MODULE 5, LESSON 2

METHODS AND TOOLS FOR EXPLORATION FOR POLYMETALLIC NODULES IN THE AREA

LECTURE NOTES

Hello dear colleagues, for this presentation I'd like to give you a brief overview on the methods and tools required for the exploration of polymetallic nodules in the deep ocean. My name is Carsten Rühlemann and I'm head of the marine geology group at BGR, which is a German geological survey based in Hannover. The BGR holds two licenses for the exploration of mineral resources in the deep ocean, one for polymetallic nodules in the Clarion Clipperton zone of the Eastern Pacific Ocean and the other one for massive sulfides in the central Indian Ocean basin.

On the right-hand side of this slide here you can see the most important tool actually for marine exploration, namely a suitable vessel, which is not so easy to find. This photo shows the German research vessel Sonne, which offers excellent conditions for the exploration work, due first of all to its stable position even in rough weather and above all the possibility of deploying our sampling and observation equipment over the side of the ship here right in the middle. This is a position where vessels have the least heave due to the swell or in the bad weather.

The Sonne research vessel is also equipped with numerous cranes, which are also important for handling the equipment. Here's the A-frame and several high-quality laboratories and also state-of-the-art scientific instruments. So only a few vessels worldwide provide these conditions and sometimes it's really difficult for us to charter a ship in case the Sonne is not available.

This map shows all exploration areas that the International Seabed Authority has contracted so far. The international ocean is that one shown here in dark blue and then in light blue are those areas that are the exclusive economic zones of the individual states. In principle, there are three types of deep-sea marine resources that are being explored in the international ocean.

Polymetallic nodules like this one here are found in the Clarion Clipperton zone in the eastern Pacific Ocean, but also in the central Indian Ocean basin. Here also is a contract area from an Indian contractor. The metals of interest shown here, there are manganese, nickel, copper, cobalt and molybdenum and the water depths is where they are found are between 4,000 and 6,000 meters.

Another resource is manganese crust, which grow on seamounts, on the rocks of seamounts. The water depth is between 800 and 2,500 meters and the most massive crusts form on the oldest seamounts and those exist mainly here in the western Pacific Ocean. Both the metals of interest are again manganese, but mainly copper and titanium, also nickel and some various elements.

So finally, massive sulfides, the current exploration licenses for the massive sulfides exist in the North Atlantic Ocean and in the Central Indian and Western Indian Ocean. They occur along mid-ocean spreading ridges, such as here in the Atlantic Ocean, where the tectonic plates of the ocean's crust move apart. There are 19 exploration licenses for polymetallic nodules and 17 of them are located in the Clarion Clipperton zone here and the area marked by the white rectangle is that one that shows a close-up here on this next slide of the CCZ.

The 17 license areas are marked in yellow and the BGR contract area, which consists of two parts here in the east and right in the middle, is highlighted in red. So the areas shown in grey-blue, like this one for example, are reserved areas which can be awarded to applicants from developing countries. The green areas, 13 of them, show areas of particular environmental interest in which neither exploration nor mining is allowed.

The Clarion Clipperton zone has an extension of 5,000 kilometers from west to east and about 1,000 kilometers from north to south from the Clarion fracture zone to the Clipperton fracture zone, the total size is about 5 million square kilometers. Of this, 1.2 million square kilometers have been allocated as license areas and around 2 million square kilometers, the green areas, are protected from mining. That is about 40 percent of the CCZ is not open for mining.

The main task in the exploration of polymetallic nodules are the mapping of the surface topography of the seabed, the measurement of nodule abundances, that is the mass of nodules per square meter, and the geochemistry, which is the metal concentration of the nodules. Based on this information, topography and abundance and metal concentration, we can identify economically interesting areas, which are then investigated in detail.

So extensive environmental studies are also part of the exploration process, but I will not go into this in detail here, as it could be on the scope of my presentation. Furthermore, many contractors are also involved in the development of metallurgical methods for extracting the metals from the manganese nodules, as well as a development of mining technology to be used in the deep sea at the water depths of 4 to 5 kilometers, which means at pressures of 400 to 500 bars. So in the following, I will concentrate on the first three points mentioned in my list, seafloor topography, module abundance, and identification of economically valuable areas.

The most important geological exploration methods are shown in this figure. First of all, a mapping of the seafloor topography must be carried out during which the so-called backscatter signal, here in grey, is recorded together with the information on the asymmetry, which is water depths at certain sites. This kind of overview mapping has a relatively low resolution.

In order to map individual areas of interest at high resolution, deep-towed multi-beam devices or side-scan zoners are towed a few tens of meters above the seafloor. Those tools also use hydroacoustic methods, similar to this one here, multi-beam deployed at the hull of the ship. For detailed investigations of the occurrence or non-occurrence of nodules, we use a video sledge, which is towed a few meters, usually two to four meters above the seabed.

And we use box corers to collect sediment from the seabed with the nodules lying on top. During the hydroacoustic survey, the seabed is mapped along parallel vessel tracks, shown here in black, using a multi-beam echo sounder, which is installed below the hull of the ship. At a water depth of 4,000 meters, one strip is about 15 kilometers wide.

The resolution of the data is between 40 and 100 meters per pixel. So mapping an area of 75,000 square kilometers takes about 20 full-ship days, that is 24 hours per day. And this is what the eastern part of the BGR license area looks like. it covers an area of 60,000 square kilometers, here from west to east it's 300 kilometers. And you can see extensive abyssal plains, which are punctuated by plenty of seamounts here. The seamounts are extinct volcanoes from the mid-ocean ridges, where the oceanic crust was formed several tens of millions of years ago.

Some of these seamounts have considerable height. For example, the sea mount here on the far north, which rises 2,800 meters above this deep-sea plane. In addition to the few seamounts that are more than 1,000 meters high, here, here, here or here, there are around 300 smaller seamounts, which have a height of a few hundred meters.

The flat deep-sea plains, such as the one marked in yellow here or here, they would be suitable for mining. However, areas with many seamounts, such as this one, are not suitable. I already mentioned the backscatter mapping and said that backscatter signal corresponds to the volume of the acoustic signal reflected from the seabed.

The backscatter signal can be used to distinguish between rocks and sediment-covered flat areas that contain polymetallic nodules or sediment-covered areas that are free of nodules. The areas shown here in white or light gray mark regions with, so to say, high volume, which corresponds to a hard reflector, so high loudness, let's say. In this case, it's a bedrock of the seamounts.

The black spots here, on the other hand, are areas with soft sediment without any nodules. And the light gray here shows areas with large nodules, and the darker gray areas with small nodules. The backscatter signal can be classified by a special software.

This map shows the same section of the seabed that you've just seen. I just go back and forth. Shown here in red are the solid rocks of the seamounts which may be covered with sediment in its flat parts, shown in green. And however, most of the license areas covered by nodules, areas covered with nodules, are shown in yellow and blue. The yellow areas are those covered with small nodules, which have a size smaller than four centimeters, and the blue areas are covered with larger nodules with a size larger than four centimeters. If this statistical classification is carried out for the entire eastern part of the BGR license area, the following distribution results. About 2 thirds of the area is covered with sediments and small nodules, here in yellow. 9% is covered with large nodules in blue, and only 2% do not contain any nodules in dark brown. Seamounts, shown in gray here on this map, make up 1 quarter of the entire license area.

So based on the topography and the extent of nodule fields, we have identified regions that are suitable for mining, and they are marked in orange. We have chosen three of these areas, which cover a total of 4,500 square kilometers, and investigated in detail with regard to nodule abundance, but also biodiversity and environmental conditions, such as bottom current regime or trace metal concentrations in seawater and so on. In order to carry out these investigations, it is necessary to take samples from the water column, but mainly from the seafloor.

It takes around three and a half hours to recover just one single sample at a water depth of 4,000 meters. A suitable sampling strategy based on the multi-beam survey must be considered before. In other words, we need to figure out where to take how many samples and where to deploy video sledge over which distance.

This map shows in black the video sledge profiles with lengths between 10 and 30 kilometers each. And we took samples where the red dots are, that is on the sledge transects and at sites where they cross. In addition, we towed a multibeam and a side scan zoner along the gray and purple lines.

The gray line is the side scan zoner track and the purple lines here are the multibeam, deep towed multibeam lines. In general, the aim is to have as much as possible overlap between the photos and the acoustic data with the samples from the seafloor in order to be able to make a proper interpretation of the acoustic data at the photos. This image shows a section of the seabed of 11 times 4 meters covered with large nodules with diameters of more than 4 centimeters.

These nodules are actually densely packed, but the space in between them is filled with sediment. So for this reason, that because the nodules have different sizes, it's not possible to obtain the nodule abundance from the photos, which would allow to explore larger areas in a relatively short time. Instead, we have to take samples from the seafloor and this is how it looks like when the box core returns from 4000 meters of water depth to the vessel. On the very left, you can see a sample with small nodules on top of the sediment and the photo to the right shows a sample with larger nodules. These two types of samples are the most commonly found.

Occasionally, however, there are also box cores in which many small nodules occur next to some large nodules. It is possible that these different sizes represent two generations of polymetallic nodules that started growing at different times. So very rarely we get a sample on board that has no nodules in it at all. This is the case when the accumulation of sediment is too high so that the nodules get buried and eventually dissolved. So here are again the three areas we explored in detail. And the following map on the next slide corresponds to the section shown here with a red rectangle.

So we have taken in total around 300 samples from the seabed in the three economical perspective areas. Sampling is particularly dense in the subarea here in the north. And here's an example of a resource evaluation for this area based on the statistical method of creaking. The nodule abundances shown here in red in the central part deem particularly high values of 26 to 28 kilograms of nodules per square meter. Slightly lower values in yellow and green correspond to values between 18 to 24 kilograms of nodules per square meter. The statistical analysis of all three fields together revealed the quantity of 80 million tons of manganese nodules in the wet weight.

And the metal contents of these nodules amount to 17 million tons of manganese, 700,000 tons for nickel, 600,000 tons for copper, and 100,000 tons for cobalt. And the entire area here, these three areas together, 4,500 square kilometers would be sufficient for at least 15 years of mining with a single collector. So here's again two box core samples from the seabed with manganese nodules and how they typically look like.

On the left, you can see a sample from an area with small nodules. And on average, we find almost 1,000 nodules per square meter of seafloor. The average nodule abundance is 16.5 kilograms per square meter. Nickel and copper together make up 2.6 percent wet weight. And trace metals are slightly enriched as compared to big nodules. Here we have typically a little less than 300 nodules per square meter and less than 23 kilograms per square meter.

Nickel and copper are slightly higher, 2.8 as compared to 2.6 wet percent. And trace metals are slightly depleted. In any case, the difference in the average composition of the polymetallic nodules is very small as a figure on the left-hand side shows. On average, manganese nodules have about 2.6 percent nickel, copper, and cobalt. And these are average values that we measured on 344 individual nodules. The red bar covers 50 percent of all manganese nodules, nodular measurements, and the coefficient of variation is only 11 percent.

The coefficient of variation tells you how much variation there is in relation to a mean of a data set. In this case, the data set of metal concentrations. A high coefficient of variation indicates that the data points are widely spread out relative to the mean, suggesting greater variability.

Conversely, a low value suggests that the data points are closer to the mean, indicating less variability as we have it here. In this case, it means the metal concentrations are only slightly in the BGR area. But this also applies to the entire Clarion Clipperton zone with its extension of 5,000 kilometers from East to West.

In contrast, the density of manganese nodules varies much more as a coefficient of variation of 30 percent shows for the nodular abundance. There are areas where basically no nodules occur, here, and areas where we have up to 40 kilograms per square meter. Accordingly, the focus of our exploration must be on determining the nodule abundance, and this can only be done precisely with samples from the sea floor, that is, using box cores like the one I showed you earlier.

We have densely sampled the three areas of economic interest, and we therefore have a good understanding of the amount of nodules covering the seabed and those areas. However, we also wanted to estimate the resource potential of the entire eastern part of the BGR license area with a size of 60,000 square kilometers. In other words, we wanted to know how many tons of polymetallic nodules are there and where other economically nodular fields might be located.

As we only recovered a few samples outside the three prospective areas, we could not use conventional statistics such as gridding for the evaluation of the resource. Instead, we used artificial neural networks, a kind of artificial intelligence mathematics, with which we were able to estimate nodule abundances relatively well. The basis for this evaluation is the bathymetry and backscatter data which are available for the entire area.

And since the metal content is relatively constant, as I've shown, we only needed to model the nodule abundance, the mass of nodules per square meter. The artificial neural network software compared the nodule abundance determined from the box core samples with the bathymetry and backscatter values for the same location. In addition, derivatives such as the slope gradient or the orientation of the slope were used.

A total of 73 different input parameters were tested and the lowest deviation compared to the actually measured values resulted from a combination of 17 input parameters. This map here shows the result of the modeling. Red and blue and purple colors indicate high nodule abundances and yellow colors indicate low abundances between 0 and 10 square kilometers or 11 to 25 kilograms per square meter.

So, in total, the modeling study indicates that the seabed is covered with 540 million tons dry weight of manganese solids, so this is dry nodules, which would correspond to something like 760 million tons or 780 million tons of wet weight. The metal content of all these nodules together adds up to something like around 170 million tons of manganese, 7.5 million tons of nickel, 6.3 million tons of copper, and just under 1 million tons of cobalt. However, it would not be economically viable to mine all the nodules from the entire area apart from the environmental impact of such a full-scale removal of nodules.

Instead, from an economic perspective, at best only about 20 percent of BGRs in the entire license area could be considered for mining and this number of 20 percent apparently also applies to other license areas in the CCZ, as I've learned from other contractors. So, taking this figure as given, 20 percent corresponds to an area of 15,000 square kilometers, which would be sufficient for about 50 years of deep-sea mining for one company. Five decades would correspond also to a lifespan of an average large-scale land-based mine.

So, deepsea mining in this regard would be comparable to land-based mining. Well, this slide concludes my presentation and I hope that I could at least provide you with a brief impression of how the exploration of polymetallic nodules works and which tools we are using. If you like, you can increase your knowledge with references that are recommended to you and I would like to thank you, say goodbye and wish you all the best.