



MODULE 5, ELECTIVE 7

TECHNOLOGIES FOR PROSPECTION FOR MINERAL RESOURCES IN THE AREA

LECTURE NOTES

Hello everyone and welcome to the Deep Dive e-learning program organized by the International Seabed Authority. My name is Anna Lim, I'm a geophysicist by background, currently leading marine mineral solutions development in RGU. It is my pleasure to open module 5 of the programme with a lesson on technologies for prospecting for mineral resources in the area.

Before we dive into the subject of this lesson, I would like to outline the agenda for today. After a brief introduction, we will start by defining prospecting targets and revisiting their key characteristics. Next, we will discuss the challenges associated with prospecting in the area.

And once we have established the context, we will explore the key technologies used in both prospecting and later stages of exploration. We will also address aspects related to the data or information acquired with the use of various technologies. And finally, we will summarize the lesson before concluding.

To initiate a discussion on prospecting, it is important to grasp the nature of the targets we aim to discover and characterize and understand the context they are found in. The ocean floor, vast and diverse in its manifestations, presents a spectrum of morphologies. If we were to dissect the ocean crust stretching between the American and African continents like we see here, we would encounter a varied landscape, from expansive abyssal plains to dynamic mid-ocean ridges forming colossal mountain chains deep beneath the sea surface.

Within these geological settings lie various types of deep-sea minerals. Polymetallic nodules, often found in the abyssal plains such as Clarion and Clipperton zone, or polymetallic crusts that need a firm elevated substrate like sea mountains to form, or seafloor massive sulfides associated with hydrothermal venting that are observable on the surface in the form of vent chimneys. However, unlike polymetallic nodules and crusts, the primary resource of economic interest lies in the massive sulfide body concealed beneath the surface, as you see in this cartoon.

As the term implies, the focus lies on the substantial sulfide body depicted here, where chimneys, though really captivating, offer only a partial view. This scale is an important element that needs to be considered in marine mineral prospecting. When we look at the international seabed area, or the area which stretches beyond exclusive economic zones for 200 nautical miles, and here is a scale bar for 200 nautical miles for your reference, the actual scale of potential prospecting areas gets truly impressive.

It covers vast lateral extents and reaches considerable water depth, so here it's around six kilometers in this example. To summarize, the discovery and characterization of deep-sea mineral resources, or their prospecting and exploration, present unique scientific and operational challenges. First and key operational challenge is that these resources are found in deep and remote marine environments, with average water depth ranges provided in the table here, but often reaching a few kilometers on average.

In such context, technology is literally the only means for collecting any data. This further gets complicated if we consider the deposits' dimensions relative to water depth. Seafloor massive sulfides is the only deposit type that can be considered three-dimensional, with its vertical dimension reaching around 100 to 150 meters.

However, this type of deep-sea minerals has a very limited horizontal extent, again on average around 250 meters in diameter. Polymetallic nodules, on the contrary, span hundreds of kilometers horizontally, but are superficial in nature. Polymetallic crusts are relatively thin too, on average reaching about 15 centimeters in thickness, but their horizontal extent is on the order of tens of square kilometers, depending on the seamount size.

All these deposits exhibit a significant variability of local geological contexts and host rock. This variability manifests in a wide range of geophysical signatures, which have yet to become prehensively systematized. Additionally, the importance of this type of deep mineral deposits extends beyond their mineral content, playing a critical role in deep-sea ecosystems.

Such intricate nature of these formations necessitates a metallurgical approach to their mapping and investigation. To set a more practical scene, let's have a look at a prospecting example. This is a representation of a typical prospecting area for seafloor massive sulfides, consisting of 100 licensed blocks granted by the ISA, each block 10 by 10 kilometers, or in total it is 10,000 square kilometers.

And here's a challenge. This red dot, barely visible in this context, is a typical seafloor massive sulfide with a 250 meters diameter that is a target of prospecting. Referring to the previous slides, I should also note that exploration area size reflects variability of deposit dimensions for each mural time.

So, a maximum of 150 000 square kilometers can be granted for polymetallic nodules exploration and 3,000 square kilometers for polymetallic crust exploration in the area. So, in order to find this red dot for a typical SMS deposit, we need to, one, survey this area or cover this area with the data and we need to be able to resolve or to have the data of such detail that we can actually understand that it is the deposit and not just a seafloor feature. So, from a practical standpoint, it is useful to discuss various prospecting technologies in the context of, one, aerial coverage, or how much area can be covered in one pass, and spatial resolution, how much detail can be resolved from the data acquired with these technologies.

And the highest aerial coverage, actually global coverage, can only be achieved with satellite geophysics. Satellite altimetry provides full global coverage and you most likely use this data when you look at global geometric maps, such as GEBCO, that rely on this data, especially in deep sea regions where multi-beam megasonar data is very sparse. However, while these data provide great coverage, the resolution is very low, on the order of a few hundred meters.

Now, in the realm of hydrothermal vent exploration in particular, the so-called CTD casting, CTD stands for conductivity temperature depth, but these systems can also include other water physics and chemistry sensors. So, this technology is behind most hydrothermal vent discoveries to date due to relatively low cost and efficiency in finding active sites through sensing anomalies generated by hydrothermal plumes in the water column. So, here the aerial efficiency is relatively good, improved by the sturdy design where the CTD cast is actually tiled behind the vessel in a tile-yellow fashion.

But data resolution is relatively low too, often resulting in difficulties pinpointing the actual source of hydrothermal venting at the seafloor. Now, ship-based geophysics allows to cover relatively big swaths of area, providing a better spatial resolution as well, that allows to see more details both on the seafloor and in the subsurface, since we're talking about geophysics. However, data resolution and coverage both largely depend on water depth, where there is a trade-off between these two critical parameters.

The higher the water depth, the more your coverage is, but the lower the resolution of the data that you acquire. On another end of technological spectrum from satellite geophysics and prospecting applications is an ROV technology, remotely operated vehicle technology, a subsea technology that is connected to a surface vessel through a cable and allows to visually inspect the seafloor in real time, and also use manipulator arms to sample both rocks and biology. Therefore, it provides the highest resolution available.

However, this too comes with a trade-off where aerial coverage is relatively low. Finally, autonomous underwater vehicles or AUVs is the most recent technology that allows to achieve both high resolution while maintaining relatively high production coverage rates. It allows to achieve around on the order of centimeter resolution with acoustic data and millimeter resolution with optical data such as camera surveys.

This robotic solution serves really as a platform that is not tethered to the vessel and is fully autonomous. It can be programmed as well as receive commands while at depth to perform surveying at range of altitudes and depth. Therefore, it does provide a range of resolutions depending on the method and survey parameters.

While all of these technologies have their use case, I would like to discuss the AUVs in more detail because of their versatility but also the comprehensiveness of the data that they can deliver. As I mentioned before, AUV systems are fully autonomous and are not tethered to a surface vessel. But in remote environments, AUVs depend on the surface vessel for launch and recovery as well as for navigational support.

Commands and positioning updates can be communicated to and from AUV using acoustic communication links. For navigating at depth, the system is equipped with sophisticated solutions including inertial motion units, inertial navigation systems, Doppler velocity logs, altimeters, different sonars, and terrain reference navigation based on the analysis of the payload data. In essence, AUVs provide a robust platform that can acquire data near sea floor using a range of payload sensors that are mounted within the AUV.

On the right-hand side, you can see a list of sensors that can be actually simultaneously mounted but also simultaneously deployed from the AUV during a survey. Moreover, the multitude of these sensors also produces different data types. For example, multi-beam echosounder, a classical sensor in oceanography, provides not only bathymetric data helping us to understand the sea floor morphology but also backscattering strength and water column images that are extremely useful in hydrothermal vent anomaly mapping because you can get to see the deep looms as in videos but using acoustic methodology.

Synthetic aperture sonar is one of another acoustic sensors that provides ultra-high resolution sea floor image data. So we're talking about centimeter resolution here, while also providing simultaneous bathymetric data and also water column images. Sub-bottom profiler is a shallow seismic or an acoustic method that helps us to see into the subsurface.

And a number of environmental sensors measuring water physics and chemistry can be mounted in the AUV. Typical examples include sensors measuring conductivity, temperature, pressure, sound velocity, dissolved oxygen concentration, methane concentration, pH levels, turbidity, acoustic Doppler, current profiling, which are very useful for both environmental baseline assessments but also for again mapping of the anomalies in the water column for example but also evaluating the impact of possible seafloor disturbance and sediment plumes for example. Other geophysical sensors that are especially key in seafloor massive sulfide exploration and polymetallic crust exploration include magnetometers that can provide magnetic field measurements, usually it's all three components, and also electromagnetic systems.

So it can be both passive configurations measuring the spontaneous potential or the naturally occurring electric field, also three components, and active systems such as controlled source electromagnetic systems, CSEM systems, that further increase detail of what can be achieved with subsurface imaging. And finally, cameras and lasers can also deliver the ultra-high resolution of at a level of millimeters to really ground truth the prospecting targets. So again, technologies are interesting not only from the perspective of operating in this remote environments and at depth to retrieve the data from the seafloor or from near seafloor, but sensors as technological advances as well provide us with unique insights into the environments that we are surveying.

So throughout this presentation I have been interchangeably using prospecting and exploration to describe activities for finding, discovering, delineating and characterizing deep sea minerals, various types of deep sea minerals. However in practical terms and in strategic terms it is useful to also separate this into different stages such as prospecting, exploration and ground truthing, especially given the scale of prospecting areas that we have to deal with and limited time windows when we can survey in such remote areas. So normally or classically first the prospecting stage is

performed through regional mapping with the vessels.

So sheet-based mapping using multi-beam ecosystems and CTD casts are used to map the regional geology and figure out the prospectus areas for further detailed exploration. However, as I mentioned before data resolution and coverage is a function of water depth here. So, in recent years prospecting stage has been reviewed from a technological standpoint where AUVs are more and more used to really provide this more information, more detailed information as early at the prospecting stage, even where regional background data is not available.

And one way of technological optimization or increase of efficiency in this case is using multiple AUVs for these purposes. So that way you achieve both high data resolution but also high coverage. And in case of using the AUVs for that purpose you can simultaneously map the environmental baseline and especially in the case of polymetallic nodules you can actually get the detailed information that will help you to delineate the nodule fields.

So, for example with synthetic aperture sonar you can reach the efficiency of around 4.5 square kilometers per hour with latest technology and that will provide you with the five centimeter resolution which is again can be put both in prospecting and exploration stages depending on the survey goals. For detailed exploration and multi-sensor mapping AUVs are typically used across different types of deep-sea minerals and geological contexts. At this stage usually geophysical data drives exploration success especially in the case of seafloor massive sulfides and particularly in the case of finding and delineating inactive sites and similarly for polymetallic crusts.

Multiphysics is really required and that can be provided with AUVs. And finally, to confirm the targets to ground truth the data and the models built from the previous stages we mount ground truthing with AUVs and RVs are possible. So, cameras can be used to visually inspect the areas but also in addition to that several sensors can be mounted on both AUVs and RVs to provide additional insight into the subsurface and local conditions.

So once again different technologies can be used for different use cases and we should definitely acknowledge the differences between different deep sea mineral types and the contexts that they are found at. But the latest trends show us that technologies such as AUVs can be used as strategic assets spanning the entire exploration spectrum from initial prospecting to ground truthing. Before we conclude I would like to highlight that whatever is the technology it is only a part of the solution.

The real value comes from a combination of various tools such as vessels, AUVs, RVs, sensors that can be deployed from these platforms and all that should be understood along with the limitations of this technology and should be strategically deployed and optimized for performance for best performance and efficiency. And in turn that should be always coupled with the ability to harness vast potential of the data we collect where integration is key. It should be underscored that there is a delicate balance between leveraging the technological capabilities and recognizing the nuances and intricacies of the data they provide in the context of deep-sea mineral exploration and prospecting.

And prospecting success is really increasingly driven by the data, by the comprehensiveness of the data and particularly in prospecting the occurrence of pulse positives and pulse negatives can significantly impact the decisions made. Pulse negatives occur when a survey or testing incorrectly indicates the presence of a target mineral resource when none exists and conversely pulse positives occur when the survey failed to detect the presence of target mineral resource that actually exists. Addressing this challenge of pulse positives and negatives requires a really comprehensive understanding of the underlying geological environmental factors that we can derive from the data and only from the comprehensive data sets that contain multiple physical and chemical information.

And the value of this information of the data in turn should be considered both in terms of potential value gains for the new information and losses in value due to the absence of information. So once again we should take the systematic and strategic approach to use of any technology in order to achieve best results. In summary, technology is truly indispensable for accessing deep sea environments and it is the only way for us to study these environments where remote sensing offers efficiency in prospecting efforts.

We have looked at different types of technologies, different types of platforms and autonomous underwater vehicle technology stands at the forefront of innovation and deep-sea exploration. Its adaptability and ability to gather comprehensive multi-sensor data sets make it a valuable asset in the field and success in prospecting requires a thorough understanding of both target resources and their surrounding context as we discussed in the first half of the lecture. Different types of resources require distinct exploration approaches tailored to their unique characteristics.

For example, geophysical methods, especially electromagnetic methods, are key for prospecting seafloor massive sulfides and polymetallic crusts, while acoustic seafloor imaging, notably synthetic aperture sonar, enables efficient prospecting of polymetallic nodule deposits and habitat mapping. And it is only by leveraging the technological advancements we can enhance the effectiveness and efficiency of deep-sea mineral prospecting endeavors and really further our understanding of these environments. Thank you for attending the first lesson of module 5 and I would like to leave you with a short video and EEV launch from the mid-Atlantic reach.

A truly deep dive.