Acoustic Backscattering Properties of Polymetallic Nodules from the Indian Ocean Basin: Results from a Laboratory Measurement

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***Abstract*—The abundance of deep-sea polymetallic nodules (PMN) can be assessed effectively using acoustic backscatter data. Controlled experiments can help us understand this capability in greater detail enabling us to optimize the sonar operating parameters for better performance. However, it is difficult to obtain PMN from deep-sea regions in sufficient quantities to study them in controlled conditions. We explore the possibility of replacing these PMN with artificial nodules by comparing the acoustic backscatter intensities of artificial nodules and PMN from the Indian Ocean Basin in a laboratory experiment. Results from our laboratory measurements reveal that the backscatter intensity from a bentonite sediment layer covered with PMN/artificial nodules, is significantly higher than returns from bentonite with no nodule coverage. Furthermore the intensity of acoustic backscatter from artificial nodules matches that of actual PMN. This indicates that for future studies, we can use these artificial nodules as proxies in place of real PMN to perform initial acoustic testing.**

***Index Terms*—Indian Ocean Basin; Polymetallic nodules; Multibeam imaging sonar**

I. Introduction

Polymetallic nodules (PMN) are found in large quantities in the deep-sea regions of the major oceans of the world. These PMN consist of metals of high commercial value such as manganese, nickel, cobalt and copper. The occurrence of PMN across these oceans has been well-studied [1]–[3]. As studies have reported that the distribution of PMN on the deep-sea floor is not uniform [2], [4]. Hence, in order to get a full understanding of nodule coverage in these regions for prospecting purposes, there is a need for cost-effective PMN estimation techniques that are capable of surveying large expanses of seabed.

Initial methods developed to estimate the coverage of PMN have been highly labour and time-intensive [5], [6]. Some quantification methods rely on box-corer sampling and optical images of the seabed captured using a camera mounted on an autonomous underwater vehicle [7]. Recent methods utilize underwater acoustic equipment that have a wider area of coverage. Several studies have shown a qualitative relationship between the acoustic returns of the sidescan sonar and the abundance of PMN [8], [9]. In our previous work, we used a dataset of sidescan sonar seabed backscatter images collected from the Clarion-Clipperton Fracture Zone to successfully formulate a data-driven model for PMN abundance estimation [10]. Apart from sidescan sonar, multibeam imaging sonar (MBIS) could also be an effective method to quantify PMN acoustically [11].

Controlled experiments on PMN using such acoustic equipment could shed light on the physics of how these methods work. By establishing a better understanding of these detailed workings, we will be able to optimize the equipment's operating parameters in order to get maximum information

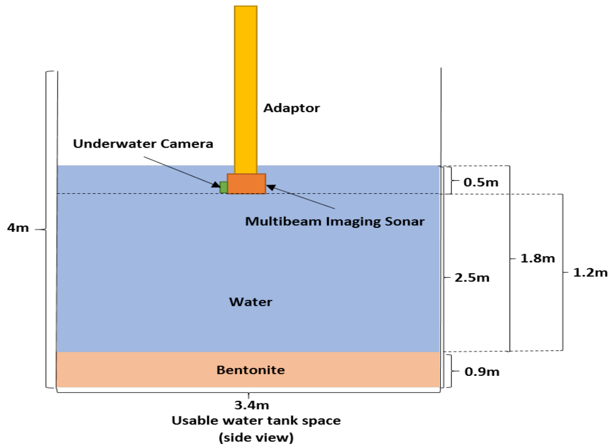

Fig. 1. Cross-section of test tank used in controlled backscatter experiments. The MBIS and camera are mounted on a pole, pointing downward towards the bentonite bed, which may be placed with PMN/artificial nodules of varying nodule densities and distribution.

during underwater surveys. However, PMN from deep-sea regions are difficult to obtain in sufficient quantities to be studied in controlled laboratory setups. In the face of this limitation, using suitable proxies for these PMN could help us test our acoustic surveying methods as a first-step validation. Essentially, the acoustic backscatter properties of PMN can be attributed to their physical properties such as composition, hardness, surface roughness and size. If we are able to use proxies which closely match these physical properties, we can pre-test our acoustic techniques on them before deploying them in field trials.

In this study, we investigate the acoustic backscatter from both PMN collected from the Indian Basin Ocean, as well as artificial nodules, all within a controlled testing tank environment. We compare the backscatter of the artificial nodules against that of the real ones, and assess whether we can substitute the real PMN with artificial nodules for future acoustic testing prior to deployment in deep-water regions. In addition, through this study we also assess whether MBIS backscatter data collected using a particular operating frequency yields acoustic information on the PMN abundance in deep-sea regions.

The paper is organized as follows. In section II, we describe the collection of data via our controlled lab experiment. Section III presents details of how the data is processed, and section IV presents the results. Finally, section V concludes the paper.

II. Data Collection

This work was carried out in collaboration with National Institute of Ocean Technology (NIOT). Data were collected using a NIOT's test tank facility in Anna University's Department of Mining Engineering. The test tank setup used in the study is shown in Fig. 1. Sodium bentonite, a substance that makes up the sediment in deep-sea regions [5], was mixed in its dry powdery form along with water to obtain a clay-like consistency to a swelling pressure of approximately $2.5\,\mathrm{kPa}$. This mix was laid along the entire length of the tank bottom to a depth of $0.9\,\mathrm{m}$ as a proxy for the seabed in deep-sea regions where PMN are usually found.

The acoustic system used in this study was a Tritech MBIS operating at a frequency of $720\,\mathrm{kHz}$ with a swath of $120\,^{\circ}$ and a vertical beamwidth of $20\,^{\circ}$. The MBIS was attached to a holding adaptor and positioned $0.5\,\mathrm{m}$ below the water surface and $1.2\,\mathrm{m}$ above the bentonite layer. A video camera was also attached to the holding adaptor providing an optical foot print of the area being imaged by the MBIS during the experiment.

The artificial nodules used in this study were made using clay and sawdust. These were manufactured by subjecting these mixtures to air-curing process and subsequent firing in the kiln to achieve the density, hardness, and an aggregate impact test index similar to that of an actual PMN [5].

The tank bottom was divided into 11 areas, each of size $3.4\,\mathrm{m} \times 0.75\,\mathrm{m}$. In each area, PMN and artificial nodules were placed onto the bentonite layer in varying distribution as shown in Fig. 2. There was some separation between sections, calculated based on the MBIS's vertical beamwidth specification. This ensured that the MBIS did not capture acoustic backscatter data from neighbouring sections when it was positioned in the middle of a particular section, as shown in the camera image in Fig. 3. In addition, small reflective strips were placed at intervals of $1\,\mathrm{m}$ on the bentonite surface. This facilitated position-tracking of the MBIS's insonified area via the optical camera as it traversed along the length of the tank.

The center of each section was insonified by the MBIS for 10 seconds and data were collected for a comparative study of acoustic backscatter from different areas.

III. Data Processing And Analysis Method

All MBIS backscatter data collected are of binary format that are processed into sectorial images of $1\,\mathrm{cm}$ pixel resolution with 256 beams and a swath of $120\,^{\circ}$ as shown in Fig. 4 (a). These sectorial images are converted into grayscale (value range of 0 to 255) as shown in Fig. 4 (b), because we are interested in analyzing the intensity of the backscatter. As the sectorial images are noisy towards the outer region (larger angles), for analysis we only extract images that are within $\pm 20\,^{\circ}$ around the MBIS's vertical, as shown in Fig. 4 (c).

We aim to evaluate the average intensity of returns from the bentonite surface layer where the nodules are placed. The average diameter of PMN/artificial nodules used in the experiment is around $7\,\mathrm{cm}$. They are placed such that approximately $2\,\mathrm{cm}$ of their diameter is buried in the bentonite layer. Thus, for areas with PMN/artificial nodules, we extract and evaluate pixels starting from the top exposed part ($5\,\mathrm{cm}$) of the nodules above the bentonite layer, down to $2\,\mathrm{cm}$ below the bentonite surface layer, as shown in Fig. 4 (d). In the areas where there are no nodules atop the bentonite layer, we extract the returns from the top $2\,\mathrm{cm}$ of the bentonite surface for our analysis, as shown in Fig. 4 (e).

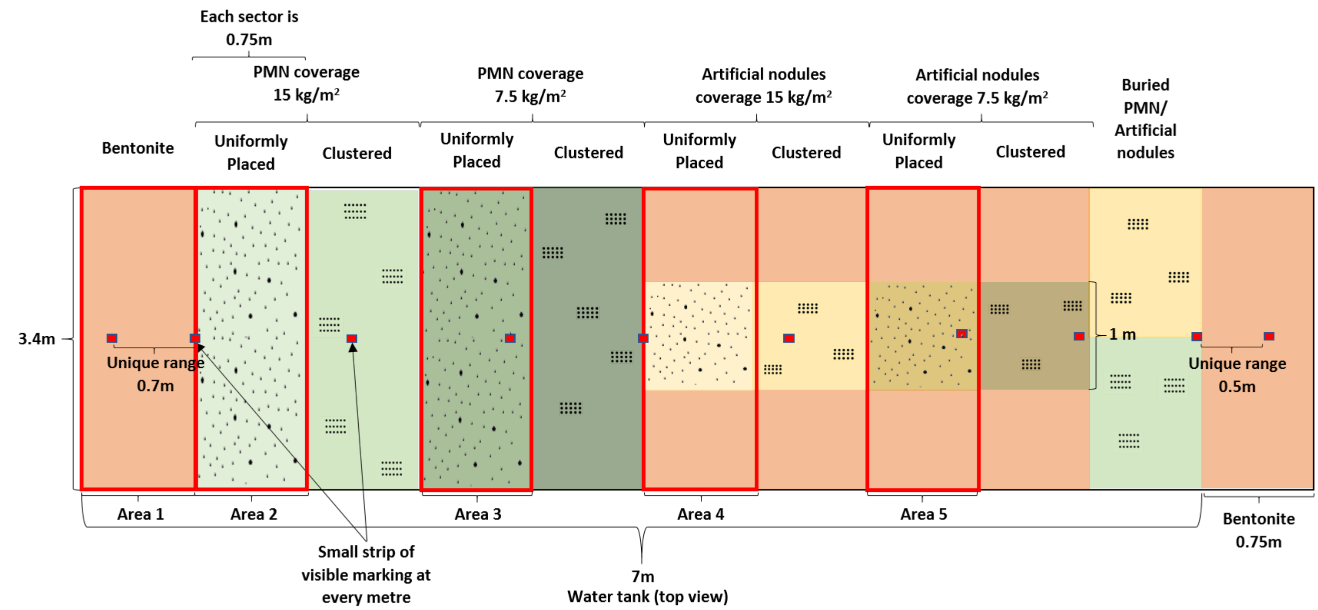

Fig. 2. Overview layout of PMN and artificial nodules placed within the testing tank.

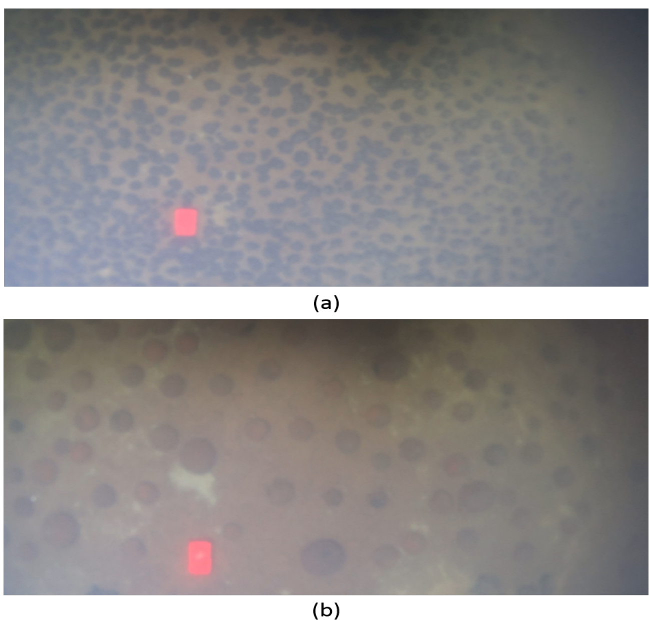

Fig. 3. (a) Photograph showing the MBIS insonified area of bentonite surface with $15\,\mathrm{kg/m^2}$ PMN density coverage. (b) Photograph showing MBIS insonified area of bentonite surface with $15\,\mathrm{kg/m^2}$ artificial nodules density coverage.

The reflective strips placed periodically on top of the bentonite layer yielded high backscatter, which manifested as outliers in the backscatter data. These outlier returns from the reflective strips are removed before calculating the mean intensity of the extracted pixels of the top of the bentonite/nodules from the processed backscatter data.

The rationale for extracting a different width of MBIS data for processing in the case of the bentonite-only area can be explained through one of our controlled experiments, shown in Fig. 5 (a) and (b). From the area of interest shown within the red circle in Fig. 5 (a), it can be seen that the pixels populating the area above the bentonite surface layer represent empty space (a grayscale of value of almost 0 in terms of intensity returns), whereas from the area of interest shown within the red circle in Fig. 5 (b), the presence of PMN lead to non-zero values for pixels in the area above the bentonite surface layer. In practical applications, since acoustic data is usually processed from the top-most point where there are visible returns, we choose to extract 2 cm from the top in areas where there is only bentonite.

TABLE I
CALCULATED MEAN INTENSITY OF PROCESSED MBIS BACKSCATTER IMAGES COLLECTED FROM SELECTED TANK AREAS. THE MEAN INTENSITY IS CALCULATED FROM THE EXTRACTED PIXEL STRIPS (WITH A GRAYSCALE RANGE VALUE OF 0 TO 255) AS SHOWN IN FIG. 4 (D) AND (E).

Area	Area Description	Mean Intensity
1	Bentonite layer with no PMN/artificial nodules	20.2
2	$15\,\mathrm{kg/m^2}$ PMN uniformly placed	46.9
3	$7.5\,\mathrm{kg/m^2}$ PMN uniformly placed	33.5
4	$15\,\mathrm{kg/m^2}$ Artificial nodules uniformly placed	33.5
5	$7.5\,\mathrm{kg/m^2}$ Artificial nodules uniformly placed	33.8

IV. RESULTS AND DISCUSSION

The mean intensities for the selected areas of interest are tabulated in Table I. It can be seen that the mean intensity of acoustic returns from the area with only bentonite

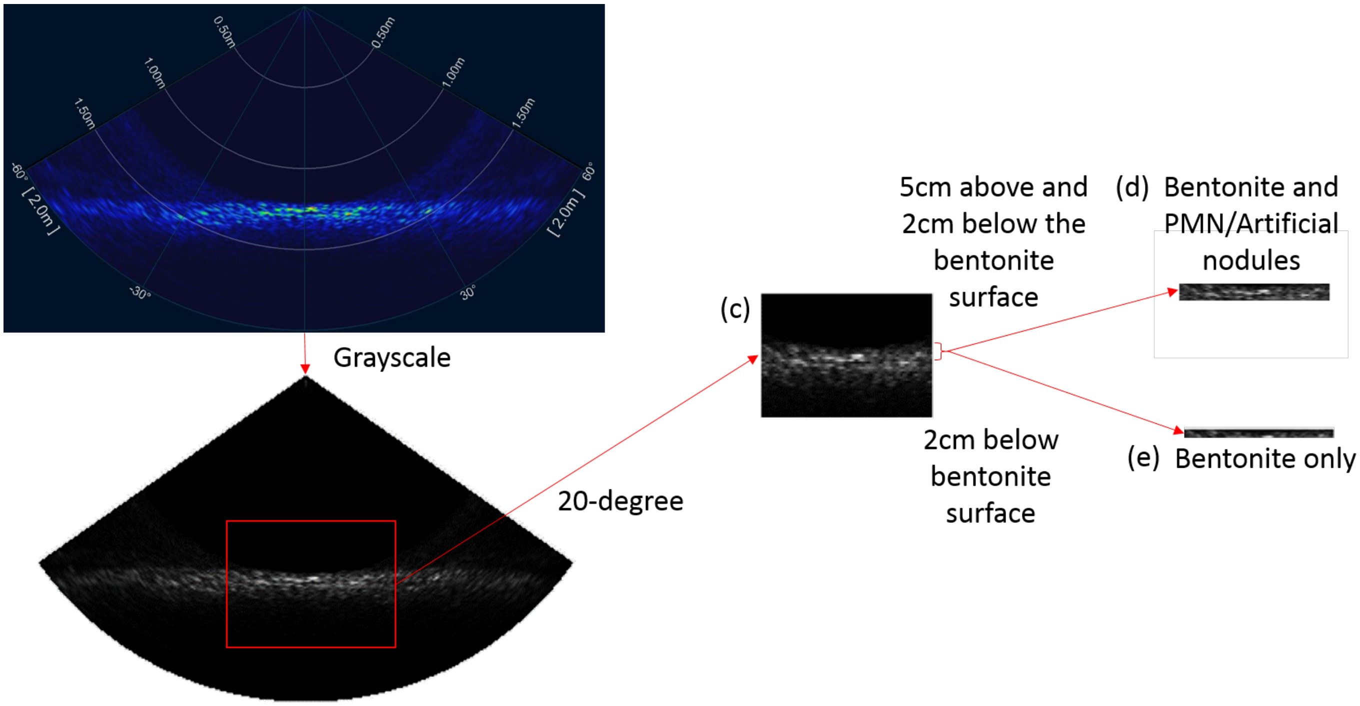

Fig. 4. Overview of steps involved in the processing of the MBIS backscatter images. (a) A 120° swath MBIS backscatter image. (b) Grayscale version of MBIS backscatter image. (c) A swath of $\pm 20^\circ$ around the MBIS's vertical is extracted for further analysis. (d) Pixel strips extracted for analysis, for regions with only bentonite. (e) Pixel strips extracted for analysis, for regions where nodules were placed on the bentonite layer.

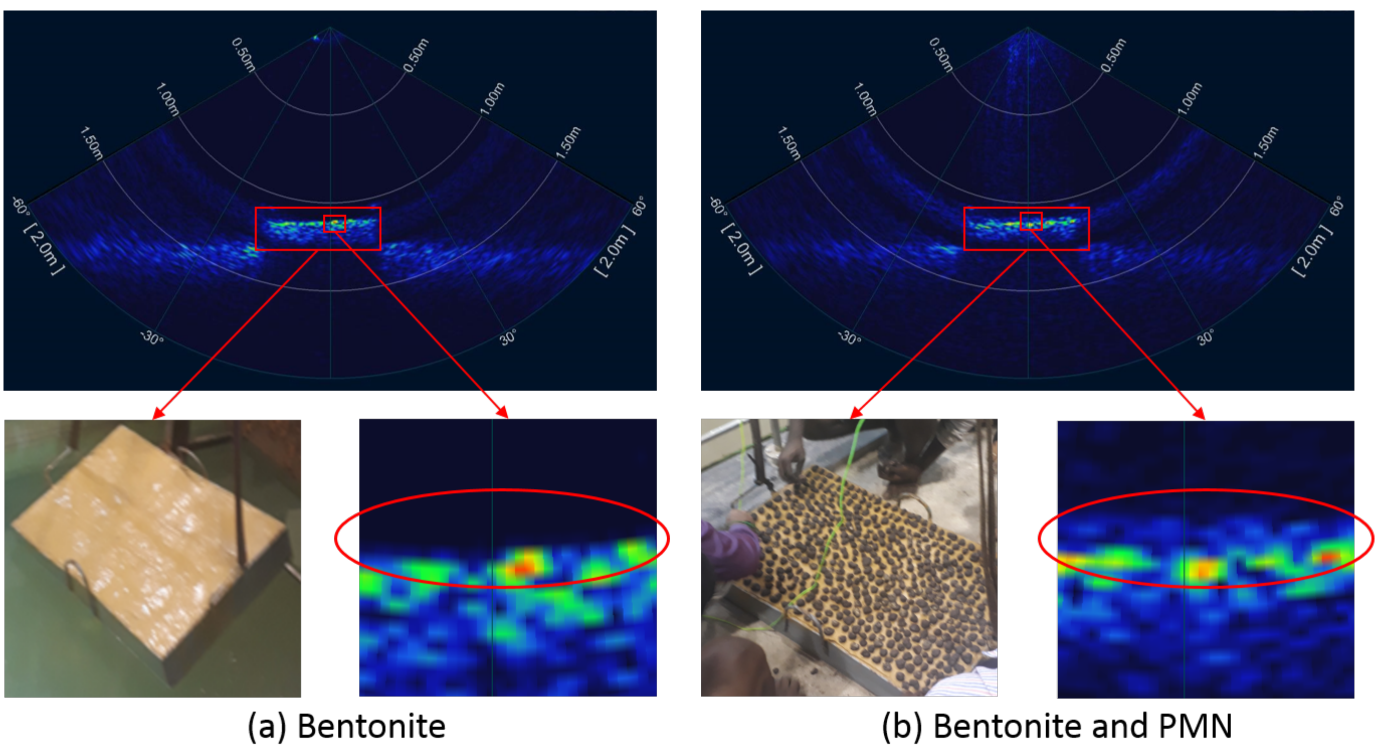

Fig. 5. A controlled experiment to ascertain that the MBIS is capable of distinguishing a bentonite surface with or without PMN coverage. (a) In one test-case, a tray filled with bentonite is lowered onto the tank bottom for MBIS imaging. (b) In a subsequent test-case, PMN are uniformly placed on the tray of bentonite which is lowered onto the tank bottom for MBIS imaging. As highlighted by the red ovals, the presence of PMN can be observed as acoustic returns from the region above the bentonite surface in the MBIS backscatter image, in contrast to (a).

is significantly lower when compared to areas containing PMN/artificial nodules. Furthermore, the mean intensity increases with the abundance of real PMN, as the intensity from the $15\,\mathrm{kg/m^2}$ nodule density area is greater than that of the $7.5\,\mathrm{kg/m^2}$ nodule density area. This indicates that MBIS backscatter images contain sufficient information which can aid PMN abundance estimation. It could potentially replace or supplement existing sidescan sonar information in our data-driven approach, and help improve its PMN abundance estimation performance [10].

The results also showed that there is a similarity in mean intensity between area distributed with PMN and artificial nodules, especially in the case where the abundance is $7.5\,\mathrm{kg/m^2}$. A difference in mean intensity is observed between $15\,\mathrm{kg/m^2}$ nodule density areas of uniformly placed PMN and artificial nodules. This is because the uniformly placed artificial nodules are of comparatively larger diameter, causing the artificial nodules to occupy an overall smaller coverage area when compared to the distribution of PMN in the $15\,\mathrm{kg/m^2}$ area as shown in Figure. 3 (a) and (b). This resulted in a lower mean intensity due to the additional empty space (grayscale value of 0 in intensity returns) found in between the artificial nodules.

Nevertheless, the intensity from both the areas with some artificial nodule coverage is significantly higher than that from bentonite area with no nodule coverage. These show that we can at least partly address the unavailability of sufficient quantity of PMN from deep-sea regions for laboratory based testing by using artificial nodules as proxies.

During the experiment, 300 frames of MBIS backscatter images are collected from each area. The intensity boxplots for images from selected areas, corresponding to the values shown in Table I are shown in Fig. 6. From the boxplots of these selected 5 areas, it can be seen that there is an insignificant amount of mean intensity variability from each of these areas, showing the reliability of the data collected for our analysis. In addition, these boxplots also reaffirmed the results that the mean intensity of acoustic returns from bentonite-only area is lower compared to areas with PMN/artificial nodules.

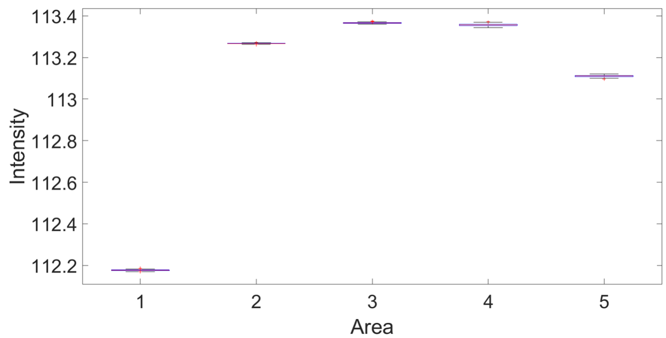

Fig. 6. Boxplots showing the mean intensity from 300 frames of 120 ° swath MBIS backscatter images from selected tank areas 1 to 5 as shown in Fig. 2.

V. Conclusion

In this work, we collected and analyzed acoustic backscatter returns from nodules in a laboratory setting. We compared backscatter from areas with no nodule coverage, or different levels of coverage of PMN/artificial nodules. We observed that:

- MBIS backscatter data allows us to distinguish whether the bentonite region is covered with PMN or not, from the intensity of the returns alone. The intensity increases with increase in abundance. This can potentially be used as additional information to estimate PMN abundance in deep-sea regions. One way of doing this could be by using a data-driven approach to assess the abundance [10]. Looking at further statistics of the backscatter and its correlation to PMN coverage may yield further insights on how MBIS can be used to assess PMN properties.
- The acoustic backscatter intensity of sediment regions covered by artificial nodules partly matches that with real PMN, and is distinctly higher than backscatter intensity from sediment regions with no nodule coverage. This means we can substitute PMN with artificial nodules for testing acoustic equipment prior to field deployment.

Future works include subjecting the MBIS backscatter data to a machine-learning method that learns any underlying relationship patterns between different areas of varying nodule density.

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