

EXTENSION OF THE NARMADA – SON LINEAMENT ON THE CONTINENTAL MARGIN OFF SAURASHTRA, WESTERN INDIA AS OBTAINED FROM MAGNETIC MEASUREMENTS

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Abstract. Magnetic total intensity values and bathymetric data collected on the continental margin off Saurashtra were used to prepare magnetic anomalies and bathymetric contour maps. The magnetic anomalies are considered to have been caused by the Deccan Trap flood basalts which underlie the Tertiary sediments. Interpretation of the magnetic data using two-dimensional modelling method suggests that the magnetic basement is block faulted and deepens in steps from less than 1.0 km in the north to about 8.0 km towards the southern portion of the study area. The WNW–ESE trending faults identified in the present study extend across the Saurashtra continental margin between Porbandar and Veraval and appear to represent a major linear tectonic feature. The relationship of these fault lineaments with the regional tectonic framework have been discussed to indicate that they conform better as the northern boundary faults of the Narmada rift graben on the continental margin off Saurashtra.

1. Introduction

The valleys of the Narmada – Son river in India, which lie almost in a straight line form a ENE–WSW trending lineament, Figure 1, (West, 1962) which parallels the Satpura orogenic trend (Figure 2). It is considered as a major tectonic boundary – a geofracture dividing the Indian shield into a southern peninsular block and a northern foreland block (Biswas, 1982). Different geological boundaries coincide with this line in a remarkable manner. To the north of it no Gondwana (Permo–Carboniferous) rocks are found and to the south of it no Vindhyan (Precambrian) rocks occur. According to West (1962) and Chaubey (1971) this line represents an ancient feature connected with a deep seated crustal lineament, which has remained an area of crustal weakness since its inception. From available geophysical information Mishra (1977) concluded that parts of the Narmada–Son lineament represent a typical rift structure and the lineament extends into the Arabian Sea upto the Murray Ridge. Crawford (1978) compared similar structures and traced the extension of the lineament into Madagascar and even Somalia and Ethiopia. Biswas and Deshpande (1983) considered this rift to be complementary to the East African rifts.

The western continental margin of India between Bombay and Saurashtra (Figure 2) therefore represents a situation where a continental rift meets the Arabian sea and cuts across the present day passive margin. The proximity of the

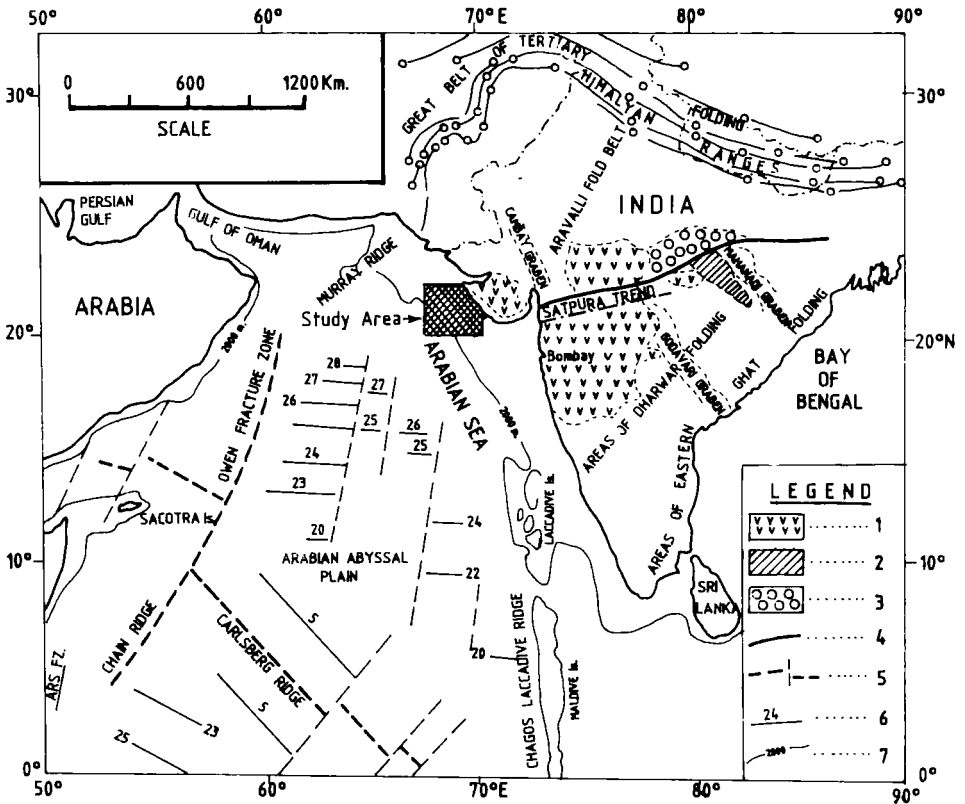


Fig. 1. Generalized geological and tectonic setting of India and significant physiographic features of the adjoining Arabian Sea. (1) Deccan Trap (lava flows); (2) Gondwana formations; (3) Vindhyan formations (after Gubin, 1968); (4) Narmada-Son Lineament (after Mishra, 1977); (5) Segment of mid-ocean ridge crest with offset shown by thin dashed lines; (6) Magnetic Lineation with anomaly numbers (after Naini, 1983); (7) Simplified bathymetric contours (in m).

major offshore oilfields of India (e.g. Bombay High and its satellite structures) on the flank of this complex geological environment perhaps adds another dimension to its importance.

Narmada graben is formed in the western part of this lineament by faults parallel to it which continues westward across the present continental shelf (Biswas and Deshpande, 1983). In the offshore areas, a fault coinciding with the straight edge of the south-eastern Saurashtra peninsula (Figure 2) represents the northern boundary of this graben (Biswas and Deshpande, 1983; Murthy and Mishra, 1981; Rao and Srivastava, 1981). The east-west fault north of Bombay High was considered by Biswas (1982, in Figure 1) as the southern boundary of this graben. However further westwards the boundaries of this rift graben so far remain undefined. Based on the bathymetric and magnetic data collected by the National

Institute of Oceanography (NIO) as well as published data including the multi-channel seismic reflection surveys by the Oil & Natural Gas Commission (ONGC) an attempt has been made in this paper to demarcate the northern boundary fault of the Narmada-Son graben on the continental margin off Saurashtra.

2. Geological Framework

The Saurashtra Offshore Basin is located on the western continental shelf of India (Figure 2). Towards the north a pronounced palaeohigh, the Saurashtra Arch, separates this basin from the Kutch Offshore Basin to the north. The eastern limit is marked by the Saurashtra Peninsula and to the south it is bounded by the Narmada Graben. The approximately east-west trending synclinal axis between Bombay High and Saurashtra coast was considered as the Narmada graben by Agrawal and Singh (1981). Deep seismic surveys and wells drilled by the ONGC on the western continental shelf revealed that paleocene to Eocene sediments overlie either the Late Cretaceous/Early Tertiary basaltic lava flows (known as Deccan Traps) or Archean/Precambrian granitic gneisses (Sahay, 1978; Basu *et al.*, 1980). More than 6000 m of sediment cover is reported in the axial part of this fault controlled depression (Mitra *et al.*, 1983; and Figure 8).

The Saurashtra Peninsula is bordered by major faults and rift basins to its north, south and east and forms a horst block in relation to the surrounding area (Figure 2). The structural and tectonic style is largely controlled by the NE-SW Precambrian Aravalli trend. The major part of the peninsula is covered by Deccan Trap basaltic flows. However, Cretaceous sediments crop out in the northeastern part and a thin veneer of Tertiary and Quaternary sediments occur along western, southern and eastern coasts.

The onshore Narmada Basin occupies a rifted graben developed during Late Cretaceous where marine sediments were deposited in a progressively deepening environment until the end of the Cretaceous. The sedimentation ended abruptly as a result of regional uplift which was followed by activity that deposited the Deccan Trap in early Paleocene time (Biswas and Deshpande, 1983).

The Deccan Trap basalts cover an area of about 500,000 sq. km in western and central India. It is considered that the fractures associated with several continental rifts in India provided the fissures for outpouring of a major part of these flow basalts (Krishna Brahmam and Negi, 1973). Palaeomagnetic studies of the Deccan Trap basalts (Sahasrabudhe, 1963; Wensink *et al.*, 1977) revealed that thick flows near the bottom acquired reverse magnetic polarity (with a remanent inclination around $+50^\circ$ and declination of $+130^\circ$) whereas thin flows at the top acquired normal magnetic polarity (with a remanent inclination about -50° and declination of $+320^\circ$). Study of the basalts drilled from the offshore areas of Bombay (Gopala Rao, 1984a; 1984b), indicated that these basalts are with reverse magnetic polarity (with a remanent magnetization around 3.0 A/m and inclination around $+50^\circ$) and

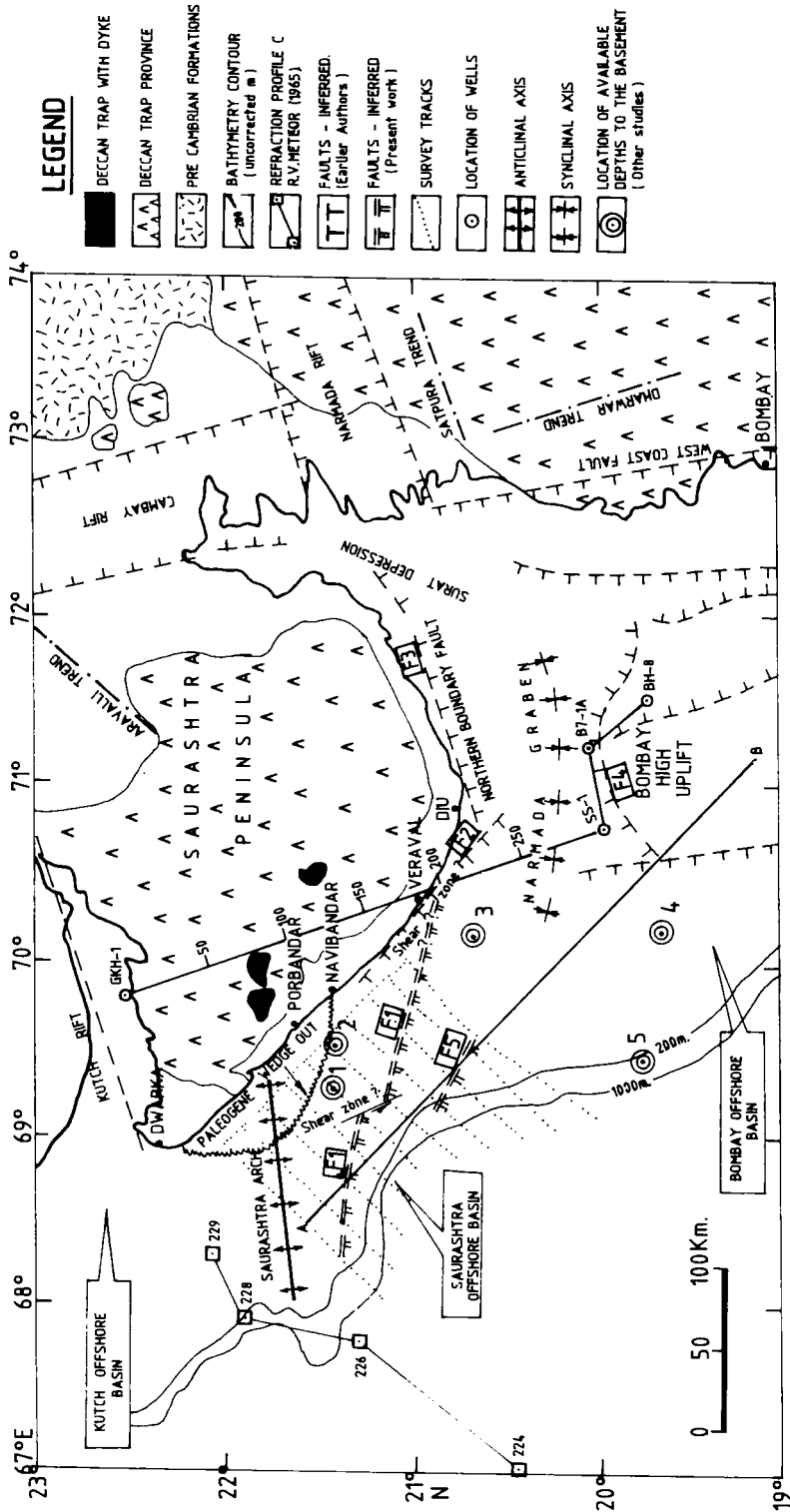


Fig. 2. Generalized main structural features and geological sketch map of the continental margin between Bombay and Dwarka. Features and nomenclature after Rao and Srivastava (1981), Agrawal and Singh (1981) and Biswas (1982). Survey tracks are shown by dotted lines.

induced magnetization around 1.1 A/m. The reverse and normal polarity terms are used according to the position of the Indian subcontinent on the southern hemisphere during the period of the volcanic activity with SE declinations and downward inclinations, and NW declinations and upward inclinations respectively. Although the age and the range of age of the Deccan Trap basalts in India have been the subject of much debate, there is general consensus that the basalt flows of western India were extruded between 65–60 m.y. ago (Alexander, 1981) during Paleocene.

3. Data

The study area was surveyed during the 84th cruise of *RV Gaveshani* of the NIO in December 1980 (Figure 3). The primary position control along the tracks was maintained with a Decca Navigator (West Coast of India – Bombay Chain) which was augmented, as and when available with the positions determined with reference to the shore with the ship's radar. Final adjustment of the tracks were manually achieved by considering the most consistent positions. The tracks were spaced at about 18 km and the error in the positions are not likely to exceed more than 1500 m during the surveys. The bathymetric data were collected with a Simrad EQ echosounder and the bathymetric map is shown in Figure 3. The total magnetic field was measured by a Barringer Proton Precession Magnetometer towed 150 meters aft of the vessel. The diurnal variation at the Alibag magnetic observatory (18° 38' N, 72° 52' E) was used to apply diurnal correction to the magnetic data. The residual magnetic total intensity anomalies were calculated by removing the International Geomagnetic Reference Field (IGRF) of 1980 as regional field. The residual magnetic total intensity anomalies (plotted perpendicular to the track) and the anomalies contour map are presented in Figures 4 and 5 respectively.

4. Results and Discussion

4.1. BATHYMETRY

The continental shelf off Saurashtra Peninsula with an average slope of the sea floor of about 1:1100 is relatively smooth. The shelf is wider in the northern and southern portion as compared to the central part (Figure 3), being narrowest along track 84E. The continental slope between tracks 84A and 84E strikes approximately north-south, but it changes abruptly into a west-northwesterly trend in the areas north of track 84E. The steepness of the slope (between 200–1500 m depth contour) which is about 1:26 south of track 84E increases significantly to about 1:12 towards the north. Therefore it appears that the bathymetry of the slope changes both its trend and steepness approximately along 21° N latitude.

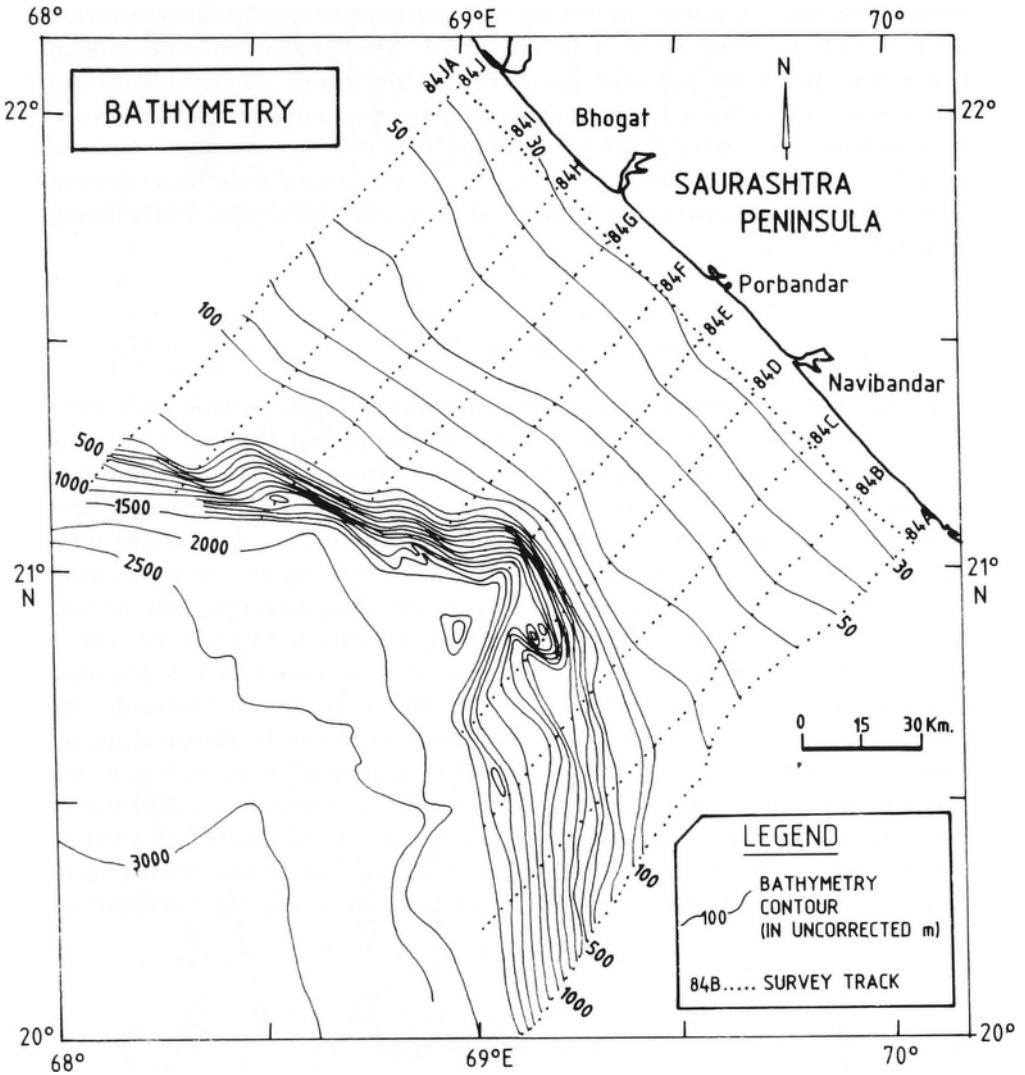


Fig. 3. Bathymetric map of the Saurashtra continental margin (in uncorrected meters). Contour intervals: upto 100 m isobath, 10 m; between 100 and 1500 m isobaths, 100 m; afterwards 500 m. Dotted lines represent survey tracks. Tracks are annotated with cruise and track number. Additional data from Indian Naval Hydrographic Office (Hydrographic Charts).

4.2. MAGNETIC ANOMALIES

A series of very high frequency (wavelength about 3 km) anomalies are observed over the inner shelf north of Porbandar landward of the 60 m isobath (Figure 5). An approximately east-west trending zone characterized by high amplitude anomalies (peak to peak amplitude of the order of 700nT) extends from the

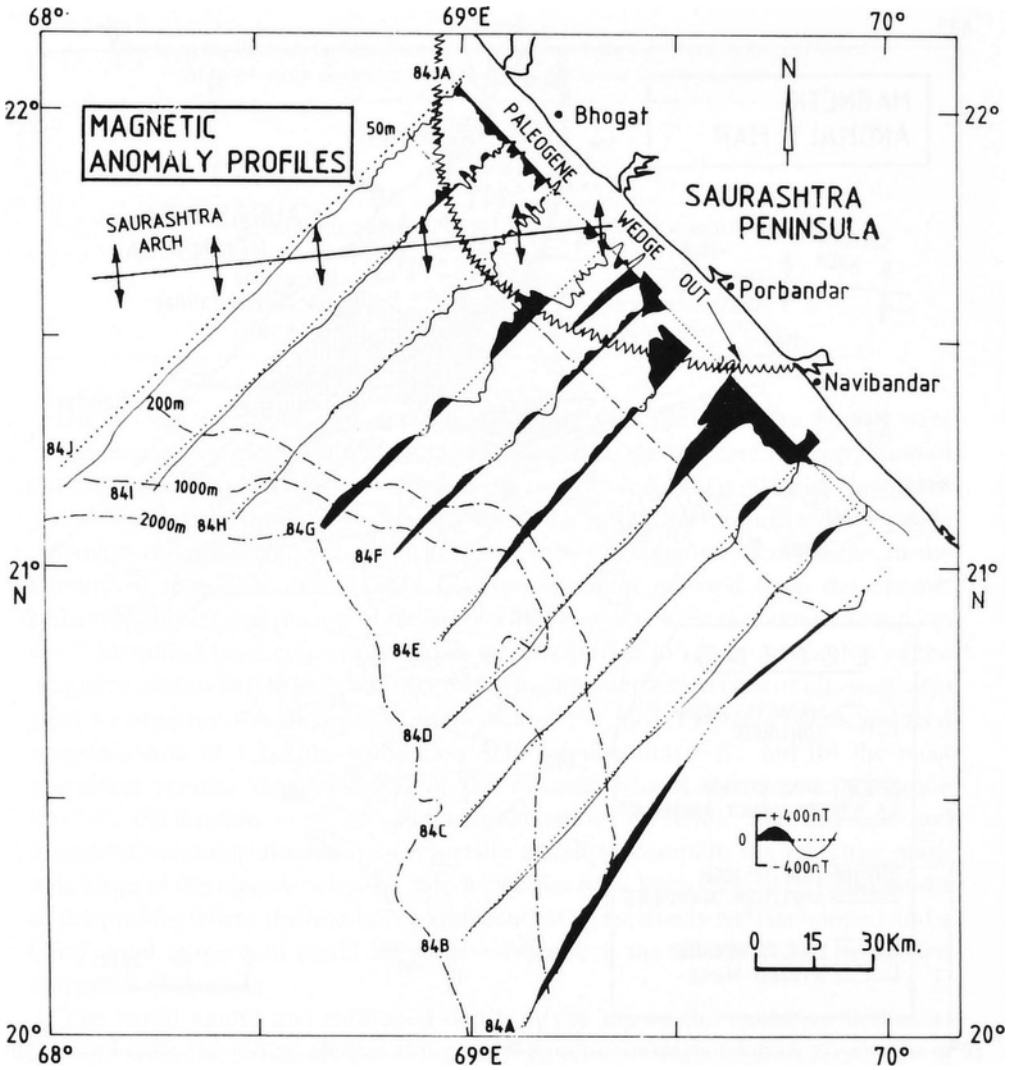


Fig. 4. Total magnetic intensity anomalies on the Saurashtra continental margin plotted perpendicular to the tracks.

nearshore areas between Porbandar and Navibandar up to about the 60 m isobath. The inner shelf south of Navibandar is marked by the absence of high frequency anomalies but it is characterised by well developed WNW-ESE trending anomalies. The outer shelf and slope (between 50 to 2000 m contour) north of Porbandar is characterised by rather low amplitude anomalies, whereas the outer shelf and slope south of track 84E are marked by broad wavelength, approximately east-west trending low amplitude anomalies.

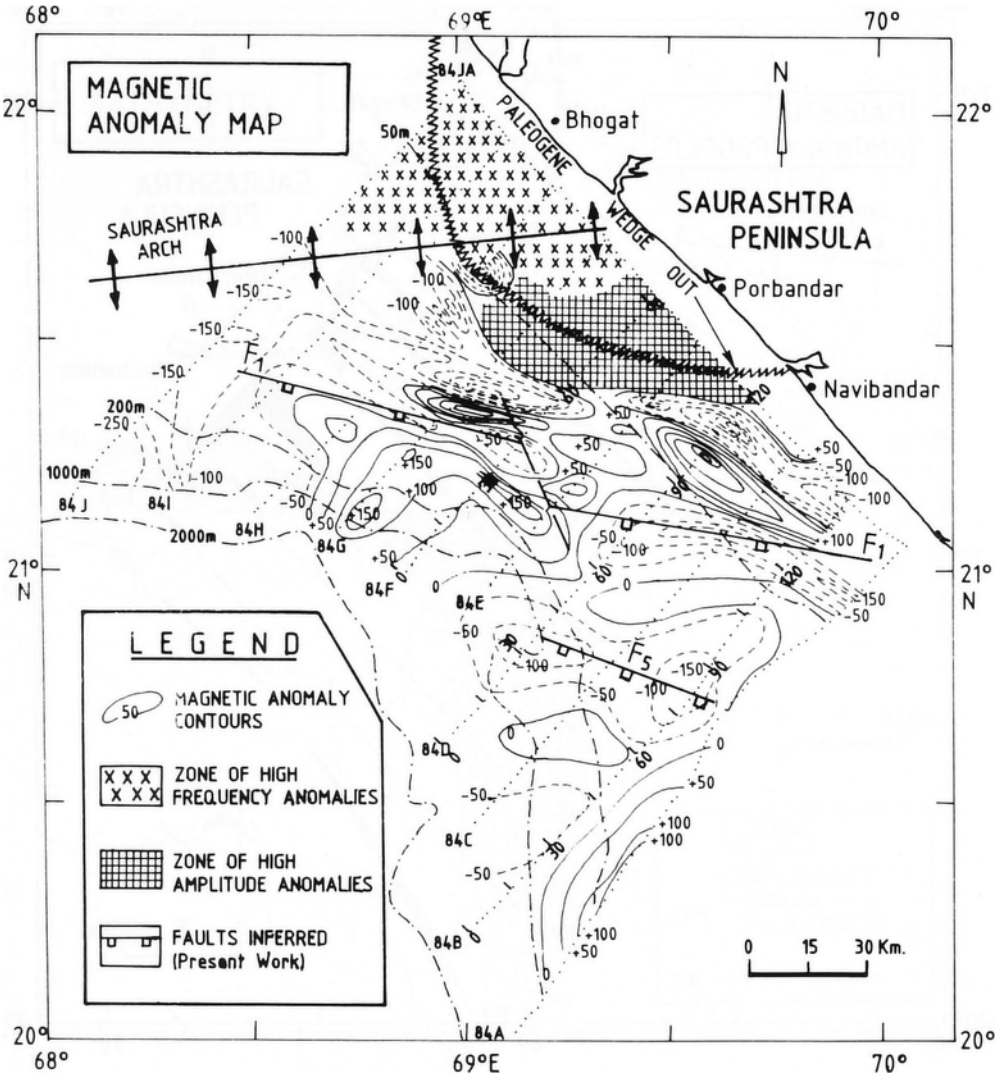


Fig. 5. Total magnetic intensity anomalies contour map of the Saurashtra continental margin. Contour interval 50 nT. Positive value contours are solid lines and negative value contours are dashed. Tracks B, D and F are annotated with km marks.

The magnetic anomalies are assumed to have been caused by the Deccan Trap basalts. This assumption is felt to be fairly reasonable because, (a) Deccan Traps are exposed on the Saurashtra Peninsula, (b) published seismic refraction results indicate their presence below the Tertiary sediments in the offshore Saurashtra basin (Rao, 1967) and (c) several wells drilled in the adjacent Bombay offshore basin confirmed the presence of Deccan Trap basalts.

Table I
 Depths to the basement on the Saurashtra continental margin, based on the published results of other geophysical studies. Locations are shown in Figure 2.

Location	Method	Depth to the basement (km)	Source
1	Seismic reflection	0.8	Agarwal and Singh (1981)
2	Seismic refraction	1.3	Naini (1980)
3	Seismic reflection	4.0	Mitra <i>et al.</i> (1983)
4	Seismic reflection	8.0	Mitra <i>et al.</i> (1983)
5	Gravity	8.8	Gopala Rao (1976)

Due to relative elongated shape of the anomalies the causative bodies were approximated to be two-dimensional and therefore a quantitative interpretation of the magnetic data was carried out using the two-dimensional modelling method of Talwani and Heirtzler (1964). The depths to the top of the causative bodies were decided primarily using the published results of other geophysical studies in the vicinity of the study area (Table I). The basement inferred from the seismic reflection studies and the top of the layer with P-wave velocity of about 4.0–4.5 km sec⁻¹ identified from refraction studies were regarded to represent the top of the magnetic bodies in this area. Further following magnetization constraints were also used to generate the theoretical anomalies of the model bodies, (a) an induced magnetization of 1.1 A/m, inclination +30°, declination -1°; and (b) the most consistent reverse magnetization of the onshore basalts (remanent inclination = +50°, declination = +130° and magnetization 3.0 A/m). The induced and remanent magnetizations were vectorially added to compute the effective magnetization of the causative bodies. Model studies have been carried out along most of the profiles where the anomalies are found to be relatively well developed and a fairly good agreement could be achieved between the observed and computed anomalies (Figure 6).

The aerial extent and estimated depth to the top of the causative bodies as inferred from the model studies along the magnetic anomaly profiles are shown in Figure 7. On the inner and mid shelf areas northwest of Porbandar no model studies could be done, because the anomalies are either very high frequency or are very much subdued. We feel that the high frequency anomalies on the inner shelf north of Porbandar suggest that the basalts occur at very shallow depth. Similarly the subdued and short wavelength nature of the anomalies on the mid shelf areas north of Porbandar perhaps indicate the presence of thin layer of basalts. The east-west trending high amplitude anomalous zone between Porbandar and Navibandar appears to have been caused by bodies at about 1.0 km below sea level. Onshore in the vicinity of Navibandar Kaila *et al.* (1980) reported the presence of about 1.3 km thick Trap below about 400 m of Tertiary sediments. This Trap body might be continuing offshore, causing the east-west trending high

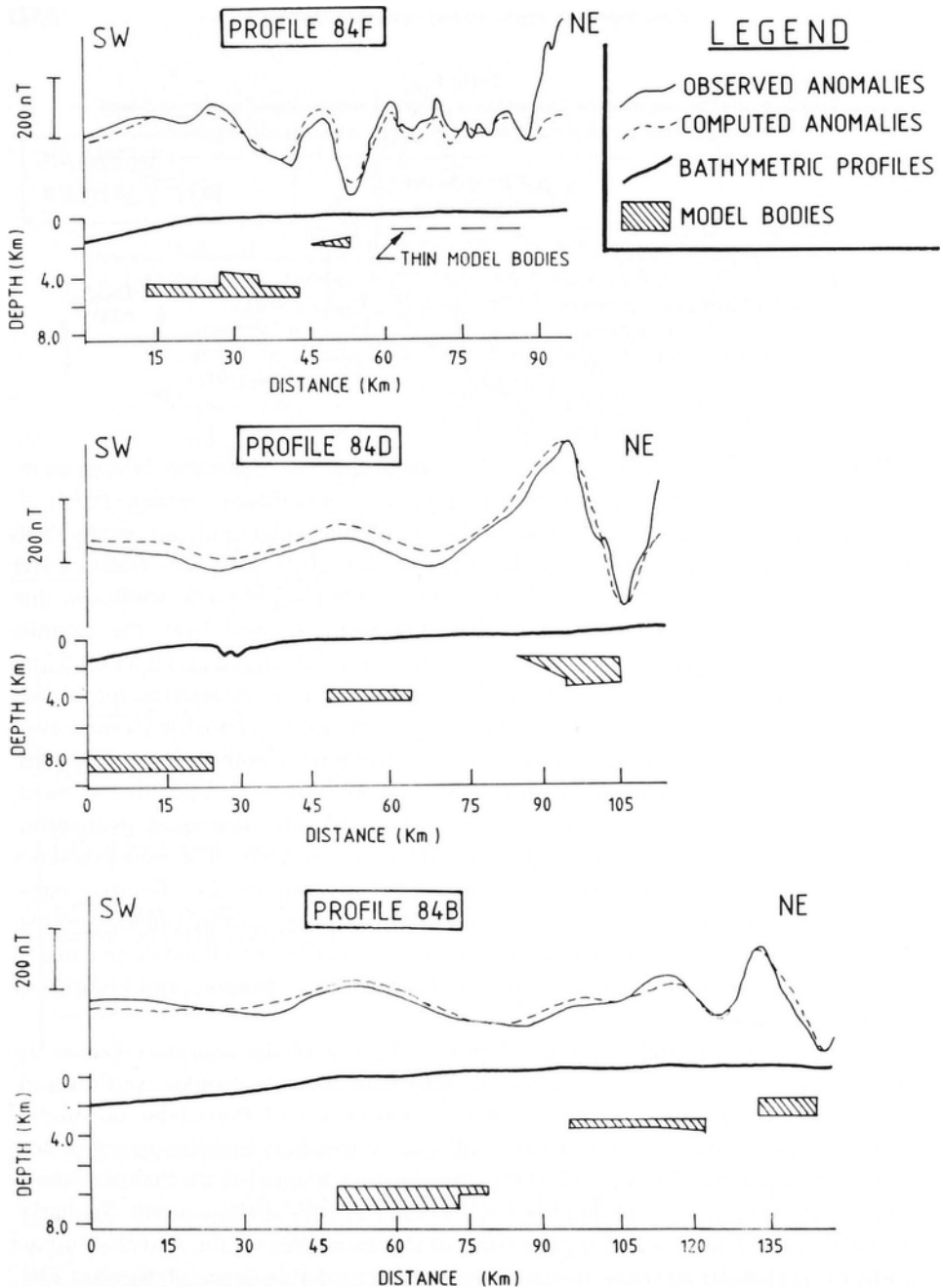


Fig. 6. Total observed and computed magnetic intensity anomalies and bathymetry along representative profiles across the Saurashtra continental margin. Computed anomaly profiles are generated by two-dimensional magnetic block models at bottom. Bottom curves are bathymetric profiles. Following magnetization parameters were used for computing anomaly profiles (a) Induced: magnetization = 1.1 A/m, inclination = +30°, declination = -1° and (b) Remanent: magnetization = 3.0 A/m, inclination = +50°, declination = +130°.

amplitude anomalies off Porbandar. The WNW-ESE trending anomalies on the inner shelf off Porbandar are caused by sources at about 2.0 km level, further south the sources appear to be at 4.0 km level and the anomalies at the outer shelf and shelf edge (south of track 84E) probably originate with bodies at 8.0 km below the sea level.

To sum up it appears that on the continental margin off Saurashtra Peninsula the magnetic basement is present at different levels, the bodies trend approximately WNW-ESE and deepen in steps from shallow (~ 1.0 km) off Porbandar to about

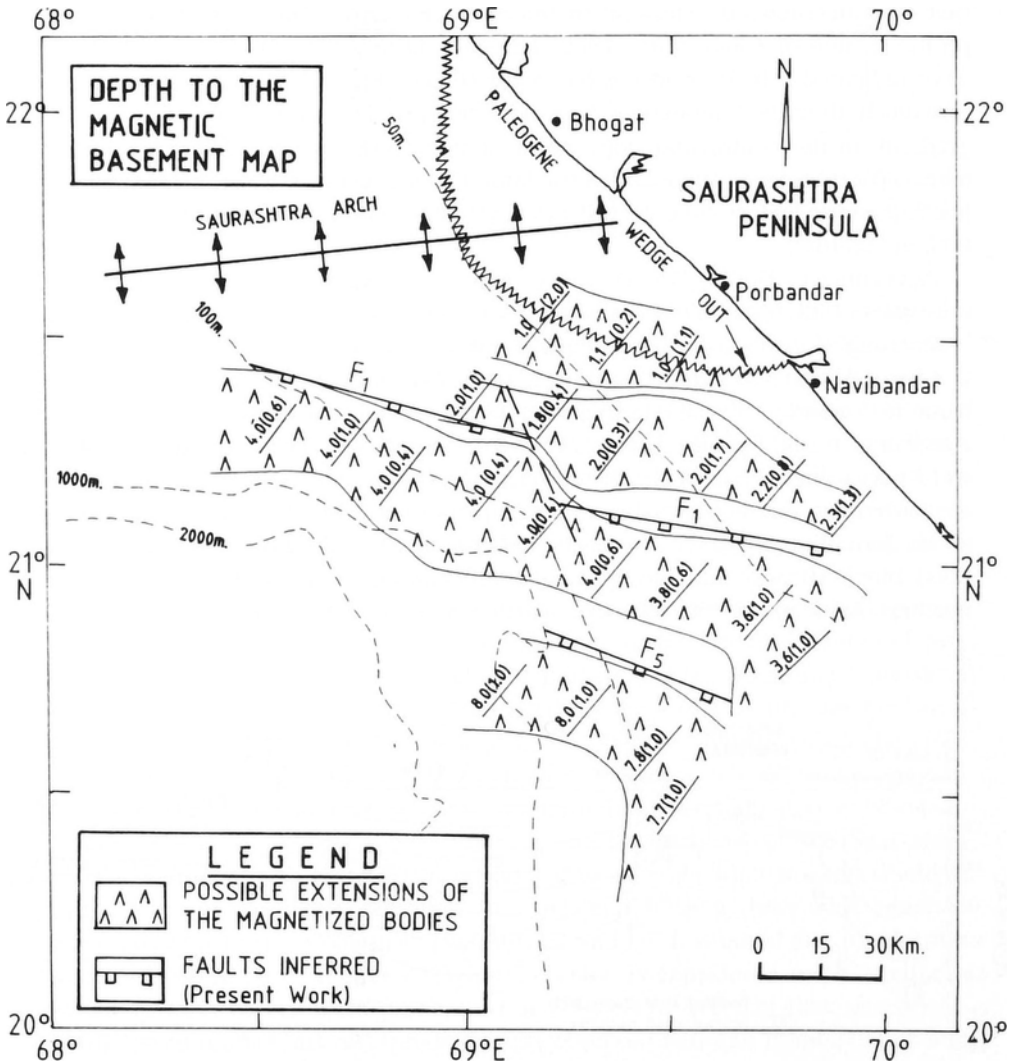


Fig. 7. Map showing the possible extensions of the magnetized bodies on the Saurashtra continental margin (as inferred from the two dimensional magnetic block models). Values on the bodies indicate average depth to the top and bracketed values indicate the average thickness of the bodies (in km).

8.0 km towards south. Rapid increase in the depths-to-magnetic basement therefore appears to have been caused by the block faulted nature of the basement and the edges of the model bodies follows closely these fault lineaments. The fault lineaments F1 and F5 thus inferred from the present study are marked in Figure 2. These faults extend across the study area; particularly the fault F1 could be mapped as a single continuous feature with minor offset along perhaps a shear zone marked as F2 in Figure 2. It can be seen (Figure 2) that the shoreward extension of the lineament F1 crosses the section in Figure 8 just north of 200 km mark, where the presence of a fault was indicated by Sahay (1978). Again we observe (Figure 2) that the offshoreward extension of lineament F1 crosses the refraction seismic profile section of Closs *et al.* (1969) between stations 226 and 228, where they have indicated a faulting in the basement (Figure 9). It is further seen that the previously described anomalous west-northwesterly trend and steep topographic gradient on the continental slope north of track 84E also parallels these lineaments. We therefore conclude that the fault lineaments F1 and F5 represent major linear tectonic features and we will examine their relationship in terms of regional tectonic features.

According to Boillot (1981), continental rifts correspond to zones where the lithosphere undergoes extension, several kilometres of crustal thinning occurs and fault troughs develop with subsequent thick sedimentary accumulations. The continental crust also gets enriched by magma intrusions and extrusions emanating from the mantle. In the Narmada-Son rift all these features are observed. According to the hypothesis for graben formation (Bott, 1979) when the downward-narrowing wedge of the brittle upper crust subsides, outflow of material in the underlying ductile part of crust accompanies uplift of adjacent regions either by the formation of horst or by elastic upbending. Saurashtra peninsula which is a horst block (Biswas and Deshpande, 1983) can be considered as the uplifted northern flank of the rift. However further west on the continental margin off

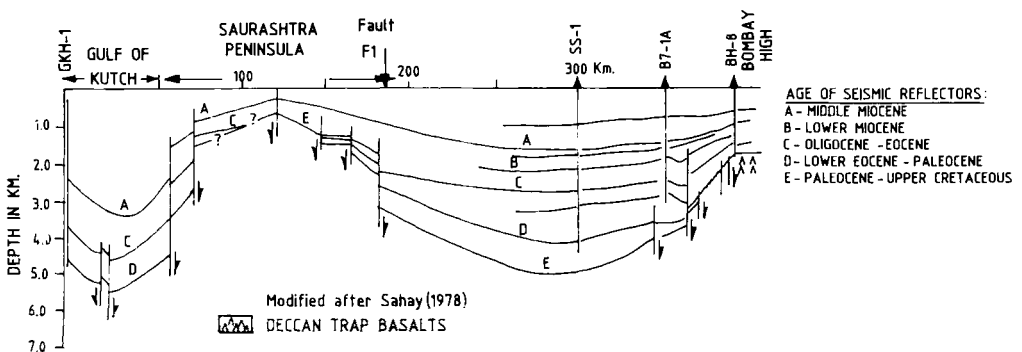


Fig. 8. Geological section based on seismic and well data from Saurashtra Peninsula to Bombay High (after Sahay, 1978). Location of the wells are shown in Figure 2.

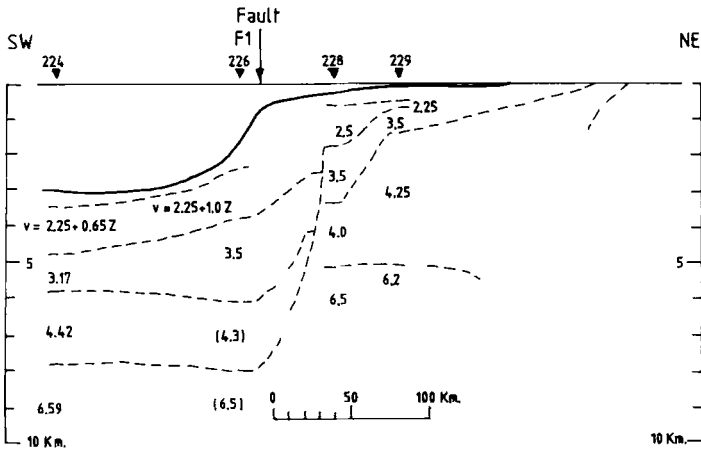


Fig. 9. Seismic refraction results obtained on the Saurashtra continental margin (after Closs *et al.*, 1969). Refraction data was collected on R.V. Meteor in 1965. Location of section is given in Figure 2. Velocities are in Km/sec.

Saurashtra, the only major structure which may represent an uplifted basement is the Saurashtra Arch (Figure 2) which is located far in the north off Porbandar. Ramaswamy and Rao (1980) indicated that Saurashtra Arch is the seaward extension of the Saurashtra peninsula. Agrawal and Singh (1981) concluded that a gentle variation in the Tertiary sediment thickness in the Saurashtra Basin indicates a stable depositional environment, which supports the existence of the arch even before the beginning of the Tertiary sedimentation. Rao and Srivastava (1981) reported a noticeable increase in the thickness of the sedimentary sequences immediately south of this Saurashtra Arch.

Thus it is tempting to speculate that on the Saurashtra continental margin the lineaments F1 and F5 (Figure 2) perhaps represent the set of parallel faults defining the northern boundary of the Narada rift graben and the adjoining Saurashtra Arch represents the associated uplifted northern flank of the rift. Our preferred geological model across the Narmada graben is illustrated in the schematic cross section AB, Figure 10. Figure 2 shows an offset between faults F3 and F1 both of which is considered to represent the northern boundary fault of the Narmada graben. The presence of a fault along the southwest coast of the Saurashtra Peninsula (fault F2 in Figure 2) was postulated by several earlier workers (Poddar, 1964; Mitra *et al.*, 1983). We infer that the fault F2 is a shear zone which is responsible for the offset observed in faults F1 and F3. It is noted that, the further westward extension of fault F4 (Figure 2) which is considered as the southern boundary fault of Narmada graben is not very clear. We feel that, the north-northwest to south-southeast trending faults observed between Bombay High and present day shelf edge (Ramaswamy and Rao; 1980) restricts the further westward extension of faults which defines the southern boundary of this graben.

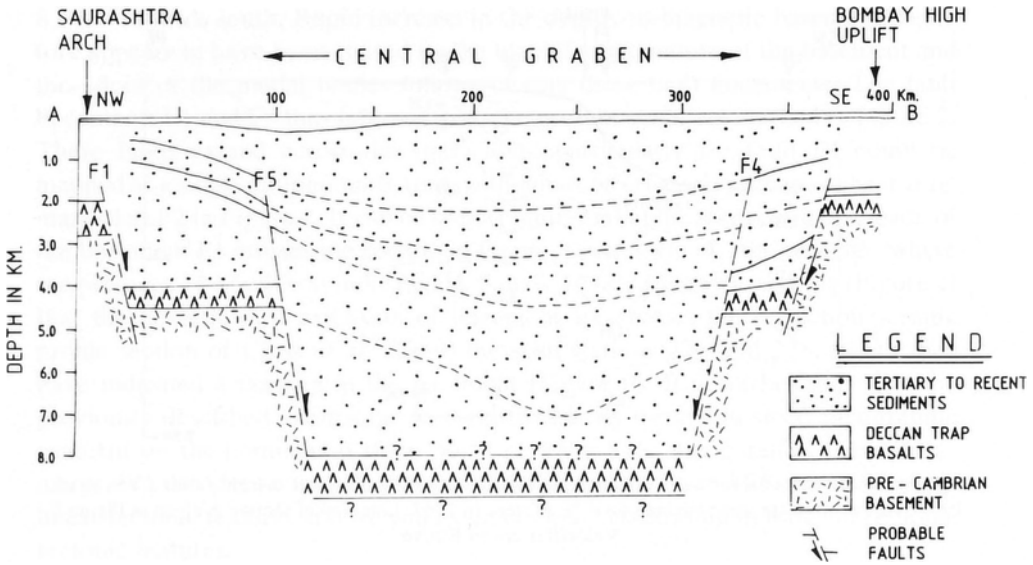


Fig. 10. Schematic cross section along the Saurashtra continental margin illustrating the preferred geological model across the Narmada graben. Location of the section is given in Figure 2.

5. Conclusions

(1) The magnetic anomalies on the Saurashtra continental margin are predominantly caused by Deccan Trap basalts. The magnetization direction indicates that these basalts were perhaps extruded during the early period of Deccan Trap activity in western India.

(2) The magnetic basement of the Saurashtra continental margin area is block faulted and deepens in steps from less than 1.0 km in the north to about 8.0 km towards the southern portion of the study area depicting a predominant WNW-ESE trend.

(3) This WNW-ESE trend represents the trends of some major linear tectonic feature possibly the continuation of the Narmada-Son lineament on the continental margin off Saurashtra.

(4) The approximately WNW-ESE trending faults extending across the Saurashtra continental margin which are identified in the present study may represent the set of parallel faults defining the northern boundary of the Narmada rift graben in this area and the Saurashtra Arch may be the uplifted horst forming the northern flank of this rifted graben.

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References

- Agrawal, R. K. and Singh, V. B.: 1981, 'Continental Shelf off Kutch-Ratnagiri Coast-a Regional Analysis of Seismic Data', in R. Prasada Rao (ed.) *Geological Interpretation of Geophysical Data*, Institute of Petroleum Exploration, Dehrn Dun, pp. 19-26.
- Alexander, P. O.: 1981, 'Age and Duration of Deccan Volcanism; K-Ar Evidence', in K. V. Subba Rao and R. N. Sukheswala (eds.), *Deccan Volcanism and Related Basalt Provinces in Other Parts of the World Geological Society of India*, Memoir No. 3. Bangalore, pp. 244-258.
- Auden, J. B.: 1949, 'Dykes in Western India', *Trans. National Inst. Sci. India* **3**, 123-157.
- Basu, D. N., Banerjee, A., and Tamhane, D. M.: 1980, 'Source Areas and Migration Trends of Oil and Gas in Bombay Offshore Basin, India', *Amer. Assoc. Petrol. Geol. Bull.* **64**, 209-220.
- Biswas, S. K.: 1982, 'Rift Basins in Western Margin of India and Their Hydrocarbon Prospects with Special Reference to Kutch Basin', *Amer. Assoc. Petrol. Geol. Bull.* **66**, 1497-1513.
- Biswas, S. K. and Deshpande, S. V.: 1983, 'Geology and Hydrocarbon Prospects of Kutch, Saurashtra and Narmada Basins', *Petroleum Asia J.* **6**, 111-126.
- Boillot, G.: 1981, 'Geology of Continental Margins', Essex: Longman Group Ltd.
- Bott, M. H. P.: 1979, 'Subsidence Mechanisms at Passive Continental Margins', in Joel S. Watkins (ed.) and others, *Geological and Geophysical Investigations of Continental Margins*. AAPG Memoir **29**, Tulsa, Oklahoma, U.S.A., pp. 3-19.
- Chaubey, V. D.: 1971, 'Narmada-Son Lineament, India', *Nature Phys. Sci.* **232**, 38-40.
- Closs, H., Bungenstock, H., and Hinz, K.: 1969, 'Ergebnisse Seismischer Untersuchungen im nordlichen Arabischen Meer', *Meteor'-Forsch.-Ergebn., Reihe C.* **2**, 1-28.
- Crawford, A. R.: 1978, 'Narmada-Son Lineament of India Traced into Madagascar', *J. Geol. Soc. India* **19**, 144-153.
- Gopala Rao, D.: 1976, 'A Preliminary Interpretation of Two Marine Gravity Profiles on the Continental Shelf Margin West of Bombay (India)', *Marine Geology* **22**, M31-M35.
- Gopala Rao, D.: 1984a, 'Marine Magnetic Anomalies off Ratnagiri, Western Continental Shelf of India', *Marine Geology* **61**, 103-110.
- Gopala Rao, D.: 1984b, 'Marine Geophysical Studies of Basement off Bombay Coast, India' Ph.D. thesis. Department of Geophysics. Andhra University.
- Gubin, I. E.: 1968, 'Seismic Zoning of Indian Peninsula', *Bull. Int. Inst. of Seismology and Earthquake Engineering* **5**, 109-139.
- Kaila, K. L., Tewari, A. C., and Sarma, P. L. N.: 1980, 'Crustal Structure from Deep Seismic Sounding Studies along Navibandar - Amreli Profile in Saurashtra, India', *J. Geol. Soc. India* **3**, 218-232.
- Krishna Brahmam, N. and Negi, J. G.: 1973, 'Rift Valleys Beneath Deccan Traps (India)', *Geophys. Res. Bull.* **11**, 207-237.
- Mishra, D. C.: 1977, 'Possible Extensions of The Narmada-Son Lineament Towards Murray Ridge (Arabian Sea) and the Eastern Syntaxial Bend of The Himalayas', *Earth and Planetary Science Letters* **36**, 301-308.
- Mitra, P., Zutshi, P. L., Chourasia, R. A., Chugh, M. L., Ananthanarayanan, S. and Shukla, B.: 1983, 'Exploration in Western Offshore Basins', *Petroleum Asia J.* **6**, 15-24.
- Murthy, T. V. G. R. K. and Mishra, S. K.: 1981, 'The Narmada-Son Lineament and the Structure of The Narmada Rift System', *J. Geol. Soc. India* **22**, 112-120.
- Naini, B. R.: 1980, 'A Geological and Geophysical Study of the Continental Margin of Western India, and the Adjoining Arabian Sea Including the Indus Cone', Ph. D. Thesis, Columbia University, New York.
- Naini, B. R. and Talwani, M.: 1983, 'Structural Framework and the Evolutionary History of the Continental Margin of Western India', in J. S. Watkins and C. L. Drake (eds.), *Studies in Continental Margin Geology*. AAPG Memoir **34**, Tulsa, Oklahoma, U.S.A., pp. 167-191.
- Poddar, M. C.: 1964, 'Mesozoics of Western India - Their Geology and Oil Possibilities', Report of the

- 22nd session of the International Geological Congress, New Delhi, *Proceedings of Section I, Geology of Petroleum*, pp. 126-143.
- Ramaswamy, G. and Rao, K. L. N.: 1980, 'Geology of the Continental Shelf of the West Coast of India', in Andrew D. Miall (ed), *Facts and Principles of World Petroleum Occurrence*, Can. Soc. Petrol. Geol., Memoir 6, Calgary, Alberta, Canada, pp. 801-821.
- Rao, T. C. S.: 1967, 'Seismic Refraction Measurements in the Gulfs of Cambay and Kutch', *Proc. Symp. Upper Mantle Project*, Hyderabad, India, pp. 342-347.
- Rao, R. P. and Srivastava, D. C.: 1981, 'Seismic Stratigraphy of West Indian Offshore', in R. Prasada Rao (ed.), *Geological Interpretation of Geophysical Data*, Institute of Petroleum Exploration, Dehrn Dun, pp. 49-57.
- Sahasrabudhe, P. W.: 1963, 'Palaeomagnetism and the Geology of the Deccan Traps', in M. S. Krishnan and S. Balakrishna (eds.), *Seminar on Geophysical Investigations in the Peninsular Shield*, Osmania University, Hyderabad, pp. 226-243.
- Sahay, B.: 1978, 'Geology of the Bombay High and Adjoining Structures', *Second Offshore South East Asia Conference*, Signapore, pp. 1-11.
- Talwani, M. and Heirtzler, J. R.: 1964, 'Computation of Magnetic Anomalies Caused by Two-Dimensional Structures of Arbitrary Shape', in G. A. Parks (eds.), *Computers in the Mineral Industry*, Stanford Univ. Publ. Geol. Sci. 9, 464-480.
- Wensink, H., Boelrijk, N. A. I. M., Hebada, E. H., Priem, H. N. A., Verdurmen, E. A. T., and Verschure, R. H.: 1977, 'Paleomagnetism and Radiometric Age Determinations of the Deccan Traps, India', *IVth Int. Gondwana Symp.*, Calcutta, 11, 832-847.
- West, W. D.: 1962, 'The Line of the Narmada and Son Valleys', *Current Sci.* 31, 143-144.