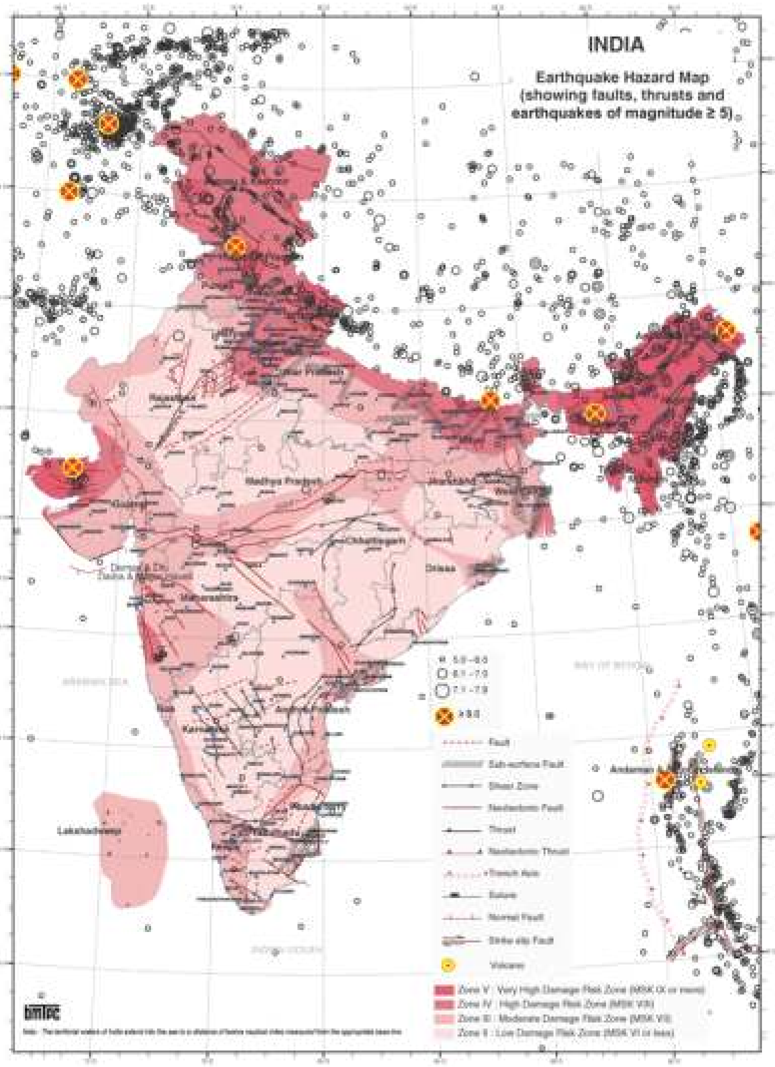

Fig. 3: Vulnerability Atlas of India. A map based on digitized data of SOI, GOI, BIS, Seismic Zones of India Map, IS:1893-2002 and Seismotectonic Atlas of India and its Environs, GSI. Publisher: BMTPC, Building Materials and Technology Promotion Council, Ministry of Housing and Poverty Alleviation, Government of India.

SEISMIC AND GEOPHYSICAL DATA OF STUDY AREA:

Table 6.2 represents the records of available recent and historical earthquake data from various resources. This data indicate that the magnitudes of earthquakes are in the range of 2.2 to 5.4M and focal depth ranges from near surface to 33km. The plots of seismic frequency versus magnitude (Fig. 4) exhibit that the frequency ranges from 4.1 to 5.0M.

Figure 5 is a lineament map of the study area wherein the data of epicenters of earthquakes are superimposed. This map indicates that the most of the epicenters of recent earthquakes coincide with 1) the lineaments; the order of dominance is L3, L4 and L5, and 2) more concentration of epicenters along L3 and L4 and at intersection of NW-SE and ENE-WSW lineaments. This map also shows that the magnitudes of earthquakes along L3 and L4 are higher in the range of 2.2 to 5.0M, while magnitudes are lower along L5 (3.4 to 3.9). The focal depth of earthquakes along L3 lineament and the areas adjacent to it are relatively deep and most of them are at the depth around 33 km and few of them are medium to shallow depth (5 to 10km). The focal depths along L4 and L5 are 15 to 33km and 10km respectively. Thus it tends to infer that the weak zones exist along L3 and L5 up to the depth of 33km.

Figure 6 is a geophysical map published by GSI, showing the thickness of DVP, Bouger gravity contours, Moho depths and a fault line traversing the lava flows and basement. The major lineaments, the coastline, coastal belt and escarpment are parallel to Moho depth contours. The L3 lineament shows continuation with the fault recorded by the GSI.

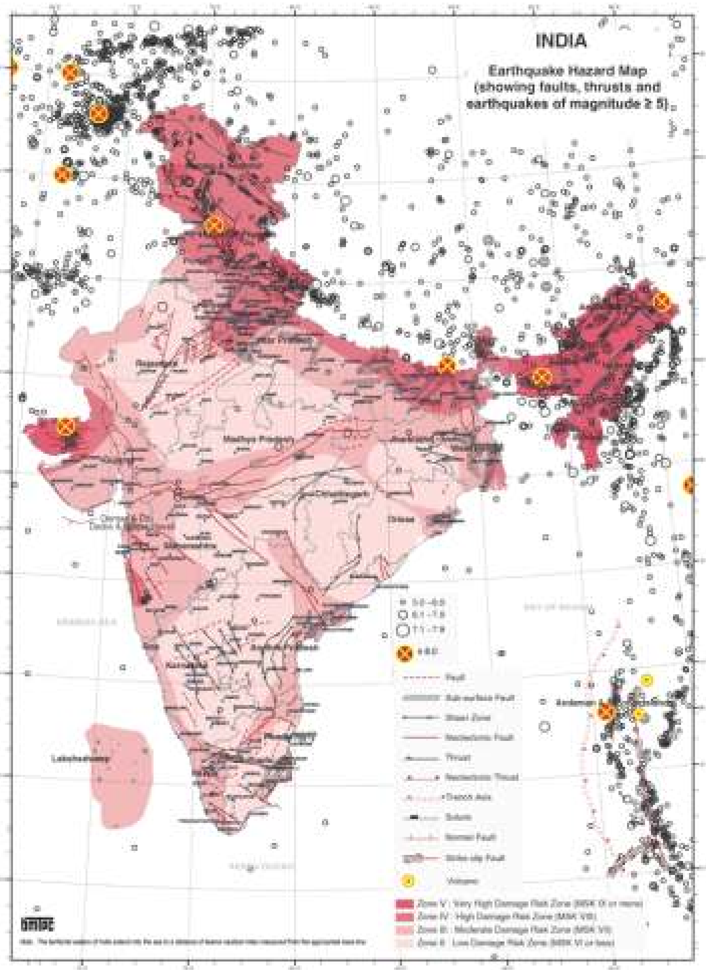

Table 2: Seismic data of the study area.

No	Lat	Long	Mag.	Depth	Date	Reference
1	17.00	73.30	5.0	0.0	28/05/1941	S&W
2	17.00	73.30	3.0	0.0	04/08/1951	S&W
3	17.00	73.40	5.4	0.0	06/04/1965	IMD
4	17.00	73.50	4.3	0.0	19/05/1967	R&M
5	17.00	73.30	4.0	0.0	12/10/1967	S&W
6	17.00	73.30	4.0	0.0	12/10/1967	S&W
7	17.00	73.30	5.0	0.0	12/10/1967	S&W
8	16.90	73.60	5.0	0.0	12/10/1967	S&W
9	16.60	73.50	5.0	0.0	12/10/1967	S&W
10	16.60	73.30	5.0	0.0	12/10/1967	S&W

11	16.60	73.29	3.4	0.0	20/11/1979	J&S
12	17.02	73.86	4.5	33.0	10/04/1980	ASC
13	16.95	73.79	5.4	3.0	20/09/1980	ASC
14	16.84	73.70	5.0	3.0	20/09/1980	ASC
15	17.02	73.83	5.0	33.0	25/09/1983	ASC
16	16.87	73.40	0.0	10.0	06/05/1987	IMD
17	17.00	73.70	4.9	33.0	12/08/1993	IMD
18	16.88	73.68	3.8	10.0	20/03/1997	J&S
19	17.00	73.68	4.1	10.0	20/03/1997	IRIS
20	16.84	73.52	2.4	15.0	16/10/1999	IMD
21	16.84	73.48	3.0	9.0	27/02/2000	IMD
22	16.87	73.70	5.1	33.0	04/06/2000	ASC
23	17.04	73.50	4.2	33.0	12/08/2000	J&S
24	16.90	73.75	5.2	33.0	03/12/2000	ASC
25	16.83	73.51	4.5	0.0	08/02/2001	ASC
26	17.04	73.94	3.1	5.0	15/03/2005	IMD
27	17.03	73.71	3.9	0.0	15/03/2005	ASC
28	16.82	73.25	3.8	10.0	26/03/2005	ASC
29	17.00	73.60	3.9	0.0	26/03/2005	ASC
30	16.95	73.31	3.9	0	26/05/2005	ASC
31	17.00	73.75	4.9	33	30/08/2005	ASC
32	17.00	73.30	3.0	0.0	26/12/2005	S&W
33	16.89	73.60	3.7	10	21/05/2006	ASC
34	16.91	73.71	3.9	0.0	21/05/2006	ASC
35	17.04	73.72	2.2	2.0	07/07/2006	IMD
36	17.03	73.68	2.6	5.0	12/07/2006	IMD
37	16.97	73.45	3.9	0.0	20/08/2007	ASC
38	16.96	73.70	4.8	10.0	24/11/2007	IMD
39	17.00	73.30	4.0	0.0	30/07/2008	S&W

S&W: Stacey Martin and Walter Szeliga, http://ascindia.org/menu/gquakes.htm.; IMD: India Meteorological Department; R&M: Radha Krishna, M. and Mahadevan, T. M. (2000); J&S: Jaiswal and Sinha, (2005), www.earthquakeinfo.org; ASC: www.asc-india.org; IRIS – Incorporated Research Institutes for Seismology, New York; http://www.iris.edu

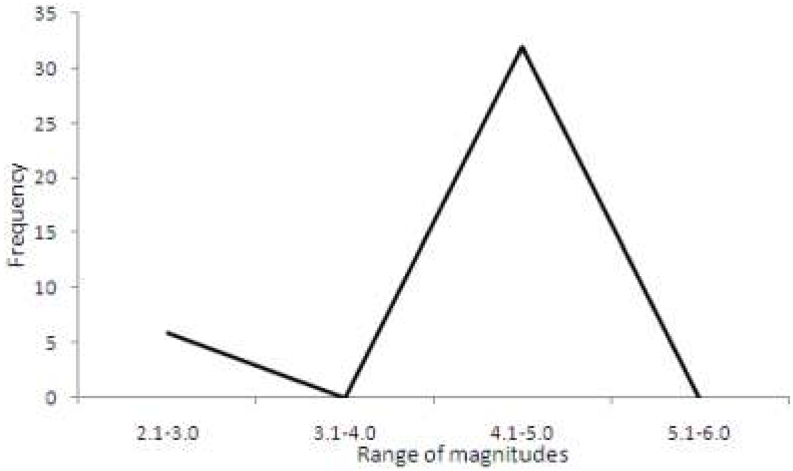

Fig. 4: Frequency curve of the magnitudes of earthquakes occur in the area.

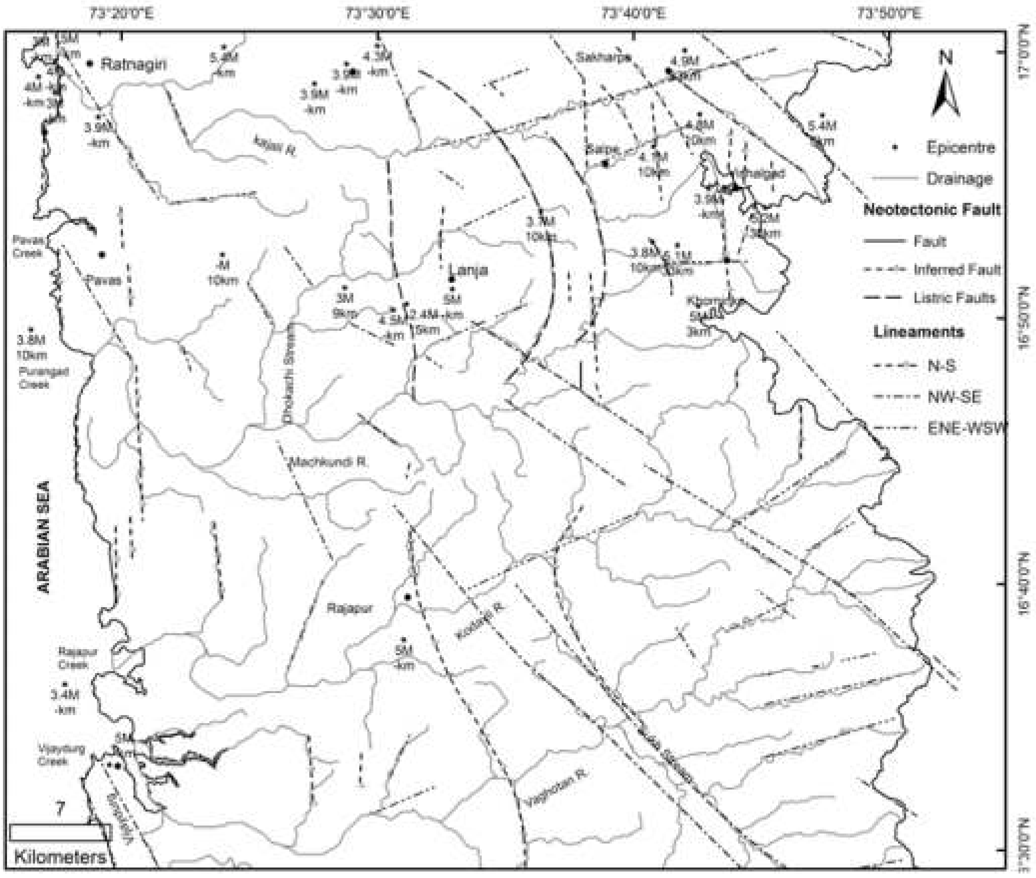

Fig. 5: Seismo-lineament map of the study area. Locations of Seismic events are supplemented with magnitude and depth of focus. – km indicate no record of depth.

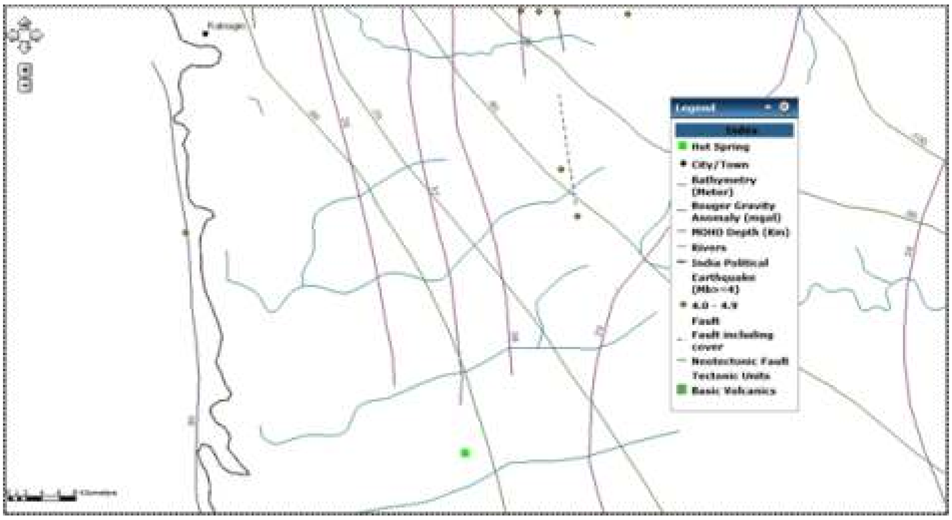

Fig. 6: Geophysical data map of the study area. Blue straight lines represent DVP thickness, green lines indicate Bouger gravity contours, red contours depicts Moho depths and dashed line indicate fault including cover. (Online map published by GSI, http://www.portal.gsi.gov.in/gismap/seismotectonicmap/default.aspx)

BATEMETRY:

The term "bathymetry" originally referred to the ocean's depth relative to sea level, although it has come to mean "submarine topography," or the depths and shapes of underwater terrain. In other words, bathymetry is the underwater equivalent to topography. Bathymetric charts are typically produced to show seafloor relief or terrain as contour lines (called depth contours or isobaths). Bathymetric maps can also be represented by Digital Terrain Model and artificial illumination techniques to illustrate the depths being portrayed. Variations in sea-floor relief may be depicted by color and contour lines isobaths. Bathymetric data analysis helps to get a picture of the sea? oor and mapping morphotectonic features.

Advances over the past two decades in the development of geospatial tools for processing bathymetry have enabled the observation that has revolutionized our understanding of deepwater systems and processes (Sager et al., 2004). Clark et al., 1992, published a comprehensive study of submarine river channel morphologies and lithology worldwide, concluding that the geometry of submarine channels is dominantly influenced by the geometry of the receiving basin. Nayak, et al, 2011, have reported the existence of river channels and depositional environments in the offshore region by shallow seismic data. Kundu and Pattanaik, 2011, have mapped the submarine river channels along the west coast of India with the help of bathymetric digital data and established analytical relationship between on-land and submarine streams by GIS method.

Results of Bathymetric DEM:

Figure 7A represent DEM of the study area and the offshore region of west of it, whereas, figure 4B represents a digital profile along X-Y line shown in figure 7A. This DEM depicts inland as well as offshore physiography of bathymetry and relief of the continental shelf and slope. The digital profile indicates that the shelf is relatively flat and gently sloping towards SW. A steep slope between -1000 to -3000m separates continental shelf and slope. The continental shelf narrows towards south. The trend of the continental slope is NNW-SSE. The relief, aspects of slope and submarine drainage channels tends to separate the continental shelf broadly into two subzones; eastern and western. Eastern subzone is very gently sloping while western subzone is flat. Submarine channels in the eastern subzone are in E-W direction while that in western are NE-SW direction.
Figure 7 C is the slope aspect map generated using bathymetric DEM. The slope aspect map shows the dominance of aspect in the NNW and west directions. Discontinuities in the slope aspect and sudden change in the orientation of marine channels are distinctly seen and these were the criteria used to recognize and demarcate the lineaments (Fig 6D). The pattern of offshore aspects is nearly identical to that of aspects of the study area. The trends of lineaments are mainly N-S and NW-SE direction. Thus, offshore lineaments (Fig. 7D) well coincide with the submarine faults and the trend of RatnagiriGraben (Biswas, et al, 1987) and the inland lineaments, inferred faults and to the offshore extension of Vijaydurg fault (Gujar et al, 1986).

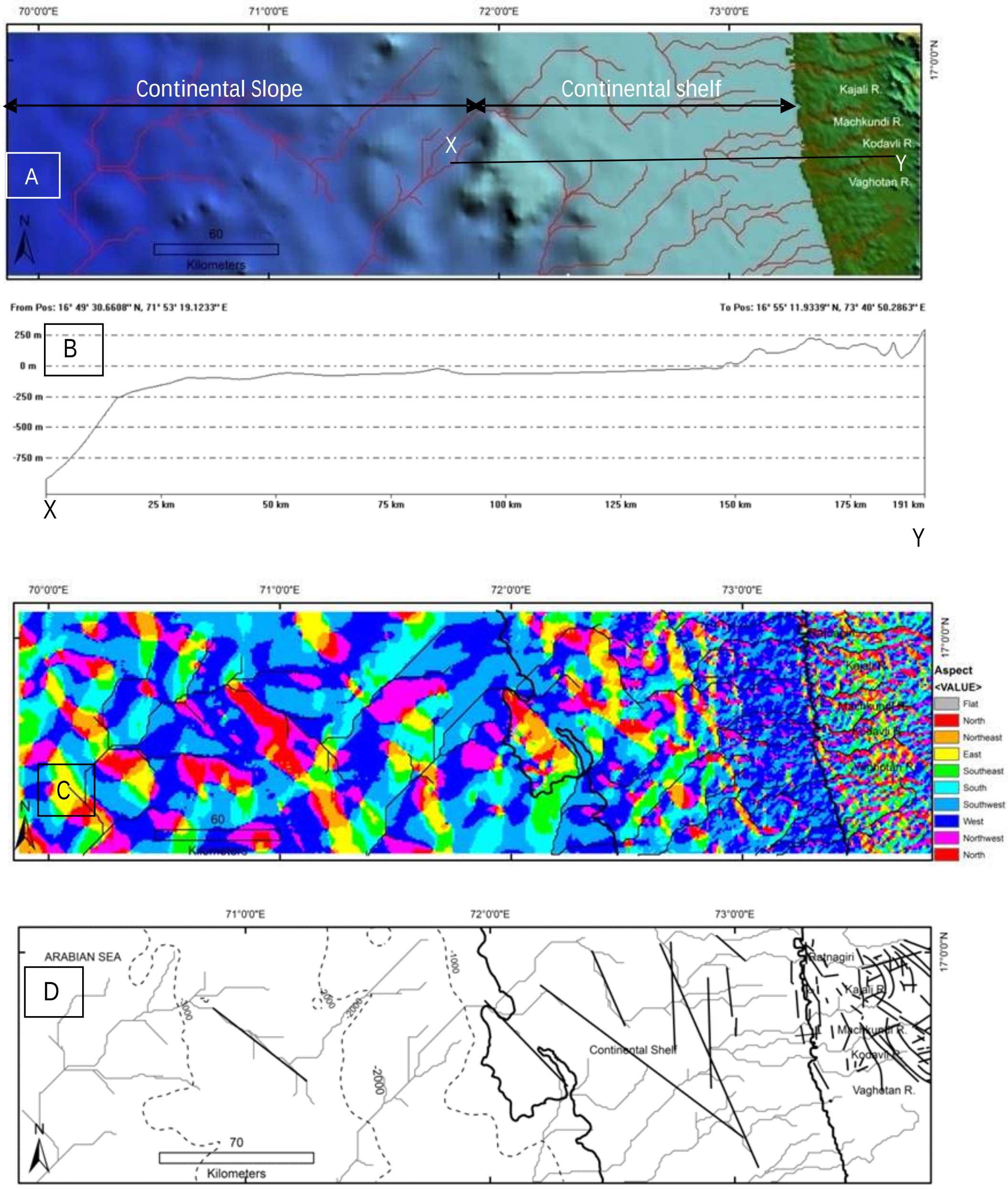

Fig. 7: (A) DEM of the study area and bathymetry overlaid by offshore streams. X-Y: a line along which digital section has drawn, (B) A digital cross section along X-Y as shown in figure 6.6 (A), (C) Aspect map and (D) Offshore lineament map.

The submarine channels coincide with the inland major river channels (Fig. 7A and D). The channels of Machkundi, Kodavli and Vaghotan extend as submarine channels and meet in the middle of the continental shelf and form a major submarine channel. This submarine channel and another channel, which is offshore extension of Kajali River makes an abrupt right angled turn to flow towards south and north respectively. The DEM (Fig. 7A) exhibits the difference in relief and features on the bathymetric surface. DEM and profile discriminate the areas of low relief, flat to gently sloping continental shelf region from moderately WSW sloping continental slope. The profile along X-Y in figure 7B show relief features of the continental slope and shelf as well as coastal plains of the study area.

CONCLUSION

Locations of epicenters of recent seismic records coincide with the inferred N-S faults viz., L1 to L5. L3 fault shows continuation with the fault marked by GSI (Fig.6). L5 coincides with WCF. L4 coincides with the weak zone and the line of hot springs passing through Rajapur hot-spring. The concentration of epicenters along the L3 lineament is more than the concentration occur along other lineaments, suggests that the L3 fault is more active than other faults. The Figure 6.6 shows that the westerly flowing inland streams are extending in the sea and following the same direction up to the eastern continental shelf. There is change in the direction of submarine channels when crossing NNW-SSE lineaments. The bathymetric lineaments are parallel and are oriented in the N-S and NNW-SSE directions. Thus, bathymetric study supports the presence of offshore extensional deformation structures (Fig. 2).

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