

Mapping and analyses of two coralline banks in the western continental margin of India using multibeam echosounder data

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Six and eleven profiles of bathymetric and backscatter data are drawn from the gridded (rasterized) maps of the two banks, the Gaveshani Bank and another, an unnamed bank (at latitude 13°43.5' N, longitude 73°42' E) respectively. The existence of six and five classes of data is established with respect to the Gaveshani and the unnamed bank through the use of Artificial Neural Network (ANN) based unsupervised self-organizing map (SOM) architecture, for determining the number of data classes, and corresponding 60 and 209 segments using fuzzy c-means (FCM) algorithm for segmentation. The segmented profiles of each bank are overlaid on the respective gridded backscatter maps to examine the seafloor morphology associated with the distribution of the overlying sediment material. Lower backscatter intensities (-60 to -30 dB) are observed with respect to the unnamed bank, whereas in the case of Gaveshani bank, the backscatter intensities were varying from -30 to -15 dB, indicating relatively higher intensity in comparison to the unnamed bank. This portends reduced sediment deposition on the Gaveshani bank due to erosion.

[**Keywords:** MBES, Bathymetry, Backscatter, Seafloor Roughness, ANN, SOM, PDF]

Introduction

Multibeam echosounder systems (MBES) allow acquisition of high-resolution bathymetric data¹⁻⁵ along with co-registered backscatter data that is often used for interpretation of seafloor roughness characteristics. The processed bathymetry and backscatter data respectively provide large-scale as well as fine-scale seafloor roughness. Preprocessing of bathymetric and backscatter data is necessary for any numerical modelling as it require stationary input data. An alternative to dimensional reduction applications, involving input vectors for a specific output, soft-computing techniques like artificial neural networks (ANNs) can be employed for such computationally intricate tasks. The ANN-based self-organizing map (SOM) architecture can be trained using unsupervised competitive learning on an unknown data set (input) to produce low-dimensional representation, i.e. primary classifications^{6,7}. SOM can be utilized in real time survey applications, to formulate a decision to evaluate the number of data class⁸. The recently developed technique utilizing ANN and SOM has been used to analyze the

multibeam data of the Gaveshani bank located ~100 km off Malpe, in the southern Indian state of Karnataka, and an unnamed bank 37 km north of the Gaveshani bank in the eastern Arabian Sea. The two banks lie in the western part of the peninsular shield of India, which is a mosaic of various tectonic provinces dating in age from early Archaean to late Proterozoic^{9,10} and were subject of qualitative studies in the past¹¹. General orientation of the two structural features is NNW-SSE and parallel to the Dharwarian orogenic trend. The study area is characterized by thick Neogene and Palaeogene carbonates with minor shale. The main drainage in the coastal area trends in general East-West direction and flows to the Arabian Sea in the west. Rivers such as the Gangavali, Sharavati and Netravati flow across the coastal plain and have an annual runoff of $1.5 \times 10^{13} \text{ m}^3 \text{ yr}^{-1}$ of water. The Gaveshani bank is about 1500 m wide and located at a depth of 38 m¹². Seafloor surrounding the bank appears to be flat or having a low gradient. Sediment composition of the seafloor around the bank is predominantly carbonates, consisting of corals, mollusks fragments and foraminifera shells along

with silty sand¹³. In this paper, the banks and the contiguous area around it have been studied using the newly developed seafloor classification technique to understand the overlying surficial sediment distribution. The other unnamed bank¹⁴, rising 24 m from the seafloor with a maximum length of 5900 m and about 4300 m width, lies below water depths of 55 m. Both the banks exhibit distinct geomorphic features. The unnamed bank is affected by intense erosion whereas the Gaveshani bank is unaffected by any such attrition¹⁵. The computational analyses carried out in this work underscore the geomorphic importance of the ANN-SOM based seafloor classification technique employed in the assessment of the morphological data of the two coralline banks. In this study, the multibeam data of the Gaveshani bank¹² and the unnamed bank¹⁴ are being investigated.

Materials and Methods

The MBES data¹⁶⁻¹⁷ for this study was acquired using EM1002 Multibeam Echo Sounder (Kongsberg AS) operating at 95 kHz installed on board CRV Sagar Sukti. Gridded rasterized maps (bathymetry and backscatter data) of Gaveshani and the unnamed bank were generated, from which 6 and 11 data profiles were selected corresponding to the two banks. A total of 5870 data values of the six selected profiles (each of bathymetry and backscatter data) of the Gaveshani

bank were used. The area covered that comprises of the coralline bank and its contiguous area is nearly 3.5 km². In the case of the unnamed bank a total of 28743 data values from the 11 profiles (each of bathymetry and backscatter data) were utilized. The water depths around the unnamed bank varied from 79 m around the bank to 55 m on the top of it. The extent of the area of the unnamed bank and its adjacent seafloor is 13 km². Fig. 1 shows variation in backscatter intensity of the two banks. The bathymetric data was processed using Neptune software incorporating corrections for propagation, refraction errors and tide. Backscatter data was processed using PROBASI II¹⁸, for data normalization and then imported to CFLOOR (Cfloor AS) software for gridding (resolution: > 2.2 × 2.2 m) and improved visualization. The backscattering strength of Gaveshani bank and the unnamed banks ranged from (-30 to -15 dB) and (-60 to -30 dB) respectively.

Generally, angular backscatter data strength proffer higher values at normal incidence compared to the outer beam angles, particularly in the case of a smooth seafloor. Such backscatter data engender artifacts at the time of data acquisition. Performing sonar-related preprocessing of the backscatter data, the artifacts along the centre beam path are greatly cleared out by using a median filter. Offline corrections are occasionally carried out to compensate

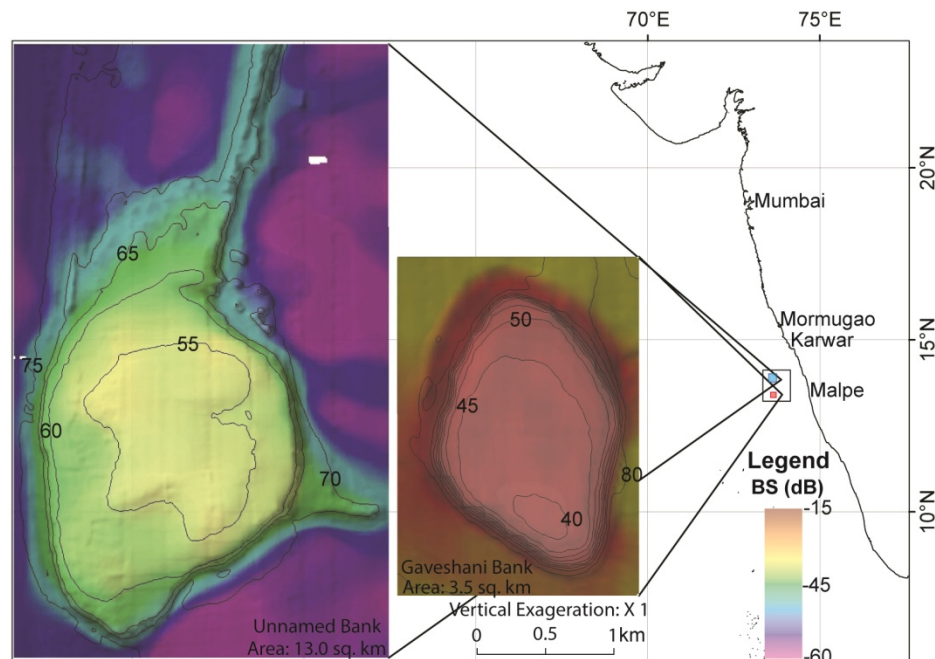


Fig. 1 — Location of the study area and the two banks, Gaveshani with an area of 3.5 km² and the unnamed bank with an area of 13.0 km², Backscatter map depicting the variation in backscatter strength (dB) ranging from -60 to -15 dB, along with bathymetric contours.

for the outer beams backscatter strength data in such a way that the effect of the angular backscatter strength is eliminated. The quality of the image data is further enhanced utilizing the four-stage image processing technique¹⁹⁻²¹. Work developed here demonstrates that the employed data processing technique can efficiently classify the survey area using linear data traces (backscatter / bathymetric) varying along the geographical south to the north (Fig. 2). These traces are represented by 'profiles'. Six such profiles (each of bathymetry and backscatter data in the case of Gaveshani bank), extracted from the gridded maps, holds 995 data points in each profile, and the distance between two consecutive data points (along the profile) being nearly 2.2 m. The average separation between the six parallel profiles is ~300 m. Whereas the eleven data profiles of the unnamed bank possess 2613 data points and the distance between the two consecutive data points (along the profile) being 1.6 m. The average separation between two consecutive profiles of the eleven parallel profiles is ~280 m. The six and eleven backscatter data profiles of the Gaveshani bank and the unnamed bank respectively were subjected to preprocessing individually as described earlier in Chakraborty *et al.*⁷. A moving average filter is applied to smoothen out short-term fluctuations. Corresponding depth values associated with the backscatter data are used to obtain the local

seafloor roughness. The “roughness” parameter can be considered as the deviation of the depth value about the local linear trend of the data. Large deviations with respect to the local linear trends are indicative of rough seafloor surface; else the surface can be considered smooth²². Large scale roughness parameters are estimated for every nine data points (~20 m) of the depth data profiles. With respect to the profile segmentation application carried out here, the two characteristics (roughness and backscatter) are incorporated as input feature vectors into the SOM network.

The algorithm for data segmentation, as well as the methodology utilized for the segmented data, has been adapted from De and Chakraborty²³. Flowchart of the technique adapted is presented in Fig. 3. The SOM architecture employed comprises of a flat one-dimensional neuron grid. The SOM network consists of a grid of 50 output neurons that accepts the feature vectors representing the backscatter and roughness parameters as input, to estimate the number of classes in the data. Neurons in the grid compete among themselves to get activated on presenting the input data to SOM. In order to determine the number of classes using the SOM architecture, the input feature vectors of each data point are presented and the closest neurons are selected to be the firing neurons for the input data. To begin with the training

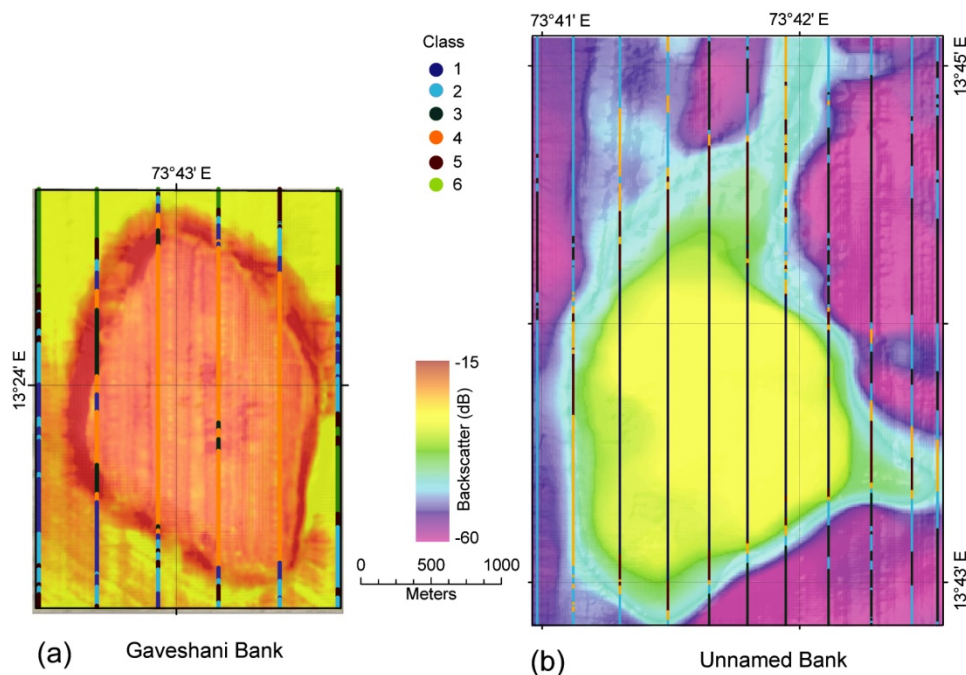


Fig. 2 — (a) Six backscatter profiles classified into six different classes (depicted in color) overlaid on rasterized backscatter map in the case of Gaveshani bank, (b) Eleven profiles, five classes in the case of the unnamed bank.

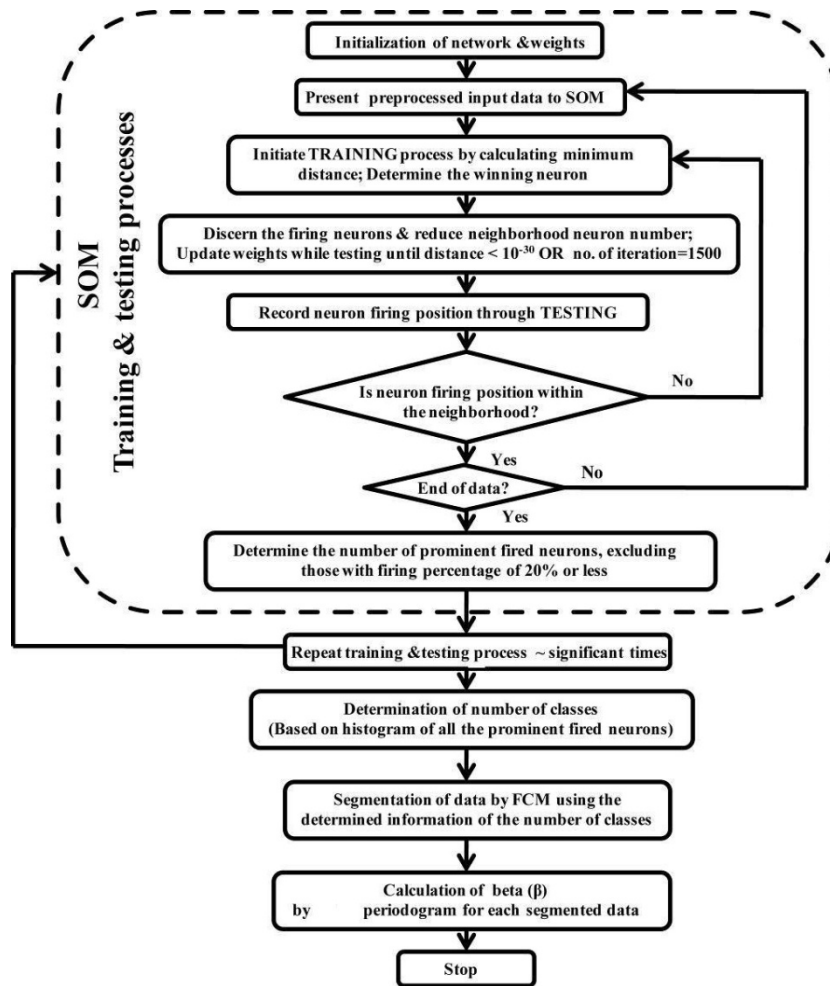


Fig. 3 — Flow chart of the method employed for determining the number of data classes using SOM and FCM (adapted from Chakraborty et al.⁶).

process, two input feature vectors, depth based seafloor roughness and backscatter values are presented as the training sample. Once the training is completed, the incidence of the excited neurons during the testing processes is plotted. If the testing results throw up the winning neuron within a group of trained neuron, it is assumed that it belongs to the same class as the data where it was trained, or else the training / testing process is reinitiated. The representative percentages of the number of times the neurons have been fired for the entire data set are plotted as bar diagram with respect to the number of neurons. The maximum number of classes that exist are equal to or above the number of occurrences i.e., 20% of the highest neuron firing [Fig. 4(a) and (b)]. SOM helps to ascertain the number of classes by counting the occurrences of the number of prominent neurons. For instance, at the one time training-testing process of the profile data, the highest neuron firings

occurred at the neuron position 10. The rest were observed at 17, 30, 38, 44 and 48 as shown in [Fig. 4(a)] in the case of the Gaveshani Bank (that can be viewed as an example). Similarly as shown in [Fig. 4(b)] for the unnamed bank, the neuron firings occur at 5, 26, 33, 37 and 41. The testing and training process for the entire data set is repeated ~100 times. The neuron numbers produced during the multiple training-testing processes using the SOM are plotted in a histogram indicating the major classes [Fig. 4(c) and (d)]. Thereafter, fuzzy C-means (FCM) method (www.mathworks.com) is employed, utilizing the predetermined number of data classes, for segmentation of the backscatter data of the profiles. The six classes generated from the training and testing of the firing neurons correspond to the six segmented sets of the backscatter data from the profiles [Fig. 4(c)] of the Gaveshani bank and five segments for the unnamed bank [Fig. 4(d)]. The FCM

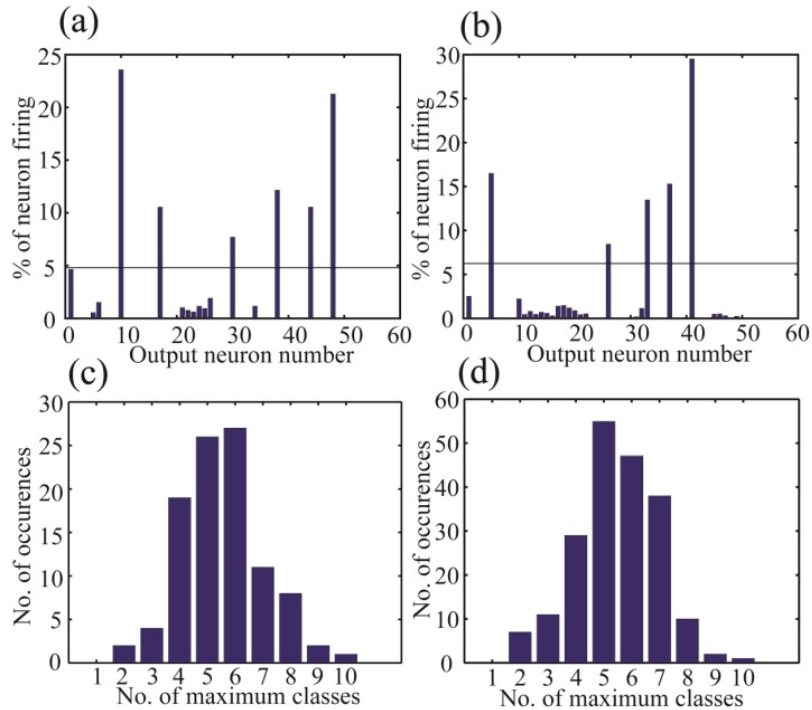


Fig. 4 — (a and b) The horizontal lines represent the line of 20% of the maximum number of neuron firings. The six bars above the line indicating six classes in the case of Gaveshani bank and five classes in the case of the unnamed bank obtained from one training-testing process for different moving averaging scheme of input data, (c and d) histograms of the number of occurrences of maximum number of classes obtained from the ~100 training-testing process employing SOM analysis i.e., indicating no. of classes available in the datasets of Gaveshani and the unnamed bank respectively.

generated segmented profiles (color coded) overlaid on the backscatter map using Geographic Information System software ArcGIS can be seen in [Fig. 2(a) and (b)]. This process helps to obtain the number of classes available in a given dataset without any prior information. Thereafter FCM is employed using the information of the number of classes determined by SOM to segment the datasets of the firing neurons to obtain the segmented sets of the original bathymetric profile data. MATLAB based FCM algorithm is utilized for clustering the profile data to generate the segments.

In order to confirm the validity of the number of classes obtained using SOM and FCM, histograms of the 6 and 11 backscatter profiles data of the two coralline banks (Gaveshani and the unnamed bank) were fitted using multimodal curves. Probability Density Functions (PDF) of the backscatter strengths has been computed. The estimated scaling amplitude (to scale the height of the curve), mean and standard deviation of the PDF components were used. These parameters were estimated from the curve fitting between the experimental and predictive PDFs, which involved a comparison between the estimated correlation coefficients and the sum square of the

residuals ($-SSR$ criteria)²⁴. The mixtures of the normal distribution of the six components could be ascertained in Gaveshani bank [Fig. 5(a)] and five components in the unnamed bank [Fig. 5(b)].

The highest correlation coefficients and the lowest errors (SSR) have been considered in determining the predictive components and the resultant (mixture) PDFs through the use of the experimental data⁷. The study carried out here supports the fact that the backscatter data depict the same number of classes in the data sets as determined by the SOM-based study.

Results and Discussion

The segmentation of the six profiles could produce 60 distinct segments from the six classes of the Gaveshani bank data and 209 (separated) segments in the case of the unnamed bank. It can be seen that the larger segments are stretching over the top of the bank [Fig. 2(a)]. The backscatter strength values of the summit of the Gaveshani bank range from -20 to -15 dB, i.e. very high backscatter. Overall the backscatter strength of the summit and the sloping uneven sides of the coral bank varies within the (-30 to -15 dB), which is indicative of the fluctuation

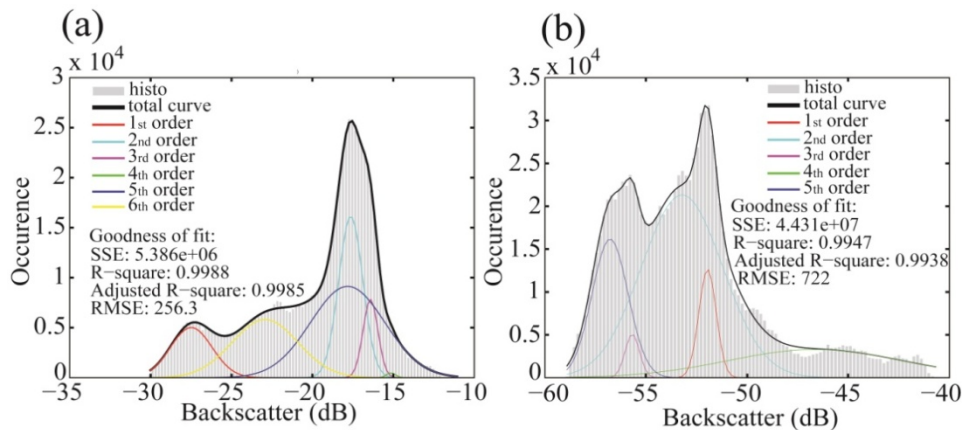


Fig. 5 — Occurrences of backscatter strength (dB) with respect to the rasterized backscatter pixels of the two coralline banks and the fitted multi-modal curves of the total, and the six and five PDF components of; (a) Gaveshani bank; (b) The unnamed bank.

due to the rugged edges along the rise. The six segmented profiles of Gaveshani data classified into six classes overlaid on the rasterized backscatter map that is classified based on Jenks method is presented for the Gaveshani bank [Fig. 2(a)]. Likewise 209 segments were obtained using SOM and FCM in the case of the unnamed bank using the eleven backscatter intensity profiles. Here too we can observe that the larger segments bestride the summit of the unnamed bank. However, the backscatter values of the unnamed bank vary from -49.5 to -30 dB atop the summit of the bank. Whereas the backscatter strength from the entire area show greater fluctuation -60 to -30 dB. The present analyses reveal that the backscatter intensity of the summit of the unnamed bank is comparatively lower than the Gaveshani bank. The five classes obtained from the data profiles of the unnamed bank using SOM and FCM techniques are overlaid on the backscatter map [Fig. 2(b)]. Similar to the case of the Gaveshani bank, it can be seen that there is increased segmentation over the edge of the banks than on the summit.

The seafloor classification and characterization techniques, utilized here for categorizing the two coral banks, were earlier employed for a seepage dominated seafloor from the WCMI. While comparing backscatter intensity of the two coral banks, the Gaveshani bank summit backscatter strength is higher. Comparatively the lower backscatter strength of the unnamed bank summit having a lower elevation (24 m) than the Gaveshani bank (42 m) at comparable water depth (~ 80m), persuade us to explore alternatives to explain the morphological differences between these two coral banks. During the SW monsoon (June-September) the rainfall is high and the rivers carry maximum sediment

load to the continental shelf. There is a southerly coastal surface current about 150 km wide^{4, 25} that is observed in water depths of 50 m on the continental shelf. The mean current speed and direction during the southwest monsoons are 12.6 cm/sec and 94.5° N respectively. South of 15° N, intense coastal upwelling occurs during the SW Monsoon. Similarly, during the NE monsoon (November-February), the southerly surface current is replaced by a northerly surface current. A bottom current of about 40 km width in the depth interval 100-250 m, with characteristic of Bay of Bengal waters, prevails during both the SW and NE monsoons. However, it becomes progressively weaker from south to north, and is not detected beyond 20° N. Regional oceanic circulations, characterized by seasonal reversal of monsoon-driven surface and bottom currents, summer upwelling and winter down welling, create an unstable oceanographic conditions over the WCMI at ~ 250 m water depth. Two coralline banks being situated at 80 m depth, the observed coral bank characteristics and morphological differences between the two coral banks are unlikely to be caused due to the bottom currents. The coral banks are 37 km apart in the N-S direction and therefore the possibility of bottom current effects are implausible. We look for other possible causes in order to find out the cause of the morphological differences in terms of backscatter data between the two coral banks. The two coralline features are situated on the left bank of a buried channel (Fig. 6).

The channel could have been originally formed as fluvial drainage. Bathymetry data of Gaveshani bank indicates a larger coral growth¹³. Possibly the Gaveshani bank lying on the top of a sub-aerial headland is devoid of fluvial erosion and deposition

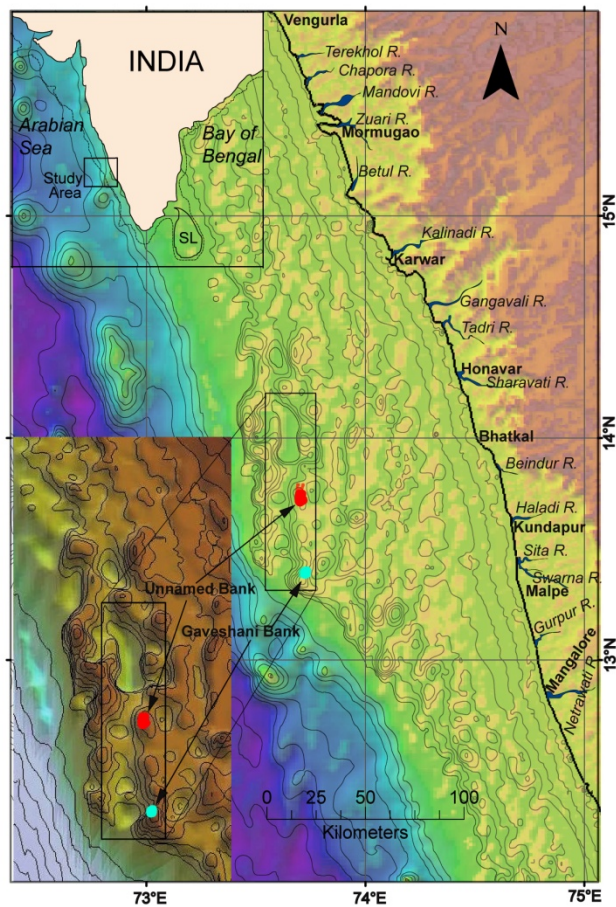


Fig. 6 — Site location with insert bathymetry from SRTM data. The two coralline banks can be seen lying on a buried channel that was originally formed as fluvial drainage. The bathymetry (insert) depicts a paleolagoon and the Gaveshani bank on the top of the submerged promontory (adapted from Chakraborty *et al.*¹²).

effects and unaffected by back filling effect. On the other hand, the unnamed coral bank comprising of live and dead corals¹⁰ situated on lowland and has less backscatter strength. Sediment grab samples from this area have revealed pebbles also suggesting an erosion effect. The pebbles can be traced to an inland source of fluvial origin earlier than the Holocene period²⁶. The coastal areas of Bundair, Honavar and Mangalore (along the Netravati River) with similar coarse quartz pebbles could be a most likely source^{27,28}.

Conclusions

The acoustic backscatter strength of the Gaveshani and the unnamed coralline bank ranges from -15 to -30 dB and -30 to -60 dB respectively. The high backscatter (> -20 dB) can be attributed to the coral growth, sediment type and relief. Generally the coarse-grained sediment along with abundant shell

material reveals high backscatter strength. In relation to the greater depth (~ 80 m) where the seafloor gradient is gentle, the backscatter strength is found to be generally low (< -22 dB).

In this paper, this technique has been adopted to characterize the seafloor backscatter data acquired utilizing the MBES system of the two coralline banks. The technique can also make use of data acquired using SBES (Single Beam Echo Sounding System). The data-driven approach based on SOM and FCM segmentation can be used to estimate the fine-scale roughness parameters from the PSD of the backscatter profiles. Both the banks lie in the proximity of a buried channel and exhibit relatively higher backscatter intensity on the summit of its bank. Backscatter intensity values of Gaveshani are higher than that of the unnamed bank. Gaveshani bank is lying on a buried promontory and has less sedimentary deposits compared to the unnamed bank that is located in relatively deeper waters where the erosion and depositional rate are also comparatively higher. However, with the rapidly decreasing depth values along the edge of the banks, the backscatter intensity displays an increasing trend. Variation in backscatter intensity on the summit of the unnamed bank is indicative of higher sediment accumulation.

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