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Seamounts in the Central Indian Ocean Basin: indicators of the Indian plate movement

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Abstract. The study of seamount parameters in the tectonically most-complicated and least-understood Indian Ocean assumes importance since their properties vary as a function of tectonic setting, physics of lithosphere, conduit geometry and chemical composition of magma. More than 100 such seamounts ranging in summit height (h) from 300 to 2870 m, are indentified in the oceanic crust between Indian continent and Mid-Indian Ridge (MIR) and South-East Indian Ridge (SEIR). Most of the minor seamounts ($h < 1000$) are found in the southern part of the study area. Major seamounts ($h > 1000$ m) are roughly distributed in two groups—the northern group on Cretaceous Oceanic Crust and southern group on Pliocene-Miocene Oceanic Crust. On an average northern group seamounts (SM 1 to 6) are taller, wider and flatter than those from the southern group. These seamounts appear to be the result of continuous growth from tapped, moving magma chamber while stress depleted magma and inconsistent Indian Plate movement during Mid-Tertiary are attributed to the origin of southern group of smaller seamounts. Distribution and morphology of seamounts as a whole indicate their formation either from Reunion hotspot or from two separate hotspots in the geological past.

Keywords. Seamount; morphology and distribution; Indian Ocean tectonics; Indian plate movement; Hotspot origin.

1. Introduction

Seamounts are surface manifestations of magma eruption within the oceanic crust triggered by tectonic activities and deep-seated mantle upwellings. Morphology of seamounts varies with local and regional tectonic setting and thermophysical properties of underlying lithosphere. Thickness of sediment cover, chemical composition of magma, conduit geometry (Batiza and Vanko 1983; Wood 1984); hydraulic potential, flow rate, viscosity and gravity pull of ascending magma (Lacey *et al* 1981) are the other factors that influence the morphology of seamounts.

The present study which is the result of an extensive bathymetric survey carried out in the Central Indian Ocean Basin (CIOB), attempts to correlate tectonic control on seamount formation with plate movements in the area. The contribution of nearby hotsposts (Reunion, Prince Edward, etc.) towards the distribution and morphology of mid-plate seamounts has also been accounted for.

2. Data

The basic data on distribution and morphology of seamounts were collected from an area bounded by 0° to 20° South and 72° to 84° East (figures 1 and 2). Bathymetric

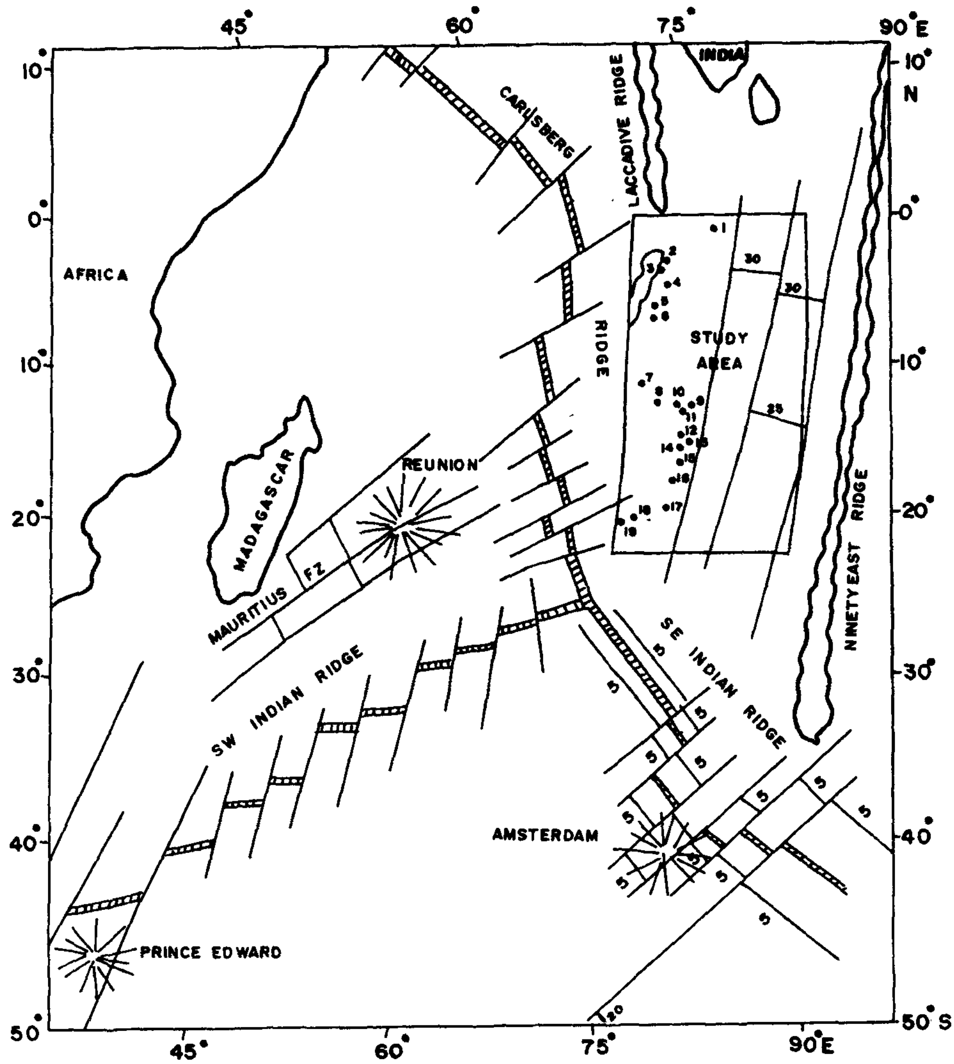

Figure 1. Map showing the tectonic features in the Indian Ocean alongwith different ridge segments (MIR, SEIR, SWIR, RTJ). Aseismic ridges viz. Chagos-Laccadive and 90 east and hotspot centres are also shown (after Condie 1982). The demarcated study area shows locations of major seamounts with height > 1000 m.

surveys along a number of predetermined tracks in the study area have encountered many small and large seamounts ranging in height from 300 m to as much as 2870 m. In this paper 19 major ($h > 1000$ m) and about 109 minor ($h = 300$–1000 m) seamounts constitute the data set. Other small topographic elevations were not considered as a clear demarcation of their size and shape was not possible.

Morphological parameters of seamounts such as summit height (h), basal width (Wb), summit width (Ws) represent only apparent values as data was collected through a wide beam echosounder. These three parameters were measured for major seamounts (tables 1 and 2) whereas only summit height and basal width were measured for all minor seamounts (table 3). Schematic sections depicting the methods followed for

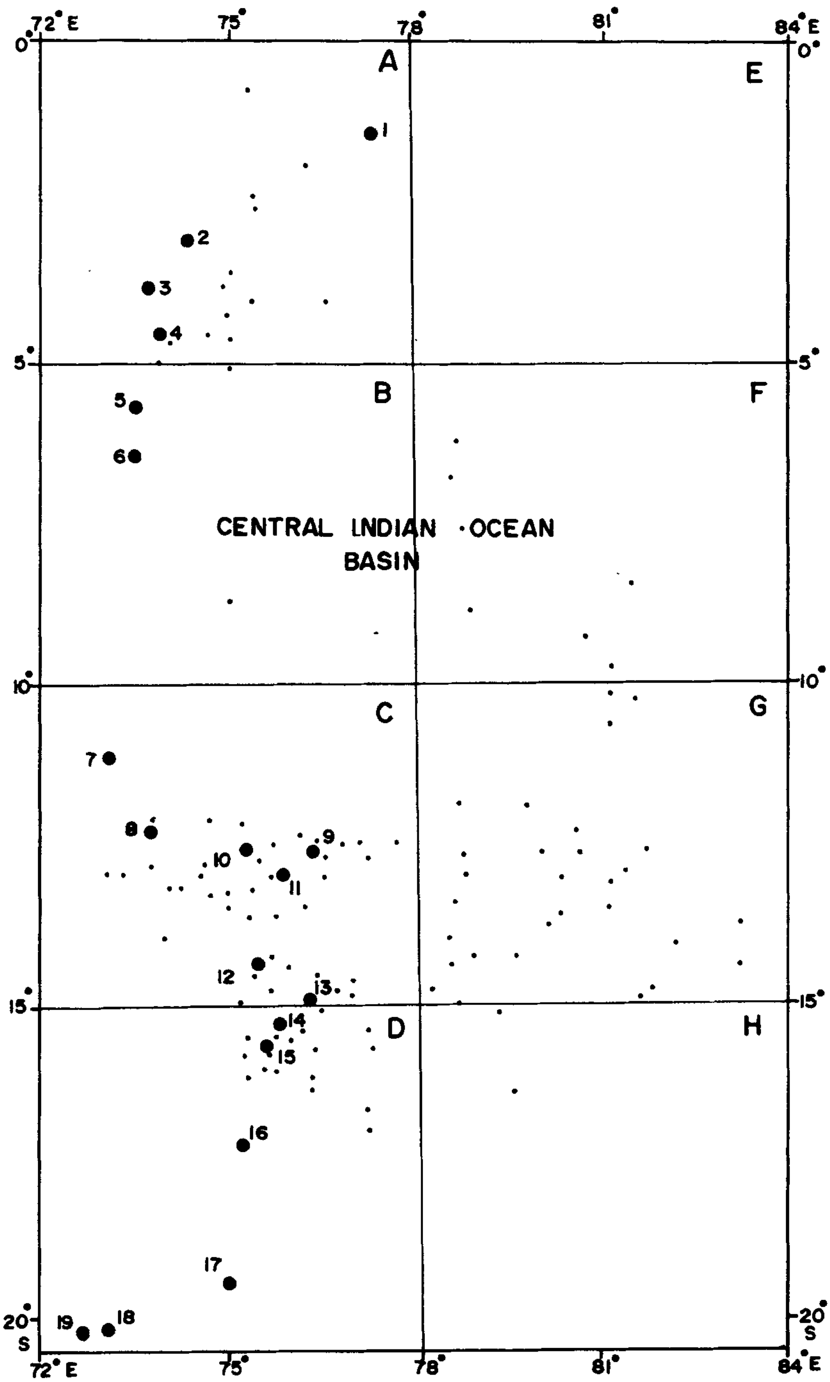

Figure 2. Study area showing locations of major ($h > 1000$ m) and minor ($h < 1000$ m) seamounts in quadrants A–H. Each quadrant is 5° × 6°. Quadrants A, B, E, F correspond to cretaceaous oceanic crust; C, G to eocene-oligocene oceanic crust; and D, H to miocene oceanic crust.

Table 1. Morphology of major seamounts.

Sm No.	Summit depth (m)	Summit height h(m)	Width (× 1000 m) Summit (Ws)	Basal (Wb)	Flatness f	h/Wb	Slope angle (deg.)
1.	2800	1450	1·39	4·07	0·34	0·3562	47
2.	4000	1050	3·96	23·77	0·16	0·0442	6
3.	2640	2430	10·54	55·50	0·19	0·0438	7
4.	3930	1050	5·60	12·54	0·44	0·0837	16
5.	2505	2850	20·17	114·28	0·18	0·0249	3
6.	2500	2870	81·62	130·48	0·62	0·0220	7
7.	3550	1250	4·53	18·50	0·24	0·0676	10
8.	4100	1000	1·50	17·39	0·08	0·0575	7
9.	4250	1130	2.00	9.50	0·21	0·1189	17
10.	4400	1000	3·96	29·06	0·14	0·0344	5
11.	4275	1020	2·09	13·69	0·15	0·0745	10
12.	4200	1100	1·66	13·88	0·12	0·0792	10
13.	4400	1100	5·14	14·74	0·35	0·0746	13
14.	4215	1185	4·63	19·24	0·24	0·0616	9
15.	4610	1125	6·60	33·45	0·20	0·0336	5
16.	3450	1050	0·89	7·95	0·11	0·1321	16
17.	3650	1600	6·03	21·64	0·28	0·0739	11
18.	3500	1220	3·44	19·24	0·18	0·0634	9
19.	3420	1300	1·42	14·24	0·09	0·0913	11

Table 2. Average morphology of major seamounts from the northern and southern groups.

Average	Summit depth (m)	Summit height (m)	Summit width (× 1000 m)	Basal width (× 1000 m)	Flatness	h/Wb	Slope angle (deg.)
Northern group (SM 1 to 6)	3062	1950	20·54	56·77	0·32	0·0958	14·33
Southern group (SM 7 to 19)	4001	1160	3·37	17·88	0·18	0·0740	10·23

measuring some of these parameters are shown in figure 3. In addition, flatness (f) and slope angle were calculated for major seamounts according to Smith (1988). The thickness of the acoustically transparent sediment cover from the summit and flank regions of few seamounts was also measured.

3. Distribution of seamounts

Major seamounts in the study area show local but distinct variation in distribution and appear to have been distributed in two groups (figure 1). The northern group, comprising of 6 seamounts (SM 1 to 6), has a general trend NNE–SSW. The remaining 13 seamounts (SM 7 to 19), forming the southern group are distributed in an arc close to Mid-Indian Ridge (MIR).

To get a better picture of distribution of minor seamounts the whole study area

Table 3. Morphological parameters of minor seamounts.

Quadrant	Total no. of smt.	Summit* depth m	Summit* height (*h*) m	Basal* width (*Wb*) km	*h*/*Wb**
A	13	4185–4700 (4400)	350–810 (570)	2·96–42·18 (18·75)	0·012–0·115 (0·049)
B	2	4575–4830 (4702)	420–550 (485)	6·66–7·40 (7·03)	0·057–0·083 (0.070)
C	40	4130–5130 (4690)	320–950 (528)	3·89–43·84 (13·35)	0·014–0·116 (0·048)
D	16	3725–4825 (4372)	300–975 (625)	3·14–35·70 (13·94)	0·019–0·215 (0·072)
E	—				
F	7	4370–4900 (4576)	300–900 (736)	6·29–51·80 (21·09)	0·015–0·130 (0·062)
G	28	2750–5060 (4371)	300–975 (540)	4·80–26·64 (12·43)	0·020–0·160 (0·058)
H	3	4400–4800 (4400)	510–790 (650)	2·70– 9·50 (6·10)	0·025–0·189 (0·107)

* The top values show range and value in paranthesis shows average.

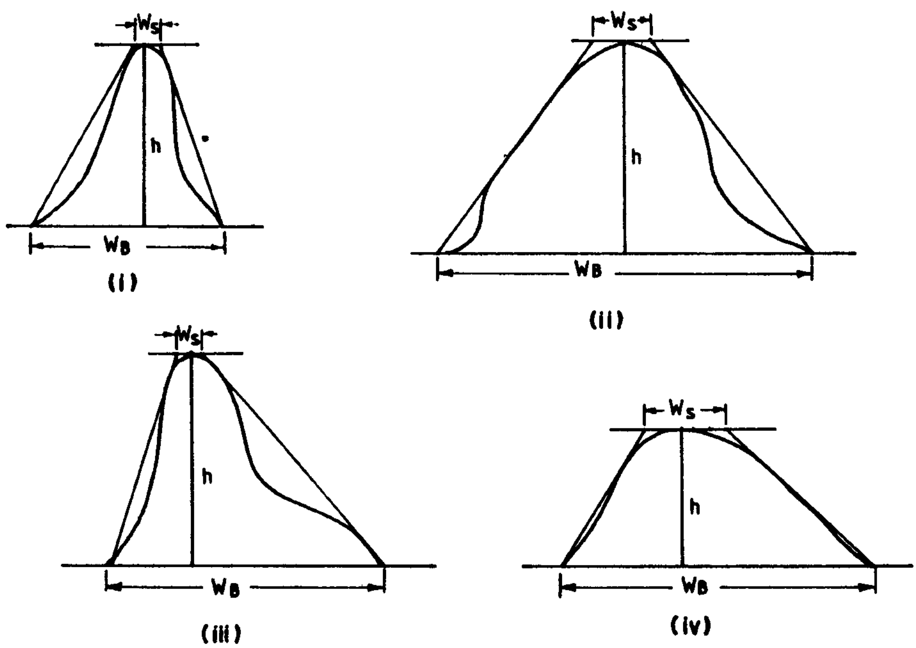

Figure 3. Schematic sections depicting the method for measuring summit height, width and basal width of major seamounts.

was divided into 8 quadrants (A–H) of 5° × 6° each (figure 2). Quardrant C accounts for maximum population of minor seamounts (40, average $h = 528$ m) followed by quadrant G (28, avg. $h = 540$ m), quadrant D (16, avg. $h = 625$ m) and Quadrant A (13, avg. $h = 570$, table 3). Quadrant E is devoid of any seamounts—major or minor. It is found that about 80% of minor seamounts and 68% of major seamounts are located in the southern part of the study area between latitudes 10°S and 20·5°S (quadrant C,D,G,H). Again no major seamount but only 35% of minor seamounts are located in the eastern part of the study area (quadrant E–H). The most populated quadrants, however, are the C and D (SW part of study area) and together account for about 51% and 68% of minor and major seamounts respectively.

4. Seamount morphology

Morphological parameters of individual major seamounts are shown in table 1 and the average values for northern and southern groups of major seamounts are given in table 2. The apparent summit depth and summit height of these seamounts vary from 2500 m to 4400 m and 1000 m to 2870 m respectively. The contact between seamount base and surrounding seafloor is sharp in case of taller seamounts and that becomes gentler with seamounts of lesser height. Summit height of major seamounts shows strong correlation ($r = 0{\cdot}909$) with basal width (figure 4a), and summit width (figure 4b, $r = 0{\cdot}736$). Flatness of the seamounts is insignificantly correlated to summit height ($r = 0{\cdot}428$, figure 4c) and basal width ($r = 0{\cdot}436$, figure 4d). However, summit width shows strong correlation with basal width ($r = 0{\cdot}849$ figure 4e) and flatness ($r = 0{\cdot}715$, figure 4f). All the correlation coefficients are tested at 95% confidence level. On an average major seamounts in the Indian Ocean have height and summit width 8% and 23% respectively to their basal width. In the Pacific Ocean, however, seamount height is found to be 10% to their basal diameter (Smith 1988).

Apparently grouped major seamounts in the northern part show morphological difference to those of southern part (table 2). The average height of northern group of seamounts is 1950 m compared to 1160 m of those in the southern group. The northern group of seamounts with average summit and basal width of 20·55 km and 56·77 km respectively is wider than those of the southern group (3·38 km and 17·89 km respectively). The study demonstrates that the northern group of seamounts is taller, wider, and flatter than its counterparts at the south.

Average values of morphological parameters for all the 109 minor seamounts have been shown in table 3. These seamounts are found between water depth of 2750 m and 5130 m; their summit height ranges from 300 m to 975 m and basal width from 2·96 km to 51·80 km. The maximum and minimum water depth at which summits of these seamounts were encountered are 4702 m (quadrant B) and 4371 m (quadrant G) respectively. Similarly seamounts of quadrant F (736 m) are the highest and those of quadrant B (485 m) are smallest. In case of basal width, seamounts of quadrant F are the widest (21·09 km) and those of quadrant H are the narrowest (6·10 km). If we leave aside values from quadrant B and H where sample sizes are very small, we find that unlike major seamounts these minor seamounts also show a significant positive relation between their summit height and basal width. Taller the seamount the wider would be the base. The summit height of minor seamounts is about 5% to their basal width.

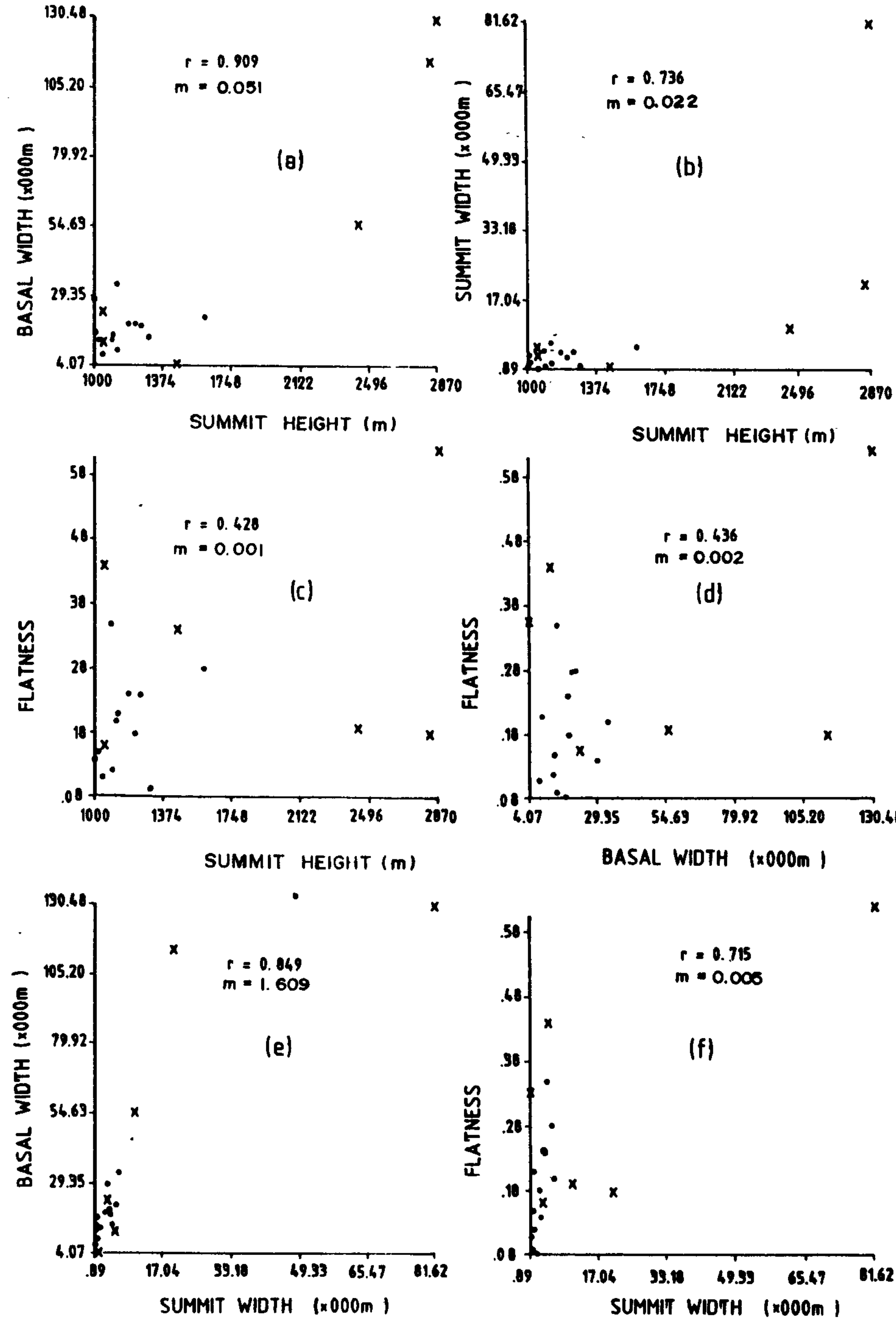

Figure 4. Plots of relationships among various morphological parameters of major seamounts. Solid circles represent southern group, whereas crosses represent northern group of major seamounts. r = correlation coefficient and m = slope of the best fitting line.

Seamount summit in some cases is found to be collapsed by about 100–200 m which could be due to either volcanic crater or subsidence of peak as a result of lithospheric cooling (Crough 1983). These features are found in major seamounts occurring in the northern part of the study area. Taller seamounts appear to have deeper depression of wider dimensions. The thickness of the acoustically transparent layer of sediment (ATL), found on the flanks of northern group of seamounts, varies from 6·5 m to 39·13 m. This thickness seems to depend on the depth of carbonate compensation in the water column and is less or insignificant on the southern group of seamounts occurring at greater depth.

5. Discussion

The study area is the product of seafloor spreading about Mid-Indian Ridge (MIR) and South-East Indian Ridge (SEIR). The resultant push from these two ridges onto the adjoining oceanic crust set northward movement of the Indian Plate at different velocities in the geological past. Data on basement age as deduced from magnetic anomalies (Patriat and Segoufin 1988) show that seamounts of quadrants A, B, E and F are on Cretaceous Oceanic Crust, those of D and H on Miocene Oceanic Crust while those of C and G occur on Lower Tertiary Oceanic Crust.

The presently studied seamounts unlike those from the Pacific Ocean (Vogt 1974) are not spaced at a uniform distance. Average spacing between major seamounts from northern group occurring on Cretaceous Oceanic Crust is higher (153 km) than that from the southern group occurring on Tertiary Oceanic Crust (115 km). A similar observation was made for minor seamounts of northern (quadrants A, B, E, F) and southern (quadrants C, D, G, H) part. This non-uniform spacing could be due to variable speed at which the Indian plate moved in the past. This observation is quite consistent with the higher spreading rate (Patriat and Achache 1984) of the Indian plate during Cretaceous-Early Tertiary.

Both the major and minor seamounts show a fairly good degree of morphological variation among their northern and southern groups. Older oceanic crust of Cretaceous age in the northern part is perforated by volcanic seamounts of greater height and width. Major seamounts in the north appear to have formed by the process of persistent growth where volcanoes continuously grow from a tapped magma chamber below the lithosphere after moving away from hotspot (Condie 1982; Fornari *et al* 1988).

Distribution and morphology of seamounts from southern quadrants reflect the unstable and erratic period in the history of Indian Ocean tectonics caused by the collision of the Indian Plate to the Eurasian Plate. Inconsistency in the direction and speed of the Indian plate during Oligocene-Miocene period did not probably give the required time and scope for ascending magma to produce seamounts of greater height.

The Rodrigues Triple Junction (RTJ), as reconstructed from magnetic anomalies (Liu *et al* 1983; Patriat and Achache 1984) was located at 38°S and 50°E in some geological past. It had since then moved northeastward and is presently positioned at 25·52°S and 69·46°E (Condie 1982). The Indian Plate has also moved in a similar fashion. During Cretaceous the southern tip of India was stationed at 40°S and 47°E and is presently located at 8°N and 77°E (Condie 1982). From the distribution and morphology of these seamounts and the nature of movement of Indian Plate as well as RTJ in geological past a complex source and mode of origin for the two groups of seamounts could be envisaged.

The taller and wider seamounts in the north might have formed first from magma laden conduit of Reunion hotspot during Cretaceous time. Partially spent magma (stress-depleted magma, Cueleneer *et al* 1988), from the same hotspot during Mid-to late-Tertiary, thus, could give rise only to seamounts of lesser height and width as is observed in the case of southern seamounts.

An alternative to this would be that while the northern group of seamounts could have had their origin from Reunion hotspot, another hotspot, Prince Edward, could as well account for the southern group of seamounts. Prince Edward hotspot, like other hotspots (Condie 1982; Crough 1983; Molnar and Stock 1987) would have moved to its present location from a northeastern place in geological past.

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