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COOK ISLANDS POLYMETALLIC NODULE DEPOSIT

Technical Report and Supporting Documentation for the Cook Islands Polymetallic Nodules Resource Estimate

Report prepared for:	COOK ISLANDS SEABED MINERALS AUTHORITY Avarua, Rarotonga, Cook Islands
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Executive Summary

The Seabed Minerals Authority (SBMA) of the Cook Islands has commissioned RSC to undertake a mineral resource estimate for a polymetallic nodules deposit located in the Cook Islands Exclusive Economic Zone (EEZ) and prepare a technical report to summarise the results. The Report's effective date is 22 March 2023.

The Cook Islands polymetallic nodule deposit is located in the South Pacific Ocean from 166.8–155.3°W and 5.7–25.1°S with a geographic mean centre of 160.6°W, 16.5°S. While the nodule deposit is known to extend beyond the EEZ, the Project Area is limited to within the EEZ boundary. The Project Area includes an area (referenced in this Report as '16-159' or 'Central Area'), which contains closer sample spacing and bathymetric data.

SBMA is a Cook Islands Government agency. It does not hold any mineral titles (often called 'permits', 'licences' or, 'tenements') but administers the seabed mineral titles for Cook Islands. By the effective date of this Report, three exploration licences have been granted.

Nodules were first found in the Project Area by RV Vitiaz in 1963. After a series of expeditions in the 1970s, Japan International Corporation Agency and the Metal Mining Agency of Japan (JICA-MMAJ) conducted a series of systematic exploration expeditions between 1985 and 2000. Between 1995 and 2015, historical resource estimates were published; however, none were reported in accordance with any contemporary CRIRSCO-affiliated code. Several scoping studies were produced in conjunction with these reports, with mostly positive outcomes, the key issue being assumed future metal prices rather than envisaged engineering solutions.

Polymetallic nodules are part of a spectrum of ferro-manganese precipitates that are found throughout the world's oceans. The Cook Islands is distinctive in having:

a. relative ancient and stable ocean crust; coupled with
b. very low-modelled net export of organic material to the seabed; and
c. the interpreted influence of a long-lived deep-water ocean current.

Much of the seabed in the southeast and eastern sides of the EEZ are abyssal plains; these are interrupted by several seamount chains as well as a large oceanic plateau in the northwest. While nodules are found on the plateau and may be present on parts of the seamounts, only the abyssal plain-hosted deposits are expected to be present in sufficient qualities and quantities to have reasonable prospects of eventual economic extraction. Knowledge of the geology of the seabed of the Project Area is based on a geomorphological interpretation of the GEBCO grid and magnetic survey (1:3,000,000 scale), supported by historical sampling and acoustic survey. These constrain the stratigraphy and classify the various types of clay-ooze found on the seabed, as well as characterising the form and quality of nodules found in different locations. The 16-159 Area was surveyed by multibeam echosounder survey as well as other acoustic methods and supported by closer-spaced sampling, allowing for a more detailed geological map (1:500,000 scale) to be made.

Polymetallic nodule abundance and elemental grades vary throughout the Project Area but are much more consistent within the 16-159 Area. Abundance is the term used to describe the number of nodules found in a given sample area; it is measured in kilograms per square metre because nodules are typically formed on the seabed as a single layer of precipitate, several centimetres thick, so are, in effect, a two-dimensional deposit. Four grade classes can be defined, with 1) a high Co type being currently the focus of economic interest. There are also: 2) a high Ni type, found so far only in low abundances, 3) a low Co and low Ni type and 4) a transitional type. The geographical distributions of these types overlap but are, to some extent, distinct and can be explained in terms of the abovementioned net export or organic material and deep-water ocean current.

Exploration work used to support the MRE was not conducted by SBMA, but by other organisations on behalf of the Cook Islands Government (either directly through a marine research permit or via South Pacific Applied Geosciences Commission programmes). Exploration conducted by JICA-MMAJ data is the most systematic and comprehensive dataset available, providing 81% of abundance and 51% of grade samples in the compilation dataset for the Project Area and 98% of the abundance and 94% of the grade samples used in the 16-159 Area. Most (95%) of physical samples taken by JICA-MMAJ, used free-fall grabs (FFG) supported by seabed photographs. More recently in 2019, samples were collected in and around the 16-159 Area, using FFGs, by two companies: Cook Islands Investment Corporation Seabed Resources (CIICSR), and Ocean Minerals LLC (OML), under marine scientific research permits.

The MRE process initially involved declustering of data, reprojection of data onto a custom equal area projection (required because the project spans two Universal Transverse Mercator zones) and imposition of a series of geological, geographic, statistically supported (abundance and grade) domains. Within each domain, summary statistics indicate the data has a low coefficient of variation and monomodal distributions with low to moderate skew. The spatial continuity of abundance, Co, Cu, Fe, Mn, and Ni was independently modelled in the horizontal plane.

Experimental semi-variograms were modelled with relatively low γ_0 values and one or two spherical structures. All variograms display reasonable structure for global estimation and are compatible with the classification of Indicated and Inferred Mineral Resources. A block size of 50 km x 50 km was used, with sub-blocks of 25 km x 25 km. In the 16-159 Area, a block size of 12.5 x 12.5 km was used. Estimation used ordinary kriging in progressively wider passes. Validation methods included visual and comparison of means as well as validation plots. Sensitivity testing through variance of the parameter settings found the estimate to be robust. A multifactor scorecard was also applied to data quality to support the classification of the estimate.

The Mineral Resource has been classified following the guidelines defined by the JORC Code (2012). Mineralisation within is classified in the Indicated and Inferred categories (Table 1). A cut-off of 5 kg/m^2 nodule abundance was selected based on consideration of previous studies of comparable deposits and grade-tonnage relationships in the different areas. No material has been classified as Measured.

Table 1-1: Mineral Resource Statement at nodule abundance cut-offs of 5 kg/m^2.

Classification	Cut-off (kg/m^2)	Abundance (wet) kg/m^2	Nodules Mt (wet)	Metal Grade (%)				
				Co	Cu	Fe	Mn	Ni
Indicated	5	26.7	304	0.50	0.15	18.5	15.4	0.25
Inferred	5	14	6,400	0.4	0.2	17	16	0.4
Global	**5**	**14.4**	**6,700**	**0.44**	**0.21**	**17.4**	**15.8**	**0.37**

Notes:
1. The Mineral Resource is reported in accordance with the JORC Code (2012).
2. The Mineral Resource is contained within the Cook Islands Exclusive Economic Zone.
3. Mineral Resources have been rounded to reflect their confidence. Some totals do not add up exactly due to rounding.
4. Abundance is the wet weight (kilograms) of polymetallic nodules per square metre.
5. Dry tonnages were not estimated, free moisture levels (i.e. not water of crystallisation) vary but are in the order of 30% on a wet basis.

The MRE is supported by consideration of minerals harvesting (mining) and metallurgical processing methods, which have been addressed in past scoping studies and in more contemporary studies for the polymetallic nodule deposit in the Clarion Clipperton Zone (CCZ). Careful attention was paid to environment, social and governance issues, including the social setting of the Cook Islands, and the existing governance framework — both domestically and in terms of international conventions —that the Cook Islands is a signatory to.

In assessing the reasonable prospects for eventual economic extraction, the Competent Person has considered conceptual mining, metallurgical and economic parameters as well as environmental and social aspects. It is more likely than not that minerals harvesting of the Mineral Resource estimated in this report would be technically and economically viable once appropriate studies are completed. There is exploration potential within and outside the boundary of the MRE, and recommendations are provided to further extend and improve the datasets for any future estimates and associated assessment of reasonable prospects of eventual economic extraction.

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Acronyms

Acronym	Description	Acronym	Description
2D	2 Dimensional	**DNA**	Deoxyribonucleic Acid
AAS	Atomic Absorption Spectroscopy	**DOC**	Dissolved Organic Matter
AD	Arm Dredge	**DOMES**	Deep Ocean Mining Experimental Study
Al_2O_3	Aluminum Oxide	**DQO**	Data Quality Objective
ALS	Australian Laboratory Services	**DSDP**	Deep-sea Drilling Program
AMML	Australian Minmet Metallurgical Laboratories	**eDNA**	Environment Deoxyribonucleic Acid
As	Arsenic	**EEZ**	Exclusive Economic Zone
AUV	Autonomous Underwater Vehicle	**EIA**	Environmental Impact Assessment
B	Boron	**ENSO**	El-Nino Southern Oscillation
BaO	Barium Oxide	**ESIA**	Environmental and Social Impact Assessment
BC	Box core	**EU**	European Union
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe	**EUR**	Euro
BGRIMM	Beijing General Research Institute for Mining and Metallurgy	**EWC**	East-West Center
BPOA	Barbados Program Of Action	**FAO**	Food and Agriculture Organisation
CaO	Calcium Oxide	**FDC**	Finder installed continuous Deep-sea Camera
CCD	Carbonate Compensation Depth	**Fe**	Iron
CCOP/SOPAC	Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas	**Fe_2O_3**	Ferric Oxide
CCZ	Clarion-Clipperton Zone	**Fe-Mn**	Ferromanganese
CDC	Continuous Deep-sea Camera	**FeO**	Iron (II) Oxide
CIC	Cook Islands Company	**FFG or FG**	Free-Fall Grab
CIICSR	Cook Islands Investment Corporation Seabed Resources	**FOB**	Free Onboard Incoterms (International Commercial)
CIPA	Cook Islands Port Authority	**FS**	Feasibility Study
Co	Cobalt	**GCS**	Geographic Coordinate System
CO_2	Carbon Dioxide	**GDP**	Gross Domestic Product
CRIRSCO	Committee for Mineral Reserves International Reporting Standards	**GEBCO**	General Bathymetric Chart of the Oceans
CTD	Conductivity Temperature Depth	**GIS**	Geographic Information System
Cu	Copper	**GLONASS**	Global Navigation Satellite System
CV	Coefficient of Variation	**GPS**	Global Positioning System
DFAT	Department of Foreign Affairs and Trade	**GSR**	Global Seabed Resources

Acronym	Description	Acronym	Description
HM2	Hakurei Maru No. 2	**MMAJ**	Metal Mining Agency of Japan
HMNZS Tui	Her/His Majesty New Zealand Ship	**MMC**	Marae Moana Council
HMS	Her/His Majesty Ship (Great Britain)	**MMR**	Ministry of Marine Resources
HMZ	Habitat Management Zone	**Mn**	Manganese
ICI	Infrastructure Cook Islands	**MnO_2**	Manganese Oxide
ICP	Inductively Coupled Plasma	**Mo**	Molybdenum
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy	**MoT**	Ministry of Transport
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy	**MOTU**	Molecular Observable Taxonomic Units
IMF	International Monetary Fund	**MP**	Manihiki Plateau
INDEX	Indian Deep-sea Environment Experiment	**MPA**	Marine Protected Area
IOM	Inter-Ocean Metal	**MRE**	Mineral Resource Estimate
IONF	Indian Ocean Nodule Field	**MS**	Mass Spectrometry
IRENA	International Renewable Energy Agency	**MV**	Motor Vessel
IRR	Internal Rate of Return	**Na_2O**	Sodium Oxide
ISA	International Seabed Authority	**NAA**	Neutron Activation Analysis
ISO/IEC	International Organisation for Standardisation	**NBS**	Narrow-Beam Echosounder
JICA	Japan International Corporation Agency	**NDSMG**	Norwegian Deep Seabed Mining Group
JOGMEC	Japan Oil, Gas and Metals National Corporation	**NES**	National Environment Service
JORC	Joint Ore Reserves Committee	**NGO**	Non-Governmental Organisation
JPIO	Joint Programming Initiative Healthy and Productive Seas and Oceans	**Ni**	Nickel
K_2O	Potassium Oxide	**NNSS**	Navy Navigation Satellite System
KODOS	Korea Deep Ocean Studies	**NOAA**	National Oceanic and Atmospheric Administration
LC	Large Gravity Corer	**NORI**	Nauru Ocean Resources Incorporated
LECO	Laboratory Equipment Corporation	**NPB**	North Penrhyn Basin
LFPR	Labor Force Participation Rate	**NPV**	Net Present Value
Ma	Mega Annum	**NZD**	New Zealand dollar
MBES	Multi-Beam Echosounder	**OML**	Ocean Minerals LLC
MFEM	Ministry of Finance and Economic Management	**OMZ**	Oxygen Minimum Zone
MFES	Multi-Frequency Exploration System	**P_2O_5**	Phosphorus Pentoxide
MgO	Manganese Oxide	**PAAS**	Post Archaean Australian Shale
MGR	Marine Genetic Resources	**Pb**	Lead

Acronym	Description	Acronym	Description
PDR	Precision Depth Recorder	**SPB**	South Penryhn Basin
PFS	Pre-Feasibility Study	**SPC**	Pacific Community
POC	Particulate Organic Carbon	**STAR**	Scottish Transport Application and Research
Pt	Platinum	**TAG**	Technical Advisory Group
QA	Quality Assurance	**Ti**	Titanium
QAT	Quality Acceptance Testing	**TiO_2**	Titanium Dioxide
QC	Quality Control	**TOML**	Tonga Offshore Mining Limited
QGIS	Quantum Geographic Information Systems	**TSX**	Toronto Stock Xchange
RAC	Religious Advisory Council	**UK**	United Kingdom
rDet	Regulated Direct-Energy Transfer	**UNCLOS**	United Nation Convention Law of the Sea
REE	Rare Earth Elements	**UNDP**	United Nation Development Program
REY	Rare Earth Elements and Yttrium	**US**	United States
RL	Reduced Level	**USBL**	Ultra-Short Baseline
RSC	RSC Limited	**USD**	United States dollar
RV	Research Vessel	**USGS**	United States Geological Survey
SBMA	Seabed Minerals Authority	**USNEL**	United States Naval Electronic Laboratory
SBP	Sub-Bottom Profiler	**UTM**	Universal Transverse Mercator
SC	Spade Core	**V**	Vanadium
SCI	Southern Cook Islands	**WGS72**	World Geodetic System
SD	Standard Deviation	**WGS84**	World Geodetic System
SEC	Security Exchange Commission (United States)	**XRD**	X-Ray Diffraction
SiO_2	Silicon Dioxide	**XRF**	X-Ray Fluorescence
SMS	Seafloor Massive Sulfide	**Y**	Yttrium
SOLAS	Safety Of Life At Sea Convention	**Zn**	Zinc
SOPAC	South Pacific Applied Geoscience Commission	**Zr**	Zirconium
SOPs	Standard Operating Procedures		

Units of measurement

Unit	Description	Unit	Description
Bt	billion tonnes	**lb**	pounds
cm	centimetres	**m**	metres
g	grams	**m^2**	square metres
g/cm^3	grams per cubic centimetre	**mbsl**	metres below sea level
kg/m^2	kilograms per square metre	**mm**	millimetres
kHz	kilohertz	**ppm**	parts per million
km	kilometres	**wt%**	weight percent
km^2	square kilometres	**Mt**	million tonnes
kt	kilotonnes	**t**	tonnes

1 Introduction and Terms of Reference

1.1 Scope

The Seabed Minerals Authority (SBMA) of the Cook Islands has commissioned RSC to undertake a mineral resource estimate (MRE) for a polymetallic nodules deposit located in the Cook Islands Exclusive Economic Zone (EEZ) and prepare a technical report to summarise the results.

The work that RSC has undertaken for this project includes a thorough review of all available data and reports, review of sampling procedures, statistical analysis and validation of data, mineral resource estimation, review of conceptual mining methods and review of conceptual economic assumptions and metallurgy.

SBMA is a Cook Islands Government agency. It does not hold any mineral titles (often called 'permits', 'licences' or, 'tenements') but administers the seabed mineral titles for the Cook Islands. The MRE summarised here is reported and classified in accordance with the JORC Code (2012) and will assist SBMA in the management of the resource and associated marine environment for the ultimate benefit of the Cook Islands people.

1.2 Qualifications, Experience and Reliance on Other Experts

The work completed by RSC and SBMA and the subject of this report was carried out by the following people:

- **John Parianos** is the Competent Person responsible for all sections of the report, except section 7. Dr Parianos is a member of the AIG, has a PhD in marine geology from the University of Évora (2021) and is a full-time employee and Technical Director at Cook Islands Seabed Minerals Authority under the Australia-Pacific Partnerships Platform. His experience includes exploration, assessment and evaluation of seabed nodule deposits in the Cook Islands and CCZ as well as with the management and delivery of full value chain scoping studies of this deposit type. Dr Parianos has been the principal author of technical papers involving the regional and project-scale geology of nodule deposits and their mineral resources. He has presented to professional seabed mining industry conferences, contributed to resource estimation workshops involving the seabed mineral industry, and has also been involved with expert working groups addressing seabed mining policy.
- **René Sterk** is a fellow of the AusIMM and a Chartered Professional Geologist (CP Geo) with the AusIMM. Mr Sterk is the Competent Person responsible for section 7 of the report. Mr Sterk holds an MSc in Structural Geology and Tectonics from the Vrije Universiteit Amsterdam (2002) and is a full-time employee and Managing Director of RSC, an independent international consulting group. His experience includes assessment and evaluation of seabed nodule deposits near New Zealand, Cook Islands and in the CCZ. Mr Sterk has been the principal author of technical papers concerning seabed sampling techniques and code-compliant documentation of seabed resources. He has presented to professional seabed mining industry conferences, facilitated resource estimation training workshops for the seabed mineral industry, and has also been involved with expert working groups addressing seabed mining policy.

- **Stephie Tay** is a project geologist at RSC and an associate of the AusIMM. Ms Tay gained an MSc in Geology from the University of Otago. She has experience in geological reporting, GIS mapping and mineral resource estimation. Ms Tay has worked on a number of polymetallic nodule deposits in the CCZ and Cook Islands. Under the supervision of the Competent Persons, Ms Tay conducted data verification, statistical analysis and resource modelling, and is a co-author of this report, acting under the supervision of the Competent Person.
- **Rima Browne** is the Senior Technical Officer at the Cook Islands Seabed Minerals Authority. Miss Browne has a BSc in geography from the University of Auckland (2017). Her experience includes nodule exploration and assessment, GIS mapping, data compilation and sector research within the Cook Islands. Under the supervision and guidance of the Competent Persons, Ms Browne compiled the dataset for this project, conducted data verification, and co-authored several sections of the report, under the supervision of the Competent Person.
- **Olivier Bertoli** is the General Manager Resources and Reserves at RSC. He has extensive experience in advanced geostatistical modelling: 2D methods, recoverable resources estimation, conditional simulations and multivariate modelling. Mr Bertoli trained in applied mathematics and geostatistics from the Paris School of Mines and is a Member of the AusIMM. Mr Bertoli has experience with a wide range of commodities including precious and base metals, mineral sands, diamonds, iron ore, coal deposits, and polymetallic nodules. Mr Bertoli supported the geostatistical component of the resource estimation reported in section 7, under the supervision of the Competent Person.

1.3 Independence Declaration

The relationship of RSC with SBMA is based on a purely professional association. This report was prepared in return for fees based on agreed commercial rates, and the payment of these fees is in no way contingent on the results of this report.

1.4 Sources of Information

The following data were provided by SBMA:

- historical sample data and associated expedition reports, which include method descriptions and limited quality control data;
- geomorphological map and associated geological domains; and
- GIS files that show the extent of the EEZ.

This information includes historical and recent reports, reports on expeditions (cruises), associated acquired data and recent compilations of this work. All available spatial referenced data, including chemical analyses, contents of grab samples, photographs, maps, survey lines and limited biological data, have been compiled into a GIS database. Much of the information was received from the Pacific Community (SPC), which was previously known as SOPAC. SPC acquired the data from Japan International Corporation Agency ('JICA'; see sections 3 and 5). Other data compilations are referenced in Section 3.

1.5 Site Visit

Rima Browne and John Parianos (SBMA) have both visited the Project Area on separate expeditions to collect physical and photographic evidence of nodules using free-fall grabs and box cores, respectively. The free-fall grabs observed by Rima Browne were collected during the CIICSRNOD19 expedition as described in Section 5.2.

1.6 Definitions

The Cook Islands Government refers to the collection of polymetallic nodules as ‘minerals harvesting’, as nodules can be collected without any cutting, while the term ‘mining’ refers to extraction practices that involve cutting of the material involved. This application of terms has some equivalents outside of the Cook Islands (e.g. AMC and others, 2021), but currently, at least, the term ‘mining’ is often extended to include the collection of polymetallic nodules (e.g. International Seabed Authority, 2020). In this report, both terms are used and can be interchanged.

1.7 Disclaimer

The opinions, statements and facts contained herein are effective as of 22 March 2023, unless stated otherwise in this report.

Given the dynamic nature of the mining industry, conditions can change significantly over relatively short periods of time. Consequently, actual results and performances may be more, or less, favourable in the future and their disclosure does not represent the legal opinion of the authors.

For disclosure of information relating to socio-political, environmental and other related issues, the authors have relied on information provided to RSC.

Results of evaluation and any opinions or conclusions made by RSC are not dependent on prior agreements or undisclosed understandings concerning future business dealings with SBMA.

The authors of this report are not qualified to provide extensive comment on legal issues associated with Cook Islands polymetallic nodule deposit described in this report.

Similarly, the authors are not qualified to provide extensive comment on risks of any nature (operational, sovereign, terrorist or otherwise) associated with the Cook Islands polymetallic nodule deposit.

This document contains certain statements that involve several risks and uncertainties. There can be no assurance that such statements will prove to be accurate; actual results and future events could differ materially from those anticipated in such statements.

The information, conclusions, opinions, and estimates contained herein are based on:

- information available to RSC at the time of preparation of this report;
- assumptions, conditions, and qualifications set out in this report; and
- data, reports, and other information supplied by SBMA and other third-party sources.

The opinions, conclusions and recommendations presented in this report are conditional on the accuracy and completeness of the existing information.

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The statements and opinions expressed in this document are given in good faith, and in the belief that such statements and opinions are not false and misleading at the date of this report. RSC reserves the right, but will not be obligated, to revise this report and conclusions, if additional information becomes known to RSC, after the date of this report.

RSC assumes no responsibility for the actions of the company or others with respect to the distribution of this report.

2 Project General Summary

2.1 Project Description and Location

The Cook Islands polymetallic nodule deposit is located in the South Pacific Ocean from 166.8–155.3°W and 5.7–25.1°S with a geographic mean centre of 160.6°W, 16.5°S (Figure 2-1). While the nodule deposit is known to extend beyond the EEZ, the Project Area is limited to within the EEZ boundary ('Project Area'; Figure 2-1).

The Project Area includes an area (referenced in this Report as '16-159' or 'Central Area'), which contains closer sample spacing and bathymetric data.

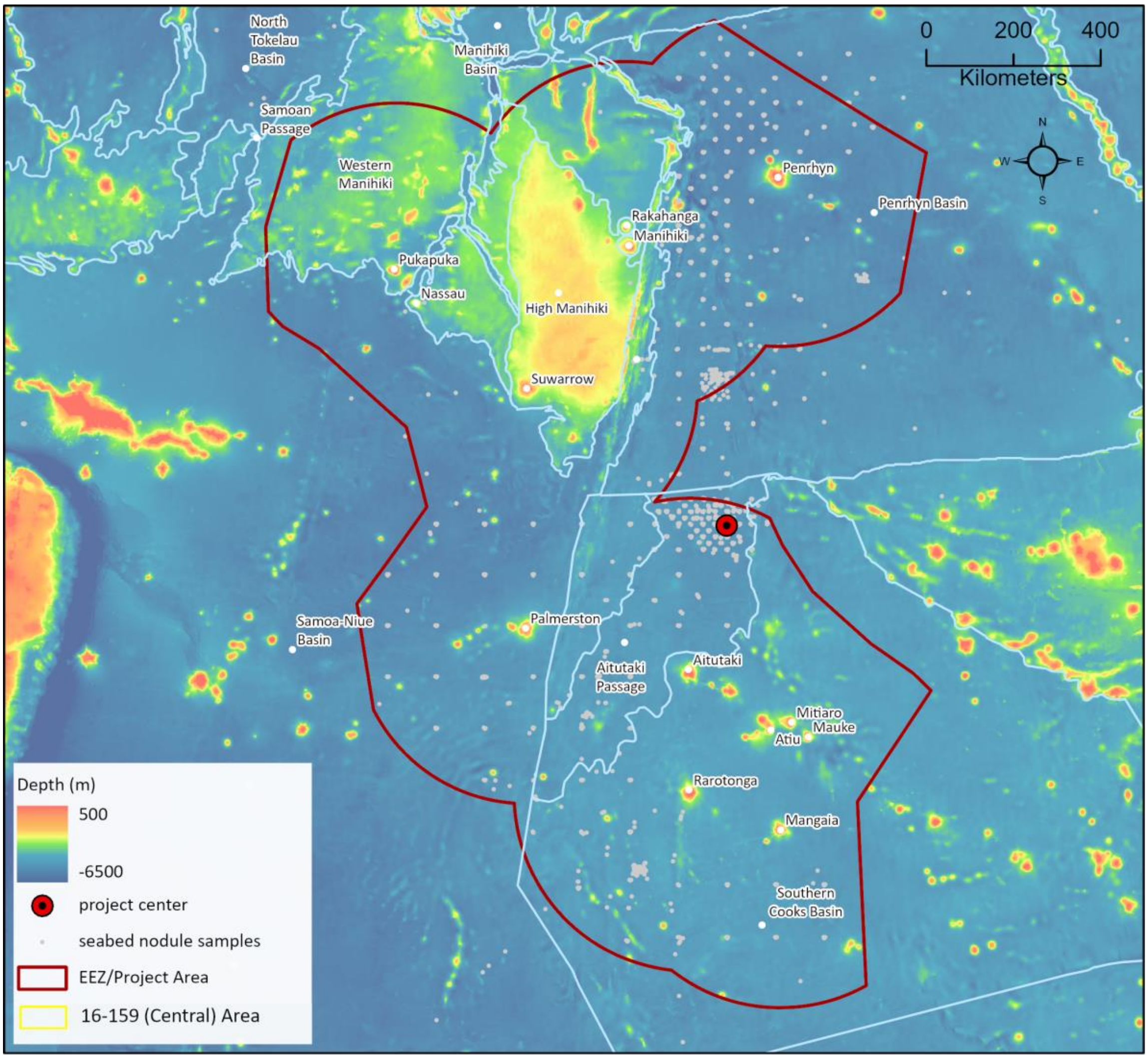


Figure 2-1: Project Area.

Due to the extensive size of the polymetallic nodule deposit around the Cook Islands, a naming convention based on relative or absolute location was established. JICA and the Metal Mining Agency of Japan (MMAJ) – collectively JICA-MMAJ – devised a longitude/latitude-based regional system which was implemented during the South Pacific Applied Geoscience

Commission (SOPAC) sampling programme that included the Cook Islands and extended to the other side of the antemeridian (JICA-MMAJ, 1986). Kenex (2014a) also developed a longitude/latitude alphanumerical-based system as part of its prospectivity study. However, in SBMA's opinion, neither of those naming conventions were easy to use and a new convention is defined here.

Specifically:

- Geographic zones within the Project Area are referred to in terms of the nearest degree of latitude and longitude at the geographic centre of the zone. The zone may extend by several degrees in either direction.
- Latitude is referred to first as the deposit is predominantly north-trending and the vectors of mineralisation (bottom water currents and surface primary productivity) are also typically oriented towards north.
- Smaller zones are scalable so that the naming convention code can include decimal degrees.

Some examples of the application of this new naming convention are included in Figure 2-2.

2.2 Tenure and Ownership

SBMA is a Cook Islands Government agency. It does not hold any mineral titles (often called 'permits', 'licences' or, 'tenements') but administers the seabed mineral titles for Cook Islands.

SBMA was established by the Cook Islands Government Cabinet on 26 June 2012. The purpose of the SBMA is to develop the seabed minerals sector to maximise the benefit of the national seabed mineral resources for the Cook Islands people and development partners, while also taking social and environmental considerations into account. Under the *Seabed Minerals Act 2019*, the Minister for Minerals and Natural Resources has responsibility for the overall management of the seabed minerals sector. The day-to-day regulation of seabed minerals activity is the responsibility of SBMA, headed by the Seabed Minerals Commissioner.

The main regulatory tool for the management of the seabed minerals sector is a standardised licencing system under which Cook Islands registered companies or individuals can apply for licences to carry out seabed mineral prospecting, exploration, and mining operations in return for meeting explicit and enforceable obligations. The objective of the licencing system is to ensure that mineral rights are allocated to companies that have the requisite financial standing, expertise, experience, and reputation to support seabed minerals exploration and exploitation in the Cook Islands.

There are four types of seabed mineral licences available to suit the various phases of seabed minerals activity: prospecting, exploration, retention, and mining licences. A seabed mineral licence holder is guaranteed security of rights, including the right to proceed from minerals exploration to mining once the commercial feasibility and environmental sustainability of mining have been established and proven, in return for the satisfactory performance of the required specific and enforceable commitments by licence holders, as set by SBMA and recorded as terms and conditions of the licence.

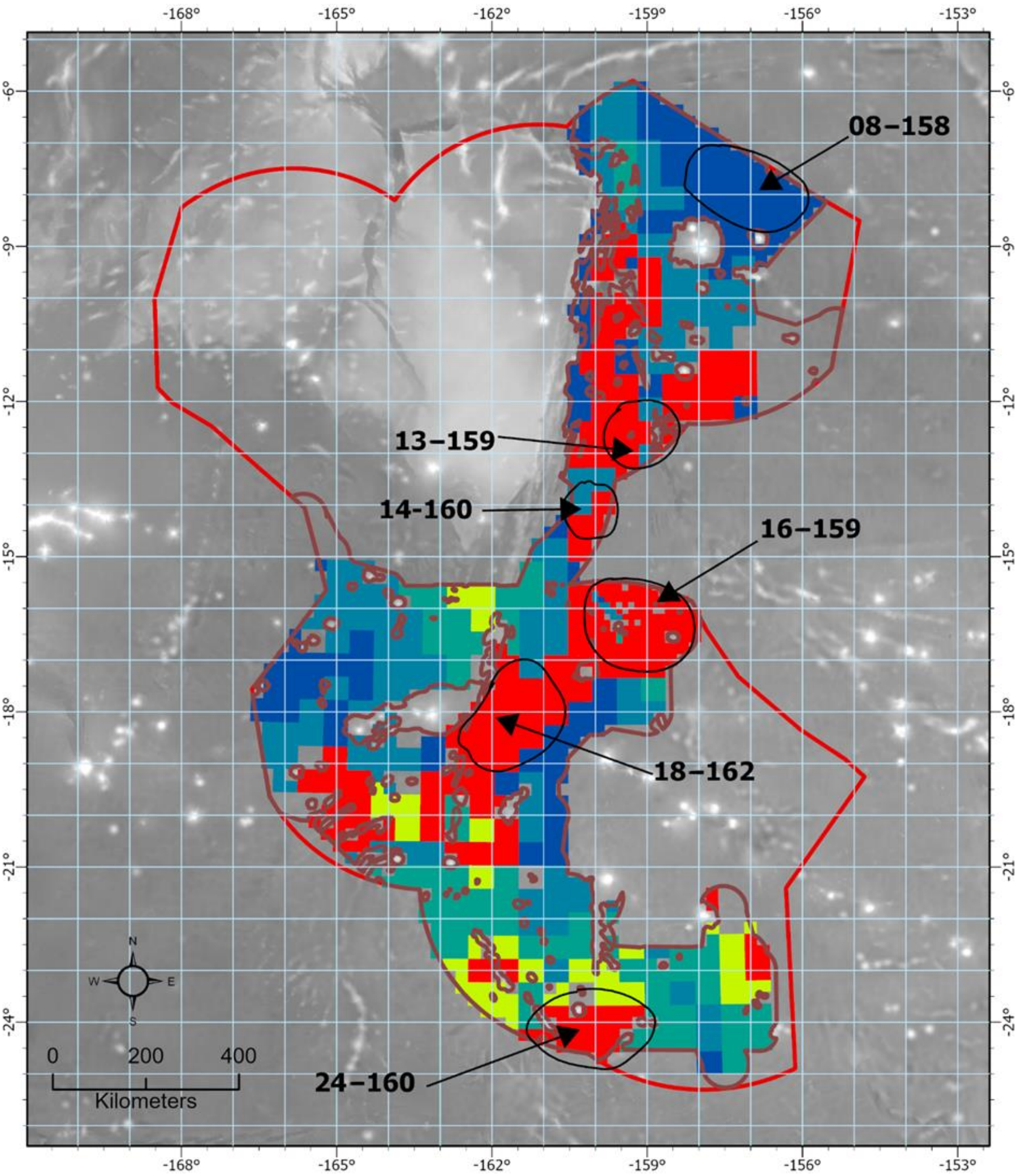


Figure 2-2: Examples of the new naming convention for select areas.

In 2016, an agreement between the Cook Islands Government and Ocean Minerals LLC (OML) was signed to reserve areas of the seabed within the Cook Islands EEZ for future exploration. OML's subsidiary, Moana Minerals Limited, reserved the right to prospect and explore for rare earth element (REE)-enriched sediments in five separate areas. In 2017, Moana Minerals signed a second agreement for the exploration of polymetallic nodules over two contiguous areas of the original five (Figure 2-3).

In 2018, a declaration was made by the responsible Minister to reserve areas of seabed in the Cook Islands EEZ for seabed minerals. This declaration gave Cook Islands Investment Corporation Seabed Resources Limited (CIICSR), a joint venture between Global Seabed Resources (GSR) and Cook Islands Investment Corporation (on behalf of the Cook Islands Government) exclusive rights to apply for an exploration title (Figure 2-3).

In late 2020, the Government of the Cook Islands announced a tender for seabed mineral exploration licences. In February 2022, after a period of licence application assessment, the government announced the issuance of licences to three companies: CIC Limited, CIICSR Limited and Moana Minerals Limited.

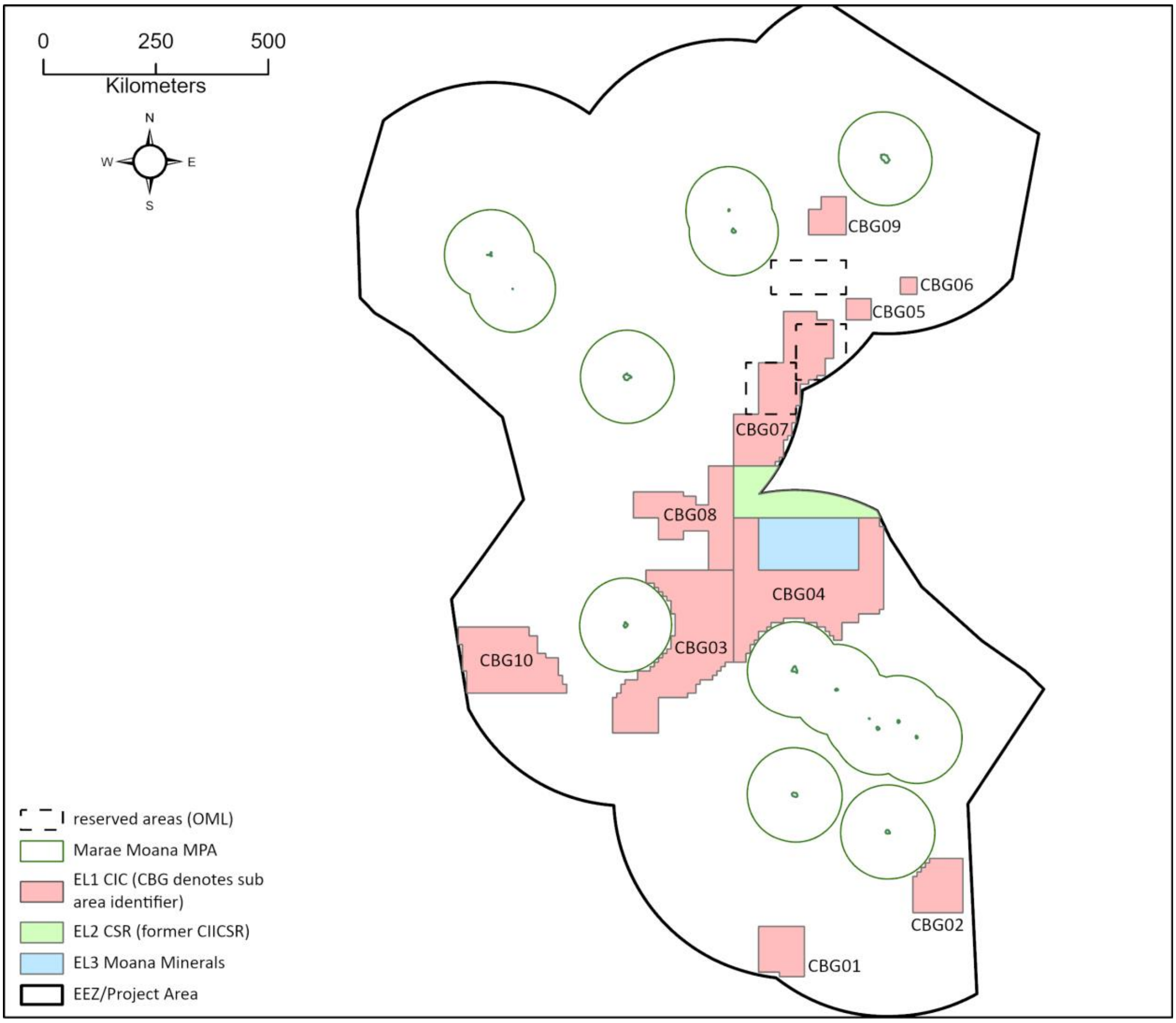


Figure 2-3: Map of granted licences and reserved areas.

2.3 Royalties and Taxes

Royalties are dealt with in the Seabed Minerals (Royalties) Regulations 2013. The regulations state that holders of a mining licence are liable for a royalty equal to 3% of the export value of minerals recovered under a mining licence. The export value of minerals recovered is the free-on-board (FOB) price received. Transfer pricing considerations are included in Income Tax (Transfer Pricing) Regulations 2014.

Under the *Seabed Minerals Act 2019*, any royalties paid to the Crown or the Authority (SBMA) are to be managed by the Ministry of Finance and Economic Management separately from other public money within an established sovereign wealth fund.

The *Income Tax Act* (consolidated as of 2019) contains provisions concerning various tax issues, including:

- tax payable by local companies (20%; all licence holders are required to be local companies) as well as foreign contractors (28%);
- deductions and exempt income (for example, deductions related to ongoing exploration and remedial work and environmental funds);
- ring-fencing of accounts and income to jurisdiction;
- write-downs and capital gains tax;
- withholding tax; and
- additional profits tax, including adjustments and instalments.

2.4 Environmental Liabilities and Permits

There are no known environmental liabilities in the Project Area. However, the Project Area does include 50-nautical mile exclusion zones (termed Marine Protected Areas) established under the *Marae Moana Act 2017*.

Activities under the *Environmental Act* and forthcoming Environment (Seabed Minerals Activities) Regulations (expected to be promulgated Q1 2023) are managed under a tiered system: Tier 1 activities are managed under the exploration licence, Tier 2 activities require Environmental Consent, and Tier 3 activities require an Environmental Permit after submission of an Environmental Impact Assessment.

2.5 Access

The Project Area is located ~1,500 km from Pago Pago, American Samoa; ~3,400 km from Auckland, New Zealand; ~7,000 km from Los Angeles, USA; ~5,000 km from Brisbane, Australia, and ~9,500 km from Shanghai, China (Figure 2-4). The Project Area is only accessible via ship. Exploration operations are conducted by ocean-going vessels and there are no access restrictions. The area is open to shipping and fishing vessels; therefore, public notices to mariners are required to be filed for any deployment of equipment, moorings, or operations that could affect shipping.

Figure 2-4: Logistics hubs/ports in the Pacific region. Modified from Fathom Pacific and ERIAS Group (2021).

Most vessel movements within the EEZ are through-traffic, typically travelling between the Americas and Southeast Asia, Australia, or traffic moving between island groups. Large numbers of vessels are tracked to the west of Cook Islands, in Samoa and to the east, near Tahiti. On a global scale, shipping and total vessel traffic in the EEZ are generally low, but commercial shipping is critical to the delivery of products to Cook Islands and the economy in general. Avatiu Harbour on Rarotonga is the main commercial harbour in Cook Islands and receives most of the SOLAS (Safety of Life at Sea Convention) vessels, including dry cargo, cruise ships and yachts.

Cook Islands Port Authority (CIPA) manages the international seaport in Rarotonga (Port of Avatiu) and is a 100% state-owned entity (Asian Development Bank, 2005). Reconstruction of the Avatiu harbour was completed in 2013 to provide a deeper harbour and increased capacity to cater for larger vessels. The Port of Avatiu is limited in size and infrastructure, which places restrictions on the size class of ships that can be accommodated. Two international shipping lines service Cook Islands on an approximate three-week cycle.

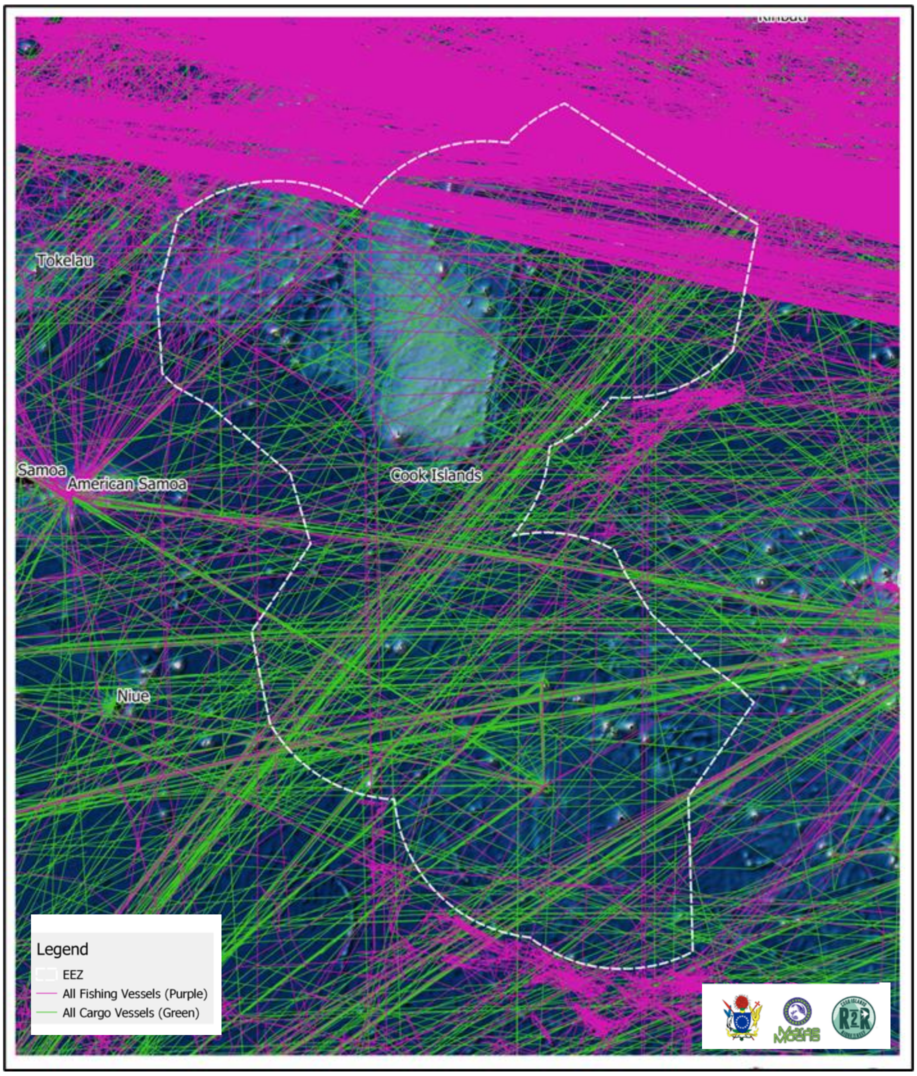


Figure 2-5: Cook Islands vessel traffic 2013–2014. Source: R2R (SUMA workshop, 2019).

Island Councils administer unregulated harbour facilities on the other islands, with technical support provided by the Ministry of Infrastructure Cook Islands (ICI) and CIPA. Inter-island shipping is essential and is offered by the private sector, with the overall quality being at a low standard that requires improvement.

2.6 Climate

Cook Islands lie within the extensive and persistent trade wind zone of the South Pacific. It has a tropical, mild maritime climate (21–28°C) with a pronounced warmer, wet season during November to April, when two-thirds of the ~2,000 mm annual rain falls, and a cooler, dry season from May to October.

The warmer season coincides with the cyclone season for the South Pacific region. Cyclones tend to form to the far west of the northern Cook Islands and migrate towards the southeast, often reaching latitude 15°S if not further south.

The climate is often strongly influenced by large inter-annual variations and the El Niño Southern Oscillation phenomenon. During El Niño years, the southern Cook Islands experience a reduction of rainfall, by up to 60% of the annual rainfall, while in the northern Cook Islands rainfall increases by up to 200%. The situation reverses during the La Niña phase.

A climate risk study for the Cook Islands by Asian Development Bank (2005) focussed on the potential for extreme wave and wind events primarily driven by tropical cyclones. Annually, the Cook Islands receive between zero and three cyclones with an increase in tropical cyclone frequency during El Niño conditions. Table 2-1 presents a model for return periods for extreme wave events and Table 2-2 presents return periods for high winds (for Rarotonga).

Table 2-1: Return periods for significant onshore wave heights, Rarotonga. Abbreviations: LO = likelihood of occurrence; RP = return period. Modified from CCAIR findings (Asian Development Bank, 2005).

Return Period (Years)								
Sea Level (m) (at least)	Present Day		2025		2050		2100	
	RP	LO	RP	LO	RP	LO	RP	LO
2	2	0.51	2	0.59	2	0.65	1	0.75
4	4	0.25	3	0.31	3	0.35	2	0.45
6	10	0.10	8	0.13	7	0.15	5	0.21
8	30	0.03	23	0.04	18	0.05	12	0.08
10	112	0.01	80	0.01	62	0.02	39	0.03
12	524	0	349	0	258	0	149	0.01

Table 2-2: Estimates of return periods for given maximum wind speeds, Rarotonga. Abbreviations: LO = likelihood of occurrence; RP = return period. Modified from CCAIR findings (Asian Development Bank, 2005).

Return Period (Years)					
Wind Speed	Kirk	Observed Data	GCM Based Maximum Wind Speed Data		
(m/s)	(1992)	(1972–1999)	1961–1990	1991–2020	2021–2050
28.5	2	2	1	1	1
33.9	5	5	2	2	2
37.5	10	11	3	4	4
38.8	13	14	5	5	6
41.9	25	29	18	16	14
44.9	50	57	60	45	31
47.8	100	113	120	95	64

2.7 Bathymetry

Bathymetry for the Cook Islands is based on the GEBCO_2021 grid (GEBCO Compilation Group, 2021), which has a resolution of 15 arc-seconds equating to 463 m at the equator (or 460 m at longitude 6, 445 m at 16 arc-seconds and 419 m at 25 arc-seconds). Approximately 80% of the data within the EEZ are based on indirect satellite interpolation and 20% on direct-single, or more commonly, multi-beam bathymetry.

The EEZ displays widely varying bathymetry that includes abyssal plains, seamounts, troughs, and a major plateau — the Manihiki Plateau (Cronan, 2013; see also Section 4.1.2). Any future nodule harvesting would be limited to parts of the abyssal plains. Geomorphologically, abyssal plains include abyssal hills and areas of volcanic knolls (Section 4.1.4). The abyssal plains are often spatially defined into basins such as the 4,500–5,500 m below sea level (mbsl) Penrhyn Basin, the 4,000–5,400 mbsl Southern Cooks Basin and the 4,500–5,500 mbsl Samoa-Niue Basin (Figure 2-6). The Aitutaki Passage, a subtle (300–400 m deep) depression within the abyssal plain, connects the Samoa-Niue Basin with the Penrhyn Basin through the slightly shallower Southern Cooks Basin and is thought to be an important control for the high cobalt grade reported in nodules collected from the EEZ (Section 4). The Penrhyn Basin is often subdivided into northern and southern basins, based on their latitudes relative to Penrhyn Island.

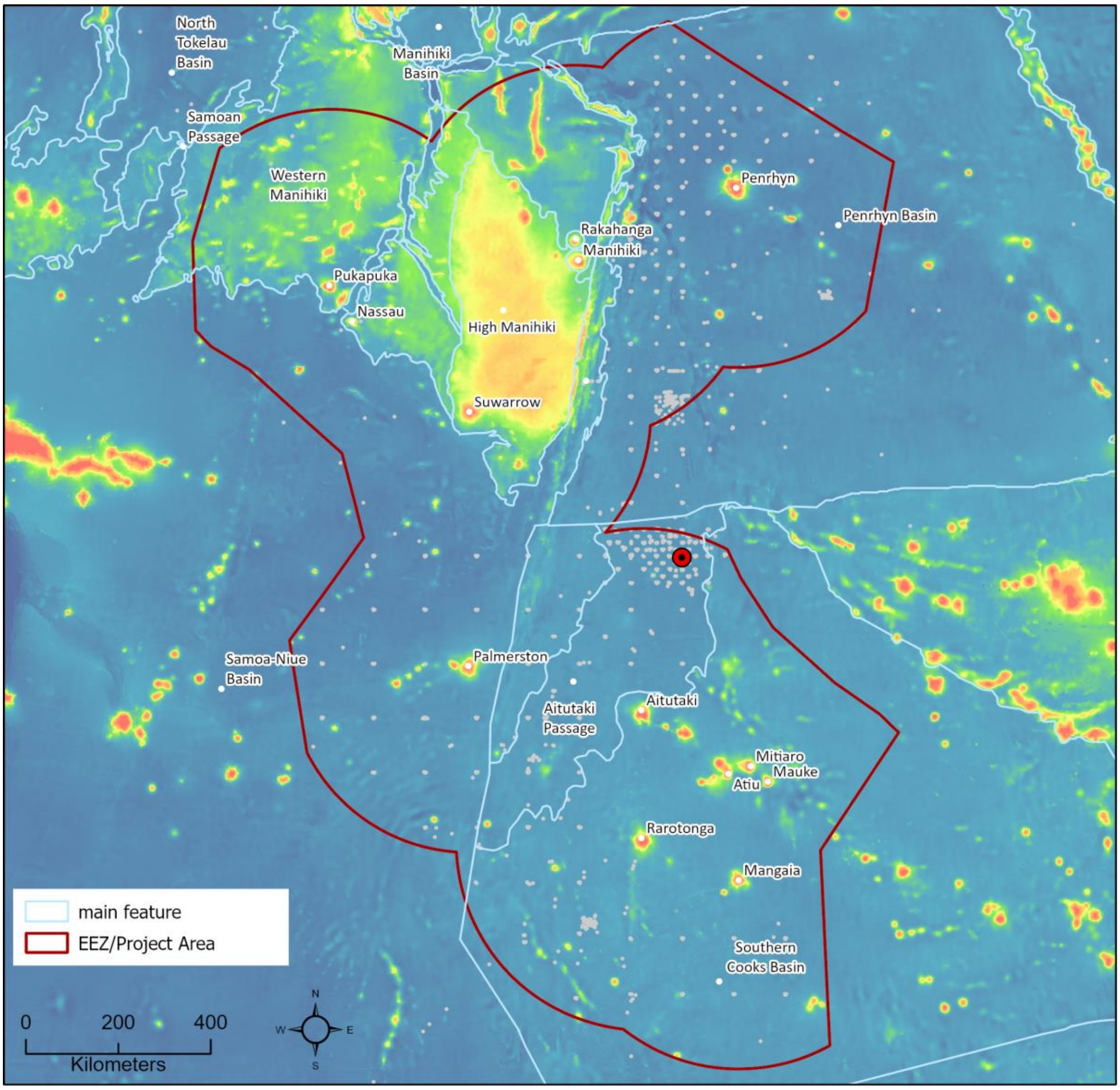


Figure 2-6: Bathymetric zones in the Project Area.

2.8 Background Information on Cook Islands

2.8.1 Geographic Setting and Demographics

The population of Cook Islands at the time of the last census (2016) was 17,434 (including 2,599 temporary residents (Fathom Pacific and ERIAS Group, 2021)). Since the previous census in 2011, the population has decreased by 2% and more broadly, the population has been in a state of decline since 1996 (GCI, 2018b). Approximately 70% of the resident population lives in Rarotonga, with a population density of 2,205 inhabitants per square kilometre (GCI, 2018b). Around 20% of the population lives on the other eight islands of the southern group (GCI, 2016). Around 10% of the population lives in the northern group of Pa Enua, more than 1,250 km from the capital.

The population is currently ageing as younger people leave the islands for education, training and employment opportunities elsewhere. Today, there are at least nine times as many Cook Islanders living in New Zealand and Australia compared to locally (Department of Foreign Affairs and Trade, 2021). The Cook Islands Government notes that continuing depopulation is a significant threat to the development of the nation (GCI, 2018a).

Cook Islanders can trace their ancestry on the southern islands back to Tahiti and the Marquesas over 1,000 years ago. Cook Island tradition also says some of the New Zealand Māori migrations originated in their islands, and there is a strong traditional connection between the Rarotongans and the New Zealand Māori today.

2.8.2 Political Situation and Cultural Heritage

The Cook Islands is a self-governing island state in free association with New Zealand and fully responsible for internal affairs (2001 Joint Centenary Declaration of the Principles of the Relationship between New Zealand and Cook Islands). It has a parliamentary representative democracy within a constitutional monarchy (Wikipedia, 2021). The King of New Zealand, represented in the Cook Islands by the King's Representative, is the Head of State; the prime minister is the head of government and a multi-party system. New Zealand retains some responsibility for external affairs, in consultation with the Cook Islands. In recent years, Cook Islands has taken on more of its own external affairs, establishing diplomatic relations with other countries. Executive power is exercised by the government, while legislative power is vested in both the government and the islands' parliament. The judiciary is independent of the executive and the legislatures.

The Constitution of the Cook Islands took effect on 4 August 1965 (Wikipedia, 2021) when the Cook Islands became a self-governing territory in free association with New Zealand. The anniversary of these events in 1965 is commemorated annually on Constitution Day, with week-long activities known locally as the Te Maeva Nui celebrations.

The Parliament of the Cook Islands has 24 members, elected for a five-year term in single-seat constituencies. There is also a House of Ariki, composed of high chiefs, which has a purely advisory role. The Koutu Nui is a similar organisation consisting of sub-chiefs. It was established by an amendment in 1972 of the *House of Ariki Act 1966*.

The Cook Islands is part of the geo-cultural region of Oceania — a 'continent of islands' — which covers nearly a third of the Earth's surface (Fathom Pacific and ERIAS Group, 2021). Cultural landscapes are at the interface between nature and culture, tangible and intangible heritage, biological and cultural diversity; they represent a tightly woven net of relationships that are the essence of culture and people's identity (Rössler, 2001). Cultural landscapes are perhaps the most appropriate way to recognise the unique heritage of the Pacific region, as they reflect the inseparable relationship between people and their environment (Smith and Jones, 2007).

Cultural landscapes in Cook Islands are represented by traditional agricultural systems and practices, land tenure systems, the sacred and/or symbolic significance of natural features, and traditional natural resource management techniques (Smith and Jones, 2007).

Traditional customary land and sea management practices, underpinned by traditional authority/leadership systems, land tenure systems and traditional knowledge of ecosystems, resources, and the environment are particularly important in understanding the cultural values of seemingly natural landscapes and seascapes across the Pacific. In Cook Islands, these management practices are represented by a system of ra'ui, whereby the gathering or collecting of particular foods or plants at certain times of the year and/or from certain places is restricted.

The ocean is integral to the origin stories, traditional knowledge, and cultural values of Cook Islanders, and the ocean plays a key role in the identity of Cook Islanders, from traditional to modern beliefs. Traditional knowledge comprises an intimate understanding of the relationships between natural systems (and how to manage them for the benefit of communal society), traditional practices, the weather or natural events, navigation and seafaring, and the routes that linked island communities.

The Pacific Island region is currently one of the most underrepresented regions on the World Heritage List. Cook Islands has no World Heritage sites or landmarks.

2.8.3 Seabed Minerals Government Policies

There are several relevant government policies (Figure 2-7), which are outlined below:

- Cook Islands National Seabed Minerals Policy (2014): sets out the rationale and vision for high-level policies that will guide the planning and implementation of the Cook Islands' sustainable management of the seabed mineral resources and enable the wise regulation of seabed minerals activities.
- *Seabed Minerals Act 2019*: continues to mandate the regulatory body and establishes the Seabed Minerals Licensing Panel and Advisory Committee, and processes to follow when applying for or renewing prospecting/exploration/mining licences and retention leases. The *Seabed Minerals Act* sets out the various standards to be met, along with timeframes and provisions for non-compliance.
- *Seabed Minerals Amendment Act (2015, 2020 and 2021):*
    - 2015: various amendments to the *Seabed Minerals Act 2009,* most of which are to enable the government of the Cook Islands to allocate reserved areas of the seabed for strategic arrangements of national benefit, to create an annual holding fee, to clarify that an offer document cannot be issued by SBMA until relevant requirements under the *Environment Act 2003* have been met, to change the original licence term for an exploration licence from four to five years, and to change the renewal term for an exploration licence from two to five years.
    - 2020: various amendments to the *Seabed Minerals Act 2019*:
        - to provide greater certainty and predictability in applications and other processes under the Act;
        - to expand and clarify the obligations of title holders under the Act; and
        - to make a minor amendment to a change made by the Act to the *Environment Act 2003*.
    - 2021: various amendments to the *Seabed Minerals Act 2019*:
        - to clarify that only companies incorporated in the Cook Islands and registered under the *Companies Act 2017* may apply for a prospecting permit, an exploration or mining licence, or a sponsorship certificate; and

  - to include transitional provisions for licence applications that have not yet been determined.
- Seabed Minerals (Exploration) Regulations (2020): supplements the *Seabed Minerals Act* and *Seabed Minerals Amendment Act* by providing more detail about application requirements for the exploration phase of seabed minerals activities. SBMA has the mandate to create more regulations to govern the various aspects of seabed minerals activities.

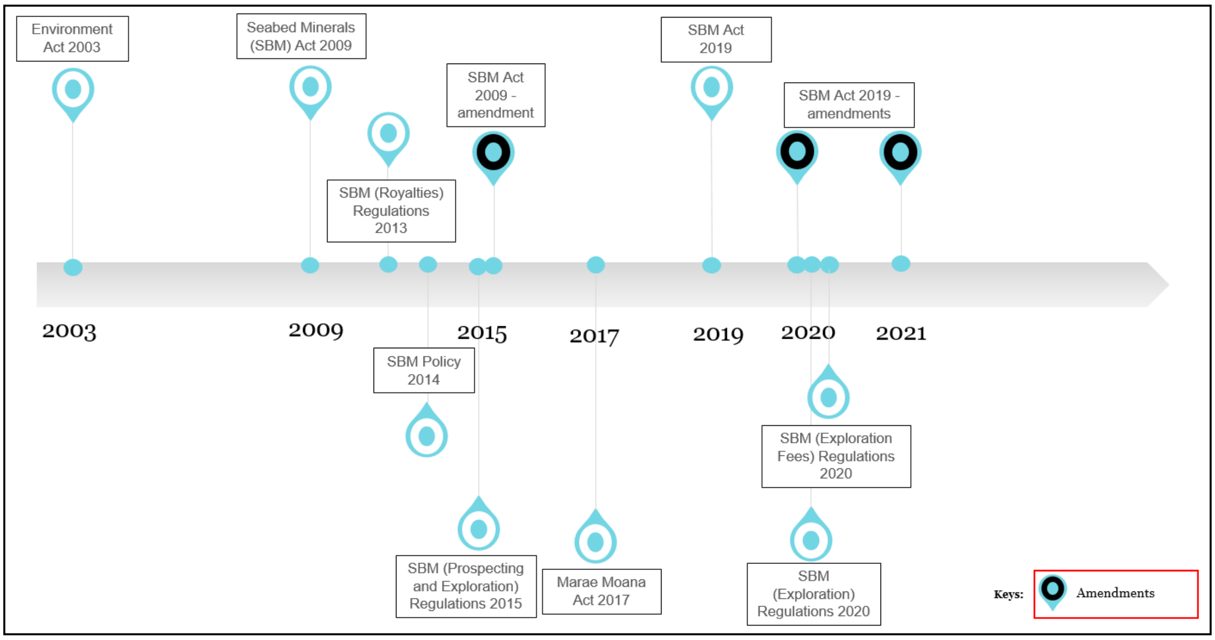


Figure 2-7: Timeline of the development of Cook Islands legislation.

2.8.4 Economy

The Cook Islands economy has experienced sustained economic growth, averaging 5.5% gross domestic product (GDP) growth per year from 2012–2018, and 7.0% in 2018 (Asian Development Bank, 2019; Fathom Pacific and ERIAS Group, 2021). The per-capita GDP for Cook Islands is high relative to many other Pacific Island countries; however, due to its heavy reliance on tourism, the country's economy has sustained a significant reduction in economic activity due to the COVID-19 pandemic, with more than 70% of industries experiencing a negative growth in 2020 (GCI, 2020). The effect of the COVID-19 pandemic was reflected in a decline in GDP in 2020 (Figure 2-8).

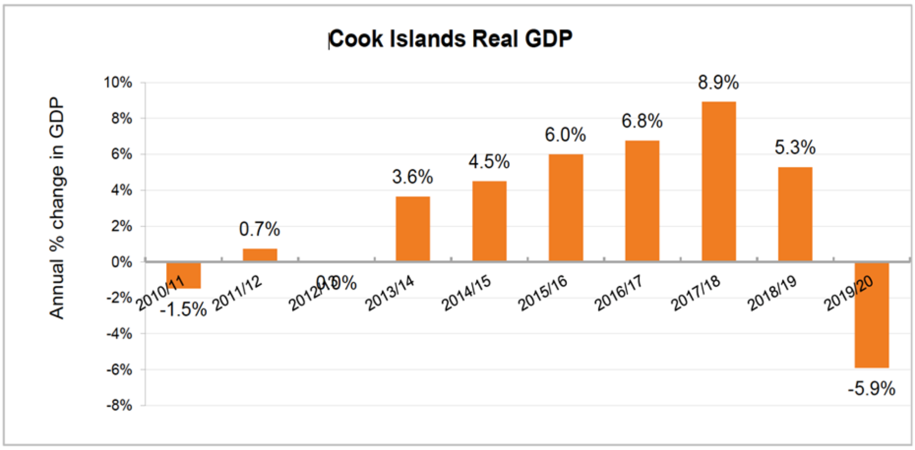


Figure 2-8: GDP variation 2010–2020.Source: Cook Islands Economic Development Strategy 2030.

The Cook Islands' economy faces challenges relating to limited natural resources, remoteness from major trade and industrial centres, inadequate infrastructure and a small labour force (IMF, 2020; Department of Foreign Affairs and Trade, 2021). Despite these constraints, Cook Islands has developed a successful tourism industry, which is the primary driver of the economy. Approximately 80% of the activity is centred on Rarotonga, and Aitutaki is the other significant tourist destination (GCI, 2016). At the time of the last census (2016), the services sector was the largest employer in Cook Islands, comprising the accommodation and food service sector (20.9%), the wholesale and retail trade sector (15.8%), and the public administration sector (15%) (GCI, 2018a). The sectoral economy broken down further for the 2019/2020 year is shown in Figure 2-9.

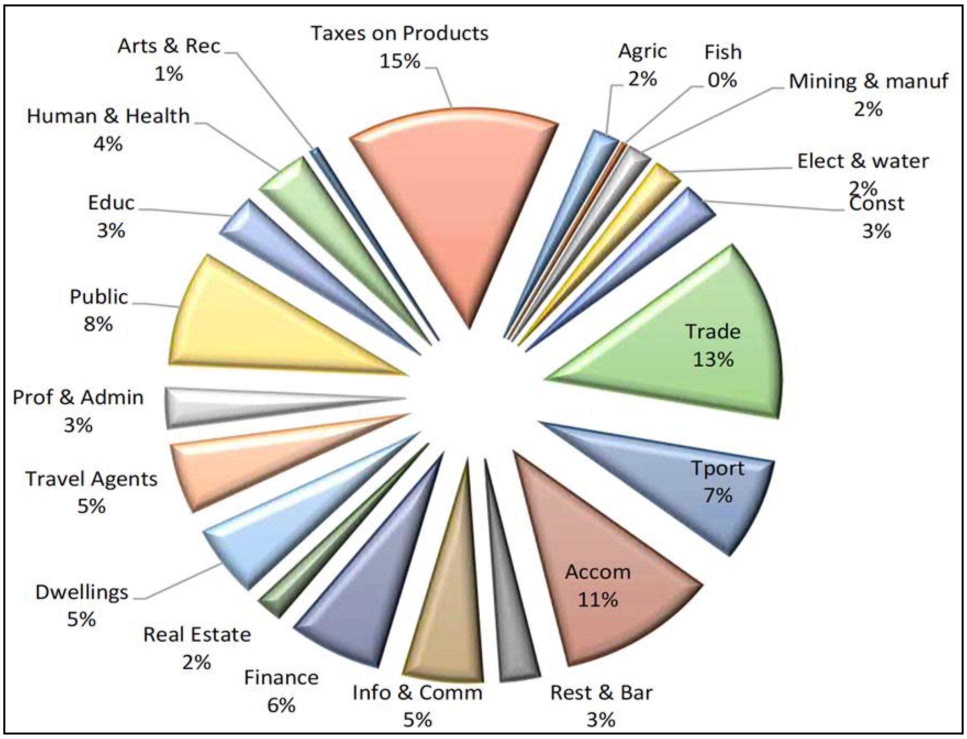


Figure 2-9: Proportional contribution of industry sectors to Cook Islands economy – 2019/2020.Source: Cook Islands Economic Development Strategy 2030.

The total labour force of Cook Islands at the last census (2016) was 7,774 people, which can be broken down into the self-employed (988), paid employees (6,028), unpaid workers and volunteers (305), and the unemployed (453). The Labour Force Participation Rate (LFPR) of 71.9% was slightly higher for males (77.2%) than for females (67%). The unemployment rate was 5.8% (GCI, 2018b).

Wages and salaries make up an average of 60% of household income across urban and rural populations (GCI, 2018a). Wages are supplemented by household-managed businesses, rental income, and pensions or social benefits. In 2016, the average annual income of the resident population 15 years and older was NZD 17,221 (NZD 18,677 for males and NZD 15,856 for females). Income levels in Rarotonga were more than double that in the outer islands. Over 12% of the population had no income, and 3.3% had an annual income of more than NZD 40,000 (GCI, 2018b).

Figure 2-10 identifies the occupations held by the resident Cook Island population during the 2016 census. Females were more dominant in service roles like shop assistants, housekeeping and caregiving, while males tended to work in trades, crafts and technical roles (GCI, 2018a).

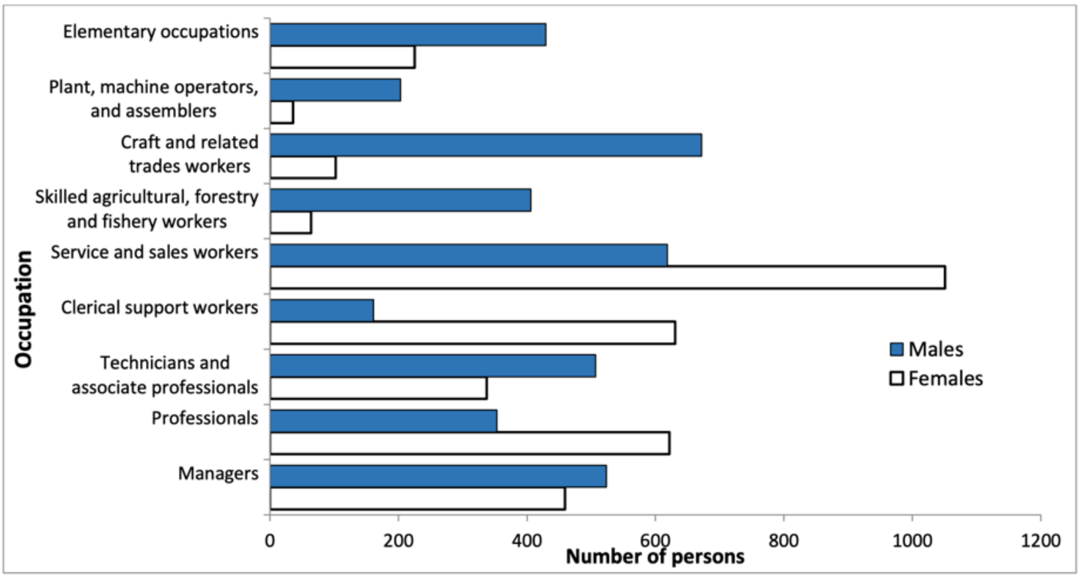


Figure 2-10: Occupations held by Cook Islanders in 2016Source: GCI, 2018a.

2.8.4.1 Land Ownership

All tenure in Cook Islands is derived from the Crown, and is divided into two categories:

- customary land, which is also referred to as uninvestigated land; and
- native freehold land, which is also referred to as investigated land.

While the most readily accessible land on Rarotonga was investigated decades ago, an estimated 95% of the land in Cook Islands is uninvestigated land (COA and Government, 2008).

The *Cook Islands Act 1915* provides for the recognition of land and other customary practices such as customary land, land titles, succession, and other Indigenous customs. The Act defines customary land as 'land which, being vested in the Crown, is held by Natives or the descendants of Natives under the Native customs and usages of the Cook Islands'. While the term 'Native' is no longer commonly in use, its definition is considered to include those who trace their heritage to Cook Islands.

Since a Land Court ruling in 1957, ownership of customary land is now hereditary and is divided equally among the descendants of an owner after their death.

Customary land ownership is complicated further by the fact that most customary landowners are not Cook Islands residents (Crocombe, Tongia and Araitia, 2008).

Almost all valuable land in Cook Islands is registered as 'native freehold title' and is primarily held by:

- the Crown, where it needs land for its own public purposes (i.e. public land);
- native Cook Islands landowners, who have established their rights to an award of 'native freehold' title; and
- the Cook Islands Christian Church.

Individuals with freehold title can make use of that land through occupation rights, leases, vesting orders (which allow for the transfer of land to a 'Native' (defined under the *Cook Islands Act*) or a descendant to provide a site for a dwelling), or a partition order (which is used to separate out different family interests from a common block). The fragmentation of native freehold titles has opened the way for some Cook Islanders (many living overseas) to acquire large areas of land through occupation rights, leases or other means (Crocombe, Tongia and Araitia, 2008).

2.8.4.2 Commercial Fisheries and Aquaculture

The pelagic fishery (targeting species such as yellowfin tuna, albacore tuna, skipjack tuna, bigeye tuna, mahi mahi, wahoo, and billfish) in the EEZ consists of a longline fishery with vessels based both locally and operating from ports of neighbouring countries. The pelagic purse seine fishery consists predominantly of vessels flagged to the United States (US), Korea, Kiribati, Vanuatu and the European Union (MMR, 2020).

The longline fisheries in the EEZ and adjacent high seas are characterised by two fleets: vessels of the southern fishery and those of the northern fishery. The southern fishery, based out of Rarotonga, comprises small-scale vessels carrying out fresh fish operations to produce fish for domestic and international markets. The northern fishery is based principally out of Pago Pago (American Samoa) and targets albacore tuna for canning (MMR, 2020). Foreign vessels are restricted to fishing outside the 50 nm Marae Moana (Marine Protected Areas) set aside areas, around each island to avoid conflict with artisanal fishing practices.

The main economic benefit derived from commercial fishing is the revenue received by the Ministry of Marine Resources (MMR) from treaties and fishing licences. Cook Islands receives revenue from USA and the European Union via fishing licences and agreements that allow ships from these jurisdictions to access tuna stocks within the EEZ. Under the Sustainable Fisheries Partnership agreement with the European Union, ship owners are expected to contribute up to ~NZD 6.8 million for three years from 2021, of which NZD 1.7 million will support Cook Islands' initiatives within the sectoral fisheries and maritime policy.

Starting in the 1980s, black-lipped pearl oysters (*Pinctada margaritifera*) were cultured and seeded on Manihiki Islands to produce black pearls and a black pearl industry has since grown in Cook Islands (FAO, 2021). The pearls are commercially cultured in the Manihiki and Penrhyn lagoons in the northern group of islands and have become one of the country's largest exports, valued at NZD 5–10 million. The Cook Islands MMR is encouraging the spread of pearl farming to other islands (Department of Foreign Affairs and Trade, 2021). Apart from pearl culture, aquaculture production in Cook Islands is small and limited to subsistence and semi-commercial production of tilapia, milkfish and clams. The top priorities were pearls, giant clams, trochus, and tilapia (Asian Development Bank, 2015). Developing marine resources within the EEZ is a primary priority of the Cook Islands Government (Asian Development Bank, 2015; Department of Foreign Affairs and Trade, 2021).

2.8.4.3 Linkages between Energy Usage and Nodule Harvesting

A polymetallic nodules industry in the Cook Islands could:

- place additional demands on the energy budget of the economy; and
- allow the economy to make a significant contribution to the global energy transition.

The presence of polymetallic nodules in the EEZ represents a major potential provisioning service. Exploring and commercialising nodule harvesting, undertaking scientific research, and considering the impacts and societal benefits of nodule harvesting is a global undertaking. Evaluating the possibility of harvesting polymetallic nodules is a Cook Islands Government priority (Department of Foreign Affairs and Trade, 2021).

Other mineral resources that occur in the deep-sea include seafloor massive sulphide deposits, mineralised sediments and cobalt-rich ferromanganese crusts (SPC, 2016a; SPC, 2016b). While the later deposit types have also been identified in the EEZ, seafloor massive sulphide deposits have not been found and the tectonic setting of the country is not particularly permissive.

Since 2011, Cook Islands has embarked on a programme of renewable energy development to improve its energy security and reduce greenhouse gas emissions. However, in 2018, only 5% of its energy came from renewable sources, and 100% of this was from solar (IRENA, 2021). While the ocean provides opportunities for energy generation, there are no known offshore renewable energy projects in Cook Islands.

In line with global efforts to reduce greenhouse gas emissions and ultimately transition to renewable energy, Cook Islands has committed to reducing its reliance on diesel power. With assistance from development partners in New Zealand, Japan, Australia, and international financing groups such as the Asia Development Bank and the UN Development Programme, the Cook Islands Government is investing in solar technologies. The development of deep-sea mining is expected to generate new emergent technologies and present opportunities for technology transfer and cross-over to other industries.

2.8.5 Natural Resource Management

The Cook Islands has no mining industry outside of industrial quarrying. Traditionally, Cook Islanders had access to land and sea (through rights given by the Ariki), and therefore, had access to the variety of natural resources provided by the islands. Poor soils and limited resources, weather events, overpopulation, conflict, disease, and isolation all contributed to Cook Islanders developing natural resource management practices (ra'ui).

Traditional marine management in the Pacific Islands region predates Western models for marine protection. Concepts such as the ecosystem approach, adaptive management, and marine protected areas had been in use in the Pacific Islands long before they became part of the international conservation dialogue (Vierros et al., 2010).

The concept of ra'ui continues today and is embedded in some modern legislation (notably that of the *Marae Moana Act 2017*). However, the role of ra'ui, relative to other regulations, is not always clear (Vierros et al., 2010).

3 History and Previous Work

This section summarises the previous expeditions conducted to collect polymetallic nodule samples and previous MREs carried out within the Project Area. The work conducted in the Project Area to date has been completed by international research groups and government-funded organisations. The technical data resulting from the major expeditions conducted including sampling, abundance calculations, sample depth, geophysical, and other work that is relied on in the MRE reported here, is described in Section 5; quality control and quality assurance are described further in Section 6.

3.1 Exploration History

3.1.1 Regional Polymetallic Nodule Exploration

Polymetallic nodules were first discovered on the ocean floor in 1873 by the HMS *Challenger*, 250 km southwest of Ferro Island in the Canary Group, Atlantic Ocean (Murray and Renard, 1891). This pioneering expedition circled the globe and traversed both the western Clarion-Clipperton Zone (CCZ) and parts of the south Pacific, although not the Cook Islands EEZ (Figure 3-1).

The possibility of exploiting polymetallic nodules was not seriously considered until the middle of the 20th century. Glasby, Ma and Backer (1980) noted that while studies investigated the distribution of seafloor nodules in the Pacific in the mid-20th century, there was an absence of data for the southwest Pacific. The first expedition to find significant abundance in the southwest Pacific was the Scripps Institution of Oceanography's Downwind expedition in 1957 (Menard and Shipek, 1958).

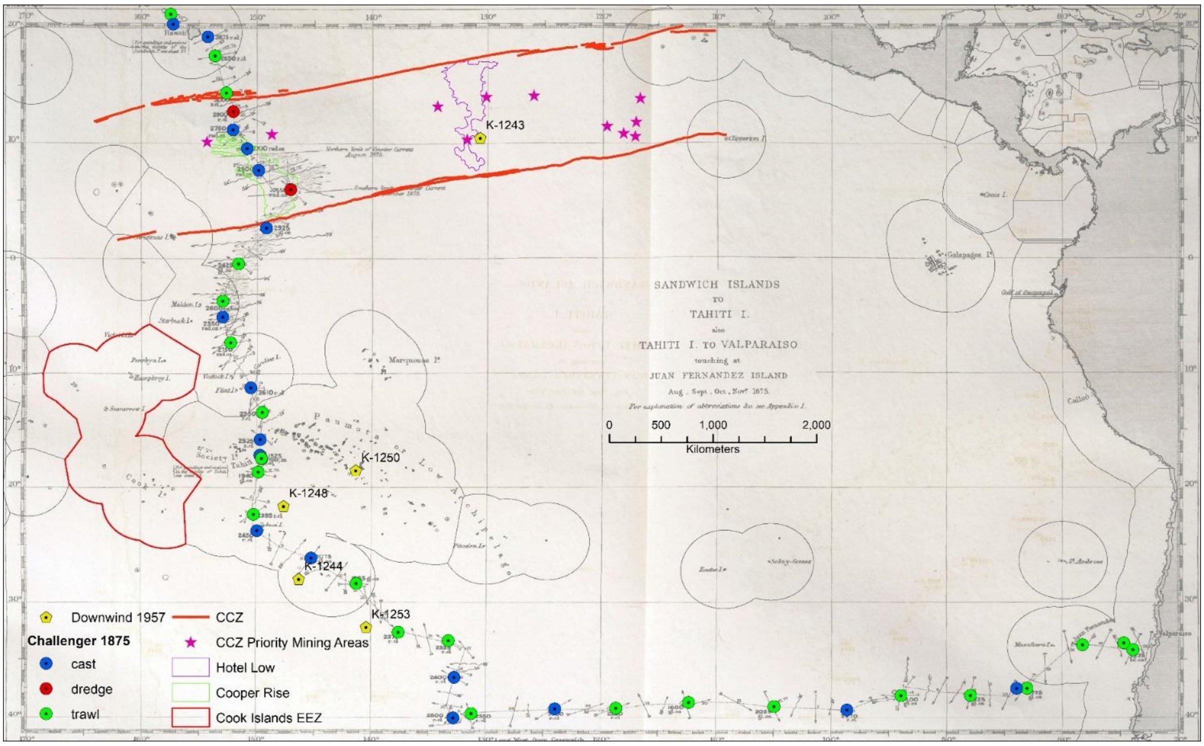


Figure 3-1: South Pacific transects and sample stations for HMS Challenger (1875) and Downwind (1957) expeditions. Location data from Natural History Museum UK (2014) and Menard and Shipek (1958); CCZ features from Parianos and Madureira (2021).

A generalised map of nodule distribution in the Pacific only became available in 1974, when an English translation of Skornyakova and Andrushchenko (1974) was published. The expansion of research efforts into polymetallic nodules in the southwest Pacific resulted from the expansion of the study of oceanography in general and a need for smaller island nations in the South Pacific to understand the seabed resource around them (Glasby, Ma and Backer, 1980). With rapidly increasing interest in seabed nodules in the region, the Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) was established in 1972. This was an intergovernmental, regional organisation with 21 member countries, under the Economic and Social Division of the United Nations. The purpose of CCOP/SOPAC was to promote offshore mineral and petroleum prospecting.

In the 1980s, following the protracted development of the CCZ and the United Nations Convention on the Law of the Sea (Lipton, Nimmo and Parianos, 2016), SOPAC coordinated an extensive regional exploration programme including the territorial waters of Kiribati, Tokelau and the Cook Islands. A wide range of exploration groups was involved, such as Ifremer (L'Institut Français de Recherche pour l'Exploitation de la Mer), but much of the systematic work was carried out by JICA-MMAJ (Japan International Cooperation Agency and the Metal Mining Agency of Japan).

3.1.2 Nodule Exploration in the Cook Islands

A timeline of seabed survey expeditions to the Cook Islands is presented in Figure 3-2. Table 3-1 identifies the different expeditions and summarises the ships used, location, and work programme for each expedition, and whether the data collected is incorporated into the database used for the resource estimation presented in this Report.

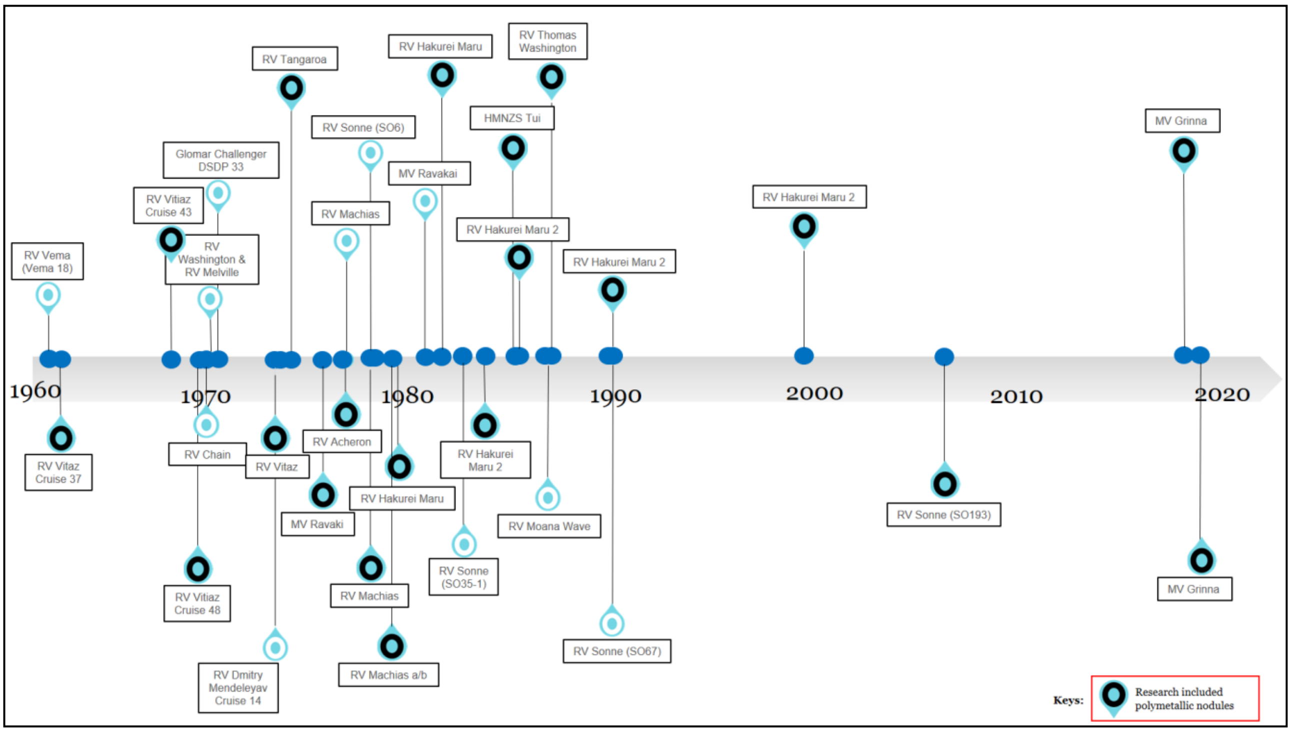


Figure 3-2: Timeline of expeditions in the Cook Islands Until the end of 2021.

The first expeditions to definitively identify the presence of nodules in the Cook Islands were the RV *Vitiaz* (1963–1970) and RV *Dmitry Mendeleyev* (1975) (Table 3-1; Skornyakova et al., 1990). These expeditions were under the leadership of P L Bezrukov, who secured a marine scientific research permit from the Cook Islands Government. The government also supplied T Masters as an observer. The expedition is thought to have taken dredge samples around the southern island group and in the south Penrhyn Basin (Figure 3-3). In 1974, the RV *Tangaroa* completed a circuitous sampling transit from New Zealand that included the seas south of Rarotonga (Meylan, 1974).

The 1976, Ravakai expedition by SOPAC built on the results of the previous work. It was the first of several expeditions that used locally based ships. The expedition collected 12 free-fall grab samples on the western side of the Penrhyn Basin returning across the Manihiki Plateau. This was followed by the 1977 Acheron expedition around the southern group; the UNDP charter vessel *Machias* conducted short expeditions between 1977 and 1980 (Table 3-1); and an early voyage of the RV *Sonne* (SO6) in 1978.

In 1980, the Geological Survey of Japan carried out the Wake-Tahiti transect which passed through the EEZ (Usui, 1984). In addition to the Wake-Tahiti transect, more detailed studies were carried out along the transect of interest to the Cook Islands, including the GH83-3 area (area 14-160 in Figure 2-2) in the southern Penrhyn Basin (Usui, 1994).

In 1985, the Japan-SOPAC Cooperative Study on Deep Sea Mineral Resources in the South Pacific commenced what is by far the most important series of polymetallic nodule sampling programmes in the Cook Islands region to date. The first phase of this programme (1985–1994) consisted of three expeditions in the Cook Islands region on the RV *Hakurei-Maru No. 2* in 1985, 1986 and 1990 (Cronan, 2013). The first two expeditions took place in the Penrhyn Basin and the third in the southern Cook Islands.

In 1987, the Scripps Institution of Oceanography used the RV *Thomas Washington* to conduct transects in the north Penrhyn Basin. Unlike previous nodule expeditions in the EEZ, which mostly had a resource evaluation aim, the intention of the expedition was to collect polymetallic nodules and associated sediments in a range of sedimentary environments in order to understand the factors causing variability in the nodules and to construct a geological/chemical model to aid in future nodule exploration in the region (Cronan, 1987; Cronan and Hodkinson, 1994). In 2000, the Japan-SOPAC Cooperative Study carried out a follow-up expedition in the Cook Islands region on the RV *Hakurei-Maru No. 2*, surveying areas in more detail in particular the Central Area (16-159). The results served to confirm and refine the conclusions from earlier expeditions with regard to the location of polymetallic nodules and the relative quality of the 16-159 area (JICA-MMAJ, 2001).

Other expeditions through the 1990s and 2000s tended to focus on the Manihiki Plateau, until 2019/2020 when commercial groups carried out two marine scientific research expeditions using the local ship MV *Grinna* to confirm nodule abundance and quality of the nodules in their reserved areas in the south Penrhyn Basin.

In February 2022, three exploration licences were granted to commercial companies wanting to explore the possibility of commercial development of high cobalt (Co) nodules in the EEZ. The first of these companies started exploration in early July 2022 using the MV *Seasurveyor*. Marine research expeditions in the EEZ are listed in Table 3-1.

Table 3-1: Summary details of marine research expeditions in the EEZ. Data collected from these expeditions were collated and used to inform the MRE reported in this Report. N = data were not used in MRE. Y = Data were used in MRE.

Year	Vessel (Expedition)	Location and Work Programme	Data Used
1962	*RV Vema (Vema 18)*	Manihiki Plateau; seismic survey, seabed sediments	N
1963	*RV Vitiaz Cruise 37*	Penrhyn Basin and southern-western Cook Islands; polymetallic nodules	Y
1967/68	*RV Vitiaz Cruise 43*	Southern Cook Islands; polymetallic nodules	Y
1970	*RV Vitiaz Cruise 48*	Penrhyn Basin and southern Cook Islands; polymetallic nodules	Y
1971	*RV Chain (Chain 100)*	Manihiki Plateau; seismic survey	N
1972	*RV Thomas Washington (SOUTHTOW 10,11,12)*	Manihiki Plateau; seismic survey and dredging	N
1972	*RV Melville (CATO 3)*	Manihiki Plateau; seismic survey, seabed sampling	N
1973	*Glomar Challenger DSDP 33*	Manihiki Plateau; seabed drilling	N
1974	*RV Tangaroa*	South and southwest of Rarotonga; polymetallic nodules	Y
1973	*RV Vitiaz*	Cook Islands; polymetallic nodules	N
1975	*RV Dmitry Mendeleyev Cruise 14*	Southern Cook Islands; polymetallic nodules	Y
1976	*MV Ravakai*	Between Rarotonga and Penrhyn; polymetallic nodules, metalliferous sediment and phosphate	Y
1977	*RV Acheron*	Southern Group; precious coral, polymetallic nodules	N
1977	*RV Machias*	Northeast of Rarotonga, polymetallic nodules	N
1978	*RV Machias*	Penrhyn and Samoa Basins; polymetallic nodules and precious coral	Y
1978	*RV Sonne (SO6)*	Aitutaki Passage; polymetallic nodules	Y
1980a	*RV Machias*	Northern Cook Islands; polymetallic nodules and precious coral	Y
1980b	*RV Machias*	East of Penrhyn Island, Penrhyn Basin, Penrhyn, Manihiki, Nassau Islands; polymetallic nodules, precious coral and phosphate	Y
1980	*RV Hakurei-Maru*	South Penrhyn Basin; polymetallic nodules	?
1983	*MV Ravakai*	Slopes of Rakahaga and Manihiki Atoll; precious coral	N
1983	*RV Hakurei Maru*	South Penrhyn Basin; polymetallic nodules	Y
1984	*RV Sonne (SO35-1)*	Manihiki Plateau; seabed sampling	N
1985	*RV Hakurei-Maru No. 2*	Western Penrhyn Basin, eastern margin of the Manihiki Plateau and the north of Penrhyn Island; polymetallic nodules	Y
1986	*HMNZS Tui*	Manihiki Plateau and adjacent southwest sea areas; Co-rich crust, polymetallic nodules	Y
1986	*RV Hakurei-Maru No. 2*	Western edge of the southern Penrhyn Basin (to the east of the Manihiki Plateau; polymetallic nodules (some data used in this MRE)	Y
1987	*RV Moana Wave*	Cook Islands: Suwarrow Trough, eastern Manihiki Plateau, Rakahaga-Manihiki island area; Co-rich crust and metalliferous sediments	N
1987	*RV Thomas Washington*	Northern Cook Islands and adjacent High Seas; polymetallic nodules, Co-rich crust, deep sea sediments and the Calcite Compensation Depth	N
1990	*RV Sonne (SO67)*	Northeast edge of Manihiki Plateau; complex of volcanic cones and mineral resources	N
1990	*RV Hakurei-Maru No. 2*	Southern Cook Islands; polymetallic nodules	Y
2000	*RV Hakurei-Maru No. 2*	Southern Penrhyn Basin; polymetallic nodules	Y
2007	*RV Sonne (SO193)*	Manihiki Plateau and Samoa Basin; Fe-Mn crusts and nodules	N
2019	*MV Grinna*	Southern Penrhyn Basin CIICSR reserve area; polymetallic nodules (data used to verify grades and nodule abundance)	Y
2019/2020	*MV Grinna*	Southern Penrhyn Basin OML reserve area - polymetallic nodules (data used to verify grades)	Y

Note: Excludes transects by other research vessels that collected single-beam or multi-beam sonar data.

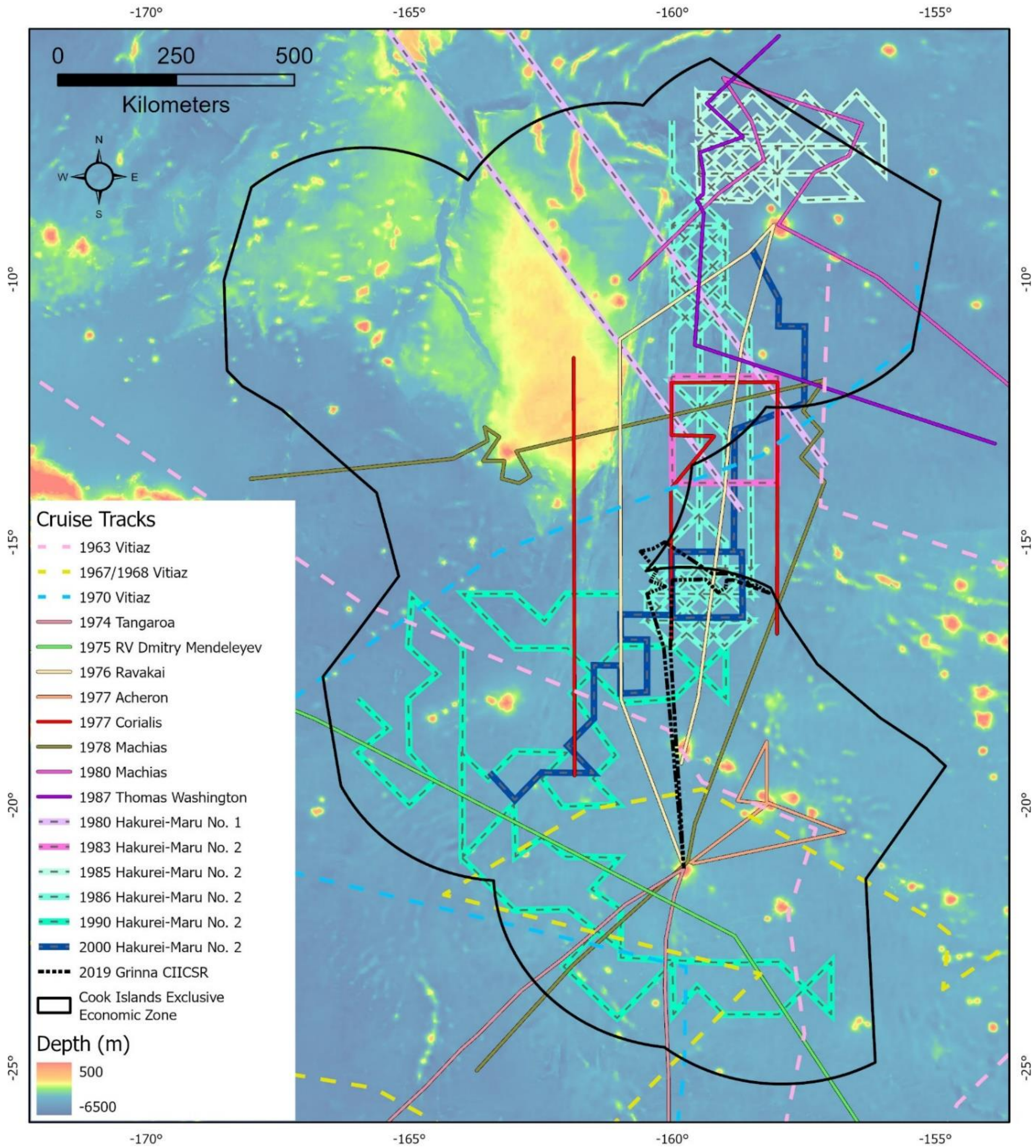


Figure 3-3: Cook Islands nodule sampling expeditions.

3.1.3 Past Data Compilations and Syntheses

As exploration was conducted in and around the Project Area, many individuals and groups started to compile the data collected and draw conclusions from the data. Below is a brief discussion of the different compilations and syntheses of the different individuals and groups conducted, previously summarised by Cronan (2013). The data used in the mineral resource estimate presented in this Report are partly sources from these compilations.

The Scripps Institution of Oceanography database was the first attempt to draw together all the nodule data available in the Pacific. The database is currently maintained and updated by the International Seabed Authority (ISA). Using the Scripps database, McKelvey et al. (1983) identified an exploration target between 158–160°W, 1–3°S, which McKelvey et al (1983) claimed to contain >1.8% combined Ni and Cu. McKelvey et al. (1983) also identified a second, larger target between 124–160°W, 0–18°S, with nodules containing >1% combined Ni and Cu.

Syntheses of Cook Islands regional polymetallic nodule data started in the early 1980s. Exon (1981) compiled historical nodule data from the Cook Islands from various sources and concluded that the North Penrhyn Basin and the South Penrhyn Basin were the most prospective parts of the region for nodules, principally between 5,000 and 5,600 m depth. Other areas such as the Manihiki Plateau, Samoan Basin and southwest Penrhyn Basin had average grades of 0.67–1.07% combined Ni, Cu and Co, and variable nodule abundances (Exon, 1981). The compilation work continued with the inclusion of data collected from the eastern Central Pacific Basin (Exon, 1983). Exon (1983) noted some samples contained nodules of higher Ni and Cu concentrations than either the North Penrhyn Basin or the South Penrhyn Basin (up to 3.42% combined Ni and Cu), including the area between 160–168°W, 2–7°S. However, this area had been poorly sampled in Exon's compilation and thus his suggestion that this area might be of economic importance for Ni- and Cu-rich nodules needed to be verified by further work. This work was further discussed by Glasby et al. (1987).

In 1983, Aplin completed a PhD thesis that focussed on the relationship between nodule and crust composition and associated sediments. Aplin (1983) concluded that reactions occurring in an organic-rich surface sediment layer and involving the reductive remobilisation of Mn oxide and the release of trace metals from labile components are important in forming Mn-, Ni- and Cu-rich nodules. This organic-rich surface sediment layer is restricted to within 3° of the equator at 175°W, but is increasingly widespread towards the east, occurring between 0–12°S at 145°W. The thesis was supported by almost 60 new nodule analyses (Aplin and Cronan, 1985; Appendix 6 in Cronan, 2013).

In 1988, Cronan carried out a synthesis of all available nodule and crust data in and adjacent to the EEZ (Cronan, 1989; Cronan, Hodkinson and Miller, 1991). A series of maps were produced which formed the basis of the discussion of nodule grade and abundance in the EEZ. The maps were updated in Cronan (2013).

In 1995, the MMAJ compiled polymetallic nodule data from the southwest Pacific, including the Cook Islands region (JICA-MMAJ, 1995). The compilation incorporated most of the previously collected data (per the above history) but did not include the results of the RV *Thomas Washington* 1987 expedition. In addition to providing point data throughout the region, MMAJ also produced contoured maps of nodule abundance distribution and Ni, Cu and Co grades. This publication was widely distributed to SOPAC and its member countries in whose economic exclusion zones the surveys were conducted.

Also in 1995, the East-West Center (EWC) in Hawaii produced a report entitled *Economic and Development Potential of Manganese Nodules within the Cook Islands Exclusive Economic Zone* (Clark et al., 1995), using much the same data as in the Japan-SOPAC Atlas (ibid). This EWC report presented maps of nodule abundance and Mn, Ni and Cu contents, but went further than previous syntheses and reported an economic model of harvesting and processing of Cook Islands nodules. Like any economic analysis, the EWC report was valid only for the time and the economic conditions under which it was prepared.

The Bechtel Corporation (San Francisco) also reported an economic assessment of Cook Islands nodules (Bechtel Corporation Mining and Metals, 1996). As discussed in section 3.4.1 below, the assessment included many assumptions but concluded that a nodule mining project for Co in the EEZ would be feasible provided the price of Co did not drop below USD 16.75/lb in April 1996 dollar terms.

Building on the Bechtel report, Lund and Søreide (2001) and Søreide (2003) conducted a sensitivity analysis by varying the price of Co, the capital costs and the operating costs. The study (section 3.4.2) concluded that the project economics are more sensitive to changes in Co price than to changes in capital and operating costs and identified new possible nodule processing methods for metal extraction. Nevertheless, it was concluded that at 2001 Co prices of around USD 15/lb, the project was not feasible.

In the early 2000s, research focussed on the inter-relationships between South Pacific nodules and crusts continued at the Imperial College London (Verlaan, Cronan and Morgan, 2004; Verlaan, 2008). The research also on biological processes associated with polymetallic nodules and Fe-Mn crusts. Verlaan (2008) concluded that primary producer–mediated complexation of several elements by organic ligands in solution may contribute to explaining a pattern of distinctive associations observed between compositional variations for these elements in the deposits studied and variations in the level of primary productivity. Verlaan (2021) also included the Cook Islands in a regional review of ferromanganese nodules and crusts.

The estimate by joint agencies discussed below (section 3.3.5; Hein et al., 2015) included a comprehensive review of the past work as well as some synthesis of the mineral endowment.

Building on the joint agencies study, in 2015 and then again in 2020, SBMA issued tenders to release areas for mineral exploration. The tenders included detailed administrative information for applicants as well as digital data (GIS based) compilations, including most of the reviews and estimates covered in this section.

3.2 Production History

To date, no commercial production of nodules from the Project Area has taken place. Engineering studies, including consideration of production, are discussed in Section 3.4.

3.3 Previous Resource Studies

Qualified Persons, employed by RSC, have previously estimated mineral resources, and reported these in compliance with NI 43-101, for two areas in the Project Area (located in the Aitutaki–South Penrhyn Basin area). These estimates were based on legacy data collected during the cruises described in section 3.1.2. These estimates were completed for private companies; they have not been published on the TSX (Toronto Stock Exchange), are confidential to RSC's clients, and cannot be reported here.

Other legacy tonnage and abundance estimates, summarised in the following subsections, were not carried out by Qualified or Competent Persons and were not reported in accordance with any contemporary CRIRSCO-affiliated code. Any reference made in text in this section to “mineral resource”, “resource estimate” or similar, are direct quotes from the reports in which these estimates are summarised and are not to be interpreted as equivalent to Mineral Resources as defined in JORC or CIM codes.

3.3.1 Pacific Islands Development Program (1995)

An EEZ-wide ‘resource estimate’ (Figure 3-4) and ‘economic study’ was conducted at the EWC for the Pacific Islands Development Program (Clark et al., 1995). The estimate covered 652,000 km^2 of the EEZ, and, using a cut-off grade of 5 kg/m^2, reported 7,474 Mt of nodules containing 32 Mt of Co, 24 Mt of Ni, and 14 Mt of Cu. These figures “refer to the total mineral inventory, not what may be recoverable, which could be 60–70% lower” (Clark et al., 1995). The method of estimation is not described.

The EWC ‘inventory estimate’ was the basis for the Bechtel development study (section 3.4.1).

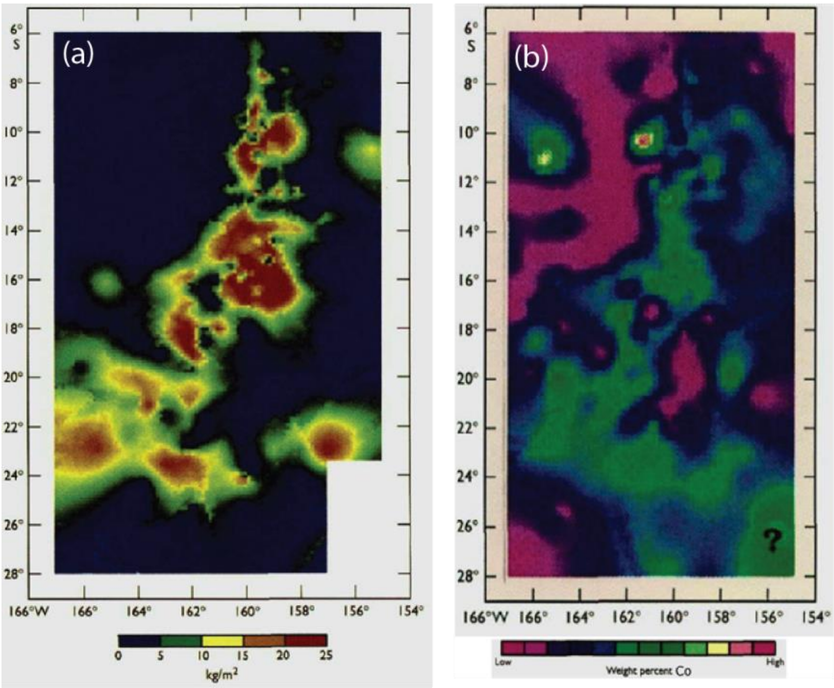


Figure 3-4: 1995 inventory estimates for (a) abundance and (b) Co. Source: Clark et al. (1995).

3.3.2 SOPAC (2001 and 2003)

SOPAC reported ‘resource estimates’ over the highly prospective area 16-159 (Central Area in Figure 3-5) located in the south Penrhyn Basin (Kojima, 2001; Okamoto, 2003). The SOPAC report was based entirely on sampling undertaken during the JICA-MMAJ expeditions in 1985,1986, 1990 and 2000.

The estimation methodology was based on a polygonal method adopted by Kohpina and Usui (1996) in the northern part of the Central Pacific Basin.

The estimate used the following steps:

1) An area with available nodule data were divided into a series of polygons centred at individual stations by drawing perpendicular bisectors of combined lines between sampling stations.
2) A uniform value was assumed to be equal to the average of the samples within each polygon.
3) The 'nodule inventory' within each polygon was calculated by the following equation:

   $R_N = A*(1-W)*S$ (where: R_N = nodule resource, A = nodule abundance, W = water content, S = area of polygon).
4) The resource potential in the area was obtained by summing the inventory for all polygons located within the area.

Details are unclear, but the area covered by the 'resource' was quoted at a range of nodule abundance cut-offs: ≥15 kg/m^2 (130,000 km^2), ≥25 kg/m^2 (20,000 km^2) and ≥30 kg/m^2 grading at 0.51% Co (8,000 km^2). The sample stations identified in areas with a nodule abundance of ≥30 kg/m^2 are reported in Table 3-2 and labelled the 'Promising Site' within the Central Area.

Within the 'Promising Site', SOPAC reported a resource of 186 Mt (dry) nodules [261 Mt (wet)], with an average nodule abundance of 32.6 kg/m^2.

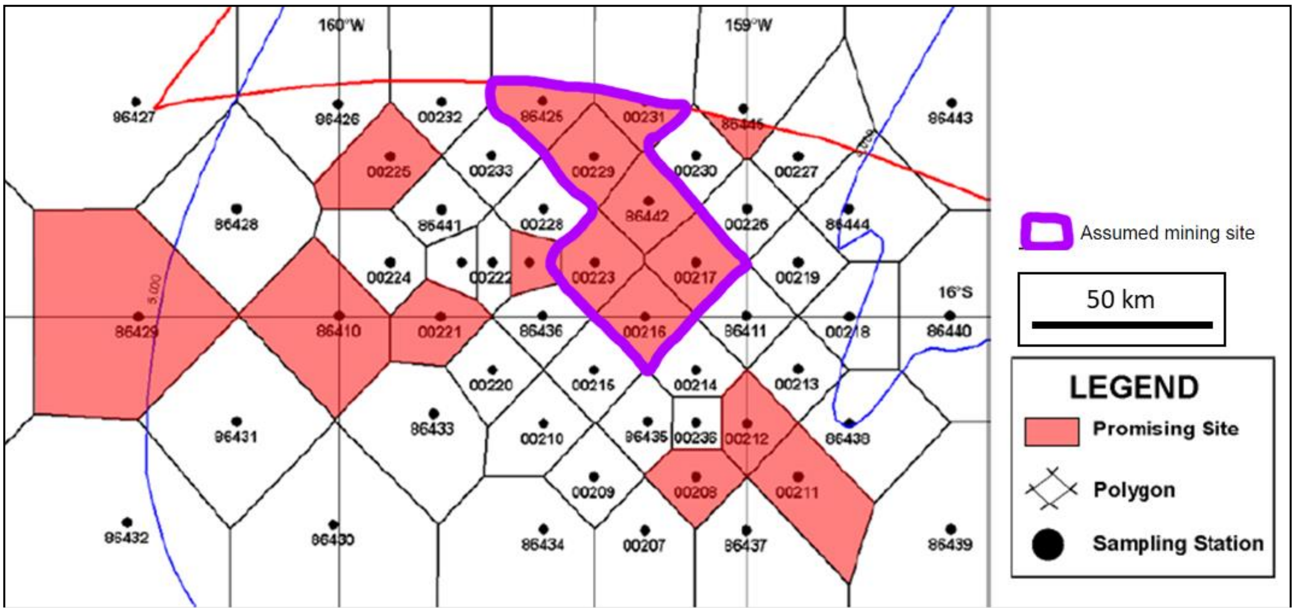


Figure 3-5: Map of the Central Area and Promising Site (in pink) estimation polygons used for the 2003 resource estimation. The magenta polygon represents the 2001 assumed mining site.

Table 3-2: Summary of the polymetallic nodule abundance and Co grade in 'Promising Site'.

Station No.	Abundance (kg/m^2)	Water Content (%)	Co Grade (%)	Area (km^2)	Nodule Resources (kt)	Co Resources (t)
86410	33.09	31.10	0.49	1,031	23,506	115,178
86425	34.57	28.60	0.48	304	7,504	36,017
86429	31.00	31.50	0.56	2,177	46,229	258,880
86442	31.54	30.50	0.55	369	8,089	44,487
86445	32.93	26.40	0.51	99	2,399	12,237
00208	31.18	22.20	0.50	325	7,884	39,419
00211	32.39	27.93	0.54	651	15,197	82,062
00212	31.14	23.73	0.55	325	7,719	42,454
00216	34.81	29.96	0.53	373	9,094	48,199
00217	32.16	25.99	0.46	378	8,997	41,386
00221	36.66	23.37	0.46	403	11,321	52,078
00223	33.08	30.33	0.58	368	8,481	49,191
00225	30.44	22.94	0.46	522	12,245	56,325
00229	32.96	27.52	0.52	369	8,815	45,839
00231	32.93	24.91	0.51	205	5,069	25,852
00234	30.63	33.63	0.44	185	3,761	16,548
Total				**8,084**	**186,309**	**966,153**

The estimate included a number of mining assumptions based on the previous Bechtel Corporation Mining and Metals (1996) study, such as 50% of the nodules could be recovered by seabed mineral harvesting and 80% of the contained cobalt in those nodules could be recovered in metallurgical processing (Kojima, 2001; Okamoto, 2003). This equated to 111 kt Co metal in the assumed mining site (Kojima, 2001) and 386 kt Co metal in the Promising Site (Okamoto, 2003); the latter figure at that time equated to ~10 years of global consumption.

3.3.3 Cronan (2013)

Cronan (2013) conducted an estimate of nodule abundance, and reported average grades of Co, Mn, Ni, Cu and Ti (Figure 3-6). The 'resource estimate' is summarised in Table 3-3. The methods and any assumptions used in the estimate are unknown. The estimate was completed for smaller sections of the EEZ and combined for a total resource of the EEZ.

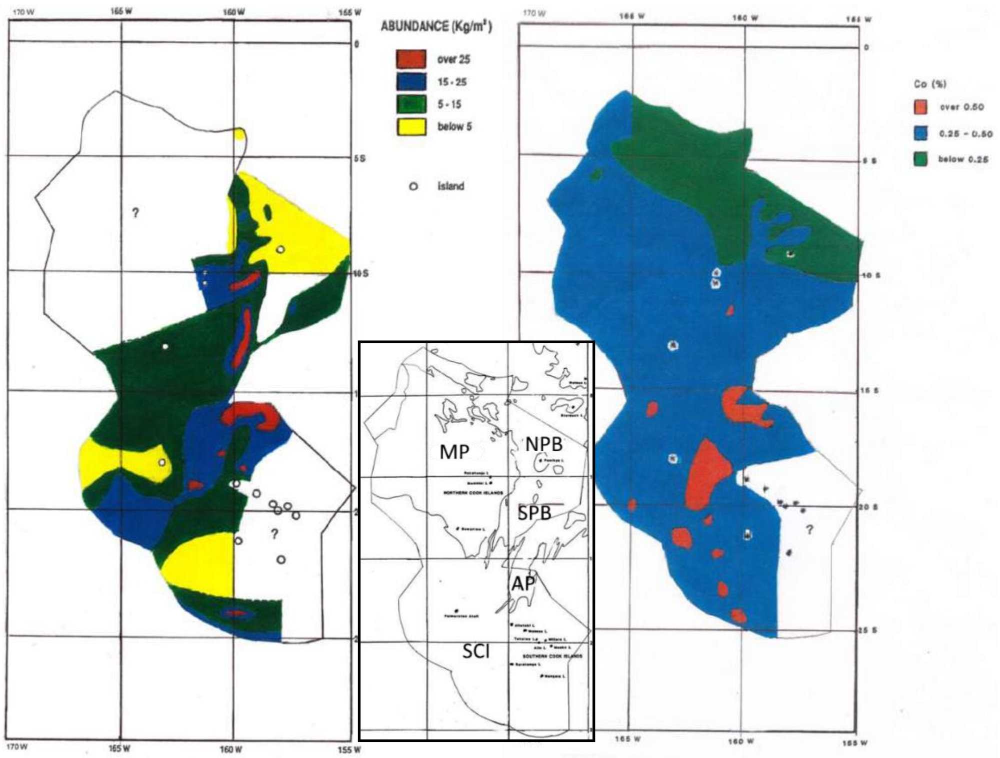


Figure 3-6: Abundance and Co inventory model and sub-areas.Areas modelled include North Penrhyn Basin (NPB), South Penrhyn Basin (SPB)/Aitutaki Passage (AP), Manihiki Plateau (MP), Southern Cook Islands (SCI).

Table 3-3: Cronan (2013) resource estimate.

Area	Nodules (Mt)	Grade (%Co)	Grade (%Mn)	Grade (%Ni)	Grade (%Cu)	Grade (%Ti)
North Penrhyn Basin	616	0.27	20	0.55	0.31	1.1
South Penrhyn Basin/Aitutaki Passage	2,832	0.48	15	0.28	0.16	1.1
Manihiki Plateau	692	0.33	17	0.39	0.21	1.1
Southern Cook Islands	6,127	0.42	20	0.36	0.16	1.9
Total EEZ	10,266	0.42	18	0.35	0.17	1.6

Note: there are fewer samples with Ti analyses and samples are further apart than samples for the other elements.

3.3.4 Kenex (2014)

In 2014, Kenex conducted a study for the SBMA that included a prospectivity study and a probabilistic valuation study over the EEZ.

3.3.4.1 Prospectivity Study

Kenex's prospectivity study included the following.

- Compilation of all relevant geological, chemical, topographic and cadastral data over the study area into a GIS database.
- Production of predictive maps for possible source, transport, trap and metal deposition.

- Spatial analysis of the following geological parameters as important for predicting polymetallic nodules deposition in the EEZ:
  - association with depths between 4,800 m and 5,200 m;
  - association with areas below the interpreted carbonate compensation depth;
  - association with flat seabed per the GEBCO grid (slope <0.1°);
  - proximity to mapped seamounts;
  - relationship with interpreted oceanic crust of the lower Cretaceous;
  - association with areas with interpreted lower sediment rates; and
  - relationships with existing data for Mn, Fe, Co, Cu and Ni chemistry.
- Production of a prospectivity map (Figure 3-7) over the study area using Bayesian weights of evidence techniques.
- Production of a list of spatially distinct targets within the very prospective and highly prospective areas, ranked by probability of containing high abundances and quality of nodules.

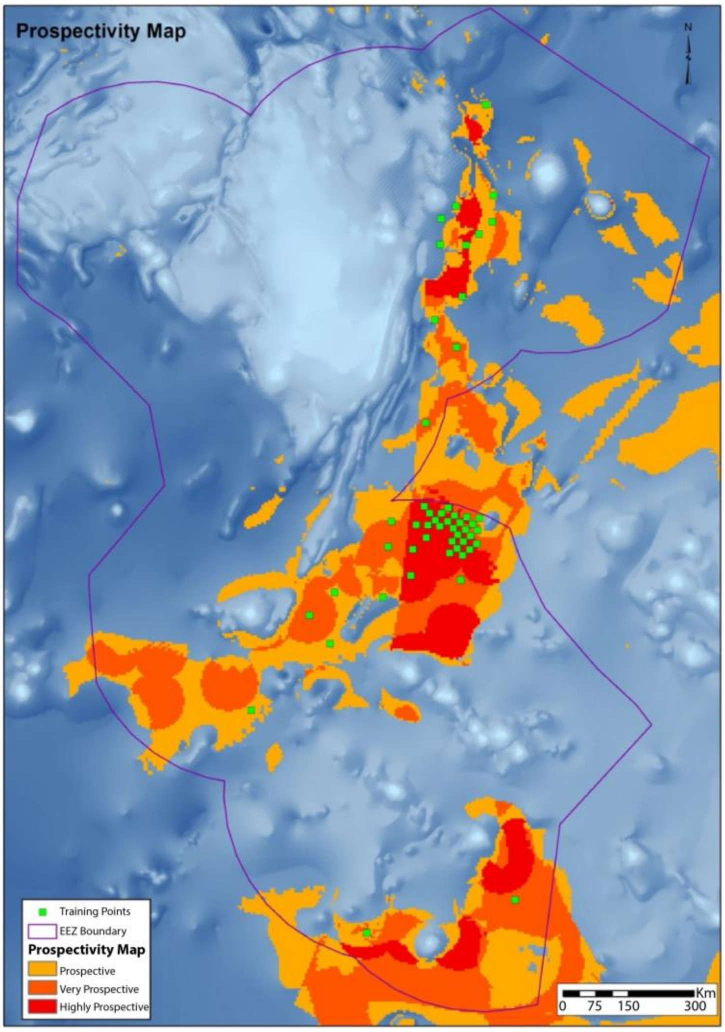


Figure 3-7: Prospectivity map for polymetallic nodule formation in the EEZ. Source: Kenex, 2014a.

The study (Figure 3-7) reiterated that parts of the EEZ have a high potential for polymetallic nodule resources. Based on the data available at the time, Kenex concluded:

- ~10% of the EEZ is prospective for polymetallic nodules,
- ~6% of the EEZ is very (above average) prospective; and
- ~2% of the EEZ is highly (upper quartile) prospective.

3.3.4.2 *Probabilistic Valuation Study*

Kenex's 'probabilistic valuation study' (Kenex, 2014b) involved statistical and geostatistical reviews of nodule sample data in the EEZ to enable the estimation of the scale of the polymetallic nodule deposit. Interpolation/extrapolation for Co, Cu, Ni, Mn and Ti used inverse distance methods, 5 km × 5 km grid cells, and the results were domained (sub-sampled) using the prospectivity model (Figure 3-7). A polygon defined by the limits of the sampling was used to constrain the valuation.

Results were reported at a range of nodule abundance cut-offs (7, 10 and 20 kg/m^2) with higher priority and higher confidence areas returning between 6.0, 5.3 and 2.6 Bt (dry) nodules, respectively, and lower priority and/or lower confidence areas returning approximately 1.5, 0.7 and 0.1 Bt (dry) of additional material (e.g. Figure 3-7). Grade cut-offs were not applied; typically, the Co grades are in 0.18–0.25% range, except for some very high abundance areas (≥20 kg/m^2) where Co grades are ~0.5%.

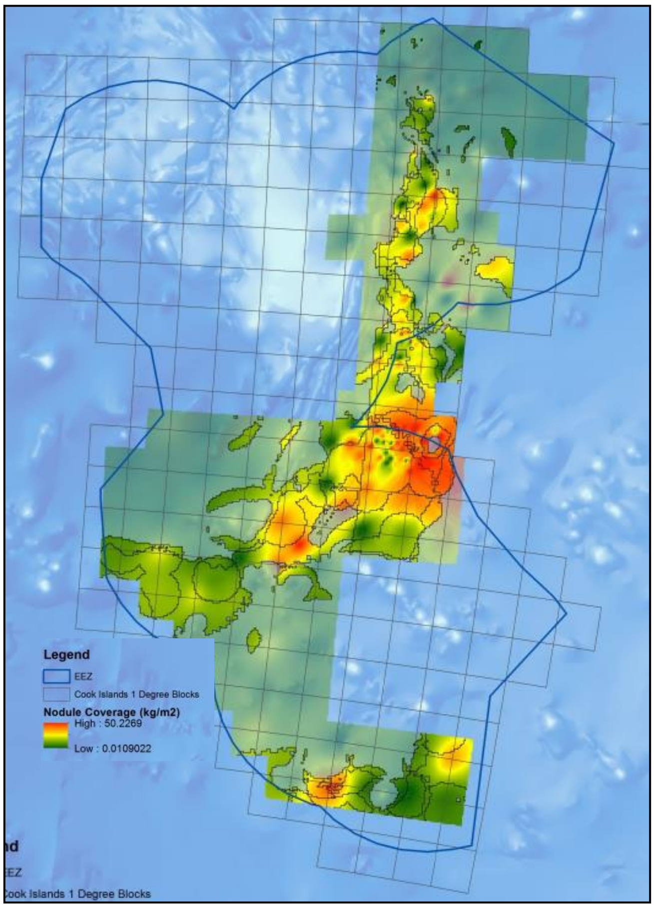


Figure 3-8: Nodule Abundance estimate (in kg/m^2) constrained by the mineral prospectivity model.

3.3.5 Joint Agencies (2015)

Following a presentation at the 2013 STAR conference, the United States Geological Survey (USGS) led a resource estimate with participation from scientists at Japan Oil, Gas and Metals National Corporation (JOGMEC), Cook Islands Seabed Minerals Authority (SBMA) and South Pacific Applied Geosciences Commission (SOPAC) (Hein et al., 2015). The estimate was based on the four JICA-MMAJ expeditions conducted between 1985 and 2000, the same data used to inform the estimate reported in this Report. The data were used to generate a map that defines the statistical distribution of nodule abundance throughout the EEZ, excluding the Manihiki Plateau (Figure 3-9). Hein et al. (2015) defined six areas with potential economic interest (A–F). The estimation method was not detailed.

The joint agencies estimated that the EEZ contains ~12.1 billion wet metric tons of Mn nodules. This is a significant difference compared to the lower total tonnage estimates by Kenex, and this MRE.

Like Kenex and this MRE, the joint agencies' resource estimate excludes the Manihiki Plateau, which does not contain nodule abundances considered by Hein et al. (2015) to be of potential economic interest. Each of the six areas (A–F) is ~20,000 km^2 and each would support between three and seven 20-year mine sites. Area A (Figure 3-9 or area 13-159 in Figure 2-2) contains the largest dry tonnages of Mn, Ni, Cu, V, Mo and W, and Area B (or area 16-159 in Figure 2-2) contains the largest dry tonnages of Co, ΣREY, Zr and Nb.

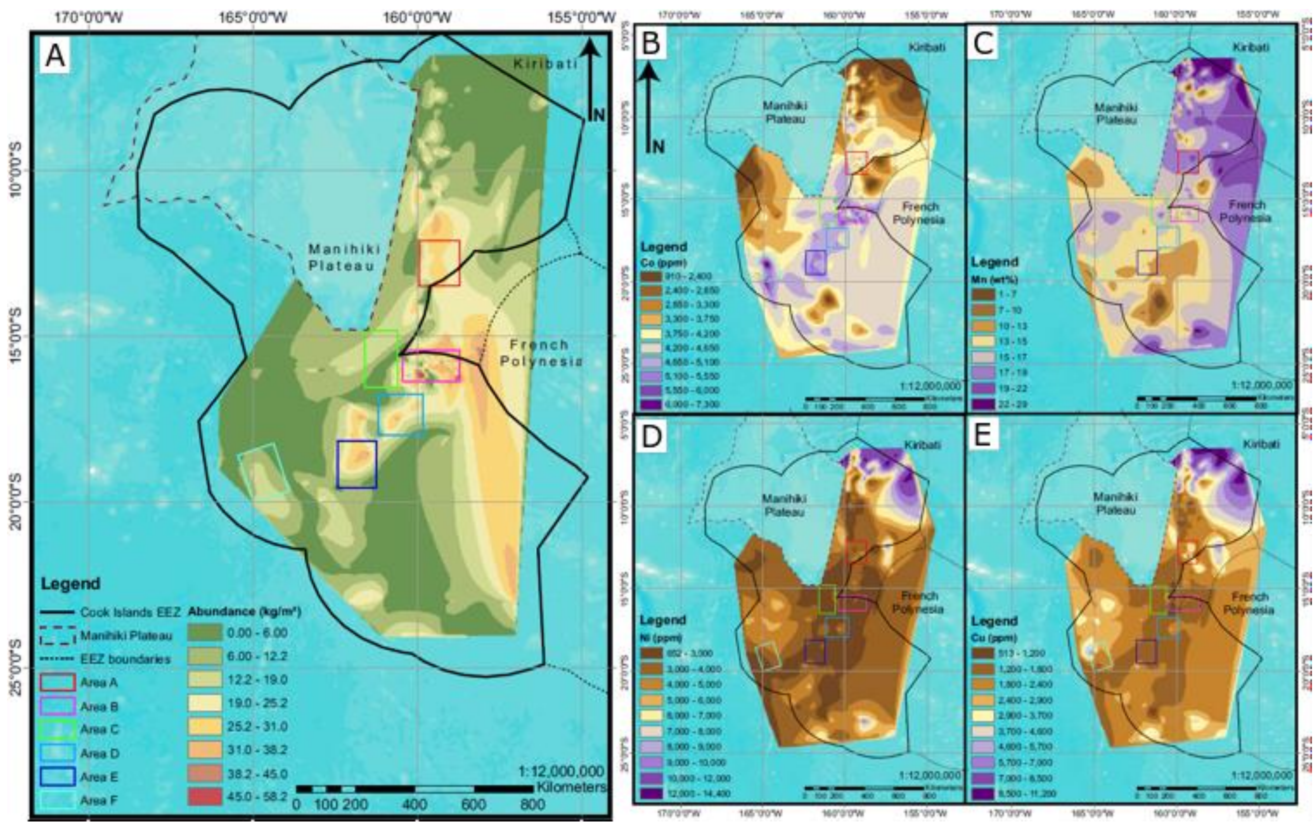


Figure 3-9: Maps displaying the different estimates conducted by the joint agencies from Hein et al. (2015). A) Abundance (kg/m^2); B) Co (ppm); C) Mn (wt%); D) Ni (ppm); E) Cu (ppm).

3.4 Other Studies

To date, four 'scoping-level' studies have been completed for the Cook Islands nodules deposit. These studies were not undertaken by Qualified or Competent Persons and were not reported in accordance with any CRIRSCO-affiliated reporting code. They did not result in the classification or reporting of mineral reserves.

3.4.1 Bechtel (1996)

Bechtel Corporation Mining and Metals (1996a) undertook a study (referenced here as the 'Bechtel Project') of the commercial mining of polymetallic nodules in the Cook Islands, which was based on the 'resource estimate' carried out by the EWC (Clark et al., 1995). This study highlighted the higher nodule abundance and Co grades in the Cook Islands compared to the CCZ and the Central Indian Basin. The study covered economical, technological, environmental, legal and political issues of the potential project.

The Bechtel Project proposed a harvest rate of 1,097,360 tonnes (wet) of nodules per year. This would produce 2,652 dry tonnes of Co or 10% of the world's then (1996) annual consumption. Bechtel's proposed mining method was trawl harvesting in the Aitutaki Passage using four trawlers. Each trawler would transfer the nodules onto three bulk carrier vessels of ~30,000 t capacity for transportation to a processing plant, located near Whangarei, New Zealand. The nodules would be processed using a combination of pyrometallurgy and hydrometallurgy. The total capital cost was estimated at USD 435 million, with a corresponding operating cost of USD 47 million per annum. The study concluded that a nodule mining project for Co in the EEZ would be feasible provided the price of Co did not drop below USD 16.75/lb in April 1996 dollar terms. The project did not consider economic recovery of other metals present in the nodules.

3.4.2 Norwegian Deep Sea Mining Group (2001)

The Norwegian Deep Seabed Mining Group (NDSMG) carried out a new evaluation of the Cook Islands' nodule potential (Lund and Søreide, 2001). NDSMG evaluated a 200,000 km^2 area around the Aitutaki Passage where the passage enters the south Penrhyn Basin. Within this area, Lund and Søreide (2001) reported an average nodule abundance of 20 kg/m^2 and an average Co grade of 0.45%. NDSMG noted that the most prospective areas for mining are poorly explored, and the area could benefit from large-scale mapping to refine the understanding of the prospective areas.

NDSMG developed an alternative nodule mining solution (Figure 3-10) which consists of:

- subsea harvesting system;
- riser/lifting system (using a winch rope); and
- surface vessel.

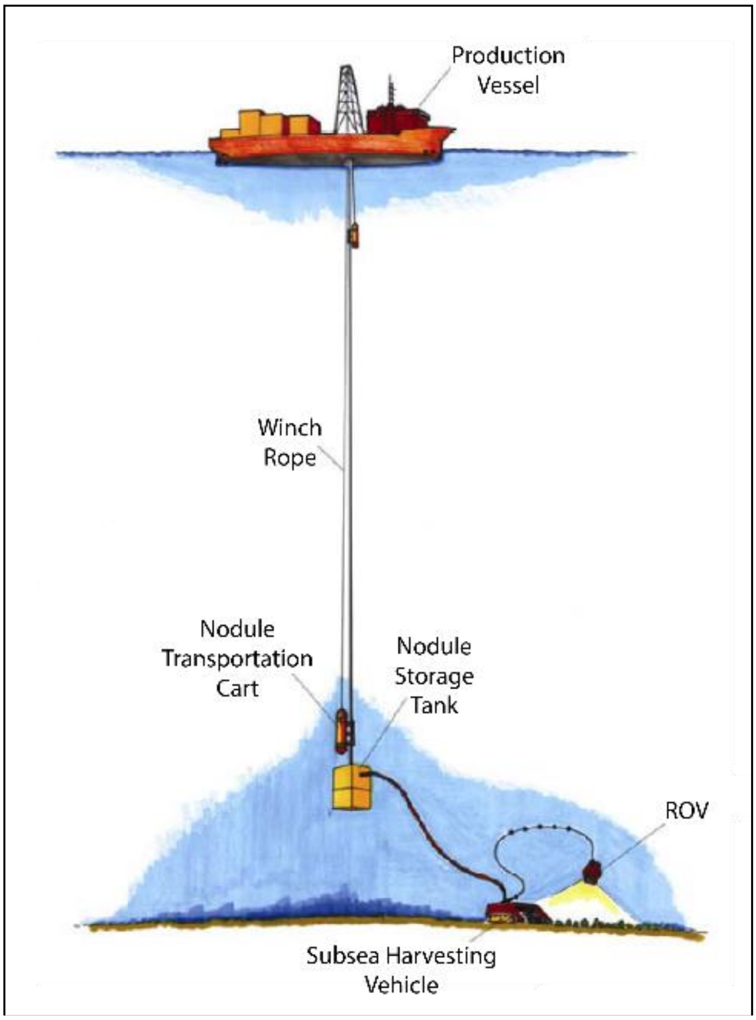


Figure 3-10: NDSMG's proposed nodule mining system.

NDSMG's economic and sensitivity analysis indicated that assuming a mine with an economic life of 20 years and a Co price equal to USD 15/lb, the resulting NPV (net present value) would be USD 187 million, and the IRR (internal rate of return) would be equal to 2.7%. The project did not consider economic recovery of other metals present in the nodules.

The project was therefore deemed infeasible with the technology then available and prevalent metal prices.

3.4.3 Imperial College (2010)

The high-level study by Belkabir (2010) was commissioned by the Commonwealth Secretariat on behalf of the Cook Islands Government to review nodule harvesting and metallurgical processing. The study also reviewed taxation concepts, environmental impacts and financial modelling.

Nodule harvesting and metallurgical options were reviewed at a high level, being taken from past studies focussed on the CCZ (i.e. differences between the CCZ and Cook Islands in terms of seabed geotechnical properties and bulk composition were not specifically considered). For the model assumptions, a mechanical conveyor collector and riser harvesting system were used, along with sulphuric acid leaching.

The financial modelling included a range of scenarios (mostly involving financing) and sensitivity analysis. The study concluded that at the 2010 metal prices, development of the project gave positive, if modest, returns (NPVs between USD 51 million and USD 544 million from a peak investment exposure of USD 1.2 billion; IRRs of 12.65–19.49%), but still had some key areas of risk given the rates of return (which nonetheless were competitive with other nickel laterite projects of the time).

3.4.4 Cardno (2016)

This cost-benefit focussed 'scoping study' (Cardno, 2016) also included seafloor massive sulphides in Papua New Guinea and Co-rich crusts in the Marshall Islands as well as Co-rich nodules in the Cook Islands. The 2015 Joint Agencies mineral resource estimate was used as the basis. Minerals harvesting was conceived to involve multiple tracked collectors feeding a buffer and vertical riser. A range of processing options were considered at a high level, but it identified metallurgical processing as being at the lowest level of technological readiness. Capital and operating costs were collected from a range of published studies. This study also tackled environmental costs including CO_2 offset costs, accident costs, and ecosystem services. It looked at options in terms of the value chain, i.e. direct ship ore, integrated operation with metallurgical plant overseas, in-country processing, as well as different metals basket options. The only option with attractive financial returns was the integrated operation with the metallurgical plant being located overseas and a metals basket with at least Co, Mn, Ni, and Cu. At the order of magnitude level, it found seabed minerals returns to the Cook Islands to be potentially comparable with tourism and fishing.

4 Geological Setting and Mineralisation

4.1 Regional Geology

4.1.1 Global Distribution of Nodules

Polymetallic nodules with various grades of base metals are found in submarine settings worldwide (Monget, 2015). This widespread distribution was recognised by the early 1970s when Kennecott Exploration surveyed all the major ocean basins (Figure 4-1). Nodules form at a wide range of depths, from 4,000–6,000 m below sea level in the mid Pacific to 200 m below sea level in the Gulf of Bothnia (Boström, Wiborg and Ingri, 1982) and 30 m in the Baltic Sea (Anufriev and Boltenkov, 2007). The location of nodule formation is reflected in nodule chemistry. Nodules with relatively high Co grades are found within the EEZ (Table 4-1) – often accompanied by high nodule abundances.

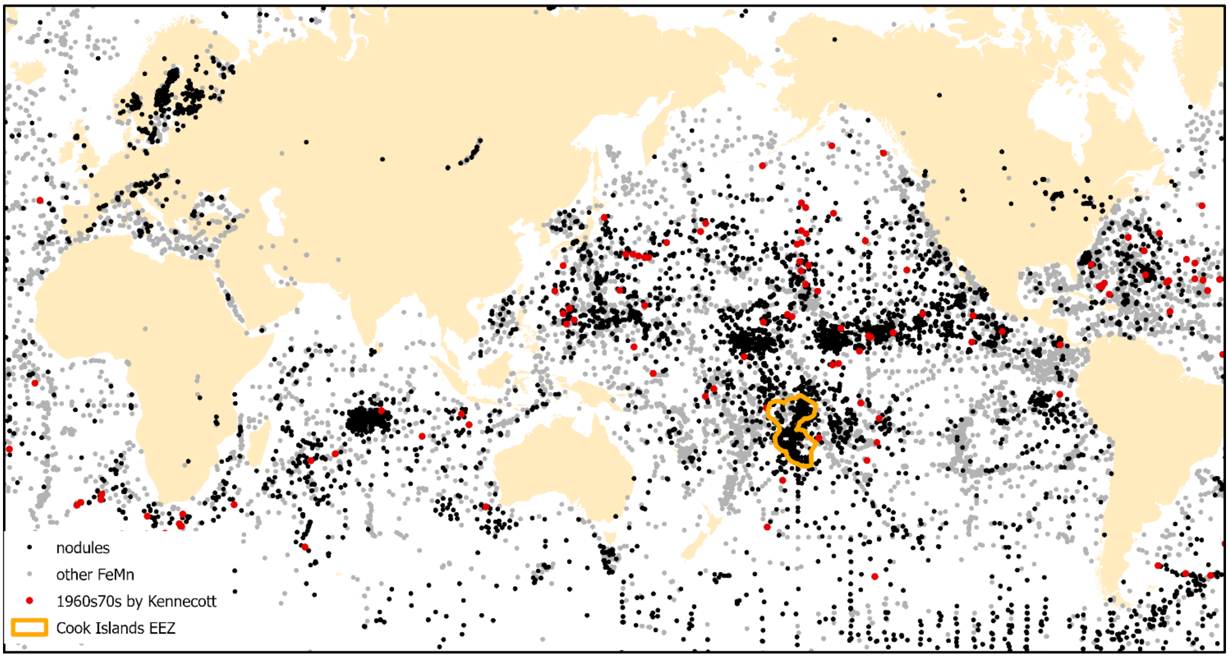


Figure 4-1: Fe-Mn crust and nodule samples collected from around the world. Sourced from Kennecott Corporation (1965); Monget (2022).

Table 4-1: Summary of global nodule grades. Modified from McKelvey, Wright and Bowen (1983). Data for the Cook Islands and South Penrhyn Basin–Aitutaki Passage are summarised from the dataset used in this project.

Element (wt%)	All Pacific Ocean	Cook Islands	South Penrhyn Basin–Aitutaki Passage	Clarion-Clipperton Zone	Atlantic Ocean	Indian Ocean
Mn	20.1	16.3	16.2	26.3	13.3	15.3
Fe	11.4	15.8	16.5	6.6	17.0	14.2
Ni	0.76	0.44	0.37	1.20	0.32	0.43
Cu	0.54	0.27	0.21	0.98	0.13	0.25
Co	0.27	0.38	0.42	0.20	0.27	0.21

4.1.2 Tectonic Setting

The Cook Islands include some of the oldest seafloor known (90–124 Ma; Müller et al., 2016). To the northwest, the Manihiki Plateau is dated ~123–124 Ma (Taylor, 2006; Timm et al., 2011), and might be part of a much larger submarine large igneous province that rifted apart shortly after its formation. The plateau has boundary faults and horsts on its northern and eastern sides as well as internal and broadly sub-parallel rift zones (Winterer et al., 1974; Figure 4-2). Dating of the region is compromised by a lack of detailed seabed magnetic data and much of the formation formed during the Cretaceous long normal period (Chron 34, 124.6–84 Ma).

There are abyssal plains to the south and east of the plateau that can be spatially defined as three basins (Figure 4-2). The basins are bound by a combination of fracture zones and volcanic rises. The Penrhyn Basin is to the east, the Samoa-Niue Basin is to the south and the newly named Southern Cooks Basin is to the southeast. The abyssal plains include areas of long linear abyssal hills, as well as zones almost entirely covered with small volcanic knolls. The abyssal plains to the southwest strike east, parallel to an inactive spreading centre located further south called Laperouse, while those to the northeast strike north, parallel to bounding fracture zones and to abyssal hills located further to the east. The change in orientation of the abyssal hills occurs within the western Penrhyn and eastern Southern Cooks basins in association with a series of north-northwest trending troughs newly termed the Rakahanga Rifts (Figure 4-2). These rifts are interpreted to have been one arm of a triple junction associated with the breakup of the plateau shortly after formation (Larson et al., 2002). The locations of presumed spreading centres that formed some of the abyssal plains are not clearly locatable (unlike the Osbourne Trough for example), but asymmetric spreading is related to plume-ridge interaction, which might explain some of the smaller, more complex arrangements of abyssal hills (e.g. as suggested elsewhere by Müller et al., 1998). While the age of formation of the east-trending abyssal hills can be constrained to the mid-Cretaceous by spreading rate estimates (Taylor, 2006), the age of the north-trending hills is harder to constrain (Larson et al., 2002).

The fracture zones bound the different basins and the Manihiki Plateau. The Manihiki Plateau has a rough parallelogram plan, including the orientation of internal rifts typically trending to the northwest or north-northeast. These orientations are distinct from the oceanic plate segment fracture zones (e.g. Marquesas and Austral, which typically trend to the west-southwest, with associated volcanic chains and the Rakahanga Rifts trending to the north–northwest). Within the Project Area, the newly named Manihiki-Palmerston Fracture Zone is most prominent. The Manihiki-Palmerston Fracture Zone defines the eastern side of the Manihiki Plateau but extends south, incorporating interpreted entrained plateau fragments up to ~120 km south of Palmerston Island. Further to the south, the fracture zone disperses into what might be a horsetail arrangement of accommodation fractures.

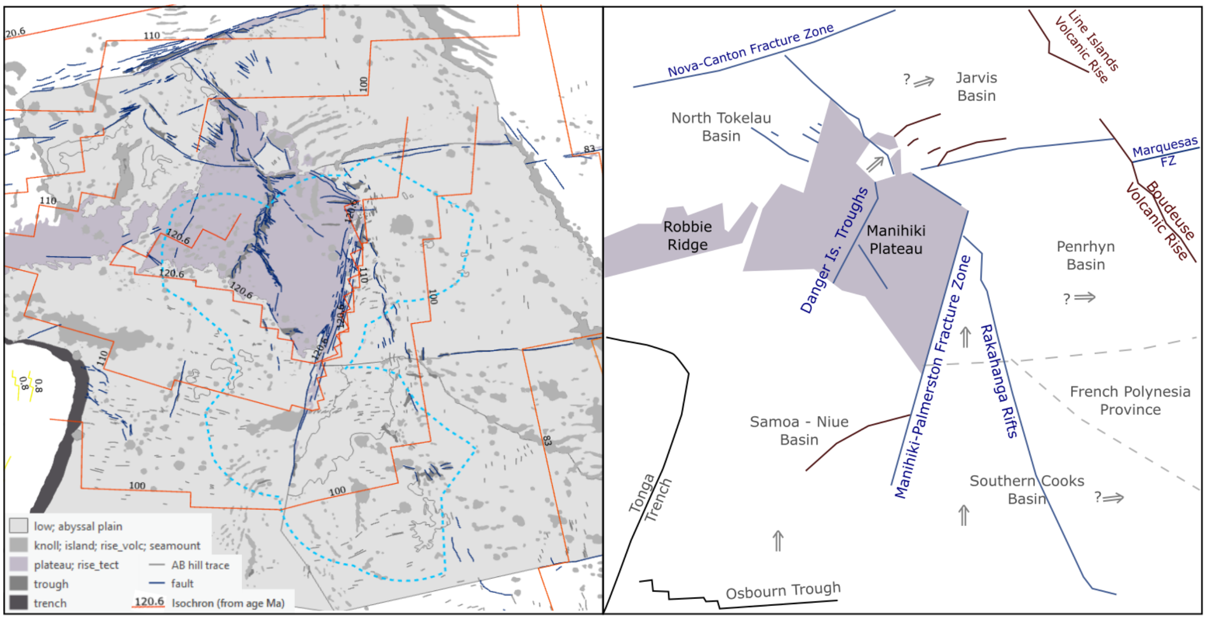


Figure 4-2: Tectonic setting of the EEZ.

Volcanic edifices are superimposed onto the seabed geology (Figure 4-3). These include isolated chains of seamounts and knolls as well as more continuous volcanic rises. The chains are in a variety of orientations, but predominantly west-northwest trending and some are interpreted to have resulted from hotspot activity (Wessel and Kroenke, 2008; Jackson et al., 2020). One key exception, is the short curvilinear northeast-trending seamount chain summiting at Palmerston Island adjacent to the Manihiki-Palmerston Fracture Zone that is associated with similarly oriented hills and may represent accommodation structures from the Manihiki-Palmerston Fracture Zone . Knolls and seamounts are found on the plateau as well as the abyssal plain, not least in the western Manihiki Plateau.

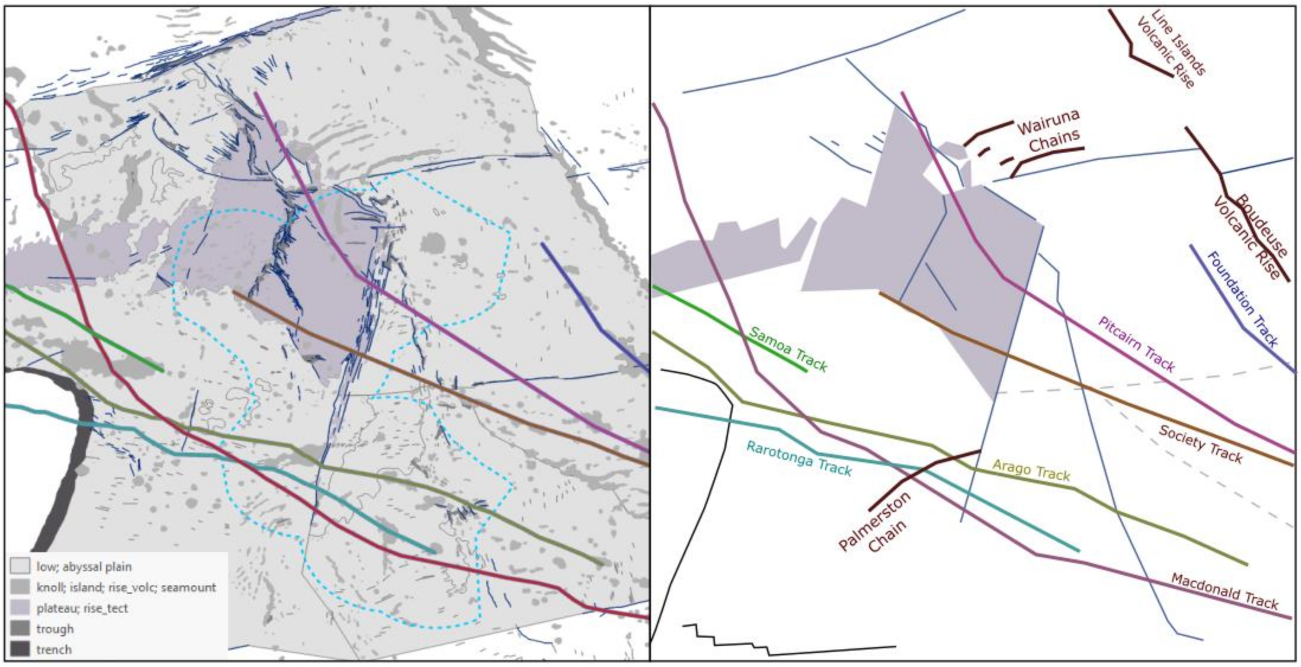


Figure 4-3: Volcanic chains and hotspot tracks Tracks after Wessel and Kroenke (2008) and Jackson et al.(2020). Refer to Figure 4-2 for the names of other features.

4.1.3 Ocean Currents

Two major oceanic currents are thought to influence mineralisation in the EEZ. These supply important well-oxidised bottom water to the EEZ (Glasby et al., 1986). In the northern part of the EEZ region, the westward-flowing Southern Equatorial Current system is an important oceanographic feature (Figure 4-4). A divergence along the equator leads to the upwelling of nutrient-rich waters, stimulating high biological productivity. The Southern Equatorial Current system is the northern limb of an anticlockwise circulating gyre within which the EEZ sits. Biological productivity in the southern part of the EEZ is low (Lutz et al., 2007; Cronan, 2013).

A second posited major current in the EEZ is the northwards flow of the Antarctic Bottom Water, which flows between the seafloor and ~3,500 m. This has been inferred to flow to the northeast along the Aitutaki Passage (e.g. Usui, 1983). The Antarctic Bottom Water also flows along the ridge just south of the Nova-Canton Trough (Yamakazi, 1992) and around the northeastern margin of the Manihiki Plateau to enter the North Penrhyn Basin (Figure 4-4). Interpreted strengthened flow of the Antarctic Bottom Water during the Palaeogene or Cretaceous has been attributed to the formation of polymetallic nodules (Usui, 1994).

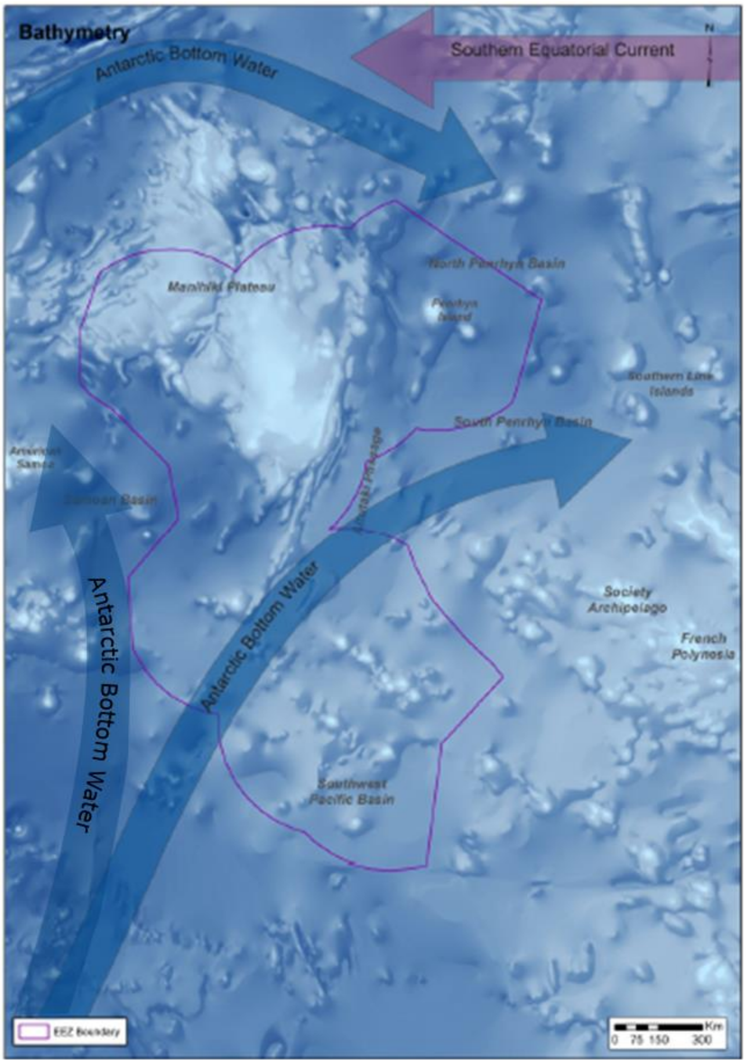


Figure 4-4: Schematic of ocean currents in and near the EEZ. Sources: Kenex (2014a); Cronan (2019).

4.1.4 Seabed Geomorphology

The 2021 GEBCO grid was used as the basis for a 1:4,000,000 scale geomorphological map of the Cook Islands seabed (Figure 4-5). This was supplanted with multi-beam echosounder bathymetric data, regional magnetic field data and mapping from the literature review.

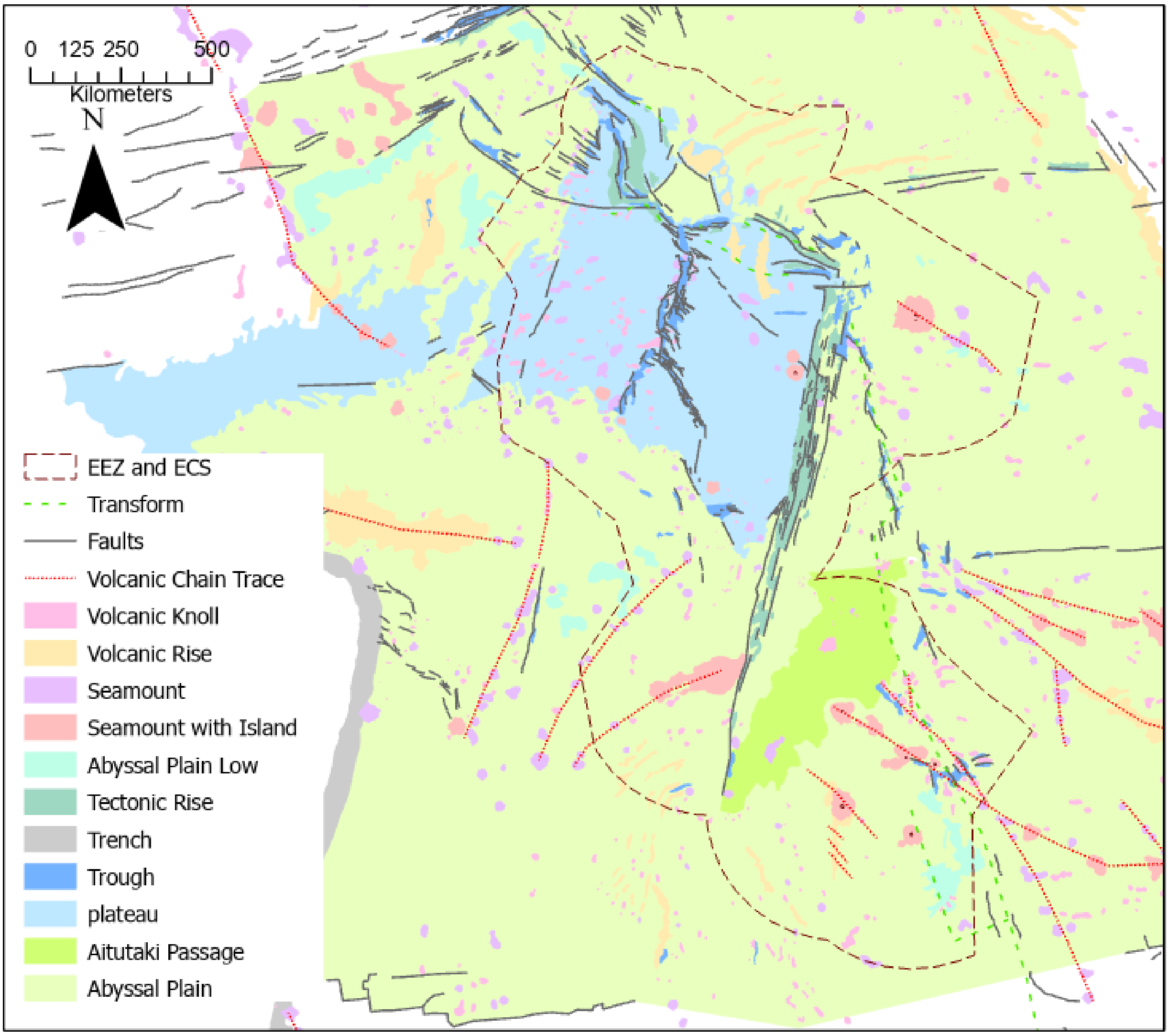


Figure 4-5: Seabed geomorphology for the Cook Islands and surrounds Source: Browne, Parianos and Murphy (2023). EEZ: exclusive economic zone; ECS: Extended Continental Shelf application.

Mapped units comprise the following:

- Abyssal plains are generally areas with limited relief except for abyssal hill traces and small knolls. They are typically presented as 'basins' bound by major features such as transform fracture zones, plateaux and volcanic rises. Abyssal hill traces are an example of abyssal hill orientations from the parts of the GEBCO grid composed from MBES (multi-beam echosounder) data. These are not shown in Figure 4-5, but are shown in the map presented by Browne, Parianos and Murphy (2023). Abyssal plains are interpreted to be the domain containing significant polymetallic nodules within the EEZ.

- Abyssal plain lows are restricted areas of abyssal plains characterised by slightly greater depth (100–300 m) than adjacent plains.
- Knolls are probable volcanic edifices <1,000 m, found on plains and plateaux. Only the larger knolls were mapped either as singular (usually circular) or compound forms. They are often found among seamount chains but may form their own chains.
- Seamounts are probable volcanic edifices >1,000 m, found on plains and plateaux. They often form chains at a wide variety of orientations, including the Hawaiian-Emperor orientation. The chains often grade into volcanic rises (see below). Seamounts are mapped as singular (usually circular) and compound forms. Islands within the EEZ are mapped seamounts that breach the sea surface. The existence of flat-topped edifices located on the Manihiki Plateau may support a past shallower position.
- Volcanic rises are typically elongated rises of probable volcanic origin. They merge into volcanic chains and the compound forms of seamounts. Some rises are very extensive, including the Boudeuse Volcanic Rise at the eastern limit of the Penrhyn Basin. Volcanic chains are lineaments of interrupted alignments of seamounts and knolls.
- Plateaus are extensive areas of the seafloor elevated (500–2,000 m) relative to the plains. They do not present evidence of abyssal hills; all units are very likely part of the much older Manihiki Plateau, which is known to have significant sediment cover (in some places ~1 km thick). Some parts of the plateaus have more knolls than other parts; it is not known if this is due to later volcanic activity or different amounts of sediment cover.
- Tectonic rises are typically elongate rises of probable tectonic origin. Most are located along the northern and eastern edges of the Manihiki Plateau, as well as along the Manihiki-Palmerston Fracture Zone which trends to the southeast of the plateau.
- Troughs are narrow/elongated and usually aligned – depressions that are 500–1,000 m deep. They are found cutting both plains and plateaus.
- Mapped faults are mapped breaks in the seabed bathymetry either at a high angle to prevailing abyssal hill traces or of too great a magnitude to be the normally faulted escarpments of abyssal hills.

In 2000, JICA collected 15 kHz MBES data over an area called 16-159 (or Central Area in Figure 4-6). A comparison between the GEBCO and the MBES data conducted by SBMA indicates there is a good correlation between the datasets. However, the MBES data have not been incorporated into the GEBCO product.

4.1.5 Islands

All islands making up the Cook Islands (Figure 2-1) are seamounts, but they have a variety of landforms (Table 4-2). The islands are thought to have mostly formed from hotspot volcanism (Wessel and Kroenke, 2008; Jackson et al., 2020), although Jackson et al. (2020) also describe a second phase of volcanism on Rarotonga and Aitutaki that is not thought to be derived from hotspot activity.

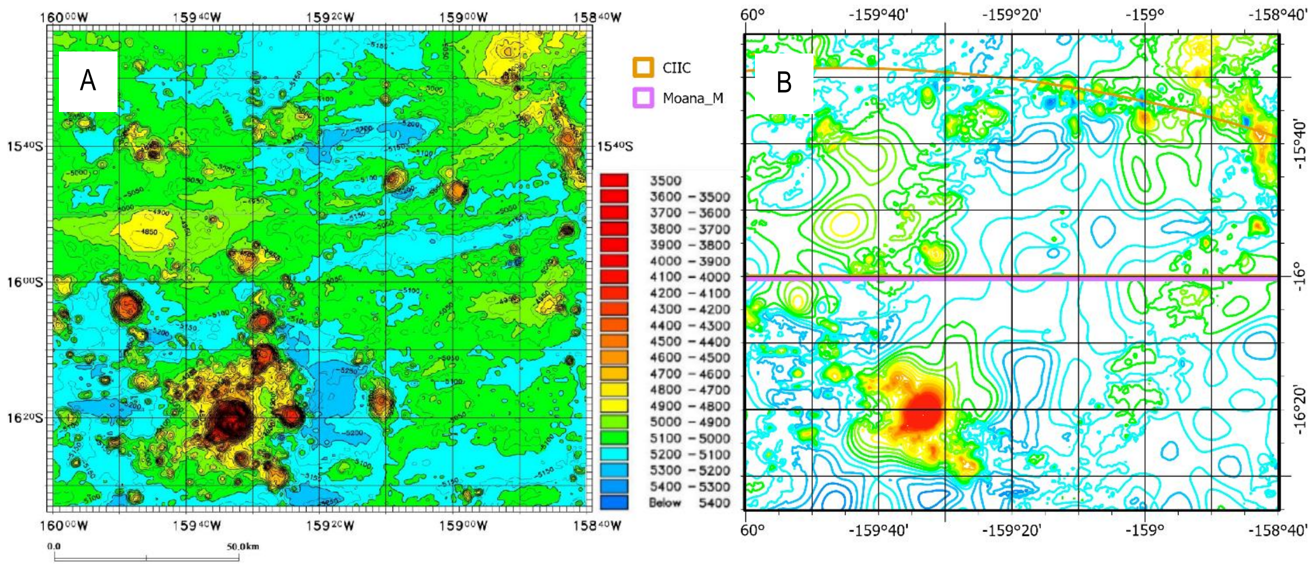


Figure 4-6: Comparison between MBES and GEBCO data. A) MBES bathymetric map JICA-MMAJ (2001); B) Bathymetric contours extracted from GEBCO (2021).

Table 4-2: Attributes of the Cook Islands. Table adapted by Fathom Pacific and ERIAS Group (2021) from the 5th *National Report to the Convention on Biological Diversity* (National Environment Service, 2017).

Region	Island	Land Area (km^2)[1]	Highest Elevation (m)[2]	Landform	Inshore Marine Habitats	Use
Northern Group	Penrhyn	10	3	Atoll	Lagoon	Inhabited
	Rakahanga	4	3	Atoll	Lagoon	Inhabited
	Manihiki	4.9	5	Atoll	Lagoon, brackish ponds	Inhabited
	Pukapuka	3.8	4	Atoll	Barrier reef, deep lagoon	Inhabited
	Nassau	1.3	9	Sand Cay	Barrier reef, deep lagoon	Inhabited
Southern Group	Suwarrow	0.4	3	Atoll	Lagoon	Wildlife Reserve
	Palmerston	2.1	5.3	Atoll	Lagoon, fringing reef	Inhabited
	Aitutaki	18	124	Almost-atoll	Lagoon, saltwater marshes, fringing reef	Inhabited
	Manuae	6.2	10	Atoll	Fringing and barrier reefs, lagoon	Wildlife Reserve
	Mitiaro	22.3	15	Makatea[3]	Fringing reef	Inhabited
	Takutea	1.0	5	Sand Cay	Fringing reef	Wildlife Reserve
	Atiu	26.9	72	Makatea	Fringing reef	Inhabited
	Mauke	19.1	29	Makatea	Fringing reef	Inhabited
	Mangaia	48.3	169	Makatea	Fringing reef	Inhabited
	Rarotonga	67.4	652	High Island	Fringing coral reef and shallow lagoon	Inhabited

Notes:
1. These figures were provided by Dan-Olaf Rassmussen, National Environment Service, based on measuring polygons of areas from 2010 satellite images.
2. Source: Wood and Hay, 1970
3. Makatea refers to a raised reef platform island. For atolls, land was defined as areas with some vegetation cover.

4.2 Local Geology

4.2.1 Stratigraphy

Stratigraphy on the abyssal plains is based on sub-bottom profiles carried out and interpreted by JICA (JICA-MMAJ, 2001). On the eastern side of the Manihiki Plateau, there are also seismic profiles interpreted by Ai et al. (2008) from the CATO3 and KIWI12 expeditions which correlate to Deep Sea Drilling Program (DSDP) site 317 (Schlanger and Jackson, 1976; The Shipboard Scientific Party, 1976).

The deepest units are the ultramafic rocks occasionally found on the lower slopes of the plateau (Winterer et al., 1974; Andreev et al., 2008), but the basement is predominantly basaltic lavas and associated breccias (Winterer et al., 1974; Schlanger and Jackson, 1976). The exposure of ultramafic rocks is limited and poorly understood. No structural comparison with outcrops found in oceanic core complexes has been undertaken to date (Maffione, Morris and Anderson, 2013).

Isolated examples of basaltic rocks are described by JICA-MMAJ (2001) from ~160 km west-southwest of Palmerston and DSDP33 on the Manihiki Plateau. The olivine basalt breccia described by JICA-MMAJ was collected using a free-fall grab (FFG) and thus likely relates to recent volcanism (e.g. as found in the CCZ by Parianos, 2022). The basaltic basement in the DSDP hole is a likely tholeiite.

On the Manihiki High Plateau, the seismic and drilling indicates that there is ~900–1,000 m of sedimentary cover over the basalt basement; the basal units are 300–400 m of mixed volcaniclastic sandstones and limestones (Maestrichtian-Aptian) that in part may have been deposited subaerially, overlain by ~300 m of chalk (Eocene to mid-Miocene) with an uppermost 200 m of calcareous ooze (the eastern side of the Plateau is 1000–2,000 m shallower than the adjacent abyssal plains and hence likely well above the lysocline).

Total sedimentary thickness on the abyssal plains is less well constrained but the sub-bottom profiles carried out by JICA-MMAJ suggest up to several tens to hundreds of metres of sediment. The uppermost clay-ooze layer is described in Section 4.2.2.

4.2.2 Clay-Ooze Types

Seabed clay-ooze hosts the polymetallic nodule deposit considered here and most of the attendant fauna. It is also likely to be the tractive medium for any self-powered future nodule collection system.

4.2.2.1 Mineral Based Classification

The most comprehensive study of the seabed clay-ooze is by JICA-MMAJ (1986, 2001) which found predominantly siliceous clays and much rarer calcareous oozes (often in shallower areas). Classification of the sediment type was based on optical microscopy (smear slides) and is supported by x-ray diffraction (XRD) analysis.

Studies in the CCZ indicate there is a transition from calcareous oozes to siliceous clays associated with the position of the calcite-lysocline and carbon concentration depth (Lipton, Nimmo and Parianos, 2016).

The JICA-MMJA 2001 dataset includes 90 sediment samples (Table 4-3), predominantly collected by FFG, as well as box cores (BCs; also known as spade cores; SC) and gravity corers (large corers; LC). The total number of samples collected during the 1985 expedition is not specified but a minimum of five samples were collected from four sites.

Table 4-3: Sediment sample types by area. Compiled from JICA-MMAJ (1986, 2001)

	JICA 'Southern' 18-162		JICA 'Central' 16-159		JICA 'Northern' 10-159		JICA 1985 07-158	JICA-MMAJ Classification Standard	
	#	Proportion (%)	#	Proportion (%)	#	Proportion (%)	#	Total Fossil (%)	Remarks
Brown clay	5	42	64	96	11	100	3	<10	
Insoluble brown clay	6	50	2	3	0	0		<10	Similar to the above but poorly soluble and relatively impermeable
Calcareous clay	1	8	1	1	0	0	1	10-30 and siliceous <5	Mostly foraminifera; in the 1985 area this is also termed calc-siliceous clay
Zeolite clay							1		Zeolite content >5%
Total	12	100	67	100	11	100	5		

The vast majority of the abyssal plains seabed in the Project Area sampled by JICA-MMAJ is composed of brown clay. There is some association of more calcareous clay-ooze with seamounts or other shallower areas. This is supported in the northern part of the project, with several samples analysed by Cronan, Rothwell and Croudace (2010) and more calcareous sediments only found further to the north (4°S and north).

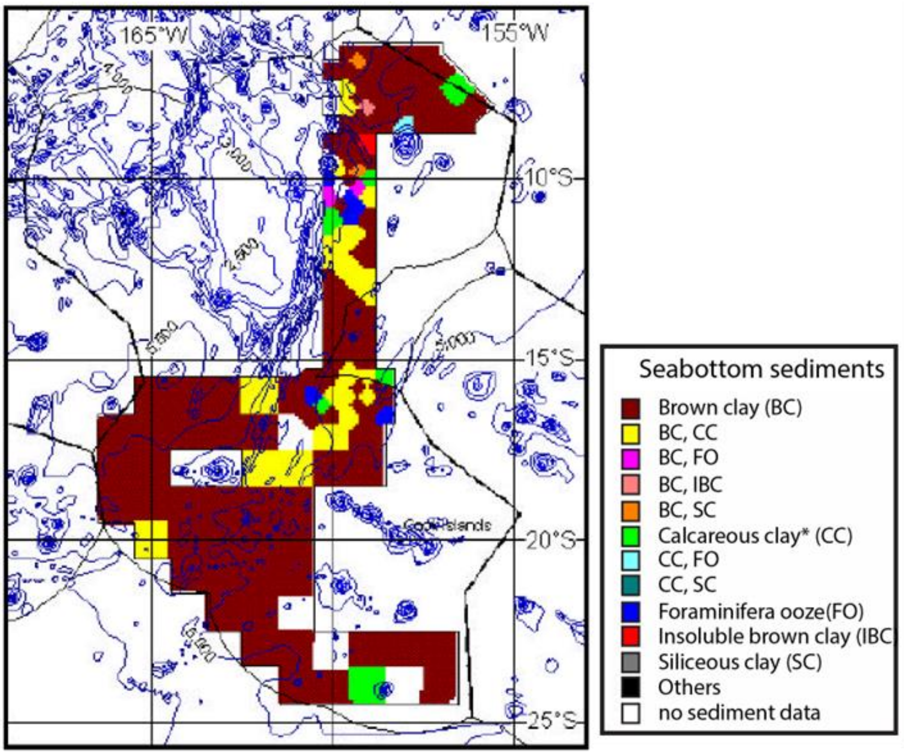


Figure 4-7: Seabed sediments determined from JICA-MMAJ cruises. Source: Kojima (2001).

The key seabed clays in the Project Area are discussed in more detail by JICA-MMAJ (2001), which is reproduced with only minimal edits below.

4.2.2.1.1 Brown Clay

Almost all brown clay is dark reddish-brown in colour; dark brownish-red clay is found rarely. Almost all brown clays have 5YR3/2 tone in Munsell Soil Colour Charts, and those with 5YR3/3, 2.5YR3/2 and 2.5YR3/4 tone occur rarely.

The main constituents of this clay include clay minerals, siliceous organic remains and calcareous organic remains. Brown clay also includes minor amounts of amorphous material, volcaniclastics, zeolites, barite, ichthyolith, and micro-nodules (ferromanganese oxides).

The siliceous organic remains are radiolaria and sponge spicules and they occur in almost all samples in small amounts (<1%). Calcareous organic remains consist of foraminifera and coccolith. Foraminifera occurs in approximately one-third of the samples and mostly in amounts <1%, with some exceptions reaching 5%. Coccolith occurs in approximately half of the samples and the content is <1%.

Micro-nodules occur in almost all samples. Most of the micro-nodules have minute grain size and the content is predominantly <1%, with exceptions reaching several per cent.

Brown clay consists mostly of minute clay particles, but some include silt-fine sand. The sand consists of micro-nodules and somewhat solidified mud.

4.2.2.1.2 Insoluble Brown Clay

Insoluble brown clay has a mineral composition similar to brown clay, but it has strong adhesiveness and does not disperse in water easily. The cohesion of clay particles is observed microscopically and is aggregates of these cohesion grains.

The colour of this clay is dark reddish-brown, similar to brown clay or somewhat darker, and is 5YR3/2, 5YR3/3 and YR2.5/2 in Munsell Soil Colour Charts.

The micro-nodules found in this clay are slightly coarser than those of brown clay. The micro-nodules account for ~1% by volume and are more oxidised.

4.2.2.1.3 Calcareous Clay

Samples containing more than 10% organic remains were collected from two localities, and typically contained ~15% calcareous remains. The colour is dark yellowish-brown to dark reddish-brown and is 10YR4/4 and 5YR3/2 in the Munsell Soil Colour Charts.

The contents are ~15% foraminifera and calcite with 1% coccolith. Small amounts of radiolaria, spicules and micro-nodules are also found.

4.2.2.1.4 Zeolitic Clay

Zeolitic clay is similar to brown clay but is defined by its relatively high zeolitic content (>5%).

Typically, most brown clay materials in the EEZ contain zeolitic minerals. There was only one sampling point where the sample contained >5% of zeolitic minerals.

4.2.2.2 *Clay-Ooze Types at Shallow Depths*

JICA-MMAJ (2001) reported the results of several gravity cores (large cores) collected to examine the changes in sediment types with depth (Figure 4-8). The cores were predominantly collected from Central Area (16-159), and one core was collected from the Northern (10-159) and Southern (18-162) areas, respectively (Figure 4-8 and Table 4-3).

The cores reveal an inconsistent mix of brown clay and insoluble brown clay down to three metres below the surface. Beds of crust and volcanic siltstone are also occasionally present. Trace fossils also indicate highly variable age-thickness to pre-Pliocene (>5.3 Ma) and pre-Miocene (>23 Ma) times (Figure 4-8). In the Northern Area (10-159), the sediment is more or less consistent as seen in a 4.47-m-deep gravity core collected further south (~11-159 area) reported by Cronan et al., (2010), which is comprises dusky red-brown zeolite-bearing clay that dates to the Miocene (>5 Ma).

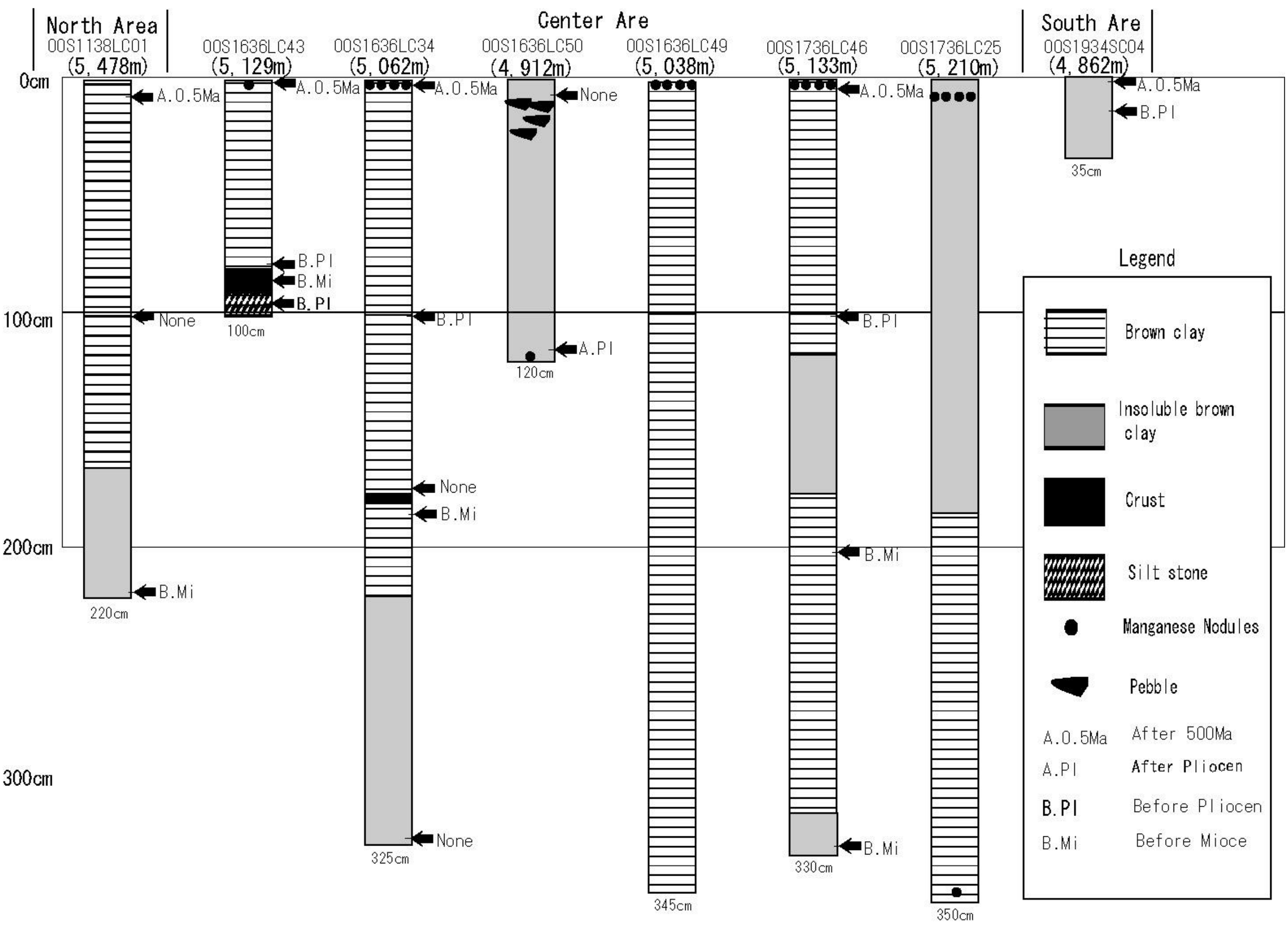


Figure 4-8: Gravity cores collected by JICA-MMAJ.

4.2.2.3 Sub-Bottom Profiling Based Classification

JICA-MMAJ (2001) used a sub-bottom profiler (SBP) to characterise the different sediment types below the seabed. The SPBs are only effective at identifying sediment ~2 m below the seabed. JICA-MMAJ used a narrow-beam SBP with a frequency of 3.5 kHz. Estimated depth of penetration varies by section, but JICA-MMAJ reports 50–100 m of penetration depending on how acoustically translucent the sediment cover was. Sediment types were characterised by the sectional return from the profiler, with particular attention paid to the common existence of a transparent uppermost layer (Figure 4-9).

Modern exploration vessels have a wider range of digital SBP systems to choose from (e.g. 2–9 kHz Kongsberg SBP 29 system and 0.5–7 kHz Teledyne Parasound), but it is likely that the sediment profile types identified by JICA-MMAJ have current relevance. JICA-MMAJ (2001) reports SBP profiles from different parts of the Project Area, including the 13-159, 16-159 and 18-162 areas. Maps produced from the resulting SBP data for the 16-159 Area are presented in Figure 4-9.

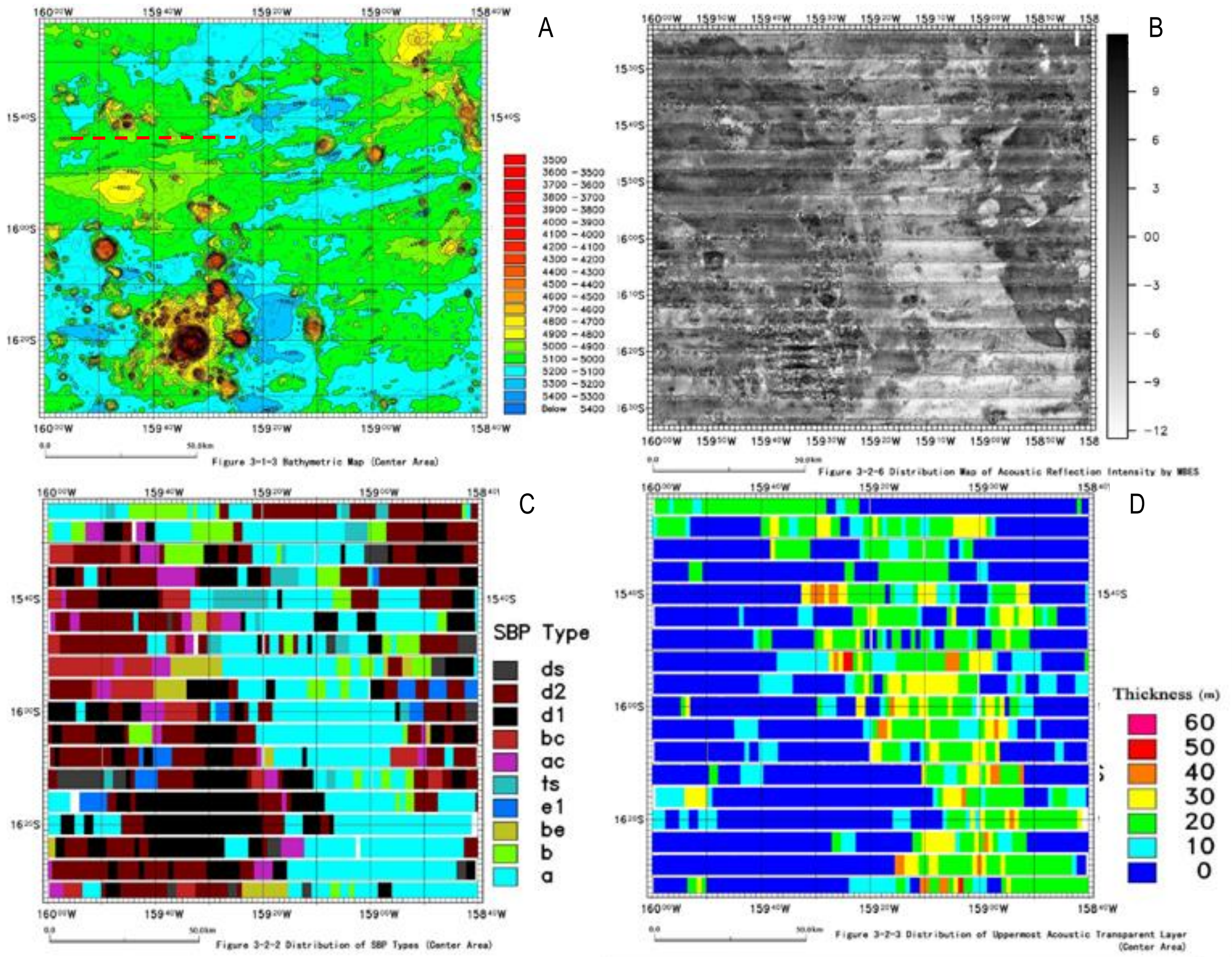


Figure 4-9: Example of MBES bathymetry. (A) backscatter (B), SBP surface sediment (C) and thickness of the uppermost acoustically transparent layer (D). Source: JICA-MMAJ. Dashed red line on the bathymetry is the photograph profile in Figure 4-29.

As indicated in Figure 4-9, the different types of SBP sediment profiles and bathymetry often correspond. Specifically, the types of profile with acoustically transparent uppermost layers (e.g. types a and b) tend to be found in topographically flat areas, whereas the acoustically opaque uppermost layers (e.g. types d1 and d2) tend to be associated with seamounts, knolls and topographic highs. Each type classified by JICA-MMAJ (2001) is described in sections 4.2.2.3.1 and 4.2.2.3.2.

There is also a clear correlation (at least in Central Area 16-159) between sediment profile type and nodule type, which is consistent with the nodule formation model (Figure 4-26).

4.2.2.3.1 Acoustically Transparent Uppermost Sediment Layers

- **Type a** consists of two layers: transparent and opaque layers. The lower opaque layer is strongly and darkly recorded and thus can be distinguished from the upper transparent layer. The thickness of the transparent layer is 10–40 m but is predominantly <20 m thick in the EEZ.
- **Type b** consists of transparent and opaque layers similar to Type a, but the lower opaque layer is not always clearly defined. The thickness of the transparent layer is 10–60 m.
- **Type be** consists of transparent and opaque layers. The thin opaque layers are intercalated in the uppermost part of the transparent layer. The thickness of the upper opaque layer is 5–10 m and 50–60 m of the lower opaque layer.
- **Type el** consists of alternating transparent and opaque layers. Type el sediments occur relatively infrequently.
- **Type ts** consists of a transparent layer present in the uppermost part of the sedimentary profile. The boundary to the opaque layer is not clear because of acoustic scattering caused by topographic relief.

4.2.2.3.2 Types with acoustically opaque uppermost layer

- **Type ac** consists of transparent-opaque layers similar to Type a, but the boundary with the lower opaque layer is clear. However, the uppermost part of the upper layer, namely the seafloor surface, is not a single line, but an opaque layer ~10 m thick. This type is transitional in acoustic character from Type d2, which will be mentioned later, and the upper transparent layer was treated as 0 m.
- **Type bc** is similar to Type b with transparent-opaque layers. However, the thickness of the opaque layer exceeds 50 m, and the boundary is typically not clear. The seafloor surface is not recorded as one line, as in the case of Type ac, but is an opaque layer ~10 m thick. The thickness of the upper transparent layer was also treated as 0 m.
- **Type c** consists of three sequential layers: opaque, transparent, and opaque. This type is almost non-existent in 16-59 (Central Area), but many instances are observed in 18-162 (Southern Area per JICA; Figure 4-7).
- **Type d1** is composed only of opaque layers. It is inferred to indicate exposed rocks and the distribution typically corresponds with seamounts and knolls.
- **Type d2** consists only of opaque layers similar to Type d1. Type d2 occurs in topographically flat areas and not on seamounts and knolls. Type d2 typically correlates to coarser surface sediments and consolidated sediments.
- **Type ds** consists of opaque layers, but the records are not clear because of the scattering of waves by seafloor topography.

4.2.3 16-159 (Central Area)

Compared to the rest of the EEZ, the geology of the 16-159 Area is well constrained due to systematic MBES and SBP surveying and denser sampling (Figure 4-9) conducted by JICA-MMAJ (2001).

The 16-159 Area comprises abyssal hills striking east-northeast with heights of 100–200 m and a 5–20 km spacing (Figure 4-10). The north-eastern corner of the area has volcanic edifices associated with the Rakahanga Rifts (sections 4.1.2 and 4.1.4). There are numerous volcanic knolls scattered in the Central Area, especially to the southwest. The MBES backscatter and SBP data (Figure 4-9) were interpreted by SBMA. Three main sediment types were identified (Figure 4-10), all of which host nodules. Mapped volcanic rises are either an usually elevated abyssal hill or may indicate inflation from shallow intrusions ahead of seamount formation, which has been described in the CCZ (Parianos, 2022).

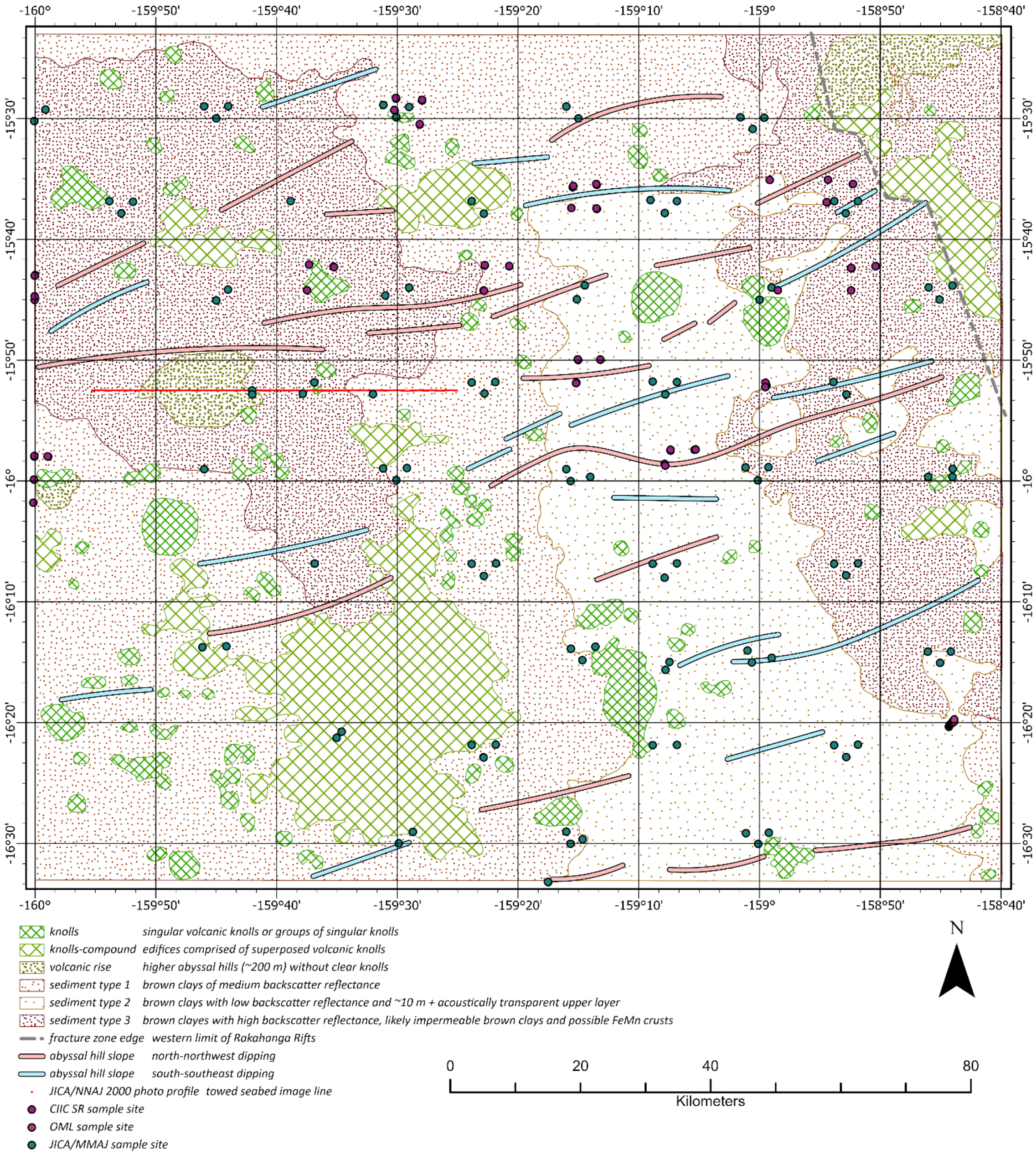


Figure 4-10: Seabed geology of Central Area 16-159.

Additional characterisation of the different units is provided in Table 4-4. A geological domain for the MRE (the entire area with the exclusion of knolls) is provided in Section 7.2.1.

Table 4-4: Seabed units in Central Area 16-159.

Unit	Sediment types (SBP)	Nodule characteristics	Other comments
Sediment type 1 *(moderate backscatter reflectance)*	Variable (<20 m) thickness, uppermost transparent layer and lower opaque layer (e.g. Figure 4-9) (mixed type a, d2>b, ds etc.)	High abundances, mix of spherical and ellipsoidal forms (e.g. Figure 4-15)	Effectively the default sedimentary unit. Opaque layers may be associated with coarser sediments, but this is not confirmed
Sediment type 2 *(low backscatter reflectance)*	Thick (20–30 m) uppermost transparent layer (predominantly type a)	High abundances dominated by spherical forms	Associated with flatter and slightly lower area of seafloor (may pond sediments from the west-southwest)
Sediment type 3 *(high backscatter reflectance)*	Typically thin (<10 m) to absent uppermost transparent layer, and often thick opaque layer (mixed d2>bc>ac, be, a etc.)	Medium to very high abundances ellipsoidal and other forms	May have more abundant crusts. MFES data have a high proportion of quasi-anomalies
Knolls *(bathymetric edifice and mottled backscatter reflectance)*	Typically absent uppermost transparent layer (type d1)	Often very low abundances. Highly variable forms including pebble; area is under-sampled due to lack of mining potential.	Includes rugged topography and likely abundant crusts. Excluded from Mineral Resource domain.

4.2.4 Distribution of Nodule Abundance

The distribution of nodule abundance (from sampling to date) is presented in Figure 4-11. While a causal genetic relationship between abundance and different grade types has not been confirmed, Figure 4-12 demonstrates that high abundances of nodules correlate to nodules rich in Co (but not the converse) and nodules rich in Ni have only been found in low abundances in the EEZ. Other types of nodules (low Co-low Ni and transitional) can be found in a wide range of abundances.

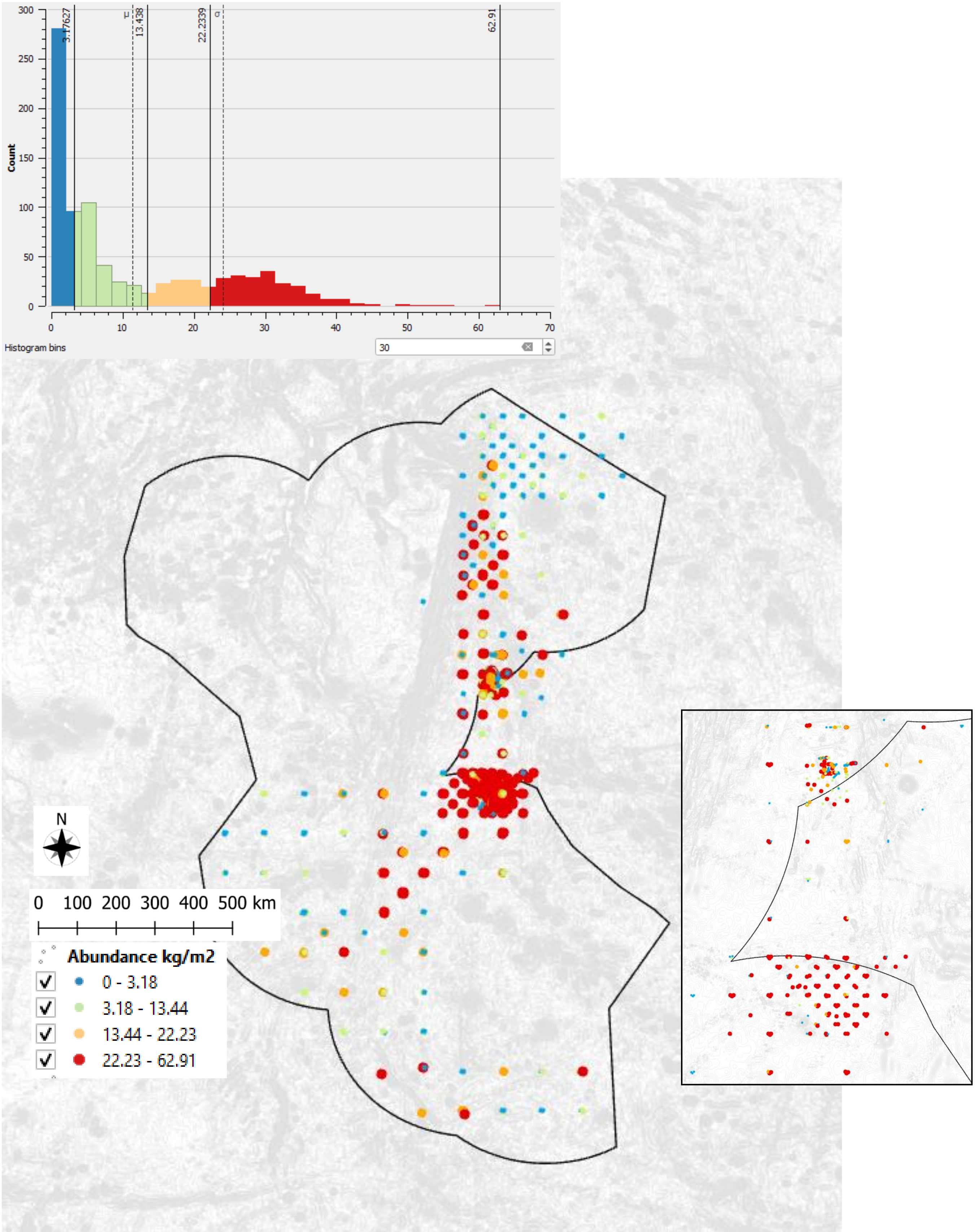


Figure 4-11: Distribution of nodule abundance. Background is greyscale bathymetry.

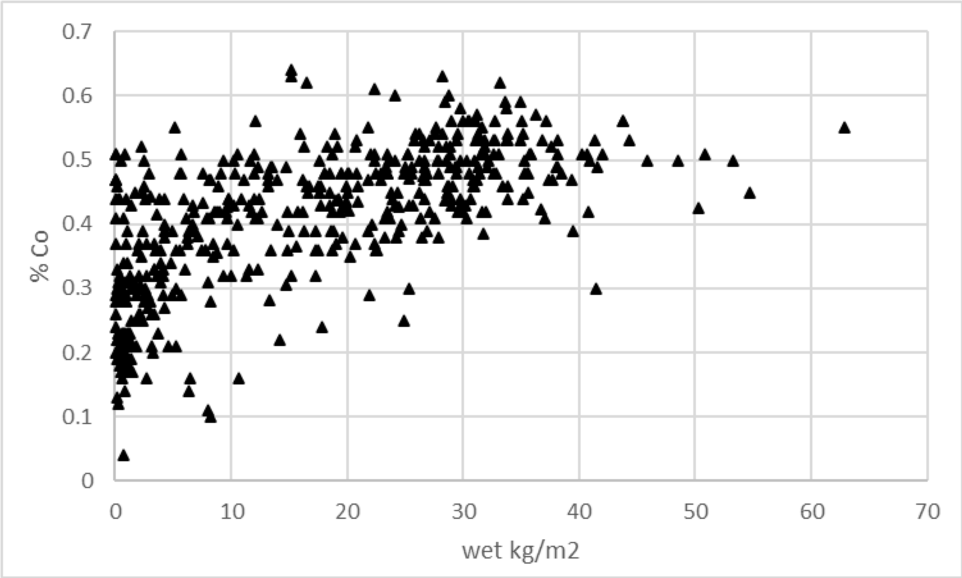


Figure 4-12: Nodule abundance versus Co grade.

4.2.4.1 Estimation From Photographs

The use of nodule size from seafloor photographs to estimate nodule abundance in the CCZ has been attempted since at least the early 1970s (Kaufman and Siapno, 1972; Felix, 1980). This is in part due to estimating nodule weight as CCZ nodules have a consistent density (Section 5.1.4.5). Estimation of nodule weight is typically done empirically, but Yu and Parianos (2021) determined the key principles and mathematics behind the relationship in terms of size distributions of nodules for given areas (or facies). Adequately understanding the distribution can in some cases allow abundances to be accurately estimated with simple counts of nodules or even measurements of nodule coverage (Yu and Parianos, 2021).

The key principles and assumptions made by Yu and Parianos (2021) include:

- Nodules are ellipsoidal in shape.
- Within a sampled domain, nodules have a similar size ratio between the three principal axes.
- The size of the nodules within the sample domain follows a distribution (typically a Generalised Rayleigh Distribution).

While many nodule fields in the CCZ contain nodules that align with these principles (Felix, 1980; Parianos, Lipton and Nimmo, 2021; Yu and Parianos, 2021), there are two key limitations in using scaled photographs to estimate nodule weights nodules (Felix, 1980; Parianos, Lipton and Nimmo, 2021; Yu and Parianos, 2021):

- degree of cover – some nodule fields have clay-ooze obscuring part or all of the nodule; and
- application to a nodule facies that is highly irregular size, especially thickness.

However, well-calibrated (unbiased) size-weight relationship can give accurate results (at the scale of the entire sample photograph) in many situations simply due to the large sample size (number of nodules in a photograph).

4.2.5 Geochemistry of Nodules: Other Metals

It is well-known that polymetallic nodules contain high abundances of Co, Cu, Fe, Mn and Ni; however, other metals considered to be of potential economic interest include Ti, rare earth elements including yttrium (REY) and Mo. These other metals are not included in the MRE as there are not enough chemical analyses to support the estimate. However, Ti and REY are both associated with high Co nodules (Figure 4-13) and may prove with further investigation to be valuable by-products in metallurgical processing. Similarly, Mo is more closely associated with high Ni nodules.

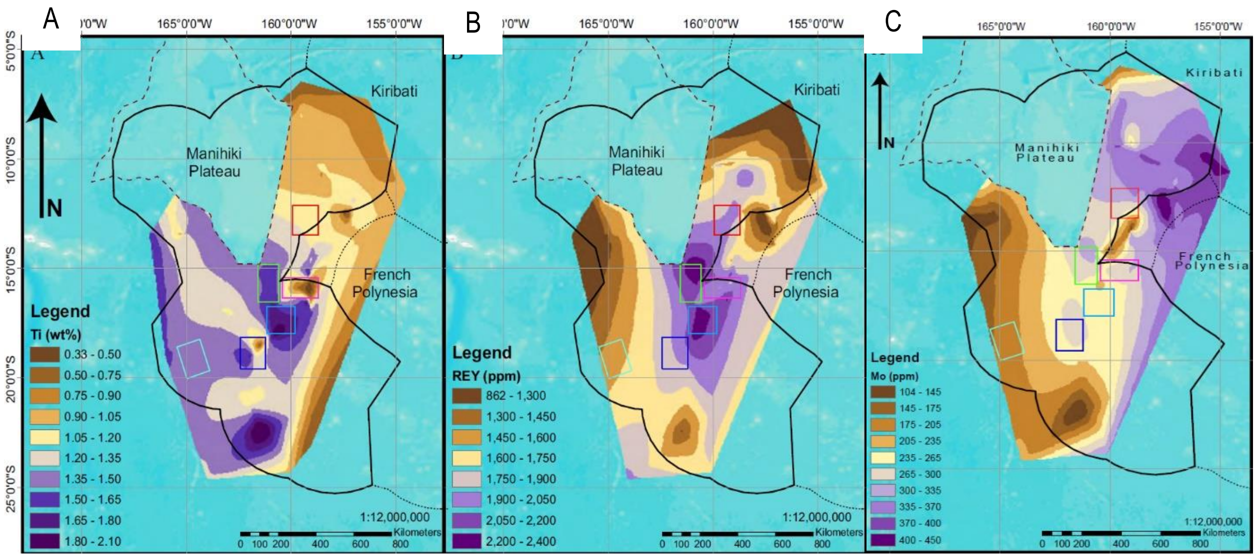


Figure 4-13: Distribution of Ti (A), REY (B) and Mo (C) Source: Hein et al. (2015).

The REY in nodules is relatively enriched in the heavy REEs compared to land-based deposits (Wall, 2021; Figure 4-14) but lower than some REY-bearing clay-ooze found on the seabed (e.g. Kato et al., 2011; Pak et al., 2018; Takaya et al., 2018).

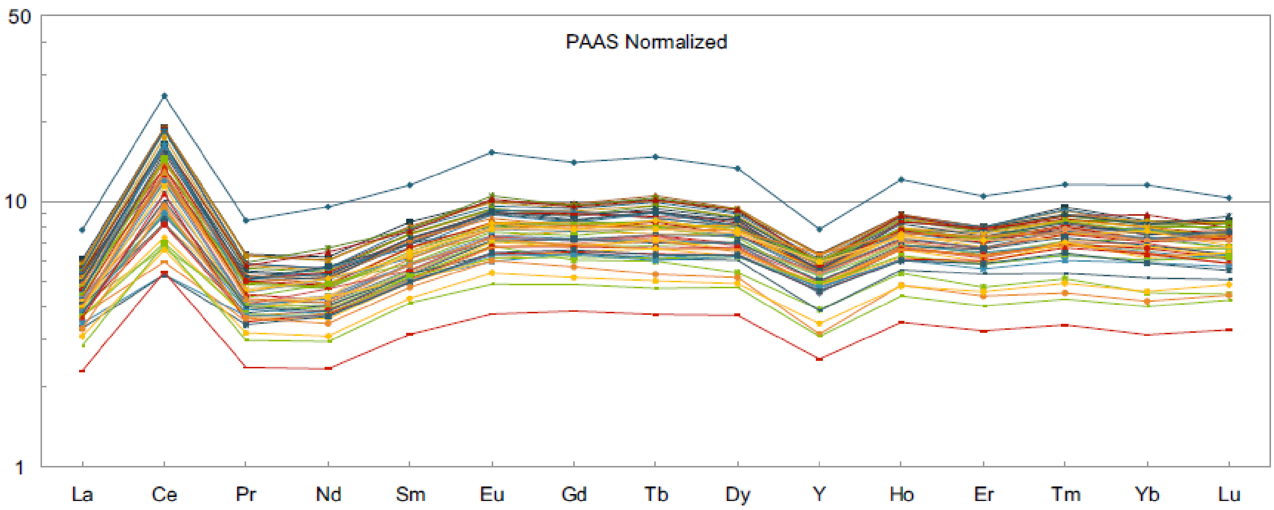


Figure 4-14: Relative REY contents from the Cook Islands) Source and sample information: Hein et al. (2015). PAAS is Post Archaean Australian Shale in Taylor and McLennan (1985).

4.2.6 Nodule Morphology and their Distribution

As nodules are the slowest-growing feature on the seabed, their form likely reflects their origin (Parianos, 2022). Nodules grow so slowly that they can record several million years of magnetic reversals (Yi et al., 2020).

At least half a dozen different nodule classification schemas for nodule types or morphology in the CCZ have been proposed (Parianos, 2022), with a schema proposed by the ISA proving to be relatively universal (International Seabed Authority, 2010). None of these have been applied to date in the Cook Islands and the classification used by JICA-MMAJ is the most widespread (JICA-MMAJ, 1986, 1987, 1991 and 2001).

Figure 4-15 and Figure 4-16 characterise the nodule morphology logged by JICA-MMAJ, and the following points are noted.

- The surface of Cook Islands nodules is typically smoother (and certainly less botryoidal) than CCZ nodules. Smooth nodules are generally associated with hydrogenetic origins (Figure 4-26) and the JICA-MMAJ logging suggests the top and bottom of the nodules formed in a similar way. This is common for all types except the pebble type.
- A cross-section through the EEZ nodules indicates a smoother outer layer but more open inner layers. Open structures in the CCZ are associated with diagenetic growth (sub-oxic formation of buserite). The distinction in the Cook Islands nodules is currently not clear and there is scope for further research using scanning electron microscopy.
- Pebble-type nodules identified by JICA-MMAJ are smoother and thus closer in form to the ISA's S-type nodules, (which are the type in the CCZ thought to have been formed by hydrogenetic processes). Similar to S-type nodules in the CCZ, pebble-type nodules in the Project Area are typically found on hard substrates such as exposed volcanics or crusts.
- Cook Islands nodules typically have a core of some type of light-coloured material, possibly sedimentary in nature. Based on the colour of the core, these are not composed of the host brown clay-ooze so could instead be precipitated opal. Nodule formation, therefore, may be related to the distribution of these starter seed materials, which in turn may relate to local conditions of SiO_2 super-saturation and any associated silica lysocline.
- There is little variance in free moisture content or density in the nodules logged by JICA-MMAJ and reported numbers are similar to those from the CCZ (Parianos, 2022), indicating there is unlikely to be any genetic distinction based on these parameters.

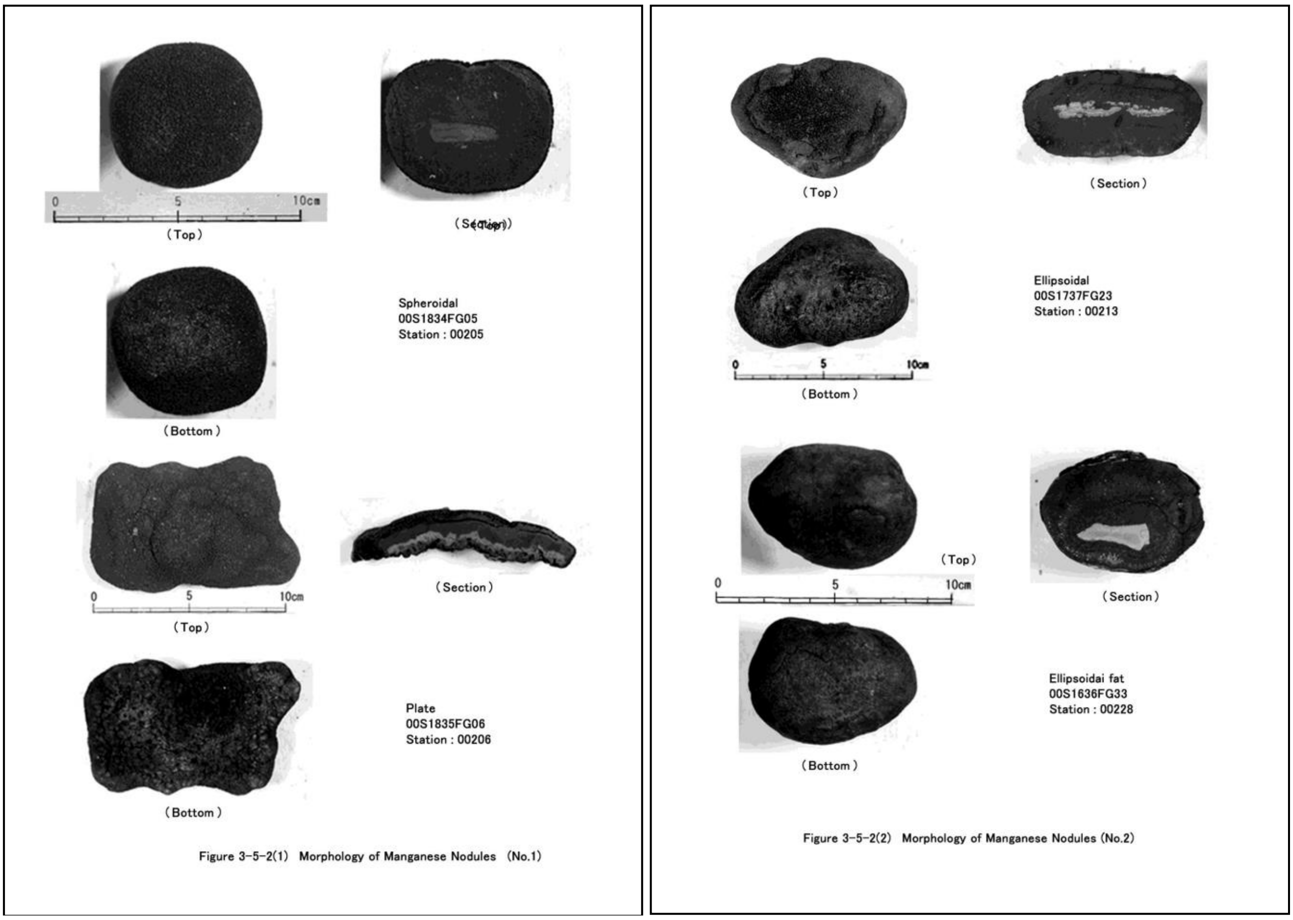
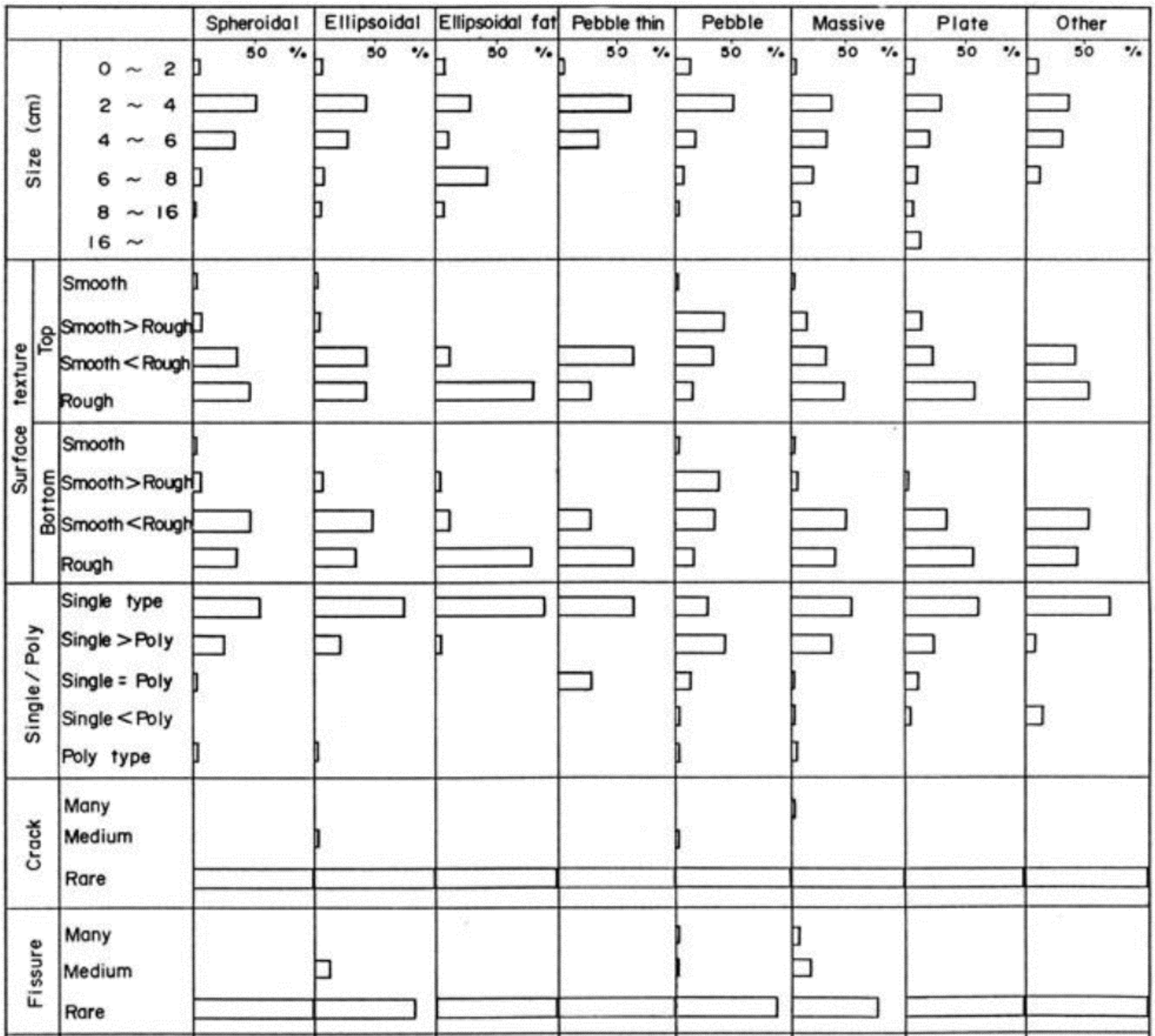


Figure 4-15: Example photographs of different nodule forms. Source: JIAC-MMAJ (2001).



		Spheroidal	Ellipsoidal	Ellipsoidal fat	Pebble thin	Pebble	Massive	Plate	Other
Moisture content (%)	Mean	29.61	29.70	29.29	29.50	29.52	28.93	29.99	34.10
	Standard deviation	1.96	1.42	—	2.52	2.03	1.97	3.96	1.25
	Maximum	36.36	36.36	29.29	32.65	31.91	31.43	34.81	34.79
	Minimum	23.40	27.30	29.29	27.27	20.83	6.25	24.30	31.58
Density	Mean	1.99	2.00	1.97	1.98	2.01	1.99	2.00	1.97
	Standard deviation	0.04	0.02	—	0.03	0.03	0.05	0.10	0.03
	Maximum	2.13	2.20	1.97	2.00	2.15	2.67	2.12	2.00
	Minimum	1.90	1.98	1.97	1.92	1.97	1.88	1.76	1.93

Figure 4-16: Physical properties associated with morphology of manganese nodules. Source: JICA-MMAJ (2001).

Data gathered by JICA-MMAJ indicate that different nodule types (as classified by nodule morphology) are found in higher concentrations in different areas of the EEZ. The northern part of the Cook Islands (8-158) typically contain rougher and ellipsoidal nodules (JICA-MMAJ, 1986), while the centre and to the south parts (e.g. 16-159 and 18-162) often have smooth round to irregular forms (Figure 4-17; JICA-MMAJ, 1987, 2000 and 2001). Nodules from the Northern Area are associated with a region of higher primary productivity (Figure 4-31). In the CCZ, nodules with a rough exterior reflect a higher component of diagenetic growth.

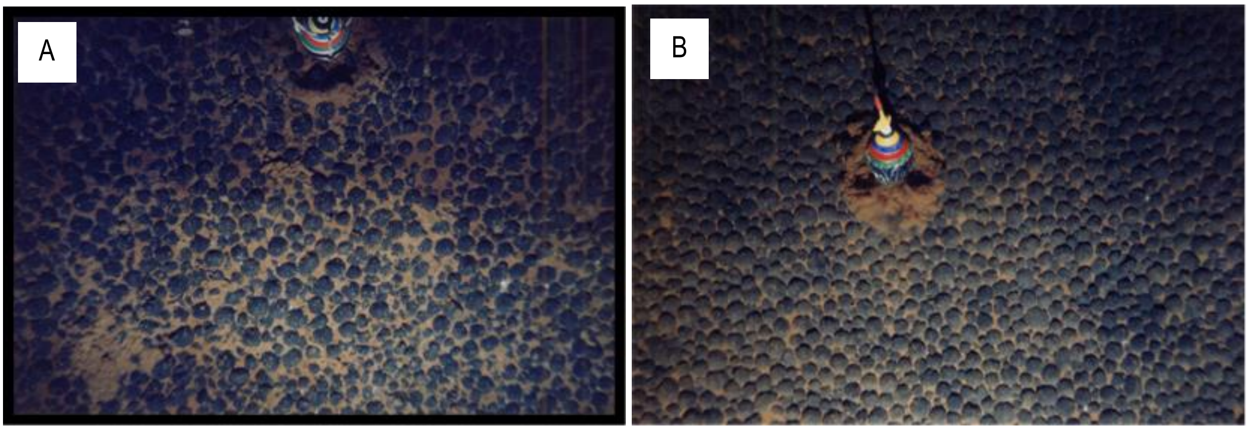


Figure 4-17: Ellipsoidal (A) and spherical (B) nodule forms at 7°S and 16°S, respectively. Weight is 10 cm in diameter (L-7°S). Source: JICA-MMAJ (1986, 1987).

JICA-MMAJ mapped nodule morphology types over the Central Area and identified a correlation with bathymetry and sediment type (Figure 4-18 and Figure 4-9).

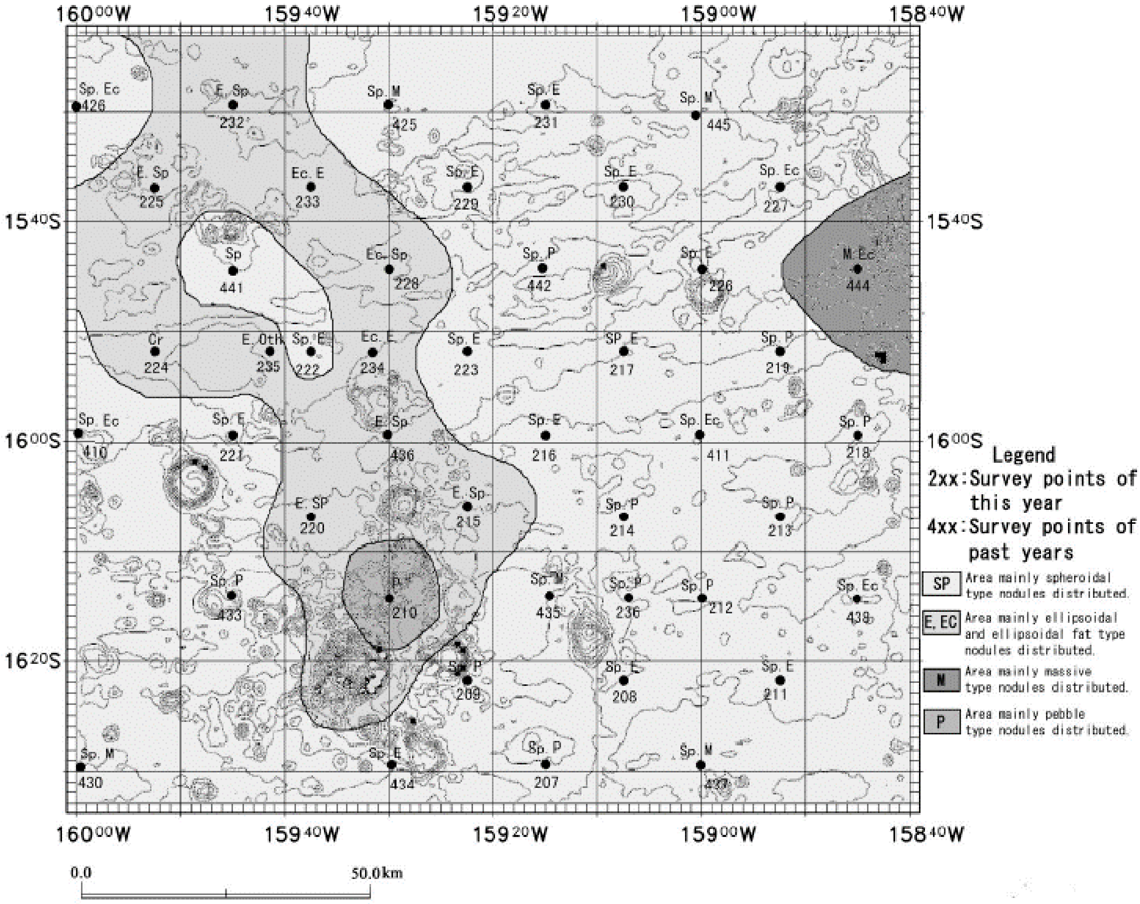


Figure 4-18: Morphology distribution map of manganese nodules (Central Area 16-159). Source: JICA-MMAJ (2001).

Locally there can be a slight change in grade with nodule size (Figure 4-19). The reason for this is not known; however, the change may be due to smaller nodules in some facies being proportionally slightly more diagenetic.

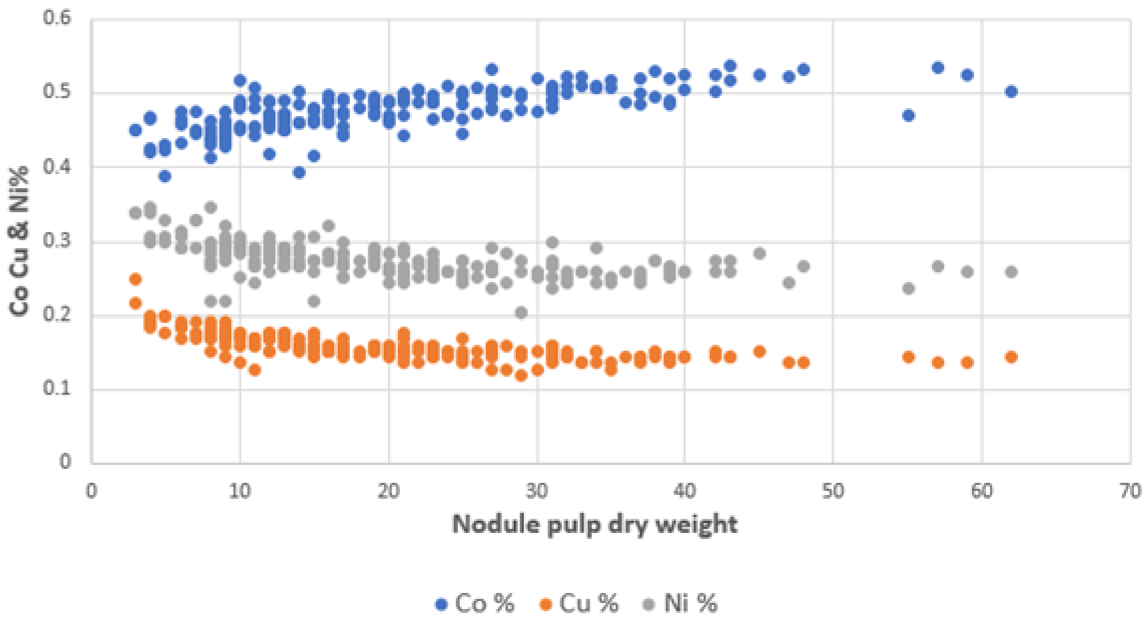


Figure 4-19: Nodule size versus grade from OML's 2019 MSR expedition (in/nearby Central Area 16-159). Single nodules were used; thus, pulp weight approximates dry nodule weight. Source: Seaborn (2020).

4.3 Controls on Mineralisation

4.3.1 Controls on Grade

Nodule composition varies and is interpreted to be related to their environment of enrichment (see also Section 4.4).

Nodules found in the EEZ can be grouped into four different classes defined by metal grade as presented in Table 4-5. These groups are discussed in sections 4.3.1.1 to 4.3.1.4. Maps presenting the grade distribution of Co, Fe, Mn, Ni and Cu are presented in Figure 4-20 to Figure 4-24. The spatial distribution and grade relationships between the four nodule grade types are illustrated in Figure 4-25.

Note nodule grades in any area can contain multiple classes and any included sediment decreases the overall metal grades.

Table 4-5: Nodule grade types in EEZ.

	Co-Fe vs Mn-Ni-Cu	Comments and distribution (Figure 4-25)
High Co	Co >0.26 % Fe >13% Mn <20% Ni <0.40% Cu <0.30%	Includes the highest abundances of nodules, found in the southern Cook Islands and western side of the south Penrhyn Basin
Low Co, low Ni	Co <0.35% Fe ~>13% (typically) Mn ~<20% Ni <0.40% Cu ~<0.30%	Wide distribution but more common in the southern Cook Islands
High Ni	Ni $\geq$0.9% Co ~<0.26 Fe <15% Mn >15% (mostly >20%) Cu >0.6%	Predominantly found in the northern Penrhyn Basin and adjacent parts of Kiribati
Transitional moderate Co, moderate Ni	Co <0.26% Fe ~10–15% Mn >12% Ni ~0.40-–0.90% Cu ~0.30–0.60%	Wide distribution but more common in the northern Penrhyn Basin

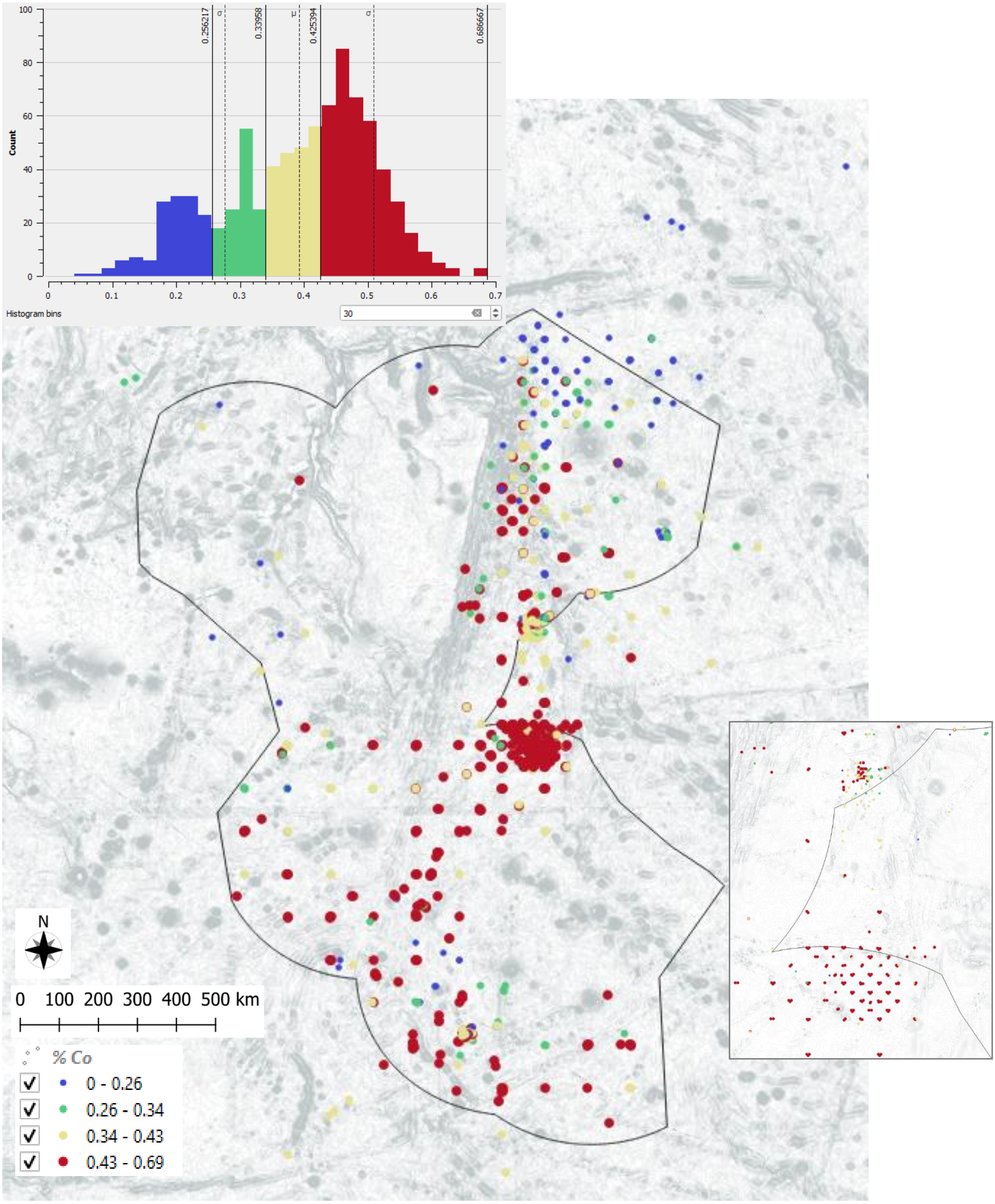


Figure 4-20: Distribution of Co grades overlying greyscale bathymetry.

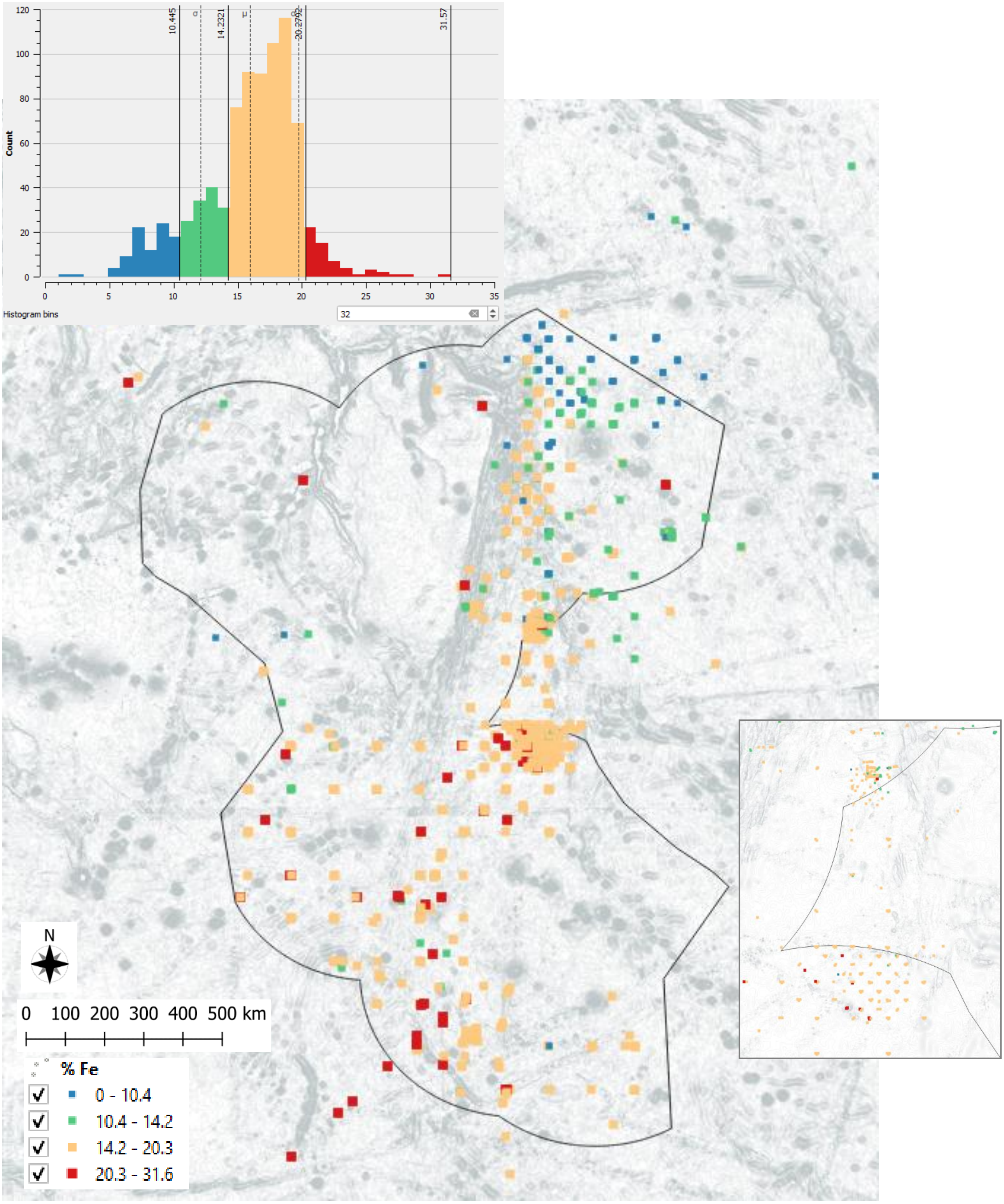


Figure 4-21: Distribution of Fe grades overlying greyscale bathymetry.

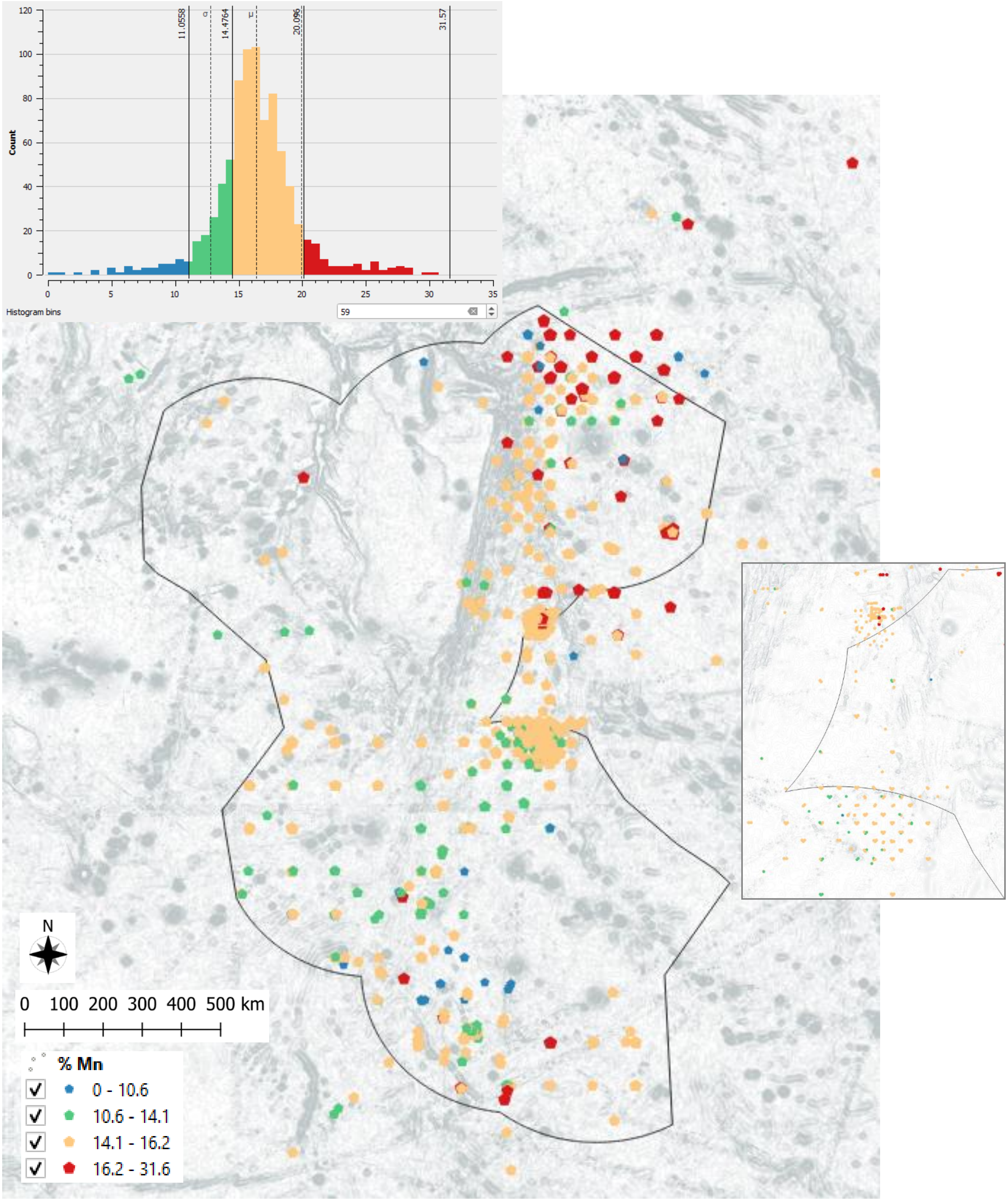


Figure 4-22: Distribution of Mn grades overlying greyscale bathymetry.

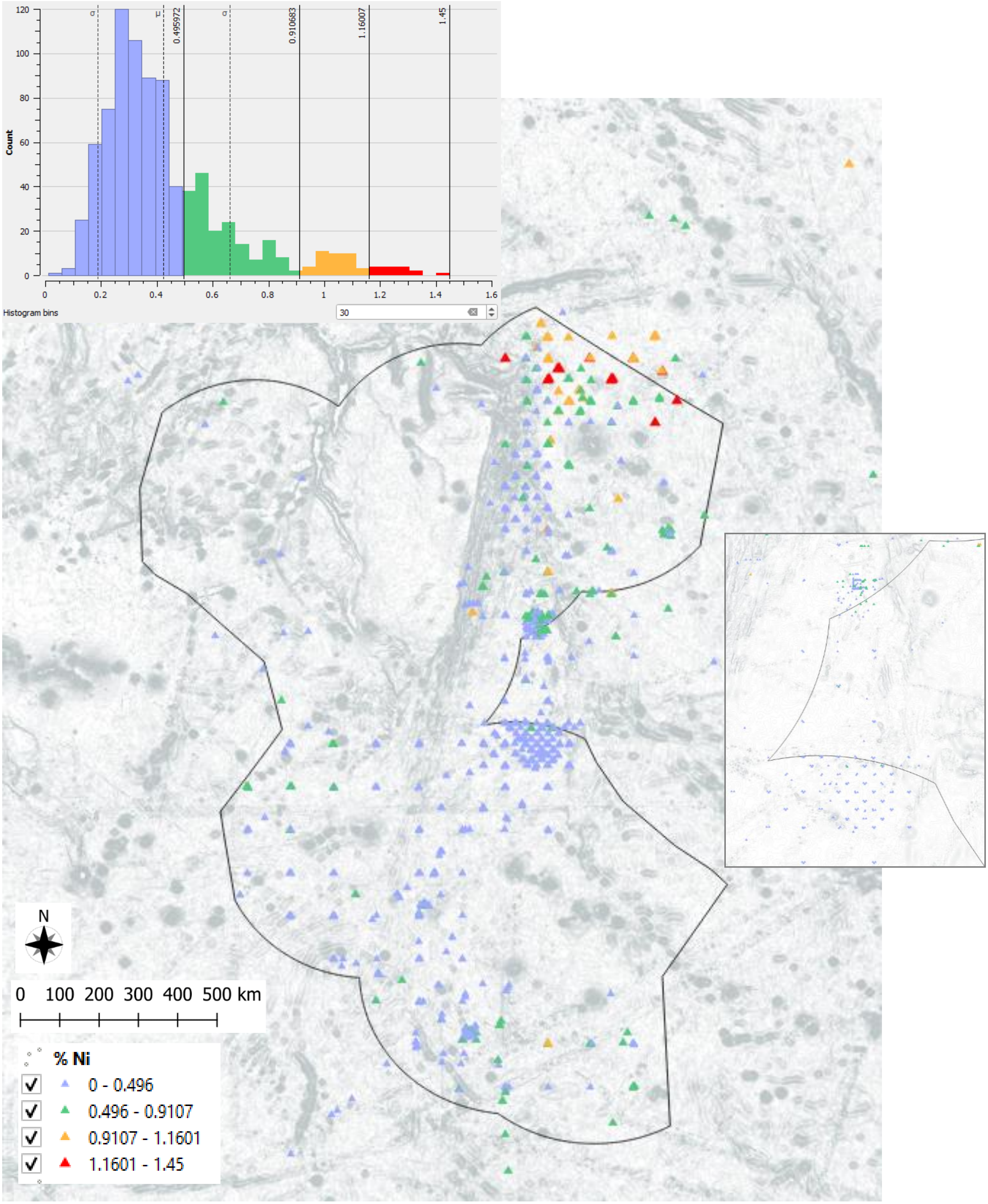


Figure 4-23: Distribution of Ni grades overlying greyscale bathymetry.

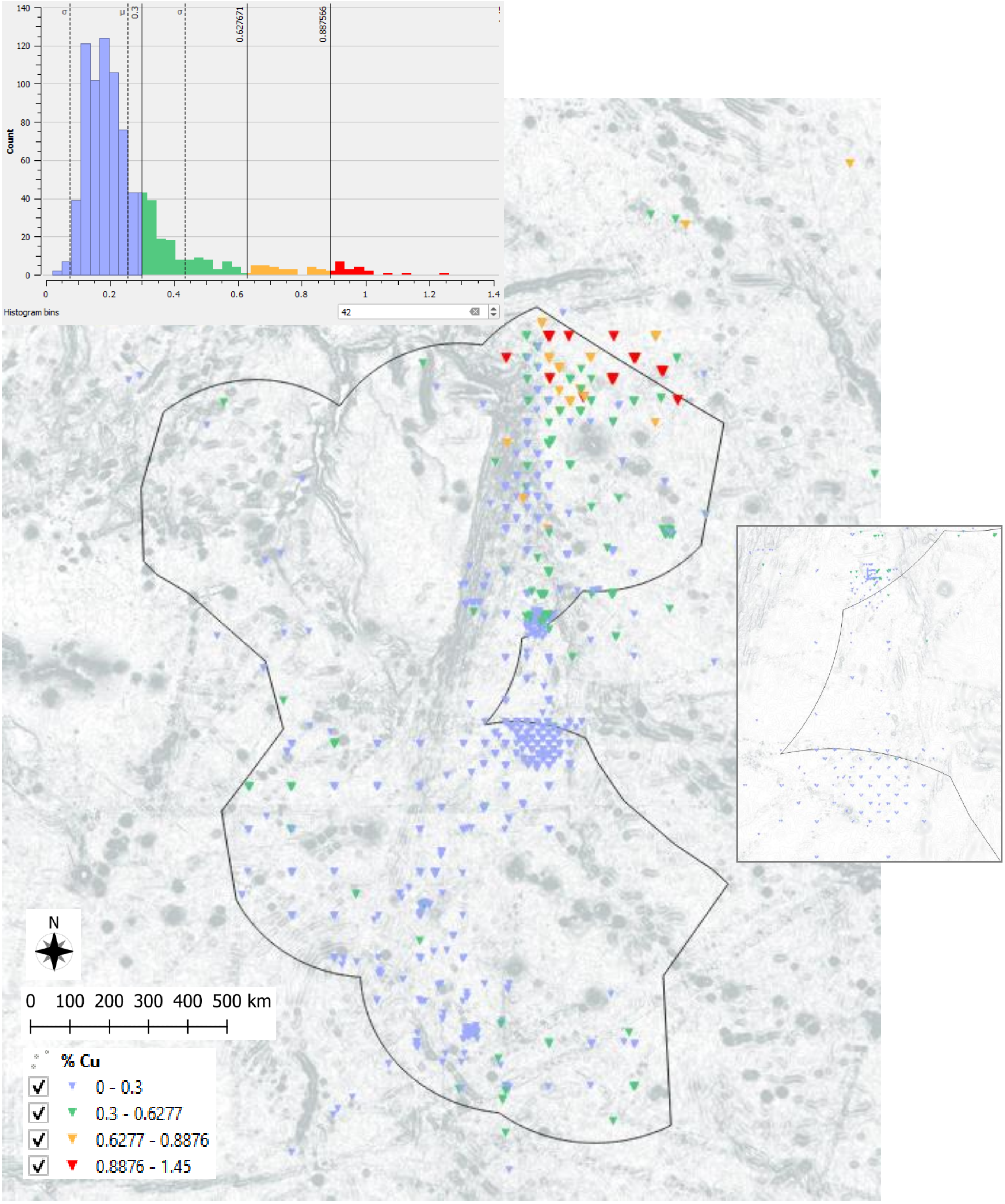


Figure 4-24: Distribution of Cu grades overlying greyscale bathymetry.

Figure 4-25: Spatial distribution and grade relationships between nodule grade types.Coordinates are from a custom Lambert azimuthal equal-area projection centred on 16°S and 161°W.

4.3.1.1 High Co Nodules

The first group of nodules that can be identified have greater Co concentration (≥0.26% Co) compared to other known nodule occurrences. The reason for the higher grades is likely due to a combination of a high proportion of hydrogenetic growth, promoting the relative accumulation of Co ions in the oxic vernadite crystal structure (Fe is ≥13%) and a more highly oxygenated bottom water mass. Similar controls on mineralisation are described from ferromanganese crusts on seamounts and guyots where Co grades are typically ≥0.5% and have reported ≥1% Co (Hein and Morgan, 1999; Hein and Koschinsky, 2014). Influence from a particular current of bottom water mass (Antarctic Bottom Water) is somewhat supported by the distribution of these nodules in the southern Cook Islands, focusing on where the Aitutaki Passage enters the south Penrhyn Basin and along abyssal plains next to the eastern margin of the Manihiki Plateau.

4.3.1.2 Low Co, Low Ni Nodules

Low Co and low Ni (<0.26 Co, <0.6% Ni) nodules are usually nearly identical in bulk chemistry (Fe, Mn) to the high Co nodules, with the exception the Co grade is lower. This is interpreted to reflect a less effective influence or function of the Antarctic Bottom Water mass posited above. Some of the samples have lower Fe and Mn and may reflect dilution from seeds of other material, but this cannot be confirmed without analysis for elements such as Si and Al, among others.

4.3.1.3 High Ni Nodules

This second main type of nodule is located in the northern part of the EEZ at similar transitional levels of primary productivity compared to the CCZ. High Ni (≥0.9% Ni and up to 1.45% Ni) nodules from the EEZ have broadly similar Ni and Cu grades compared to nodules from the western CCZ. Thus, the control of mineralisation is expected to be very similar if not identical to that described from the CCZ, i.e. release of metals from microorganisms dissolving as they drop below the lysocline and dissolve (Morgan, 2003; Lipton, Nimmo and Parianos, 2016).

4.3.1.4 Transitional-Moderate Co, Moderate Ni Nodules

These are thought to be a hybrid between the high Co and high Ni nodules discussed in sections 4.3.1.1 and 4.3.1.3, especially with regard to Fe and Mn.

4.4 Mineral Deposit Model and Known Comparable Deposits

4.4.1 Ferromanganese Deposits

Sedimentary ferromanganese precipitates are found throughout the EEZ. Polymetallic nodules are found on the abyssal plains as well as on the Manihiki Plateau; however, the Manihiki Plateau has been poorly sampled (Cronan, 2013). Ferromanganese crusts are present around the Manihiki Plateau (Andreev et al., 2008; Uenzelmann-Neben, 2012), and are seen among the nodules in the abyssal plains (JICA-MMAJ, 1986, 1987).

Ferromanganese nodules and crusts can form in both hydrogenetic and diagenetic settings (Figure 4-26), and for diagenetic nodules under both oxic and sub-oxic conditions (Morgan, 2003; Hein and Koschinsky, 2014; Wegorzewski and Kuhn, 2014; Parianos, 2022). Typically, nodules form growth layers, which reflect changes between oxic and sub-oxic conditions, and are perhaps related to blooms in surface microorganisms from glacial/interglacial periods.

Ferromanganese crusts are briefly discussed below; however, these are not considered part of the MRE.

There are different three types of ferromanganese crust:

- Hydrogenetic massive crust is the most common and can be identified in photographs as it forms on hard substrates such as basalt, and is not covered by sediment (Figure 4-27 and Figure 4-28).

- Diagenetic crust fragments have been sampled in a few free-fall grabs (Figure 4-27). It forms on/in clay-ooze with crust coating what may be opal-CT (Cristobalite and/or Tridymite).
- Diagenetic massive crust has been found buried in several gravity/large cores and may be associated with sedimentary disconformities (Figure 4-8). It forms on/in clay-ooze.

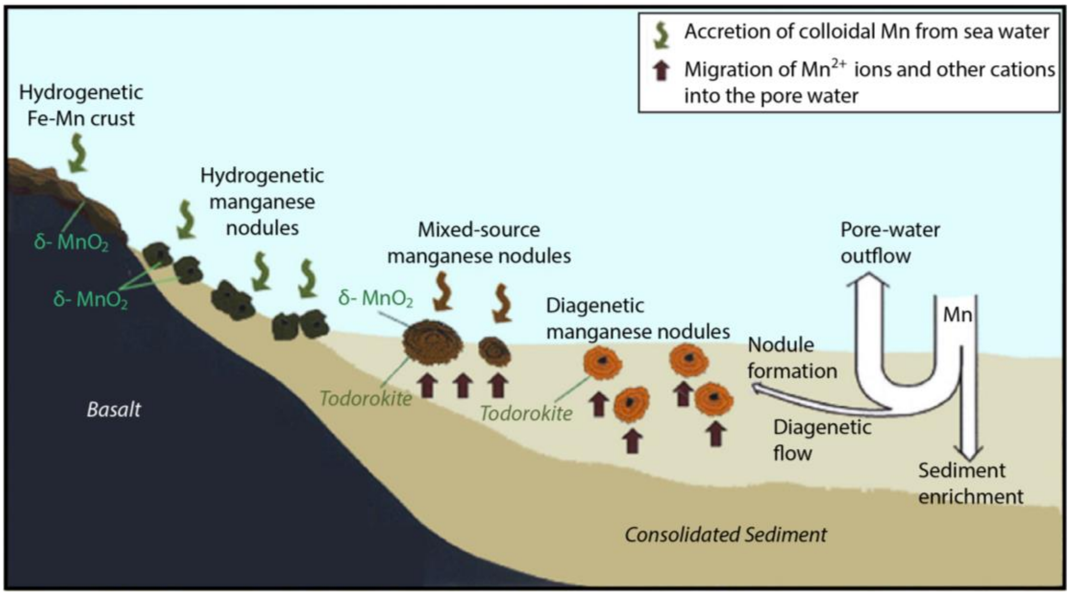


Figure 4-26: Diagram of the formation of hydrogenetic, diagenetic and mixed-source nodules and hydrogenetic crusts by precipitation from seawater and/or sediment pore water. Source: Hein et al. (2013).

These three types of crust are also seen in the CCZ (Menot, Galeron and Saget, 2010; Parianos, 2022). Chemical analysis is not known to have been done on the massive crusts. The sample of crust fragments in Figure 4-27 has a similar chemistry to nearby nodules with slightly (~10%) lower Co and Fe and greater Ni, Mn and Cu.

Hydrogenetic massive crusts are found on the abyssal plain (Figure 4-28 and Figure 4-29) and on the Manihiki Plateau and seamounts (Figure 4-30). Hydrogenetic and diagenetic crusts both typically form well below the interpreted oxygen minimum zone (OMZ) in the EEZ, suggesting a well-developed OMZ may not be required for the formation of such crust. Hydrogenetic massive crusts are common on some parts of the abyssal plain ~10°S and especially 15°52'S (Figure 4-28 and Figure 4-29), indicating future work might be required to specifically map and domain the massive crusts to exclude them from higher confidence MREs. Some of the mineralised crust may be associated with abyssal hill escarpments or volcanic knolls that will likely be domained out in any event due to unmineable conditions (steep slopes). Diagenetic crusts seem to be rare and are unlikely to be material in the MRE; however, crust fragments may be collected along with the nodules.

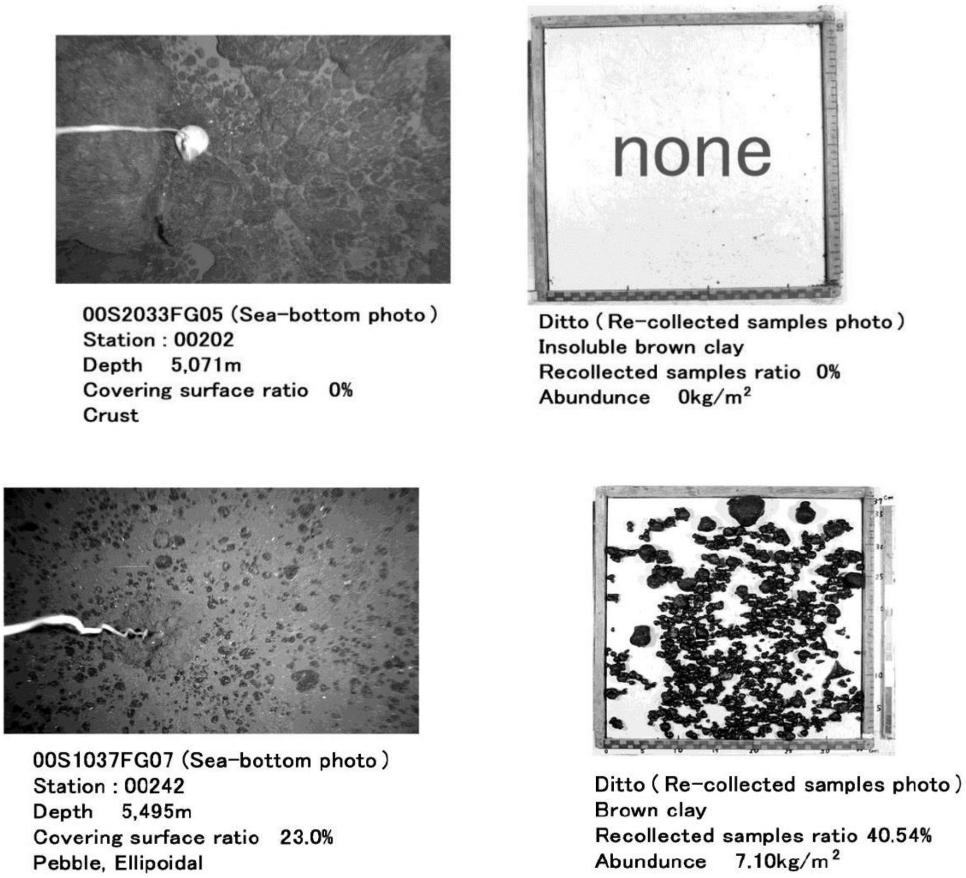


Figure 4-27: Examples of hydrogenetic massive crust and possible diagenetic crust fragments. Photographs at the right of the sample collected by the free-fall grab sampler carrying the seabed camera. Source: JICA-MMAJ (2001).

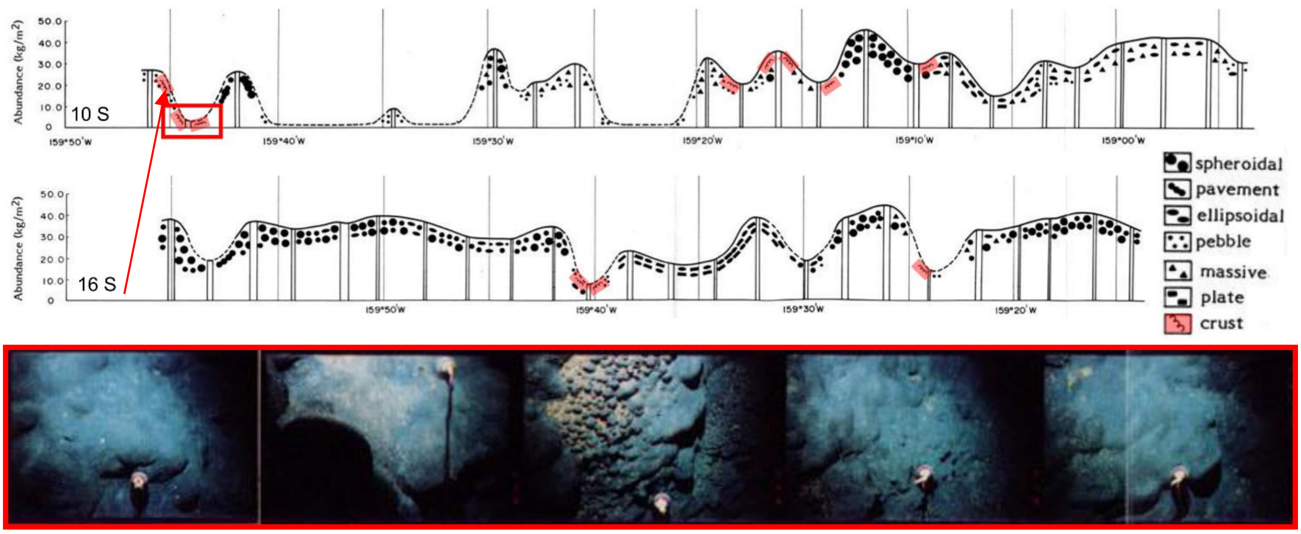


Figure 4-28: Example of towed camera data showing disposition of massive crusts on an abyssal plain. Modified from JICA-MMAJ (1986). Note vertical axis is abundance not seabed elevation. Hydrogenetic massive crusts tend to be associated with 'hilly areas'.

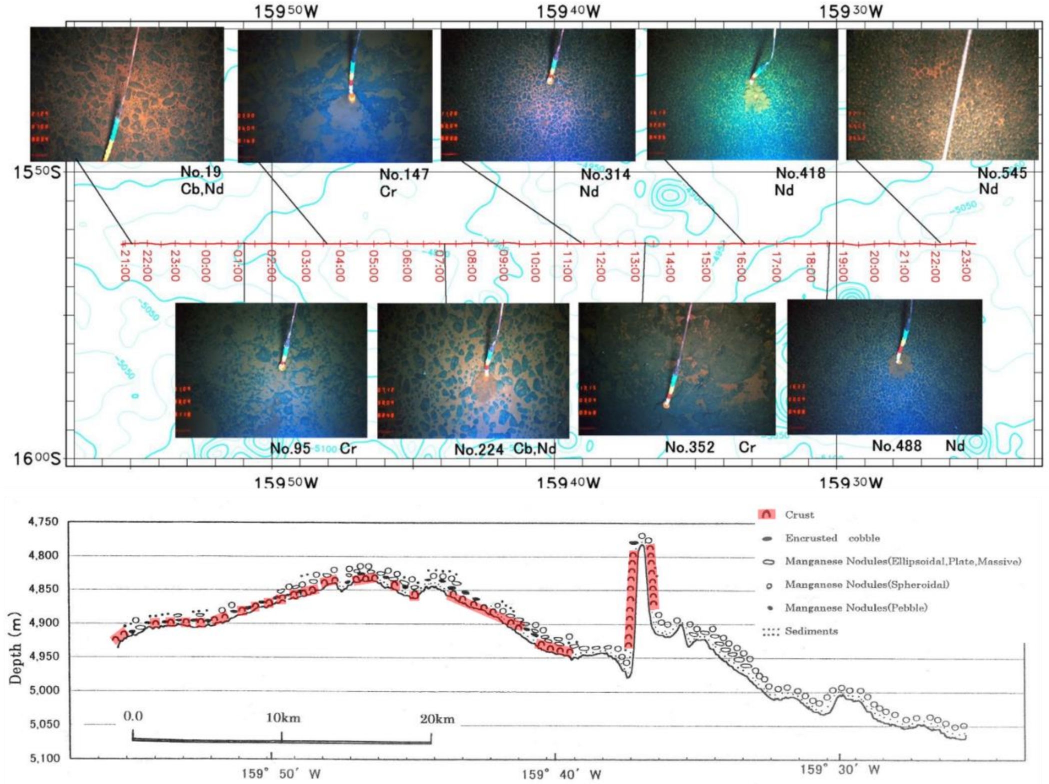


Figure 4-29: Example of towed camera data showing the disposition of nodule types and massive crusts on knolls and adjacent plains. Modified from JICA-MMAJ (2001). Location of this line is mapped in Figure 4-9.

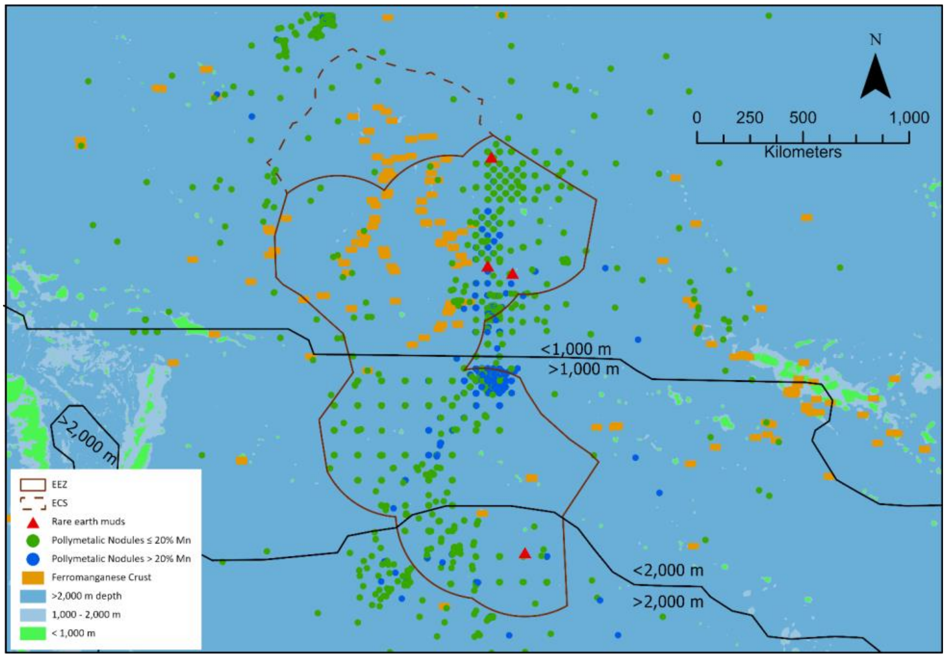


Figure 4-30: Crust locations outside of the nodule fields and depth of oxygen minimum zone. Data from Andreev et al. (2008) and Boyer et al. (2018).

4.4.2 Polymetallic Nodule Deposits

Polymetallic nodule deposits are found in many of the world's oceans. The Cook Islands deposit is distinguished by the high Co grades (≥0.26%) and high nodule abundances (>20 kg/m²).

Polymetallic nodule deposits comprise various forms of ferromanganese concretions called nodules arranged in a thin layer on the seabed or just below, buried under ~5–10 cm of sediment. Key aspects in the formation and disposition of a potentially economic metal grade nodule type ferromanganese deposit are:

- The process for the formation of any type of ferromanganese precipitate is distinct from the process of enriching them in base metals such as cobalt, nickel and copper.
- A high-quality nodule deposit requires, over a long period of time, both the right conditions to form abundant nodules and the right conditions to enrich the slowly growing nodules.
- Nodule formation also requires operating mechanisms that prevent the ferromanganese nodules from being buried or becoming a solid crust. A range of processes are evaluated by Parianos (2022) and biological activity and seabed currents are interpreted to be the dominant processes resulting in nodule form and formation.

In the central Cook Islands, higher Co grades are associated with a hypothetical, relatively oxic, bottom water current (Antarctic Bottom Water). This current is interpreted to have been long-lived and to have maintained oxic conditions (promoting elevated Co and Fe over Ni and Mn) as well as possibly preventing sediment from settling on the nodules.

In the north-eastern Cook Islands, higher Ni and Cu grades are associated with higher primary productivity (surface plankton). Net export of this may have also helped lead to sub-oxic conditions and higher Ni and Mn grades –similar to that described in the CCZ (Lipton, Nimmo and Parianos, 2016) (Figure 4-31).

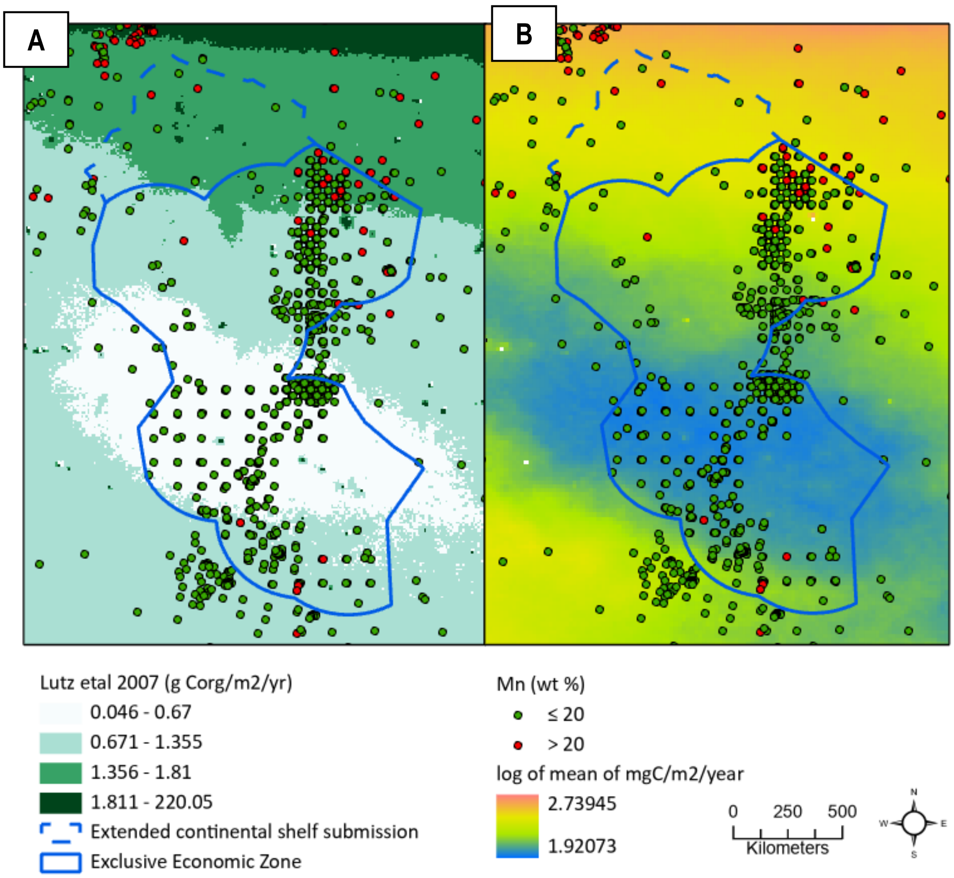


Figure 4-31: Nodules in the Cook Islands relative to A) net organic export B) current surface primary productivity.

5 Exploration Data, Sampling, Processing, Analysis

This section presents the results from exploration programmes conducted in the Project Area, and describes the processes used to obtain those exploration results. SBMA has not conducted exploration expeditions itself. The mineral resource estimate presented in this Report is underpinned by exploration data collected by:

- JICA-MMAJ, through a regional programme for SOPAC;
- CIICSR, through a research permit; and
- OML, through a research permit.

5.1 JICA-MMAJ 1985–2000 Expeditions

Between 1980 and 2001, MMAJ carried out numerous expeditions on behalf of JICA as part of the Japan-SOPAC regional cooperation. This regional cooperation included work in Kiribati, Cook Islands, Fiji, Tonga, Solomon Islands, Papua New Guinea and the Marshall Islands (JICA-MMAJ, 2000). JICA-MMAJ also conducted expeditions in international waters including the Central Pacific Basin (Usui, 1983, 1994), with the GH83-3 expedition focusing on an area in the south Penrhyn Basin (13-159).

Specifically, four expeditions focussed on the Cook Islands:

1. *Hakurei-Maru No. 2*: 23 September to 30 October 1985 (JICA-MMAJ, 1986). This expedition focussed on an area in the north at 07-158 (Figure 5-1).
2. *Hakurei-Maru No. 2*: 4 September to 22 October 1986 (JICA-MMAJ, 1987). This expedition covered a north–south area west of the Manihiki Plateau including focus areas at 10-160 and 16-159 (Figure 5-1).
3. *Hakurei-Maru No. 2*: 17 September to 26 October 1990 (JICA-MMAJ, 1991). This expedition covered a broad area in the south (Figure 5-1).
4. *Hakurei-Maru No. 2*: 19 May to 24 June 2000 (JICA-MMAJ, 2001). This expedition covered much of the area covered in the 1986 expedition as well as the central part of the area covered in the 1990 expedition focusing on the Central Area (16-159) (Figure 5-1).

These expeditions are considered together in this section as they had a high degree of commonality in techniques even if their locations were partly discrete (Figure 5-1). The sampling and results from the GH83-3 expedition are not discussed below as the expedition was carried out following different processes and was not reported in the same way (e.g. Usui, 1994).

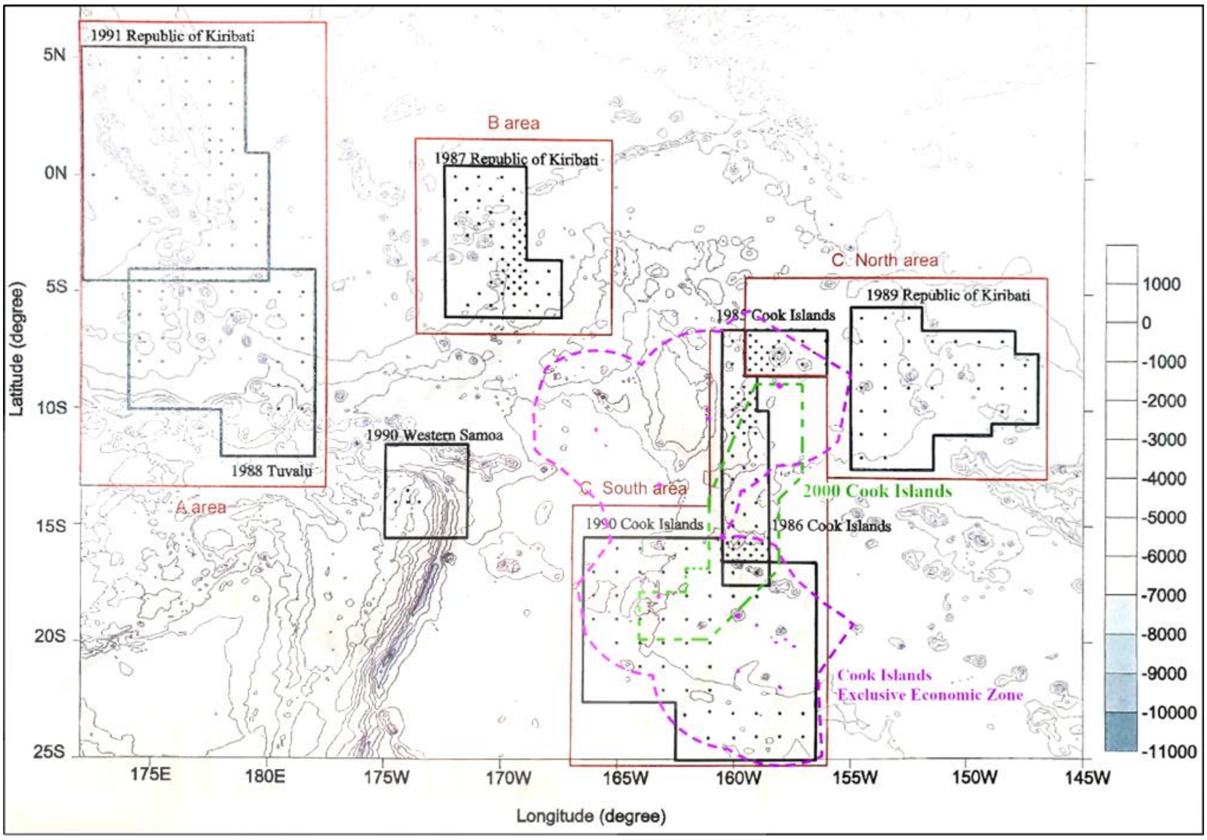


Figure 5-1: Areas of research in the Cook Islands by JICA-MMAJ Sources: JICA-MMAJ, 2000 and 2001.

The *Hakurei-Maru No. 2* was the vessel used for all four expeditions. It replaced the *Hakurei-Maru No. 1*, which had been used in an earlier expedition in the region (including the GH83-3 programme). When delivered in 1980 (Japan Oceanographic Data Center, 2022), the *Hakurei-Maru No. 2* was state of the art and the vessel was in service with MMAJ (Metal Mining Agency of Japan) until 2012 (Japan Oil Gas and Metals National Corporation, 2010; VesselFinder, 2022). *Hakurei-Maru No. 2* had a length of 89 m and gross tonnage of ~2,100 t. The vessel could carry 24 researchers and had eight laboratories (Japan Oceanographic Data Center, 2022). While it did not have dynamic positioning, it did have a bow thruster that helped position the vessel precisely for certain tasks.

Figure 5-2: *Hakurei-Maru No 2.*

The *Hakurei-Maru No. 2* deployed a wide range of tools while working in the Cook Islands, including free-fall grab (FFG or FG in Figure 5-3), spade (or box) corer (SC in Figure 5-3), gravity corer, dredge, towed camera and sub-bottom profiler (SBP) (Figure 5-3 and Figure 5-4). A 15 kHz multi-beam echosounder (MBES) was also only used on the 2000 expedition (MBES was new technology at the time). Table 5-1 summarises the data collected by JICA-MMAJ during the four expeditions to the EEZ.

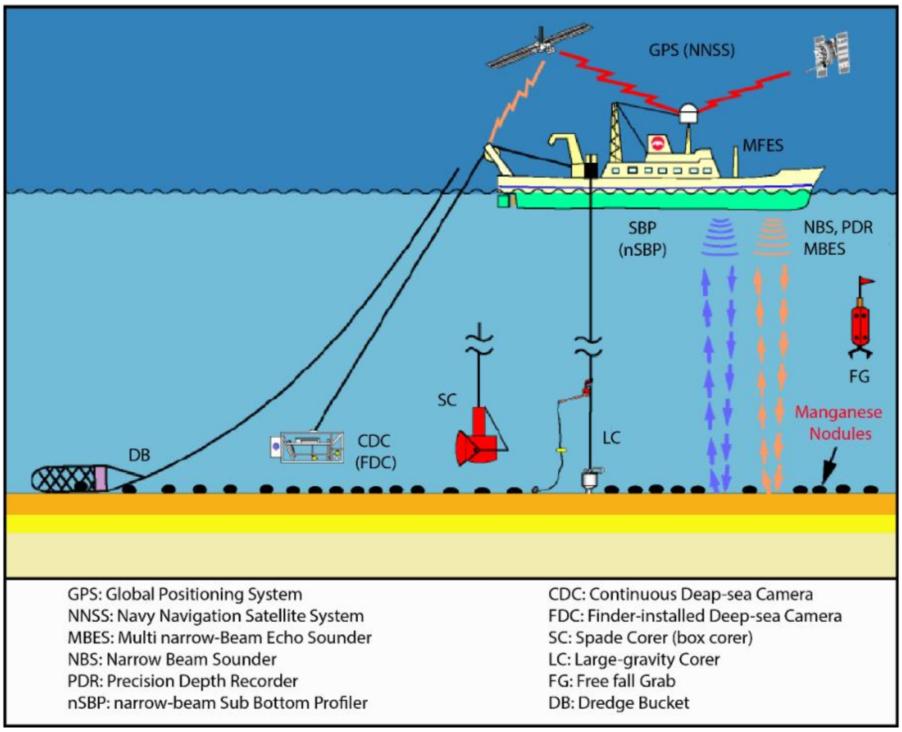


Figure 5-3: Schematic of sampling tools used on JICA-MMAJ expeditions. Source: Okamoto, 2003.

Figure 5-4: Sampling tools used on JICA-MMAJ expeditions.

Table 5-1: Summary of JICA-MMAJ data.

Vessel & Expedition Year	Sample Method	Sample Sites	Nodule Abundance Used in Study	Chemistry Used in Study
Hakurei-Maru No. 2 (1985)	FFG (or FG)	110	110	81
	BC (or SC)	4	4	4
	FFG/SC camera	99, included in above sites	0	0
	CDC	168	0	0
Hakurei-Maru No. 2 (1986)	FFG	176	161	143
	BC	4	4	4
	FFG/BC camera	174, included in above sites	0	0
	FDC	288	0	0
Hakurei-Maru No. 2 (1990)	FFG	143	143	104
	BC	4	2	2
	FFG/BC camera	?	0	0
	FDC	172	172	0
Hakurei-Maru No. 2 (2000)	FFG	96	95	78
	BC	8	5	5
	LC	7	7	6
	AD	1	0	1
	FDC	574	0	0

5.1.1 Survey, Topography, Digital Terrain Model

Locations for the JICA-MMAJ samples were recorded by satellite navigation systems, i.e. the ship's coordinates at the point of deployment of the sampling equipment (FFG sampler, BC and LC). Subsea positioning, which measures the location of the sampling equipment on the seafloor, was not available at the time of sampling. Sample depth was measured acoustically by the ship at the time of deployment. Details regarding the different satellite navigation systems used on the different expeditions are reported in Table 5-2.

Table 5-2: JICA-MMAJ navigation systems.

Expeditions	Satellite system	Comments
1985, 86	Navy Navigation Satellite System (NNSS) or Transit	Corrected positions between updates from the NNSS (Doppler rangefinder) indicate a surface accuracy of 200–500 m. The system likely used WGS72 as the geographic coordinate system (GCS).
1990	GPS + NNSS	GPS is likely Navstar. Accuracy of the system at the time of surveying is likely to be approximately 200 m. WGS84 as GCS.
2000	GPS + GLONASS	Accuracy of the system at the time of surveying is likely to be 20–60 m. WGS84 as GCS.

The majority of samples were collected by FFG samplers dropped from the vessel (~95% of those by JICA-MMAJ). The FFG samplers could drift due to surface and subsurface currents. The location of the FFG was recorded from the ship's position during deployment, not the physical location the FFG sampler collected the sample. The precision location data of FFG samples is estimated to be in the order of 100–500 m against a typical spacing of between 25 and 100 km. Free-fall grab samplers descend rapidly and are typically not significantly affected by ocean currents through the water column. Strong currents (<3 knots) tend to only occur in the surficial tens to hundreds of metres, which can cause the FFG to drift once it resurfaces. The difference between sample launch and recovery locations was >1 km.

Other sampling devices (e.g. BC and LC) were lowered from the vessel, typically using a winch; this process is slower and without the modern ultra-short baseline (USBL) positioning method, drift is a more serious concern. Any errors are likely to be of the order of hundreds of metres against sample spacings of tens of kilometres.

RSC notes that sample locations provided in the JICA-MMAJ reports do not position of the samplers on the seafloor, or any calculation used to estimate the sample location. Therefore, the sample positions cannot be validated precisely.

JICA-MMAJ reported sample locations in latitude and longitude. Modern global positioning systems (GPS) typically report in WGS84. In 1987, the NNSS was the first to adopt WGS84 (National Oceanic and Atmospheric Administration, 2022), therefore, SBMA assumes WGS72 was the coordinate reference system used for the 1985 expedition (Holland, Eisner and Yionoulis, 1977; EPSG, 2020). In the Cook Islands, the difference between the two datums is minor, with the largest variance in the north of 17.6 m offset to 255° and 16.1 m to 252° in the south. All sample data used were originally inputted in latitude/longitude but were translated to a Lambert azimuthal equal-area projection for the MRE.

JICA-MMAJ also supplied some data to SOPAC in projected coordinate systems (Table 5-3).

Table 5-3: JICA-MMAJ Mercator projections. Source: (JICA-MMAJ, 2000), 2000 projection deduced.

Year	Sea Area	Southwest corner		Northeast corner		Central Meridian	Reference Latitude
		Latitude	Longitude	Latitude	Longitude		
1985	Cook Islands (I)	8.5°S	159.5°W	6.5°S	156.0°W	158.0°W	7.0°S
1986	Cook Islands (II)	17.5°S	160.5°W	6.5°S	158.5°W	159.0°W	12.0°S
1990	Cook Islands (III)	25.5°S	166.5°W	15.5°S	156.5°W	161.5°W	20.0°S
2000		22°S	167°W	7°S	155°W	166°W	19.75°S

The location of the towed systems including continuous deep-sea camera (CDC) and finder installed continuous deep-sea camera (FDC) were estimated based on Pythagoras' Theorem using the depth measured by the depth meter mounted on the FDC and the towing cable length, assuming that the FDC was always in a straight line behind the ship (JICA-MMAJ, 2001).

Samples and survey lines were also prefixed/coded based on year of work and location within a regional grid. The example shown in Figure 5-5 is for the 2000 JICA-MMAJ expedition, but the grid was designed to extend and applied regionally per Figure 5-1.

164° w 163° w 162° w 161° w 160° w 159° w 158° w 157° w

9° s	(1032)	(1033)	(1034)	(1035)	(1036)	00242 (1037)	(1038)
10° s	(1132)	(1133)	(1134)	(1135)	(1136)	(1137)	00241 (1138)
11° s	(1232)	(1233)	(1234)	(1235)	(1236)	(1237)	00240 (1238)
12° s	(1332)	(1333)	(1334)	(1335)	(1336)	(1337)	00239 (1338)
13° s	(1432)	(1433)	(1434)	(1435)	(1436)	(1437)	(1438)
14° s	(1532)	(1533)	(1534)	(1535)	(1536)	(1537)	(1538)
15° s	(1632)	(1633)	(1634)	(1635)	00217 (1636)	00218 (1637)	(1638)
16° s	(1732)	(1733)	(1734)	(1735)	00207 (1736)	00211 (1737)	(1738)
17° s	(1832)	(1833)	00205 (1834)	00206 (1835)	(1836)	(1837)	(1838)
18° s	(1932)	(1933)	00204 (1934)	(1935)	(1936)	(1937)	(1938)
19° s	00201 (2032)	00202 (2033)	00203 (2034)	(2035)	(2036)	(2037)	(2038)
20° s							

Legend
□ : Survey Area
(2032) : Area
00201～00242:Sampling Points

Figure 5-5: Sample/survey grid used by JICA-MMAJ (2001).

5.1.2 Geophysics

JICA-MMAJ expeditions made extensive use of geophysical data based on their experience over the previous decades in the CCZ and Central Pacific Basin region. Geophysics laid the foundation for mapping and sampling the seabed during the exploration programmes.

5.1.2.1 Single-beam Echosounders

Single-beam echosounders were used to survey the seabed prior to sampling. These include a 30 kHz narrow-beam echosounder (NBS) and a 12 kHz precision depth recorder (PDR). The echosounders were used to provide more precise bathymetry than what was available from global maps of the day (e.g. Smith and Sandwell, 1997; Figure 5-6) and the single-beam data were integrated into the global datasets year on year (Scott, 2003). Between 1990 and 2002, Japan was the third largest contributor of data for this purpose (Scott, 2003).

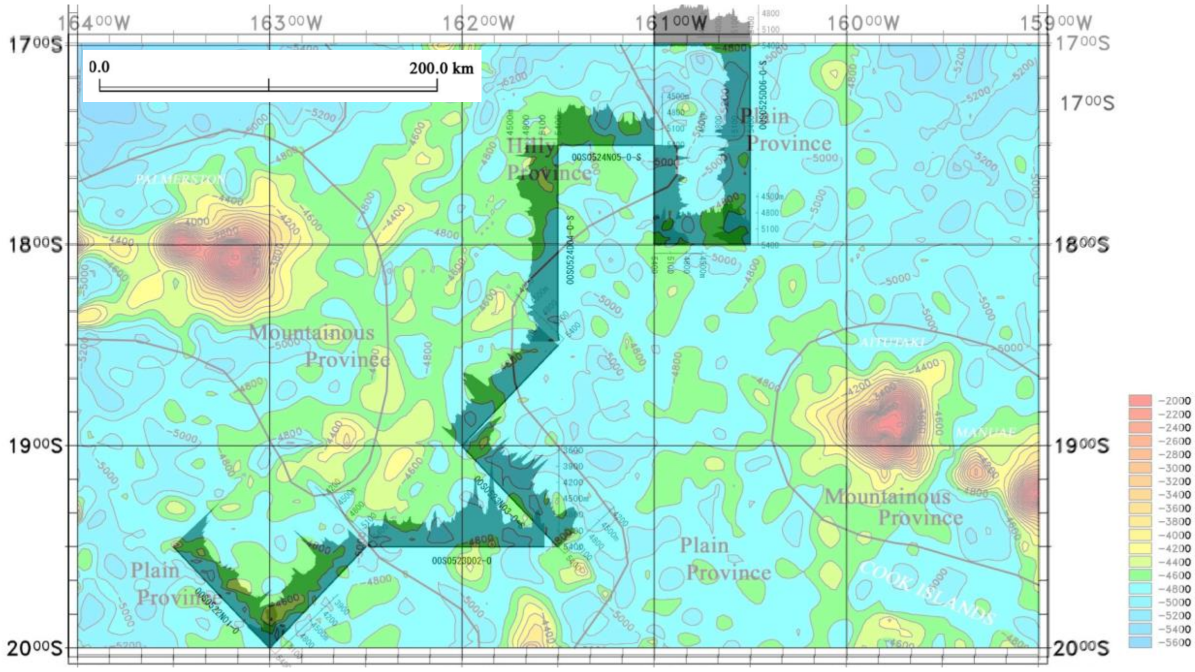


Figure 5-6: Superimposed single-beam echosounder profile on satellite-derived bathymetry in Area 18-162Modified from JICA-MMAJ (2001); Area 18-162 was its 'Southern Area'.

5.1.2.2 SBP and Sediment Types

A survey of the subsurface sediments was carried out by 3.5 kHz narrow-beam SBP simultaneously with the seafloor topographic survey. Basic information regarding subsurface sediments including the thickness of an uppermost transparent layer and acoustic stratigraphic types were interpreted from the SBP data (see Section 4.2.2). Profiles were recorded every five minutes and distribution maps of SBP types and thickness of the uppermost transparent layer were drawn.

5.1.2.3 Multi-Beam Echosounder

The 15 kHz MBES system installed on *Hakurei Maru No. 2* for the 2000 expedition is not specified but is thought to be an Atlas Hydrosweep DS (Deep-Sea), which was a popular model of the era (Atlas Hydrographic, 2012; Various, 2022). Both bathymetry and backscatter products were produced (Figure 4-9; JICA-MMAJ, 2001).

The 16-159 (Central) area was covered by the MBES survey, and importantly, the survey was successful in clearly defining nodule-bearing clay-ooze versus seamounts and knolls (Figure 4-9, Section 4.2.3). The MBES survey in other areas was restricted to the single path of the vessel.

5.1.2.4 Multi-Frequency Exploration System

A Multi-Frequency Exploration System (MFES) integrates the 30 kHz NBS, 12 kHz PDR and 3.5 kHz SBP. According to JICA-MMAJ (1986, 2001), the reflection intensity of the waves transmitted from these acoustic instruments and the synthetic reflectivity of the three frequencies was pursued (diffusion attenuation and absorption attenuation of each frequency in seawater are considered in the measurements). This synthetic reflectivity (*Rt*) is used to calculate the area occupancy ratio (*S*) of the polymetallic nodules (the ratio of the seafloor covered by polymetallic nodules in 1 m^2) using the following equation:

$$S = a \times Rt + b \qquad (1)$$

Parameters *a* and *b* are assumed to have a linear relationship. However, in exploration, abundance is more important than area occupancy ratio, and area occupancy ratio must therefore be converted into abundance. The relationship between the two is obtained by the following equation:

$$\text{Abundance (kg/m}^2\text{)} = \text{Area occupancy ratio} \times f \text{ (kg/m}^2\text{)} \qquad (2)$$

Parameter *f* is a weight coefficient. This coefficient is calculated by sampling and its exact value is unknown at the time of the MFES survey, but in JICA-MMAJ (2001), a provisional value of 22 kg/m^2 was used based on previous work in the region. The implication is that the MFES values will coincide with the polymetallic nodule abundance when the weight coefficient of the nodules is 22 kg/m^2. The weight coefficient obtained by subsequent sampling in the Central Area (Area 16-159 in Figure 5-7) varies considerably from 10–60 kg/m^2, with an average of 38 kg/m^2. This indicates that the average abundance of the polymetallic nodules in Area 16-159 is higher than assumed for the provisional coefficient and the provisional MFES values are likely significantly lower than the actual values. Adjustment of the weight coefficient was thus carried out per equation (3):

$$\text{Estimated abundance by MFES} = \text{MFESobs} \times fo/fp \qquad (3)$$

Where *MFESobs* is estimated abundance; *fo* is coefficient of the locality of estimation; *fp* is provisional weight coefficient (22 kg/m^2) and *fo* is polymetallic nodule abundance/area occupancy ratio.

During the 2000 survey, MFES data were calculated every 12 seconds and a running average of 15 measurements was calculated by the data processing system and stored as the final data. The MFES abundance values were assigned to orthogonal lattice points. The nodule abundance and area occupancy ratio data acquired from sampling were used to obtain the indirectly interpreted abundance by MFES of each lattice point.

An MFES survey is typically carried out in lines (following the ship track for the sampling), but at the 16-159 (Central Area), a survey block was completed (Figure 5-7a).

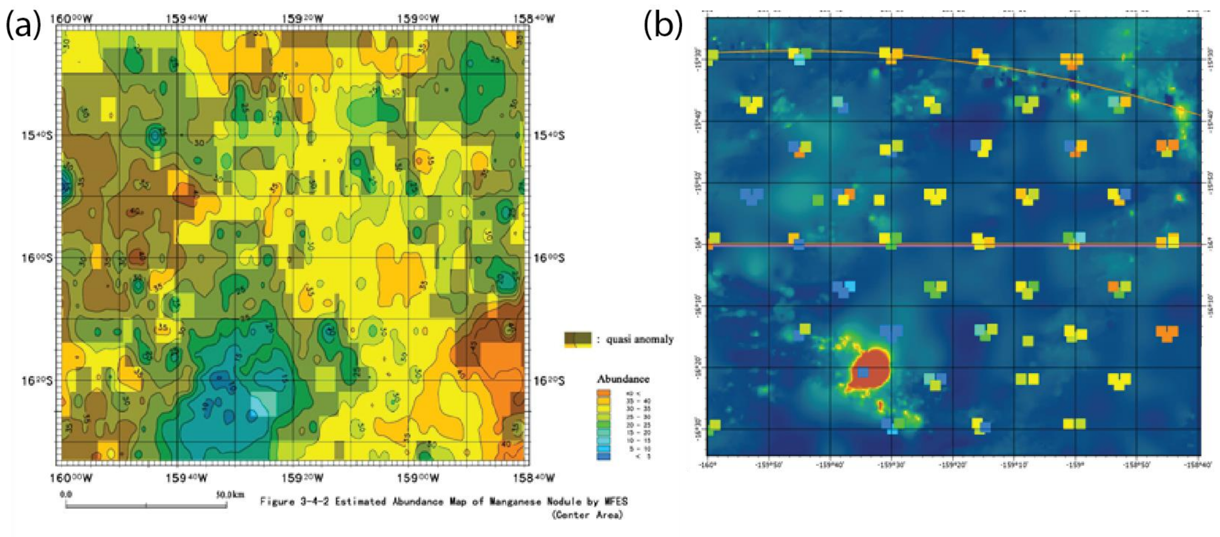


Figure 5-7: (a) Estimated nodule abundance using MFES data compared to (b) physical sample abundance results at Area 16-159. Quasi-anomaly is understood to be a return influenced by occasional hard substrate, i.e. crusts or basalt.

MFES data are not commonly used in polymetallic MREs (e.g. International Seabed Authority, 2014); however, the results do provide some measure of support for the continuity demonstrated in the physical sampling.

5.1.3 Mapping and Geology

In addition to the MBES and MFES maps, JICA-MMAJ mapped nodule forms (Figure 5-8) and compiled contour maps from single-beam bathymetric data and contours/swath maps of seabed clay-ooze types from the SBPs (Figure 5-9).

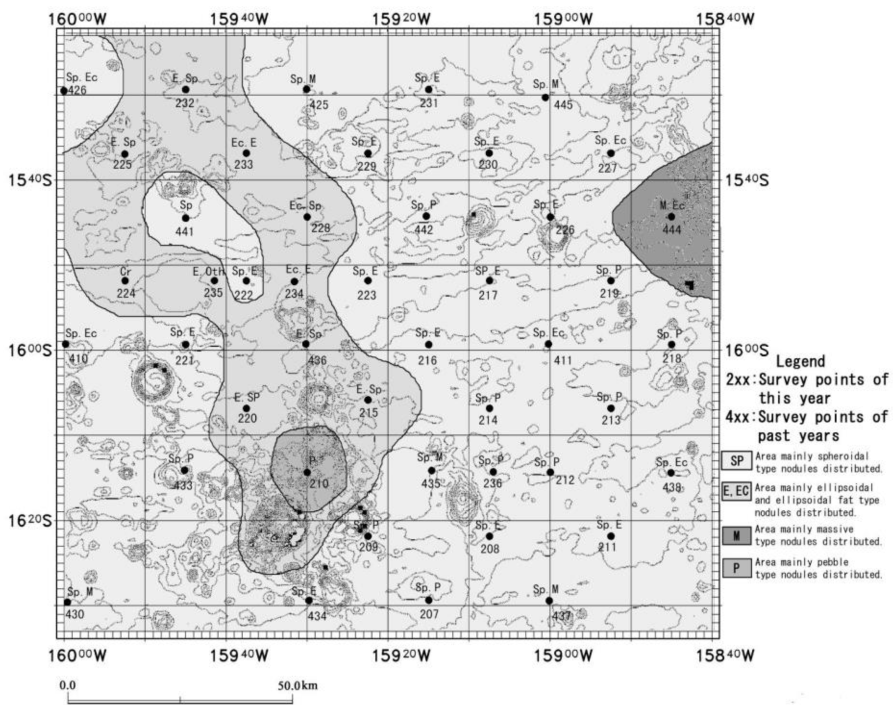


Figure 5-8: Example of a map of nodule forms in Area 16-159 (Central Area).

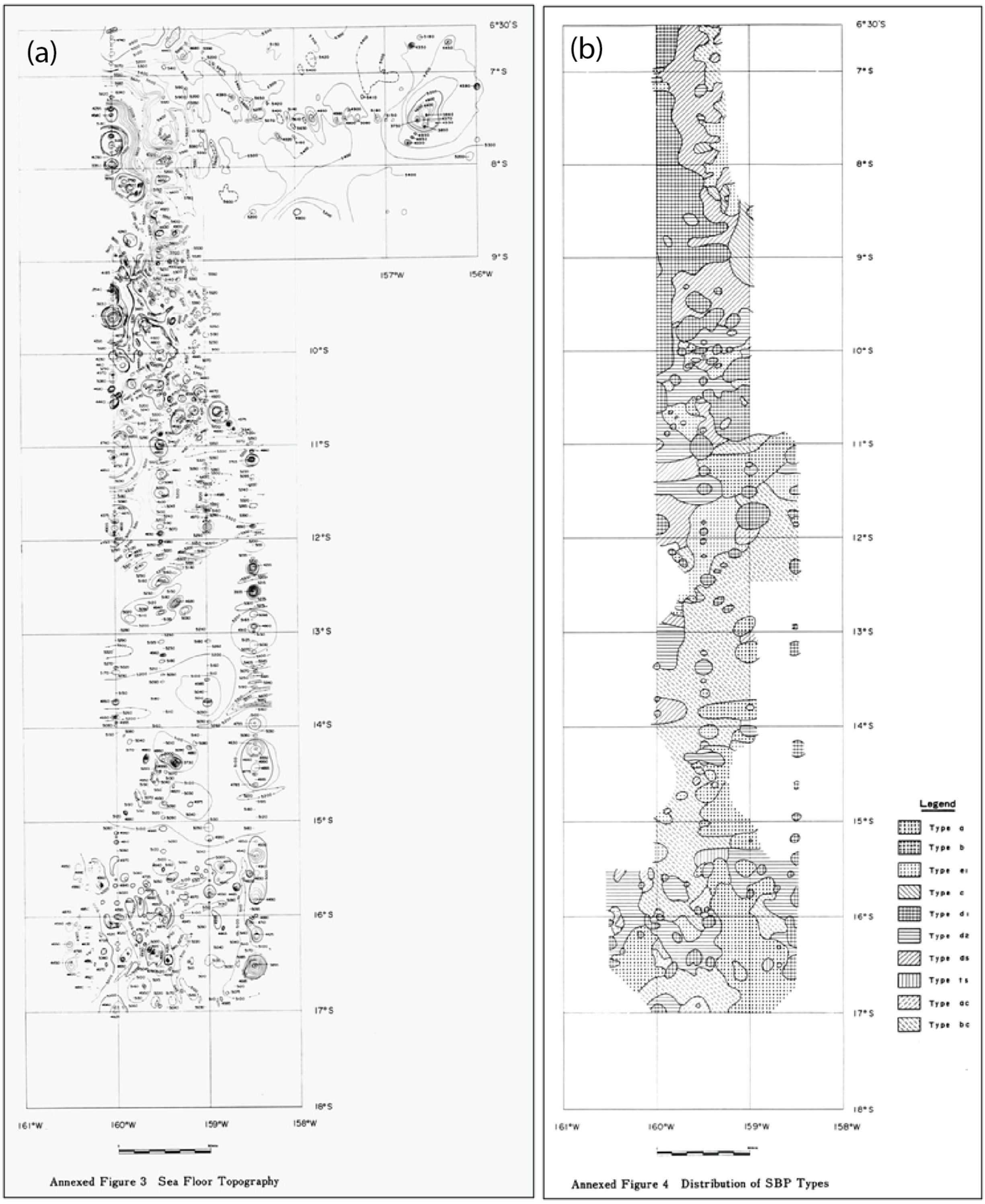


Figure 5-9: Examples of maps from the 1986 JICA-MMAJ expedition. A) seafloor bathymetry map; b) map of SBP types.

5.1.4 Seabed Sampling

JICA-MMAJ expeditions collected several free-fall grab (FFG), box core (BC, also known as spade core, SC) and large gravity core (LC) samples, which contributed to the majority of the samples in the polymetallic nodule database for the Project Area (Section 7.1). This included 20 BC, seven LC, and over 500 FFG samples (Figure 5-10).

Figure 5-10: Samples collected by JICA classified by sample type.

5.1.4.1 Seabed Sample Locations and Replicates

Typically, JICA-MMMAJ sampled following 0.5–1° (~50–100 km) spacing. Sample spacing was reduced to 0.25° (~26 km; offset grid, e.g. Figure 5-8) in Area 16-159 and to 20 km in Area 13-159 (GH83-3). Some sample lines were ~1.5 km apart.

JICA-MMAJ was systematic in positioning samples throughout the project (Figure 5-1). There were two key steps in the process: 1) survey station selection and 2) sample site selection, qualified as follows:

- Primary survey stations were located on degree points and centred to the degree points, in effect, an offset ~42 nm grid (Figure 5-11) infilled at half the spacing then defines the secondary survey stations.

- Each survey station usually comprised three sample sites, 1.4–2 nm apart, arranged in an inverted triangle (Figure 5-12; Figure 5-13). The northern edge usually comprised two FFG sites and at the southern point of the triangle, either a FFG or BC (usually only four sites per expedition). During the 2000 expedition, an LC was also used to sample the southernmost site. Sampling was typically completed in a clockwise direction.

Due to the close nature of the triplicate sampling, the samples can be interpreted as a primary sample followed by two replicate samples.

The number of samples collected and sampling types used in this study are listed by expedition in Table 5-1.

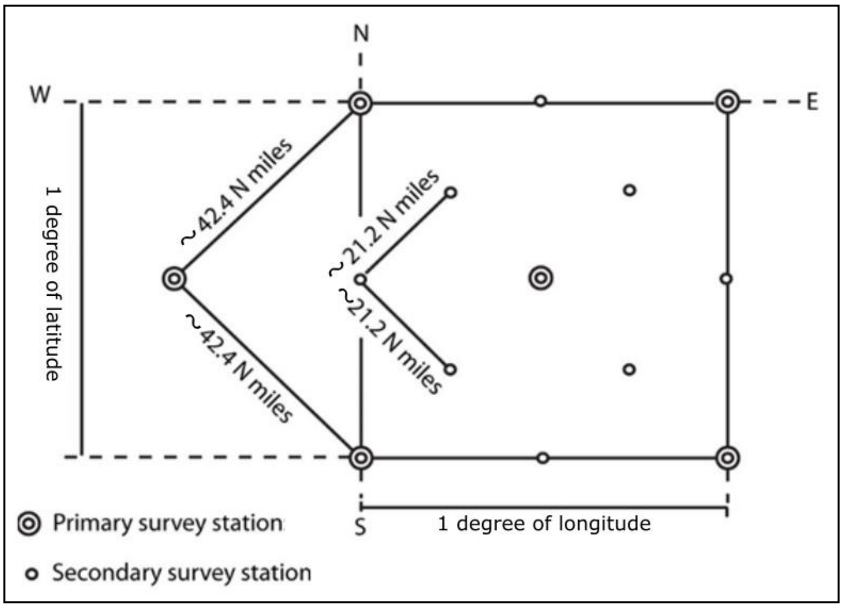


Figure 5-11: Standard station spacing layout for JICA-MMAJ expeditions.

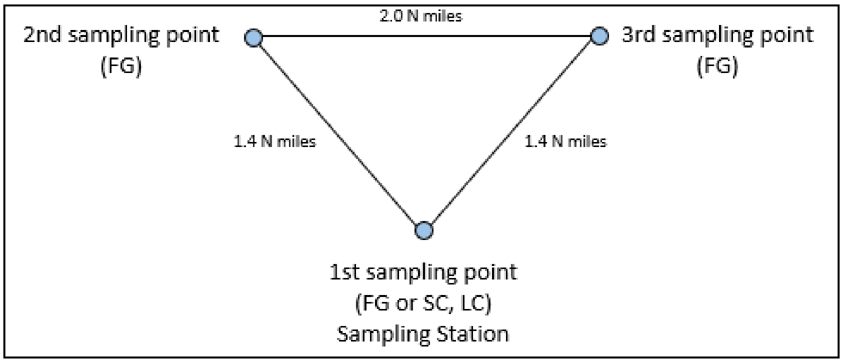


Figure 5-12: Standard sampling point layout for JICA-MMAJ expeditions.

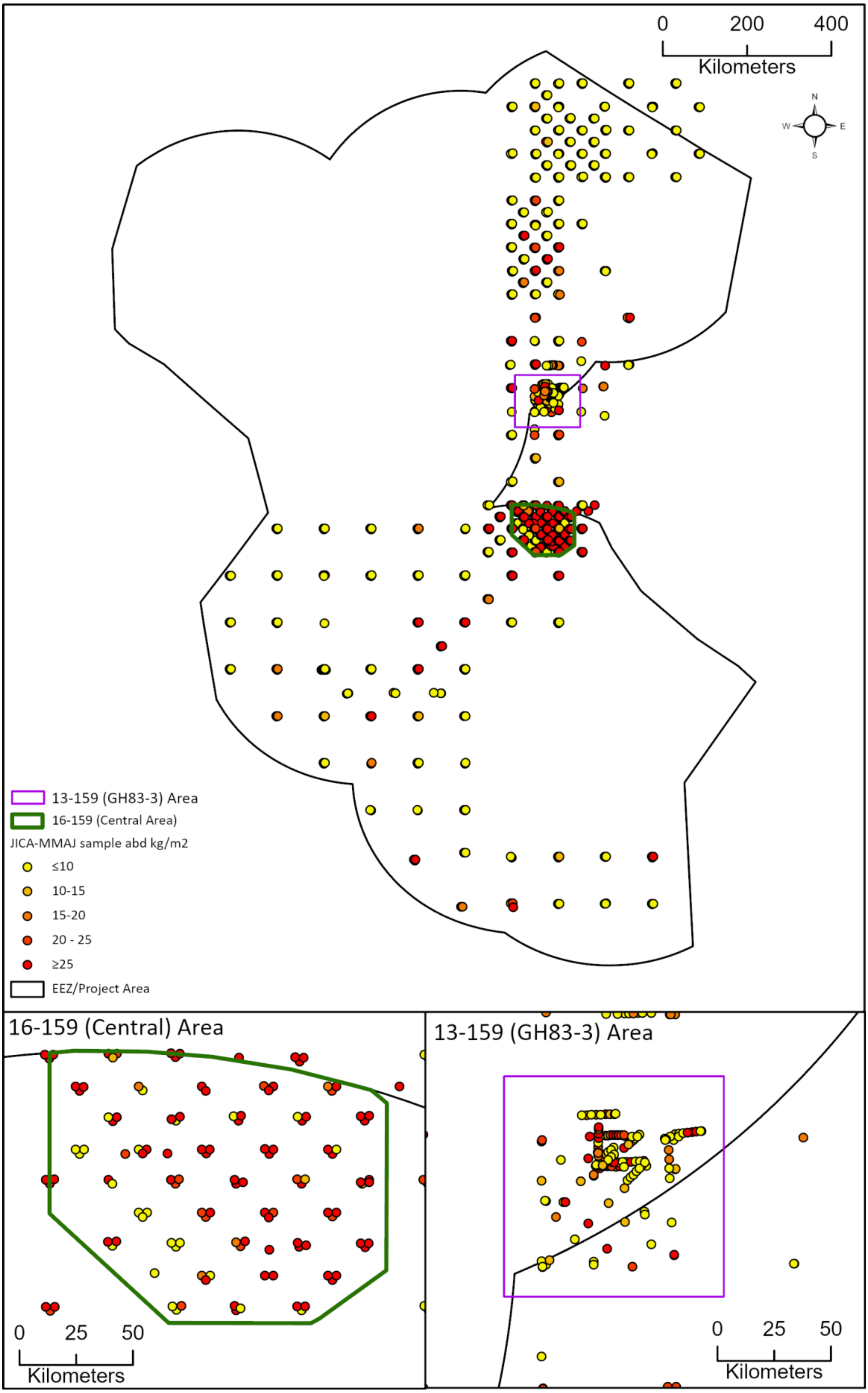


Figure 5-13: Samples collected by JICA-MMAJ following a triangular sample station pattern.

5.1.4.2 Sampling Equipment

Approximately 95% of the samples during the JICA-MMAJ 1985–2000 expeditions were collected using a 0.13 m^2 Preussag model FFG (Figure 5-3, Figure 5-4). The principles of how a FFG operates are depicted in Figure 5-14. A FFG is an untethered sampling method (it is not attached to the ship). Typically, a series of FFG samplers would be deployed, then the ship would return later to collect the re-surfaced FFG. The FFG is loaded up with ballast weights, which causes negative buoyancy. Therefore, when the FFG is deployed over the side of the ship it sinks to the seabed. A net or wire basket is fixed to the base, in an open clam shell position. When the FFG hits the seabed, the trigger plate is activated by the impact. The ballast weights are released, and as the FFG starts to ascend, the jaws of the net or basket close, capturing nodules in its path. Two buoys, located in the main frame of the FFG, provide buoyancy returning the FFG to the sea surface for retrieval by the exploration team. The Preussag model FFG has a sampling area of 0.13 m^2. The FFG jaws scrape the seabed to collect the sample. Sediment and small nodules wash out of the net during the ascent.

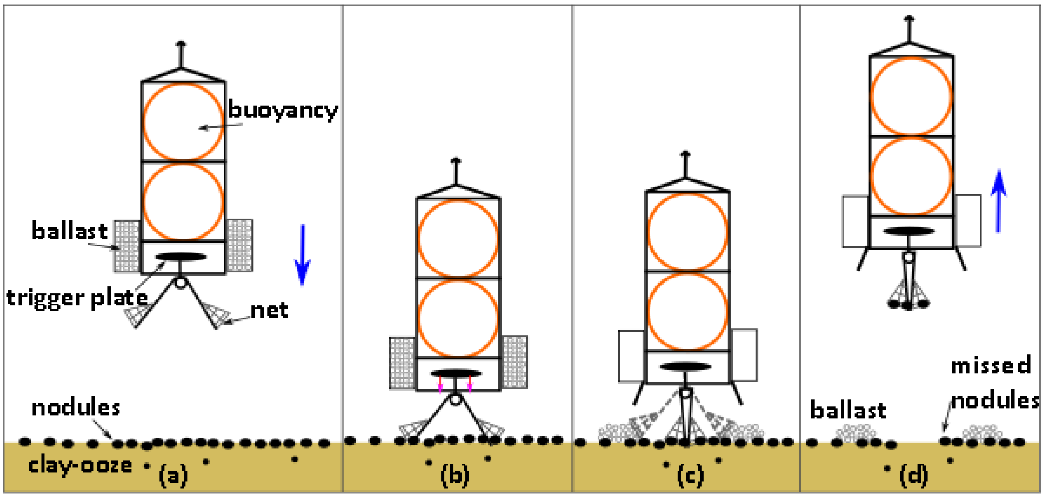


Figure 5-14: Principles of FFG operations. Adapted from Lee et al., (2008).

Approximately 4% of the samples were collected using BC (Figure 5-3, Figure 5-4). The principles of how a BC operates are depicted in Figure 5-15. The model of BC used was not specified, but from photographs, it appears to be a USNEL 0.25 m^2 model. A BC is a tethered sampling method, meaning the sampling equipment is always attached to the ship. The BC is lowered to the seabed by a winch. Once it reaches the seafloor, the box sinks into the soft sediment, and the spade is triggered. As the BC is pulled from the seafloor by the winch, the spade rotates, slicing through the sediment and comes to rest sealing the base of the sampling box. This prevents the sample from washing out of the base of the sample box as it is brought to the surface. The advantage of the BC is that it collects a relatively undisturbed sample, with the nodules sitting on top of the sediment. However, one potential issue with the BC is that spade may fail to figure when it lands on or near deep sea crust. This is because the box may fail to penetrate into the sea surface due to the hard crust or the BC spade may not be able to cut through and seal the box, leading to sample loss.

Approximately 1% of samples were collected using an LC (Figure 5-3 and Figure 5-4). Large gravity corers were only deployed during the 2000 expedition. The model or specifications including the length and diameter of the LC were not specified. Based on stratigraphic columns produced for the LC samples, recovered cores ranged from 1.0–3.5 m. Nodules were predominantly recovered from the upper 10 cm of the seafloor.

Free-fall grabs and BC were often equipped with a still camera. The camera would take a photograph of the seafloor using a trigger weight before the sample was collected (see Section 5.1.5).

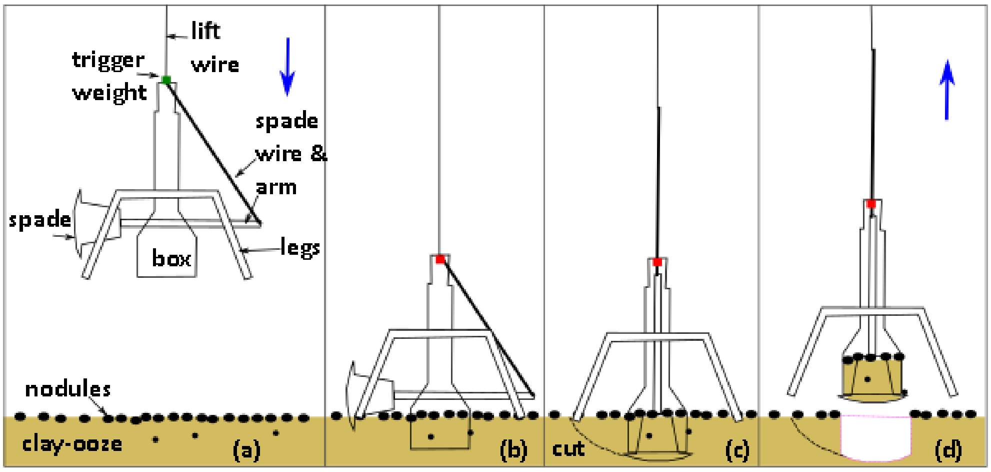


Figure 5-15: Principles of BC operations. Adapted from Lee et al., (2008).

5.1.4.3 *Nodule Morphology*

Once the nodules had been recovered, JICA-MMAJ recorded the different nodule morphologies. There are eight different morphologies which are described in Table 5-4. Spheroidal-type nodules are the most prominent followed by pebbly-type. Nodules are predominantly 2–6 cm in diameter, but rare nodules >16 cm were also recovered.

Table 5-4: JICA-MMAJ nodule morphology descriptions.

Nodule morphology	Description
Spheroidal	Spheroidal nodules are perfect to near-perfect spheres. The diameter of spheroidal nodules is typically >3–6 cm, maximum ~8 cm. The short to long diameter ratio is >0.75. Spheroidal nodules can have a variety of surface textures, including smooth and rough.
Ellipsoidal	Ellipsoidal nodules have a flattened spheroidal external form full of fine concavities and convexities, with a rough surface. Ellipsoidal nodules typically have fractures. The short to long diameter ratio is >0.5.
Ellipsoidal fat	Ellipsoidal fat nodules are a variation of the spheroidal nodules and are more irregular and larger than the ellipsoidal nodules. The short to long diameter ratio is between 0.5 and 0.75.
Pebble thin	Pebble thin nodules are small, thin and circular to oval. They are pebble sized and have a smooth surface without irregularity. The short to long diameter ratio is > 0.25 and the long diameter of the nodule with smooth surface is typically >4 cm.
Pebble	Pebble nodules typically have a diameter of 2–4 cm and are more equant than the pebble thin nodules. The surface is smoother compared to the spheroidal and ellipsoidal nodules. These nodules are sub-angular to sub-rounded in shape.
Massive	Massive nodules are similar to the spheroidal and the ellipsoidal (thin) nodules; however, these nodules form in various shapes including irregular angular shape and a plate shape, with large diameters (e.g. >10 cm). The surface texture also varies from rough to smooth.
Plate	Plate nodules have a relatively rough surface. They are thin (a little like tiles) and often circular.
Other	This includes unclassified small nodules with shapes that are difficult to determine, such as stick shaped ones, etc.

5.1.4.4 Nodule Abundance

Nodule abundance is reported in wet kg/m^2 and is typically calculated by dividing the wet nodule weight by the area of the sampling device (0.13 m^2 for the Preussag FFG and 0.25 m^2 for the USNEL BC).

The process of calculation of nodule abundance is not stated clearly in the JICA-MMAJ reports, but SBMA and RSC assume it was calculated following standard practice. It was possible for the sampler to fail to recover a sample (i.e. the BC spade or FFG jaws failed to trigger, or the FFG sampler was damaged upon recovery and there was evidence nodules had been lost (i.e. net damage)), nodule abundance was estimated from nodule coverage reported in seafloor photographs taken during sampling.

JICA-MMAJ stated that failed samples were rare; however, JICA-MMAJ did not record any statistics on failed samples. JICA-MMAJ also did not report which samples use an estimated abundance versus calculated nodule abundance (JICA-MMAJ, 1987, 1991).

Nodule abundance was estimated from seafloor photographs by the following regression formula:

$$\text{Estimated nodule abundance (kg/m}^2\text{)} = (1.9505 \times r^{2.1875} \times N) / 1000 \times (0.157 \times r + 0.3992) \quad (4)$$

where r = average size (cm), N = number of polymetallic nodules (number/m^2).

This approach assumes nodule size exhibits a normal distribution and that there is a constant ratio between the three axes, something which may be valid in parts of the Cook Islands nodule field where there are spheroidal nodules.

The average size of the nodules could be estimated as a trigger weight of known size was captured in all still photographs collected during FFG and BC sampling. RSC is unsure how widely the calculation was applied to FFG samplers and to what extent the data is included in the MRE.

A summary of the abundance data collected by JICA-MMAJ is summarised in Table 5-5.

Table 5-5: Summary of the abundance data collected by JICA-MMAJ.

	1985 Expedition	1986 Expedition	1990 Expedition	2000 Expedition	1985–2000 Expeditions
Count	114	165	319	112	710
Mean	3.18	18.0	6.14	21.0	10.76
SD	0.48	1.18	0.40	1.36	0.47
Minimum	0.01	0.01	0.00	0.00	0.00
Maximum	31.9	62.91	35.9	44.3	62.91
Median	1.09	21.9	4.30	25.9	4.80

SBMA also studied this approach. Some preliminary relationships are presented in Figure 5-16. The size-weight relationship can be approximated by a simple power law equation:

$$y = 1.2x^{2.55} \quad (5)$$

where y = nodule weight in grams; x = nodule major axis length (diameter) in centimetres.

However, relationships were seen to vary by nodule form, and it is likely that formulae may need to be calibrated and customised on a case-by-case basis for higher precision local estimates, although the variance is slight between most of the nodule morphology and sizes. A key exception is platy, irregular shaped nodules.

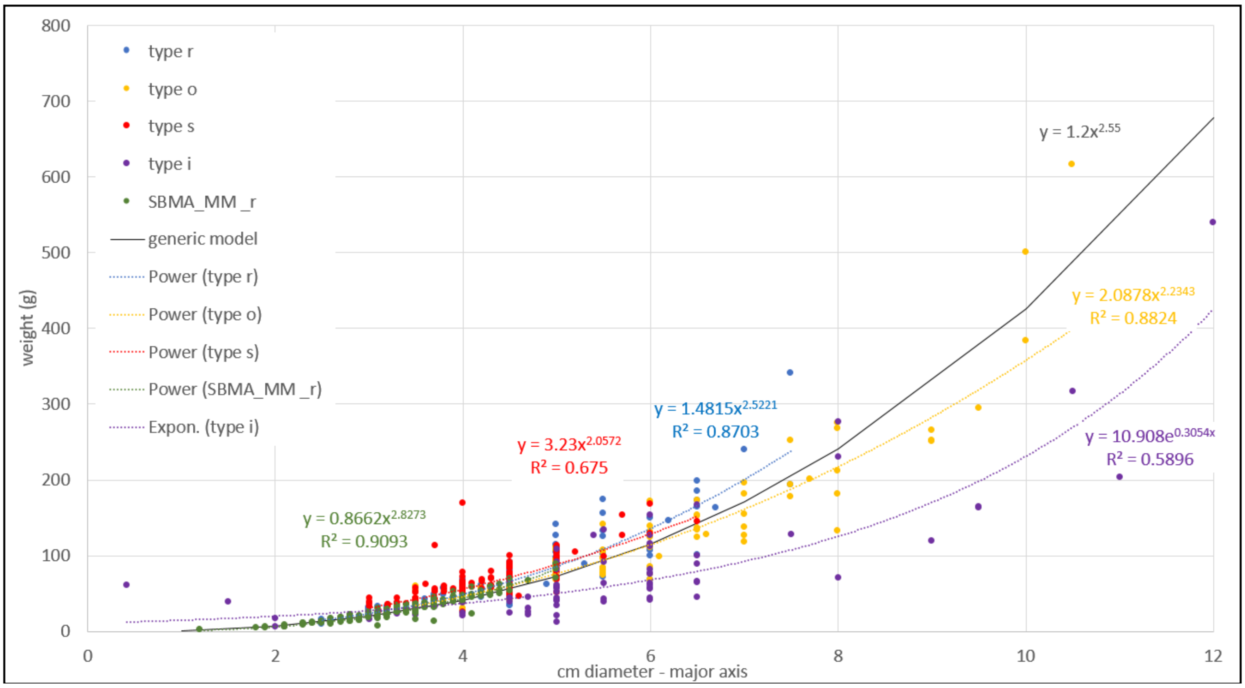


Figure 5-16: Nodule size-weight relationships. Compiled by SBMA from data and nodules supplied by CIICSR and Moana Minerals (2019 MSR expeditions). s = spherical, o = ovoid, r = rounded, i = irregular.

5.1.4.5 Nodule Density

Wet nodule density was measured by JICA-MMAJ; however, the details of the methodology to collect data were not reported. There is some variance in the wet nodule density measurements (Figure 5-17); however, the mean of 1.97 is representative for the nodules within the Project Area for the purpose of resource estimation.

During the 2000 expedition, dry nodule density was also determined. The samples were dried to a constant weight at 110˚C, and ground in an agate mortar. Approximately 10 g of crushed nodules was weighed in a pycnometer and heated for two hours in a water bath after adding distilled water. After 24 hours, the temperature was measured, and the pycnometer was weighed. However, the results were not published.

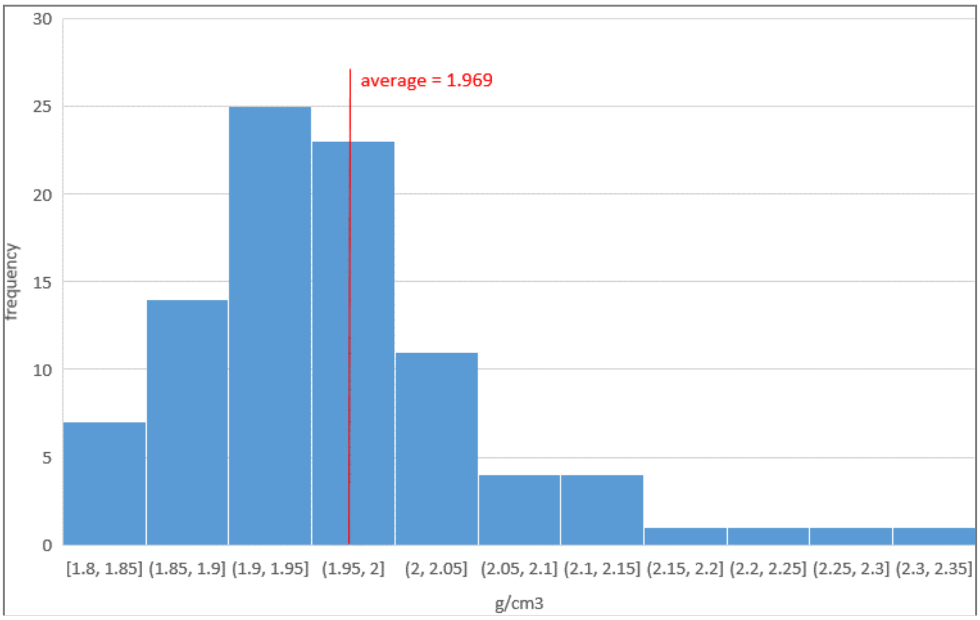


Figure 5-17: Nodule wet densities. Data from JICA-MMAJ (2001).

5.1.4.6 Moisture Content

Water content was obtained by measuring the weight loss after drying (JICA/MMAJ, 2001). Wet samples were weighed, and then dried until they reached a constant dry weight. The moisture content was recorded as the weight ratio of wet to dry samples. The average length of time required to fully dry samples was not recorded. The average moisture content of the samples is 30%.

5.1.4.7 Sample Preparation

Samples were prepared for chemical analysis at sea. Nodules were dried at 105°C for an unknown length of time. Once dry, nodules were crushed and ground into a briquette for analysis. RSC assumes that the samples underwent several splitting stages before being analysed. Preparation equipment was manufactured by Yoshida Seisakusho. No other details regarding sample preparation were available to RSC to review.

5.1.4.8 Analysis

JICA-MMAJ analysed polymetallic nodules both at sea using an onboard laboratory equipped with X-ray fluorescence (XRF) and at independent laboratories on shore. Onboard, the nodules were analysed for Cu, Co, Fe, Mn and Ni. The XRF analysis equipment was manufactured by Rigaku Denki. Both nodules and sediment were analysed.

On shore, a selection of nodules was analysed by petrography, X-ray diffraction (XRD) and minor element assaying (method not reported). The equipment and details on the analysis were not available for RSC to review. Fifty nodule samples were analysed from the 1985 and 1986 expeditions, respectively, on shore.

Ten samples collected during the 1990 expedition were analysed onshore by unspecified methods. Onshore analysis analysed more analytes compared to ship-based analysis. Major analytes included SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO_2, MgO, CaO, BaO, Na_2O, K_2O, P_2O_5 and loss on ignition, and minor analytes included Pb, Zn, S, V, Mo, B, As, Y, Zr, and Pt.

Samples collected from the 2000 expedition were analysed at ALS Chemex Canada using a combination of ICP-emission spectrometry, fire assay – ICP, ICP-MS and LECO for nodules and ICP-emission spectrometry, titration, ICP-MS, LECO, NAA (neutron activation analysis) and AAS (atomic absorption spectroscopy) for sediments. Quoted numbers of samples analysed are higher than the number collected (Table 5-1) – it is presumed that various unspecified splits and forms of nodules and layer sediments were analysed separately. JICA-MMAJ was aware that chemical analysis of nodules can be complicated by the fact that they are typically hygroscopic (Terashima, Usui and Imai, 1995; Parianos, 2022), although details of the process to mitigate any adverse effect this may have caused are not known.

5.1.5 Seabed Photography

Seafloor photographs were collected by JICA-MMAJ using a variety of different camera methods. Still cameras were attached to FFG and BC sampling equipment to take a photograph of the seafloor before the samples were collected (Figure 5-18). A weight attached to the sampling equipment would hit the seabed, triggering the shutter on the camera. Once the sample was on deck another photograph would be taken before on-deck processing would begin.

Camera model and specifications including lighting set-up are unknown. JICA-MMAJ processed the photographs in a dark room process which implies film cameras were used until at least 1986 (Figure 5-19). A video camera was used for the collection of towed camera images (JICA-MMAJ, 2001). RSC assumes digital still imaging was used in later expeditions as the technology was available at the time.

Camera equipment was also towed behind the ship (e.g. continuous deep-sea cameras (CDC) and finder installed continuous deep-sea cameras (FDC). Examples of photographs collected by CDC and FDC are presented in Figure 4-28 and Figure 4-29, respectively. The camera system mounted on the FDC included a still camera, a TV camera and a conductivity, temperature and pressure measuring (CTD) system. The FDC was towed at 1 knot typically along an east–west trending survey line (the height above the seafloor is not specified). Polymetallic nodule distribution was observed in real time via TV and a still photograph was taken at 100 m intervals.

There are many benefits of seabed photographs. Photographs collected from cameras mounted to FFG/BC samplers (e.g. Figure 5-4) can be used to verify the primary sample collected. If there is a poor correlation between the primary sample and corresponding seafloor photograph (e.g. sample loss or failed sample), JICA-MMAJ would estimate the nodule abundance from the seafloor photograph (see Section 6.2.4.4). Nodule abundance could also be estimated from photographs captured using towed methods (see Section 6.4.3). Seabed photographs, in particular from towed cameras are useful to assist geological interpretation, identifying megafauna and assessing geological and grade continuity.

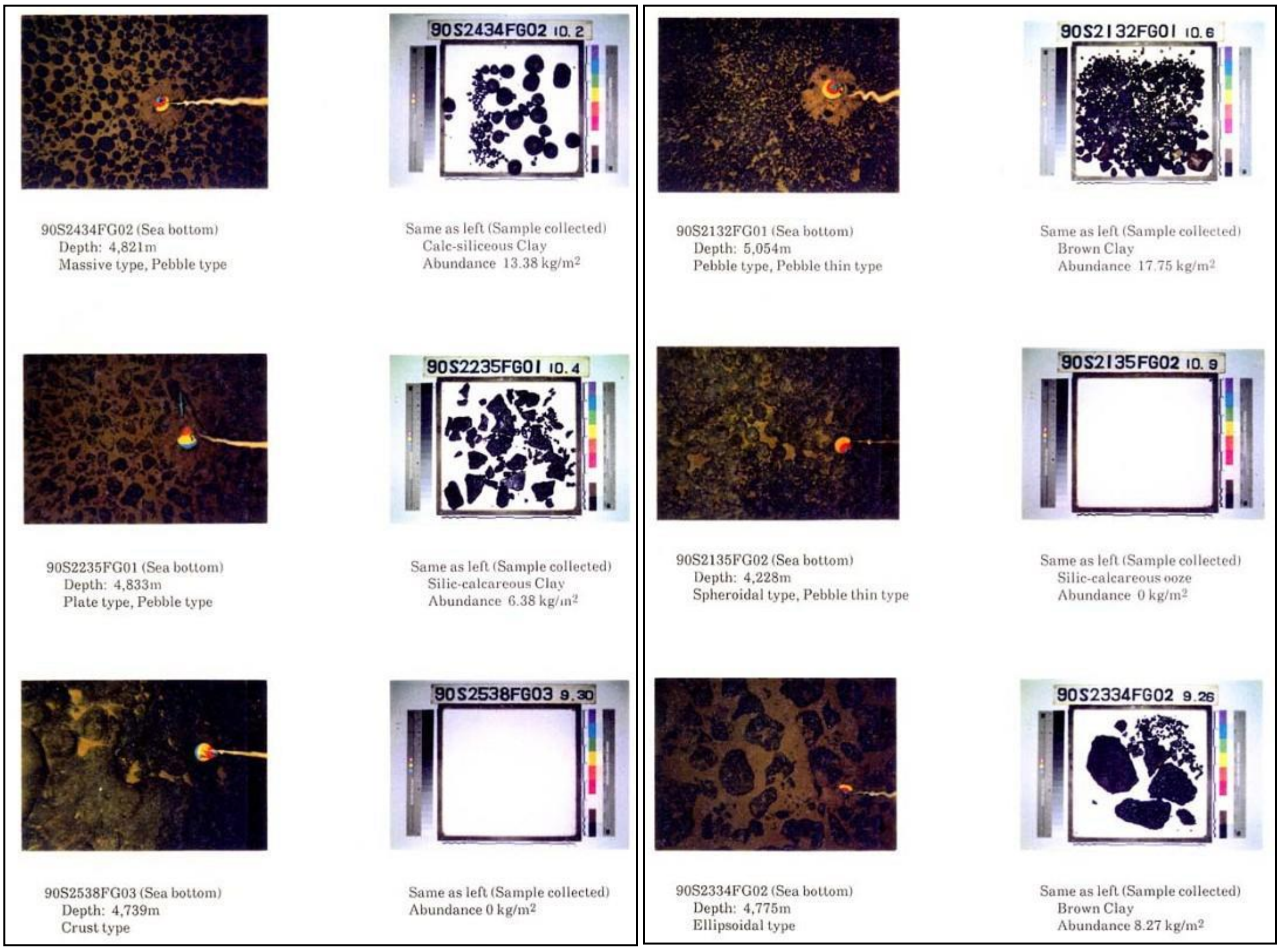


Figure 5-18: Example JICA-MMAJ FFG seabed and sample imagesSource: JICA-MMAJ, 1991.

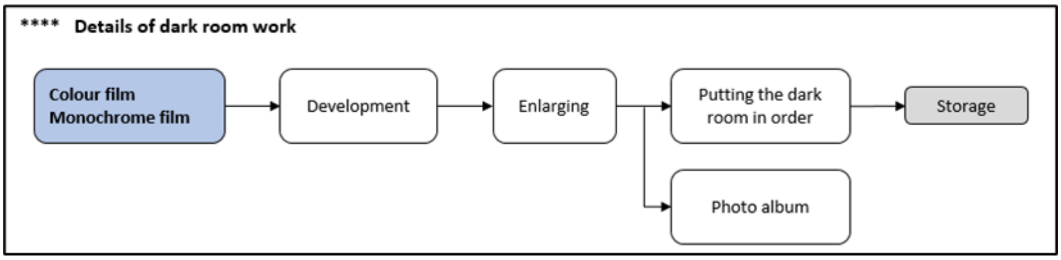


Figure 5-19: JICA-MMAJ darkroom procedures. Source: JICA-MMAJ (1986, 1987).

5.1.6 Metallurgy

The JICA-MMAJ reports do not specifically mention metallurgical work on Cook Islands nodules as part of the planned exploration work and no mention was able to be found in scientific literature in the public domain.

While Kojima (1996) reviews metallurgical studies by MMAJ, these appear to be focussed on the CCZ nodules, and the MMAJ-developed smelting and chlorine leaching process is not likely to work with Cook Islands nodules due to their relatively high Fe grade (see also Section 7.11.3).

5.1.7 Sediment Classification

Clay-ooze sediment recovered from the Project Area is predominantly composed of brown clay and some calcareous sediments. Clay-ooze classification is presented in Table 5-6 and clay-ooze type descriptions are presented in Table 5-7.

Table 5-6: JICA-MMAJ classification of bottom clay-oozes.

	Fossil	Siliceous	Calcareous[1]	Remarks[2]
Brown clay	<10%			
Insoluble brown clay	<10%			Impermeable
Siliceous-calcareous clay	10–30%		>5%	Siliceous fossil > calcareous fossil
Calc-siliceous clay	10–30%	>5%		Calcareous fossil > siliceous fossil
Foraminifera clay	>30%			Foraminifera dominant

[1] Radiolaria, diatoms, silicoflagellate, sponge spicule
[2] Foraminifera, calcareous nanoplankton

Table 5-7: JICA-MMAJ bottom clay-ooze descriptions. Source: JICA-MMAJ, (1987).

Clay-ooze type	Description
Brown clay	The main component minerals of brown (mostly Munsell Colour Chart 5YR3/2) clay in the survey area are clay minerals, siliceous biogenic components/fragments and a small amount of amorphous material, pyroclastic material, zeolites, barite, ichthyolith and micro-nodules. Siliceous creature shells are typically low in abundance in the clay and comprise of a small amount of radiolaria (<5%) and silicoflagellates.
Insoluble brown clay	Has a similar mineral composition to brown clay. Insoluble brown clay is brown-yellow colour (Munsell Colour Chart 5YR3/2 to 10YR4/4), high viscosity (as sticky as birdlime), and very poorly soluble in water. In the JICA 1986 survey area, insoluble brown clay is sampled only at three sampling points.
Calcareous sediments	Calcareous clay-ooze sediments are classified according to the quantitative ratio of calcareous biogenic debris and siliceous biogenic debris. In the survey area, foraminifera ooze, calcareous-siliceous clay and siliceous-calcareous clay are present. The ooze and different clays consist of foraminifera debris with minor radiolaria, and trace amounts of sponge spicules, micro-nodules and zeolites.

5.2 CIICSR Marine Scientific Research 2019 (CIICSRNOD19)

Exploration work by Cook Islands Investment Corporation Seabed Resources (CIICSR) was used to corroborate and support the work of JICA-MMAJ, especially in the northern part of Area 16-159 where CIICSR samples in effect infill the grid completed by JICA-MMAJ. A brief discussion on sampling equipment and methods is discussed below. Unless referenced otherwise, the information in this section is sourced from Charlet (2019, 2022). Work was carried out under a research permit but CIICSR was granted an exploration licence in early 2022 (Cook Islands Seabed Minerals Authority, 2022a).

The CIICSRNOD19 expedition took place from 9 to 25 September 2019, including two days for mobilisation and two days for demobilisation, using the locally based MV Ginna II.

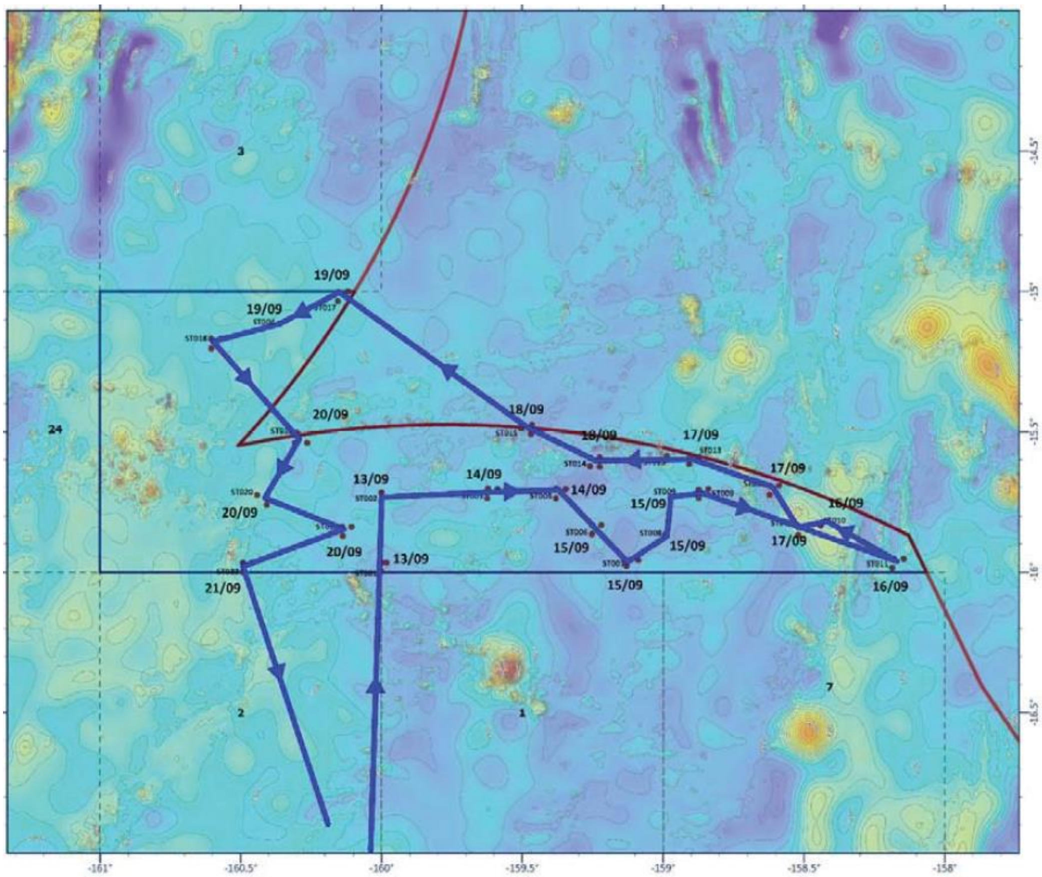


Figure 5-20: Vessel path for the CIICSRNOD19 MV Grinna expedition.

5.2.1 Survey, Topography, Digital Terrain Map

CIICSR is presumed to have used Navstar GPS for navigation. Sample depth is estimated from the bathymetric chart of the area.

Like JICA-MMAJ, CIICSR used the deployment point as the sampling coordinates as the FFG samplers were observed to quickly sink below the sea surface. However, CIICSR measured the distance between the moment of deployment and the recovery at the surface (Table 5-8).

Table 5-8: CIICSR FFG sampler deployment to recovery offsets.

Offset – deployment to recovery	Distance (m)
Minimum	29
Maximum	1,501
Average	577

5.2.2 Seabed Sampling

The CIICSRNOD19 expedition had three objectives:

1. Test a new generation FFG sampler.
2. Obtain information that corroborates historical sampling and extend the exploration pattern into new areas.
3. Gather sufficient sample for description, reference, and analysis (including geochemistry, metallurgy, and other technological considerations).

Expedition sampling involved de Meyer FFG samplers (Figure 5-22 and Table 5-9) at 21 'survey stations' (Figure 5-21). CIICSR usually deployed two to four FFG devices at each 'sampling station' point; these were arranged in a triangular pattern at each survey station (Figure 5-21). Like JICA-MMAJ, the sampling stations were usually a cluster of three per survey station, unlike the JICA-MMAJ survey where several FFG samplers were deployed – each to increase sample payload and meet the third above-described objective.

The jaws of the FFG sampler opened 40 cm × 40 cm to sample an area of 0.16 m^2. Nodule abundances (kg/m^2) were calculated by multiplying the weight of nodules recovered by the sampled area. No additional factors were applied to compensate for the possible loss of sample by the FFG unit used. CIICSR considered sample loss to be limited, based on camera footage of the sampling process.

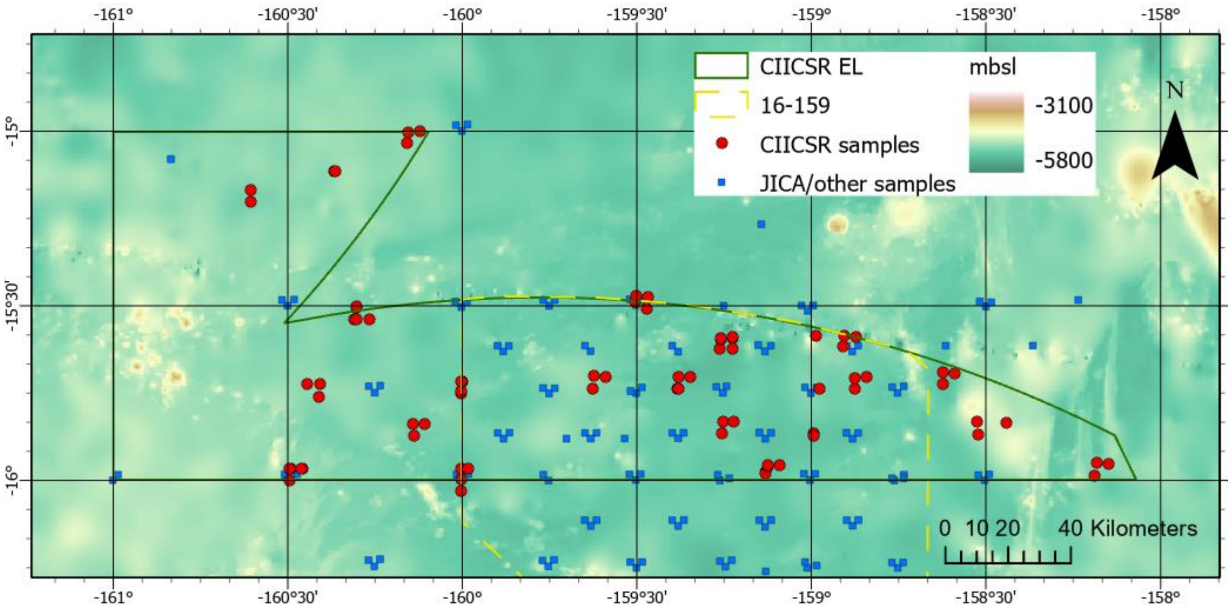


Figure 5-21: Sampling locations – CIICSRNOD19 expedition.

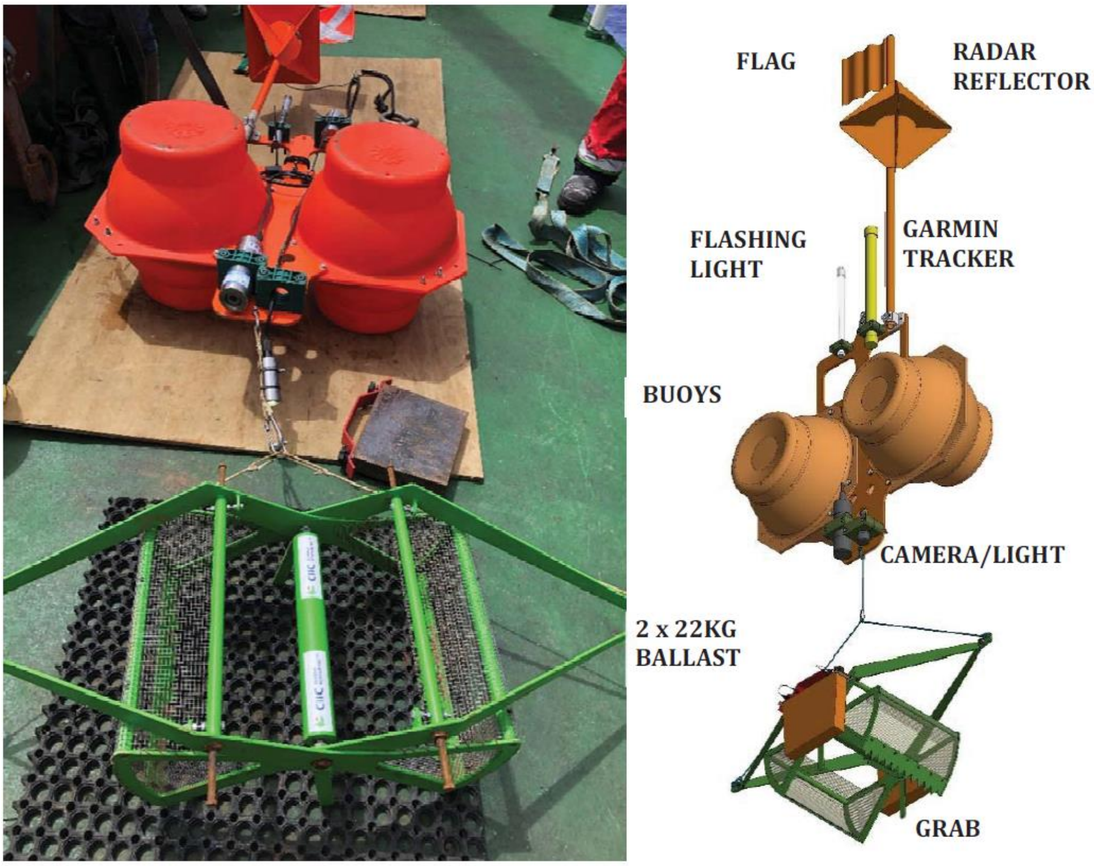


Figure 5-22: Key elements of the de Meyer model FFG sampler used by CIICSR and OML.

Table 5-9: Main parameters of the de Meyer FFG sampler.

Parameter	Values
Length × width × height (m)	0.717 m × 0.510 m × 2.85 m
In-air weight (kg)	~75
Submerged weight (kg)	20 to -5
Max. amount of buoyancy (kg)	52
Ballast	2 × 22 kg steel weights
Flotation	2 × 11” glass spheres
Max. sample weight (kg)	16
Sampling surface (m^2)	0.166
Net mesh size (mm)	5 × 5
Surface indicators	Mast, flag, radar reflector, Novatech LED light, optional Novatech GPS beacon

Multi-element chemical analysis of the nodule samples was done by ICP-AES (inductively coupled plasma atomic emissions spectroscopy) and ICP-MS (inductively coupled plasma mass spectroscopy) at ALS-Global Vancouver, with check analyses using broadly similar techniques carried out at SGS Burnaby. Both laboratories are certified to ISO/IEC 17025:2017. CIICSR prepared a certified reference material (CRM) for use as a standard and had a quality assurance and quality control (QA/QC) audit completed by independent consultants (Charlet, 2022).

5.2.3 Seabed Photography

At each station, one or two FFG samplers were typically equipped with a deep-sea camera and a lighting system. The images are of very limited value as there is no scale (although it could be possible to use the length of the sacrificial weight as a proxy) and because the camera was mounted at top of the FFG sampler, thus obscuring the view (Figure 5-23). A total of 37 images were recovered from the 128 FFG sampler deployments.

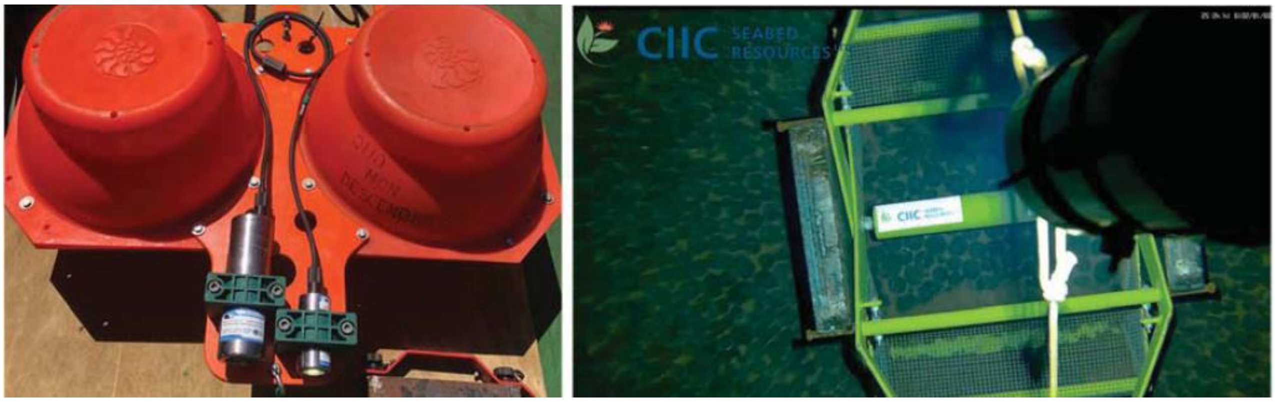


Figure 5-23: CIICSR camera system and example of touchdown image.

5.2.4 Metallurgy

CIICSR is contemplating metallurgical work under its exploration licence (Cook Islands Seabed Minerals Authority, 2022a). Charlet (2022) notes that two main metallurgical processing methods under discussion are using SO_2 (recycled SO_2) and the Cuprion process. A third processing method (pyrometallurgical) still requires to be fully assessed.

5.3 OML Marine Scientific Research Expedition 2019

Exploration work by Ocean Minerals LLC (OML) was used to corroborate and support the work of JICA-MMAJ, especially in the southeastern part of Area 16-159, where a group of samples were taken. Unless referenced otherwise, the information in this section is sourced from Meyer, Flynn and Smit (2020). Work was carried out under a research permit but OML subsidiary Moana Minerals Ltd was granted an exploration licence in early 2022 (Cook Islands Seabed Minerals Authority, 2022b).

The OML 2019 expedition re-used much of the equipment of the CIICSRNOD19 expedition (Section 5.2), including vessel, navigation systems and FFG samplers (including camera system) and this information is not repeated here. The expedition took place from 25 December 2019 to 2 January 2020. Inclement weather during the expedition meant OML only spent 2.5 working days on-site. Samples from proposed reconnaissance sites (Figure 5-24) were thus not collected.

The objectives of the expedition were to collect polymetallic nodules for metallurgical testing and processing/mineral extraction studies and to commence baseline environmental research.

5.3.1 Seabed Sampling

OML deployed FFG samplers 50 times in four locations (Figure 5-24). The grabs were grouped together to maximise yield per the abovementioned objectives.

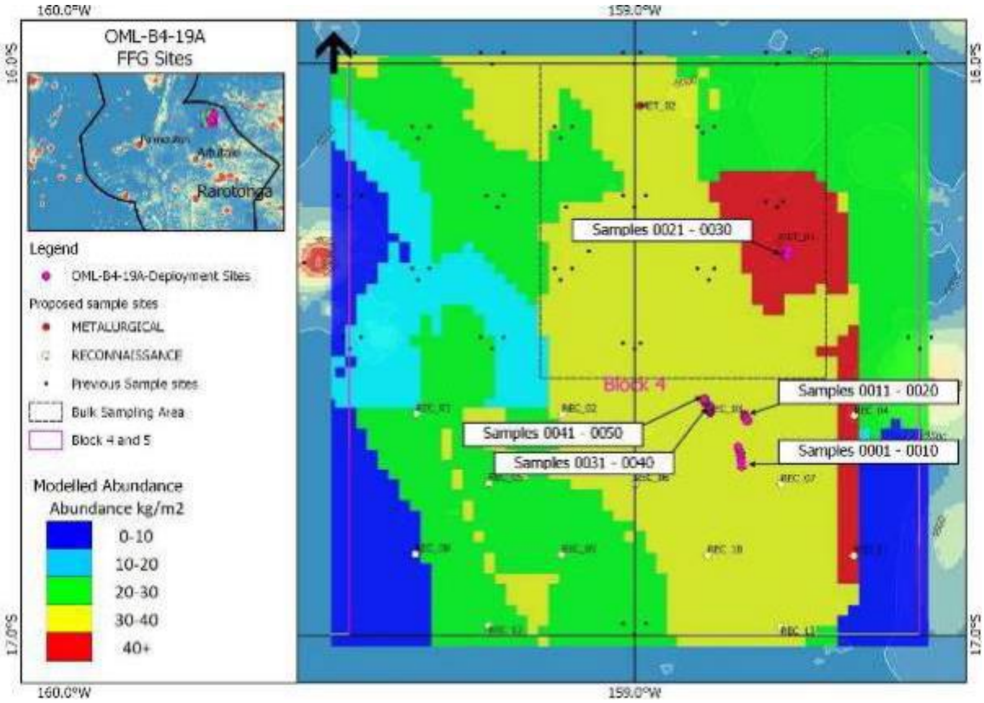


Figure 5-24: OML 2019 sample sites.

Splits of the nodule samples were weighed, dried and pulverised at AMML (Australian Minmet Metallurgical Laboratories Pty Ltd) Gosford, before multi-element chemical analysis by XRF (X-ray fluorescence) (ME-XRF26s) and ICP (ME-MS81 for REY) at ALS-Brisbane (Seaborn, 2020). The ALS-Brisbane laboratory is certified to ISO/IEC 17025:2017.

For possible future study of biology (meiofauna to microfauna sized), samples of sediment (~20 g) were available for sampling from most grabs, and these were preserved in undenatured absolute ethanol in addition to 2–3 nodules and associated rinsate. No visible signs of benthic organisms were observed in any of the grabs.

5.3.2 Water Column Profiling

Three Valeport conductivity, temperature and pressure profiling instruments (CTDs) were programmed to make a recording at every 1 m depth change through the water column, resulting in a profile of the water column structure from the surface to the seabed on descending and ascending legs. Aside from the measurement of some baseline environmental conditions, this information also proved useful in establishing the speed for the descent and ascent times of the FFG units.

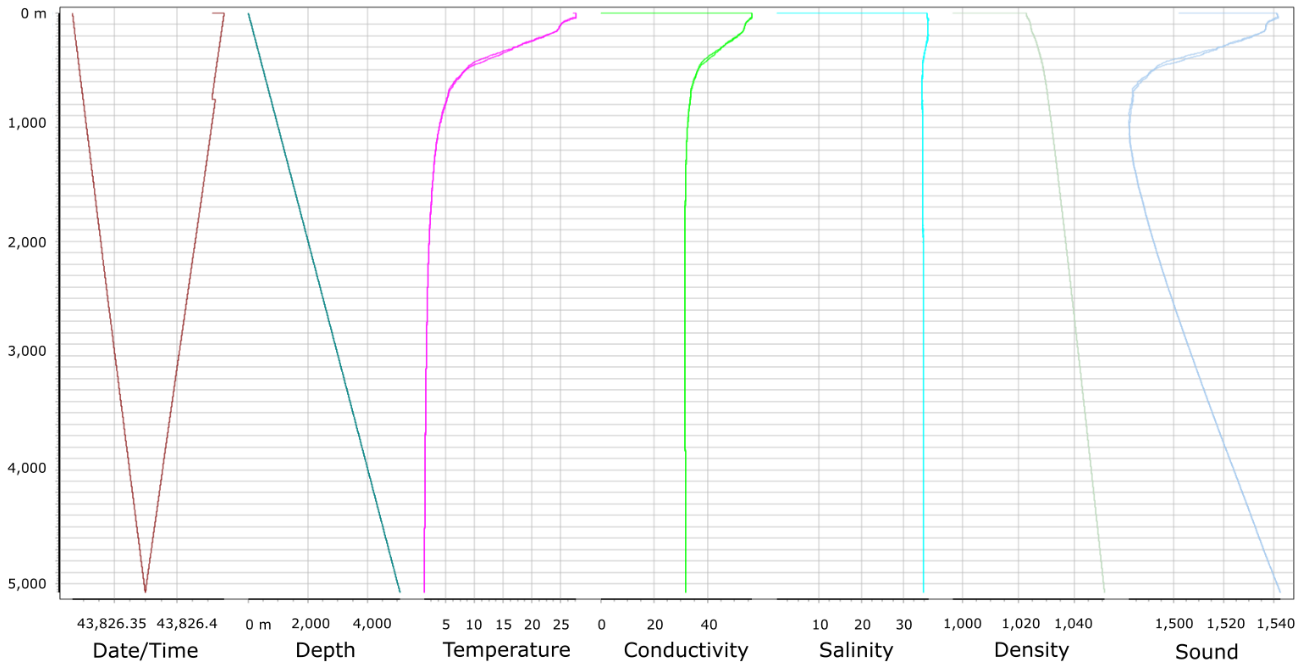


Figure 5-25: Example water column profile data (OML-4B-19A-0042).

5.3.3 Metallurgy

A bulk sample of nodules (wet weight of 111 kg) from the 50 FFG sites was sent to the Beijing General Research Institute for Mining and Metallurgy (BGRIMM) processing laboratory (Meyer, 2022). BGRIMM conducted tests on both the ammonium sulphate and ammonium carbonate versions of the Cuprion process.

The BGRIMM bench-scale laboratory work was based on adaptations of the flowsheets reported previously by the Kennecott process team on its ammonium carbonate Cuprion process, and the ammonia reductive leaching process (both carbonate and sulphate adaptations of the Cuprion process) by BGRIMM researchers. A simplified outline of the final selected process flowsheet is shown in Figure 5-26.

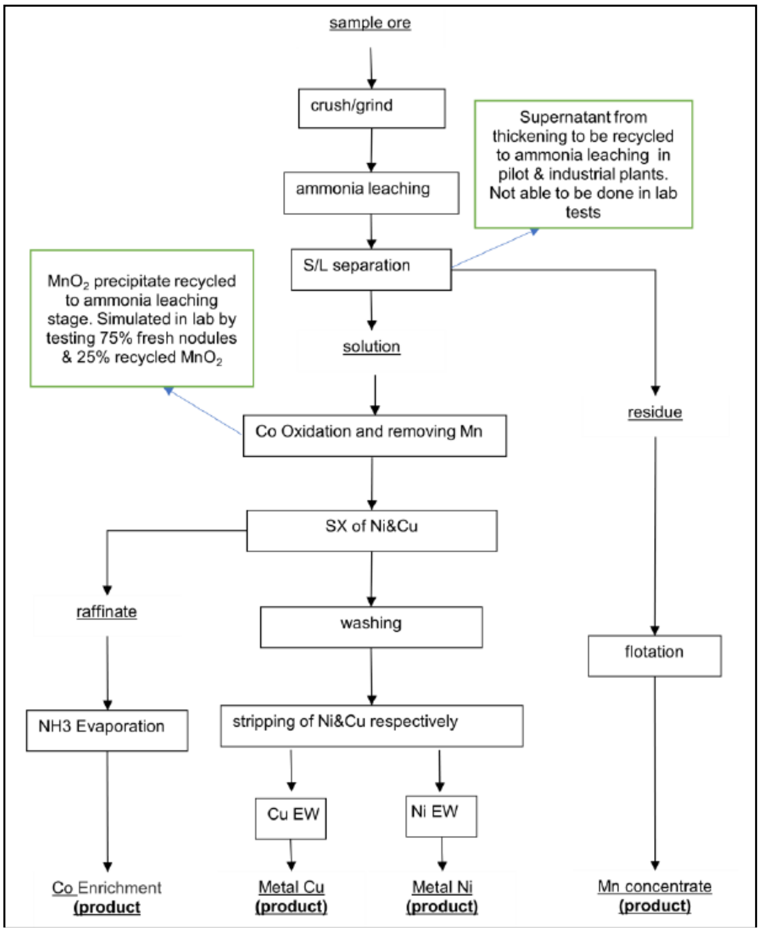


Figure 5-26: Simplified flowsheet of extraction and recovery of Co, Ni, Cu and Mn from Cook Islands nodules.

Key points of the test programme include the following.

- Initial leaching test results supported the ammonium sulphate version of the Cuprion process.
- Solids density in the leaching process varied between 2.5% and 10%.
- Leaching time varied from one to four hours.
- Oxidation of the filtered leachate has the potential to remove manganese as a MnO_2 precipitate. This can then be recycled to the leaching stage where a reaction with carbon dioxide would form manganese carbonate, with subsequent recovery.
- Extraction results of over 93% Co, 85% Ni, 61% Cu and 60% Mn were achieved.
- Initial laboratory tests indicate that there would probably be negligible (<1%) losses in recovering nickel and copper products from the leachate, and that over 99.9% Co could be recovered from the leachate with a cobalt hydroxide grade of ~58%.
- Concentrate containing 30% Mn at 83% recovery was achieved, with further optimisation of Mn concentrate grade recommended in future work.
- Rare earth elements (REEs) remained in the residue and did not leach. Again, future development is recommended.

6 Data Quality

The data quality of the data collected by JICA-MMAJ across four expeditions is discussed below. These data are used to inform the mineral resource estimate. Data not used to inform the estimate are not discussed below in terms of their data quality. However, data collected by CIICSR and OML were used to verify samples collected by JICA-MMAJ in Area 16-159.

6.1 Data Quality Objectives

Every data collection process implicitly comes with expectations for the accuracy and precision of the data being collected. Data quality can only be discussed in the context of the objective for which the data are being collected. In the minerals industry, the term 'fit for purpose' is commonly used to convey the principle that data should suit the objective. In the context of data quality objectives (DQOs), fit for purpose could be taken to mean 'meeting the DQOs'.

Different DQOs are associated with different project stages. For the assessment of the Mineral Resources in the EEZ, data should be of a quality that is fit for the purpose of classifying in at least the Inferred category in accordance with the guidelines of the JORC Code (2012). The objective of 'classifying a Mineral Resource at least as Inferred' sets a requirement for the level of quality of the data and determines the DQO.

6.2 Quality Assurance

Quality assurance (QA) is about error prevention and establishing processes that are repeatable and self-checking. It is better to have simpler processes and fewer steps as this reduces the potential for errors to be introduced into the sampling process. This goal can be achieved using technically sound, simple prescriptive standard operating procedures (SOPs) and management systems.

QA has not been explicitly described by JICA-MMAJ for every step in the sampling, preparation and analytical work carried out during its exploration campaigns; however, its sampling processes generally are described well. Even though the work completed by JICA-MMAJ (1985–2000) was very systematic, and generally supported by 'method descriptions', there is limited documentation of quality assurances in place. The main difference between a method description and an SOP is the level of detail provided, and therefore the degree of freedom an operator has to complete the procedure described. In the case of SOPs, the procedure is described in a detailed, step-by-step manner, whereas method descriptions provide a more general overview of a task. Many details are unknown as the expedition reports were not written with the intent of informing an MRE in accordance with guidelines of the JORC Code (2012). The data used in the MRE were collected several years ago; therefore, none of the processes could be audited.

6.2.1 Location

6.2.1.1 Vessel Location

An SOP detailing the location of the vessel was not available for review. Method descriptions were available in the expedition reports. The JICA-MMAJ expedition reports the vessel location was initially recorded (in 1985 and 1986) by NNSS (Navy

Navigation Satellite System), assisted by GPS (assumed to be Navstar), but later cruises (2000) used GPS (Navstar) with backup from GLONASS (Global Navigation Satellite System; Table 5-2). Datum(s) used by the navigation systems are not specified and was assumed by SBMA based on the age of the survey. GPS is known to record positions in a standard format. The use of NNSS and GPS was best practice at the time the data were collected. Based on the method description, the Competent Person considers that there is some risk with respect to the DQOs and this has been taken into account when classifying the Mineral Resource.

6.2.1.2 Sampler Location

An SOP detailing the sample location was not available for review. Method descriptions were provided in the expedition reports. The JICA-MMAJ expedition reports indicate that there was no navigation equipment attached to the samplers; therefore, the vessel location at the time of deployment was used as a proxy for the sample location. This was standard practice at the time the sampling was conducted and is still working practice for FFG samplers. Based on the navigational equipment on board the vessel, RSC assumes the sample location accuracy is ~200–500 m for samples collected between 1985 and 1990, whereas samples collected in 2000 are assumed to have an accuracy of ~60 m. Based on the method descriptions and assumption of locational accuracy, the Competent Person considers that there is some moderate risk with respect to the DQOs and this has been taken into account when classifying the Mineral Resource.

6.2.1.3 Towed Camera Location

The JICA-MMAJ reports state that the position of towed cameras (CDC or FDC) was estimated using calculations of layback (Pythagoras theorem) from the vessel location at time of operation. There was no navigation equipment attached to the cameras. This system was best practice at the time the data were collected but is no longer considered best practice as modern USBL systems are more accurate. The reports do not include clear enough language and instructions regarding the DQOs and how the process should be quality controlled (for example by comparing bathymetric data). There is also no mention of the tow-line catenary by JICA-MMAJ even though its effect would have been significant. Maximum errors are expected to be 1–2 km and would not affect the geological interpretation that considered the results of the towed camera photographs.

6.2.2 Geological Logging

An SOP on the geological logging was not available for review. The JICA-MMAJ expedition reports include the methods and descriptions used to describe the samples. Much of the deposit geology discussed in Section 4 is derived from logging carried out by JICA-MMAJ.

A geological description of each sample was recorded at the time of collection, with the classification of the nodules based on size distribution, morphology (such as smooth vs botryoidal) and shape (such as aspect ratio). Classification of the polymetallic nodule morphology is shown in Table 5-4. A description of the geology at the site is also provided and includes sediment type, silica percentage, calcite percentage, transparent layer type and thickness. Much of the geological data associated with the samples were sourced from the logging, photographs and SBP. This was considered best practice at the time the data were collected and is still considered standard practice for polymetallic nodules and seabed samples.

Based on the data available, the Competent Person considers the geological logging procedures do not pose much risk with respect to the DQO.

6.2.3 Density and Moisture Content

An SOP regarding the collection of density data and moisture content was not available for review. Moisture content data and wet density of the nodules (often erroneously referred to as 'specific gravity') are reported in the MMAJ-JICA datasheets. Method descriptions were provided for the collection of dry density.

Based on the lack of operating procedures (and consequent lack of reasonable control processes) for the density and moisture data, the Competent Person considers the overall quality assurance of the density and moisture data to be lacking. This deficiency does not affect the estimation of nodule abundance itself; however, it does affect the accuracy of the calculation of contained metal. This has been accounted for in the overall Mineral Resource classification, and has been captured in the summary of project risks in Section 9.

6.2.4 Grade

6.2.4.1 Primary Sample

An SOP regarding the collection of the primary sample was not available for review. Method descriptions in the form of flowcharts, tables and charts detailing the handling of seabed samples were included in expedition reports and were available for review (Figure 6-1 and Figure 6-2). The flowcharts outline the onboard processing of the nodules; however, they do not outline the steps in place to deploy and recover sampling equipment.

The primary sample is the nodule (±sediment) collected from the seabed by FFG or SC. Several variables can affect the quality of the primary sample. Quality assurance of the primary sample (either FFG or BC) typically consists of selecting the right size sampling equipment, applying modification to ensure the sample is not lost during ascent, using appropriate winch speeds (for BC samples only), minimise the FFG recovery time to control sample washout, and have an understanding of the seedbed conditions (e.g. sampling polymetallic crust or high slope regions can cause the sampling mechanism to fail or trigger early). A good SOP assures the quality of the sample by making sure all these factors only have a minimal impact.

Samples were predominantly FFG with a sample area of 0.13 m^2. Freefall grabs are advantageous as multiple samplers can be deployed at one time; however, BC samplers are superior in terms of sample quality as they tether to the ship (associated with higher location accuracy) and are less prone to losing nodules during the ascent and recovery phase of the sampling. At the time of the historical expeditions, FFG sample supplemented with minor BC sampling was standard industry practice; however, it is no longer considered best practice (BC are the preferential sampling tool).

JCA-MMAJ collected triplicate samples at each site, in a triangular pattern, with each sample ~2.6 km apart. This is good practice to improve precision for each ~4.5-km^2 composite sample site, by invoking the principle of 'taking many increments'. These triplicate samples were collected for the majority (~80–100%) of samples in each expedition (Figure 6-3). In the 16-159 area, 41 clusters of samples were collected (Figure 6-6): in 36 cases, all three samples were collected and in five cases, two samples were collected. Of the 41 clusters, eight included a single BC sample and two FFG samples. It also provides a good benchmark for the γ_0 in the variograms, as a presentation of short-range abundance variability (see section 7.4.1)

Due to the historical nature of the samples, the Competent Person has not audited the process. Based on the method descriptions and sampling equipment used, the Competent Person considers that there is a moderate risk with respect to the objectives and this has been taken into account when classifying the Mineral Resource.

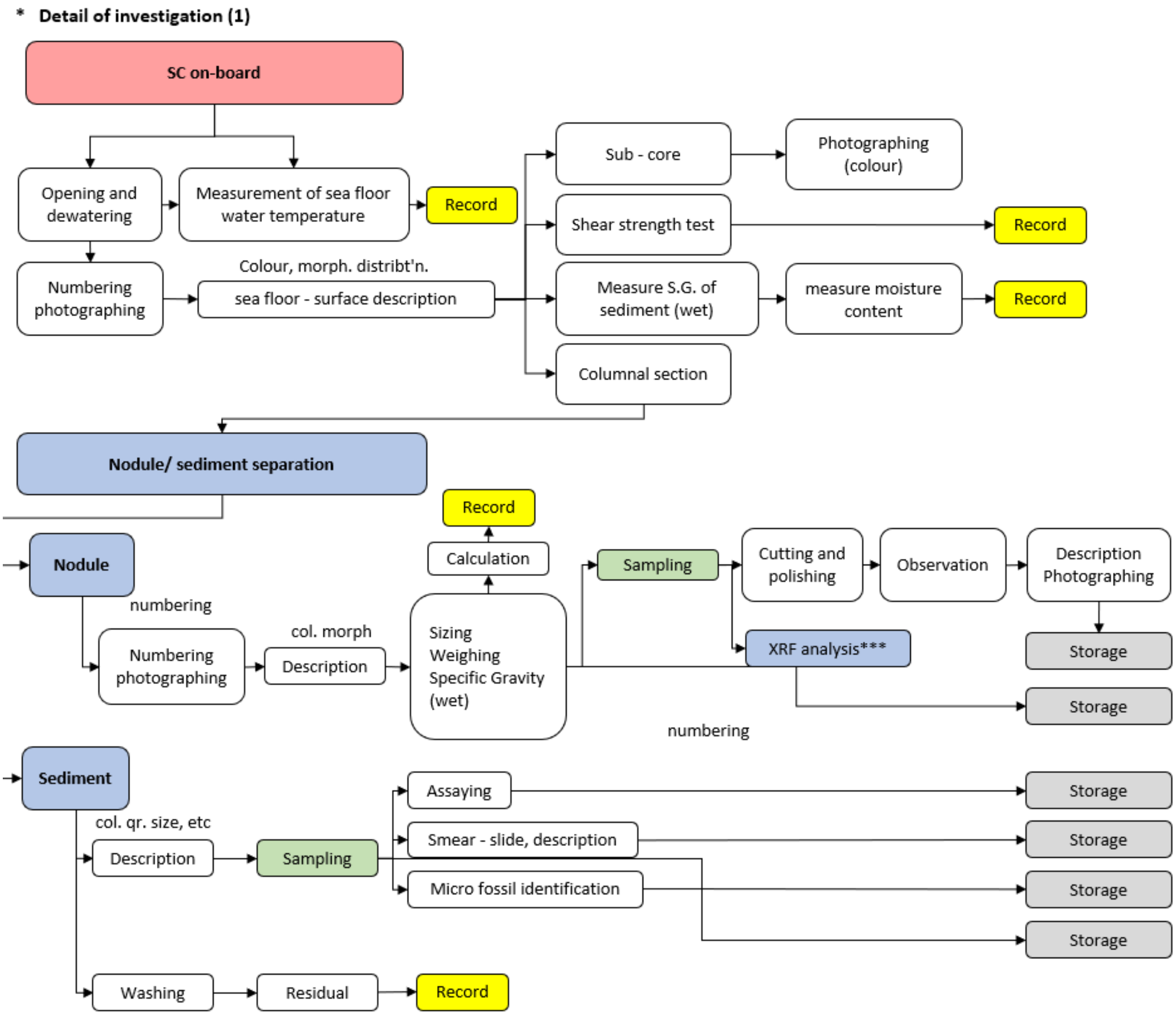


Figure 6-1: JICA-MMAJ spade (box) corer sample processes in place on all cruises. *** Detailed XRF analysis/sample preparation flowchart is given in Figure 6-4.

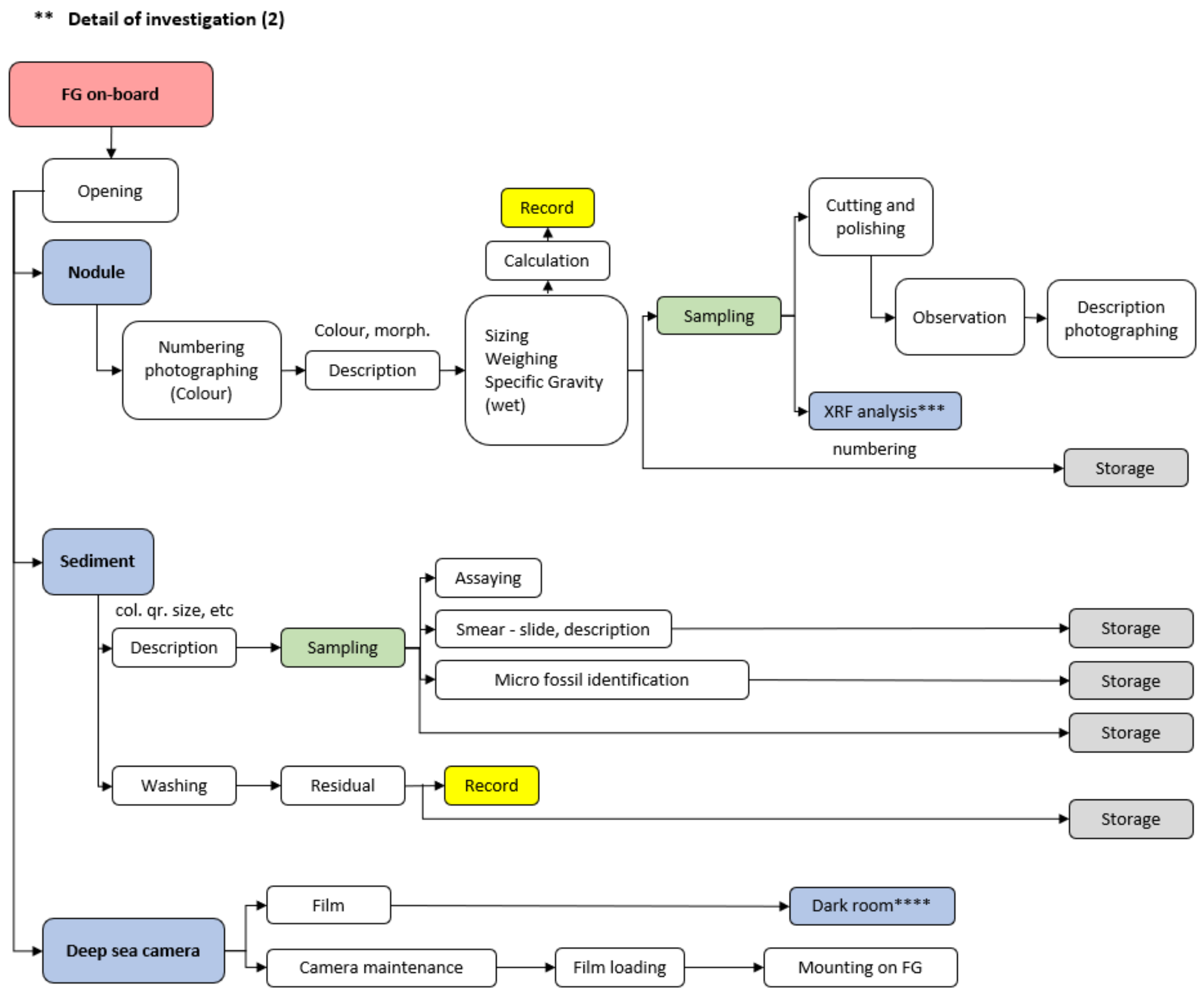


Figure 6-2: JICA-MMAJ free-fall grab sample processes in place on all cruises. Note *** Detailed XRF analysis/sample preparation flowchart is given in Figure 6-4 **** Detailed darkroom flowchart is given in Figure 5-19.

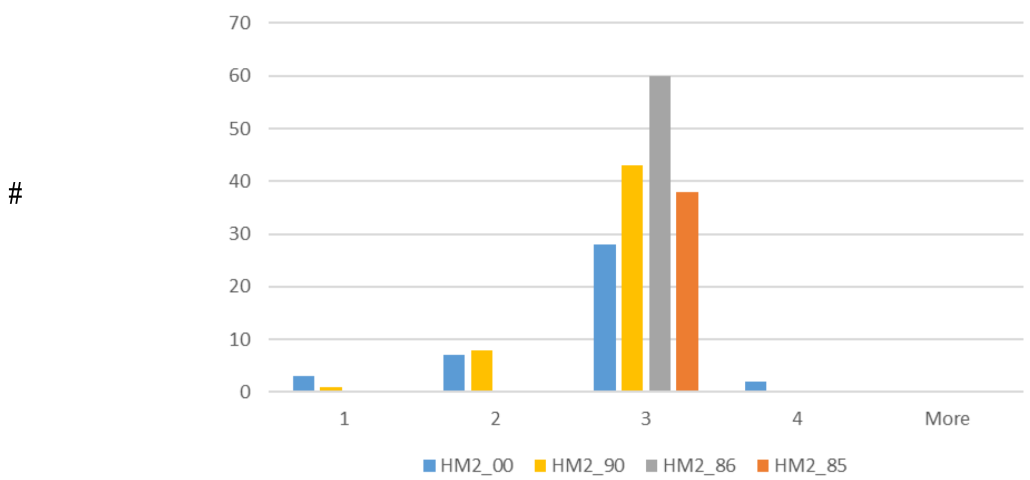


Figure 6-3: Numbers of samples per JICA-MMAJ cluster HM2 stands for Hakurei Maru No. 2 (expedition vessel) and the suffix digits are the year of the expedition.

6.2.4.2 Sample Split

An SOP regarding sample splitting was not available for review. No information on the number of splits or splitting methods has been recorded. Based on flowcharts provided for FFG and BC sampling, RSC assumes the primary sample was split a minimum of three times (XRF analysis, petrographic analysis, archive samples), and it was likely the XRF sample underwent additional splitting as it was crushed and ground into a briquette for analysis.

Due to the lack of information regarding the sample preparation and sample splitting procedures, the Competent Person considers there is a moderate risk with respect to the DQO and this has been taken into account when classifying the MRE.

6.2.4.3 Analytical

The chemical analysis of nodule and clay-ooze samples by JICA-MMAJ was conducted on board the ship and at independent laboratories on shore. An SOP outlining the analytical procedures was not available for review. However, the expedition reports outlined some of the procedures in place, including the process of inserting check analyses.

All JICA-MMAJ expeditions (1985, 1986, 1990, 2000) reference on-board analysis XRF for Ni, Cu, Co, Mn and Fe of nodules (see flowchart in Figure 6-4). In addition, a sub-sample of nodules and sediment was analysed at on-shore laboratories. The laboratory used for the 1985, 1986, and 1990 samples is unknown. The 2000 expedition samples were analysed at ALS Chemex, Canada.

Polymetallic nodules are hygroscopic and readily absorb moisture depending on the humidity and temperature, which can cause samples and standards to become compromised. It is, therefore, best practice to dry the samples immediately prior to any analysis. The flow chart outlining the sample preparation and analysis does not include an additional drying step (Figure 6-4). JICA-MMAJ do state that samples collected as part of the 2000 expedition were stored in a desiccator to minimise moisture. However, due to the highly hygroscopic nature of polymetallic nodules, the nodules can continue to draw moisture out from the desiccator. Wet samples can cause the analysis to under-report the metal grade, especially when using analytical methods that use mass balance e.g. XRF (Parianos, 2022).

In the Competent Person's opinion, JICA-MMAJ's documentation demonstrates some understanding regarding the hygroscopic nature of the samples, but better assurances are required for future work programmes (i.e. internationally accredited laboratories with SOPs supplied, including additional drying steps). The Competent Person considers the risk associated with the analytical process to be likely to be low to moderate.

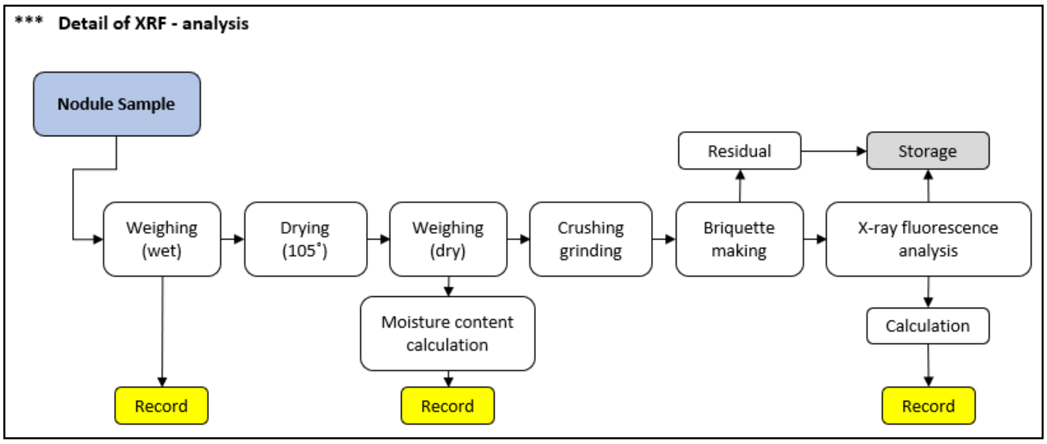


Figure 6-4: JICA-MMAJ on-board sampling preparation and XRF analysis***.

6.2.4.4 *Nodule Abundance from Samples*

An SOP for the calculation of nodule abundance was not available to review. Expeditions reports were reviewed, and these contained some detail on the calculation of nodule abundance. Nodule abundance is reported as the weight of recovered nodules over the area of the sampling tool. JICA-MMAJ measured the wet weight of recovered nodules per sample on the vessel (JICA-MMAJ, 1987). There are no details stating exactly how the nodules were weighed, including consideration of vessel heave (using continuous reading scales and averaging multiple measurements is standard practice).

Due to the lack of information regarding the sample preparation and sample splitting procedures, the Competent Person considers there is some minor risk with respect to the accurate calculation of abundances and this has been taken into account when classifying the MRE.

6.2.5 Acoustic Survey

An SOP regarding the acoustic survey was not available for review. However, the expedition report did include a flowsheet outlining the collection and integration of acoustic survey results and navigation data (Figure 6-5). The flowsheet is presented at a very high level but describes industry best practice at the time the data were collected. The data collected are historical in natures, hence the collection process was not audited by the Competent Person. The Competent Person considers that there is a moderate risk with respect to the DQOs and this has been considered when classifying the Mineral Resource.

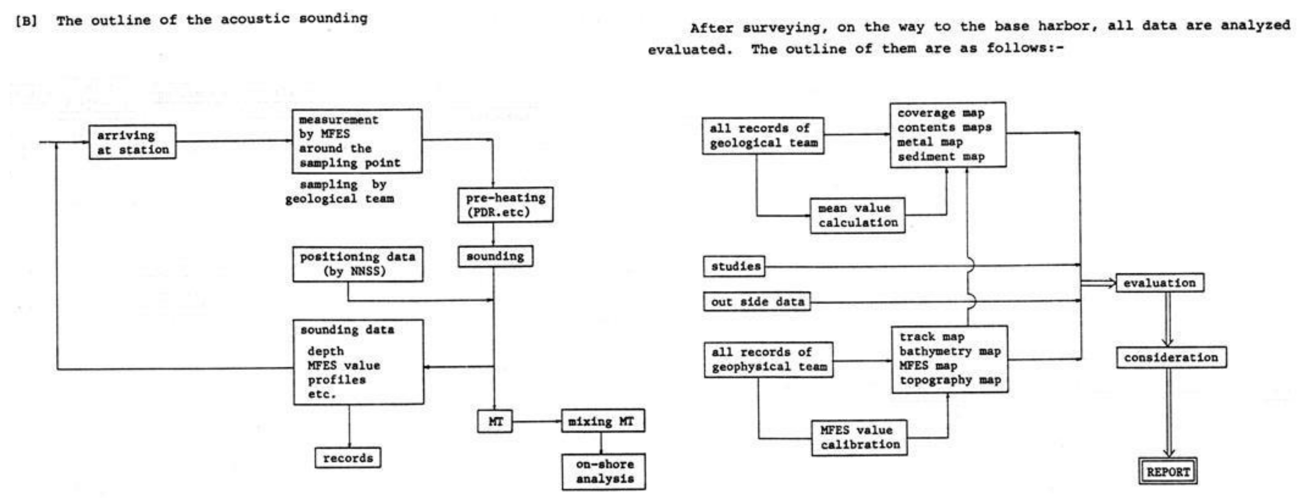


Figure 6-5: Acoustic sounding and processing flowsheet Source: JICA-MMAJ (1987).

Note that the above flowsheet incorporates several acoustic measurements:

- single-beam measurements using a 30 kHz NBS;
- a 3.5 kHz SBP to measure the acoustic stratigraphy and interpret different units per a standard schema presented in detail in Figure 4-7 and Figure 4-9 (Section 4.2.2.3);
- an MFES to predict nodule abundances – this process is summarised in section 5.1.2.4, and discussed in some detail in JICA-MMAJ (1986 and 1987) but was not used in the MRE; the MFES survey in Area 16-159 correlated adequately with nodule abundances from samples (Figure 5-5); and
- a 15 kHz MBES in 2000 to map the seafloor (Figure 4-9); this was principal in the mapping and domaining for the 16-159 (Central) area (Figure 4-10). Very little is known about the MBES system and nothing about any QA applied.

6.3 Quality Control

The purpose of quality control (QC) is to detect and correct errors while a measuring or sample collection system is in operation. The outcome of a good QC programme is that it can be demonstrated that errors were fixed during operation and that the system delivering the data was always in control.

Good QC is achieved by inserting and constantly evaluating checks and balances. These checks and balances can be incorporated at every stage of the sample process (location, primary sample collection, preparation, and analytical phases) and, if in place, should be monitored during data collection, allowing the operator to identify and fix errors as they occur. Table 6-10 lists each activity, whether QC was known to be in place and an assessment of the control risk of that activity. Only activities critical to the MRE are discussed in this section.

6.3.1 Location

It is not known whether JICA-MMAJ had any QC checks in place such as duplicate-triplicate location recording when collecting surface location data. There is likely significant precision error associated with FFG location data, as the location of the sample is recorded from the vessel's deployment location, not the point the FFG sampler collects the sample on the seafloor. This is still current practice for FFG sampling (e.g. by CIICSR). Due to the nature of the sampling method, RSC assumes BC samples have a higher degree of location accuracy compared to FFG samples.

No quantitative QC data were collected, and it cannot be conclusively established that the sample location data collection process was always in control. The location error may therefore be substantial; however, given the very low spatial variability, the risk associated with the location of the sample can be considered low.

6.3.2 Density

It is not known whether JICA-MMAJ had any QC checks in place such as weighing a 2 kg reference weight. Due to the lack of QC data, the Competent Person cannot conclusively establish that the collection of density data were always in control.

6.3.3 Primary Sample

The quality of the primary sample can be monitored by comparing with seafloor photographs. The nature of seabed surface sampling allows for the sample footprint to be reviewed in photographs. The bulk of the samples used in the MRE are FFG samples taken by JICA-MMAJ. Cameras were attached to the frame of the FFG and collected a still photograph before the sample was collected. Although not documented in an SOP, and although no results of this control mechanism are recorded anywhere, it is reasonable to assume that JICA-MMAJ would have used the photos to broadly validate the effectiveness of the FFG to recover material at each sample site. The process was not observed nor audited by the Competent Person and only some selected examples of this process are available for the Competent Person to validate (e.g. Figure 5-18).

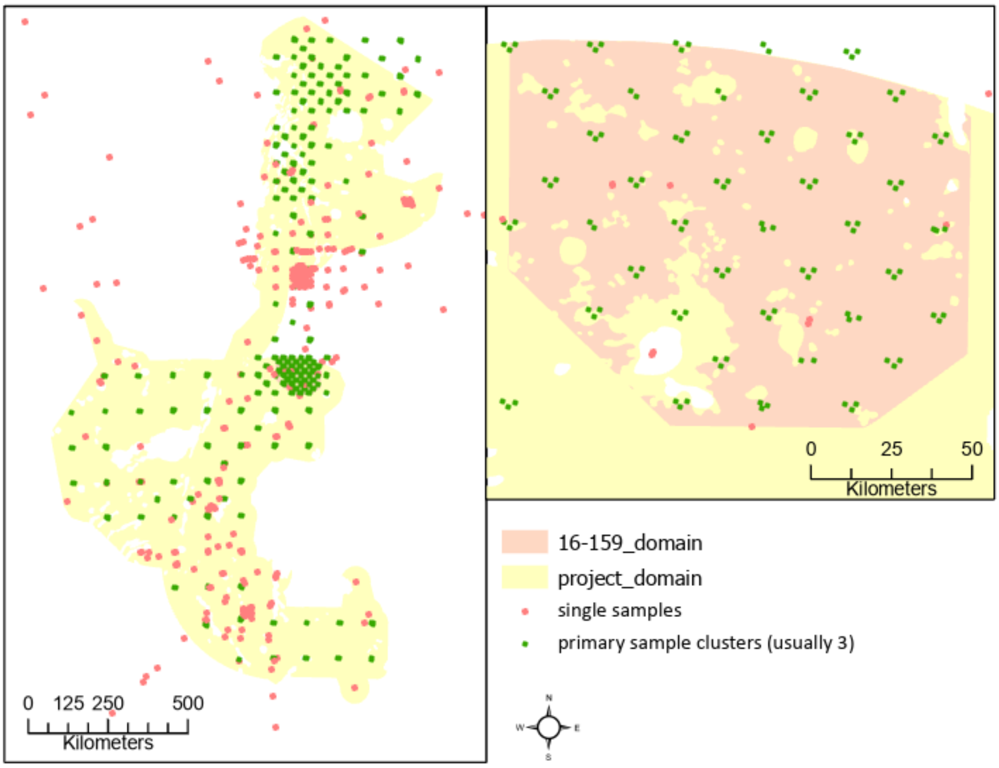


Figure 6-6: JICA-MMAJ sample clusters and other sample data.

JICA-MMAJ also collected repeat samples (Figure 5-12, Figure 6-6), which can be used to monitor repeatability as a rough measure of primary sample quality. No record was kept of any failed samples; however, there are sample stations that only show one or two samples instead of three (Figure 6-3). RSC assumes the missing sample(s) is due to sample failure, which would suggest some measure of quality control on the primary sample.

Although there are no records of QC data, there is some evidence of quality control on the primary sample, and the risk to the expected resource outcomes is likely to be low to moderate.

6.3.4 First-, Second-, Third-Split

The sample splitting processes (coning-and-quartering, splitting after coarse-crushing, splitting after pulverising) can be monitored by the collection of a duplicate sample. The consistency of the splitting process can be broadly assessed by tracking the relative difference of the duplicate pairs over time, with excessive variance between the pairs indicating a potential issue.

Datasheets published in expedition reports indicate eight duplicate analyses (out of 106 data entries; Table 5-1) and five duplicate analyses (out of 89 data entries) were collected during the 1990 and 2000 expedition, respectively. There is no record of what splitting stage these data represent. Sample weight for each split is also not recorded.

Due to the lack of informing data, the Competent Person cannot comment on whether the sample preparation processes were in control, and this carries some risk forward into the resource estimate.

6.3.5 Analytical

The procedure for controlling the quality of the analytical process involves the repeated and continuous evaluation of certified reference material (CRM) samples. Laboratories generally insert such reference material samples into the sample stream, evaluate these, and make corrections to the system when errors occur.

The samples were predominantly analysed on the vessel during the expeditions; however, no records of any CRM analysis exist and it is difficult to confirm whether these on-board analytical analysis were always in control. This poses some risk to the accuracy and precision of metal grade data, and hence the accuracy and precision of the estimate, and this has been taken into account in the classification of the resource.

6.4 Quality Acceptance Testing

Quality acceptance testing (QAT) is where a final judgement of the data is made by assessing the accuracy and precision of the data for those periods where the process was demonstrated to be in control, and separately for those periods where the process was demonstrated to be not in control. Accuracy and precision are evaluated, and a final pass or fail assessment is made based on the DQOs.

6.4.1 Location

There are no quantitative QC data on the location recording process and quantifying the quality of the data based on statistically defined thresholds is therefore not possible. Based on the review of the processes (Section 6.2.1), and the relatively minor impact of location error on the global mineral resource considering the very long variogram ranges and low short-range variability, the location data are considered to be fit for the purpose of estimation and classification in the Inferred and Indicated Mineral Resource category.

6.4.2 Density

There are no quantitative quality control data on the density determination process (section 6.3.2). It is therefore not possible to accept the quality of the data based on statistically defined thresholds. Given that there are also no documented procedures for the density determination that demonstrate some measure of quality assurance, it is not possible to comment on the quality of these data. This does not affect the accuracy and precision of abundance estimates; however, it does affect the quality of the estimation of contained metal, which will carry forward in any down-stream financial analysis or scoping studies. This has been taken into account in the classification of the resource.

6.4.3 Primary Sample

The representativity of a primary sample can be assessed by 'twin samples' using a method that provides a superior (i.e. more representative) sample quality. In polymetallic nodule deposits, twin sampling using a superior sampling technique is difficult to execute as it is hard to control the exact placement of the sampling equipment (with sample location selection being difficult to control at ~5,000 m below the sea surface).

JICA-MMAJ collected triplicate samples, which can be used as a proxy for quality control. In a classic exploration data analytical sense, these are triplicates, and any consistent bias of each of the increments with respect to the others within the cluster could be an indication of sampling quality issues[1]. Triplicate samples were collected in a triangular formation, and sample pairs (samples A and B, B and C and A and C) from Area 16-159 were compared to assess the quality of the primary sample.

RSC reviewed quantile-quantile plots comparing samples A and B, B and C and A and C, which indicate a good correlation for abundance and all metal grades. Wilcoxon signed-ranked tests indicate there is no statistically significant bias between any of the sample pairs with the exception of Co grade between sample B and C.

The variance between all three sample pairs for each sample location can also be used as a proxy for sample quality, with the *assumption* that any observed 'large' variance would be due to sampling errors and not due to natural inherent variability. This analysis is a loose 'back-door' validation on the interpretation of γ_0 in the variograms as well, and can be used during exploration programmes as a proxy for quality control as it may indicate failed sampling (section 6.3.3).

The average CV from the sample pairs was calculated across the different analytes (Co, Cu, Fe, Mn, and Ni) and nodule abundance within Area 16-159 (Table 6-1) based on Abzalov (2008). There are not many comparable exploration datasets

[1] Due to failed samples at some of the sample sites, RSC only reviewed two samples from each of those sites.

available to compare against, but in the Competent Person's opinion, the average CV is appropriate with respect to the DQO.

In the Competent Person's opinion, there is good grade continuity between the sample triplicates and this has been taken into account in the classification of the resource.

Table 6-1: Summary of average CV for triplicate sample pairs.

Sample Pair	A-B	B-C	A-C	Average
Abundance	60.3%	63.%1	53.7%	59.3%
Co	11.9%	8.0%	9.9%	9.9%
Cu	21.3%	17.4%	17.5%	18.7%
Fe	5.3%	6.2%	7.9%	6.4%
Mn	4.8%	4.6%	4.6%	4.7%
Ni	16.7%	13.3%	14.5%	14.8%

Sample site photographs also provide a good, yet semi-quantitative, proxy to this twin sampling process, e.g. collected by FDC, CDC or camera fixed to the FFG sampler. JICA-MMAJ (JICA-MMAJ, 1987) carried out a comparison of abundance estimates between FFG samplers and towed camera (FDC) photographs for the Hakurei Maru 1986 expedition as recreated in Table 6-2. The relative difference between abundance grade at each FFG station ranges and corresponding estimated nodule abundance from FDC images ranges from -166% to +195%. The variability between abundance grades reduces significantly when averaging the triplicate samples (-0.09% to +0.23%). However, due to the small sample population, it is not possible to draw statistically meaningful conclusions regarding the accuracy and precision of the primary sample. The FDC photographs were not available for review.

Table 6-2: HM2_86 Comparison of abundance obtained by FFG sampling and FDC survey.

FFG Sampling			FDC Survey		
Station	Value of sampling point	*Average*	*Average*	Value of sampling point	**Station**
86410	43.88	*33.09*	*28.15*	37.8	**01-01**
	16.62			18.5	**02-02**
	28.78				
86436	22.07	*26.09*	*31.67*	38.9	**01-15**
	33.81			17.9	**02-01**
	22.38			38.2	**02-02**
86448	46.68	*23.96*	*19.05*	0.5	**03-08**
	3.35			36.6	**04-01**
	21.85			20.1	**04-02**
86417	34.58	*34.11*	*37.30*	29.3	**04-15**
	35.62			40.5	**04-06**
	32.12			42.1	**04-17**

The FFG, LC and BC samplers were often equipped with a still camera which collected a photograph before the sample was collected. Images from only six sample pairs (four FFG, one BC and one LC) from the JICA-MMAJ 2000 expedition were available to review, and therefore, due to the small sample population, it is not possible to draw statistically meaningful conclusions regarding the accuracy and precision of the primary sample. Comparison between the seabed photograph and deck sample photograph is presented in Figure 6-7, and the nodule coverage percentage for each photograph is reported in Table 6-3.

The available data demonstrate that the accuracy and precision of nodule abundances were fit for purpose for estimation and classification in Indicated category for those areas with enough sample density.

Table 6-3: Comparison of nodule coverage calculated from the primary sample and seabed photograph. Photographs for each comparison is presented in Figure 6-7.

Sample ID	Sampling Equipment	Nodule Coverage Photograph	Nodule Coverage Primary Sample	Comment
00S2033FG05	FFG	0%	0%	Seabed photograph indicates ferromanganese crust present, no nodules.
00S1736LC25	LC	74.2%	44.2%	LC are typically used to collect sediment samples and are not a suitable sampling method to collect polymetallic nodules for the purpose of measuring nodule abundance due to their relatively small core size.
00S1736SC31	BC	78.2%	70.0%	
00S1736FG27	FFG	84.4%	81.1%	
00S1636FG30	FFG	74.2%	64.9%	
00S1037FG07	FFG	23.0%	40.54%	Higher percentage of recovered nodules than observed in seabed photograph suggests there are a number of buried nodules (<5 cm depth).

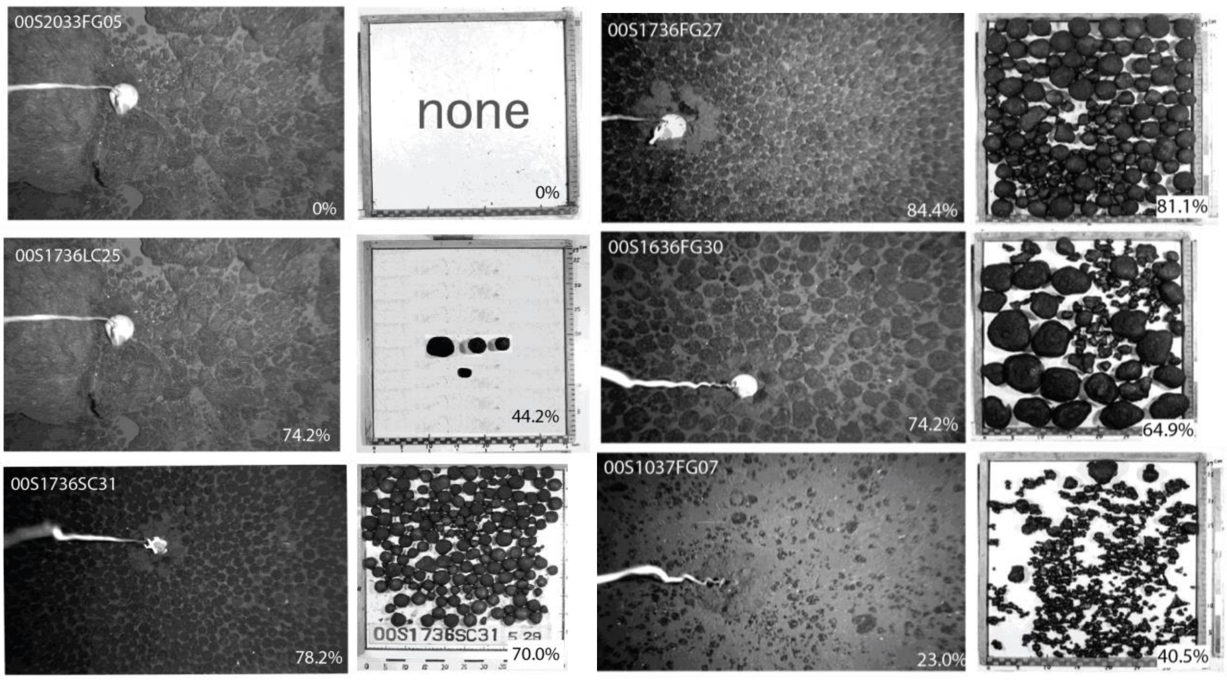


Figure 6-7: Comparison between seabed image and deck image. Nodule coverage is reported for each photograph.

6.4.3.1 *Comparison with Recent Sampling*

The JICA-MMAJ samples were compared with recent FFG samples (2019) collected by CIICSR and OML to assess the quality of the historical samples within Area 16-159 (Central). A pseudo-nearest-neighbour analysis was conducted using sample pairs within a 10 km radius, resulting in a total of 10 sample pairs for abundance and 12 sample pairs for metal grades. No samples collected by OML were included as they were greater than 10 km away from the historical sampling. A Wilcoxon signed-rank test was conducted to compare the sample means and assess if there is any bias between the sample pairs. No statistically significant bias at 95% confidence is reported in the abundance, Co, Cu, Fe and Ni sample pairs; however, a bias towards the JICA-MMAJ samples for Mn is reported and is clearly visible in the box and whisker plot (Figure 6-12).

Despite the small sample size, in the Competent Person's opinion, the comparison between the JICA-MMAJ and CIICSR sample pairs indicates a good agreement except for Mn and the comparison provides additional confidence to support the use of the JICA-MMAJ data in the MRE.

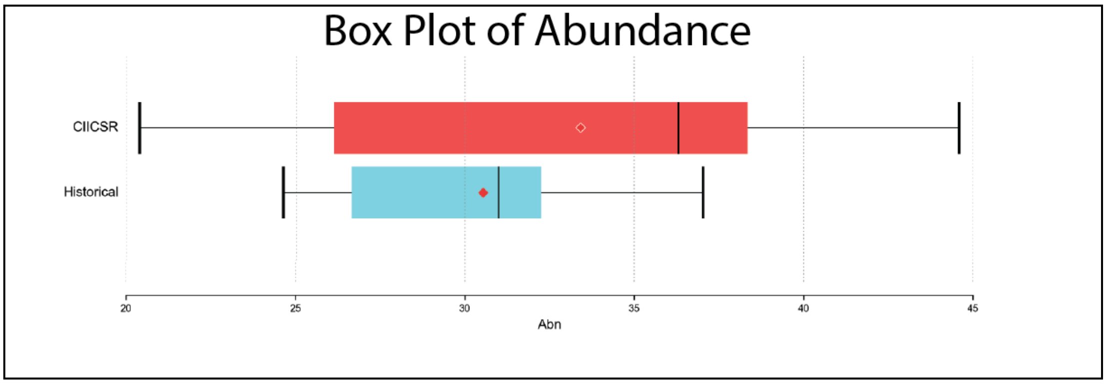


Figure 6-8: Comparison of abundance sample pairs.

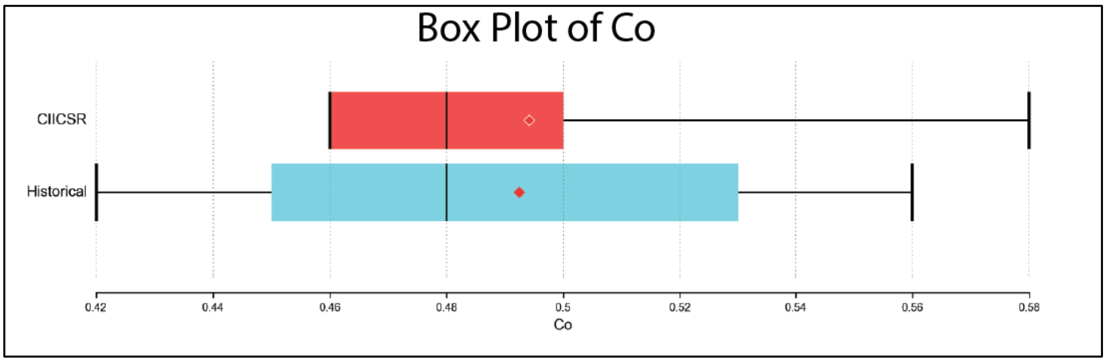


Figure 6-9: Comparison of Co sample pairs.

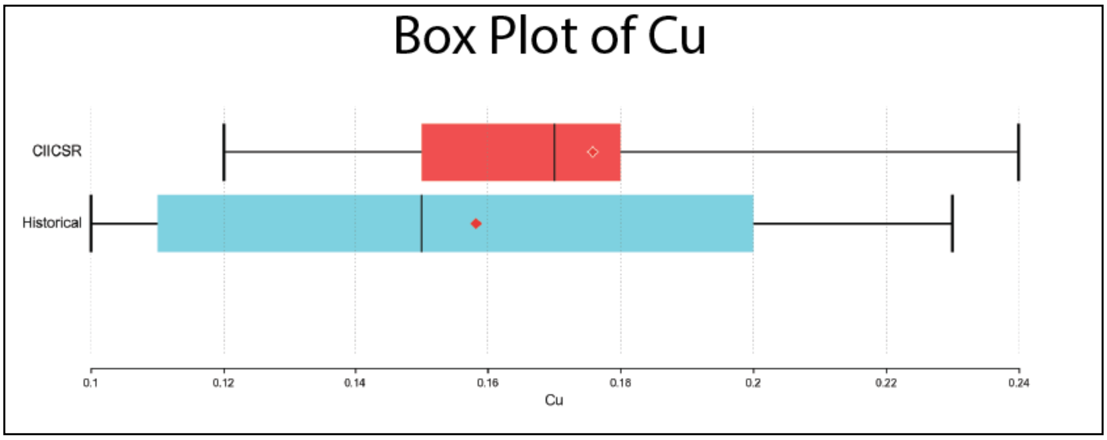


Figure 6-10: Comparison of Cu sample pairs.

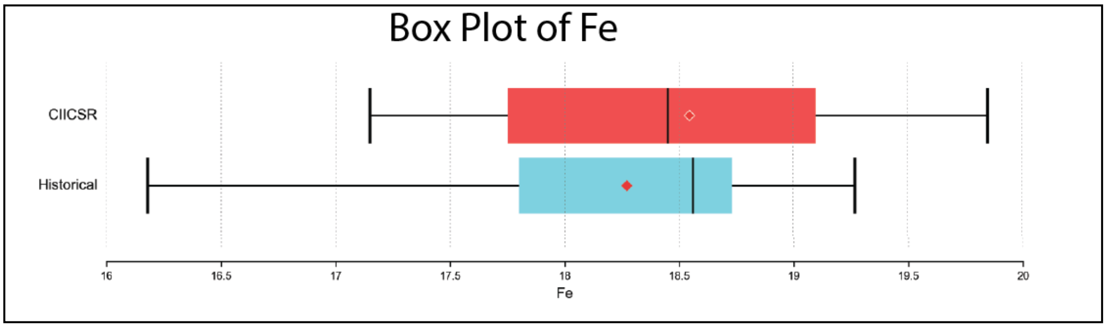


Figure 6-11: Comparison of Fe sample pairs.

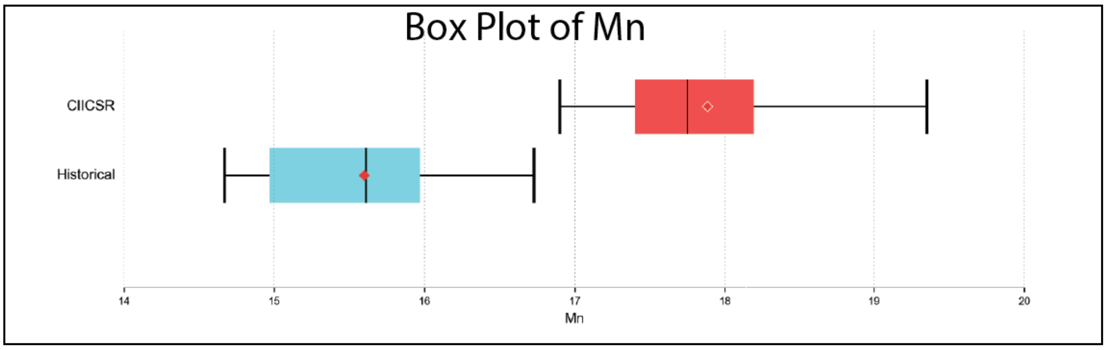


Figure 6-12: Comparison of Mn sample pairs.

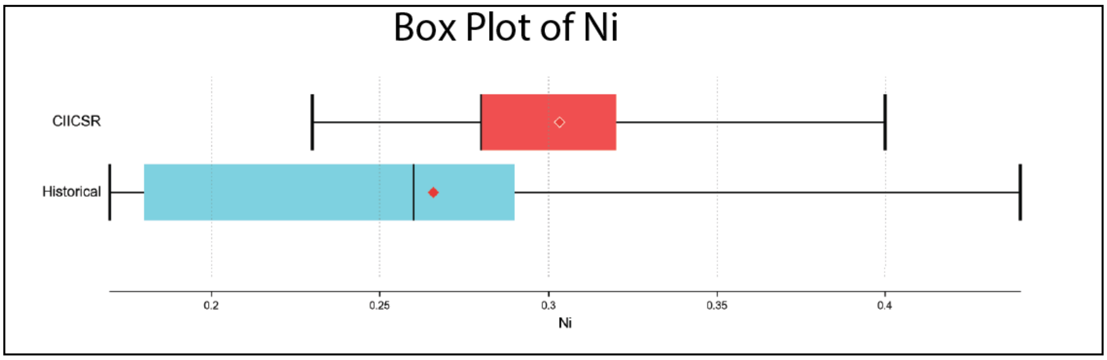


Figure 6-13: Comparison of Ni sample pairs.

6.4.3.2 Comparison with Acoustic Data

A qualitative comparison between the nodule abundance data and MBES interpretation was conducted. Nodule abundances are expected to be lower in the location of knolls and seamounts and higher in some areas of clay-ooze covered abyssal plains. This is seen to be the case in Area 16-159 (Figure 6-14).

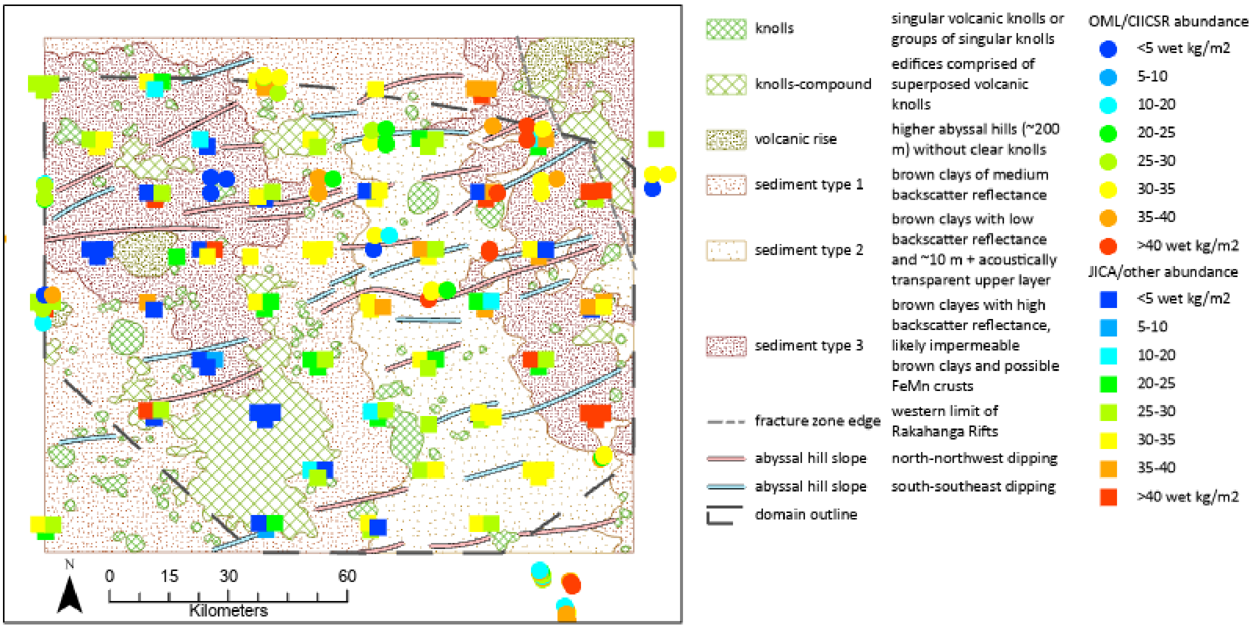


Figure 6-14: Comparison of abundances in FFG samples and interpreted surface geology – Area 16-159.

6.4.4 First-, Second-, Third-Split

A total of 13 duplicate samples were collected from unknown splitting stages across two expeditions. The correlations between the pairs are generally fair to good (Figure 6-15); however, some samples show consistent bias that may be due to clay-ooze inclusion in some samples if the samples were split before the crushing/grinding step in the processing flowsheet (Figure 6-4). Due to the small duplicate sample population, which is also spread across different expeditions, it is not possible to draw statistically meaningful conclusions regarding the accuracy and precision of the splitting process. It is therefore not possible to determine the quality of the data based on statistically defined thresholds.

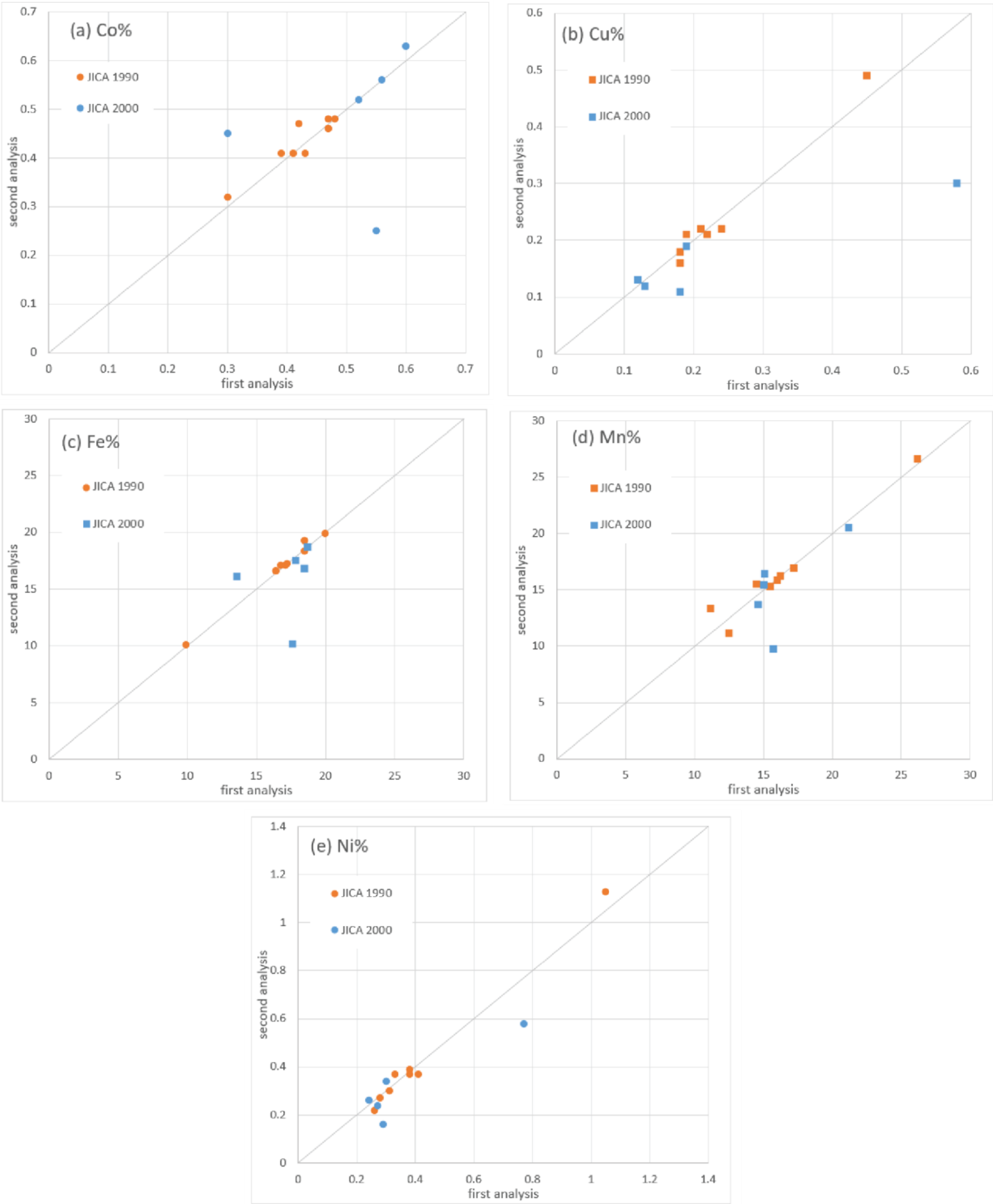


Figure 6-15: Duplicate pair scatter plots. (a) Co; (b) Cu; (c) Fe; (d) Mn; and (e) Ni.

6.4.5 Analytical

Umpire analysis was completed on a selection of sub-samples at onshore laboratories. Available test results are presented by expedition.

The Hakurei Maru 1985 and 1986 expeditions (JICA-MMAJ, 1986, 1987) compared 50 samples between the on-board XRF and on-shore wet chemical analysis. JICA-MMAJ examined the accuracy and precision of the analytical results by means of regression analysis and used t-tests to compare the difference of means. The results of the analysis conducted by JICA-MMAJ are summarised in Table 6-4 to Table 6-9. The raw data or plots of the data for these analyses were not available to RSC for review. This means that standard-practice accuracy and bias testing cannot be applied and the findings of JICA-MMAJ cannot be verified. The below therefore summarises the analysis and conclusions as reported by JICA-MMAJ.

For the 1985 expedition, JICA-MMAJ reported that there is a very good correlation between the on-board XRF and on-shore wet chemical analysis with regression (correlation) coefficients >0.97 (Table 6-4). Relative bias for the different elemental analyses for both methods ranges from -15% to +25% (Table 6-5, Table 6-6), with the bias reported for Co significantly larger than the other elements.

For the 1986 expedition, JICA-MMAJ reported that there is an excellent correlation between the on-board XRF and on-shore wet chemical analysis with regression (correlation) coefficients >0.98 (Table 6-7). Relative bias for the different elemental analyses for both methods ranges from -20% to +5% (Table 6-8, Table 6-9), with the bias reported for low-grade Ni and Cu larger than the other elements.

Check analysis was not conducted for the 1990 and 2000 JICA-MMAJ expeditions. Therefore, it is not possible to assess the accuracy and precision of the analytical process for these expeditions.

Based on the regression analysis and t-tests as reported by JICA-MMAJ, in the opinion of the Competent Person, the accuracy of the analysis process as determined by check analysis is acceptable with respect to the DQO. Larger biases are reported for some elemental analyses, and the Competent Person recommends additional sampling and analysis using internationally accredited laboratories to confirm the elemental grade of the polymetallic nodules within the Project Area. The Competent Person considers the availability of umpire check analyses to be a key support for the classification of Indicated resources classification in areas of high sample density (Area 16-159).

Table 6-4: HM2_85 On-board to on-shore linear correlation coefficients.

Element	a	b	Correlation Coefficient
Ni	1.09	-0.023	0.97
Cu	0.96	0.046	0.97
Co	1.07	0.037	0.96
Mn	1.06	-1.48	0.99
Fe	1.05	-0.007	0.99

Y = aX + b;
a = regression coefficient
b = constant term

Table 6-5: HM2_85 On-board to on-shore regression analysis for low-grade and high-grade populations.

Element	Population	Average Grade Assayed On Board	Bias[1]	Accidental Error Estimated	Relative Bias[1]
Ni	Low-grade	0.30%	0.004%	± 0.044%	1%
	High-grade	1.10%	0.076%	± 0.058%	7%
Cu	Low-grade	0.20%	0.038%	± 0.030%	19%
	High-grade	0.80%	0.013%	±0.043%	2%
Co	Low-grade	0.20%	0.050%	± 0.013%	25%
	High-grade	0.40%	0.064%	± 0.024%	16%
Mn	Low-grade	7.0%	-1.03%	± 0.466%	-15%
	High-grade	24.0%	0.045%	± 0.396%	0.2%
Fe	Low-grade	7.0%	0.311%	± 0.286%	4%
	High-grade	16.0%	0.720%	± 0.374%	5%

[1] Calculation for bias and relative bias are unknown. Bias and relative bias were calculated by JICA-MMAJ

Table 6-6: HM2_85 On-board to on-shore T-test results and estimated biases.

Element	Average Grade Assayed On Board	Bias	Accidental Error Estimated	Relative Bias	T Calculated	t
Ni	0.65%	0.032%	± 0.032%	5%	2.70	2.69
Cu	0.44%	0.029%	± 0.023%	7%	3.39	"
Co	0.28%	0.052%	± 0.013%	18%	10.9	"
Mn	16.1%	-0.427%	± 0.290%	3%	3.9	"
Fe	11.0%	0.472%	± 0.207%	4%	6.1	"

t degree of freedom: 4 and 5, significant level ±1%; accidental error of the data assayed on board means provability 95%

Table 6-7: HM2_86 On-board to on-shore linear correlation coefficients.

Element	a	b	Correlation Coefficient
Ni	1.09	-0.0904	0.99
Cu	1.00	-0.0341	0.99
Co	0.92	0.0287	0.99
Mn	0.98	-0.9457	0.98
Fe	0.92	1.2253	0.99

Y = aX + b;
a = regression coefficient
b = constant term

Table 6-8: HM2_86 On-board to on-shore regression analysis for low-grade and high-grade populations.

Element	Population	Average Grade Assayed On Board	Bias[1]	Accidental Error Estimated	Relative Bias[1]
Ni	Low-grade	0.30%	-0.062%	± 0.020%	-20%
	High-grade	0.80%	-0.016%	± 0.036%	-2%
Cu	Low-grade	0.30%	-0.035%	± 0.011%	-12%
	High-grade	0.80%	-0.037%	± 0.030%	-5%
Co	Low-grade	0.30%	0.005%	± 0.013%	0.2%
	High-grade	0.60%	-0.019%	± 0.015%	-3%
Mn	Low-grade	13.0%	-1.168%	± 0.521%	-9%
	High-grade	20.0%	-1.288%	± 0.298%	-6%
Fe	Low-grade	10.0%	0.467%	± 0.276%	5%
	High-grade	20.0%	-0.291%	± 0.226%	-1%

[1] Calculation for bias and relative bias are unknown. Bias and relative bias were calculated by JICA-MMAJ

Table 6-9: HM2_86 On-board to on-shore T-test results and estimated biases.

Element	Average Grade Assayed On Board	Bias	Accidental Error Estimated	Relative Bias	t Calculated	t
Ni	0.36%	-0.052%	± 0.020%	-14%	7.14	2.70
Cu	0.23%	-0.035%	± 0.011%	-15%	8.81	"
Co	0.42%	-0.005%	± 0.011%	-1%	1.28	"
Mn	16.9%	-1.26%	± 0.249%	-7%	13.6	"
Fe	15.8%	0.026%	± 0.200%	0.2%	0.349	"

t degree of freedom: 4 and 5, significant level ±1%; accidental error of the data assayed on board means provability 95%

6.5 Data Verification

Data verification is the process of checking and verifying hard-copy logs and digital records for accuracy, ensuring the data on which Mineral Resource estimates are based can be linked from digital databases or records to log sheets and drilling or sampling intervals. It is an additional verification process to determine that QA and QC processes have been effectively applied, and that these were working to assure and control the quality of the data. Data verification is carried out after samples have been collected, assays have been returned, and data have been stored in the database. Where relevant, data verification may also include check sampling carried out by the Competent Person, especially if SOPs are not available or difficult to audit, and QC data are limited to demonstrate processes were in control.

Data verification was conducted by SBMA under the guidance of the Competent Person. A Microsoft Access database was compiled from data submitted to the Cook Islands Government. The data underwent data verification checks against sample sheets published in the appendix of the expedition reports (Figure 6-16). Duplicate entries were removed from the database. Minor inconsistencies were found and corrected, and the Competent Person confirms that the data on which the MRE is based are verified.

No check sampling has been conducted by the Competent Person due to the historical nature of the samples, and it is unknown if the samples have been retained.

Data file around the Cook Islands(North Area) (No.1)

Sample No (Station)	Location				Manganese Nodules															Geology					Remarks
					Size distribution (%)						Abun-dance (Kg/m^2)	Shape	S.G. Wet	H_2O (%)	XRF Analyses (%)						Sediment		*T.P.L		
	Latitude	Longitude	Depth (m)	Topography	0-2 cm	2-4 cm	4-6 cm	6-8 cm	8-16 cm	16- cm					Ni	Cu	Co	Mn	Fe		* Sil%	* Cal%	type	thick (m)	
86S1037FG01	09°00.02'S	159°00.06'W	5,532	(Hilly) Flat	89	11					0.43	Sp. P	2.00	32.5	0.78	0.52	0.21	17.46	9.66	IBC	4	0	c	0	
86S1037FG02	08°59.09'S	159°01.01'W	5,534	(Hilly) Flat	87	13					0.41	Sp. P	2.00	26.5	0.79	0.53	0.22	18.09	9.93	IBC	5	0	c	0	
86S1037FG03	08°59.01'S	158°58.99'W	5,536	(Hilly) Flat	100						0.43	Sp. P	2.00	23.4	0.79	0.53	0.21	17.23	9.47	IBC	5	0	c	0	
(85518)																									
Average			5,534		92	8					0.42	Sp. P	2.00	27.5	0.79	0.53	0.21	17.58	9.68						
86S1037FG04	09°30.03'S	159°00.03'W	5,397	(Hilly) Flat	13	67	20				8.43	P. E	2.01	25.7	0.38	0.21	0.36	15.66	13.36	BC	5	0	ds	0	
86S1037FG05	09°28.89'S	159°01.03'W	5,309	(Hilly) Flat	1	47	39	13			30.09	M. Sp	2.02	31.0	0.38	0.21	0.41	18.49	14.80	BC	3	0	ds	0	
86S1037FG06	09°28.69'S	158°59.10'W	5,439	(Hilly) Flat	24	60	16				5.22	P. Oth	1.99	31.1	0.45	0.24	0.30	14.32	12.81	BC	1	0	ds	0	
(86460)																									
Average			5,382		7	53	32	9			14.58	M. P	2.01	29.9	0.39	0.22	0.39	17.33	14.23						
00S1338SC01	12°30.00'S	157°29.99'W	5,199	(Hilly) Flat	25	34		41			1.84	Sp. Ec	1.92	24.01	0.77	0.58	0.30	21.17	13.59	B C			d2	0	
00S1338FG02	12°29.01'S	157°31.00'W	5,203	(Hilly) Flat	100						1.00	P	2.00	30.07	0.97	0.58	0.28	20.69	11.30	B C			d2	0	
00S1338FG03	12°29.00'S	157°28.99'W	5,205	(Hilly) Flat	100						1.58	P	1.98	28.19	1.03	0.57	0.31	21.63	11.90	B C			d2	0	
(00239)																									
Average			5,202								1.47	P.Sp	1.94	25.69	0.84	0.58	0.29	21.13	12.94						
00S1238FG01	11°30.00'S	157°30.00'W	5,257	(Hilly) Flat	16	11	29	44			16.53	Sp. Ec	1.86	27.04	0.39	0.20	0.46	17.01	16.02	B C			bc	0	
00S1238FG02	11°29.00'S	157°30.98'W	5,297	(Hilly) Flat	21	24	33	22			18.04	Sp. P	1.88	28.94	0.45	0.24	0.48	17.71	16.27	B C			ds	0	
00S1238FG03	11°29.00'S	157°29.00'W	5,299	(Hilly) Flat	5	43	52				26.72	Sp. Oth	1.91	20.71	0.37	0.22	0.47	17.40	17.18	B C			d2	0	
(00240)																									
Average			5,284		12	29	41	18			20.43	Sp.P	1.89	24.45	0.39	0.22	0.47	17.35	16.63						
00S1138LC01	10°30.00'S	158°00.00'W	5,478	(Hilly) Flat							0.00									B C			d2	0	
00S1138FG02	10°29.00'S	158°01.00'W	5,497	(Hilly) Flat	8	30	20	42			7.41	Oth. P	1.93	25.63	0.63	0.40	0.36	19.11	14.39	I B C			ds	0	
00S1138FG03	10°29.00'S	157°59.01'W	5,349	(Hilly) Flat							0.00									—			d1	0	
(00241)																									
Average			5,441		8	30	20	42			2.47	Oth. P	1.93	25.63	0.63	0.40	0.36	19.11	14.39						
00S103 7 FG01	09°30.01'S	158°30.01'W	5,495	(Hilly) Flat	45	46	9				7.10	P. E	1.95	29.91	0.522	0.3179	0.3824	18.4552	14.902	B C			d2	0	
00S103 7 FG02	09°29.00'S	158°31.00'W	5,497	(Hilly) Flat	21	73	6				7.59	Sp. P	2.00	18.75	0.5367	0.3169	0.434	20.10	15.414	B C			d2	0	
00S103 7 FG03	09°29.00'S	158°29.01'W	5,478	(Hilly) Flat	32	49	19				9.65	Sp. P	1.94	21.1	0.536	0.3363	0.427	19.6582	16.202	B C			d2	0	
(00242)																									
Average			4,490		32	56	12				8.11	P.Sp	1.9616	22.93	0.5321	0.3249	0.4162	19.4452	15.577						

*Sil% :siliceous fossil% , Cal% :calcareous fossil%, T.P.L:Transparent Layer

Figure 6-16: Example JICA-MMAJ sample sheetSource: JICA-MMAJ, 2001.

6.6 Security and Chain of Custody

Detailed security and chain of custody information is not available. However, the Competent Person considers there is a low risk of fraud, security breach or other risks associated with the sample chain of custody because JICA, MMAJ, Pacific Community and SBMA are all governmental organisations without financial incentive to commit fraud by inflating or deflating results. In addition, the abundance and grade data are of low variance and thus difficult to manipulate significantly without making elaborate, widespread and sophisticated adjustments. These would be easily detected from the data analysis, especially given the fact that both the abundance and grade data are corroborated between different exploration campaigns, both within the Project Area and the 16-159 area. Regardless, the Competent Person recommends that any future exploration programmes have SOPs in place for sample handling and chain of custody, combined with auditable sign-off sheets.

6.7 Data Quality Summary

A summary of JICA-MMAJ processes in relation to MRE, QA (quality assurance), QC (quality control) and QAT (quality acceptance testing) is given in Table 9-1.

Table 6-10: Summary of JICA-MMAJ processes with regards to MRE, QA, QC and QAT.

Activity	Use in MRE	Quality Assurance		Quality Control		Quality Assurance Testing against Data Quality Objectives		
		Documentation of Procedures	Other	Present	Control Risk	Results and Comments	Inferred	Indicated
JICA-MMAJ Seabed Sampling								
GPS surface location of vessel and deployment points	Referenced as proxy for seabed x-y location	Use of NNSS±GPS referenced only; datum had to be inferred (Table 5-2). In 2000, use of GLONASS as well as GPS (Navstar) should have reduced chance of errors.	Standard practice	No	Low as measurement is straightforward and any errors easily detectable due to systematic nature of sampling used.	No quantitative QC data collected. Data considered fit for purpose.	OK	OK[2]
Location of sampling equipment	**Critical** as x-y location needed in model	Method description only	Standard practice for FFG samplers	No	**Moderate** risk, known accuracy is hundreds of metres	No quantitative QC data collected. Data considered fit for purpose.	OK	OK[1]
Sample replicates/ triplicates	**Critical** as FFG samplers have a reputation for occasional poor sampling and abundance is more variable than grade	Method description and diagram (Figure 5-11, Figure 5-12)	Standard practice for FFG samplers	Yes	**Moderate** as FFG samplers are thought to sometimes fail to sample accurately	Example of a good QC check implemented to control the quality of the primary sample.	OK	OK[1]
Logging of samples	Referenced as nodule types in Area 16-159 relate to seabed clay-ooze type and thus to the geological interpretation that forms the domain	Method descriptions and flowchart (Figure 6-1, Figure 6-2, Table 5-4, Table 5-6, Table 5-7)	Leading practice	No	Low as nodule forms are readily classified	No quantitative QC data collected, but provides support for the quality of other data collection processes. Data are fit for purpose.	NA	OK[1]
Chemical analysis of samples	**Critical** as Co, Mn, Fe, Ni, Cu are estimated in the model	Method description and flowchart (Figure 6-4), laboratories referenced but not usually specified; duplicates in datasheets	Lacks detail	Yes	Low-moderate as QC processes in place, also nodule grades have low variance. No CRMs were inserted to monitor the analytical process.	Quantitative QC data collected. Data considered fit for purpose.	OK	OK[1]
Weight of samples	**Critical** as abundance is estimated in the model	Description and flowchart (Figure 6-1, Figure 6-2); no duplicates	Lacks detail	No	**Moderate** as there is a lack of documentation stating if vessel heave was accounted for. No standard weights were measured.	Results of FFG samplers correlate well in Area 16-159 against MBES seabed interpretation (Figure 6-14), i.e. low abundances in FFG samplers dropped above seamounts and knolls	OK	OK[1]

[2] In areas with sufficient data density

Activity	Use in MRE	Quality Assurance		Quality Control		Quality Assurance Testing against Data Quality Objectives		
		Documentation of Procedures	Other	Present	Control Risk	Results and Comments	Inferred	Indicated
Density and moisture	Referenced for completeness as not needed for MRE but will likely be material modifying factors	Description and flowchart (Figure 6-1, Figure 6-2, Figure 6-4); no duplicates	Lacks detail	No	Low as both values have low variance so errors easy to spot	No quantitative QC data collected. Results correspond to data collected from other nodule fields (e.g. CCZ). Data are fit for purpose.	NA	NA
JICA-MMAJ photography								
Seabed photographs from FFG sample	Referenced as used to estimate abundance in some cases	Description and flowchart (Figure 6-2), duplicates only between seabed and sample (on surface)	Leading practice	No	**Moderate** as camera sometimes malfunctions due to severe operating conditions	Quantitative QC data collected – good correlation between photographs and FFG data. Data are fit for purpose.	OK	OK[1]
Estimation of nodule abundance	**Critical** as used to support or replace weight if FFG sampler deemed to have not sampled correctly	Description only	Standard practice	No	Low as process demonstrated to be reliable statistically	No quantitative QC data collected. Data considered fit for purpose.	OK	OK[1]
Deck sample photographs	Illustrate geology and effectiveness of seabed photography	Description and flowchart (Figure 5-19)	Standard practice	No	Low as process straightforward	No quantitative QC data collected; however, correlates well with seabed images (e.g. Figure 5-18). Data considered fit for purpose.	OK	OK[1]
Photos of seabed from FDC	Helps in understanding seabed geology	Description only	Standard practice	No	Low as process straightforward – malfunctions reduced as camera is not pressure cycled and housing opened as with FFG sampler	No quantitative QC data collected. Photographs correlates adequately with bathymetry and backscatter. Data are fit for purpose.	NA	OK[1]
Location of FDC	Referenced to place FDC images of seabed	Description only	No longer used	No	**Moderate** as method described may not adequately account for the tow cable catenary	No quantitative QC data collected. Location correlates adequately with bathymetry and backscatter. Data considered fit for purpose.	NA	OK[1]
JICA-MMAJ seabed acoustic survey								
Single-beam (sounding) depth	Referenced (estimate sample depth), but does not impact MRE	Description and flowchart for early expeditions (Figure 6-5)	Past and standard practice	No	Low as a standard process actively monitored and managed on the vessel	No quantitative QC data collected. Data considered fit for purpose.	OK	OK[1]
Sub-bottom profiler	Used in geological interpretation of Area 16-159; input into the geological domain	Description only	Standard practice	No	Low as a standard process actively monitored and managed on the vessel	No quantitative QC data collected. SBP data correlates well with MBES bathymetry and MFES (Figure 4-9). Data considered fit for purpose.	NA	OK[1]

Activity	Use in MRE	Quality Assurance		Quality Control		Quality Assurance Testing against Data Quality Objectives		
		Documentation of Procedures	Other	Present	Control Risk	Results and Comments	Inferred	Indicated
MFES	Referenced as used in geological interpretation of Area 16-159 and thus domain	Description only	No longer used	No	**Moderate** as system is complicated, needs local calibration and is prone to psuedo anomalies	No quantitative QC data collected. MFES correlates well with FFG abundance data (Figure 6-14). Data considered fit for purpose.	NA	OK[1]
MBES bathymetry	Used in geological interpretation of Area 16-159; input into the geological domain	Brief description only	Lacks detail	No	Low as a standard process actively monitored and managed on the vessel	No quantitative QC data collected. MBES bathymetry correlates well with satellite and transit bathymetry (GEBCO) (Figure 4-9). Data considered fit for purpose.	NA	OK[1]
MBES backscatter	Used in geological interpretation of Area 16-159; input into the geological domain	Brief description only	Lacks detail	No	Low as a standard process actively monitored and managed on the vessel	No quantitative QC data collected. Backscatter correlates well with MBES bathymetry and MFES (Figure 4-9). Data considered fit for purpose.	NA	OK[1]

7 Mineral Resources

7.1 Informing Data

The MRE is based on historical BC and FFG data collected prior 2000 (Table 3-1). The data informing the MRE are stored in an MS Access database compiled by SBMA and were verified by the Competent Person. The database is made up of historical data, collected by companies/organisations before SMBA was established.

A majority of the data informing the MRE was collected by JICA-MMAJ 1985–2000 expeditions (Section 5.1), which accounts for 81% of the abundance samples, and ~52% of the grade samples. In addition, in 1983 JICA-MMAJ conducted the GH83-3 expedition (which focussed exclusively in the 13-159 area), which accounts for 16% of the abundance samples and 11% of the grade samples. Within Area 16-159, samples collected by the JICA-MMAJ 1986 and 2000 expeditions account for 98% of the abundance samples and 94% of the grade samples informing the MRE.

In the Competent Person's opinion, this provides a robust dataset, of suitable quality, to use in estimation.

7.1.1 Data Handling

The sampling method (Section 5.1) involved collecting three samples, in a triangular formation, spaced only a few kilometres apart. The resultant clustered sampling pattern may negatively impact variography and estimation processes, and the three samples were therefore averaged together, with the average value assigned to the barycentre of the locations of the three samples. This resulted in a database of samples spaced closely (~20–25 km), moderately (~50 km) and far apart (~100 km).

This process is effectively the same as the process of compositing drill-hole samples, or the averaging of two pulp results to represent one single metre of drilling in classic terrestrial exploration settings and reduces the variance in the dataset used in estimation. This process is only statistically valid if all sites have a similar amount of increments, as the averaged data of sites with only two samples will show higher variances than those where three samples were used to create the average. In this case, there are only a few sites with less than three samples and this is considered by the Competent Person to have little impact on the estimate.

7.1.2 Location Data

The Project Area is large enough to encompass two different Universal Transverse Mercator (UTM) zones. Therefore, the location data were transformed into a custom reference system using Lambert azimuthal equal-area projection, with the origin at 160°W, 16°S. Due to the large sample spacing, the unit for the custom reference system is kilometres. The custom coordinate reference system was created in ArcGIS and imported into QGIS. Both software programs were used to transform location data for various informing data (i.e. sample location data, domain shapefiles). Reduced level (RL) was set to 0 for all samples to create a 2D dataset.

7.2 Interpretation and Model Definition

7.2.1 Geological Domains

Geological domains are important to provide a first-order constraint on estimation populations and should reflect the controls on mineralisation. Nodule abundance varies throughout the EEZ in response to topography, hydrodynamics and sedimentation rates. Localised structures, including steep slopes and depressions, also influence the rate of nodule accumulation.

SMBA has undertaken considerable work to define geomorphological domains in the EEZ and wider seabed. Geomorphological domains were created in ArcGIS and include abyssal plains, islands, knolls, low zones, plateaus, tectonic rises, volcanic rises, seamounts, trenches and troughs. Nodule formation is primarily linked with the abyssal plains. The MRE was constrained within a single geological domain based on the modelling of the abyssal plains and excludes seamounts and knolls as current mining technology cannot harvest nodules on slopes >5° (Figure 7-1). The geological domain has a lower confidence in areas with limited sampling (e.g. Manihiki Plateau and southeast of Aitutaki Passage), and estimation has been further restricted to the higher-confidence part of the geological domain.

The geological domain was constricted to the Project Area (EEZ). Due to limited informing data in particular areas, the geological domain was further restricted to the Penrhyn, Southern Cooks and Samoa basins.

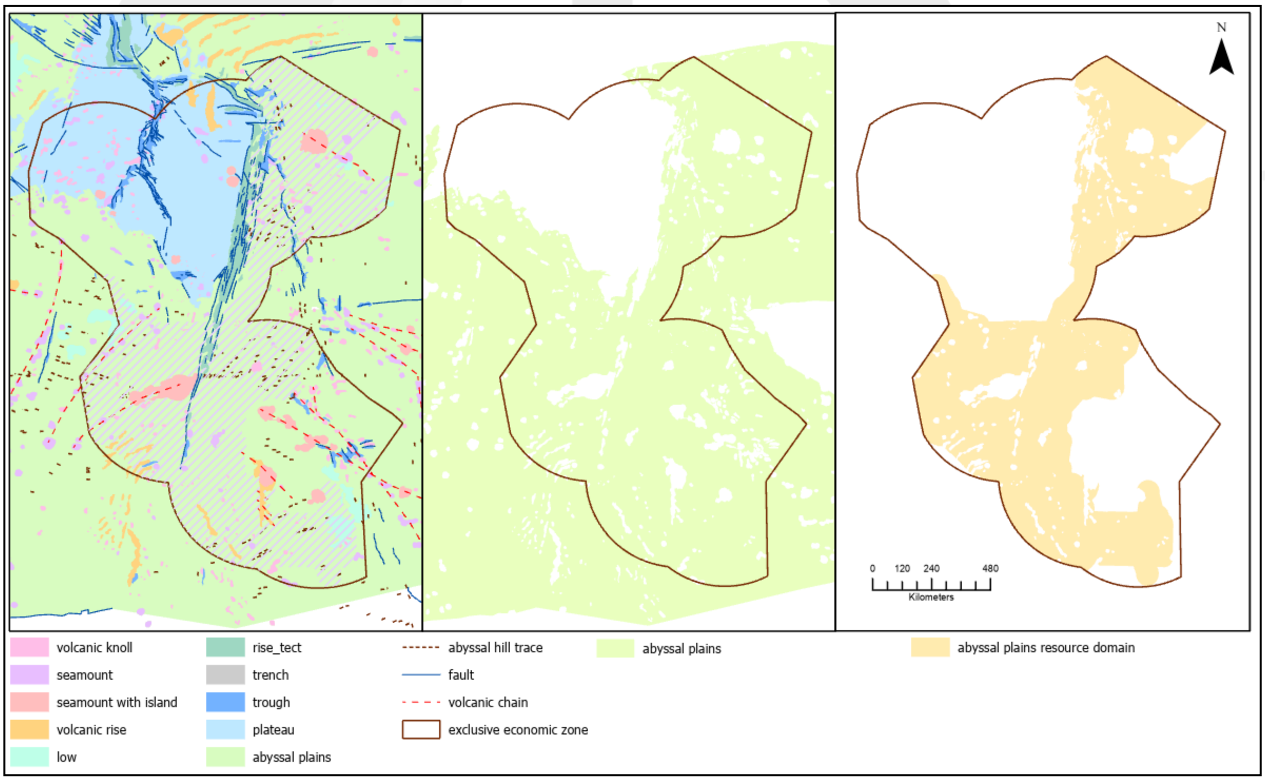


Figure 7-1: Seabed geomorphology map, abyssal plains unit and abyssal plains domain used for the MRE.

The modelling of the abyssal plains is more detailed over the 16-159 (Central) Area. The Central Area was the focus of many historical expeditions, with multiple sampling campaigns, including bathymetry collected by MFES. The geological domain over 16-159 (Central) Area benefits from that additional level of geological input and excludes knolls, knoll-compounds, and volcanic rises (Figure 7-2).

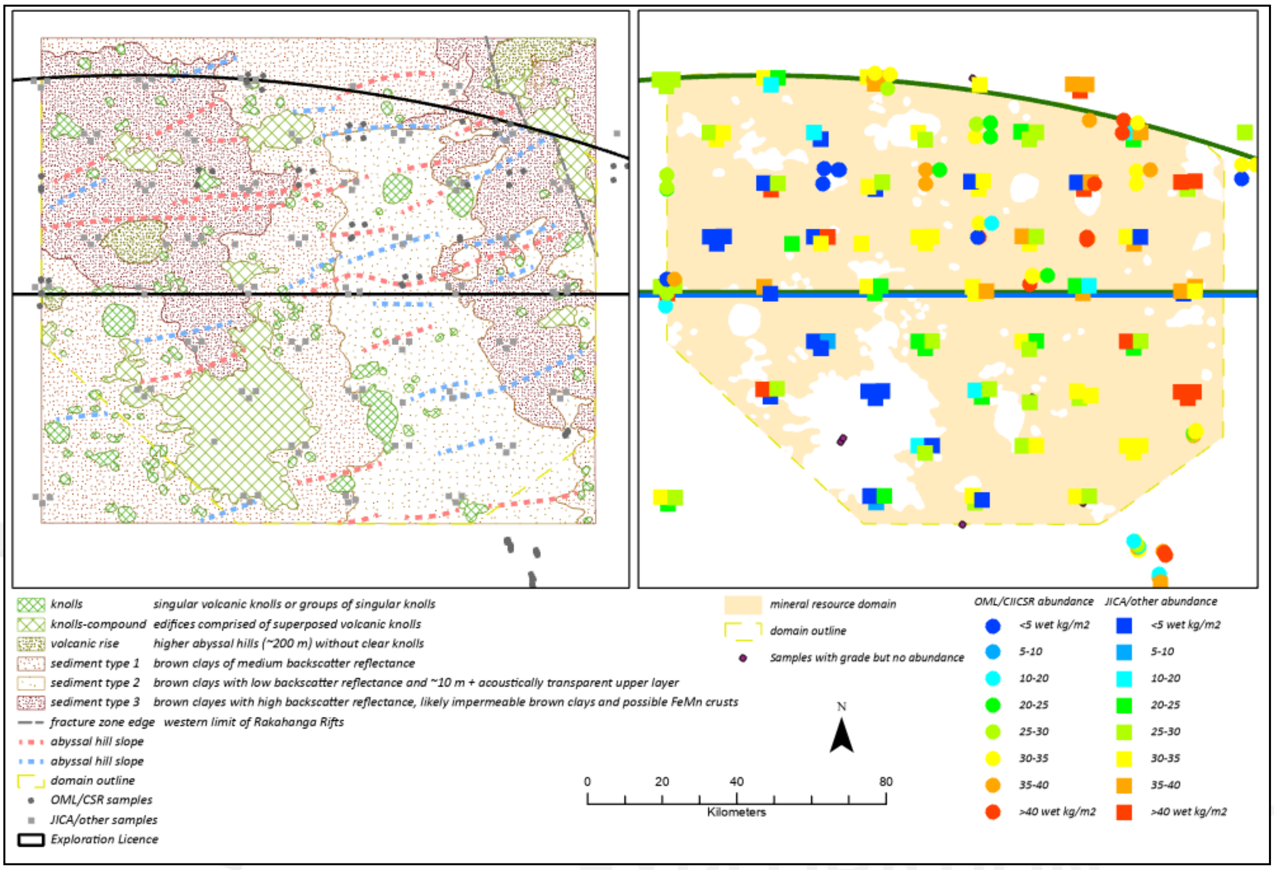


Figure 7-2: Geological domain for Area 16-159.

7.2.2 Estimation Domains

7.2.2.1 Abundance

A visual assessment and statistical review of abundance values revealed a high-abundance sub-population within the main geological domain (abyssal plains). An estimation domain was created using an implicit RBF numeric indicator model to honour this population. The abundance cut-off, separating high-abundance from low-abundance areas and reflecting different controls on mineralisation, was determined at 10 kg/m^2. The indicator model was interpolated using an isotropic search, which resulted in a relatively contiguous domain with north–south trend in the north, and a northeast trend in the south (Figure 7-3). The high- and low-abundance domains were reviewed by a visual assessment of their continuity and by comparing domain statistics (mean, variance, CVs). This demonstrated monomodal distributions, with consistent mean and variance across the domains.

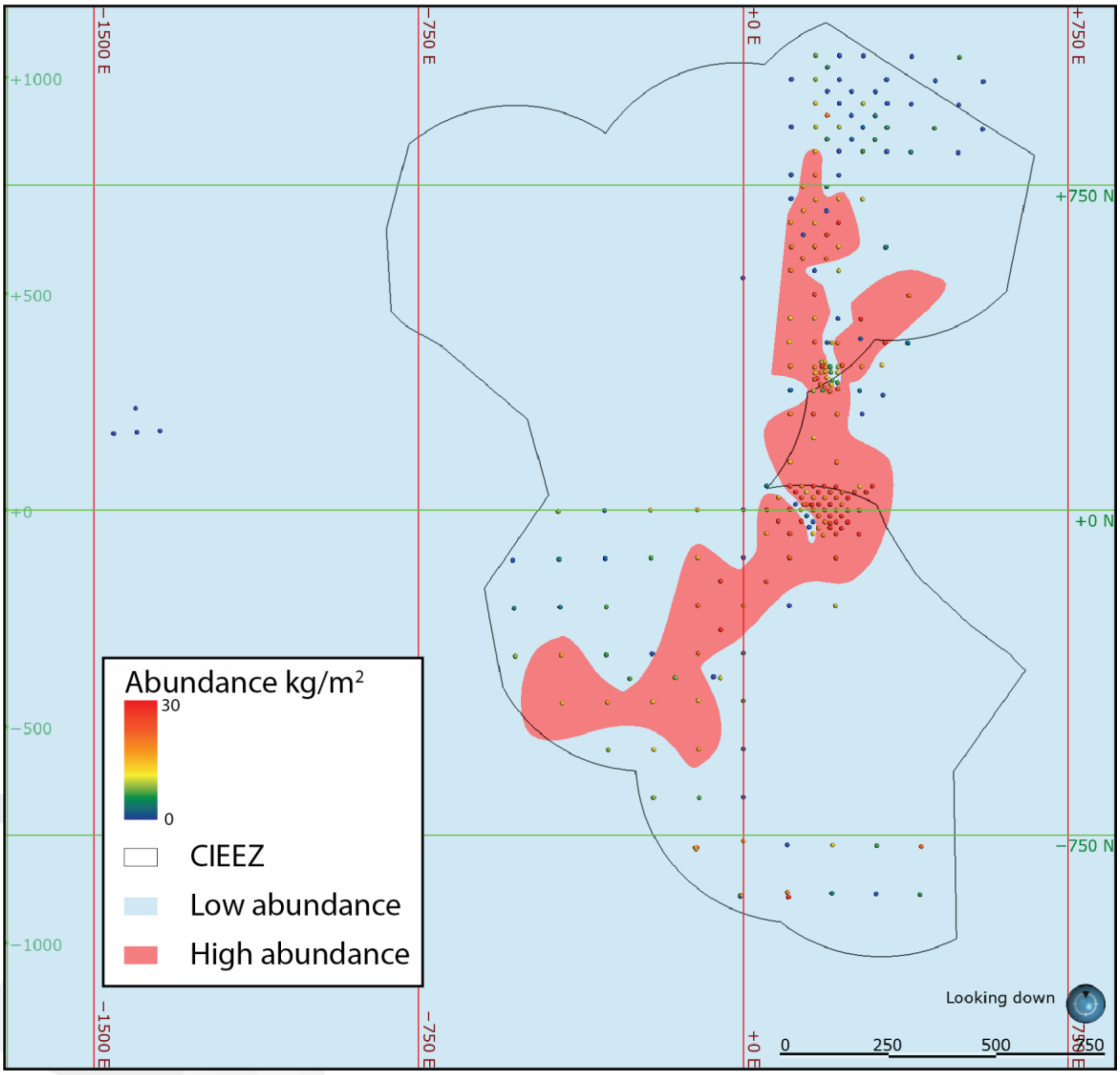


Figure 7-3: Plan view of the high- and low-abundance estimation domains.

7.2.2.2 Geochemistry

As noted in section 5, there are broad-scale nodule geochemistry trends throughout the EEZ. After reviewing the histograms and spatial trends of Cu, Co, Fe, Mn and Ni grades, a high-grade Ni population (>0.8%) was identified to the north of the North Penrhyn Basin (Figure 7-4). This domain also corresponded with high Cu (>0.5%) and Mn (>20%) and low Co (<0.2%) and Fe (<10%).

This northern domain was excluded from the experimental variography analysis. Removing samples from this small, isolated domain that displayed a slightly different statistical signature to the rest of the area of interest helped sanitise the underlying variogram structure for all elements for the rest of the area. To test the sensitivity of this decision, the estimation was run for both options (no high-metal-grade domain vs a high and a low-grade domain) and shown to be relatively insensitive to the domaining decision.

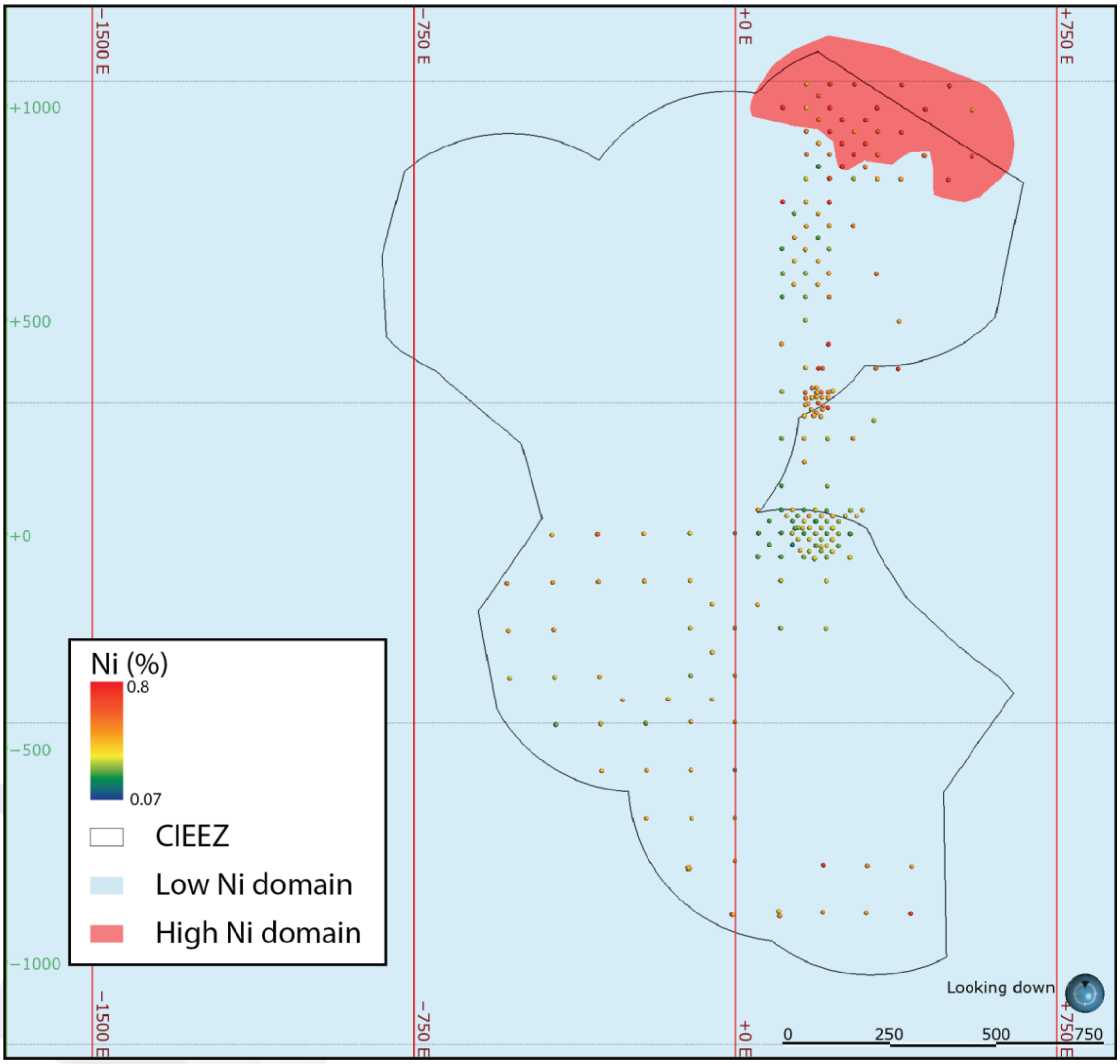


Figure 7-4: Plan view of the high Ni domain.

7.2.3 Risk of Extrapolation of Data into Areas of Low Data Density

There are large areas within the EEZ that have not been sampled, including the Manihiki Plateau and southern Cook Islands around the Aitutaki, Aitu, Mitiaro islands. To prevent extrapolating the MRE into areas of low data density, the estimation domain was further constrained to a smoothed buffer distance of 50 km, away from sample sites.

7.2.4 Alternative Interpretations

At a large scale, the controls on mineralisation and nodule abundance are generally well understood and supported by the data; however, smaller-scale controls such as ridge morphology and seamounts need higher-resolution bathymetric data to better define these zones. The Competent Person considers that, at this stage in the project, at this level of data resolution, and at this classification level, alternative interpretations of the geology and mineralisation are possible; however, they are not likely to generate models or estimates that are significantly different.

7.3 Summary Statistics and Data Preparation

7.3.1 Sample Support

Sampling has been conducted using varying methods and sample sizes over the history of the project. In total, ~60% of the samples were collected by free-fall grab (normally abbreviated to FFG; note JICA-MMAJ use the acronym FG) and ~1.5% (n=22) were collected by BC (note JICA-MMAJ use the term spade corer or SC). The remaining samples were collected by large (gravity) corer (<1%, abbreviated by JICA-MMAJ to LC), continuous deep-sea camera systems (14%), and likely dredging (24%).

The variance due to sample volume difference is not expected to influence the precision of the estimate significantly and all data, regardless of their support were included in the estimate.

7.3.2 Estimation Domain Statistics

The statistics for abundance are weighted by 25 km × 25 km cell delustering weights. The high-abundance domain displays very low skew, low coefficient of variation (CV) and a monomodal distribution (Table 7-1, Figure 7-5). The low-abundance domain displays moderate skew (due to the presence of isolated high values). The populations of Co, Cu, Fe, Mn and Ni concentrations all display low CVs and monomodal grade populations (Table 7-2, Figure 7-6, Figure 7-8). The Cu and Ni populations are most affected by the northern high-Ni isolated domain.

Table 7-1: Summary statistics of abundance estimation domains.

Domain	Count	Mean (kg/m²)	SD	CV	Variance	Minimum (kg/m²)	Q1 (kg/m²)	Q2 (kg/m²)	Q3 (kg/m²)	Maximum (kg/m²)
High abundance	230	22.0	11.2	0.43	126	0.00	20.4	28.0	34.5	56.1
Low abundance	105	5.0	6.6	1.32	43.0	0.00	0.56	2.71	7.4	35.9

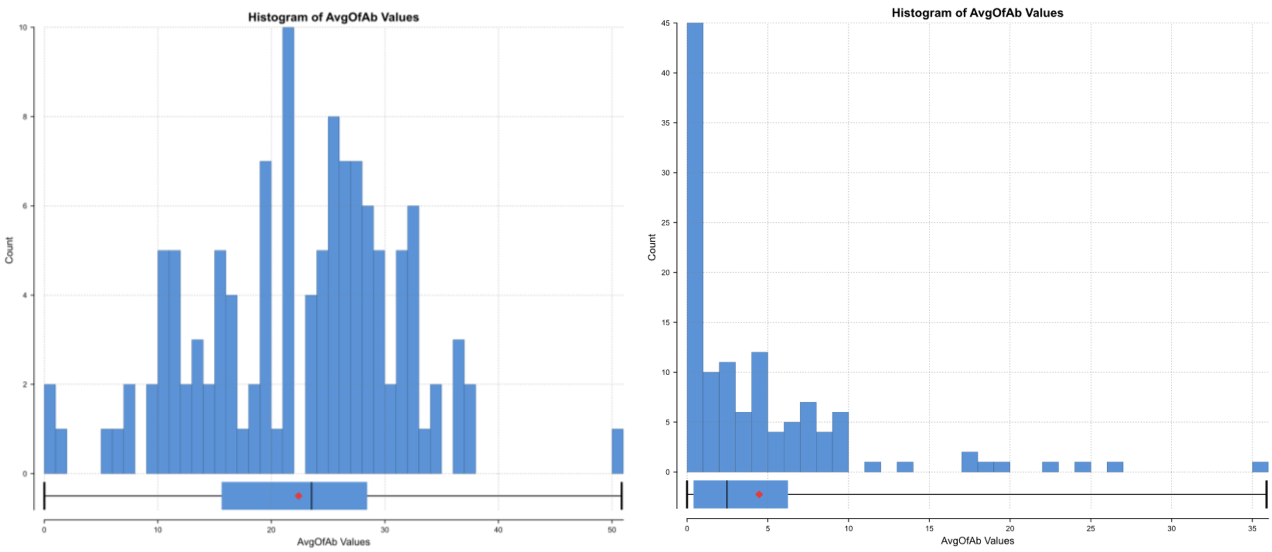


Figure 7-5: Histogram of high abundance estimation domain (left); low abundance estimation domain (right).

Table 7-2: Summary statistics of elemental concentrations.

Element	Count	Mean (%)	SD	CV	Variance	Minimum (%)	Q1 (%)	Q2 (%)	Q3 (%)	Maximum (%)
Co	359	0.42	0.11	0.25	0.01	0.11	0.36	0.45	0.49	0.70
Cu	359	0.25	0.18	0.72	0.03	0.10	0.15	0.18	0.26	0.98
Fe	359	15.90	4.88	0.31	23.83	1.20	14.33	17.50	18.91	26.32
Mn	360	16.18	3.36	0.21	11.28	1.43	15.07	16.47	17.54	28.80
Ni	359	0.40	0.25	0.62	0.06	0.11	0.26	0.30	0.46	1.90

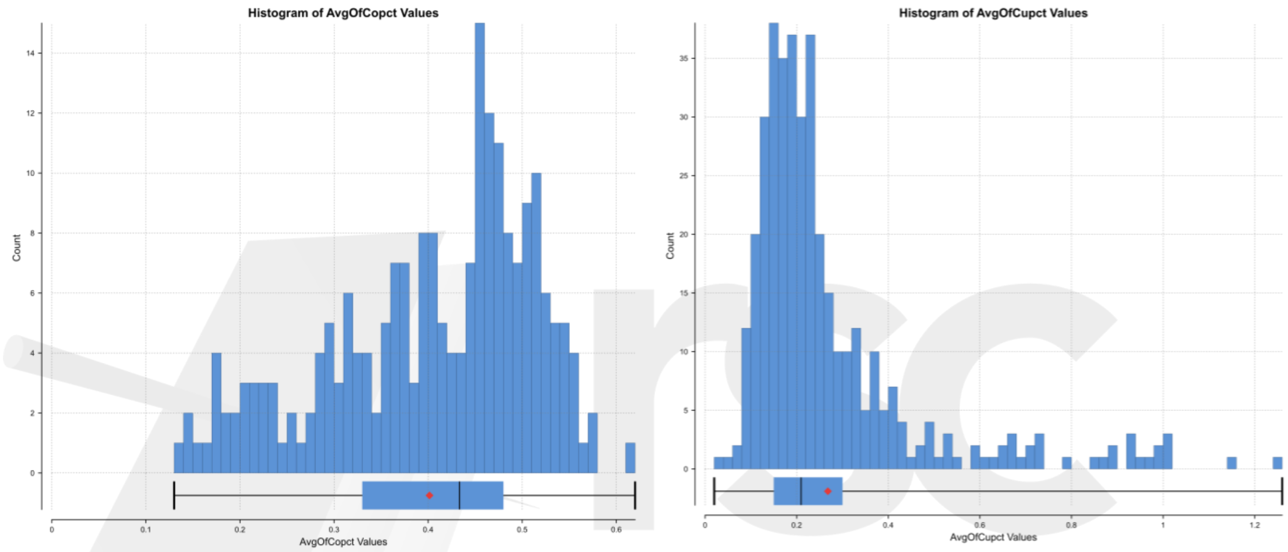


Figure 7-6: Histogram of Co and Cu estimation domains.

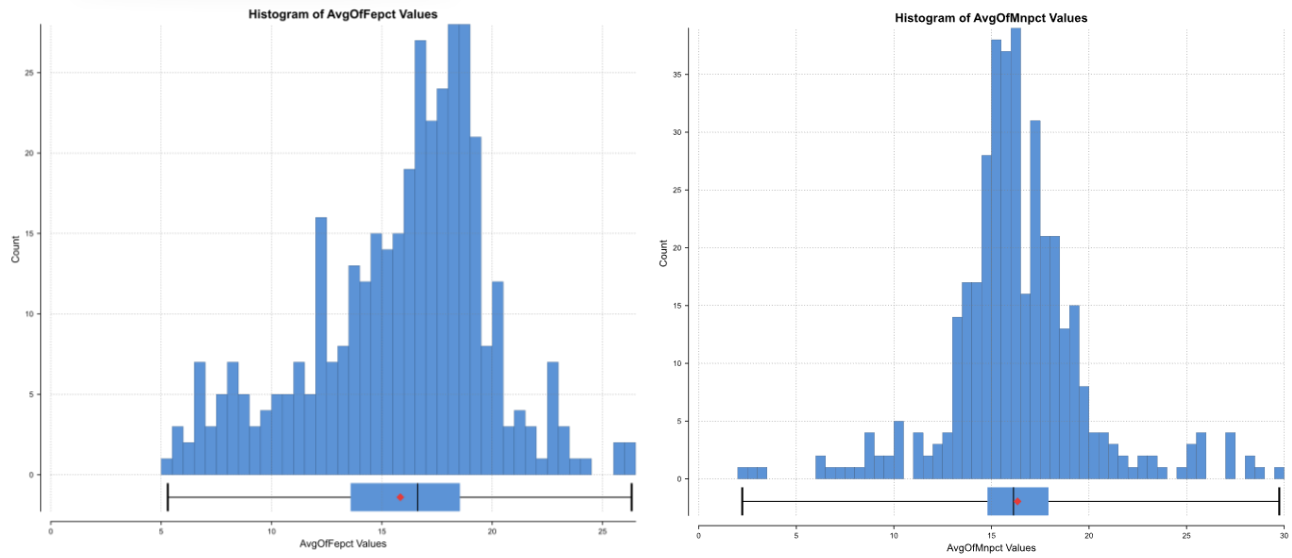


Figure 7-7: Histogram of Fe and Mn estimation domains.

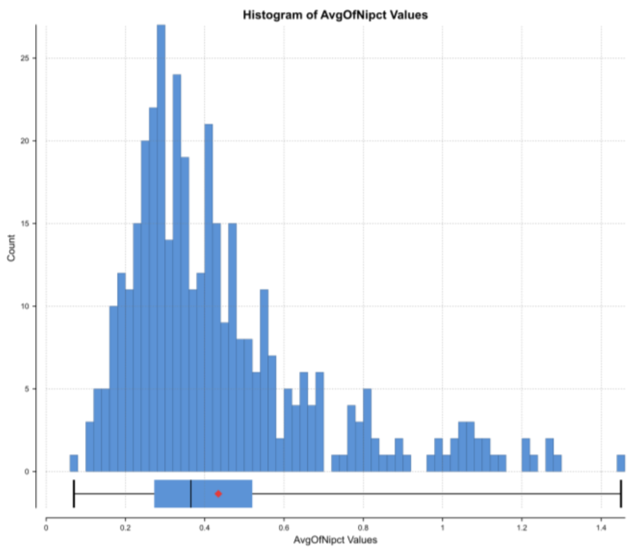


Figure 7-8: Histogram of Ni estimation domain.

7.4 Spatial Analysis and Variography

7.4.1 Variogram Analysis

The spatial continuity of abundance, Co, Cu, Fe, Mn, and Ni was independently modelled in the horizontal plane.

Experimental semi-variograms were modelled with relatively low γ_0 values (<0.10 except for Co (0.15) and abundance in the high-abundance domain where γ_0 is at 0.42) and one or two spherical structures. All variograms display reasonable structure for global estimation and support classification of Indicated and Inferred mineral resources.

For the abundance data, the major direction (180°) was determined from the direction of maximum abundance continuity within estimation domains. This direction was found to match the continuity of Co grades. The major direction for Fe is 225° and Ni is 215°. Clear trends of mineralisation were not evident for Cu and Mn. These variables were modelled using omni-directional variograms.

Abundance results show more variance than grade results, which is expected, and the 16-159 area shows less variance than the global Project Area.

Table 7-3: Abundance variogram parameters.

Estimation Domain	Structure	Model Type	Relative Sill	Range Major (km)	Range Semi-Major (km)
High abundance		Nugget	0.4		
	1	Spherical	0.3	55	55
	2	Spherical	0.3	230	65
Low abundance		Nugget	0.1		
	1	Spherical	0.9	160	115

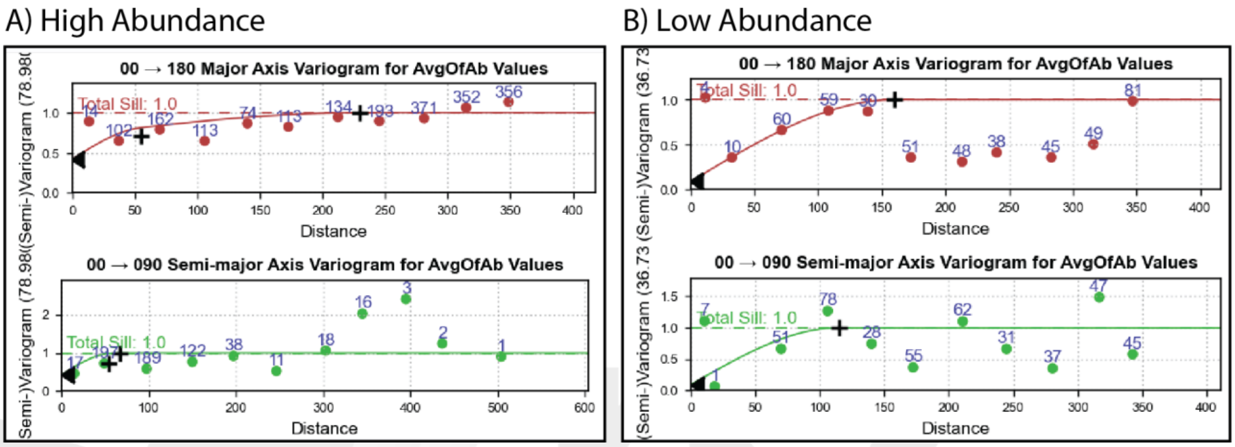


Figure 7-9: Experimental semi-variogram models for abundance within the A) high-abundance domain and B) low-abundance domain.

Table 7-4: Variogram parameters for Co, Cu, Fe, Mn and Ni.

Element	Structure	Model Type	Relative Sill	Range Major (km)	Range Semi-Major (km)
Co		Nugget	0.2		
	1	Spherical	0.8	260	190
Cu		Nugget	0.1		
	1	Spherical	0.9	570	570
Fe		Nugget	0.0		
	1	Spherical	0.3	60	25
	2	Spherical	0.7	575	555
Mn		Nugget	0.1		
	1	Spherical	0.6	120	120
	2	Spherical	0.3	500	500
Ni		Nugget	0.1		
	1	Spherical	0.3	95	75
	2	Spherical	0.6	610	420

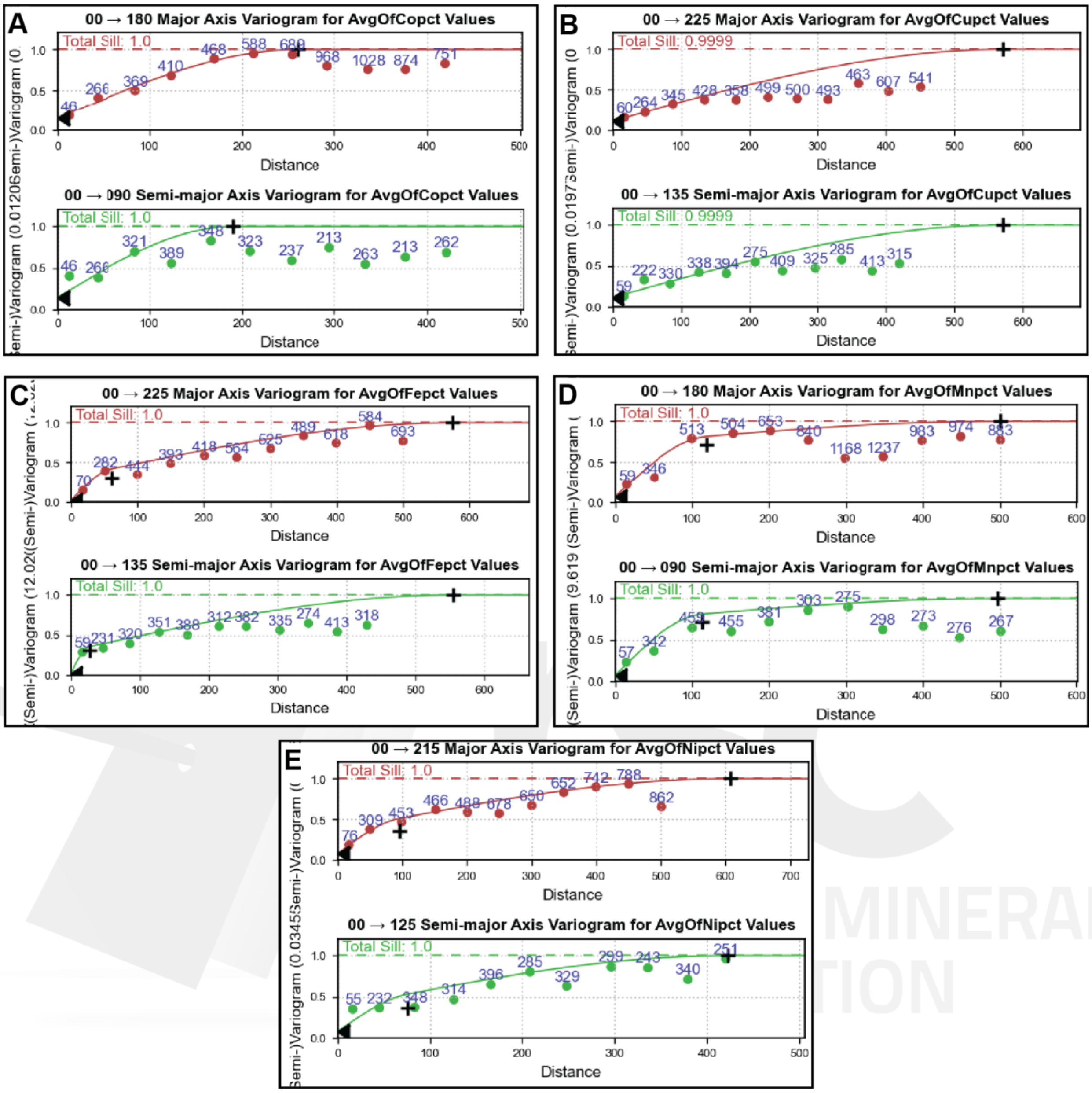


Figure 7-10: Experimental semi-variogram models for A) Co, B) Cu, C) Fe, D) Mn, and E) Ni.

7.5 Block Model

A block size of 50 km × 50 km was selected for estimation based on sample spacing. Block model definitions are outlined in Table 7-5. The parent blocks were discretised to 5 km x 5 km (x-y). The parameters and dimensions are based on sample spacing. Sub-blocking of 25 km × 25 km was applied to gain a better definition of the geomorphological domain. A sub-block of 12.5 km × 12.5 km was used in the 16-159 (Central) Area. Overall, the block model contains 966 50-km^2 blocks, 4,042 25-km^2 blocks and 132 12.5-km^2 blocks.

Table 7-5: Block model definitions. Custom Lambert azimuthal equal-area projection used.

Axis	Origin	Parent Block Size (km)	Smallest Sub-Block Size (km)	Length (km)
x	-600	50	12.5	1,200
y	-1,025	50	12.5	2,125

7.6 Search Neighbourhood Parameters

Given the 2D nature of the deposit, nodule abundance and metal grade estimate search neighbourhood applied a static ellipse of 100 km x 70 km. The blocks not informed by this search pass were estimated in a second or third pass. The second and third search pass increased in size, 150 km x 100 km and 200 km x 100 km, respectively. The long axis of all the search passes was orientated to the north. A minimum of four samples and a maximum of 32 samples were used for all abundance estimates (the three passes), and a minimum of four samples and a maximum of 16 samples were used for all metal grade estimates. The search neighbourhood parameters are considered appropriate to support a robust estimate.

The search neighbourhood parameters are summarised in Table 7-6.

Table 7-6: Search neighbourhood parameters.

Parameter	Pass 1	Pass 2	Pass 3
Ellipsoid range NS–EW (km)	100 × 70	150 × 100	200 × 100
Minimum samples	4	4	4
Maximum samples (abundance, metals)	32, 16	32, 16	32, 16

7.7 Estimation

7.7.1 Domain

Block abundances and elemental grades were estimated using ordinary kriging, a robust linear unbiased estimation method, fit for the purpose of 2-dimensional abundance and grade estimation. Hard domain boundaries were used for the nodule abundance domains following an assessment of abundance variability across domain boundaries (Figure 7-11).

7.7.2 Grade

Summary statistics for the estimated block values for abundance, Co, Cu, Fe, Mn, and Ni are provided in Table 7-7. A comparison of sample and block model means is given in Section 7.8.

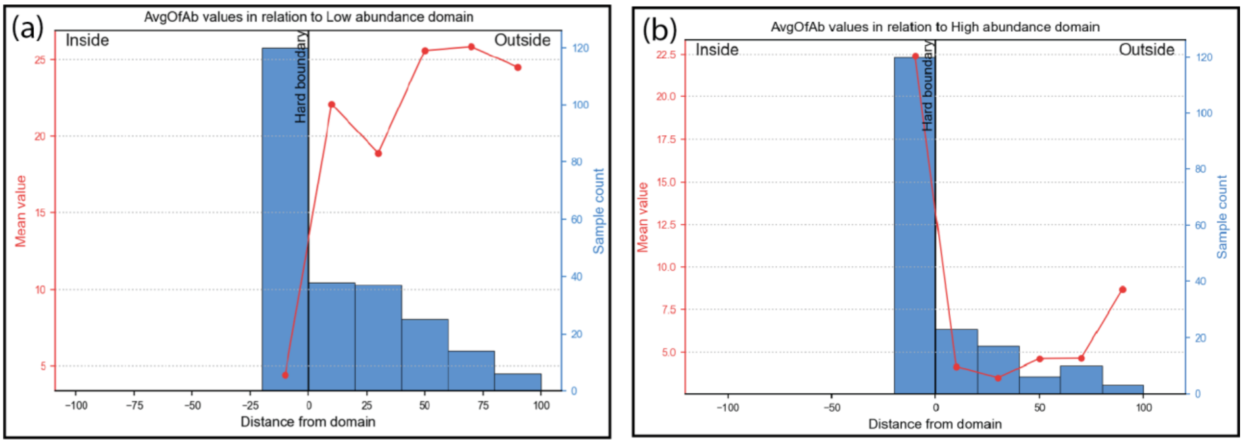


Figure 7-11: Contact analysis plots for (a) low abundance domain and (b) high abundance domain.

Table 7-7: Summary statistics.

Variable	Mean	SD	CV	Variance	Minimum	Median	Maximum
High Abundance	21.41	7.36	0.34	54.24	1.29	23.09	33.27
Low Abundance	5.29	3.60	0.68	12.97	0.30	4.12	20.55
Co %	0.39	0.08	0.21	0.01	0.16	0.53	0.41
Cu %	0.26	0.13	0.50	0.02	0.08	0.23	0.90
Fe %	16.15	2.92	0.18	8.54	6.93	16.76	21.82
Mn %	16.17	2.18	0.13	4.77	8.93	16.10	24.94
Ni %	0.44	0.17	0.39	0.03	0.18	0.41	1.10

7.7.3 Density

Nodule wet density was recorded during historical expeditions (JICA-MMAJ, 2001; Section 5.1.4.5); however, its estimation was not required for the estimation of wet tonnages which are obtained from the direct estimation of abundance (wet kg/m^2). RSC incidentally notes that there is some variance in the wet nodule density measurements collected but considers the mean of ~2 g/cm^3 to be indicative of the wet density for the nodules within the Project Area.

7.7.4 Moisture

Nodule moisture content was recorded during historical expeditions, resulting in an average of around 30% moisture or free water content in nodules (Section 5.1.4.6). RSC has estimated wet tonnages of nodules only from the estimation of abundance (wet kg/m^2) and did not derive dry tonnages via the estimation of moisture content due to the low confidence in moisture content values of nodules within the Project Area.

7.8 Validation

The estimates (abundance, Co, Cu, Fe, Mn and Ni) were validated through visual inspection of the input grade and output estimate (Figure 7-12), global statistical comparisons between the sample mean value and estimated block mean (Table 7-8, Table 7-9), and swath plot analysis orientated in northing and easting slices (Figure 7-13, Figure 7-14). At the resolution of the parent cell estimate, the validations support acceptable representation of the model against the input grades.

Table 7-8: Mean comparison of sample and estimate abundance grades. No top cutting was applied.

Domain	Sample Mean (kg/m^2)	Block Model Mean (kg/m^2)	Mean Difference
Low abundance	4.98	5.23	5%
High abundance	22.03	21.42	3%

Table 7-9: Mean comparison of sample and estimated metal concentrations. No top cutting was applied.

Element	Sample Mean (%)	Block Model Mean (%)	Mean Difference
Co	0.42	0.39	-7%
Cu	0.25	0.26	4%
Fe	15.90	16.15	2%
Mn	16.18	16.17	0%
Ni	0.40	0.44	9%

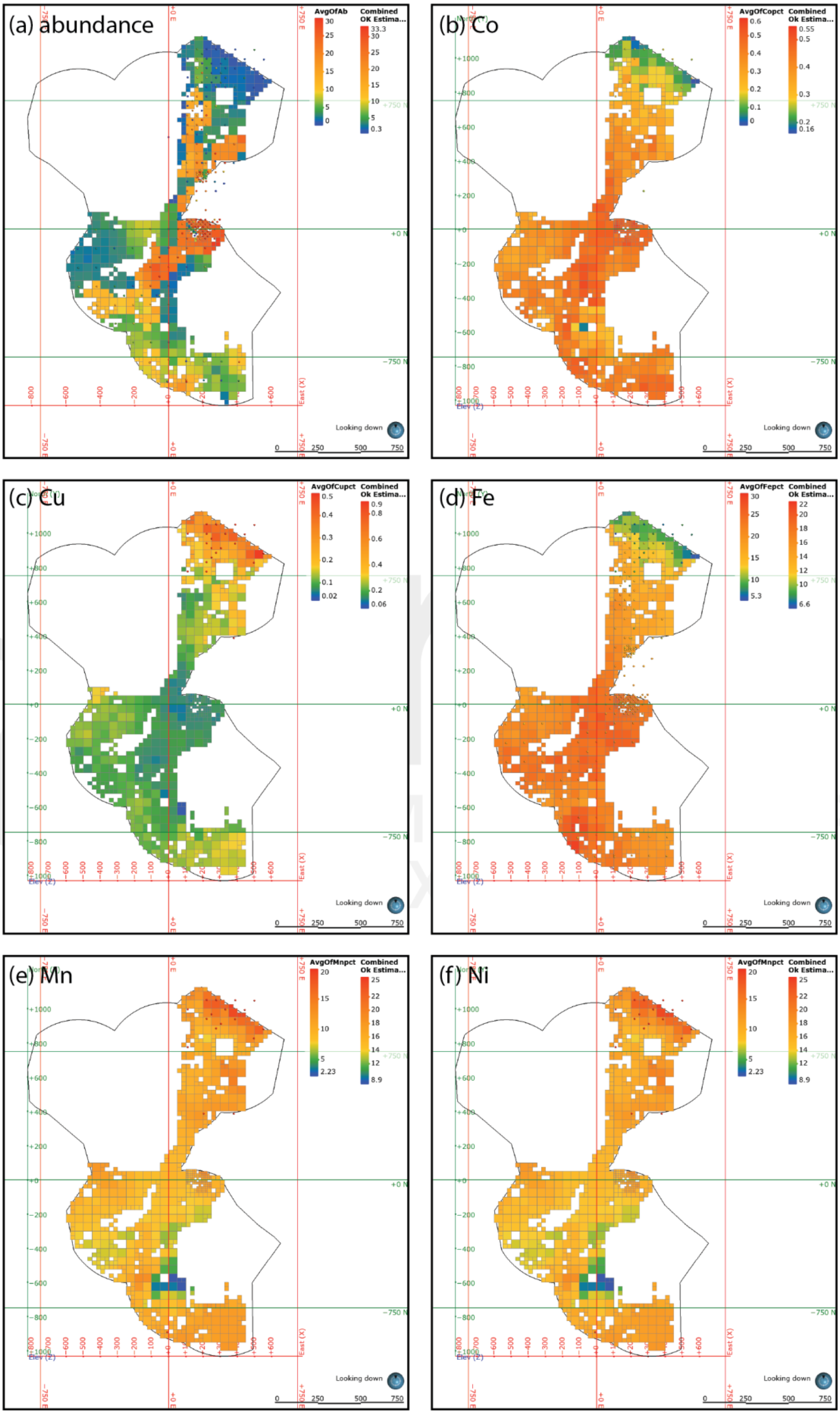


Figure 7-12: Plan view of estimated block grade and sample data. (a) abundance; (b) Co; (c) Cu; (d) Fe; (e) Mn; and (f) Ni.

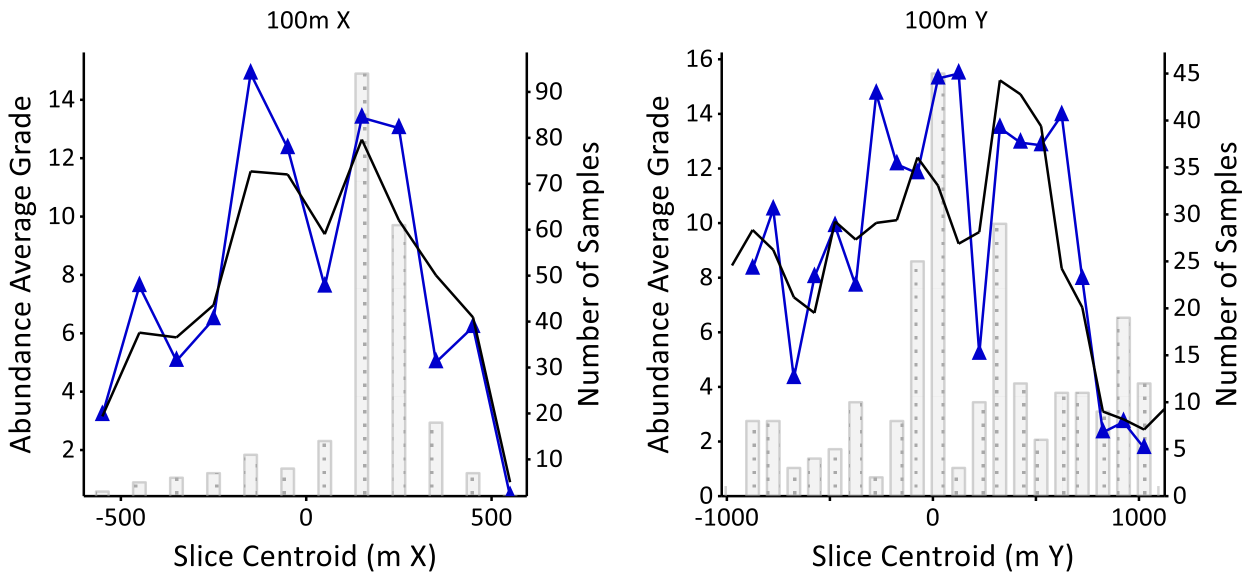


Figure 7-13: Swath plots displaying the average sample (blue) and estimated (black) abundance grades. (left) abundance grades along easting slice; (bottom) abundance grades along northing slice (100 m x 100 m).

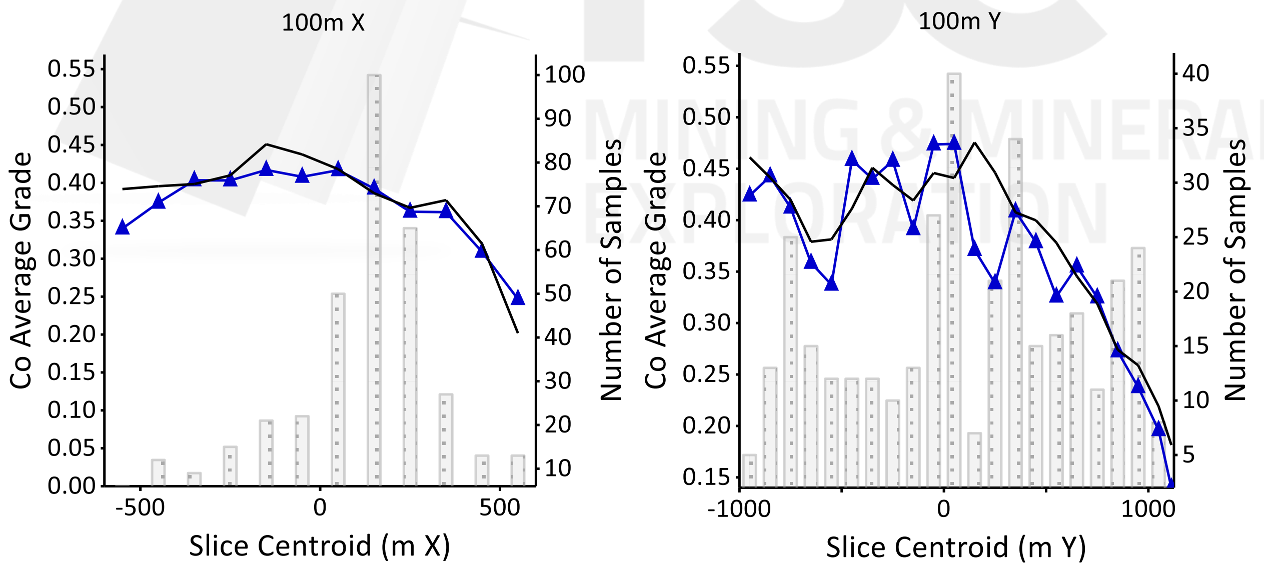


Figure 7-14: Swath plots displaying the average declustered samples (blue) and estimated (black) Co grades. (left) Co grades along easting slice; (bottom) Co grades along northing slice (100 m x 100 m).

7.9 Sensitivity Testing

Sensitivity testing was carried out to assess the robustness of the estimate, by assessing the effect that different estimation parameter settings have on the estimate. Different sensitivity tests were conducted to test the effects of:

- estimating abundance with and without estimation domains (e.g. an 'unconstrained' vs 'constrained' estate);
- different neighbourhood search parameters, including:
  - orientation of sample ellipse.
  - sample definition informing the estimate; and
- different block sizes.

All sensitivity tests revealed the different estimates are stable relative to changes in estimation parameter settings. The scatter plots (Figure 7-15 to Figure 7-17) show a good level of correlation between estimators based on isotropic estimation searches vs estimators based on north–south elongated estimation searches for all elements.

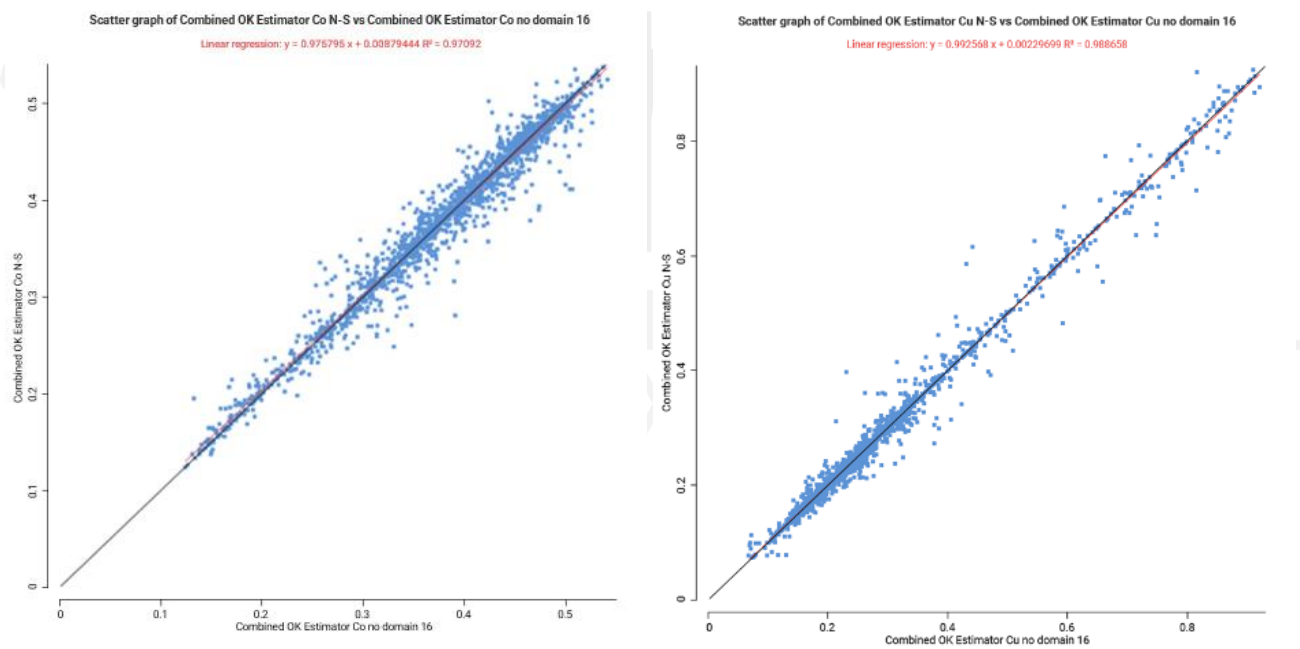


Figure 7-15: Cobalt and Cu scatter plots displaying the sensitivity of the estimators to the neighbourhood orientation.

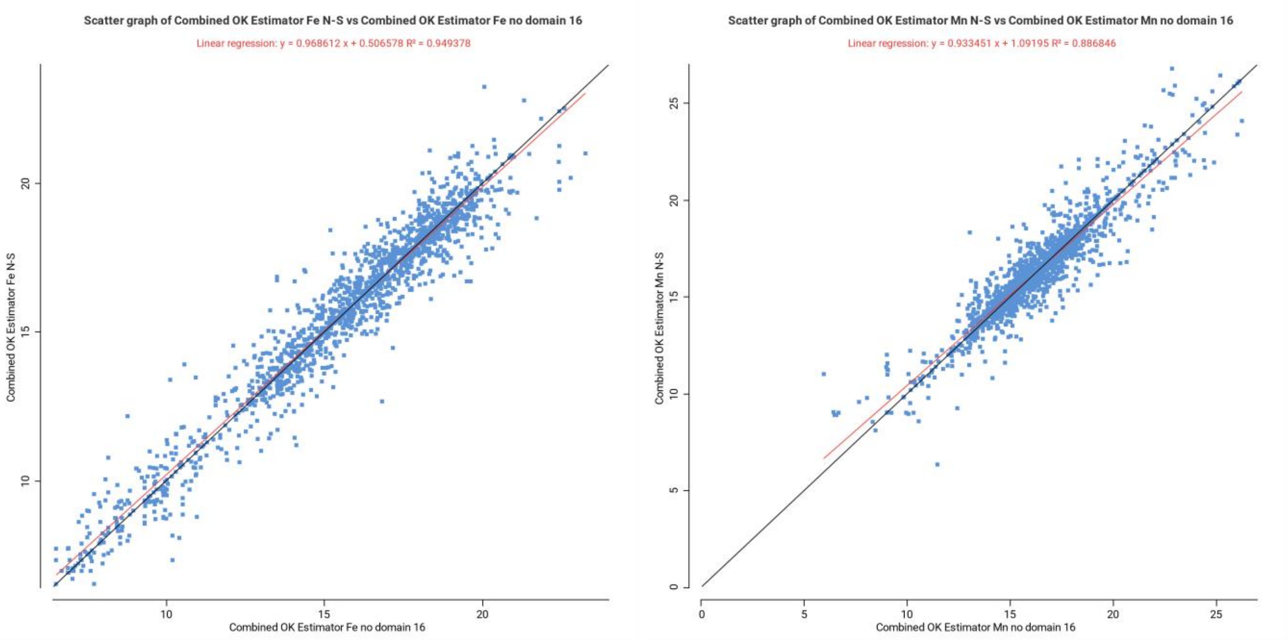


Figure 7-16: Iron and Mn scatter plots displaying the sensitivity of the estimators to the neighbourhood orientation.

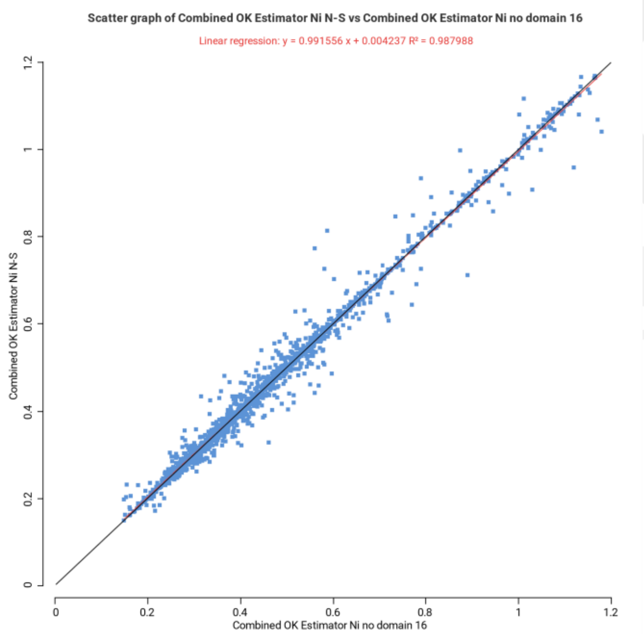


Figure 7-17: Nickel scatter plots displaying the sensitivity of the estimators to the neighbourhood orientation.

7.10 Multifactor Scorecard Modelling

RSC's multifactor scorecard analysis considers data quality, confidence in the geological domain modelling and local estimation precision to derive an overall semi-quantitative measure to support mineral resource classification.

For data quality mapping, each sample is assigned a ranking based on a set of criteria (including sample type and quality of the sample; Section 6), resulting in the ranks outlined in Table 7-11. Mapping the data quality ranking is performed using an interpolation scheme that favours nearby information (ID1 with a maximum of six samples used).

Table 7-10: Data quality ranking applied to samples of various sample types.

Sample Type	Rank	Comment
BC	1	Historical BC sample. No SOP available to review. Limited quantitative control data (or none).
FFG	5	Historical FFG sample. No SOP available to review. Limited quantitative control data (or none).

The confidence in the geological interpretation is based on mapping the ranking outlined in Table 7-11.

Table 7-11: Ranking system to characterise geological confidence.

Geological Confidence	Rank	Comment
Good geological support	1	Good resolution bathymetry, paired with additional supporting information to define geomorphology and detailed nodule dimension studies
	2	Good resolution bathymetry but lies at boundary between geomorphological domains
	3	Lack of narrow-beam sub-profiler support
	4	Satellite bathymetry
Poor geological confidence	5	Inferred (GEBCO) bathymetry

Finally, local estimation precision is also mapped using the kriging variance obtained for abundance with a generic variogram model that averages the key features (sills and ranges) of the individual domain variograms using the undomained dataset.

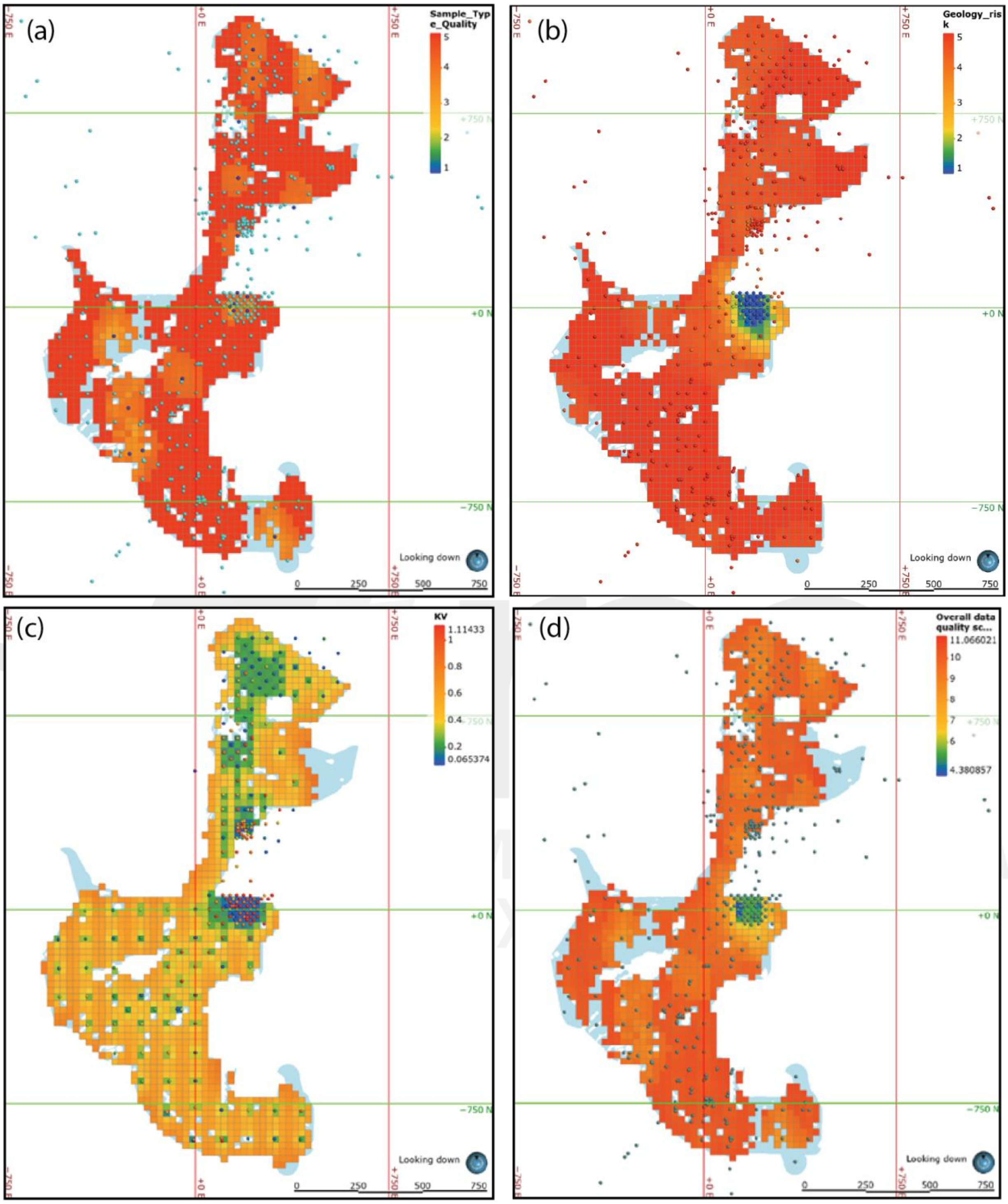


Figure 7-18: Maps of the various data quality estimations performed. A) data quality rank; B) geological support/confidence rank; C) kriging variance; D) overall estimation confidence. Scale: 1 = high quality, 5 = low quality.

7.11 Classification

7.11.1 Mineral Resource Classification

The Mineral Resource has been classified following the guidelines defined by the JORC Code (2012).

The mineralisation within the Mineral Resource has been classified in the Indicated and Inferred categories (Table 7-12). The Mineral Resource has been reported at a cut-off of 5 kg/m^2 nodule abundance, which was selected based on the consideration of previous studies of comparable deposits (section 7.11.2). The Mineral Resource tonnage is stated as wet tonnes and no material has been classified as Measured.

The majority of the polymetallic nodule Mineral Resource is classified as Inferred. It does not constitute a Mineral Reserve and therefore does not have demonstrated economic viability. The portion that is classified as Indicated may lead to the definition of an economically mineable part (Mineral Reserve) after taking all relevant Modifying Factors (including ore losses and mining dilutions) into account. The determination of Modifying Factors necessitates work at Pre-Feasibility Study (PFS) or Feasibility Study (FS) levels that demonstrate – at the time of reporting – extraction can be justified.

The classification of the Mineral Resource is based on sample quality (section 7.10), confidence in geological understanding, and on the quality of the estimate itself, as broadly determined during the validation process. Caution should be exercised if Inferred Mineral Resources are used to support technical and economic studies such as Scoping Studies. In general, the volume and grade of the Inferred Mineral Resource have been estimated based on limited geological evidence and sampling. Geological evidence is sufficient to imply, but not verify, geological and grade continuity and is based on exploration, sampling and testing information gathered through appropriate techniques. Area 16-159 (Central Area) has sufficient geological evidence to verify geological and grade continuity. Area 16-159 also has a higher concentration of higher-quality samples (BC samples with good QA/QC data), supporting the classification of Indicated Mineral Resources. It is expected that a proportion of the Inferred Mineral Resource could be upgraded to higher confidence classifications with additional exploration.

Table 7-12: Mineral Resource Statement at nodule abundance cut-offs of 5 kg/m^2

Classification	Abundance (wet) kg/m^2	Nodules Mt (wet)	Metal Grade (%)				
			Co	Cu	Fe	Mn	Ni
Indicated	26.7	304	0.50	0.15	18.5	15.4	0.25
Inferred	14	6,400	0.4	0.2	17	16	0.4
Global	**14.4**	**6,700**	**0.44**	**0.21**	**17.4**	**15.8**	**0.37**

Notes:
1. The Mineral Resource is reported and classified in accordance with the JORC Code (2012).
2. The Mineral Resource is contained within the Cook Islands Exclusive Economic Zone.
3. Mineral Resources have been rounded to reflect their confidence. Some totals do not add up exactly due to rounding.
4. Abundance is the wet weight (kilograms) of polymetallic nodules per square metre.
5. Dry tonnages were not estimated, free moisture levels (i.e. not water of crystallisation) vary but are in the order of 30% on a wet basis.

7.11.2 Cut-off

The Mineral Resource has been reported at a cut-off of 5 kg/m^2 nodule abundance, which was selected based on consideration of previous studies of comparable deposits (Clark et al., 1995; Lipton, Nimmo and Parianos, 2016; Lipton, Nimmo and Stevenson, 2021). Grade-tonnage-abundance curves are presented in Figure 7-19 for the total Mineral Resource (Inferred & Indicated).

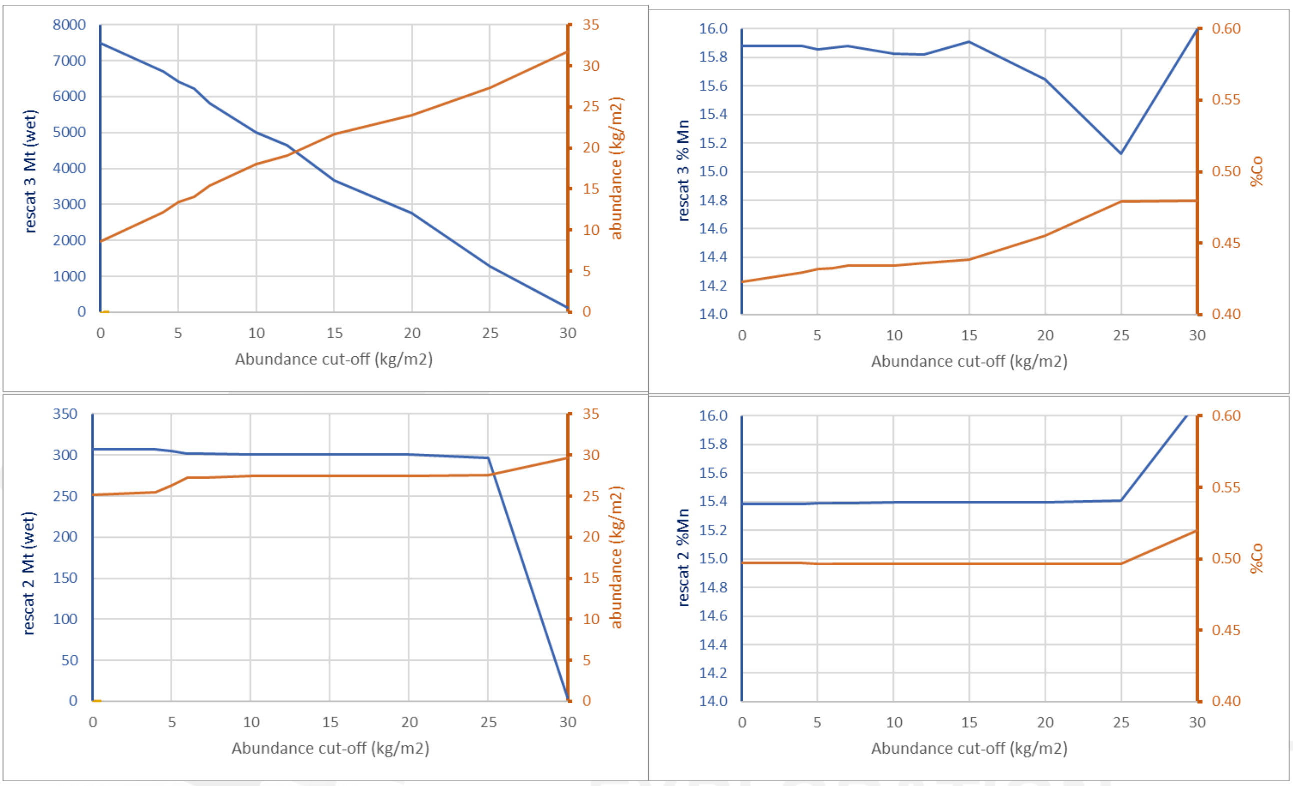


Figure 7-19: Grade–tonnage curves. rescat (resource category) 3 is Inferred, rescat 2 is Indicated.

The selection of the cut-off abundance does not consider partially developed technology that has been developed to concentrate nodules on the seabed (Parianos et al., 2014; Parianos, Berndt and Plunkett, 2014; Manocchio, Yu and Parianos, 2020; Yu et al., 2020). If such technology would be successfully developed, lower-abundance cut-off grades may become more appropriate.

7.11.3 Mining and Metallurgical Methods and Parameters

Four development studies previously published on the Cook Islands nodule deposit are covered in Section 3.4. These can be considered to be at a scoping level, as for example, none are supported by Indicated Mineral Resources (or Probable Ore Reserves) sufficient to cover hypothetical payback of development capital. Three of these studies (in 1996, 2010 and 2016) found development of a project to be ‘economically justified’, the fourth (in 2001) indicated that the project was uneconomic at prevailing cobalt metal prices (USD 15/lb vs USD 23/lb on 5 August 2022).

Globally, minerals harvesting of polymetallic nodules has not yet proceeded past the integrated pilot stage, but technical methods are not likely to be a serious issue in eventual economic development of polymetallic nodule resources. Integrated (collector, lift system and surface vessel) piloting of a nodule minerals harvesting system first took place in 1975 at a depth ~1,000 m on the Blake Plateau offshore Florida, USA, by Deepsea Ventures (Lipton, Nimmo and Parianos, 2016). Subsequent integrated pilot programmes were carried out in the CCZ in 1978 (4,500–5,000 m), and offshore South Korea in 2016 (Hong et al., 2021). In 2021, a collector test was conducted in the CCZ by ISA contractor GSR (Muñoz-Royo et al., 2022), and in late 2022, another integrated test was conducted by ISA contractor NORI recovering ~3,000 t of nodules (The Metals Company, 2022a). All piloted concepts have been broadly similar, with most using either a drill ship or a converted bulk carrier as the surface vessel, hydraulic or airlift riser with pipe based on drilling string used at similar depths for oil and gas exploration and a combination of towed collector sleds or self-driving tracked or screw-drive vehicles. Lifting concepts using cable and skips have been proposed (Xiao et al., 2019; Hong et al., 2021) but not piloted, although it is noted that sample dredging is in effect a simple form of cable lifting. Nodules are located offshore and thus have some logistical and operational parallels with offshore oil and gas (e.g. requirements for a floating production storage and offloading facility) and with blue ocean fishing (e.g. refuelling, reprovisioning and remanning of work vessels).

Nodules are located at significant depths (~5,000 m in the Cook Islands) but do not require overburden removal, rock cutting, or mine panel specific infrastructure and development. The location of nodules can also be measured accurately ahead of collection implying equipment utilisation could be more precisely managed. Dilution of nodules is unlikely in terms of inclusion of seabed clay-ooze due to the nature of hydraulic collector heads used in piloting (Office of Ocean Minerals and Energy, 1981). However, the Mineral Resource almost certainly includes areas of lower nodule abundance that would be inefficient to collect. It is reasonable to expect that these would be excluded in short-term mine plans as the nodules are relatively easily mapped from autonomous underwater vehicle (AUVs) or other towed acoustic-optical packages (e.g. Lipton et al., 2016, 2021; Kuhn and Rühlemann, 2021; Parianos et al., 2021; Parianos, 2022). As the samples used to estimate the Mineral Resource were taken on a regular grid, low abundance areas within the domain should have been sampled as well and will be excluded in the MRE via an abundance-based cut-off.

Trans-shipment of nodules from the main production vessel to bulk carriers is described and modelled in AMC Consultants, (2021). Large volumes of nickel laterite, iron ore fines and bauxite are transported by sea routinely; these ores need to be safe from the possibility of liquefaction in the hold (Maritime and Coastguard Agency, 2014; Maritime Cyprus, 2019; International Martime Organization, 2020; Parianos, 2022).

Reports on conceptual minerals harvesting for polymetallic nodules have been published for the NORI-D area (AMC Consultants, 2021) as part of an SEC (U.S. Securities and Exchange Commission) SK-1300 initial assessment for that project. In this concept, a series of tracked collectors follow the surface vessel along a coverage path pattern (Figure 7-20). The same report proposes an optimised schedule to harvest the NORI-D area. The schedule is presented at a coarse scale (4-year increments) and appears to exclude consideration of abyssal hill slopes and smaller knolls.

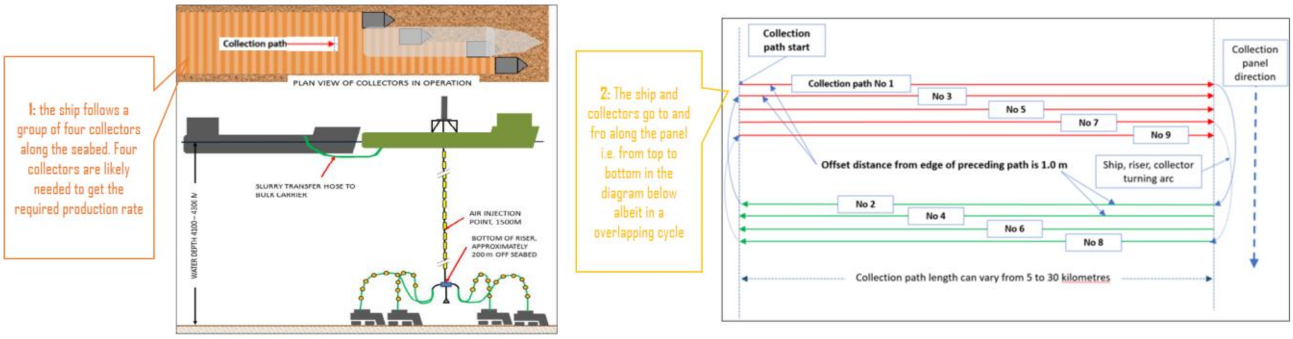


Figure 7-20: Nodule mineral harvesting concept. Source: (AMC Consultants, 2021).

To date, economic viability of a nodule minerals harvesting system has not been demonstrated for Cook Islands nodules. However, AMC Consultants (2021) provides economic indications for CCZ nodules (Table 7-13), albeit for a large-scale operation. They note that fuel prices have greatest impact on operating costs. The Metals Company (2022b) also announced economic terms for the small-scale start-up of nodule mining in the CCZ with EUR 150/wet tonne expected to decrease 20% by the time production reaches 1.3 million wet tonnes per annum. When the in-situ metal basket value of Cook Islands nodules (i.e. USD 600/dry tonne in McCormack, 2016) is compared with the operating costs in Table 7-13, the effective margin suggests that projects have a high likelihood of being economic. It is also worth noting that seabed minerals harvesting in the Cook Islands will likely have some logistical advantages over equivalent operations in the CCZ.

Polymetallic nodules are a bulk oxide type ore and are generally amenable to processing like other broadly similar ore types such as nickel-cobalt laterites and manganese oxide ores. Metallurgical processing of Cook Islands nodules is not known to have progressed past the desktop stage. Kojima (1996) was part of the JICA-MMAJ team in the Cook Islands – he summarises processing options for nodules in general but does not specifically mention the Cook Islands nodules. Smelting of Cook Islands nodules is unlikely to be effective as the high iron content of the nodules would report with the base metal alloy (B Zhao, 21 June 2022, personal communication). It is for this reason, that high iron limonitic nickel laterites tend to be processed using hydrometallurgical methods. Prior to applying for an exploration licence in 2021, Ocean Minerals submitted a 111 kg bulk sample to BGRIMM (Beijing General Research Institute for Mining and Metallurgy). BGRIMM has been carrying out research on various processes for extracting metals from nodules over many years. BGRIMM was to conduct processing tests on both the ammonium sulphate and ammonium carbonate versions of the Cuprion process (Seaborn, 2020). A Cuprion circuit could selectively extract the cobalt, nickel and copper, and the iron-manganese-rich tailings could in theory be subsequently smelted to produce a ferromanganese alloy (B Zhao, 21 June 2022, personal communication).

Economic viability of a metallurgical process route for Cook Islands nodules is not known to have been estimated let alone demonstrated. However, it is likely that economic mineral processing is possible. The processing cost included by AMC Consultants (2021) in Table 7-13 is for a pyrometallurgical process route which has higher power requirements and cost. A hydrometallurgical leaching circuit also has potential to extract some of the metals of interest not included in the MRE (REE, Mo and Ti) as by-products.

For Cook Islands nodules, Co is expected to be the most valuable metal. Cobalt demand is currently driven by its use in special steels used in the aviation industry as well as battery cathodes (e.g. Chu et al., 2022) and battery demand is currently being driven by growth in the use of electric vehicles, which could be roughly six-fold over the next 10 years (Figure 7-21).

Table 7-13: Published nodule mining and processing cost estimate for a 12.5 million wet tonnes per annum operation. Source: AMC and others (2021).

Section	Average Operating Cost over Life of Mine (USD million/annum)	Average Unit Cost (USD/t - wet tonnes nodules recovered)	Average Unit Cost (USD/t - dry tonnes processed)
Off-shore	240.7	19.3	25.40
Shipping	254.4	20.4	26.84
On-shore	1,286.2	103.1	135.71
Other	25.0	2.00	2.64
Total	**1,806.3**	**144.85**	**190.59**

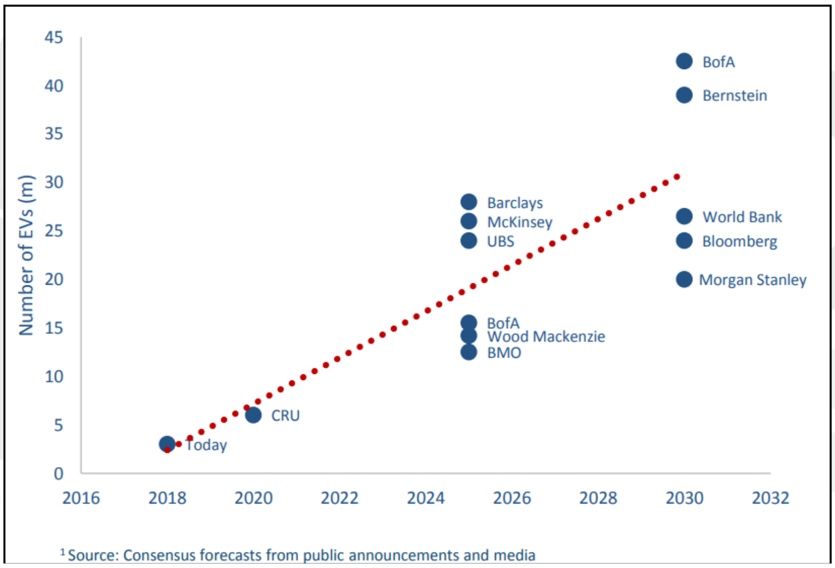


Figure 7-21: Forecasts for future electric vehicle growth. Source: Horizonte Minerals (2019).

7.11.4 Reasonable Prospects of Economic Extraction

In assessing the reasonable prospects for economic extraction, the Competent Person has considered conceptual mining, metallurgical and economic parameters as well as environmental and social aspects.

Environmental and social aspects form important aspects of reasonable prospects of economic extraction (RPEE). Due to their importance, section 8 is dedicated to environment, social responsibility and governance.

In accessing RPEE, the Competent Person has considered all the available environmental baseline studies and evaluated the political and world-view on marine mining. Although it may take some time to develop laws and appropriate mitigation for environmental risks, on balance, it is more likely than not that in the reasonably foreseeable future economic extraction may become reasonable.

All exploration and mineral harvesting operations would have to be undertaken from vessels. The mineral harvesting vessel would supply its own power requirements. It is assumed that water for mineral harvesting and processing (washing and sieving) would be sourced from the sea. Fine material (return sediment) would be returned to the seafloor at a yet-to-be-determined depth. The retained nodules would be stored in the ship's holds. It is anticipated that mining would be from a specialised deep-water mineral harvesting vessel. Material would be transported to shore by the mineral harvesting vessel or by transport bulk carrier vessels loaded at the site. Supply and crewing logistics as well as medical evacuation could be from nearby islands that are one to two days steaming distance (the shortest distance between two ports) away.

From the review in sections 7.11.2 and 7.11.3, it is more likely than not that minerals harvesting of the Mineral Resource estimated in this report would be technically and economically viable once appropriate studies are completed.

8 Environmental, Social Responsibility, Governance

Environmental and social aspects are some of the key modifying factors that impact RPEE. Seabed mineral exploration and mining is frequently in the mainstream news and new studies are constantly being published. This section summarises the knowledge and information available at the time of this report.

8.1 Environmental Setting and Current Issues

A common statement with regards to the marine minerals and the environment is that the current level of knowledge and understanding is low (Haugan, 2015; National Ocean Service, 2021; Ashworth, 2022). However, marine environmental programmes related to polymetallic nodules date back to the mid-1970s, e.g. the Deep Ocean Mining Environment study run in the CCZ by National Oceanic and Atmospheric Administration (NOAA; Bischoff and Piper, 1979). More recently, numerous environmental expeditions to the CCZ have led to a rapid increase in publications, e.g. UK Seabed Resources (2021), as well as more comprehensive ecosystem models (National Oceanic and Atmospheric Administration, 2021) and related regulations (International Seabed Authority, 2013).

This section covers what is currently known about the Cook Islands environmental setting.

8.1.1 Exploration Environment Programmes and Impacts

Exploration licences granted in the Cook Islands require applicants to submit detailed work programmes, including Environmental Management Programmes, that seek to describe the marine environment prior to any consideration of further development. The Environmental Management Programmes are reviewed by an independent panel (Licencing Panel) that includes selected experts in the deep-sea minerals marine environment. The programmes are also public documents and available from the SBMA website.

Cook Islands environmental legislation is broadly aligned with equivalents in other jurisdictions such as the ISA and New Zealand, and exploration activities are managed through a tier system at both Act and Regulations levels. Activities expected to have minimal impact (such as MBES survey, box coring and FFG sampling) are permitted under the exploration licence (an expedition notice is required to be submitted beforehand). Activities likely to have greater impact (such as large-scale sample dredging) require an environmental consent, and activities such as trial mineral harvesting will require an approved and fit-for-purpose Environmental Impact Assessment (EIA) and a comprehensive Environmental Management and Monitoring Programme.

Draft standards and guidelines seek to encourage innovation, focussing on reducing exploration impacts to as low as reasonably possible, e.g. through use of lower-impact sacrificial ballast.

8.1.2 Environmental Impacts from Minerals Harvesting

The exact nature of impacts (or pressures) from minerals harvesting of nodules is still very much unknown due to a lack of existing examples, testing and studies.

Polymetallic nodule harvesting has only been demonstrated at pilot scale, with collectors with or without attached risers operating for a few hours or days. A list of relevant programmes is included in Section 7.11.4.

Conceptual views on minerals harvesting and associated impacts usually fail to properly express scale (both globally in terms of the deposit, and locally in terms of landform and deposit internal continuity), which is understandable given the spatial complexity of any likely operation. The pilot programmes of the late 1970s (Lipton, Nimmo and Parianos, 2016) as well as benthic impact experiments of the time (Lipton, Nimmo and Parianos, 2016; Jones et al., 2017) provide some useful information on plume extents and organism recovery, e.g. Figure 8-10, but these tests are predicated on technology that is unlikely to be used industrially in any near future.

8.2 Environmental Studies

The natural setting of the marine environment has been summarised by Fathom Pacific and ERIAS Group (2021). Little is known of the benthic communities of the Cook Islands seabed but the decades of studies in other nodule fields can be used as a proxy to help understand patterns of species diversity and abundance on abyssal nodule fields. Most of the Cook Islands nodule field is in a different benthic biogeographic zone to the CCZ, so differences in community composition are expected. However, the general environmental principles influencing biological distributions, and limiting factors to biomass, are likely to apply.

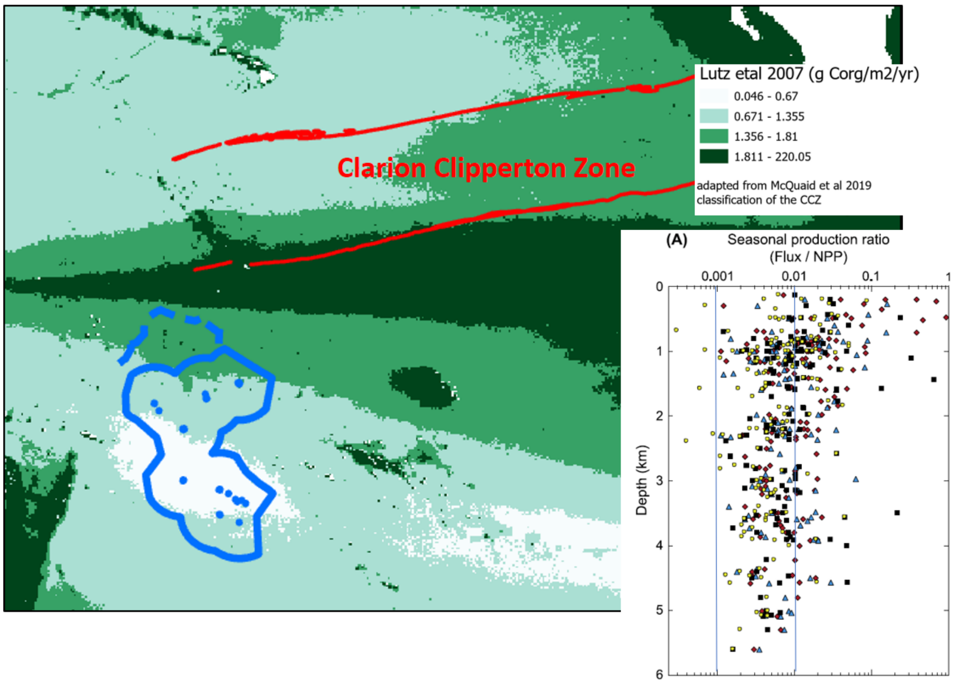


Figure 8-1: Net organic export in the Cook Islands and CCZ. Modelled from: Lutz et al.(2007); McQuaid, Washburn and Howell (2019). The dashed blue line is the Cook Islands Extended Continental Shelf submission.

One key differentiating factor is the relatively low rate of surface primary production in most of the Cook Islands, which is expected to result in low rates of particulate organic matter delivery to the seafloor (Figure 8-1), limiting nutrient sources for benthic organisms. While there may be low nutrient concentrations in the surface and midwater environment, the benthic boundary layer (water column close to the seafloor) can have locally, relatively high concentrations due to interactions with the seafloor. Sediment type in the much of the Cook Islands seabed (predominantly red-brown mineral clays) is another factor that is likely to differentiate biological communities from those in the CCZ where biogenic oozes are more common.

Discussion regarding the marine environment often relates to different areas and zones (Figure 8-2). This section of the report considers the benthic zone (seabed-overlying water) versus the pelagic (mid water) and surface zones.

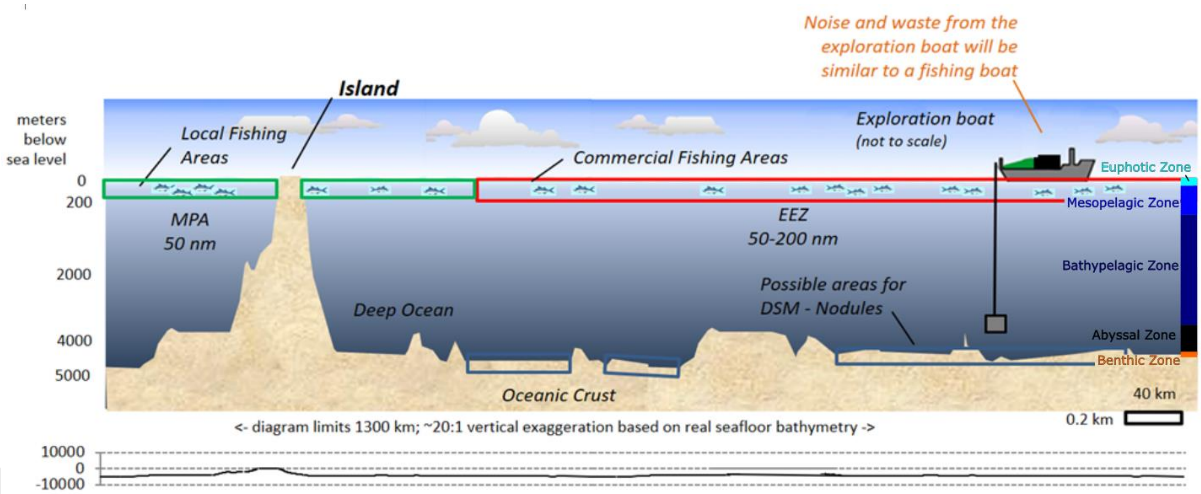


Figure 8-2: Schematic section of ocean zones and areas.

8.2.1 Benthic Zone

The average depth of the seabed within the Project Area is 5,103 m, well below the global average of 3,700 m (National Oceanic and Atmospheric Administration, 2023). Thus, the collective biomass of benthic communities in the Cook Islands abyssal basin are amongst the deepest globally. As observed in the CCZ, the abundance and body size of organisms decreases below ~>4,000 m ocean depths. Communities are dominated by microfauna (bacteria) and meiofauna communities, but this does not necessarily translate to reduced biodiversity. Studies from the CCZ have revealed a high diversity of organisms that are characteristic of nutrient-limited niche environments, albeit with many species in sampling campaigns represented by singleton records. The species sample record is currently very limited in the Cook Islands, but the animals described by JICA-MMAJ (2001) are of very similar types to those described for Kiribati and the CCZ (Tilot et al., 2018; Simon-Lledó et al., 2019, 2020; Bribiesca-Contreras et al., 2022).

Nodules provide a hard substrate for the attachment of sessile invertebrates. Prokaryote microfauna communities are expected to be key to sediment biogeochemistry and hence overall ecological function in the abyssal plains ecosystem but studies to date in the Cook Islands are non-existent. Eukaryote sediment infauna is expected to be dominated by organisms in the meiofauna size range, but this is similarly under-researched. Some macrofauna sediment infauna have been logged by JICA-MMAJ (McCormack, 2016), and based on the CCZ and Indian Ocean Nodule Field (IONF) this may be dominated by polychaete worms, crustaceans (isopods, amphipods and tanaids), and molluscs (bivalves and gastropods; e.g. Ingole et al., 2001; Stoyanova, 2014). Furthermore, Glover et al. (2002) reported near-ubiquitous distributions of 30–40 polychaetes (90% of the total polychaete assemblage) among sites that were 3,000–4,000 km apart.

Fathom Pacific and ERIAS Group (2021) considered that the patchiness and low abundance of abyssal fauna, combined with technical sampling and taxonomic constraints, would complicate efforts to construct an exhaustive baseline species list. Rather, indicators of ecosystem function and condition are required to inform impact assessments and design monitoring programmes that can be operationalised. The extensive work carried out within the CCZ has shown that traditional taxonomy is complex and labour intensive (Mullineaux, 1987; Thiel et al., 1993; Veillette et al., 2007; Miljutina et al., 2010; Radziejewska, 2014; Raschka et al., 2014; Stoyanova, 2014; Kamenskaya et al., 2015; Martinez-Arbizu, 2015; Vanreusel et al., 2016; De Smet et al., 2017; Gooday et al., 2017; Pape et al., 2017). The patchy distributions and generally low abundance of fauna also represents a major sampling and interpretation challenge. Environment DNA (eDNA) approaches, genetic taxonomy tools, and ecosystem-based assessments have proven to be useful in bolstering, and in some areas replacing, traditional taxonomic style studies.

8.2.1.1 Microfauna Composition and Function

As discussed in Fathom Pacific and ERIAS Group (2021), microfauna (bacteria, archaea, and microscopic eukaryotes <32 μm in size) are key to ecological function in deep-sea sediments. Although a microbiological survey has not been reported for the Cook Islands, organisms in this size range are typically orders of magnitude more diverse and abundant than any other size range. Microfauna plays a key role in carbon cycling and the microbial food web, mediating the transfer of energy from suspended and sedimented detritus to the larger size ranges (e.g. Figure 8-1). Biogeochemical processes described by the interactions between oxygen, nutrient and physicochemical characteristics of sediments, and the biological activity of microfauna and other size ranges such as nutrient recycling and bioturbation, are key to the maintenance of ecological function.

Genetic techniques are critical to understanding microbial communities, and sediment biogeochemistry is key to understanding ecological functioning of those communities. In recent times, next-generation sequencing technologies have enabled the development of eDNA techniques which target intracellular and extracellular DNA directly from sediment samples. These DNA techniques generate biodiversity indices and allow analyses based on phylogenetic trees.

Microfauna are also the most likely source of marine genetic resources, genetic material that may be of value outside of marine minerals (Rabone et al., 2019, Hayes, undated, Leary et al., 2009). In mid-2022, SBMA partnered with academic institutions in the UK and Pacific region to research marine genetic resources in a programme called the DEEPEND Project.

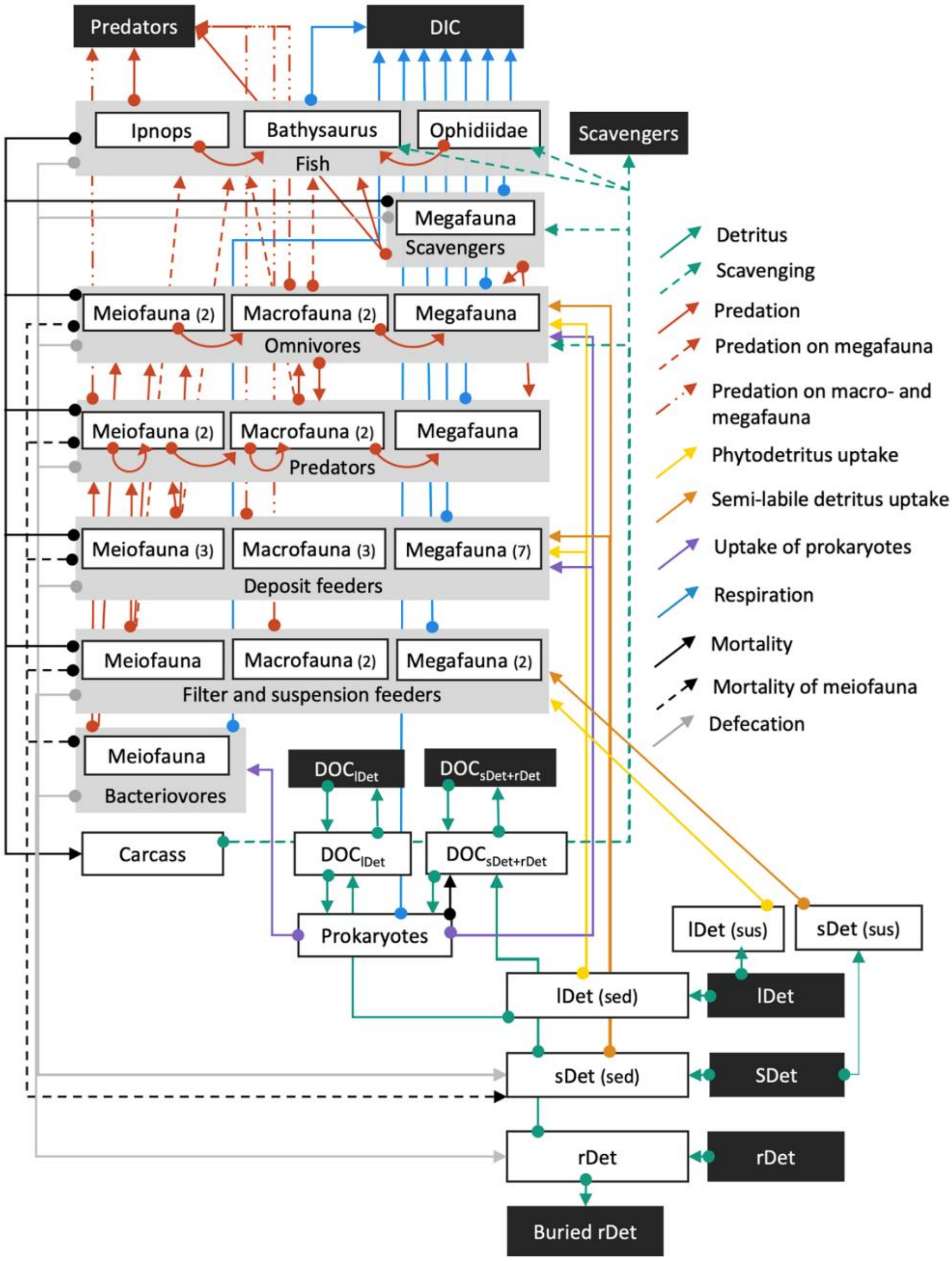


Figure 8-3: Schematic representation of an abyssal seafloor food web showing the prokaryote transfer of detrital food sources to large organisms. Source: de Jonge et al.,(2020). DOC = dissolved organic matter, lDet (sus) = suspended labile detritus, lDet (sed) = labile detritus within sediments, sDET (sed) = semi-labile detritus in the sediments, rDet = refractory detritus.

8.2.1.2 *Meiofauna Composition and Function*

While not yet studied in the Cook Islands, meiofauna (32–500 µm or 0.032–0.5 mm) represent the size class mostly likely to help characterise ecosystem composition and function due to their relatively high abundance and ease of sampling compared to macro- and megafauna. In the CCZ, deep-sea meiofauna communities tend to be dominated by Loricifera and

Tardigrada, Copepoda, Kinorhyncha, Nematoda, and Foraminifera. Meiofauna generally play a role in the transfer of energy from bacterial communities to macro- and megafauna. Nematodes are typically the most abundant meiofauna in deep-sea sediments. In the central Pacific, nematodes constitute 44–56% of the total meiofauna (Lambshead and Boucher, 2003). The majority are deposit-feeders with diverse feeding specialisations that maximise partitioning of limited food resources (Gourbault and Renaud-Mornant, 1990).

The taxonomic identification of meiofauna is a highly specialised and laborious field affected by globally diminishing expertise. As mentioned previously, the previous focus on taxonomic treatments of meiofauna, while advancing the taxonomic field, has made little progress on advancing understandings of ecological function and the use of the information to inform decisions about environmental management of mining (Fathom Pacific and ERIAS Group, 2021). Radziejewska (2014) exhaustively summarised the state of knowledge of deep-sea meiobenthos diversity and community composition. A recurring observation in deep-sea meiofauna studies is that rare and new species of meiofauna, represented by singletons or small numbers of individuals, prevail in any new sampling of the deep-sea environment. For example, in a presentation on copepods at a 2015 ISA-convened workshop of meiofauna taxonomists and contractors, Martinez-Arbizu (2015) documented 677 species, 99.3% of which were new to science and 56.3% of which were represented by a single individual.

In the CCZ, nematodes are reported to constitute the vast majority of the meiofauna (Gourbault and Renaud-Mornant, 1990; Radziejewska, 2014; Stoyanova, 2014), with harpacticoid copepods the second most abundant group, (but only at ~5–8% of total abundance; Radziejewska, 2002). Numbers of nematode species for a given study often reach into the tens to hundreds in both the CCZ, IONF and South Pacific, e.g. Stoyanova (2014), Miljutina et al. (2010), Singh, Hodda and Ash (2013), and Lambshead and Boucher (2003).

Fathom Pacific and ERIAS Group (2021) note that the high variability in meiofauna results is indicative of patchy distributions of meiofauna, varying attention and skill levels applied to taxonomy, and sampling issues that limit comparability. To contextualise the figures above for CCZ nematode richness, comparisons with other ecosystems are made in Table 8-1.

Table 8-1: Nematode species numbers in different ecosystems

Ecosystem	# Species	Comments
Abyssal plains with nodules	80–500	CCZ, IONF, South Pacific per above references
Other non-nodule abyssal provinces	~80–150	Lambshead and Boucher (2003); Miljutina et al. (2010)
Hydrothermal vent mussel beds, east Pacific Rise	17	14 genera and 11 families (Copley et al., 2007)
Cold seeps	30	(ChEss, 2010)
Tropical Australian mangrove systems	205	Alongi (1987)
Sandy beaches in Australia and Europe	~58–108	Nicholas and Hodda (1999); Gheskiere et al.(2004)
Rainforest soils	up to 430	Ettema et al. (1998)

The response of meiofaunal abundances to fluxes in the concentration of photosynthetically derived particulate organic carbon reaching the seabed seems well established (Thiel et al., 1989, NEIRA et al. (2001), Rex and Etter (2012) and Kalogeropoulou et al. (2010). It is thus expected that meiofauna abundances in the Cook Islands will be lower than in the

CCZ based on Figure 8-1. Evidence from the CCZ also indicates that meiofauna communities are spatially variable (patchy distributions, variability at small spatial scales equivalent to that at large spatial scales) and fluctuate temporally in response to environmental conditions.

Radziejewska (2014) reported total meiofauna density in the wide range of 10–200 individuals per 10 cm^2 in deep-sea sediments in the CCZ, which is one to two orders of magnitude lower than meiofauna density recorded in shallower marine waters and continental shelf regions. Singh, Sautya and Ingole (2019) report comparable nematode density (72 and 91 ind. per 10 cm^2) from nodule areas of the Indian Ocean.

The evidence for variance between nematode density in nodule-bearing vs nodule-free areas is equivocal, with Miljutina et al. (2010) and Stoyanova (2014) reporting less in CCZ nodule-bearing areas, and Gourbault and Renaud-Mornant (1990) finding no difference.

In the French contract area of the CCZ, total nematode density in 2012 was significantly higher than it was in 2004, although nematode diversity was lower in 2012 (Miljutin, Miljutina and Messié, 2015). This was driven mainly by an increase in density of non-selective deposit-feeders and led to the difference in surface primary productivity.

Fathom Pacific and ERIAS Group (2021) conclude that evidence from the CCZ also suggests that any new meiofauna sampling in a new deep-sea province is expected to yield species new to science and is unlikely to exhaustively define taxonomies on a time scale of a single exploration programme of work. A key learning from the CCZ experience is that matters of taxonomic identification should not overwhelm the key requirement of assessing ecological function, establishing large area indicators of environmental condition, and multi-contractor activities contributing to regional assessment.

8.2.1.3 Macrofauna Composition and Function

A major challenge with macrofauna (0.5–20 mm; note JICA-MMAJ used 0.5–40 mm) is their effective sampling. Nonetheless, macrofauna composition found in the Cook Islands by JICA-MMAJ (2001) is consistent with findings from long-term studies in the CCZ that benthic macrofauna is usually dominated by four classes: Polychaeta (class of phylum *Annelida*), *Crustacea* (subphylum of Arthropoda), Bivalvia and Gastropoda (both classes of phylum Mollusca). Among the crustaceans, the orders Isopoda, Amphipoda and Tanaidacea are typically the most abundant. These classes and orders typically constitute as much as 90% of the macrofauna diversity in the CCZ. Notably, very similar community composition and relative dominance at these high levels of taxonomic identification were recorded from the Indian Ocean INDEX site (Ingole et al., 2001).

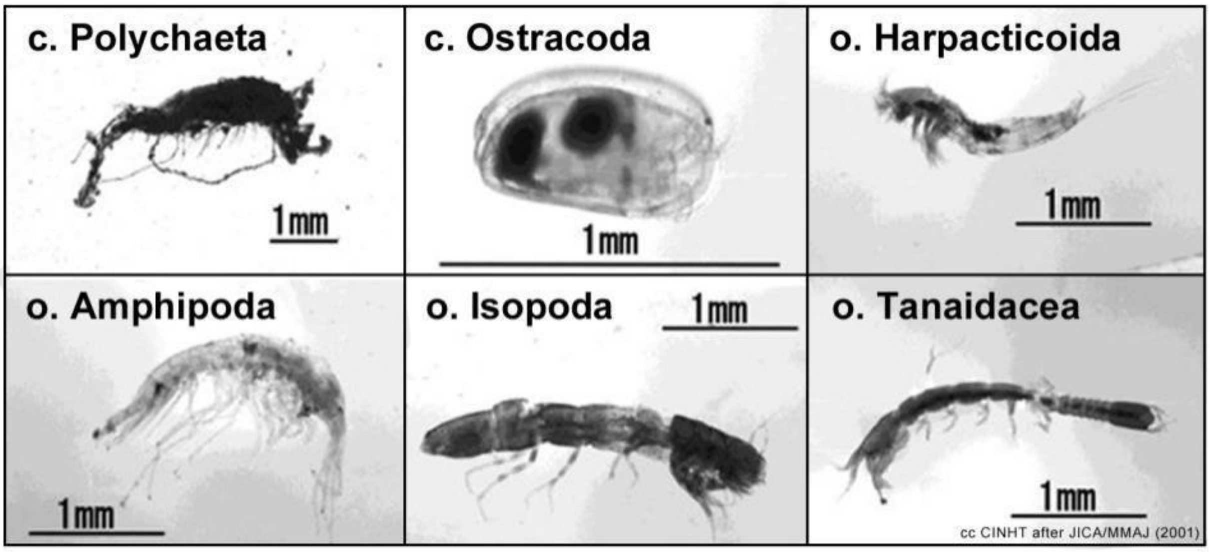


Figure 8-4: Example macrofauna from the Cook Islands. Sources: JICA-MMAJ (2001) and McCormack (2016).

Even at the species level of identification (Glover et al., 2002) showed similar near-ubiquitous distributions among Pacific abyssal basin polychaetes with 30–40 species (90% of which were new to science) making up 90% of the assemblage at sites separated by distances of 200–3,000 km. Indeed, this phenomenon of large geographic distributions of novel or previously undescribed taxa is a recurring theme of deep-sea benthic biology where singleton records of a new species are presumed to have restricted distribution, but then subsequent sampling uncovers the same species across large areas. However, Glover et al. (2002) also acknowledged the likelihood that under-sampling is likely masking any regional differences. This is a common attribute of deep-sea macrofauna sampling which stems from the fact that deep-sea benthic fauna is diverse and that there are a high number of rare species (Hessler and Jumars, 1974; Paterson et al., 1998). Genetic tools have also revealed high diversity and rarity. Raschka et al. (2014) reported that 25% of all polychaete specimens recovered from extensive sampling in the CCZ were represented by singletons.

Bearing in mind the above comments, it is notable that the tens to low hundreds of polychaetes species within Figure 8-5 compare with figures for polychaete species diversity in continental shelf and slope sediments of 319 species in Portugal (Martins et al., 2013), 428 species in the North Sea (Quiroz-Martinez, Schmitt and Dauvin, 2012) and 554 species in the Gulf of California (Hernández-Alcántara et al., 2014).

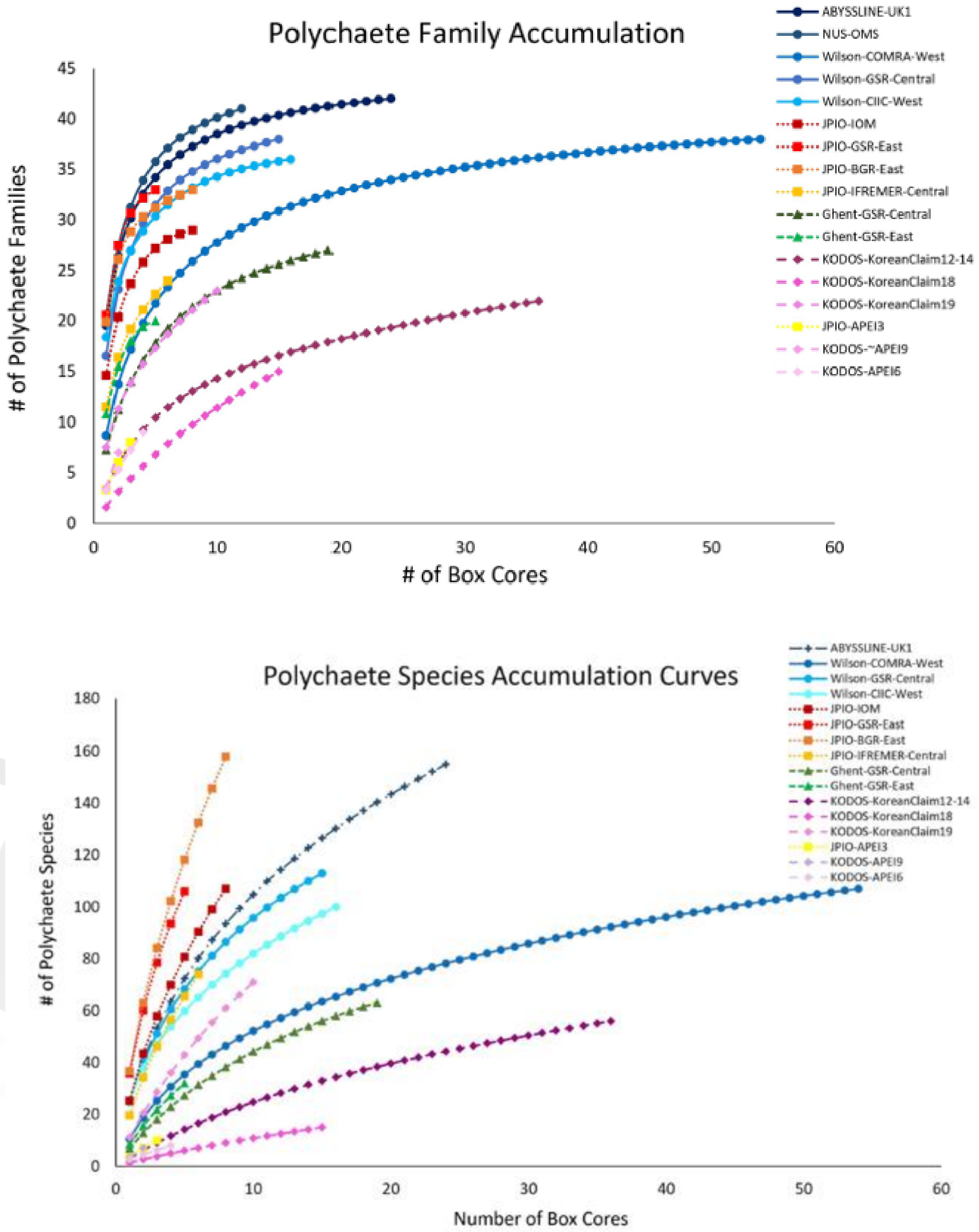


Figure 8-5: Polychaete accumulation curves in CCZ contract areas. Source: Washburn et al., (2021).

An alternative approach to detailed morphological taxonomy is to use a genetics approach, but initial studies at least should be expected to find high diversity among rare samples. For example, of the 233 identified polychaete Molecular Observable Taxonomic Units (MOTUs – putatively unique genetic sequences as a proxy for 'species') in the German and French CCZ contract areas, 60% were singletons and 12% were shared between claim areas ~1,300 km apart (Janssen et al., 2014). Similar results were reported for isopods: 70% of the 96 MOTUs identified were represented by singletons, but in this case only 2% were shared between claim areas. Decreasing the spatial range to 60 km between a potential mining area and a preservation reference area, similarity between MOTUs increased to 27% for polychaetes and 13% for isopods (Raschka et al., 2014).

Based mostly on the CCZ, macrofauna abundances range from the high tens to high hundreds per square metre (International Seabed Authority, 2014; Stoyanova, 2014). Similar to meiofauna, the diversity and abundance of macrofauna vary in response to organic (phytodetrital) input (Levin and Gage, 1998; Levin 1991) and this response has also been documented for foraminifera (Enge et al., 2011). Benthic foraminifera likely play a significant role in the cycling of POC through infaunal food webs and may ingest up to 10% of the total flux of organic matter (Altenbach, 1992).

In a recent analysis of 477 BC samples across multiple contract areas of the CCZ, Washburn et al. (2021) identified multiple scales and sources of spatial and temporal variability, sampling-related problems in interpretations, high occurrence of taxa being represented by singleton or doubleton specimens, and overall cited major impediments to 'understanding baseline conditions of macrofaunal biodiversity'. Washburn et al. (2021) suggest that 'much more extensive macrofauna sampling' is required, but also hinted at the landscape-scale, habitat-based approaches that relate to the drivers of infaunal distributions. Such conclusions need to be borne in mind when considering embarking on a single-licence holder baseline macrofauna study.

8.2.1.4 Megafauna Composition and Function

Megafauna (>2 cm or >4 cm for the historical JICA-MMAJ work) is visible to humans and Fathom Pacific and ERIAS Group (2021) note that megafauna is often the focus of stakeholder interest in the deep-sea, including the topic of the apparently low abundances in the Cook Islands. Ecologically, megafauna is among the least abundant and lowest diversity groups, owing principally to the effects of pressure and lack of food resources.

In 2000, JICA-MMAJ (2001) undertook the most comprehensive biological survey in the Cook Islands to date. This included an FDC (towed camera) survey that identified the following five phylums and eight biogroups (down to order), as well as trace fossils of mounds, faeces and trails (Figure 8-6, Figure 8-7 and Figure 8-8).

i. Phylum Porifera → (**sponge -** 593 individuals seen in 2000 FDC programme)

ii. Phylum Cnidaira

Class Scyphozoa → (**jellyfish** - 10)

Class Anthozoa

Order Pennatulacea → (**seapen**)

Order Actiniaria → (**anemonefish**)

iii. Phylum Anthropoda

Class Crustacea

Order Macrura → (**shrimp** - 74)

iv. Phylum Echinodermata

Class Holothurioidea → (holothurian or **sea cucumber** - 70)

Class Euasteroidea→ (now an unused subclass under Asteroidea, **starfish** - 44)

v. Phylum Vertebrata

Class Osteichthyes → (**fish** - 60).

The appearance of a total 733 benthos individuals was equates to an average appearance per hour (based on a FDC tow speed is ~1 knot) of ~27 individuals, ~5 times the number of observed planktonic and nekton organisms.

It was noted that many sea cucumbers, mounds and trails were predominantly observed near outcrops of crust, while faeces were observed where zones of abundant small polymetallic nodules occur. As sea cucumbers do not form mounds, many sediment-eating organisms that were not observed by FDC probably inhabited the area and formed the mounds (both on the crusts and on the sediments between the crusts).

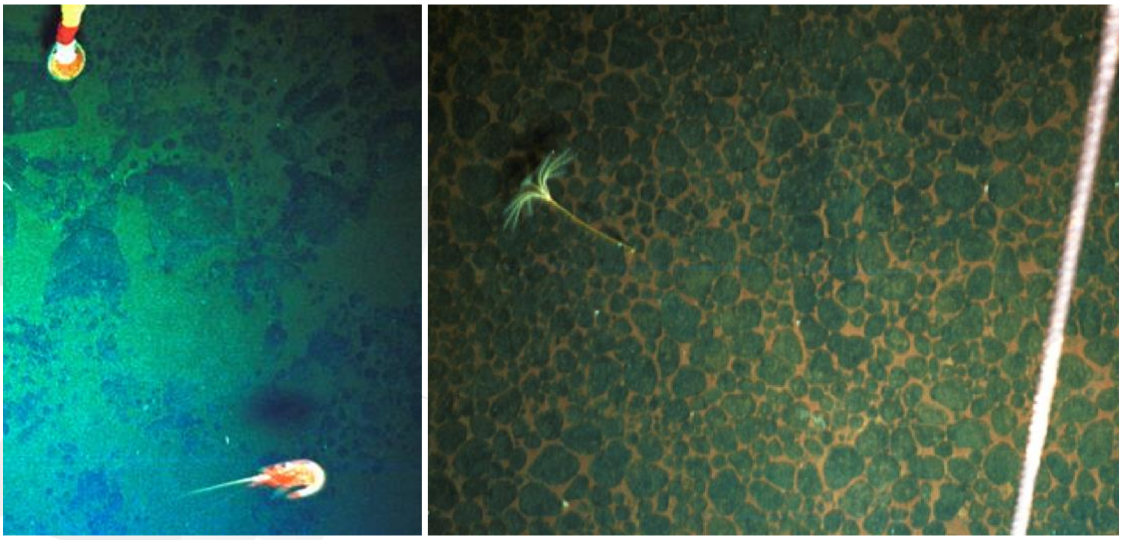


Figure 8-6: Examples of megafauna – shrimp (L) and crinoid (R). Note that weight is estimated at 5 cm diameter, coloured rope sleeve segments at 10 cm long and plain rope at 1.5 cm diameter.

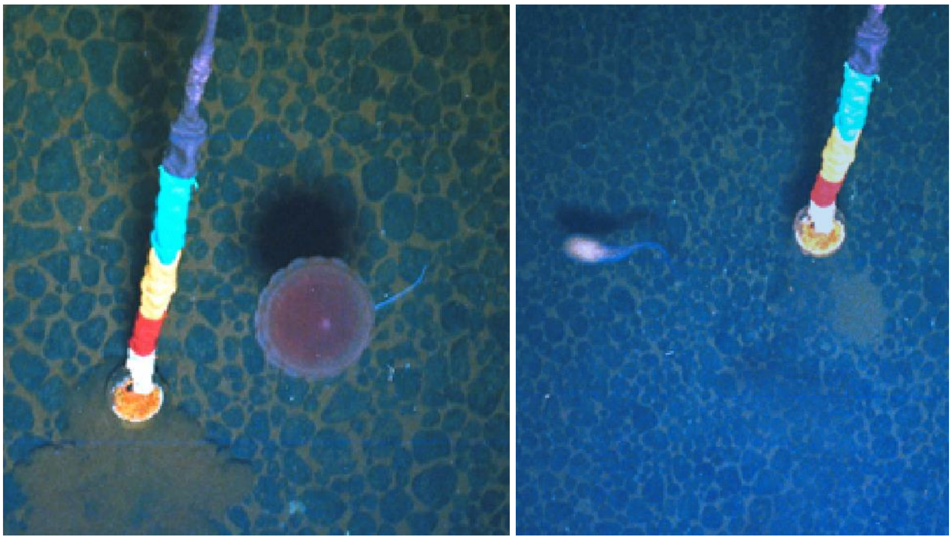


Figure 8-7: Examples of megafauna – jelly fish (L) and rat tailed fish (R).

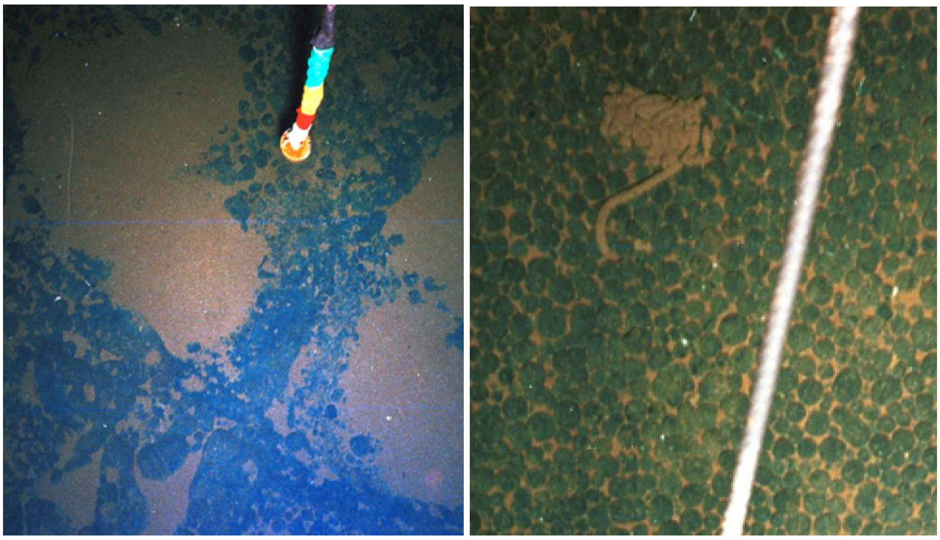


Figure 8-8: Examples of seabed trace fossils – mound (L) and waste case (R).

The above results are broadly compatible with results from the CCZ summarised by Fathom Pacific and ERIAS Group (2021). Bottom photographs at the DOMES A, B and C sites (4,400–5,400 m depth), covering a total area of 81,355 m^2, showed that echinoids (urchins), ophiuroids (brittle stars), actiniarians (anemones) and holothurians (sea cucumbers) made up at least 80% of the total megafauna. Porifera (sponges), Cnidaria (anemones and medusae), Crustacea, Bryozoa and Holothuroidea were the dominant taxa reported by Bluhm (1994). The main groups colonising nodules were Porifera, Crinoidea (feather stars), Gorgonaria (sea fan corals) and Antipatharia (black corals). Some of these growths were colonised by other forms such as Cirripedia, mobile Amphipoda, Isopoda and Ophiuroidea to make species complexes. Serpulidae, Brachiopoda, Actiniaria, Corallimorpharia and Ascidiacea were other common epifauna groups on hard substrates. On soft sediment substrates, Holothuroidea, Echinoidea, Asteroidea, Ophiuroidea and Crustacea were the main taxa (Bluhm, 1994). A dominance of holothurians, which are deposit feeders (ingest particles from the sediment), in megafauna communities was also reported in the Tonga Offshore Mining Limited (TOML) contract areas of the CCZ (Simon-Lledó et al., 2020). The dominance of deposit feeders in the CCZ is consistently reported in megafauna studies. However, in Kiribati, suspension feeders (ingest particles from suspension) were most abundant, potentially as a result of the relatively high near-bottom currents modelled for this area (Simon-Lledó et al., 2019).

In 1,523 seabed photographs in the CCZ, Bluhm (1994) recorded 80 megafaunal taxa (some morphospecies and some formal species). By way of comparison, 110 taxa were identified from 3,309 seabed photographs and 18 hours of video in the central South Pacific and the disturbance and recolonisation area of the Peru Basin by the same authors, 53 of which were common to the CCZ. From an unknown number of photographs in the CCZ only, Tilot (1992) cited in Bluhm (1994) recorded 228 'species', indicating relationships between species diversity and sampling effort and spatial variability as seen in macrofaunal communities. Simon-Lledó et al. (2020) analysed 20,667 seafloor images and identified 256 megafauna taxa excluding foraminifera (which were the numerically dominant megafauna but excluded from their analysis). Megafauna morphospecies curves reported by Jones et al. (2019) show considerable maturity in characterisation (Figure 8-9), even if genetic and taxonomic typing has some way to go (Bribiesca-Contreras et al., 2022).

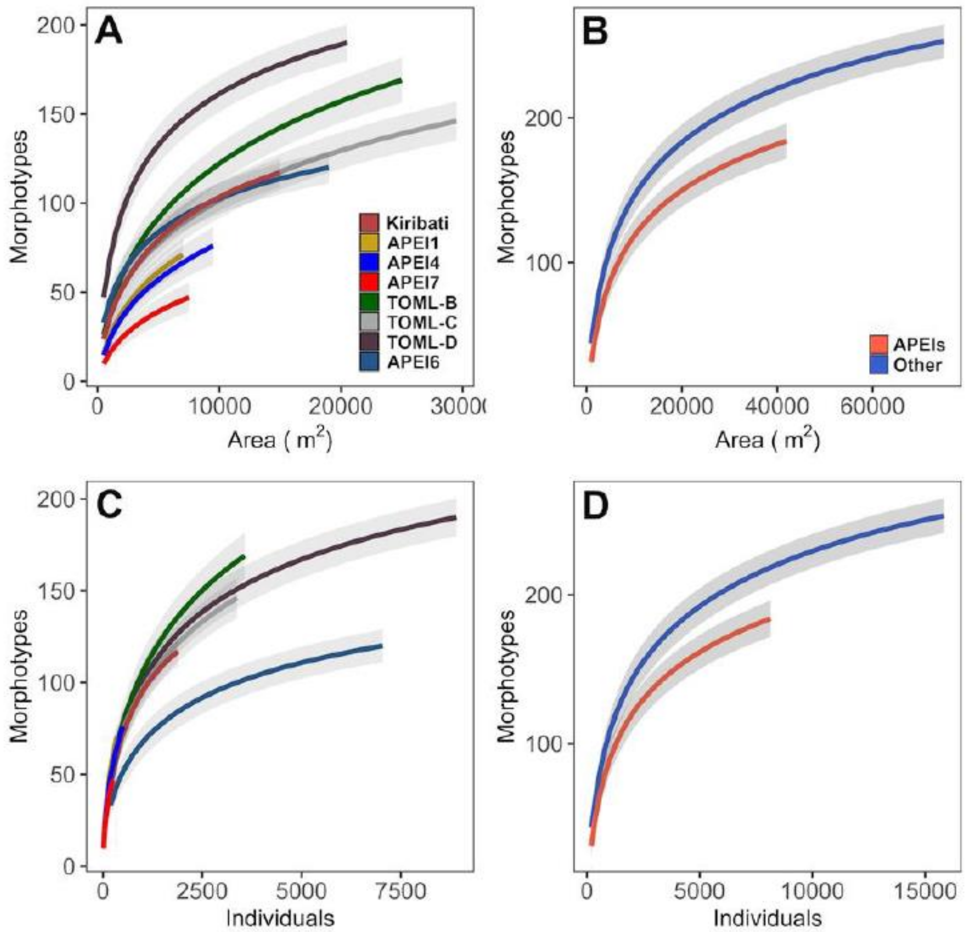


Figure 8-9: Megafauna morphospecies curves from the CCZ and Kiribati. Source: Jones et al. (2019), Kiribati data are from the Phoenix and Northern Line Islands areas.

Estimates of total megafauna density (all animals >2 cm or >4 cm in some studies) reported in multiple studies in the CCZ are highly variable. At the low end of the range, Tilot (1992), Heckler and Paul (1977), Pawson (1988), and Foell et al. (1986) (all cited in Bluhm, 1994) report values of 287–498 ind. per 10,000 m^2. At the mid-levels of the range, (Morgan et al., 1993) cites values of 263–1,140 ind. per 10,000 m^2. At the high end of the range, Bluhm (1994) cites considerably higher values of 3,081–4,165 ind. per 10,000 m^2. Bribiesca-Contreras et al. (2022) reported maximum megafauna density (excluding foraminifera) in the TOML areas of 0.44 ind. m^2 (4,400 ind. per 10,000 m^2). It is potentially instructive that this gradient of increasing megafaunal density reported in scientific papers is positively correlated to the year of publication, which is probably associated with increasing image quality and taxonomic knowledge. Thus, the relatively low observation rate reported by JICA-MMAJ (2001) might be expected to increase if modern high-resolution imagery is used.

8.2.1.5 Foraminifera Composition and Function

Foraminifera occur in all marine environments and exist in meiofaunal, macrofaunal and megafaunal size ranges; however, to date they appear to be unreported from the Cook Islands. In the meiofaunal–macrofaunal size range, foraminifera can comprise over half of the total infauna abundance and are diverse in the CCZ.

Xenophyophorida are agglutinated protists that have previously been classified as sponges or their own distinct group, but are now recognised to be within the phylum Foraminifera. In the deep-sea environment, benthic foraminifera are common in sediments and hard substrate communities (Gooday et al., 1992) and they are particularly abundant in the CCZ nodule fields (Kamenskaya et al., 2015). Benthic foraminifera (classed as xenophyophores by the authors) were observed in 70% of seabed photographs and 30% of BCs in the Russian claim area (Gooday et al., 2017).

Megafauna-sized foraminifera are expected to play important roles in micro-habitat formation (e.g. benthic flow modification, provision of stable substrate, trapping of particulate organic matter) and in trophic linkages with meiofauna and macrofauna (Gooday et al., 1992; Levin, 1991). Indeed, assemblages of metazoans and foraminifera inhabit the cavities and interstices of xenophyophore tests (Kamenskaya et al., 2015) in a similar way that sponge stalks have been found to harbour diverse meiofauna associations (Beaulieu, 2001). Evidence from DNA testing indicates that some foraminifera are widespread throughout the world's oceans (LeCroq et al., 2009). Gooday, Goineau and Voltski (2015) observed that some foraminifera morphospecies are widely distributed across the world but other species are known only from Pacific or CCZ samples and may be endemic. Similarly, Nozawa et al. (2006) reported clear differences between Pacific and Atlantic assemblages of infaunal foraminifera. Disturbance–recruitment experience at other deep-sea locations suggest that foraminifera may be among the first groups to recolonise disturbed sites (Van Dover, Berg and Turner, 1988). Given they are common and respond to environmental gradients, foraminifera have been proposed as a useful indicator of environmental disturbance and a foraminifera-based index has been applied in oil-and-gas settings (O'Malley et al., 2021).

Larger epifaunal foraminifera, most notably the xenophyophores and komokiaceans, and nodule-attached foraminifera, are discussed further in the megafauna section as they generally occur in agglutinated forms >2 cm.

The average density of the megafaunal foraminiferal xenophyophores: 1,600 ind. per 10,000 m^2 (with a maximal value of 120,000 ind. per 10,000 m^2 ;Kamenskaya et al., 2015) appears to be significantly higher than the metazoan megafauna in the CCZ. The ecological role of this group is under-appreciated at this time, mainly because taxonomists disagree about classification and their biology is so unknown that it is not even possible to distinguish living from dead colonies in imagery. However, they are the most abundant biological structure on the seabed and Levin (1991) indicates that they likely harbour communities of meiofauna and thus are likely to represent islands of disproportionately high biological activity in their immediate vicinity. Therefore, they are likely to be important in the benthic cycling of nutrients (Altenbach, 1992).

8.2.2 Pelagic and Surface Zones

Per the review in Fathom Pacific and ERIAS Group (2021), the Cook Islands pelagic environment is part of the large pool of Western South Pacific oceanic water. Biochemically, the oceanic waters of Cook Islands are part of the large South Pacific Subtropical Gyre Province that spans from Easter Island to Samoa (Longhurst, 2007). The country is located to the south of, and potentially outside the influence of, the South Equatorial Current (SEC). The dominant midwater masses are the cold Antarctic Intermediate Mode Water (~1,000–3,500 m depth) and Antarctic Bottom Water (from ~3,500 m depth to the seabed; Sokolov and Rintoul, 2000; Bostock et al., 2013). At abyssal depths, there is a relatively stable temperature, and any variation would be driven by large-scale processes such as seasonal variation and climatic events such as cyclones and El Niño–Southern Oscillation (ENSO). The most ecologically significant process in the pelagic zone is diel vertical migration, being the mass movement of micronekton from deep to shallow strata (0–200 m) at night, and their return during the day. This process brings these deep-dwelling species within foraging range of pelagic predators, where they constitute a large proportion of the diet of tunas and other apex predators, and the process contributes to 'the biological pump' that transports sunlight-derived energy down to the unlit deep-sea.

In Cook Islands, large-bodied predators such as tunas, billfishes and dolphinfish are of most interest to commercial fisheries. Sharks and cetaceans (whales and dolphins) also occur and there are 25 marine protected areas surrounding Cook Islands, including shark and whale sanctuaries (Ministry of Marine Resources, no date a; Ministry of Marine Resources, no date b). The Cook Islands oceanic environment also supports a diverse marine seabird fauna with regionally significant colonies of sooty terns, lesser frigatebirds, red-footed boobies, and red-tailed tropicbirds in the northern islands. The southern group maintains a large colony of red-tailed tropicbirds, great frigatebirds, red-footed boobies and brown boobies.

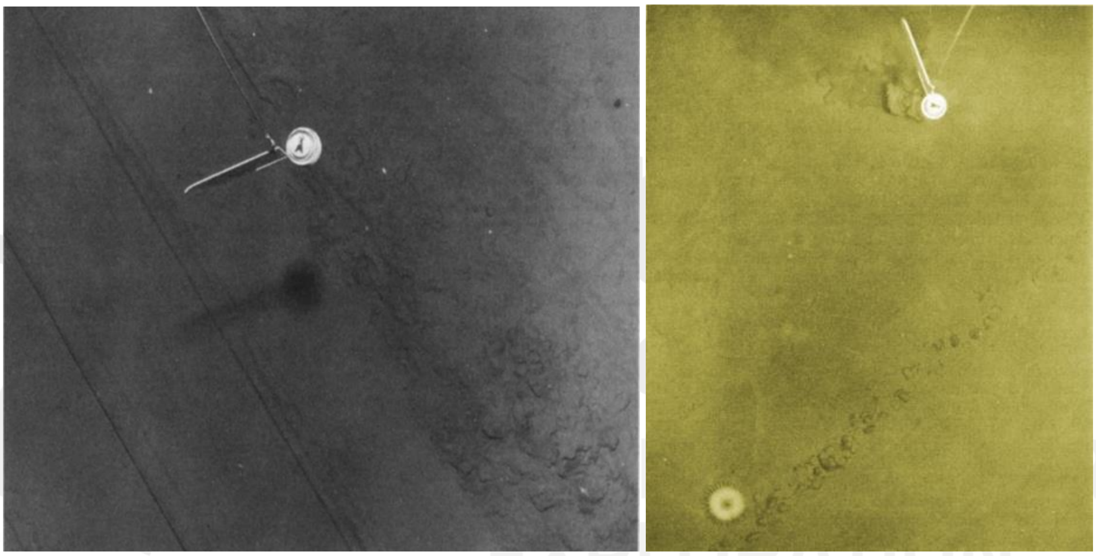


Figure 8-10: Seabed ~1 year after mining test in CCZ. Source: Ozturgut, Lavelle and Burns (1981) test by Ocean Management Inc. in 1978, reported by NOAA, compass is 8 cm in diameter.

In 2018 and 2021, BGR (2018) and Global Sea Mineral Resources (2018) conducted tested collector prototypes, then in 2022, The Metals Company (2022) conducted and integrated mining test. When post-test surveys are complete, it may prove possible to apply learnings from these to inform impact assessments in the Cook Islands (Mormede, Baird and Roux, 2021).

Lists of potential impacts and a description of possible issues related to them does not make them real, even if they are useful as checklists for modelling and monitoring programmes, e.g. as used in Fathom Pacific and ERIAS Group (2021). Cumulative impact assessment modelling (Dunstan et al., 2019) may help to put such list items in context (priority and uncertainty).

Compared to a typical terrestrial metals mines, a seabed polymetallic nodule minerals harvesting operation has some environmental differences.

Mineral harvesting is:

- very unlikely to produce mine waste or tailings as such (but will involve agitation of the seabed clay-ooze);
- very unlikely to involve the construction of any permanent or semi-permanent mine infrastructure (such as haul roads, shafts etc); and
- very likely to involve shipment of material from the Cook Islands to a metallurgical process plant overseas (i.e. join the existing seaborne trade of bulk oxide ores).

At this stage, the environmental impacts associated with metallurgical processing (including generation of plant tailings) are unknown. However, it is reasonable to assume that such impacts would be roughly similar to those from existing bulk oxide metallurgical process plants.

Per the Cook Islands governance framework (Section 8.4), development proponents need to supply an independently reviewed Environmental Impact Assessment prior to any consideration for an application for a minerals harvesting licence. The onus on the proponents to demonstrate that the development will not lead to serious harm in the marine environment.

8.3 Social Setting

As noted by Fathom Pacific and ERIAS Group (2021), investigation of polymetallic nodules and the associated harvesting opportunities is consistent with Cook Islands' national goals and strategies, which promote resource development while balancing the associated environmental and social impacts, including the Cook Islands Seabed Minerals Policy (2014), the Te Tarai Vaka Environment and Social Safeguards Policy, and the Te Kaveinga Nui (Cook Islands National Sustainable Development Plan 2016-2020).

8.3.1 Domestic Stakeholders

The people of the Cook Islands are the owners of the mineral resource as specified in the *Seabed Minerals Act 2019*. They are represented in effect by three institutions: Government, House of Ariki (and Koutu Nui) and the Church. These are detailed further in Table 8-2.

Table 8-2: Elected representatives of Cook Islanders and delegates. Source: Fathom Pacific and ERIAS Group (2021).

Stakeholder	Interest/influence
Cook Islands Government	
Seabed Minerals Authority (SBMA)	The *Seabed Minerals Act 2019* establishes the SBMA as a statutory agency of the Government of Cook Islands. The SBMA is responsible for the licensing of exploration and exploitation activities. Interface between the Government and the community is via the Cook Islands Seabed Minerals Advisory Board, comprised of a chairperson (appointed by the responsible Minister), the Seabed Minerals Commissioner, five members representing the island communities of Cook Islands, and additional members as required. The SBMA is responsible for issuing an exploration permit and must ensure that the principles of the *Environment Act 2003* are upheld, i.e. controlling the permitting of activities that have the potential to cause significant environmental impacts.
National Environment Service (NES)	The Cook Islands NES is the agency responsible for permitting, monitoring and enforcing environmental laws under the *Environment Act 2003.* The NES also plays an important role in research and stakeholder engagement in the areas of sustainable development of seabed mining in Cook Islands.

Stakeholder	Interest/influence
	The NES is responsible for approving seabed minerals development EIAs and setting conditions of the environment permit.
Marae Moana Council (MMC)	The *Marae Moana Act 2017* establishes the entire EEZ as an area to be managed for the primary purpose of protecting and conserving the ecological, biodiversity, and heritage values of the Cook Islands marine environment. The Marae Moana Council (MMC) and its Technical Advisory Group (TAG) and Coordination Office are responsible for the zoning of the marine environment and any associated regulations. The Council is chaired by the Prime Minister and comprises the opposition lead, representatives from the private sector, traditional leaders, the NGO sector, the religious sector through the Religious Advisory Council, as well as a representative from the Southern Cook Islands and a representative from the Northern Cook Islands. The TAG is comprised of representatives from the Office of the Prime Minister, NES, MMR (Ministry of Marine Resources), SBMA, Ministry of Transport, House of Ariki or Koutu Nui, and NGOs with marine science and social policy expertise. The Coordination Office sits within the Office of the Prime Minister and coordinates implementation of the Policy, any revisions required, and the development of the Marae Moana Action Plan. On Rarotonga, the MMC oversees implementation of the Marae Moana Policy (2016–2020) and associated Action Plan relating to the Rarotonga coast as well as offshore throughout Cook Islands.
Ministry of Marine Resources (MMR)	The MMR is a government department tasked with ensuring the sustainable development of the living and non-living marine resources for the benefit of the people of Cook Islands. The marine environment contains many of the nation's major exploitable natural resources. Currently, marine resources are exploited through aquaculture (black-lipped pearls), offshore fishing (tuna and other pelagic species) and coastal reef fisheries (trochus, aquarium fish, reef fish, etc).
Ministry of Finance and Economic Management (MFEM)	The MFEM (Ministry of Finance and Economic Management) is a government ministry responsible for advising the Government on financial and economic issues. The MFEM publishes regular economic forecasts and reports, including social and economic statistics. Recently (2021), the MFEM also published a National 10-year Economic Development Strategy that establishes five priorities to drive economic development.
Ministry of Transport (MoT)	The MoT (maritime section) is responsible for the administration of the *Maritime Transport Act 2008* and associated rules and regulations. The maritime section is also responsible for ensuring obligations under international maritime laws and conventions are met. In addition, the maritime section has responsibilities related to aids to navigation and maritime safety information. The MoT also regulates civil aviation.
Ministry of Marine Resources (MMR)	The MMR will be interested in offshore biological assessments and will hold data on fisheries resources that will be used in the Environmental and Social Impact Assessment (ESIA).
Cook Islands Ports Authority (CIPA)	The Cook Islands Ports Authority (CIPA) will have an interest in any development in and/or use of the port facilities and a mandate to ensure sustainability of existing services in Rarotonga.
Cook Islands Ministry of Cultural Development	The Ministry may have an interest in informing the assessment of potential impacts on tangible and intangible cultural heritage.
Traditional Leaders	
House of Ariki	The House of Ariki is a parliamentary body made up of high chiefs that is tasked with representing the best interests of the people of Cook Islands. The body advises Government on traditional matters such as land ownership and custom. In Parliament, the House of Ariki may be asked to respond, through expression of opinion, and/or to make recommendations to the elected Parliament on matters that may affect the welfare and/or interests of the people of Cook Islands. The composition includes one Ariki from each of the inhabited outer islands with Rarotonga represented by six Ariki.
Koutu Nui (Council of Traditional Leaders)	In 1972, the *House of Ariki Act* was expanded to make room for a second national body of traditional leaders: the Koutu Nui. Its legal function is to consider and make recommendations to Parliament and the House of Ariki on matters 'relating to the customs, traditions (and usages of the indigenous people) of the Cook Islands'. Recommendations or resolutions are conveyed by the Koutu Nui to the House of

Stakeholder	Interest/influence
	Ariki's through the Clerk of the Parliament or to the Government of Cook Islands through the Prime Minister. Any (undisputed) titleholder can choose whether they want to become part of the Koutu Nui.
Religious Leaders	
Religious Advisory Council (RAC)	The Cook Islands Religious Advisory Council (RAC) was founded in 1968. Established to discuss vital religious issues, it comprises six church denominations: the Cook Islands Christian Church, Roman Catholic Church, Church of Jesus Christ of Latter Day Saints, Seventh Day Adventist Church, Assemblies of God Church and Apostolic Church. The Cook Islands Government may refer religious matters for the Council to review, seek views from the RAC's perspective when public reaction over statements or programmes made through the news media, TV, radio and community has religious connotations.

The abovementioned stakeholders have an active role in seabed minerals matters through at least three avenues. Firstly and secondly though representatives on the SBMA Advisory Committee and SBMA Licencing Panel who are key parts for the permitting process (Section 2.2), and thirdly through participation on the TAG which considers spatial management of Marae Moana protected area.

Non-governmental organisations (NGOs) are another group of important stakeholders; however, they are not considered further here. This is because their organisation is not formalised and their associations often opaque. Domestic NGOs are understood to have some measure of collaboration and cooperation with international NGOs and there are an increasing number of these focusing on seabed minerals development in other parts of the world, especially the CCZ.

8.3.2 Existing and Promised Ecosystem Services

Ecosystem services are services provided by the natural environment to humans. They include supporting and regulating services, provisioning services and cultural services per the summary in Table 8-3.

Table 8-3: Summary of deep-sea ecosystem services. Sourced and summarised mostly from Fathom Pacific and ERIAS Group (2021).

Service	Summary
Circulation, Nutrient Cycling and Climate Regulation	The vast volumes of cold deep-sea water masses below 1,000 m are isolated from the atmosphere. They circulate globally, create a buffer for the carbon and nitrogen cycles, and regulate climate. Ocean circulation is a supporting and regulating service due to the connection between water mass structure and movement, nutrient cycling, and climate regulation and CO_2 exchange (Thurber et al., 2014). The biological pump is the primary source of energy to the abyssal seafloor in the open ocean. This process involves the sinking of particulate organic carbon (POC) generated in the productive sunlit ocean surface waters, as well as the progressive degradation of labile compounds, and transport of materials to the seafloor. The processes of upwelling and diel vertical migration of zooplankton and micronekton is another way nutrients are re-suspended back into the surface and subsurface layers. At abyssal depths and other areas where surface primary production is low, the quantity of carbon and quality of nutrition is generally low, limiting the benthic biomass able to be sustained. The deep-sea water column and seabed, therefore, provide both supporting services (e.g. facilitating the production of biomass) and regulating services (e.g. sequestering carbon and cycling nutrients).
Primary and Secondary Production	Primary production is a process that is limited to the sunlit surface waters of the ocean; however, it occurs on a vast scale and drives many of the trophic interactions of human value (e.g. sustaining food webs that support fisheries and megafauna). Primary production can reach the seabed in the form of 'falls' of pelagic organisms (e.g. whale falls) or debris (e.g. terrestrial plant material). These spatially constrained inputs of primary production can create isolated secondary production on the seafloor in the form of chemosynthetic production and biomass growth in heterotrophic organisms. Recently, there is new appreciation for the amount of primary chemosynthetic production generated below the sunlit waters of the open ocean water column by microbes

Service	Summary
	feeding on the vast pool of dissolved inorganic carbon. This process of chemosynthetic production also uses other compounds which are provided by the progressive degradation and repackaging of sinking POC. Organic carbon degradation and assimilation in the formation of biomass is one of the major supporting services of consideration for fisheries. The respiration of most organisms involved in secondary production is stored in the deep-sea, and therefore, the deep-sea provides a notable regulating service. Seabirds play a major role in ingesting and transporting production from the ocean's upper layers to terrestrial environments (Otero et al., 2018). The presence of large seabird colonies in Cook Islands may indicate that these predators play a significant role in open ocean processes. Furthermore, there has been recent insight into the importance of production enhancement and nutrient mixing via the feeding whales, dolphins, tunas and other large-bodied predators (Roman and McCarthy, 2010).
Offshore Fisheries	Harvested species include yellowfin tuna, albacore tuna, skipjack tuna, and bigeye tuna, as well as mahi mahi, wahoo and billfishes. On 1 January 2017, quotas for albacore tuna and bigeye tuna fished from Cook Island waters were implemented. There has been a ban on the commercial fishing of shark within the EEZ since 2012. Local and foreign vessels (primarily from Japan, Korea and Taiwan) target tuna – mainly by longline – for the export sashimi market and canneries, particularly those in American Samoa and Fiji. Seasonal trends dictate the catch rates in Cook Islands' longline fisheries. Generally, first and fourth quarter catch rates and total catch are low, signalling the off-season, and second and third quarter catches are the peak of the fishing season. The southern extent of the longline fishery is typically ~15°S; however, recent longline fishing effort has extended further south. In 2017, 45% of key tuna species were caught below 15°S. The purse seine fishery in the EEZ is a surface fishery targeting schooling skipjack tuna in the tropical waters of the Western and Central Pacific Ocean. Catches are unloaded at canneries in Pago Pago, American Samoa (Ministry of Marine Resources, 2017). It operates in the northernmost waters of the EEZ, north of 13°S which is also north of Moana Minerals' licence area.
Nearshore Fisheries	Pelagic and reef-associated fish species in the coastal zone are important to subsistence, artisanal, and small-scale commercial fisheries in Cook Islands. Near-shore fisheries operate away from commercial fishing as mandated by the 50 nm commercial fishing exclusion zone around all islands in the *Marae Moana Act 2017*. The majority of near-shore fishing occurs in the coastal zone (Gillett, 2016) and not in the oceanic environment over the South Penrhyn Basin. The Cook Islands artisanal fishery operates from all inhabited islands, primarily targeting tuna and pelagic species. Catches are consumed locally and sold through local markets.
Harvesting nodules and other minerals	The presence of polymetallic nodules in the EEZ is a major potential provisioning service. The exploration and commercialisation of these nodules provide major opportunities to further understand the relatively understudied Cook Islands deep-sea environment. Nodule harvesting can also provide alternative sources of revenue and skills development to the people of Cook Islands. To date, no seafloor massive sulphides or Co crusts have been identified in the EEZ. The REE-enriched sediments occur in the deep-sea and this potential mineral resource has been the subject of preliminary prospecting.
Aquaculture	A variety of marine aquaculture projects have been developed and undertaken but none are associated with deep offshore waters in the EEZ. Mariculture developments of round pearls using the black-lipped pearl shell (*Pinctada margaritifera*) have grown a black pearl industry in Cook Islands. Efforts in Cook Islands are also being made to commercially develop milkfish (*Chanos chanos*) culture and capture fisheries based on trochus shell (*Trochus niloticus*).
Bioprospecting and Marine Genetic Resources	The deep-sea is considered a potential source for novel natural products containing pharmaceutical properties. These products would be of potential value to biomedicine and cosmetic industries. As of mid-2022, SBMA is part of a pilot project in this area called DEEPEND.
Communications	In Cook Islands, the Manatua subsea cable comes to shore at Rarotonga and Aitutaki and connects to the global internet via Samoa and Tahiti. The cable passes through the southern part of the deposit but to date has not been covered by licence applications.
Shipping	On a global scale, shipping and total vessel traffic in the EEZ is generally low but commercial shipping is critical to the delivery of products to Cook Islands and the economy in general.
Cook Islands Cultural Heritage, Spiritual Existence and Identity	The open ocean is integral to the origin stories, traditional knowledge and cultural values of Cook Islanders. The *Marae Moana Act 2017* upholds these values, and they are witnessed throughout everyday life. It is recognised that this factor will be paramount in the social acceptability of Cook Islands deep-sea mining, and that excellent environmental performance will be of utmost importance in gaining that acceptability.

Service	Summary
Recreation, Leisure and Aesthetic Experience	In Cook Islands, particularly given the high reliance on tourism that capitalises on aesthetic experience, leisure and marine-based recreational activities, the oceanic environment provides a key cultural service in these areas. There is no indication that the project activities will occur in vicinity of tourism-related activities. However, perceptions around experiential use of the marine environment can interact with this ecosystem service.
Marine Scientific Research and Education	The oceanic environment in general holds scientific research and education values, many of which will actually be accessed in the deep-sea mining exploration program.
Global Culture	Deep-sea references and awareness of the open ocean's 'wildness' hold an important place in human culture and imagination. In addition to being a wildlife habitat that humans admire and wish to preserve, the oceanic deep-sea environment is central to many ancient and modern civilisations, in the form of mythologies, stories and literature, art, music and technological development.
Other services	These are not thought to be of material use (to date) in the Cook Islands. They include energy sourcing and generation, storage and sometimes detoxification of waste, and military uses. It is worth noting, however, that neighbouring Kiribati is being used for military purposes.

8.3.3 Transparency and Opportunities for Public Consultation

Transparent processes are an essential part of effective environmental and social governance. In the Cook Islands seabed minerals sector, public involvement includes:

- public consultation via draft release at key stages of the drafting of legislation, including publication of comments received from stakeholders;
- public consultations (Talanoa or townhall meetings) on new scientific endeavours involving the marine environment;
- regular press releases on government seabed minerals events;
- publication of summaries of licence applications;
- publication of environmental management programmes; and
- publication of granted exploration licences (which include exploration work programmes and financial commitments by licence holders).

Most information is available on the SBMA web page, including the licence information on a dedicated cadastre-based portal. Not all information is public. Confidentiality provisions in the *Seabed Minerals Act (2019)* protects the rights of licence holders in regard to commercially sensitive information.

8.4 Governance Framework

The governance framework in the Cook Islands is unique in that there is the overarching *Marae Moana Act 2017*. This establishes the entire EEZ as an area in which marine biodiversity, cultural values, and subsistence fishery resources are protected. The *Marae Moana Act 2017* is founded on the traditional principles of rāʻui, a form of traditional spatial management applied in ancestral society that also reflects modern marine spatial and ecosystem-based management approaches. The Act is also based on the traditional belief that the ocean has mana (spiritual authority).

The Act is administered by the Marae Moana Council that is chaired by the Prime Minister and comprises the opposition lead, a religious leader, a representative of the finance ministry, and community leaders.

The regulations of this Act require development activity to be screened-in as allowable spatially defined activity. This is a subtle but important distinction of assessing any mining operations for inclusion into a 'protected' area regime, and adds additional layers of precaution that are already inherent in global considerations of deep-sea nodule harvesting.

Deep-sea licence applications received by the SBMA have all been assessed against the Marae Moana principles of ecologically sustainable use.

The complementary role of SBMA and NES (see Table 8-2) is key in governance of seabed minerals. While both agencies have administrative, technical and legal expertise, seabed minerals development cannot progress with approval from these independent agencies.

8.4.1 Conservation Areas

As mentioned above, the entire EEZ is a protected area under the *Marae Moana Act*. Implementation of the Act requires a spatial management plan that ensures that any development is in keeping with the explicit principles of the Act. Currently, the Act demarcates a 50 nm zone around each of the 15 islands (Figure 8-11). These are called Marine Protected Areas and only artisanal fishing and tourism is nominally allowed within these areas as well as transiting marine traffic.

As part of the spatial management plan for Marae Moana, seabed habitat management zones (HMZs) have also been defined (Figure 8-11). These are a based on a simplified seabed geomorphological interpretation (Figure 4-5) as well as modelled net export of organic carbon (Lutz et al., 2007). These HMZs (and expected updates) and other ocean management zones (e.g. Wendt et al., 2018) will populate and maintain the spatial management plan.

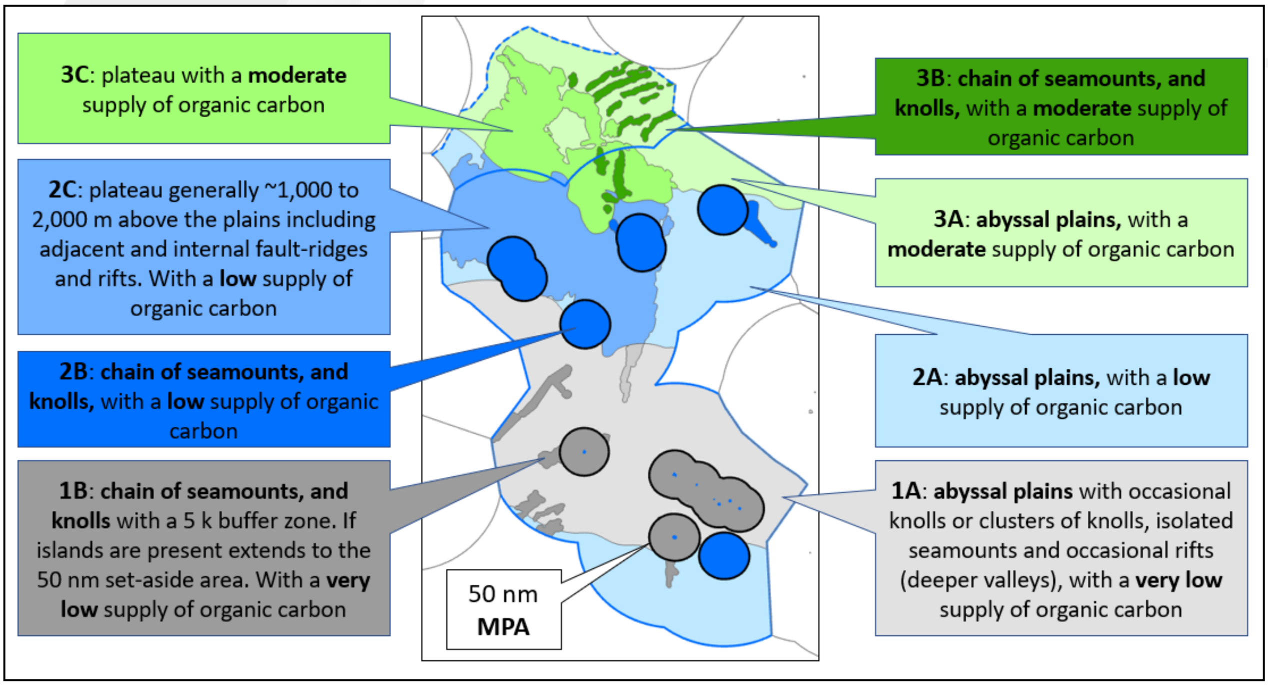


Figure 8-11: Habitat Management Zones and Marine Protected Areas for the EEZ and extended continental shelf (submission)

8.4.2 Regulatory Regime: International Treaties and Arrangements

The Cook Islands is signatory to a number of overarching international treaties (Table 8-4). The Cook Islands also has strong links to the International Seabed Authority via UNCLOS and with New Zealand via the 2001 Joint Centenary Declaration of the Principles of the Relationship between New Zealand and Cook Islands. The Cook Islands regulatory regime thus aims to meet or exceed any requirements developed under UNCLOS, while leveraging off the extensive proven regulatory regime working in New Zealand.

Table 8-4: Relevant international treaties.

Treaty	Description
United Nations Convention on the Law of the Sea (1994) from the third UN Conference (1973–1982) Montego Bay, Jamaica	An international agreement that establishes a legal framework for all marine and maritime activities. 320 articles and nine annexes governing all aspects of ocean space -definition including maritime delimitation, environmental control, marine scientific research, economic and commercial activities and the settlement of disputes relating to ocean matters. Part XI (1994) covers seabed minerals.
Convention on Biological Diversity (1992) (CBD), adopted at the 1992 United Nations 'Conference on Environment and Development' in Rio de Janeiro, Brazil	Aims to conserve biological diversity and species in natural surroundings, and to rehabilitate degraded ecosystems. Activities which may adversely affect biodiversity require: • Article 7. Identify and monitor impacts. • Article 8. Establish a system of protected areas (including within the marine environment). • Article 14(a). Conduct environmental impact assessments. • Article 14(c). Promote consultation. The Convention on Biological Diversity (CBD) adopts an ecosystem approach as its primary framework for action, defining the 'ecosystem' as a dynamic complex of plant, animal, and micro-organism communities and their non-living environment, interacting as a functional unit.
Produced at the 1992 United Nations 'Conference on Environment and Development' in Rio de Janeiro, Brazil	Recognises the importance of preserving the environment to the success of long-term economic progress. The following principles particularly address issues in regard to the management, protection, and preservation of the environment: • Principle 2. States are responsible to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond limits of the national jurisdiction. • Principle 3. The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations. • Principle 4. Environmental protection shall constitute an integral part of the development process. • Principle 7. States shall cooperate to conserve, protect, and restore the Earth's Ecosystem. • Principle 9. States should cooperate to strengthen capacity-building for sustainable development by improving scientific understanding. • Principle 10. Environmental issues are best handled with participation of all concerned citizens. • Principle 11. States shall enact effective environmental legislation. • Principle 14. States should cooperate to discourage or prevent relocation or transfer of substances that cause severe environmental degradation. • Principle 15. The precautionary approach shall be widely applied. • Principle 16. Internalisation of environmental costs so the polluter bears the costs of the pollution. • Principle 17. Environmental impact assessments shall be undertaken for activities that are likely to have a significant adverse impact on the environment.

Treaty	Description
	• Principle 19. Prior and timely notification of adverse transboundary environmental effects.
The Convention on Conservation of Nature in the South Pacific (Apia Convention) 1976	Aims for conservation, utilisation and development of the natural resources of the South Pacific region through careful planning and management for the benefit of present and future generations. • undertaken to create protected areas to safeguard representative samples of natural ecosystems, superlative scenery, striking geological formations, and regions and objects of aesthetic, historic, cultural, or scientific value (art.2); • commit to not alter national parks so as to reduce their area except after the fullest investigation; their resources are not to be subject to commercial exploitation and hunting, and collection of species is to be prohibited and provision is to be made for visitors (art. 3); • agree to maintain lists of indigenous fauna and flora in danger of extinction and to give such species as complete protection as possible (art. 5); and • provision may be made as appropriate for customary use of areas and species in accordance with traditional cultural practices (art. 6).
Convention on Biological Diversity (1992) - Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation (ABS)	Provides a legal framework for the effective implementation of one of the three objectives of the CBD: the fair and equitable sharing of benefits arising out of the utilisation of genetic resources. The '2020 Aichi Targets' include a target that by 2020, parties are to implement at least 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services that are ecologically representative and connected.
1992 United Nations 'Conference on Environment and Development' – Agenda 21	A non-binding voluntarily implemented action plan for sustainable development. It outlines key policies for achieving sustainable development that meets the needs of the poor and recognises the limits of development to meet global needs. Specific chapters applicable to environmental management of deep-sea minerals development include: • Chapter 8. Integrating environment and development in decision-making • Chapter 15. Conservation of biological diversity • Chapter 17. Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas and coastal areas, and the protection, rational use and development of their living resources
Nouméa Convention (1982) **The Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (Noumea Convention), adopted in 1982.**	Promotes two main objectives: 1) to prevent, reduce, and control pollution from any source; and 2) to ensure sound environmental management and development of natural resources. Article 8 'Pollution from Seabed Activities' of the Nouméa Convention states, 'The Parties shall take all appropriate measures to prevent, reduce, and control pollution in the Convention Area, resulting directly or indirectly from exploration and exploitation of the seabed and its subsoil'. Article 17 'Scientific and Technical Co-operation': 1) the Parties shall co-operate, either directly or with the assistance of competent global, regional, and sub-regional organisations, in scientific research, environmental monitoring, and the exchange of data and other scientific and technical information related to the purposes of the Convention; and 2) in addition, the Parties shall, for the purposes of this Convention, develop and co-ordinate research and monitoring programmes relating to the Convention Area and co-operate, as far as practicable, in the establishment and implementation of regional, sub-regional, and international research programmes. The Noumea Convention is complemented by two Protocols: the Dumping Protocol and the Pollution Emergencies Protocol, which are applicable to Parties' EEZs and to areas of the high seas beyond national jurisdiction that are completely enclosed by these EEZs. In particular, Parties must prevent, reduce, and control pollution caused by discharges from vessels, resulting directly or indirectly from exploration and exploitation of the seabed and its subsoil. It contains an EIA requirement, which must include opportunity for public comment and consultation with other States which may be affected.

Treaty	Description
The International Marine Minerals Society Code for Environmental Management of Marine Mining **Voluntary code for environmental management of marine mineral activities (exploration and exploitation)**	1. Environmental principles for marine mining: • to observe the laws and policies and respect the aspirations of sovereign States and their regional sub-divisions, and of international law, as appropriate to underwater mineral developments; • to apply best practical and fit-for-purpose procedures for environmental and resource protection, considering future activities and developments within the area that might be affected; • to consider environmental implications and observe the precautionary approach; • to consult with stakeholders and facilitate community partnerships on environmental matters throughout the life cycle of operations; • to maintain an environmental quality review programme and deliver on commitments; and • to report publicly on environmental performance and implementation of the code. 2. A set of operating guidelines for application at a specific mining site. Guidelines to set an environmental management programme for an exploration or extraction site, which can be used by all stakeholders, including Government agencies, intergovernmental and non-governmental organisations, scientists, and local communities to check environmental management plans and their implementation.
Convention on the Conservation of Migratory Species of Wild Animals (CMS) **1979 Convention on the Conservation of Migratory Species**	Platform for the conservation and sustainable use of migratory animals and their habitats.
Memorandum of understanding for the Conservation of Cetaceans and their habitats in the Pacific Islands region (2006)	Recognises that cetaceans are integral to the marine environment and connect ecosystems and cultures. Recognises they are highly migratory and therefore dependent on conservation measures across a wide area. Agreement to: • Take steps to conserve all cetaceans that occur in the Pacific Islands region. • Ratify or accede international instruments that enhance protection. • Review enact or update legislations as appropriate. • Implement an Action Plan that will address threat reduction, habitat protection, research and monitoring, education and awareness, information exchange, capacity building, strangling and entanglement responses, sustainable and responsible tourism, and international cooperation. • Facilitate exchange of information.
Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing States, 2005	Actions and strategies in 19 priority areas of the Barbados Programme of Action for the Sustainable Development of Small Island Developing States (BPOA), which address the economic, environmental and social developmental vulnerabilities facing islands. Priority areas include climate change and sea-level rise resources, energy resources, biodiversity resources, science and technology, human resource development, etc. The BPOA identifies culture as a key pillar of sustainable development.

On 4 March 2023, a biodiversity beyond national jurisdiction (BBNJ) United Nations high seas treaty was agreed by an intergovernmental conference. The treaty will provide a legal framework for establishing marine protected areas in international waters to protect against the loss of biodiversity. This treaty applies only to international waters; therefore, does not directly apply to the Project Area as it is fully located within the Cook Islands EEZ.

8.4.3 Regulatory Regime: Domestic Legislation, Policies, Standards and Guidelines

The domestic regulatory regime of the Cook Islands (notably Table 8-5) takes cognisance of the above-mentioned overarching international treaties.

Table 8-5: Relevant Cook Islands legislation

Instrument	Description	Responsible Department/Agency
Marae Moana Act (2017)	Requires that the EEZ be managed for the primary purpose of protecting and conserving the ecological, biodiversity and heritage values of the Cook Islands marine environment. Founded on the traditional principles of 'rā'ui' – a form of traditional spatial management applied in ancestral society. Allows for seabed mining.	Marae Moana Council, Marae Moana Technical Advisory Group, and other agencies
Seabed Minerals Act (2019), Seabed Minerals Amendment Acts (2020 and 2021), Seabed Minerals (Exploration) Regulations (2020), Environment (Seabed Minerals Activities) Regulations (2020), Seabed Minerals (Royalties) Regulations (2013)	Sets out the governance requirements for the licensing of exploration and exploitation activities. Upholds the requirements of the *Environment Act (2003)* and establishes compliance requirements.	Seabed Minerals Authority, Seabed Minerals Commissioner, Seabed Minerals Advisory Committee
Cook Islands Environment Act (2003)	Core legislation under which an ESIA will be conducted, and which controls the permitting of activities that have the potential to cause significant environmental harm. Environment (Seabed Minerals) regulations are in draft.	Cook Islands National Environment Service
Marine Resources Act (2005)	Establishes the entire EEZ as a whale and shark sanctuary. This declaration provisions for the protection of whale and shark species against commercial exploitation and the management of tourism, fisheries, and scientific research and other activities that have the potential to intentionally or inadvertently interact with these species.	Ministry of Marine Resources
Cook Islands Natural Heritage Trust Act (1999)	Establishes a Cook Islands Natural Heritage Trust with the necessary resources and powers to investigate, identify, research, study, classify, record, issue, preserve, and arrange publications, exhibitions, displays, and generally educate the public on the science of, and traditional practices and knowledge relating to, the flora and fauna of Cook Islands.	Cook Islands Natural Heritage Trust

9 Risks

The risks, with respect to estimation and classification for the project are summarised in Table 9-1. The most pertinent risks have also been noted throughout the report.

RSC used a first-principles approach in the risk assessment for the mineral resource estimate, first ascertaining whether appropriate procedures are in place to assure the quality of estimation process data and output information, and to determine compliance with best practice.

RSC specifically reviewed the performance of checks and balances that were in place to ensure that the data-collection, interpretation and modelling processes were in control and delivering consistent data/information to inform downstream processes or reports. This approach is presented in this report in a simple tabulated format, using the JORC Table 1 as a guide. For each section, there are comments on the availability of the information, the overall quality of the data or the work related to the section, and the effect on project risk. The high-level review includes an assessment of all matters relevant to mineral resource estimation. A summary table is presented for the project, with a rating value provided for the availability of data, and perceived risks.

Table 9-1: List and analysis of risks.

Item	Data/Information Availability	Score (1–10)	Impact Factor (1–5)	Risk Factor	Comments
Database format	Good	8	2	Low	The data informing the MRE are stored in an MS Access database compiled by SBMA from historical JICA-MMAJ reports and Excel spreadsheets submitted by the current permit holders (OML and CIICSR).
Primary sampling techniques	Average	6	4	Moderate	The MRE is based on FFG and BC data collected between 1985 and 2000. The SOPs from historical expeditions were provided. Sampling techniques followed best practice at the time of sampling; however, these methods can no longer be considered to fully follow best practice.
Primary sampling recovery	Poor	2	3.5	Moderate-High	Sampling recovery records are difficult to establish since the historical reports do not state which samples failed or how many samples failed. The only indication recorded by JICA-MMAJ relates to the failure of the trigger mechanism (sample failure) in some instances. In case of FFG malfunction, abundance was estimated using accompanying seabed images. Most samples were collected by FFG and dredging (60% and 24%) and only a small portion (<2%) by BC. BC sampling generally provides high sample recoveries, due to its ability to consistently extract intact samples from the seafloor. FFG samples have significantly lower nodule recoveries compared to BC samples. The Competent Person considers the lack of recovery data for the historical data to be a risk to the accuracy of the abundance estimate due to the inherently challenging nature of seafloor sampling at such depths.
Logging	Good	8	2	Low	Geological logging was completed to a high standard. Although, individual sample logs were not available to review.
Sub-sampling techniques and sample preparation	Poor	3	3	Moderate	There is limited information on how or if samples are split or prepared for analysis. One historical report indicates nodules were crushed, dried and stored in a desiccator before analysis; however, previous reports do not comment on sub-sampling techniques or sample preparation.
Quality of assay data and laboratory tests	Poor	5	3.5	Moderate-Low	Duplicate analyses show good agreement. Correlation of grades with later sampling programmes is good in the 16-159 (Central) area. Polymetallic nodules are hygroscopic and can readily draw moisture out of the atmosphere. JICA-MMAJ published on the issue, and noted that during onshore analysis of the samples, nodules were temporarily stored in a desiccator before analysis. However, steps taken to account for the hygroscopic nature of the samples for analysis connected on the ship are not known.
Verification of sampling and assaying	Good	4	2.5	Low	SBMA checked digital copies of the historical data collected by JICA-MMAJ against the original scanned reports. Minor transcription errors were identified and corrected immediately. Samples collected by current licence holders were used to verify the results of the historical sampling. The comparison indicates the global nodule abundance in the Central Area recorded by JICA-MMAJ is lower than that recorded by CIICSR and OML. This supports the well-known flaw of FFG sampling that it underestimates nodule abundance.

Item	Data/Information Availability	Score (1–10)	Impact Factor (1–5)	Risk Factor	Comments
Location of data points	Average	4	3	Moderate	The location of data points refers to the ship's location at the time of sampling rather than the actual sample on the seafloor. The scale of potential error is thought to be small (typically <1%) compared to the sample spacing. The Competent Person notes that due to the scale of the project and that typically the average coordinates of three sample points collected at one sample station were used to inform the MRE, the discrepancy between the two location points does not have a significant impact on the MRE.
Data spacing and distribution	Average	4		Moderate	Sample spacing varies over the project from ~25–100 km. Large portions of the EEZ have not been sampled (e.g. eastern parts of the EEZ) and are therefore excluded from the MRE. The Competent Person considers the sample spacing in the 16-159 (Central) area sufficient to support the Indicated classification of the Mineral Resource. The Competent Person deems the sample spacing and distribution for the rest of the project to be sufficient to support Inferred classification of the Mineral Resource.
Bulk density	Average	4	3	Low	Wet density of the nodules was calculated, although the process was not documented. Density was not used to estimate wet nodule abundance, and therefore, the Competent Person considers the risk to the MRE low.
Sample security	Absent	-	2	Moderate	No chain-of-custody SOP or documentation was available for review. Therefore, RSC was unsure what procedures were in place on the ship and after sampling regarding sample security. The Competent Person considers it unlikely that the sample security will pose a material risk to the Mineral Resource classification as grades between nodule samples have low variance.
Database integrity	Good	8	3	Low	SBMA compiled and maintain the database.
Geological interpretation	Average	5	4.5	Moderate	For the project, interpretation is limited to geomorphology (abyssal plains with limited resolution of volcanic knolls). A higher-resolution bathymetrical map and more detailed geological interpretation (abyssal hills versus knolls/seamounts) are only available for the 16-159 (Central) area.
Estimation and modelling: domaining	Good	8	4.5	Moderate	The domaining at this stage of the project is adequate to support an Indicated Mineral Resource in the 16-159 (Central) area. Bathymetry and slope data are required to better understand the spatial distribution of nodule abundance throughout the rest of the project area, but the domaining is adequate to support an Inferred Mineral Resource. During sensitivity testing, it was determined that the abundance domaining strategy had little effect globally on estimated abundance values and resulting wet tonnes.
Estimation and modelling: compositing	Good	5	2	Low	Sample triplicates were composited, and the barycentric of the three points was adopted as the composite location.
Estimation and modelling: grade capping	Good	8	3.5	Low	The domains have low to very low CV values. Capping of abundance and elemental grade populations was not required.
Estimation and modelling: variography	Good	8	3.5	Low	All variograms display reasonable structure (in particular low g_0 values) to support acceptable levels of global estimation precisions compatible with the estimation of Inferred Mineral Resources.

Item	Data/Information Availability	Score (1–10)	Impact Factor (1–5)	Risk Factor	Comments
Estimation and modelling: interpolation/ extrapolation	Good	7	4	Moderate-Low	Interpolation is controlled by kriging weights within each domain. RSC considers the interpolation and extrapolation of relatively sparsely sampled abundance and grade data over such a large region to pose a risk to the MRE in some areas. RSC notes that historical data has a limited quality and will likely not support any future upgrade of Mineral Resource classification based on augmented geological information alone (verification sampling will be necessary to achieve that outcome). Extrapolation typically does not exceed 50% of sample spacing, and the extrapolation distance is considered reasonable by the Competent Person.
Estimation and modelling: block size	Good	8	4	Low	A stepped block size was selected for estimation based on sample spacing and spatial continuity as modelled by the variograms over the EEZ. A block size of 50 km × 50 km was used, with a sub-block size of 25 km × 25 km selected to provide higher resolution around the edges of the domain. A block size of 12.5 km × 12.5 km was selected in the 16-159 (Central) area to provide greater resolution where the classification is upgraded.
Estimation and modelling: checks and validation	Good	8	4	Low	The model was validated through visual validation, mean comparison checks, estimation of data quality, and a review of swath plots. RSC considers the block model to be robustly estimated with block grades representative of the input data.
Estimation and modelling: cut-off	Average	4	4.5	High	No commercial mining of seafloor nodules has occurred to date, and cut-off assumptions are based on unproven mining scenarios.
Estimation and modelling: density	Average	6	1	Low	The density of nodules was measured using standardised methods. Density was not estimated in the MRE as the nodule weights/abundance and the MRE are in wet kg/m^2 and tonnes, respectively.
Estimation and modelling: classification	Good	8	4	Low	The 16-159 (Central) area; ~12,000 km^2 is classified as Indicated. The rest of the model ~720,000 km^2 is classified as Inferred. Wide sample spacing, less precise geological domaining, and issues with data quality, prevented the rest of the Mineral Resource from being classified at a higher level of confidence.

10 Exploration Potential

The exploration potential for polymetallic nodules in the Cook Islands EEZ is significant. The EEZ is known to have a high potential for Co-rich polymetallic nodules, and the MRE reported here has helped identify some additional areas of exploration potential (Figure 10-1).

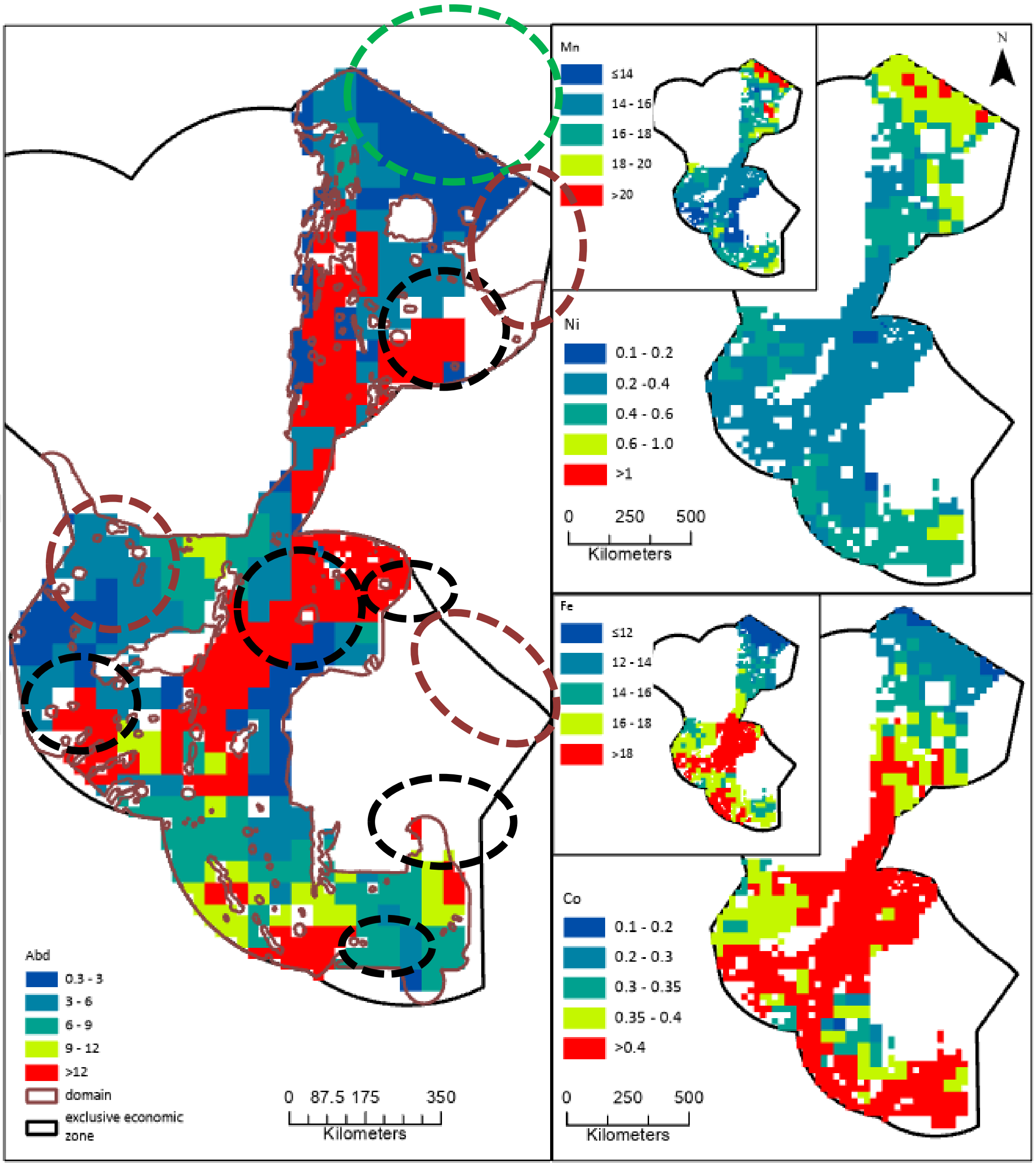


Figure 10-1: Some suggested nodule exploration areas in the Cook Islands. An area of higher abundance and high Ni grade nodules is indicated by a green dashed circle. Extensions to areas of higher abundances of high Co nodules are indicated by black dashed circles, and unexplored or equivocally explored areas are indicated by brown dashed circles.

To date, exploration within the Project Area has mostly been directed along the eastern side of the Manihiki Plateau and Aitutaki Passage, specifically the 13-159 (GH83-3) and 16-159 (Central) areas. Exploration programmes elsewhere in the EEZ could attempt one or several different approaches i.e.:

1. Extension programmes to known 'good' areas, where there is little or wide-spaced sampling, e.g. directly southwest or south of 16-159 or northeast of 13-139;
2. Infill programmes, where wide-spaced sampling results have mixed results e.g. north of Penrhyn Island where grades of Ni and Mn are high but abundance in sampling to date is very low.
3. Wider exploration programmes, where there is equivocal or no sampling e.g. west of Palmerston Island (near where the AABW is also interpreted to flow; e.g. Figure 4-4) or southwest of Penrhyn Island northeast of Aitutaki Island;

For the extension and infill programmes (approaches 1 and 2 in the above list), an MBES survey is recommended as the next step. This technology was only available to JICA-MMAJ in its final expedition and so was not applied to early-pass nodule exploration in new areas. In the CCZ, MBES has been shown to be effective at mapping nodule deposits (Lipton, Nimmo and Parianos, 2016; Parianos, Lipton and Nimmo, 2021), albeit once backscatter responses are semi-quantitatively tested against nodule abundance.

For the wider exploration programmes (approach 3 in the above list), the size of the area involved could readily make MBES programmes expensive and risky until nodule grades are better understood. Thus, wide-spaced (50-100 km) FFG programmes may be best to start with. It should be noted however that in some areas of the seafloor, e.g. within the Cooper Rise area of the CCZ (Jin, 2014) or the GH81-4 area of the Central Pacific Basin (Usui, 1983), grades can vary significantly between volcanic knoll/ridge areas and adjacent abyssal plains, the detail of which may be difficult to realise without an MBES survey.

Once the MBES survey is completed, sampling of prospective areas above should follow a maximum sample spacing of ~30 km based on the current modelled continuity for nodule abundance and elemental grade. Box core sampling is considered best practice for sampling for polymetallic nodules (Section 5.1.4). However, in the vicinity of ferromanganese crusts, FFG samplers should be considered due to BC sampling issues (e.g. BC/spade failure can occur when sampling near crust). Sampling programmes should be supported by scaled seabed images.

Of special note is the area of higher abundance with high Ni grade has been identified in the northeast of the EEZ (Figure 8-2 or 08-158 in Figure 2-2). To date, FFG samples with wide sample spacing collected by JICA-MMAJ have reported low nodule abundances (JICA-MMAJ, 1986); however, as nodule abundance likely relates to the stability of a permissive geochemically active layer (e.g. Lipton, Nimmo and Parianos, 2016; Figure 4-31), the potential for higher abundance areas cannot yet be ruled out. The northeastern area of the EEZ does not have any MBES survey data, which is a useful dataset to aid exploration target identification.

Whenever possible, future exploration should also include check samples to validate historical samples collected between 1985 and 2000 (JICA-MMAJ, 1986, 1987, 1991, 2001).

11 Interpretation and Conclusions

The Cook Islands polymetallic nodule deposit is being explored for possible development, and the Cook Islands Government wants to learn more about the deposit's disposition (Section 1). This MRE captures the current understanding of the deposit ahead of planned exploration programmes by three licence holders (Section 2).

Nodules were first recovered in 1800s and were found in the Cook Islands in the early 1960s (Section 3). The bulk of exploration data used in this MRE were collected in the mid-1980s to 2000 by JICA-MMAJ (four expeditions). Work appears to have been done systematically and to a high standard (Section 6); however, original datasheets or field notebooks were not available for review. Therefore, the historical data cannot be fully validated. For the purpose of MRE, the historical sampling undertaken lacks full documentation of sampling procedures, and limited quality control data (sections 5 and 6). RSC has assessed the risks associated with the available data and deems the data acceptable given the level of confidence in the MRE (sections 6 and 9).

The historical work conducted by JICA-MMAJ is supported by additional new information conducted by SBMA, CIICSR and Moana Minerals as outlined below:

- Geomorphological interpretation of the GEBCO 2021 grid (Section 4) which defines abyssal plains and domains the deposit (Project Area; Sections 1 and 7).
- New geological interpretation of a small MBES survey conducted by JICA-MMAJ in the 16-159 (Central) area (Sections 1 and 4) which further domains the deposit in the area more precisely, and excludes all volcanic knolls in the area (Section 7).
- In 2019, CIICSR and Moana Minerals collected samples in their respective contract areas, predominantly in the 16-159 (Central) area. These data were used independently to verify historical abundance and grade data (Section 6).

In general, the deposit shows evidence of strong geological and grade continuity. Even though it was not possible to fully validate the sampling, nodule abundances and elemental grades do not show significant outliers. Photographic images provide evidence of continuous zones of high nodule coverage on the seafloor, and results from the nodules' geochemistry show low variance in the values.

The Mineral Resource is based predominantly on historical data. A multi-factor scorecard was used to rank the data based on the geological confidence and quality of the sampling (Section 7). Domaining was completed based on seabed geology (limits of abyssal plains as mentioned above), grade (high and low Mn types related to a net export of surface primary productivity to the seabed; Section 4), and abundance (high abundance zone that may relate to the Antarctic Bottom Water; Section 4).

Estimation was performed using 2D ordinary kriging on the parameters of wet nodule abundance (kg/m^2), Co, Mn, Ni, Cu, and Fe grade (%). A block size of 50 km × 50 km was selected with sub-blocking to 25 km × 25 km. In the 16-159 (Central) area, the block size was reduced to 12.5 km × 12.5 km, which is supported by closer sample spacing in the area (Section

7). The use of 2D estimation is considered appropriate because the deposit has significant lateral continuity and no relevant vertical variability.

RSC regards the available data and sample continuity as suitable to support an Inferred Mineral Resource for the Project Area and an Indicated Mineral Resource within the 16-159 (Central) area (Section 7).

RSC's analysis indicates that a potentially economically extractable polymetallic nodule Mineral Resource exists in the Project Area. A cut-off grade of 5 kg/m^2 was selected based on the consideration of previous studies of comparable deposits (Section 7). Parts of the deposit include some of the highest nodule abundances and Co grades known for nodules world-wide. Published studies from the Cook Islands and other jurisdictions indicate that mineral harvesting is likely to be technically possible and potentially economically viable (Section 7), but it is noted that this report does not include a specific economic evaluation. The Cook Islands Government and exploration licence holders express strong support for contemporary requirements and expectations in the area of Environmental and Social Governance (Section 8).

Significant adjacent areas outside the interpolated blocks also have good exploration potential for similar abundance and grade (Section 10).

12 Recommendations

The Mineral Resource in the Project Area assists the Cook Islands Government and other stakeholders in its management and development of the deposit. The MRE is heavily reliant on historical data collected from the 1980–2000s. The collection of additional data via work programmes by commercially licenced explorers or by other means such as government-funded projects could be used to verify historical data and update the MRE. RSC recommends the inclusion of the following in the next stage of exploration:

- Prepare prescriptive SOPs for all sampling, sample preparation, analysis, and chain of custody including but not limited to sample collection by BC/FFG, sample splitting, density, moisture content, and acoustic surveys (e.g. bathymetric survey).
- Bathymetric survey (≥70 m resolution) of the seafloor using a 12 kHz or better MBES survey to map the seafloor (as was achieved in the 16-159 Area).
- Additional sampling by BC or FFG methods (de Meyer model or similar). Sampling should be used to verify the historical data, but also decrease the wide sample spacing. Historical data were analysed for a limited suite of elements (Co, Cu, Fe, Mn and Ni). Modern laboratory techniques should be used to analyse a larger suite of elements, including rare earth elements.
- Sampling areas peripheral to the block model. The extent of the block model was restricted based on grade and geological continuity. Some areas of the EEZ remain under-explored and the deposit is open in all directions.
- Sampling and measurements to better characterise the marine baseline environment, especially in terms of spatial variability. Environmental and geological sampling are both important for marine exploration projects. Often legislation requires the collection of environmental baseline data.

Nodule sampling can be done by either FFG or BC methods, but it is noted that BC sampling is the superior sampling method as it is associated with a higher location accuracy compared with FFG sampling and is more accurate in terms of estimating nodule abundance. However, the benefit of using FFG samplers is that more than one sampler can be deployed at one time. The issue of FFGs biasing low on nodule abundance may be compensated by having FFGs take an accurately scaled picture of the seabed and using appropriately accurate nodule size-weight relationships to indirectly estimate and confirm nodule abundance.

The understanding of reasonable prospects of economic extraction can also be materially improved by carrying out a scoping study, in effect an update of studies completed by Bechtel in 1996 and NDSMG in 2001. RSC recommends future studies also focus on environment, social and governance.

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