

Morphometric Studies on a part of Central Indian Ocean

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Abstract

Morphometric and slope angle studies carried out on a part of Indian Ocean Basin have shown that gentle slope angle ranges dominate, 92% of the area represented by 0–3° slopes. Young's hypothesis of log-normal distribution of slope angle frequencies is found to be valid for deep sea topographic data also. Elevation-relief ratios and ruggedness values are relatively high for the southern portion of the study area whereas these values are less in the northern portion. Some of the features like abyssal hills and the seamount recorded in the region might have been formed due to volcanism. Some secondary topographic features could have resulted due to post-depositional processes. Slope angle, elevation-relief and ruggedness can be used in inferring certain features in the oceanic surface.

INTRODUCTION

The study of slopes and surface processes has been an integral part of geomorphological studies since the Second World War. Form of the ground surface is an important aspect in establishing relationship between geomorphology and other factors of environment.

Just as in the case of land surface, the deep sea-floor also consists of many abyssal hills, valleys etc., abyssal hills being the largest physiographic units (Rona *et al.* 1974). Just as the study of the slopes and morphometry form a basis for geomorphological studies on land, similarly, morphometric studies can be effectively carried out on the seafloor also. Slopes provide a basis on which by successive combination into larger units, general geomorphology of an area can be constructed. Quantifying and representing the seafloor ruggedness is a tougher task compared to that of land. Submarine geomorphology is especially challenging because of the inability to observe the processes involved and the topography first-hand (Leply, 1966). Data obtained from echosounding has to be relied on to study sea-bed morphology.

The study of deep sea bed morphology is of interest not only academically but also from an economic point of view. The data on deep sea bed will be essential to evaluate methods and to analyse costs for exploitation of marine manganese deposits, if occurring. Further, sea-bed relief is an indication of the underlayers and the conditions in which the soft superficial sediments have accumulated. Bottom relief features will have strong influence on movement and distribution of water masses and also on sediment transport, turbidity and chemical activity. Study of the topography of the seafloor and objective methods for its analyses are important in solving many problems concerned with origin and form of earth's

crust, evolution and distribution of magnetic and gravity fields and in the investigation of dynamic processes in oceans (Belousov *et al.* 1965). Topographic configuration of ocean-floor plays an important role in many aspects of ocean dynamics (Bell, 1975). Bottom roughness influences the flow at the boundary layer (Chris Paola, 1985). This, in turn, influences the genesis of manganese nodules in the deep sea. Distribution of sediments in terms of particle size and thickness is largely dependent on seafloor steepness (Agopova, 1965).

The quantitative study of the depth data is essential as the particle size and sediment thickness is largely influenced by steepness. A study of slope angles and elevation-relief ratio can be used to characterise geomorphic provinces, separate regions and major topographic elements (Agopova, 1965). Surfaces with same slopes possess certain features in common in relation to relief-forming processes. Thus, it is quite essential that slope angle, morphometric and related studies are carried out on deep seafloor data.

In this paper, the results of slope angle and elevation-relief ratio studies on a part of Central Indian Ocean Basin are presented.

AREA

The study of the morphometry and the slope analysis is carried out on a part of the Central Indian Ocean Basin between longitude 75°E to 76°E and latitude 12°15'S to 13°15'S. Echosounding data along the ship's track collected during different cruises conducted by the National Institute of Oceanography, Goa, has been used. The average depth in the area is 5200 m. The structural features in this area seem to follow a regular trend (nearly north-south). A series of north-south trending fracture zones perpendicular to the southeast Mid-Indian Ocean Ridge are present in the Central Indian Ocean (Fairbridge, 1966, p. 280).

METHODOLOGY

Data used in this study is mostly taken from the latitude-wise tracks with quarter degree spacing Echosounding carried out by the Raytheon Deep Sea Echo-sounder and recorded on the Line Scan Recorder. The recorder was adjusted to 4 sec/4 sec delay in order to have better resolution of topography. The analog records obtained from the echosounding were digitised manually. These digitised values were used for preparation of bathymetric profiles, slope angle and contour maps. Bathymetric profiles are drawn along east-west tracks of survey lines with a vertical exaggeration of 1 : 27.5. These profiles provide general information regarding the topography of the area. Contour map was also prepared using manually digitised depth values. For the purpose of calculation of the slope angles using the manually digitised depth values, a FORTRAN programme was written and run on NORDSK DATA (ND-520) computer. A slope angle map was prepared for an area of 60 × 60 nautical miles using these slope angle values.

RESULTS AND DISCUSSION

Bathymetry and Geomorphology

Prominent geomorphic feature in the study area is the seamount encountered along the 13° latitude (Fig. 2, line 2). This seamount reaches to a height of over

1000 m and has a basal extension of 6 nautical miles. Extension of this feature is seen in profile along $13^{\circ}15'S$ also (Fig. 2, line 1). Apart from this, there are a couple of abyssal hills. One of them is seen in line 1, extending in lines 2 and 3 also with a height of 550–600 m. Another prominent hill of 250–300 m is present in profiles 1–4 at and around $75^{\circ}04'$. A valley (350 m deep) is observed at $75^{\circ}1'E$ along line 1.

It is observed that generally the seafloor is somewhat rugged along profiles 1, 2 and 3 (southern portion of the study area Fig. 2) and is comparatively plain along profiles 4 and 5 (northern portion of the study area, Fig. 2, line 4 and 5).

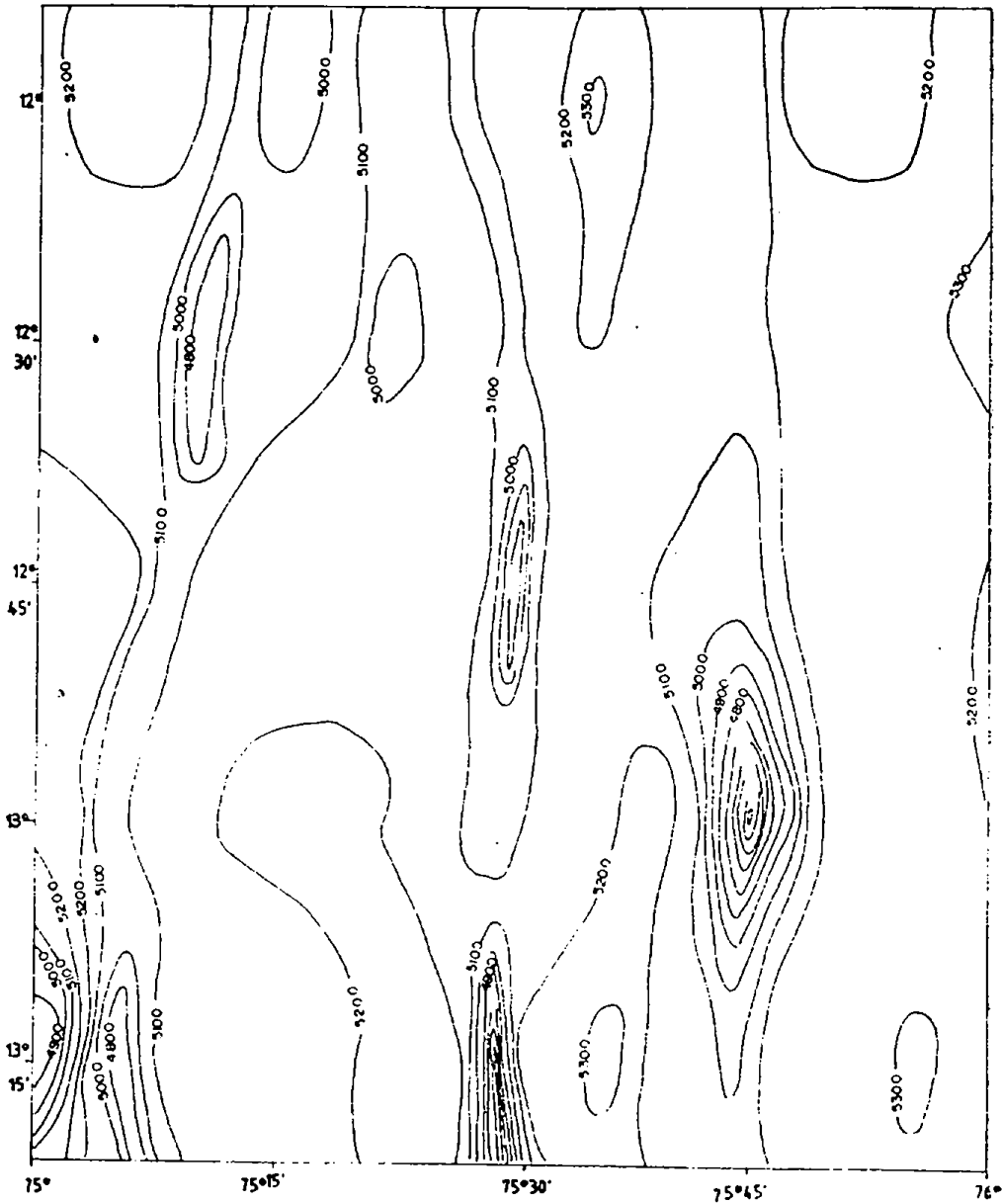


Figure 1. Depth contour map of the area (contour interval 100 m.)

Slope angles

Slope angle map (Fig. 3) prepared using the slope angles calculated using the digitised depth values shows the prominence of gentler slopes (0–3 degrees). However, steeper slopes are concentrated in some patches. These of high slope angles correspond to the hilly regions as seen from the contour map and the bathymetric profiles (Figs. 1 and 2). Contours of slope angles 1, 3, 5 and 7 are closely spaced around $75^{\circ}30'$ and $75^{\circ}0'$ to $75^{\circ}10'$ Longitudes. The trend of closely spaced contours is almost north-south.

Along each line, slope angle values were calculated at intervals of 1.8 km. Of the 304 angles computed, 199 angle frequencies fall within the range of 0–1 degree (66.5% of the total). The angle frequencies for the steep angles is less in all the lines (5% for the whole area). The steep slopes are more rapidly altered than the gentle slopes and hence the survival time for the gentle slopes is more (Young, 1972, p. 167). Young's hypothesis for slope angle frequency as applicable to the terrestrial landforms is tested for the slope values calculated for the deep sea floor of Central Indian Ocean. Young's hypothesis states that the angle frequency shows an approximately log-normal distribution irrespective of whether landscape is formed predominantly of steeper or gentle slopes. A log-normal graph angle frequency vs slope angle ranges was plotted for the whole area and a linear regression between the two was observed. The equation obtained for the regression line is $\log Y = 2.44 - 1.375X$ where Y = frequency of angles and X = slope angle ranges. The coefficient of correlation between the two variables is -0.937 .

The average slope in the whole of the study area is 1.3056 degree maximum slope being over 15° observable at line 2. The average depth is 5116.06 m. Table I gives the line-wise break up of average slopes, standard deviation of slope angles and their skewness. It is observed that the standard deviation is more in lines 1, 2 and 3 and less in lines 4 and 5.

Table II shows the area enclosed in per cent by different angle ranges. It is observed that 72.2% of the area has 0–1 degree of slope angle and 19.6% of the area has 1–3 degree. 0–3 degree slope angle thus accounts for 91.8% of the total study area which is in conformity with the slope angle frequency data. Gentler slopes predominate distinctly over the steeper slopes. Only 8.25% of the area has angles over 3 degrees.

Elevation-Relief Ratio and Ruggedness

Elevation-relief ratio is one of the important measures of seafloor ruggedness. Now-a-days it is often used as a substitute for the tedious and time consuming hypsometric analyses of geomorphologic data (Pike and Wilson, 1971). Elevation relief ratio (E) is calculated by the following formula :

$$E = \frac{\text{Mean elevation} - \text{minimum elevation}}{\text{maximum elevation} - \text{minimum elevation}}$$

Table III gives average depth, minimum and maximum depth and elevation-relief ratio for each of the five lines and for the whole area. Line 2 is quite rugged and has a very high E of 0.82. Line 5 has the least E of 0.199. High E characterises broad somewhat level surfaces occasionally broken by depression and

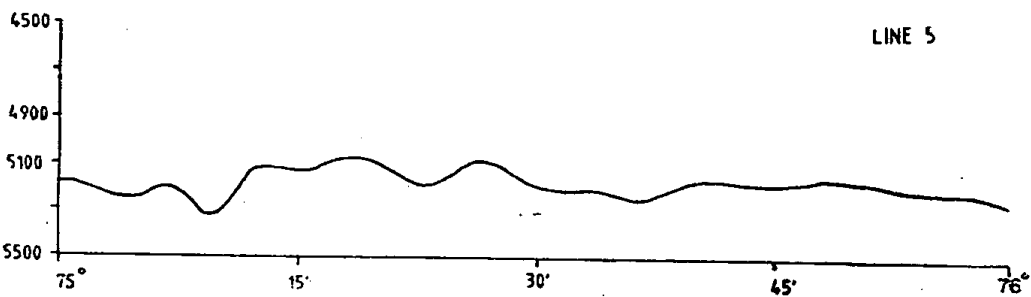
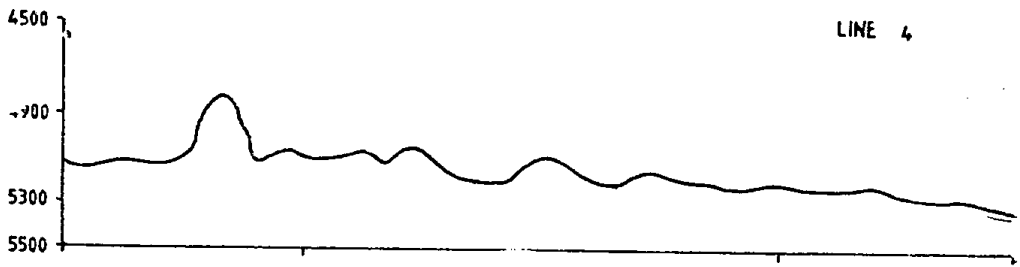
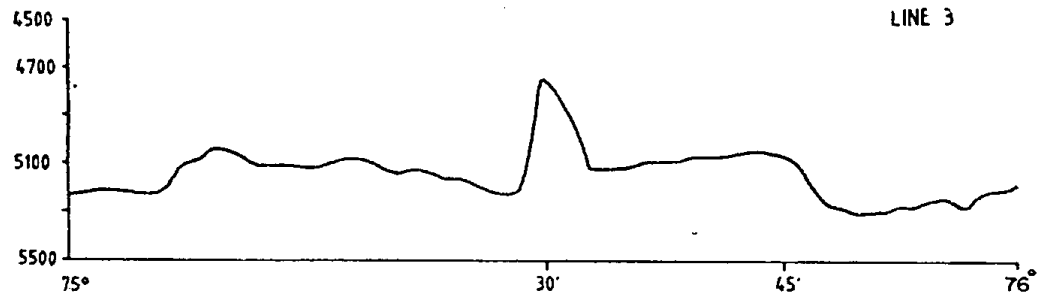
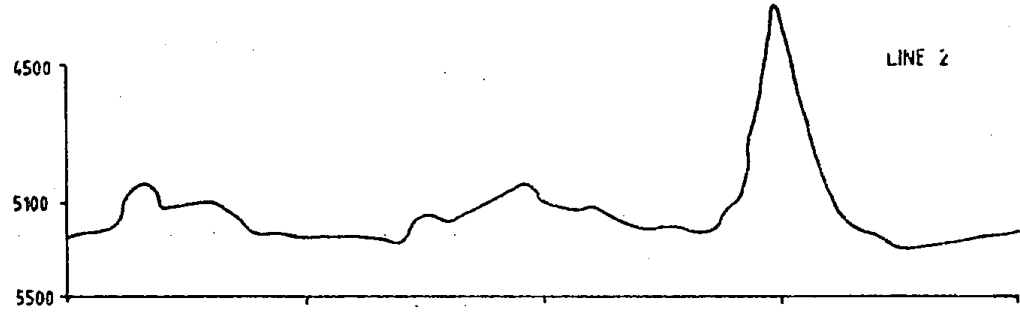
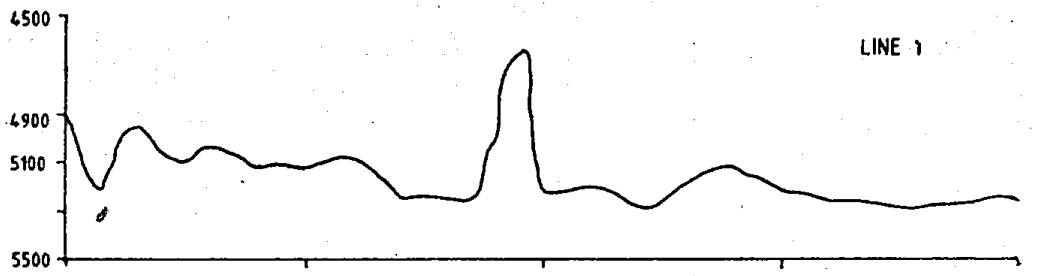


Figure 2. Bathymetric profile Lines 1, 2, 3, 4 and 5 (Vertical exaggeration 27.7).

highs and Low E characterises terrains with isolated relief features standing above extensive level surfaces. The elevation relief ratio for the whole area is 0.788 which means that generally the study area has a fair number of depressions and highs.

The concepts of ruggedness and REL (Sum of depth differences along a profile) have recently emerged as factors for morphometric analyses of sea bed data (Froidefond and Berthosis 1984). REL is the sum of differences in elevation between different points on a line segment and ruggedness is the difference between REL and maximum amplitude for the segment. Table III gives REL, amplitude and ruggedness for different lines and their averages. Lines 1 and 2 have high value of ruggedness of 2620 and 2369. Though it was observed that line 2 has the highest

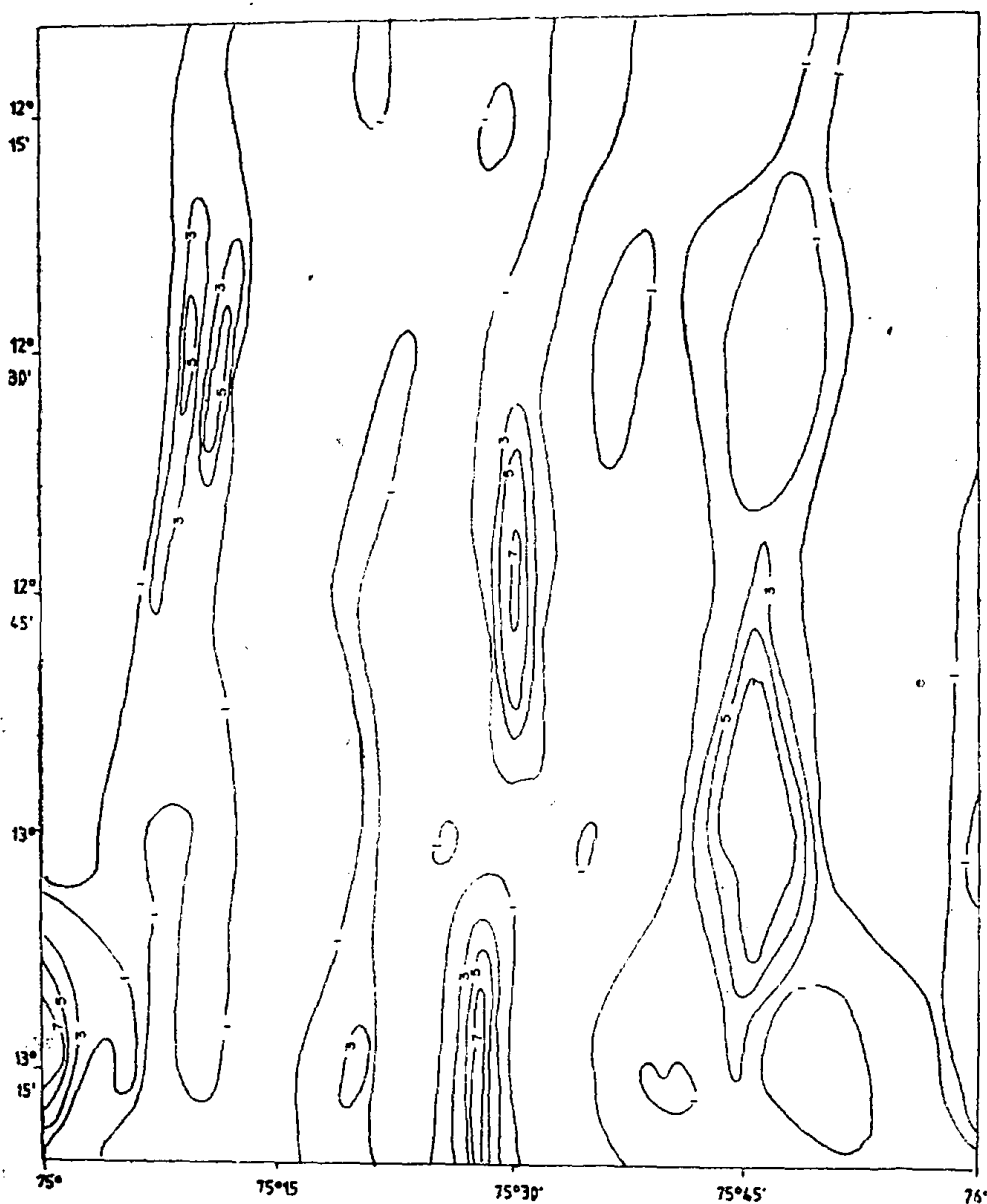


Figure 3. Slope angle map of the area.

TABLE I. Mean slope angle and standard deviation and skewness of slope angles for lines 1-5 and whole area.

Line No.	Average slope angle (DEG.)	Standard deviation of slope angle	Skewness of slope angle
1	1.8156	3.050	34.44
2	1.8764	2.897	21.31
3	1.1322	2.081	15.19
4	0.9030	1.267	5.75
5	0.8180	0.623	0.52
Whole area	1.3056	2.219	20.30

TABLE II. Showing area enclosed in per cent by different angle ranges.

Slope angle range	Area enclosed in per cent	Cumulative % area enclosed
0-1	72.2	72.2
1-3	19.6	91.8
3-5	6.25	97.05
5-7	1.9	98.95
Over 7	1.05	99.99

TABLE III. Showing the mean, minimum and maximum depth and elevation-relief ratios REL, amplitude and ruggedness for 5 lines and whole area.

Line No.	Average Depth (M)	Minimum depth (M)	Maximum Depth (M)	Elevation-relief Ratio (E)	Maximum minus minimum (AMP)	REL sum of depth diff.	Ruggedness (REL-AMP)
1	5121.31	4650	5350	0.673	700	3320	2620
2	5101.63	4245	5290	0.82	1045	3414	2369
3	5116.39	4730	5305	0.672	575	2145	1570
4	5103.27	4820	5320	0.567	510	1714	1204
5	5137.70	5085	5350	0.199	350	1575	1225
Whole area	5116.06	4245	5350	0.788	636	2237.6	1601.6

elevation-relief ratio (0.82), line 1 has maximum ruggedness. Lines 4 and 5 are having less ruggedness values, and the overall average ruggedness is 1601.6. By and large the elevation relief ratio, ruggedness, slope angle data and the bathymetric profile data indicate that the southern portion of the study area is rugged and the northern part is comparatively plain.

Structure and Tectonics

Structurally, the southern portion of the area seems to be complex. The presence of a seamount and abyssal hills in this part as also some of the valleys confirm the point. However, the exact processes which resulted in these features is not clear. One of the possible reasons may be the creation of crust during seafloor spreading (Menard, 1967). Menard suggested that high relief indicates slow spreading and low relief indicates fast spreading. Hills can also be formed due to post-depositional faulting along steeply dipping normal faults (Luyendyk, 1970). Motion can be non-uniform across fracture zones in ocean basins and strike-slip motion may occur along fractures. Secondary topographic features can result from these motions. Varying spreading rates can also be responsible for the relief features on the seafloor. The differential movement in the crustal segments is taken up in the stress field of the fracture zones (Andrews, 1971). Segments of crust bounded by fracture zones may interact with each other because of varying and differential spreading rates and may, in turn, give rise to secondary topographic features. The dredge sample collected from the seamount in this area consists of ferromanganese crusts formed on basalts. It is, therefore, likely that this feature is of volcanic origin.

SUMMARY

A detailed survey of seafloor of a part of the Central Indian Ocean Basin shows varying bathymetry characterised by a couple of abyssal hills, a prominent seamount and a deep valley. Structurally, the area is quite complex, especially the southern portion of the area. The geomorphic features have a nearly north-south trend. Though the average slope angle for the study area as a whole is 1.3056, in patches, very high slope angles of over 15 degrees are noted. Dominance of gentler slopes (0-3 degree range making up 92%) suggests a higher survival time. The hypothesis of log-normal distribution of slope angles and their frequency of occurrence over the land areas is found to be applicable for deep seafloor data also. From the elevation-relief ratio and ruggedness data of the area, it is concluded that lines on the southern side of the study area have high E (elevation-relief ratio) and high ruggedness values corresponding to higher average slope angles and rougher bathymetric terrain. The northern portion of the area has low E and low ruggedness value reflecting isolated high relief features standing above extensive levelled area. For the whole area, ($E=0.788$ and $ruggedness=1601.6$), it can be stated that somewhat level surfaces are punctuated by occasional depressions and highs. Such kind of studies have not been carried out extensively in world oceans and it is not possible to generalise based on this limited data. For this purpose similar type of studies are essential in different provinces of world oceans.

The scope of the present study is very limited as the track spacing of echosounding data used for slope angle and morphometric studies is only 25 km (1/4

degree). Closer grid surveys might elucidate minor topographic variations which could not be picked from the present study.

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