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STRUCTURAL FEATURES OF THE OCEAN BOTTOM OFF THE WEST COAST OF THE INDIAN SUB-CONTINENT*

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ABSTRACT

Geological and Geomorphological studies have lead to the belief that the ancient Indian shield extends upto the west of Laccadive Islands. The Murray Ridge is believed to be a continuation of the geoanticlinal structure of West Pakistan into the Gulf of Oman. Geophysical investigations carried out during the International Indian Ocean Expedition Programme have proved that the Laccadive-Maldive ridge system as of volcanic type rather than a continental relic and the Murray Ridge as the continuation of Carlsberg Ridge in North-Northeast direction.

The presence of thick Deccan Trap material near Bombay Coast and the north-south aligument of the Laccadive-Maldive ridge system have lead to the presumption that the volcanism which originated in the Chagos area continued into the continent producing the ridge system and the Deccan Traps as well.

This paper summarises the results of recent geophysical studies in the Arabian Sea including those obtained by the author off the West Coast of India. Based on these results, the crustal structure and the extension of the ocean bottom features of the Arabian Sea along the west coast of the Indian sub-continent are discussed.

INTRODUCTION

DURING the International Indian Ocean Expedition programme several geophysical investigations have been carried out in the North-west Indian Ocean to study the crustal structure of the ocean bottom. The results obtained from the seismic refraction measurements over the Chagos-Laccadive ridge by ARGO and HARIZON (Francis and Shor, 1966), the topographic and magnetic surveys over the Murray Ridge by DAIRYMPLE (BARKER, 1966) the METEOR II and METEOR II-INS KISTNA seismic investigations over the North Arabian Sea (Closs and Hinz, 1967 ; Rao, 1967) are summarised.

After the completion of the expedition programme, total magnetic field measurements have been made over the continental shelf off Bombay and Kathiawar Coast (Rao, 1970). Seismic refraction experiments have also been conducted over the continental shelf off Konkan Coast (Rao, 1970a).

Inferences derived from the geological and geomorphological evidences, mainly of Davis (1928), Willis (1932), Sewell (1935) and Ermenko and Datta (1968) are also briefly summarised.

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Results of the recent geophysical investigations discussed in the succeeding page regarding the origin and continuity of the Chagos-Laccadive and Murray Ridge systems reveal that these two systems are composed of thick volcanic material and as such they are of oceanic origin rather than continental relics as believed to be from the geological evidences.

Position locations of the seismic stations and the magnetic profiles, results of which are discussed in this paper, are shown in fig. 1.

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GEOPHYSICAL INVESTIGATIONS

A. *West Coast of India*

(i) *Bombay and Kathiawar Coast:* Seismic refraction measurements conducted by METEOR II—INS KISTNA (Closs and Hinz, 1767; Rao, 1967) have indicated four layers (Figs. 2a and 2b). The sedimentary layers over the continental shelf are relatively thin. They attain their maximum thickness of more than 4000 m over the continental slope. Off Bombay, the layer with velocity more than 4.0 Km/s is observed at only two stations (213 and 221). At station 217, the basement layer is uplifted forming a 'High', similar to the 'Kori High' (Stn. 238, Fig. 5 a) located off Karachi by METEOR II (Closs and Hinz, 1967).

Total magnetic field anomalies off Bombay (Fig. 6) show a sharp anomaly of about 180 gammas over the inner shelf (around 19°30'N, 72°E) and another anomaly of less magnitude (over the midshelf. The total field anomalies recorded of Porbandar and Dwaraka (Fig. 7) and along the western part of the profile off Bombay (Fig. 6) are similar. Preliminary analysis of these anomalies indicate a 'High' associated with faults over the inner shelf, possibly related to the 'Great duke' of basic rock (Glannie, 1934; West 1959; Takin, 1965; Harbison and Bassinger, 1970), and a fault system, considered to be the westward extension of the Narmada fault over the midshelf off Bombay. The anomalies recorded off Kathiawar Coast are attributed to the presence of anticlinal features over the continental shelf.

Considering that the layer with velocity more than 4.0 Km/s consists of Deccan Trap-wash material, it is assumed that the two stations (213 and 221, Fig. 1) off Bombay correspond to the trap intrusive centres through which lava might have fissured out and extended the Deccan Traps into the Arabian Sea. Krishnan (1960) has mentioned that the Traps may have continued initially for some distance west off Bombay and faulted down possibly in the Miocene. The High delineated from the seismic results and the anticlinal features derived from the magnetic anomalies over the self off the Kathiawar Coast have established the extension of the Kori High in NW-SE direction from Karachi to the outer-self off Bombay (Rao, 1970). It is also presumed that the Kori High may extend further down to join the Chagos-Laccadive ridge (Hari Narain, *et al.*, 1968; Closs, *et al.*, 1969; Rao, 1970).

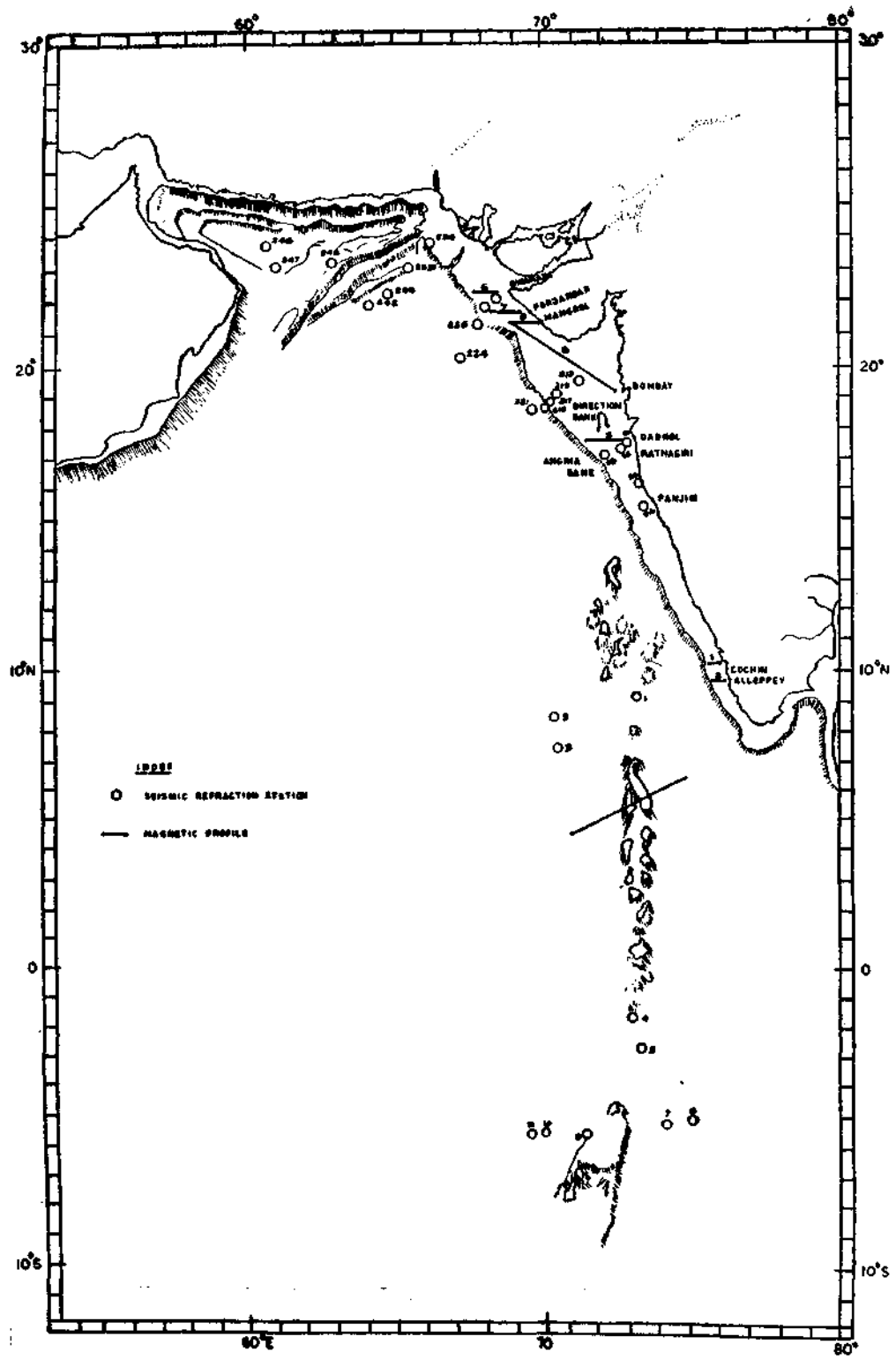

Fig. 1. Position location map.

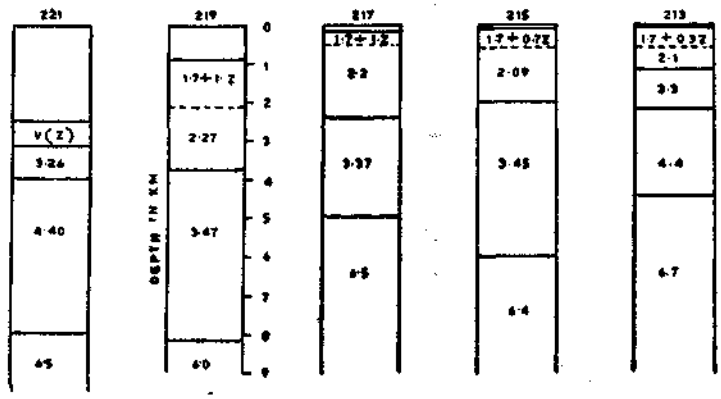

Fig. 2a. Crustal layers off Gulf of Cambay.

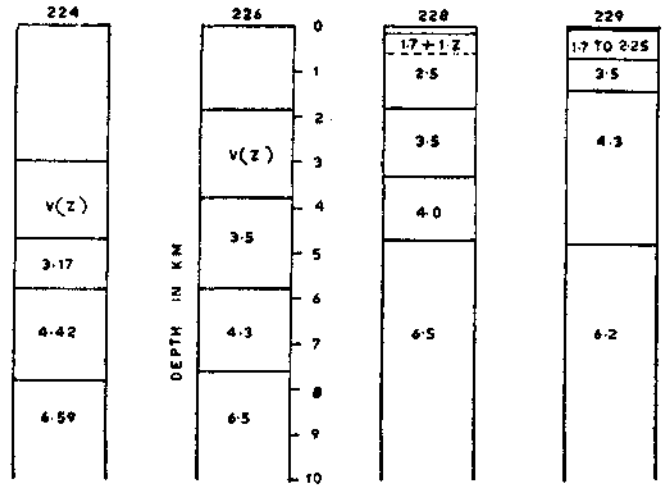

Fig. 2b. Crustal layers off Gulf of Kutch.

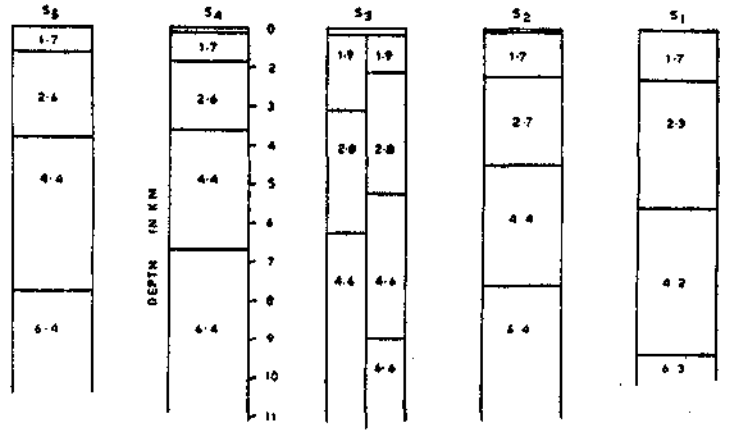

Fig. 3. Crustal layers off Konkan Coast.

(ii) *Konkan Coast :* Seismic refraction experiments at five stations (S1 to S5, Fig. 1) over the continental shelf off Konkan Coast show three layers overlying the basic crustal layer (Fig. 3). Over the midshelf (Stn. S2), the basement layer is uplifted and thus forms a 'High' similar to that present over the outershelf off Bombay (Fig. 2b). The basement layer is more than 8000 m deep over the innershelf off Dabhol (Stn. S1) and it continues to be at fairly deeper levels over the innershelf all along the Konkan Coast (Stns. S4 and S5) compared to that over the midshelf (Stn. S2). Magnetic profile off Dabhol shows an anomaly over the outershelf (Fig. 8), possibly due to an anticlinal feature.

From the relative dispositions of these two 'Highs' over the continental shelf off Konkan Coast with respect to the 'Kori High' (over the outershelf) and the 'High' over the innershelf off Bombay, it is concluded that the Chagos-Laccadives ridge continues north as sub-bottom Highs in two branches (Rao, 1970a). One of these branches extends in SE-NW direction to join the Kori High through the Angria Bank and the other branch extends in South-North direction into the Cambay Basin through the 'High' over the innershelf off Bombay (Rao, 1970) and the fracture system in the Gulf of Cambay (Sengupta, 1967).

(iii) *Kerala Coast :* Total magnetic field measurements are made along one profile over the continental shelf off Cochin (Rao and Namboodiripad, 1968). The total field anomaly sharply rises to 3400 gammas within 20 Km from the coast. Over the midshelf it remains fairly uniform around 2200 gammas. Over the outer shelf it again tends to increase (Fig. 9).

Preliminary analysis of these anomalies shows a fault within 20 Km from the coast. It is believed that this fault might have caused the downfaulting of the coastal region. Over the midshelf, the anomaly shows a trough-like feature filled with thick sediments.

B. *Chagos-Laccadive Ridge*

Results of the seismic measurements over the Chagos-Laccadive ridge (Francis and Sho, 1966) are given in figure 4.

About 5 Km thick of volcanic layer (velocities 3.85 and 5 Kms) is observed overlying more than 10 Km of crustal layer (6.84 Km/s) between Laccadives and Maldives (Stn. 1). The Mohorovicic Discontinuity, (7.97 Km/s) is just over 17 Km deep. Between Maldives and Chagos (Stns. 4 and 5), 4 to 5 Km thick layer with velocity 6.13 Km/s, is present. The thickness of this layer is similar to the thickness of the volcanic layer observed between Laccadives and Maldives but the velocity is fairly high. They consider this also as volcanic layer since the velocities of this order have been observed in the volcanic material of the Hawaiian Archipelago (Shor and Pollard, 1964). It is presumed that the Moho discontinuity in this area cannot be at a depth less than 20 Km. Over the Chagos (Stns. 8 and 9), the layers with velocities of 3.01, 4.76 and 6.79 Km/s that are typical of coral, volcanic and basic crustal material respectively, (Raitt, 1957) are observed. They conclude that the Chagos-Laccadive Ridge is a continuous feature resulting from the volcanic layer generally between 4 and 5 Km thick.

These results are consistent with the earlier inferences derived from the gravity and magnetic data. Glennie (1936) found large negative isostatic gravity anomalies over the Maldive islands and considered the ridge as more likely to consist of a

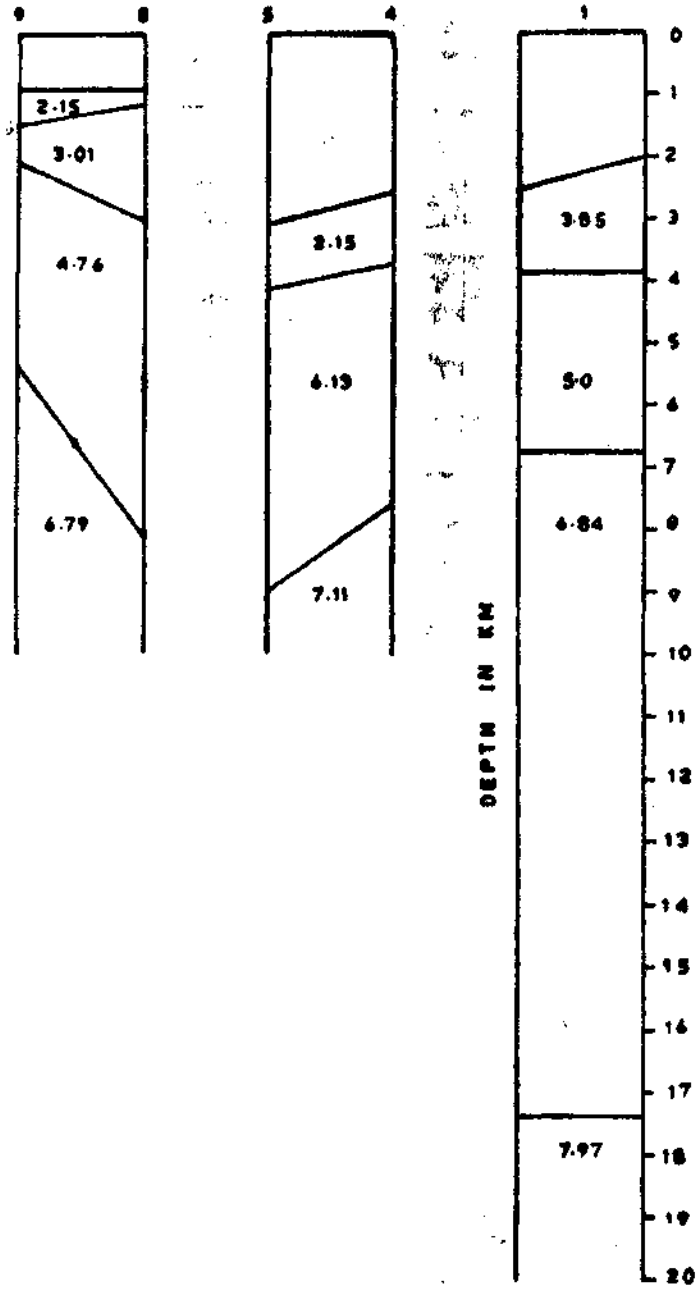

Fig. 4. Crustal layers over Chagos-Laccadive Ridge.

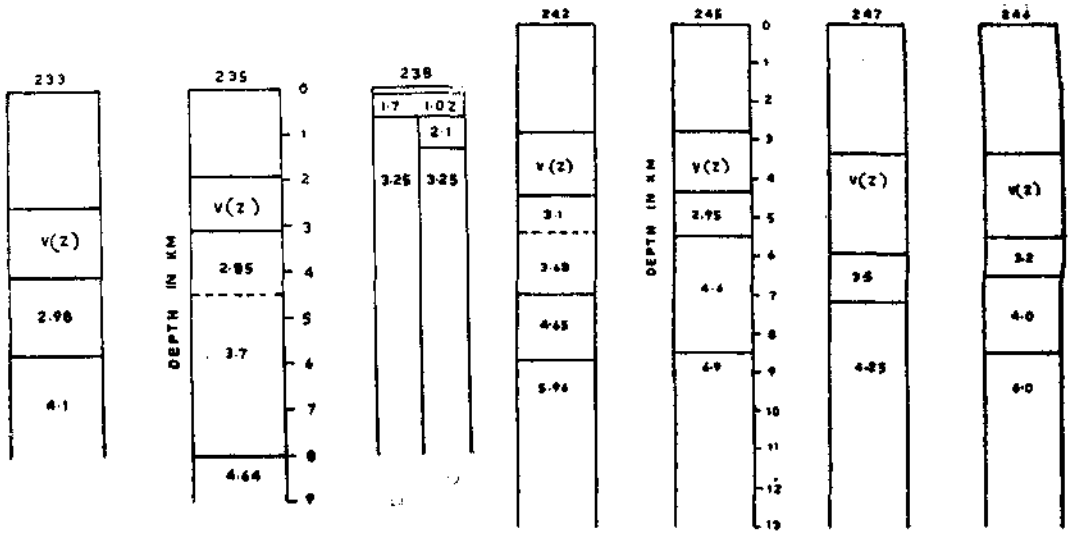

Fig. 5a. Crustal layers off Karachi.

Fig. 5b. Crustal layers off Gulf of Oman.

great thickness of coral rock resting on an upwarp in the ocean floor than to be a continental relic. Large magnetic anomalies observed over the Maldive region (Admiralty, 1963) also suggest that the coral has a basalt foundation.

Francis and Shor (1966) further believe that the volcanism which produced the Chagos-Laccadive Ridge originated in the Chagos and might have moved northward on into the continental shelf to produce the Deccan Traps.

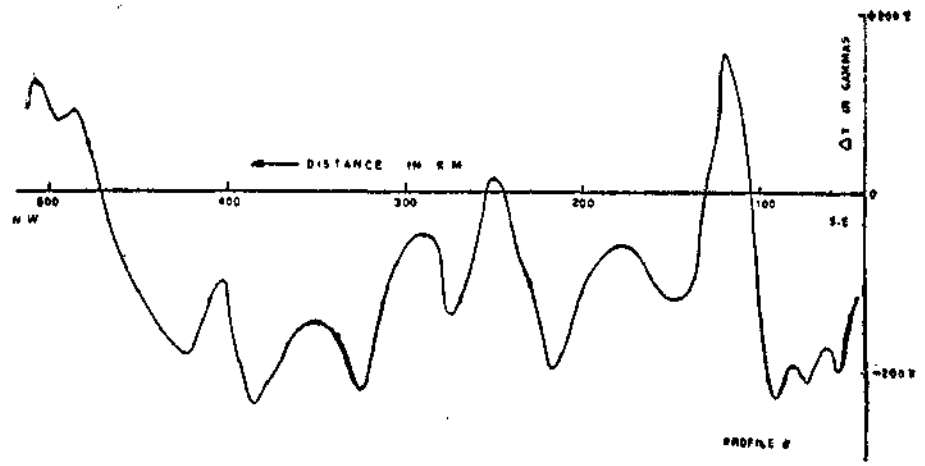

Fig. 6. Total magnetic field anomaly off Bombay.

C. *Murray Ridge*

Topographic and magnetic investigations of HMS DALRYMPLE over the Murray Ridge have indicated isolated and elongated topographic features such as guyots, seamounts and trenches. Most of these features fit well with the magnetic model computed using a magnetic susceptibility of 10^{-2} e.m. u/cm^3 which shows that the magnetic contrast extends beneath the present bed. Barker (1966) therefore concludes that the Murray Ridge is unlikely to be of continental origin and probably of volcanic complex.

Seismic refraction measurements of METEOR II over the Murray Ridge (Closs *et al.*, 1969) show a layer of volcanic material over the Murray Ridge. To the north-west and south-east of Murray Ridge, four consistent and well defined layers are present (Fig. 5b). The layer with velocity 5 to 6 Km/s which seems to be typical of the structure of the continental crust, is absent.

GEOLOGICAL AND GEOMORPHOLOGICAL INVESTIGATIONS

A. *Chagos-Laccadive Ridge*

Bottom contours in the Chagos-Laccadive region show that the base on which the coral reefs and atolls are perched is a magnificent mountain range that rises at its southern end from a depth of over 2000 fms. The breaks of differing magnitudes in the range are quite comparable to the passes in the mountain ranges over land (Sewell, 1935). Soundings around Maldives (Agassiz, 1903), show that the Chagos plateau is in direct line of continuation of the main range. The great plateau on which the Maldives are situated is interrupted by Eight-degree channel and Nine-degree channel that separate the Maldives from the Laccadives. The Laccadives continue the line of submarine range to the north for a further distance of 250 miles where they approach close to the edge of the continental shelf off the west coast of India. Further continuation of the main chain of submarine peaks and plateau join the Angria Bank and Direction Bank situated over the continental shelf off the Konkan Coast (Sewell, 1935). Sewell further believes that these great submarine ranges continue through the Gulf of Cambay into the Aravalli mountains off Rajputana (present Rajasthan) whose main trend is in the northeast-southwest direction. He suggests that the Satpura range to the east of Gulf of Cambay runs in west to east direction as a loop of the Aravalli range.

Davis (1928) opines that the atolls of the Laccadive and Maldive region are perched on top of the fault blocks derived from the remains of the Gondwanaland.

On the basis of biological evidence of migration between India and Africa, Willis (1932) has visualised an N-shaped land bridge which could have been present at least during the Permian, connecting Africa with India through Madagascar, the Seychelles, Saya De Malha ; the Chagos-Maldives-Laccadive Archipelagoes. He further believes that a portion of the Indian Ocean floor like that of the Laccadive Sea as well as a part of the Arabian Sea has subsequently undergone considerable subsidence.

Ermenko and Datta (1968) have carried out geological investigations in the Laccadive group of islands and found that the main trends (the Dhanwars in NW-

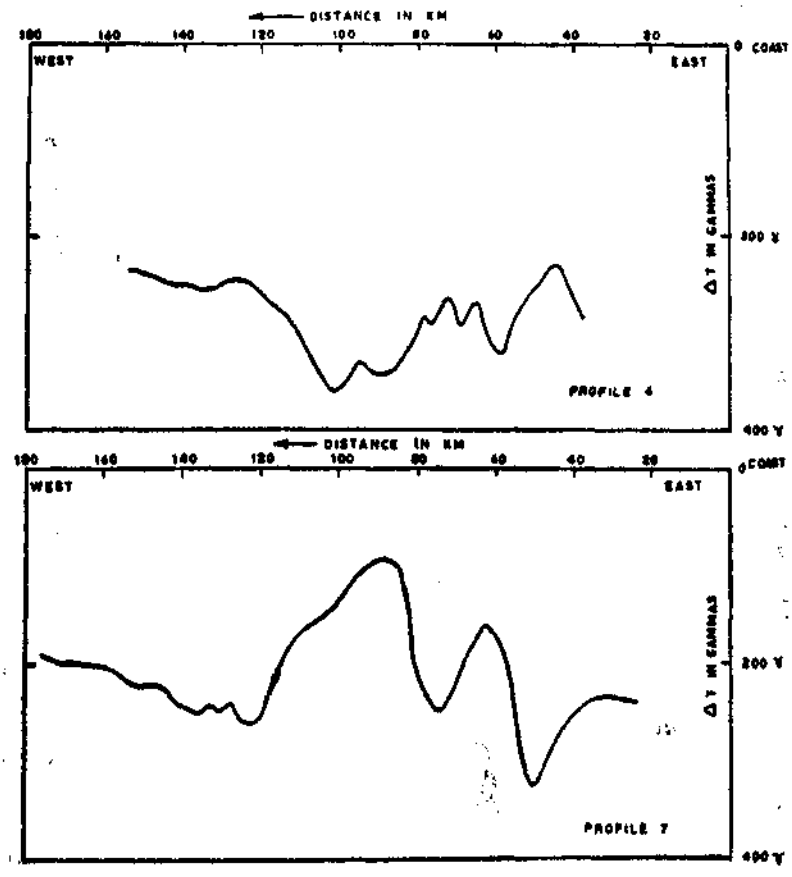

Fig. 7. Total magnetic field anomaly off Porbandar and Dwaraka.

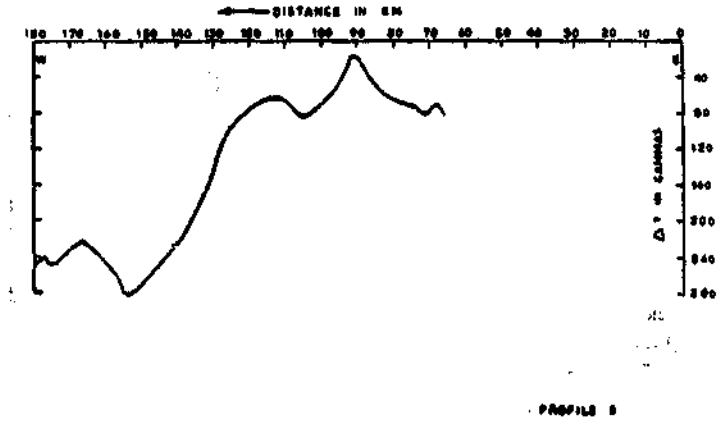

Fig. 8. Total magnetic field anomaly off Dabhol.

SE, the Aravallis or the Eastern Ghats in NE-SW directions as well as the sub-latitudinal and sub-meridional trends) that determine the grains of the various geomorphologic and morphostructural elements of the southern part of India are also present in the Laccadives region. They conclude that the ancient part of the Indian shield extends upto the Laccadive Islands and that the transitional zone between the continental and oceanic crust passes to the west of the Laccadives.

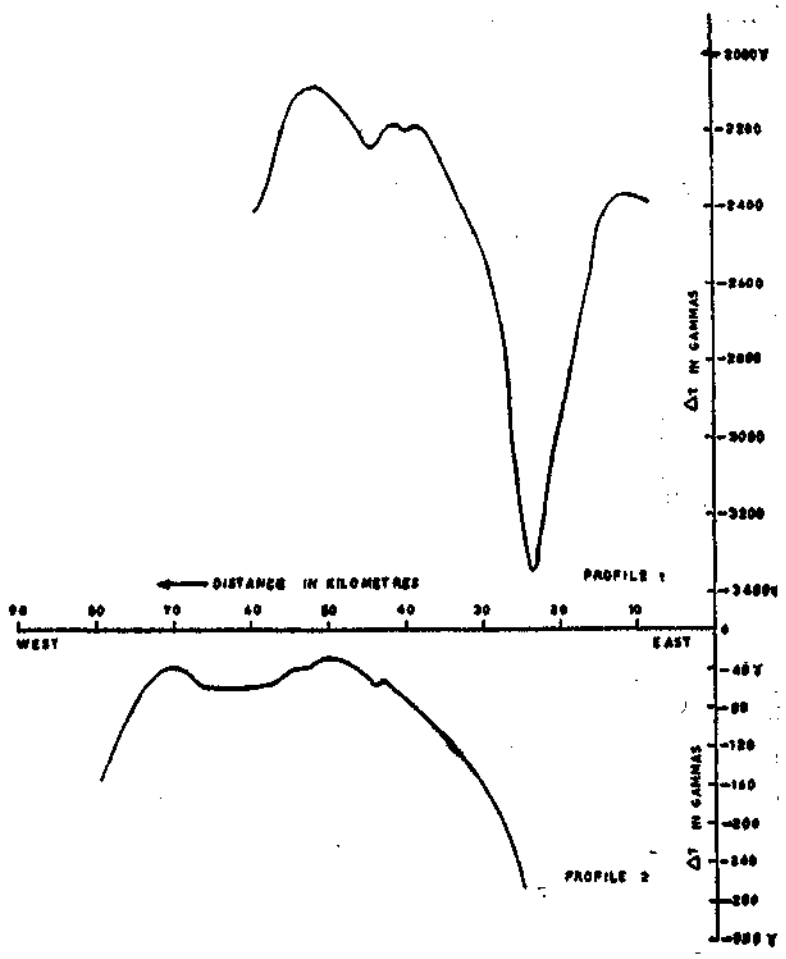

Fig. 9. Total magnetic field anomaly off Cochin.

B. *Murray Ridge*

Regarding the Murray Ridge ; Hunting Survey Corporation (1960) has assumed that the geoanticlinal structures of West Pakistan and Oman to be continuous features through the Murray Ridge and the continental rocks of the area now submerged under the Arabian Sea having been downfaulted in the Miocene. On the other hand, Wiseman and Sewell (1937) proposed that the Murray Ridge was continuous with the Kirthan mountains and that its southerly extension became a branch of the Carlsberg Ridge.

Discussion

While almost all geological and geomorphological evidences lead to the belief that the Chagos-Laccadive Ridge and the Murray Ridge are of continental origin and are the extensions of either the geoanticlinal structures or the mountain ranges over land into the ocean, the geophysical investigations reveal that they are composed of volcanic material and that they resemble the oceanic ridge systems rather than the mountain systems over the land.

The crustal structure of the Chagos-Laccadive Ridge reveals that it is a linear volcanic ridge, extending about 1500 m in south-north direction, with about 4 to 5 Km of thick volcanic material throughout its length (Francis and Shor, 1966). Linear ridges of this size are well-known in the Pacific ocean. Ninety-East Ridge is another example in the Indian Ocean itself. The linearity is believed to result from the control of the rising magma by faulting and such Archipelagoes are found to develop in one direction only.

Menard (1964) proposes that the group of volcanoes which develops along a part of major fault, produces an encircling moat and arch and the new volcanoes tend to develop in the region of tension where the arch intersects the major truncation. Francis and Shor (1966) feel that the absence of such moat and arch in the case of Chagos-Laccadive Ridge may perhaps be owing to the proximity of the Carlsberg Ridge to the south-west and the Peninsular India to the north-east. However the Russian Bathymetric chart of the Indian Ocean (Academy of Sciences, USSR, 1963) shows a small trench east of the Chagos Ridge. In regard to the arch, the same chart shows patches of shallow water between 200 and 300 Km, west of the Maldives. These distances are almost in the same range as those for the crest of the arches around the Pacific Archipelagoes. Patches of shallow water are also present west of Ninety-East Ridge.

Sewell (1935) believes that the great submarine ranges, on which the coral reefs and atolls of Chagos, Maldives and Laccadives have developed, form a mountain range extending northwards to join the Aravalli mountains of Rajputana. He further suggests that the Satpura range to the east of Gulf of Cambay runs in west to east direction as a loop of the Aravalli range. Seismic and magnetic investigations off Kathiawar Coast (Rao, 1970) and those off Konkan Coast (Rao, 1970a) have identified Highs beneath the ocean bottom over the continental shelf. These Highs have, however, indicated that the Chagos-Laccadives Ridge extends further north as sub-bottom Highs in two branches, in south-north direction through the High over the innershelf off Bombay, into the Cambay basin and the other in SE-NW direction over the outershelf to join the Kori High (Fig. 10). Further Sengupta (1967) mentions that the seismic surveys on land have not brought out any evidence in support of the southward turn of the Aravalli trend and its continuation along the Cambay basin. Thus the geophysical results establish that the Chagos-Laccadive Ridge along with the Highs over the continental shelf form a unitary submarine ridge system rather than its being the extension of the continental mountain ranges.

Topographic and magnetic investigations over the Murray Ridge have lead to the conclusion (Barker, 1966) that the Murray Ridge is of volcanic complex and is unlikely to be of continental origin. Mathews (1963) suggests that the Murray Ridge is a northward continuation of the Carlsberg Ridge. He adds that the southerly extension of the Murray Ridge was a transcurrent fault which has dis-

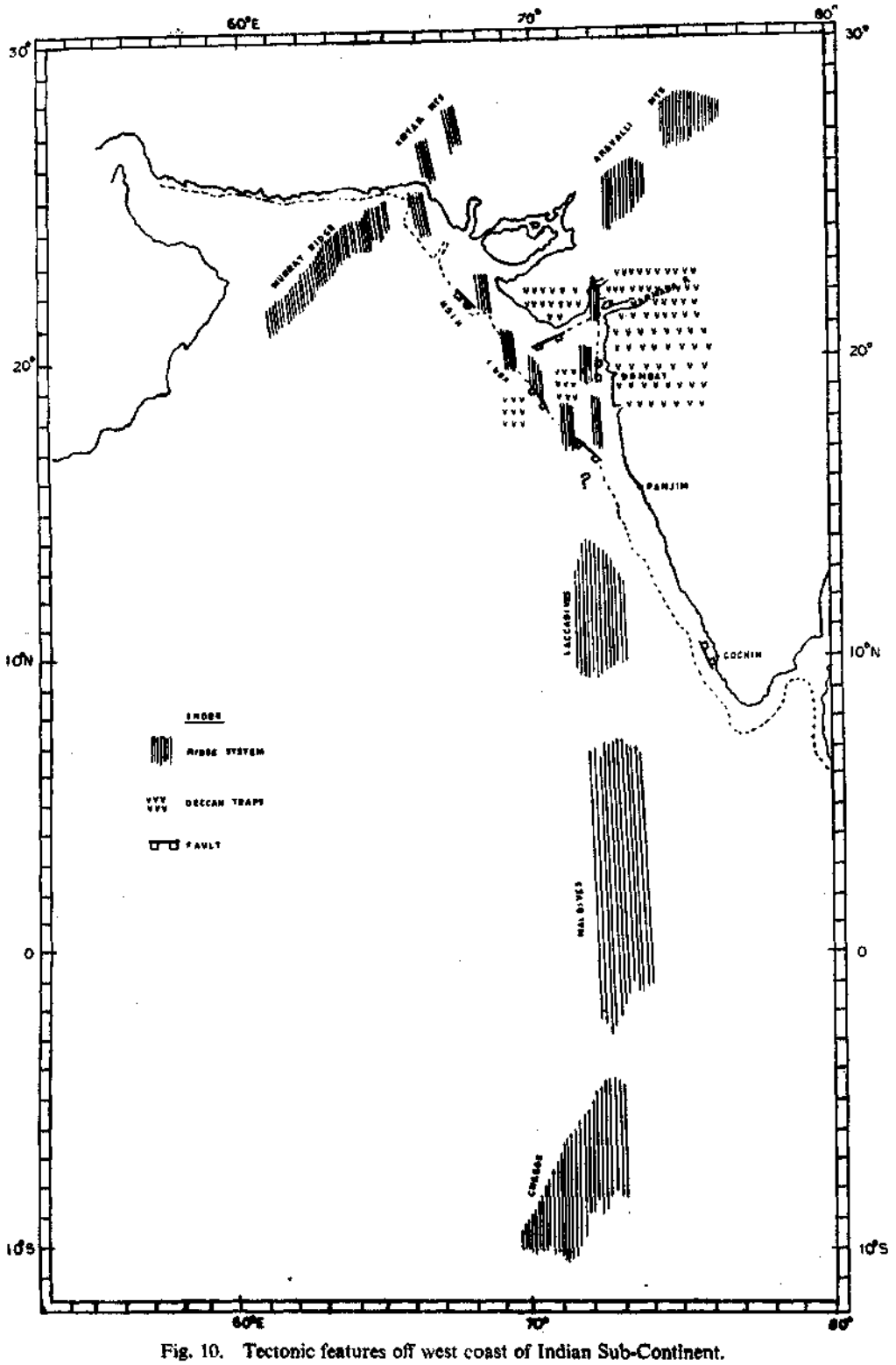

Fig. 10. Tectonic features off west coast of Indian Sub-Continent.

placed the crest of the Carlsberg Ridge to about 170 miles. These results are contrary to the assumption that the Murray Ridge forms either the connecting link between the geoanticlinal features of the West Pakistan and Oman (Hunting Survey Corporation, 1960) or the extension of the Kirthar mountains into the Arabian Sea (Wiseman and Sewell, 1937). Further, on the basis of absence of a typical layer of continental crust (velocity 5 to 6 Kms) on either side of the Murray Ridge, Closs and Hinz (1967) conclude that the crust of the northern Arabian Sea is of transitional nature changing from oceanic to continental type.

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