Polymetallic Nodules

Sean Aldrich[1], Stephie Tay[1], Michael Gazley[1]

[1]*RSC Mining and Mineral Exploration, 109 Princes Street, Dunedin, New Zealand.*

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ABSTRACT

Polymetallic nodules are an untapped resource located on the seafloor. Nodules are a source of manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), and cobalt (Co). The exploitation of polymetallic nodules for Co could supply stability to the Co market, which is currently controlled by erratic production in the Democratic Republic of Congo. The advancement in deep-sea exploration equipment (e.g. autonomous underwater vehicles) and machine learning approaches have the potential to improve the quality of data collected and the confidence in resource estimations.

International markets are experiencing significant disruption and change; a significant driver of this is the desire to move away from fossil fuels to those powered by rechargeable batteries. This change in energy source has a significant impact on the supply and demand of the raw commodities that are required for the production of batteries. For example, there has been a significant increase in the consumption of cobalt (Co) which has exposed issues with raw supplies and corporate practices that do not align with the consumer demands. These issues result in pressure to find alternative sources of Co or alternative products.

A potential alternative source of Co are polymetallic nodules. Polymetallic nodules are an untapped resource on the bottom of many of the world's oceans; they are rich in Co, plus manganese (Mn), iron (Fe), nickel (Ni) and copper (Cu). Since 2010, interest in assessing the polymetallic deposits has increased considerably, largely driven by the rechargeable battery market. Cobalt is a technologically important metal that has many diverse uses. The leading use of Co (up to 50%) is in rechargeable batteries including lithium-ion, nickel-cadmium, and nickel-metal-hydride batteries, where Co is found in the cathode (Slack *et al*., 2017; Cobalt Institute, 2020). This is followed by superalloys, where the temperature stability of these alloys makes them suitable for turbine blades and gas turbines and aircraft jet engines.

Global production of Co in 2019 was 140 Mt with the Democratic Republic of Congo (DRC) the world's largest producer of Co (~70% in 2019) and the DRC possesses approximately 50% of global Co reserves (USGS, 2020). The DRC has a monopoly over global Co productions and has created a supply concentration issue, with supply often erratic due to its unstable political environment. With the continued projected increase in Co consumption, the Co-market has room to diversify to give long-term customers confidence in the industry and encourage them not to seek alternative products.

Polymetallic nodules are found on the seafloor from 3,500–6,000 m depth and nodules cover vast areas of the abyssal ocean floor, with notable deposits found at the Clarion-Clipperton Zone (CCZ), Peru Basin, Penrhyn Basin (including Cook Islands exclusive economic zone (EEZ)) and Central Indian Basin. Development of polymetallic nodule deposits could open the Co market to other countries including non-mining countries (i.e. Cook Islands), thus reducing the global supply risk.

The first polymetallic nodules were discovered during the 1872–1876 voyage by HMS *Challenger* in the Atlantic Ocean (Murray & Rednard, 1891). The expedition recovered nodules from the Atlantic, Pacific, Southern Indian oceans, and the China Sea. Polymetallic nodules gained commercial interest from the 1960s, with interest from companies from the USA, West Germany, Japan, Canada and other industrialised states. In 2001, the International Seabed Authority issued the first exploration contract of polymetallic nodules in the CCZ and recently the Cook Islands has developed the framework for future exploitation of these deposits within its EEZ. No consortia or country has commenced commercial mining.

The processes that form polymetallic nodules result in fields of nodules on the surface of the seafloor. These fields are essentially two dimensional and can extend over hundreds of square kilometres. The deposits also have minor variation in elemental abundances, with continuity in grade over many tens of square kilometres. Polymetallic nodules form due to hydrogenetic or diagenetic processes. Hydrogenetic nodules form on top of abyssal sediment, where the minerals precipitate from cold ambient seawater. The metals in seawater are concentrated by adsorption onto ultrafine particles of Fe- and Mn-oxide that are attracted, electrostatically to one another in the water column (Hein and Koschinsky, 2013; Hein *et al*., 2020). Diagenetic nodules form under the top layer of sediment in oxic-to-suboxic conditions from pore fluids that consist of seawater modified by chemical reactions within the sediment. Nodules can be of a mixed origin forming from both hydrogenetic and diagenetic processes (Halbach *et al*., 1981; Hein *et al*., 2020).

Hydrogenetic and diagenetic processes have an influence on chemical composition and outer texture. Hydrogenetic nodules have a smooth outer surface, have Mn/Fe ≤5 and enriched in high-field-strength elements, Ce, Te, Pt and Co. Nodules from the Cook Islands EEZ are typically hydrogenetic in origin (Kuhn *et al*., 2017). Diagenetic nodules on the other hand have a rough surface, have Mn/Fe >5 and are rich in Ni, Cu, Ba, Zn, Mo, Li and Ga (Kuhn *et al*., 2017). Nodules from the Peru Basin are typically diagenetic in origin, whereas nodules from the CCZ and northeast Pacific exhibit a mixture of diagenetic and hydrogenic origin, with predominantly diagenetic input (Wegorzewski & Kuhn, 2014).

The first step to determine if nodule deposits can be commercially exploited is to assess the historic data and estimate the mineral resources. Much of the available data is from government-sponsored investigations during the 1970s to 1990s. “Grades” are presented using a wet nodules kg/m^2. Assessing polymetallic nodule deposits do present a unique set of challenges for explorers. Data are a mixture of seafloor samplers and image data. Sampling tools range from dredges to freefall grabs to large box corers. All have issues with data quality which can influence the classification of the resource.

To date, only a few resource estimates have been completed, and those completed using historical data are mostly classified as an inferred resource. To improve the resource classification the sample spacing and quality of collected data and imagery needs to improve by using standard operating procedures (quality assurance), checks (quality control) and a determination of if it is fit for purpose (quality testing).

Autonomous underwater vehicles can collect high-quality imagery and bathymetry data. Machine learning techniques can log, categorise, and calculate nodule abundance from the seafloor images and support resource estimates. Using these techniques could result in a significant cost reduction in the exploration stage, further pushing these deposits all along the project development pathway.

Cobalt consumption will continue drive the demand for Co to be sourced from large seafloor deposits. A shift in the production centres could see non-mining countries potentially become significant (i.e. Pacific Island nations including the Cook Islands). However, challenges around sampling, resource estimation, mining and environmental considerations remain.

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