**Review of Ms No. Bg-2017-506**

Understanding Mn-nodule distribution and related deep-sea mining impacts using AUV-based hydroacoustic sensing and optical observations

By:

Anne Peukert et al.

## *1. General Comments*

In the study presented in this manuscript AUV-based, high-resolution bathymetric data was linked with optical imaging. To my understanding, there are several objectives of this study:

(i) to get information of small-scale changes in seafloor morphology which is a pre-requisite for any future mining operation;

(ii) to get a semi-quantitative assessment of nodule coverage over an area which is larger than from normal TV-sled operations;

(iii) to combine both results in order to analyze the controlling factors of nodule coverage.

There is a second part of the study which deals with a "disturbance experiment" caused by an EBS station. This part of the study reports the extension of a sediment cloud based on the optical imaging of re-settled sediment as well as if there is a controlling influence of the small-scale bathymetry on the distribution of the re-settled sediments.

This is an interesting study mainly because of its small-scale and high-resolution character. The authors showed that there is no clear and simple correlation between any single parameter such as small-scale bathymetry and their derivates, near-bottom currents, sediment thickness and so on, on one side and the manganese nodule coverage/abundance on the other. When looking at the quality of the correlation between the different parameters it becomes rather clear that these correlation coefficients are very poor and can be called semi-quantitative at best. The reason for this poor correlation may be caused by the quality of the image analysis. For instance, Kuhn & Rathke (2017) showed in a study combining seafloor images and box corer data that the Mn nodule coverage (in %) is underestimated up to factor 5 based on image analyses compared to box corer data from the same area. They argue that the activity of both benthic fauna and near-bottom currents are the main reasons for this discrepancy. The authors of this manuscript should take this study by Kuhn & Rathke (2017) into account.

In the presented manuscript there is no information about precision and accuracy of the image analysis approach but this information is necessary and must be included. Moreover, Kuhn & Rathke (2017) showed in their study that a good correlation can be established between coverage data from box corer stations and image analysis for small-sized nodules ($R^2 = 0.645$; mean nodule size < 4cm diameter). However, only a weak and inverse correlation could be found for medium to large-sized nodules ($R^2 = 0.146$; mean nodule size > 4 cm). They showed that larger nodules are fewer in numbers and are covered by sediments to a larger degree. The authors of this study should present information on the mean nodule size and should provide information if they have found a similar correlation.

Despite the semi-quantitative character of the correlation between Mn nodule coverage and bathymetric data the authors show that nodule coverage may be below a certain threshold if the BPI50 > 0, slopes ≤ 1.8° and plan curvature values > -0.02 radians/m (page 11, line 8). A higher coverage instead occurs at steeper slopes (> 1.5°), negative BPI50 values (-200 to 0) and negative plan curvature (< -0.02) interpreted as morphological depressions.

Even if I doubt the absolute number of 12.5 % nodule coverage as the threshold value I still think that the above-mentioned semi-quantitative correlations between nodule coverage and bathymetric parameters are true and important findings of this study. However, more real ground truth data from box corer stations would be necessary to verify the threshold value.

I also wonder if there are any correlations between AUV-based backscatter data (such as BS intensity) and nodule coverage?

Another approach would be to analyze the nodule coverage and the hydroacoustic data based on artificial neural networks or on random forest. Did the authors try these approaches?

The second part of the study is not known from other studies with respect to the small-scale and high resolution (at least to my knowledge). The fact that small-scale morphologic changes play a significant role in controlling the re-settlement of sediments is very interesting and important, even if this correlation also is only semi-quantitative.

What the manuscript generally lacks is real ground-truth data for Mn nodule coverage which can only be obtained from sampling with box corers. Is there any such information from the working area, e.g. from other cruises? I know that the BGR has carried out several expeditions to this area within their exploration campaign.

## *2. Specific Comments*

### Abstract

First sentence: Optical imaging data are no real ground truth data. If they could be linked with nodule coverage/abundance from box corer stations of this area, then one could speak of "ground-truth data". Otherwise, the authors should change this sentence removing the word "ground-truth".

### Nodule coverage vs. nodule abundance

The authors sometimes use the term "nodule abundance" and sometimes "nodule coverage". There is a significant difference between both: abundance means the mass of nodules per area (e.g., in kg/m²) and coverage means the seafloor areal fraction covered by nodules in %. From image analysis only the coverage can be detected and this is what the authors mean in their manuscript (e.g. refer to Fig. 5). Therefore, the authors should only use the term "nodule coverage" in the manuscript.

With respect to the precision and accuracy of the nodule coverage detected from the image analysis I can state the following: The BGR took four box corers more or less parallel and a few hundred meters to the north of the line shown in Fig. 5A. The mean nodule size areas

measured on all nodules from these box corers are: 23 cm², 23 cm², 24 cm² and 20 cm² from west to east. So, the mean nodule size is rather constant in this area and is by factor up to 3.4 higher when measured on real nodules from box corers compared to data from images. To my understanding this discrepancy is the main reason for the poor correlation coefficients and it may be caused by the observation that nodules are covered by sediments to a variable degree. But in images only the part of the nodules not covered by sediments can be analyzed and this may lead to a significant underestimation in both coverage and size of nodules as we can see it in the data presented in this manuscript.

Pit structures

The occurrence of pit structures may not only be restricted to larger depressions as stated on page 8, line 12, but could also be controlled by E-W trending linear structures as Fig. 4C may suggest.

A pit structure was sampled during SO140 with a box corer (station 107KG). There were no nodules on the sediment surface but two nodule layers at greater sediment depth (16 and 32 cm below surface; Kuhn et al., 2015). This contradicts the interpretation of the authors of this study of how larger nodules in the pit structure could have formed (page 18, line 20/21). BGR data suggest that larger nodules have a larger diagenetic fraction and thus should have grown faster. A larger diagenetic fraction, however, is only possible at sites with higher sedimentation rates and/or higher TOC content. A slightly higher sedimentation rate in areas of higher nodule coverage is also discussed by the authors of this study further down in the manuscript (page 18, line 30/31). Moreover, the pit structures are interpreted as sites of higher sedimentation rates (page 18, lines 35ff.). Why should other depressional sites behave differently in terms of the sedimentation regime?

At sites with stronger bottom currents, e.g. at sites where the near-bottom currents are channelized, nodules do have a higher hydrogenetic content and they are generally smaller and occur in higher numbers (BGR data, e.g. Rühlemann et al., 2012).

The discussion on the pit structures on page 19, lines 1-13 is wrong. During cruise SO240 one such pit was sampled with box corer and gravity corer. Pore water chemistry was not different from other sampling sites outside the pits (Kuhn et al., 2015). Moreover, heat flow measurements over such pit structures did not show any temperature anomalies. Therefore, the most likely interpretation of these structures is a type of marine carst caused by a widespread seawater circulation in the basaltic crust underneath the sediments. At sites where faults in the basaltic crust reach into the upper carbonate-bearing sediments seawater which is undersaturated in $CO_3$ moves into and reacts with the sediments causing dissolution of carbonates which in turn leads to the pit-like collapse structures on the seafloor (Kuhn et al., 2017).

Small-scale bathymetry and nodule coverage

Page 8, line 26-27: Figure 4b indicates that there is a steeper slope in sub-area A2 whereas this area is characterized by higher nodule coverage compared to sub-area A1 (Fig. 5B). This is contradictory to the statement given at page 8, line 26-27. Even if in this part of the manuscript ship-based bathymetry is compared with image analysis one should not make a

statement which is already proven uncorrect by other data (here the AUV-based high-res. bathymetry data). I suggest to omit this sentence and to discuss the different results in the discussion section.

Again the correlations provided in Fig. 6 between nodule coverage and several other parameters are very weak to non-existing, except for the median nodule size and the BPI50 in sub-area A2.

The interpretation of the distribution of the nodule coverage presented in Fig. 7 is based on these weak correlations. How does the predicted low coverage from Fig. 7 correspond with the coverage data from the AUV photo survey? Please provide a scatter plot with nodule coverage from image analyses (x-axis) and nodule coverage from the combination of hydro-acoustic data (y-axis).

Sediment plume settling

Page 13, line 30: How was the threshold of 8% nodule coverage as complete blanketing defined? Why not 0%?

Discussion about particles size in a sediment cloud (page 20/21): The assumption of Stoke's law to describe the sinking behavior of the plume particles is incorrect. Flocculation occurs at large-scale as experimental and modelling results from the JPIO project "Mining Impacts" have shown (pers. comm. A. Vink). Thus, the particles sizes should be much larger than 29 µm on average and the sinking velocities should be rather between 0.5 and 3 m/s. These higher sinking velocities may require a plume height greater than 1.6 m…?

Mn nodule growth (page 18-19)

The work of von Stackelberg & Beiersdorf (1991) describes the influence of different parameters on the Mn nodule growth. This work should be taken into account by the authors.

The publication of Knobloch et al. (2017) indicates the importance of the bathymetry and the conditions on the seafloor for Mn nodule formation.

The citation of Mewes et al. (2014) on page 18/19 may not be correct. Mewes et al. (2014) describe that at sites with medium to large-sized nodules a smaller percentage of clay particles have been found in the surface sediments. This may be due to increased activity of near-bottom currents which has removed part of the clay particles. The remaining sediment may have contained a relatively higher proportion of mobilizable Mn which was then available for Mn nodule formation.

*3. Technical Corrections*

Mixing of abundance and coverage throughout the manuscript. Please correct – see above.

Always use the term "ferromanganese nodules" in the text starting with a small letter except at the beginning of sentences.

Pay attention to the correct statement of references, e.g., always use parenthesis within a sentence (cf. page 2, line 7 and at many other lines in the text).

Page 1, line 18: mining operations (no -).

Page 2, line 21: 12 km²

Page 6, line 8/30: data citation is missing

Page 14, line 7: it must read East instead of West

Page 15, line 3: it must read west-facing slope

Page 21, line 36-39: Something is wrong with the grammar

Table A1: AUV MB (Fig. 4, not Fig. 2)

Table A2: What is the difference between mineable ridges and ridges, flat depression and depression, mineable deep depression and deep depression?

Table A3: How are the different classes (mineable versus un-mineable) defined?

Table A6: Why is BPI440st used in this table and not BPI50st?

Page 29, 1st reference: year is missing.

## *4. Cited references*


Knobloch, A., Kuhn, T., Rühlemann, C., Hertweg, T., Zeissler, K.-O., Noack, S. 2017. Predictive mapping of the nodule abundance and mineral resource estimation in the Clarion-Clipperton Zone using artificial neural networks and classical geostatistical methods. In: R. Sharma (Ed.): Deep-Sea Mining: Resource Potential, Technical and Environmental Considerations. *Springer International*, Cham, pp. 189 – 212.

Kuhn, T., Rathke, M. (2017). Report on visual data acquisition in the field and interpretation for SMnN. Deliverable D1.31 of the EU-Project *Blue Mining*. www.bluemining.eu/downloads. BGR Hannover, 34 pp.

Kuhn, T., Versteegh, G.J.M., Villinger, H., Dohrmann, I., Heller, C., Koschinsky, A., Kaul, N., Ritter, S., Wegorzewski, A.V., Kasten, S., 2017c. Widespread seawater circulation in 18–22 Ma oceanic crust: Impact on heat flow and sediment geochemistry. Geology, 45/9: 799-802. https://doi.org/10.1130/G39091.1

Rühlemann, C. and Shipboard Scientific Party (2012). Biodiversity, Geology and Geochemistry of the German and French License Areas for the Exploration of polymetallic Nodules in the Equatorial NE Pacific: BIONOD Cruise Report, Volume 1 German License Area. Hannover, 109 pp.

Von Stackelberg, U., and Beiersdorf, H., 1991, The formation of manganese nodules between the Clarion and Clipperton Fracture-Zones southeast of Hawaii: Marine Geology, v. 98, no. 2-4, p. 411-423.