MODULE 5, LESSON 3

TECHNOLOGIES FOR EXPLORATION OF POLYMETALLIC NODULES OF THE AREA

LECTURE NOTES

Hello everyone. My name is Johan Heiler and I'll be your lecturer for today. I work as head of Operations and technology at GSR, a Belgian company developing deep sea mining of polymetallic nodules in the area. And this lesson will be on one of my favorite subjects and nodule collection technology.

During the lesson, we'll first break down the nodule collection system into its key functions, and then we'll review and suggest different options for each of those functions. We'll identify the most commonly used principles for each key function, both today as well as in the past. Consequently, we'll dig a little deeper and explain how they work and what sets them apart. And finally, we'll address some of the important recent developments in nodule collector technology. Before we start off, I wanted to show you these images of famous nodule collectors developed in the 70s. On the left you can see the Lockheed Martin developed, not your collector that was on board, the Glomar Explorer centrally towed vehicle developed by OMI, and on the right OMA collection defines. Now why am I showing these and that's mainly for two reasons. First of all, they show us the long history that deep sea polymetallic nodule mining already has. Secondly, they are a testimony to the amazing ingenuity and creativity of these early developers who had to go as far as inventing equipment and systems, systems we now take for granted. This does not mean it's become a walk in the park. Requirements have changed significantly since that time, but it does tell us and does teaches to reach far and high and everything we develop.

Polymetallic nodules are unlike any other base metal resource; the particulars of these resource are essentially an understanding current technology for nodule collecting. Therefore, I listed a number of the important properties on this slide. First of all, the fact that nodules are found more than 500 nautical miles offshore and four to five thousand meters deep means that the equipment needed for those modules needs to be extremely reliable, act very predictable, and that development costs for such equipment will be high. Secondly, polymetallic nodules are essentially a 2D resource. This means that picking up such nodules will require covering large services, require mobility, flexibility and a combination of speed and width to achieve the necessary production. Thirdly, variable size and abundance, that means that collection systems need to be robust, and it also means that there is not necessarily a one-size fits all solution. Finally, the soft, cohesive soil does not only limit maneuverability, but also defines the interaction between the seabed and the pickup device, which will be essential as we will see later.

From this we can already see that both the collection itself as well as the propulsion will be key functions for a nodule collection system. This presentation will further limit only on the collection system itself and not on the riser or mining vessel. The nice and colorful table in front of you is a functional analysis of a nodule collection system. The top 4 rows describe all conceivable ways of dealing with the collection function, while the bottom 2 rows show different ways of implementing the propulsion function. For instance, in the top left row you can see agriculturally inspired solutions like Rakes and bulldozers, which is logical as not your mining does have some resemblance to potato harvest. On the top right row, where you can find more dredging inspired solutions since modules are found below the water surface and the propulsion lines, we can find solutions like tracks, wheels, towed, sleds and all other conceivable ways. The main reason for showing you this table is actually to emphasize that there's no one and final solution for this multivariate problem, and all of these solutions have a number of different potential combinations or can be hybrid versions of these solutions.

From this long list of potential combinations, a range of different concepts could be defined, selected, and evaluated. This is an exercise that has been continuously done through the last decades by different groups, and they've evaluated each of these concepts on a set of evaluation criteria as shown on left of the screen, First, he criteria of environmental impact has gained a lot of weight in the last decades, rightfully so. Any concept will be evaluated on your seabed disturbance, greenhouse gas emissions, noise emissions, etc. Secondly, obviously concepts will be rated for their efficiency, their minimal sediment intake, their selectivity, etc. Furthermore, as nodule collection systems are so deep down and hard to reach availability or the time that they are able to operate reliably will be very important. You can obviously find scalability, so the ability to increase production. Economy as well as technical risk in the list of criteria to be evaluated to come up with a certain concept. Using those criteria and for the two key functions of collection and propulsion, a number of workable concepts has been defined over the last decades.

For collection we have identified 5 we will go deeper into each of those in the next slides we use hydraulic erosion collection concept, hydraulic lift concept, mechanical passive concept, active concepts and selective concepts. For the propulsion systems, we will get those vehicles tracked vehicles, Archimedes screws and suspended or buoyant propelled collection devices. Both collection and propulsion have important design drivers that we will reencounter for each of those solutions? Let's dig a little deeper, first of all into the collection function. On screen they have picture of the hydraulic collectors of the erosion type. The top left pictures show their work in principle. Essentially, jets are pointed at the sea bit that allow dislodging the nodules, after which they are taken up into the collector. Properties of this type of collector have very limited moving parts, only water flow is used. They don't actually dig or peel into the seabed, so they have no contact with the seabed and because of the lot of large water flow, nodules are automatically washed, and there's very little risk of clogging. Thanks to a separating function, you can also say that most likely and transporting them vertically there will be low sediments in the riser or alternative vertical transport system.

However, as these collectors have jets pointed at the nodule, there will be seabed erosion and as a result. Popular examples are, for instance the KoRdi Minero II, that was tested in 2013 as shown On the far right. A second type of hydraulic collector is a so-called lifting. Its working principle is shown in the top left corner rather than pointing jets at the seabed or at the nodules, in this case, water flow is kept substantially parallel to the seabed grading and lift effect above the nodules, something like wings on an airplane. This drags the nodules into the collector and leaves as much as possible, the sediment of the seabed behind. Essentially, it has the same type of properties than the erosion collector, except that likely it will have less seabed erosion. This technology was in fact developed in the 70s at small scale and has been very popular in the latest years because of its obvious advantages. Several parties have done extensive lab tests; they've developed their own proprietary improved versions, and some parties have indeed tested these systems at scale or in situ, as could be seen on the far right. For instance, it shows mine robot by metals company GSR and Apollo 2, the mining collector developed by IHC for the Blue Nodules program.

The mechanical collectors are a very different type of not your collector. The first ones designed were typically of the passive type. They were designed in the 70s and the initial ones were actually very simple devices consisting of Rakes or pumps, typically on the flower shape that were dragged across the seabed they picked up the nodules and concentrated them towards a riser entry. Obviously they do not need to be actuated, they have no water flow and they are very simple devices, unfortunately, they did not work well. They frequently clogged, they had no ability to wash or separate nodules from the entry of the riser and for those reasons, generally all tests were unsuccessful and the concept of a passive, not your collector, was abandoned. Active mechanical collectors have a long history as well. They were both developed by the OMI and Lockheed groups in the 70s and tested in city. The performance of these collectors was elusive. The top picture shows potato type harvester module collector which is fitted with Rakes and twines that dig underneath the nodule and pick it up and pull it up a fenestrated ramp through which it is washed off its sediment. Then material is brought into a concentrator and to the riser system.

The second version on the right shows a hollow drum that scoops up nodules, washes them off the sediment and again brings the nodules to a concentrator device. Following different design iterations, mainly in Germany in the 80s, a special version of this collector was developed and constructed by Nioz and was tested at depth, although not in the area. More recently, Loki minerals published that they are developing and mechanical collector as well. Both the Nioz 1 can be seen in the top right picture the Loki one, in the bottom picture. The lack of a large water flow is an advantage in comparison to hydraulic collectors. However, these collectors do need to penetrate the top layer of soil to be able to collect nodules. Currently, since the collector type is not developed and tested to the same degree as hydraulic lift collectors, there is no comparison of its performance with this popular version, yet.

A new and note-worthy development is found in the selective mechanical collectors. These are different to the prior ones in the sense that they do not attempt to collect every nodule in their path, but rather pick up each nodule individually by choice. One company, it's called Impossible Metals, is undergoing a development programme to create a floating mechanical collector with robotic arms, which would autonomously pick up and transport, nodules to a motor vessel. The potential upside of these collectors that no seabed will need to be disturbed in locations with no nodules or nodules could be deliberately left in place. The downside of these devices are obviously their complexity, limited technology readiness and large amount of motions required to physically collect these materials.

Again, given the early development status, no comparison of its performance with the popular hydraulic lift collectors can be made at this time. Now that we have covered the five most common collection principles, we can look at the other key function of a nodule collection system. It's propulsion. Early collectors were mostly developed as towed devices, generally because of their mechanical simplicity and low power consumption. Although some actually worked, they were found to be difficult to launch and recover, and complex to operate. This can be understood as follows, given that time delay between changing the direction of a towing vessel and changing its collector at the sea, that could be several minutes, position control of these devices at the seabed was approximately, at best and obstacle avoidance would be very problematic. These devices were also prone to create what they call bow waves, whereby sediment flows onto the device by today's standard, the device, which such low efficiency and limited selectivity would not be acceptable. Therefore, the concept is now considered to be abandoned. Clearly the most popular choice for nodule mining vehicles are the track devices, although they come in different sizes and shapes, the principle is always very similar.

The ability to build relatively simple, wide and large tracks allow creating collectors with limited sinkage and yet acceptable formats include tracks which have no slippage, have been proposed to avoid solve remolding two and four track versions are found, but given the low shear strength of the soft, cohesive soil, attractive efforts always remain limited and bearing pressure has is kept low. This requires substantial buoyancy to be installed, which can be found in nearly all the pictures on the right, and find the blocks on top of the noting collectors. Typically these tracked vehicles, they can drive at up to one knot, they're relatively well controlled on seabed, allowing for short turns, stops or obstacle of violence if needed. Of course, they're inherent downside is that they disturb and they compact and remote to seabed, and they are known to create some sentiment.

I've included the vehicles propelled by Archimedes screws for historic reasons. Such a principle was used by Lockheed Martin in the 70s. It's a simple principle, using a buoyant cylinder fitted with helical flanges. On land, these devices are known to work as amphibious vehicles, often in military applications. They are absolutely proven to work and very robust in changing soil typess, but unfortunately they will typically sink in significantly, causing heavy disturbance on the seabed. They also require quite a bit of higher power than a track vehicle and since they have no apparent upside compared to the tracks, this concept is generally considered abandoned. The floating collectors, propelled by Trustors, are a bit of a new kid on the block. They are driven by recent technical advancements in things like drone technology. The best-known embodiment are the drone type collectors as proposed by client Impossible Metals and others. In this case, robots have a limited capacity they pick up nodules and bring them either directly to the service or to a concentrator device. The obvious advantage of the concept is that these robots have no contact with the seabed.

This of course means their propulsion would need to be done through trusters and it means that their height control would have to be done through buoyancy adjustment. Something which may be challenging and limiting the size of such devices as these would also not be able to mine continuously, production would generally be achieved by having large numbers of such autonomous vehicles working simultaneously, although very interesting development given the early development status, low comparison of its performance with the popular tracked vehicles can be made to date. But the development of improved collector and propulsion technology is and should still remain a core activity. Large companies have recently taken a more holistic approach and they've started the development of so-called active management systems. These systems, they combine all aspects of a mining system with all the data available. This can monitor the mine site digital terrain models, carrying prediction on environmental baseline online monitoring data from AUVs or ROVs or landers and all other types of measuring devices, and using that data, the system determines the best possible settings and the best possible pathway on the seabed at any given moment.

This all to minimize the environmental impact and optimize efficiency. Such active management systems rely on sophisticated physical and data-driven models and they apply machine learning to continuously improve and adapt. These overarching systems, they don't only allow online control of the mining system, they also allow mine planning, online monitoring and, for instance, alarming in case thresholds are passed. Finally, they can also function as a gateway for transparent monitoring by governing bodies or by any other stakeholders. The past slides have shown us different collection and propulsion technologies, they've also shown that a lot of design in testing and testing efforts have already been done by various parties in this field. It is, however, important to understand that something has recently happened. The larger scale mining tests has done by the metals company and GSR involved in extensive environmental impact monitoring programmes. As these recent trials that have handed scientists and designers with a vast amount of data in particular measurements of the behavior of sediment tools have shed some new light on the process involved already.

This now not only allows reiteration and improvement of physical models to predict such plumes and their potential impact, but will also allow adapting and tweaking current collector and propulsion designs for improved performance. Actually recently it's very clear that this topic is getting the needed attention. Several parties have worked on or are currently working on modified or new designs for nodule collection to minimize the impact such as sediment intake and plume creation. All of which will hopefully be shown in practice in the area in the near future.

Finally, I'd like to thank all of you for your time and attention and wish you all the best with completing the deep dive program. Thank you.