Geological interpretation of bathymetric and backscatter data

An article by CORINNE MELCHIOR

The Geomar Helmholtz Centre for Ocean Research Kiel carried out two cruises in the eastern equatorial Pacific back in 2015 and collected multibeam, backscatter and sub-bottom data along with other oceanographic information. This work focuses on the evaluation and processing of the echo sounder data sets. Wrong measurements encountered during the data processing are analysed and corrected. A geological classification and interpretation of the seafloor by using the ArcGIS tool »Benthic Terrain Modeler« and an algorithm for Principal Component Analysis and K-means clustering.

Angle Range Analysis | Benthic Terrain Modeler | Principal Component Analysis | K-means classification

Classifying the seafloor helps to identify pit structures lining the seafloor which possibly formed due to dissolutions in the seabed.

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1 Introduction

During the summer of 2015, the German research vessel RV »Sonne« started its cruises SO 242-1 (28th July to 25th August) and SO 242-2 (28th August to 1st October). Both research cruises were executed by the Geomar Helmholtz Centre for Ocean Research Kiel and went to the Eastern equatorial Pacific to the DISCOL (DISturbance and reCOLonization) Experimental Area where in the late 1980s a test dredging in order to a long term observation of the rehabilitation of the seafloor after a human impact has taken place. During the SO 242 cruises lava fields which seem to be of newer origin were discovered. They indicate an at least semi active volcanism. Apart from those lava structures, pockmarks were found in this area.

Based on the provided bathymetric data, the processing and assessment of it as well as the identification and description of geological features building the seafloor are part of this work. Along with that, the seafloor is classified into morphological structures and the seafloor pits are to be described and identified.

2 Study area

The study area is located in the eastern equatorial Pacific, about 400 km off the coast of Peru (Fig. 1). Its depths range from 2,400 m to 4,400 m and the dimensions of the terrain are 84 km in width and 500 km in length. It consists of the DISCOL area in the southwestern part and a total of six transit ways. It is located in the middle of the Nazca Plate where the seafloor is about 25 million years old. Therefore it is even more surprising that lava fields not covered by sediments are found in this area.

3 Data acquisition

The measuring system consisted of a Kongsberg multibeam echo sounder, the EM122 with the ability to record not only the bathymetry data but also backscatter data. The data was recorded with a frequency of 12 kHz and a survey speed of 8 knots within the research area of the DISCOL region. During the transits, the vessel drove at a speed of 12 to 15 knots (Geomar 2015). The sub-bottom data was collected with the Atlas Parasound DS3 which

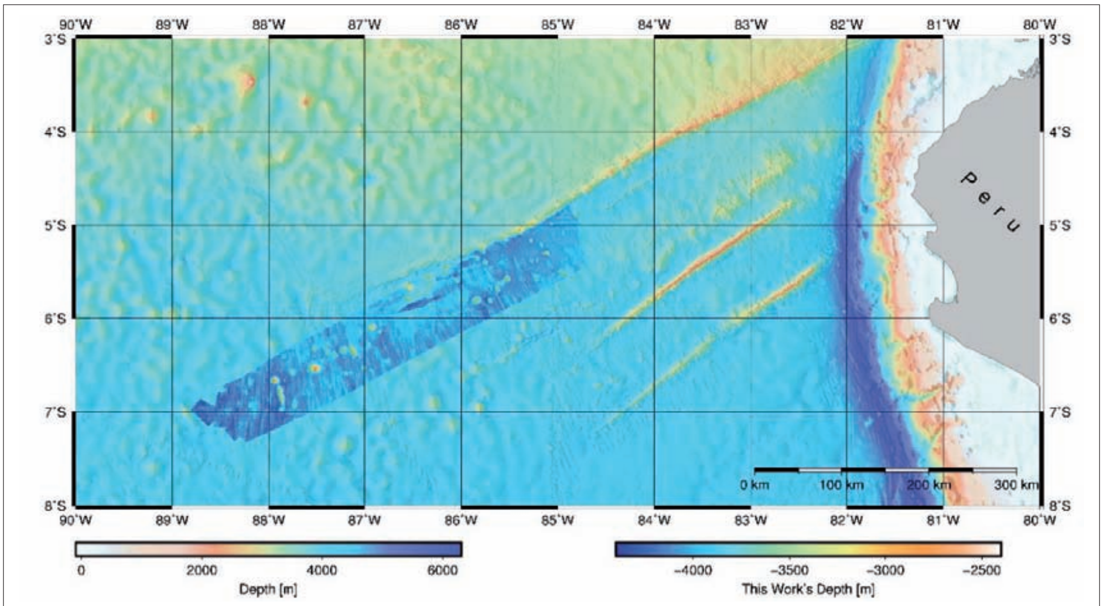


Fig. 1: Overview of the location of the surveyed area (background data: GEBCO 30 arc seconds grid, survey data: 50 m resolution)

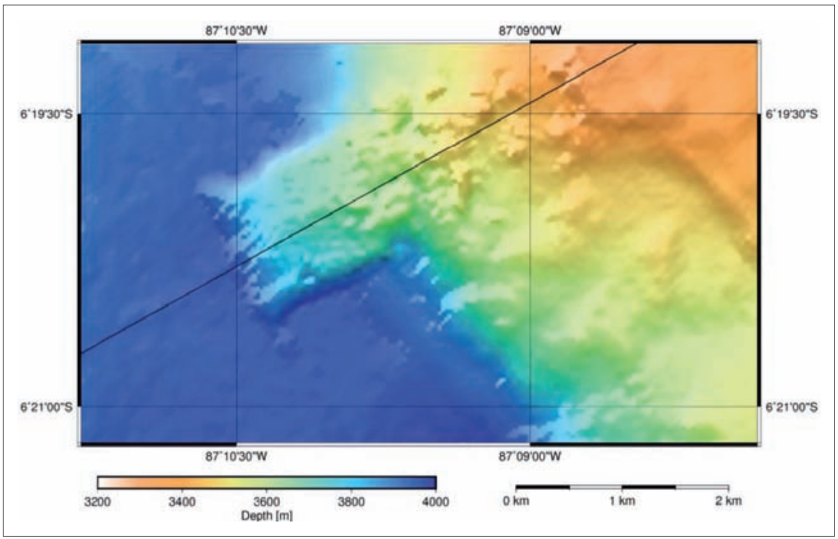


Fig. 2: Downslope error plotted with the ship track in black (grid resolution: 50 m)

is hull-mounted on the RV »Sonne«. It measures with parametric effect, where the primary high frequency was at 18 kHz and the secondary low frequency at 4 kHz. The positioning for all the recorded data was provided by the integrated Seapath MRU-GPS system.

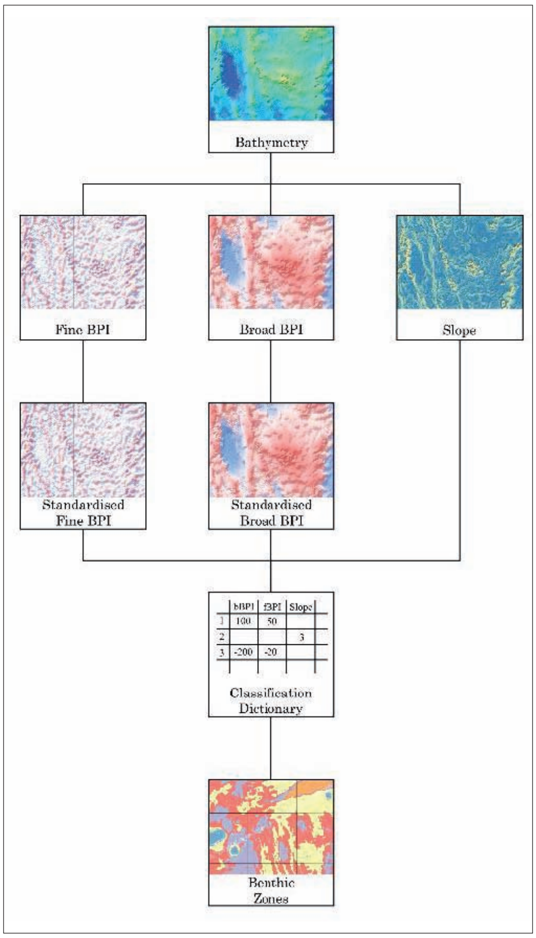
4 Data processing

4.1 Erroneous measurements

Already during the measurements and later in the processing wrong measurements in the outer beams were detected. With a closer look on the data, a pattern can also be observed. It seems that the beams along track alternate in their height, especially visible when lines overlap. Changes in height in the outer beams, especially when the up- and downwards movements are opposed to each other, is an indicator of a roll offset. A closer look on the recorded roll values, the time series plot in the processing software Qimera is used to plot the roll values over time and it shows big variations in the angle measurements. With the software the errors could not be eliminated but only minimised.

Apart from the roll errors, wrong measurements on the down slope of seamounts are observed where the slope seems to be extended (Fig. 2). A plausible origin is not recognisable. It can be assumed that during the data recording process, a logging error of depth and position occurred. Examining the beams in question for those errors gives the result that the wrong echoes are recorded by the inner beams between beam number 183 and 236. The slope extension varies between 2,000 and 6,500 m and the height difference of those wrong measurements compared to the way they should be measured varies between 150 and 230 m. Those errors on the downslope of the seamounts can unfortunately not be corrected but have to be deleted in order not to influence the later occurring computations based on the data.

Fig. 3: Workflow of the classification process within the Benthic Terrain Modeler (according to Wright et al. 2005)



4.2 Backscatter processing

Backscatter images can be created in the Fledermaus Geocoder Tool (FMGT) by QPS. The software provides a tool to extract the intensity of the backscatter data by mosaicking the snippets. It extracts the backscatter data from the processed multibeam data and creates a grid based on a cell size. Additionally, FMGT provides already a classification based on the backscatter data. The Angle Range Analysis (ARA) classifies the seafloor based on the changes of the signal's intensity over the grazing angle. It compares the measured values to mathematical models and based on their similarities the classification takes place (Fonseca et al. 2008). But since a homogeneous seafloor is assumed, the ARA is not suitable for deep sea values. Since no homogeneity is provided over a distance of about 7 km.

4.3 Benthic Terrain Modeler

The Benthic Terrain Modeler – a tool for ArcMap – helps to analyse the terrain and to classify the seafloor. Several computations can be executed. For a seafloor classification, the following terrain computations are needed: slope and standardised Bathymetric Position Indexes (BPI) for a broad radius and a fine radius as well as the bathymetry and a classification dictionary. A schematic of the workflow is shown in Fig. 3.

The Bathymetry Position Index provides information of a location – a raster cell – relative to its surrounding. The surrounding is defined by an inner and outer radius which describe an annulus – a ring-shaped element. The radii are measured

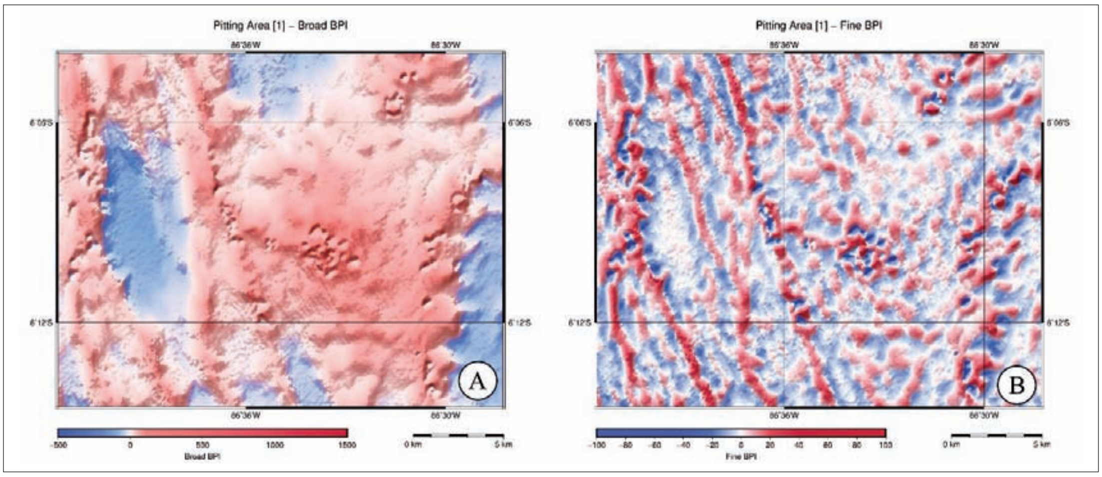


Fig. 4: Broad (A) and fine (B) BPI computations for the example area. Raster resolution: 50 m

from the centre of the centre raster cell. The mean elevation of the values within the annulus is computed and compared to the elevation value in the centre cell. If the centre cell is on a higher elevation than the computed mean value for the surrounding, a positive BPI is assigned, and if it is lower than the computed mean value within the defined radii, a negative BPI will be assigned. In case of a BPI which is close to zero, it is advisable to cross-check the terrain with the slope at this point because it can be that the point is either within a flat area, or a saddle point or on a constant slope (Weiss 2001; Lundblad et al. 2006). There are two BPI computations needed for the seafloor classification, a broad and a fine BPI. The differences are the values of the radii. The usage of the broad BPI is to identify coarse structures on the seafloor, and the fine BPI is for fine and small structures. The difference of the two types of BPIs can be seen in Fig. 4.

The next two elements needed for the BTM classification are the slope and the classification dictionary. The dictionary is the basic component of the BTM. It defines the different classes and their characteristics. It has a table structure where each row corresponds with a class and the columns define the thresholds of the used layer values. The morphological classes for classifying the data set include seamounts, basement highs, plain area as well as small and deep depressions and pits.

The BTM uses the broad and fine BPIs, standardises them for being scale independent, as well as the slope and the bathymetric grid. Each of those layers can have a lower and an upper limit. For setting those thresholds, values must be taken from the single layers by drawing profiles across each layer (see table).

4.4 Principal Component Analysis/ K-means classification

The Principal Component Analysis (PCA) is a method that extracts the main components from a variety of input variables and devides them into fewer variables. It is assumed that the input data are different from each other (Eleftherakis 2013). The output is a reduced data set containing only the principal mostly uncorrelated components. The tool therefore minimises the dimensions and complexity of the input data sets. The output component layers represent the main components. The first component is the strongest one – the one that variates the most. The second output component is the second strongest one and so on. Input layers for the PCA are, additionally to the BPIs, the slope and the bathymetry, the backscatter data and its statistics like the mean, minimum, maximum, the standard deviation and the range of the backscatter. Those are processed with the PCA and the three principal components from the output are taken for further processing. Main contributors of the three principal components are the backscatter standard deviation, mean, the broad bathymetry as well as the slope (Fig. 5).

For classifying the now reduced amount of data, the unsupervised classification method of K-means clustering is used. The algorithm iterates over the data layers until there are clusters which contain features as similar as possible but the clusters themselves are distinguishable from each other as much as possible (Amiri-Simkooei et al. 2011).

4.5 Sub-bottom profiler data processing

The sub-bottom data are mostly used for cross-checking the bathymetry data in regions around

Class	Zone	Broad BPI Lower	Broad BPI Upper	Fine BPI Lower	Fine BPI Upper	Slope Lower	Slope Upper
0	Not defined						
1	Seamounts	170	1250				
2	Basement highs	20	170	–150			
3	Plain area	–40	20	–200		0	3
4	Small depressions	–150	–40				
5	Deep depressions	–340	–150				
6	Pits	–50	170	–3421	150		50

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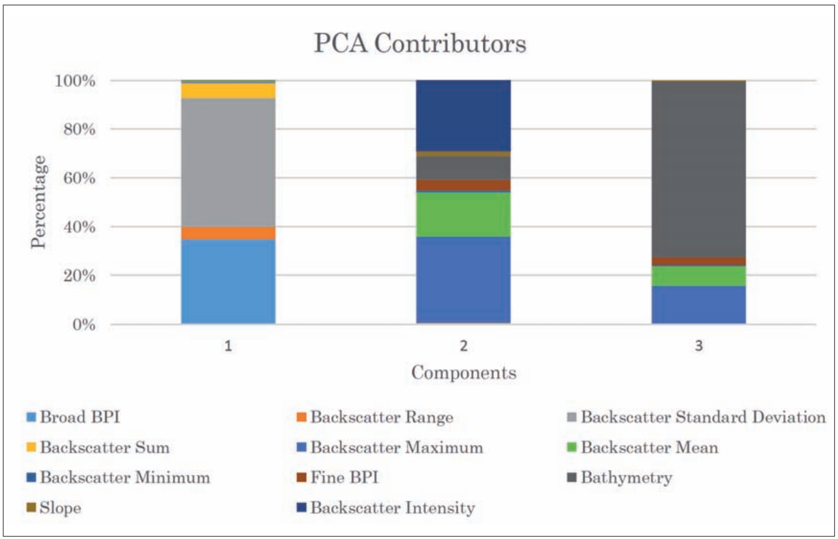

Fig. 5: The composition of the principal components created with the PCA

the pit structures. So, only the data from said areas are taken into account and prepared with the software tool Midwater from the QPS Fledermaus package. Adjustments in the grey scale of the signal's amplitude were made.

5 Results and discussion

5.1 Seafloor classification

The BTM classification delivers an output where six morphological classes have been created. The seamounts are well recognisable. Interesting are the ring-shaped depressions around the seamounts. Seamounts are usually of volcanic origin, it can therefore be that the amount of lava which built the seamount now presses on the seafloor and the weight of the mountain deforms it by pushing down. That seems to be a reasonable explanation since these depressions are of circular shape around the seamounts. Another possibility is the theory that the volume of the magma which once was under the seafloor and then emerged as lava is missing in the ground, so that the volume loss causes these depressions.

The PCA and K-means classification gives a much detailed result, but the broader structures detected in the BTM classification are also recognisable in this classification type. Some of the classes contain similar features like the BTM classification and have therefore the same class name, but others contain different or combined class elements. Hence, there is only one type of depression in the PCA/K-means classification and additional classes like ›Edges‹ and ›Slopes‹ are created. But although the classes are a bit differently shaped the two classification approaches capture similar objects and classifies them similarly, e.g. the ›Seamounts‹ and ›Basement highs‹.

By comparing both of the results – an extract of the two classifications is displayed in Fig. 6 – differences in the level of detail of the resolution of the classes can be seen. The PCA/K-means classification contains much finer structures than the one from the BTM. Especially when it comes to the areas were the pits occur. In the BTM a separate class indicates the pits, whereas in the PCA/K-means classification the pits fall within class consisting of other fine structures. They are though still recognised as features, but apparently to the classification algorithm they are not distinguishable enough from the others to result in a separate class. It seems that those fine structures derive from the fine BPI layer, since this one highlights these structures. But also the noisy outer beams covered above in this paper influence the PCA/K-means classification apparently, since the error could not be eliminated for good.

5.2 Pits

The pits are holes in the seafloor and occur all over the study area. They are also discovered north of the equator by Moore et al. (2007). Already in the bathymetry they are clearly visible. Cross profile samples on a random basis show that they reach down up to several tens of metres and have a diameter of about a few hundred metres. It is no-

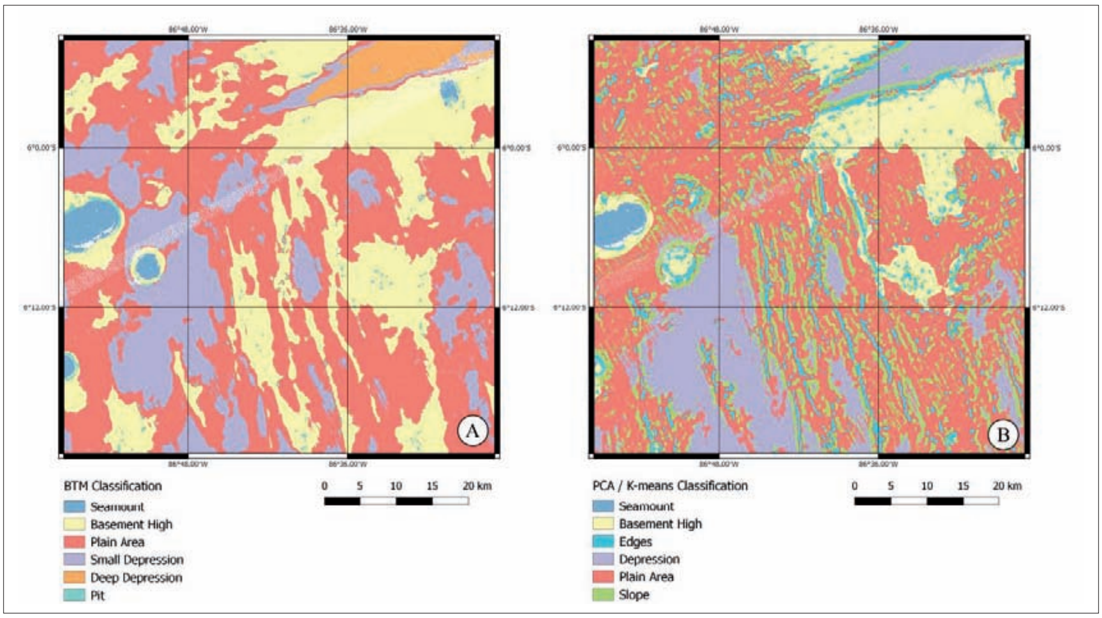

Fig. 6: Comparison of the classification results of the BTM (A) with the PCA/K-means (B) classification

ticeable that they mostly occur on elevations, sometimes long and broad ones, but also on small ridges or crests. Studies over the years show that pockmarks appear in relation to fluid flows in the seabed. And as Judd and Hovland (2007) state, pockmarks are often related to gas seepages or carbonate precipitates. Hydrothermal fluids that are responsible for the pockmark formation have their origin in the interaction of pore fluids and hot rock. It is therefore an indication for volcanism. A possible origin are eruptions of gas, pore water and sediments (Hovland et al. 2005). It is also possible that material under the surface dissolved due to hydrothermal circulation and made the top layers collapse.

The recorded sub-bottom data give a bit of an insight into the sub soil underneath the pits. The data shows that within the pits is nearly no sedimentation whereas next to the basement highs with the pits on top are sinks filled with layered sediments (Fig. 7).

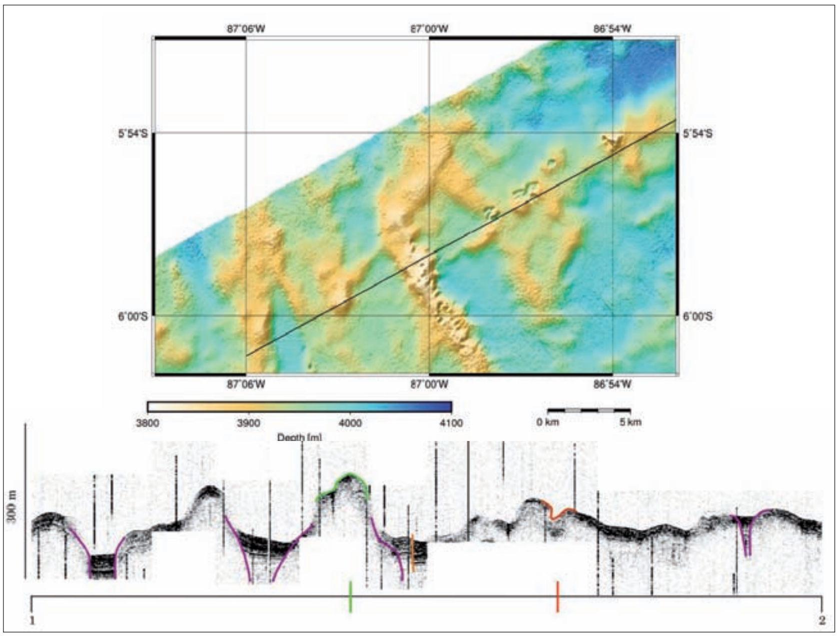

Fig. 7: Bathymetry (top) and sub-bottom profile 1 (below) over some of the pits during the transit (grid resolution top: 50 m, vertical exaggeration below: 18).

5.3 Line features

Features classified by the BTM and the PCA/K-means method are smaller ridges which spread fan-like over the whole area. They are in North-South direction in the southern part of the study area and change their direction slightly to North-East further on in the northern part. Cross-checking their position with the slope computation of the area shows that they are aligned along the maximum slope.

5.4 BTM test run in the CCZ

In order to test the BTM classification and detect the pit structures also in other parts of the Pacific, the same classification steps – including the previously created classification dictionary – were executed with data recorded during the Geomar research cruise SO239 with RV »Sonne« to the Clarion-Cliperton-Zone (CCZ). And the result shows that structures corresponding to the thresholds defined in the dictionary can be detected. Pits occur also in this second data set although their abundance is not as high as in the main data set. But they do occur and also on basement highs like seen in Fig. 8. This actually means that the parameters describing the pits are not tailored to the main data set, but can be applied to other data sets as well. Therefore the characteristics of those pits are similar to each other.

6 Conclusion and outlook

Since the classification methods used in this work were unsupervised ones and therefore only based on the available data the results look promising. It is to be assumed that much more recent volcanic activity is happening in the study area than expected. The pits are an indication for that. It is also remarkable that it is possible to detect such fine structures on the seafloor and classify them. Although the classification dictionary used in BTM classification has been created based on the data in the study area, detecting the same kind of structures in a different area of the Pacific Ocean shows that the pits must have similar characteristics. Maybe it is even possible to find them in other data sets of a similar resolution as well. But still it is not fully explained how these structures came to be. Therefore further research into the origin of the pits might be a point to look into in the future. Heat flow measurements might help to detect the hydrothermal fluids within the seabed. ⚓

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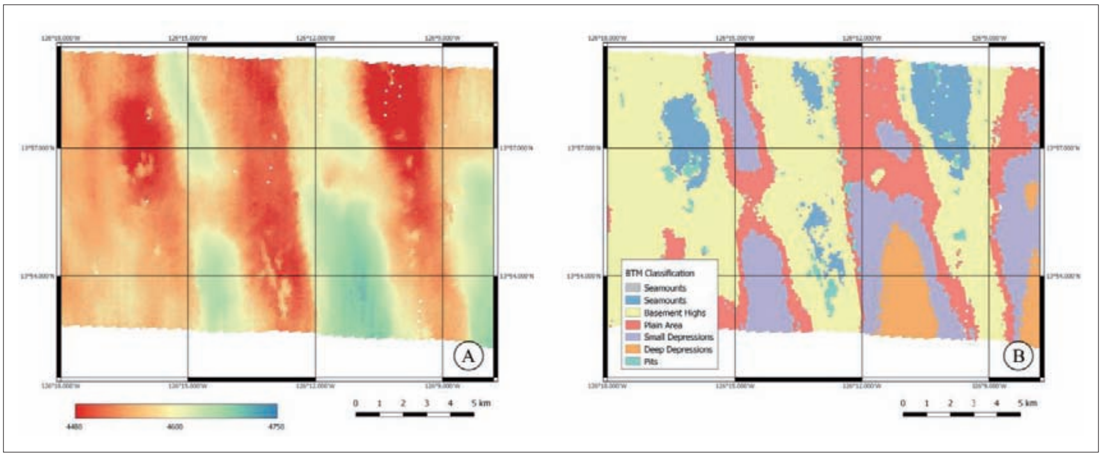

Fig. 8: Extract of the SO239 cruise data. (A) shows the bathymetry, (B) the BTM classification (grid resolution: 120 m