DEEP DIVE MODULE 3

MODULE 3, LESSON 1

MSR TECHNOLOGIES AND TECHNIQUES (OFFSHORE AND LAB-BASED)

LECTURE NOTES

Good morning, good afternoon or good evening to everyone. My name is Annemiek Vink. I am a geobiologist working in the sub-department of marine resource exploration at the German Federal Institute for Geosciences and Natural Resources, called BGR in short, and it's a great pleasure for me in this 20-minute lecture to talk you through some of the more common offshore technologies and techniques that are used for marine scientific research in relation to deep seabed mining.

Of course, due to time constraints, what I present to you today can only just be a selection of technologies that are currently available, but it does represent a suite of methods that are used by scientists and contractors alike to analyse and understand the seafloor, its resources and the environment in the deep-sea realm. The scientific research that is required to understand the deep sea environment and in relation to that, the potential impacts of deep-sea mining, whether it be for polymetallic nodules, crusts or massive sulphides, as shown here in the right-hand figure, is greatly multidisciplinary and includes many different ecosystem compartments from the ocean crust to the sediment-covered seafloor and into the entire water column right up to the sea surface. Typical activities that we as scientists need to carry out are listed here and include seafloor mapping to understand the topography and ruggedness of the seafloor, but also to quantify resource distributions and the larger animals known as megafauna that are associated with them.

We need to sample seafloor sediments, their pore waters and the animals that live in and on them to analyse sediment characteristics, biogeochemical conditions and the biodiversity distribution and connectivity of faunal species. Rock drilling may be required and we need to understand the physical and chemical oceanography of the water column in the different depth layers. For example, we need to know about currents, turbidity, trace metal concentrations and toxicity and we also need to know about the animals and the flora or the algae that live in the different layers of the water column.

With all of this, we have to remember that it's deep, it's dark, pressures at depth are extremely high, communication with technologies deployed in the ocean can be difficult. For example, we can't use radio, GPS or Wi-Fi signals as we do on land and we have an energy challenge as we can't use combustion engines underwater and all of these have to be overcome through the careful deployment of robust, resistant, fit-for-purpose and safe technologies that are generally not off the shelf and tend to come with high costs and mostly also with low availability. To start with, marine scientific research requires the use of high sea research vessels that are large enough to offer a stable working platform for the deployment of heavy equipment, even with significant wave heights of several meters and are adequately equipped with cranes, A-frames and winches to deploy and provide power to equipment down to a water depth of four to five thousand meters.

Here are some examples of such vessels from a European perspective. There are actually not that many of these worldwide and thus it can be difficult and especially costly to obtain ship time to carry out deep sea research in remote areas of the oceans. I would now like to go through some of the techniques that we can use to map features of the seafloor.

One way to do this is by projecting sound waves, for example at a frequency of 12 kilohertz, from transducers on the hull of a ship in multiple beams to the seafloor. The undulating topography of the seafloor is detected using the amplitude and phase information received back for each beam sounding. The angular coverage sector or swath width will be low in shallow waters but it can increase to several kilometers at great water depths and so it's possible to map large deep seafloor areas such as the 60,000 square kilometer area as shown here on the right within several weeks at a resolution of about 100 meters and you can see in brown, a large number of seamounts in this eastern pacific deep sea area as well as north to south trending hills in yellow and deep abyssal plains in blue and this really is the desired standard for seafloor mapping.

Should a higher resolution of up to one meter be required, acoustic mapping can also be achieved using a deep towed multi-beam system that is attached by cable to a slowly sailing ship and flies between 5 and 80 meters above the seafloor for example, the BGR home site system shown here on the right or by a completely autonomous underwater vessel a so-called AUV that is pre-programmed to fly particular transacts over the seafloor and surfaces automatically after its mission has been accomplished. With these techniques small-scale seafloor characteristics such as rock outcrops, small basin depressions and even active vent chimneys can be detected. On the left you can see the difference between resolutions of ship-based multi-beam and AUV-based multi-beam which really shows a much greater level of detail and information.

Seafloor mapping can also be undertaken by photographic documentation using pressure-resistant video and still cameras that can be mounted onto frames that are either towed behind the vessel such as a video sledge or have a propulsion system but are connected to the ship through an umbilical cable for power supply such as a remotely operated vehicle or ROV or they can be completely autonomous such as the AUV that I described previously. This equipment flies at about three to five meters above the seafloor and obviously the amount of detail seen here is of millimeter-scale resolution and it is really good enough to determine every nodule in a nodule field or even to recognize and identify species of animals that are greater than one or two centimeters in size. Photos with overlapping edges can even then be stitched together to produce mosaics of larger areas and that's shown here in the next slide where 36 AUV images have been stitched together to reflect about 35 square meters of seafloor in a nodule covered area and as you can see we very nicely depict two large sediment mounds produced by the fauna and quite a high detail on the fauna itself such as this sea anemone on the left-hand side or the sea cucumber on the right-hand side.

Seafloor areas that are covered by sediments can be sampled using what we call a box corer as shown here on the upper left-hand side. This mechanical piece of equipment is lowered down to the seafloor on a wire and basically takes a 50 by 50 centimeter bite out of the seafloor so that both the sediment surface in this case covered by nodules and the uppermost, about 40 centimeters of sediments are sampled. Once on board, geological samples such as these nodules can be size-measured and weighed to determine their abundance on the seafloor.

Their metal contents can be measured using x-ray fluorescence and the sediments can be described. Shear strengths can be measured and other physical properties such as dry bulb densities, porosities and grain sizes of the sediments can be measured. Last but not least, sediments can be sieved through 300-micrometer sieves to analyze the macrofauna such as all these pretty animals shown here on the right-hand side.

As their concentrations are generally low in deep-sea sediments, large volumes of sediment have to be sieved to obtain statistically relevant amounts of specimens of these animals. If we need a sediment sample whose upper surface is still pristine along with the bottom water in a closed core system, for example for geochemical analyses or for the sampling of the tiniest meiofaunal organisms, we often deploy a multiple corer or multi-corer as shown here, in which several short thin cores are taken from the seafloor at the same time. Concentrations of major, minor and trace elements such as iron, manganese, copper or cobalt and nutrients can be analyzed from these pore water samples as shown by the syringes here together with the mineralogical and geochemical composition of the sediments.

Oxygen penetration depths can also be measured, giving an indication of how oxygenated the sediments are. For the analysis of biodiversity, multi-cores can be analyzed in different ways. The organisms can be sieved over a 32-micrometer sieve and described individually based on their appearance, which we call morphology, or they can be genetically analyzed through the process of DNA barcoding to develop phylogenetic trees and describe similarities or dissimilarities and the geographic ranges of species in a more empirical way.

More modern and rapid approaches now work with DNA barcoding of mixed faunal specimens rather than single specimens. This is called metabarcoding or even just by barcoding the entire sediment sample that has not yet been sieved at all. That's called environmental DNA analysis.

Each of these methods has its own specific advantages and disadvantages. Sediments and fauna can also be sampled by ROV. Generally, an ROV comes with two manipulator arms that can be used to deploy different pieces of equipment, such as small tripods or frames carrying current or turbidity profilers or, for example, oxygen microprofilers that can measure the oxygen consumption in the topmost 20 centimeters of sediment over several hours and provide information on bacterial activity rates.

Faunal samples can be taken using scoops or nets or simply by grabbing them. Short sediment cores can be obtained from specifically targeted parts of the seafloor. We call this push coring.

And we can do all sorts of fancy things, such as deploying recolonization frames, as shown in the upper middle picture, in this case to test whether animals like them as a substitute substrate to grow on. We can also, for example, measure the temperatures of boiling hydrothermal vent fluids using temperature probes that measure temperatures up to 450 degrees Celsius and more. Sampling of seafloor rocks and fluids for geochemical, metal, and mineralogical analysis can be more tricky.

Smaller rock specimens and fluids can be sampled by ROV. A dredge that is pulled or scraped over the seafloor or over the flank of a seamount as a towed system can also deliver large quantities of rock material that lies relatively loosely on the seafloor. In some cases, vertical drilling into rock or ore bodies on the seafloor is necessary to analyze changes in mineralogy and metal content with depth.

For example, this is necessary to make reliable resource estimations for massive sulphide occurrences. In this case, short cores can be obtained by rock drillers that can be installed on ROVs or by larger rock drillers that are operated by installment of a platform on the seafloor. Geophysical methods such as magnetics and gravimetry can delineate conductive rocks and aid in the search for and spatial description of seafloor rock bodies such as massive sulphides.

This round yellow sled called “Golden Eye” contains a unit for controlled source electromagnetics that measures the electrical conductivity of the seafloor surface. High conductivity as shown by the red areas in the schematic on the lower right-hand side can only be explained by the occurrence of massive sulphides. The red triangles then show actually observed sulphide occurrences observed by ROV and the blue 3D volume indicates a pipe-like body of reduced magnetism which is interpreted to be the alteration halo around the uprising hydrothermal fluids.

So in this way, different methods are combined to identify areas with a high likelihood of sulphide occurrences. I mentioned in the introduction that an understanding of the ocean, its water masses and its current regions, as well as the flux of particles and material from the sea surface into the deep ocean is really important, not least while these processes determine important parameters for life on and in the deep seafloor such as sedimentation rates and food and oxygen supplying. One of the most important pieces of equipment to measure physical parameters of the water column is the CTD, a conductivity temperature depth profiler that measures parameters such as temperature, salinity, turbidity, oxygen and chlorophyll concentration vertically in the water column.

These are always point casts though, so they are taken at a particular moment in time and should data be required from any location over a longer period of time, for example throughout one year to register seasonal variation, it is possible to moor systems with a weight to the ocean floor and then acoustically release them from their weight during recovery. These moorings are equipped with floats that then allow the equipment to rise back to the sea surface from where it can then be recovered by ship. Typical instrumentation that is moored are current profilers such as ADCPs that provide current speeds and directions at high resolution, for example in hourly intervals, or these funnel-shaped sediment traps that catch sinking particles in the water column over predefined time periods and allow particle fluxes to be calculated.

CTDs are often attached to so-called rosettes that contain water bottles that can be closed at any depth in the water column and thus can provide water samples from those different horizons, right down to the sea floor. Such water samples can be filtered into three different fractions, so we can separate them into particulate, colloidal and truly dissolved fractions, and they can be chemically analysed for nutrients as well as potentially toxic elements that can become enriched, for example during the production of mining-related sediment plumes. Last but not least, different depth layers of the ocean harbour different species of animals in different size classes, from millimetre scale to the largest marine mammals that can reach dimensions of tens of metres in size.

The smaller specimens of zooplankton, such as crustaceans, smaller jellyfish or worms, can be sampled using a multi-net shown on the left here, which contains several nets that are drawn upwards through the water column and each is opened and closed at set intervals. Larger and fragile animals, such as jellyfish, can also be specifically sampled by ROV in the water column by simply scooping them up or by using a slurp gun, which is like a vacuum cleaner pipe to suck specimens into a collection bucket. On the sea floor, specimens of fish, scavengers or amphipod crustaceans can be beckoned into baited sediment, baited traps and sampled for genetic analyses in that way.

With that, I have come to the end of this deep dive into some of the most common technologies used for marine scientific research. I hope this has been an interesting dive into the spectacular depths of the deep sea. It's been a rather short dive, but I do wish you an educational experience with all the modules to come.

Thank you for listening and have a great rest of the day.