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Laxmi Ridge – A continental sliver in the Arabian Sea

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Abstract

Identification by Bhattacharya et al. (1994) of seafloor spreading type magnetic anomalies in the basin lying between Laxmi Ridge in the Arabian Sea and the Indian continent necessitates a change in plate tectonic reconstruction. Naini and Talwani (1982) named this basin the Eastern Basin and we will continue to use this term in this paper. Others, in the literature, have called this the Laxmi Basin. Previous reconstructions had assumed that the Eastern Basin is underlain by continental crust. The new reconstruction moves Seychelles' original location closer to India and ameliorates a 'space' problem in the Mascarene Basin. A new rotation pole between anomaly 28 and 34 times avoids 'skipping' of fracture zones resulting from rotation poles described earlier. The negative gravity anomaly over the Eastern Basin is a necessary consequence of a continental sliver lying between oceanic crust on either side. Seismic velocities that are slightly greater than 7 km s^{-1} under the Eastern need not be necessarily interpreted as material that underplates continental crust.

Introduction

A series of isolated offshore topographic highs trending in a NW SE direction lie about 500 to 700 km off the west coast of India. These highs rise only a few tens of meters above the Arabian Sea floor, which is at a depth of between 3500 and 4000 m. Naini and Talwani (1982) showed that these highs were peaks associated with a continuous buried structure which they named Laxmi Ridge (Figure 1). Gravity and seismic data indicated that Laxmi Ridge is quite different from a typical oceanic ridge, for instance, one consisting of a chain of seamounts. Laxmi Ridge is characterized by a distinct gravity low (both free air and Isostatic). Gravity lows are very seldom associated with ocean ridges and that by itself makes Laxmi Ridge a unique feature.

Seismic data in the Eastern Arabian Sea obtained by Naini and Talwani, 1982, and by earlier investigators (Closs et al., 1969; Shor and Pollard, 1973; Rao, 1970) consist of single channel reflection data and refraction data (sonobuoy as well as two ship). The conclusion reached by Naini and Talwani was that while Laxmi Ridge consists of continental crust, the structure of the area lying between it and the Indian continental slope (which they referred to as the Eastern Basin), was uncertain. Their preferred inference was that this area consists of rifted and subsided continental crust. This inference appears to have been generally accepted in the literature and thus the southwestern margin of the Laxmi Ridge was considered to delineate the ocean continent boundary. However, if the Eastern Basin consists of subsided continental crust and the Laxmi Ridge consists of (relatively) elevated continental crust (with the same thickness), the existence of a negative gravity anomaly over the Laxmi Ridge and a positive gravity anomaly over the Eastern Basin is difficult to explain. Magnetic data prior to the publication of data in the Eastern Basin by Bhattacharya et al. (1994) were ambiguous and did not clarify the origin of this basin. However, Bhattacharya et al. clearly showed from an examination of magnetic anomalies obtained on a detailed survey that the Eastern Basin is formed by sea-floor spreading. This paper examines the implications of the result that the Eastern Basin consists of oceanic crust:

(1) Can the negative gravity anomaly over the Laxmi Ridge be explained?

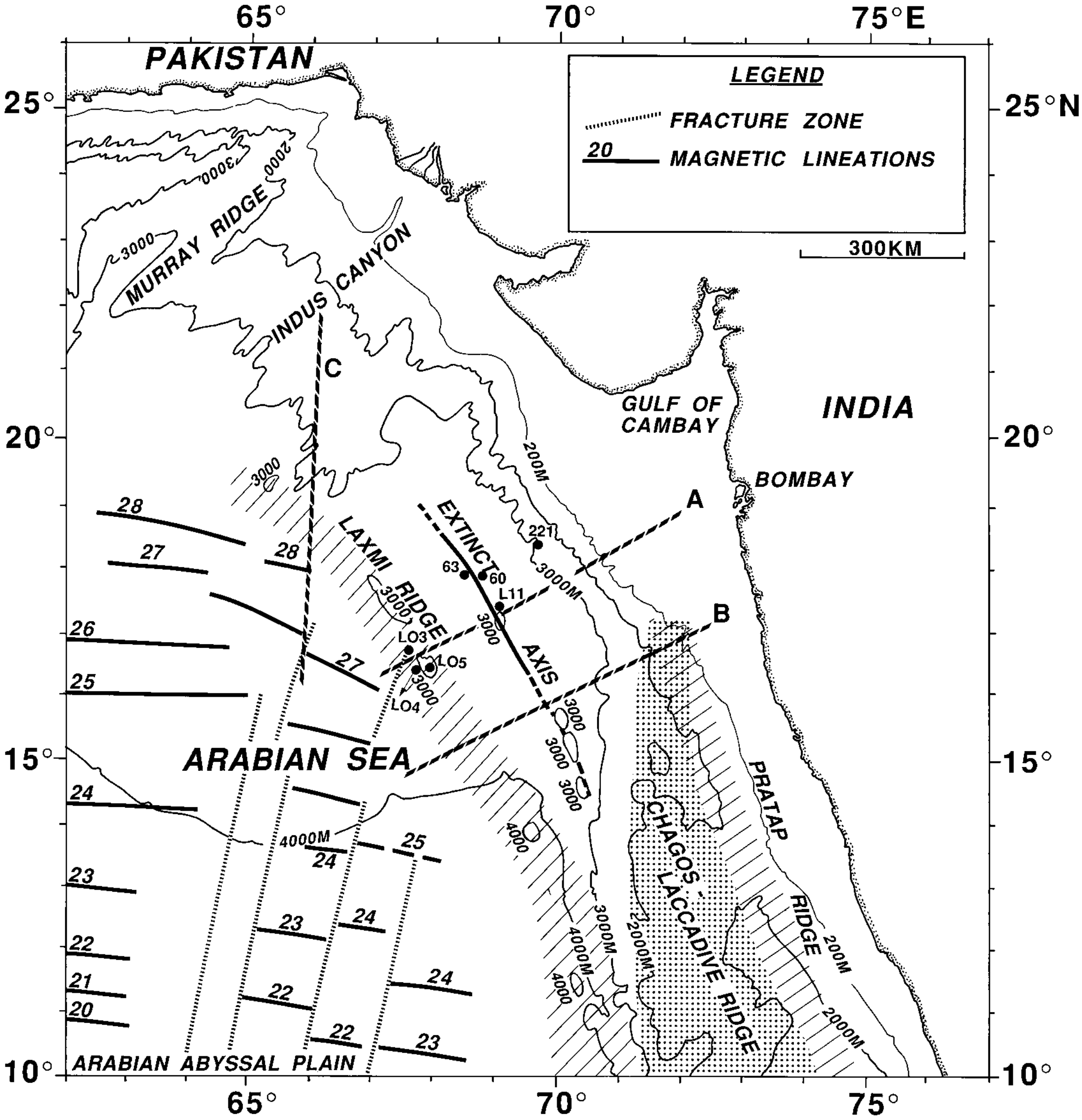

Figure 1. Laxmi Ridge is located about 5–700 km west of India's west coast. Most of the data in this figure are taken from Naini and Talwani, 1982. The positions of the magnetic anomalies and the fracture zones have been updated from Miles and Roest, 1993. The Eastern Basin lies east of Laxmi Ridge and the location of the extinct spreading axis is from Bhattacharya et al. (1994). Pratap ridge, characterized by rough basement topography (Naini and Talwani, 1982) may be conjugate to Laxmi Ridge.

(2) How are plate tectonic reconstructions of the early opening of the Arabian Sea affected, and can some of the problems arising out of earlier reconstructions be solved?
(3) The emplacement of the Deccan volcanics by the Reunion hot spot is well dated. How is this date related to the date of initiation of the opening of the Eastern Basin?
(4) Can the question of the northward continuation of the Chagos Laccadive Ridge be resolved? Does it simply continue into the Indian subcontinent or does it bend northwestward and continue parallel to the Indian margin?

We start by examining the geophysical data in some detail.

Magnetic data

Magnetic data over Laxmi Ridge and the Eastern Basin (Naini and Talwani, 1982; Bhattacharya et al., 1994) are shown in profile form in Figure 2. The inter-

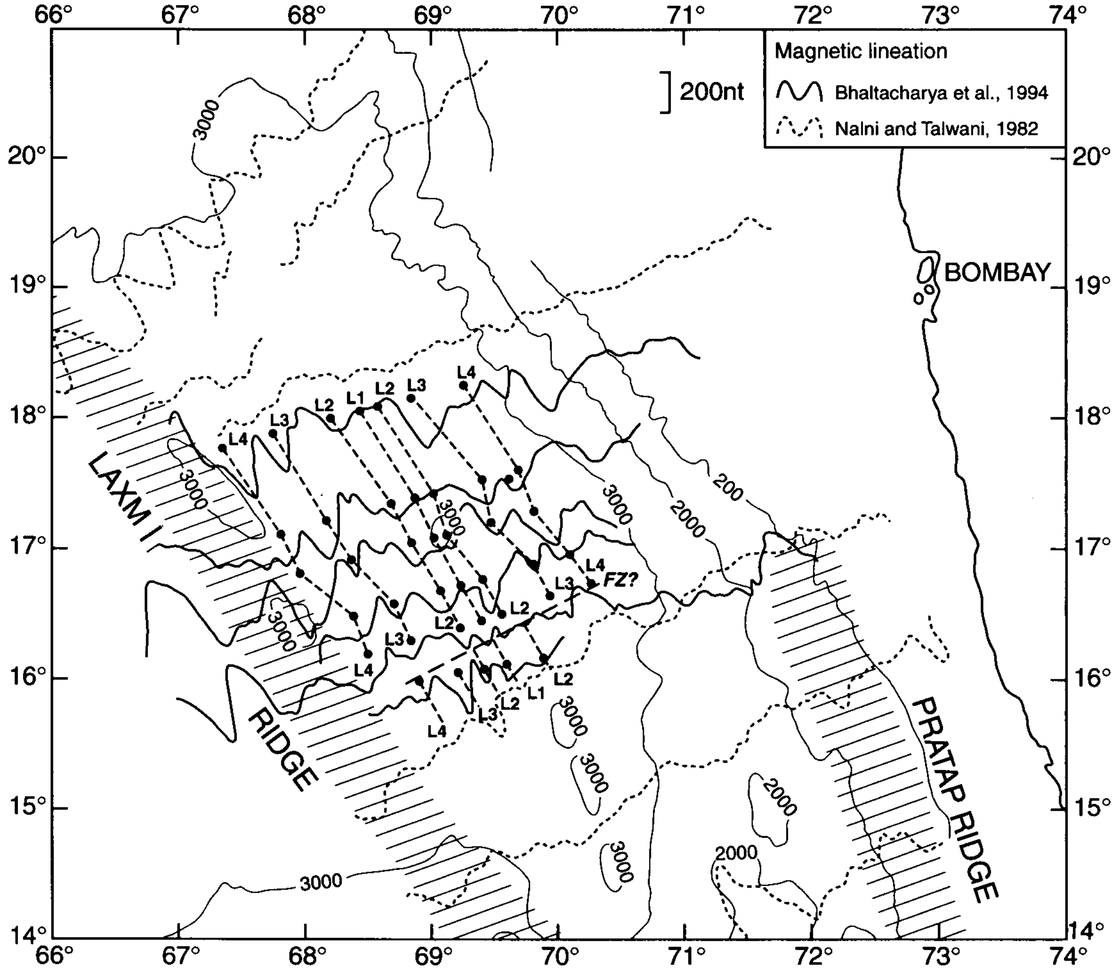

Figure 2. Magnetic anomalies in the Eastern Basin from Bhattacharya et al. (1994). Some magnetic profiles from Naini and Talwani (1982) have been added.

pretation of the magnetic anomalies over the Eastern Basin by Bhattacharya et al. as arising out of magnetic reversals and sea-floor spreading, is shown in Figure 3. By plotting a reversed profile (79–15) in Figure 3, the interpretation of these anomalies as having been caused by sea-floor spreading appears to be quite credible. Bhattacharya et al. offer two possible reversal sequences to explain the anomalies. One in which the prominent anomaly L4 is identified as anomaly 33, and the second in which L4 is identified as anomaly 31. In the first case, the time of initial opening would be between anomaly 33 and anomaly 34, and in the second case the time of opening would be between anomaly 31 and anomaly 32. In the second case, the rates of opening are quite variable, ranging from 0.26 cm yr^{-1} to 4.03 cm yr^{-1} (a factor of about 15). They are less variable in the first case, ranging from 0.4 cm yr^{-1} to 0.9 cm yr^{-1} (a factor of about 2).

Magnetic data on the Laxmi Ridge are quite irregular. Large anomalies exist along some profiles, but these have not been attributed to sea-floor spreading. Large irregular anomalies are also associated with the Chagos Laccadive Ridge, which have been attributed to its volcanic nature.

West of the Laxmi Ridge, regular sea-floor spreading anomalies have been identified by a number of authors including Miles and Roest (1993) and Naini and Talwani (1982). The oldest anomaly that was identified was anomaly 28. Miles and Roest (1993) have discussed the influences of propagating ridges on the spatial geometry of the anomalies.

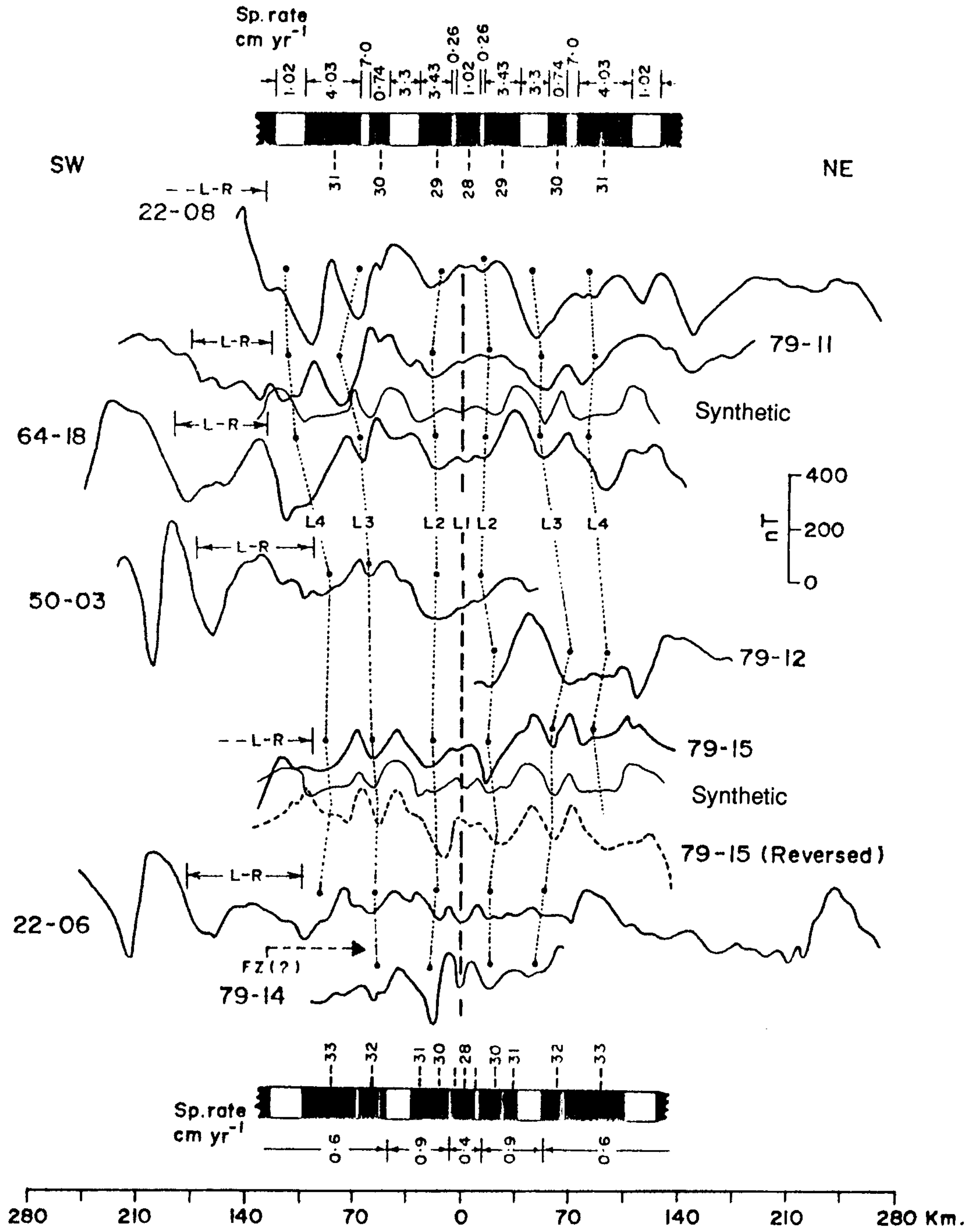

Figure 3. Two possible sea-floor spreading reversal scenarios from Bhattacharya et al. (1994). Note the similarity between 79–15 (synthetic) and 79–15 (reversed) profiles.

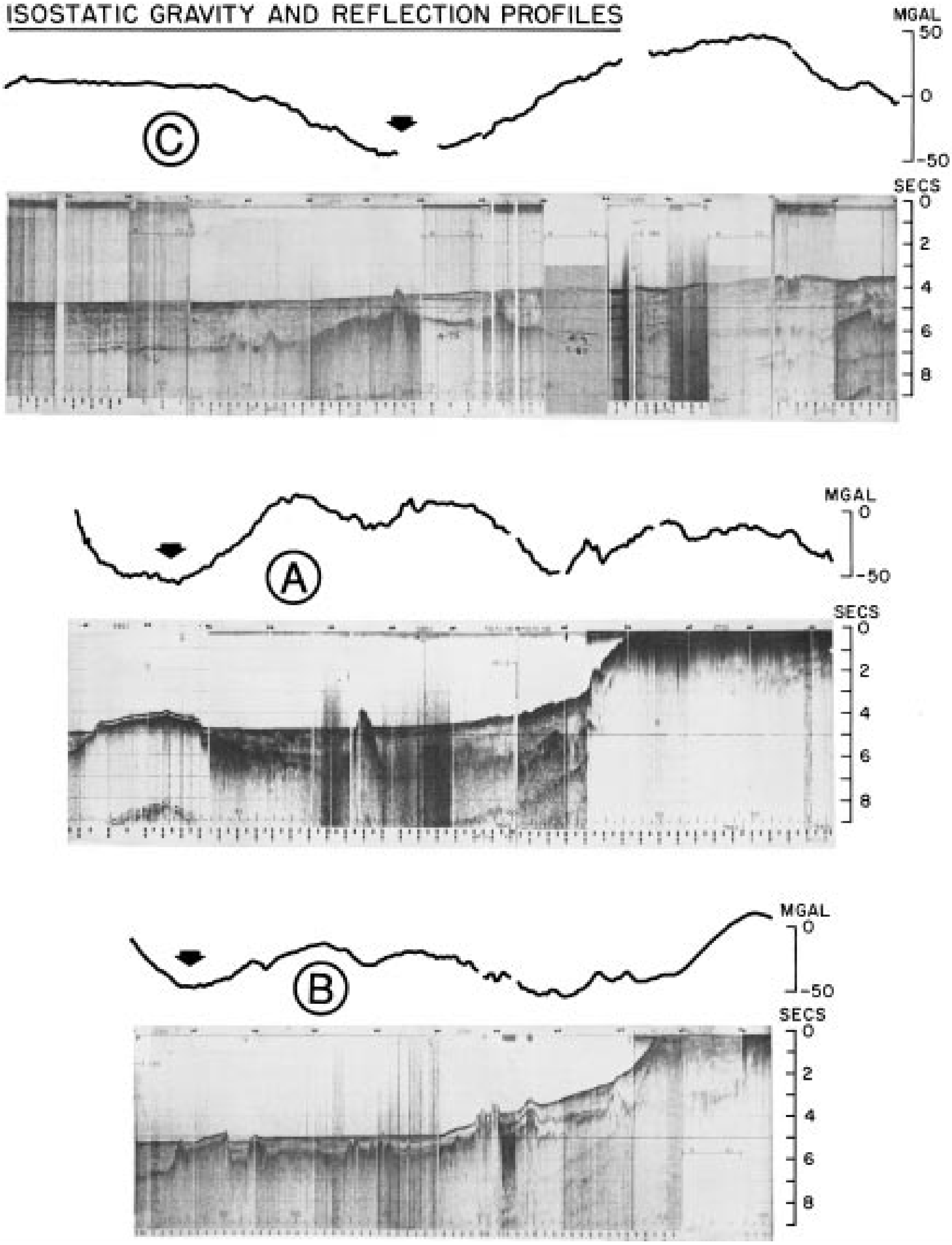

Figure 4. Single channel reflection profiles and 2D isostatic gravity anomalies over Laxmi Ridge (see arrow) from Naini and Talwani (1982).

Seismic data

Single channel seismic reflection data obtained with a small airgun along three profiles over Laxmi Ridge and the Eastern Basin (Naini and Talwani, 1982) are shown in Figure 4. Over the Laxmi Ridge energy from this weak sound source was only able to penetrate a few hundred meters of presumably unconsolidated sediments. Their velocity from wide angle sonobuoy reflection data (to be discussed later) is about 1.8 km s^{-1}. The thickness of this layer averaged from long range sonobuoy stations L03, L04, and L05 is about 300 m (Table 1). The base of this layer (best seen in profiles A and B of Figure 4) appears to represent a relatively smooth tilted surface which was probably leveled by erosion at some time in the past. It does not indicate the typical high relief that would, for example, be associated with a chain of oceanic seamounts, Seismic reflection data in the Eastern Basin, seen most clearly in profile A (Figure 4) shows sediments ponded against Laxmi Ridge. If one considers velocities less than 5 km s^{-1} to represent sediments in the Eastern Basin, then the average thickness of sediments from stations 60, 63, L11 and 221 (Naini and Talwani, 1982) is 3.1 km, which roughly agrees with the two-way travel time of 2 secs within the sediments in the Eastern Basin on profile A. (The velocity of sediments range from 1.8 to 4.6 km s^{-1}; therefore 3.1 km s^{-1} represents a reasonable average value.) However, if we had used the same criteria to identify the sedimentary layer on Laxmi Ridge, its average thickness there would not be 300 m, but about 1.1 km.

On the basis of appearance of layers in the reflection records, we believe that layers with velocities lying between 2 and 5 km s^{-1} in the Eastern Basin represent ponded sediments from the Indus cone, while layers with similar velocities on Laxmi Ridge do not represent ponded sediments. This interpretation would be consistent with the presence of a thin veneer of pelagic sediments on Laxmi Ridge and Eastern Basin; and the presence of a thicker section of underlying terrigenous sediments lying in the Eastern Basin, but absent on the Laxmi Ridge.

Seismic refraction data obtained largely from sonobuoy experiments reveal layers with velocities of 5.43 km s^{-1}, 6.2–6.3 km s^{-1}, and 7.15–7.19 km s^{-1} under both the Laxmi Ridge and the Eastern Basin. These layers are somewhat thicker under Laxmi Ridge, the minimum depth to Moho being 21 km there, while it is 16 km under the Eastern Basin.

Gravity data

Figure 5 shows that the free air anomaly over Laxmi Ridge is about 40 mgal more negative than the free air anomaly over the Western Basin, and about 60 mgal more negative than the anomaly over the Eastern Basin. In fact, the gravity low has been used to establish the extent of Laxmi Ridge. Miles and Roest (1993) have traced the gravity low westwards from about 66° E to about 64° E along a latitude just south of 19°N. There is also a negative anomaly over the continental slope and a positive anomaly over the continental shelf. Where 2D isostatic anomalies are computed, the negative anomaly over Laxmi Ridge remains relatively unchanged, but the anomalies over the continental slope and shelf are considerably reduced, showing that they can be largely attributed to the gravity edge effect at a continental margin. The gravity low over Laxmi Ridge continues south eastward, but merges into the low associated with the western flank of the Chagos Laccadive Ridge. The latter can also be attributed to an edge effect. The presence of a negative anomaly over Laxmi Ridge is quite unusual. Submarine ridges are almost always associated with positive free air anomalies.

Discussion and plate tectonic implications

Naini and Talwani (1982) proposed that Laxmi Ridge has continental crust. That proposal appears to have been generally accepted in the literature. These authors were less certain about the structure and origin of the Eastern Basin. They favored a rifting origin which implied a rifted, thinned and subsided continental crust, although they stated that ‘it is difficult to prove . . . that the area was not created by sea-floor spreading.’ They noted the similarity in crustal velocities between the Eastern Basin and Laxmi Ridge, but their main reason for favoring a continental origin for the Eastern Basin was that they were unable to identify sea-floor spreading type anomalies in the Eastern Basin. Magnetic anomalies were present there but they appeared to be irregularly located.

The demonstration by Bhattacharya et al. (1994) that sea-floor spreading anomalies exist in the Eastern Basin dispels the uncertainty regarding the origin of this area. The presence of a topographic high along the axis of the Eastern Basin, identified as an extinct axis and the great similarity between profile 79–15 and 79–15 (reversed) (see Figure 3), reversed around the extinct axis strongly supports the suggestion that the anomalies in the Eastern Basin are sea-floor spreading

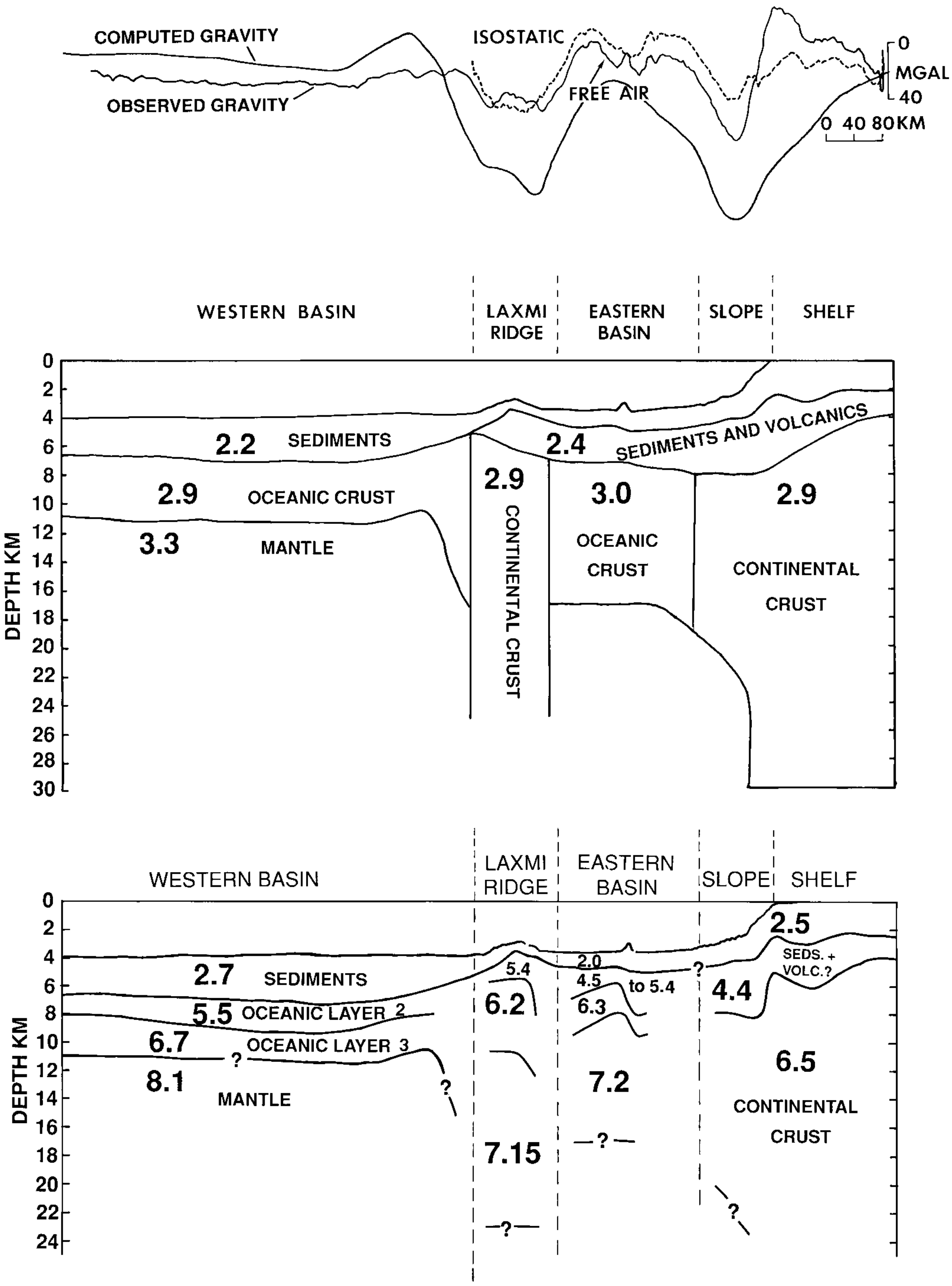

Figure 5. *Bottom*: A schematic seismic profile based largely on sonobuoy reflection and refraction data of Naini and Talwani (1982) from the Western Basin to the Indian Continental Shelf. Middle: Density profile constructed on the assumption that Laxmi Ridge has thick continental crust and lies between basins with oceanic crust on either side. *Top*: Observed (Free air and 2D isostatic) gravity anomaly profiles and a computed gravity profile from the density profile. No attempt has been made to fit the observed Free air gravity curve. The computed curve simply indicates that gravity is negative over Laxmi Ridge relative to the basins on either side.

Table 1. Seismically determined layer velocities and thicknesses at stations near profile A in Figure 1. Station 221 is a two-ship refraction station (Closs et al., 1969). The others are sonobuoy (wide angle reflection and refraction) stations from Naini and Talwani (1982). Water depth is given in kilometers. The V's and H's represent layer velocities and thicknesses, respectively.

Station ID	Latitude deg-min	Longitude deg-min	Water Depth	V1	H1	V2	H2	V3	H3	V4	H4	V5	H5	V6	H6	V7	H7	V8	H8
60	17-51	68-45.4	3.328	1.78 ± .10	0.75	2.42 ± .11	0.79	3.24 ± .31	0.59	3.5	0.42			5.3	1.40	6.3			
63	17-55.5	68-30.4	3.357	2.05 ± .09	0.67	2.35 ± .07	0.77	3.0*	1.22					5.4	2.13	6.4			
L11	17-22.1	69-03.4	3.519	1.78 ± .08	0.63	2.3*	0.71					4.6	0.41	5.4	2.73	6.4	0.7	7.3	6.47
221	18-25	69-41	2.495	v(z)	0.65					3.26	0.85	4.4	4.0			6.5			
L03	16-40.1	67-38.2	3.048	1.75 ± .14	0.40	2.28 ± .20	0.34					4.2	0.65	5.2	1.39	6.2	2.80**		
L04	16-25.5	67-42	2.811	1.80 ± .10	0.26			3.03	0.30					5.4	2.10	6.2	5.18	7.1	7.30
L05	16-27.4	67-59.3	3.136	1.82 ± .17	0.28	2.27 ± .20	0.49					4.3	0.73	5.4	3.51	6.2	4.13	7.2	10.70

*Assumed velocity. Numbers following the sign '±' refer to standard deviation of velocity (interval velocity only).
Values without standard deviation reter to refractfon (Interface) velocity.
**Minimum Thickness.

anomalies and that the Eastern Basin is oceanic and was created by sea-floor spreading.

We have to explain the seismic and gravity observations in light of the above discovery and we also have to consider its plate tectonic implications.

The main crustal layers under the Eastern Basin have velocities of about 5.43 km s^{-1}, 6.30 km s^{-1}, and 7.19 km s^{-1}. The velocities of 6.30 and 7.19 km s^{-1} are, indeed, unusual for what is considered a normal oceanic crustal velocity of 6.7 km s^{-1}. However, if we examine the crustal velocities of oceanic crust created immediately after opening (called Initial Oceanic Crust by Talwani et al. 1995) we find that the Eastern Basin crustal velocities are actually typical of such crust. The LASE experiment in the Northern Baltimore Canyon Trough (LASE Study Group, 1980) off the US East Coast typically had layers with velocity 5.1 km s^{-1}, 5.9 to 6.5 km s^{-1} and 7/3 to 7.4 km s^{-1}. The EDGE experiment off the Southern Baltimore Canyon Trough (Holbrook et al., 1994) and the Carolina Trough experiment (Trehu et al., 1989) revealed similar layering with somewhat higher upper crustal velocities, but the existence of the lowest layer of velocity 7.1 to 7.5 km s^{-1} is seen in every case. Thus, although the seismic velocities under Laxmi Ridge and the Eastern Basin are similar, their origins (except for the thin veneer of geologic sediments at the top velocity 1.8 km s^{-1} and the lowest crustal layer with velocity 7.1–7.5 km s^{-1} which apparently represents new magmatic material), are different. The material comprising the lowest layer, in addition to forming the lowest part of the Initial Oceanic Layer, also extends laterally below the continental crust where it has been referred to as 'underplating'. The Eastern Basin has a thicker sedimentary section, presumably terrigenous, which abuts against the Laxmi Ridge. The 5.43 and 6.30 km s^{-1} layers comprise the upper part of the Initial Oceanic Crust. Layers with similar velocities under Laxmi Ridge (which, incidentally, are similar to the layers under the Deccan Plateau) presumably represent continental crust.

To calculate gravity anomalies, we have constructed a schematic section in which Laxmi Ridge is believed to have a continental crust that is thicker than the oceanic crust under the Eastern Basin (Figure 5). Because the Initial Oceanic Crust has a higher seismic velocity than the normal oceanic crust, we have ascribed a slightly higher density to it. We have not tried to match the observed and computed anomalies exactly. Qualitatively, the negative anomaly over Laxmi Ridge is ascribed to the fact that it consists of continental crust that is thicker than oceanic crust on either side. Gravity solutions are not unique and the crust under Eastern Basin need not be oceanic (for gravity anomaly matching purposes) but it does need to be thinner than the crust under Laxmi Ridge.

In order to examine the kinematic plate tectonic implications of the newly discovered sea-floor spreading anomalies in the Eastern Basin we compiled the existing magnetic lineation data in the western Indian Ocean from several sources, including Norton and Sclater (1979), Naini and Talwani (1982), Miles and Roest (1993) and Bhattacharya et al. (1994). These are shown in Figure 6 (top left). Note that anomalies 28 and younger exist between Seychelles and Laxmi Ridge, on either side of the Carlsberg Ridge, and

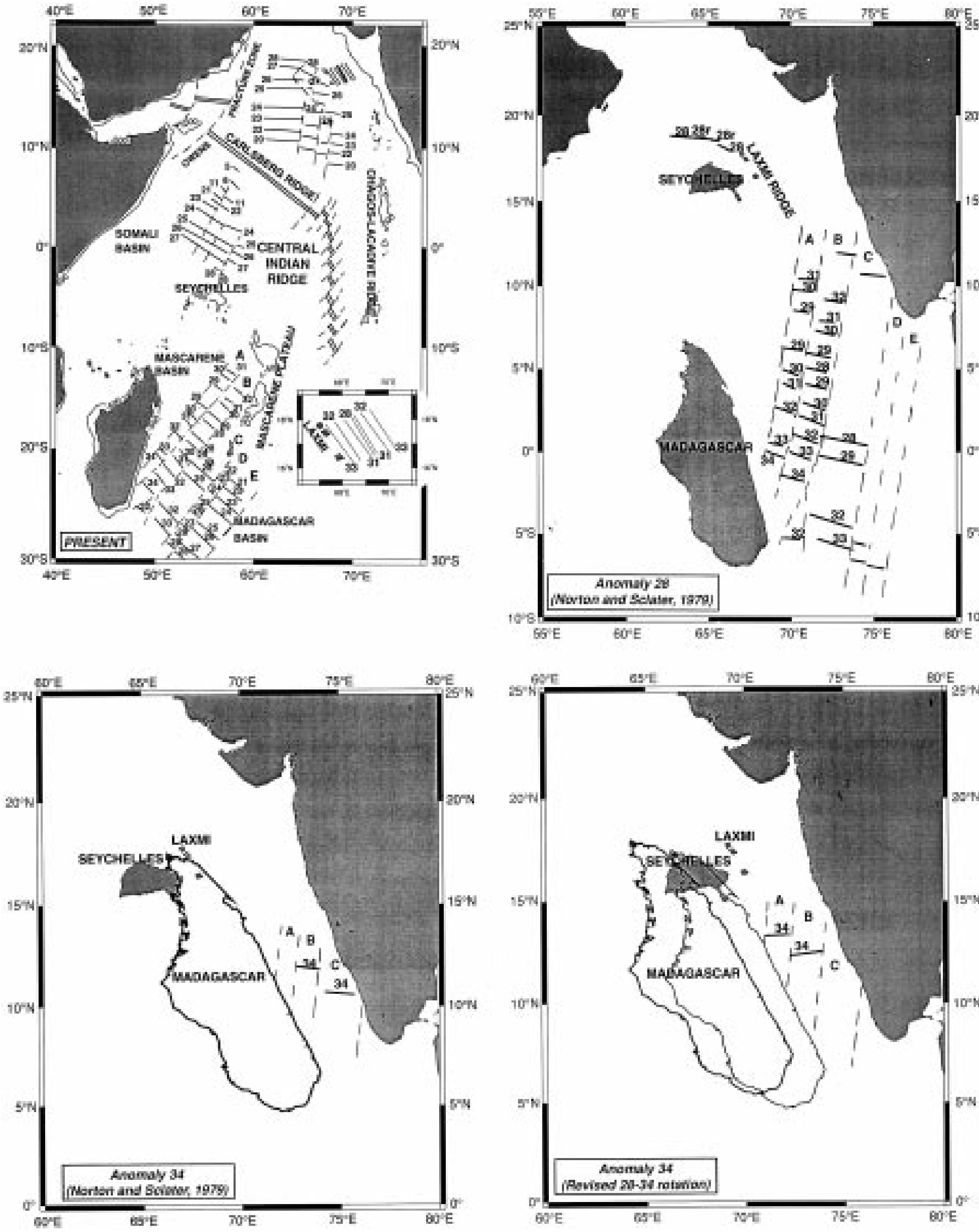

Figure 6. Top left: Magnetic lineations in the western Arabian Sea (modified from Bhattacharya et al., 1994). *Top right*: Anomaly 28 reconstruction using pole of opening given by Norton and Sclater (1979). *Bottom left*: Anomaly 34 reconstruction using pole of opening given by Norton and Sclater (1979). Anomalies 34 in this figure are obtained by rotation from their positions south of the spreading axis. Note that they have 'skipped' fracture zone from zones A and B to Zones B and C. Madagascar has moved through Seychelles (delineated by the 500m contour) and lies north-east of it. *Bottom right*: Madagascar (right location) is in the same position as in the bottom left figure. Seychelles and Laxmi Ridge have been moved east (see Table 2) to account for the spreading in the Eastern Basin. Seychelles now completely overlaps Madagascar. Madagascar (left location) is obtained by using a new pole (this paper) for the 28–34 opening (see text and Table 2). Anomaly 34 now does not skip fracture zones and the overlap of Seychelles and Madagascar is reduced.

Table 2. Rotation parameters for anomaly 28–34 interval. Indian plate is fixed. (Anticlockwise rotation is positive.)

	Pole position	Rotation
India-Madagascar (Mascarene Basin anomalies)	11° N 10° E	27°
India - Laxmi Ridge (Eastern Basin anomalies)	45° S 199° E	−2°

also south of Mascarene Plateau. They do not exist in the main part of Mascarene Basin, except for a small patch of post 28 crust laying in a zone marked B between fracture zones. Anomalies older than anomaly 28 were, until the discovery of spreading in the Eastern Basin, identified only in the eastern Mascarene Basin. They have not been identified in the western Mascarene Basin; also, as a number of authors have pointed out, the western Mascarene Basin is narrower than the Eastern Mascarene Basin. This would create a space problem upon plate reconstruction.

Figure 6 (top right) shows the reconstruction to anomaly 28 time using the pole of rotation given by Norton and Sclater. Note how on rotation anomaly 28 just north of the Seychelles (designated 28r) coincides with anomaly 28 southwest of Laxmi Ridge. We have also eliminated the space occupied by post 28 crust in the zone marked B between fracture zones east of Madagascar and moved the older anomalies 'up' along the fracture zones to take up that space. Note also how the Western Mascarene Basin is narrower than the Eastern Mascarene Basin. The 28 to 34 anomaly sequence seen in the Eastern Basin will not fit into the Western Basin.

Figure 6 (bottom left) shows the reconstruction to anomaly 34 time using the pole of rotation given by Norton and Sclater. There are two obvious problems with this reconstruction. Because of the lack of space in the Western Mascarene Basin, Madagascar, on reconstruction not only closes this Basin, but actually pushes past Seychelles. The northern tip of Madagascar now lies north-east of Seychelles. Secondly, anomaly 34 on rotation skips fracture zones. Anomalies 34 shown in this figure are the southern anomalies rotated to the north. If the Eastern Basin is closed by using the newly discovered anomalies there (rotation is given in Table 2), Seychelles now moves into the tip of Madagascar, shown by the right of the two positions of Madagascar in Figure 6 (bottom right). A new pole for rotation between anomaly 28 and 34 time was deduced by making sure that the corresponding small circles matched the fracture zones (Table 2). The magnitude of rotation was established by matching anomalies 32 and noting that the rate of rotation between anomaly 28 and 32 is twice the rate between anomaly 32 and 34. When this is done, anomaly 34 does not skip fracture zones and the overlap of Madagascar with Seychelles shown by the left of the two positions of Madagascar in Figure 6 (bottom right) is reduced. The remaining overlap is a consequence of the fact that the width of the Western Mascarene Basin, plus the space occupied by anomalies in the Eastern Basin, still is less than the width of the Eastern Mascarene Basin. Thus, the space problem is alleviated, but not completely eliminated.

The poles of rotation for the anomalies in the Eastern Mascarene Basin and in the Eastern Basin are not the same (Table 2), which implies that the poles of opening in the Eastern and Western Mascarene Basin are also different. Thus the Mascarene Basin would have to consist of two parts with a transtensional boundary between them. We are not aware of any geophysical evidence to support the presence of such a boundary.

Of Bhattacharya et al.'s two possible times of opening, we have adopted the pre-anomaly 33 opening scenario for the Eastern Basin. This has an interesting consequence. The age of the initiation of the Deccan Volcanics by the Reunion hot spot is placed at 65–67 my (Courtillot et al., 1986). If the opening is pre-anomaly 33, say around 78 my (midway between the ages of anomaly 33 and anomaly 34), then the opening predates the initiation of the Deccan volcanics and would seem to be unrelated to it. This is in contrast to the opening of other oceans (North Atlantic, South Atlantic, Norwegian Sea) for which many authors have related hot spot activity to continental break up. If, on the other hand, pre-anomaly 31 scenario is adopted for the Eastern Basin opening, the timing of (nearly 70 my) is closer to the time of arrival of the hot spot. While the earlier (pre anomaly 33) opening questions the relationship between hot spots and continental breakup, it does explain why extensive volcanism is not associated with the Eastern Basin. The subsequent jump of the opening from NE of Laxmi Ridge to SE of Laxmi Ridge at anomaly 28 time (63 my) could be associated with the proximity to the hot spot. All ages are taken from the time scale of Cande and Kent (1995).

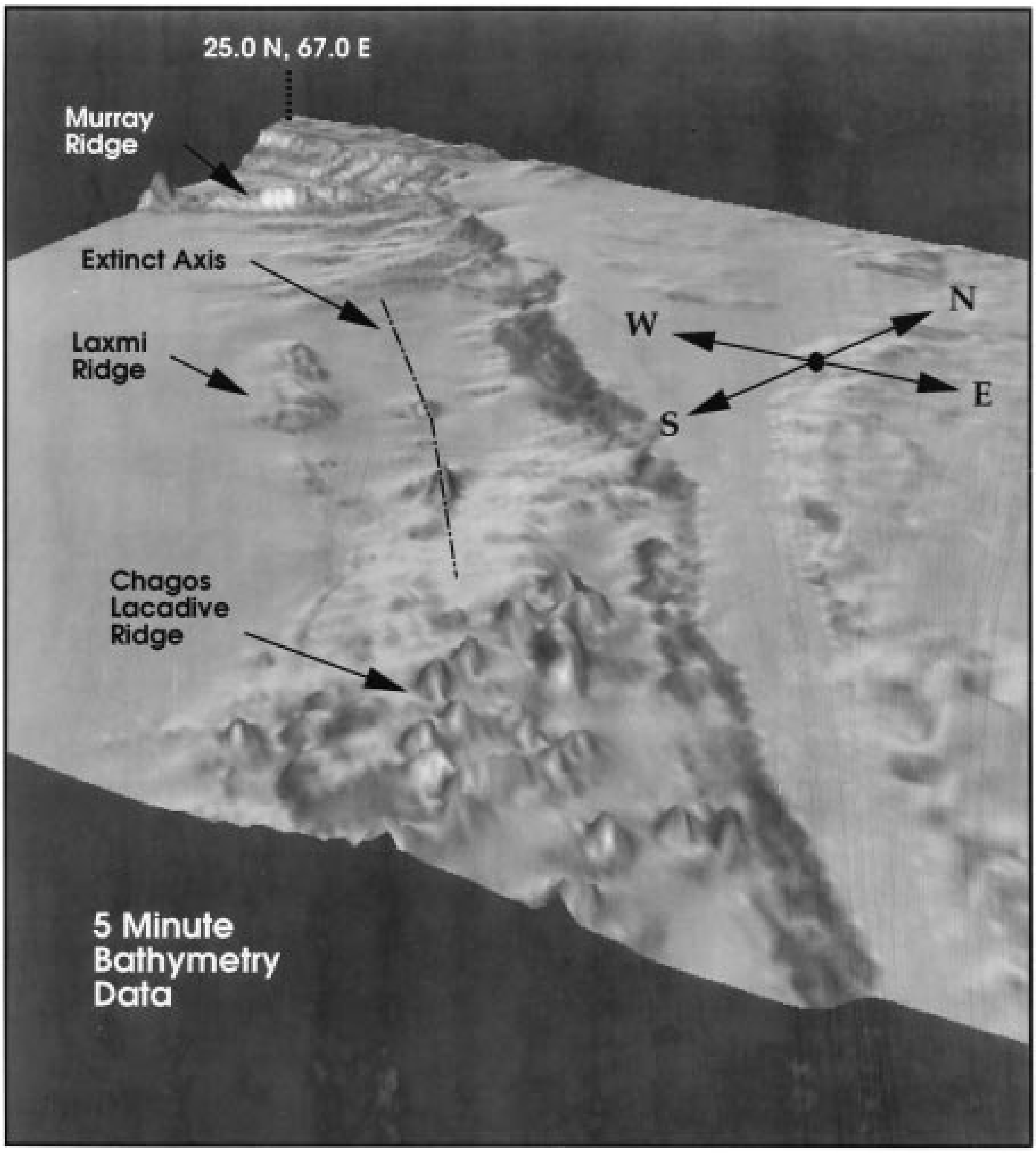

Figure 7. 3D perspective of bathymetry (obtained from NGDC) in the Arabian Sea seems to suggest that the Chagos Laccadive Ridge does not turn NW and continue parallel to the India margin, but rather, it continues northwards into India.

Naini and Talwani (1982) also speculated on the northward continuation of the Chagos Laccadive Ridge – whether it continues northward into India, or whether it bends NW parallel to the Laxmi Ridge. The subsequent determination of a sequence of accurate ages (see, for example, Duncan and Richards, 1991) which decrease from the Deccan volcanics southwards along the Chagos Laccadive Ridge (from 66 to 57 to 49 million years) would seem to establish the northward continuation of this ridge. In addition, it is now clear that the chain of topographical highs along the middle of the Eastern Basin mark the location of the axis of spreading, now extinct, whose age is greater than the age of adjacent portions of the Chagos Laccadive Ridge. In fact, the hot spot related Chagos Laccadive Ridge obscures the SE continuation of the Eastern Basin extinct axis. Figure 7 shows a 3D perspective of the offshore topography off the western margin of India. From this perspective it seems obvious that the Chagos Laccadive Ridge heads northwards into India and does not bend NW parallel to the Indian margin.

Discussion

After initial submission of this paper, three papers dealing with the same area came to the attention of the authors. Dyment (1998) makes a careful examination of magnetic anomalies in the region; but these anomalies lie oceanward of Laxmi Ridge and have no direct bearing on the precise topic of this paper.

Miles et al. (1998) believe the 7+ km s^{-1} layer to underplate thinned continental crust beneath the Eastern (Laxmi) basin; we believe, on the other hand, that this layer comprises 'Initial Oceanic Crust' similar to the crust underlying the US East Coast margin. (Talwani et al., 1995). Only when this layer extends under the adjoining continent can it be considered an underplate. By varying the thickness and topography of the 'underplate', Miles et al. fit gravity profiles. Such more or less arbitrary manipulation of gravity models prove neither the correctness of the models, nor do they establish the origin of the 'underplated' material. The axis of the Eastern (Laxmi) basin is clearly marked by topographic and local gravity highs (Figures 1 and 7, this paper, and Bhattacharya et al., 1994). Such a positive feature is compatible with the existence of an extinct ridge axis; it is not compatible with the axis of a basin overlying a thinned, rifted continental crust. But the strongest argument for the Eastern (Laxmi) basin to be underlain by oceanic crust comes from Bhattacharya et al.'s examination of lineated magnetic anomalies. We call particular attention to their reversed profile (79–15 in Figure 3) which matches their unreversed profile extremely well. We know of no case in the world's oceans that a similar match involving lineated anomalies is not attributed to sea floor spreading.

Malod et al. (1997) come to conclusions that are, in part, similar to ours. Their observation of the continuation of the Eastern (Laxmi) basin magnetic anomalies to the north, but bending westwards so that the central anomaly lies over Gop rift ties in with two other observations. Miles and Richards (1998) have shown that the Laxmi Ridge also continues northwards and bends to the west. The gravity data, satellite altimeter derived (Sandwell and Smith, 1997) as well as shipboard data, also suggest a similar bend in the Eastern (Laxmi) basin. Thus the NW–SE section of the Laxmi Ridge has the same relationship to the Eastern (Laxmi) basin and the extinct ridge axis as the W–E section has to the Gop rift.

Pandey et al. (1995) speculate on the time coincidence of the K–T boundary with the age of the Deccan flood basalts. Others have remarked on the coincidence of the latter with the start of an episode of spreading in the Arabian Sea. If the results described in our paper are correct, the age relationships become even more intriguing. The start of spreading is considerably earlier than either the Deccan basalts or the K–T boundary, and would presumably be unrelated to either of those events.

Conclusion

The postulated opening of the Eastern Basin by seafloor spreading alleviates some space problems in the kinematic reconstruction to anomaly 34 times.

The ocean continent boundary is located near the eastern margin of the Eastern Basin rather than the SW margin of Laxmi Ridge. The opening might predate the emplacement of the Deccan volcanics.

Seismic and gravity data are consistent with Laxmi Ridge being a continental sliver lying between oceanic crust on either side.

Acknowledgements

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