
Seafloor characterization of the mound and channel provinces of the Porcupine Seabight - an application of the multi-beam angular backscatter data

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Summary. In this study multi-beam angular backscatter data acquired from the eastern slope of the Porcupine Seabight are analysed. Processing of the angular backscatter data using NRGCOR software was made for twenty-nine locations comprising different geological provinces like: carbonate mounds, buried mounds, seafloor channels, and inter channel areas. A detailed methodology is developed to produce a map of shape invariant (normalized) backscatter data by correcting the local angular backscatter values. The present paper involves detailed processing steps and related technical aspects of the normalization approach. The presented shape invariant backscatter map possesses 12 dB dynamic range in terms of grey scale. Clear distinction is seen between the mound dominated northern area (Belgica province) and the Gollum channel seafloor at the southern end of the site.

A qualitative analyses of the calculated mean backscatter values i.e., grey scale levels, utilizing shape invariant backscatter data generally indicate backscatter values are highest (lighter grey scale) from the mound areas followed by buried mounds. The backscatter values are the lowest from the inter channel areas (lowest grey scale level). Though moderate backscatter values (medium grey level) are observed from Gollum and Kings channel data, and significant variability within the channel seafloor provinces. The segmentation of the channel seafloor provinces are made based on the computed grey scale levels for further analyses based on the angular backscatter strength. Three major parameters are utilized to classify four different seafloor provinces of the Porcupine Seabight by employing a semi-empirical method to multi-beam angular backscatter data. The predicted backscatter response [?] which has been computed at 20° is the highest for the mound areas. The coefficient of variation (CV) of the mean backscatter response is also the highest for the mound areas. Interestingly, the slope value of the buried mound areas are found to be the highest. However, for channel seafloor of moderate backscatter response presents the lowest slope and CV values. However, a critical examination of the inter-channel areas indicates less variability within the estimated four parameters.

A detailed visualization of the terrain model and the normalized backscatter data is presented on the accompanied CD-ROM.

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Key words: angular backscatter, mounds, Porcupine Seabight

1 Introduction

Large scale oceanographic explorations are presently continuing around the Porcupine Seabight area, which is located towards the south-west of Ireland. This area is an embayment of the north Atlantic continental margins. It's importance due to the dominant hydrocarbon resources are not unknown [1], and on-going experiments are important due to the involvement of higher order variability (in terms of physical and geological settings) around this area [2]. This area shows northward flowing slope current following north Atlantic continental slope contours. Geologically, it is a sedimentary environment controlled by drift deposits, and highly complex channel and levee systems. The Porcupine Seabight area possesses dominant carbonate mounds ([3], [4]) and channel systems related structures, and understanding of the seafloor morphological aspects were initiated by applying long and short range side scan sonar data, extensive sediment sampling and single channel seismic profiles ([5], [6] and references therein and [7]).

Recent initiatives of the European Union's 'GEOMOUND' programme provided detailed high resolution multi-beam bathymetric survey results from the Porcupine Seabight area during the RV Polarstern expedition ANTXVII4 [8]. Analyses of bathymetric data reveal interesting features at the eastern slope of the Porcupine Seabight starting from numerous mounds and associated buried mounds which are part of the Belgica mound province at the northern end of the area followed by the east-west trending Kings channel and Gollum channel systems (bathymetric map of the above reference).

Apart from acquiring seafloor topographic data, seabed characterization can also be implemented using angular backscatter data. The multi-beam backscatter data were acquired simultaneously with the bathymetric data (Hydrosweep DS-2). Though, qualitative side scan sonar based backscatter data analyses and quantitative texture analyses of the surrounding areas closed to the presently studied locations are available ([7], [9], and [10]), but no quantitative multi-beam angular backscatter analyses were so far been made from the Porcupine Seabight.

In order to study various seafloor systems, a semi empirical approach for the angular backscatter data of GLORIA side scan sonar was implemented by [11]. Such classification technique for the seafloor sections involves the shape, variance, and magnitude of the angular response of the measured multi-beam angular backscatter strength and is applied in this study.

In this paper, section two deals with the processing of the angular multi-beam Hydrosweep DS-2 backscatter data. It also involves the data normal-

ization technique due to the angular backscatter strengths which provides a segmented seafloor based on the sediment lithology of the varying mounds and channel seafloor from the Porcupine Seabight. A mention about the survey sites are included in the section three along with a presentation of the shape invariant backscatter results from the mounds and the channel seafloor. An semi-empirical method is applied to the multi-beam dataset to employ seafloor classification in section four.

2 Multi-beam Backscatter Data Processing

The multi-beam echo-sounding system Hydrosweep DS-2 operates at 15.5 kHz [12]. It uses beam-forming technique to generate 59 Pre-Formed Beams (PFBs) covering beam angles from -45° to $+45^\circ$. The received signals are pre-amplified and corrected for real-time transmission loss in Time Varied Gain. These 59 beams are sampled and converted into echo root mean square voltages using a window of -6 dB around the central peak amplitude. In order to compute seafloor acoustic backscatter strength, off-line data processing algorithm known as 'NRGCOR' is employed [13]. Necessary system settings are stored and available for backscatter processing. The computed gain-corrected electrical signal values are converted into acoustic echo levels by employing receiving voltage response. The next step of the 'NRGCOR' algorithm is a geometric correction using the beam-wise bathymetric data for the computation of the seafloor slope (along track and across track slope) and true angles of incidence on the seafloor. Third important step is a computation of the seafloor area insonified by each beam. The computed backscatter strength is used for the present study with appropriate binning at 1° incidence angle interval.

The angular backscatter strength is a function of seafloor characteristics and angular backscatter shape variations are dominant due to the closeness of the beams to the normal incidence direction. For smooth seafloor sediments, this function varies steeply compared to rough seafloor surface. However, to generate a backscatter map similar to the bathymetry for seafloor interpretation such systematic effect needs to be removed [14]. The shape invariant backscatter data provide a sufficient basis for first order seafloor classification based on the sediment lithology [14]. In order to remove the angular dependency from the presently studied area of the Porcupine Seabight, a scheme is proposed in this paper.

The original processed backscatter output file of the 'NRGCOR' comprises of the backscatter strength values (with respect to the incidence angles and beam numbers) and position data. At the very beginning, stored backscatter strength values with respect to the 1° binned incidence angles are averaged utilizing entire 'NRGCOR' processed dataset (Figure: 1 a). Then, this averaged angular backscatter function is utilized to normalize each set of the angular backscatter strength with respect to a reference incidence angle. Since, fluctuations of the backscatter data are dominant close to the normal incidence

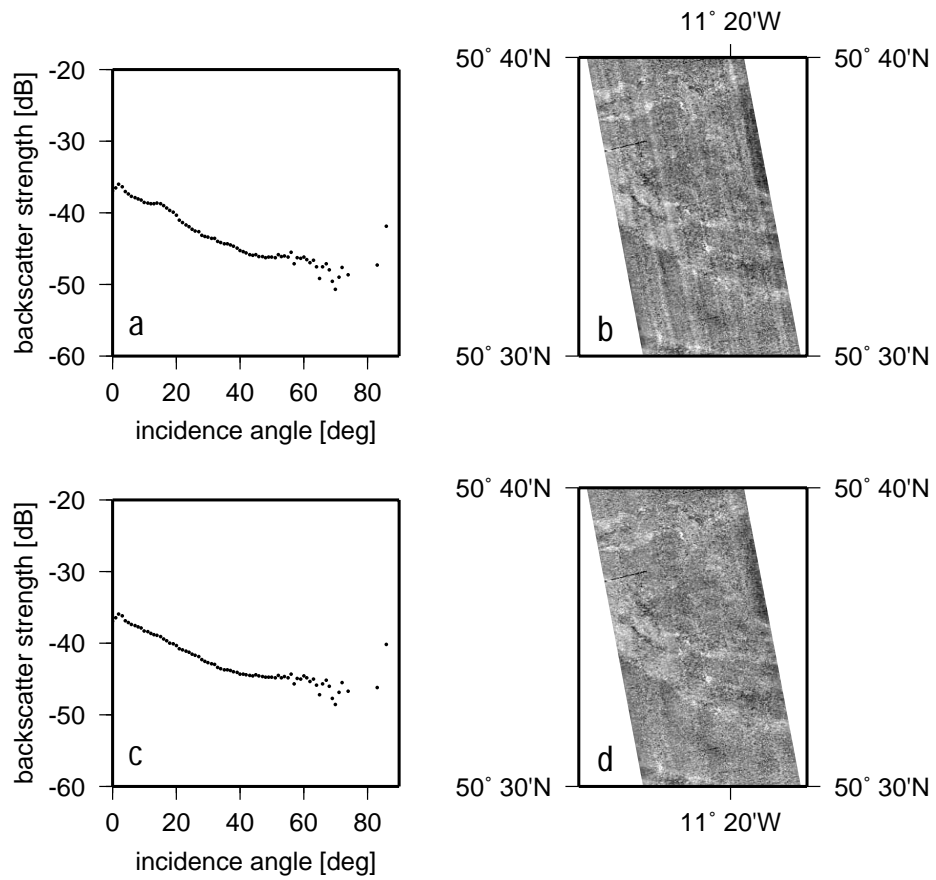


Fig. 1. Changing of the shape invariant backscatter map by applying mean angular backscatter function and beam pattern determined during the processing. Figure 1a shows the mean angular backscatter function of the area. This function has been removed from the data shown in figure 1b. Beam pattern effects visible in figure 1b (track line parallel artefacts) are removed from the data in figures c and d which show significant improvement between incidence angle 10° to 20°. Figures b and d show a combination of five parallel track lines of the same area.

direction we have chosen 10° angle as a reference angle. The results of such process allow to remove the angular effect in the sense that, the mean angular fall of the backscatter strength is removed from the data (Figure: 1b).

However, fluctuations parallel to the ship tracks and local variations are still seen in the normalized data. The effects of seafloor type on the backscatter are expected to be normalized in the angular backscatter strength values. Therefore, the systematic effect which is consistently appearing in the normalized data (few parallel lines around the track lines) (Figure: 1b) is realized to be related with the beam-pattern effect. This systematic effect due to the beam-patterns (function of beam number) are recovered from the normalized shape invariant backscatter data on ping by ping basis as an average backscatter value with respect to the beam number. An improvement of the 10° - 20° angular part of the mean angular backscatter strength of Figure (1a) is seen in the Figure (1c) where the averaging of the angular backscatter data is carried out after incorporating corrections due to the beam-pattern effect. The effects due to the beam-patterns are found to be removed considerably at the end of the initial process (Figure: 1d). In a similar manner, further iterations prove to be effective in normalizing the entire Porcupine Seabight area data set. We have employed in total three iterations to remove the beam-pattern effect along with the normalizations, which has considerably improved the present set of data. However, more number of iterations can be made for the improvement of the image quality, but an increase in the height of the angular backscatter function towards the higher incidence angles are realized when iterations are increased. This is due to the correlation of the incidence angle and beam number within the chosen areas for averaging.

Such technique provides grey scales compatible with the seafloor sediment lithology of the area which can form an useful basis of homogenous seafloor segments. Interestingly, the achieved homogeneously segmented data can be utilized for seafloor characterization. Once iterations are completed, a grid has been calculated out of the point distributions of the backscatter data. The grid size of 50 m and data points within a radius of 75 m around each grid point were used to calculate the grid cell value. These settings correspond to the largest footprint size of the beams and averaging is being made. On the whole, the multi-beam backscatter processed data free from mean angular backscatter shape parameters from the Porcupine Seabight area is presented in figures (2 a) and (2 b). A grey scale dynamic range of 12 dB (-42 dB to -30 dB) is observed to be varying within the shape invariant backscatter image, which comprises of mound and channel systems. The grey level contrast variations among different feature types are distinctly clear for the Porcupine Seabight backscatter data.

3 Porcupine Seabight - Study Area Description and Angle Invariant Backscatter Data

The Porcupine Seabight extends approximately from 49° N to 52° N latitudes and from 14° W to 11° W longitudes. For the present study, we have processed multi-beam data acquired between the $50^{\circ}25'$ N and $51^{\circ}40'$ N latitudes at the eastern margin of the Porcupine Seabight [8]. In order to keep consistency in the backscatter processing, the area chosen for this backscatter study is lying within the deep sea mode of the multi-beam system (i.e., within 800 m to higher depths) since the operational aspects e.g., transmission beams and reception beams, coverage, and pulse lengths are changing in different modes.

The morphology of the investigation area can broadly be separated into a mound region in the northern part and a channel region in the south. A clear difference in grey scale level can be noticed while comparing between the northernmost end mound system and southern-end channel system (Figure: 2) of the study area. Towards the north of $50^{\circ}15'$ N latitude, imprint of the giant mound occurrences in the bathymetric maps are reported [8]. Though, we have presented shape invariant multi-beam backscatter data operated in the deep sea mode, overlying bathymetry is presented for the entire area covered during the RV Polarstern expedition. Towards the northern part of the survey area (Figure: 2 a), few blank parallel lines are seen which should be considered as a data gap due to survey utilizing medium depth mode which is not considered here. The relative backscatter values (since calibration of multi-beam Hydrosweep system is impossible due to its large array size ~ 3.0 m) varying from the highest backscatter -30 dB (light grey scale) to the lowest i.e., -42 dB (dark grey scale) are observed within the area. Mounds of the Belgica province are present in this northern part. Details of the Belgica mound province are also given in [17] (this volume). A complex grey scale i.e., combination of grey scales varying from lighter to medium is observed within the clustered mound area of seven mounds (mc, having average value of -34 dB within the area marked in figure: 2a). In addition, four isolated mounds having moderately higher backscatter are shown. Table:1 provides dimensional aspects of these mounds along with the mean backscatter values acquired from the shape invariant data. The backscatter level in the mound area is varying from the highest value (-32.20 dB) for the northernmost mound (m1) to the lowest (-33.97 dB) for the mound (m2). Associated medium grey levels though negligibly close to the mound structures may be identified as a shadow zone, and insignificant in the multi-beam backscatter data. No correlation is obtained with the dimensional aspects of the mound and backscatter values from this area. The seafloor in the wider surroundings of the mound cluster shows high backscatter but no further mound occurrences were found there. Thus, the lighter grey scale is not solely due to the existence of mounds but surrounding seabed is also affected. Darker grey scale around -37 dB are seen for the associated background sediment areas. Patchy high backscatter regions having light grey scales (-30 dB) are also observed in this mound dominated

Area code	Number of measurements	Area covered [km ²]	Mean BS (shape invariant) [dB]	Remarks
m1	1531	1.44	-32.20	500m E-W, 850m N-S, Ht 100/15m
m2	1451	1.34	-33.97	500m E-W N-S, Ht 90/20m
m3	3103	3.59	-32.74	800m E-W, 2000m N-S, Ht 90/50m
m4	3185	2.75	-33.88	700m E-W, 1400m N-S, Ht 160/70m
m5	1952	1.74	-37.18	1400m E-W, 1100m N-S, Ht 70/20m
mc	15429	14.67	-34.36	
bm1	967	0.98	-32.80	
bm2	856	1.01	-34.17	
bm3	813	0.88	-35.30	
bm4	1022	1.22	-34.49	
kcm1	9047	8.13	-37.80	
kcm2	15329	15.46	-38.66	Level changed
skc up	11534	11.03	-36.66	
skc low	8268	10.09	-39.47	
ic1	14773	15.54	-39.64	
ic2	22339	29.26	-39.27	
ic3	13001	10.11	-38.40	
gc1-1	3812	7.45	-37.03	
gc1-2	6338	7.82	-38.88	
gc1-3	9120	7.61	-37.31	
gc1-4	5756	6.11	-41.16	
gc4-1	4874	8.68	-36.61	
gc4-2	5271	5.78	-38.28	
gc4-3	4092	3.37	-36.07	Level changed
gc4-4	5004	3.46	-41.70	
gc5-1	9510	7.03	-37.33	
gc5-2	5735	4.65	-37.22	
gc5-3	2365	1.77	-35.35	
gc5-4	1901	1.28	-40.34	

Table 1. Statistical parameters of the areas under study including number of measurements, covered area and mean shape invariant backscatter value (BS). The remarks section gives extension and height of the individual mounds. Ht represents the height of the downslope / upslope side of the mounds.

channel areas. The channels within the seafloor slope closer to mound areas are due to the current scouring which leaves coarser material in the seafloor while sweeping away the fine materials. Parallel examinations of figure 2a and the bathymetry map of [8] around the mound structures indicate directions of coarse grained material flow along the depth contours. Reports about the existence of the seafloor ripples or sediment waves in the mound dominated ridge areas were made which are found to be perpendicular to the surface gradient [18], [19]. Ripple sizes having wavelength up to 100 m and height varying from 1 m to 2 m, are only visible in the Digital Terrain Model analyses (Figure 6a of [8]). ORE Tech side scan sonar (operating frequency of 30 kHz) lines (ORAT 4 and 9) from the Intergovernmental Oceanographic Commission (IOC) initiatives [6] indicates the presence of two suspected barrier reef mounds at the core sampling locations TTR7-AT-19G ($51^{\circ}78.88'N$ and $11^{\circ}48.59'W$) and 20G ($51^{\circ}17.82'N$ and $11^{\circ}41.78'W$) [?]. At TTR7-AT-19G top (0-5 cm) sediments of foraminiferal sand with silt are obtained. Sediment sample descriptions of the TTR7-AT-20G core are found to be similar as TTR7-AT-19G. We could locate barrier reef mound (m5) at sediment sampling location of TR7-AT-19G with low bathymetric height. Backscatter strength at the sediment sampling locations TTR7-AT-19G is lower (-37.76 dB) and corresponds to backscatter of background sediments. The TTR7-AT-20G location is situated on the lower 'terrace' slope, and is not considered for our study. Four buried mound structures of variable sizes occur in the study area having mixed backscatter level varying from -32.80 dB to -35.30 dB for (bm1) to (bm4) (Figure: 2a). The backscatter levels of the buried mounds are comparable with the backscatter level obtained from the mounds. Bathymetry wise a pronounced depression is observed south of the mound province having very high backscatter. The presence of strong backscatter (-30 dB) at the slope in the topographically depressed area indirectly attests the presence of active seafloor current which may be guiding coarse material towards the depressions. Two parallel low backscatter bands showing northeast to southeast orientation extend between $51^{\circ}10'N$ and $51^{\circ}20'N$ and have a width of about 1 km. Though no close link with the bathymetry is seen, but backscatter indicates down-slope currents and sediment transport.

The middle part of the investigation area is characterized by two canyons which cut the generally smooth sloped margin, ending in a rather changeable deeper area (Figure: 2b). 20° steep canyon flanks are observed and the southern canyon has a width of 2 km at the seafloor. Similarly, the northern channel (Kings Channel) shows a variable structure and a mean width of 4 km. We have chosen our study data at the mouth of this channel (kcm1). The second site was chosen slightly away from the channel mouth towards the area indicated as sediment slump (kcm2). The variability in the sediment lithology is observed within the two chosen areas. In general, this area has mixed backscatter level. However, higher backscatter level (-37.80 dB) is seen for the (kcm1) areas compared to the area (kcm2) i.e., -38.66 dB. The presented grey scale levels (Figure: 2b) of the backscatter data can establish the

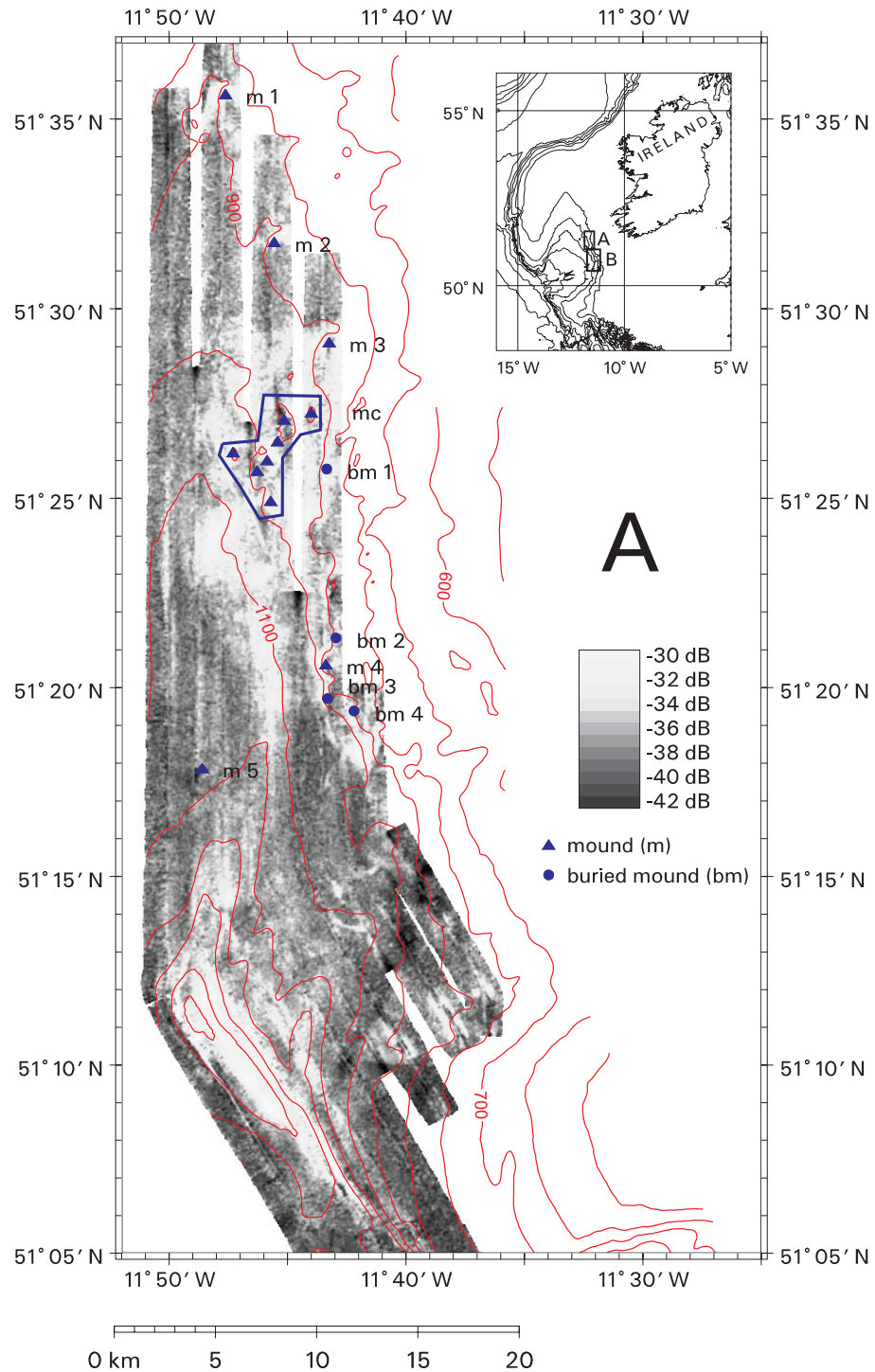
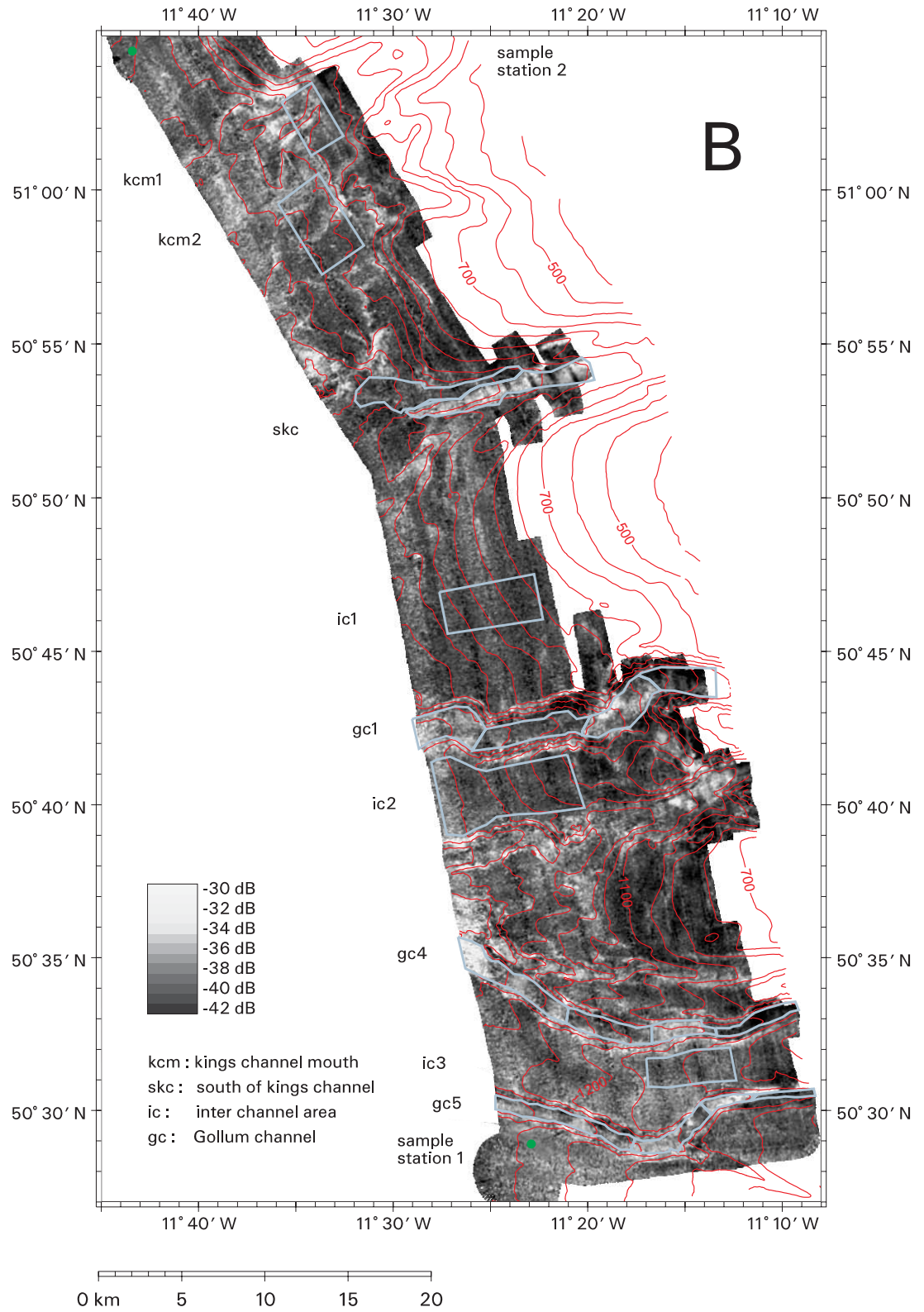


Fig. 2. Backscatter map of the shape invariant backscatter data recorded in the deep sea mode of the Hydrosweep DS-2 multibeam system. 100 m bathymetric contour lines are also accommodating this figure. In figure 2a the locations of the mounds and buried mounds are drawn using triangles and circles respectively. Figure 2b gives the boundaries of the areas used for backscatter analyses.



difference between the areas. In this region, the existence of current generated symmetric seafloor ripple patterns (wavelengths varying from 0.1 m to 0.3 m and height of 2.0 cm to 5.0 cm) affect the seafloor backscatter, which were associated with drop-stones as reported by [5]. However, towards the southern end of the Kings channel, areas devoid of current generated ripples indicate dominant bio-turbidity effects. Dominant fine sand with associated fine materials are reported here. Given grain size distribution indicate the area has 'silty sand' as similar as mound site [2] and [5]. Distinctly different backscatter level variations are seen from the channel sections (skc) top end (-36.66 dB) with respect to the associated lower seafloor channel end (-39.47 dB) towards the southern end of the Kings channel area. Though, exact sediment distribution is unavailable from this area we consider 'silty sand' seafloor like in the Kings channel mouth area (kcm). However the 3 dB fall towards the western side of (skc) suggests significant changes of the seafloor micro roughness in this channel. The Gollum channel system is one of the very few lengthy leveed channel system known from the NW European margin. It is a striking looking tributary system with sinuosity and narrow steep sided channel. The continental seafloor towards the eastern side of this channel system varies between the depth of 400 m to 800 m., whereas for the western side it is observed to be varying up to the 1700m in the study area. The northernmost channel (gc1) of the five channel systems, is the widest and deepest (Figure: 2b). It reaches an incision of about 400 m, whereas other channels have a depth of 200 m. The width of this extreme channel reaches up to the 1.5 km at the bottom compared to the other channels having a width of 1km [8]. Within these channels, various types of the channel proceedings are observed. The northernmost channel shows straight proceedings, whereas two southernmost channels show formidable extent of meandering while proceeding to the southeast side (gc4 and gc5).

[5] had reported about the detailed morphological aspects of the Gollum channel system. According to their observations and understandings (based on the references of [2]), the channel floors having 0.0 m to 0.3 m of thick blanket deposit of flocculant fine grained organic detritus - origin of phytoplankton, and its varying concentration in the channel floor are due to the funnelling into the topographic depression. Sediment beneath the phyto-detritus layer appeared to be monotonous white ooze. All the sediment samples (five stations) from various locations with varying water depth (400 m to 2800 m) are indicative of 'silty clay' sediments: (10% fine sand, 15-20% silt and 70% clay). For present study, backscatter data from three complete channel systems are considered out of the five surveyed channels i.e., northernmost channel (gc1) and channel numbers (gc4) and (gc5) towards the southern end. In view of complexity of the two channels (gc2, and gc3), backscatter data analyses are avoided from these two channels. Interestingly, indications of slope failure is seen in the backscatter plot within the intermediate area of channel systems (gc2 and gc3), which are not being considered for present study. Indication of such slope failure was clearly absent in the bathymetric plot. An examination

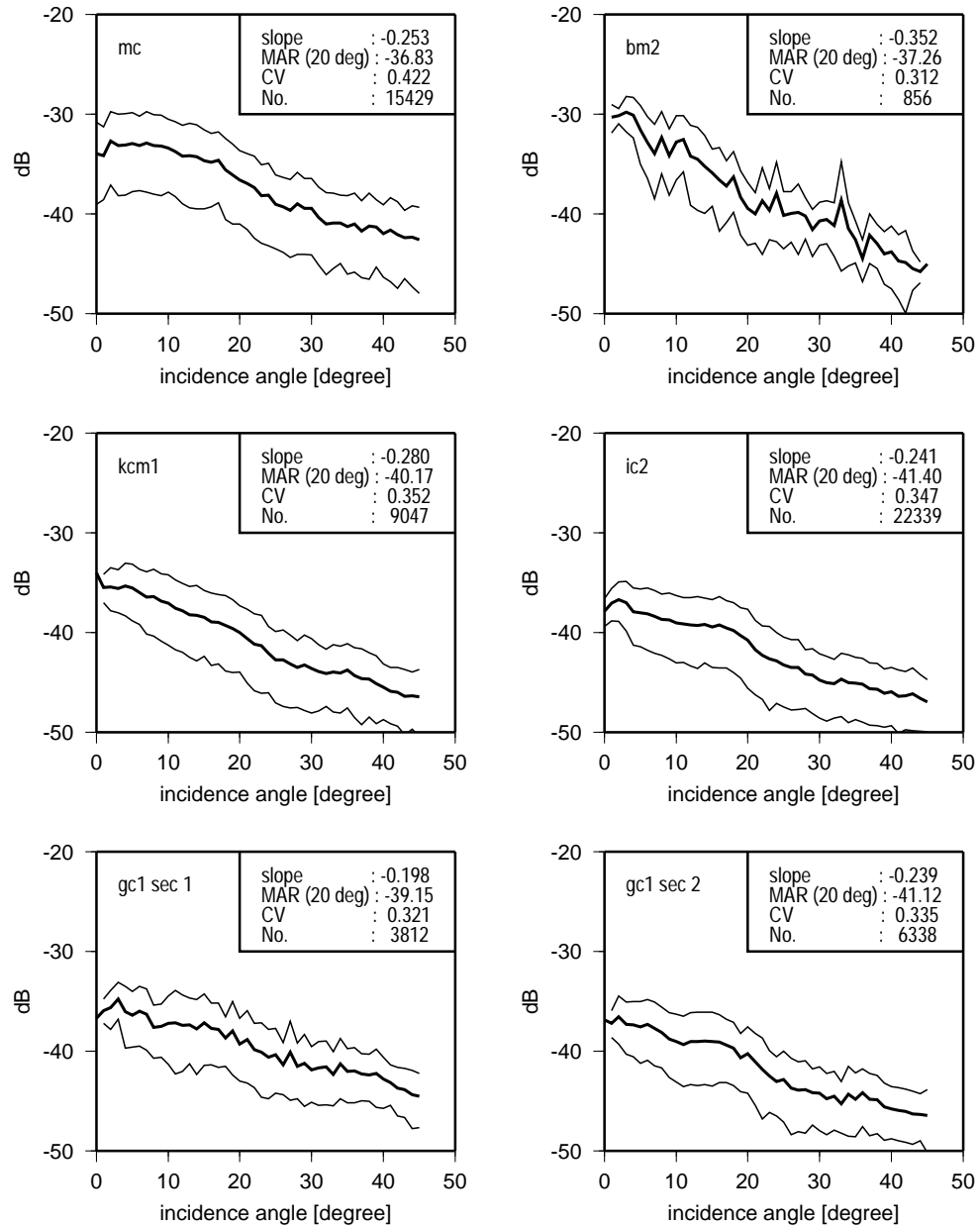


Fig. 3. Mean angular backscatter response (thick lines) and associated standard deviation (thin lines) of six seafloor segments: mound cluster (mc), buried mound (bm2), Kings channel mouth (kcm1), inter channel area (ic2) and two sections of the northernmost Gollum channel (gc1 sec 1, gc1 sec 2). The calculated parameters slope, mean angular response at 20 incidence angle (linear regression fit), coefficient of variation (CV) and number of measurements are given inside the figure box.

of the shape invariant backscatter data (Figure: 2b) for the northernmost steep channel (gc1), four segments are observed in terms of backscatter level variation indicative of sediment lithology. Towards the western end section of this channel (gc1) section 1 shows moderately lighter grey scale (-37.03 dB) followed by the medium grey scale (-38.88 dB) in the channel section 2. then again relatively higher backscatter (-37.31 dB) is observed in section 3. The dark grey i.e., lowest backscatter is observed for the flank section of this channel section 4 (-41.16 dB), having dominant ridge structures. Moderately lighter grey scale in certain parts of the Gollum channel system can be correlated with the presence of the white ooze having stiff gelatinous texture as observed by [5], and is dominant at the sections of the channel where it is constricted. In section 2 of this channel, medium grey level cannot confirm presence or absence of phyto-detritus layer, though the multi-beam data acquisition was conducted during the month of June (2000). Similar ideas may be drawn about the grey scales for the other two channels (gc4 and gc5). For channel (gc4), the backscatter levels are varying from: -36.61 dB, -38.28 dB, -36.07 dB and -41.70 dB for the sections from 1 to 4 respectively. Similar variations are observed within the channel (gc5) also. However, the grey scale variations (sediment lithology) within the channel sections suggest that the chosen segments are fairly homogenous

4 Seafloor Classification Using Angular Backscatter Response - A Semi-empirical Approach

The local variations in the shape of the angular backscatter strength can be determined by estimating 'mean angular backscatter response' with lines corresponding to +/- standard deviations from the mean [11]. Regression fits to such angular backscatter curves from different seafloor areas can be utilized to compare their shape related parameters. The 'slope' of the mean angular backscatter response curve along with the estimation of a predicted backscatter response at a known angle and the average ratio of the standard deviation to the mean i.e., Coefficient of Variation (CV) are important classification parameters. These estimated three parameters are utilized as classification parameters for the present study. The area angular backscatter response curves are computed by averaging the measured backscatter strength values within particular angle bins on linear scale (equation 4 in [11]). Similarly, +/- standard deviations from the average values are also computed using (equation 5). Figure: 3 provides the mean angular variations in backscatter strength with respect to the incidence angle for a specific areas (total six area types): cluster of mounds (mc), buried mound (bm2), channel mouth of the Kings channel system (kcm1), area between the channel 1 and channel 2 (ic2) within the Gollum channel area. Also, similar variations are presented for two adjacent sections (sections 1 and 2) of the Gollum channel (gc1) system seafloor having different textures (Figure: 2b). Distinctly different shape of the backscatter

response patterns are observed for these areas. In order to keep the homogeneity aspects of the data, very close area data were selected around the mound and buried mound area. Due to the limited data amount from buried mound, fluctuations are seen in the mean angular response and standard deviation curves. The estimated standard deviation values from these areas indicate small range of variations within the 3.5 dB, also indicating generally homogeneous seafloor. Predicted mean angular response for the 20° incidence angle (estimated by use of regression fit) is found to be the highest (-34.76 dB) for mound area (m1), and the lowest (-43.19 dB) for the Gollum channel area (gc4). Similarly, the absolute value of the slope for the buried mound areas (bm3) are found to be the highest (0.367) and the lowest for Gollum channel (gc4) section 1 seafloor (0.172) respectively. The coefficient of variation (CV) is comparatively higher (0.422) for clustered mound (mc) area and the lowest (0.312) for the buried mound area (bm2). The estimated values are provided within figure:3 for different Porcupine Seabight area seafloor types, which gives enough ground to differentiate among seafloor facies. However, inclusion of more data from different facies may provide an useful trend of the parameters for a specific type of seafloor in the study area.

Area	BS (20 °) [dB]	Slope [dB /deg.]	CV	Remark
Mound	-34.76 to -39.40	-0.219 to -0.291	0.333 to 0.422	Highest BS and highest CV of all
Buried mound	-35.68 to -38.30	-0.185 to -0.362	0.312 to 0.367	Highest slope of all
Inter channel	-40.38 to -41.79	-0.229 to -0.254	0.336 to 0.349	-
Channel	-37.12 to -43.19	-0.172 to -0.258	0.312 to 0.392	Lowest slope and lowest CV of all

Table 2. Parameters of the different facies in the study area, backscatter strength at 20 degrees (linear regression fit), slope (linear regression fit), coefficient of variation (CV). Remark section gives specific aspects of the facies.

Table: 2 presents estimated parameters for different acoustic facies from the Porcupine Seabight. Most of the parameters are found to be dominant for the mound, buried mound and channel facies. Comparatively, limited activities may be underlined from the inter channel area seafloor data.

In figure:4 , three inter parameter relationship plots for mound, buried mound, Kings channel mouth seafloor, Gollum channel seafloor, and inter channel areas are provided. Figure: 4a provides a scatter plot between the slope versus a predicted backscatter value at 20° (regression fit) for all the locations. Overall, a moderate correlation among slope and predicted backscatter at 20° is seen among the data from seafloor areas of the Porcupine Seabight. As already explained, the predicted 20° degree angular backscatter is estimated by means of regression fit to the mean angular backscatter response curves following the methods given by [1]. This value is somewhat different from the average angular backscatter strength. We have estimated a cor-

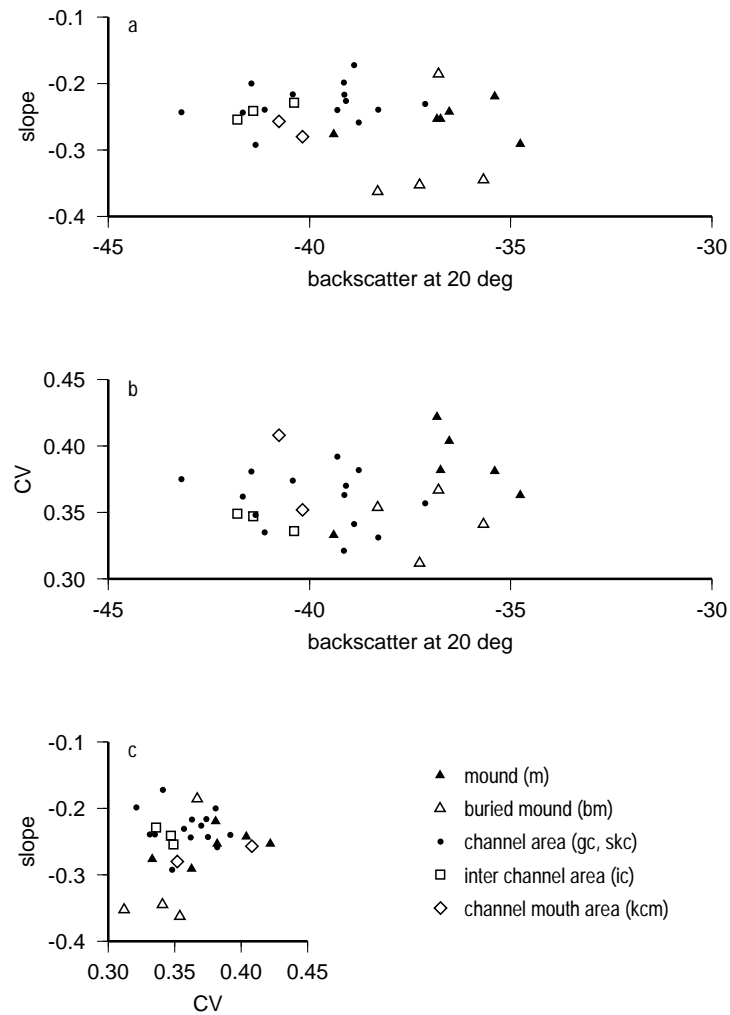


Fig. 4. Statistical characteristics of the analysed seafloor segments. Figure 4a shows the slope of the linear regression fit of the backscatter data versus the backscatter strength (linear regression fit) at 20 degrees. Figure 4b shows the coefficient of variation (CV) versus backscatter strength at 20 degrees (linear regression fit) and the slope of the linear regression fit of the backscatter data versus the CV is shown in Figure 4c.

relation coefficient between the average backscatter strength and predicted backscatter values at 20° for entire data sets. 97.5% correlation is obtained which indicates that the estimated 20° predicted backscatter response can be an alternative to the mean angular backscattering strength at least for our data. Within a limited changes of a slope values, variations in the 20° backscatter response is dominant for the Gollum channel seafloor which is indicative of a strong change of channel seafloor backscatter. Similarly, dominant variations of backscatter response is seen for generally higher slopes of the buried mound. However, for carbonate mounds (higher backscatter and moderate slope), and inter-channel seafloor areas (ic1-ic3) (low backscatter and moderate slope) data clusters were found to be localized within a very closed areas. For the cluster of seven mounds, the slope and 20° predicted backscatter values are in accordance with the other isolated mound data. No significant parametric variations are observed between the Kings channel mouth areas (kcm1 and kcm2), whereas for other two data points from the channel system (skc) south of the King channel indicate higher variations. The significant changes of the backscatter values within a limited slope values for the Gollum channel seafloor may indicate a presence or absence of a seafloor material contributing towards the change. Occasional presence of white ooze within the channel seafloor is well correlated with the backscatter, however, cannot be connected with the phyto-detritus layer within the Gollum channel seafloor [2]. Figure: 4b provides a plot between the CV with respect to the predicted backscatter values at the 20° incidence angles. CV values are found to be decreasing with respect to the increase in the 20° backscatter response for mound area data (a fairly good correlation). For buried mound area, no such relation is seen i.e., CV is independent to the backscatter response. For Gollum channel area seafloor, higher variations of the backscatter responses are found to be unrelated with the CV. Though very limited sites are available from the inter channel areas, but a very negligible fall in CV is seen with the backscatter response. On the whole, we surmise that a moderate correlation among the CV and 20° predicted backscatter is observed for total dataset. Figure: 4c presents a plot between the CV versus slopes. No correlation is observed between these two parameters when entire dataset was considered. For mound and buried mound areas, moderate and fairly good correlation is seen respectively. Within the channel seafloor, poor correlation is observed between the CV and slope parameters. Overall, the slope of the backscatter curves does not show significant change for various seafloor regimes within the Porcupine Seabight.

5 Conclusion

In this work, an analyses of the multi-beam angular backscatter data acquired from the eastern slope of the Porcupine Seabight area are carried out. Processing of the angular backscatter data using NRGCOR software is made for

twenty-nine locations to classify different geological provinces like: carbonate mounds, buried mounds, seafloor channels, and inter channel areas from. A detailed methodology is developed to produce shape invariant (normalized) angular backscatter map to clarify different seafloor sediment lithological aspects. Such presentation has advantage above the raw angular backscatter data since the impact of the incidence angle is removed. The presented shape invariant backscatter map possesses 12 dB dynamic range in terms of grey scale and reflects the lithology of various seafloor features. Clear distinction is seen between the mound (Belgica province) dominated northern side and the Gollum channel seafloor from the southern end of the site. A qualitative analyses of the calculated mean backscatter values i.e., grey scale levels, utilizing shape invariant backscatter data generally indicate backscatter values are highest (lighter grey scale) from the mound areas followed by buried mounds. The backscatter distribution also shows that mound structures not only impact their immediate vicinity, but also the wider surroundings illustrate mound-typical backscatter values (grey scale). However mound related backscatter patterns only exist within the depth range of the mounds. Patchy backscatter variations at 'off mound' locations might correlate with inhomogeneous occurrences of corals in mound areas [7]. Reported contour currents are also supported by the backscatter data. High backscatter around the mounds was also stated by (side-scan, 30 kHz) [7] however, by means of multi-beam backscatter data analyses the main part of the margin was covered. The backscatter values are the lowest from the inter channel areas (lowest grey scale level). Though moderate backscatter values (medium grey level) are observed from Gollum and Kings channel data, but data show significant variability within the channel seafloor provinces. The segmentation of the channel seafloor provinces are made based on the computed grey scale levels for present analyses as well as further studies based on the angular backscatter strength.

The application of the semi-empirical approach employed to the angular backscatter data provides three major parameters to classify the four major seafloor provinces of the Porcupine Seabight seafloor. Implementation involves the shape, variance, and magnitude of the angular response applied to the measured multi-beam angular backscatter strength data and provides effective classification and comparisons. The predicted backscatter response at 20° dB is the highest for the mound areas. The Coefficient of variation (CV) of the mean backscatter response is also the highest for the mound areas. This indicates higher seafloor roughness compared to the surrounding sediments. However, reduced volume roughness is also expected in the mound associated areas. Interestingly, the slope values are found to be the highest for the buried mound area. However, for channel seafloor of moderate backscatter response presents the lowest slope and the CV values. Interestingly, a critical examination of the inter-channel areas indicates less variability within the estimated four parameters.

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