

indicate that polymetallic SMS deposits in the Pacific region have higher copper concentrations with significant enrichment in gold and silver.

Recently, marine mining appears to be feasible under specific conditions including:

- (1) high precious (gold and silver) and base metal grades (e.g. copper, zinc and lead);
- (2) site location close to land, i.e., within the territorial waters and EEZ of coastal states;
- (3) relatively shallow water depth, i.e. an average depth of not exceeding 2,000 metres.

Under those circumstances, massive sulphide mining can be economically attractive considering that the entire mining system is portable and can be moved from one mine site to another in a matter of days. Additionally, SMS mining will likely focus on relatively small areas of the seafloor and largely be restricted to the surface (strip mining) and shallow sub-surface to recover sulphide mounds and chimney fields.

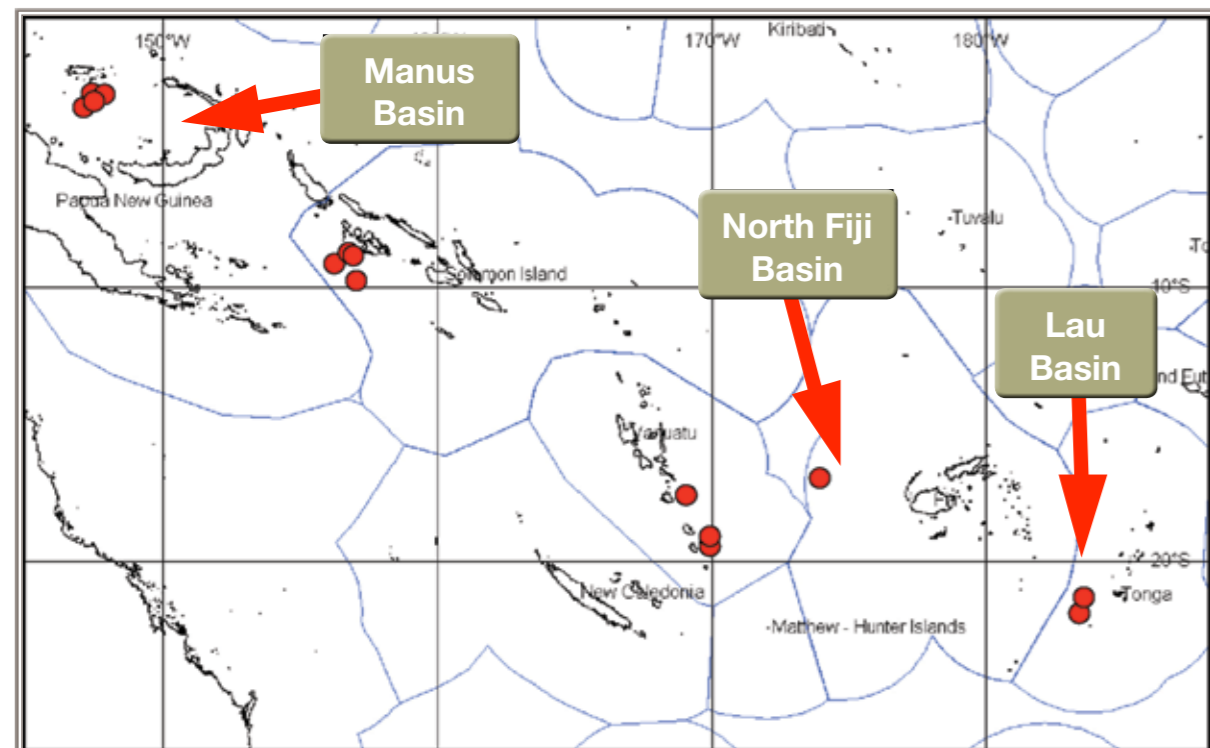


Figure 5. Locality map of known and potential SMS deposits in the Southwest Pacific.

## Known Deep Sea Mineral Resources in the Pacific Islands Region

The occurrence of Manganese Nodules, CRC and SMS are recognised within the EEZ of many Pacific Island Countries (PICs). Resource evaluation has confirmed that the potential for seabed mining in the region is significant. Known occurrences of these three types of polymetallic mineral deposits within the EEZ of various PICs are tabulated below:

Country	MN	SMS	CRC
Kiribati	✓		✓
Cook Islands	✓		
Tuvalu	✓		✓
Niue	✓	✓	
Papua New Guinea		✓	
Vanuatu		✓	
Solomon		✓	
Fiji		✓	
Tonga		✓	
Samoa			✓
Marshall Islands			✓
Federated States of Micronesia			✓
Palau		✓	

Abbreviations: MN – Manganese Nodules.

## Industrial Uses of Major Metals that occur on the Seabed

A summary of the uses of major metals that occur in seabed polymetallic mineral deposits is tabulated below:

Element	Symbol	Uses	Comments
<b>Manganese</b>	Mn	Manganese is a metal with important industrial metal alloy uses	Found often in combination with iron, and in many other minerals
<b>Nickel</b>	Ni	Chiefly valuable for alloys, especially many superalloys, and particularly stainless steel as in chemical plants, petroleum refineries, electrical appliances, and motor vehicles.	Nickel is magnetic, and is very often accompanied by cobalt
<b>Copper</b>	Cu	Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity	Minerals such as the sulphides: chalcocite ( $\text{Cu}_2\text{S}$ ), bornite ( $\text{Cu}_5\text{FeS}_4$ ), covellite ( $\text{CuS}$ ), chalcocite ( $\text{Cu}_2\text{S}$ ) are sources of copper
<b>Cobalt</b>	Co	Used in the preparation of magnetic, wear-resistant, and high-strength alloys as in the electrical, communications, aerospace, and engine and tool manufacturing industries.	Cobalt is usually not mined alone, and tends to be produced as a by-product of nickel and copper mining activities.
<b>Iron</b>	Fe	Its low cost and high strength make it indispensable in engineering applications such as the construction of machinery and machine tools, automobiles, the hulls of large ships, and structural components for buildings.	Iron is the most widely used of all the metals, accounting for 95% of worldwide metal production.
<b>Gold</b>	Au	Used as money, a store of value and in jewellery. Pure gold is too soft for ordinary use and is typically hardened by alloying with copper or other base metals.	It is a highly sought-after precious metal and occurs as nuggets or grains in rocks.
<b>Silver</b>	Ag	Used in many industries the major ones being jewellery, silverware and alloys.	It has the highest electrical conductivity of any element and the highest thermal conductivity of any metal.

## Conclusion

Based on previous exploration results, the potential of deep sea minerals that occur on the seabed within national jurisdiction of PICs are variable ranging from mere mineral occurrences to highly prospective zones. Through ongoing and systematic resource characterisation in which more geological data are made available, the potential of any mineral deposit can be categorised. With increased geological knowledge and confidence mineral resources can be upgraded from which the exploitability of any deposit can be determined.

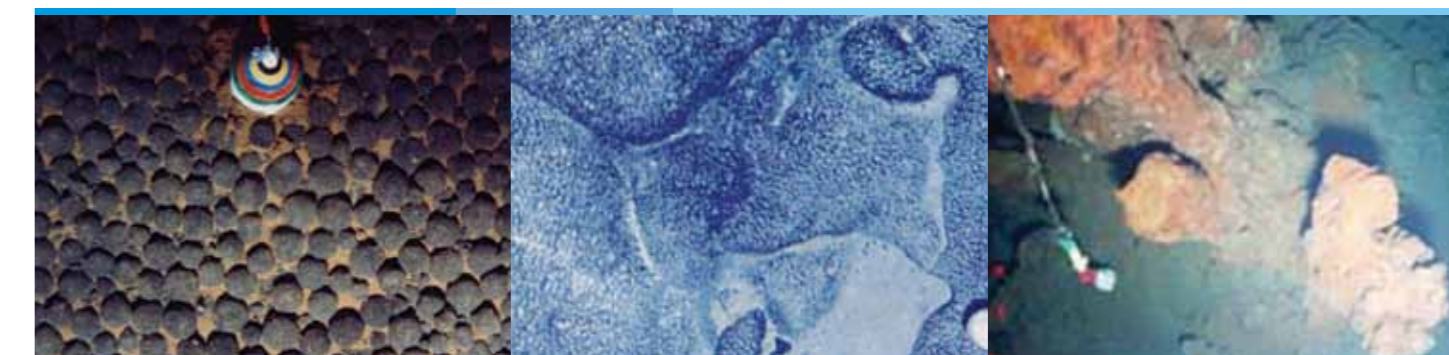
Recent interests in deep sea minerals are mostly confined to Seafloor Massive Sulphides and this is because of the exceptionally high metal grades associated with SMS compared to Manganese Nodules and Cobalt-rich Crusts. However, with the generally increasing trend of commodity prices coupled with the development of new seabed mining technologies the economic viability of Manganese Nodules and Cobalt-rich Crust deposits may also be realised in the foreseeable future. If this happens, many PICs are expected to become involved with and benefit from the extraction of seabed minerals.



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## SPC-EU EDF10 Deep Sea Minerals (DSM) Project



## Information Brochure 6 Deep Sea Minerals Potential of the Pacific Islands Region

## Introduction

Deep-sea minerals that occur within the Exclusive Economic Zones (EEZs) of many Pacific Island Countries (PICs) are increasingly being recognised as a future potential source of revenue and economic development. In the PICs, approximately eight million people live on small landmasses dispersed over the large span of the Pacific Ocean. These islands have a combined land area of 550,000km<sup>2</sup> compared to an area of 38.5 million km<sup>2</sup> of ocean territory or EEZs (Figure 1), a ratio of 1:70. For many of the smaller PICs, deep-sea minerals may represent the only exploitable natural resource sector apart from fish.

Apart from minor occurrences of other minerals such as phosphate and metalliferous sediments, there are three major types of polymetallic mineral deposits that are recognised on the world's deep seafloor environment today, namely, Manganese Nodules, Cobalt-rich Crusts (CRC), and Seafloor Massive Sulphide (SMS).

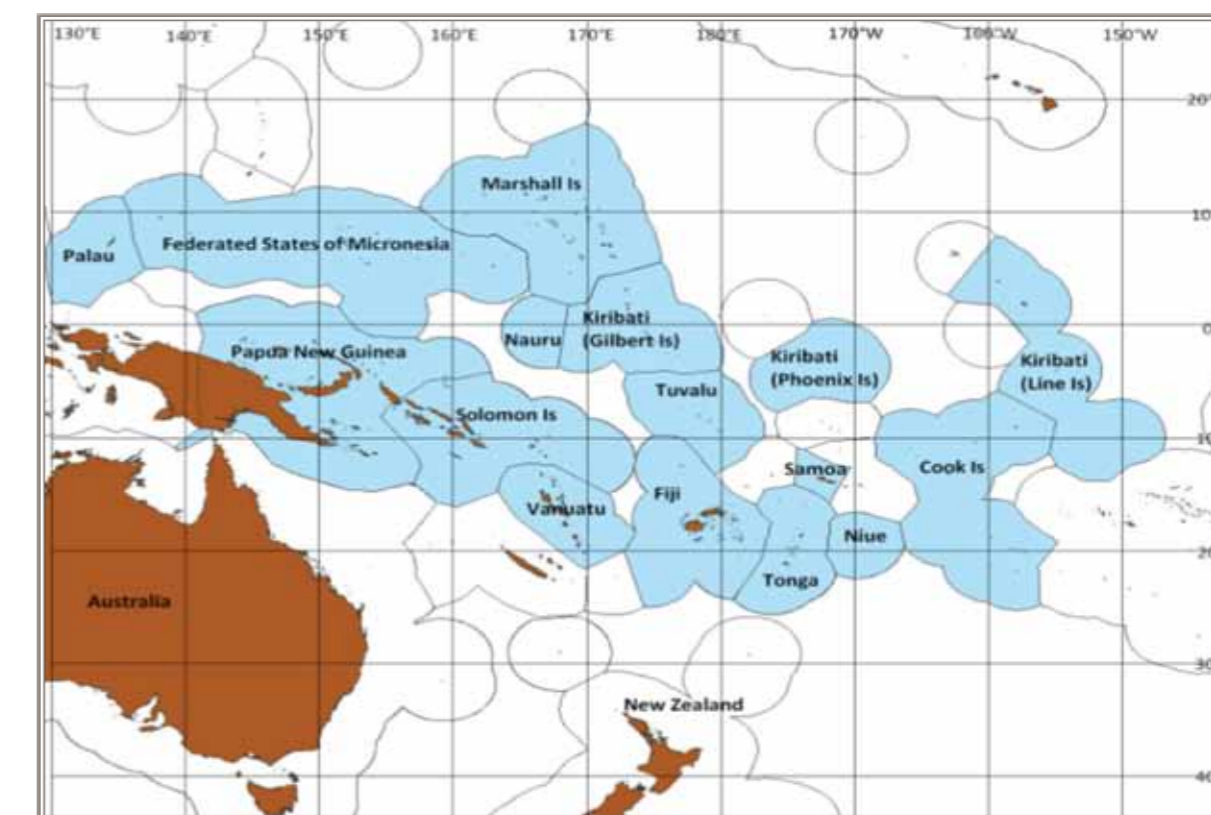


Figure 1. Map of the Pacific Island Countries showing the extent of their respective EEZs.

This information brochure presents a general overview of deep sea minerals exploration history and their potential in the Pacific Islands region today.

## Exploration History

Ever since the discovery of polymetallic Manganese Nodules in the Atlantic Ocean in 1873, there has been persistent curiosity about seabed minerals. It was not until after World War II that significant effort was placed on exploring Manganese Nodules in response to increased demand for metals during the post-war economic boom.

In the Pacific Islands region, marine minerals exploration was at a modest level until the early 1970s when increases in metal prices and the need for secure supplies of strategic minerals generated renewed interest in deep sea minerals. SOPAC was engaged in deep sea minerals exploration in the region between the early 1970s to mid 2000 in partnership with Pacific Island Countries and multinational agencies.

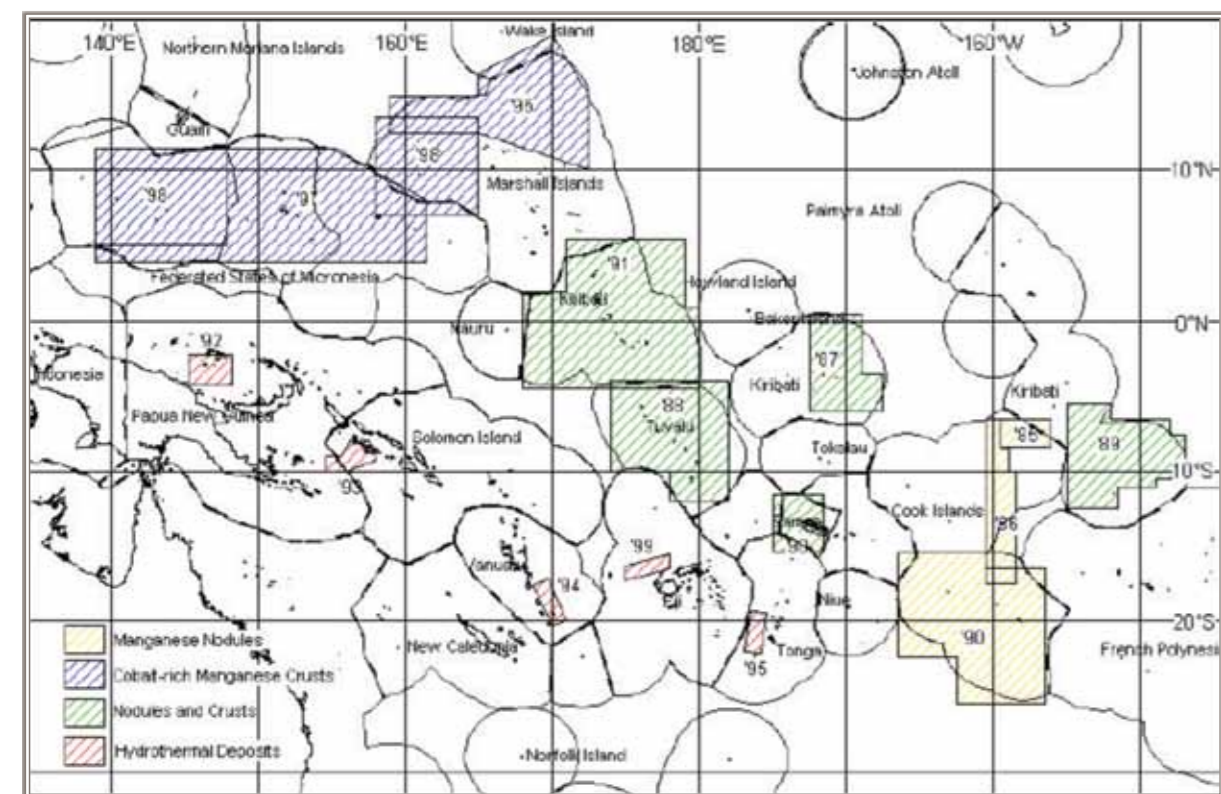


Figure 2. Locality map of the survey areas and minerals targeted within the EEZ of PICs during Phase 1 of the Japan-SOPAC Cooperative Study.

Exploration interests in the region were initially focused on Manganese Nodules in the 1970s and investigations for Cobalt-rich Crust did not commence until the 1980 survey of the Phoenix Islands in Kiribati. This was followed by the discovery of hydrothermal vents in the Lau Basin in 1982 and 1984. The first Seafloor Massive Sulphide (SMS) deposit in the region was confirmed in 1985 in the Manus Basin that is located to the north of PNG. Between 1985 and 2005, a twenty one year marine mineral prospecting was undertaken in twelve PICs through the collaborative efforts of the Government of Japan and SOPAC. The locality map of areas surveyed during phase-one of this program is shown in Figure 2. The aim of this Japan/SOPAC cooperative programme was to assess the resource potential for the three target mineral types (i.e. Manganese Nodules, CRC and SMS) in the region.

The discovery of SMS deposits in the Manus back-arc Basin triggered renewed offshore exploration interest in the early 1990s in PNG and high grade base and precious metals were confirmed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia that led to commercial exploration interests in the region. Nautilus Minerals Inc (Nautilus) was first granted with an offshore exploration license in PNG in 1997, followed by the commencement of exploration in the Manus Basin in 2005. Nautilus was granted a license to commence mining in the Manus Basin in January 2011.

The history of mineral exploration and discovery in the region is summarised in chronological order below:

- Early – Mid 1970s: Manganese Nodules;

- Mid 1970s – Mid 1980s: Manganese Nodules, Precious Coral, Metalliferous Sediments, Phosphate;
- 1980: Commencement of Cobalt-rich Crust exploration in the Phoenix Islands, Kiribati;
- 1982 and 1984: Discovery of hydrothermal vents in the Lau Back-arc Basin;
- 1985: Discovery of SMS deposit in the Manus Basin PNG;
- 1985 – 2005: Ongoing assessment of Manganese Nodules, Cobalt-rich Crust and Seafloor Massive Sulphide deposits;
- 1991: High base and precious metal grades in SMS deposits were confirmed in the Manus Basin by the CSIRO;
- 1997: Exploration license was issued to Nautilus by the government of PNG for SMS exploration in the Manus Basin;
- 2005: Nautilus commenced SMS exploration in the Manus Basin PNG;
- 2011: Nautilus was granted a mining license by the PNG Government.

## Resource Economic Potential

### Manganese Nodules

Nodules of economic interests have been found in four areas: the Clarion-Clipperton Fracture Zone in north-central Pacific Ocean, the Penrhyn Basin in south-central Pacific Ocean, the Peru Basin in the south-east Pacific, and the centre of the north Indian Ocean.

In the Pacific Islands region the most promising deposit in terms of nodule abundance and metal concentration known to date occurs within the EEZ of the Cook Islands. Other potential areas are the two eastern island groups of Kiribati (Phoenix and Line) and to a lesser extent the Gilbert Islands (Kiribati) and within the EEZ of Tuvalu (Figure 3) and Niue.

An economic evaluation of the feasibility of Manganese Nodule mining was first introduced by Mero (1977) and considered the following criteria: 1) abundance, 2) metal content, 3) aerial extent and continuity, 4) water depth, 5) seafloor topography, 6) nodule size, 7) characteristics of surface sediments, 8) obstructions to mining systems, 9) distance to port, 10) weather and 11) currents. According to this study, a nodule deposit is considered economic, if nodule abundance exceeds 5 kg/m<sup>2</sup>; Ni plus Cu content exceeds 2.8 % on dry basis; it covers an area of at least 10,000 km<sup>2</sup>; the slope of seafloor is less than 10 %; and gangue material (waste) is less than 20 %.

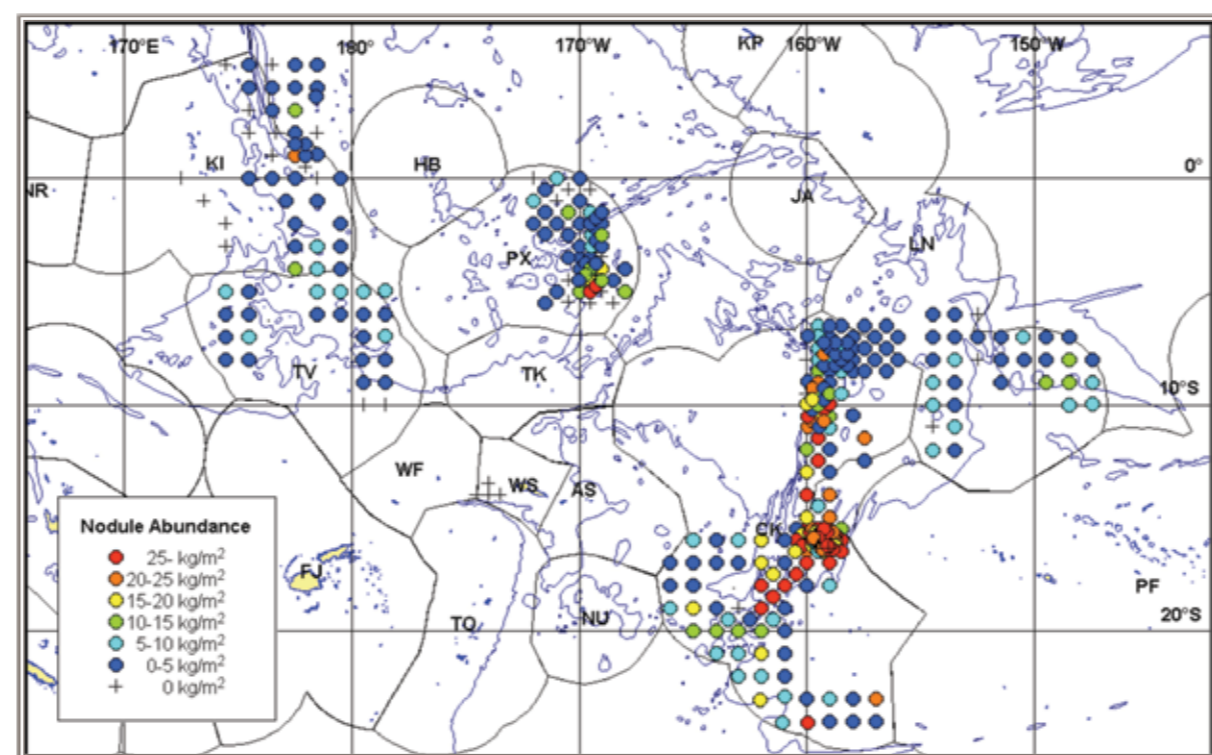


Figure 3. Manganese Nodules abundance map of the Pacific Islands region.

Despite the many studies that have been carried out since that time to estimate favourable conditions for commercial exploitation of manganese nodules, fluctuating world metal prices, mining technology development, metal grades and other factors will continue to dictate the economic viability of any future mining operations. Sufficient high grade nodules must be harvested to make a profit rather than simply gathering and processing large quantities of nodules.

### Cobalt-rich Crust

Based on grade, tonnage, and oceanographic conditions, the central equatorial Pacific offers the best potential for crust mining, particularly within the EEZ of Johnston Island (USA), the Marshall Islands, and international waters in the Mid-Pacific Seamounts. The EEZs of French Polynesia, Kiribati, and the Federated States of Micronesia must also be considered as potential crust locations (Figure 4) and minor occurrences of crusts have also been recorded in Tuvalu, Samoa and Niue.

Cobalt-rich Crust mining is much more technologically challenging than Manganese Nodule mining as crusts are attached to rock substrates. For successful mining, it is essential to recover crusts without collecting substrate materials, which would significantly dilute the ore grade. Cobalt is the most important of the elements in nodules and crusts with respect to the price and as a strategic metal that is indispensable for superalloys used in jet aircraft engines. A 1985 preliminary economic assessment of crust mining and processing operations concluded that they were not at that time economically viable.

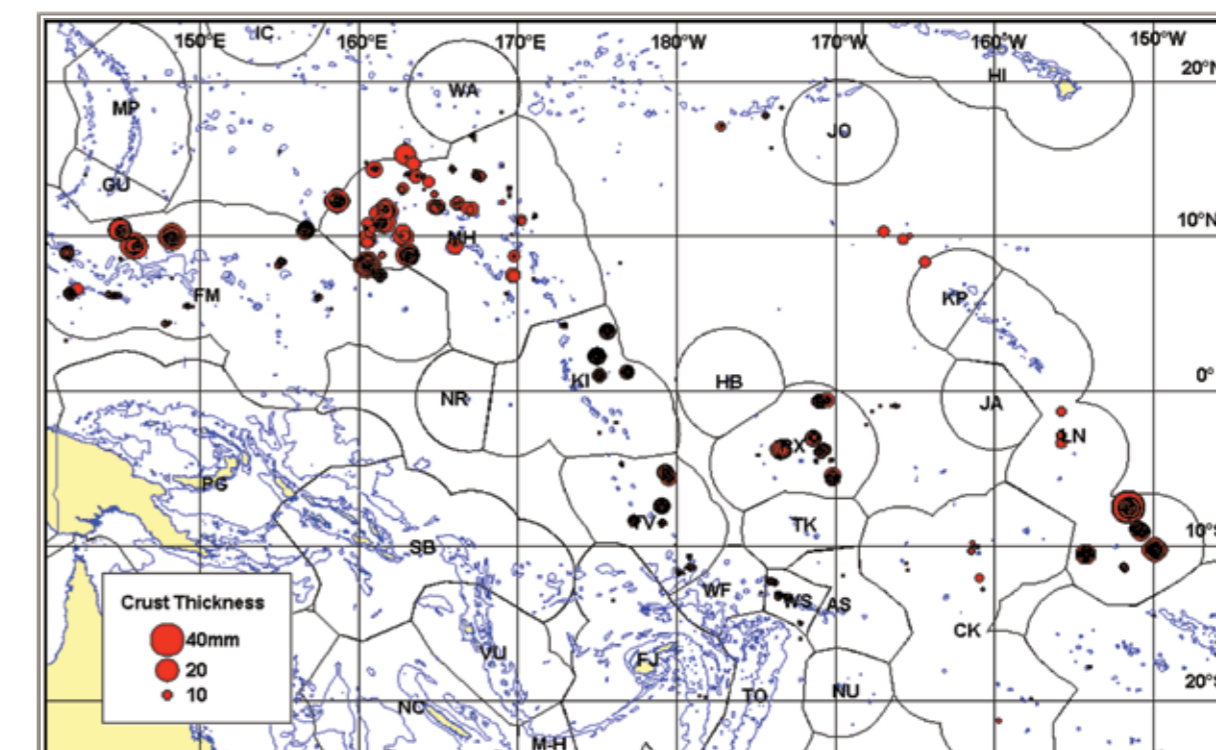


Figure 4. Cobalt-rich Crust occurrence map within the EEZ of PICs.

### Seafloor Massive Sulphide

More than 200 sites of hydrothermal mineralisation are known to occur on the seafloor and based on previous exploration and resource assessment about ten of these deposits may have sufficient size and grade to be considered for future mining.

These potential sites include the Atlantis II Deep in the Red Sea (Saudi Arabia & Sudan), Middle Valley (Canada), Explorer Ridge (Canada), Galapagos Rift (Ecuador), and the East Pacific Rise 13°N in the Pacific Ocean, the TAG hydrothermal field in the Atlantic Ocean, as well as the Manus Basin (Papua New Guinea), the Lau Basin (Tonga), the Okinawa Trough (Japan), and the North Fiji Basin (Fiji) in the western and south-western Pacific (Figure 5). All of these sites except two (East Pacific Rise 13°N and TAG hydrothermal field) are located within the EEZs of coastal states.

Apart from PNG, Fiji and Tonga, SMS deposits or indications of SMS deposits are also reported to have occurred within the waters of Solomon Islands, Vanuatu and Palau. Ongoing exploration and resource evaluation