Evidence of continental crust in Laxmi Basin (Arabian Sea) using wavelet analysis

A. Chamoli* & V.P. Dimri

National Geophysical Research Institute, Hyderabad-500 007, India

*E-mail: chamoli_jp@rediffmail.com

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The spectral analysis of bathymetry along 17°12'N latitude between the longitude ~60°E and 73°E has been done using wavelet transform. The profile covers all the major features of the region including Western Basin, Laxmi Ridge, Laxmi Basin, Panikkar Ridge, continental slope and continental shelf. The wavelet coefficients at different scales $a = 1, 2, 4, 8, 16, 32$ showed that the signatures are different on the left and right regions of the Laxmi Ridge. On the basis of these signatures, the profile has been divided into different sections and wavelet variance analysis for these sections has been done. The calculated exponent $\beta$ has the value ~2.0771 for whole data set and ~1.9367, 2.838, 2.9911 and 2.8750 corresponding to Western Basin, Laxmi Basin, region from Laxmi Basin up to continental shelf and region covering continental slope and continental shelf respectively. The fractal dimension corresponding to these values are 1.53, 1.1, 1.0 and 1.06 respectively. The values of $\beta$ and fractal dimension show that the spectral behaviour of crust of Laxmi Basin is near to continental shelf and slope, which indicates the nature of crust of Laxmi Basin as continental.

[Key words: Wavelet transform, fractal dimension, bathymetry, Laxmi Basin, spectral analysis, Arabian Sea, Laxmi ridge, Panikkar ridge, crust]

Introduction

Laxmi Ridge, about 500 to 700 km off the west coast of India, is a prominent feature which divide the continental margin of western India and the Arabian Sea into two basins. This ridge trends NW-SE and located approximately in between 14.5°N to 19°N (Fig. 1). The basin to the western side of ridge up to Carlsberg Ridge is termed as Western Basin and the basin to the eastern side of the ridge up to western margin of India is termed as Eastern Basin. Laxmi Basin is a sub-basin in the Eastern Basin parallel to the western margin of India. The nature of crust in the Laxmi Basin is an important issue for paleographic reconstructions of western Indian Ocean.

Different opinions exist on nature of crust of Laxmi Basin in the previous works. Naini & Talwani favored the rifted and subsided continental crust in the Eastern Basin on the basis of thickness of the crust and absence of sea-floor spreading type magnetic anomalies. Bhattacharya et al. explained the magnetic anomalies over Eastern Basin by sea floor spreading, which indicated that Eastern Basin is oceanic. However, the Western Basin has regular sea-floor spreading magnetic anomalies. Singh suggested the Deccan head mushrooming, which has modified the crust beneath Laxmi Basin with a huge

![Fig. 1—Location of the profile of the study.](image-url)
magmatic intrusion. Krishna \textit{et al.} has interpreted the nature of crust of Laxmi Basin as continental with emplaced magmatic bodies using integrated geophysical studies. Bansal \textit{et al.} interpreted revised gravity over the Indian Ocean and concluded occurrence of continental crust below the Laxmi Ridge and Basin.

In the present study, the spectral analysis of the bathymetry of the western Indian Ocean has been carried out along a profile using wavelet transform. The exponent in the power law relation between wavelet variance and scale was calculated for different segments of the profile and this exponent is correlated with different features of bathymetry to deduce the nature of crust.

**Wavelet Transform Analysis**

The spectral analysis of bathymetry can be done by considering it as a time series along a linear track. In the case of bathymetry data, the dependence of power spectral density on the wavelength shows power law behaviour\(^7\). This type of behaviour is characteristics of self-affine fractals\(^8\). Self-affine fractals are generalization of fractional Brownian motion and fractional Guassian noises\(^9,10\). Generally, the spectral analysis is done using Fourier transform\(^1\). Recent applications of wavelet transform\(^9,12,13\) suggest that it is efficient for spectral decomposition exhibiting good spatial resolution, which cannot be achieved by Fourier transform. Further, the wavelet transform provides a way to analyze the non-stationary nature, which is common in geophysical data\(^14,15\). The wavelet analysis has applications in signal processing\(^16\) and interpretation of marine gravity and magnetic data\(^17\). Wavelet theory has been applied to seafloor bathymetry and topography, which revealed the structures, which were not resolved in the raw data\(^18,19\).

In the wavelet domain a signal is decomposed in wavelets of finite duration and the corresponding wavelet is called the mother wavelet. The mother wavelet can be represented as:

\[
\psi_{a,b}(x) = \psi \left( \frac{x-b}{a} \right) \quad \text{... (1)}
\]

where \(a > 0\) is scale (dilation) parameter and \(-\infty < b < \infty\) is translation parameter.

The mother wavelet satisfies the following condition:

\[
\int_{-\infty}^{\infty} \psi(x) dx = 0 \quad \text{... (2)}
\]

For a function \(h(x)\), the continuous wavelet transform is defined as:

\[
W[h](a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} \psi^*(\frac{x-b}{a}) h(x) dx \quad \text{... (3)}
\]

Here \(\psi^*(x)\) denotes the complex conjugate of \(\psi(x)\). The scale parameter ‘a’ corresponds to the wavelength/frequency contributions in the signal. The small scale corresponds to short wavelength contributions and large values of scale correspond to long wavelength contributions in the signal.

The mother wavelet used may be orthogonal or non-orthogonal. There is no well-defined criterion for choosing the mother wavelet. However, different applications on various data sets have shown that the orthogonal wavelets give good results for compression and other applications. For analyzing the topography/bathymetry data, orthogonality is not required\(^13\). We have chosen ‘Mexican hat’ wavelet (Fig. 2), which has also been used for analyzing topography data\(^9,13\). Mexican hat wavelet is defined as the second derivative of the Gaussian probability function and mathematically given as\(^20\):

\[
\psi(x) = c.\exp(-x^2/2).(1-x^2) \quad \text{... (4)}
\]

where \(c = 2/(\sqrt{3\pi}V_4)\). The spectral analysis of data series is done by variance analysis of wavelet

![Fig. 2—Wavelet function of Mexican hat wavelet.](image)
transform at different scale. If the time series considered is self-affine, then wavelet variance \( V \) has a power law dependence on the scale parameter ‘\( a \)’ as:

\[
V \sim a^\beta
\]  

(5)

The power law exponent \( \beta \) in Eq. (5) is equivalent to the exponent \( \beta \) found in Fourier spectral analysis in which the power law dependence between power spectral density and frequency is analyzed. The power law exponent \( \beta \) is related to fractal dimension as:

\[
\beta = \frac{5 - D}{2}
\]

(6)

Data Analysis

The Seafloor topography data has been derived from SRTM (Shuttle Radar Topography Mission) 30 plus data, which is fusion of SRTM and land topography with, measured and estimated seafloor bathymetry. A profile has been extracted along 17° 12′ N latitude between the longitude ~60°E and 73°E with average interval ~0.93 km (Fig. 1). The relief of Laxmi ridge is ~0.5 km from surrounding topography. The bathymetry along the profile (Fig. 3) shows the prominent features of Laxmi ridge and Panikkar ridge.

The Seafloor topography data along the profile has been transformed using Mexican hat wavelet (Eq. 4) as given by Eq. (3). The wavelet coefficients have been calculated for the scales \( a = 1, 2, 4, 8, 16, 32 \) which are shown in Fig. 4. The variance for various scales \( a = 1, 2, 4, 8, 16, 32, 64, 128 \) have been calculated. The frequencies (F) corresponding to the scales have been calculated using the following equation:

\[
F = \frac{F_c}{a \cdot \Delta}
\]

(7)

Fig. 4—Calculated wavelet coefficients using Mexican hat wavelet for scales (A) \( a = 1 \); (B) \( a = 2 \); (C) \( a = 4 \); (D) \( a = 8 \); (E) \( a = 16 \) and (F) \( a = 32 \).
where ‘a’ is the scale, ‘F_c’ is the center frequency of a wavelet and ‘F’ is the frequency corresponding to the scale.

The plot between log of variance and log of (1/F) has been analyzed in terms of exponent β. This plot has been calculated for different sections of data to analyze various topographic features (Fig. 5). Figure 5a shows the bathymetry profile and sections corresponding to various features, which are individually analyzed. First, the variance analysis is carried out to the whole data and then to the different sections. The fractal dimension of bathymetry has also been calculated by Eq. (6).

**Discussion**

Various approaches for interpreting the nature of crust of Laxmi Basin have been carried out using different data sets such as gravity, magnetic, bathymetry and seismic data. Using spectral analysis of bathymetry data, it is possible to further refine the results and interpret the behaviour of crust below the various features. The wavelet coefficients (Fig. 4) show the spectral as well as spatial behaviour. The wavelet coefficients at extremes of profile (particularly low value at small distances) have not been included in interpretation as this part has noises due to edge effects. The behaviour-change starts from the Laxmi ridge (distance ~800 km). The curves of wavelet coefficients at different scales (Fig. 4) appears to be smooth for region left of Laxmi ridge (distance ~800 km), i.e., western basin. However, the region from Laxmi ridge towards the continental shelf shows different spectral signature than the western basin. Thus, this change in behaviour has been further studied by doing variance analysis after dividing the profile in different sections. The value of exponent β for whole data along the profile is 2.0771 (Fig. 5b) which shows the spectral signatures of Brownian motion ($\beta = 2.0$) and correlates well with the power law scaling of general topography of the Earth. The value of β for section A, B, C and D of profile (Fig. 5) is 1.9367, 2.838, 2.9911 and 2.8750 corresponding to Western Basin, Laxmi Basin, region from Laxmi Basin up to continental shelf and region covering continental slope and continental shelf respectively. The last three values of β and fractal...
dimension (D) clearly show the distinct behaviour from the first value. The value of $\beta$ and D, which correspond to Laxmi Basin, is comparatively near to $\beta$ and D value for continental slope and shelf than the $\beta$ and D value for Western Basin. This shows deviation of nature of crust of Laxmi Basin from Western Basin, which has been confirmed to be oceanic. The spectral behaviour of crust of Laxmi Basin is near to continental shelf and slope, which shows the nature of crust of Laxmi Basin as continental.

Generally, seismic, gravity and magnetic methods are used for studying the crustal behaviour below the ridges and basins. The wavelet analysis and fractal dimension may also be a useful tool for understanding the nature of the crust.

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References: