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Power law relation of bathymetry and gravity roughness with age of oceanic crust below Ninety East Ridge

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In this study altimeter gravity and ship track bathymetry data from National Geophysical Data Center (NGDC) is explored to investigate the relation between roughness of gravity and bathymetry data to the age of oceanic crust over 90°E Ridge. The gravity and bathymetry profiles are selected over the ridge at places of known ages from Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP). The gravity and bathymetry data are gridded at sampling interval of 1' 12'' and profiles are extracted on the DSDP and ODP sites. The roughness of gravity and bathymetry data is computed as the square root of the average squared deviation about a linear trend. The roughness varies as a power –1.31 and -1.59 of age for bathymetry and gravity data. The mean fractal dimension is found to be 1.54 and 1.46 for bathymetry and gravity data. The roughness of bathymetry and gravity data varies with age with different power law. It is also interesting to note that the roughness of bathymetry decreased with age, which indicates modification of bathymetry data in the older (northern) portion of the ridge with continuous depositions of Bengal fan sediments.

[**Key words:** Gravity, bathymetry, roughness and power law, age of oceanic crust, ninety east ridge, ODP, DSDP]

Introduction

The Indian Ocean is evolved through the breakup of Eastern Gondwana land into Australia- Antarctica and Greater India in the Late Jurrassic/ Early Cretaceous[1-6]. The Eastern Indian Ocean is overlain by 85 °E and 90° E ridge and many fractures zones (Fig. 1). The 90°E ridge is one of the world's longest volcanic ridge extends more than 5000 km from 18 °N to 34 °S in N – S direction[7,8]. It emplaced during the northern movement of Indian plate over the Kerguelen hotspot during the period 38 - 82 Ma due to transform motion. The northern part (north of 10 °N) of the ridge is buried under the thick sediments of Bengal fan[4,8]. The ages found from DSDP and ODP sites were monotonically decreasing from north to south whereas ages found from magnetic data did not show such trend[7].

The aim of this study is to establish a relation between roughness of gravity and bathymetry data with age of oceanic crust below the 90°E Ridge. The roughness is independent of precise knowledge of the location of the ridge axis, whereas amplitude and polarity of the ridge axis anomaly depends strongly on the location of the ridge axis[9].

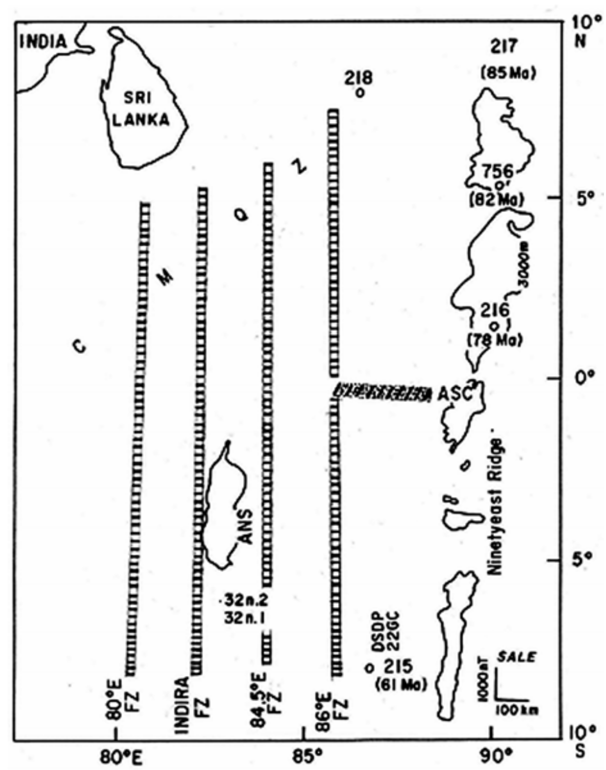

Fig. 1—Study area map (after Krishna et al. [6]). Afanasy Nikitin Seamount (ANS), Cretaceous Magnetic Quit Zone (CMQZ) and various fracture zones (FZ) i.e. 80°E, Indira, 84.5°E and 86°E are also shown.

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The gravity, bathymetry and ratio (effective elastic thickness) of gravity/bathymetry varies with the spreading rate and age of oceanic surfaces[9]. The relation between gravity and bathymetric roughness and spreading rate of mid oceanic ridges is well established[9, 10]. The different nature of the seafloor was created by different spreading rates[11, 12]. Malinverno[10] reported that roughness is inversely proportional to the square root of the spreading rate of mid ocean ridge flank, whereas Goff[13] and Small[12] contradicted the power law relation between roughness and spreading rate. The bathymetry of a ridge provides information about: (1) depth below sea level; (2) axial morphology and (3) roughness of ridge axis and flanks[14].

Satellite and Ship Track Data

The satellite gravity data[15] provides uniform coverage of entire ridge with 10 km spatial resolution and an accuracy of 5-10 mGal. The ship track bathymetry data over 90 °E ridge is taken from NGDC dataset[16]. Both the datasets were gridded at sampling interval of 1’ 12’’ and extracted along profiles over the sites of Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) of about 280 km length with an average sampling interval of

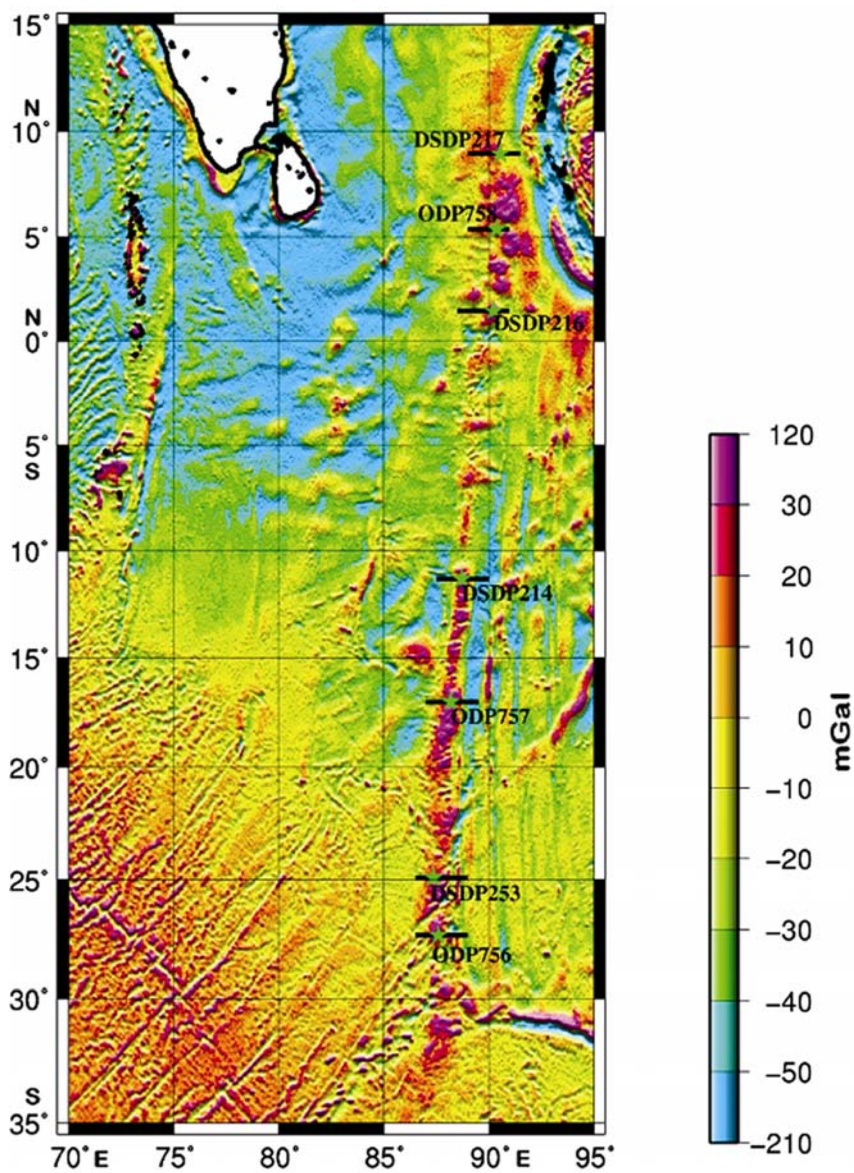

Fig. 2—Satellite gravity data over 90° E ridge and parts of Indian Ocean. The profiles over DSDP and ODP sites are also shown.

1.98 km. Total 7 profiles were extracted at the places of information from DSDP and ODP sites (Fig. 2). The satellite gravity data over 90°E ridge and parts of Indian Ocean is also presented in Fig. 2. The profiles were selected by avoiding the known fracture zones. The roughness of gravity and bathymetry data also varied with the length of the profile[17] if length is <100 km.

Results and Discussion

The linear trend is removed from each profiles and roughness is calculated as root mean square of deviations form the linear trend[10]. The gravity data of the area is controlled by the crustal structure/mantle temperature and reflected in the roughness of the data[12, 18]. To see the relation between roughness and age, the log of roughness of bathymetry and gravity data are plotted against the log of age (Fig. 3). The slopes of fitted straight line to the plot of log RMS roughness and log age are found to be -1.31 and -1.59 for bathymetry and gravity data (Fig. 3b and 3d). Therefore a power law relation exists between the roughness and age with a slope of -1.31 and -1.59 for bathymetry and gravity data. The roughness of both the datasets follows a power law relation with different power. It is also noted that the roughness decreases with age, may be due to the smoothing of bathymetry by sedimentation in the northern part of the 90 °E ridge.

Fractal dimension of the bathymetry and gravity are also calculated by using the Fast Fourier Transform. The Fourier transform was calculated by removing the trend from the data. The relation between the power spectrum and frequency can be written as:

$$P(f) \sim f^{-\beta} \quad (1)$$

where P(f) is power spectrum, f is wavenumber and β is scaling exponent. In logarithmic scale the slope of fitted straight line to the plot of power spectrum versus frequency shall provide the scaling exponent

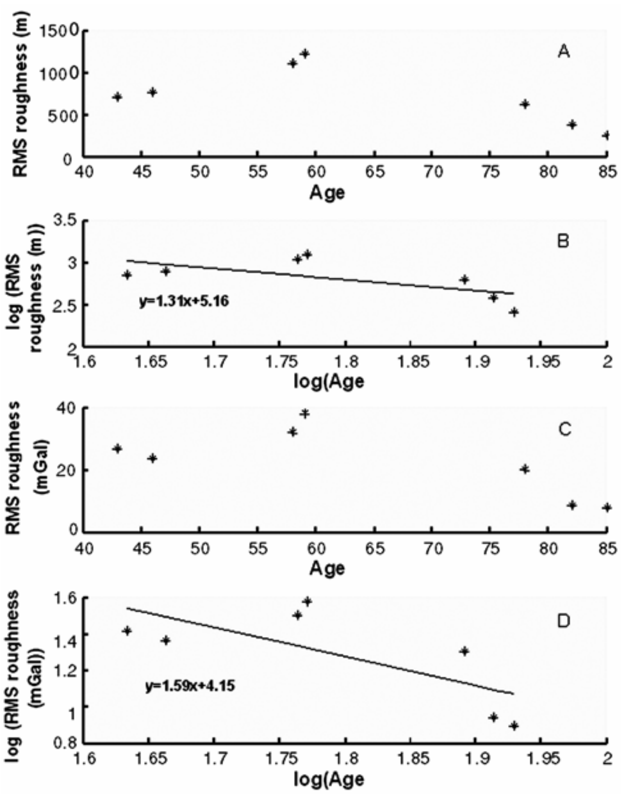

Fig. 3—(A) Root mean square (RMS) roughness of bathymetry plotted against the age found from DSDP and ODP sites; (B) plot of log RMS roughness of bathymetry versus log of age;(C) RMS roughness of the satellite gravity data plotted against the age and (D) plot of log RMS roughness of the satellite gravity versus log of age.

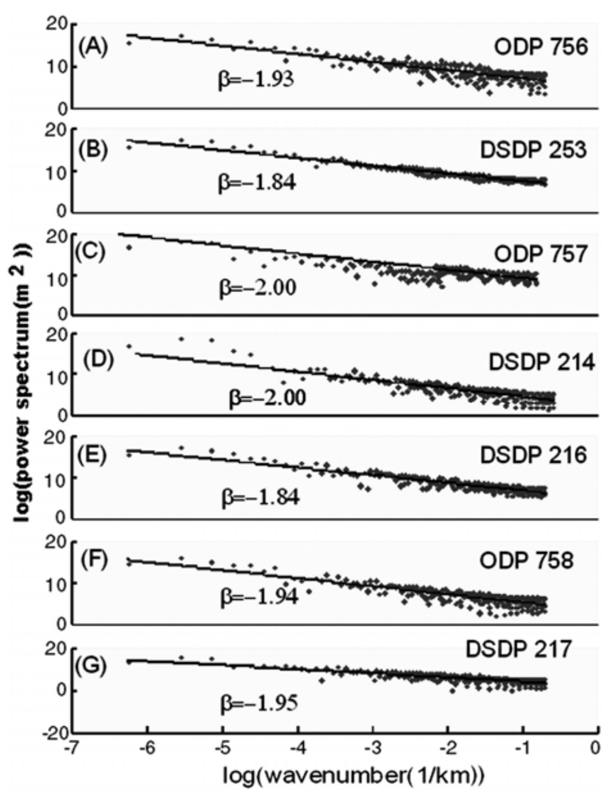

Fig. 4—Plots of log (power spectrum) versus log (wave number) of the bathymetry data along the profiles extracted over (A) ODP756; (B) DSDP253; (C) ODP 757 and (D) DSDP 214; E) DSDP216; (F) ODP758; (G) DSDP 217. The scaling exponent is also shown.

(β). The scaling exponent and fractal dimension (D) is related as[19]:

$$D = (5-\beta)/2 \quad (2)$$

Log- log plots of the spectral power density versus frequency show a good power – law dependence for all profiles and shown in Fig. 4 for bathymetry and in Fig. 5 for gravity data. The calculated values of fractal dimensions are presented in Tables 1 for bathymetry and gravity data. The mean value of fractal dimension is found to be 1.54 ± 0.033 for bathymetry data and 1.46±0.088 for gravity data. The fractal dimensions are not showing any trend with age of the oceanic crust. The fractal dimension value close to 1.5 indicates Brownian noise.

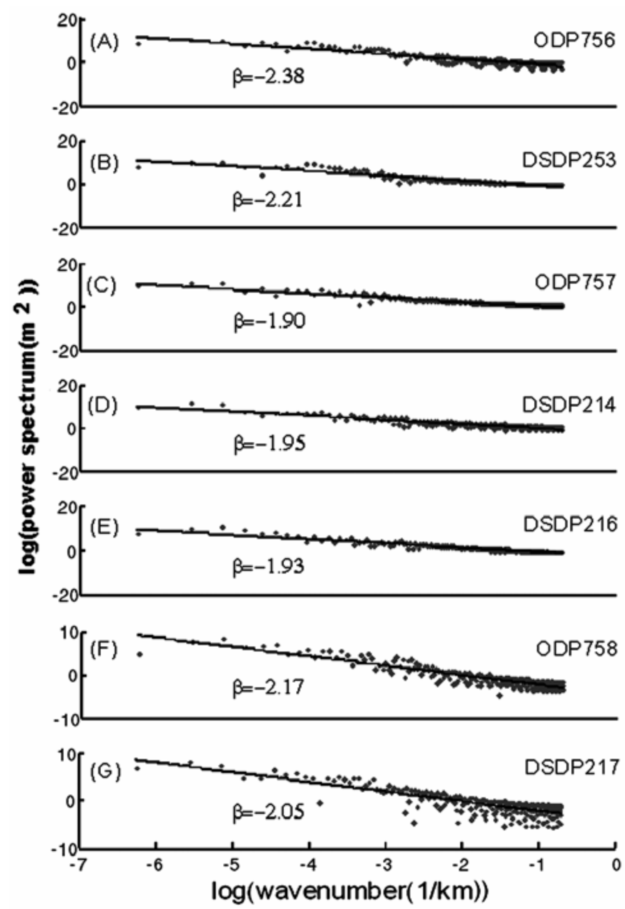

Fig. 5—Plots of log (power spectrum) versus log (wave number) of the gravity data along the profiles extracted over (A) ODP756; (B) DSDP253; (C)ODP 757 and (D) DSDP 214; E) DSDP216; (F) ODP758; (G) DSDP 217. The scaling exponent is also shown.

Table 1—Fractal dimension estimated from the profile data over DSDP and ODP sites for the bathymetry and satellite gravity data

Profile	Fractal Dimension of bathymetry	Fractal Dimension of satellite gravity data
ODP756	1.54	1.31
DSDP253	1.58	1.40
ODP757	1.50	1.55
DSDP214	1.50	1.52
DSDP216	1.58	1.54
ODP758	1.53	1.41
DSDP217	1.53	1.47

Conclusion

The satellite gravity and ship track bathymetry data are analyzed to establish a relation between the roughness of gravity and bathymetry with age. The power law relation is found between roughness of bathymetry and gravity data with age. The bathymetry over the older oceanic crust in the north part of 90 °E ridge is modified by deposition of Bengal fans and resulting in the decrease in roughness. The fractal dimensions indicate closeness of bathymetry and gravity data to the Brownian noise.

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