stable as thought of and are prone to seismic activities though to a much lesser extent compared to plate boundaries[17]. Continental shields largely consist of two parts, namely mobile belts and cratons. Mobile belts consisting of rifts, thrusts, etc. have been active in the geological past, and are therefore more prone to seismic activities compared to the cratons which show very little tectonic activity during geological past. However, it has been found that in several cases intraplate earthquakes occur on secondary faults instead of first order faults like thrust and rifts[18]. Association of intraplate earthquakes with gradient of gravity anomaly and intrusions as in the present case has also been reported by McGinnis and Ervin[19] which may be caused by inhomogeneities in rigidity[20]. McKeon[21] has suggested that local high stress concentration could occur within the intrusions and at their contacts with host rock.

The Bouguer anomaly map of the epicentral area of Latur earthquake has delineated several low-amplitude small wavelength anomalies of shallow origin. Their modelling along two profiles has delineated some high- and low-density bodies in the basement at different depths. The low-density bodies which almost coincide with conductive body, delineated from MT measurements may be fluid-filled fractured zones. The low-velocity layer is also reported in this area at almost similar depth[2]. The high-density bodies may represent lithological changes due to high-density metasediments and metavolcanics rocks which are exposed south of Deccan volcanic province or basic intrusions in the basement. The presence of rocks of different densities suggests the area to be very heterogeneous, which is also indicated by the presence of high frequency content and longer signal duration of aftershocks[22]. Intrusive bodies can provide path for seepage of meteoric water and can reduce the permeability and porosity and increase the fluid pressure. The lower value of the heat flow[23] suggests fluid to be water which might have percolated through fractures and faults from surface or been trapped there, being released from various geological processes. Fractures filled with high pressure fluid provide an ideal environment for slippage of rocks due to even small accumulation of stresses leading to an earthquake[24,25]. It is, therefore, likely that the interaction of changes in regional stress regime, local stress and fluids in fractured basement in epicentral area may be responsible for these seismic activities.

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Tectonic reorganization in the Indian Ocean: Evidences from seafloor crenulations

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Multibeam bathymetric data from seafloor area of 24,568 km^2 constrained between magnetic anomaly 18 and anomaly 25 in the Central Indian Ocean Basin (CIOB) reveal presence of three types of seafloor lineaments. Deformation of seafloor across these lineaments, oriented in N–S, NW–SE and E–W directions, vary in time and space. A sharp change in nature and orientation of these seafloor lineaments, as well as of magnetic anomalies, occurs along 73°E long., which appears to act as contact between older crust

n the east (~ 56 Ma) to the younger crust on the vest (~ 38 Ma). This sharp contact along the 73°E ong. probably suggests a structural discontinuity, eflecting variation in crustal accretion at the ridge rest in the past.

GEOMORPHOLOGICAL studies in the Central Indian Ocean Basin (CIOB) assume importance due to the presence of two types of crust, formed simultaneously from two lifferent spreading ridges at variable speeds in the geological past. This makes CIOB to be the best site o test variation in seafloor characteristics in response o changing spreading rates. The crust generated from idges bears impressions in the form of ridge parallel abyssal lineaments, fault scarps and folds[1–3]. These variable rates of crust formation, and offsets of the seafloor due to fracture zone have given rise to structural and opographic complexities in the larger part of the CIOB. Detailed multibeam bathymetry study in the CIOB reveals intense axial ridge parallel faulting and folding, the nature and intensity of these flexures (in terms of amplitude and wavelength) and nonuniform spacing of fault scarps implies pronounced effect of regional tectonic activities[2–5]. Seasat gravity and stress regime data when combined with the detail bathymetric data strongly suggest that formation and nature of the seafloor crenulation in the CIOB are spreading rate dependent and probably

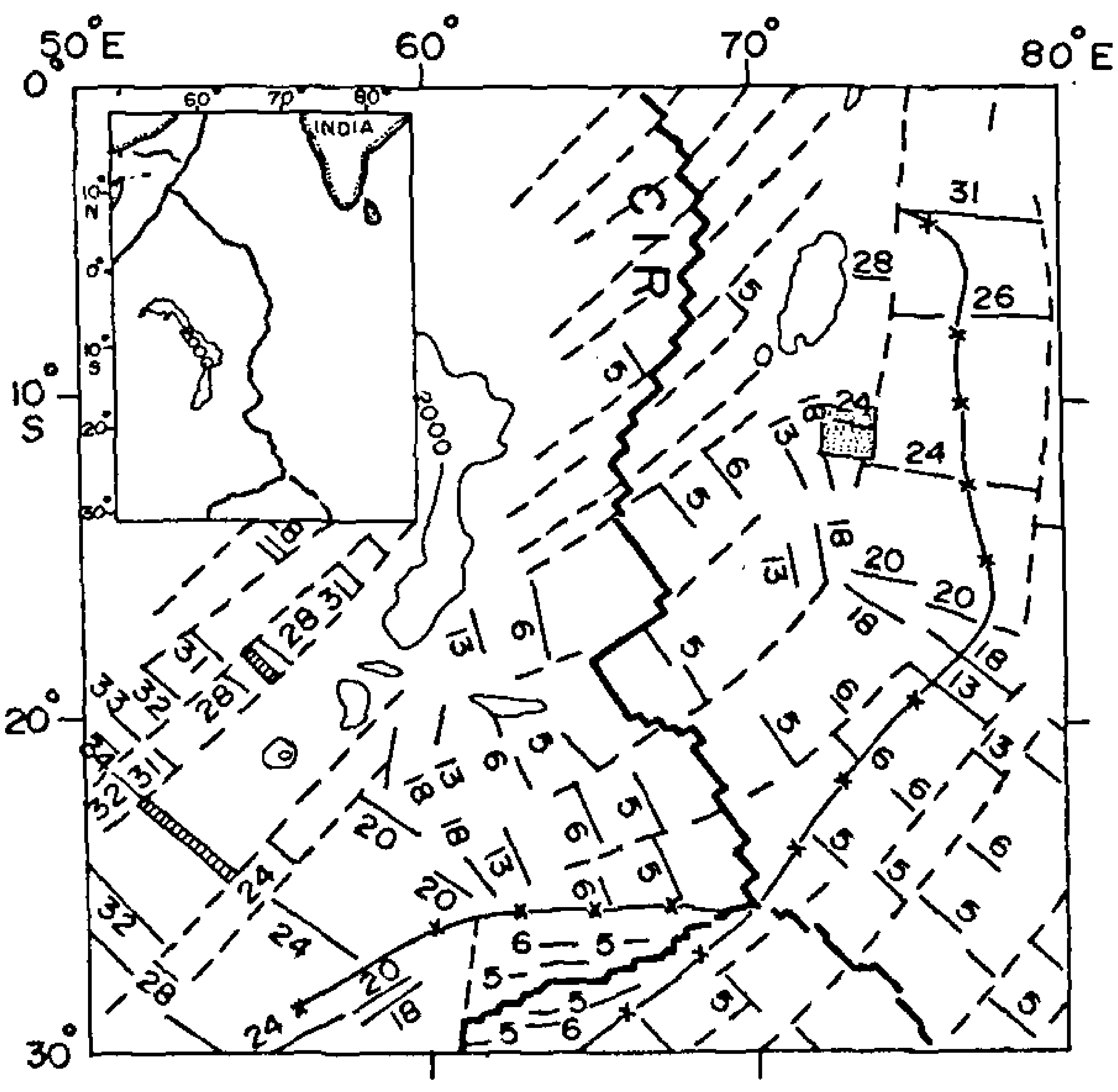

Figure 1. Detail tectonic configuration of the present day Central Indian Ocean Basin (after ref. 6). Dashed lines are trace of the fracture zones and transform faults across Central and Southeast Indian ridges. Numbered lines are magnetic anomalies with numbers. Box filled with dots on the eastern side of the CIR indicates the study area. Trace of triple junction on the Indian plate is shown by solid line with star. Closed contours are Chagos ridge and Mascarene plateau.

reflect the migration and upwelling history of the melt at the active ridge crest[2].

To test earlier findings, a comparatively smaller part of CIOB was chosen for the present study (Figure 1). The study area draws significance from the fact that it includes three types of lineaments of variable orientations. Such differences in orientation are also manifested in the disposition of magnetic anomalies[6]. An attempt is made in this paper to document such variations and later examine briefly the structural fabric of the area in the context of regional tectonic frame, particularly during the days of major reorganization at anomaly 18 time.

The study area is bounded by the lat. 10°33′S and 11°53′S and long. 72°36′E and 74°06′E (Figure 1), covering total seafloor area of 24,568 km^2. The data used for present study were collected using hydrosweep, a multibeam seafloor bathymetry survey instrument. Instead of conventional single beam echo-sounder, which provides a spot depth along the survey track, hydrosweep with acoustic pulse from 59 beams generated from the hull-mounted transducers provides much detailed contoured bathymetry with a seafloor coverage of twice the water depth. The study area is comprised of crusts of two contrasting and variable ages. The crust east of approximately 73°E long. is constrained by magnetic anomalies 23 (~ 50.6 Ma) corresponding to the southern limit and A25 (~ 56) to its northern boundary[5–7]. In contrast, the seafloor west of 73°E long. is constrained by magnetic anomaly 18 (~ 40–38 Ma)[6]. The major part of the underlying crust of the study area (particularly the eastern part), thus appears to have formed at relatively faster rate from the Indian ocean ridge at an estimated speed of 150 mm/year full rate[5–7].

The area also encompasses a major, long and wide 73°E fracture zone (shown in Figure 2 along 73°30′E long.), two seamounts and three types of abyssal lineaments. The width of the fracture zone increases towards south, averaging about 15.4 km in the present study area (range 13.8 km to 17 km)[2]. Two seamounts were located; one circular and large, about 2100 m in height is located on the west of the fracture zone, while the other, comprises of three small abyssal hill summits with a common base, is located east of the fracture zone. The 73°E fracture zone and seamount characteristics would be dealt with separately.

In general, bathymetry of the western part of the study area is more rugged compared to the eastern part. Seafloor lineations distinctly differ in orientation from each other, and characteristically one does not overlap the other. Seafloor lineaments are mostly comprised of folds and fault scarps, and are collectively termed seafloor crenulations. The E–W oriented lineaments are termed type A lineaments, which are restricted to the seafloor located east of the 73°E long. West of this long. two types of lineaments occur. South of 11°S lat. the lineaments are oriented in NW–SE direction and are termed type B, while north of 11°S lat. lineaments are oriented in N–S direction and are termed type C (Figure 2). To understand basinal geomorphology of the study area in terms of compressive and tensional stress, bathymetric data along 7 short profiles, covering more than 251 km in length, are analysed. These profiles are chosen particularly across all the three types of lineaments and then mutually compared to assess the degree of disturbance or nature of crenulations. Profiles 1, 2 and 3 are taken across the E–W trending lineaments, profiles 4 and 5 are drawn across NW–SE lineaments, while 6 and 7 run across N–S lineaments (Figure 2, Table 1). Seafloor crenulations (folding and faulting) along three typical profiles each representing one type of lineaments are shown in Figure 3.

The E–W oriented type A lineaments encompass fault scarps, elongated small abyssal hills, and folded seafloor. Profile 1 runs across the crenulations on the eastern side, while profiles 2 and 3 run on the western side of the fracture zone. The seafloor along profile 1 shows lower degree of crumpling. Wavelength of the crenulated seafloor varies between 11 km and 22 km, and amplitudes ranged between 50 m and 110 m. Water depth along this profile, however, does not vary much (4890 to 5050 m). Along profile 2, seafloor is found to be intensely crumpled; wavelength of the crumpling varies between 4.2 km and 15.5 km and amplitude ranges

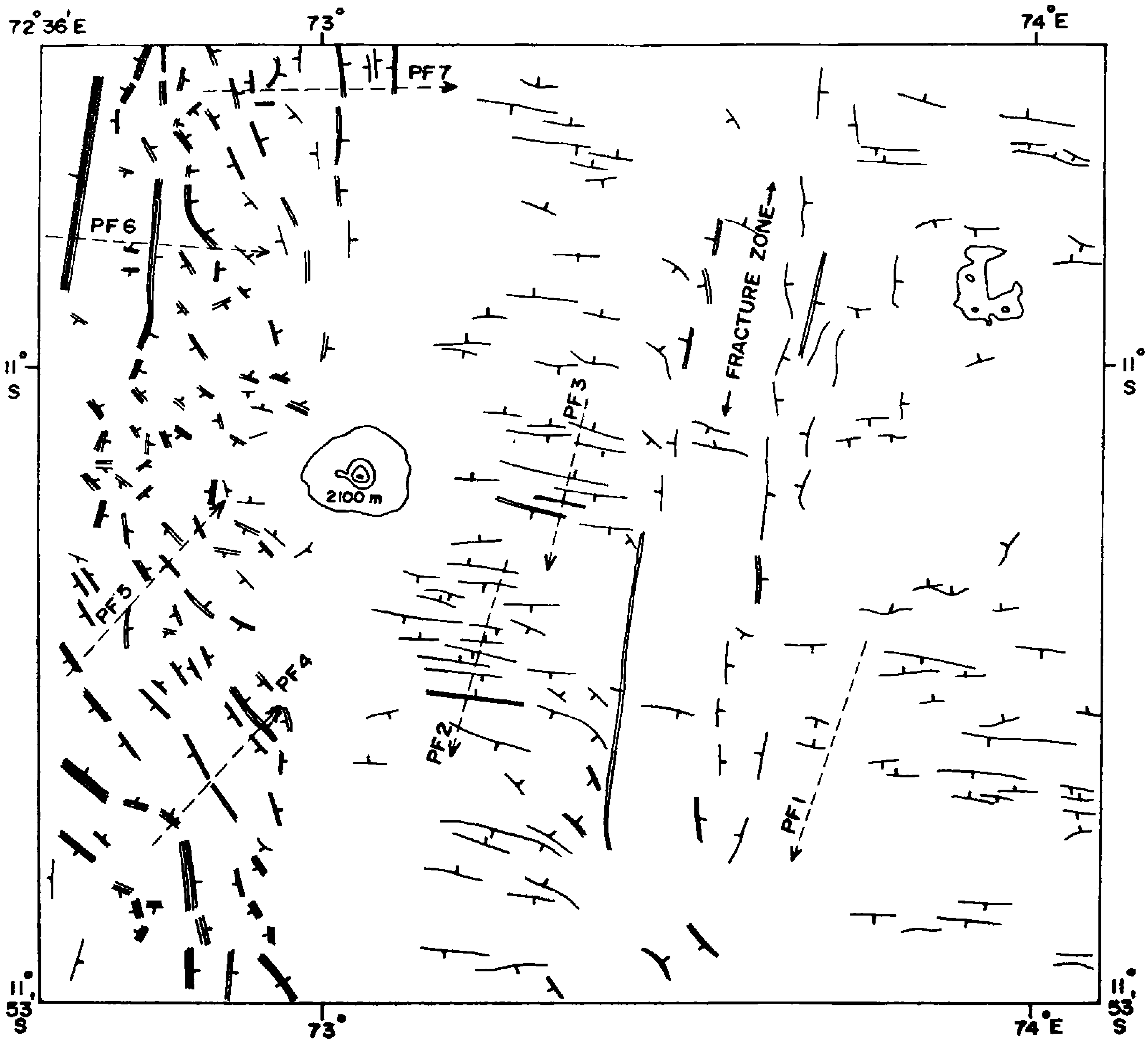

Figure 2. This map is prepared from multibeam seafloor bathymetry data and shows seafloor lineaments which are fault scarps and folds. Location of the profiles is shown by dashed lines and are represented with profile numbers from PF1 to PF7. The average depth of the seafloor is 5000 m, and the seafloor lineaments are represented by lines with dip direction. Single line represents faults with fall of 100 to 200 m, two lines indicate faults with displacement of > 200 to 500 m, three lines are faults with more than 500 m displacement, and four lines with displacement of more than 1500 m. In some cases single lines represent straight contour trend. The closed contour lines represent seamounts. Seamount on the west is > 2100 m high. Note the spacing between the lineaments; lineaments are closely spaced on the western side of the 73°E longitude. The NNE–SSW oriented 73°E fracture zone is marked.

between ~30 m and 425 m. Water depth along this profile varies between 4570 m and 5200 m. Profile 3 runs across the seafloor located between the large seamount on the west and the 73°E fracture zone on the east. Seafloor along this profile is intensely disturbed. Compared to seafloor disturbance recorded along other profiles, wavelength of the seafloor crumpling along profile 3 has been less, between 4.2 km and 8.1 km, although amplitudes of such crumpling have been quite high, ranging between 30 m and 330 m (Table 1). In the southwestern part of the study area, the NW–SE trending seafloor lineaments predominate. Along both the profiles 4 and 5, these seafloor lineaments show high degree of crumpling. The amplitude of such crumpling is enormous, ranging between 100 and 800 m along profile 4, and 40 to 375 m along profile 5. However, wavelength of the seafloor crenulation (= deformation) along these profiles has been low 4.4–22 and 10.4 km respectively. Water depth variation along these profiles is between 4200 and 5400 m in profile 4, and 4600 and 5800 m along profile 5 respectively. Results of profiles 1 to 5 help understand the nature of crenulated deformation of the seafloor in response to the then prevailing stress regime.

Table 1. Seafloor geomorphology in the study area

Lineation type	Profile no.	Profile orientation (degrees)	Profile length (km)	Crenulations Amplitude (m)	Crenulations Wavelength (km)
Type A					
	1	N17E	38.3	50–110	11–22
	2	N12E	35.7	30–450	4.2–15
	3	N10E	25.1	30–330	4.2–8.1
Type B					
	4	N44E	41.6	100–800	4.5–22
	5	N23E	35.1	40–375	10.4
Type C					
	6	N97E	33.7	1550	–
	7	N87E	37.7	130–350	13–17

In the northwestern corner of the study area, between lat. 10°33′S and 11°S and long. 72°36′E and 73°06′E, the seafloor lineaments are very closely spaced and oriented in N–S direction. These lineaments show a sharp fall in depth of seafloor to western boundary amounting to throw of few hundreds of metres. More particularly, around lat. 10°45′S the throw has been maximum, along western boundary the throw amounts to about 2400 m while along the eastern boundary, the throw is about 700 m. Two profiles 6 and 7 run across these type C lineaments. Along profile 6, variations in the water depth are from 3475 to as low as 5800 m. A deep trench is clearly seen along this profile, following a steep rise in height of ~2300 m across the western boundary of type C lineaments. The abrupt rise is followed towards east by minor uneven plateaus for a

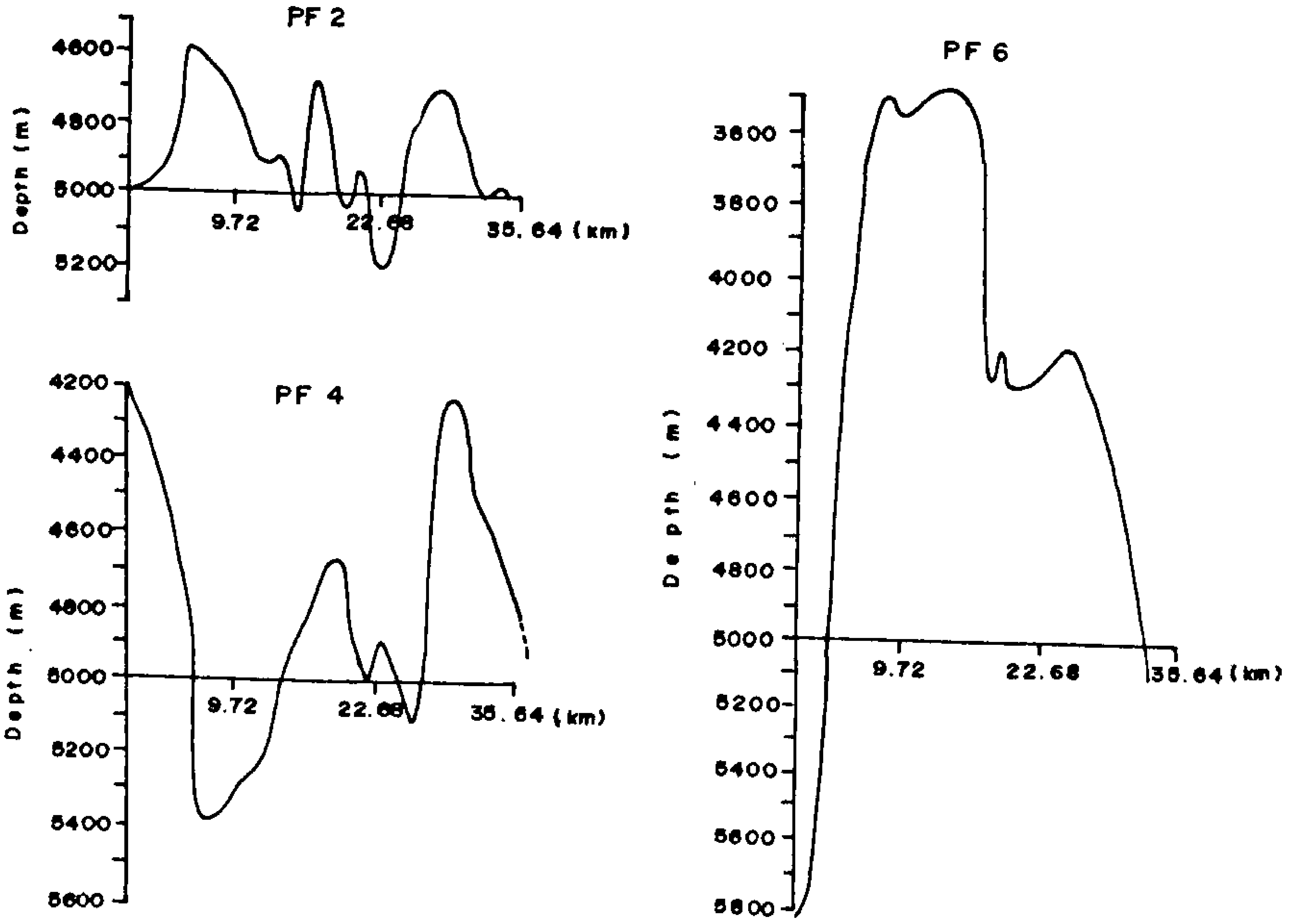

Figure 3. Bathymetric profiles across the three types of lineaments present in the study area. PF2 is drawn across type A lineament, PF4 across type B, while PF6 is taken across type C lineament. Location of these profiles in the study area is shown in Figure 2. Note the remarkable variation in the amplitude of deformation reflecting anomalous stress regime.

distance of about ~ 13 km and then another steep fall towards east in two steps; first by 800 m, followed by the second fall of 900 m (Figure 3). Profile 7 runs across the seafloor a little northeast of the profile 6. Throughout its length profile 7 represents uneven seafloor. The amplitudes of the seafloor unevenness (crumpling) vary between 30 and 350 m, with wavelength ranging between 13 and 17 km (Table 1). From the regional tectonic angle, this prominent N–S lineament appears to be an extension of Chagos ridge and associated trench formed by the eruption of Reunion hotspot. Additional survey has recently been made in this area to understand detail geotectonics of these lineaments, which will be published separately.

From the orientation of the lineaments located in the study area, it appears that 73°E long. and the 11°S lat. forms certain boundaries. The 73°E long. separates the type A lineaments from B and C types, while along 11°S lat. B and C types of lineaments are separated. Broadly, the seafloor on the eastern side of the 73°E long. is comparatively less crenulated, and shows low amplitude and high wavelength of seafloor deformations; whereas the seafloor on the western side of the 73°E long. shows high amplitude and low wavelength crenulations. Since intensity and degree of ridge parallel lineaments reflect the spreading conditions at the ridge crest regime[2], seafloor on the eastern part of the study area with low amplitude and high wavelength crenulations seems to have been generated at faster spreading rate. Seafloor covered by type B lineaments, on the other hand, shows low wavelength and high amplitude crenulations compared to type A, suggesting its generation at comparatively slower rates. Along this lat. orientations, nature and intensity of the seafloor crumpling varies strikingly.

On plotting the tectonics of the present study area on the map of the Indian ocean magnetic anomalies of Royer *et al.*[6] (Figure 1), it is seen that a sharp contact in bathymetry separates the magnetic anomalies 18 and 24. Incidentally, the orientation of the magnetic anomaly 18 corresponds to the seafloor lineaments of the B type (NW–SE directed) and that of A 24 with the A type (E–W oriented) seafloor lineaments. And the boundary between these two groups of lineaments runs along 73°E long. Further, magnetic[6–7] data suggest that seafloor on the west of the 73°E long. was generated during A18 (i.e. between 40 Ma and 38 Ma), when large scale plate tectonic reorganizations in the Indian ocean occurred. In contrast, area east of 73°E long. shows older anomalies A23–A25 (50.6 Ma–56 Ma). On a much broader scale, the seafloor details in the study area seem to agree with earlier findings[6–9], that direction of plate movement in the Indian Ocean had changed from NNE to ENE during the time between A20 and A18. And as a result of such a change in plate movement, the area around 73°E long. (including 73°E fracture zone) must have been tectonically activated to a large extent and intensity.

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