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Technical Report Summary

TOML Mineral Resource, Clarion Clipperton Zone, Pacific Ocean

DeepGreen Metals Inc.

In accordance with the requirements of SEC Regulation S-K (subpart 1300)

AMC Project 321012
26 March 2021

1 Executive summary

A large deposit of polymetallic nodules is located in the Clarion Clipperton Zone (CCZ) of the northern central Pacific Ocean. Despite the nodules being located at great depths (4000 to 6000 m), they were explored with considerable success between the mid-1960s to the present day using a variety of increasingly sophisticated deep-sea technologies. In early 2012, Tonga Offshore Mining Limited (TOML), then a 100% owned subsidiary of Nautilus Minerals Inc., acquired an Exploration Area of 74 713 km^2 of the CCZ. In line with the requirements of the relevant oversight body (International Seabed Authority or ISA) TOML is sponsored by the government of the Kingdom of Tonga. The contract for exploration of polymetallic nodules was approved in July 2011, and then formalised on 11 January 2012. The Exploration area consists of six separate areas (termed Areas A to F) scattered across the CCZ (Figure 1.1).

TOML commissioned AMC Consultants Pty Ltd (AMC) to prepare a Technical Report in accordance with the Canadian National Instrument 43-101 reporting standards (NI43-101) and Form 43-101F1. The Report presented the results of exploration and related studies carried out between 2013 and 2016 and an updated Mineral Resource estimate (AMC, 2016). The Mineral Resource statement was prepared in accordance with the SEC Regulation S-K (subpart 1300).

In 2020, DeepGreen Minerals Inc (DeepGreen) acquired the polymetallic nodule exploration contract awarded by the ISA to TOML. DeepGreen commissioned AMC Consultants Pty Ltd (AMC) to recompile the NI43-101 Technical Report (AMC, 2016) as a Technical Report Summary in accordance with SEC Regulation S-K (subpart 1300). AMC understands that DeepGreen may file this Technical Report Summary with the Securities Exchange Commission as part of an S-4 filing to support the merger between Sustainable Opportunities Acquisition Corporation and DeepGreen Metals Inc.

Exploration and development efforts in the CCZ started in the 1960s by state sponsored groups from Russia, France, Japan, Eastern Europe, China, Korea and Germany. Several commercial consortia also explored between the 1960s and the 1980s and in some instances their descendants are still involved to the present day. No commercial mining operations have yet been established in the CCZ. However, a variety of collectors, pick-up systems, and metallurgical processing flow sheets were tested, and several integrated “demonstration scale” systems operated in the CCZ for several months in the late 1970s. Processing test-work has encompassed a variety of hydrometallurgical and pyrometallurgical flow sheets, usually with good results.

The climate is largely warm, and equatorial surface currents vary by season but are not generally very strong. Wave heights and frequencies are relatively moderate (for the open ocean). Storms are significant for part of the year as a major tropical cyclone belt covers the southern side of the CCZ, approximately one cyclone traverses any given area each year. The deposit is distal from major sea routes used by commercial transport vessels and is marginal to tuna fisheries. No communication cables cross the region.

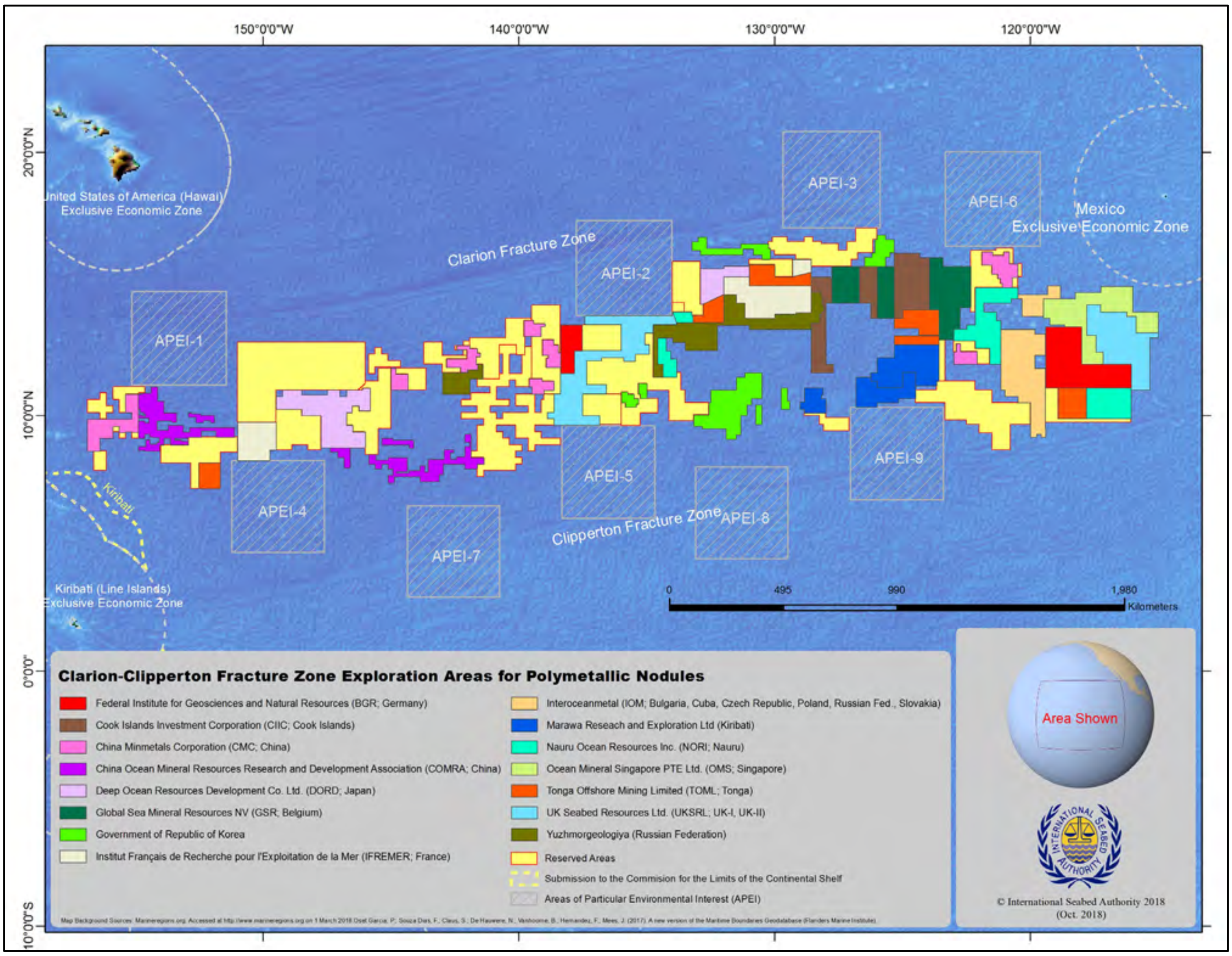
The worldwide occurrence of polymetallic nodules has been known since the late 1800s. They form by the precipitation of metals either directly from ocean waters or via decomposing microorganisms and/or their waste matter in the benthic sediments. The specific conditions of the CCZ (water depth, latitude and seafloor sediment type) are believed to be the key controls on the formation of the CCZ nodule deposit, which is believed to be the largest and highest Ni-Cu-Co grade deposit of this type in the world. Nodules are typically 4 to 6 cm and up to 10 cm in diameter.

Unlike most land deposits, seafloor nodule deposits are characterized in terms of abundance, measured in units of wet kg/m^2. This is because both the primary exploration method (surface sampling) and likely recovery method (surface collectors or rakes) are unlikely to work at any significant depth below the seafloor (i.e., 0 to 30 cm). Abundances are typically reported as wet weights due to the practicalities of handling the nodule samples, the wet density of studied nodules is around 2 t/m^3 irrespective of the nodule size. Studies show nodules to contain around

29% free water and 16% water of crystallisation (incorporated into the complex manganese and iron oxy-hydroxide minerals of formation).

In 2012, Golder Associates Pty Ltd estimated an Inferred Mineral Resource for the entire TOML tenement Area. Part of this data was collected by previous explorers including pioneer contractors representing Japan, Russia and France. This data was obtained directly from the ISA and was not supplied with quality assurance or quality control data. However, verification was possible by cross comparison between all of the six pioneer contractors (also Korea, Germany and an eastern European consortium) who have so far supplied the ISA with data across what is effectively a single large deposit.

Figure 1.1 Location of the Clarion Clipperton Zone



Source: https://www.isa.org.jm/map/clarion-clipperton-fracture-zone, downloaded 18 February 2021

Data collected by TOML in 2013 and 2015 supports the historical data but also is of sufficient quantity and quality to allow estimation of an Indicated Mineral Resource for five sub areas within TOML Areas B, C, D and F called B1, C1, D1, D2 and F1. More detailed data collected by TOML has also allowed estimation of a Measured Mineral Resource for a single sub area within TOML Area B. Chain of custody, sample security, Quality Assurance and Quality Control were documented in detail for the TOML data.

The key data sets behind the Inferred Mineral Resource estimate for TOML Areas A through E are surface samples obtained by free fall grab samplers, although a few results from box-corers were also included. Free fall grab samplers are the standard sampling method as they are the most productive tool available. They are believed to underestimate the actual abundance, as smaller nodules may escape some grabs during ascent and larger nodules around the edge of the sampler may be knocked or fall out during the sampling process. This may introduce some conservatism to the Inferred Mineral Resource estimates.

The key data behind the Inferred Mineral Resource estimate for TOML Area F and the Indicated and Measured Mineral Resources are box-corers and measured photographs. Box-corers take longer to collect than free fall grab samplers, but they are believed to have less bias. Photos cover a much greater area than either free fall grabs or box-cores. The weight of individual nodules can be accurately estimated from the length of their long or major axis; a relationship first discovered in the 1970s. Using the box-core samples as calibration devices, TOML was able to measure the size of nodules on several hundred photographs in Areas B and C. Abundance is shown to be related both to nodule coverage in photos and to acoustic response (backscatter) from regional survey. These data thus provide very detailed indications of nodule abundance and continuity.

Many of the records of the sampling procedures used by the pioneer contractors were not available to the Qualified Persons, but it is likely that all of the pioneer contractors followed similar procedures to that used by TOML. Nodule abundance (wet kg/m^2) was derived by dividing the weight of recovered nodules by the surface area covered by the open jaws of the sampler or corer (typically 0.25 to 0.75 m^2). A split of the nodules was dried, crushed and ground to enable grade determination via standard analytical methods (typically atomic absorption spectrometry, X-ray fluorescence or inductively coupled plasma methods), either on the vessel or back on shore. Specific nodule chemical standards were used for instrument calibration. TOML also present the results of field, submitted and laboratory duplicates of nodule samples.

Analysis of the data reveals that, as a consequence of their origin, nodule grades vary only slightly across the CCZ, with spatial continuity of the abundance, Mn, Ni, Co, and Cu grades often ranging from the order of several kilometres up to several tens of kilometres. Nodule abundance is sometimes less continuous than grade, as it is also subject to local changes in net sedimentation (a consequence of seafloor slope, slumping, erosion and local currents).

The TOML Exploration Area has been split into two domains: areas with polymetallic nodules; and areas predominately without polymetallic nodules. The multibeam bathymetry and the backscatter data was used to interpret the parts of TOML Area B to F with no polymetallic nodules.

Estimation of tonnage and grade for the TOML Exploration Area within the CCZ was undertaken using only sample data within the TOML Exploration Area. Six block models were constructed using the programs Gstat 1.1-3 and R 3.2.5, one for each TOML Exploration Area (A to F), in three passes. The first pass used a parent block dimension of 1.75 km by 1.75 km and filled the areas defined as Measured Mineral Resource. The second pass for Indicated Mineral Resource used a parent block size of 3.5 km by 3.5 km while the third pass for Inferred used a parent block size of 7.0 km by 7.0 km.

The modelling methodology used for estimating the Mineral Resource was determined through careful consideration of the scale of deposit, mechanism of nodule formation, geological controls and nature of the sampling method. The approach involved estimating nodule abundance and grades into a two-dimensional block model with abundance used for calculating tonnage. Abundance and grades were estimated using Ordinary Kriging (OK) with comparison (not reported) estimates using Inverse Distance Weighting (IDW) and nearest neighbour (NN). The modelling methodology is similar to the method applied by the ISA (2010) for its global estimate which was produced by a multi-disciplinary effort that involved recognised subject matter experts.

The Mineral Resource estimate, with an effective date of 31 December 2020, is presented in Table 1.1. The Mineral Resource estimate at an abundance cut-off of 4 wet kg/m^2 is the selected base case scenario considering a non-selective bulk mining operation.

Table 1.1 Mineral Resource estimate, in situ, for the TOML exploration area within the CCZ at a 4 kg/m^2 nodule abundance cut-off

TOML Area	Classification	Tonnes (x10^6 wet t)	Abundance (wet kg/m^2)	Ni (%)	Cu (%)	Co (%)	Mn (%)
A	Inferred	114	11.0	1.1	1.0	0.2	25.0
B	Measured	3	11.8	1.3	1.0	0.2	27.6
B	Indicated	14	11.1	1.3	1.1	0.2	28.6
B	Inferred	63	9.1	1.2	1.0	0.3	25.9
C	Indicated	15	8.6	1.3	1.2	0.2	30.5
C	Inferred	115	9.0	1.3	1.1	0.2	28.2
D	Indicated	29	12.2	1.3	1.2	0.2	30.1
D	Inferred	102	9.0	1.3	1.2	0.2	28.8
E	Inferred	58	10.6	1.3	1.1	0.2	28.7
F	Indicated	12	21.6	1.5	1.2	0.1	32.5
F	Inferred	244	16.6	1.4	1.2	0.1	32.2
Total	**Measured**	**2.6**	**11.8**	**1.3**	**1.0**	**0.2**	**27.6**
Total	**Indicated**	**69.6**	**11.8**	**1.3**	**1.2**	**0.2**	**30.3**
Total	**Inferred**	**696**	**11.3**	**1.3**	**1.1**	**0.2**	**29.0**

Note: Tonnes are quoted on a wet basis and grades are quoted on a dry basis, which is common practice for bulk commodities. Moisture content was estimated to be 28% w/w. These estimates are presented on an undiluted basis without adjustment for resource recovery.

The TOML Mineral Resource estimates are supported by an Initial Assessment carried out on behalf of DeepGreen for the neighbouring NORI Property (AMC, 2021). The polymetallic nodule deposits in NORI Area D are very similar to those in TOML Areas A to F and the QPs consider that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas. The NORI Property IA is directly relevant and applicable to the TOML Property for the reasons set out below:

- This polymetallic nodule mineral field within the CCZ is essentially a single mineral deposit almost 5,000 km in length and up to 600 km wide. The size and level of uniformity of mineralization is unmatched by any mineral deposit of similar value on land.
- The mechanism of formation of the nodules is interpreted to be essentially identical across the entire CCZ, with only minor local variations. Consequently, there is relatively little difference between the size, shape or metal content of the nodules from one area to another.
- The morphological features of the seafloor are similar in the TOML and the NORI Areas
- All Areas are administered under a common legal framework.
- There are no physical or logistical barriers between the Areas. Their location may simply influence shipping costs.

The commonality between the polymetallic nodule deposits in NORI Area D and the TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. The Technical Report Summary for NORI Area D assessed the following mining development scenario:

The IA proposes that nodules will be collected from the seafloor by self-propelled, tracked, collector vehicles. No rock cutting, digging, drill-and-blast, or other breakage will be required at the point of collection. The collectors will be remotely controlled and supplied with electric power via umbilical cables from production support vessel (PSV). Suction dredge heads on each collector will recover a dilute slurry of nodules, sediment, and water from the seafloor. A hopper on each vehicle will separate sediment and excess water, which will pass out of the hopper overflow, from the nodules, which will be pumped as a higher concentration slurry via flexible hoses to a riser. The riser is a steel pipe through which nodules will be transferred to the surface by means of an airlift.

The PSV will support a riser and lift system (RALS) and its handling equipment, and will house the airlift compressors, collector vehicle control stations, and material handling equipment. All power for off-shore equipment, including the nodule collecting vehicles, will be generated on the PSV. The PSVs will be equipped with controllable thrusters and will be capable of dynamic positioning (DP), which will allow the vessels and risers to track the collectors. Nodules will be discharged from the RALS to the PSVs, where they will be dewatered and temporarily stored or transferred directly to a transport vessel."

A combined pyrometallurgical and hydrometallurgical mineral processing scenario is envisaged. The first part of the pyrometallurgical process is the Rotary Kiln Electric Furnace (RKEF) process that is widely used in the nickel laterite industry. The second pyrometallurgical step (sulphidisation of the alloy produced in the first step to form a matte and then partially conversion in a Peirce-Smith converter to remove iron), while not widely practiced, also has commercial precedent at the Doniambo plant of Societe Le Nickel in New Caledonia.

Sulphuric acid leaching of matte from the pyrometallurgical process has precedent in the platinum group minerals (PGM) industry. Although copper producers typically have a solvent extraction step before electrowinning of their copper, direct copper electrowinning is done in most PGM refineries, where nickel and cobalt are also significant pay-metals. This is to maximise nickel recovery and minimise operating expenses. The nickel and cobalt are purified using solvent extraction, ion exchange and precipitation, which are all commercially proven hydrometallurgical processes. Battery grade nickel and cobalt sulphate are then crystallised from the purified solutions.

The pyrometallurgical process forms two by-products as well as the matte for the hydrometallurgical refinery:

- Electric furnace slag containing silica and 53% MnO that is intended to be sold as feed to the Si-Mn industry.
- A converter aisle slag that could be used for aggregate in road construction or other applications.

The hydrometallurgical refinery generates iron residues that would, for a stand-alone plant, require disposal. However, these streams can be recycled back to the pyrometallurgical plant for re-treatment and recovery of entrained pay metals.

Selection of ammonia as a principal reagent in the hydrometallurgical refinery means that an additional by-product—ammonium sulphate—is generated. This could be sold into the fertiliser industry.

The copper cathode quality from direct electrowinning, without a solvent extraction step, is expected to be ≥99.9% Cu. Quality of the matte produced in the pyrometallurgical plant will have an impact on this, including the potential carryover of impurities beyond values assumed for the purpose of the IA.

The production of battery-grade nickel and cobalt sulphates is targeted instead of nickel or cobalt cathodes or other intermediate products.

In summary:

- All parts of the proposed process have commercial precedents in similar or analogous industries, however not as a whole continuous flowsheet.
- Pay-metals are recovered in the following forms:

  - Copper cathodes with an expected quality of ≥99.9% Cu.
  - Battery-grade nickel sulphate.
  - Battery-grade cobalt sulphate.
- Rather than generating large waste streams, the process produces by-products including high manganese content furnace slag and ammonium sulphate.

The process assumptions used in this study will need to be verified as the project proceeds.

The QP considers that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

The infrastructure requirements for the development of commercial production in the TOML Areas, apart from the minerals processing facility, will be modest compared to terrestrial resources projects of similar production capacities.

The site and host country for the minerals processing facility has not yet been confirmed. The site must be serviced by grid power, reticulated water, and natural gas. A location will be selected that is close to an industrial port, and near an existing municipality from which labour can be sourced.

A preliminary assessment of the transportation fleet for transfer of nodules from the CCZ to an existing deep-water industrial port equipped with bulk offloading facilities was examined (AMC, 2021). The IA assumed that chartered vessels would be used to transport the dewatered nodules to the port of Lazaro Cardenas, Michoacan, Mexico, 960 nm from the NORI Area D reference site. The vessels would be converted bulk mineral carriers with dynamic positioning (DP) to allow tracking behind the production support vessels during operations. The method of offloading, known as tandem offloading, is well established for offloading of oil production vessels in remote areas of the world.

AMC has considered the market for the nickel, copper, cobalt and manganese products that might be recovered from the polymetallic nodules in the TOML Areas.

CRU International Limited (CRU) was commissioned by NORI to provide market overviews for the four main products from the NORI Area D Project: nickel sulphate ($NiSO_4$), cobalt sulphate ($CoSO_4$), copper, and a manganese product (CRU, 2020). CRU expects growth in these markets.

CRU expects copper and $NiSO_4$ prices to rise in real terms by 2035, while manganese ore and $CoSO_4$ prices are forecast to remain flat, due to current prices being at or near a high point in the cycle, recent fall in prices, and expected modest growth in the global steel industry after the COVID 19 epidemic. The long-term cost of production is expected to rise for both copper and $NiSO_4$, helping to support prices.

The QPs consider that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas and the IA completed for the NORI Property is directly relevant and applicable to the TOML Property. The QPs consider that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

Recommended future work on the TOML Exploration Area will focus on:

- Further exploration to raise the Inferred Mineral Resources to Indicated and Measured status. The proximity of TOML Area F to NORI Area D suggests that TOML Area F should be a priority.
- Detailed studies to develop key modifying factors to a point where a Mineral Reserve may potentially be estimated;
- Environmental baseline work to support an EIS;

- Concept study work on engineering and commercial aspects leading to trial mining;
- Trial mining.

Contents

Tables

Figures

List of Acronyms and Terms

AAS	Atomic Absorption Spectroscopy
AP	Abyssal Plain
AH	Abyssal Hills
APEI	Areas of Particular Environmental Interest
Abundance	Abundance of polymetallic nodules expressed in kg/m^2
AFERNOD	Association Française pour l'Étude et la Recherche des Nodules
ALS	ALS Group or ALS Laboratories
AMC	AMC Consultants
AMR	Arbeitsgemeinschaft Meerestechnisch Gewinnbare Rohstoffe
ANOSIM	Analysis of Similarity
ASMOD	Adaptive Spline Modelling of Observation Data
AUV	Autonomous Underwater Vehicle
BC	Box Corer
BIE	Benthic Impact Experiment
BGR	German Consortium
BL	Bottom left
BR	Bottom right
BRT	Boosted Regression Trees
C	Centre
CAPEX	Capital Expenditure
CATAMI	Collaborative & Annotation Tools for Analysis of Marine Imagery & Video
CCD	Calcite Compensation Depth
CCZ	Clarion Clipperton Zone
CEA	Commissariat à l'Energie Atomique
CIIC	Cook Islands Investment Corporation
CIM	Canadian Institute of Mining, Metallurgy and Petroleum
CGL	Reference material CGL131 (nodule geochemical standard)
CLB	Continuous Line Bucket Group
CMECS	Coastal and Marine Ecological Classification Standard
COC	Chain of custody
COMRA	China Ocean Mineral Resources Research and Development Association (Chinese Consortium)
COR	Committee of Representatives
CSMF	conservation significant marine fauna
CV	Coefficient of variation
DAS	Acid pressure digestion system
DEME	Dredging, Environmental & Marine Engineering or DEME Group
DNA	Deoxyribonucleic acid
DOMA	Deep Ocean Minerals Association
DOMCO	Deep Ocean Mining Co.
DOMES	Deep Ocean Mining Environmental Study
DORD	Deep Ocean Resources Development Company (Japanese Consortium)
DSSRS	Deep Sea Sediment Re-suspension System
EC	European Commission
eDNA	Environmental DNA
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
ENSO	El Niño–Southern Oscillation
EPR	East Pacific Rise
EUNIS	European Nature Information System
FFG	Free fall Grab samplers
FGDC	US Federal Geographic Data Committee
FIGNR	Federal Institute for Geosciences and Natural Resources (German Consortium)
FPSO	Floating Production Storage and Offloading

GEBCO	General Bathymetric Chart of the Oceans (www.gebco.net)
GEMONOD	Groupement pour la mise au point des MOyens nécéssaires à l'exploitation des NODules
GH	Graben horst
GPO	Government Printing Office
GSR	Global Sea Mineral Resources
Gstat	program for modelling geo-statistical data in one, two or three dimensions
G-TEC	G-TEC Sea Mineral Resources
GU	Gently undulating
HEBBLE	High-Energy Benthic Boundary Layer Experiment
HPAL	High temperature and high pressure sulfuric acid leach process
ICP-AES	Inductively couple plasma atomic emission spectrometry
ICP-MS	Inductively couple plasma mass spectrometry
ICP-OES	Inductively couple plasma optical emission spectrometry
IDOE	International Decade of Ocean Exploration
IDW	Inverse Distance Weighting estimation method
Ifremer	Institut Français de Recherché pour l'Exploitation de la Mer
IHC	Royal IHC or IHC Merwede
INCO	International Nickel Corporation
IOM	Interoceanmetal Joint Organization (Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia Consortium)
ISA	International Seabed Authority
ITLOS	International Tribunal for the Law of the Sea
JAG	US Navy Judge Advocates General's Corps
JET	Japan Deep Sea Impact Experiment
JORC	Joint Ore Reserves Committee
JPI Oceans	Joint Programming Initiative Healthy and Productive Seas and Oceans
KADOM	Korean Association of Deep-Ocean Mineral Development
KCON	Kennecott Consortium
KEI	Kennecott Exploration Inc
KIGAM	Korea Institute of Geology, Mining and Materials
KIOST	Korean Institute of Ocean Science and Technology
KMPC	Korea Mining Promotion Corporation
KORDI	Korean Ocean Research and Development Institute (now known as KIOST; Korean Institute of Ocean Science and Technology)
KRISO	Korea Research Institute of Ships & Ocean Engineering
L	left
LAE	Long Axis Estimation
LMS	Lockheed Martin Systems
LOI	Loss on ignition
LTC	Legal and Technical Commission of the ISA
MAK	YMG MAK-1 sidescan sonar
MAPR	Miniature (mini) autonomous plume recorder
MBES	MultiBeam Echo Sounding
MFES	Multi-Frequency Exploration System
MIR	YMG Towed sonar & photo platform
MITI	Japanese Ministry of International Trade and Industry
NI 43-101	Canadian National Instrument 43-101
NIOT	National Institute of Ocean Technology
NOAA	National Oceanic and Atmospheric Administration
NOAA NWS	US National Oceanic and Atmospheric Administration, National Weather Service
NOD-P-1	NOD-P-1 is a geochemical reference standard
NORI	Nauru Ocean Resources Inc
NORIA	NOdules RIches et Abondants
NORMED	Chantiers du Nord et de la Méditerranée

NN	Nearest Neighbour estimation method
OK	Ordinary Kriging estimation method
OMA	Ocean Mining Associates
OMCO	Ocean Minerals Co. (US Consortium)
OMI	Ocean Mining Incorporated
OMS	Ocean Mineral Singapore Pte Ltd
OPEX	Operating Expenditure
ORP	Oxygen Reduction Potential
PMA	Priority mining areas
PREPCOM	Preparatory Commission
PTFE	polytetrafluoroethylene
QAQC	Quality Assurance and Quality Control
QP	Qualified Person
QQ	Quantile-quantile
%RSD	% relative standard deviation
R	Right
R-type	Rough type nodules
R-S-type	Rough-smooth type nodules
REE	Rare Earth Elements
ROV	Remotely Operated Vehicle
ROTV	Remotely Operated Towed Vehicle
RSR	Reciprocating States Regime
SA-SSS	Synthetic aperture side scan sonar
SIO	Scripps Institution of Oceanography
SIS	Sequential indicator simulation
SOEST	School of Ocean and Earth Science and Technology, University of Hawaii
SOSI	Sound Ocean Systems Inc
SSS	Sidescan sonar
S-type	Smooth type nodules
TL	Top left
TM	Total metals
TOML	Tonga Offshore Mining Limited
TPA (tpa)	Tonnes Per Annum
TR	Top right
TSS	Total suspended sediment
UGI	YMG underwater geotechnical instrument
UH	Undulating hills
UK	United Kingdom
UKSR	UK Seabed Resources
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea 1982
UNOETO	United Nations Oceans Economics and Technology Office
USBL	Ultra Short BaseLine
USGS	United States Geological Service
US/USA	United States/United States of America
USNEL	United States Naval Electronic Laboratory
USSR	Union of Soviet Socialist Republics
UTM	Universal Transverse Mercator Cartesian coordinate system
V/H	Vertical on horizontal (vertical exaggeration in a profile or section)
WA	US state of Washington
WGS	World Geodetic System
WOR	World Ocean Review 2010
XRF	X-ray fluorescence
YMG	State Enterprise Yuzhmorgeologiya (Russian Federation Consortium)

Elements

Al	Aluminium
As	Arsenic
Ba	Barium
Ca	Calcium
Ce	Cerium
Ce	Cerium
Cl	Chlorine
Co	Cobalt
Cu	Copper
Dy	Dysprosium
Er	Erbium
Eu	Europium
F	Fluorine
Fe	Iron
Gd	Gadolinium
Ho	Holmium
La	Lanthanum
La	Lanthanum
Lu	Lutetium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Nd	Niobium
Nd	Neodymium
Ni	Nickel
Pb	Lead
PGM	Platinum Group Minerals
Pm	Promethium
Pr	Praseodymium
Pt	Platinum
REE	Rare Earth Elements
S	Sulphur
Sc	Scandium
Si	Silicon
Sm	Samarium
Sr	Strontium
Tb	Terbium
Te	Tellurium
Ti	Titanium
Tm	Thulium
Y	Yttrium
Yb	Ytterbium
Zn	Zinc
Zr	Zirconium

Direction – Azimuth Abbreviations

N	North
E	East
S	South
W	West
NNE	North North East
NE	North East
ENE	East North East
ESE	East South East

SE	South East
SSE	South South East
SSW	South South West
SW	South West
WSW	West South West
WNW	West North West
NW	North West
NNW	North North West

Symbols and Units

°	Degree
°C	Degrees centigrade
(aq)	Aqueous
µm	Micrometre
cm	Centimetre
g/t	Grams per tonne
Gt	Giga (billion) tonnes
kg	Kilogram
kg/m^2	Kilograms per square kilometre (abundance)
km^2	Square kilometres
kn	Knot
kWh/t	Kilowatt hour per tonne
m	Metre
M	Mole
Mt	Million tonnes
Mwt	Million wet tonnes
m/s	Metres per second
m^3	Cubic metre
mbsl	Metres below sea level
mm	Millimetre
Mwt	Million tonnes (wet)
nm	Nautical mile
ppb	Parts per billion
ppm	Parts per million
s	Second(s) or soluble
t/m^3	Tonnes per cubic metre

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2 Introduction

A large deposit of polymetallic nodules is located in the Clarion Clipperton Zone (CCZ) of the northern central Pacific Ocean. Despite the nodules being located at great depths (4,000 to 6,000 m), they were explored with considerable success between the mid-1960s to the present day using a variety of increasingly sophisticated deep-sea technologies. In early 2012, Tonga Offshore Mining Limited (TOML), a 100% owned subsidiary of Nautilus Minerals Inc. acquired an Exploration Area of 74 713 km^2 of the CCZ. In line with the requirements of the relevant oversight body (International Seabed Authority or ISA) TOML is sponsored by the government of the Kingdom of Tonga. The contract for exploration of polymetallic nodules was approved in July 2011, and then formalised on 11 January 2012.

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In 2020, DeepGreen Metals Inc (DeepGreen) acquired the polymetallic nodule exploration contract awarded by the ISA to TOML. DeepGreen commissioned AMC Consultants Pty Ltd (AMC) to recompile the NI43-101 Technical Report (AMC, 2016) as a Technical Report Summary in accordance with SEC Regulation S-K (subpart 1300).

2.1 Purpose of the Technical Report Summary

AMC understands that DeepGreen may file this Technical Report Summary with Securities Exchange Commission as part of an S-4 filing to support the merger between Sustainable Opportunities Acquisition Corporation and DeepGreen Metals Inc.

2.2 Sources of information and data

This Technical Report Summary was recompiled from an NI43-101 Technical Report which documented exploration and estimation of Mineral Resources in the TOML Area (AMC, 2016). No new exploration data or modifications to the Mineral Resource estimate have been presented, except that the Mineral Resource has been quoted at a cut-off of 4 kg/m^2 abundance. The new cut-off is based on the estimates of costs and revenues presented in the Initial Assessment (IA) of the Mineral Resource contained in NORI Area D (AMC, 2021). The polymetallic nodule deposits in NORI Area D are similar to those in TOML Areas A through F and the QP considers that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas.

2.2.1 International Seabed Authority data

The historical sample data used as the basis for the Mineral Resource estimate in this report was obtained by Golder Associates directly from the ISA (Golder Associates, 2013). The data was also obtained separately by TOML.

Under the principles of the Law of the Sea, developed nation contractors explore then relinquish or return 50% of their initial Exploration Area to the ISA. As part of this process the ISA requires each pioneer contractor to provide all sample data to a robust centrally managed database within the ISA. The ISA then analyse these data to verify that the two areas are of equal economic value. The analysis and acceptance, or otherwise, of the data by the ISA indicates a degree of verification and validation of these data.

The ISA also supplied TOML with other data in numerous reports (referenced accordingly in the text) and the Mining Code administered by the ISA. These reports as well as structure and authorities of the ISA are publicly available from the ISA website (http://www.isa.org.jm).

The authors of this report neither supervised nor were involved with the preparation, compilation and management of data supplied by the ISA. The ISA compiled these data from multiple and independent Contractors and other sources. These data can be relied upon for the following reasons:

- The ISA has an imperative to manage these data properly and fairly in order to maintain credibility and minimize disputes amongst its many stakeholders (the nations of the world) and to date AMC is unaware of any such disputes being raised in the context of data quality and management;
- The ISA operates independently of any particular government or commercial stakeholder;
- These data have been used as part of a CCZ wide study and mineral inventory estimation exercise (ISA, 2010), which involved experts not employed by the ISA, or TOML, and these data were deemed to be of suitable reliability by the ISA for this exercise.

2.2.2 TOML exploration data

In addition to the above ISA data, TOML collected data including:

- 64,432 km^2 of multibeam sonar bathymetry and backscatter response and interpretation thereof collected during a campaign in 2013 on the RV Mt Mitchell;
- 13 nodule bulk samples and analysis thereof collected on the above 2013 campaign;
- 113 quantitative estimates of nodule abundance from box-core sampling collected during a campaign in 2015 on the RV Yuzhmorgeologiya;
- 161 quantitative estimates of nodule abundance from 587 line km or 20,857 frames of seabed photography collected on the above 2015 campaign, as well as logging of megafauna from the photos and 192 hours of continuous video;
- 4 nodule bulk samples and analysis thereof collected on the above 2015 campaign;
- 280 line km of sidescan and sub-bottom profile sonar survey and interpretation thereof collected on the above 2015 campaign;
- 334 profiles of water chemistry and sea column characterization data and analysis thereof collected on the above 2015 campaign;
- Biological taxonomy (in progress) of 3195 samples collected on the above 2015 campaign.

2.3 Field involvement

Mr John Parianos visited the CCZ from 4 September to 7 October 2013 on board the RV Mt Mitchell and from 4 August to 10 October 2015 on board the RV Yuzhmorgeologiya. He spent a total of approximately three months within the CCZ surveying and sampling the TOML Exploration Areas.

2.4 Personnel

The Sections that each of the Qualified Persons (QPs) were responsible for are summarised in Table 2.1. In addition, each of the QPs contributed to Sections 22–24, where relevant to the Sections for which they were primarily responsible.

AMC has relied upon information provided by the registrant in preparing its findings and conclusions regarding some aspects of modifying factors, as set out in Section 25.

Table 2.1 List of Qualified Persons responsible for each section

Qualified Person	Responsible for the following report Sections:
AMC Consultants Pty Ltd	Sections 1–3, 8, 9, 11.1 – 11.8, 11.9.1, 11.9.2, 11.9.3, 11.9.4, 11.9.8, 11.9.9, 12, 16–25
Canadian Engineering Associates Ltd	Sections 10, 11.9.6, 14
Deep Reach Technology Inc	Section 11.9.5, 11.9.7, 13, 15
John Michael Parianos, MSc (Earth Sciences), MAIG	Sections 4, 5, 6, 7

2.5 Reliance on other experts

The QPs have relied upon other experts for some sections in this report. These are summarised in Table 2.2.

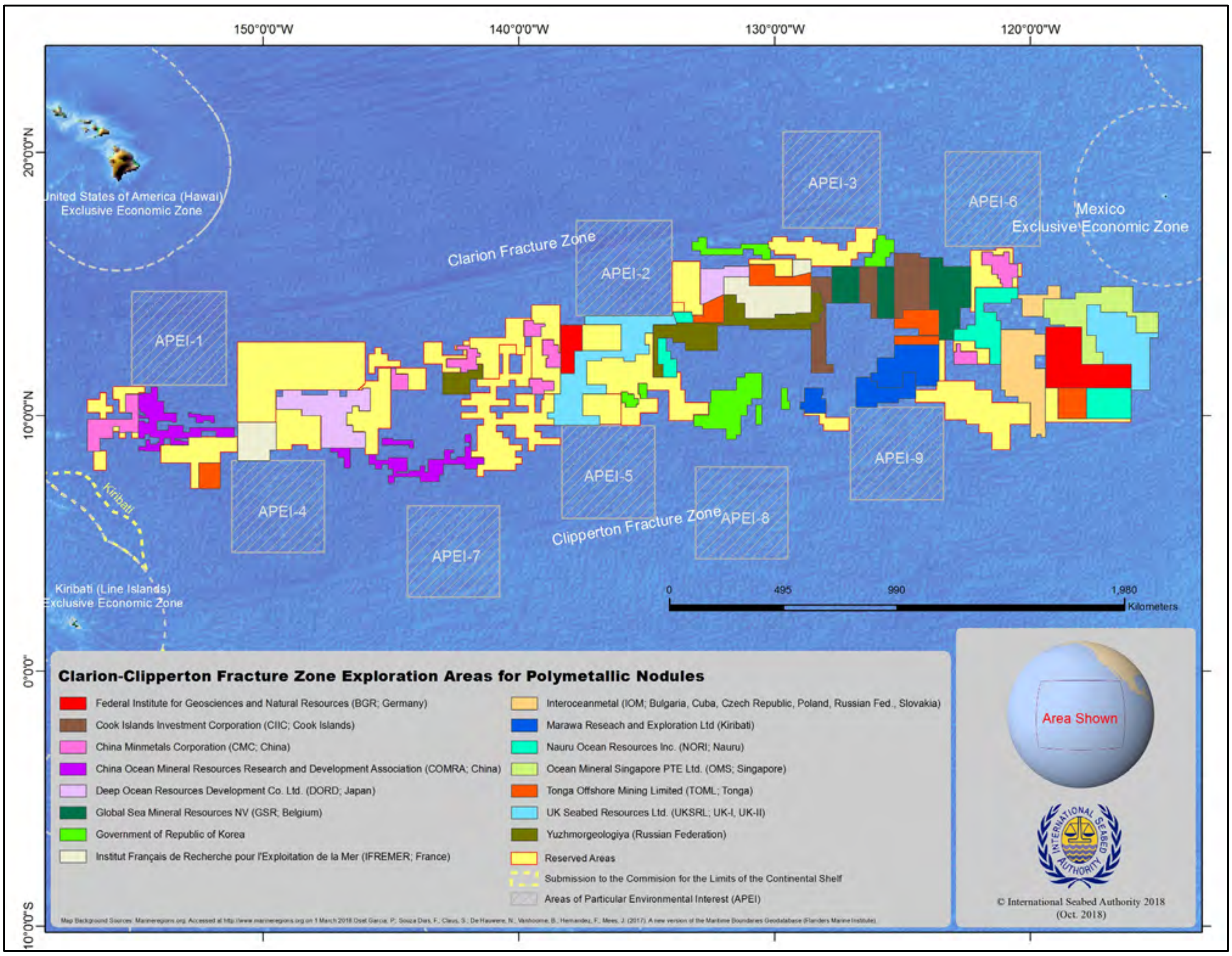
Table 2.2 Reliance on other experts

Expert	Report Sections:
Picton Group Pty Ltd	Section 17

3 Property Description and Location

The TOML exploration rights are located within the Clarion Clipperton Zone (CCZ) located in the Pacific Ocean Figure 3.1). The western end of the CCZ is approximately 500 km ENE of Kiribati and approximately 1,000 km south of the Hawaiian island group. The CCZ extends over 4,500 km ENE, in an approximate 750 km broad trend with the eastern limits located approximately 2,000 km west of southern Mexico.

Figure 3.1 Location and contractors in the Clarion Clipperton Zone



Source: https://www.isa.org.jm/map/clarion-clipperton-fracture-zone, downloaded 18 February 2021

3.1 Tenements and Permits

Tonga Offshore Mining Ltd (TOML), a 100% owned subsidiary of Nautilus Minerals Inc., was sponsored by the Government of the Kingdom of Tonga in its application for approval of a "plan of work for exploration for polymetallic nodules" by the International Seabed Authority (ISA) under the terms of the United Nations Convention on the Law of the Sea 1982 (UNCLOS) and the Mining Code of the ISA (specifically the Regulations for Prospecting and Exploration of Polymetallic Nodules).

The ISA approved the plan of work in July 2011 and this led to signing of a "contract for exploration for polymetallic nodules" by the ISA and TOML on 11 January 2012, that formalised an "Exploration Area" (tenement or licence; Figure 3.1, Table 3.1), a term of 15 years for the contract, and a programme of activities for the first 5-year period. The contract also formalised the rights of TOML around security of tenure leading to a "contract for exploitation". The contract does not cover minerals other than polymetallic nodules but in this context the ISA is obligated to ensure that no other entity operates in a manner that might unreasonably interfere with TOML.

The TOML contract area comprises six separate blocks (A through F) in the CCZ with a combined area of 74,713 km^2 (Table 3.1 and Table 3.2). These areas were previously explored by Pioneer Investors.

Table 3.1 TOML exploration area in the CCZ

Exploration Area	Reserved Block	Area (km^2)
Area A	Block 2	10,281
Area B	Block 15	9,966
Area C	Block 16	15,763
Area D	Block 20	15,881
Area E	Block 21	7,002
Area F	Block 25	15,820
Total		**74,713**

Table 3.2 TOML area extents

Area	Minimum Latitude (DD)	Maximum Latitude (DD)	Minimum Longitude (DD)	Maximum Longitude (DD)	Minimum UTM X (m)	Maximum UTM X (m)	Minimum UTM Y (m)	Maximum UTM Y (m)	UTM Zone
A	7.167 N	8.167 N	151.667 W	152.510 W	553972	647187	792205	902968	05N
B	13.580 N	14.667 N	132.000 W	133.200 W	694518	824685	1502009	1623605	08P
C	15.000 N	15.800 N	128.583 W	131.000 W	284947	544791	1658371	1747847	09P
D	13.125 N	14.083 N	123.583 W	125.333 W	247293	437022	1451031	1557860	10P
E	12.750 N	13.083 N	123.583 W	125.333 W	246693	436796	1409563	1447513	10P
F	9.895 N	11.083 N	117.817 W	118.917 W	289835	410804	1093917	1225828	11P

DD – Decimal degrees, UTM - Universal Transverse Mercator map projection

To date, no exploitation licences for extracting minerals from the seafloor within the Area have been granted.

3.1.1 United Nations Convention on the Law of the Sea

The international seabed area (otherwise known as the Area) is defined as the seabed and subsoil beyond the limits of national jurisdiction (UNCLOS Article 1). Figure 3.2 shows a map of the Area (blue zone) as well as 200 nautical mile exclusive economic zones (grey zone) and extended continental shelf zones (orange zone). Figure 3.3 shows the relationships between depth, distance and jurisdiction.

The principal policy documents governing the Area include:

- The United Nations Convention on the Law of the Sea, of 10 December 1982 (The Convention).
- The 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982 (the 1994 implementation Agreement).

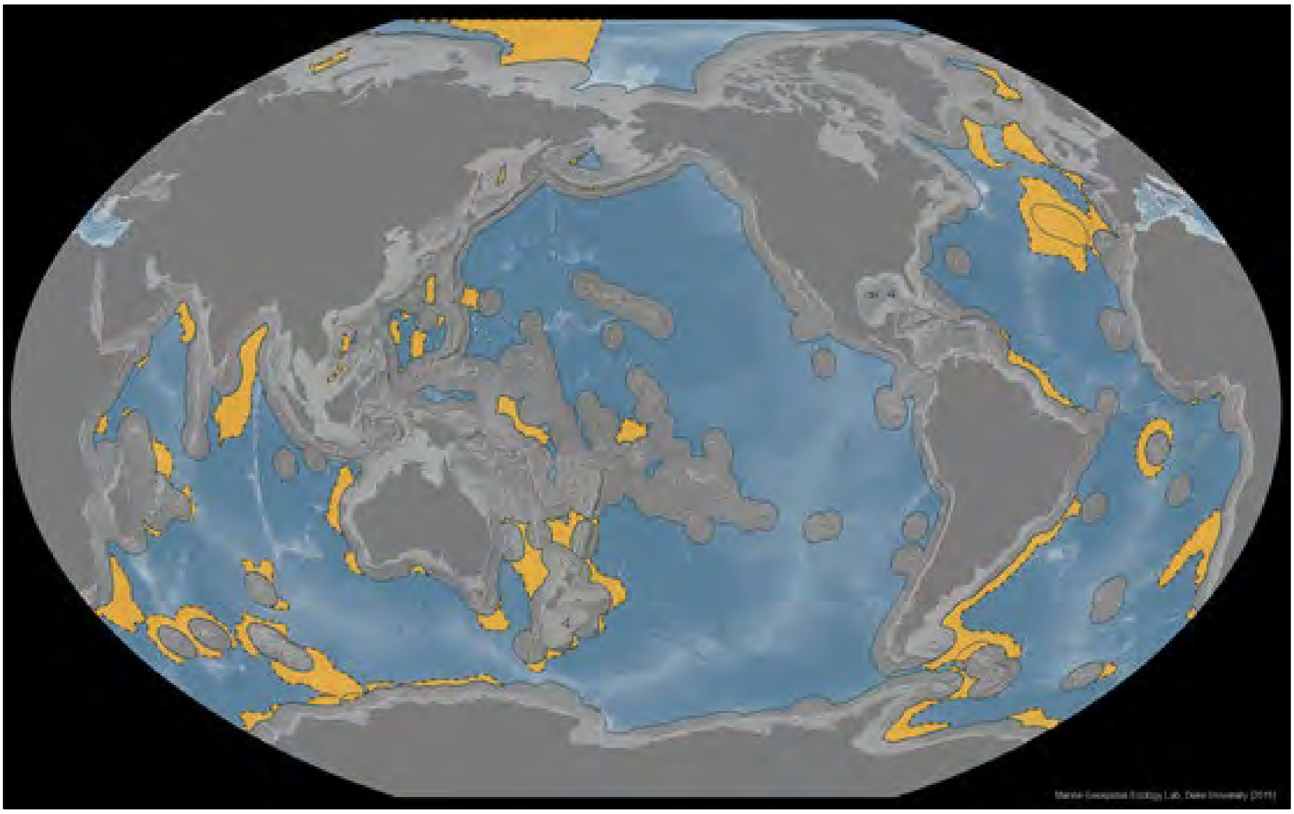
The Convention deals with, among other things, navigational rights, territorial sea limits, exclusive economic zone jurisdiction, the continental shelf, freedom of the high seas, legal status of resources on the seabed beyond the limits of national jurisdiction, passage of ships through narrow straits, conservation and management of living marine resources in the high seas, protection of the marine environment, marine scientific research, and settlement of disputes.

Part XI of the Convention and the 1994 Implementation Agreement deals with mineral exploration and exploitation in the Area, providing a framework for entities to obtain legal title to areas of the seafloor from the ISA for the purpose of exploration and eventually exploitation of resources.

The Convention entered into force on 16 November 1994. A subsequent agreement relating to the implementation of Part XI of the Convention was adopted on 28 July 1994 and entered into force on 28 July 1996. The 1994 Implementation Agreement and Part XI of the Convention are to be interpreted and applied together as a single instrument.

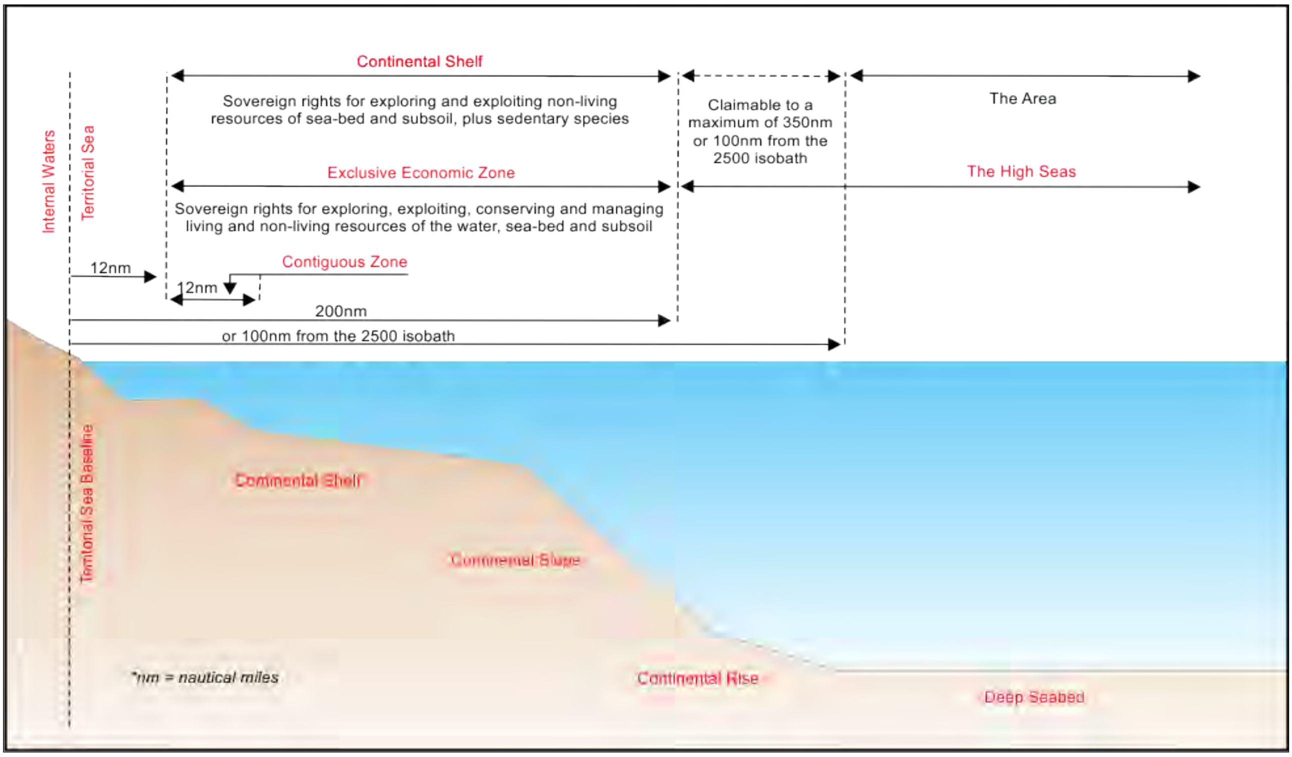
As of 20 August 2020, the Convention had been signed by 167 States (countries) and the European Union. The United States of America is currently not a party to the Convention.

Figure 3.2 Map of seafloor jurisdictions



Note: International seabed area map (blue zone) as well as 200 nautical mile exclusive economic zones (grey zone) and extended continental shelf zones (orange zone). Source: Marine Geospatial Ecology Lab, Duke University (2011).

Figure 3.3 Maritime space under the 1982 UNCLOS



Source: DeepGreen - adapted from UNCLOS, 1982

3.1.2 International Seabed Authority

The ISA is an autonomous international organisation established under the Convention and the 1994 Implementation Agreement to organise and control activities in the Area, particularly with a view to administering and regulating the development of the resources of the Area in accordance with the legal regime established in the Convention and the 1994 Implementation Agreement.

All rules, regulations, and procedures issued by the ISA to regulate prospecting, exploration, and exploitation of marine minerals in the Area are issued within a general legal framework established by the Convention and the 1994 Implementation Agreement.

To date, the ISA has issued (https://www.isa.org.jm/mining-code/ Regulations):

- The Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area (adopted 13 July 2000; the Regulations).
- The Regulations on Prospecting and Exploration for Polymetallic Sulphides (adopted 7 May 2010).
- The Regulations on Prospecting and Exploration for Cobalt-Rich Ferromanganese Crusts in the Area (July 2012).

The ISA is currently working on the development of a legal framework to regulate the exploitation of polymetallic nodules in the international seabed area.

In 2014, the ISA completed a study looking at comparative extractive regulatory regimes. This was followed in March 2014 with a stakeholder survey seeking comments on what financial, environmental, and health and safety obligations should be included under the framework (ISA 2014).

In March 2019, the Council of the ISA released the advance and unedited text (English only) of the Draft Regulations on Exploitation of Mineral Resources in the Area (ISBA/25/LTC/WP.1)

(ISA, 2018). The revised draft incorporated the consideration of requests addressed to the Legal & Technical Commission by the Council during the first part of the 24th Session in March 2018, comments by the Commission, and also reflected the responses to the first draft from stakeholder submissions. The ISA declared a target of July 2020 to have the regulations approved, however the July session was deferred as a result of COVID-19 pandemic.

Pursuant to paragraph 15(a) and (b) of Section 1 of the annex to the 1994 Implementation Agreement, which relates to article 162 (2)(o)(ii) of the Convention, the ISA Council must also adopt such exploitation regulations within two years of a formal request being made by any State which intends to apply for approval of a plan of work for exploitation.

3.2 TOML Obligations

The contract for exploration for polymetallic nodules contains conditions covering such areas as obligations of the sponsoring state, environmental obligations, marine scientific research, fees, and work programmes.

3.2.1 Work Programme

Under ISA requirements contractors are required to submit five-year work programs. The first TOML five-year work program was completed in 2016 and reviewed and accepted by the ISA in late 2016.

For the second five-year period ending in 2022 TOML proposed the following program.

- Continue environmental baseline work;
- Complete pilot testing;
- Complete geotechnical studies;
- Complete feasibility studies;
- First draft EIA/EMP;
- Continue training.

TOML noted that the program was:

- Dependent on success at each stage;
- Subject to change based on findings at hand at any particular time; and
- Reliant on funding which in turn is dependent to some extent on macro-economic conditions and development with regards to the Authority and its stakeholders.

As a result of the financial state of the company, TOML did not progress at the rate intended until TOML was purchased by DeepGreen in March 2020. TOML currently plans an aggressive program of offshore campaigns in 2021 – 2023 focussing on resource assessment and environmental base line studies with the objective of upgrading the TOML F resource area to Indicated Mineral Resource status and completing environmental baseline studies and ESIA for the TOML F resource area.

TOML plans to collaborate closely with NORI on offshore technology development as well as progressing in parallel proprietary nodule collection technology developed by TOML. TOML and NORI will collaborate closely on the development of nodule processing solutions.

3.2.2 Royalties and Taxes

Royalties and taxes payable on any future production from the property will be finalised once the ISA has developed an ‘exploitation code’. This was formally proposed as a project by the Secretary General of the ISA and endorsed at the 17th Annual Session of the ISA. Any code will need to honour the key principles of UNCLOS.

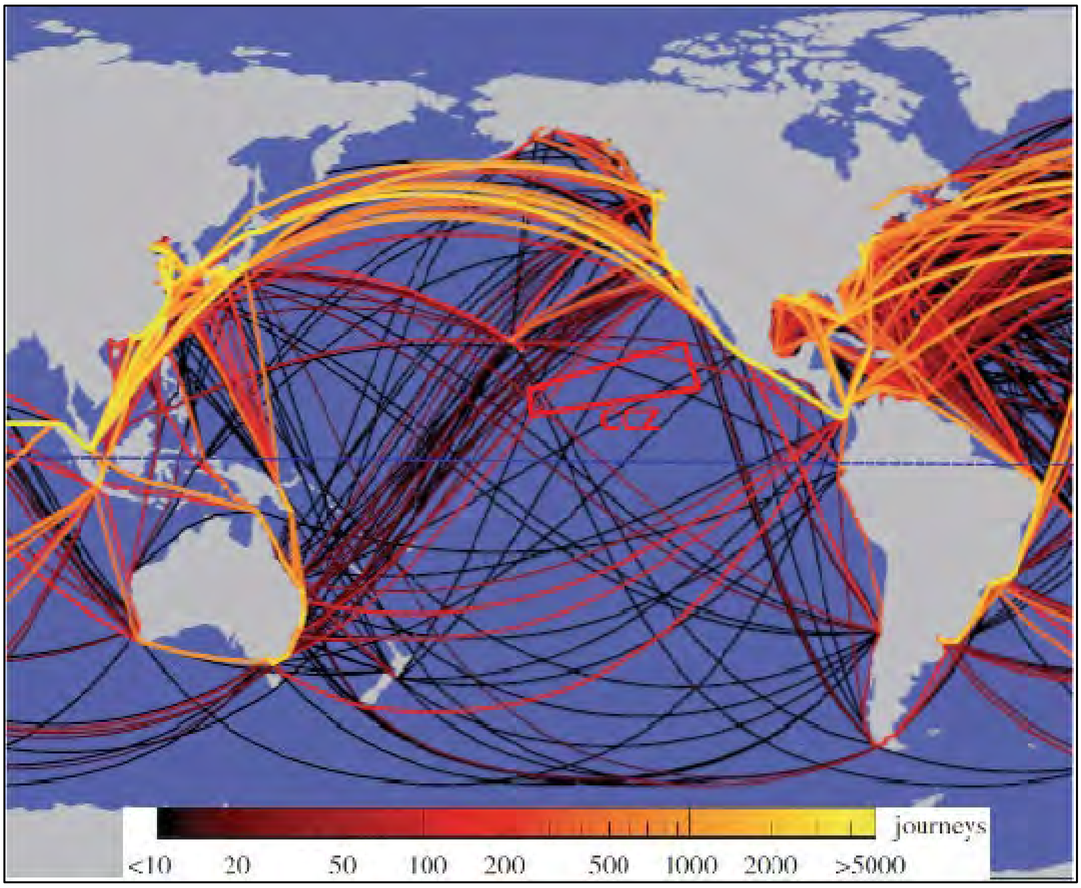
TOML has agreed to pay a royalty with the Tongan government for each tonne of nodules collected from the TOML area from commercial operations in return for sponsorship.

4 Accessibility, Climate, Local Resources, Infrastructure and Physiography

4.1 Accessibility and infrastructure

The CCZ lies between Hawaii and Mexico and is accessible by ship from various ports in the United States and South America. As the CCZ deposit does not include any habitable land and is not near coastal waters, there is no requirement to negotiate access rights from landowners for seafloor mining operations. All personnel and material will be transported to the project area by ship. The region is well located to ship nodules to the American continent or across the Pacific Ocean to Asian markets. The CCZ is generally outside major shipping lanes as indicated in Figure 4.1 which shows the global cargo shipping network, illustrating the trajectories of all cargo ships bigger than 10,000 gross tonnage during 2007.

Figure 4.1 Global cargo shipping network



Note: Colour scale indicates the number of journeys along each route. Adapted from Kaluza et al. 2010.

4.2 Climate

The CCZ has a tropical oceanic climate, with average temperatures of from 20 °C to 32 °C. Minimum and maximum temperatures generally occur in March and September, respectively (ISA 2001), and the average sea surface temperature is 25 °C. The CCZ is located in open ocean and is subject to tropical weather patterns.

Off-shore operations are planned to run throughout the year, with the exception of hurricane events, which are expected to occur once every three years for any given location. Tropical hurricanes are difficult to predict due to their erratic frequency but have high intensity over short periods and occur mostly during the period from May to October (Tilot, 2006, GSR 2018).

5 History

Manganese precipitation in the deep oceans has probably been a widespread natural process for at least the last 500 million years, which is probably when the deep-oceans first oxidized (Fike et al. 2006). The nodules currently found on the seabed within the Clarion Clipperton Zone (CCZ) are constrained by the age of the Pacific Ocean crust itself and published dating indicates that they are probably no more than several million years old (e.g., Chang et al, 2005).

This history of exploration of the CCZ can be considered in four periods:

1 The discovery of the Clarion Clipperton Zone (1875-1969).
2 The International Decade of Ocean Exploration (1970-1981).
3 The Reciprocating States Regime and the Pioneer Investors (1982-1995).
4 The International Seabed Authority (1996 to present day).

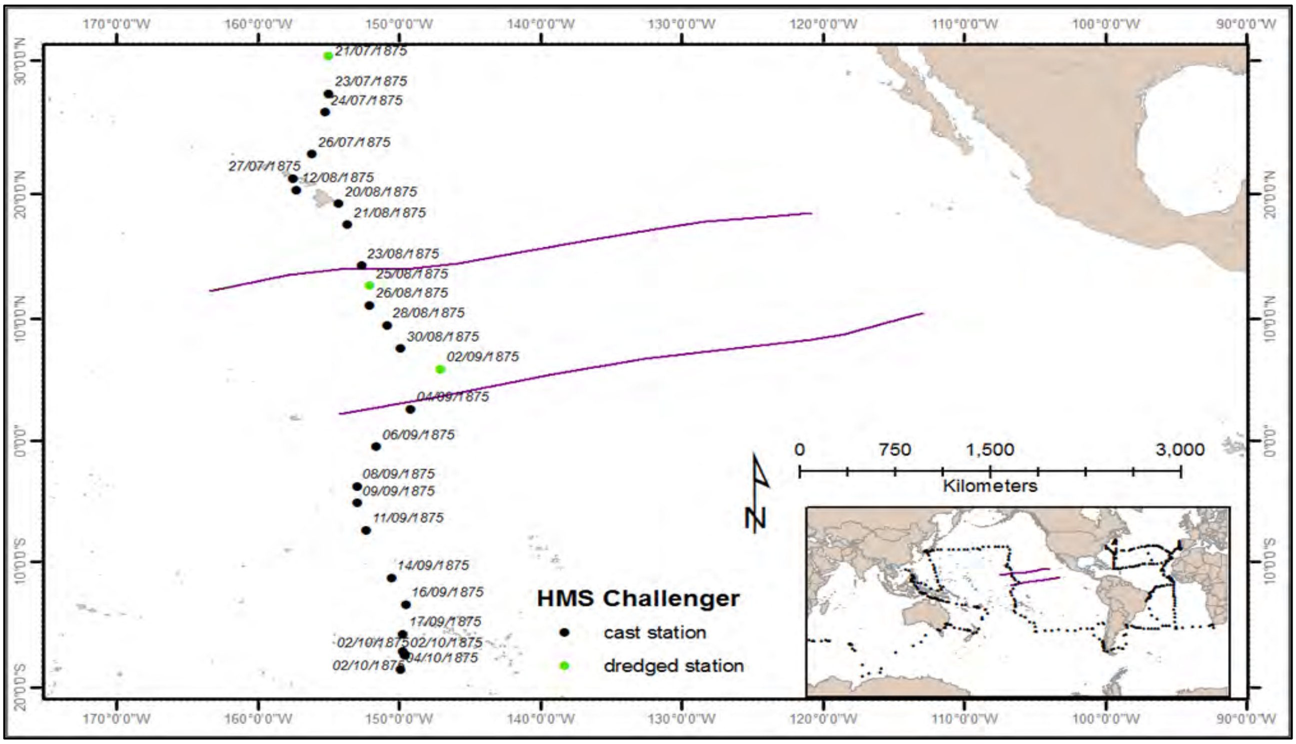
5.1 1875–1969: Discovery of the Clarion Clipperton Zone

5.1.1 First Samples

Polymetallic nodules were first reported in the Arctic Kara Sea (Ingri, 1985) and then by the British HMS Challenger expedition, in February 1873, in the Atlantic Ocean off the Canary Islands (Murray and Renard, 1891). Fossil nodules had already been found in the Alps by C.W. von Giimbel in 1861 (Jenkyns, 1977).

Although the HMS Challenger was primarily sail driven, new technology in the form of a steam engine enabled her crew to winch up nodule samples at 50 of the 343 seabed sample stations surveyed by the ship. Two of these sample stations are in what was later to be called the CCZ (Murray and Renard, 1891; Figure 5.1).

Figure 5.1 Path of the HMS Challenger



Location data from Natural History Museum UK, (2014)

The expedition resulted in numerous oceanographic discoveries including the widespread nature of nodule deposits on the deep-ocean floor. Confirmation of the extent of nodules in the Pacific was made by a contemporary of Murray and Renard, Alexander Agassiz (Mero, 1965) who made several expeditions aboard the US Fish Commission's USS Albatross around the turn of the century, including one through the central Pacific to the Marquesas Islands. At this time nodules were only seen as items of scientific curiosity.

5.1.2 Commercial Recognition

After the Second World War a Swedish expedition reportedly recovered nodules (United Nations, 1979), and interest in exploring seabed nodules started to increase again in the 1950s (as reflected in the publication rate on the subject; Meylan et al, 1976), with people like John Mero (Mero, 1965) promoting their potential with some success. Early exploration efforts and discussion were spread around the planet but based on less than 100 samples collected from the CCZ, Mero predicted the occurrence of many millions of tons of deposits with nickel and copper concentrations each greater than 1% as well as significant manganese and cobalt (Mero 1965).

Two of the early explorers in the 1960s were the USSR and the US companies Kennecott Exploration Inc and Deepsea Ventures. All started exploring in areas other than the CCZ, and it was only in the late 1960s and early 1970s that it became apparent that the CCZ had the best nodule fields in the world in terms of both grade and abundance (McKelvey et al, 1979). By the late 1960s and early 1970s, these explorers had been joined by others. Their efforts are detailed in subsequent sections.

5.1.3 USSR

The USSR started an integrated marine research programme in 1949, led by the USSR Academy of Sciences. Regular expeditions commenced with the RV Vitiaz and later the RV Dmitri Mendeleyev, starting with at least three campaigns to the Indian Ocean (Bezrukov and Andrushchenko, 1972; Bezrukov, 1962, 1963) then in the southwest Pacific (e.g., Skornyakova et al. 1990), including the Penrhyn Basin near the Cook Islands, and then in the central Pacific (Bezrukov, 1969). Over twenty years, some seventeen Soviet expeditions included at least some research on nodules.

By the late 1960s the focus of Soviet exploration shifted to the Clarion Clipperton Zone. Hundreds of samples and thousands of photos were taken along with seafloor bathymetry mapping during two campaigns. Some mineral inventory estimates were also made (Skornyakova and Andrushchenko, 1964).

5.1.4 Kennecott

Source Dave Felix and John Halkyard (pers comm. 2015), unless referenced otherwise.

Kennecott Copper Corporation became interested in manganese nodules in part based on the publications of Dr. John Mero (e.g., Mero, 1965) and work being done at Scripps Institution of Oceanography in the 1960s. Through their subsidiary Bear Creek Mining, Kennecott's first exploration campaign dates back as early as 1962, when 10 tons of nodules were dredged from a site west of Baja California. For the next few years, the group relied on technical associations with oceanographic research campaigns (Killing, 1983) but Kennecott followed up with two more of their own campaigns in 1967. That year, newly designed free fall grabs were used for the first time during the "Clarion" campaign, while the "Confidence" campaign investigated a portion of the CCZ with 143 sample stations, bottom photos and dredge hauls.

In 1969, Kennecott Exploration Inc (KEI) was formed and between 1970 and 1974 KEI conducted another seven campaigns, with progressively more detailed sampling and survey work including dredging for bulk samples (up to 197 tons of nodules and 400 cubic ft of sediment in 1972; Isaacs, 1973). In 1970, on the Crux Campaign, KEI discovered what they called the Frigate Bird deposit in the eastern CCZ (Figure 5.4).

Many exploration techniques and nodule deposit characterization methods were developed and used successfully, but these were never publicly released. Some of the techniques developed at this stage are still used today (e.g., large diameter box-coring and photographic analysis (Felix, 1980).

5.1.5 Deepsea Ventures Inc

Deepsea Ventures' first campaigns were in the mid-1960s in both the Atlantic (Blake Plateau off Florida) and Pacific (ISA, 2004). They were supported by US academic efforts (e.g., Fuerstenau et al, 1973) which focussed on the geochemistry of nodules and their metallurgical processing.

In the summer of 1970, the company conducted successful collector and air-lift trials at a depth of 762 m on the low metal grade nodule deposits of the Blake Plateau (Kaufman and Latimer, 1971; Lecourt and Williams, 1971; Geminder and Lecourt, 1972; United Nations, 1979). Deep Sea Ventures equipped the Deep-Sea Miner, a 6,750 t freighter, with a 25 m derrick and a 6 m by 9 m central pool (the space from which the subsea devices are deployed). The nodules were raised by airlift, a system previously tested in a 250 m mine shaft (ISA, 2004). The towed collector sled was fitted with a series of tines to exclude material above a certain cut-off size and thereby reduce the chance of pipe string clogging. Material passing the first set of tines was channelled to the suction point by a second set of more closely spaced tines. The first nodules arrived aboard the mining vessel on July 30, 1970. Pumping rates between 10 and 60 tons/hour were successfully achieved during this pre-production mining trial (EC, 1997).

German groups also started working with Deepsea Ventures in 1970 (Backer and Fellerer, 1986) and were more formally involved when Deepsea Ventures went on to form the OMA consortium in the mid-1970s. OMA by then had changed focus to their claim area covering the higher-grade nodules in the central CCZ.

5.2 1970–1981: The International Decade of Ocean Exploration

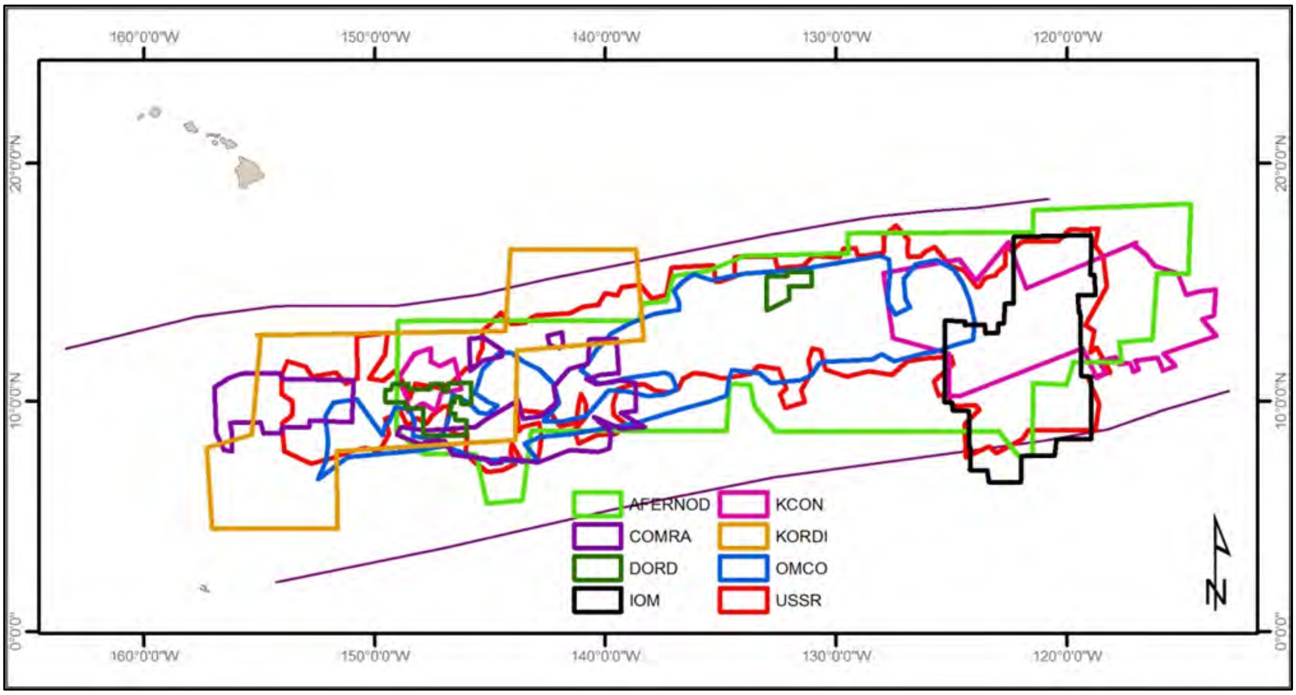
As interest grew through the 1960s, more and more commercial and government funded organizations started exploring the oceans, especially within the CCZ.

The International Decade of Ocean Exploration (IDOE) was an international, collaborative programme to improve the use of the ocean and its resources for the benefit of mankind. It nominally spanned 1970 to 1980 (DOMES, 1981). By 1975 IDOE counted 46 nations as members, including cold world adversaries, the USA and USSR. The US participation was coordinated by their National Science Foundation. Programmes managed by IDOE were mostly scientific in nature including a large environmental research component. IDOE was charged to "Improve worldwide data exchange through modernizing and standardizing national and international marine data collection, processing, and distribution."

The United Nations was keenly aware of the significance of exploiting resources under international jurisdiction and debated how this resource should be managed. On 12 December 1970, the General Assembly of the United Nations adopted 2749 (XXV) "Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction" (United Nations, 1970). This followed negotiations which took place in a specially established Seabed Committee. This document declares the bed and ocean floor, beyond the limits of national jurisdiction, to be the common heritage of mankind (Guntrip, 2003).

The UN's efforts eventually led to development of the Third United Nations Convention on the Law of the Sea, but with a regulatory regime not yet in place, this period of the International Decade of Ocean Exploration is characterized by totally independent and usually overlapping areas of exploration as shown in Figure 5.2.

Figure 5.2 Examples of the overlapping exploration areas of some of the first explorers



Sources: ISA, (2010), Menot et al (2010), Jeong et al (1994)

5.2.1 USSR

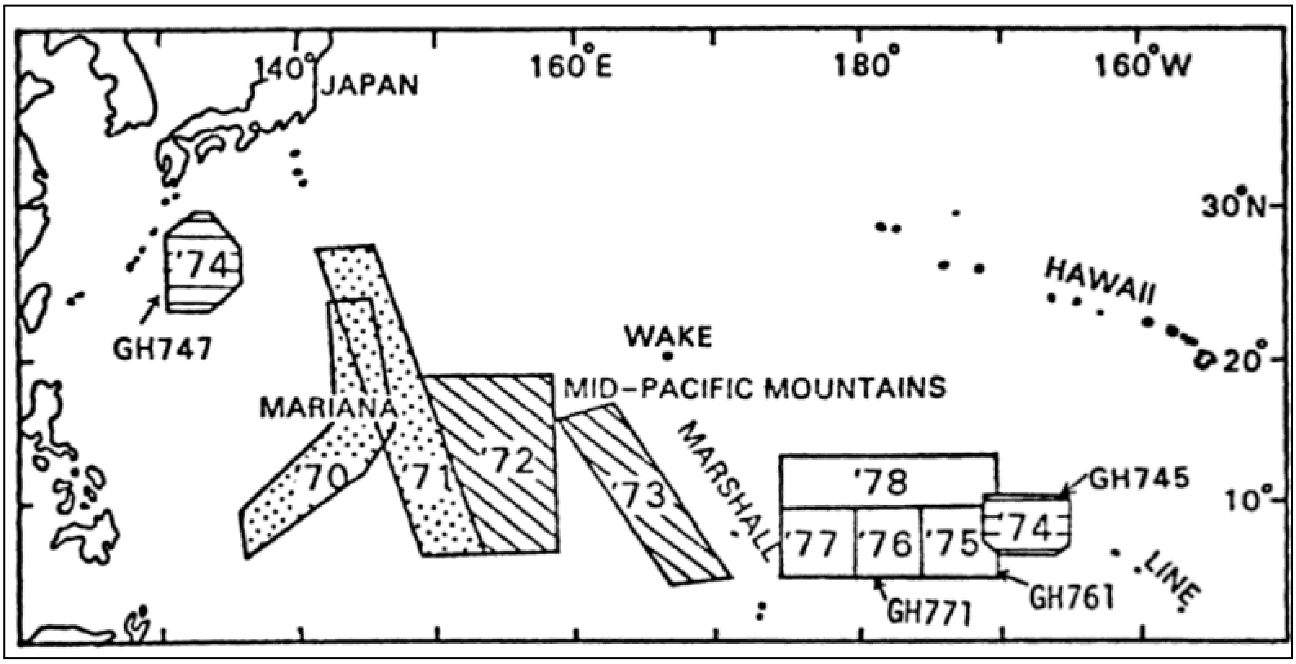
Source Andreev (pers com March 2016), unless referenced otherwise.

During this period Soviet studies of the ocean floor continued from their efforts in the 1960s. From 1976 the USSR Academy of Sciences was joined by State scientific-production enterprises “Sevmorgeologiya” (St.-Petersburg) and “Yuzhmorgeologiya” (Gelendzhik), subordinated to the Ministry of Geology of the USSR. Publications from this period include monographs (Bezrukov, 1976, 1979; Volkov 1979) and numerous magazine articles (e.g., Bazylevskaya, 1973, Skornyakova et al. 1981).

5.2.2 Japan

Japanese companies were easily the most prolific participants in nodule exploration and development in the 1970s, usually through large consortia such as DOMA and DORD (UNOETO, 1979). Japanese government efforts started in 1974 using their newly commissioned research vessel the Hakurei-Maru which was given two main projects: "Marine geological investigations on continental shelves and shores around Japan" and "Investigations on deep-sea manganese nodule deposits" which focused mostly on the Central Pacific Basin (Figure 5.3). These efforts concluded in 1984.

Figure 5.3 Areas researched by the Geological Survey of Japan in the 1970s



Source: UNOETO, 1979

5.2.3 Kennecott Consortium (KCON)

Kennecott continued their exploration in the early 1970s attracted by the large informal resource estimates for nickel and other metals. Kennecott also commissioned preliminary feasibility studies of mining by Lockheed Missiles and Space Company and Global Marine Development, Inc., starting in the late 1960s. Kennecott's corporate processing research centre in Lexington Massachusetts was charged with developing a metallurgical process for nodules with the Kennecott Computing Center in Salt Lake City being made responsible for resource estimates.

As the scale of the needed investment and level of required offshore expertise became apparent, Kennecott reached out and sought partners to share the risk. The KCON consortium was formed in 1974 based on the petroleum industry model of an operator (Kennecott Copper Corp) responsible for execution of work and supporting partners. The partners were Kennecott (50%), Rio Tinto Zinc (20%), Noranda (10%), Consolidated Gold Fields (10%) and Mitsubishi (10%) (Killing, 1983). Subsequently Rio Tinto Zinc sold half their shares to BP Petroleum Development Ltd. The Consortium was led by a Committee of Representatives (COR), which approved plans and budgets, and a Technical Advisory Committee (TAC) of technical experts from each partner which helped prepare the plans and review progress. Several engineers from the partner organizations were seconded to the KCON laboratories, principally the Ocean Mining Laboratory in San Diego, California.

The exploration work described above ended up with two areas of interest for KCON (Figure 5.4):

1 The Albatross area in the central part of the CCZ, which ultimately became the "USA4" license in 1984 (U.S. Department of Commerce) under the Reciprocating States Agreement (Figure 5.13).

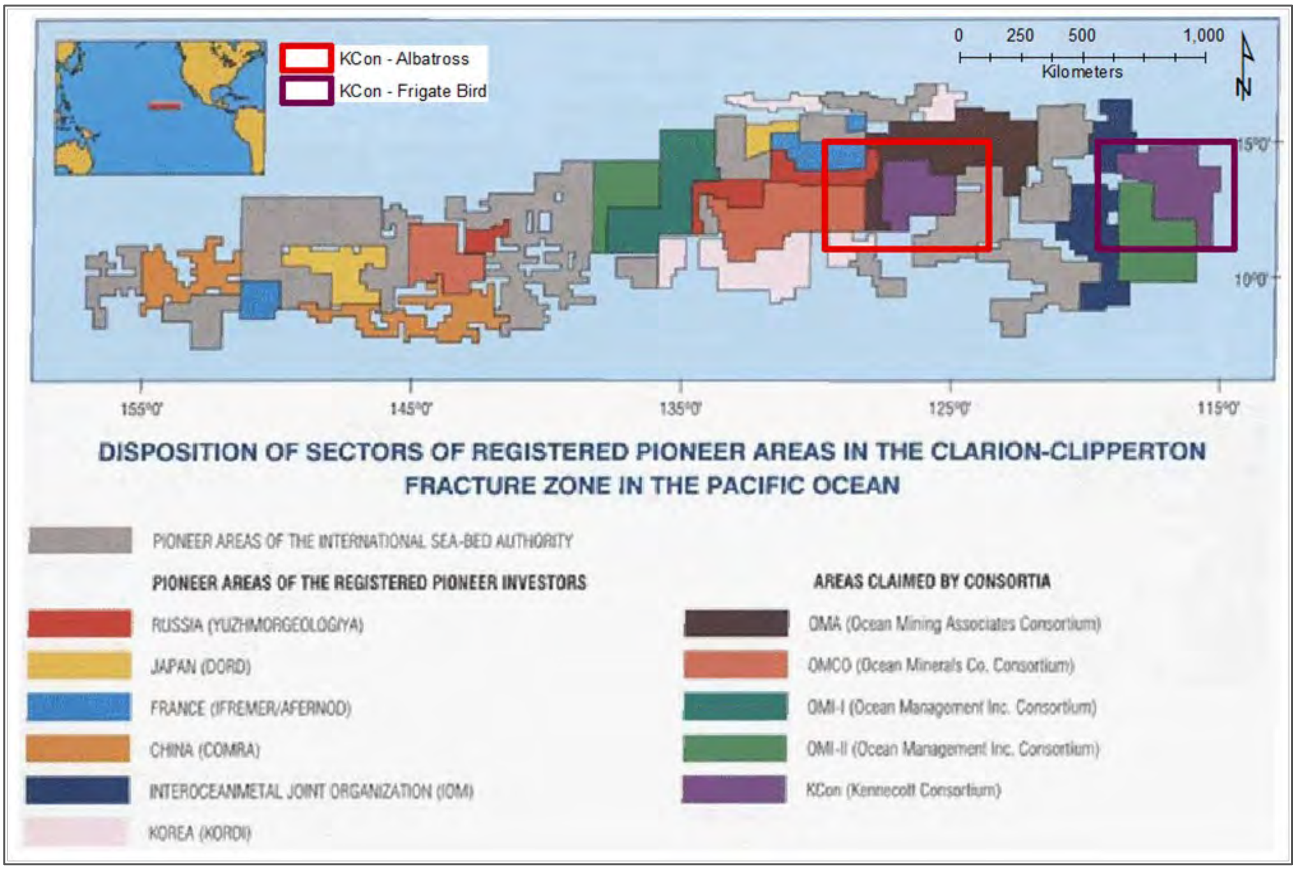
2 The Frigate Bird area in the eastern part of the CCZ which ultimately became the "UK" License in the early 1980s.

This consortium developed many of the best exploration techniques used in the CCZ including large capacity box-coring and photographic survey (Felix, 1980). Ultimately KCON reached an unpublished "inferred reserve" for parts of their concessions (David Felix pers comm. 2015). This included definition of "mineable units" on the seafloor.

Once exploration was completed the consortium developed mining system designs, numerical models and tested various components of a commercial mining system (Halkyard 1980, 1982). The development work included a towed nodule pick-up system which was tested at approximately 1/5th scale (Morgan, 2011; Heine and Suh, 1978), a hydraulic and airlift system which was tested on land (Burns and Suhm, 1979; Doyle and Halkyard, 2007), and study of nodule attrition including several pump loop simulations, material handling and transportation (Halkyard, 1979).

Metallurgical development included pilot scale testing of the patented "Cuprion" atmospheric pressure ammoniacal leach process (Skarbo, 1975; Agarwal and Beecher, 1976; Agarwal et al, 1978). A 200-ton bulk sample of nodules collected in 1972 (Isaacs 1973) were intended for a large-scale metallurgical pilot test. These nodules were stored in Safford, Arizona, however the samples were disposed of in the 1990s.

Figure 5.4 Kennecott priority areas of interest in the CCZ



Modified from Yamazaki (2008b)

A comprehensive cost estimate of a commercial mining venture was carried out by KCON between 1978 and 1980. The mining and processing research conducted by KCON in the 1970s was consolidated into a commercial system design and execution plan. This work was performed by Bechtel Corporation with support for the mining system provided by Global Marine Development, Inc. Two sites were selected for the land-based processing plant: Southern California near Los Angeles and the West Coast of Mexico at Lazaro Cardenas, Michoacan, Mexico. Bechtel developed preliminary Cuprion plant designs and cost estimates for both sites. Extensive investigations were conducted into permitting requirements and options for tailings disposal. Lazaro Cardenas was under development as a deepwater port and an industrial hub to support Mexico's industrialization plans. Meetings were held at a high level with Mexican officials who were encouraging KCON to consider a development at Lazaro Cardenas.

The cost estimate was based on a 3 Mtpa manganese nodule project producing about 88,000 lb per year of nickel and associated copper, cobalt and molybdenum. KCON never considered manganese a viable product. The overall conclusion of the KCON/Bechtel study was that at the time nodules could be cost competitive with new sources of nickel, but not with current sources (Dubs, 1983). Also, Kennecott and other industry representatives believed the then terms of the newly negotiated Law of the Sea Treaty would introduce unacceptable risk to the project.

KCON worked with government officials and other interested consortia in establishing a framework which would permit restructuring of Part XI of the Law of the Sea Treaty in a form acceptable to KCON and other active mining consortia. However, as time dragged on KCON progressively wound up their operations, stopping active exploration and closing their Ocean Mining Lab in La Jolla in 1981.

KCON applied for and received an exploration license for a segment of its exploration area under the US Deep Seabed Hard Minerals Resources Act in 1984 (USA-4). Although some ad hoc evaluation continued after this, in May 1993, KCON abandoned their license under the US Act. The consortium was dissolved. In June 1993, Ocean Minerals Company (OMCO) submitted to NOAA an exploration license application from the former KCON license area USA-4. OMCO also acquired the exploration data for the KCON sites.

5.2.4 Ocean Mining Associates (OMA)

The OMA consortium comprised Essex Minerals Company (US), Union Seas Inc (Belgium), Sun Ocean Ventures (US), with Deepsea Ventures Inc the consortium's service contractor (ISA, 2004).

In 1976, six years after the Drake Plateau trials discussed above, OMA started a programme to trial mine nodules in the CCZ. OMA equipped the Wesser Ore, a 20,000 ton iron ore carrier, with a moon pool, a derrick and revolving thrusters. The ship had the two central holds converted for equipment and the moon pool, a forward hold set aside for general use and three holds combined into two for nodule storage. The ship's derrick was covered by a distinctive dome, whose purpose was mostly to keep proprietary technology hidden. The nodules were collected by a suction dredge towed on skis behind a rigid riser and were raised by airlift. The collector was at 1/5th scale except for the collector inlets which were at full design scale.

The ship renamed Deepsea Miner II (Figure 5.5), conducted its first tests in 1977 at 1,900 km southwest of San Diego, California. The tests were suspended because the electric connectors along the pipe string were not completely waterproof. Early in 1978, two further trials encountered new difficulties when the dredge floundered in bottom sediment and a cyclone struck. The latter situation was dangerous as the riser could not be retrieved in time (it took well over 6 hours to recover), so the ship had to ride out the full fury of the storm (later voyages included an emergency explosive detachment system for the riser). Finally, in October 1978, 550 tonnes of nodules were lifted in 18 hours, at a maximum capacity of 50 ton/h. The test was stopped after a blade broke in a suction pump. Ultimately the nodules recovered were taken to Belgium (home of Union Seas Inc) and used for attrition testing in a three-phase loop system (University of Virginia (2015)).

Figure 5.5 Ocean Mining Associate's Deepsea Miner II

Source University of Virginia (2015)

5.2.5 AFERNOD

Unless referenced otherwise source is Ifremer (1994) or Menot et al. (2010).

French interest in exploration and mining of Pacific nodules dates back to the mid-1960s but field work commenced in early 1970 when the Company "Société Le Nickel" (SLN) and the National Centre for the Exploitation of Oceans (CNEXO), which later became today's Ifremer (Institut Français de Recherche pour l'Exploitation de la Mer), began studying the nodule deposits, focusing near the Marquesas Island Group (French Polynesia) (IFREMER, 1994, Menot et al, 2010).

In 1974, the Commissariat à l'Energie Atomique (CEA) and the Chantiers de France-Dunkerque, which in the meantime became Chantiers du Nord et de la Méditerranée (NORMED), formed a joint venture called Association Française d'Étude et de Recherche des Nodules Océaniques (AFERNOD). AFERNOD focused more on the CCZ.

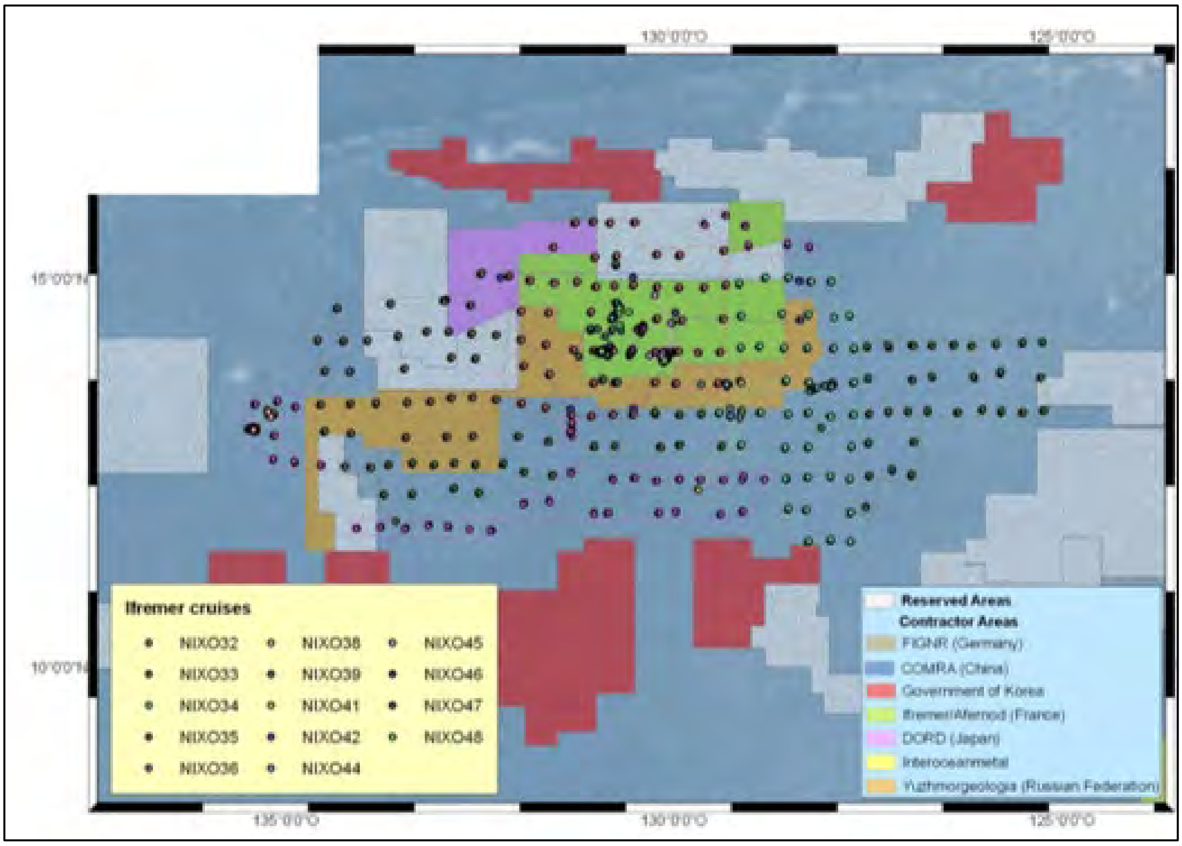
In 1984 Ifremer and CEA (via their subsidiary TECHNICATOME) formed GEMONOD (which stands for Groupement pour la mise au point des MOyens nécéssaires à l'exploitation des NODules) which led the development programme of the technology of exploitation of nodules funded by the French government until 1988. Thereafter Ifremer resumed management of all aspects of the project.

AFERNOD used four research ships for most of their work during the 1970s, the Coriolis, the Noroit, the Suroit, and Jean Charcot. They also used one of the world's first AUVs, the Epaulard, and the manned submersible Nautile.

Between August 1975 and September 1976, the French explored the entire CCZ at a wide but systematic scale with nine campaigns (called NIXO20 to 28). A wide range of technology was used in the exploration effort, but it appears that clusters of free fall grabs were typically used at each sample site.

Analysis of exploration results of the area led to definition of two domains, with one having more continuous grade characteristics. For the next phase the AFERNOD selected an area with consistent grade and typically higher abundance, the 431,500 km^2 "NORIA" area (NOdules RIches et Abondants). The eastern parts of this area coincide with KCON's Albatross Area (Figure 5.6). Work at NORIA between 1976 and 1977 started with several thousand kilometres each of sonar, magnetic and seismic survey. This was followed by six campaigns of sampling and photographic survey.

Figure 5.6 Samples in the NORIA Area



Source: Menot et al. (2010)

A "mining area" of 150,000 km^2 was then selected from the NORIA area for further work starting in 1979. This worked focused on mapping the seafloor topography and nodule abundance. The latest technologies such as multibeam echo sounding (MBES) and AUV survey were brought to the problem as well as more detailed towed surveys.

5.2.6 Ocean Mining INC. (OMI)

Unless referenced otherwise the following is sourced from Brockett (pers comm. 2016) or Brockett et al. (2008).

The International Nickel Company (INCO) first became interested in deep-ocean mining for manganese nodules back in 1958, but it was not until late in 1971 that INCO opened its Ocean Mining Development office in Bellevue, WA. During those early years, INCO contracted with outside organizations (John Mero, Dames and Moore, and Deepsea Ventures) to assist with exploration activities including several survey campaigns. INCO then explored in their own right with the MV Growler.

A first generation mechanised self-generating collector concept delivered by contractor Ocean Science Engineering in 1972, proved unworkable in trials in Discovery Bay, Puget Sound.

INCO made the decision to develop their collector systems in-house and set about designing what became internally known as the “Electro-Hydraulic” (EH) collector that was subsequently patented in 1976. INCO constructed a version of the EH collector designed to be tested on a cable and scheduled a deep-sea collector test in the CCZ in the early 1970s. Unfortunately, the collector, its instrumentation system, and a 7600 metre electro-mechanical tow cable were lost during a shallow water test off the coast of Oahu, Hawaii. That loss triggered INCO’s decision to search for joint venture partners leading to the formation of OMI.

In 1975 the OMI consortium was created, led by INCO and including AMR of Germany, DOMCO of Japan and SEDCO of the USA.

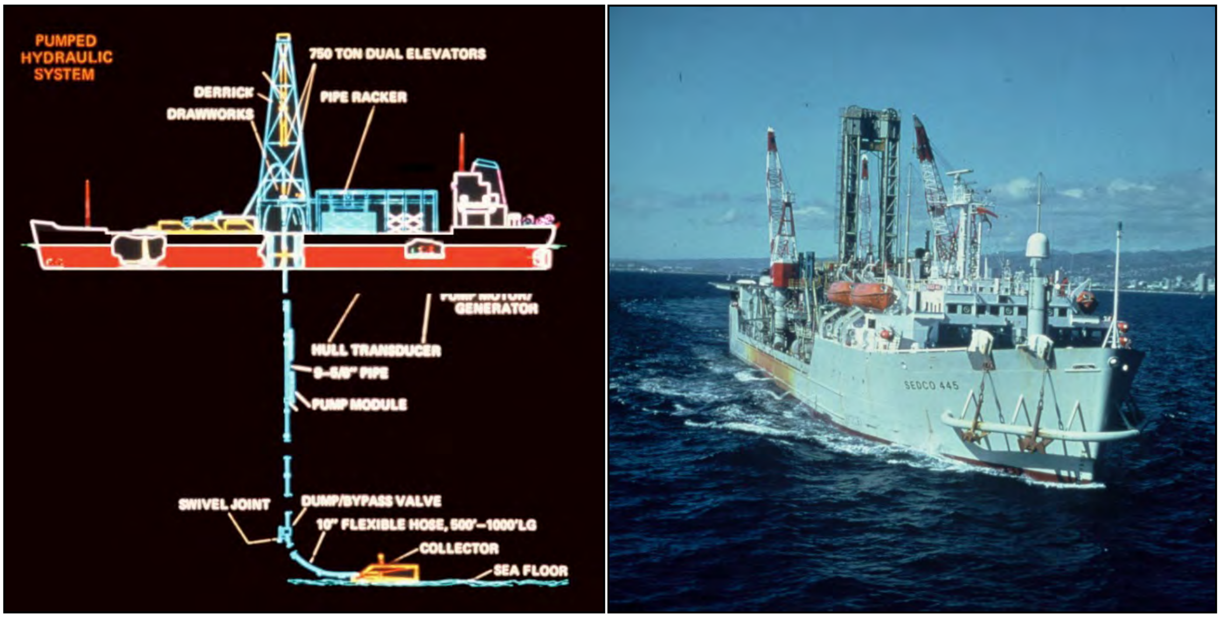
AMR was given responsibility for the exploration programme within OMI and INCO was assigned responsibility for collector development (Brockett and Kollwentz, 1977). However, both AMR and DOMCO assisted with the design and construction of prototype test collectors. INCO excavated a land based collector test facility in Redmond, WA, and early in 1976 tested eight collectors of various designs.

In 1976 the OMI collector team used the RV *Valdivia* to conduct in-situ collector tests in the CCZ. Two collectors were chosen for a subsequent pilot mining test; the DOMCO hydraulic design and the AMR cutter blade scraper design. Two of the hydraulic collectors were constructed, one with a two metre wide active collection width and one with a three metre wide collection width.

The developmental mining system tested was configured around the SEDCO 445 drill ship which was a 445’ vessel (Figure 5.7). A riser pipe assembled with 9-5/8” diameter oil field casing (Figure 5.9) extended from the gimbaled rig floor on the ship to within 50 metres of the seafloor. This gimbaled rig floor was important for safe and efficient operations and allowed the casing to be safely lowered and the collector deployed without damage. The addition of motion compensation equipment completed the list of requirements for creating the stable platform to carry out successful deep mining operations. The weight of the riser pipe, pumps, instrumentation and collector assembly was over 450 metric tons.

During the pilot mining testing, OMI tested both a hydraulic submersible pump (Figure 5.9) and an air injection lift system to raise the nodules from the seafloor to the surface. The interface between the seafloor collector and riser pipe was a structurally strengthened flexible hose to accommodate variations in seafloor bathometry. Above the flexible section of hose a deadweight was installed to control riser pipe lift-off during towing operations. Next in line was a dump valve to prevent nodule clogging in the riser pipe during mining shutdowns. There was also a vacuum relief valve in the lower assembly to prevent collapse of the flexible hose in the event the collector became jammed with nodules.

Figure 5.7 OMI Pilot Mining System Configuration and the SEDCO 445 off Honolulu



While the primary function of the collector was to gather the nodules from the seafloor, there were secondary functions; rejecting the oversized and undersized nodules, eliminating unwanted sediment, and introducing the nodules into the riser system. In addition to providing a conduit for lifting the nodules to the surface, the riser pipe was used to tow and navigate the seafloor collector through the mine site. Once on deck, an air, water and nodule separator directed the nodules to conveyors (Figure 5.10) for transporting the nodules to the ship holds and on deck storage containers. Any superfluous water and entrained sediment was returned to the ocean under supervision of NOAA environmental scientists associated with the DOMES project.

Three test campaigns culminated a four-year research and development programme by OMI to determine the technical feasibility and economic viability of deep-ocean mining at the time. The pilot mining test was conducted in more than 5,250 metres of water.

Figure 5.8 INCO electro-hydraulic collector test; DOMCO hydraulic collector launch & recovery test on the RV Valdivia

Figure 5.9 Connection of riser to collector and in-line submersible pump

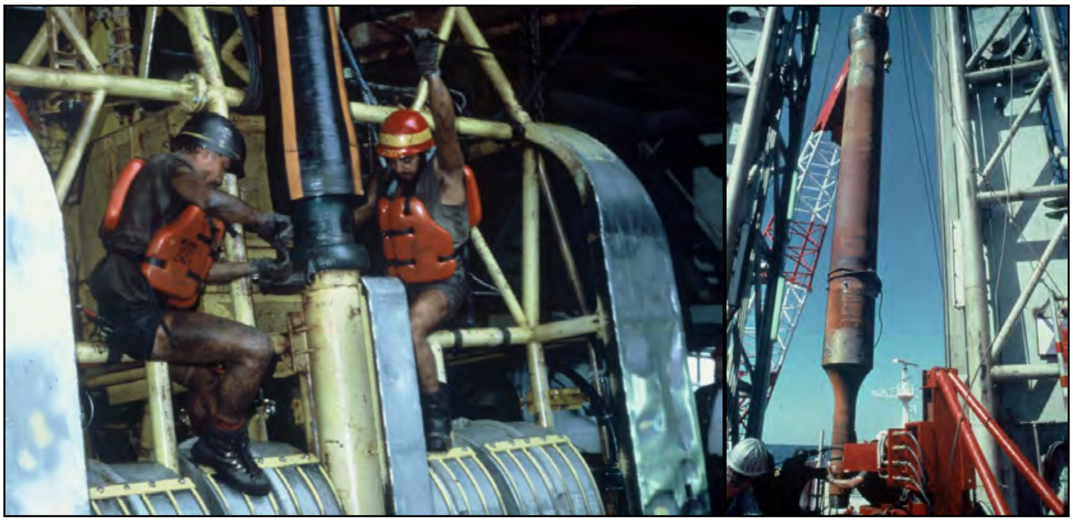
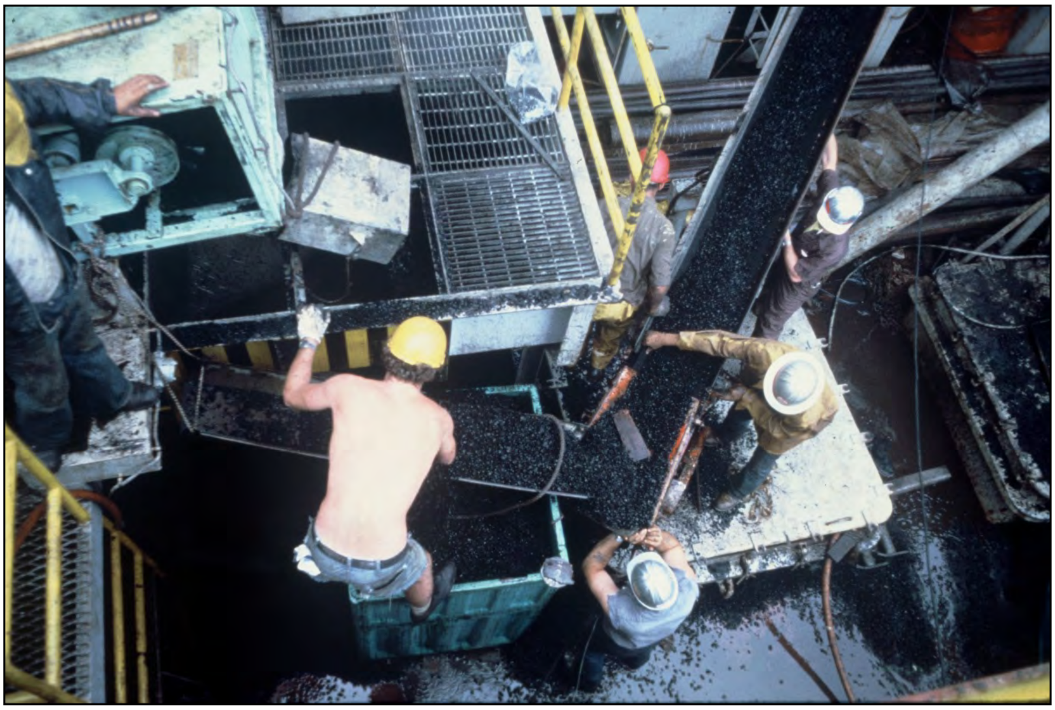


Figure 5.10 OMI Transport Conveyors Overflowing with Nodules



The OMI team, operating aboard the SEDCO 445 drill ship successfully recovered over 800 metric tonnes of nodules during these tests during the summer of 1978. The submersible pump system recovered approximately 650 tonnes of nodules while the air lift system recovered 150 tonnes. Nodule throughput varied dramatically throughout the tests with the rate exceeding 40 tonnes per hour at times causing the material handling systems and storage containers on the mining ship to overflow with nodules (Figure 5.10).

Most of the 800 tonne sample was shipped to INCO's Port Colbourne research facility for process testing and development. There it was processed into Ni-Cu-Co matte which was distributed to the consortium partners for further evaluation.

Kollwentz (1990) discusses the challenges faced by OMI (and thus by the other commercial consortia) both leading up to, during, and most critically after the successful pilot mining trial. Issues relating to the project specifically revolved around management and related technology development (the nodule consortia were some of the earliest large complex joint ventures; Killing, 1983).

5.2.7 Ocean Minerals Company (OMCO)

Ocean Minerals Company comprised US and Dutch interests, namely: Ocean Systems of Lockheed Missiles and Space Company Inc., Amoco Minerals Co, Billiton International Metals BV and Boskalis Westminster (UNOETO, 1979).

In 1978, following the end of the infamous Project Azorian (CIA, 2012), OMCO rented the Glomar Explorer from the United States Government (Spickerman, 2012) to use as the pilot mining vessel. The Glomar Explorer (Figure 5.11) had been built to raise a sunken Russian submarine but had used nodule mining as a cover story. The OMCO partners thus sought to leverage off much of the already completed engineering work.

OMCO conducted an extensive exploration campaign across the CCZ (Golder Associates, 2013) with a minimum of six campaigns utilising the MV Governor Ray between 1978 and 1981. Work included sampling (Spickerman, 2012), photography and video survey. Footage of some of the exploration work and subsequent pilot mining trials can be found at Periscope Film (2013).

The pilot mining vessel had dynamic positioning, a 33,000 ton displacement and a length of 180 m. It utilized a sophisticated system to deploy the pipe string and electric power conduits (ISA, 2004). Its large moon pool (61×22 m) facilitated the handling of a large collector and buffer. OMCO built a motorized collector outfitted with Archimedes screw-drives to crawl over soft sediment (Figure 5.11).

Initial experiments were at a depth of 1,800 m off California, but the first full tests were south of Hawaii at the end of 1978. These first tests were suspended because the doors of the moon pool refused to open. Finally in February 1979, the operation was carried out with more success. In addition, much data was assembled by the ship's advanced computer system. These operations succeeded in demonstrating that OMCO's basic approach to dredging and lifting worked (ISA, 2004).

Figure 5.11 OMCO Screw-drive collector and pilot mining vessel, the USNS Hughes Glomar Explorer

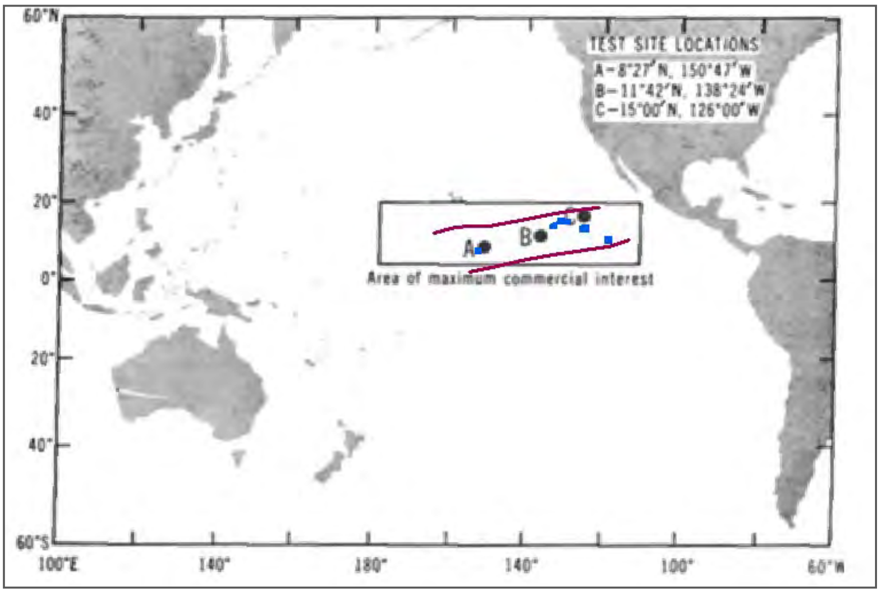
Sources: Spickerman (2012); Strauss (2014)

5.2.8 DOMES

In order to meet requirements of national environmental legislation, the United States in 1975 initiated a comprehensive research programme called Deep Ocean Mining Environmental Study

(DOMES; Bischoff and Piper 1979; DOMES, 1981; Thiel et al, 1997). The study was described as a Draft Programmatic Environmental Impact Statement and characterised the environment in the CCZ region (which was included in a rectangular area called also the DOMES area) and the impacts of its potential mining.

Figure 5.12 DOMES baseline sites in the CCZ, within the DOMES area



Modified after Piper et al. 1979 with CCZ boundaries and TOML areas.

Phase I of the programme, called DOMES I, was undertaken by the National Oceanic and Atmospheric Administration (NOAA) of the US Department of Commerce to provide environmental baseline information on three representative mining sites (A, B, C) in the Pacific manganese nodule province. Each covered an area of approximately 200 km by 200 km and was chosen in consultation with industry and the scientific community.

The programme was run by NOAA's Pacific Marine Environmental Laboratory with significant input from academia. Twelve campaigns of NOAA's research vessel RV Oceanographer were carried out from August 1975 through November 1976, totalling approximately 240 ship days at the three sites. Scientific disciplines represented were physical oceanography (studies of solar radiation and ocean currents), biological oceanography (studies of phytoplankton and benthic fauna), chemical oceanography (studies of nutrient chemistry and suspended matter), and marine geology (studies of sediment, nodules, acoustic stratigraphy).

DOMES II involved monitoring of the effects of the OMI and OMA pilot trials described above (e.g., Ozturgut et al, 1981). The OMI and OMA systems required discharge of return water from the lift system, and this was monitored and characterised. Estimates of lift and collector impacts for a 5,000 dry metric tonne per day operation were also made.

Data review and reporting included assessment of required resources for mining and on-shore processing marketing and cost-resource-safety trade-off estimates.

DOMES was designed primarily as a data gathering effort and final data reports were submitted to NOAA by early 1978. Data collected concurrently by other workers was included with the DOMES data for completeness, with a book of key findings and data published in 1979 (Bischoff and Piper 1979). The final official Draft Programmatic Environmental Impact Statement was issued in 1981 (DOMES, 1981; Ozturgut et al, 1997). The conclusions of the study at the time were that for a commercial operation most issues were likely not of serious concern, but with key focus on:

- Surface discharge from a typical riser lift system would have no long term impact and would be very small at the scale of the CCZ. A question remained on impact of particulate matter on fish larvae.
- Impact from a typical seabed collector would be clearly adverse to benthic organisms at the site, but that on the scale of the CCZ impact would not be significant. Recolonisation rates were unknown. High rates of biodiversity and ecosystem function were addressed but not examined in depth and the inevitability of islands of undisturbed seafloor within the mine sites was pointed out.
- Extent and impact of sediment plumes generated at the seafloor was still largely unknown and demanding of further investigation. The benthic impact experiments discussed below were then designed to specifically address this point (Ozturgut et al, 1997).

5.3 1982–1995: The Reciprocating States Regime and the Pioneer Investors

By 1980, the Third United Nations Conference on the Law of the Sea had been running for eight years and a successful outcome was far from certain (Churchill and Lowe, 1988). The process was drawn out by a need for consensus in the sessions as earlier attempts to use majority votes had proven unsatisfactory.

In the early 1980s legislative efforts to manage deep-sea mining (and specifically development of the CCZ nodules) split with:

- The United Nations establishing a specific Preparatory Commission (PrepCom; at the eleventh session) to look at defining principles and regulations to implement the 1982 Act and to encourage Pioneer Investors into the Area (this was often related to trying to get particular states to sign UNCLOS);
- Establishment of the Reciprocating States Regime (RSR). This directly involved USA, Japan, France, West Germany, United Kingdom and by distant association the USSR, China, and what became the IOM consortium. The RSR was either planned as a bridging system until UNCLOS could be sorted out or was an alternative system altogether (Churchill and Lowe, 1988).

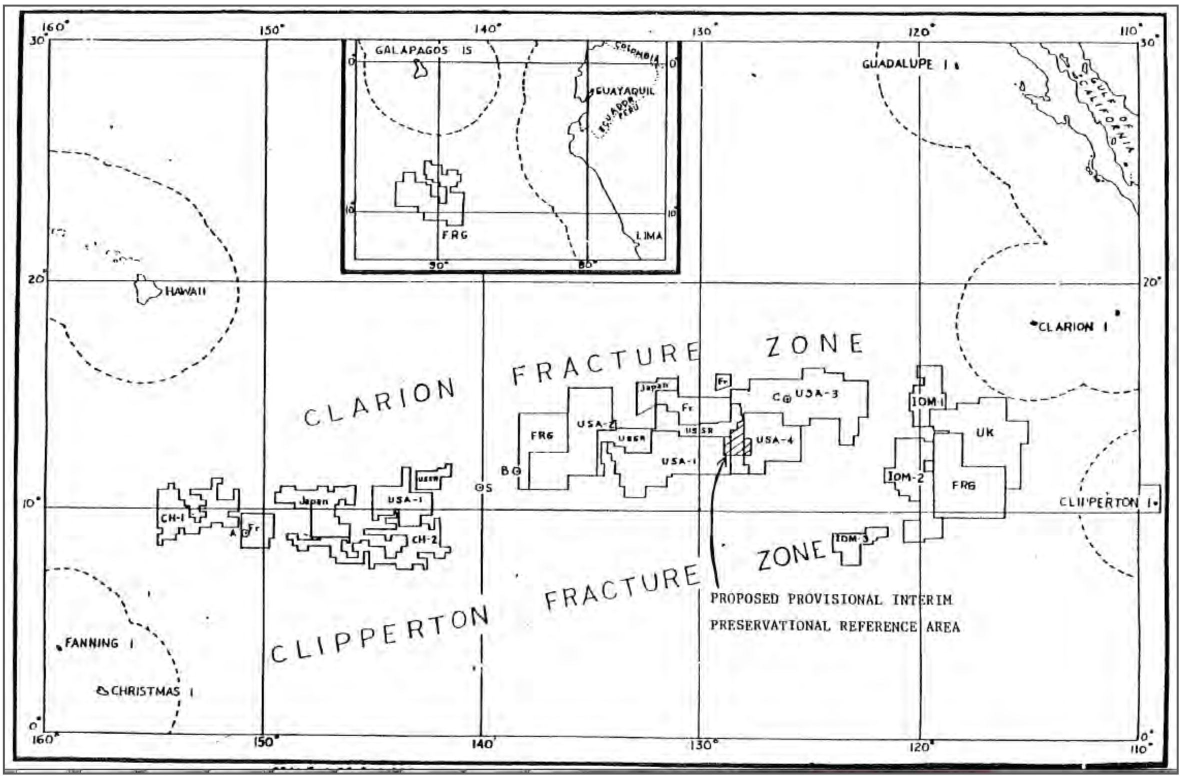
The UN was keen to close out UNCLOS and recognised the need to attract a group of Pioneer Investors on more attractive terms than originally envisaged (Resolution II). Many of the groups that had worked in the Area in the 1970s had the desire to register and protect past work with the hope that UNCLOS was imminent. After several initial attempts to progress discussions, the USSR and India registered first as Pioneer Investors in early 1984. With concerns about losing security of tenure, France and Japan followed suit in late 1984.

Issues with the applications, in part relating to overlapping areas, meant that most of these applications were resubmitted along with others in 1987 and 1988. In the meantime PrepCom worked on regulations, the RSR was progressed further, and the nations concerned discussed the issues at the UN and in other forums.

The RSR worked by mutual co-operation whereby each participating state:

- Established domestic deep mining legislation of a broadly similar basis and
- Met and agreed that mineral rights granted under their respective domestic legislation would not overlap (Figure 5.13).

Figure 5.13 Operating Areas under the Reciprocating States Regime, circa 1993



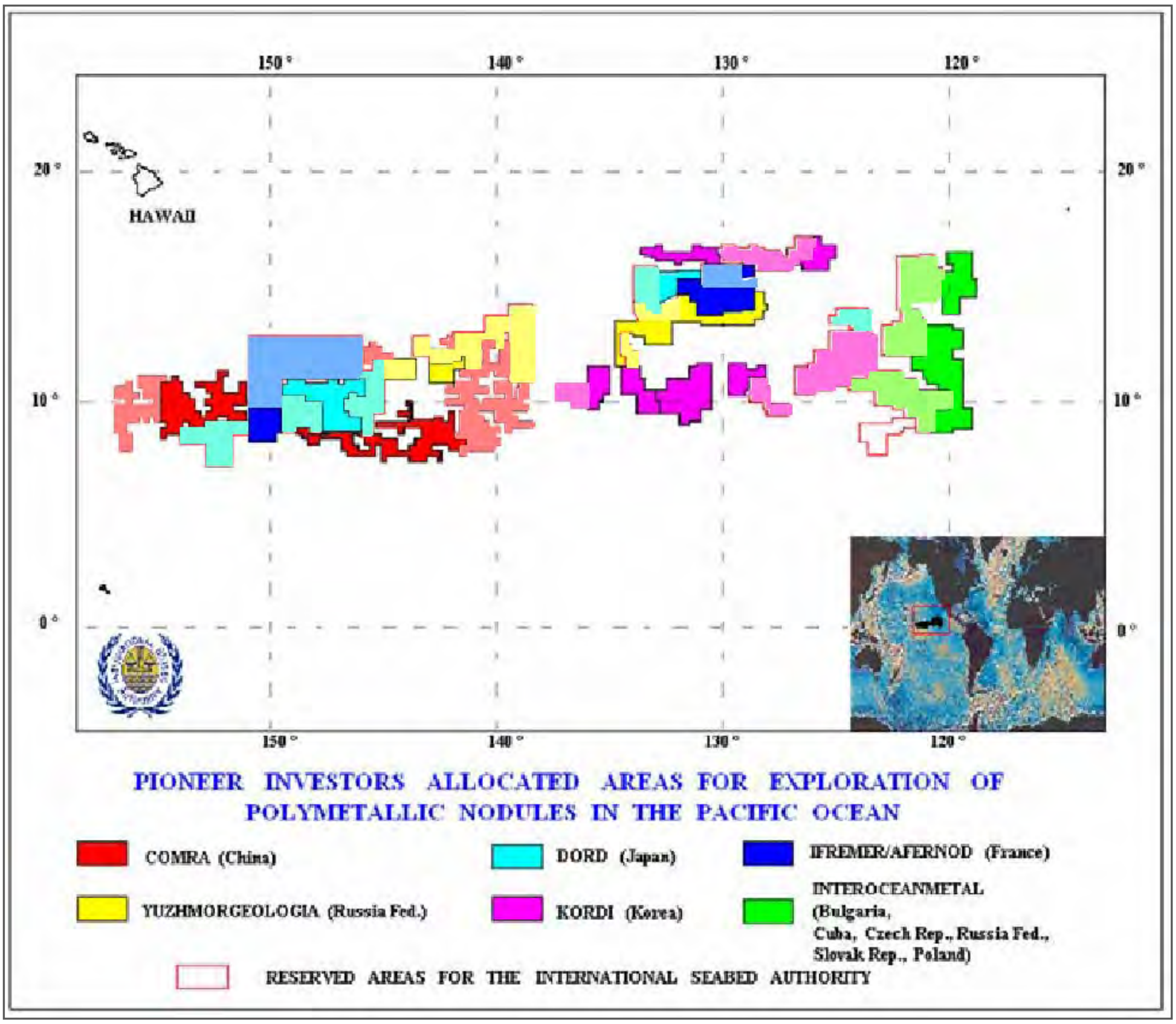
Source: NOAA (1993)

The RSR worked well in terms of removing the issues of the overlapping work programmes (and subsequent claims) that characterised the previous decade. By 1993 there were 18 “operating areas” recognised by the US (Figure 5.13) with all but one in the CCZ Most of these areas are now encompassed within the ISA contracts and returned areas (Figure 3.1). Today only three of these operating areas are still in force outside of UNCLOS, these being the USA-1 (two blocks) and USA-4 areas, all issued to Lockheed Martin under the US Deep Seabed Hard Minerals Act (NOAA, 2016). The deep-sea mining legislation developed by the other members of the Reciprocating States Regime is however still of value as domestic legislation is required in any event by Sponsoring States under UNCLOS.

Between 1989 and 1994 the commercial consortia started shutting down their nodule programmes and the UN Secretary General seriously tackled the idea of modifying Part XI (Ranganathan, 2014). In 1994, revisions to Part XI (at this stage called “The Boat Paper”) had progressed to point of widespread (if not complete) acceptance. The resulting Agreement on Implementation was included into UNCLOS and adopted as a binding international Convention.

Issuance of the Agreement of Implementation lead to a raft of ratifications from UNCLOS signatory states, but despite it being drafted largely in concession to the United States, the United States has not yet ratified UNCLOS, although it did provisionally sign the Agreement of Implementation. By this time the registration of the seven Pioneer Investors was complete. This included the six shown in Figure 5.14 as well as India (with a contract in the Indian Ocean). The Pioneers received special terms including application fees at cost of administration (up to USD 250,000) and the right to apply for 150,000 km^2 in the first instance (returning a 150,000 km^2 area of equal value at that time; Figure 5.14), reducing to their preferred 75,000 km^2 over the next fifteen years.

Figure 5.14 Retained and returned (lighter shade) areas of the pioneer investors in the CCZ



Modified after ISA (2003) and Ifremer (1994)

5.3.1 Deep Ocean Resources Development

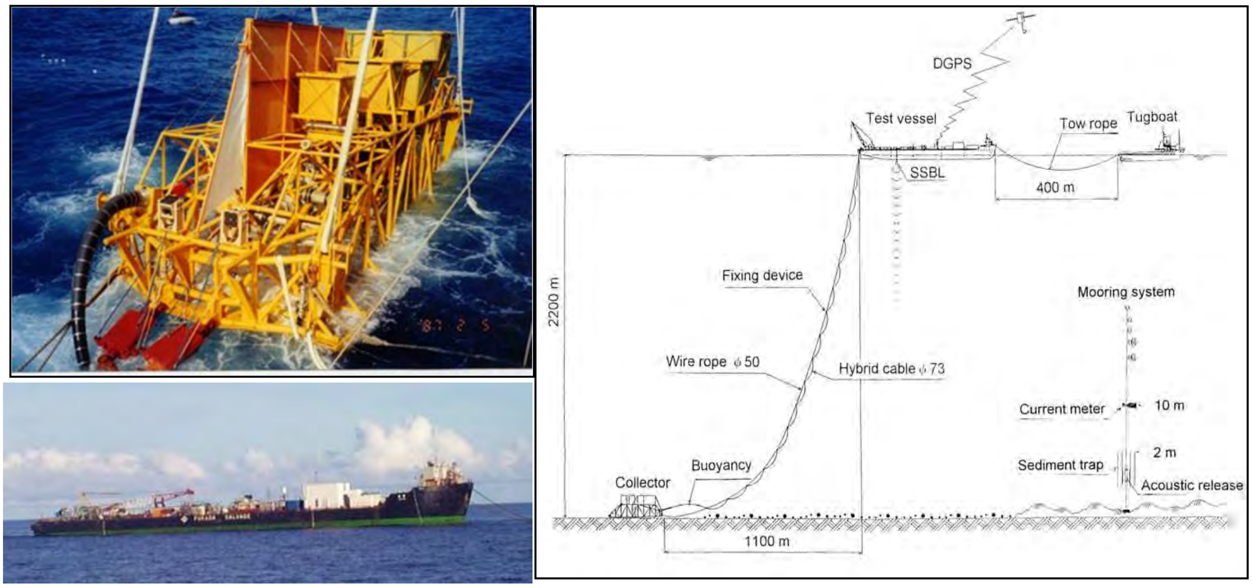
DORD has its origins in DOMA (Deep Ocean Minerals Association) a consortium of some 39 different Japanese companies that was formed as a public corporation in 1974 but with oversight by the Japanese Ministry of International Trade and Industry (MITI). DORD was then established in 1982, specifically for the development of polymetallic nodules. However, since the mid-1990s, it has been involved in other deep-sea mineral resource types and hydrocarbon research (DORD, 2013). DORD is 75.83% owned by Japan Oil, Gas and Metals National Corporation with the remainder distributed amongst some 43 commercial companies (DORD, 2013).

DORD began manganese nodule exploration activities in 1983 and was formally accepted as a Pioneer Investor in late 1987. DORD reports through the Japanese Agency of Industrial Science and Technology to MITI. Between 1981 and 1989 it spent some JPY20 B (~USD80 M at the time; Kajitani, 1990). Much of the research and development expenditure was on a mining system concept, models and simulations and pilot development by the Technology Research Association involving:

- Towed collector based on the OMI Asakawa design but incorporating a crusher;
- Lift system (either pumping or airlift);
- Flexible hose connection to collector that was key for helping managing heave and seafloor irregularities as well as landing and recovery operations; and
- Pumps and compressors and their efficiency.

In 1997, as part of the pilot programme of component testing, a trial was made using a towed collector without crushing or lifting (Figure 5.15). This was on a seamount southeast of Marcus Island (Minami-Tori-shima) at 2200 m and nodules were successfully collected (Yamazaki 2008, Yamazaki, 2011).

Figure 5.15 1997 Japanese collector, barge and trial schematic



Source: Yamazaki (2006)

In 1996, ahead of the seamount trial, DORD paused work in the CCZ, resuming only in 2008.

5.3.2 China and COMRA

Formal Chinese interest in deep-sea marine science and development is believed to date back to the mid-1970s with the leadership of Deng Xiaoping (Takeda Jun'ichi, 2014; Hoagland et al, 1992).

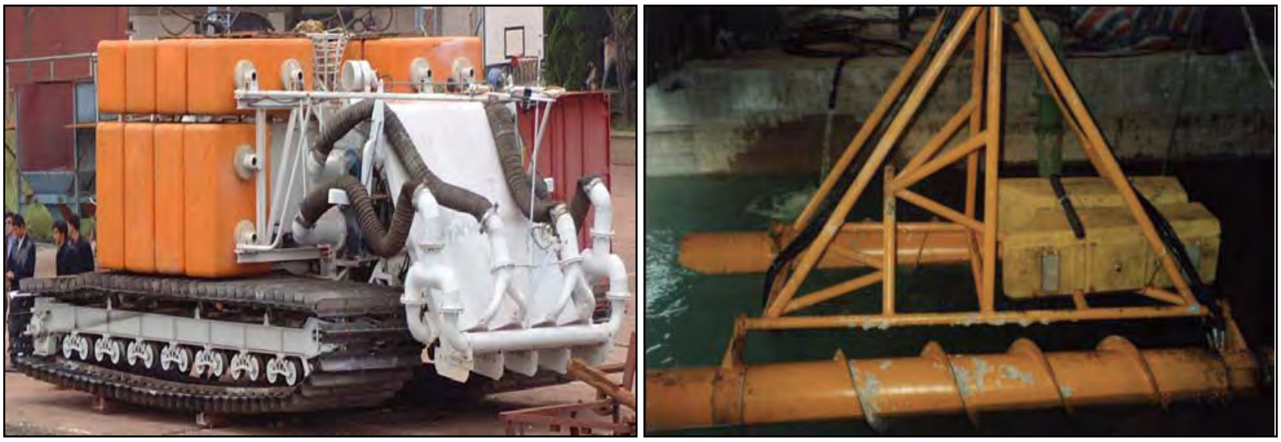
The first known marine surveys took place in 1978 (RV Xiang Yang Hong 05; COMRA, 2013a), 1983 and 1985 (RV Xiang Yang Hong 16 in the central Pacific; Hoagland et al, 1992; Glasby, 1986). Between late 1986 and 1987 a campaign to the CCZ covered 48,000 km^2.

Between 1991 and 2013, COMRA organized some 16 ocean expeditions to its area in the CCZ (COMRA, 2013b). Ultimately it delineated some 20 Gt of "mineral rich areas" (COMRA, 2013a), using in part an acoustic system called MFES (Multi-Frequency Exploration System; ISA, 2010).

In 2001, COMRA was involved with research institutes in pilot-miner trials in a test pool (2.8 m deep) and later in shallow water (~150 m deep; Li and Jue, 2005; COMRA 2013c). The tests included: trials of track and screw drive vehicles (Figure 5.16); determination of power requirements; ability to navigate obstacles; spud types for tracks; the ability to make turns; and the effect of sideloads. Tendency to accumulate mud is not specifically mentioned. Test work showed that the test tracked vehicle worked better than the test screw drive vehicle (Li and Jue, 2005) so a tracked vehicle was used as basis for the pilot vehicle.

Trials started June 2001 and in September the first successful production test were achieved with collection of 900 kilograms of synthetic nodules. At around the same time lifting tests were done using pumps and pipes in an old mine shaft (to 230 m).

Figure 5.16 Chinese pilot scale tracked and test screw-drive subsea vehicles



Source: Li and Jue (2005)

5.3.3 GEMONOD

AFERNOD continued working on the CCZ project for the French government until around 1984 when they were joined by GEMONOD (Groupement pour la mise au point des MOyens nécessaires à l'exploitation des NOdules), which focused on the mining and processing sides of the project (Ifremer, 1994).

Work at this time included provision of samples for metallurgical test work, more detailed seabed geotechnical work and accurate characterisation of the types of seabed obstacles. The geotechnical work included using the Nautile submersible to take shear vane readings on carefully selected sites during the 1988 NIXONAUT campaign (Cochonat et al., 1992).

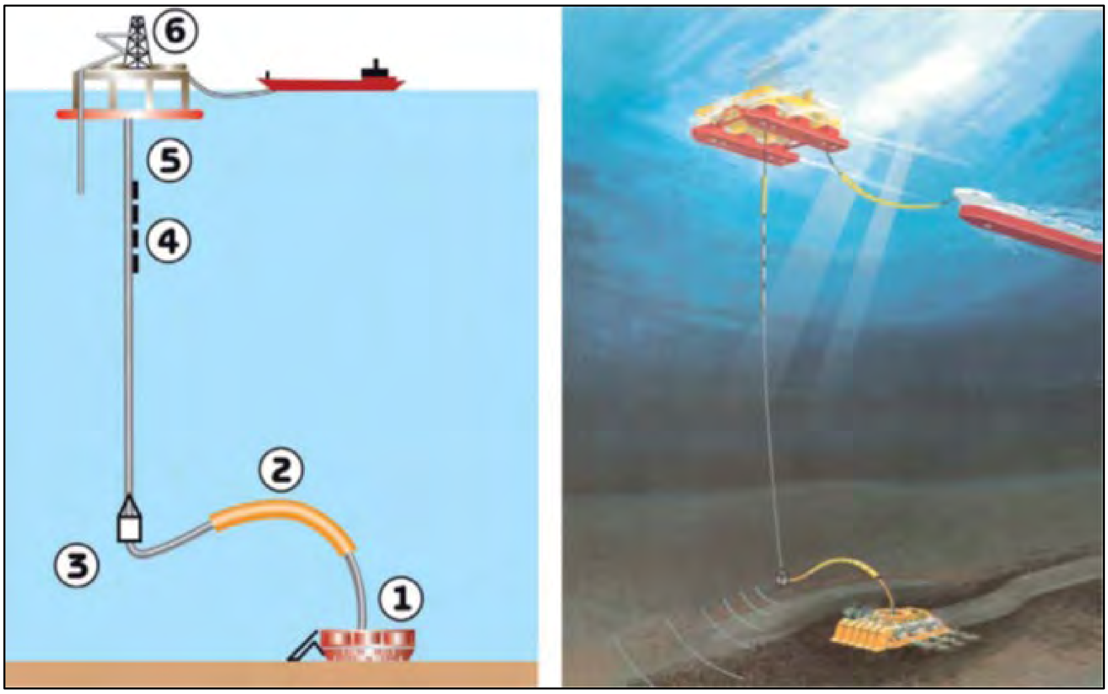
Much of the photographic and video data collected by Ifremer at this time was studied by biologists and is encapsulated in a detailed study on the megafauna (animals > 2 cm in size) of NIXO45 by Tilot (2006). This includes some of the first detailed photos of animals and landforms on the seafloor of the CCZ and a quantitative analysis of the megafauna present.

A 25 tonne metallurgical sample was collected from 49 dredge deployments. A trial mining site was also selected, called NIXO 45, and this area was surveyed and sampled in detail.

AFERNOD and then GEMONOD also considered a variety of possible mining systems during this period including one of the most exotic ever taken to testing phase. Initially in the 1970's the continuous line bucket system was favoured (ISA, 2001b) but by the mid-late 1970s survey had discovered terrain obstacles on the ocean floor, such as blocks, steps, cliffs and potholes, convincing French engineers that a bottom collector independent of a surface vessel was needed.

In 1980 they worked on the concept of a free-shuttle mining system (Ifremer, 1994) consisting of a series of independent vehicles that would dive on their own to the ocean floor. Reaching the bottom, they would dump ballast to position themselves and would start to collect the nodules. After loading 250 t of nodules, they would drop additional ballast and start their ascent to the surface. It was found during the feasibility study that the system would be too expensive, because the 1,200 t weight of the shuttles far exceeded their 250 t loading capacity. Nonetheless in 1985 a prototype pilot scaled vehicle (PLA-2 6000; Préleveur Libre Autonome) was built and in late 1987 tested in the Mediterranean where it demonstrated flight, landing, seafloor movement, and return to surface (ISA, 2001b).

Figure 5.17 GEMONOD crawler and hydraulic lift system



Source: Herrouin 2009. (Crawler (1) hose (2) buffer (3) pumps (4) rigid pipe (5), semisubmersible platform (6))

By the mid-1980s GEMONOD determined that hydraulic systems seemed to have the greatest potential (Ifremer 1994; Herrouin 2009; ISA 2001b, 2004). GEMONOD's system (Figure 5.17) consisted of: a semi-submersible surface platform; a 4,800 m rigid steel pipe string, and a flexible hose, 600 m long and with a 38 cm internal diameter, connecting the bottom of the pipe string to a dredge on the seabed. This hose would form an arc, allowing the dredge to deviate from the route followed by the surface platform so as to avoid obstacles. The self-propelled dredge would be 18 m long, 15 m wide and 5 m high, weighing 330 t for 78 t buoyancy. Crawling on the bottom, it would collect nodules and condition them for pumping through the flexible hose. Ore carriers would transport the nodules from mining ship to port, where the processing plant would be located.

GEMONOD also looked at mineral processing, both hydrometallurgical and pyrometallurgical options (Ifremer, 1994). This included a pilot processing plant for ammonia/acid leach circuits built in Fontenay-aux-Roses by CEA (ISA, 2001b), and smelting tests by MetalEurop.

5.3.4 USSR and Russia

Studies by the USSR Academy of Sciences increased markedly in number in the 1980s. New advances were in the study of the composition and structure of nodules, as well as local factors (e.g., Kazmin, 1984; Andreev, 1994). However, the most extensive research was carried out by the Ministry of Geology (through institutes such as Yuzhmorgeologiya) of the USSR. These studies included the Indian Ocean, but focused for the most part on the CCZ, and each year between 1982 and 1987 there were four or five marine expeditions (S. Andreev pers comm. 2016). Work included development of high-quality towed sonar and photo platforms (e.g., MAK, MIR and Neptune that are still used today), as well as samplers and navigation systems.

During the 1980s and early 1990s the Soviet explorers examined of the order of 3 million km^2 area in the CCZ, with a network of stations at an average density of ~ 50×50 km. Studies included bathymetric, gravimetric and magnetometric observations, acoustic research, as well as bottom sampling. On the sections of the CCZ regarded as promising for the future development application, the station spacing was reduced to 25×25 km, and towed sonar and video-photography was added.

On May 16, 1988 the USSR formally became a Pioneer Investor through Yuzhmorgeologiya, and since then the Ministry of Geology effectively halted all nodule related work outside the CCZ. Up until 1997, YMG performed around 12,000 line km of deep-towed acoustic survey (typically side-scan and sub-bottom profiling) and 8,900 line-km of deep towed photo-television survey and collected about 1100 seafloor samples. The results of this work greatly clarified ideas about the structure of localized accumulations of the nodules.

In parallel with this work the Russians considerably intensified research and development into the extraction and processing of nodules. This included pilot testing of both pyrometallurgical and hydrometallurgical processing in 1989.

During 1988 and 1989 Yuzhmorgeologiya and Sevmorgeologiya also were closely involved in geological studies of the eastern part of the CCZ in order to prepare the applications created before the Interoceanmetal Joint Organization. This included results from some 11 research campaigns.

5.3.5 Interoceanmetal Joint Organisation

Interoceanmetal Joint Organization (IOM) was formed on 27 April 1987, based on an Intergovernmental Agreement and started operations in December that year (Kotlinski et al, 2008). In early 1991 IOM registered as a Pioneer Investor with PrepCom with their Certificate of Registration issued in July 1992. Present IOM member states are: Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, and Slovakia. Past members included Vietnam and East Germany.

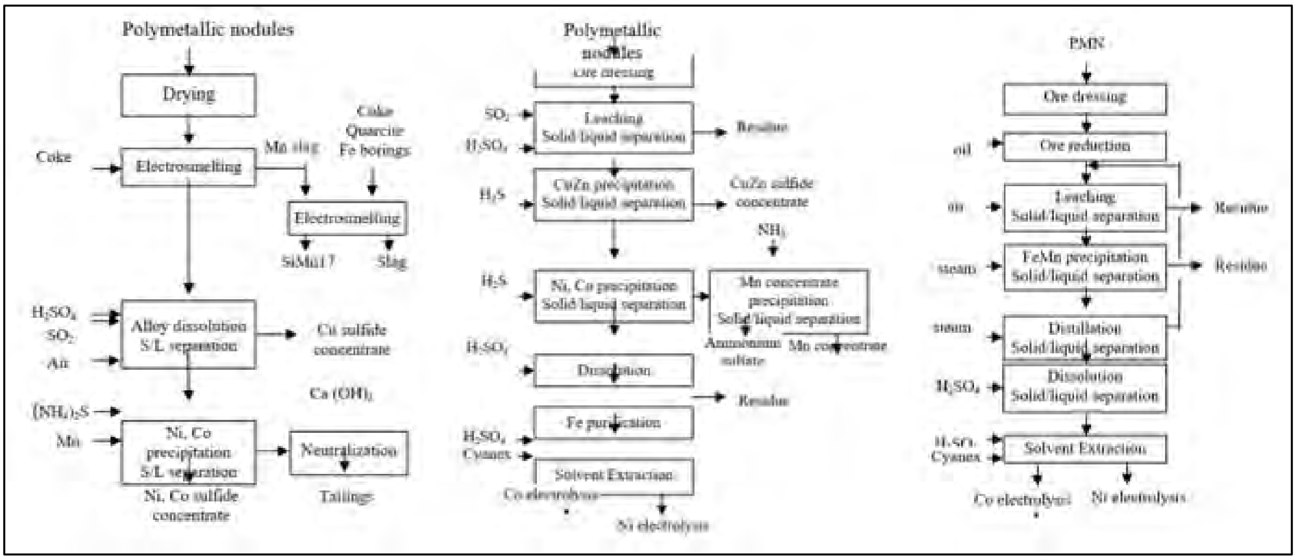
After its establishment, the IOM focused on regional geological and geophysical surveys within the CCZ in 1988 and 1989. After surveying 540,000 km^2 (including TOML Area E), IOM's claim with PrepCom concerned 300,000 km^2, all in the eastern part of the CCZ. Between 1987 and 2010 they were involved in some 20 research campaigns (Stoyanova, 2010).

In the mid to late 90s IOM started research into mining and minerals processing. Concept design of a possible mining system included computer simulations of the effects of the marine environment on the mining system, movement of the mining vessel and nodule miner and effects of the movement on the transport rise pipe length paid out, and riser pipe deformation. The simulation showed that the riser pipe shape deformation depends mainly on mining vessel movement speed and can be controlled by horizontal forces applied at low speeds.

Experiments were also done for nodules of different shapes and sizes for nodule and water velocity measurements at upward flow in the hydraulic laboratory at in the Department of Water Engineering and Hydrotransport of the Agricultural University of Wroclaw, Poland. The mixture phase velocity measurements were carried out with application of radioisotope-tagged natural and synthetic nodules. A volume concentration as high as 10% was used in a pipeline of 150 mm diameter, that could be considered for a trial or commercial system.

Metallurgical research included desktop development of a pyro-hydrometallurgical processing circuit at the University of Chemical Technology and Metallurgy, Sofia, Bulgaria and Hutny projekt, Bratislava, Slovakia (Figure 5.18).

Figure 5.18 Preliminary metallurgical processes studied by IOM



Pyro-hydrometallurgical (L), acid leach (C) and ammonia leach (R) processes. Source: Kotlinski et al. 2008

Hydrometallurgical acid leach nodule processing was also studied at CNIGRI Moscow, Russia, including benchtop test-work and hydrometallurgical acid and ammonia leach processing options at the Nickel Research Centre in Moa, Cuba. All of the process route options studied gave good metal recoveries but there were clear (unpublished) differences in terms of likely capital and operating costs.

5.3.6 Benthic Impact Experiments

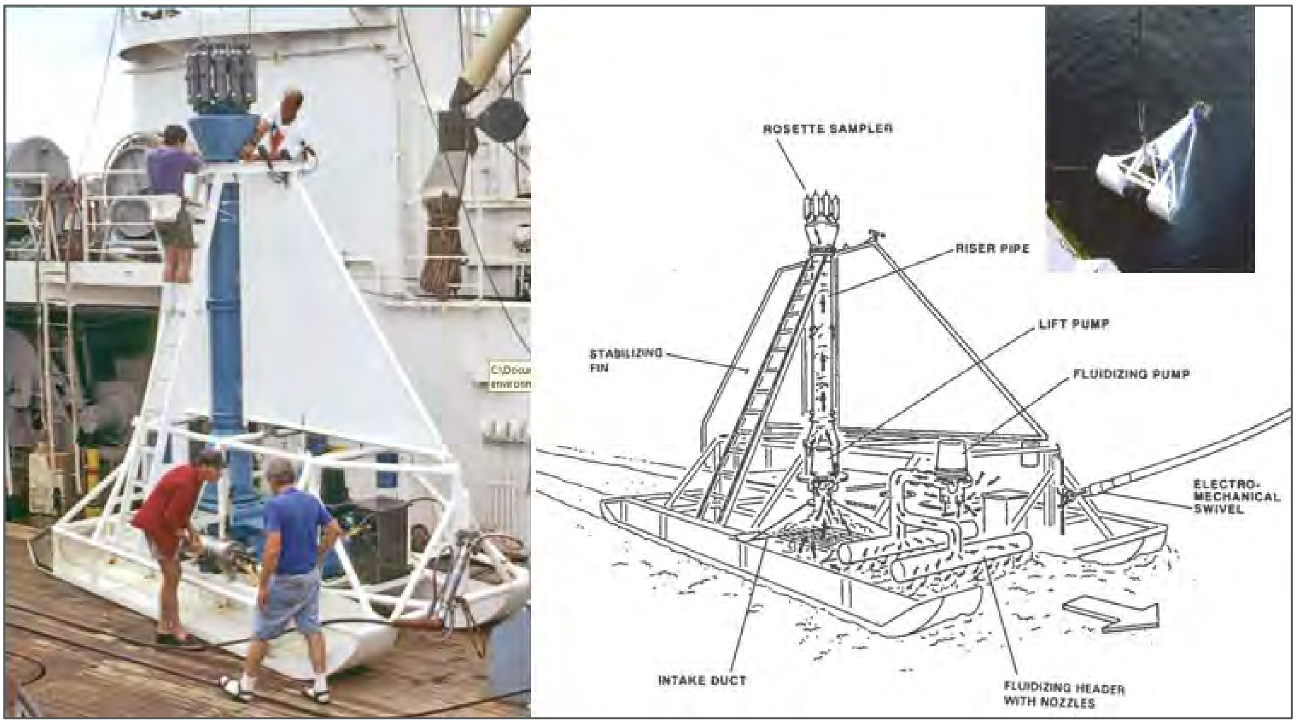
Benthic impact experiments were born out of US environmental studies in the 1970s, including DOMES. The first known disturber system was built in the late 1970s by Sound Ocean Systems Inc (Brockett 2016, pers comm.).

After several attempts by different groups to build an effective disturber and monitoring system, Sound Ocean Systems designed and built a disturber system, the second generation DSSRS-II (Figure 5.19) to lift and then suspend sediments at 5 to 10 m above the seafloor using two 7.6 hp pumps. Testing in early 1993 was followed with a cruise to the CCZ (BIE-II) with YMG, including baseline survey, recovery of the previous year's sediment traps and a programme of 49 tows. This time the disturber worked "well" and sediment was dispersed. Key conclusions from the trial (Ozturgut et al, 1997) were positive, i.e.:

- Sediment dispersed as a turbidity flow rather than as a low density plume - initial estimates of the far field range of dispersion may have been overestimated;
- Burial of up to 1–2 cm thick appeared not to have the catastrophic effect that was once predicted as both meio- and macrofauna appeared to burrow or recruit to the deep-sea benthos if needed;
- Some questions would remain until a full scale mining test is monitored.

The impact assessment of the site, when revisited after 9 months, indicated that, while some of the meiobenthos showed a decrease in abundance, the macrobenthos showed an increase in their numbers, probably because of increased food availability (Yamazaki, 2011). The site was then revisited again in 2000 by YMG and the key finding was that "Decreasing of macrofauna is observed on physical disturbed areas (on disturber tracks) but not on the areas of re-sedimentation" (Melnik and Lygina, 2010). Note that with a commercial mining system, that sediment from mined areas will be progressively redeposited alongside or immediately behind the collector or concentrator.

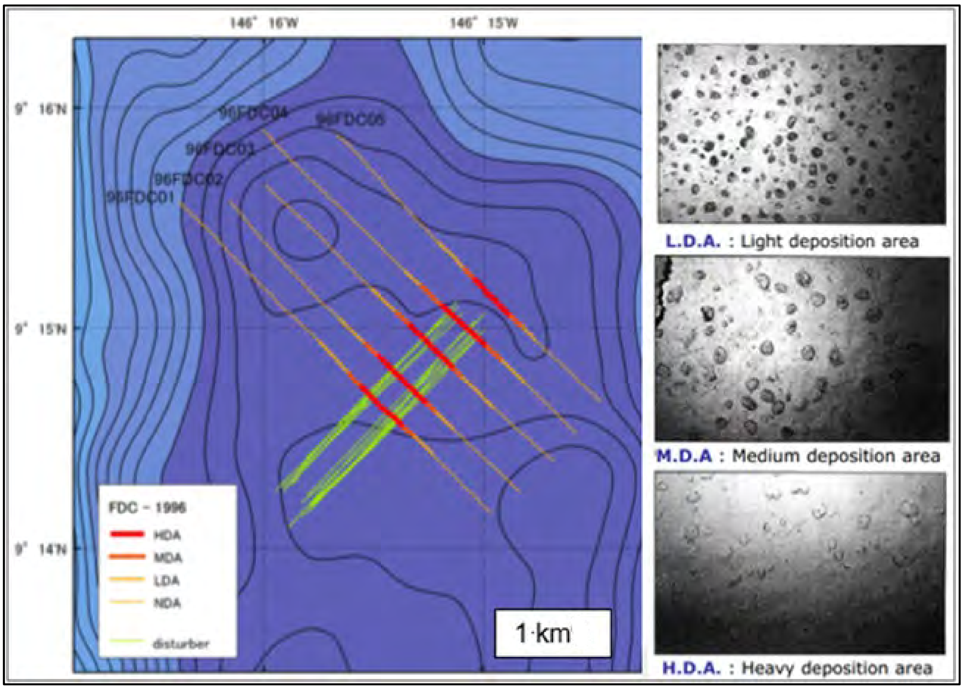
Figure 5.19 DSSRS-II Benthic Disturber



Modified from: Stoyanova (2010), Brockett (1994)

Subsequently the DSSRS-II "benthic disturber" was used by several other groups. One of the best reported experiments was JET (e.g. Yamazaki et al 1997; Yamazaki and Kajitani, 1999; Yamazaki, 2011). This study included baseline data collection, sediment traps, current meters etc, but the Japanese also developed a quantitative photographic analysis method to try and more intensively measure distance of sediment redeposition from the disturbance tracks (Figure 5.20).

Figure 5.20 Review of the DORD 1994 JET Benthic disturber site in 1996 using a Finder-installed Deep-sea camera



Source: DORD (2010, 2014). Heavy deposition was defined as >0.26 mm (Yamazaki, 2011). NDA is no deposition.

Post-experiment observations took place just after the experiment (J2 survey), about 1 year later (J3), and about 2 years later (J4), by which stage DORD's main conclusion was that any impact had been significantly reduced. The observations centred around sediment sampling and camera surveys to determine resedimentation impact on the benthos.

Attempts were made to scale up the JET results to full commercial scale, but these were dependent on a number of fundamental assumptions including penetration depth (Yamazaki, 2011).

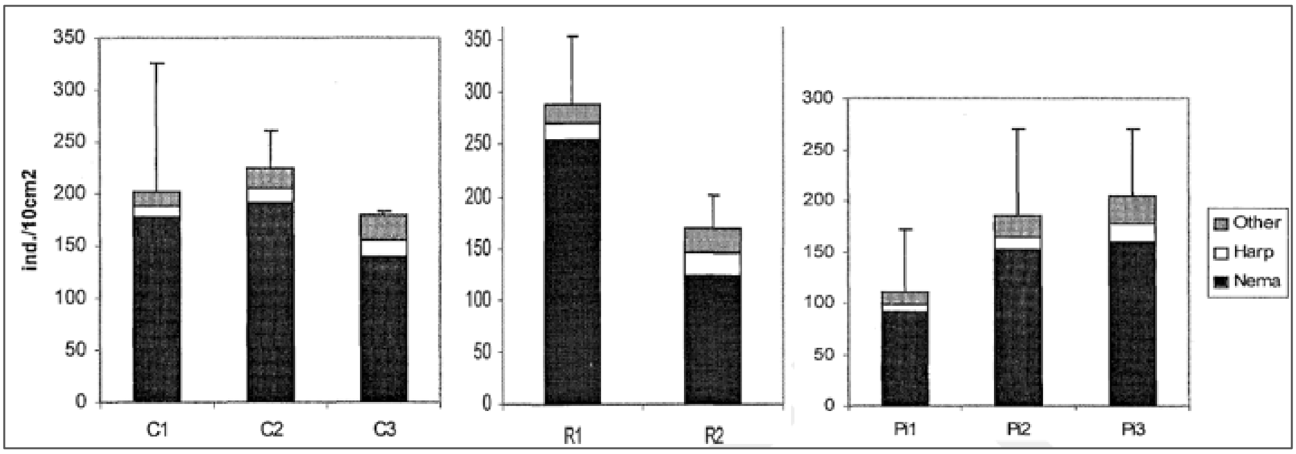
Radziejewska et al (2001) summarised three surveys at the IOM BIE site, namely those of 1995 (immediately pre and post disturbance), 1997 and in 2000. Research on the IOM site essentially:

- Struggled in 1995 to find significant impact to the meiobenthic communities outside of the tracks left by the DSSRS-II;
- Found in 1997 widespread changes (e.g., in nematode familial make-up) as a result of a phytodetritus sedimentation event (likely a natural plankton bloom event) as well as that the tracks were now substantially "levelled off", presumably due to action of currents or bioturbation;
- Found in 2000 that response to the phytodetritus sedimentation event was more or less reversed to the condition at the start of the trial.

Radziejewska et al (2001) interpreted that the implications of this are that:

- Certain significant processes take place in the abyssal communities without human intervention;
- This supports the notion of there being no absolute, inherent stability on the abyssal seafloor;
- These natural processes can induce changes of greater magnitude than induced by the benthic impact experiments (and by extension potentially by commercial production)
- That quantitative monitoring of mining impacts will be challenged by the naturally occurring variations.

Figure 5.21 IOM BIE meiobethos populations for control, resedimentation and impacted area stations



Source: Radziejewska et al (2001) C1, C2, C3 are control stations in 1995, 1997 and 2000; R1, R2 are resedimentation stations in 1997 and 2000, Pi1, Pi2, Pi3 area impacted stations in 1995, 1997 and 2000. Nema is Phylum Nematoda (round worms), harp is Harpacticoida (copepod crustacean)

Kim et al, (2011) looked at sinking particle flux relationships with ENSO and found up to three-fold increase against background during a moderate La Nina event in 2007/08. Significantly with regards to the IOM experiences regarding their BIE site, the winter of 1995 was also a moderate La Nina event (1996 was neutral and 1997 a 'super' el Nino; NOAA NWS, 2016).

5.4 1996 onwards: The International Seabed Authority

With entry into force of UNCLOS in 1994, the ISA technically came into existence. In actuality, the ISA started working as an autonomous international organisation, domiciled in Kingston Jamaica, two years later in June 1996. All signatories of UNCLOS are members of the ISA which operates as mandated by UNCLOS.

5.4.1 Korean Research Groups

Korean Ocean Research and Development Institute (KORDI) was established in 1973, with a broad mandate for Korean interests in marine science and engineering.

Work on CCZ nodules began as early as 1983 with three campaigns to the western CCZ in what was called the KODOS Area (Korea Deep Ocean Study; Jeong et al., 1994; Jung et al., 1997). This was followed up with two in 1989/90 in collaboration with the University of Hawaii (Kang, 2008). A combination of samples, bathymetry and seismic data was collected.

Between 1995 and 2002, KORDI focused on exploring their contract area defining mineral inventory of some 510 Mt (Kang, 2008) and environmental baseline data collection (KIOST, 2014). Exploration, environment and mine development programmes were consolidated under one government ministry.

Since 2002 their focus on environmental studies has increased, including research into a Priority Mining Area and preparations for a benthic impact experiment (KIOST, 2014). This has included detailed towed sonar surveys and sampling.

KORDI became KIOST (Korean Institute of Ocean Science and Technology) in mid-2012 and in recent times development of their advanced mining concept has been managed by KRISO (Korea Research Institute of Ships & Ocean Engineering). The concept involves a track driver collector with colander electro-hydraulic heads feeding a sub-sea buffer with inline pumps delivering to a surface vessel. As of 2015, all of the sub-sea components had been built at a pilot scale and tested in relatively shallow waters.

Lab (pool) scale testing was conducted between 2002 and 2010, as well as shallow water tests in 2009 and 2010 with a first generation device (MineRo-I). Collector efficiencies as high as 95% were achieved when the collector head was manually adjusted in terms of height above the seafloor.

Sea trials with the second generation MineRo-II were conducted in 2012 and 2013, with shallow water tracking tests (130 m) followed by a simpler deep water test (1370 m). The shallow water test included collection and subsea crushing of seeded nodules (KIOST, 2014). Sea-trials of the buffer and lift system were completed in late 2015.

5.4.2 The new developed nation contractors

In July 2006, Germany (through its geological survey Bundesanstalt für Geowissenschaften und Rohstoffe or Federal Institute for Geosciences and Natural Resources of Germany (BGR)), received an exploration contract in the CCZ. This was the first contract under UNCLOS not to have been granted to a Pioneer Investor.

Sponsored by Germany as a developed nation, the BGR claimed patrimonial links and supplied historical data of the OMI German license area to define approximately 150,000 km^2 of seabed with half entering the ISA reserved areas and half falling under their contract.

Since then, the BGR has been an active explorer and developer with numerous publications, including an informal mineral resource estimate (Ruhlemann et al, 2011; Kuhn et al, 2011 and Kuhn et al, 2012). These include modern and well document reestablishment of many of the basic relationships found in the CCZ and significant contributions to current geological understanding. BGR also commissioned preliminary work on mining and processing technology. The BGR is a partner within the JPI Oceans - Ecological Aspects of Deep-Sea Mining project.

In early 2013, UK Seabed Resources Ltd started an exploration contract in the eastern CCZ. The previous year they submitted an application, sponsored by the United Kingdom, based on the former KCON Frigate Bird area in Figure 5.4). The resultant UK 1 area was 58,000 km^2 and the equivalent returned area was promptly acquired by partner Ocean Minerals Singapore.

Field work to date by UK Seabed seems to have focused on benthic biological baseline studies, specifically two campaigns in 2013 and 2015 (AB01 and AB02) that supported the Abyssline Project (http://abyssline.info/). The project is being conducted by a consortium of seven non-profit academic research institutes (University of Hawaii, USA; Hawaii Pacific University, USA; Natural History Museum, UK; Uni Research, Norway; National Oceanography Centre, UK; Senckenberg Institute, Germany; IRIS, Norway).

In March 2016, UK Seabed signed a second exploration contract (UK2), this time for an area in the central CCZ (based on former USA-2 area held for OMI. The retained and returned areas are each about 75,000 km^2.

Global Sea Mineral Resources (GSR), formerly G-TEC Sea Mineral Resources, also started an exploration contract in early 2013. GSR is owned by dredging company DEME and sponsored by the Belgian government. GSR successfully claimed patrimonial links to Union Miniere, the Belgian member in the OMA consortium, and retained and returned areas are each about 75,000 km^2 that correspond to the former USA-3 license area. The equivalent returned area was promptly acquired by partner Cook Island Investment Corporation.

Since 2013 GSR has mounted at least one campaign of their own (GSR, 2014) with box-coring and MBES. GSR may also have participated in a JPI Oceans campaign to the CCZ in 2014 (see below).

GSR worked on nodule mining technology with IHC Merwede forming for some time a group called OceanFlore. More recently both IHC and DEME have joined the “Blue Nodule” initiative along with a wide range of other European companies and research institutions.

5.4.3 The new developing sponsored nation contractors

Nauru Ocean Resource Inc (NORI) started their exploration contract with the ISA in July 2011. The stakeholders in the company are Nauruan and domiciled in Nauru. These are the Nauru Education and Training Foundation and the Nauru Health and Environment Foundation (ISBA/17/C/9; ISA, 2011). NORI conducted a campaign to the CCZ in 2013 that included seafloor mapping and sampling.

Tonga Offshore Mining Limited (TOML) started its exploration contract with the ISA in January 2012. TOML is domiciled in Tonga. TOML was 100% owned by Nautilus Minerals Inc. which until 2016 had supported TOML in terms of managing two campaigns to the CCZ, environmental baseline data collection, mineral resource estimation (the main subject of this report) and mining and processing concept studies. In 2020, DeepGreen acquired TOML.

Marawa Research and Exploration Ltd started their exploration contract with the ISA in January 2015. Marawa's proposed scientific research and exploration programme will involve seafloor mapping, polymetallic nodule sampling as well as environmental baseline studies and environmental impact assessments in international waters (Marawa, 2012).

Ocean Mineral Singapore Pte Ltd (OMS) started their exploration contract with the ISA in January 2015. OMS is a Singapore-incorporated company majority owned by Keppel Corporation, with minority shareholders being UK Seabed Resources Ltd and Singapore-based private investment company Lion City Capital Partners Pte. Ltd., (Keppel, 2015a). Keppel is, amongst other things, a shipbuilding company, and OMS is sponsored by Singapore which was classified by the UN in 2014 as a developing nation (United Nations, 2014).

OMS has collaborated with UK Seabed regarding the second of the Abyssline campaigns (AB02; above).

In late 2013 the Cook Islands Investment Corporation (CIIC), sponsored by the Cook Islands applied for a nodule exploration contract in the reserved areas which was duly approved the following year (ISBA/20/LTC/3, ISBA/20/C/18, ISBA/20/C/29). CIIC have a formal arrangement with GSR regarding the area.

In late 2014 China Minmetals Corporation, sponsored by China, applied for a nodule exploration contract of about 73,000 km^2 in the reserved areas. This was duly approved the following year (ISBA/21/LTC/5, ISBA/21C/L.3).

6 Geological Setting and Mineralisation

6.1 Global distribution of nodules

Seafloor polymetallic nodules occur in all oceans, and the CCZ hosts a relatively high abundance of nodules. Other relatively dense zones are found in the Peru Basin in the southeast Pacific, the centre of the north Indian Ocean, and the Cook Islands. The CCZ also has the highest overall metal grades (Table 6.1).

Table 6.1 Summary of Global Nodule Grades

Element	All Pacific Ocean	Pacific Ocean outside CCZ	CCZ	Atlantic Ocean	Indian Ocean
Mn wt%	20.1	18.8	26.3	13.3	15.3
Fe wt%	11.4	12.8	6.6	17.0	14.2
Ni wt%	0.76	0.63	1.20	0.32	0.43
Cu wt%	0.54	0.41	0.98	0.13	0.25
Co wt%	0.27	0.29	0.20	0.27	0.21

Source: McKelvey et al., 1983.

Key features of the geological setting are described in this section. Further details are presented in AMC (2016).

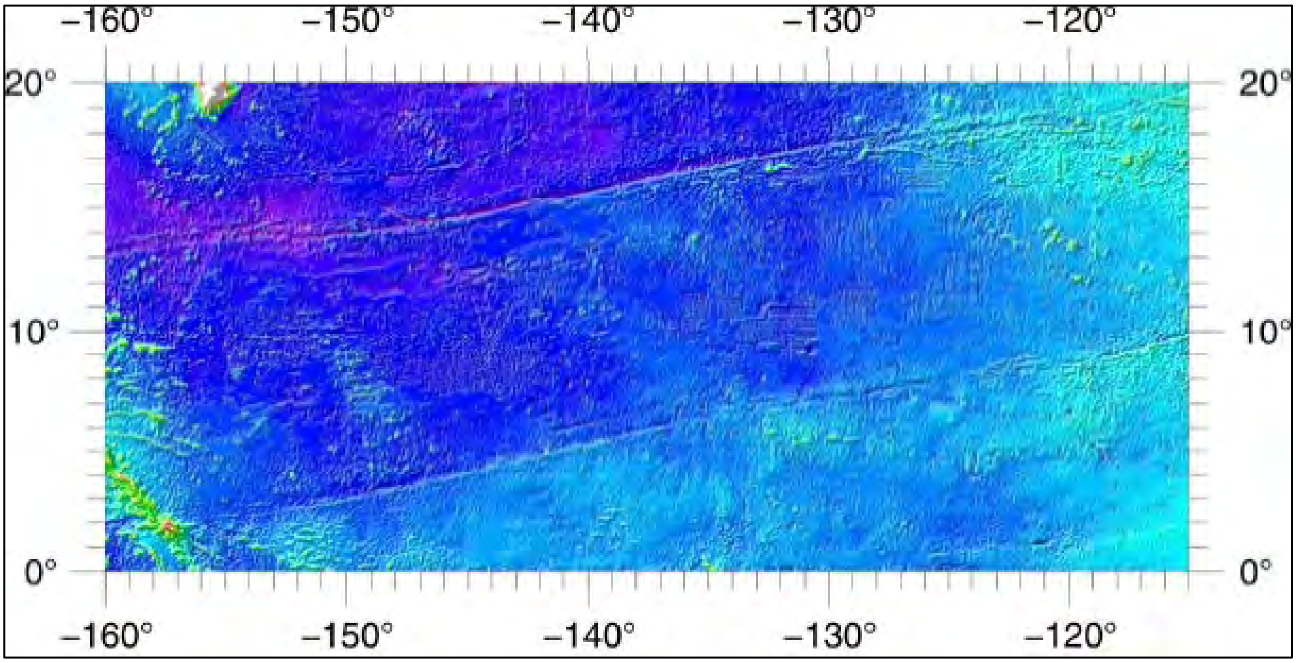
6.2 Tectonic setting and topographic features

The CCZ is defined by two major west-south-west and east-north-east trending transform fracture zones; the Clipperton Fracture Zone to the south and the Clarion Fracture Zone to the north. These fractures zones can be seen clearly on most bathymetric maps (e.g., Figure 6.1). The eastern and western limits are defined by the Mathematicians Seamounts in the east, and the Line Islands rise in the west. The CCZ seabed deepens progressively from about ~4,200 m at 115°W to ~4,800 m at 128°W, then varies between ~4,800 m and ~5,500 m until 161° W.

The CCZ seabed comprises “Abyssal Plains”, which are the largest physiographic province on Earth, covering some 70% of the area of ocean basins and 30% of the Earth's surface (ISA 2004). Within the abyssal plains province are sub-parallel basaltic lava ridges called abyssal hills, believed to have formed from graben-horst type faulting as a consequence of seafloor spreading. Strike of abyssal hills in the CCZ is north-north-west to south-south-east (locally ±20°; Figure 6.3), and they typically have an amplitude of 50–300 m (maximum 1,000 m; Hoffert 2008) and a wavelength of 1 to 10 km. The abyssal hills are punctuated by typically extinct volcanic knolls and seamounts rising 50 to 4,000 m above the seafloor. Almost all of the abyssal hills, and some of the volcanic knolls are buried beneath sediment (often up to 150 m thick).

The surficial portion of the sediment cover has a relationship with nodule quality, and it varies regionally, i.e. from predominantly carbonate and siliceous oozes in the south-eastern extreme corner, to mixed clay-ooze in the centre, to predominantly siliceous red clay in the north.

Figure 6.1 Bathymetric map of the Clarion-Clipperton Fracture Zone



Source: ISA 2010.

Figure 6.2 Formation of abyssal hills at mid-oceanic ridges

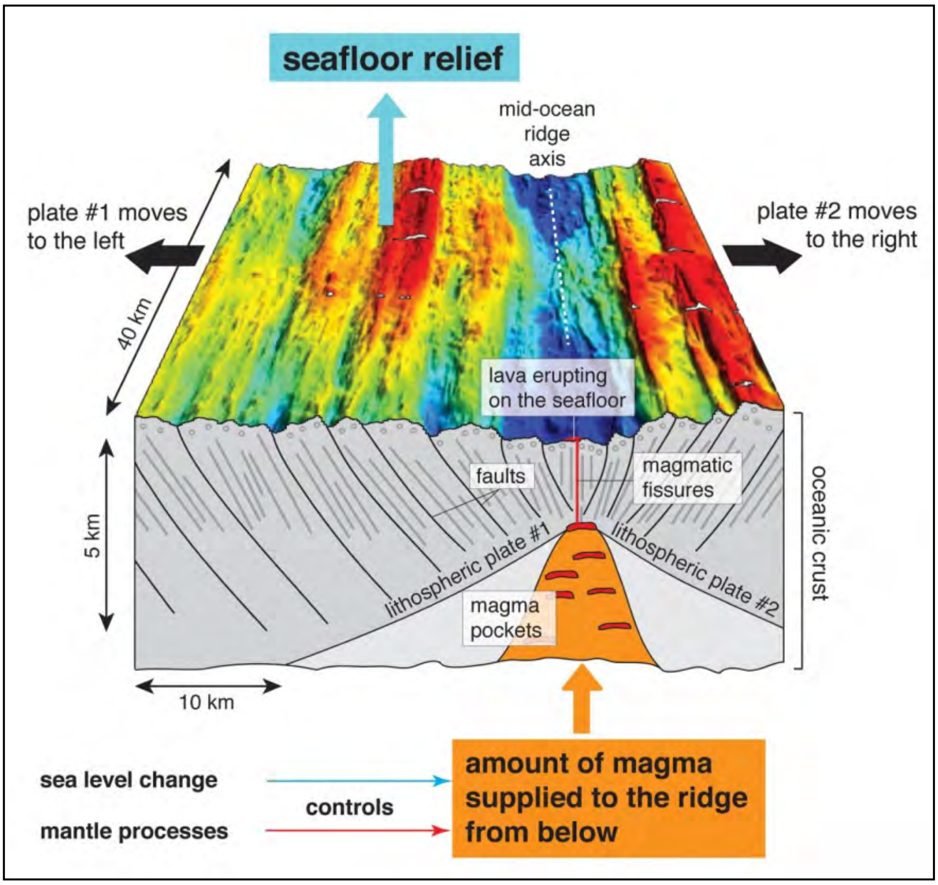
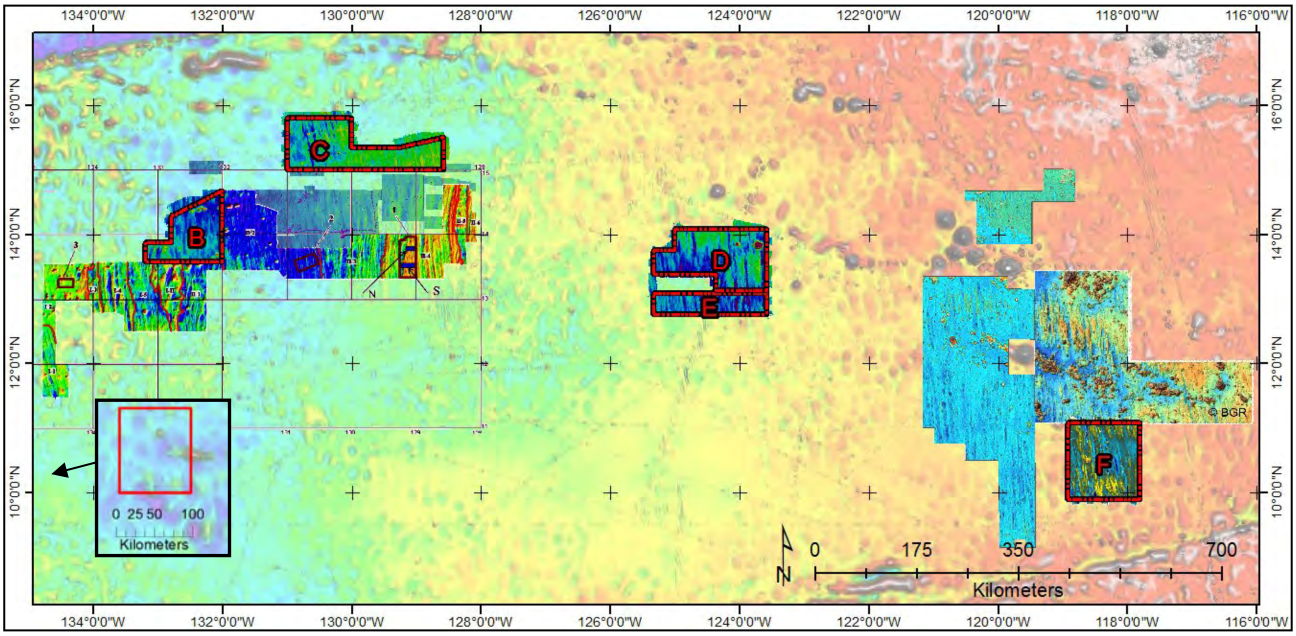


Figure 6.3 Semi-detailed bathymetry for the part of the TOML tenement area



Also some of the areas of Yuzhmorgeologiya (Melnik and Lygina, 2010), Ifremer (Fouquet et al, 2014), IOM and BGR (Knodt, 2012), (ISA, 2010) background is a Smith & Sandwell Product (ISA, 2010). Inset of TOML Area A, with location to the west

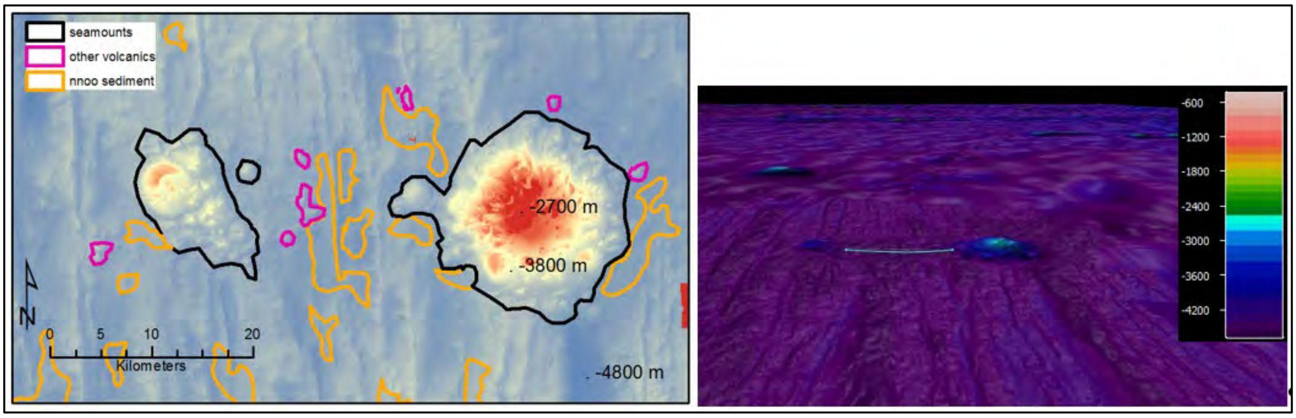
6.2.1 Seamounts, knolls, and other volcanic features

Seamounts can occur in chains (related to hotspot traces or tectonic features) or in isolation (more likely due to increased local heat flow associated with tectonic related thinning or fractures).

MBES mapping of TOML areas B-F confirmed that there are no chains of seamounts within the TOML tenement area, that isolated seamounts and cones are approximately 1.5% of the TOML tenement area, and that exposed basalt (typically sheet flows) makes up an additional 1.3%. While no MBES has yet been conducted in Area A, the Smith and Sandwell bathymetry indicates the likelihood only minor amounts of smaller seamounts in the area (Figure 6.3).

The highest single seamount (and the only one visible in the GEBCO dataset) is the ~1,000 m seamount in TOML Area D informally named “Mt Mo” (Figure 6.4).

Figure 6.4 Seamounts in TOML Area D

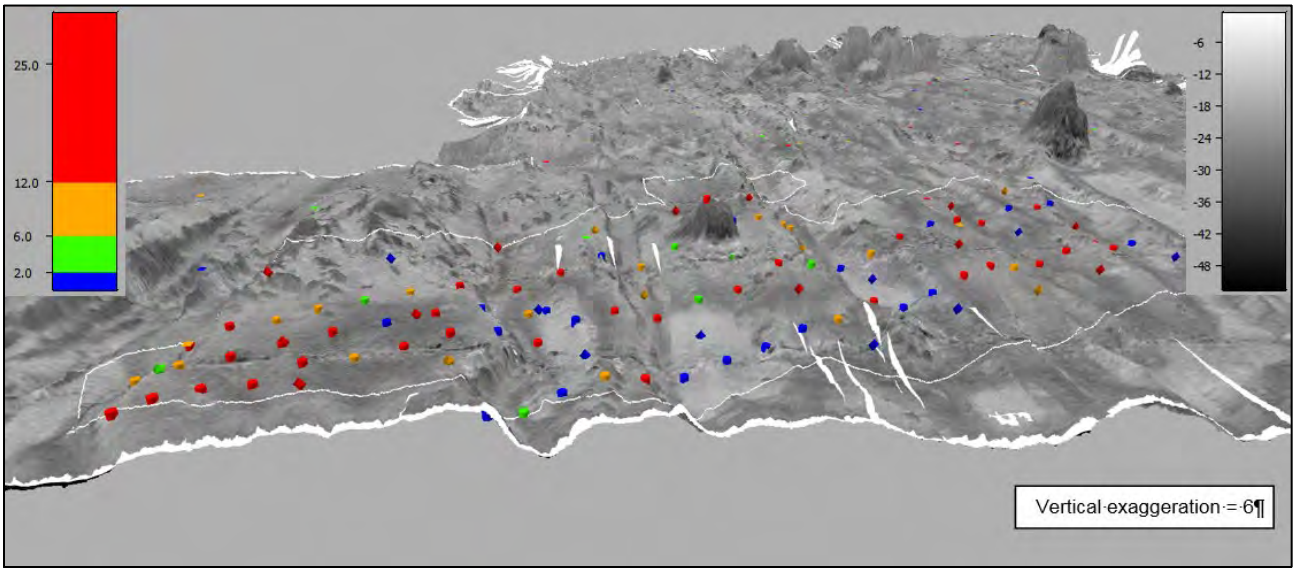


In addition to the seamounts there is evidence for other small amounts of volcanic rocks. These are typically associated with the faults amongst the abyssal hills, which likely reactivate with ongoing movement of the tectonic plate. These are typically flows in the floor of valleys or near the end of valleys.

6.2.2 Sediment drifts

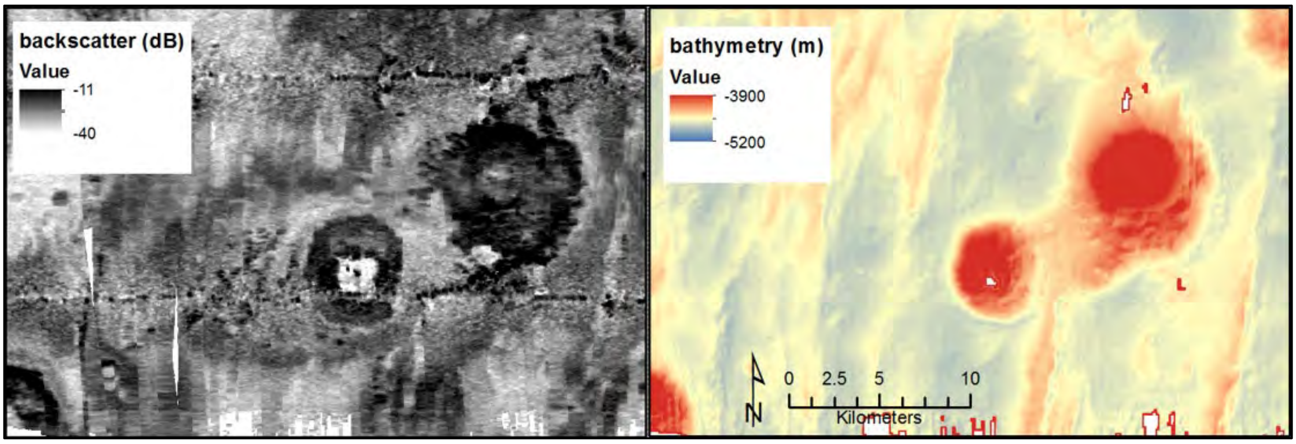
Approximately 7.4 % of TOML Areas B - F are thought to be covered by large sediment drifts (coded as Nnoo below). These can be mapped from MBES, as they are normally softer and ponded in depressions (Figure 6.5). There is also evidence for significant sediment movement elsewhere around seamounts (Figure 6.6) and at the base of steeper slopes. Without detailed MBES there is no clear indication of the amount of sediment drifts in Area A, although all historical sampling returned nodules.

Figure 6.5 Example of "ponded" sediment drifts and corresponding low nodule abundance Area B



Source: from TOML MBES backscatter and sample data; Diamonds are box-cores, cylinders are photo based, squares are historical samples. Abundance (coloured) in wet kg/m^2; acoustic absorption (backscatter; grey scale) in dB.

Figure 6.6 Example of sediment accumulating around seamounts



From MBES backscatter, TOML Area B

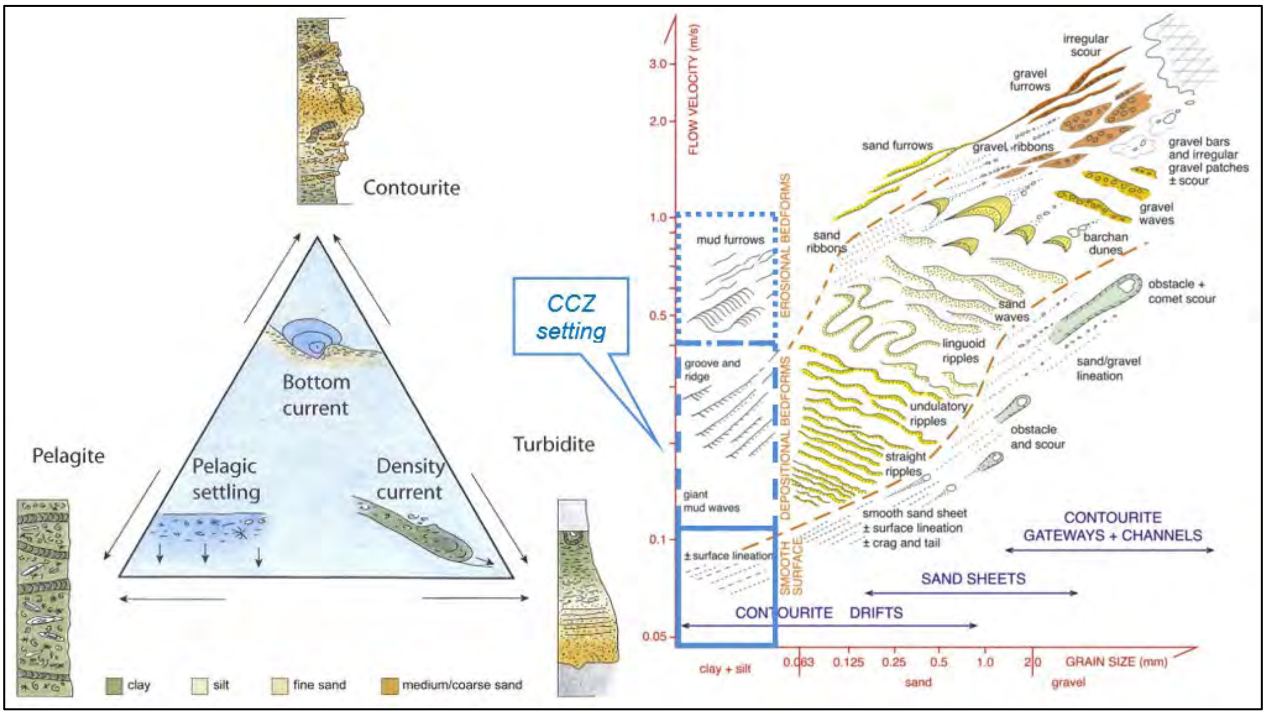
Dynamic changes in current and temperature near the CCZ seafloor have been known since the DOMES study in the late 1970s (Hayes, 1979). This includes current changes related to: tides; likely inertial reaction (e.g., to the Coriolis force); and more significant seasonal or episodic events. The seabed is typically quiet as:

- Seabed currents measured from moorings are typically low (~ 4 cm/s and up to ~12 cm/s); and
- Typically there is no detectable nepheloid layer (stirred up sediment) observed during survey.

Eddies travelling west along the CCZ are commonly observed at the ocean surface. Inall et al. (2015) describe data from a significant eddy, associating eddy surface currents of 40 cm/s at the surface with 10 cm/s currents on the seafloor of the CCZ approximately 4,100m below.

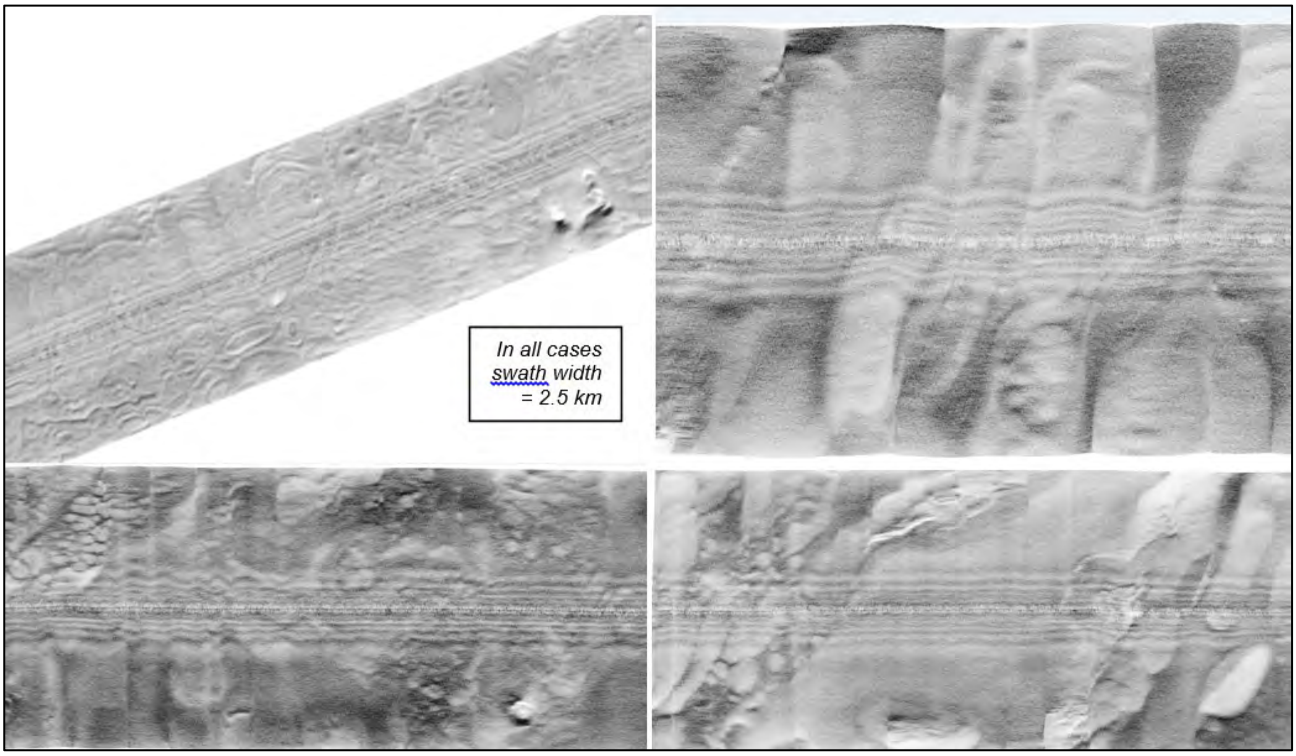
A variety of seabed deposits and patterns are observed and are interpreted to be due to seabed bottom currents (Figure 6.7, Figure 6.8).

Figure 6.7 Types of deep-sea sedimentary processes and deposits related to bottom currents



Sources: Rebesco et al (2014); after Stow et al. (2009)

Figure 6.8 Range of patterns in surficial sediment, TOML Areas D and C



Collected using 30 kHz side scan sonar which penetrates the sediment to some distance (cm to m) and which responds to sediment composition.

6.3 Polymetallic mineralisation

6.3.1 Sedimentation and nodule formation

Seafloor polymetallic nodules are composed of nuclei and concentric layers of iron and manganese hydroxides and formed by precipitation of metals from seawater. The metal accumulation rates are slow, and it generally takes millions of years to form a nodule (ISA 2004).

Nodules can be abundant in abyssal areas with oxygenated bottom waters and low sedimentation rates (less than 10 cm per thousand years). Nodules generally range from about 1 to 12 cm in their longest dimension, with the low to middle-range typically the most common (1 to 5 cm).

The specific conditions of the CCZ (water depth, latitude, and seafloor sediment type) are considered to be the key controls for its formation, along with the following factors:

- Supply of metals to the growing surface of the nodule.
- Occurrence of an oxygenated geochemically active layer at the seabed (sediment water interface).
- Effects over time on the geochemically active layer from benthic currents.
- Effects over time on the geochemically active layer from bioturbation.

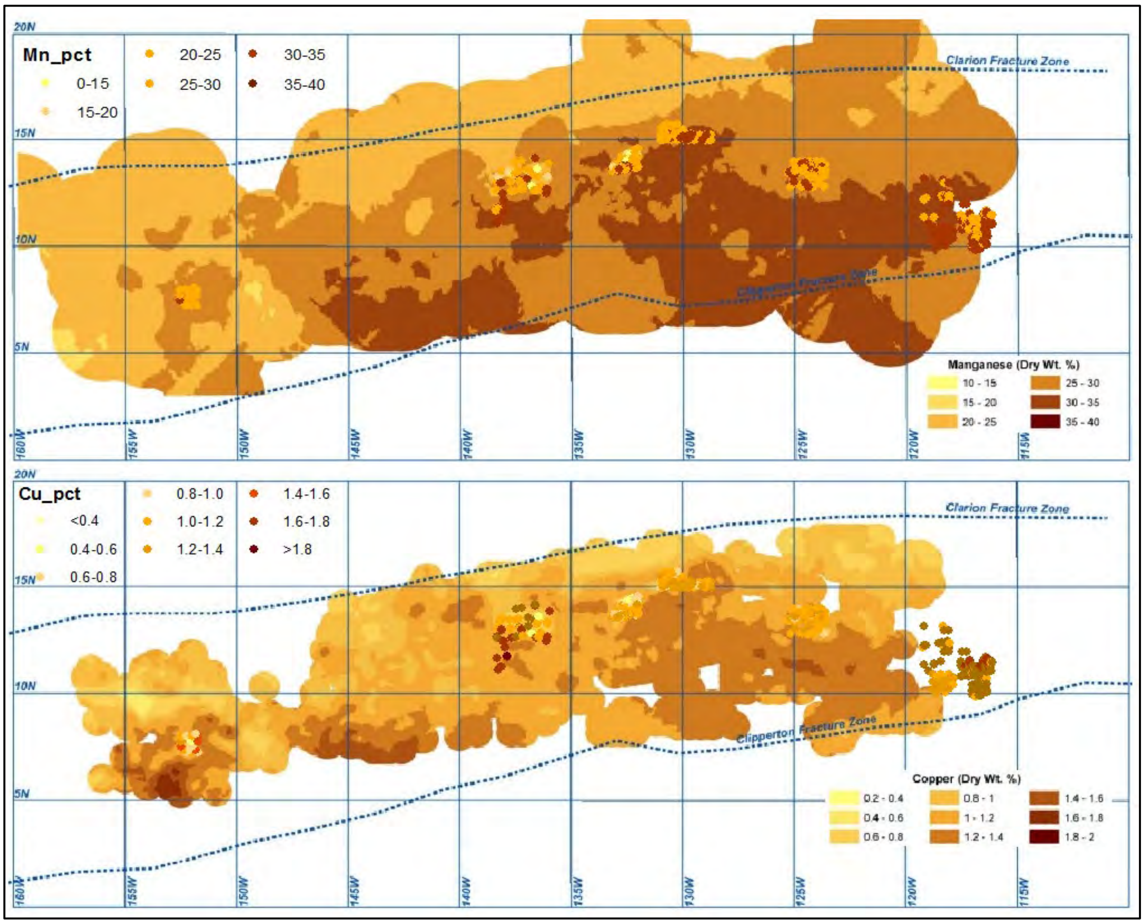
The highest values of metals in nodules are thought to be best developed on the seabed in the equatorial regions. In these regions surface waters have high primary productivity. Microorganisms accumulate metals in their growth relative to seawater and on death, they sink to the seafloor (either directly or through predator wastes), dissolve, and release the metals into the pore water of seafloor sediments. Being located away from terrestrial sources of sediments means that the metals are not preferentially accumulated by clay minerals. Commonly, the upper portion of the nodules accumulate metals directly from seawater, while the lower portion of the nodules, partially buried in sediment, accumulate metals from pore-water in the host sediments.

Sediments from the CCZ consist mostly of clays and some siliceous biological remains (e.g. frustules). Sands and larger sediments are not generally found so far from land, and any carbonate biological remains (e.g. skeletons) dissolve on the seabed in these deep-water regions faster than they accumulate. Some siliceous biological remains also dissolve at the seabed.

6.3.2 Nodule grades

Grade variation through the CCZ is well summarised by ISA (2010) and Morgan (2009) who combined datasets provided by several of the ISA contractors. Within the CCZ nodule field, nodule chemistry varies only slightly compared to the differences in mean nodule grades from other basins elsewhere in the world. The strongest trend is observed for Mn and Cu, which both increase towards the southeast (Kazmin in ISA, 2003; ISA, 2010; Morgan, 2009; see Figure 6.9). This may relate to proximity to metal sources from the East Pacific Rise or the American continents.

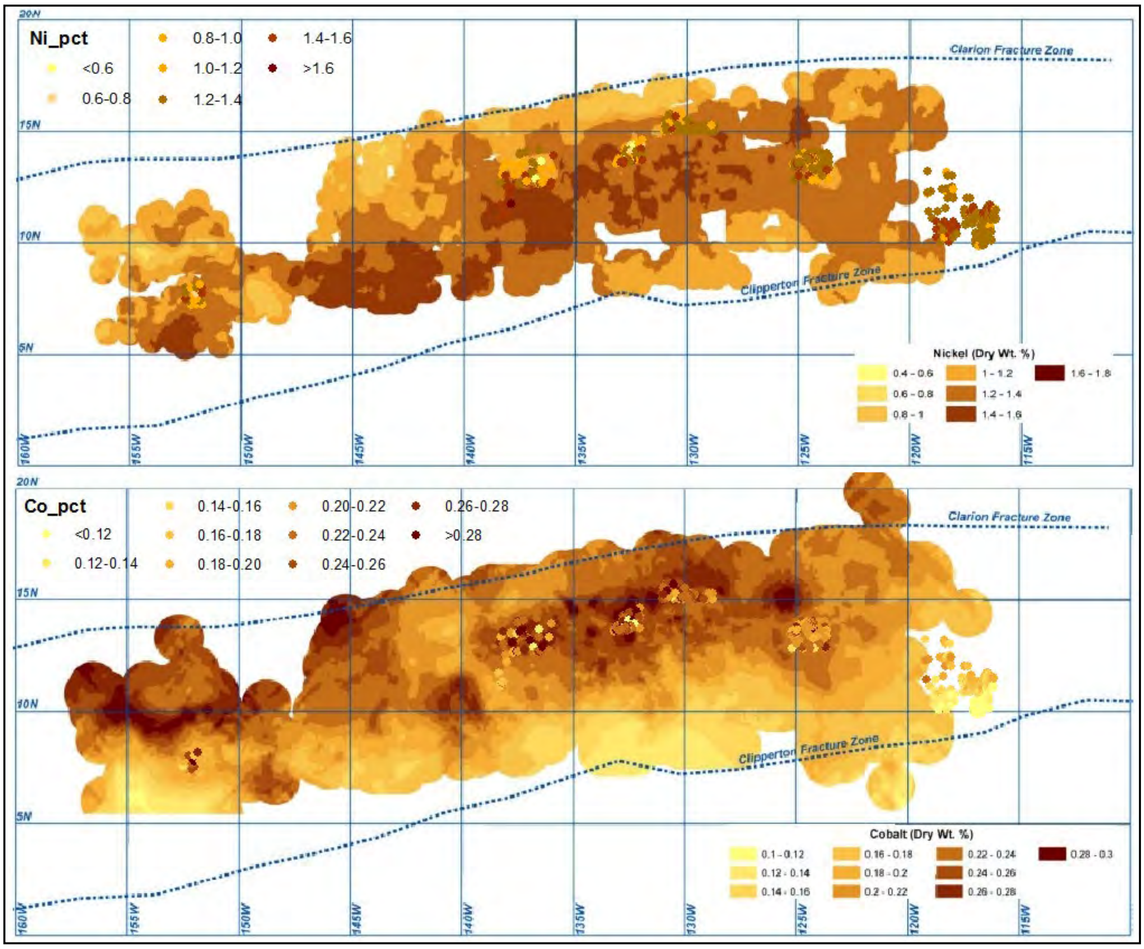
Figure 6.9 Modelled Mn and Cu grades in nodules across the CCZ



Source: Morgan (2009), point data attributed to OMI

In contrast, Ni and Co partly correlate along the central axis of the CCZ (Figure 6.10), with the Co appearing to be offset to the north from the Ni. The reason for the distribution of these metals is unknown but may relate to a lack of competition for the metals in the sediments, which have both lower chlorite and lower smectite in this region (Futterer, 2006).

Figure 6.10 Modelled Ni and Co grades in nodules across the CCZ



Source: Morgan (2009), point data attributed to OMI.

6.3.3 Grades of other metals

Grades for elements other than Mn, Ni, Cu and Co are not reported in the mineral resource for the TOML tenement area. Boxcores from CCZ15 campaign where analysed for a range of metals and these broadly agree with grades for a wider range of metals reported on Pacific nodules by McKelvey et al (1983), except for Rare Earth Element (REE) which are lower in the TOML dataset (see below). McKelvey et al (1983) do not separate out the grades of nodules from the CCZ but document average grades for nodules with Ni+Cu >1.8%, the bulk of which come from the CCZ. These are summarised below per the classification of McKelvey et al (1983) with their average grade followed by the average grade determined by TOML:

- Other base or alloy metals such as Zn (0.14%; 0.147%), Mo (0.039%; 0.064%), Ti (0.58%; 0.301%) and Pb (0.071%; 0.019%)
- Rare earth elements and other transition metals such as Sr (0.077%;0.057%), Y (0.012%; 0.009%), Zr (0.027%), Te (0.021%), La (0.019%; 0.012%), Ce (0.066%; 0.029%) and Nd (0.023%; 0.013%)
- Possible deleterious elements or reagent consumers and enhancers such as F (3%), Mg (1.57%; 1.94%), Al (2.96%; 2.47%), Si (8.26%;6.82%), S (0.319%; 0.13%), Cl (0.860%), Ca (1.73%; 1.76%), As (0.012%; <0.005% in some analysed dredge samples), and Ba (0.224%; 0.284%)

These levels of metals are supported in some cases (Zn, Mo) by data presented by Haynes et al. (1985), who also reported very limited data on Au and platinum group metals (all at the ppb level except Pt which averaged 0.1 ppm from 5 samples).

The REE values in the TOML tenement areas more closely agree with those published from the historical Lockheed Martin Exploration Area by Spickermann, (2012). This area is adjacent to TOML Exploration Areas B, D, and E. Total REE reported by Spickermann is about 0.08% (0.079% from TOML Areas A, C, B, D and F) with a median of 617 (619, TOML) ppm light REE (La-Eu) and 171 (180, TOML) ppm heavy REE (Gd-Y).

Also of interest is a clear trend of increasing Ba and S from TOML Area A, B and C to D and then to F. This trend suggests increased barite ($BaSO_4$) whose presence in turn is thought to represent increased primary productivity (or rather activity) within the diagenetic environment (Ba preferentially captures S released from decaying organic material in the sediment below the calcite compensation depth (e.g., Schulz and Zabel, 2006). This trend corresponds well with modern sea surface primary productivity.

6.3.4 Nodule abundance and estimation of tonnages

6.3.5 Nodule abundance

Polymetallic nodules lie on the seafloor sediment, often partly buried. Some nodules are completely buried, although the frequencies of such subsurface occurrences are very poorly defined. Kotlinski and Stoyanova (2006) document up to five discrete layers of buried nodules, although all were within 45 cm of the surface despite using sediment cores of 250 to 380 cm depth (i.e., all of these nodules are near surface). Other images of box corers also suggest that all or most of the nodules are at the surface. Consequently, drilling is not required for definition of the Mineral Resources.

The nodules vary in abundance, in some cases touching one another and covering more than 70% of the seafloor. They can occur at any depth, but the highest concentrations have been found on abyssal plains between 4,000 and 6,000 mbsl.

Nodule abundance is estimated either by:

- Taking a sample from the seafloor and dividing the weight of nodules by the area of the primary sampler;
- Using a photograph of nodules on the seabed to estimate their individual weight (e.g., as used by Kennecott; Felix 1980) which has been used with considerable success in some areas by TOML and dividing the weight of nodules by the area of the image.

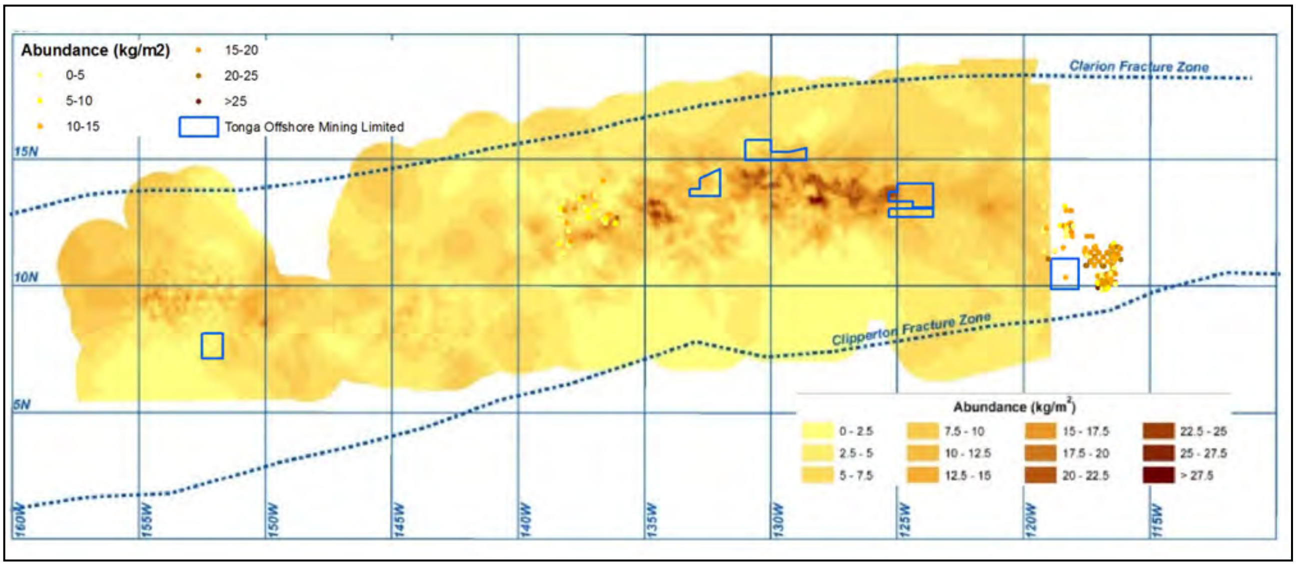
Nodule abundance is typically reported in wet kg/m^2:

- Wet weights are the most relevant in any collecting and transport operation;
- Often the nodule samples have multiple uses once collected at sea, some are for assay, others for environmental or metallurgical test work and some for reference (retaining the sample to dry and then weigh is less convenient);
- With complexity related to drying conditions and determining wet/dry density, weighing of the samples at surface is the simplest and most effective way to measure and compare nodule abundances between different campaigns and between the different contractors.

Sample aliquots were dried, crushed and pulverised before assaying. Using dry weight percent assays on wet weight mineral resource and inventory is a commonly accepted practice for similar bulk commodities that can contain significant amounts of free water (e.g., iron ore or Ni-Co laterite).

Nodule abundance variability is significantly higher than metal grades in most areas, suggesting that abundance estimation will be the key variable of uncertainty in mineral resource estimation. Figure 6.11 shows evidence of this compared to Figure 6.9 and Figure 6.10.

Figure 6.11 Modelled nodule abundance across the CCZ



Source: Morgan (2009), point data attributed to OMI.

6.4 Nodule Density and Moisture Content

6.4.1 Nodule density

Polymetallic nodules have an average wet density of about 2 t/m^3 (Table 6.2; Figure 6.12). TOML confirmed historical results from the north Pacific (Hessler and Jumars, 1974) through ~60 water displacement density measurements. The density measurements were done for both single nodules and for nodules in bulk, including fragments and sand resulting from attrition during transport and handing.

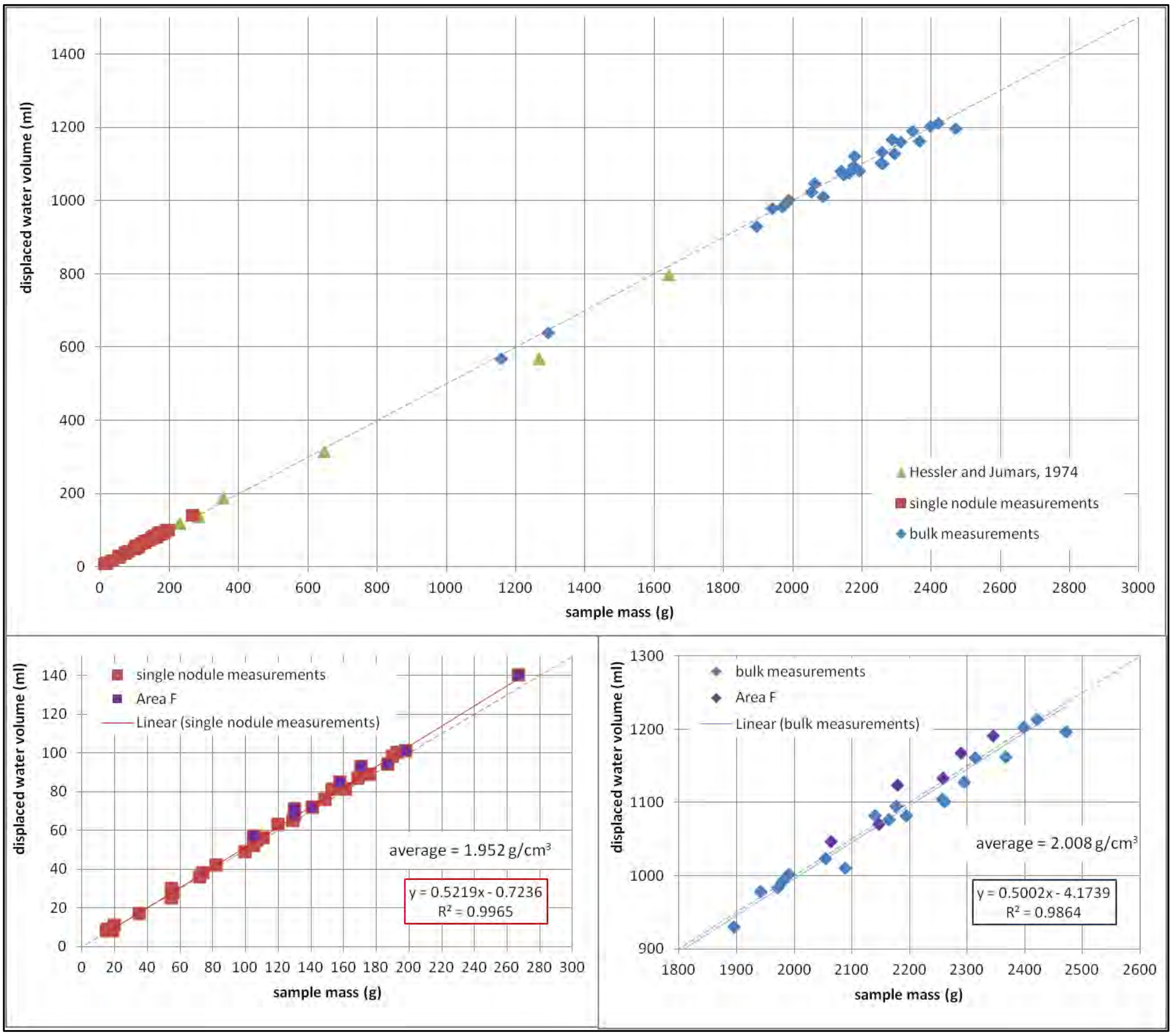
The results are similar except that the mean of the single nodules is ~2.8% lower than that of the bulk measurements. This might be due to air or water filled expansion cracks in the single nodules (that were collected ~7 months before the density measurements were made) the bulk nodule samples contained many more fragments that presumably relate to fractures along these cracks. The bulk nodule measurements are preferred over the single nodule measurements as they are likely more accurate due to larger sample size. The bulk nodule measurements also have a lower standard deviation.

Also noted is that Area F nodules might be slightly less dense than the other TOML tenement areas (Table 6.2; Figure 6.12). By averages this is of the order of 2–4%, being slightly more pronounced in the single nodule estimates. Nodule densities have not yet been measured for Area A.

Table 6.2 Nodule Density measurements TOML Area B, C, D and F

	Count	g/cm3					Standard deviation
		Min	Median	Mean	Max	Range	
Single nodules	34	1.78	1.95	1.95	2.38	0.60	0.11
Bulk nodules	27	1.94	2.01	2.01	2.07	0.13	0.03
Single nodules area F	9	1.83	1.91	1.90	1.99	0.16	0.06
Bulk nodules area F	6	1.94	1.97	1.97	2.01	0.07	0.02

Figure 6.12 Nodule densities of samples from TOML areas B-D, F, and central north Pacific



Single and bulk measurements from nodules collected during the CCZ15 campaign; historical values from Hessler and Jumars (1974)

6.4.2 Nodule water content

Exploitation of polymetallic nodules is likely to be done on a wet tonnage basis in that nodules will be transported, stored and sold without oven drying. In exploration, the abundance of nodules collected by free fall grabs or box-corers is also typically measured on the exploration vessel immediately after collection before the sample has time to air dry. Reporting a polymetallic nodule mineral resource on a wet basis is thus simpler and more appropriate than reporting on a dry basis, as is done for grade.

Total water content in wet nodules is estimated at 44% (Table 6.3), but the situation is further complicated as two main types of water are present:

- Water of crystallization included within manganese and iron oxide minerals. This was determined in TOML test work to consistently be about 16% by wet weight (including other likely trace levels of other volatiles). A very small amount of water of crystallization likely starts being removed at temperatures as low as 50–70 °C through a transformation of the manganese mineral buserite into birnessite, but most is stable until much higher temperatures (115 °C and greater; Novikov and Bogdanova (2007)).

- Free water included within pores and other cavities within the nodules including water adsorbed onto minerals – this is estimated to be around 28% by wet weight depending on the micro and macro void space in the nodules. Air-drying may remove approximately 16% (absolute) of this, with the rest by oven drying (up to 105 °C).

Estimating the water content is then complicated further again due to two properties specific to the nodules:

- The nodules have very high porosity (~50%; Ifremer, 2010) and are hygroscopic (Figure 6.13). Within a day of drying to 105°C pulped nodules will absorb at least 7% of moisture by mass if exposed to ambient air.
- Depressurization of the nodules after collection leads to mineral transformation (e.g., breakdown of feroxyhyte) and micro-fractures and fractures. Free water might be added into the cracks and micro-cracks. TOML tests suggest that four months after collection about 3% free water on a wet basis can be added into samples that are soaked in water (this 3% is not included in the totals indicated above).

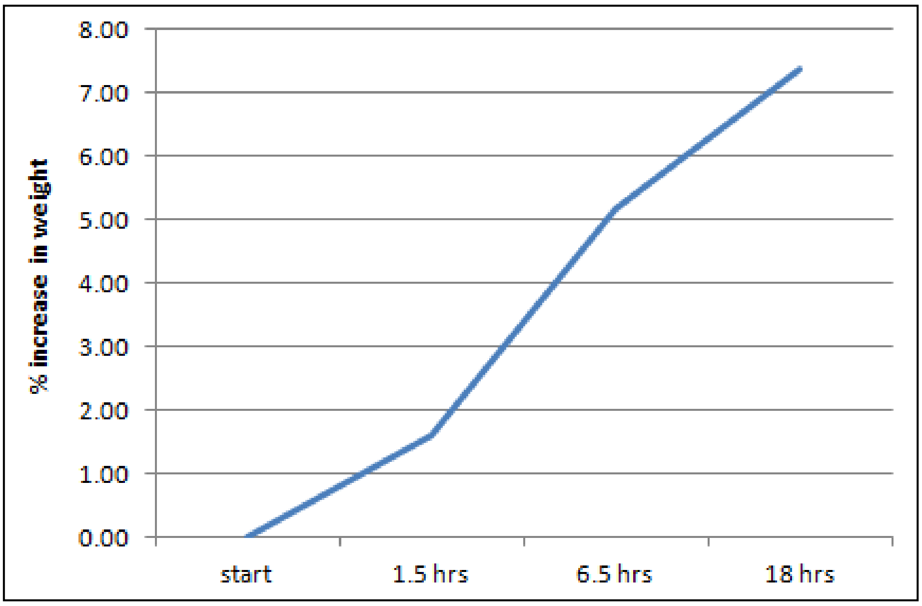
Published moisture values from the very comprehensive metallurgical reports by Haynes et al. (1985) and Fuerstenau et al. (1973) are summarised below along with TOML results.

Table 6.3 Comparison with published moisture contents

Source	Total Moisture	Free Moisture	Water of Crystallisation
Mero (1965) p233	–	30-36*	–
Fuerstenau et al. (1973)**	>22.66%	13.1%	>8.74%
Haynes et al. (1985)	45-50%	35–45% with about half able to be dried in air	5-10%
Wiedicke-Hombach et al (2012)	44%	Not specified	Not specified
TOML measurements	44%	28% with about 60% of this able to be dried in air	16%***

* drying temp not specified may include some water of crystallization; **used in the 2012 Nautilus CCZ NI43-101 report (Golder, 2013) to characterise moisture; *** includes ±2% water of crystallisation lost up to 105°C

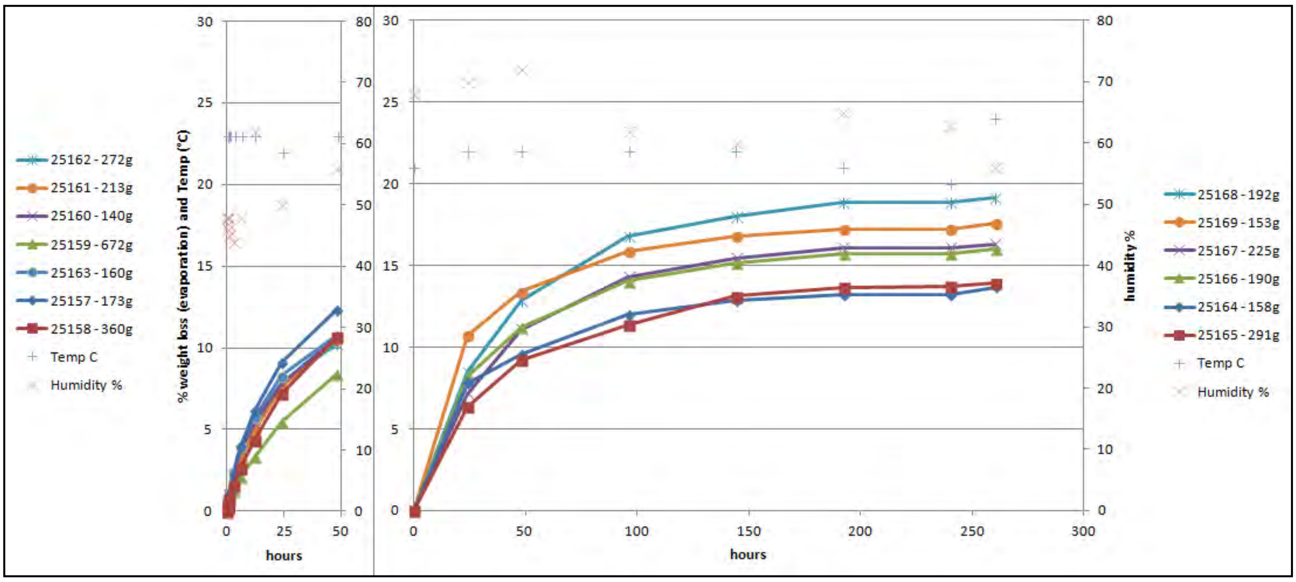
Figure 6.13 Nodule sample (pulp) absorption after drying to 105°C for 6 hours



Test work done by TOML on select nodules involved three stages of drying. Stage one was air drying at up to 260 hours at ambient temperatures of 22 °C to 25 °C and humidity of 50% to

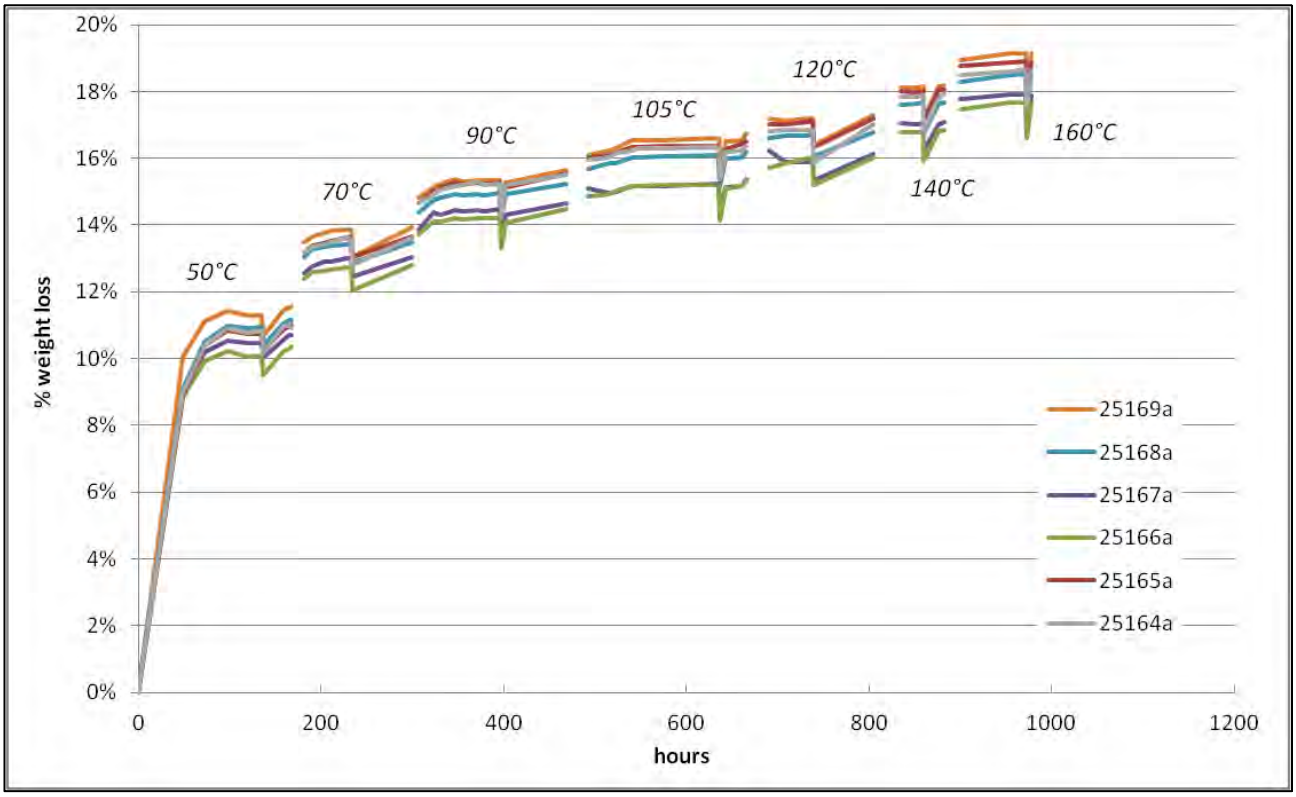
60% (Figure 6.14). Moisture content lost by the time of stabilisation (around 200 hours at these ambient temperature and humidity) varied between 13% and 19%.

Figure 6.14 Air drying results for a short term sample batch (L) and a long term sample batch (R)



Stage two was oven drying at up to 978 hours in seven temperature steps. From Figure 6.15 the moisture content lost was a very consistent 15% to 16.5% at 105°C and 18% to 19.5% at 160 °C.

Figure 6.15 Oven drying results for nodules



Between each oven drying temperature the samples were left exposed to ambient air for one hour to measure hydroscopic weight increase. Whole nodules absorbed water more slowly than pulverised nodules (e.g., Figure 6.13).

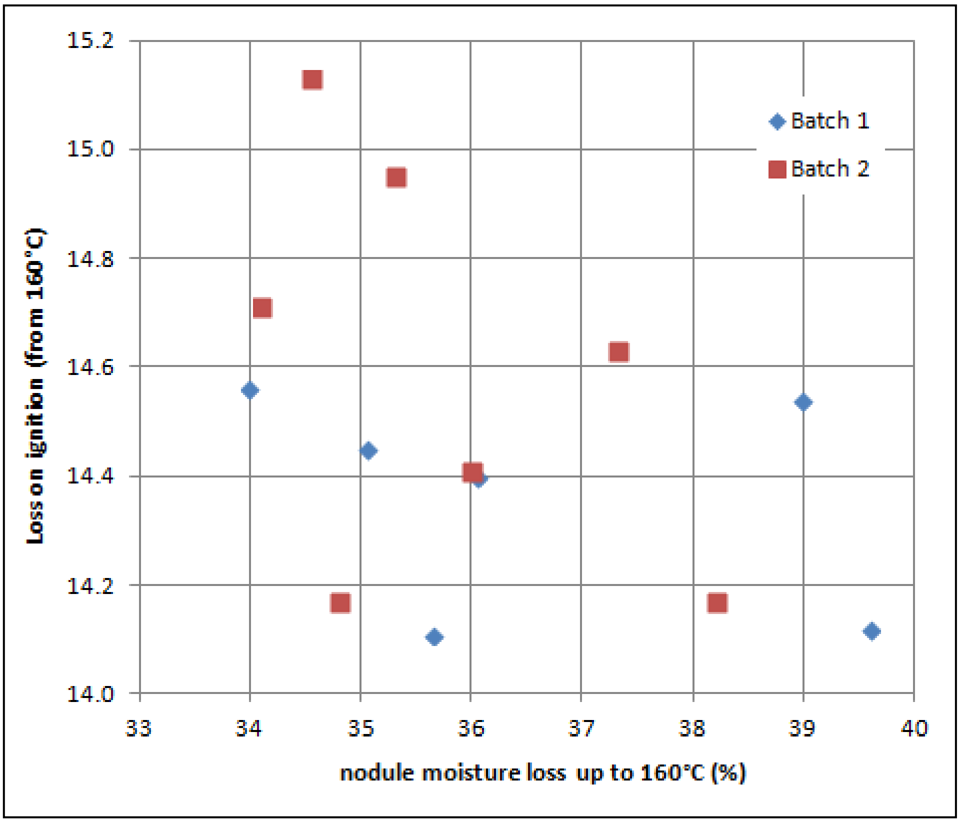
Stage three was loss on ignition (LOI) where samples were pulverised and effectively sintered at 1,000°C, driving off all moisture that might include other types of "combined water" (hydrates and labile hydroxy-compounds) and carbon dioxide although the latter is thought to be minimal in nodules.

From Figure 6.16 the LOI from 160°C was remarkably constant for the test samples between 14% and 15.2% which equates to:

- 10.6% to 11.8% from 160 °C on a starting wet basis.
- 16.8% to 18% from 105 °C. The results are comparable with other TOML analyses and figures from some sources:
  - Mero (1965) reports LOI (1100°C) of 15% to 39% averaging 25.8% but from nodules at an "air dried" level.
  - Reference material CGL131 (a nodule standard from the eastern German area in the CCZ) averaged an LOI of 16.98% from 16 laboratories, although the figure is not certified.

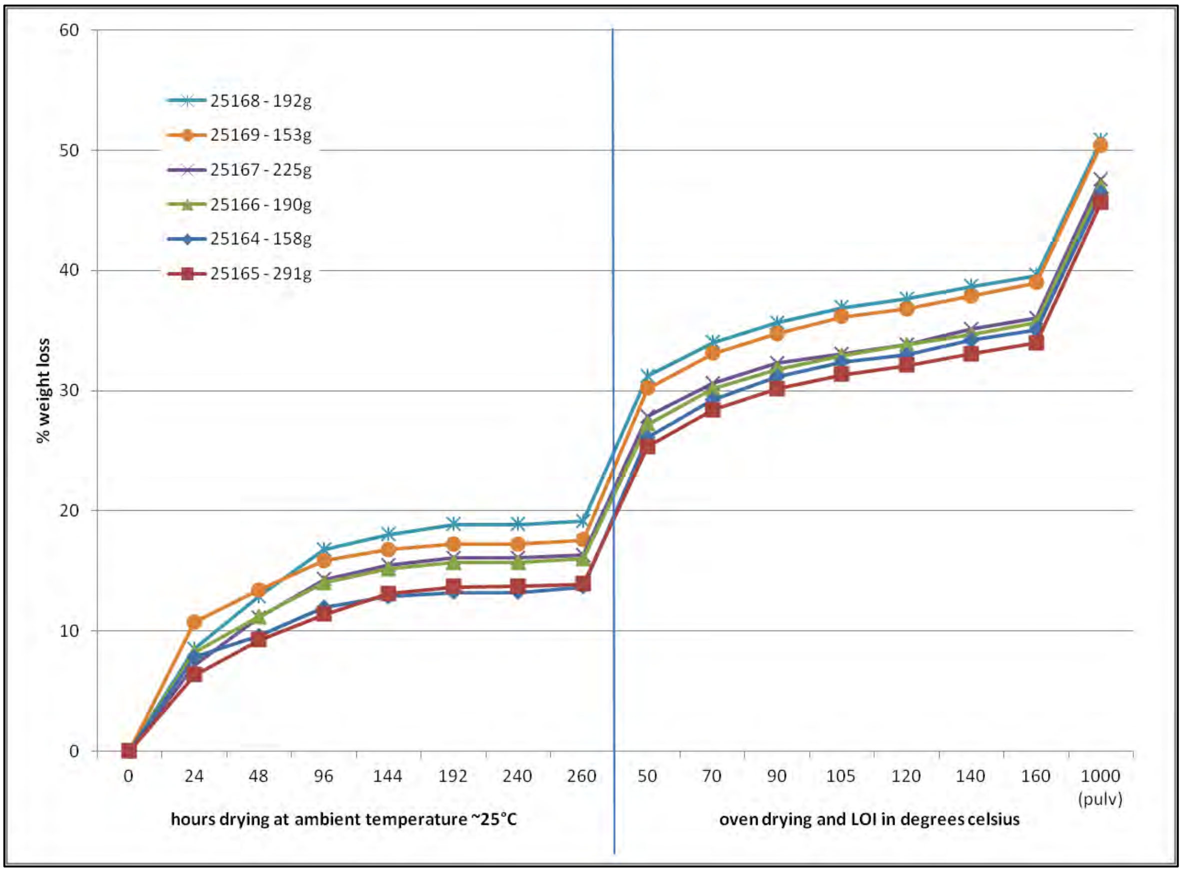
Other workers report higher LOIs (20% to 25%) but do not specify the drying method in enough detail for valid comparison. The chance of hygroscopic absorption of moisture cannot be discounted.

Figure 6.16 Loss on ignition (at 1,000°C) for two batches of TOML samples



A combined drying curve is summarised in Figure 6.17. Average total moisture content is 47% with most of the variance in total moisture apparent from the earliest stages of air-drying (48 hours at ambient temperature). With consideration of ~3% storage water absorbed into post sampling expansion cracks (see above) a standard total moisture content of 44% is derived.

Figure 6.17 Three stage drying curve for polymetallic nodules



Average total moisture content is 47% with most of the variance in total moisture apparent from the earliest stages of air-drying (48 hours at ambient temperature). After adjustment for absorbed water (determined in a separate test involving samples sealed from collection and sampled soaked before drying) an effective moisture content of 44% is arrived at.

In the estimation of moisture content (or other component) wet basis is taken before any air drying or soaking, dry basis is taken at 105 °C and a volatile free basis is taken after LOI at 1,000 °C with all volatiles removed. Other bases are mentioned in the text with the temperature specified.

6.5 Diagenetic Crusts

The minor amounts of ferro-manganese crust found in the CCZ are not the same as hydrogenetic cobalt-rich crusts typically found on the top of seamounts e.g., in the Pacific Prime Zone in the north-west Pacific Ocean (e.g., Hein and Koschinsky, 2013).Two types have been logged, both by TOML and other workers (e.g., Ifremer; Menot et al., 2010):

- Massive crust is five to ten centimetres thick and is typically found in blocks several decimetres a side but occasionally as pavement; and
- Crustal-nodules are small to medium sized (<20 cm) discrete fragments of ferro-manganese that can grade into nodules.

In total, crusts were logged in ~0.6% of the photo-profiles, with crustal nodules more common (~0.5%) and massive crusts being present only ~0.1% of the time. Neither type was collected in box-cores during the TOML CCZ15 campaign, and their extent is deemed insignificant in terms of the mineral resource estimation in Section 11.

6.6 Deposit Types

Surface and near surface polymetallic seafloor nodules are the only mineralisation type classed as a deposit in this report.

6.7 TOML Nodule Types

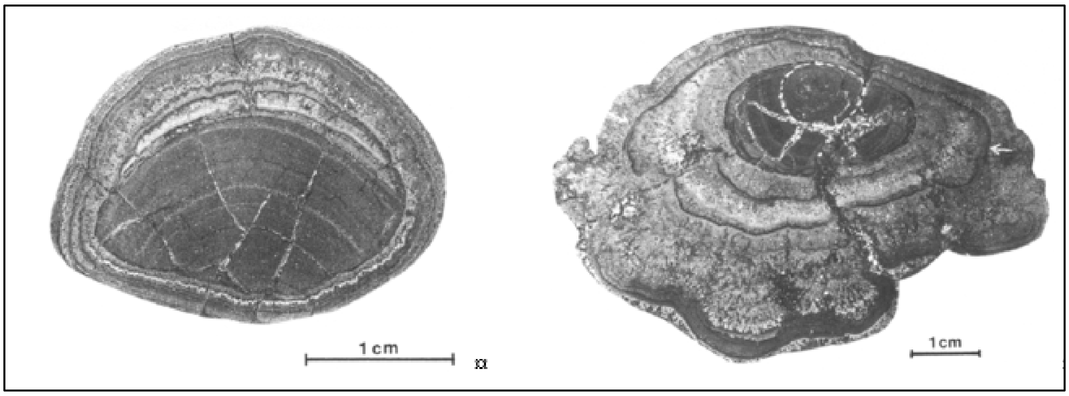
TOML's classification system was developed near the end of the CCZ15 campaign, once a wide range of characteristic nodules had been studied (Table 6.4). The classification aims to be simple and modular with two required codes (size then type, as per the ISA system) and three optional suffix codes (aspect of the nodules form, degree of fragmentation typically seen, and degree of development of botryoidal texture); as summarised in Table 6.4. Examples of type are also shown in Figure 6.18 and Figure 6.19.

Table 6.4 TOML CCZ15 Nodule classification and proportions seen in logging during CCZ15

		1:size Long Axis					
		=<2 cm		**2-5 cm**		**>5 cm**	
		s	**sm**	**m**	**ml**	**l**	**mx** (mixed)
		(small)		(medium)		(large)	18%
		8%	11%	20%	24%	18%	
2: type	**S** (smooth) 10%	*s-S 1%*	*sm-S 2%*	*m-S 1%*	*ml-S 1%*	*l-S 0%*	*mx-1%*
	RS (rough-smooth) 84%	s-SR 7%	sm-SR 8%	*m-SR 13%*	*ml-SR 22%*	*l-SR 18%*	*mx-SR 17%*
	R (rough) 6%	s-R 1%	*sm-R 2%*	*m-R 2%*	*ml-R 1%*	*l-R 0%*	*mx-R 1%*
3: aspect / oblate							
high	**regular**	**low**		**irregular**		**prolate**	
-hi	*-rg*	*-lw*		*-ir*		*-pr*	
4: fragmentation							
rare			**mod**			**common**	
-ra			-md			-cm	
5: botryoidal							
well dev.			**poorly dev**			**absent**	
-bo			-po			-no	

From Table 6.4 it is apparent that in the TOML area at least, rough-smooth nodules are the most common, especially in the medium to large size range.

Figure 6.18 Sections through a S-type Nodule (left) and a R-type Nodule with a S-type core (right)



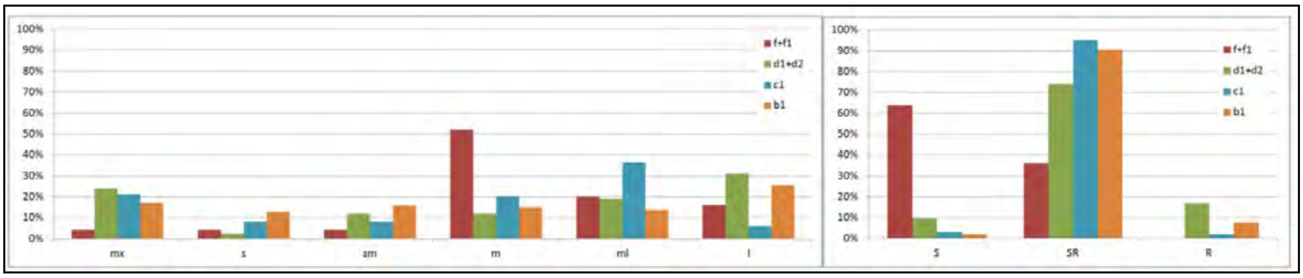
Source: von Stackelberg and Beiersdorf, (1991).

Figure 6.19 Example nodules found in the TOML area

Smooth (top left), rough-smooth (top right), rough (bottom left) and overturned rough-smooth (bottom right) types

Between TOML tenement areas B - F there are notable differences in the sizes and types of nodules present (Figure 6.20). Area F is distinctive for having generally more medium S type nodules than the other areas (although it also contains large SR type nodules of generally high aspect). Area C1 has very few truly large nodules with medium to large SRs dominating. Areas B1, and D1-D2 have a wider range of sizes again mostly (70–90%) of SR type although B1 has some discrete areas of smaller nodules. Two dredge samples from Area A contained mostly small smooth nodules, and as mentioned below one of these looks to be mostly of hydrogenetic character.

Figure 6.20 Nodule size and type within the areas sampled during TOML CCZ15



Codes are per Table 6.4

6.8 Variation in TOML Nodule Grades

Grade variation in CCZ nodules is remarkably low. Basic statistics pertaining to grade are included with the Mineral Resource data review in Section 11.

During the CCZ13 and CCZ15 TOML campaigns, dredge samples were taken for metallurgical test work and the opportunity was taken to analyse numerous (~30 per dredge) sub-samples of nodules to better establish grade variation within a small area.

These dredge sub-sample results are compared below with box-core and historical results for Ni, Cu, Co and Mn (Figure 6.21 and Figure 6.22). Bear in mind that the three datasets all cover different areas with:

- historical samples covering all of TOML A-E;
- TOML box-cores (BC) all of selected sub-areas in Areas B, C, D and F; and
- dredge samples in select locations.

Key conclusions from this comparison are that:

- There is generally good to excellent agreement between dredge samples and the more widely sampled but internally consolidated samples from box-cores;
- There is generally excellent agreement between the historical data (section 9.1) and the TOML dredge and box-core samples with the exception of Mn (higher in the TOML samples from some areas as discussed in Section 11);
- Some of the regional grade trends are seen between the TOML Areas (e.g., Area B has generally higher Ni and lower Cu than Area C, while Area F has distinctly lower Co);
- The lower grade nodules from box-cores from Area B1 seen in Figure 6.21 and Figure 6.22) tend to be found in a single area in the central-eastern part of the area (B3645 and surrounds), that is characterised by typically R-type nodules and frequently low to very low abundances;
- Area A and B nodules have a greater range in grade consistent with more variable ratios of diagenetic to hydrogenetic formation (higher Co and Fe).

Figure 6.21 Nodule variance in Ni and Cu for dredge and box-core samples in the TOML Areas

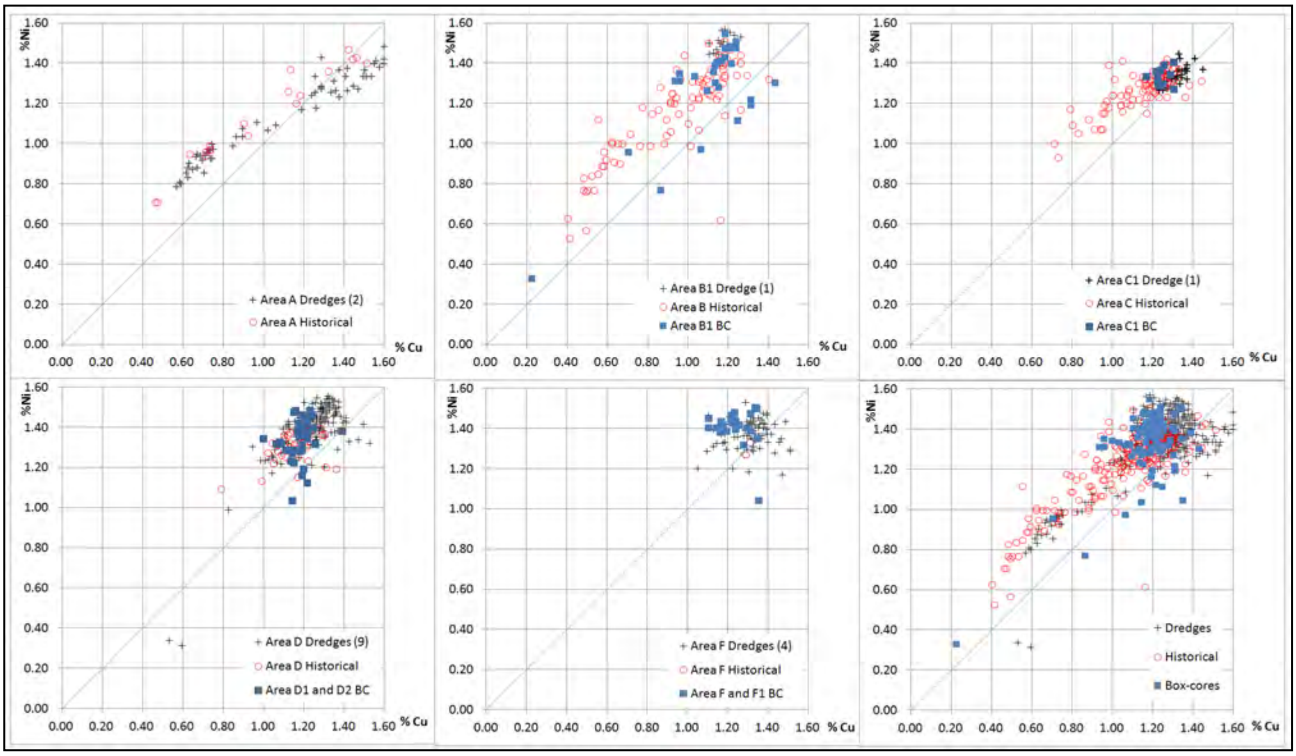
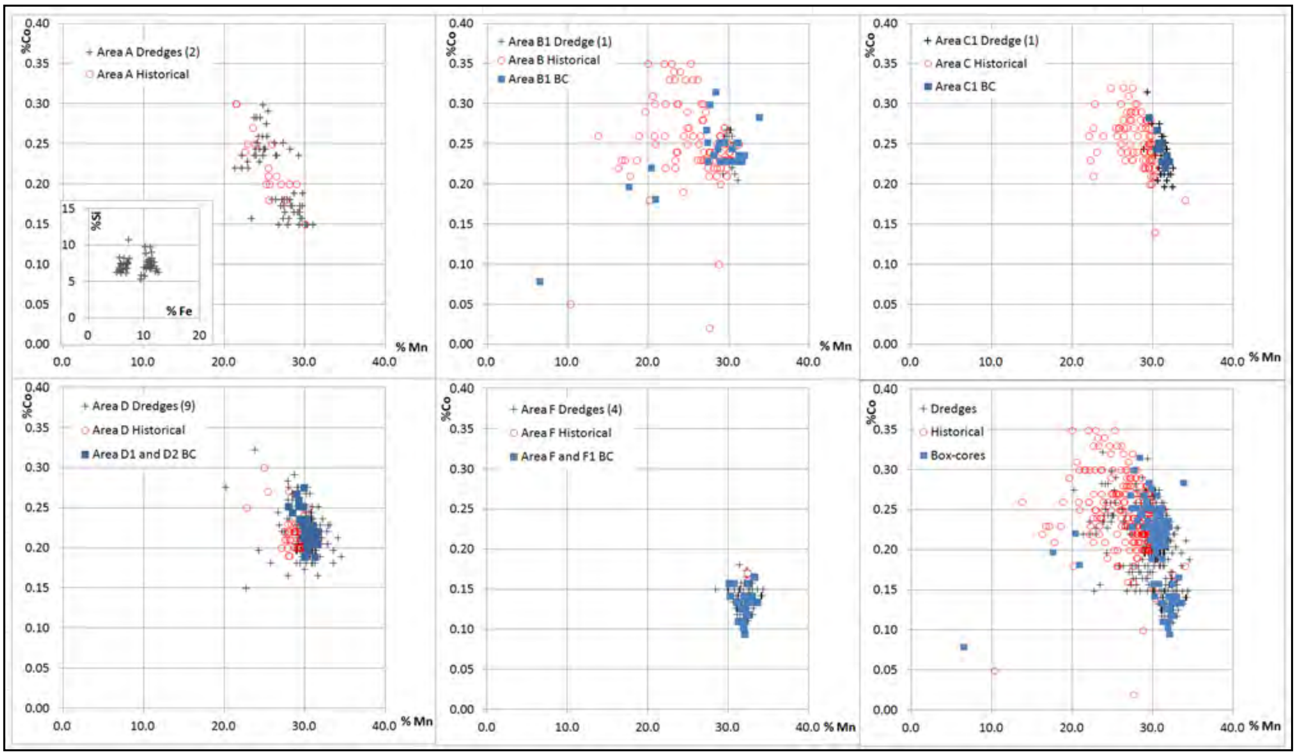


Figure 6.22 Nodule variance in Mn and Co for dredge and box-core samples in the TOML Areas



6.9 Nodule Distribution

The distribution of nodules though the CCZ is not constant, and likewise their abundance varies within the TOML contract areas. Areas with few or no nodules that can be discriminated in mapping are:

- Volcanic areas (seamounts and more recent flows)

- Slopes or escarpments (from ongoing normal faulting and both of basement basalt and overlying sediment)
- Areas of "no nodules on ooze" (Nnoo) that are thought to be areas of drifting sediments that preclude nodule formation.

As noted in Table 6.5, only the volcanic areas and Nnoo sediment drifts were domained separate to the sediment bearing nodules in the mineral resource estimate.

Table 6.5 MBES mapped seabed classification and proportions

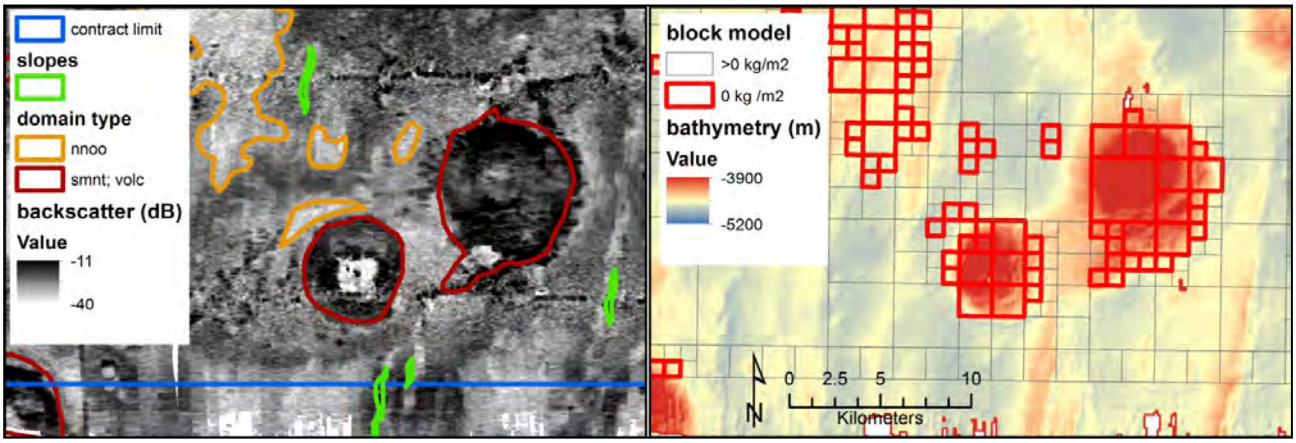
Area	Volcanic exposure	Nnoo sediment	Slopes	Nodule bearing
B	5.9	6.0	3.9	84.2
C	1.8	5.6	3.2	89.4
D + E	3.0	12.9	4.2	79.9
F	1.5	2.1	4.9	91.6

Note that without MBES survey, it is not possible to estimate the proportions of the above mapped units in Area A.

Strictly speaking, most of the above discriminated areas still contain some nodules. Small nodules are found on seamounts and in amongst the escarpments. Sediment drifts also usually contain the occasional nodule as seen in seafloor photos. There may also be nodules buried near the edge of sediment drifts.

Dealing with these areas in the mineral resource estimate is described in Section 11. Mapping based on MBES (e.g., Figure 6.23) estimates the area with no or insignificant nodules to comprises 10 to 20% of the total area (Table 6.5).

Figure 6.23 Mapped areas of volcanic rocks, slopes and Nnoo sediment in part of TOML Area B



Note that over-estimation of area of slopes is likely due to smoothing from the relatively coarse (60–120 m) resolution of the shipborne 12 kHz MBES and the nature of interpretation. Slopes were not significant enough to be domained out in the mineral resource estimate. There is also the possibility that many of the mapped volcanics of lower relief are partly covered with sediment and nodules. Box-core sampling of Nnoo type areas was done if that unit was covered by the planned sample grid in the CCZ15 campaign. Direct correlation of nodule abundance with MBES backscatter was relatively poor.

6.9.1 Importance of buried nodules

Sediment is thought to cover even surficially located nodules from time to time, due to ongoing sedimentation and the effect of seafloor currents. In many cases, grazing holothurians clear any accumulated sediment off the nodules.

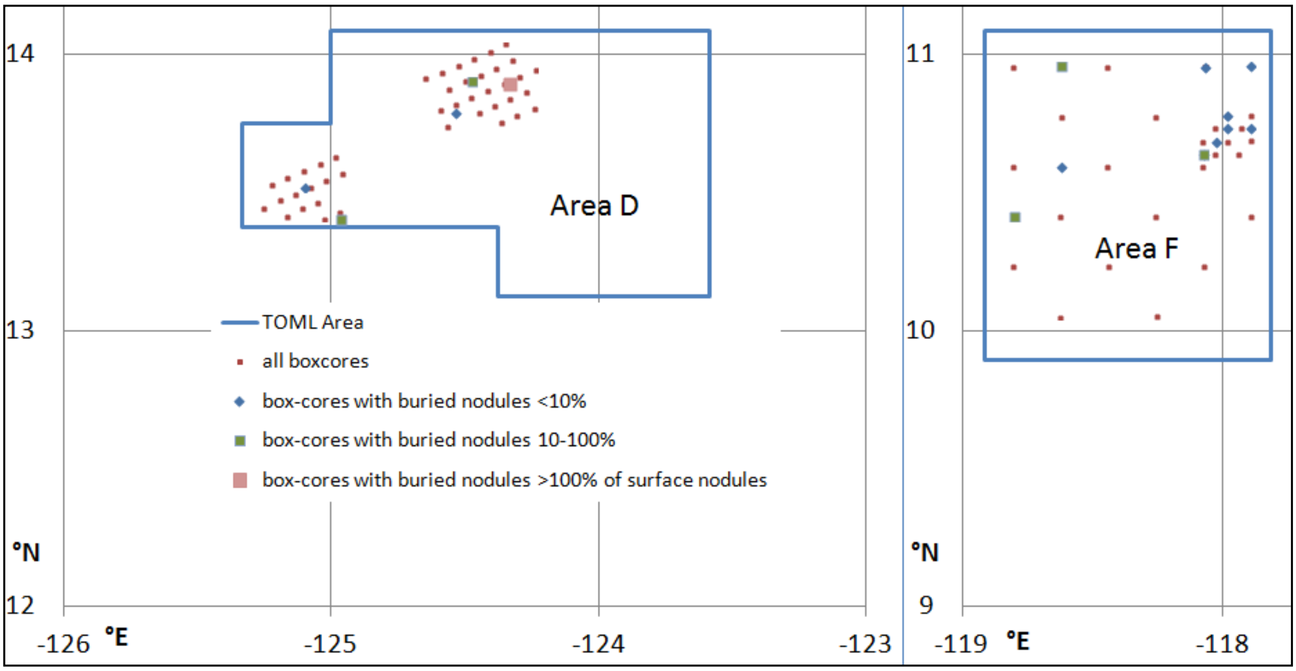
In logging during TOML's CCZ15 campaign, a clear distinction was made between:

1. **Powder** a thin coating of sediment, usually so little (~ 5 mm) that the outline of the nodule can be seen in a photograph;
2. **Cover** is up to several centimetres of sediment, obscuring the nodule completely from vision, maintaining the nodule within the geochemically active layer and with the amount of cover irrelevant to sampling and collecting methods;
3. **Buried** was defined as when there is greater than 10 cm of sediment on the nodule. Buried nodules often are below the geochemically active layer. As they are likely located too deep for a nodule collector, they were collected from the box-cores in CCZ15 purely for reference purposes and their weights and chemical analyses were **not included** in the dataset supporting the mineral resource statement.

Buried nodules often have a very soft brown powdery surface, which is thought to reflect surface 'corrosion' due to reduction and breakdown of the nodule. However, this was always seen on the surface of nodules and no extensively degraded remnants were seen. Many buried nodules have the size and textures of large to medium SR type (see TOML classification in Table 6.4 above) indicating that they were at the surface for a long period of time before burial. When present in the box-cores, the buried nodules were often found in groups at the same depth, and it is suspected that they became buried by falling into burrows due to undermining. Buried nodules tend to be larger than the average nodules found at the surface.

Buried nodules are uncommon. A total of 16 out of the 113 box cores taken during CCZ15 had buried nodules and all of these were located in Area D and F (Figure 6.24). If just Areas D and F are considered, then buried nodules were found in about 23.8% of samples which is a similar ratio to that described by Kotlinski and Stoyanova (2006) who found 22.6% within the part of the IOM contract area (59 of 261 sample sites).

Figure 6.24 Location and percentage of buried nodules found during CCZ15



7 Exploration

Exploration in the TOML tenement area comprises two main phases:

- Historical work and data collected by the pioneer contractors who returned Reserved Areas to the ISA. This work underpins much of the inferred mineral resource estimated in Section 11 and reported previously (Golder Associates, 2013).
- TOML work and data acquired by TOML during two exploration campaigns in 2013 and 2015 (called CCZ13 and CCZ15 respectively in this report). This work underpins part of the inferred mineral resource estimate as well as all of the indicated and measured mineral resource estimates.

7.1 Historical Data

Six exploration groups are known to have surveyed areas within the TOML tenement area and collected samples of polymetallic nodules. Much of this work overlapped as it predated the signing of the Law of the Sea. These include the Japanese group (DORD), the South Korean group (KORDI), the Russian Federation group (Yuzhmorgeologiya), the French group (Ifremer), the German group (FIGNR or BGR), and the consortium, Ocean Minerals Company (OMCO). The timing and location (ISA, 2003) of the OMCO sampling is known but the results are not available outside of ISA published contour maps.

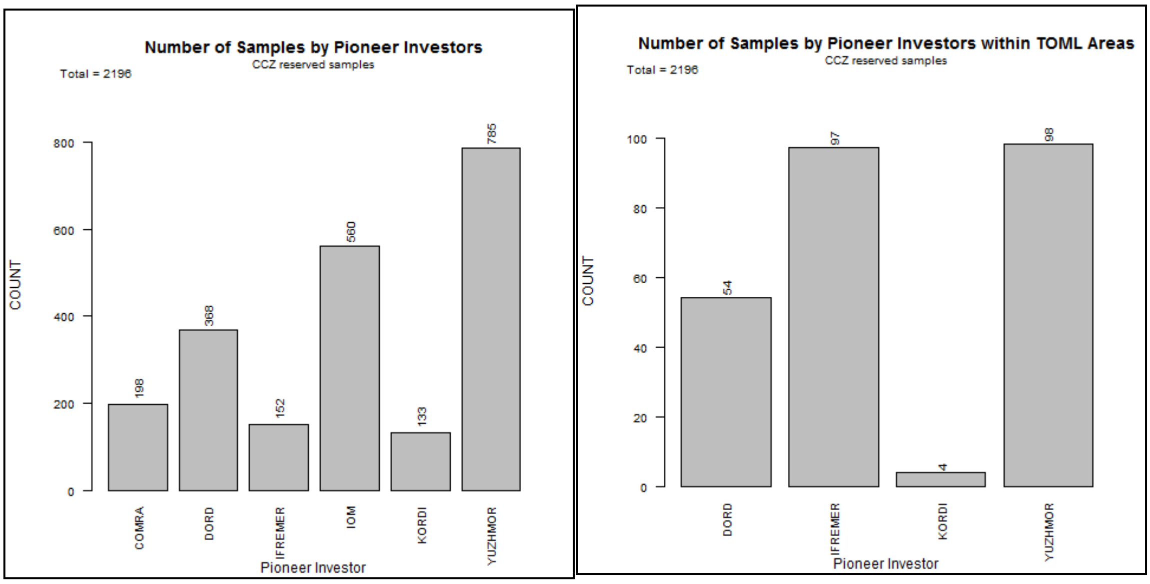
Virtually all the samples in the TOML tenement area were obtained by free fall grab (FFG) samplers, although a few results from box corers (BC) were also included. As detailed in section 7.5.6, nodule abundance (wet kg/m^2) is derived by dividing the weight of recovered nodules by the surface area covered by the open jaws of the sampler or corer (typically 0.25 to 0.5 m^2 but in some cases as much as 1 m^2). Assays were done on dried sample splits by commonly used spectrometric methods (AAS and XRF).

7.1.1 Nodule Sample Data Supplied to TOML

The TOML tenement area was a Reserved Area and as such was sampled by Pioneer Investor or developed nation sponsored contractors. These samples provided the basis of a database held and maintained by the ISA. These data were used initially to define the areas of the TOML application, and subsequently to estimate an inferred mineral resource for the part of the TOML tenement area they covered (Golder Associates, 2013).

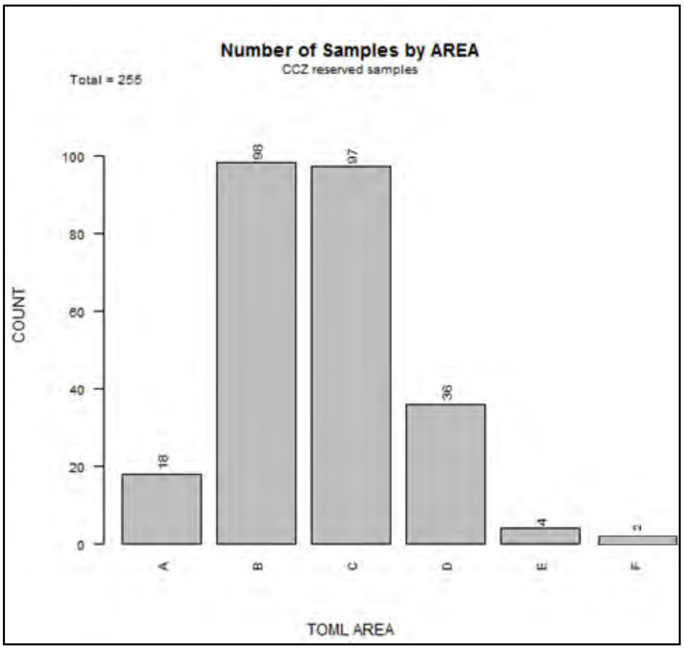
Bar plots showing the total number of samples within the TOML tenement area collected by each Pioneer Investor or developed nation contractor are presented in Figure 7.1 and Figure 7.2. The statistics for the samples that contain both abundance and grade data inside the TOML tenement area are tabulated in Table 7.1 to Table 7.6. Samples in the CCZ but outside the TOML tenement area are presented in Table 7.6.

Figure 7.1 Total Number of Samples by Pioneer Contractor.



Pioneer Contractors are sometimes referred to as Pioneer Investors

Figure 7.2 Total Number of Samples by TOML tenement areas.



Note that 8 additional samples were received for Area E from IOM (see Table 7.5).

Table 7.1 Summary of Historical Grab Samples Area A

(ex-DORD)	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m^2)
Count	18	18	18	18	18
Minimum	21.46	0.15	0.71	0.46	2.68
Maximum	30.05	0.30	1.47	1.51	17.93
Mean	25.40	0.22	1.14	1.00	10.12
Median	25.50	0.21	1.15	1.02	9.19
Standard Deviation	2.44	0.04	0.24	0.35	5.08
Coefficient of Variation	0.10	0.18	0.21	0.35	0.50

Table 7.2 Summary of Historical Grab Samples Area B

(ex-Yuzhmorgeologiya)	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m²)
Count	88	88	88	88	88
Minimum	10.30	0.02	0.53	0.40	0.03
Maximum	31.20	0.35	1.51	1.40	26.00
Mean	25.40	0.25	1.16	0.94	8.82
Median	26.55	0.25	1.23	1.02	8.09
Standard Deviation	4.19	0.06	0.23	0.26	5.87
Coefficient of Variation	0.16	0.22	0.20	0.27	0.67

Excludes samples that had no nodules.

Table 7.3 Summary of Historical Grab Samples Area C

(ex- Ifremer)	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m²)
Count	78	78	78	78	78
Minimum	22.01	0.14	0.93	0.71	1.35
Maximum	30.90	0.32	1.42	1.44	21.25
Mean	27.91	0.25	1.27	1.15	9.98
Median	28.55	0.25	1.29	1.19	9.17
Standard Deviation	2.13	0.03	0.10	0.15	4.20
Coefficient of Variation	0.08	0.13	0.08	0.13	0.42

Excludes samples that had no nodules.

Table 7.4 Summary of Historical Grab Samples Area D

(ex-DORD)	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m²)
Count	36	36	36	36	36
Minimum	22.79	0.19	1.09	0.79	0.12
Maximum	30.45	0.30	1.44	1.36	16.37
Mean	28.52	0.22	1.31	1.16	7.68
Median	28.76	0.22	1.32	1.17	7.78
Standard Deviation	1.47	0.02	0.08	0.10	4.09
Coefficient of Variation	0.05	0.10	0.06	0.08	0.53

Table 7.5 Summary Historical Grab Samples Area E

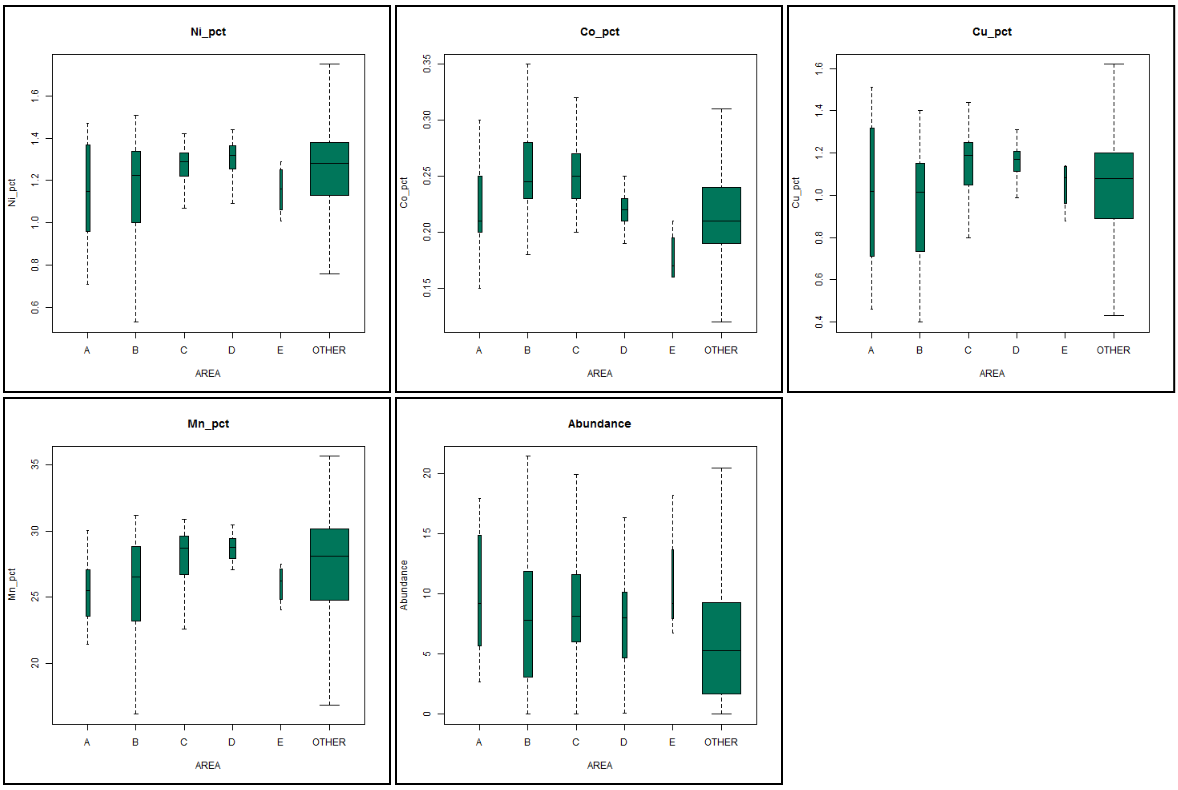
(ex-KORDI, IOM)	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m²)
Count	10	10	10	10	10
Minimum	24.04	0.16	0.96	0.69	1.48
Maximum	31.34	0.27	1.43	1.27	22.90
Mean	27.54	0.21	1.21	1.07	11.34
Median	27.17	0.22	1.21	1.11	9.22
Standard Deviation	2.58	0.04	0.18	0.17	6.82
Coefficient of Variation	0.09	0.18	0.15	0.16	0.60

Table 7.6 Summary of Historical Samples from the Reserved Areas outside the TOML tenement area

	Mn (%)	Co (%)	Ni (%)	Cu (%)	Abundance (wet kg/m^2)
Count	2188	2188	2188	2188	2188
Minimum	4.14	0.05	0.15	0.12	0.01
Maximum	35.62	3.23	1.75	1.62	52.20
Mean	27.47	0.21	1.25	1.04	8.21
Median	28.47	0.21	1.30	1.09	7.10
Standard Deviation	4.06	0.08	0.20	0.24	6.06
Coefficient of Variation	0.15	0.40	0.16	0.24	0.74

The above tables and Figure 7.3 indicate that all of the TOML tenement areas have similar ranges of grade and abundance to the rest of the CCZ deposit. The coefficients of variation of grades are low compared to most terrestrial mineral resources. Abundance values vary more widely, making abundance estimates the key variable of uncertainty in mineral resource estimation. For the historical data, sample spacing is predominantly wide (10 km to 30 km). However, there are a number of closely spaced samples (500 m to <10 km) but these are insufficient to constrain the short range controls on grade and abundance within the TOML tenement areas. TOML's own sampling (see below) serves to constrain the short range.

Figure 7.3 Box Plots of historical sample grades within the TOML tenement areas.



Box size represents 1st and 3rd quartiles centred on the median and box width reflects number of samples

Figure 7.4 Box Plots comparing the 6 Pioneer Investor Reserved Area Data Sets across the entire CCZ.

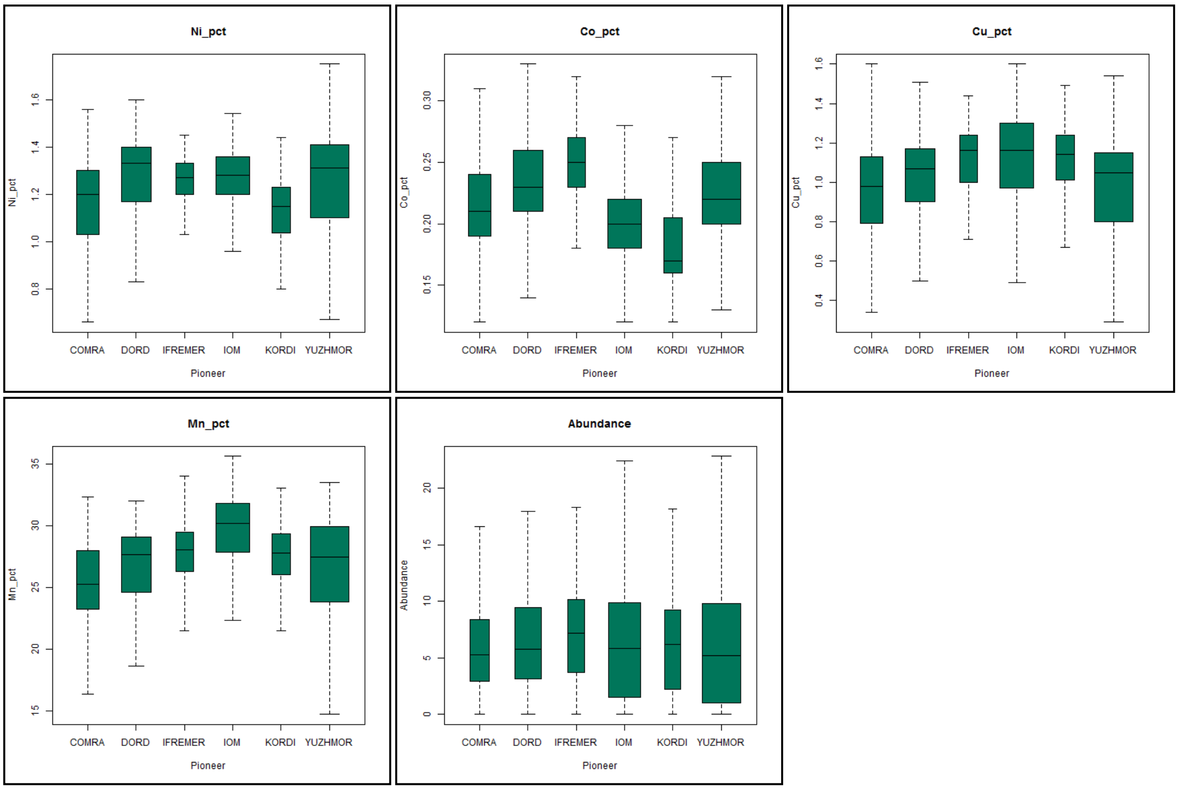
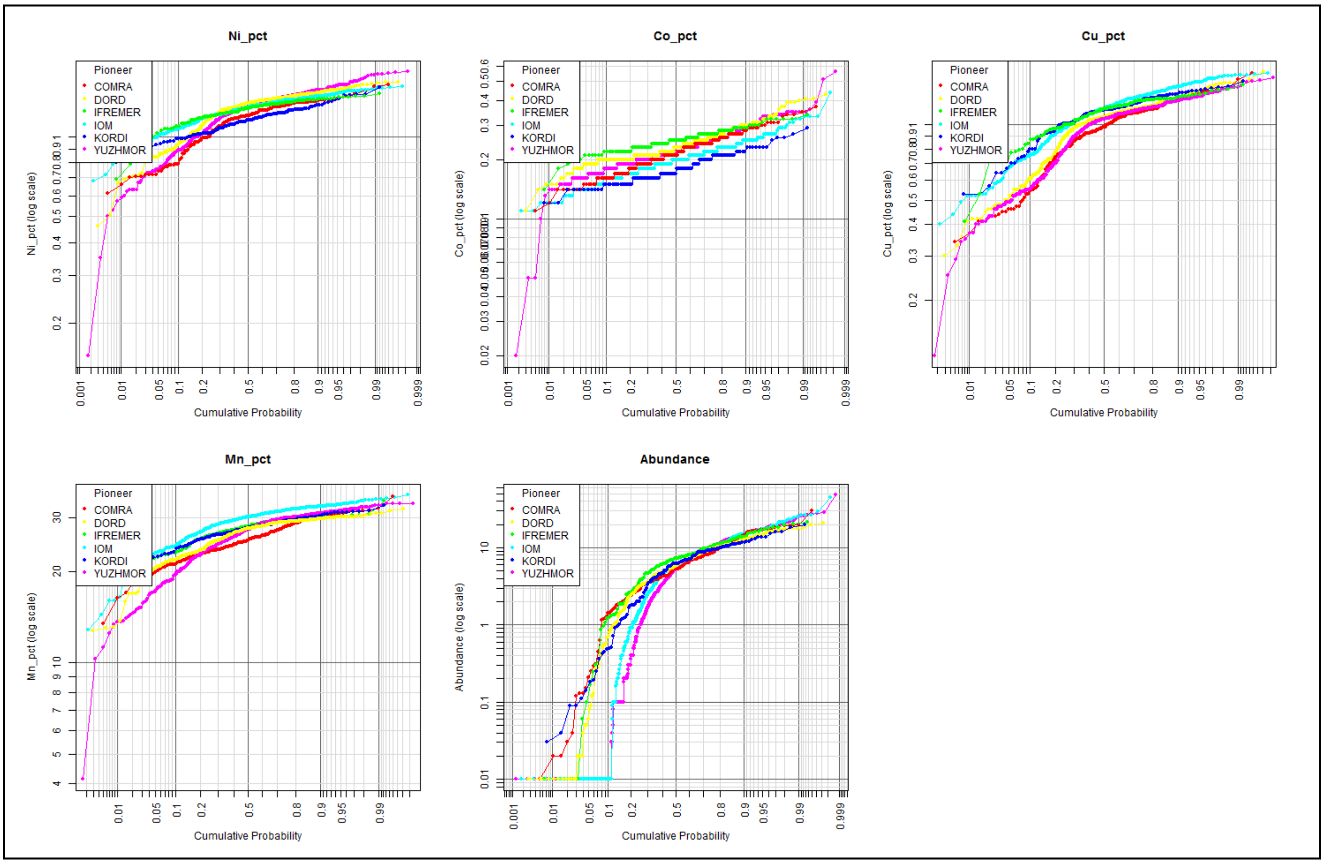


Figure 7.5 Log Probability plots comparing the 6 Pioneer Investor Data Sets.



7.1.2 Historical Sampling Method

Virtually all the historical samples used in the TOML Mineral Resource estimates were obtained by FFG samplers plus a few by BC samplers. Research has shown that free fall grab samplers consistently underestimate the actual abundance (Hennigar, Dick and Foell, 1986), but even today they are the most productive tool available for the assessment of nodule abundance. This is because a number of them can be deployed at any one time from the survey vessel allowing an order of magnitude increase in collection efficiency, i.e., approximately 10 to 20 samples per day for a FFG, versus about three samples per day for a BC that is winched to and from the seafloor.

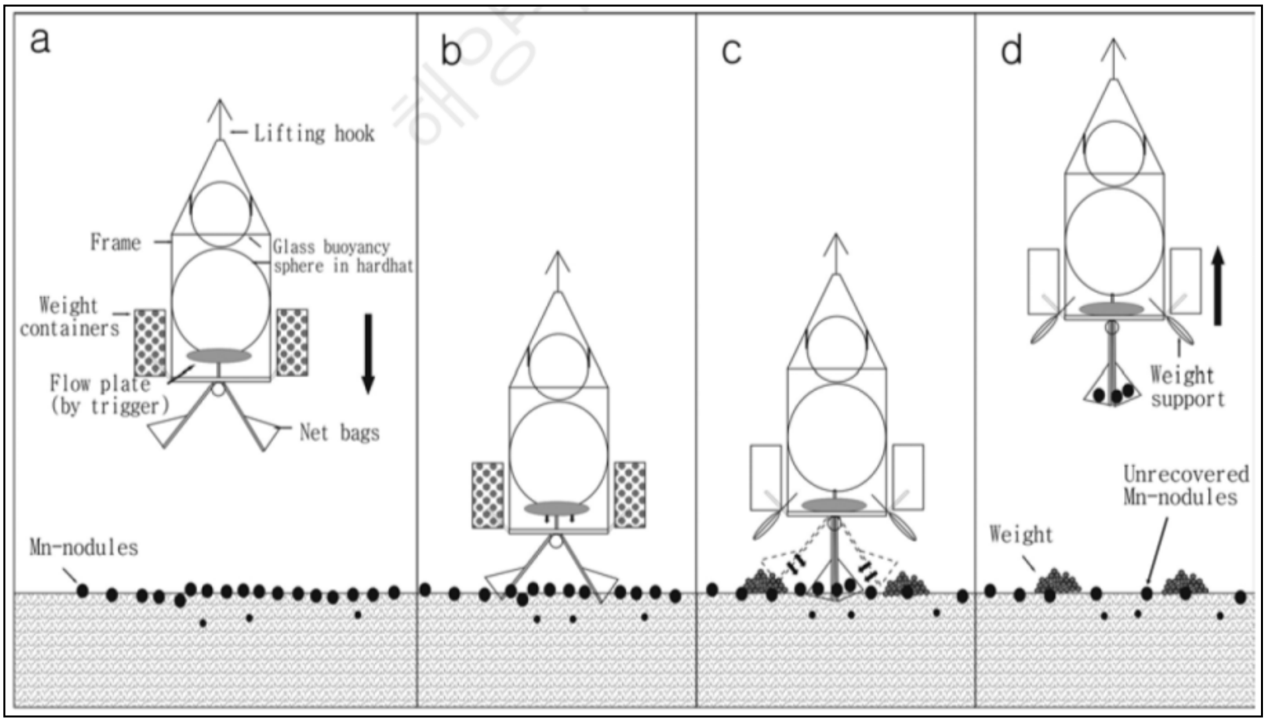
Lee et al. (2008) compared FFG and BC data in some detail. They found a wide range but consistent differences with FFG under-reporting compared to BC (Figure 7.8). They also illustrate why BC results should be much more accurate than FFG results based on mechanical effectiveness (Figure 7.6, Figure 7.7). They then recommend an overall correction factor of 1.4 to convert a FFG abundance to a BC abundance. However, they acknowledge that any simple factor lacks precision. One key issue is the size of the FFG or BC (area covered) versus the nodule diameter. Free fall grab samplers have been demonstrated to underestimate the actual abundance as smaller nodules may escape some grabs during ascent and larger nodules around the edge of the sampler may be knocked out or fall out during the sampling process.

No conversion has been applied to the TOML nodule abundance because:

- Sample collection type is not specified in the historical data (i.e. proportion and identity of BC versus FFG samples is unknown (although most are likely to be FFG).
- The size of collector and nodule sizes is not specified in the historical data.

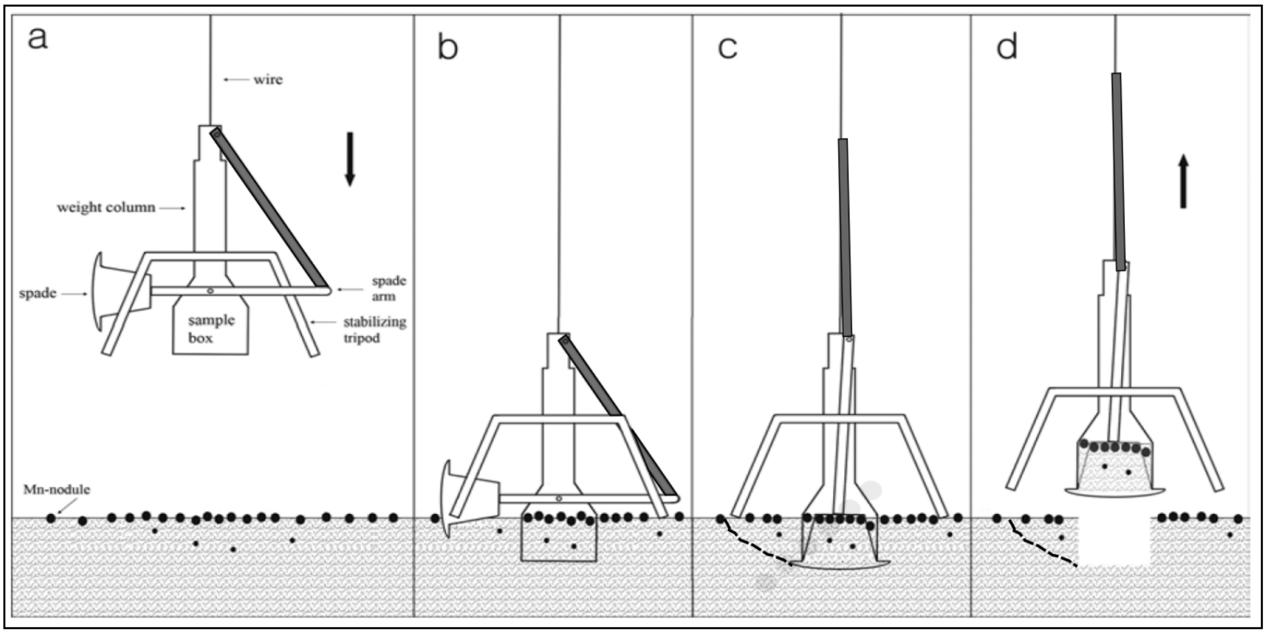
Therefore estimates of nodule abundance based on historical samples are likely to be conservative.

Figure 7.6 Cartoon showing the recovery process of nodules using Free Fall Grab



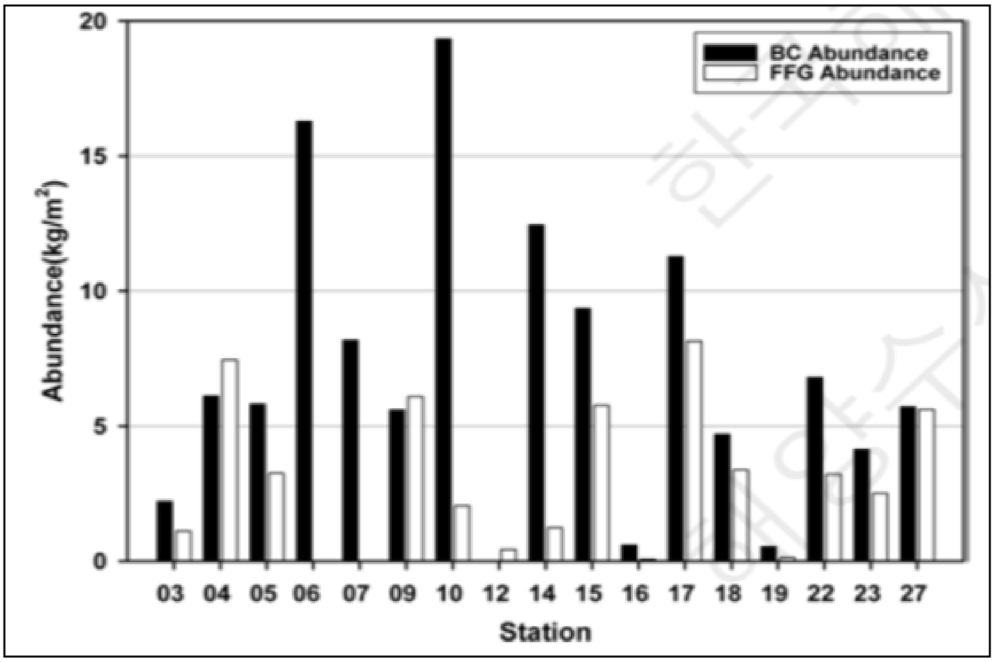
Source: Lee et al., (2008).

Figure 7.7 Cartoon showing the recovery process of nodules using Box Corer



Modified after: Lee et al., (2008).

Figure 7.8 Comparison of returned abundances from BC and FFG at test stations within the KORDI exploration area



Source: Lee et al., (2008).

Metal content in the historical samples was determined by a variety of standard analytical methods, including atomic absorption and X-ray fluorescence. Limited information is available on historical sample preparation and analytical methods. The various groups reportedly used polymetallic nodule Certified Reference Materials (e.g., NOD-P-1; Flanagan and Gottfried, 1980) for QAQC, however details of the Certified Reference Materials and analytical results were not included in the dataset supplied by the ISA to TOML and Golder.

7.2 TOML Work Programmes

In 2012, TOML realised the need for two campaigns to effectively define a mineral resource of sufficient confidence and size to likely support the building, commissioning and payback of a mining operation.

The first campaign in 2013 utilised the MBES system of the chartered RV Mt Mitchell (Figure 7.9) to map the seafloor in Areas B through F, as well as to test equipment and collect sufficient sample to confirm grades and support metallurgical test work.

The second campaign in 2015 used the experienced team and equipment spread on the RV Yuzhmorgeologiya (Figure 7.9) to sample and image mapped priority areas so that a higher confidence and expanded mineral resource could be estimated, and to collect environmental baseline and geotechnical data.

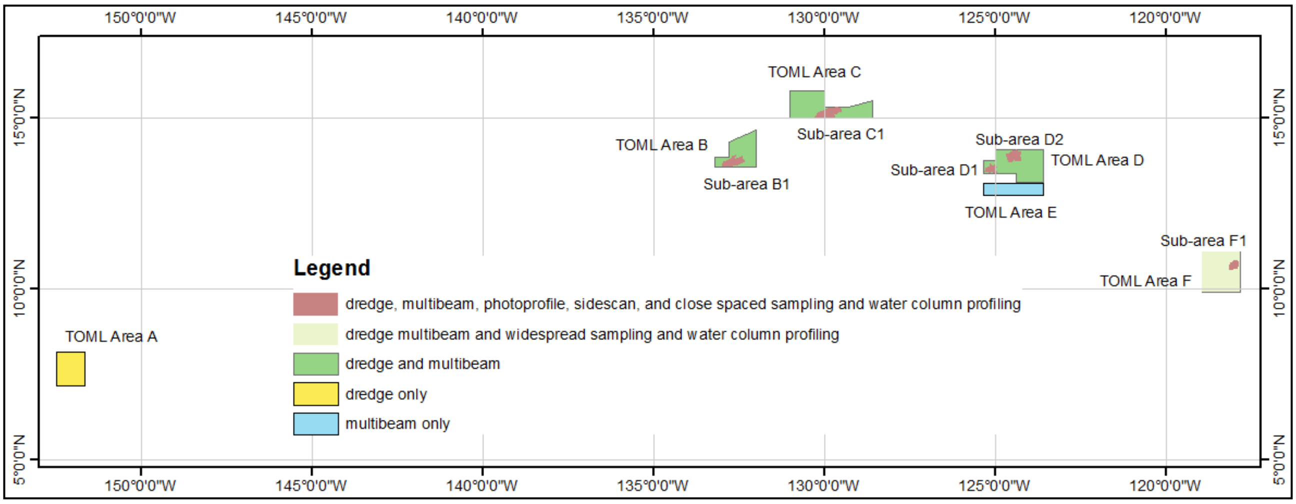
Figure 7.9 RV Mt Mitchell (CCZ13) and RV Yuzhmorgeologiya (CCZ15)

Table 7.7 and Figure 7.10 summarise collected data from each TOML area and sub-area. MBES (12 kHz MBES echosounding) includes bathymetric and backscatter products and geological geomorphological interpretation. Photo-profile includes still and video products and logging. Dredge sample data includes grade characterisation and some size distribution data. Water column includes temperature, pressure, turbidity and in some cases physical samples and current. Box-core data includes nodule grade and abundance; fauna, and in some cases vane shear and/or sediment characterisation. Deep-tow sonar includes sidescan sonar, sub-bottom profiler and micro survey and altimetry.

Table 7.7 TOML datasets by area and by campaign

	MBES km^2	Photo-profile line km	Dredge #	Water column #	Box-core #	Deep Tow Sonar line km
Area A	–	–	2 CCZ15	–	–	–
Area B	9,966 CCZ13	–	–	–	–	–
Sub-area B1	Included in B	178 CCZ15	1 CCZ13	14 CCZ15	30 CCZ15	88 CCZ15
Area C	15,763 CCZ13	–	–	–	–	–
Sub-area C1	Included in C	231 CCZ15	1 CCZ15	14 CCZ15	16 CCZ15	32 CCZ15
Area D	15,881 CCZ13	92 CCZ15	6 CCZ13	–	–	–
Sub-area D2	Included in D	47 CCZ15	2 CCZ13	26 CCZ15	26 CCZ15	120 CCZ15

Figure 7.10 Extent of TOML exploration in the CCZ



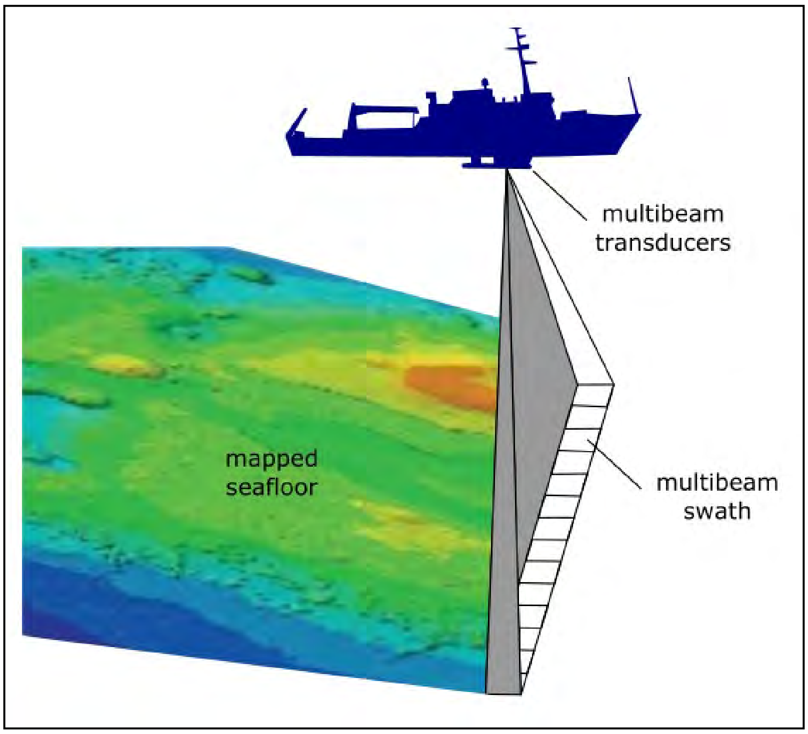
7.3 TOML Sampling Methods

Details of key resource data collection processes and methods are presented here.

7.3.1 Multibeam Bathymetry

MBES is used to determine the depth of water (bathymetry) and the acoustic reflectance (backscatter) of the seabed. It operates by transmitting a focused acoustic pulse (Figure 7.11) from a specially designed transducer across a swath across the vessel track. These pulses return as a set of receive beams that are weaker and narrower and whose arrive time varies depending on speed and distance. Thus position and depth can be measured and seafloor hardness can be qualitatively assessed.

Figure 7.11 MBES operations schematic



During the CCZ13 campaign the RV Mt Mitchell operated a hull mounted Kongsberg EM120 MBES over areas B through F. This equipment operates at 12 kHz and is capable of operation up to

11,000 m water depth. It has better than 5 m vertical resolution and ~60 m horizontal resolution for bathymetry and ~30 m for backscatter at water depths between 4,500–6,000 m. It has a maximum swath width of 6 times the water depth but the effective swath width varies from 2 to 6 times the water depth depending on the depth, sea state and heading.

The only pre-existing bathymetric data over the TOML tenement areas (excluding occasional widely spaced transit lines collected by research vessels) was the Sandwell and Smith based, satellite bathymetry (BODC, 2014). This bathymetry is calculated using mean sea levels to estimate depth to seafloor and is good for a resolution of 30 arc seconds (within the TOML areas this roughly equates to 900 m). In a general sense, this data is usually accurate to within a hundred metres vertically, but it lacks the definition necessary to define the smaller seamounts, ridges and smaller bathymetric features. No publicly available backscatter or seafloor reflectance data exists for these survey areas. As a result, conducting these MBES surveys provides TOML with a significant improvement in the vertical and horizontal resolution of the bathymetry, and with unprecedented intensity definition of the backscatter, resulting in visibly crisper, and much more interpretable imagery.

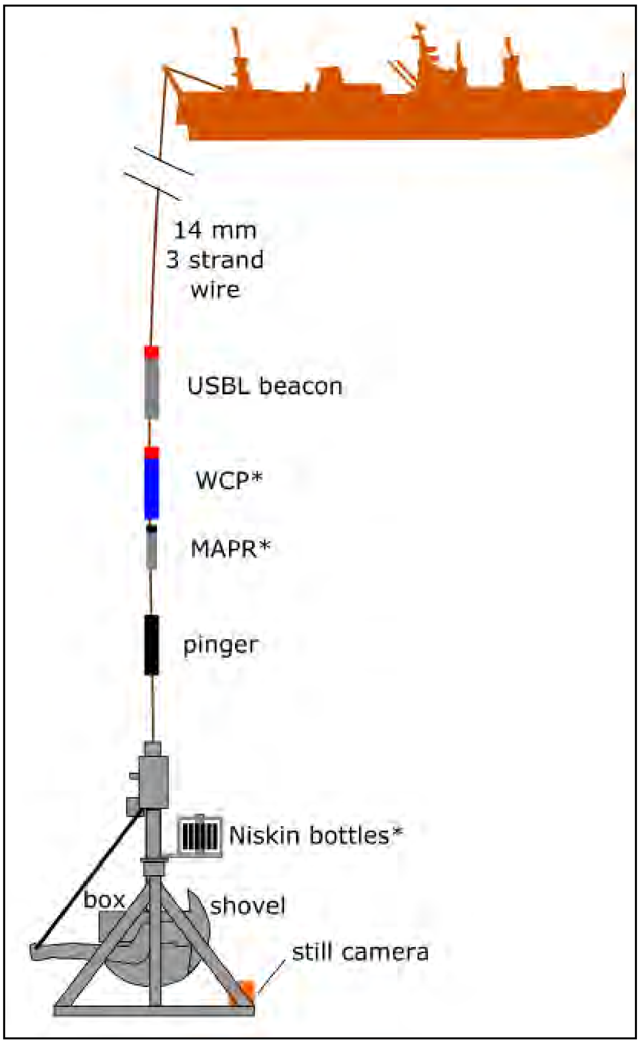
CTD (conductivity-temperature-depth) soundings were performed at each of the survey areas in 2013. The primary reason for this is that the MBES system requires an accurate full water column sound velocity profile with which to perform real time beam steering and location calculations.

7.3.2 Box-coring

Box-coring was undertaken in 2015 to collect samples for mineral resource estimation, to collect biological samples for environmental base-line measurement and to collect geotechnical data. Box-core operations adhered to the following:

- Deployment and recovery off the stern of the vessel using three strand wire and the vessel's starboard hydrographic sample winch (Figure 7.12)
- The vessel maintained minimum forward speed, typically 0.3 to 0.7 knots into result (combination of surface wind and waves)
- The box-core's progress and status (fired or not) was tracked using a signal from a 12 kHz pinger
- Landing points were within 500 m of the planned grid co-ordinates (as per Dive Plans) with the following pre-conditions:
  - Landing points avoid steeper areas (>10° slope) based on pre-existing multi-beam bathymetry
  - The hydrographic surveyors guiding the landing never sight the backscatter product of the existing multi-beam coverage (to eliminate chance of sighting bias)
  - USBL navigation provides location to within ±15 m.

Figure 7.12 Box-corer Deployment Schematic



7.3.3 Box-coring Overview

Box-corers have been used in the CCZ since the 1970s. As they collect a seabed sample effectively intact (Figure 7.7), they are seen by most workers as the best possible sampling device to estimate the nodule abundance in any given area. As such, the box-core samples were the most important contributor to the CCZ15 campaign results and by extension, to an independently validated, mineral resource estimate.

Box-corers come in different sizes: typically 0.1 m^2 or 0.25 m^2 (plan area of sample box or tube), but box-corers of 0.75 m^2 and 1 m^2 have also been used.

Smaller box-corers are good for micro-biological sampling of the epibenthic zone and are adequate for the estimation of abundant nodule resources, especially those involving smaller nodules. For accurate estimation of the abundance of larger nodules, especially in lower quantities, larger box-corers are more accurate.

The largest box-corers used in the CCZ were 1 m^2 (Afernod's Sympas system and one built by the OMCO consortium), but by all accounts, these were very large and difficult to handle. Kennecott built a 0.75 m^2 corer and used it extensively, deeming it to be an effective compromise (Felix, 1980).

7.3.4 Box-corer Equipment

Two types of box-corers were used during the TOML CCZ15 campaign:

- 0.75 m^2 box-corer manufactured by KC Denmark (80.740 code) and supplied by Nautilus Minerals (Figure 7.14). For part of the campaign, the KC box-corer included a carrousel of 12 small volume (300 ml) Niskin bottles for water sampling. Each side of the box has an internal width of just below 87 cm (there are minor variances of 1–2 mm with the corner welds), so the true area of 7569 cm^2 is used for the abundance estimation.
- 0.25 m^2 box-corer manufactured by YMG (Figure 7.15) based on a USNEL/Scripps design from the 1970s.

Figure 7.13 Details and operations with the KC box-corer

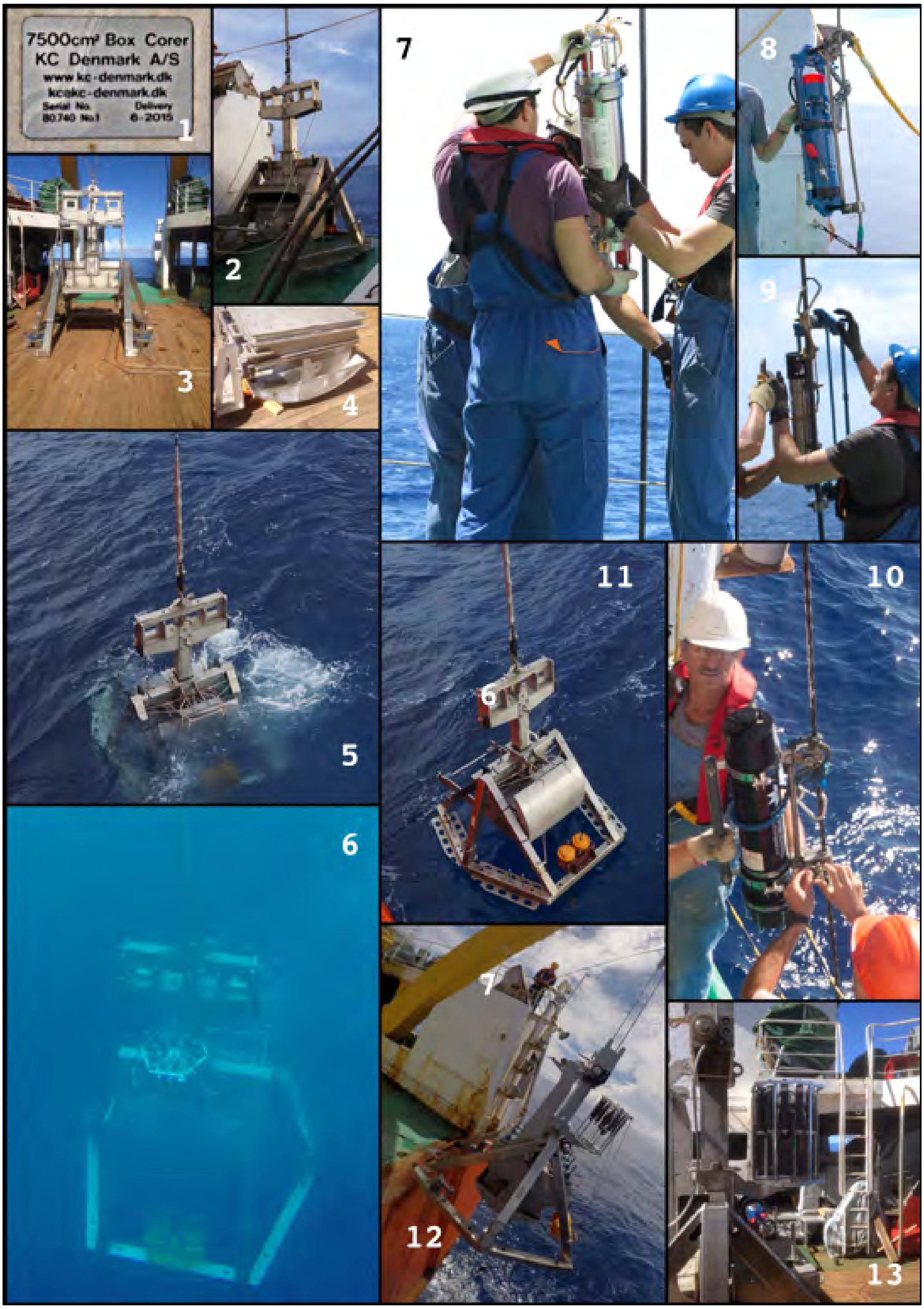


Figure 7.14 Details and recovery of the YMG box-corer

7.3.5 Nodule sampling

Logging was completed manually by the Lead Scientist on shift. The manual logs were scanned and then transposed into MS Excel.

All weights were taken using a Wedderburn Marine motion compensated scale (WM42; Serial number #3380724) that was checked and calibrated in Brisbane, Australia, before shipping to the vessel. The scale has a 40 cm x 40 cm plate with vessel motion recorded and corrected electronically. Scales are claimed to be accurate to 60 kg ± 50 g, which was as observed during the campaign. The scales were checked using 12×1.5 litre or 12×2 litre water bottles and recorded weights were consistent with the mass of water plus packaging.

Upon arrival on deck, the nodules were photographed in situ, removed from the box and weighed three times:

- 1st time with mud still attached (preliminary weight) to enable biological analysis
- 2nd time after washing in filtered salt water (washed weight)
- 3rd time several days later and after exposure to 30–90 minutes in air conditioning and removal of ponded or sweated free water (aired weight).

Note that at each stage of handling, despite due care, some attrition of the nodules occurred with loss of a small (generally <1%) of fine material (dust to sand sized). The bulk of this loss occurred at the washing stage, but it was noticeable at the aired stage as well. The rate of attrition varied by nodule type (rough nodules broke up more) and by area (the rough and smooth rough nodules in the southern part of Area F were especially soft).

The difference between the washed and other weights is illustrated below in Figure 7.16. There is almost no difference between the washed and aired weights (average for all samples over 1 kg is –0.87%; in Area F it is –1.86%), with the cause of the minor differences debatable (moisture or attrition).

Figure 7.15 Preliminary vs. washed vs. aired box-core nodule sample weights (kg)

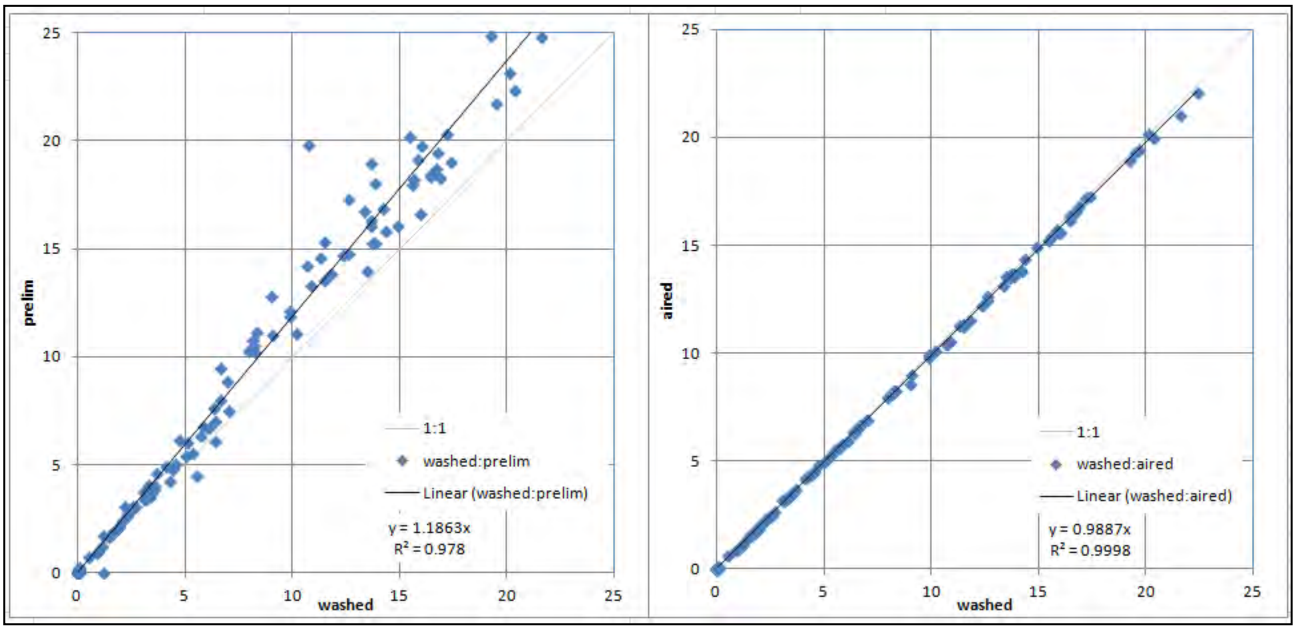
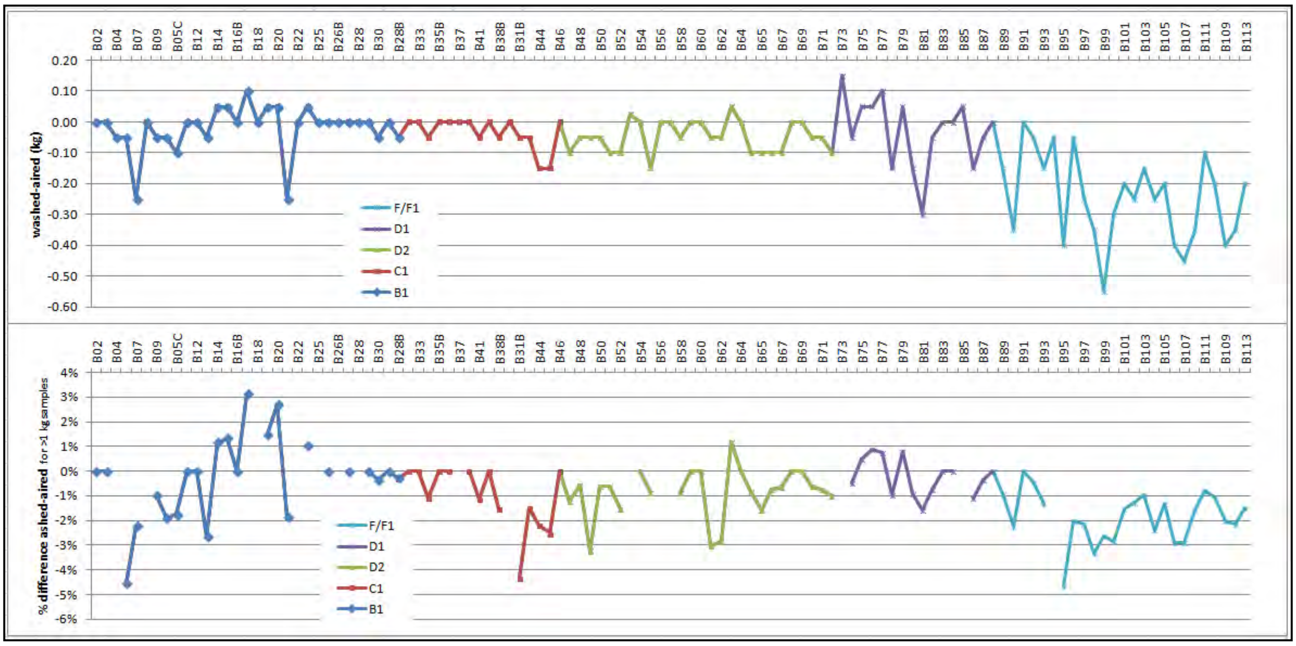


Figure 7.16 Differences in washed vs. aired box-core nodule sample weights by area



Handling of nodules was at all times supervised by the Chief or Lead Scientists, who were also the only people permitted to weigh the nodules, record the weights and seal bags and pails for transport. Nodule sampling was managed as follows (refer Figure 7.17, Plates 1 to 24):

- From the box, nodules were removed to the weighing station (in the geology laboratory or adjacent to the box-core landing spot on the back deck; (Plates 8 &13)
- Here, preliminary weight was taken and recorded, the nodules were washed, firstly the selection with observed fauna, then the rest of the nodules.
- Then the washed weight was taken and recorded (Plate 14).
- Then the nodules were carried to the geology laboratory where they were arranged and photographed by a designated scientist before temporary storage in sealed plastic bags in a designated area.
- Then at the conclusion of sampling of an area (1-7 days after collection), the samples were laid out about 6-20 at a time for airing (Plates 21 & 22).
- After 30 to 90 minutes of airing, reference and duplicate samples were selected, re-packed weighed again, sealed in plastic bags security tagged with tamper-proof tags or tape and then photographed (Plates 19 & 20).
- Then the nodules were packed into specially marked paint pails with tamper-proof tape (Plate 23).
- Duplicates were collected from roughly one in ten samples. Subsamples were taken using cone and quartering.
- Pails were then transported (escorted by Chief or Lead Scientist) to a refrigerated container (reefer) on deck for transport to Brisbane, Australia, where the main assay laboratory is located (Plate 24).
- Reference samples were placed in specially marked and labelled pails for airfreight to Brisbane, Australia (in case of loss of the reefer in transit). These samples are for general reference purposes, but also serve as backup for chemical analysis. These samples were not sealed with security tags or tamper-proof tape.
- Duplicate samples were placed in specially marked containers and labelled for air-freight to Jacobs University, Bremen, Germany, where the check laboratory is located. These samples and all container pails were sealed with tamper-proof tape.

Figure 7.17 Details and operations regarding sample processing

7.3.6 Buried Nodules

In most samples, there were no buried (i.e. >10cm) nodules although some were occasionally entrained by the sides of the box or the shovel. If present, buried nodules were separated at the point of collection from the box and were washed, weighed, and packed separately. Entrained nodules were sampled for reference purposes only and were not weighed.

7.3.7 Vane Shear Readings

Vane shear was measured in all box-cores that returned with undisturbed sediment. A 33 mm vane on a calibrated hand held shear vane device was used. Measurement location and readings were recorded on the Box-core Sample Log Sheet then transferred to a spreadsheet.

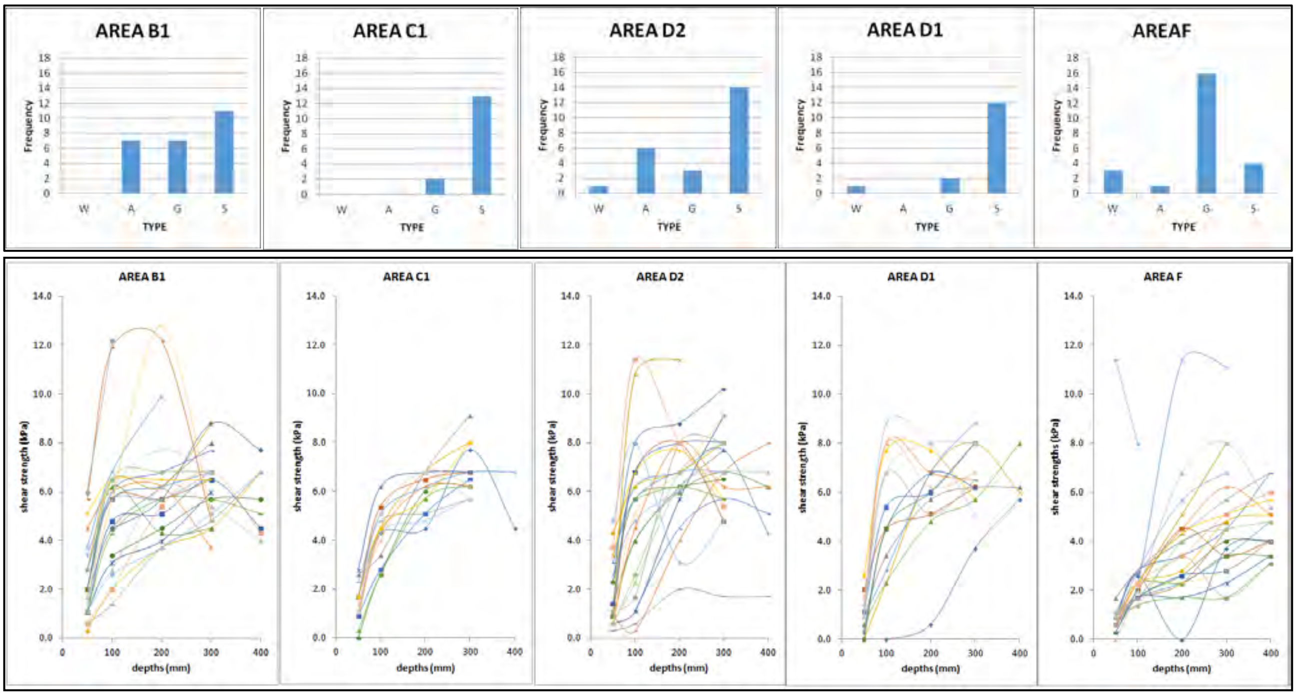
Vane shear was classified into one of four classes:

- W is mostly weak from top to base
- A is all stiff from top to base
- G is soft at the top with gradual stiffening with depth
- S is soft at the top with more sudden stiffening with depth.

Data were also reviewed by box and the most coherent reading selected. Averaging of readings was not undertaken as some measurements were taken in disturbed sediment, especially near the base. The most coherent readings were generally taken in the centre of the box.

Summary results are included in the maps further below, but the classes vary by area as shown in Figure 7.18.

Figure 7.18 Summary vane shear results from TOML CCZ15 study areas



These data shows clear differences in the uppermost part of the sediment between areas, with:

- Area C1 showing consistently suddenly stiffening ground conditions (mostly class S);
- Area D1 showing a slightly wider range to C1 including some more rapidly stiffening situations (mostly class S);
- Areas B1 and D2 have a wider range of conditions and both areas have occurrences of sediment drift (Nnoo);

- Area F (and F1) has a universally weak upper layer then generally and gradually stiffens (mostly class G).

7.3.8 Biological-Sediment sampling

Biological-sediment base-line samples were collected from the majority of box-core samples. These samples were collected in accordance with ISA Technical Study: No.10 “Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals”. If TOML is to proceed to trial mining/full scale mining, these samples will play a key role in the environmental impact assessment of the proposed mine site(s).

Samples were collected to obtain an understanding of the in-fauna and epi-benthic community composition and sediment characterisation within the TOML tenement areas. A variety of sample types were collected from each box-core, which were fixed and preserved separately for morphological and molecular taxonomy.

Sample types collected and planned analysis:

- Overlying water fauna
- Megafauna (animals greater than 2 cm)
- Nodule fauna
- Micro-fauna (animals smaller than 32 µm)
- Meio-fauna (animals greater than 32 µm and less than 250 µm)
- Macro-fauna (animals greater than 250 µm and less than 2 cm)
- Sediment chemistry
- Particle size distribution
- Special core samples. Sample type collected occasionally to capture unusual sediment characteristics of interest in their original sediment layers.

Collection method, fixing and preservation are illustrated in Figure 7.19 to Figure 7.23. Biological-sediment samples were only collected if the box-core sample was in relatively good condition. If the box-core sample was damaged during collection, or recovery resulting in the mixing of sediment layers, most sample types were not collected. Biological-sediment samples were collected in conjunction with nodule samples. However, care was taken to minimise the mixing of sediment layers during the extraction of nodules.

Between sampling events, all sampling equipment was washed thoroughly using 25 µm filtered seawater to prevent contamination of samples. Sterilised Nalgene sample containers and Whirl-Pak sample bags were used to collect samples. During the collection of sediment chemistry samples, no equipment containing metal was used in order to prevent cross-contamination due abrasion and to trace level analyses.

The following are the essential operations undertaken to collect all samples types listed above. Figure 7.17 displays the order of sample collection and processing:

- Upon retrieval of the box-core to deck and delivery of the box-core samples to science team, overlying water was siphoned off into clean pails using plastic tubing and large pipettes. The water was then poured through a 32 µm sieve and the contents collected and fixed/preserved in 99% ethanol. (Figure 7.17 – Plates 5 & 6)
- Visible mega-fauna were collected from the surface of the sample using forceps, placed in a sample container and preserved. After preliminary weighing of the nodules, selected nodules were washed over a sieve (32 µm) and the contents of the sieve collected and fixed/preserved in 6% formalin or 99% ethanol. Large mega-fauna attached to the nodules were photographed before being removed from the nodule
- The required amount of 5 cm and 10 cm PVC cores were pushed into a box-core sample to a depth of over 20 cm. Rubber bungs were then inserted into the cores (Figure 7.17 – Plates 10 & 11)
- Residue samples were collected using heavy-duty geological sample bags (Figure 7.17, Plate 12),

- PVC cores were extracted from the box-core and placed upright in pails to prevent mixing of layers. Cores were washed to prevent contamination during processing
- PVC cores were analysed either for fauna type or for sediment characterisation, using horizon measurers and core cutter (Figure 7.17 – Plates 15, 16, 17 & 18):
- Micro-fauna (2 x 5 cm diameter cores) — 0–2 cm, 2-5 cm and 5-10 cm horizons were extracted, placed in the appropriate Nalgene sample container and fixed/preserved in 99% ethanol
- Meio-fauna (4 x 10 cm diameter cores) – 0-2 cm, 2-5 cm and 5-10 cm horizons were extracted, placed in the appropriate Nalgene sample container and fixed/preserved in 4% formalin or 99% ethanol
- Macro-fauna (4 x 10 cm diameter cores) – 0-2 cm, 2–5 cm, 5–10 cm and 10–20 cm horizons were extracted and sieved (250 µm). The contents of the sieve placed in the appropriate Nalgene sample container and fixed/preserved in 6% formalin or 99% ethanol
- Sediment chemistry – 0-2 cm, 2–5 cm, 5–10 cm and 10–20 cm horizons were extracted and placed in sterilised Whirl-Pak sample bags
- Particle size distribution 0-2 cm, 2–5 cm, 5–10 cm and 10–20 horizons were extracted and placed in sterilised Whirl-Pak sample bags
- Duplicate samples – were collected
- All samples collected were labelled using the q-Core database, following a pre-determined sample numbering system
- After fixing/preservation, all samples were packed into pails and stored in a refrigerated container kept at 2–4 °C (Figure 7.17– Plate 24)
- Samples fixed in 4% and 6% formalin were transferred to buffered 99% ethanol after approximately two weeks for long-term storage and preservation.

The bulk of the samples collected were shipped to Nautilus Minerals in Brisbane, Australia. A selection of overlying fauna, nodule fauna, meio-fauna, macro-fauna and mega-fauna have been shipped to YMG, Gelendzhik, Russia for expert morphological taxonomic identification. Sediment chemistry and particle size distribution samples were sent to SGS, Cairns for analysis. The bulk of the fauna samples will be stored until they can be analysed in accordance with a yet to be scoped environmental impact statement project.

Figure 7.19 Sample Plan – Overlying fauna and nodule

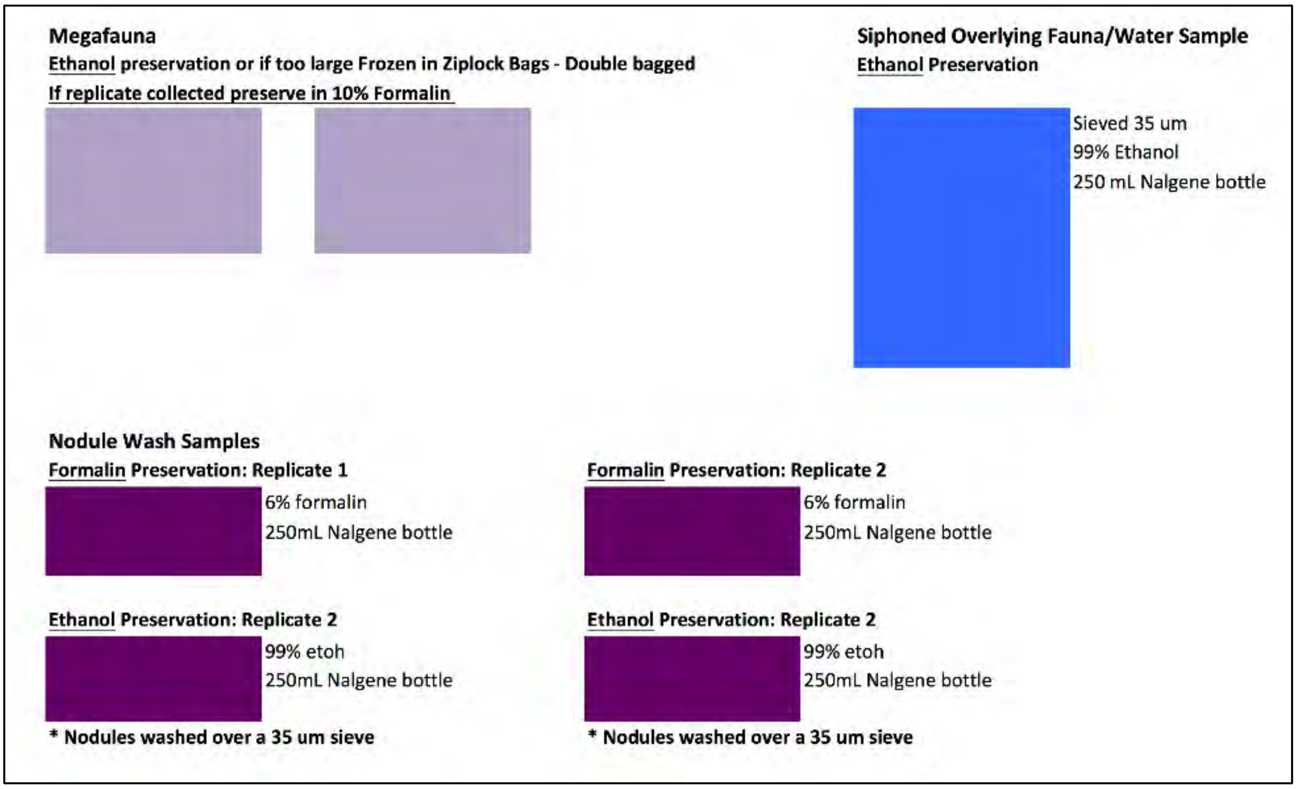


Figure 7.20 Sample Plan – Micro-fauna and box-core layout

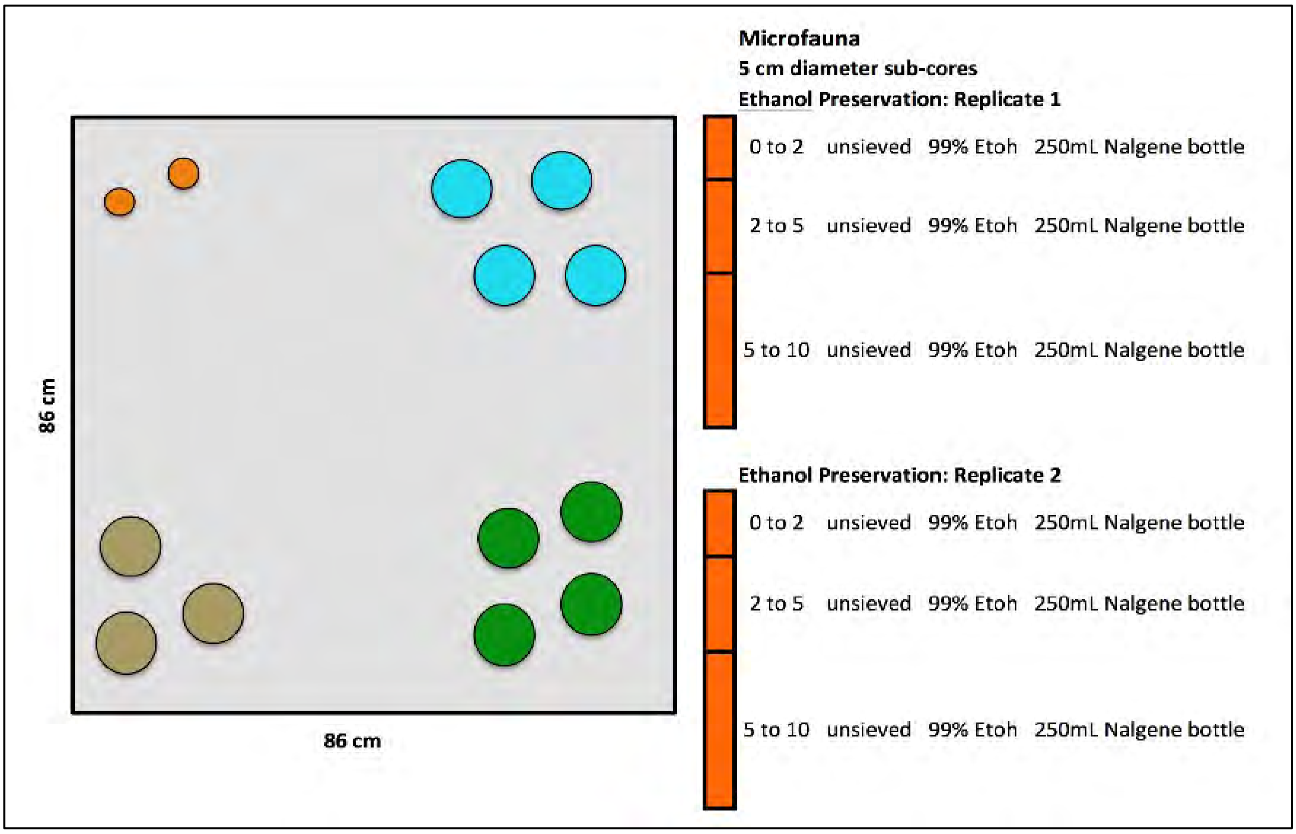


Figure 7.21 Sample Plan – Meio-fauna

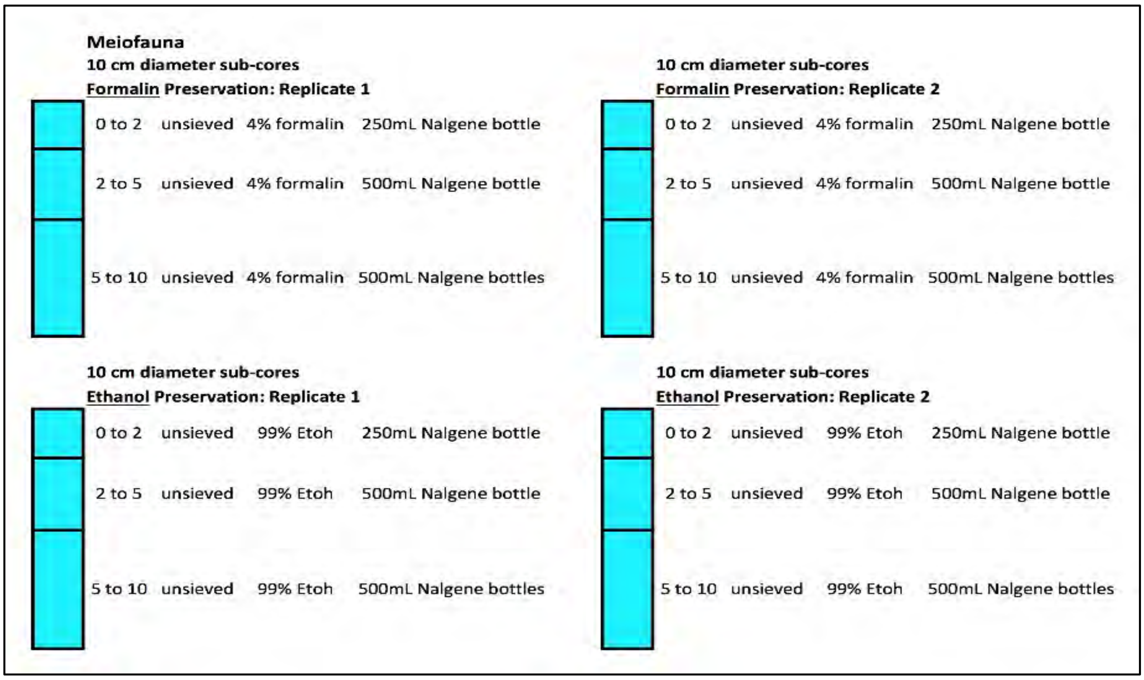


Figure 7.22 Sample Plan – Macro-fauna

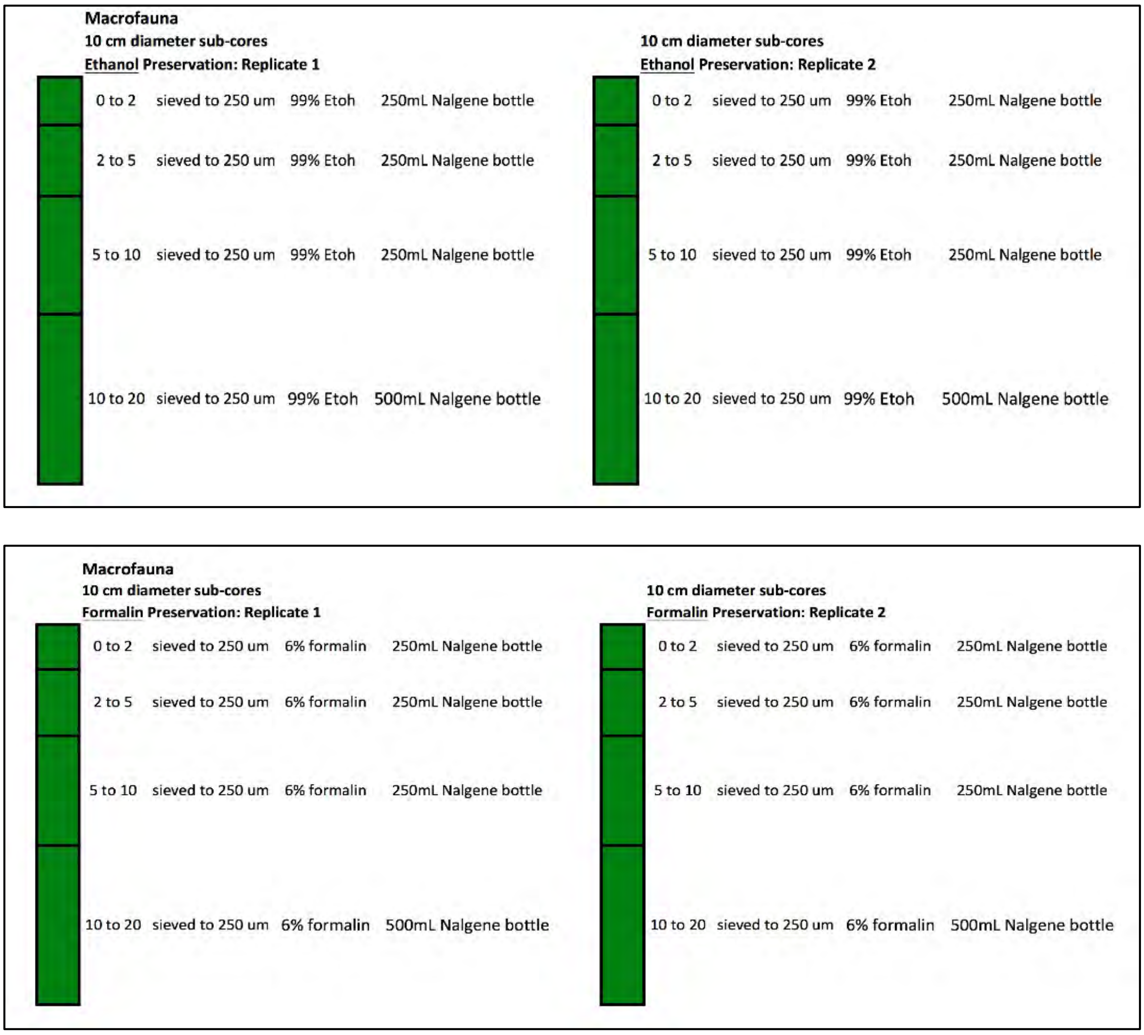
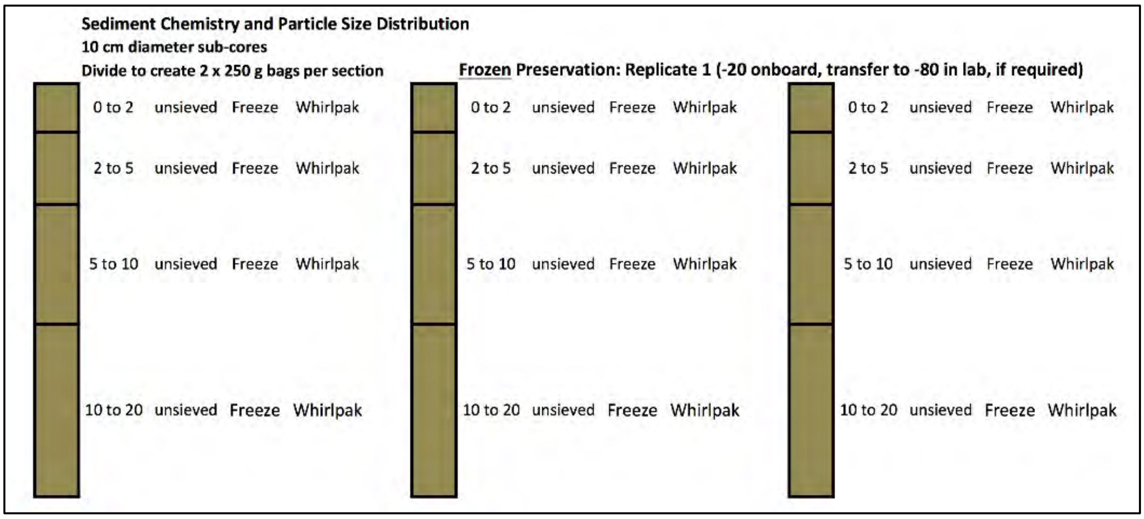


Figure 7.23 Sample Plan – Sediment characterisation



7.3.9 Sediment residue sampling

Most box-cores with good returned sediment had three samples taken after all other sampling was complete:

- Top sample was typically 0–5 cm and comprised any remaining semi-liquid layer and geochemically active layer. Typically very soft and selected by this characteristic.
- Second sample was of more solid sediment typically taken at 5–20 cm.
- Third sample was remaining to base of box, usually a further 10–20 cm down, depending on depth of penetration.
- Each sample weighed between 5 kg and 25 kg and in total about 330 samples were taken, making this the highest volume-weight sample collected and shipped.
- The sediment was taken for use in future geotechnical/engineering studies (e.g., reconstruction for traction and nodule collection bench top trials) and for reference.

7.3.10 Water sampling

Water column samples were collected during CCZ15 as part of the environmental base-line characterisation of the TOML tenement areas in order to meet the recommendations per the ISA document; Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals. Samples were collected via the Niskin bottle rosette attached to the box-corer (Figure 7.13, Figure 7.24). The Niskin bottle rosette contained 12×300 ml Niskin bottles, which were triggered using a pressure sensor. Samples were collected for both infield and on-shore laboratory analysis.

Water sample types collected were:

- Total Metals (TM) - 125 ml sterilised Nalgene container – 1 ml of nitric acid added for preservation (on-shore analysis);
- Total Suspended Solids (TSS) - 1 L sterilised container (on-shore analysis);
- pH and Oxidation-Reduction Potential (ORP) - In-field measurements – approximately 150 ml required to obtain measurements.

The water sampler (Niskin rosette) was programmed with the selected depth strata for full water sampling programme conducted in Area C, D and F and the Niskin bottles set to the open position, each time before deploying the box-core. The water-sampling programme was designed to collect samples from varying depth strata across all areas where box coring was conducted.

Depth strata sampled for the majority of samples collected were:

- 50 m
- 200 m
- 500 m
- 1,000 m
- 1,500 m
- 500 m from the seafloor
- 100 m from the seafloor
- 50 m from the seafloor

Upon recovery of box-core and Niskin rosette to deck, the Niskin bottles were processed depending on the sample type being collected. TM and TSS were collected using the appropriate sterilised sample containers and refrigerated at 4°C The pH and ORP samples were collected and taken to the water chemistry laboratory for analysis. Samples were analysed using YSI Pro10 handheld multi-probe with pH and ORP sensors. A three-point calibration was conducted on the pH sensor prior to every sampling event.

Niskin bottles were fired during the decent due to the limitations of the device, as there was no way of programming the device to delay firing at the set depth strata on ascent. To minimise the risk of contamination from residue left from previous sample, the box-core was washed out between deployments. Due to commissioning issues the water sampler was not operational until Area C. Therefore, water samples were only collected in Area C, D and F.

All water samples collected for laboratory analysis were priority hand-carried back to Brisbane and shipped to SGS Cairns for analysis.

Figure 7.24 Water Sample Collection and Water Chemistry Laboratory

7.3.11 Water column profiling

During CCZ15, water column profiles were collected as part of the environmental base-line characterisation of the TOML Areas in order to meet the recommendations per the ISA document: Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals. The majority of water column data were collected via a Mini Autonomous Plume Recorder (MAPR) with the following sensors:

- Temperature (°C);
- Turbidity (NTU);
- Depth (m).

The MAPR was deployed during most operations by attaching it to either the box-core cable (50 m above the box-corer) or the umbilical of the MAK (side-scan) or Neptune (photo-profiler) at 50 m above either instrument, see Figure 7.13-Plates 7 & 9. Upon recovery of the MAPR to deck, these data were downloaded and processed and Excel template.

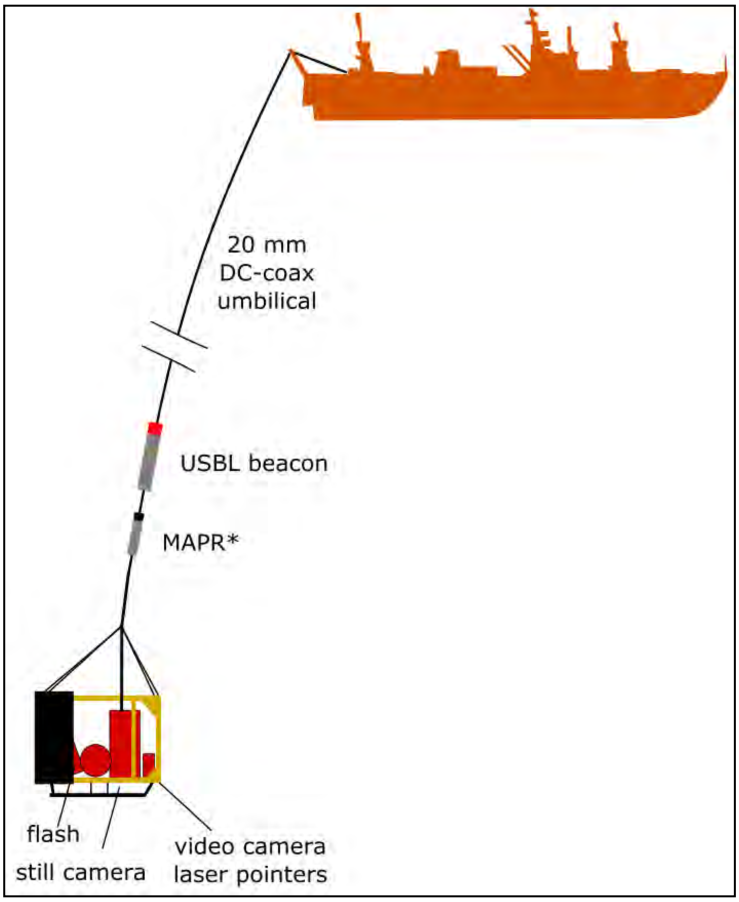
Along with the MAPR, an Aanderaa Seaguard single-point current sensor was deployed on a select number of box-core deployments in Area F.

7.3.12 Photo-Profiling Programme

Photo-profiling was undertaken to provide data on short range continuity of nodules and visual based estimates of nodule abundance for mineral resource estimation. It also provided a census of mega-fauna and macro-fauna for environmental base line measurement and habitat mapping. Finally, it helped calibrate MBES and deep towed sonar results in terms of understanding seafloor rugosity.

Deployment and recovery of the camera was off the stern of the vessel using an umbilical and the vessels aft tow winch (Figure 7.25). The system was deployed just above the seafloor with the winch operator taking line in and line out to compensate partially for vessel heave. Video was streamed constantly to the vessel where it was logged by TOML team into the Nautilus Minerals' proprietary Nautical logging system.

Figure 7.25 Neptune Deployment Schematic



Photographs were taken automatically at a prescribed altitude of 3.5 m above the seafloor, a minimum.

30 seconds apart and continually uploaded to the vessel where scientists collected them from

the central server and logged them for geology and biology. These were also subsequently logged by the TOML biologist in more detail.

Neptune lines were pre-planned to place the vessel into “prevailing result” where it maintained a forward speed of about 1.2 knots. As the line got longer, more line tended to be fed out and vessel speed tended to increase. Average velocities also tended to increase as the campaign progressed and the team optimised survey settings.

The system’s position was monitored using a 12 kHz USBL beacon except on line CCZ15-F08, where an estimate of position had to be made from line out and vessel position.

Hydrographic surveyor and bridge shared the same navigation display and the vessel was steered so that the profiles never moved more than 1 km off line and typically was well within 500 m of the planned line.

Survey data from the vessel, USBL location of the camera and attitude sensor was collected and subjected to preliminary analysis to learn more about towing dynamics.

Figure 7.26 Neptune Deployment Photographs

7.3.13 Deep Towed Sonar Programme

YMG's MAK-1M deep towed system was brought on the CCZ15 campaign primarily to map and characterise the seafloor bathymetry in detail via its 30 kHz side scan system. The system also provided useful data on seafloor composition from its 5 kHz sub-bottom profiler and on seafloor surface survey from its altimeter-USBL survey data.

Essential operation was as follows:

- Deployment and recovery of the sled and depressor was off the stern of the vessel (Figure 7.27, Figure 7.28).
- MAK lines were pre-planned to place the vessel into prevailing result where it maintained a forward speed of about 1.5 knots.
- The system's position was monitored using an integrated 12 kHz USBL beacon and altimeter.
- The system was towed behind a depressor weight about 100 m above the seafloor with slight elevation changes to follow the seabed. Speed of towing was limited by ping rate and data quality.
- Hydrographic surveyor and bridge shared the same navigation display and the vessel was steered so that the sled never moved more than several hundred metres off line.
- All processing through to delivered products was done on-board by the YMG MAK team.

As with the Neptune photo-profile systems, analysis of the sled versus ship position as well as some attitude/MAPR sensor data provided information on deep tow dynamics that might be of help in the design of future towed systems (e.g., for the Nautilus mining concept).

Figure 7.27 MAK Deployment Schematic

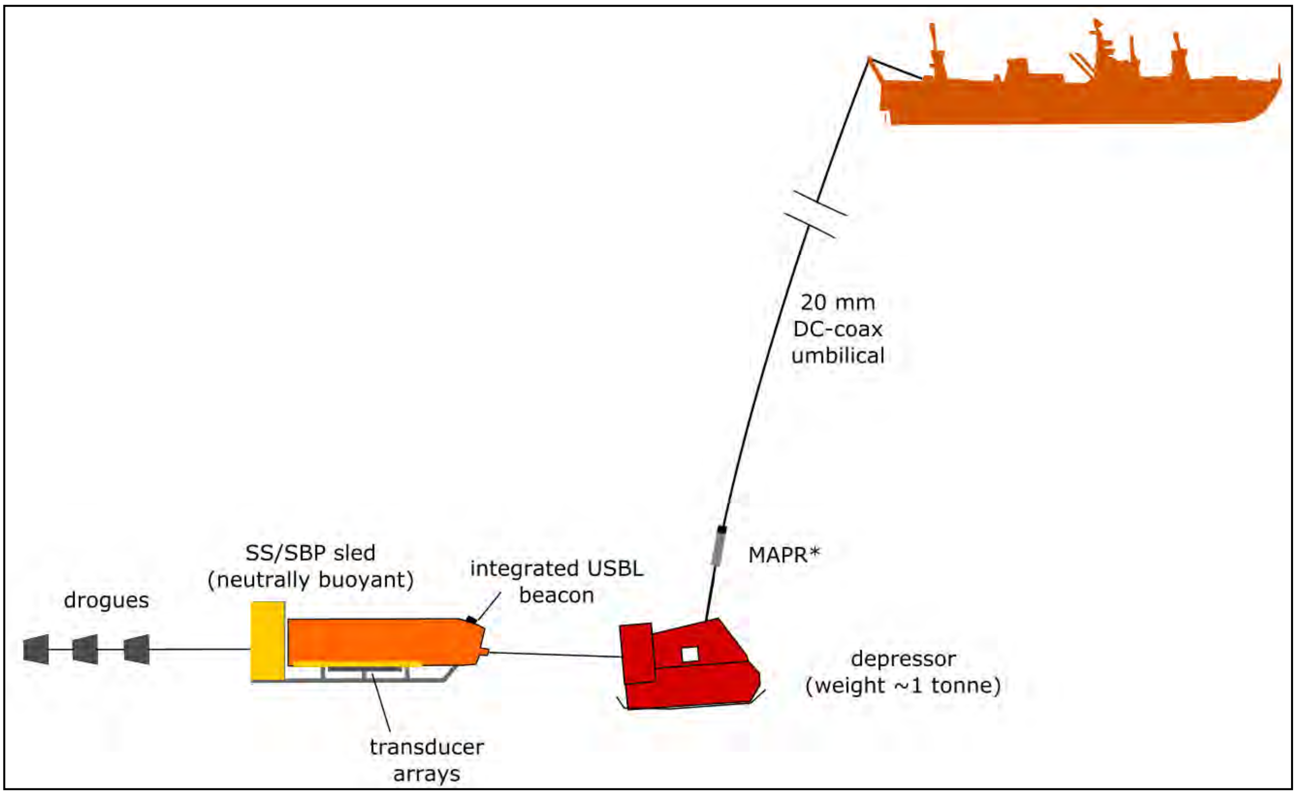
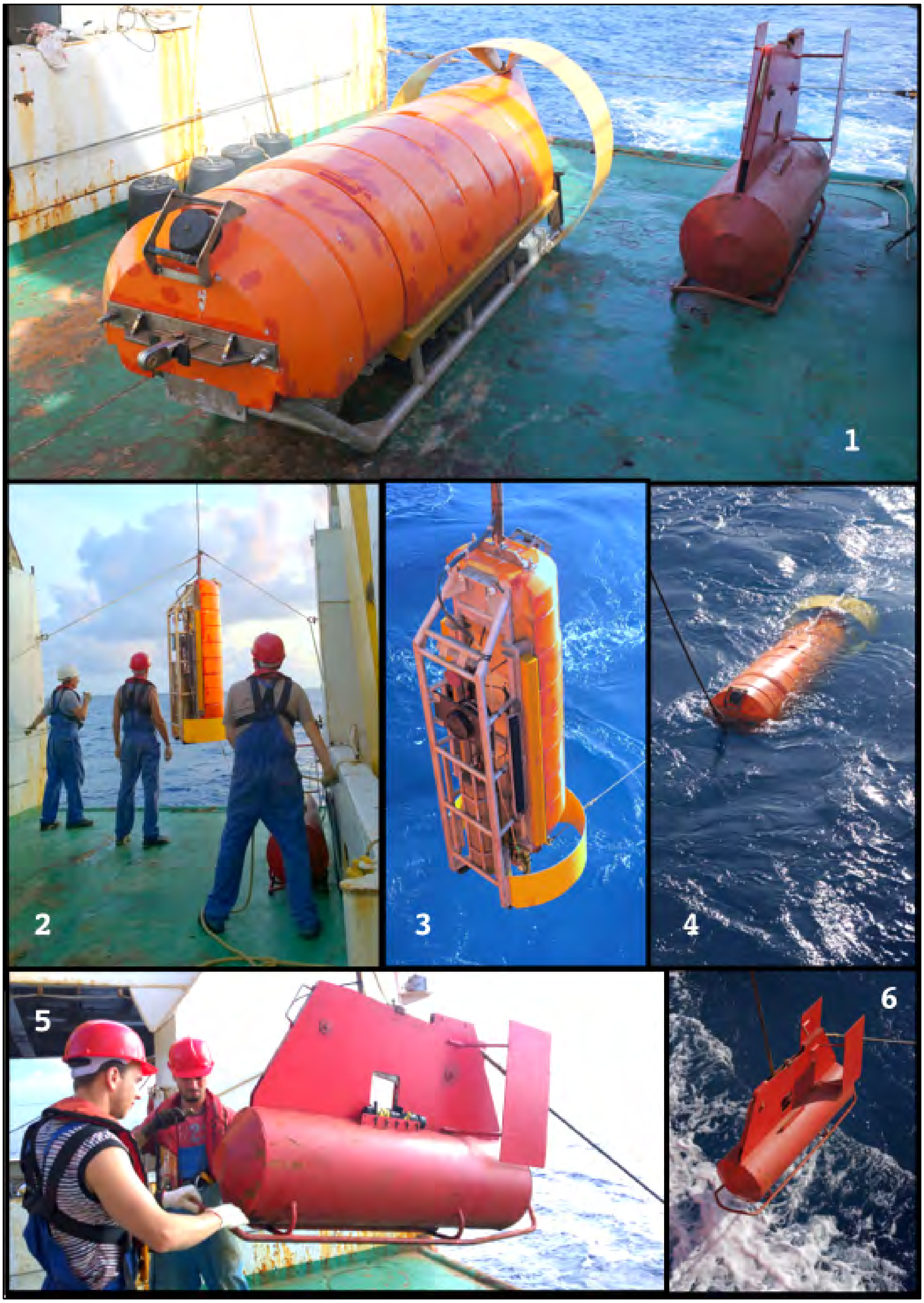


Figure 7.28 MAK Components and Deployment



7.3.14 Dredging Programmes

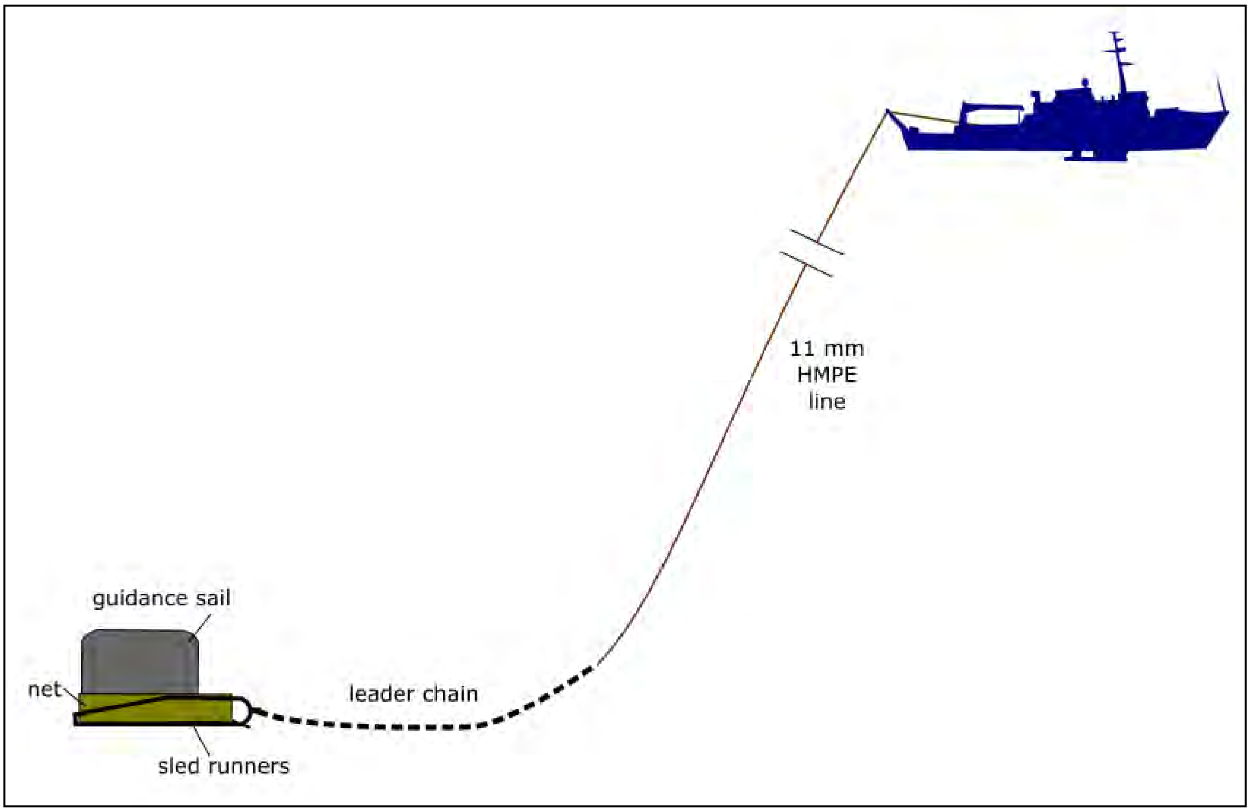
Dredging was carried out during both the CCZ13 and CCZ15 campaigns, albeit with different methodologies. The intent was to collect sample for metallurgical test work, including chemical whole rock analysis.

7.3.14.1 CCZ13 Epibenthic sled

An epibenthic sled was designed and built for the CCZ13 dredging (Figure 7.29, Figure 7.30). An epibenthic collector was chosen so as to:

- Be able to be set up to skim the seafloor collecting epibenthic and inbenthic located nodules with minimum mud;
- Be more able to clean itself of mud;
- Consequently, impact the environment less.

Figure 7.29 Epibenthic sled Deployment Schematic



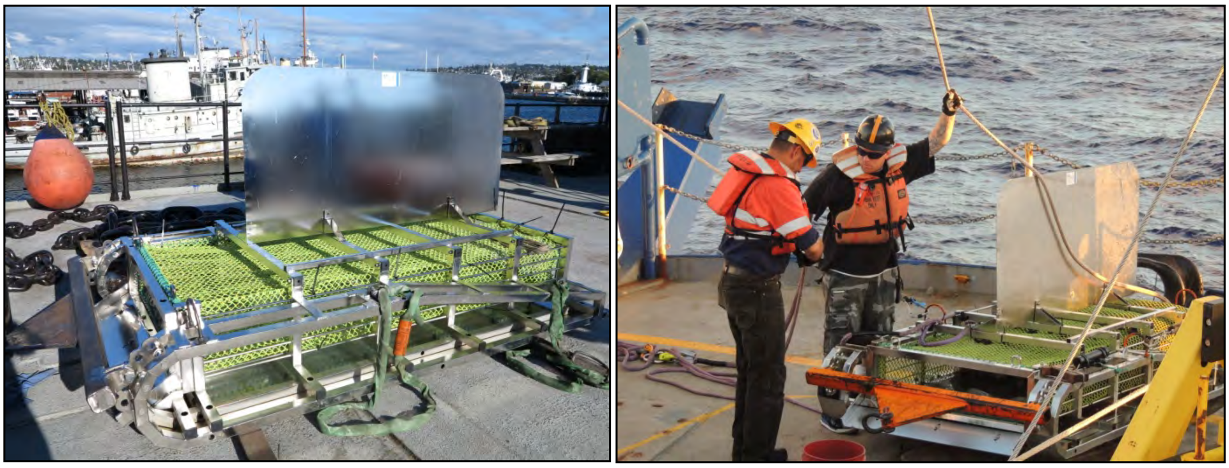
Sample handling procedures essentially comprised weighing on recovery, followed by screening (±and 3/8” or approximately 6 cm) and photography of all, or if an excess of material for the photo sheet, a typical sub-sample. Many of the nodules were broken from their time in the dredge.

After some trial and error, the approach generally taken to dredge was:

- About 1.5 km before the edge of the target zone, steam into the wind at 1.5–2.5 knots paying out line to 6–7 km.
- On reaching the bottom or the target line out slow to slowest effective forward speed (i.e., having available steerage). this was typically 0.3–0.8 kt speed over ground.
- Use line out to regulate load as transmitted to the load cell.
- Run the load between minimum (line slack) and maximum loads (lift off), decreasing the range around what was judged to be the effective towing load (this was typically a range of only about 40–80 kg).

- Once or twice during the deployment (later increased to 3–4 times) lift and lower the sled using the vessel speed to wash out excess mud that might be filling the sled (termed a "tea-bag" manoeuvre). Minimise use of the winch to avoid tipping the nose of the sled and losing sample.
- End the dredge by starting line in and speed up the boat to 2 knots.

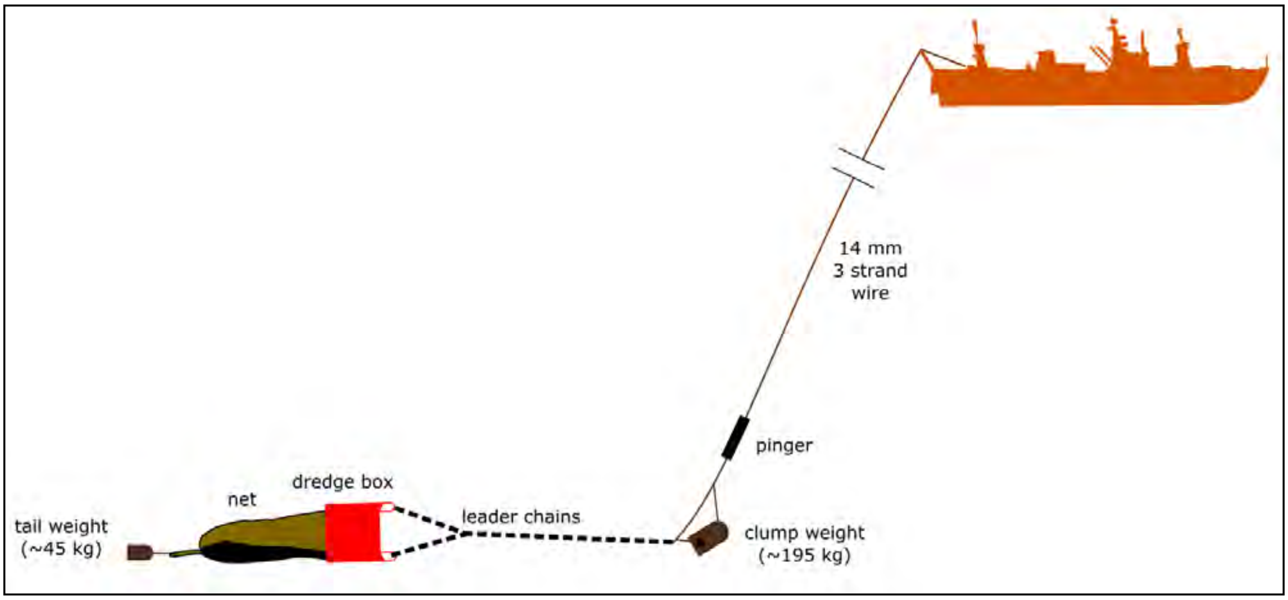
Figure 7.30 Photos of epibenthic sled



7.3.14.2 CCZ15 Galatea dredge

The dredging approach was changed in CCZ15 for reasons of practicality.

Figure 7.31 Galatea Dredge Deployment Schematic



The sample locations were picked to ensure that between the sampling of this campaign and the CCZ13 campaign, at least one dredge sample was taken in each contract area. Dredges were also the quickest and most effective way to sample Area A, albeit in a non-quantitative manner.

The process of dredging involved:

- Dredge lowered at 0.5 m/s for first 200 m then 1 m/s to the bottom, then slowed to 0.5 m/s till touching the seabed.
- Recovery to surface all the way at 1 m/s (full speed).

- The vessel maintained forward speed into the weather at all times (~0.8–1.3 knot SOG was OK no change in speed needed).
- Winch speed slowed but not stopped and the pinger trace height (~10 m) used to estimate when the dredge touches.
- "Teabag" manoeuvres used to clean the dredge between landings (each landing is about 1 minute and after lifting at about 0.7 m/s to 100 m the cleaning takes about 2–3 minutes before return to the seafloor at 0.5 m/s).
- 3–7 "teabags" were carried out depending on weight of sample required.

Figure 7.32 Operations and details of the YMG Galatea-trawl dredge

7.3.15 Marine Survey

During CCZ13 a TOML contract surveyor operated Caris HIPS (Hydrographic Data Processing System) software through the MBES system's dual head GPS array and maintained a digital survey log. Deployments and co-ordinates were written into a logbook. Communications were verbally to the bridge on the same level and via handheld radio to the back deck.

During CCZ15 RV Yuzhmorgeologiya's survey department coordinated operations and logged events (TOML personnel also kept a logbook). Various sensors (e.g., GPS, weather station, USBL) all fed to a central computer with most data read into Hydropro software. The main navigation screen from Hydropro was replicated on the bridge so that the officers there received real-time updates on current and planned movements. Communication between Hydrographer, Bridge, Pinger Operator, Winch Operator and Back Deck Supervisor was via a dedicated open intercom system. A USBL antenna was deployed through a small opening in the base of the ship and an IXSEA Posidonia 6000 gen1 system used this and an umbilical to transmit to the MAK deep tow system, and to communicate with a variety of 12 KHz beacons.

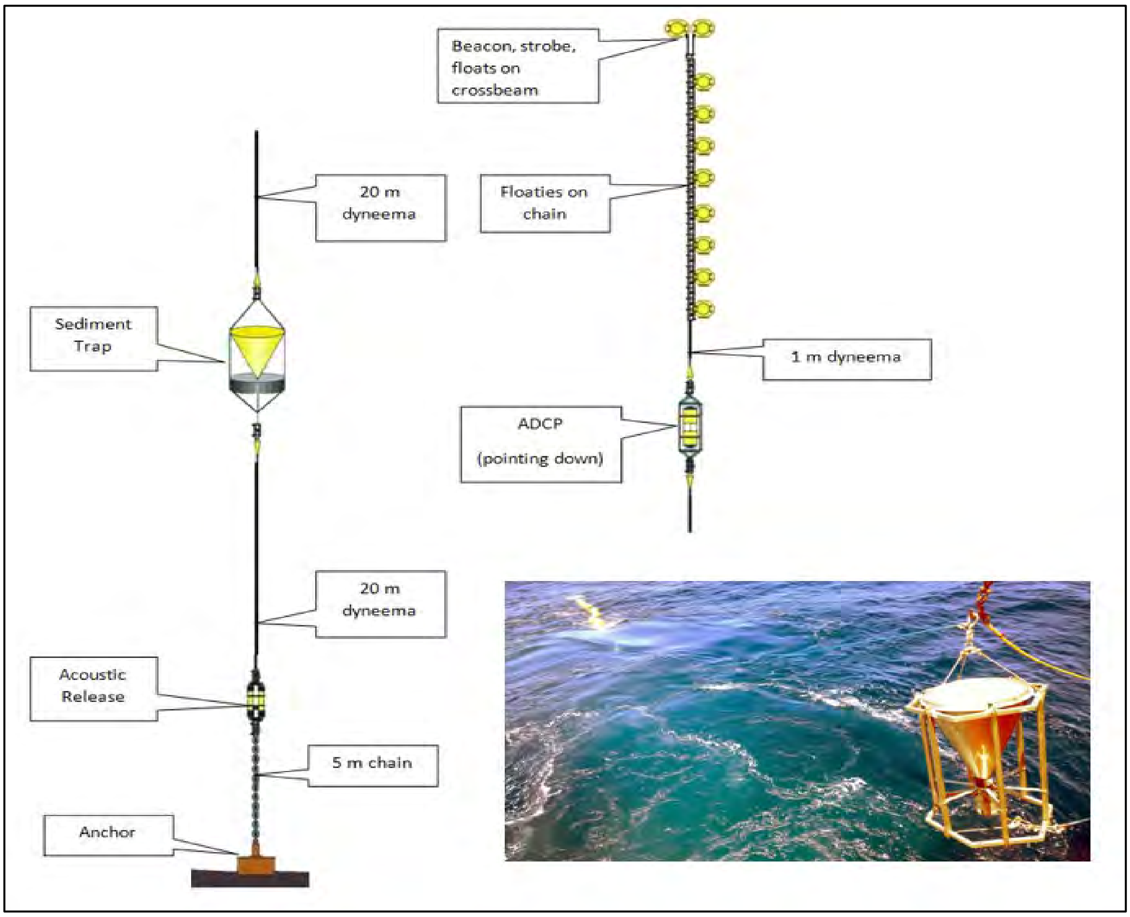
7.3.16 Other Programmes

7.3.16.1 Long Term Moorings

During and shortly after CCZ15, two moorings were deployed, one in Area C (S01) and one in Area B (S03).

The moorings were designed to be simple and inexpensive and to have a minimum two-year life (Figure 7.33). Engineering was by Sound Ocean Systems Inc based on environmental parameters provided by the Nautilus environmental team and an Erias Group (Melbourne, Australia) consultant.

Figure 7.33 CCZ15 Mooring Design and deployment of Mooring S01 in Area C



7.3.16.2 Other Environmental Data

A complete summary of environmental data collected during the CCZ15 campaign is presented in Table 7.8 below. Other specific data collected was:

- CSMF, or marine mammal observations, were recorded on a log by the bridge. During CCZ13 marine mammals were only seen outside the CCZ and during CCZ15 two mammal sightings were made with a solitary dolphin to the east of Area A and two whales (likely Sperm Whales) within Area D. Birds were seen on both campaigns but were only logged during CCZ15 (Figure 7.34)
- Weather Information, including logs, weather reports as well as interpretation of these data.

Figure 7.34 CCZ15 CSMF Events

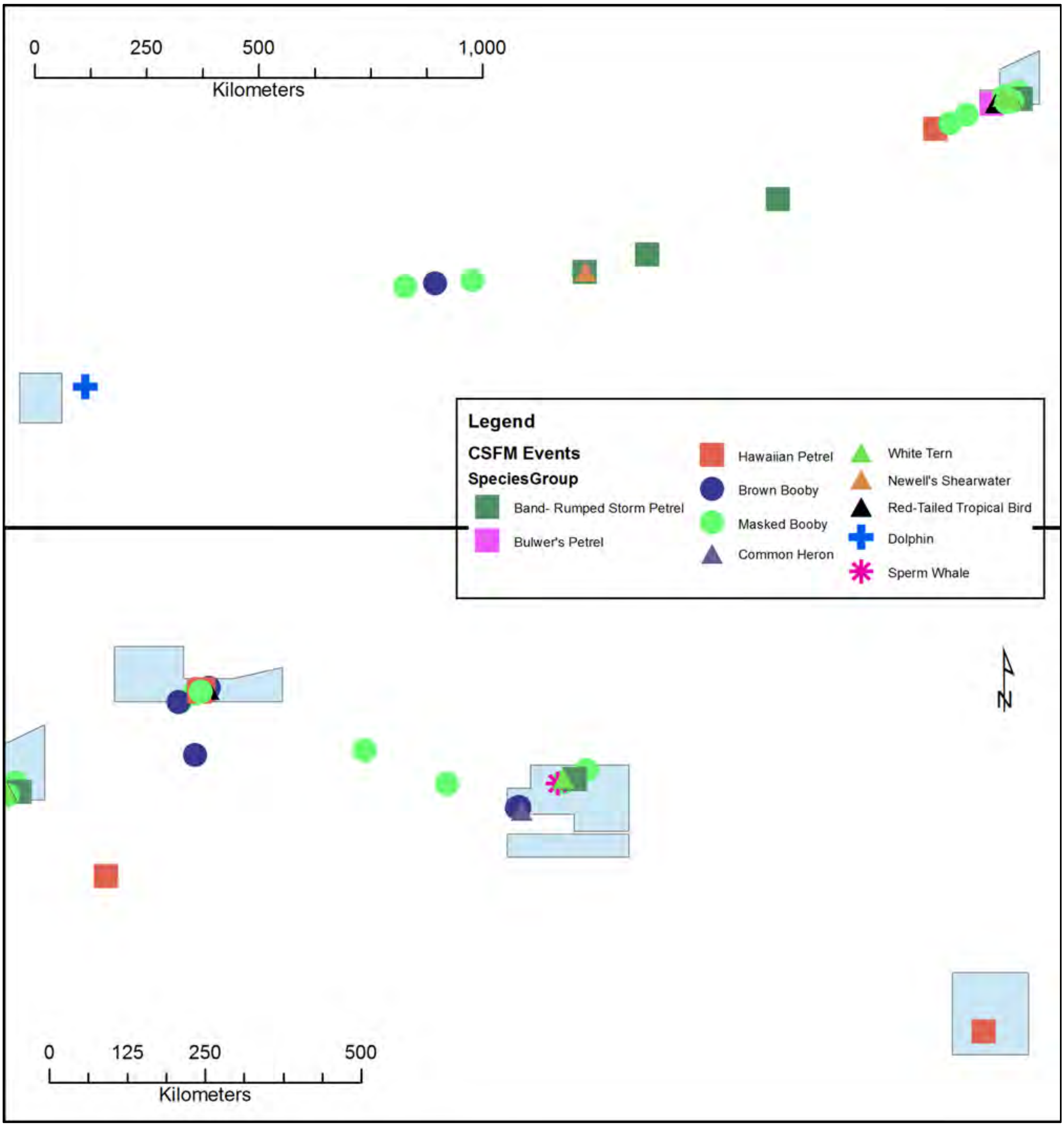


Table 7.8 CCZ15 Environmental Data Matrix

	Benthic Fauna Characterisation							Geological and Geomorphological Characterisation				Water Column Quality/Chemistry				Oceano-graphy	Ecosystem Function
	Mega	Macro	Meio	Micro	Overlying Fauna	Nodule Fauna	Benthic Fauna Morphology	SC	PSD	Geo-morphology	Substrate	TM	TSS	pH	Water Column Profiles (Temp °C & NTU)	Current Profiles	Sinking Particle Flux
Number of Samples	84	1195	997	458	78	383	see below	83	86	see below	see below	112	98	112	108	16	2
Logged Photographs	20857	20857	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Logged Video (hrs)	192	192	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Abundance	✓	✓	✓	✓	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Biological Diversity	✓	✓	✓	✓	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Community Composition	✓	✓	✓	✓	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Relation to Nodule Abundance/ Size	✓	✓	✓	✓	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Morphological Taxonomy	✓	✓	✓	NA	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Molecular Taxonomy	✓	✓	✓	✓	✓	✓	NA	✓	✓	NA	NA	NA	NA	NA	NA	NA	NA
Biotope Mapping	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NA	NA	NA	NA	NA	NA
Sampling Equipment	Photo Sled/ Boxcore	Photo Sled/ Boxcore/ Sub-cores	Boxcore/ Sub-cores	Boxcore/ Sub-cores	Boxcore	Boxcore	Photo Sled	Boxcore/ Sub-cores	Boxcore/ Sub-cores	Photo Sled / MBES / Side-Scan	Photo Sled / SBP/ MBES	Niskin Rosette	Niskin Rosette	Niskin Rosette	MAPR	ADCP / WCP	Near-Bottom Sediment Trap

Note: Sub-cores sectioned at 3 to 4 horizons, dependent on fauna type. Horizons: 0-2 cm, 2-5 cm, 5-10 cm and 10-20 cm.

Glossary							
				Photo Sled	576 line km	Side-scan + SBP	sub-bottom profiler - 286 line km
SC	Sediment Chemistry	TM	Trace Metals	MAPR	Mini Autonomous Plume Recorder	WCP	Water Column Profiler
PSD	Particle Size Distribution	TSS	Total Suspended Solids	ADCP	Acoustic Doppler Current Profiler	MBES	Multibeam Echosounder - 64,000 km2

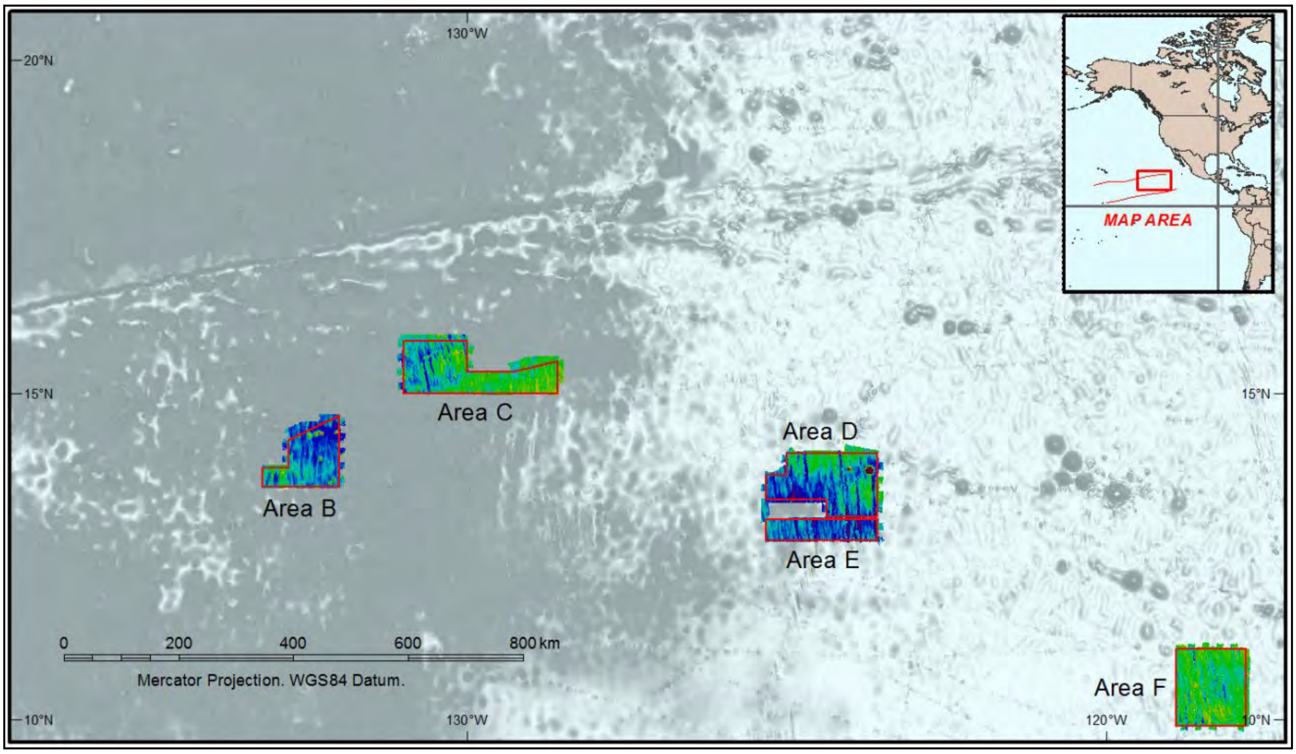
7.4 TOML Exploration Results

The exploration results discussed here include all data relevant to the mineral resource estimate. Much of the supporting data collected during the TOML CCZ13 and CCZ15 campaigns is still being processed. This includes much of the environmental and geotechnical data collected, but also includes mineralogy from samples and detailed geological interpretation from acoustic survey. This information will be reported, as relevant, at a later time.

7.4.1 TOML MBES results

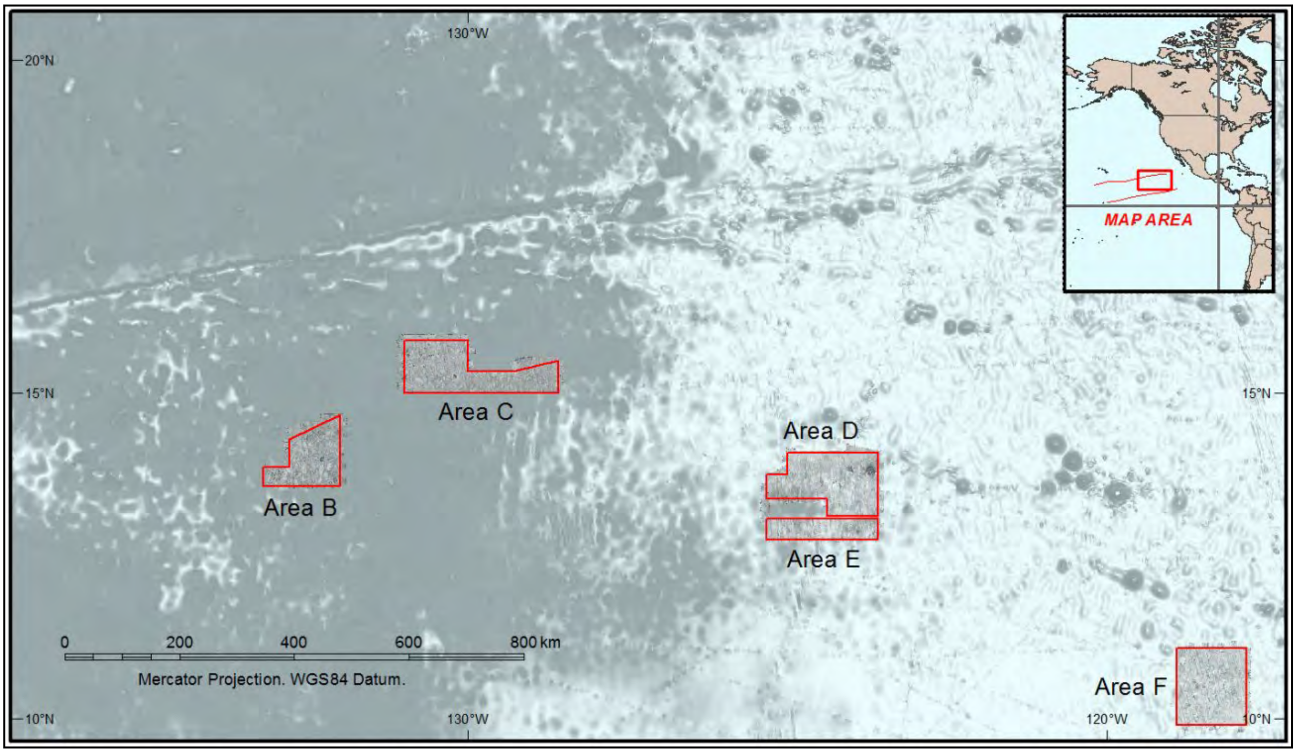
The MBES results are shown at a small scale in Figure 7.35 and Figure 7.36. The bathymetry shows that almost the entire area is composed abyssal hills and the bathymetry and backscatter together show that most of the area is covered by nodule bearing sediment.

Figure 7.35 CCZ13 MBES bathymetry coverage



Relief range blue to yellow is about 400 m scaled by each area. Background is the GEBCO bathymetric product (BODC, 2014)

Figure 7.36 CCZ13 MBES backscatter coverage



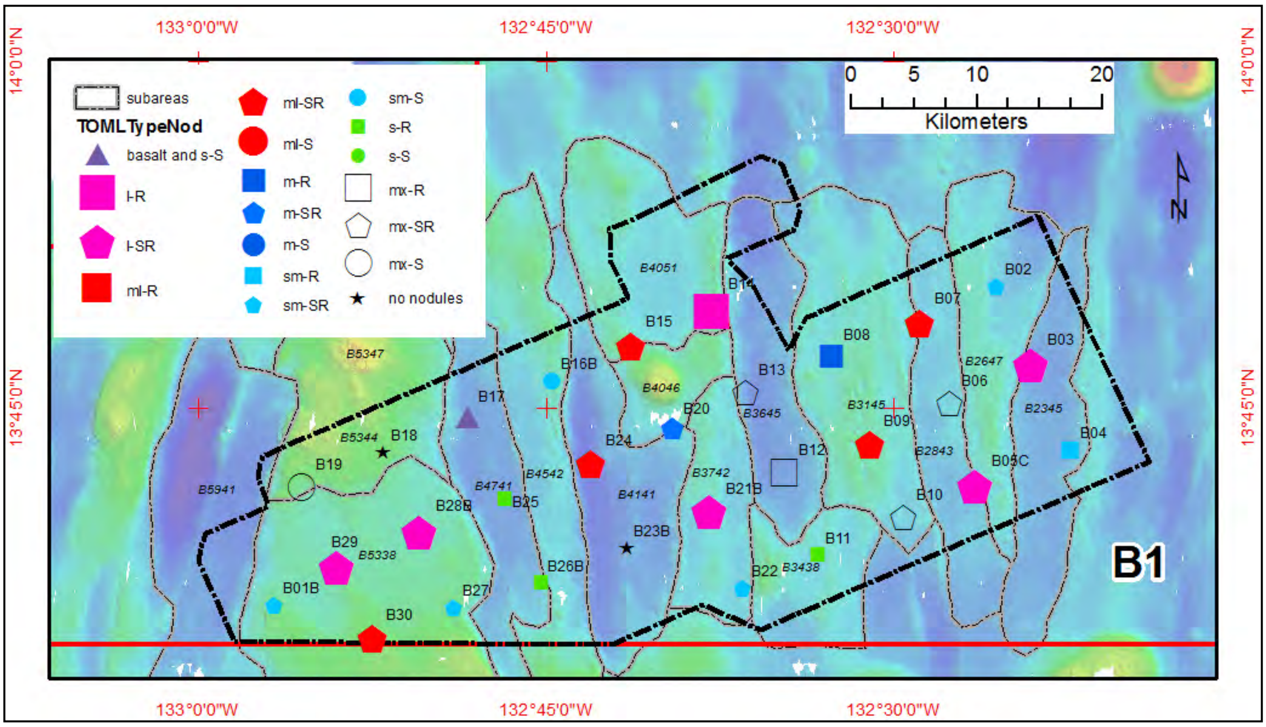
Background is the GEBCO bathymetric product (BODC, 2014)

The MBES bathymetry is used repeatedly in the following figures as the backdrop to the box-core results.

7.4.2 TOML Box-core results

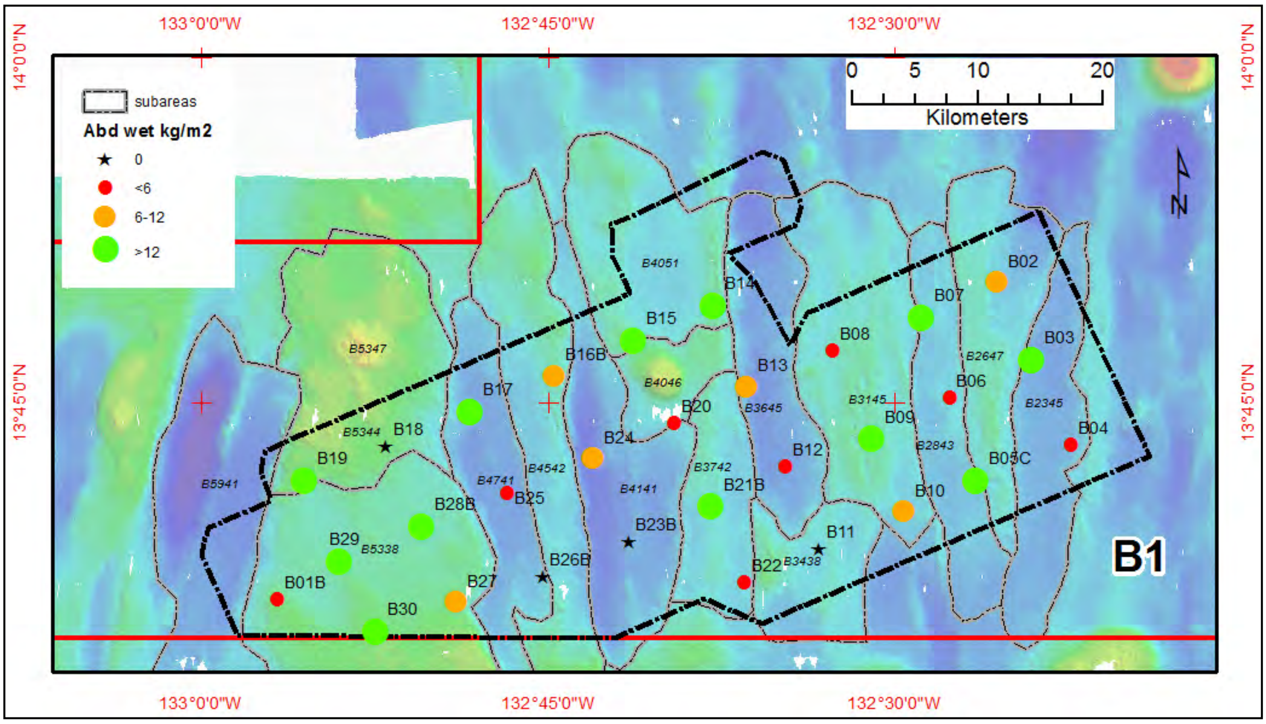
Figure 7.37 to Figure 7.51 summarises nodule and sediment characteristics of the box-core sites. Note that data exists at many of the same sites for water column characteristics and chemistry and fauna numbers and taxonomy data.

Figure 7.37 Nodule Types, Area B1



Nodule abundances are reported in wet kg/m^2, estimated using the process and principles discussed in section 7.5.6.

Figure 7.38 Nodule Abundance, Area B1



Shear strength is classified per the process and classification detailed in Section 9.3.7.

Figure 7.39 Shear Strength Class, Area B1

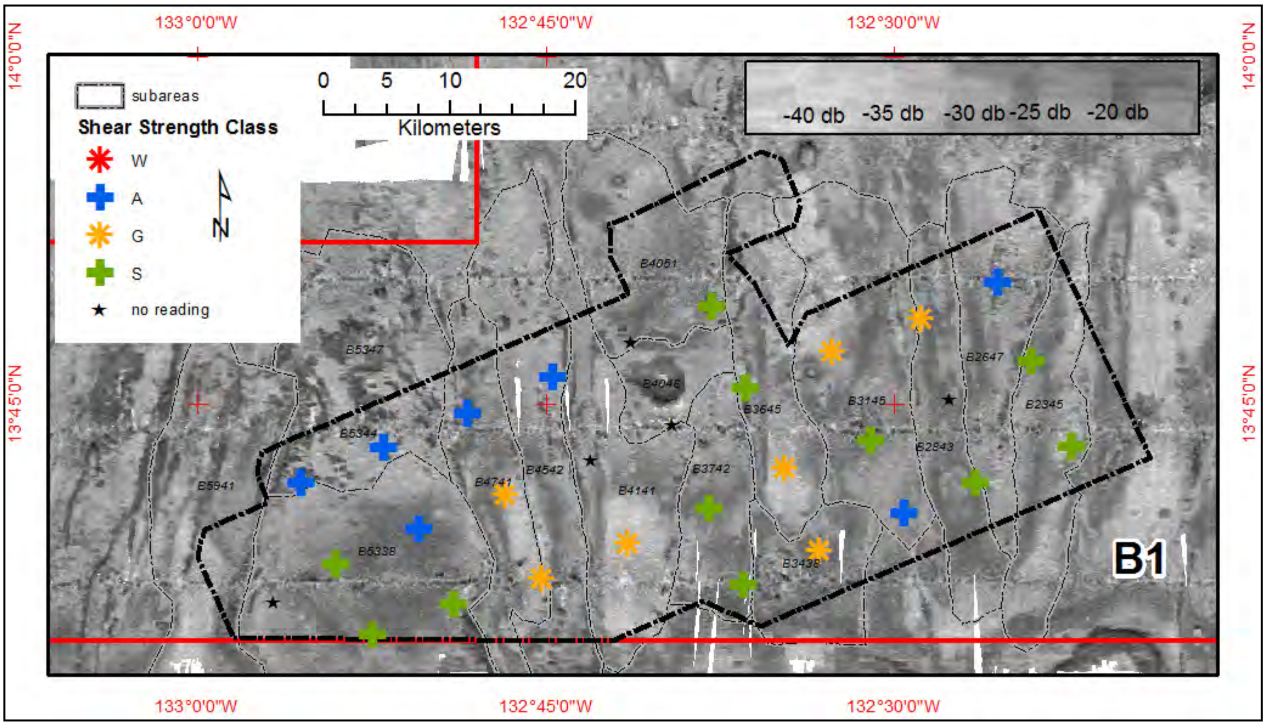


Figure 7.40 Nodule Types, Area C1

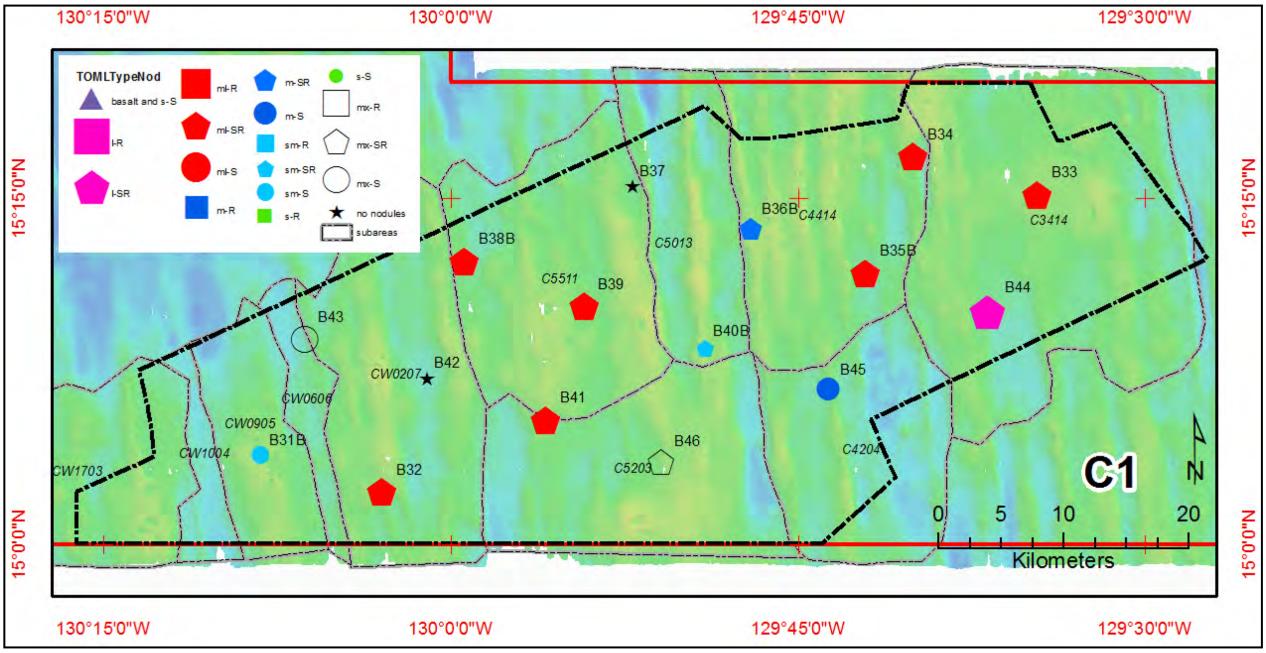


Figure 7.41 Nodule Abundance Area, C1

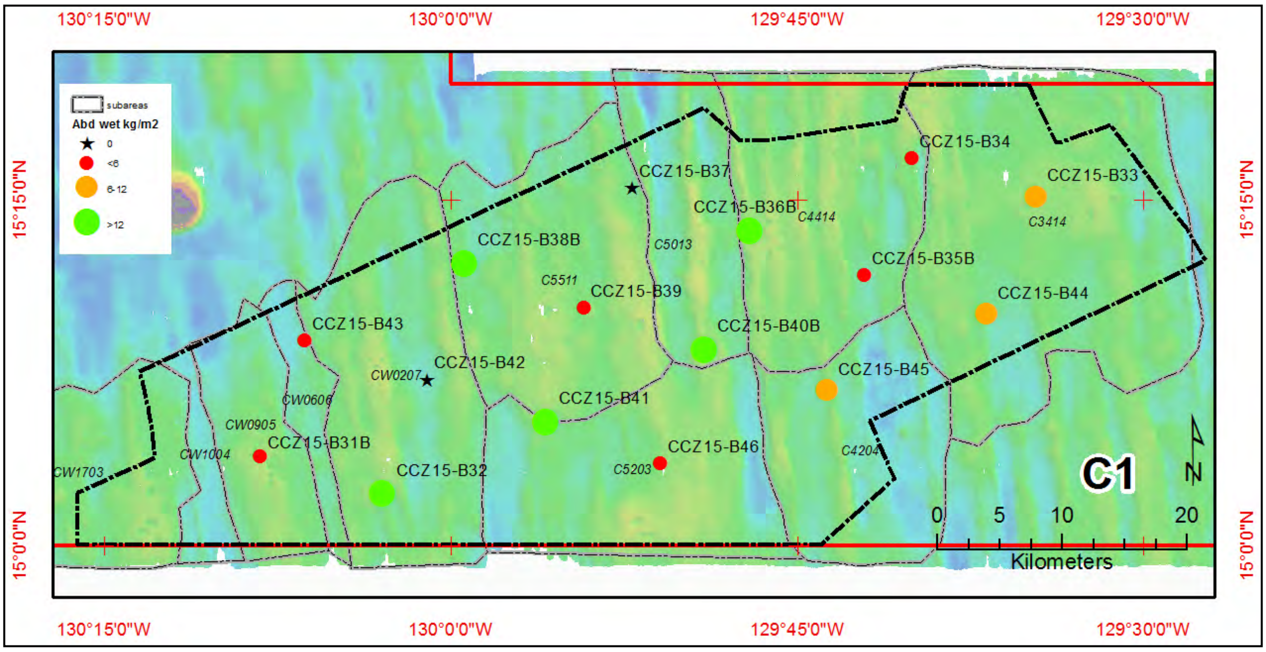


Figure 7.42 Shear Strength Class, Area C1

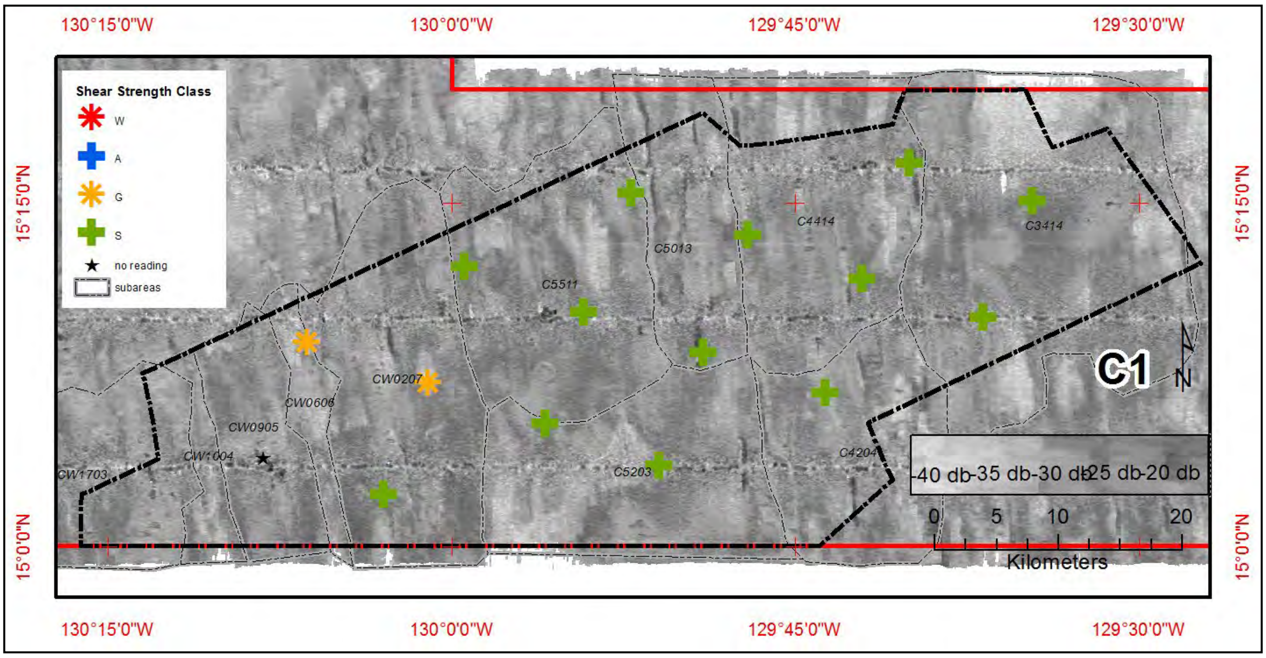


Figure 7.43 Nodule Types, Area D2

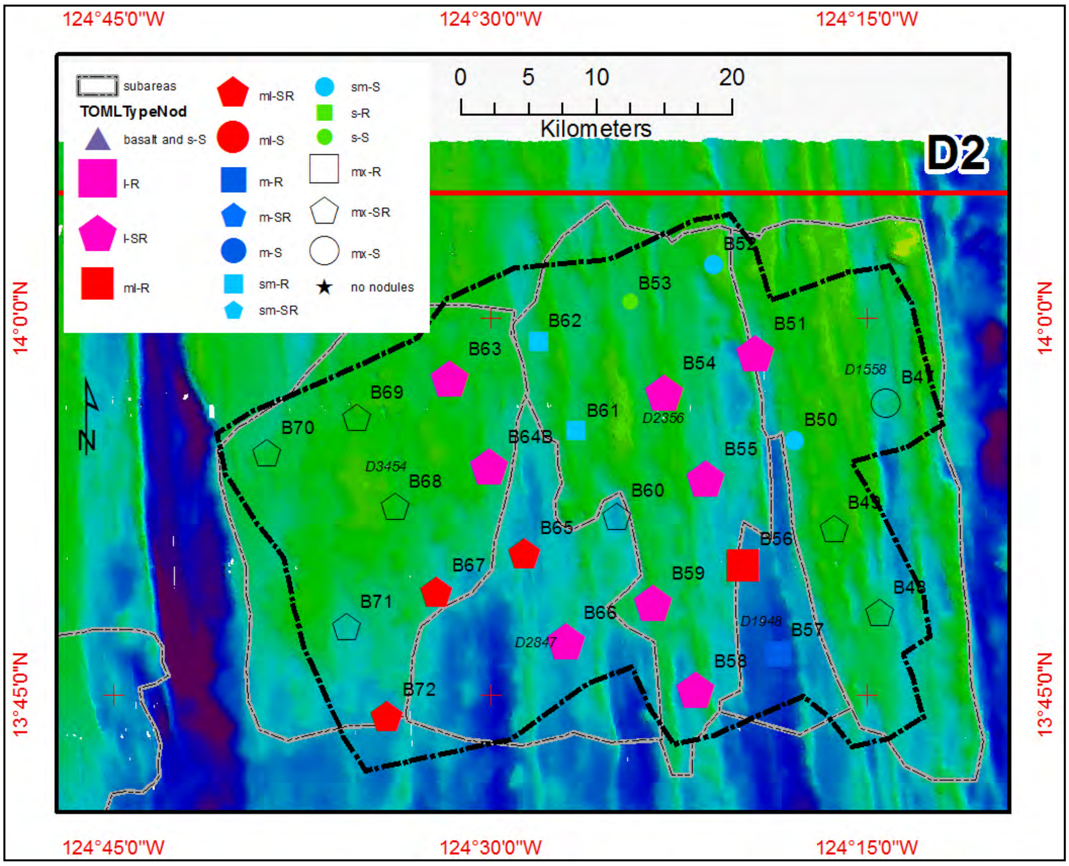


Figure 7.44 Nodule Abundance Area, D2

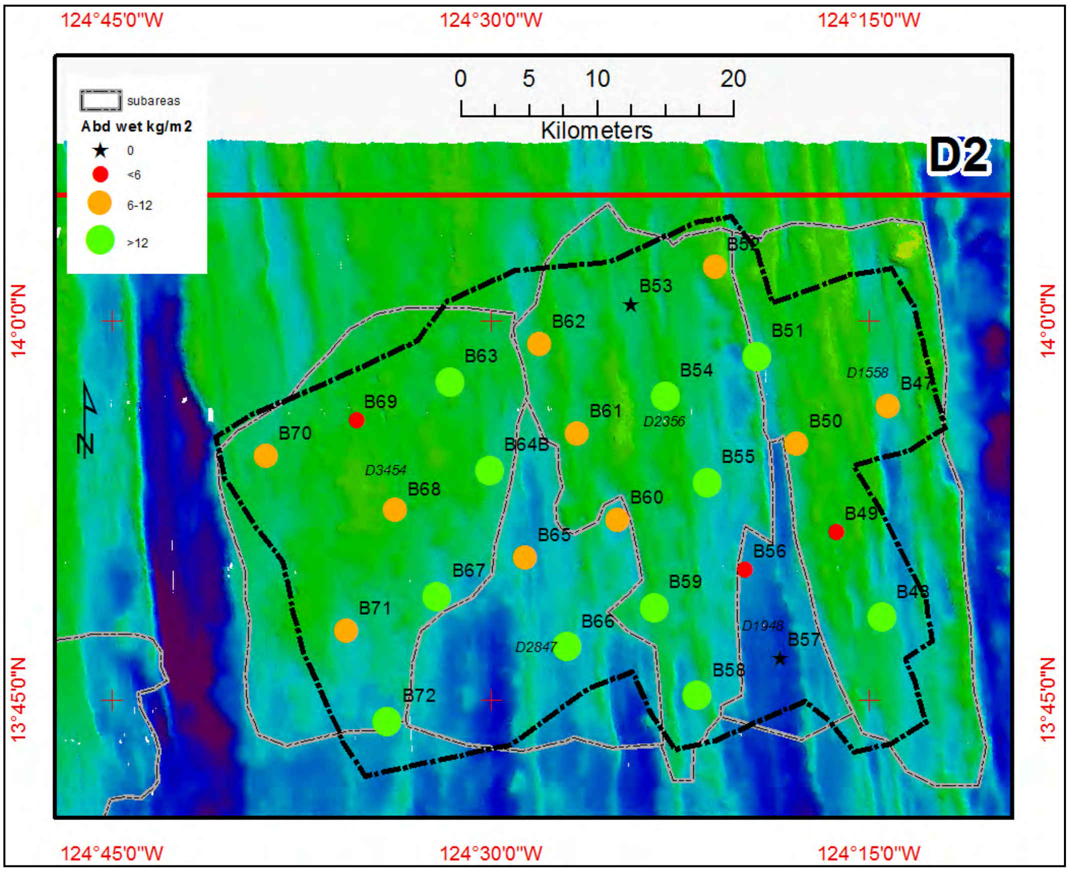


Figure 7.45 Vane Shear Strength Class, Area D2

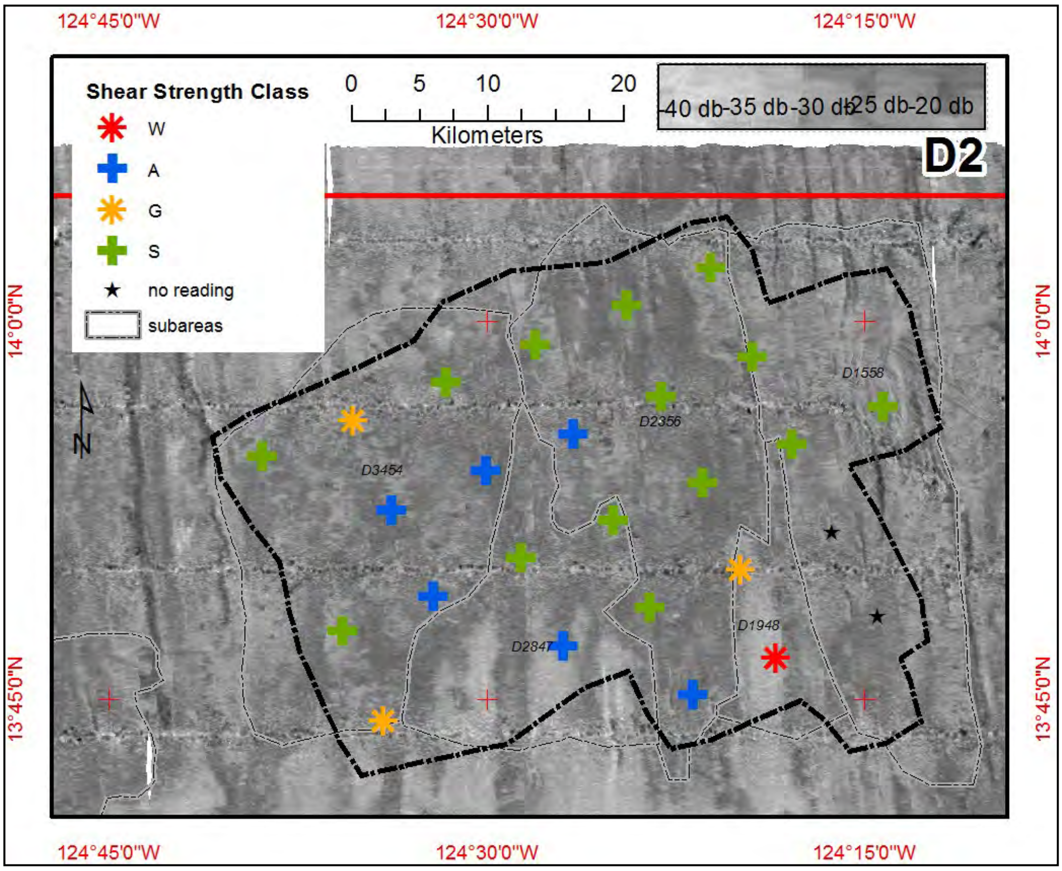


Figure 7.46 Nodule Types, Area D1

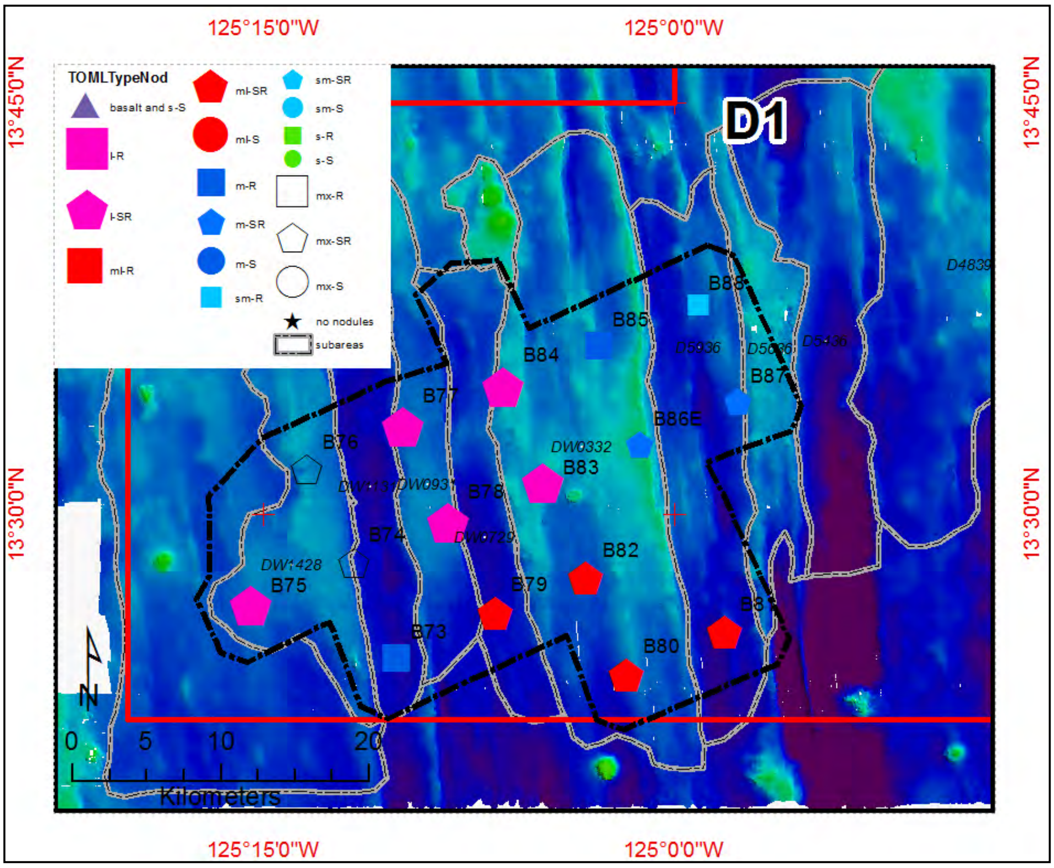


Figure 7.47 Nodule Abundance, Area D1

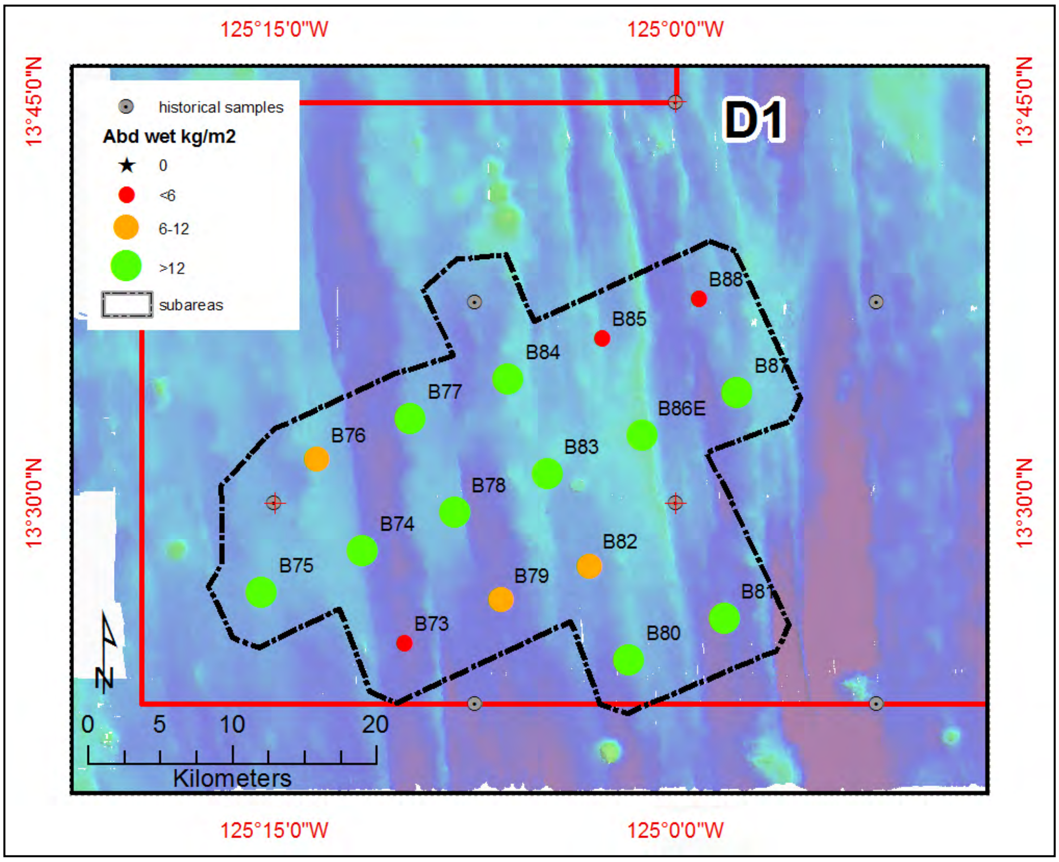


Figure 7.48 Vane Shear Strength Class, Area D1

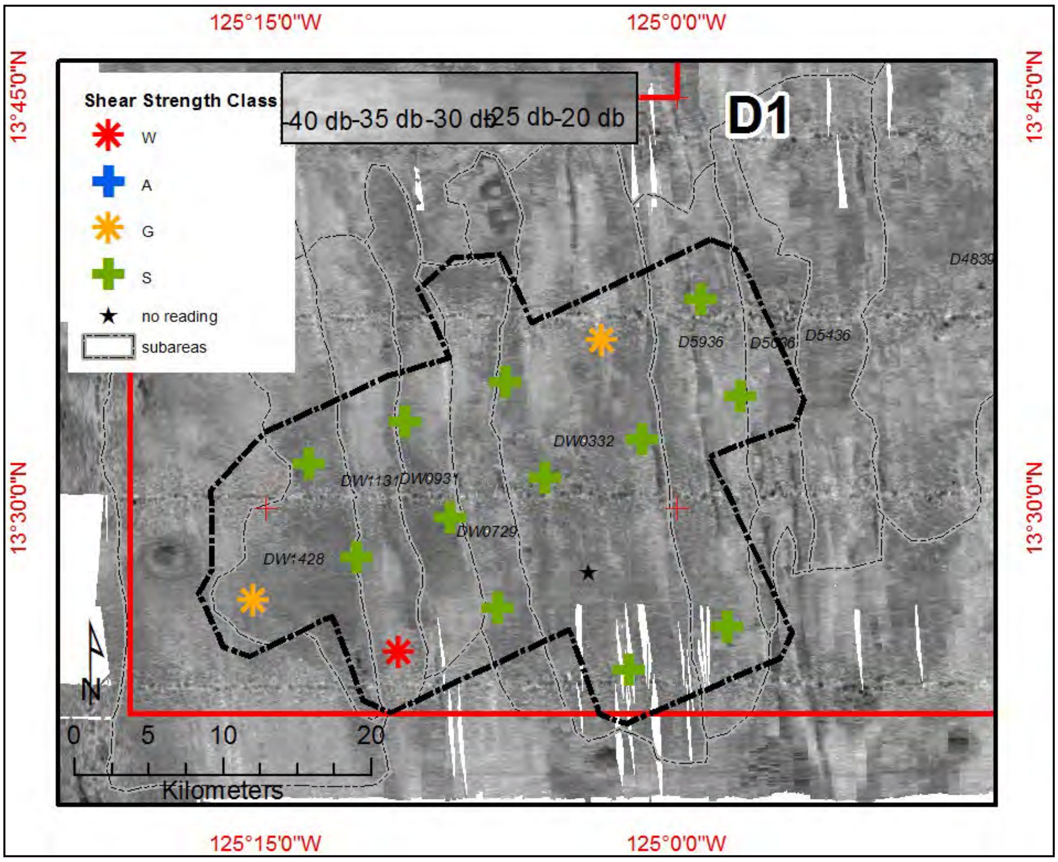


Figure 7.49 Nodule Types, Areas F and F1

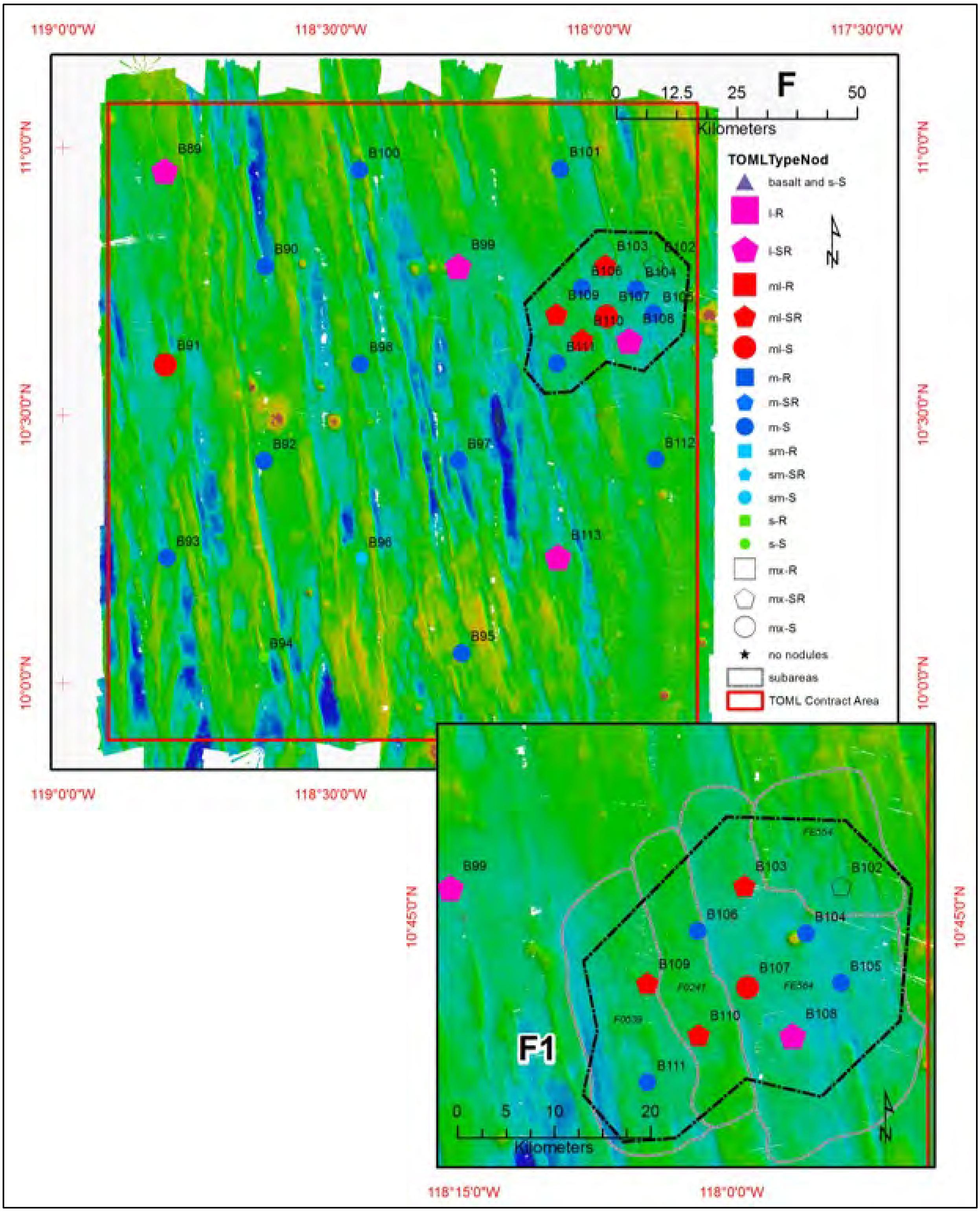


Figure 7.50 Nodule Abundance, Areas F and F1

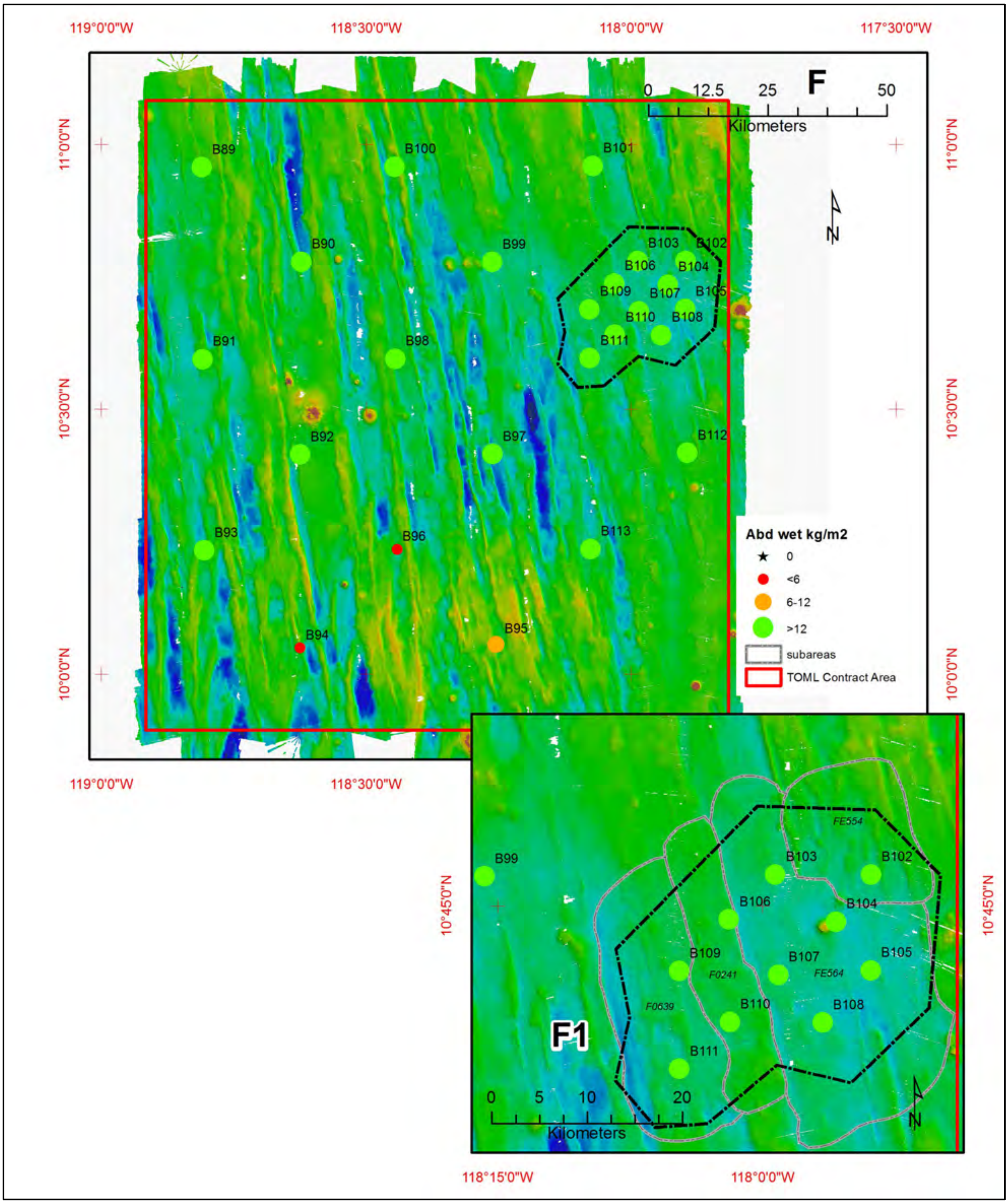
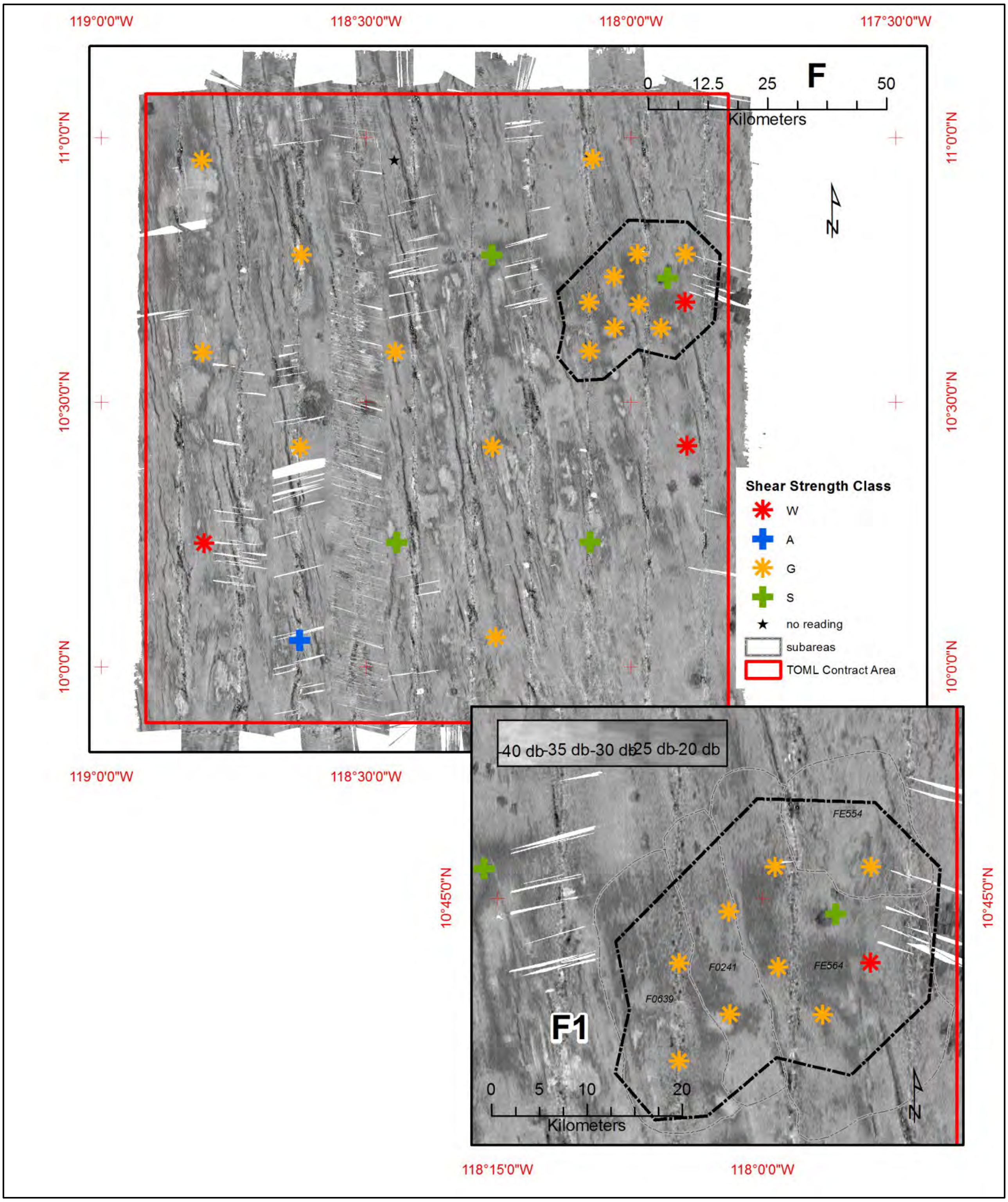


Figure 7.51 Vane Shear Strength Class, Areas F and F1



7.4.3 TOML Photo-profile results

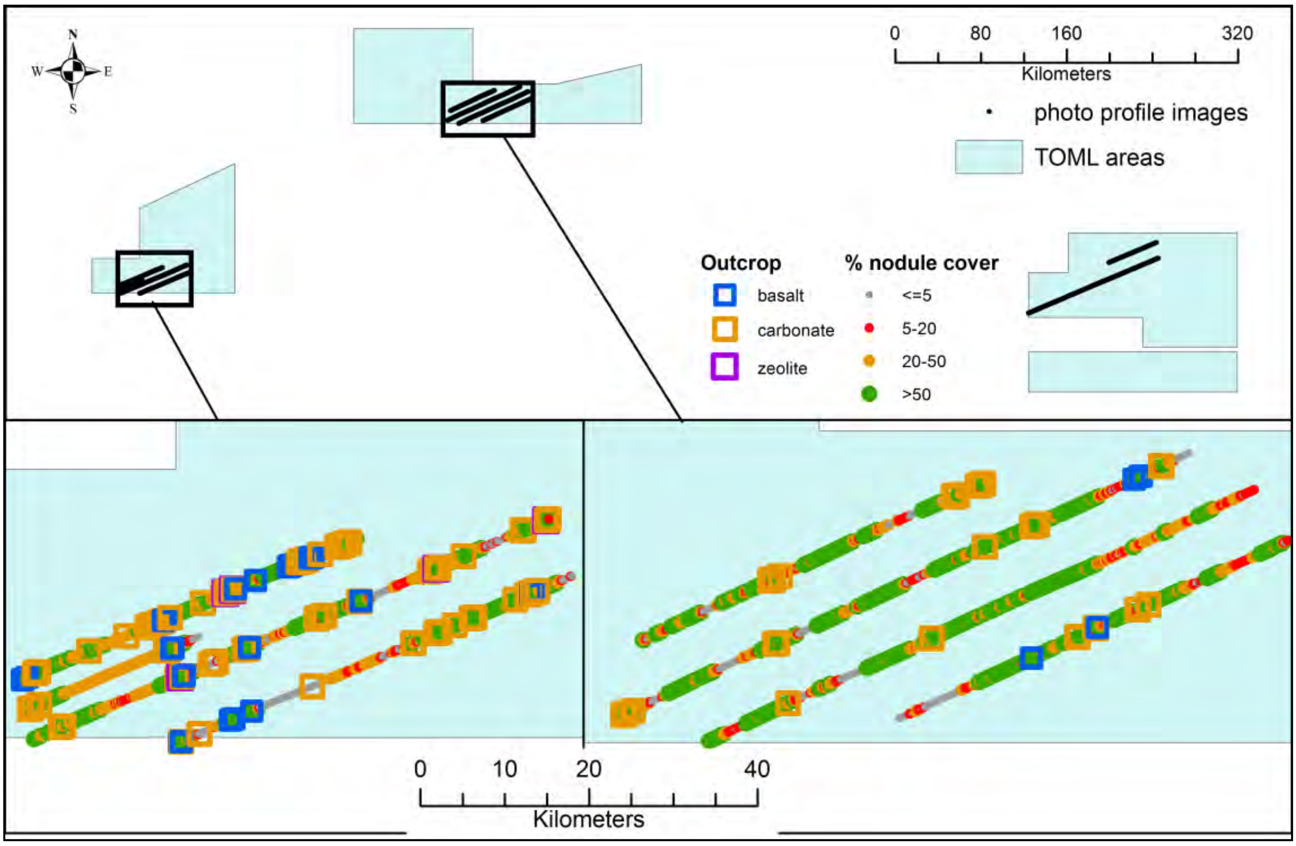
Photo-profiling provided key data on nodule type and abundance as well as for baseline logging of mega-fauna. Ten lines were completed, with one in two parts after equipment repair (Figure 7.52).

Use of photographs in nodule abundance estimations is not new and is discussed by Felix (1980) and by UNOETO (1979). These results are included with the box-core based abundance data used for mineral resource estimation.

An estimation of nodule cover (% visible cover by nodules on the seafloor) was also possible. This is much simpler to measure than nodule long axis as it is a simple colour contrast. Percentage cover does relate to abundance, but the relationship is much weaker than nodule long axis, so nodule cover was not used in the mineral resource estimate except to support interpreted and measured continuity.

When combined with observations of outcrop, the nodule coverage plots in Figure 7.52 give a good indication of the high levels of continuity for the nodules amongst the fault bounded abyssal hills. The process clearly does not work in Area D where sediment cover is high.

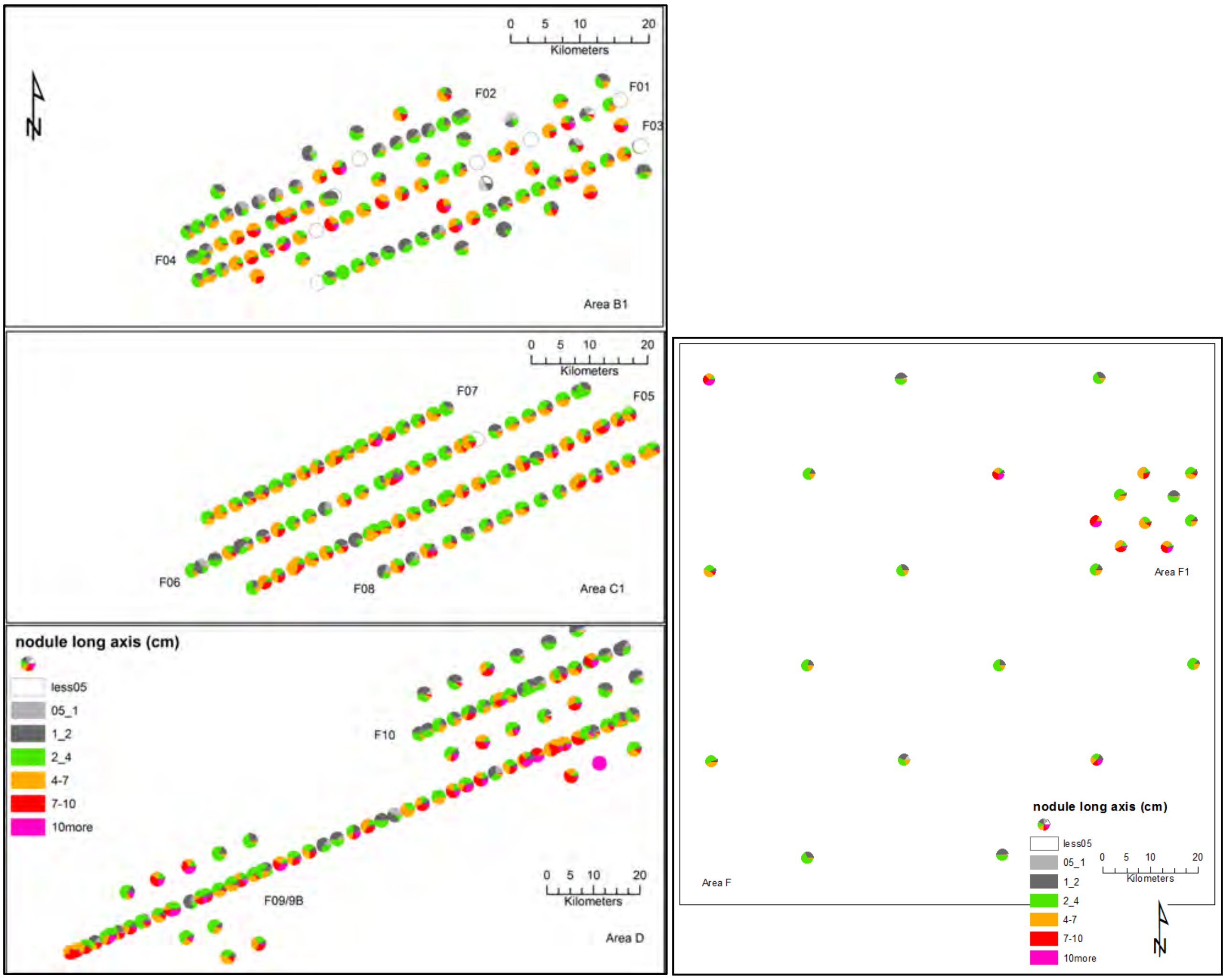
Figure 7.52 Neptune Photo-profile logging of % cover and outcrop types



Insets only shown for Area B (L) and C (R)

Nodule size analysis (combined with box core observations) is shown in Figure 7.53. An understanding of nodule sizes and other characteristics such as rugosity and strength will be useful in designing the mining system. Considerable information was collected in respect of long axis measurements taken from photo-profile images (roughly every 100th image for abundance estimation purposes).

Figure 7.53 Nodule sizes and types from photo-profiles and box-cores

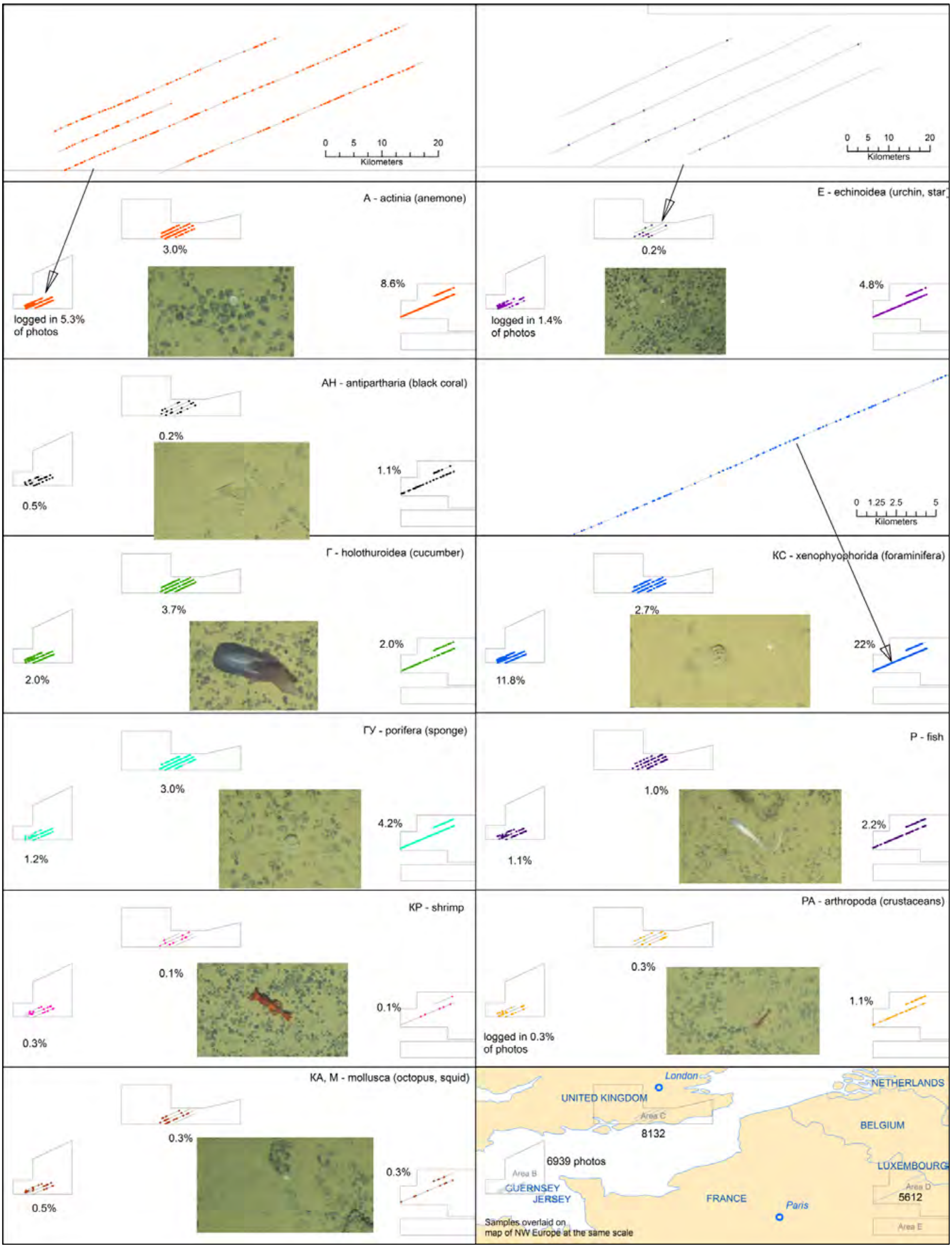


Top: B1, Middle-left: C1, Bottom-left: D1-D2, Bottom right: F and F1

All the surveyed areas host nodules of different sizes but Area B has mixed sized nodules and includes many of the smaller nodules. In Area C, nodule size increases to an average of small to medium and they are well distributed throughout. Within Area D, there is a mixture of sizes with some very large nodules found in the box-core samples. Bigger nodules were recovered from the box-corer than measured on the photo-profiling lines due to a frequent underestimation related to the sediment cover in this area. Area F has typically medium sized nodules but very large size nodules are seen in places.

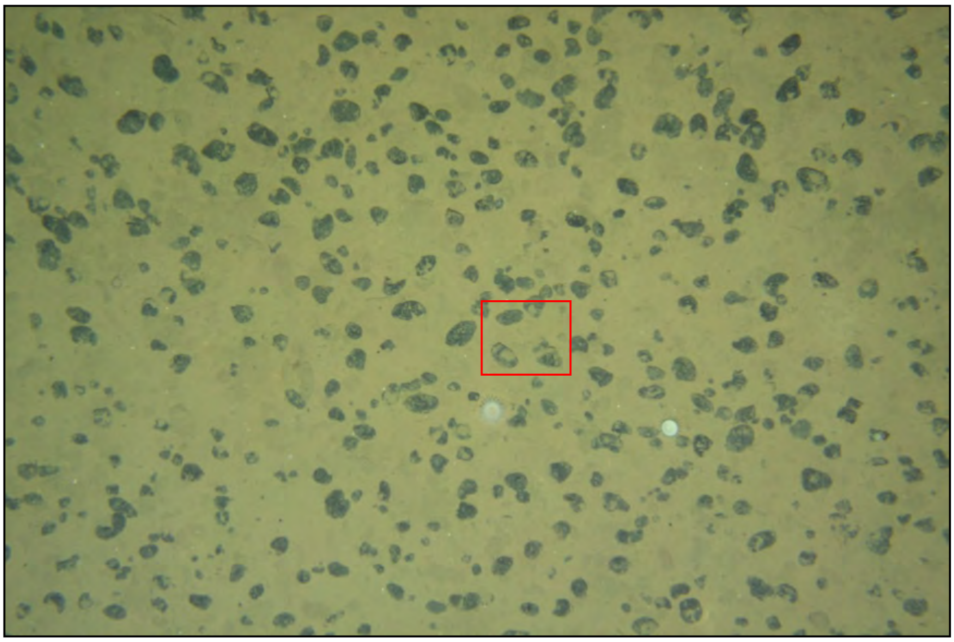
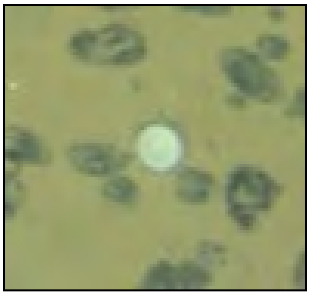
Photos were also logged as they were collected for visible megafauna with preliminary logging results in Figure 7.54.

Figure 7.54 Neptune Photo-profile preliminary logging summary distribution of megafauna



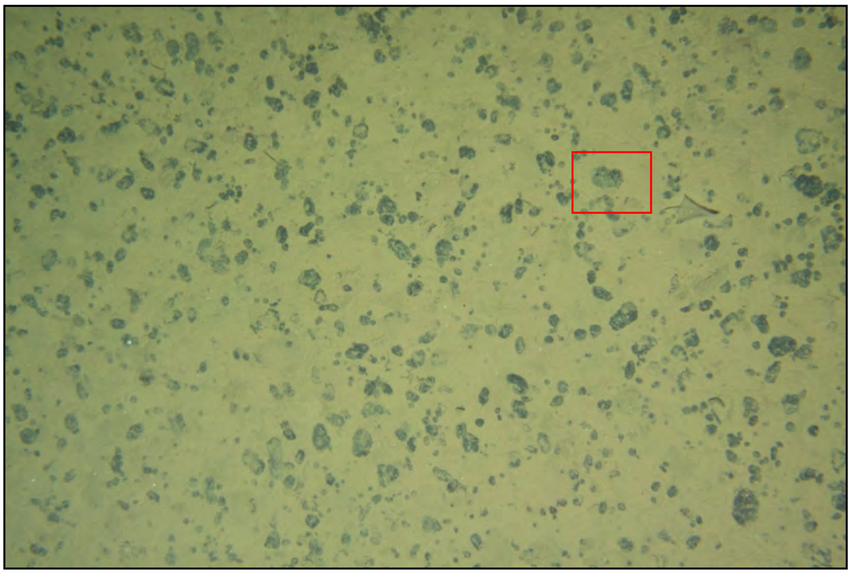
Some examples of the main types of megafauna seen in the photo-profiling conducted by TOML during the CCZ15 campaign are shown below. The photos were selected effectively at random from logging codes of the ~20,000 photos captured during that campaign.

Figure 7.55 Two genus Actinia (sea anemone) in Area C1

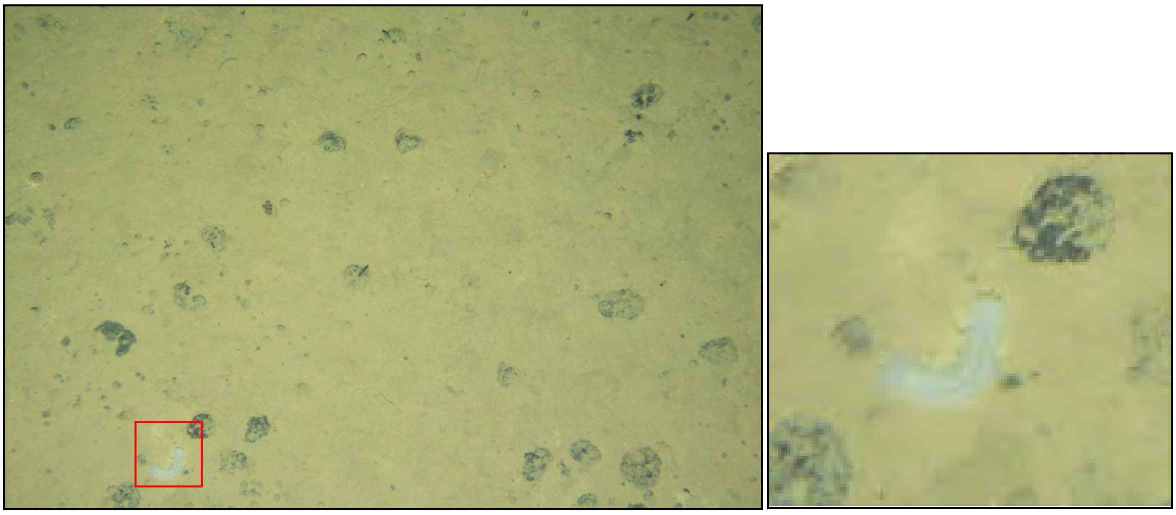
Main photo: 2.4 x 1.5 m; CCZ15-F08: 2015_09_08_154911

Figure 7.56 Order Antipatharia (black coral) in Area B1



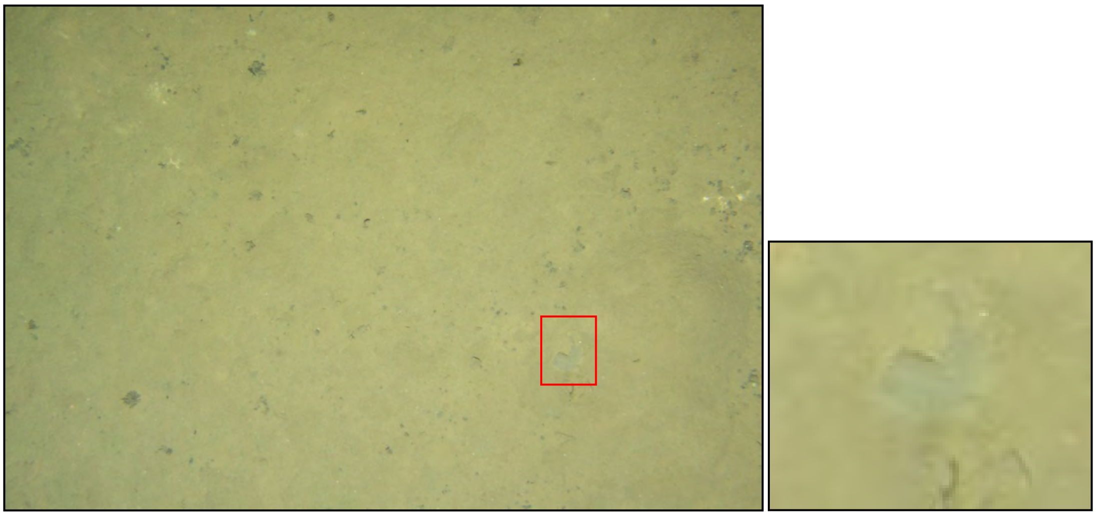

Main photo: 2.4 x 1.5 m; CCZ15-F03: 2015_08_21_205254

Figure 7.57 Class Holothuroidea (sea cucumber) in Area D



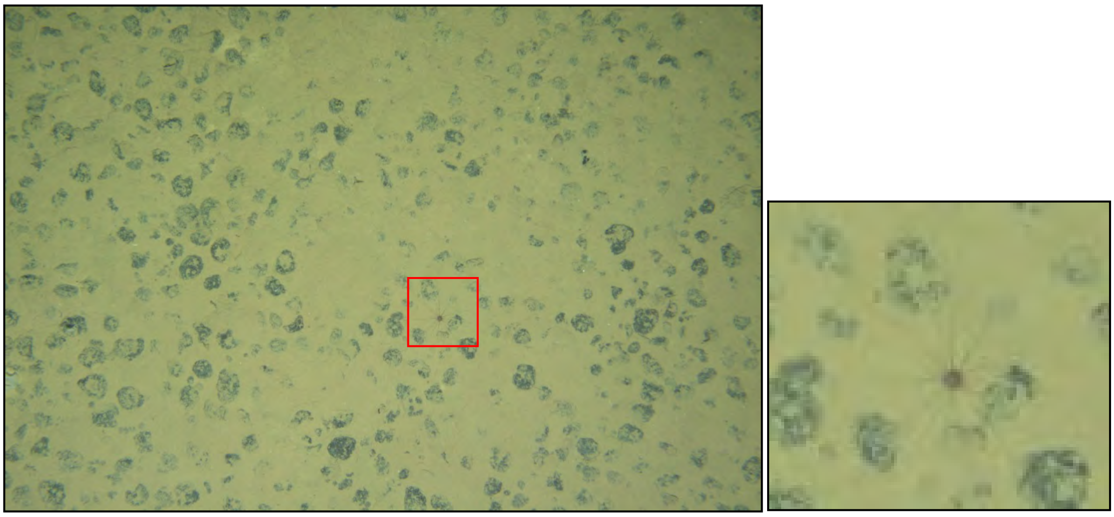
Main photo: 2.4 x 1.5 m; CCZ15-F09B: 2015_09_14_185421

Figure 7.58 Phylum Porifera (sponge) in Area B1



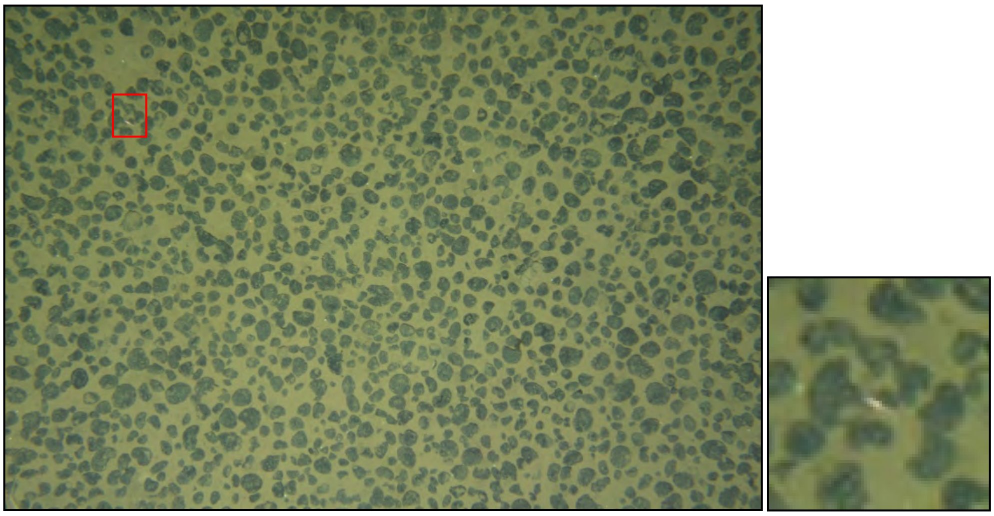
Main photo: 2.4 x 1.5 m; CCZ15-F04: 2015_08_26_082625

Figure 7.59 Class Echinoidea (sea urchin) in Area D2



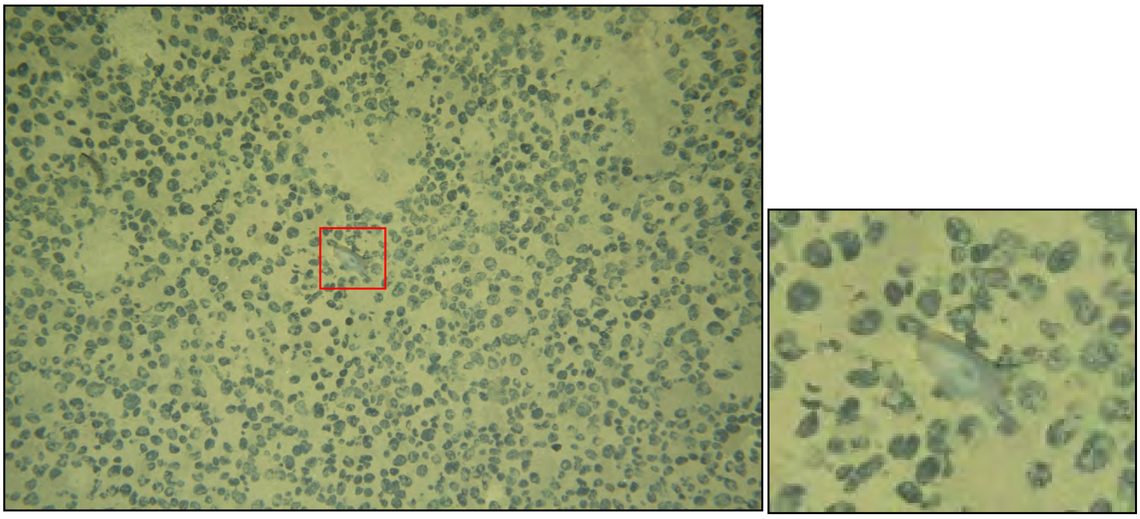
Main photo: 2.4 x 1.5 m; F10: 2015_09_16_070625

Figure 7.60 Order Decapoda (shrimp) in Area C1



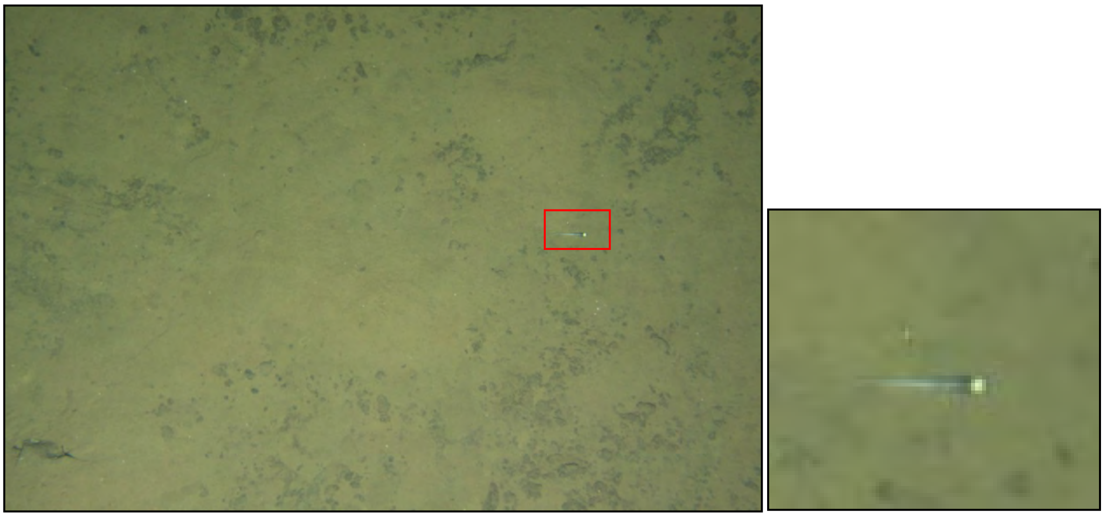
Main photo: 2.4 x 1.5 m; CCZ15-F05: 2015_08_29_060636

Figure 7.61 Order Teuthida (squid) in Area B1



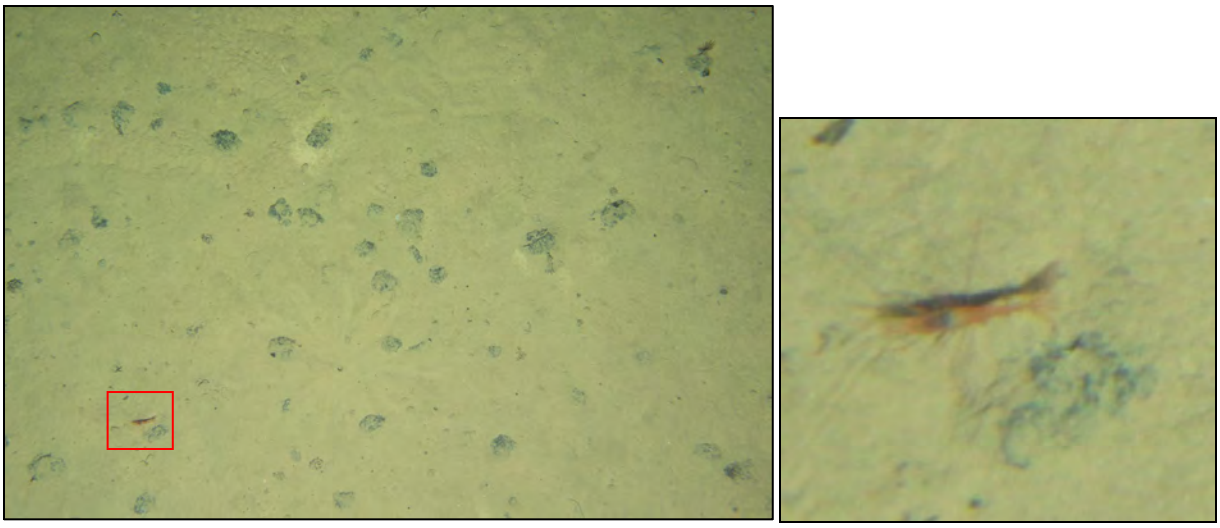
Main photo: 2.4 x 1.5 m; CCZ15-F01: 2015_08_11_110540

Figure 7.62 Fish in Area C



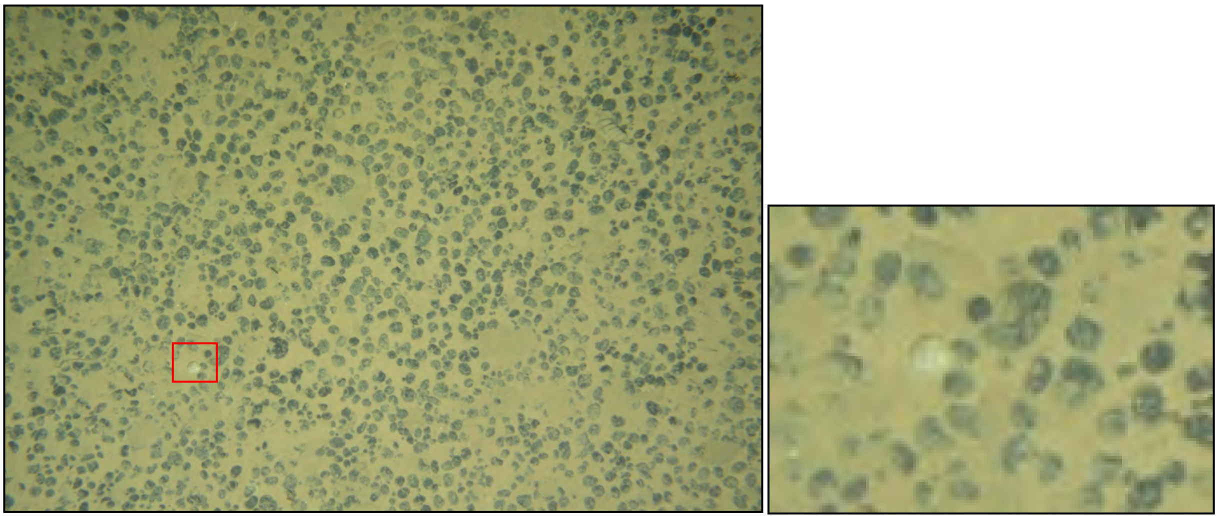
Main photo: 2.4 x 1.5 m; CCZ15-F06: 2015_09_02_190522

Figure 7.63 Phylum Arthropoda (excludes decapods) in Area D1



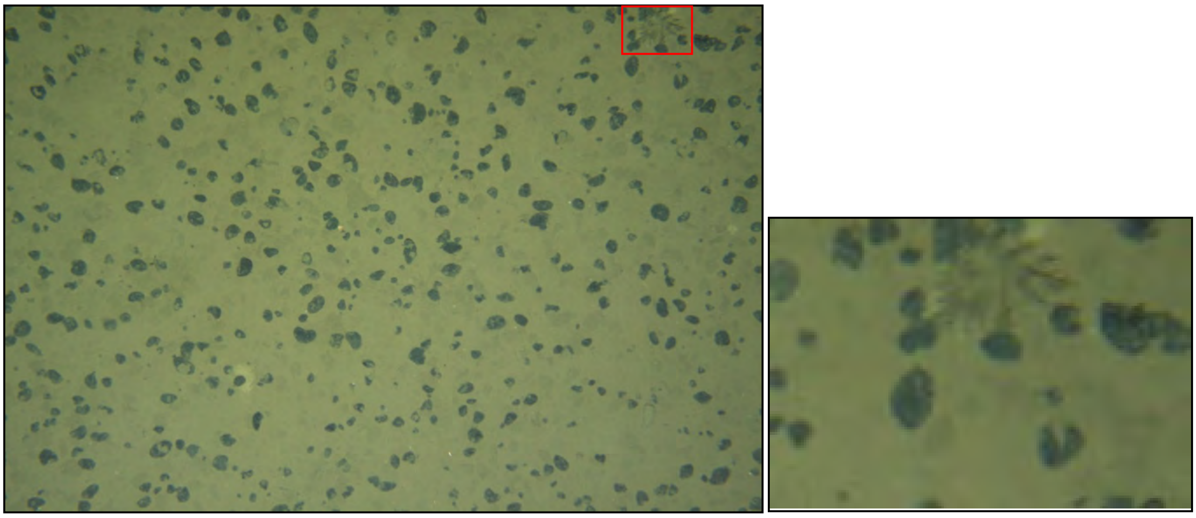
Main photo: 2.4 x 1.5 m; CCZ15-F09B: 2015_09_14_195043

Figure 7.64 Phylum mollusca (bivalve example) in Area B1



Main photo: 2.4 x 1.5 m; CCZ15-F02: 2015_08_16_195404

Figure 7.65 Class xenophyophorida (protozoan)



Main photo: 2.4 x 1.5 m; CCZ15-F07: 2015_09_03_190541

7.4.4 TOML Photo-profile based habitat mapping trial

A habitat classification scheme was developed during the CCZ15 campaign that was based on previous work in the CCZ and that adopted elements of existing classifications schemes, namely the US Coastal and Marine Ecological Classification Standard (CMECS, FGDC, 2012), the European Nature Information System (EUNIS, Davies et al. 2004) and the Collaborative and Automated Tools for Analysis of Marine Imagery (CATAMI, Althaus et al. 2015). The TOML scheme contained three components (Geomorphology, Substrate and Biological). The scheme was trialled on TOML area B1 (Figure 7.66, Figure 7.67) with the intent to apply to other areas after review.

Figure 7.66 Areas where biota was not observed

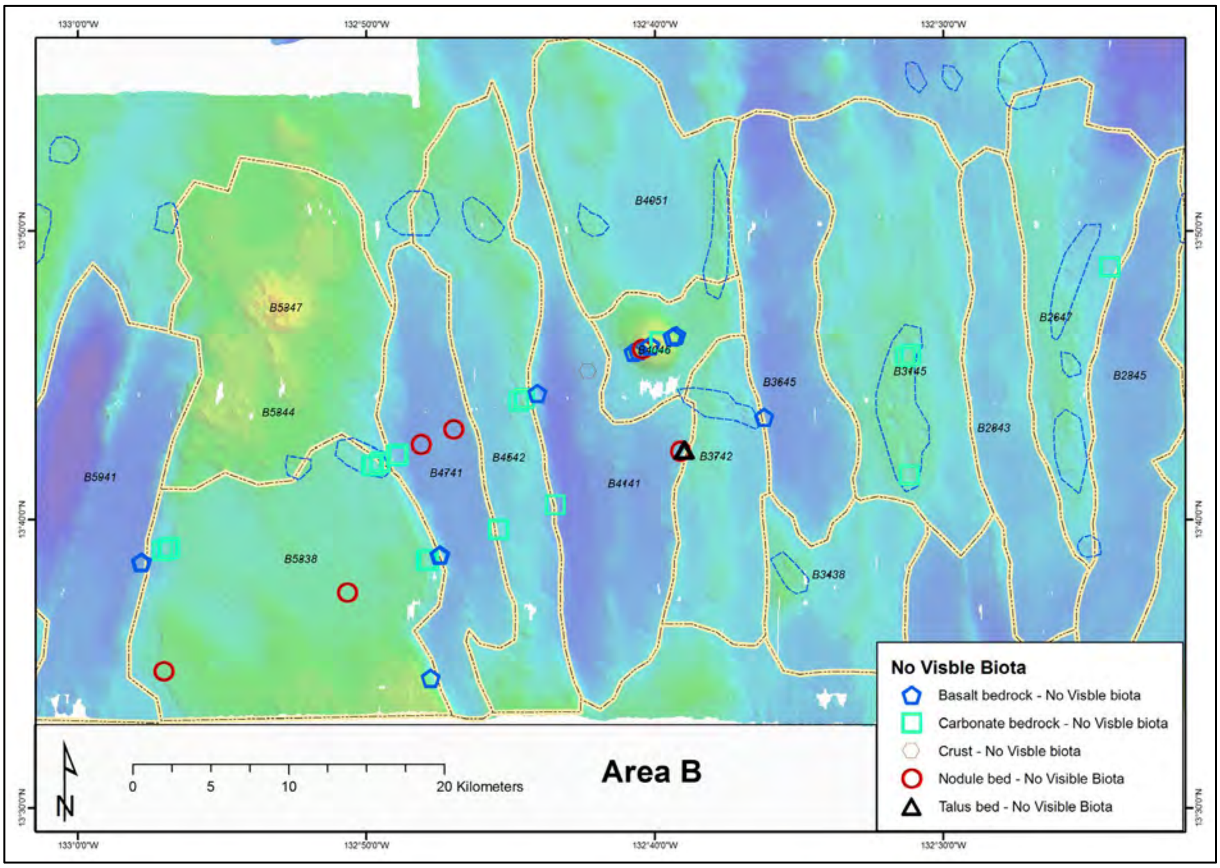
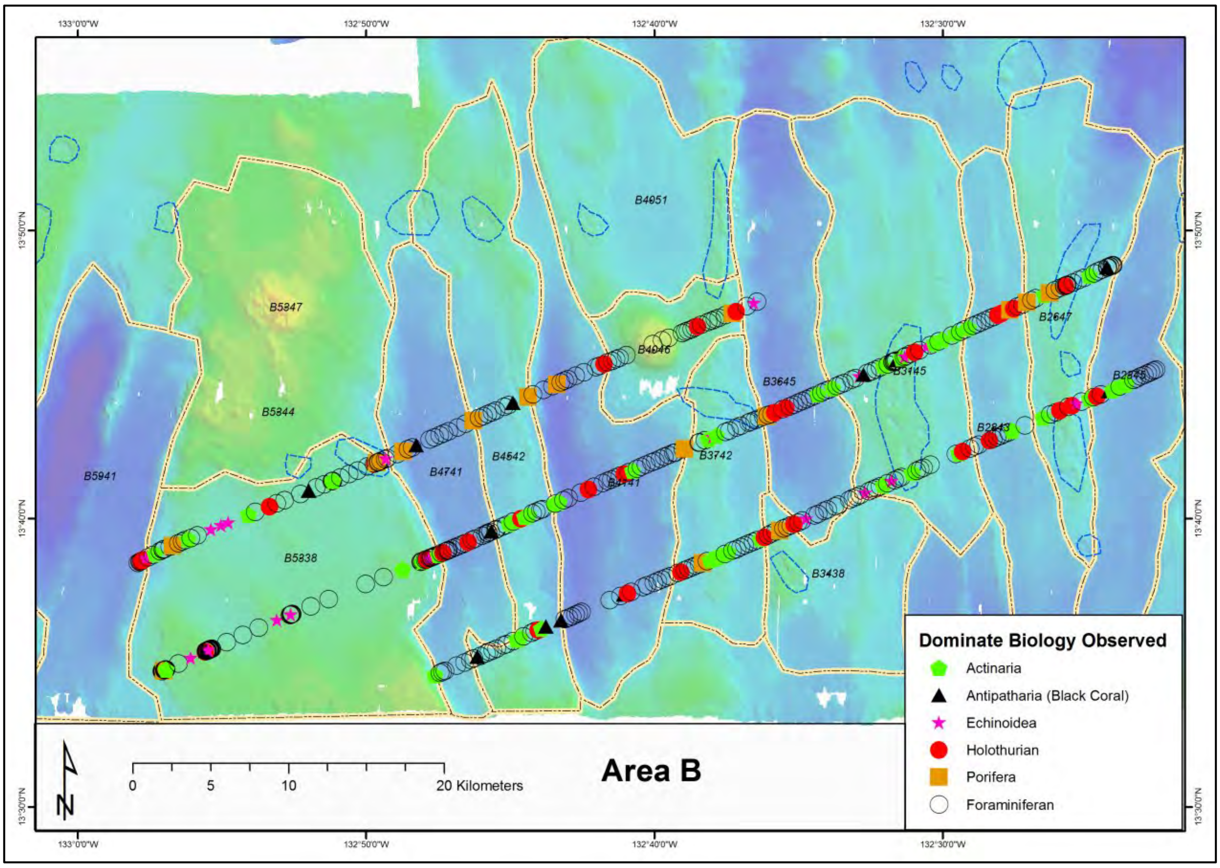


Figure 7.67 Dominant biota observed



The trial involved detailed classification of every tenth photo taken along three Neptune photo sled lines (CCZ15-F01, F02 and F03). In some areas, the number of photos logged was increased to capture seafloor features that were smaller in area.

Data were analysed to determine if there were any significant relationships between the distribution of benthic biota and the geoforms and substrate types on which they occurred. The analysis made use of boosted regression trees (BRT) via the R statistical software package (R Core Team, 2016) and multivariate cluster analysis via Primer-e software (Clarke and Gorley, 2006). The trial dataset used in the analysis was relatively small and analysis was restricted to fauna that were most abundant in photo logging. Therefore, some caution is needed when interpreting the results. BRT analysis was not extended to investigate variable interactions or predictions of habitat suitability.

7.4.4.1 BRT Results

Actinarians (sea anemones) were predominantly observed in nodule bearing sediment. The BRT results indicated that actinarians were most frequently associated with nodule cover class of 21–40%, 41–60% and >60%. They were most commonly associated with large Type C nodules.

Megafauna-sized foraminifera were observed in the majority of photographs logged. Volcanic and carbonate bedrock were the only substrates that did not support foraminifera.

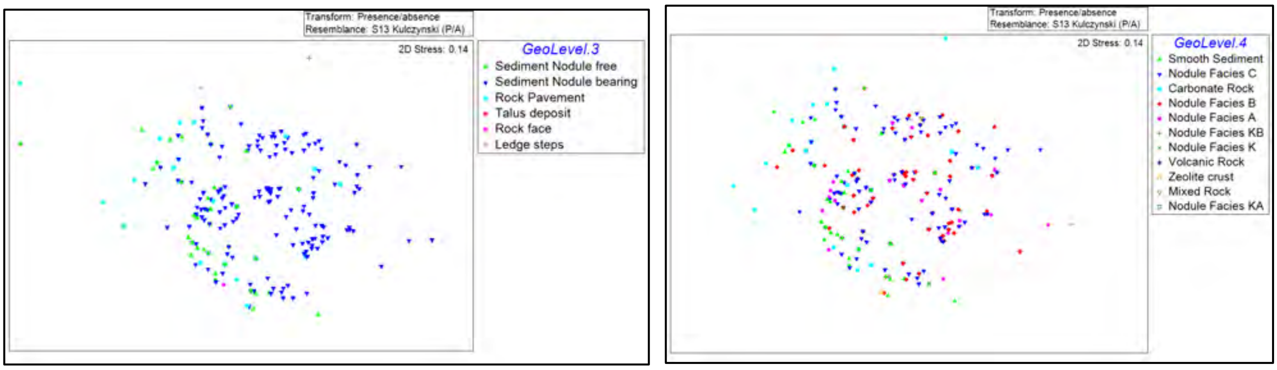
BRT analysis using a logging class “no visible biota” indicated that the seamount in Area B and step/ledge geoforms were devoid of megafauna. The substrate observed in these areas was volcanic and carbonate bedrock and crust.

7.4.4.2 Cluster Analysis Results

Morphospecies abundance was compiled for each photo frame, along with the four-level Geomorphology and Substrate components logged from each frame. Data from two photo sled lines in Area B were used in this preliminary analysis. The abundance data were transformed to presence-absence. This is the most aggressive form of transformation and so patterns detected using presence-absence data are considered to represent the strongest ecological patterns of interest to the preliminary analysis.

There was no clustering of samples according to Geoform levels 1 and 2. Samples did cluster according to Geoform Level 3 (Figure 7.68), with nodule-bearing sediment forming a somewhat dispersed cluster that overlaps with, but is distinct from, nodule-free sediments. A stress of 0.14 in the multidimensional scaling plot indicates that patterns are fairly well represented in two dimensions. A 3D plot of the same data decreased the stress to 0.1, indicating that there is an important third dimension to the data. Analysis of Similarity (ANOSIM routine) indicated that the difference between nodule-free and nodule-bearing sediments was statistically significant (Global R = 0.326, R significance < 0.05 for pairwise comparison). Rock pavement appeared to form a third intermediate and dispersed group and ANOSIM indicated that the rock pavement samples were significantly distinct from nodule-free sediments and nodule-bearing sediments.

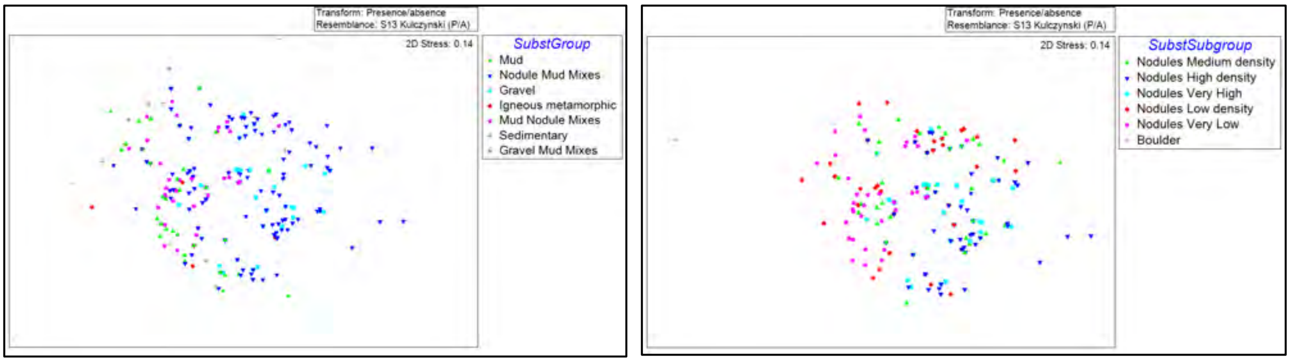
Figure 7.68 Samples (image frames) coded by Geoform Level 3 (L) and 4 (R)



At Geoform Level 4, samples from smooth sediment formed a dispersed but separate cluster from those on nodule-associated geoforms (Figure 7.68) but there was no significant clustering according to nodule facies type, a result confirmed by ANOSIM.

At the Substrate Group level (level 3 of the substrate classification hierarchy) there was dispersion among samples, but samples from nodule-mud mixes and gravels formed a group that was differentiated from mud and mud-nodule mixes (Figure 7.69). These groups represented varying dominance of nodules and ANOSIM indicated that the pairwise difference between nodule-mud mixes and mud-nodule mixes was significant. At level 4 of the substrate classification, nodule density was estimated. Again there was dispersion among samples, but those from high density (41–60%) and very high density (60+%) nodule density substrates clustered separately from the low (6-20%) and very low (1–5%) nodule density substrates (Figure 7.69). ANOSIM indicated that these groups were significantly different. Differences in community composition among substrate types may be expected because nodules represent attachment surfaces for sessile invertebrates that favour hard substrates.

Figure 7.69 Samples (image frames) coded by Substrate Group



Samples (image frames) coded by Substrate Group (level 3 of the substrate classification at L and level 4 at R)

7.4.4.3 Conclusions of Preliminary Habitat Mapping

The hierarchical physical and biological classification scheme used to log images appears to be suitably sensitive to detect gradients in megafauna community composition and relate these to physical habitat structure. Importantly, preliminary analysis indicated that high-level taxonomic identifications made using the formal scientific classification (e.g., phylum-level, which are often the only identifications possible from imagery) did not provide suitable resolution to detect differences. The concept of morphospecies identification has been adopted for megafauna in several contemporary marine studies and has been used in the CCZ for nodule-attached foraminifera, where formal taxonomic descriptions are not available (Kamenskaya et al, 2012; Veillette et al, 2007; Gooday et al, 2015).

Specific conclusions of the preliminary analysis are:

- Megafauna communities associated with nodule-free sediments differ from those associated with nodule-bearing sediments.
- Among the nodule-associated group, nodule facies (level 3 Geoform) as they were logged, was not a significant factor in structuring community composition. However, nodule density was significant.
- Based on the preliminary cluster analysis of Area B, a working hypothesis is supported for the existence of four benthic habitat types with respect to megafauna:
  - Sediment: nodule-free: smooth mud.
  - Sediment: nodule-bearing: high to very high density nodule-mud mixes.
  - Sediment: nodule-bearing: low to very low density nodule-mud mixes.
  - Rock pavement: sedimentary carbonate.

Populating Boosted Regression Tree models with additional data is expected to provide additional resolution on fauna distributions and provide a method for predictive habitat suitability modelling and thus support future impact assessment and spatial management of mining.

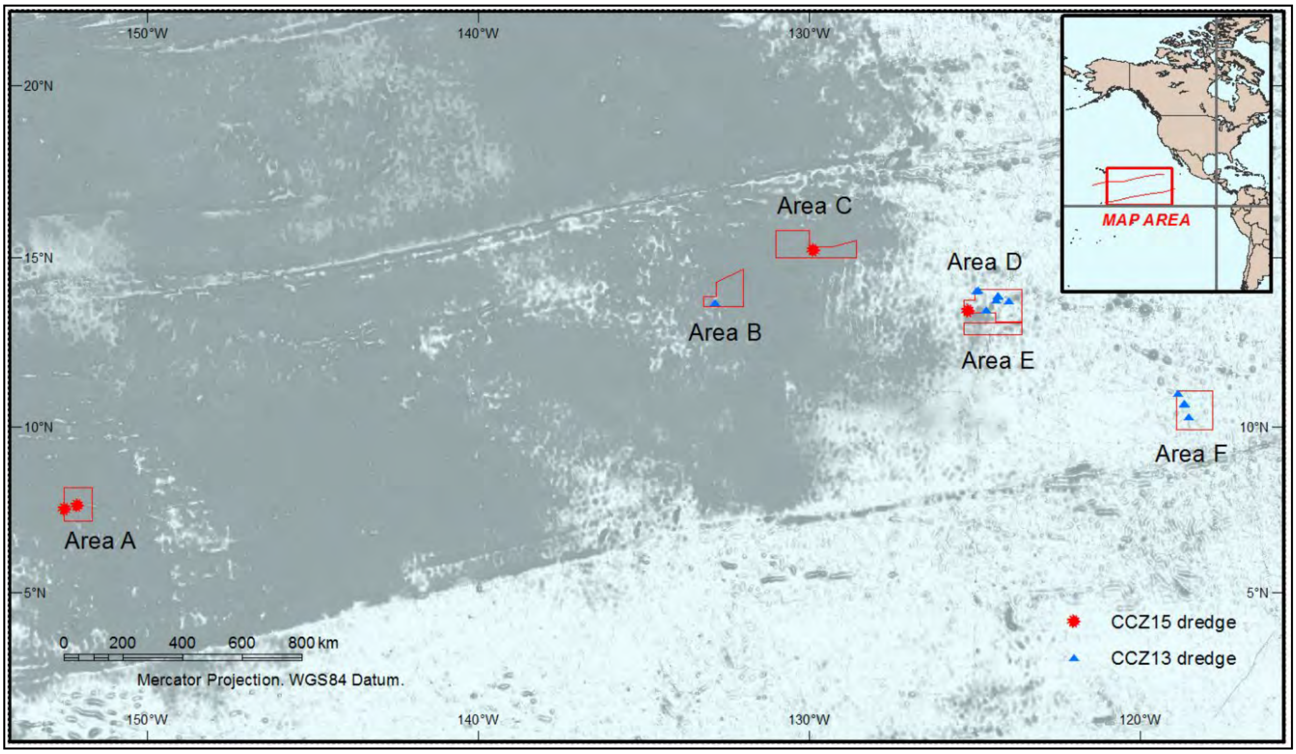
It is noted that the habitat mapping trial was done across a fairly restricted range of abyssal hill types (Physiographic Setting Subcomponent to Geoform Level 1 in Table 7-3) without any clear discrimination in biology between these types. This needs still to be reconciled with biological differences noted by Melnik and Lygina (2010) at Geoform Level 1 (their Striped, Undulated and Cloak type abyssal hills).

7.4.5 Other results

7.4.5.1 Dredging

Seventeen sites have been sampled either by epibenthic sled (CCZ13 campaign; Figure 7.30) or Galatea dredge (CCZ15 campaign; Figure 7.31).

Figure 7.70 Dredge sample locations CCZ13 and CCZ15



The samples were logged and:

- Sub-sampled extensively (up to 30 fragments per dredge sample) to confirm historical grades and to study variability in grade;
- Used in drying testwork;
- Used for metallurgical test work.

7.4.5.2 Towed Sonar - Side Scan

Sidescan sonar was used to map/characterise parts of several of the sub-areas for which an Indicated Mineral Resource is estimated. In effect these sub-areas are future options for TOML to conduct pilot, trial, and early commercial mining operations and are called Priority Mining Areas (PMA) in ISA terminology. An example of survey over the B5338 field within the B1 sub-area, is presented here.

In B5338 and the other areas, features of note on the side-scan and sub-bottom profiler can be classified into five categories:

- Texture relating to nodule coverage/size (and thus nodule abundance)
- Mapping of obstacles of concern in any future mining operation
- Detailed bathymetry (slopes and orientations of slopes)
- Textures and profiles relating to sediment types
- Features that imply a particular geological history.

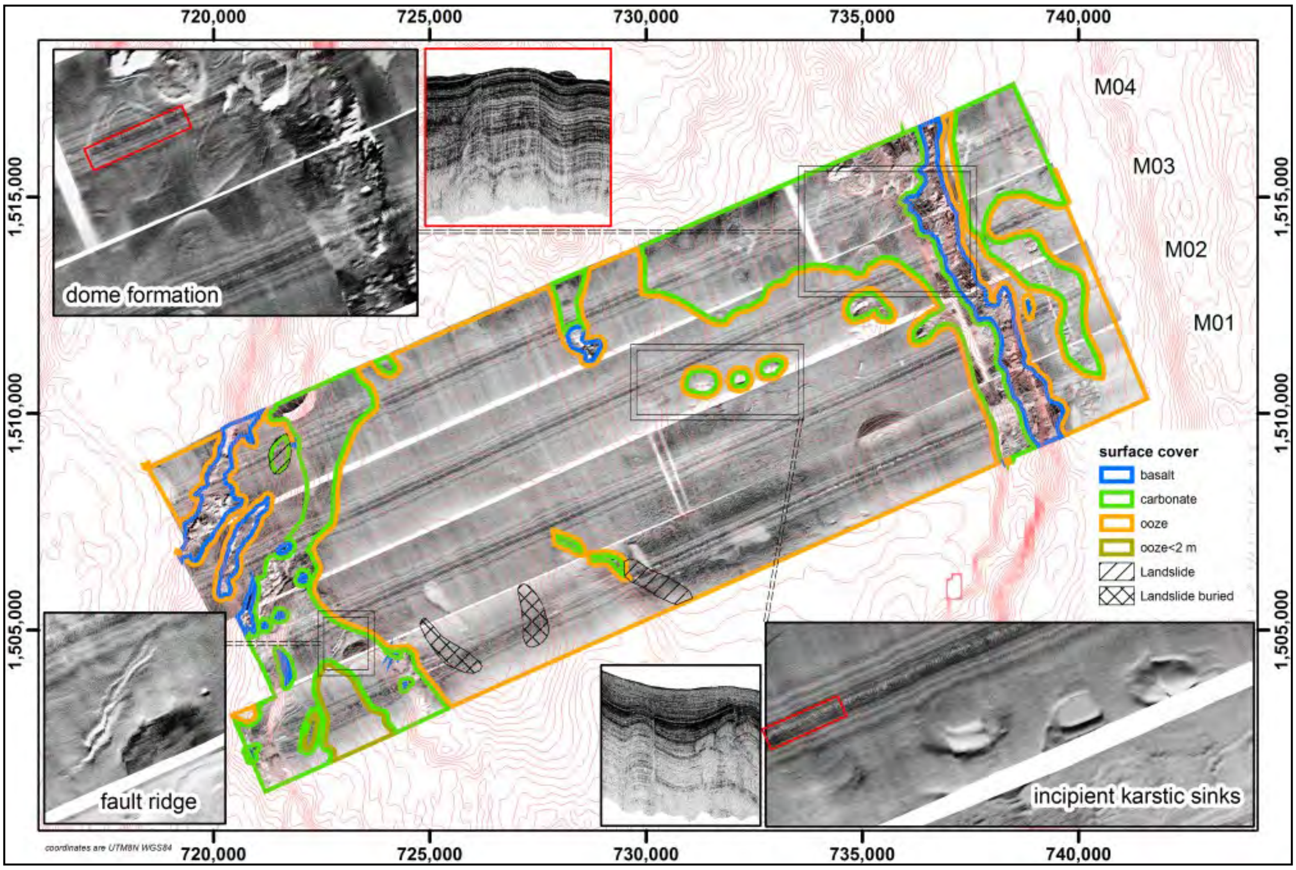
Nodule coverage in B5338 is consistent on the top of the ridge with a clear correlation with photo-profile coverage (Figure 7.52).

The most significant obstacles are the slopes defining the eastern and western boundaries of B5338, but there are also areas within the sub-area that could likely hinder a mining system. These include incipient karstic features and a basalt outcrop. There is also one steep small ridge as well as a small basalt floored karstic feature in the SW. Apart from these, however, the surface looks very smooth even with local ridge systems of several tens of metres altitude.

The sub-bottom profile data (not shown) show good development of a typical CCZ stratigraphy with thinning of siliceous ooze to the north.

In the northern area peculiar dome-shaped features (~1 km diameter) are visible on the side-scan (Figure 7.71). These appear to be the result of block faulting. Sub-surface carbonate dissolution is indicated in the sub-bottom profiler at depth both in B5338 and in adjacent valley B4741 but these do not express at surface.

Figure 7.71 Side scan coverage and geological interpretation of the B5338 field, Area B1



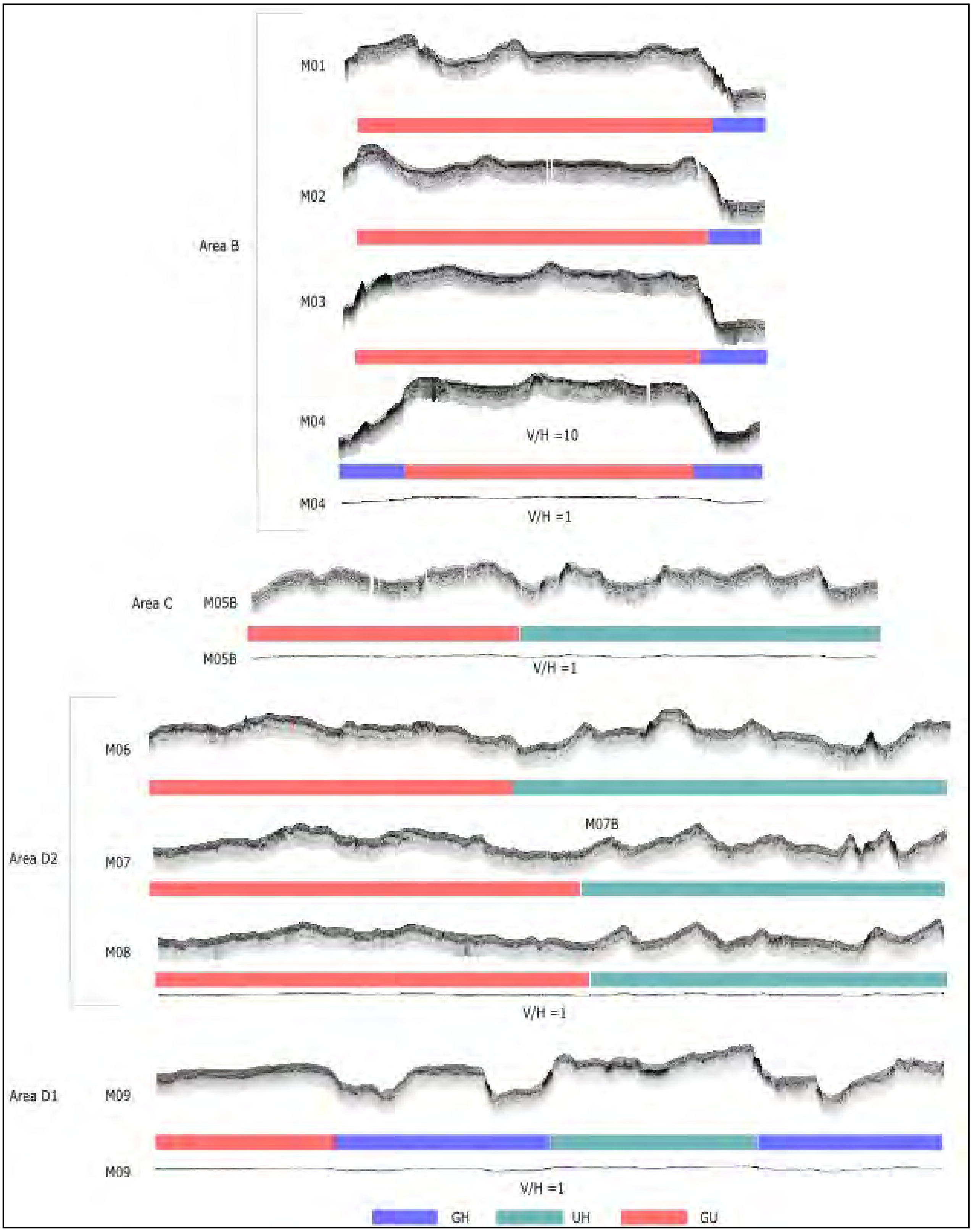
Swath is ~ 2km wide and sub-bottom profile thickness is ~ 100 m at V/H=10:1

7.4.5.3 Towed Sonar – Sub-bottom Profiler

The sub-bottom profiler was used to classify types of abyssal hills. Figure 7.72 shows profiles with three types of abyssal hill:

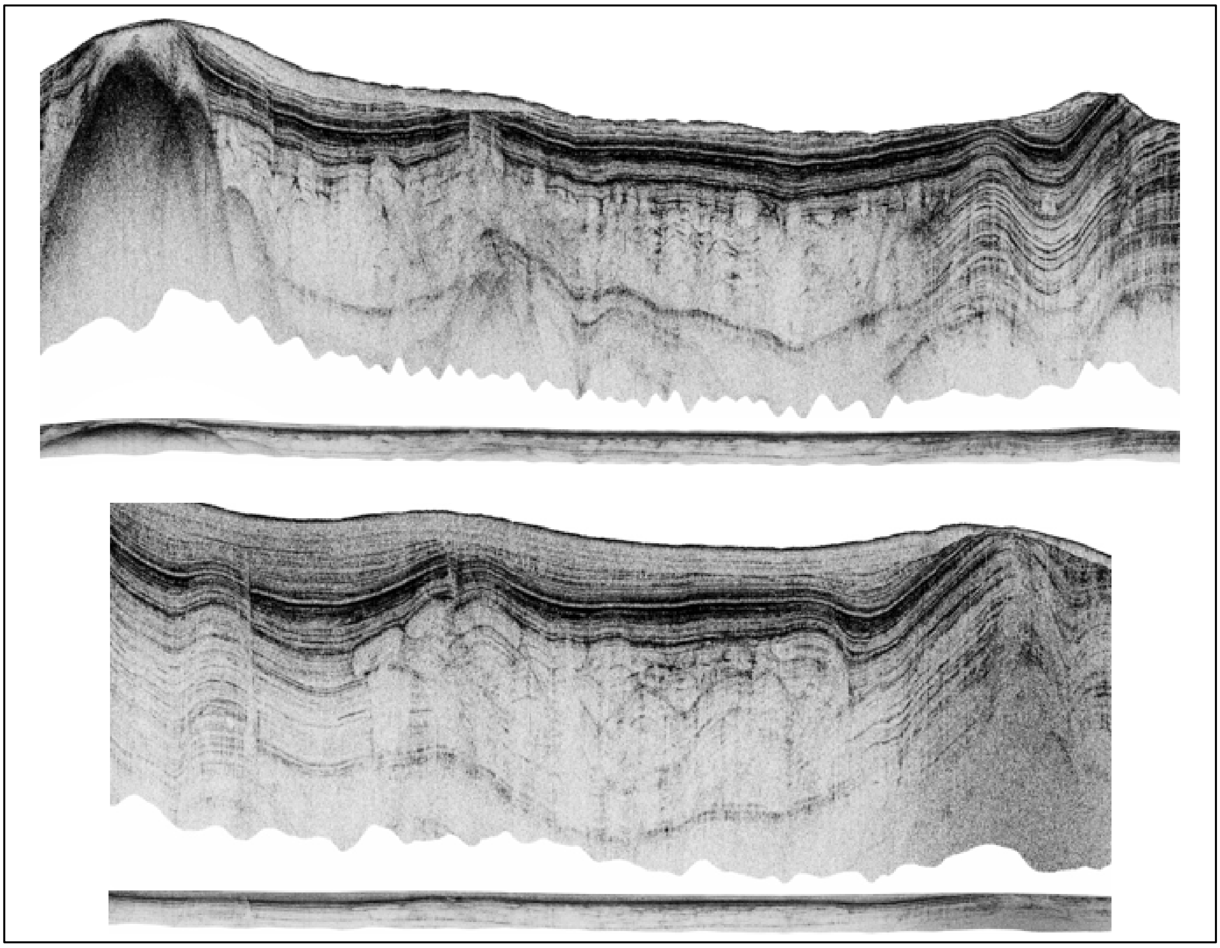
- GH stands for graben-horst and is the most rugged topography with fully developed grabens (valleys) and intermediate horsts (hills)
- UH stands for undulating hills and is less rugged than GH and typically includes half-grabens and warped rather than fault-blocked topography
- GU stands for gently undulating and is the most, gentle land form with warped gently undulating topography.

Figure 7.72 Abyssal hill classification from sub-bottom profiles



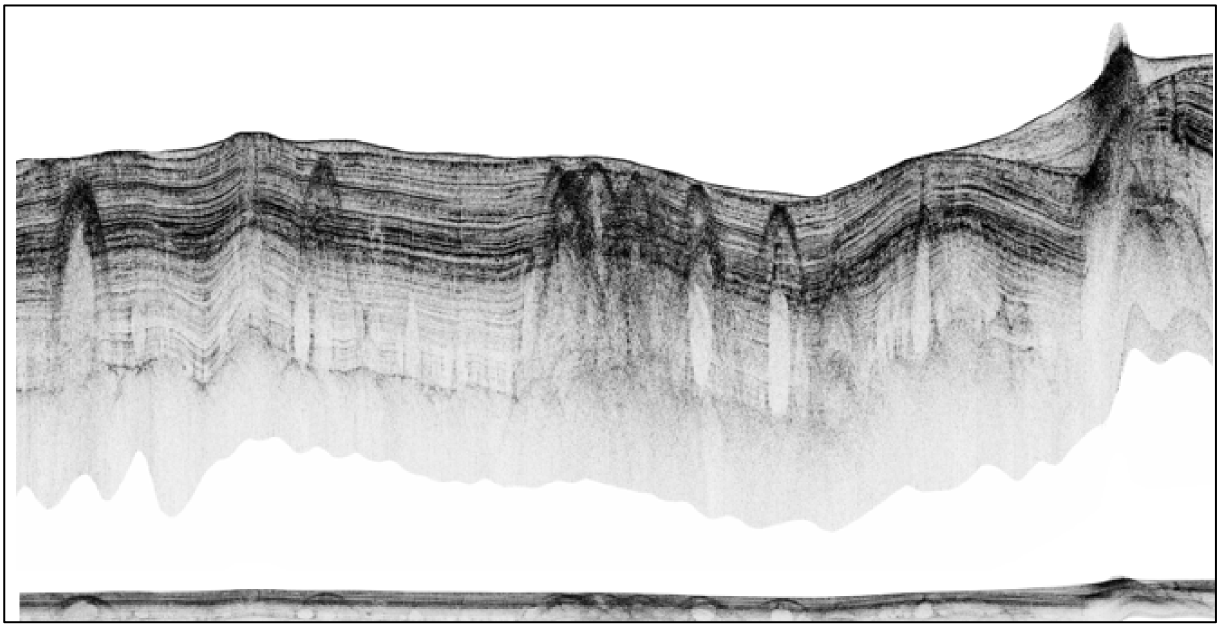
A range of other geological features can been seen on the sub-bottom profile sections, including faults, collapse features (probably related to a combination of faulting and carbonate dissolution; (Figure 7.73) and recent igneous activity including dykes (Figure 7.74) and sills (Figure 7.75). Of note are the “basin type” dissolution horizons that are found almost exclusively in grabens or down-warped areas. They have distinctly different sonar signature to the karstic features that typically form on hill crests.

Figure 7.73 Fault bound collapse-dissolution in carbonate



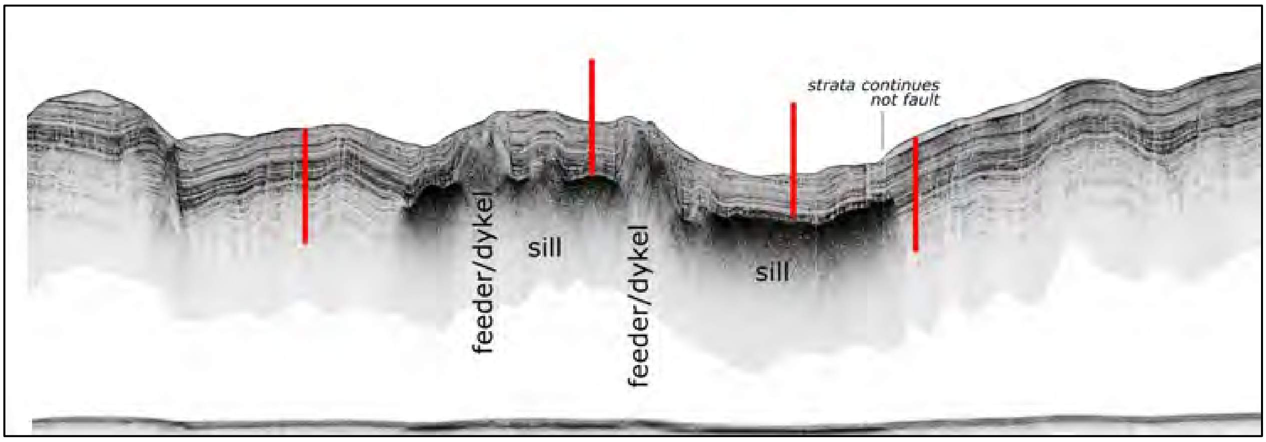
Profile is about 100 m thick: CCZ15-M04_(T), CCZ15-M03_(B) each section pair is V/H=10, and V/H=1

Figure 7.74 Possible dyke swarm in western subarea D 3454



Profile is about 100 m thick: (CCZ15-M06) section pair is V/H=10, and V/H=1

Figure 7.75 Possible late stage sill or peperite layer and feeders in DW0332, Area D1



Profile is about 100 m thick: section pair is V/H=10, and V/H=1

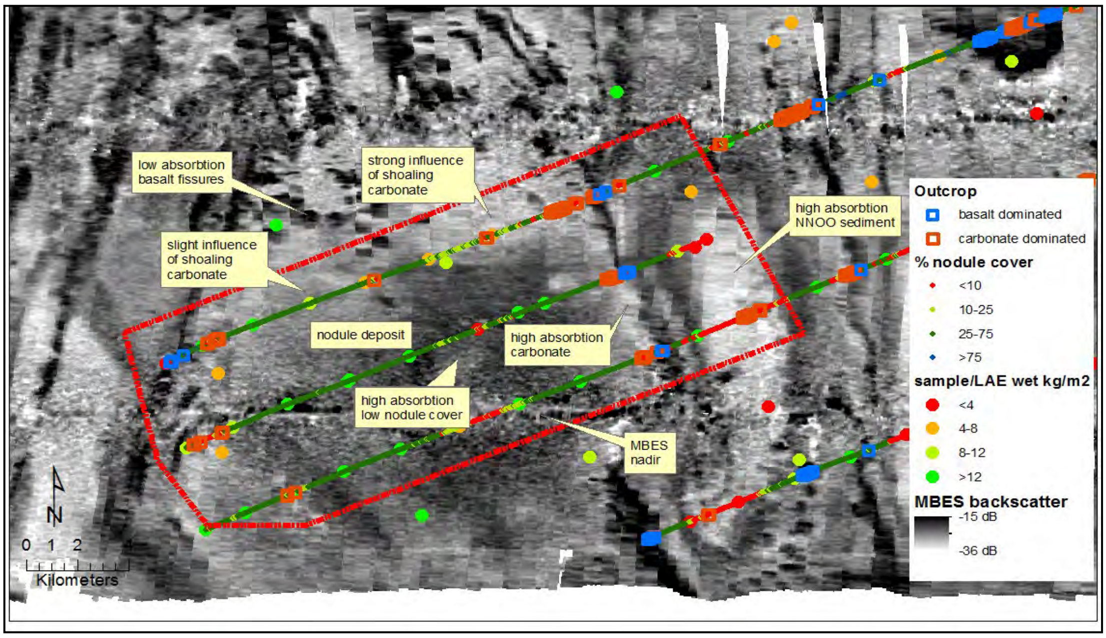
7.4.5.4 Relationship with backscatter

An indirect relationship between nodule abundance and acoustic response has been known for many years (e.g., ISA, 2010; Ruhlemann et al, 2011), and this was confirmed by the results of the two TOML campaigns. Essentially the backscatter response (or reflection) can be used in many cases to discriminate:

- Rock from sediment
- Sediment types (e.g., Calcareous versus siliceous)
- Sediment with or without nodules
- Sediment with larger or smaller nodules (and larger nodules often result in higher abundance).

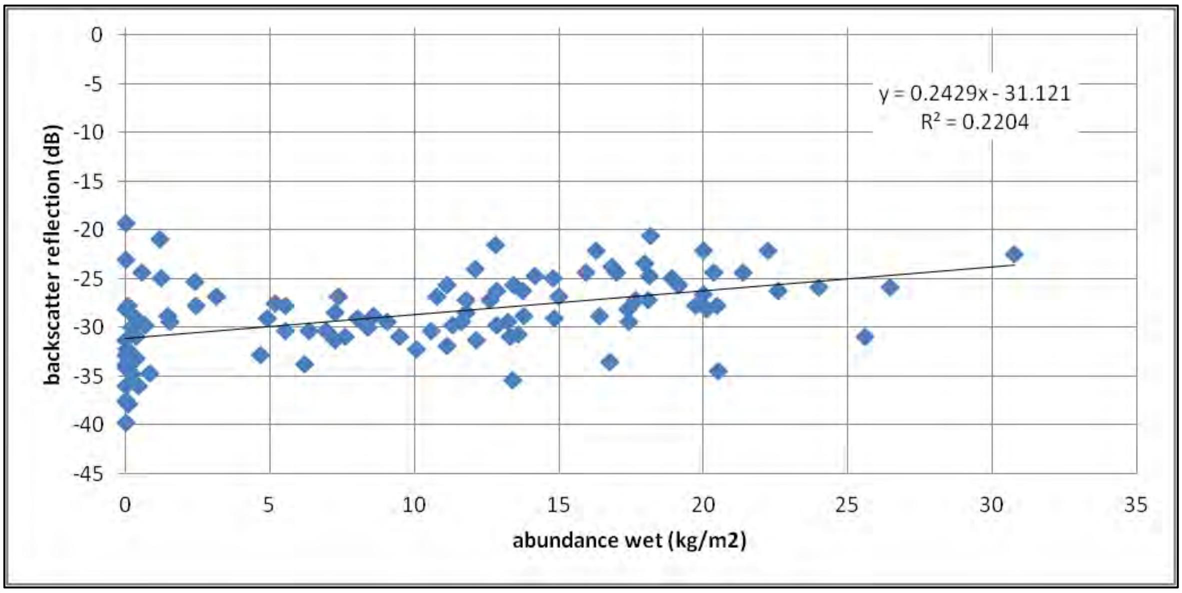
An example of characterisation is illustrated in Figure 7.76 and this response played a role in the map shown in Figure 7.71. The continuous nature of the nodules is evident from both acoustics and photo logging. Figure 7.77 quantifies the fair correspondence between abundance and acoustic reflectance and abundance and nodule coverage for TOML area B1.

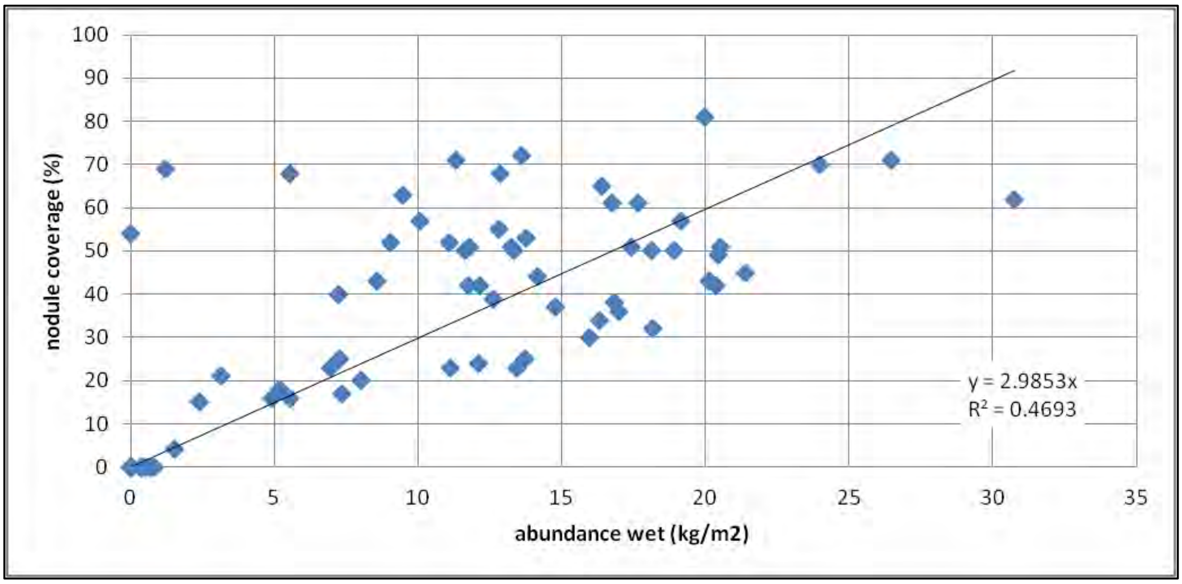
Figure 7.76 Characterised MBES backscatter response in B5338



Nodule cover from photo-profile lines ~3.5 km apart.

Figure 7.77 Relationships between abundance and acoustic reflection and nodule coverage





Area B1, include long-axis based estimates of nodule abundance

8 Sample preparation, analyses and security

8.1 Historical preparation, analysis and security

8.1.1 Historical sample preparation

The sampling programmes undertaken by previous explorers in the TOML tenement area, which comprise an important data set used here for resource estimation, include Japanese, French, and Russian data sets. In 2012, independent consultants Golder Associates (Golder, 2013) sent requests to the agencies responsible for each of these data sets but only received partial responses from Yuzhmorgeologiya (Russia; TOML Exploration Area B) and DORD (Japan; TOML Exploration Areas A and D) which are included below.

A Golder Associates subcontractor, (Dr Charles Morgan) had been previously directly involved with one of the US exploration programmes (OMCO) that was carried out during the same period as these other programmes, working as a Senior Scientist for Lockheed. This work included direct participation in resource assessment survey expeditions to the CCZ and development and implementation of sample preparation and analysis procedures. The description of sample preparation and analysis methods provided below is based on this experience.

Prior to establishment of the ISA, explorers working under different jurisdictions settled claim boundary overlaps through a process of negotiation and data exchange (e.g., NOAA, 1987). Though data were generally not exchanged until after negotiations related to exploration claim boundaries were completed, Morgan conferred with representatives of these consortia at several formal professional meetings and informal settings, comparing methods and procedures used for sample collection, analysis, and quality control. Many aspects of the OMCO procedures were used by the other explorers.

As described below, documentation of sample treatment methods has been provided by Professor Valeriy Yubko, Deputy Director of the Russian oceanographic institution Yuzhmorgeologiya, based in Gelendzhik, Russia and operating under the jurisdiction of the Russian Federal Agency of Natural Resources. Professor Yubko was a senior member of the Russian team that explored for polymetallic nodule deposits in the CCZ and delineated the Yuzhmorgeologiya exploration claim under the ISA. As shown in the following sections, the Russian methodology was very similar to the methodology practiced by the Lockheed group. Some details have also been provided by Dr Okazaki on the DORD sampling and analytical procedures. Dr Okazaki is current exploration manager for the CCZ nodule field for DORD. Ongoing use of wet weights for abundance by the BGR is also explained below.

8.1.1.1 OMCO procedures

Polymetallic nodule samples collected with FFG samplers were transferred directly from the sampler into individual plastic bins and carried below deck to the geochemical laboratory. In the laboratory they were laid out separately on a white surface marked with a scaled grid and photographed to permit determination of nodule size distribution. They were then sealed in labelled fibreglass-reinforced collection bags and stored in the ship's hold for the balance of the exploration campaign.

The bins and lay-out surface were cleaned between samples using filtered seawater and dry paper towels. No cleaning of the nodules was usually necessary, since any mud adhering to them would be swept off the nodule surface through the open mesh of the sampler collection net during the ~4,500 m ascent from the seafloor. Samples collected with box corers were processed in a similar manner, except that the adhering mud had to be rinsed off each nodule as it was removed from the box corer.

The collected sample bags were transported from the ship that almost always docked at a pier in San Diego Bay, to the Lockheed Ocean Laboratory, which was also located on the Bay at Harbor Island. Transfer of the samples from the ship to the secured laboratory storage facility was the first priority when the ship came to port and was always handled personally by the expedition crew and other Lockheed employees.

Prior to weighing, the samples were removed from the sample bags and placed in a single layer in labelled, open trays on tables in the air-conditioned laboratory for at least 12 hours to ensure a uniform degree of air drying. The samples were then weighed using a high-capacity laboratory scale and divided into two subsamples of approximately equal weight. As a portion of the nodules was to be kept uncrushed, the technicians were instructed to ensure as much as possible that both subsamples contained similar nodule size distributions to the original samples. One subsample was placed in a labelled jar and kept as a permanent archive. The second subsample was prepared for Atomic Absorption Spectrographic (AAS) analysis, as described below. This is a potential source of sample bias but OMCO minimised this risk by randomly selecting which sample was used for archive.

The second subsample was crushed using a jaw crusher (similar to the Retsch™ BB51 currently available; see Retsch, 2012) to produce a product with a maximum size of less than about 1 mm. The crushed sample was then mixed using a 3-axis shaker to achieve uniform mixing and to preclude any separation of the less dense detrital (siliceous) component from the more dense metal oxide component of the sample. The mixed sample was passed through a laboratory sample splitter as required to produce a 5 to 10 g subsample for AAS analysis. The remainder of the sample was then stored as a second, crushed archive sample. The subsample was further ground to a fine powder using a laboratory ball mill prior to assaying.

The powdered subsample was placed in a 110 °C drying oven for at least 6 hours to remove adsorbed water. It was then immediately transferred to a sealed desiccator to cool to ambient temperature. Cooled samples were weighed using a Mettler™ analytical balance and then transferred to Parr™ Teflon-lined high pressure digestion vessel. Reagent grade hydrofluoric, boric, and hydrochloric acids were introduced to the vessel, which was then sealed and heated for several hours to complete the digestion. The digested samples were then diluted as necessary with filtered, distilled water for AAS analysis using a Hewlett-Packard instrument. Standard analysis included determination of Mn, Fe, Co, Ni, Cu, Zn, Si, Ca and Mg.

Analytical accuracy was confirmed by periodic introduction of standards made from crushed, mixed, and powdered bulk nodule samples that had also been sent to three independent commercial laboratories for determination of these metal contents. Additional confirmation was achieved using standards formulated by the U.S. Geological Survey (A-1 and P-1; see Flanagan and Gottfried, 1980). These standards were subjected to the entire preparation procedure to ensure that no significant contamination was occurring and that no systematic analytical errors were being included in the process.

8.1.1.2 Yuzhmorgeologiya procedures

The measurement of abundance of nodules at the sample site was carried out using an ‘enclosed’ Ocean-0.25 grab sampler (Figure 8.1) with a 0.25 m^2 gripped surface and a depth of sampling of approximately 30 cm. The grab sampler was combined with GFU-6-8 photography unit. This device takes ocean bottom photos at the sampling point.

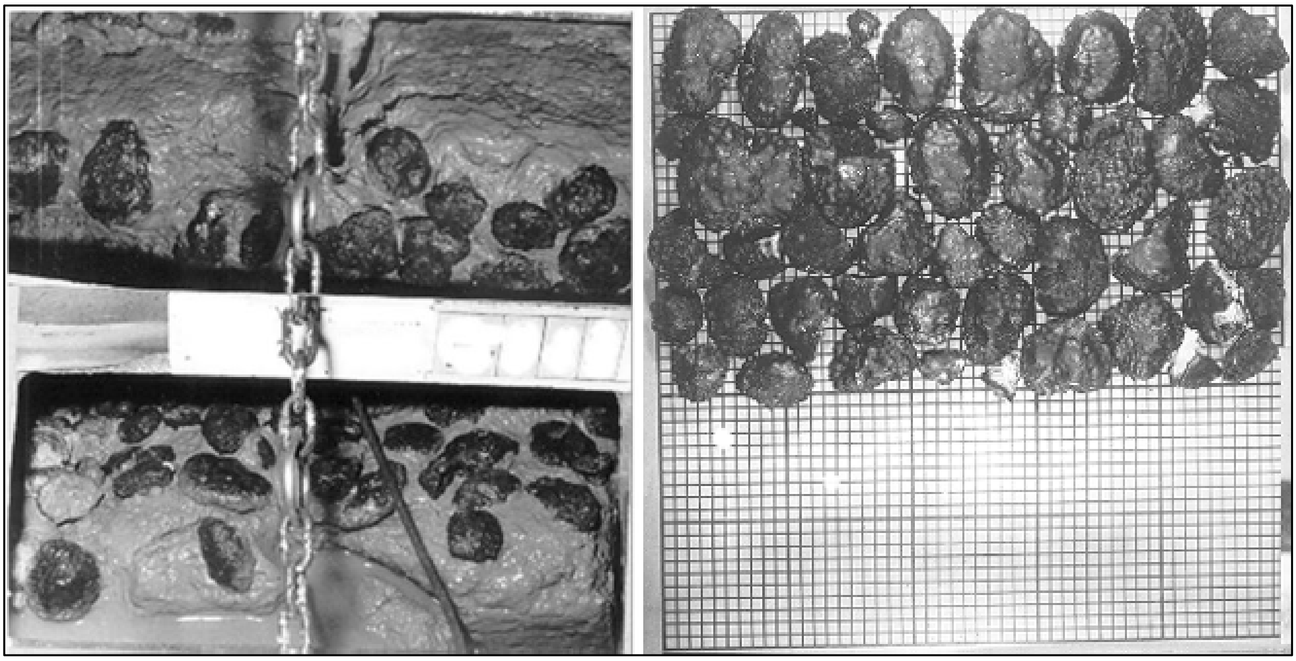
Figure 8.1 Ocean-0.25 Grab Sampler (Yubko, 2012)

The procedure for sub-sampling was:

1. Extraction of all nodules from the grab sampler (Figure 8.2).
2. Crushing of all nodules to a maximum particle size of up to 10 mm.
3. Drying (approximately 24 hours) of all samples at 105 °C until constant weight was achieved.
4. Crushing of all samples to 1 to 2 mm particle size and splitting of 400 to 500 g using a splitting device.
5. Pulverizing of the split sample (not less than 400 g) was carried out in the vibrating grinder up 100 mesh particle size (0.074 mm).
6. Formation of analytical sample (200 g) and its duplicate (200 g).

Chemical analyses were carried out on sub-samples with an approximate weight of 0.5 g, selected from the analytical sample. Determination of Ni, Cu, Co and Fe content was carried out by AAS and the content of Mn by a method of photometric (electrometric) titration.

Figure 8.2 Mn-nodules Inside Grab Sampler (left) and Outside Grab Sample (right) (Yubko, 2012)



8.1.1.3 DORD procedures

DORD's procedure for sampling (Okazaki, 2012) is understood to include:

- Each sample station is a combination of three sub-sampling points which effectively form an isosceles triangle with lengths of sides 1.4 nm, 1.4 nm and 2.0 nm.
- Collection was mostly by free fall grab, but at occasional stations a box corer was used at one of the three sub-sample points.
- In later campaigns at least (which may not include the TOML Exploration Area) a ship-borne X-ray fluorescence analyzer was used for the chemical analysis with some representative samples being assayed at an on-land laboratory to assess precision and accuracy.

8.1.1.4 BGR procedures

Ruhlemann et al. (2011) describe the sediment and nodule sampling process used by the BGR in recent times (2006) which is largely not relevant to the Pioneer Contractor data from the TOML Exploration Area. One exception however is their citing the ongoing use of a BGR procedure in the 1980s of washing sediment from collected nodules with specially cleaned seawater before determining their wet weight and converting this to a dry weight by means of a simple 30% reduction factor.

8.1.2 Historical Quality Assurance and Quality Control procedures

No systematic QAQC information is available as this information was not provided to the ISA. QAQC was known to be undertaken at the time of sampling as part of the scientific process used by each consortia (country). Data quality was assured using comparative measures between the different datasets (section 7.1.1) to prove that the samples within the TOML Exploration Area were not statistical outliers. This level of quality assurance was deemed suitable for a Mineral Resource at an Inferred level of confidence.

As part of the requirements by ISA, the Pioneer Contractors were required to relinquish half of their claim to the ISA as reserved blocks. During this process the ISA reviewed the sampling data to ensure that the splitting of the claim was even with equal abundance and grade occurring in the retained portion of the claim and the parts being relinquished. As such, the ISA has accepted the data (and quality) supplied by the Pioneer Contractors.

8.1.3 Historical adequacy of sample preparation, security and analytical procedures

Free fall grab samplers consistently underestimate the actual abundance but provide samples that can be used to determine adequate estimates of the grade of the surface nodules (Hennigar, Dick and Foell, 1986). Even today they are the most efficient tool available for sampling the nodules at the seafloor. This is because a number of them can be deployed at any one time from the survey vessel allowing an order of magnitude greater speed in collection i.e. approximately 10 to 20 samples per day for a FFG versus 2 to 3 samples per day for a BC that is winched to and from the seafloor.

In many cases, it is unknown exactly when the nodule weights have been taken by the Pioneer Contractors. Thus it has been assumed that the samples were weighed shortly after recovery on board the exploration vessels (or back at base) and usually before any splitting or crushing. This partial assumption is more conservative in any tonnage estimate than the alternative that the abundance weights are for dried nodules. It also fits well with Dr Charles Morgan's experience with sampling in the CCZ and the process description provided by Yuzhmorgeologiya.

Overall, the comparison of the sampling and assaying between the Pioneer Contractors show that the data are adequate for geological modelling and are reliable for Mineral Resource estimation at an Inferred level of confidence. This is supported by the very similar grades obtained in the TOML sampling.

8.2 TOML preparation, analysis and security

8.2.1 Sample Chain of Custody

Refer also to Section7 regarding TOML's exploration programme, including sampling methodology.

For box-core samples the Primary Sample handling from sample tube handover to lab was managed only by the TOML ship-based science team under the supervision of one Chief Scientist and two Lead Scientists.

Primary Samples were weighed on deck or in the lab (preliminary weight), washed, weighed again (washed weight) and then moved to the main lab and stored in an exclusive designated area.

At periodic intervals Primary Samples were laid out by Chief Scientist and the Lead Scientist Responsible in the main lab (which was closed to all other people during the process). After air-drying to remove surface water, the Primary Samples were weighed again (air-dried weight; used for abundance estimation for the Mineral Resource estimate) and then some samples were split for Field Duplicates by cone and quarter and for all samples by picking for Reference Samples (~1–6 nodules proportional to the sample size). The sample remaining after these splits were removed is the Main Sample, and the chemical analysis of this was used to support the grade estimation for the Mineral Resource estimate. Weight estimates were recorded on a dedicated written log by the Lead Scientists and Chief Scientist, with scanned backups, and then typed into a master Excel spreadsheet by the Chief Scientist. Recorded washed weights were included in the Daily Progress Reports sent to the head office.

Main samples were then sealed using tamperproof tape or tags into specially marked drums that were sealed with tamperproof tape. The drums were escorted by the Chief Scientist or Lead Scientist Responsible to a storage reefer on the deck of the vessel. The reefer was repacked twice during the voyage due to processing of biological samples and to aid quarantine clearance, with only partial supervision at this stage by the Chief Scientist or Lead Scientist Responsible.

On arrival into port (Panama), the container was sealed by the Chief Scientist using a padlock. Spare keys were held by the agent in case inspection was needed, but in the end, this was not required. The Field Duplicates were couriered to the specialist laboratory at Jacobs University Bremen and the Reference Samples were couriered to the Brisbane office of TOML parent company Nautilus Minerals.

The Field Duplicates were received by Laboratory Staff at Jacobs University, prepared at the BGR laboratory in Hannover and analysed using ICP at Jacobs. Results were emailed in an excel spreadsheet to the Chief Scientist.

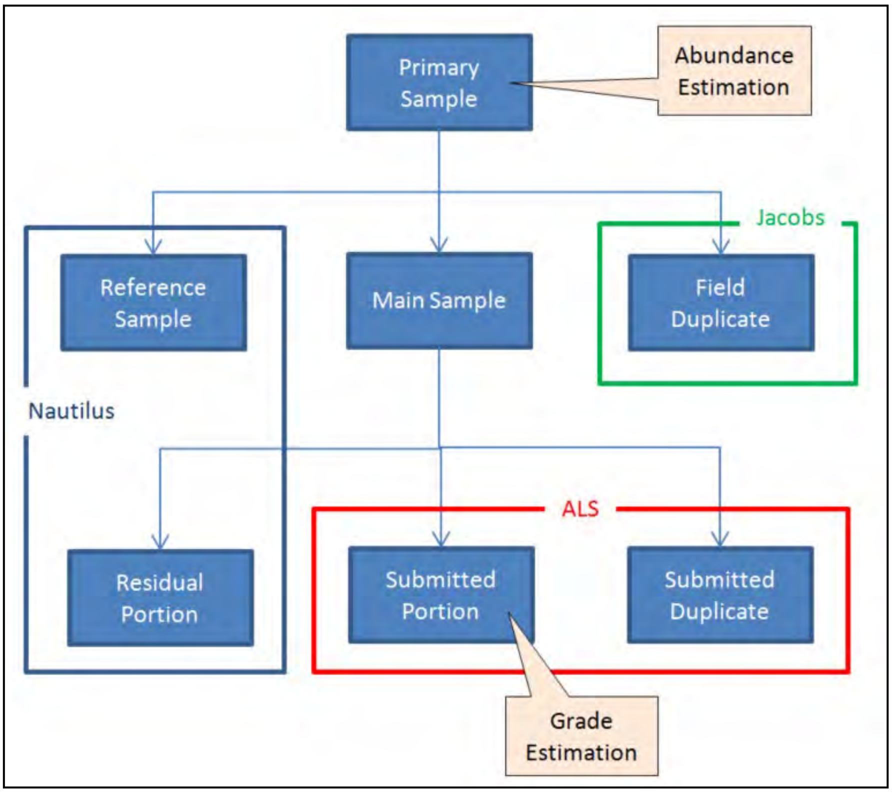
On arrival of the container into Brisbane (where the analytical laboratory is located), the opening of the container was supervised by the Mineral Resource Qualified Person. The drums were inspected and all tamperproof tape was intact. The drums were collected by an employee of Australian Laboratory Services and transported to their lab in Brisbane.

At the laboratory, the Mineral Resource Qualified Person and an assistant cone and quarter split the Main Sample again; for all samples a Submitted Portion was taken for crushing, grinding and chemical analysis, and for samples of sufficient size a Residual Portion was retained for storage. For some samples a Submitted Duplicate was also collected. The Submitted Portion and Submitted Duplicate were prepared then analysed by ALS in Brisbane using XRF (details below) and the results emailed as datasheets in excel format and by certificate in pdf format to the Chief Scientist. ALS maintain certified sample handling systems (see below) with step by step monitoring, which can be produced/interrogated on request. This includes the use of Blanks, Laboratory Duplicates and Certified Standards. Processed pulps of the submitted portion and submitted duplicate are stored at ALS for the moment. The Residual Portion was collected from ALS by TOML staff and stored in Nautilus Sample Repository in Virginia, Queensland, where it has been used for characterisation test work.

Chemical data received by the Chief Scientist is stored in raw format on a server and captured with relevant sample information within a Nautilus Acquire database system.

Sample COC is summarised in Figure 8.3. Chain of Custody for the abundance estimation has been overseen by Chief Scientist and the two Lead Scientists. Chain of Custody for the grade estimation extends from them to the Mineral Resource Qualified Person and ALS Staff. The Chief Scientist is also serving as Qualified Person for Geology and Mineralisation and for Deposit Types.

Figure 8.3 COC sample flow (box-core samples)



Process for the dredge samples was simpler as their results do not inform the Mineral Resource estimate. In both the CCZ13 and CCZ15 campaign dredge-variance sub-samples Submitted Portions were sent to ALS and Field Duplicates were sent to Jacobs. The dredge samples are bulk samples (between 40 and 800 kg) so the Reference Sample is the bulk of the material. There is no Residual Portion or Submitted Duplicate involved in the dredge samples.

Jacobs was selected as the check laboratory as it has a long history of working with nodules, including considerable work on REE. Jacobs does the analyses for the German Contractor (BGR). Samples were analysed by a combination of ICP-MS and ICP-OES.

ALS was selected as the main laboratory as it has full commercial QAQC procedures in place and is expert in analysing manganese ores. Samples were analysed by both fused disk XRF (for reported Ni, Cu, Co, Mn) and ICP-AES for trace and minor elements.

8.2.2 Laboratory analysis methods

8.2.2.1 ALS

ALS Laboratory Group in Brisbane, Australia has extensive experience in the analysis of high manganese materials by the XRF method. ALS operates quality systems based on international standards ISO/IEC17025:1999 "General requirements for competence of calibration and testing laboratories" and ISO9001:2000 "Quality Management Systems - Requirements".

ALS-Brisbane described their preparation processes as:

Samples are sorted into sequential order. Samples are then transferred to barcode labelled aluminium trays and loaded onto trolleys which are placed in a large natural gas fired oven for drying. Oven temperature is a maximum of 105 degrees but more typically, temperature is ~90 degrees. After drying, samples are jaw crushed in a Jacques jaw crusher to bring particle size to less than 10mm. Assuming samples weigh less than 3 kg, the crushed samples is then pulverised in an LM5 mill to a powder with typical particle size >85% passing 75um. Very small samples are pulverised in a smaller bowl using an LM2 mill.

Firstly for our fusion / XRF method, it is standard practice for us to:

- Place an approximate 0.33 g aliquot into a glass vial, which is then placed in an oven at 105 degrees for a minimum of 1 hour (usually more);
- The sample is then removed from the oven and immediately weighed in the vial (still warm);
- The dried sample is then transferred to the tared platinum crucible for fusion.

Note that our XRF26s procedure is specifically designed for difficult to fuse chromite and manganese ores, hence the small aliquot.

Our normal procedure for our ICP method is not to re-dry samples after the initial drying prior to crushing and pulverising. Nautilus originally specified a drying temperature of only 90 degree Celsius. However when we initially compared the nodule elements that had been reported both by XRF and ICPAES, in general, the XRF results were higher. We realised from some drying testwork we were doing and our experience with bauxites and nickel laterites that was likely due to reabsorption of moisture. We then went back and:

- Placed the boxes of pulverised samples in paper bags in an oven for 6 hours at 105 degrees;
- The box was removed from the oven prior to weighing the sample aliquots and one by one each sample was weighed.
- There was no dessication and the last few samples in the box may have been out of the oven for almost an hour prior to being weighed.

This in general resulted in ICPAES results much closer to those reported by XRF.

ALS supplied analytical data by chromite/manganese ore fused disk XRF method (ME-XRF26s) for all samples:

- LOI, Al_2O_3, BaO, CaO, Cr_2O_3, CoO, Fe_2O_3, K_2O, CuO, MgO, MnO, Na_2O, P_2O_5, SO_3, SiO_2, NiO, TiO_2, PbO, ZnO

They also supplied data by high grade four acid ICP-AES method (ME-ICP61a) for select samples (including all box-cores):

- Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Sc, Sr, Th, Ti, Tl, U, V, W, Zn

Many of the above elements were at levels below the detection limit of ME-ICP61a.

8.2.2.2 Jacobs

Jacobs is the Laboratory operated by the Integrated Environmental Studies Program Group, Earth and Space Sciences Program, at Jacobs University in Bremen, Germany. This group has been involved in nodule analysis and study for over 10 years and have been integral to much of the development of nodule standards used in the industry. They describe their preparation as follows:

> The Fe-Mn nodules provided were powdered. In case of small sample bags the whole material was first crushed and then homogenized and powdered in an achate ball mill. Material provided in large (several kilograms) sample bags was first crushed and then splitted using a riffle splitter. One representative sample split (100-200 g) was then homogenized and powdered using the achate ball mill.
>
> For sample decomposition, the nodule powders were dried for approximately 12 hours at 105 °C prior to digestion. Precisely weighed 50 mg aliquots of each dried sample were digested in 30 ml PTFE (polytetrafluoroethylene) pressure vessels using a PicoTrace DAS acid digestion system (Bovenden, Germany). The dried

powders were dissolved with ultrapure concentrated acids, initially with 5 ml of a mixture of hydrochloric (HCl), nitric (HNO_3), and hydrofluoric (HF) acids (ratio of 3:1:1, respectively), at 180 °C for 12 hours. After cooling, samples were evaporated at 120°C for approximately 2 hours to near dryness, re-dissolved with 3 ml 20% HCl and heated again at 120 °C to near dryness. The residues were taken up again in 3 ml 20% HCl and heated at 120 °C to near dryness. Finally, the residues were diluted to 50.0 g in 0.5 M HNO_3 / 0.05 M HCl and immediately analyzed.

Major and minor element analysis was carried out using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Perkin Elmer NEXION 350X quadrupole instrument) for the determination of REE, Y, Sc, Ti, Rb, Zr, Nb, Mo, Cs, Ba, Hf, Ta, W, Pb, Th, U, while Fe, Mn, Mg, Ca, Na, Al, P, Sr, Cu, Co, Ni, Zn, V were determined with Inductively Coupled Plasma Optical Spectrometry (ICP-OES, SpectroCiros SOP instrument).

Accuracy and reproducibility of chemical analyses were checked with the certified reference materials Nod-P-1 (USGS). The measured concentrations are in very good agreement with published data (Table 2), proving the accuracy of the analytical methods. We also report the method precision of the ICP-MS and ICP-OES measurements, which is defined as the precision of multiple sample decomposition and measurement of a reference standard as % relative standard deviation (%RSD). The method precision of the ICP-MS measurements is generally very good and better than 2 % for all elements of the reference standard NOD-P1 (n=4), except for Rb (3%) and Ta (9%). Method precision of ICP-OES is better than 2% for most elements, except for Ca, Co, Li, Ni, and V (<3%) and for P and V (<5%).

Jacobs thus supplied data by single acid (0.5M HNO_3) ICP-OES for all samples:

- Al, Ca, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Sr, V, Zn

They also supplied data by 0.5M HNO_3 ICP-MS for selected samples:

- Li, Be, Sc, Ti, Rb, Y, Zr, Nb, Mo, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pb, Th, U

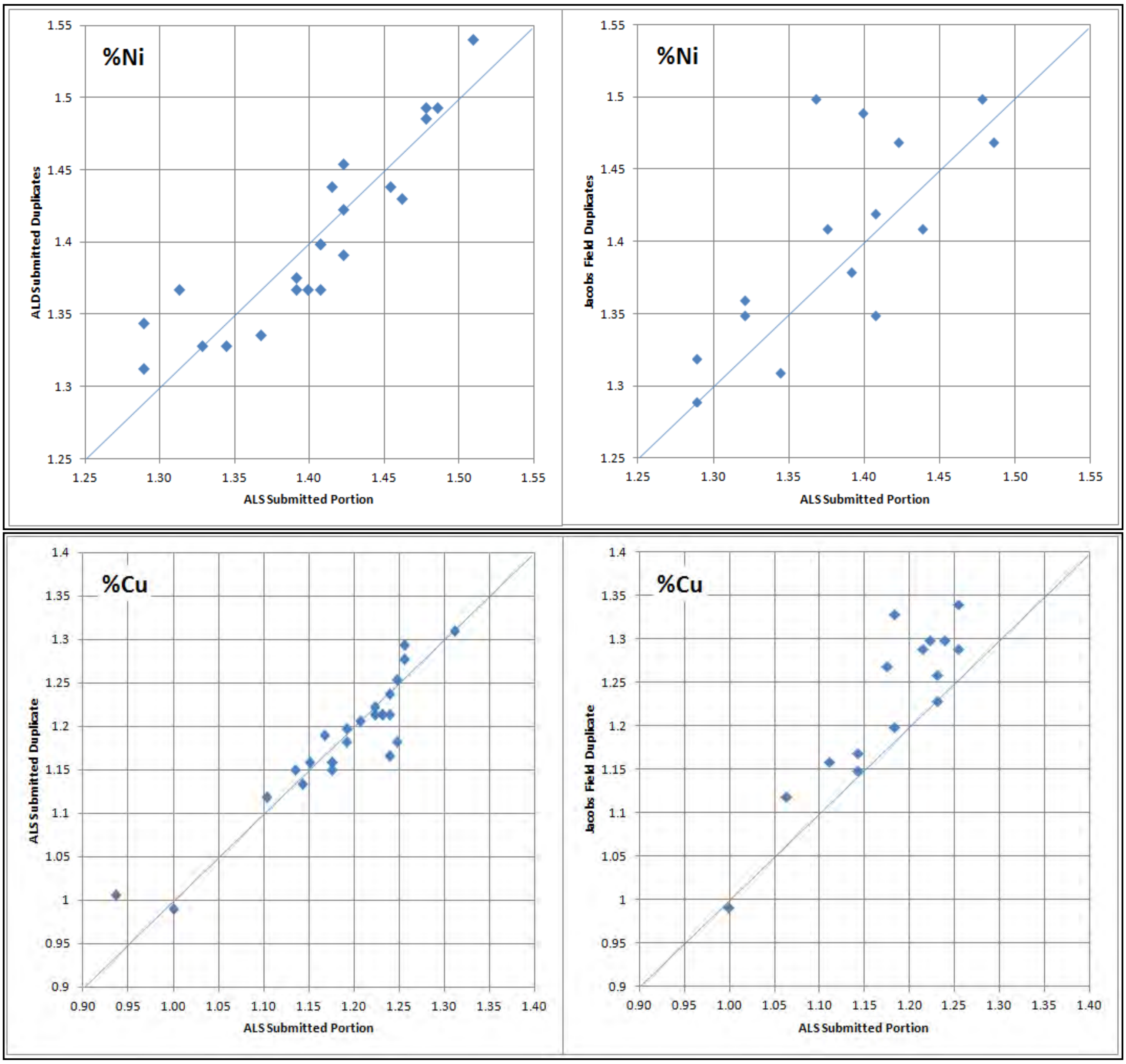
8.2.3 TOML Quality Assurance and Quality Control procedures

For the 104 box-core Submitted Portion samples submitted to ALS, 34 were duplicated (32.6%) with:

- 25 Submitted Duplicates to ALS (24.0%); and
- 15 Field Duplicates to Jacobs (14.4%).

Six Submitted Portion samples were duplicated both as Submitted Duplicates and Field Duplicates (5.7%).

Figure 8.4 Comparison of Nickel and Copper grades in duplicates



Field Duplicates from the box-core Primary Samples were produced using the cone and quarter technique once the final air-dried weighing step was completed.

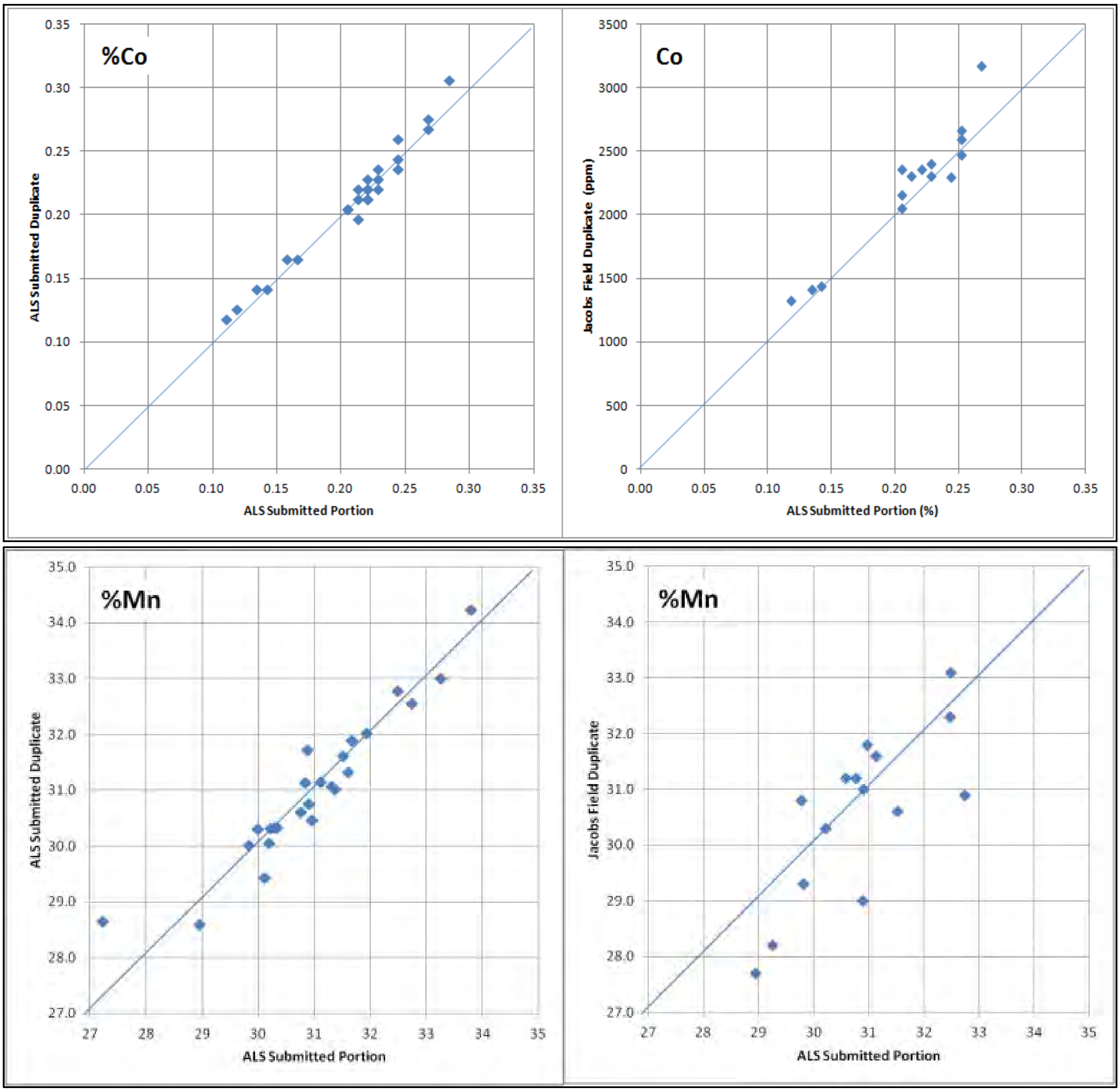
Reference samples from the box-core Primary Samples were taken at the same time but were selected on the basis of preference for entire nodules over a range of sizes and textures (if such a range was present) with an intent to include the most common forms of nodules.

Submitted Duplicates from the box-core Main Samples were produced using the cone and quarter technique.

Dredge “variance” samples were picked from all sides of the dredge pile with an attempt not to bias based on size or form. Dredge “variance” sample Field Duplicates were taken by snapping picked samples in half. These results give a good indication of the degree of inter-sample variance that might be expected.

Comparisons of duplicate results for Ni, Cu, Co and Mn are illustrated in Figure 8.4 and Figure 8.5. With Half Relative Difference analysis in Table 8.1 and Table 8.2.

Figure 8.5 Comparison of Cobalt and Manganese grades in duplicates



All Submitted Duplicates correlate very well with their Submitted Portion pairs). Field Duplicates correlate well with their Submitted Portion pairs except for high copper samples (bias high to Jacobs) and maybe low grade manganese (but the number of samples is too few to be sure and the relative difference is low; Table 8.2).

Table 8.1 Half Relative Difference Submitted Portions and Submitted Duplicates

	Co	Cu	Mn	Ni
Min	–3.44	–3.70	–2.55	–2.09
Max	3.84	2.99	1.13	1.42
Mean	–0.455	0.0995	–0.0506	0.0131

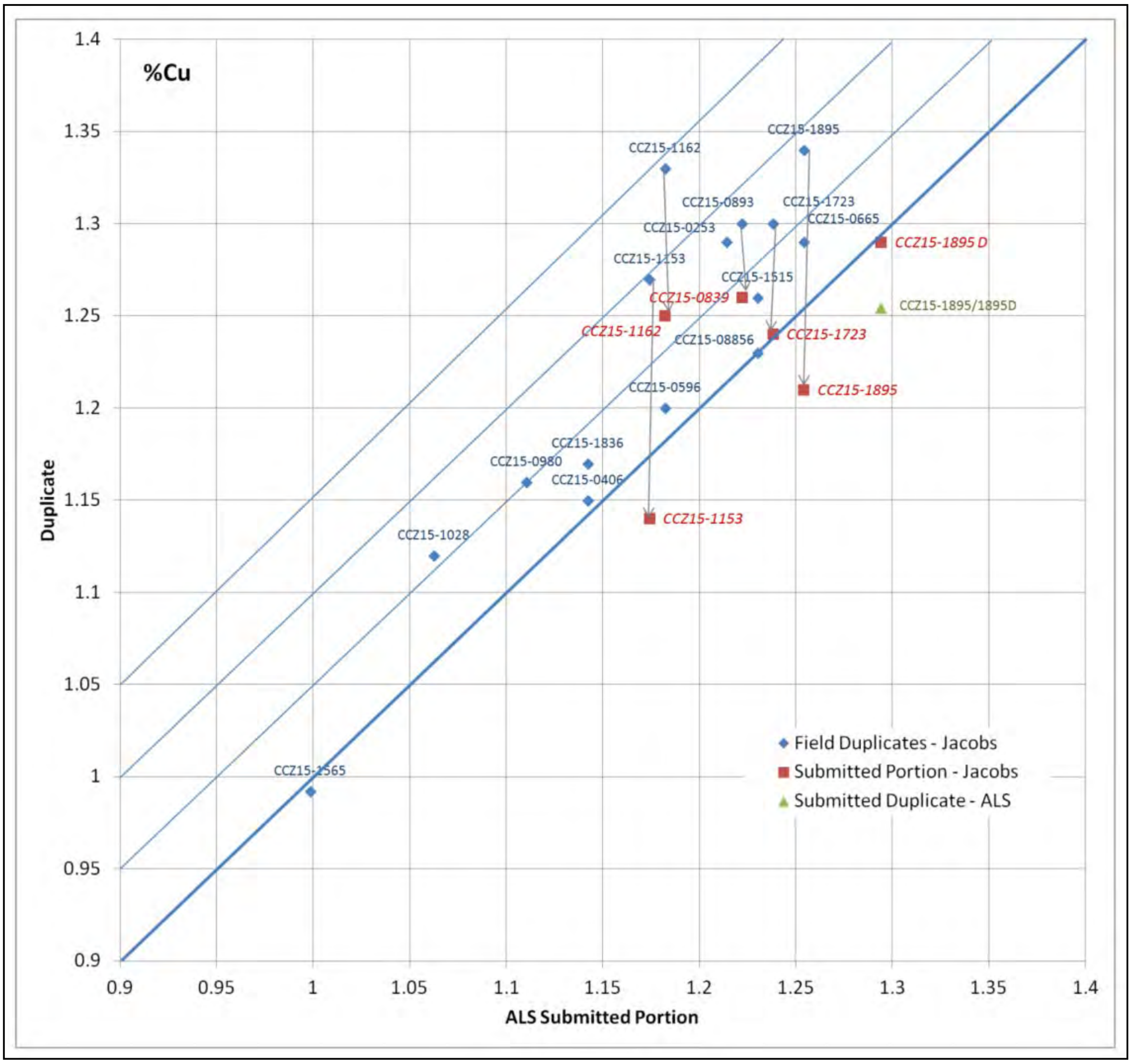
Half Relative Difference = difference between samples divided by their mean and times 0.5 and times 100

Table 8.2 Half Relative Difference Submitted Portions and Field Duplicates

	Co	Cu	Mn	Ni
Min	–8.62	–5.88	–1.70	–1.09
Max	2.93	0.330	3.15	50.0
Mean	–2.70	–2.07	0.399	30.0

Field Duplicates sent to Jacobs (analysis by ICP) generally compare very well with Submitted Portion analysed by ALS (XRF) with the exception of high copper samples (Figure 8.6), where there appears to be a bias of the order of 0.05 to 0.1 % Cu with Jacobs reading higher than ALS. On a relative basis this difference is not severe (Table 8.2).

Figure 8.6 Comparison of high grade copper duplicates



Selected high copper samples were reanalysed with additional standards by ALS without appreciable difference, then an aliquot of the Submitted Portion pulp was sent to Jacobs. Jacobs analysis of these aliquots is in broad agreement with the ALS results, indicating either contamination of the Field Duplicates during preparation or most likely a change in instrument calibration at Jacobs. The analysis supports that the ALS analysis of the Submitted Portion is valid for Cu at all grades.

8.2.4 Blanks, Laboratory Duplicates and Standards

Numbers of blanks, laboratory duplicates and standards are presented below. Note that Jacobs refers to duplicates as replicates.

Table 8.3 Blanks Laboratory Duplicates and Standards

	ALS			Jacobs
	XRF	LOI	ICP	ICP
Box-core samples analysed[i]	131			–
Laboratory duplicates	6	9	8	4[iii]
Blanks	4		8	–
Non-nodule standards	12	9	8	–
Dredge samples analysed[ii]	–			–
Laboratory duplicates	11	9	–	2
Blanks	6		–	–
Non-nodule standards	17	9	–	–
Nodule standards	5	–	–	7[iv]

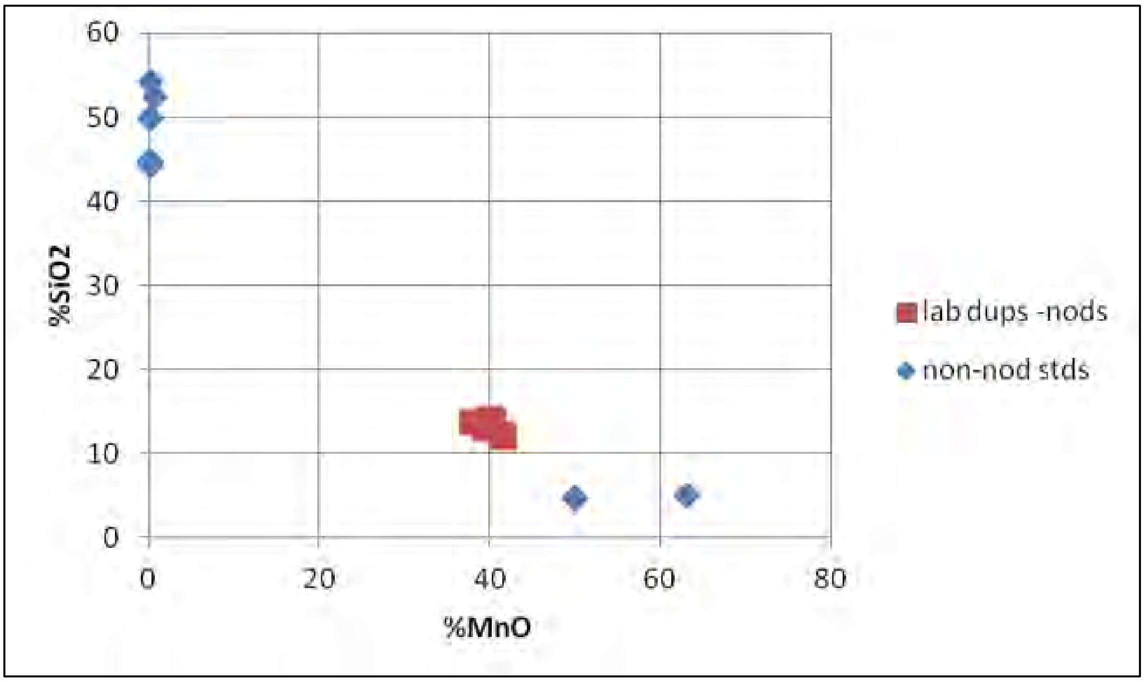
[i] Includes 25 submitted duplicates as well as a crust and a buried nodule analysed for research purposes

[ii] For the purposes of this note only samples collected during CCZ15 included here

[iii] Two duplicates being replicate digestion from the same pulp split and two being replicates from a separate pulp split

[iv] Jacobs analysed dredge and box-core samples as a single batch; ALS analysed the dredge samples approximately 7 days after the box-core samples

Figure 8.7 ALS Laboratory duplicates and non-nodule standards



All ALS blanks were below detection limit for the key elements of interest (reported in the mineral resource), i.e. Ni, Mn, Cu, Co. One batch of four blanks retuned Ga values of up to 28% of the mean for nodules but other elements were below or near detection limits.

Within the ALS box-core QAQC set, the range of non-nodule standards are compared with the laboratory duplicates in Figure 8.7 for the two most relevant elements Mn and Si. For these elements all of the analysed standards were within acceptable bounds.

Figure 8.8 ALS Laboratory duplicates compared to submitted portions

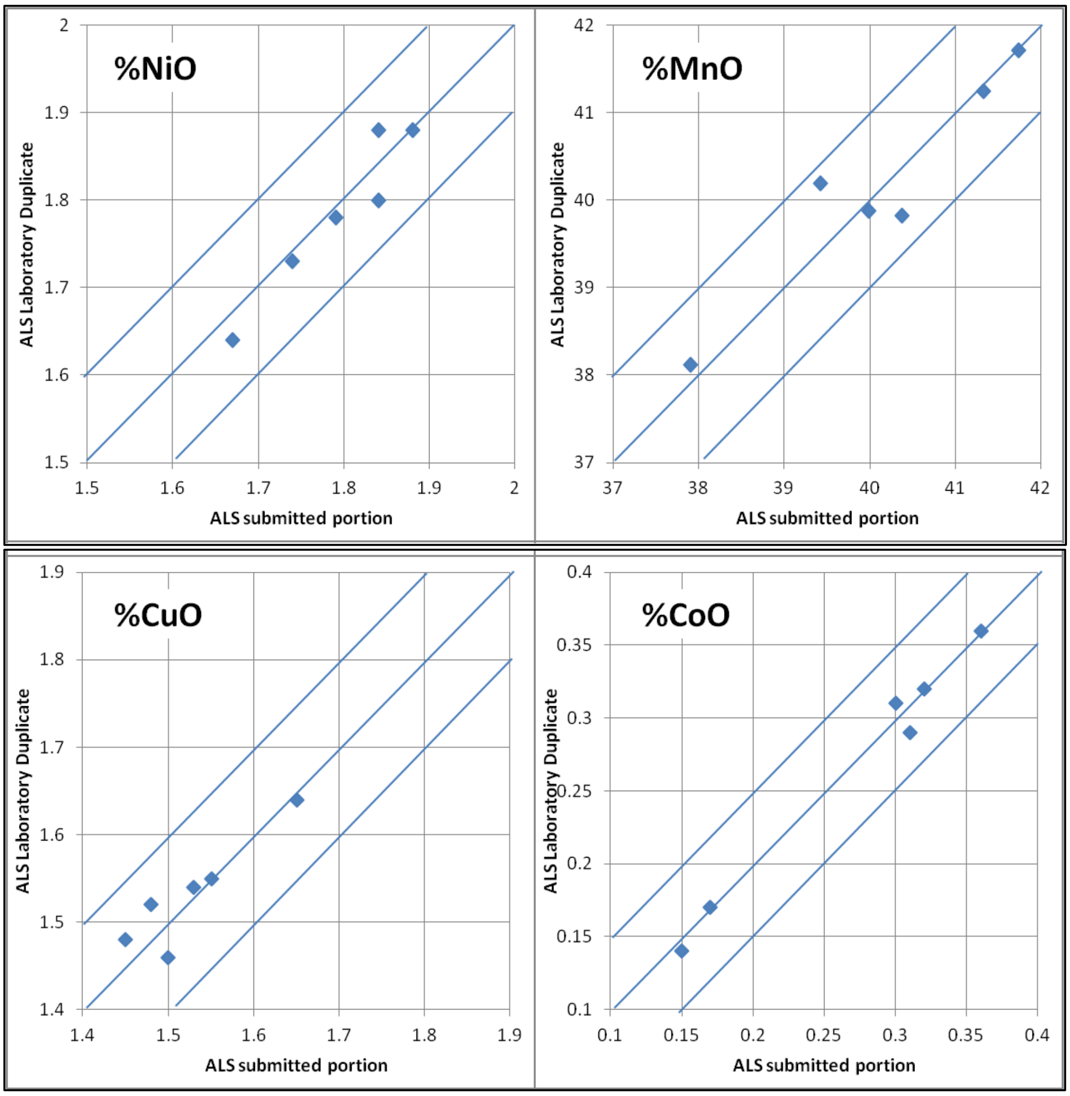
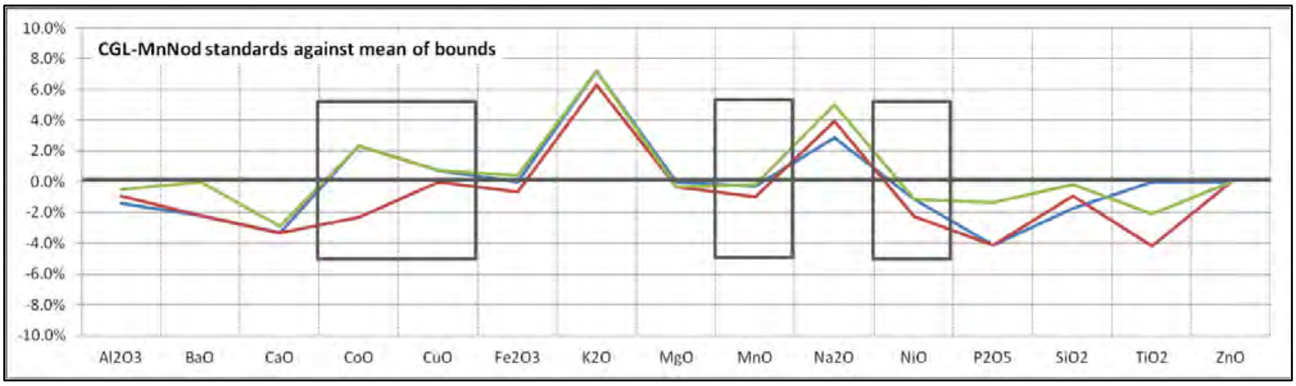


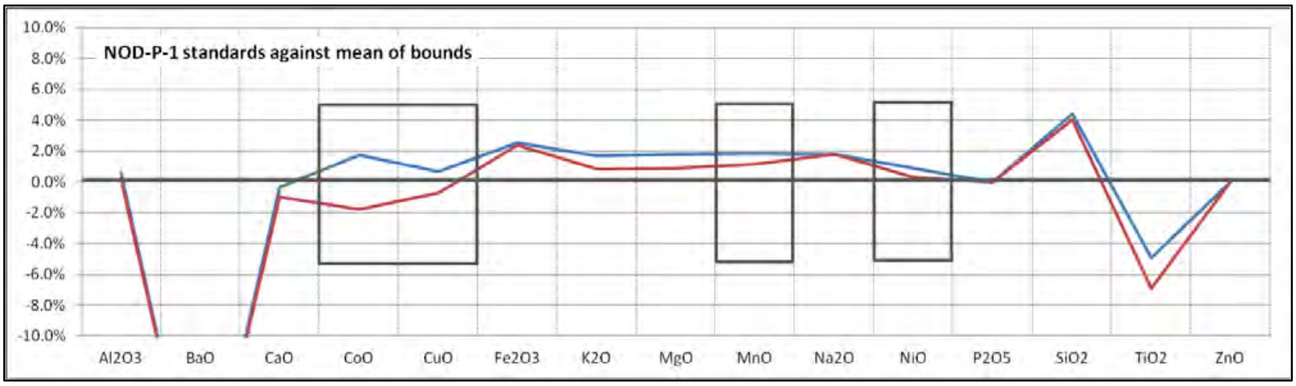
Figure 8.8 shows the close agreement between ALS laboratory duplicates (separate aliquot from pulverised material) and the original analyses of the Submitted Portions. Laboratory duplicates by Jacobs for Ni, Cu, Co and Mn are all within 3% relative agreement.

Figure 8.9 ALS performance against the CGL-131 nodule standard



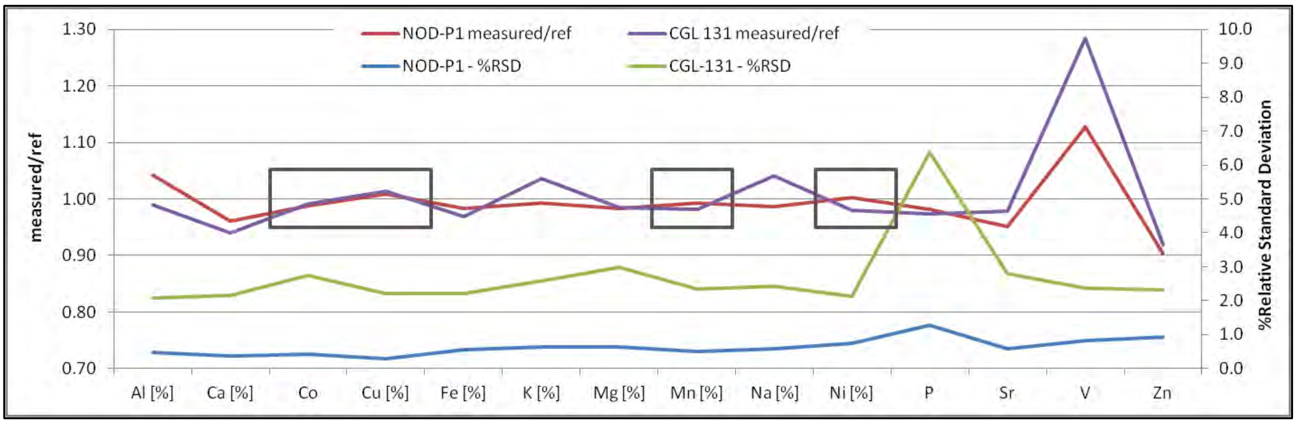
Grey boxes are ±5% relative for key elements of interest

Figure 8.10 ALS performance against the NOD-P1 standard



Grey boxes are ±5% relative for key elements of interest

Figure 8.11 Jacobs performance against the CGL-131 and NOD-P1 standards for Cu re-analysis work



Grey boxes are ±5% relative for key elements of interest – the special run of these standards are not included in Table 8.1

8.2.5 TOML photo abundance estimates Chain of Custody

Nodule abundance was estimated by TOML using two methods:

1. Physical samples using a box-corer (see COC above).
2. Long axis based estimates from photographs.

Photographs were taken during the CCZ15 campaign by contractor Yuzhmorgeologiya. The photos were transmitted from the towed camera sled in real time to a camera operator and were automatically named with the date and time (in UTC) of the survey. File posting location was on a secure server (airwalled) with access by camera operator, surveyor and geoscientists.

Location of the camera sled at the time of photography was recorded separately by the Yuzhmorgeologiya hydrographic surveyor on watch using a combination of vessel GPS and either USBL signal or estimate of position from length of line out. Survey periods are recorded in the bridge log, vessel log and daily progress reports.

Photos were logged in near real time for geology and biology, with periodic updates of photo files to the filing on the TOML master computer.

Abundance estimates were made only for select photos due to the intense nature of the work and issues with sediment cover in some areas. Normally in TOML Areas B1 and C1 every 100th photo was selected. The selected photos were georeferenced to a template in a GIS program by a geoscientist and the long axis of each nodule within selected swaths was digitised. Each photo was checked by the Lead Geoscientist on watch and by the Lead Geoscientist designated accountable for data quality. The Chief Scientist ran a routine to measure the digitised lengths and also compiled the data into a MS Access database.

Copies of the processed data were passed, via email, to the Mineral Resource Qualified Person midway through the photo-profiling programme and after the campaign.

8.2.6 TOML adequacy of sample preparation security and analytical procedures

TOML had clear and secure chain of custody for the nodule samples collected during their exploration campaigns. Sufficient Field and Submitted Duplicates have been taken to demonstrate lack of significant error in the chemical analyses. TOML also followed rigorous procedures for abundance estimation using both physical samples and photographs, with good correlation and validation.

Data storage is secure and there is no evidence of any tampering of grade and abundance measurements.

Overall, the data are reliable for Mineral Resource estimation. This is supported by the very similar grades and abundances obtained in the historical sampling.

9 Data Verification

9.1 Historical data

Sampling data were collected by six Pioneer Contractors during the 1970s to 2000s. As part of the ISA requirements to relinquish half of the registered Pioneer Contractor's claims, the data for the relinquished portions were made available to the ISA where they were archived. This entire data set was first provided to TOML in a comma delimited format, and then independently to Golder Associates in 2012 who were then compiling a technical report on this same project (Golder Associates, 2013). Mineral Resources QP in this report was the lead QP for the Golder Associates technical report.

The database provided by the ISA contains multiple independent datasets that were independently collected and sampled using similar methods (FFG or BC sampling) but with slightly different equipment and were assayed by different laboratories. Because the database contains multiple datasets the datasets can be compared with each other for the purpose of validating the internal consistency of the data. Additionally, there are a number of published summaries of data that have not been provided to the ISA but show similar mean grades to the data within the TOML Exploration Area (Table 9.1).

Golder Associates contractor Charles Morgan was familiar with the procedures and processes that were used in collecting and assaying the samples. He was also involved with collection, inspection and analysis of samples, photographs and video coverage of the polymetallic nodule deposits for Lockheed Martin while on board the exploration ship MV Governor Ray. Dr Morgan was also involved with reviewing the Pioneer Contractors work and results, through his role on the ISA Legal and Technical Commission (ISA LTC), and in the compilation of ISA Technical Bulletin No. 6.

The sample data are supported by independent third party data, have been reviewed by the ISA LTC during the process of granting licences to the Pioneer Contractors, and are maintained by the independent ISA. Golder concluded that these data are suitable for Inferred Mineral Resource estimation purposes.

9.1.1 Data independence

QP Matthew Nimmo received the available data collected from within the CCZ and the TOML Exploration Area from the ISA via Charles Morgan. The data set was received on June 22 2012 from Dr Vijay Kodagali, Senior Scientific Officer of the International Seabed Authority (Email: vkodagali@isa.org.jm) who sent the data by email in Microsoft Excel format.

This data set is identical to the one used for the resource assessment provided by TOML, verifying the source of the sample data.

The database includes all data submitted to the ISA that were collected in the Reserved Areas of the CCZ. The data were collected by parties completely independent of TOML or Nautilus Minerals and retained exclusively in the custody of the ISA prior to their transfer. The data sets were also subject to third party review by the ISA's LTC, as part of the process of granting Pioneer Contractors Exploration Areas.

9.1.2 Historical data integrity

The original assay sheets from the laboratories for the individual nodule samples within the TOML Exploration Area are not available. Neither are the quality control procedures used by the laboratories and the ISA. It is reasonable to infer that the historical data is of sufficient quality for an Inferred Mineral Resource estimate because:

- The ISA is an independent agency with significant accountability under the Law of the Sea. Part of its mandate is the receipt and storage of sea floor sampling data suitable for the estimation of nodule resources and the legally binding award of licenses. It is reasonable to assume that a reasonable level of care was applied by the ISA.

- Comparison of the six independent data sets from the CCZ shows a high level of consistency in abundance and grade and, conversely, provides no evidence of bias or systematic error in the TOML data.
- Recent TOML nodule sampling confirms the existence, and abundance and grade continuity of the polymetallic nodules within the TOML Exploration Areas.

9.1.3 Data comparisons for the entire reserved areas

The Quality Assurance/Quality Control (QAQC) data for the historical samples are not available. Some QAQC is known to have been completed at the time, but there was no requirement to submit the results to the ISA. All the Pioneer Contractors collected samples by slightly different methods and assayed using different laboratories from what is effectively a single deposit. Due to the vast size and relative consistency of grade of the deposit the comparison between the data sets can be used as a proxy for QAQC.

Data covering the reserved blocks of ISA contained only a small number of anomalous values that may be suspected to be erroneous (four out of 2212 data points). These included:

- A Co value of 3.23% (next largest is 0.56% Co).
- Two Cu values of 157.0% and 66.0% (probably 1.57% and 0.66% respectively) (next largest is 1.62% Cu).
- A Mn value of 288.0% (probably 28.8%) (next largest is 35.62% Mn).

All these anomalous values are likely data entry errors and are contained within one contractor dataset (Yuzhmorgeologiya) and do not occur within the TOML Exploration Area, these data points were not used in any way for the resource estimate.

The box plots and log-probability plots (Section 11) comparing the data sets show that the distributions for Ni, Co, Cu, Mn and abundance are very similar between the different data sets, and across the CCZ. Variations between the data sets are attributed to both spatial variability and minor differences in sampling and assaying methods.

Figures comparing the assay distributions of the samples within the TOML Exploration Area with all other available data from the reserved blocks are presented in Section 7. These plots show that Ni, Cu and Mn compare well but with divergence at the tails of the distributions, while Co and nodule abundance tend to be biased slightly lower for the TOML data.

The samples within the TOML Exploration Area used for the Mineral Resource estimate were collected by Yuzhmorgeologiya, DORD and Ifremer. These three data sets show no significant differences.

Overall the results confirm the consistency of the mineralisation across the entire CCZ and the TOML Exploration Area which form a small part of the CCZ.

9.1.4 Comparison with non-ISA sourced data

Table 9.1 lists the mean grades of the nodules from different parts of the CCZ that were based on data that is not included in the data obtained from the ISA. These mean grades are very consistent with each other and with the mean grades of the data that falls within the TOML Exploration Area.

One example is from the Scripps Institution of Oceanography (SIO) which compiled a database of polymetallic nodules information from numerous sources (referenced in the database), last updated in 1981 (NOAA, 2013 a). As a comparison exercise, this dataset was clipped to the CCZ and analysed for comparison with the available ISA database. Note that as the vast majority of these samples were collected by dredging and coring, abundances were not estimated or recorded, and therefore only grade analysis is possible. The dataset was downloaded and imported into Microsoft Access, with some minor format alteration in the process. This database was then saved and accessed directly from ArcGIS.

A polygon representing the boundaries of the CCZ was used to query the database, and create a subset containing only samples within this zone. The mean values are included in Table 9.1.

Table 9.1 Mean Grades of the CCZ Nodules from Various Sources

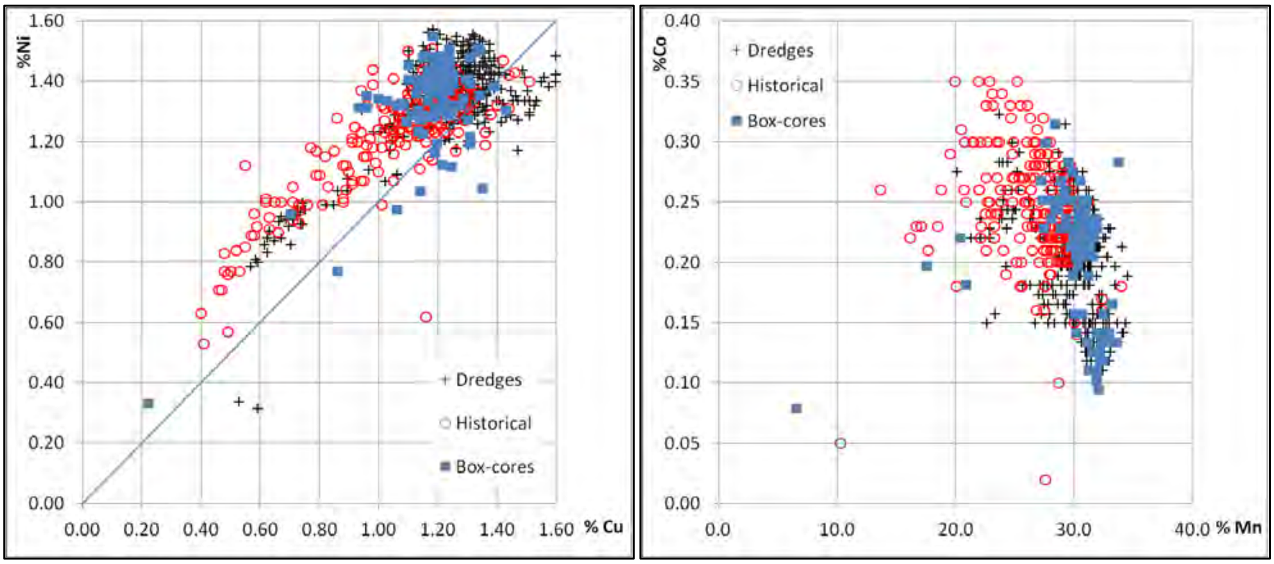
Ni (%)	Cu (%)	Co (%)	Mn (%)	Abundance (wet kg/m2)	Number of Samples	Source
1.24	1.03	0.22	27.2	6.5	2196	Data supplied by ISA (All CCZ)
1.22	1.06	0.24	26.9	8.5	255	Data supplied by ISA (TOML Exploration Area)
1.20	0.98	0.20	26.3	–	–	McKelvey et al, 1983
1.22	0.97	0.16	24.5	–	160	SIO (NOAA, 2013a)
1.29	1.19	0.23	29.1	–	–	Friedrich et al, 1983
1.28	1.16	0.23	24.6	–	–	Mielke (1975)
1.3	1.0	0.23	24.6	17	141	Ruhlemann et al (2011) west area
1.3	1.1	0.17	24.6	10	237	Ruhlemann et al (2011) east area

9.2 TOML data

9.2.1 Comparison of historical and TOML data

The CCZ13 and CCZ15 sample results of TOML were compared with historical samples. There is good correspondence given that the areas sampled are different. High Cu and Mn grades are less common in the historical samples but the ranges are the same and QA/QC for these elements show no issue with the TOML analyses of these elements.

Figure 9.1 Comparison between TOML analyses and historical analyses



The TOML analyses are from the submitted portion; the same plots by area are included in Section 6

9.2.2 Nodule variation test work

Grade variation between nodule box-core samples is very low, with coefficients of variation typically around of 0.05 to 0.2 compared to nodule abundance which is typically around 0.5 to 0.7 (Table 9.2). Even extensive sub-sampling (dredge “variance” samples) did not expose any significant variance in grades (CV <=0.06).

Table 9.2 Coefficients of variation for historical and TOML nodule samples

Number of samples		Area / sample type	Coefficient of variation				
Primary	Sub	Nodules	Mn	Ni	Cu	Co	Abundance
2	60	Area A TOML Dredge “variance”	0.09	0.18	0.34	0.22	n/a
18	0	Area A Historical	0.10	0.21	0.35	0.18	0.50
27	0	Area B1 TOML BC	0.20	0.21	0.21	0.18	0.90
1	20	Area B1 TOML Dredge “variance”	0.02	0.03	0.04	0.09	n/a
89	0	Area B Historical	0.17	0.20	0.27	0.22	0.67
14	0	Area C1 TOML BC	0.02	0.03	0.03	0.07	0.73
1	30	Area C1 TOML Dredge “variance”	0.03	0.03	0.04	0.11	n/a
87	0	Area C Historical	0.08	0.08	0.13	0.13	0.44
38	0	Area D1 and D2 TOML BC	0.03	0.07	0.05	0.09	0.61
10	187	Area D TOML Dredge “variance”	0.06	0.10	0.10	0.12	n/a
42	0	Area D Historical	0.05	0.06	0.08	0.10	0.53
12	0	Area E Historical	0.10	0.15	0.17	0.18	0.56
25	0	Area F and F1 TOML BC	0.03	0.06	0.06	0.13	0.23
4	82	Area F TOML Dredge “variance”	0.03	0.05	0.08	0.10	n/a
2	0	Area F Historical	0.00	0.03	0.01	0.04	0.27

The dredge “variance” samples were groups of up to 30 sub-samples collected from each dredge in order to study the grade variance or nugget of a sample point. As the dredges were often landed several times in a deployment a much larger range was covered than would be expected in a single box-core.

Figure 9.2 compares the CVs of the historical data and TOML dredge and box-core samples. The size of the circle is proportional to the CV (or spread) of the grades of the samples.

9.2.3 Nodule long-axis estimate validation

Photographs were used by commercial explorers in the 1970s to estimate polymetallic nodule abundance (Felix, 1980; Kaufman and Siapno, 1972).

The benefits of photos over physical sampling were immediately recognised, i.e.:

- Quicker and cheaper
- Larger primary sample (area)

This relationship works through measurement of each nodule’s long (or major) axis and the outcome is much better than estimates from photo-based nodule coverage or acoustic response. The process of estimating the weight of nodules was called Long-Axis Estimation (LAE).

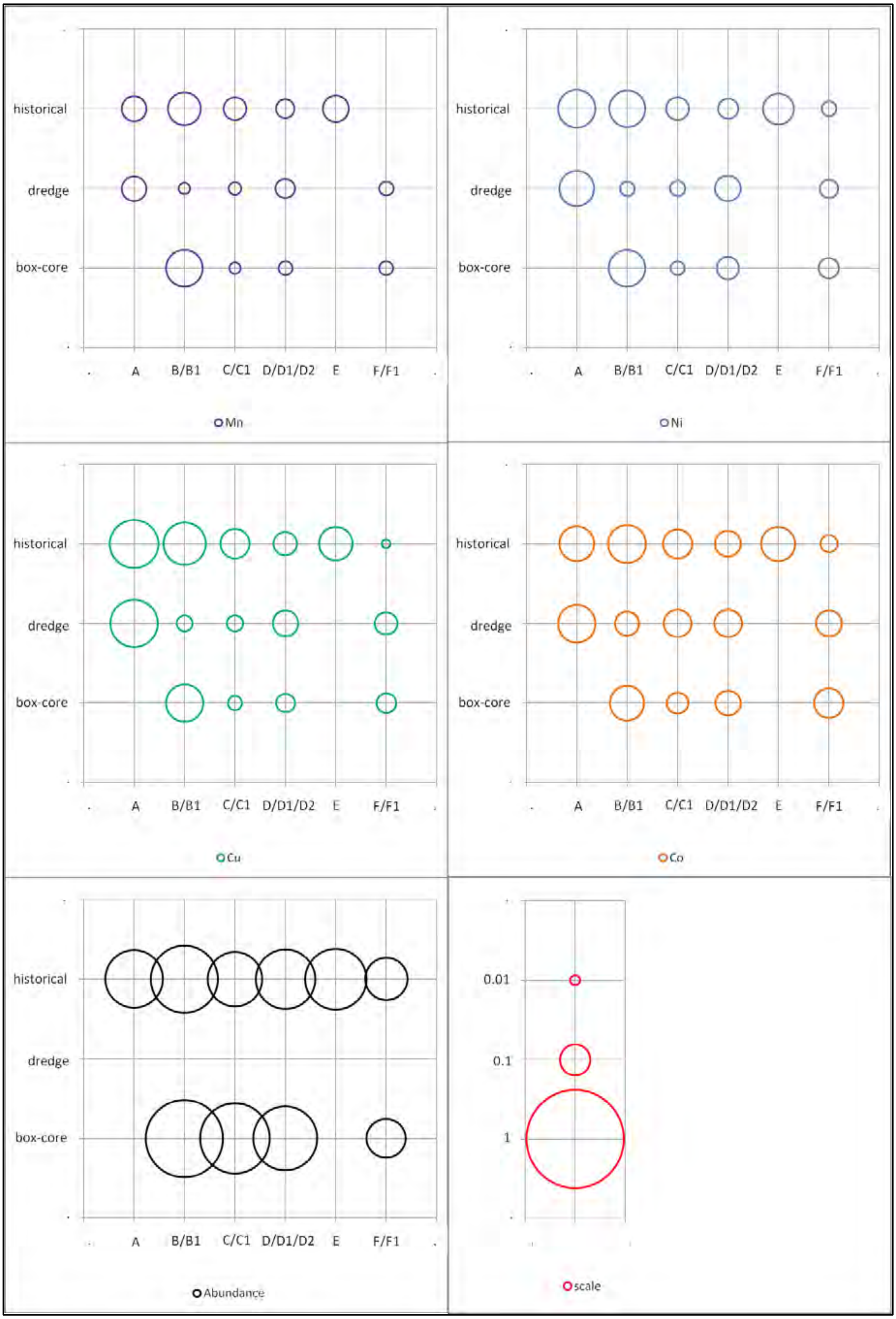
As discussed below, a key limitation of photo-based abundance estimation was that in some areas sediment ‘powder’ or ‘cover’ was sufficient to mask too many of the nodules to allow an accurate estimate. A correction factor might be possible in some of these cases, but this has not been applied to date on the TOML areas as it is likely crude and development requires more work.

Felix (1980) proposed a formula for nodules within part of the Kennecott area as follows:

$$\mathrm{Log}_{10}\mathrm{wt.} = (2.71)(\log_{10}\mathrm{LA\_cm}) - 0.18$$

Where wt. is the wet mass of the nodule in grams and LA_cm is the long or major axis of that nodule in centimetres. This formula was modified slightly in both TOML Areas B1 and C1 based on calibration results.

Figure 9.2 Comparison of coefficients of variation for historical and TOML nodule samples



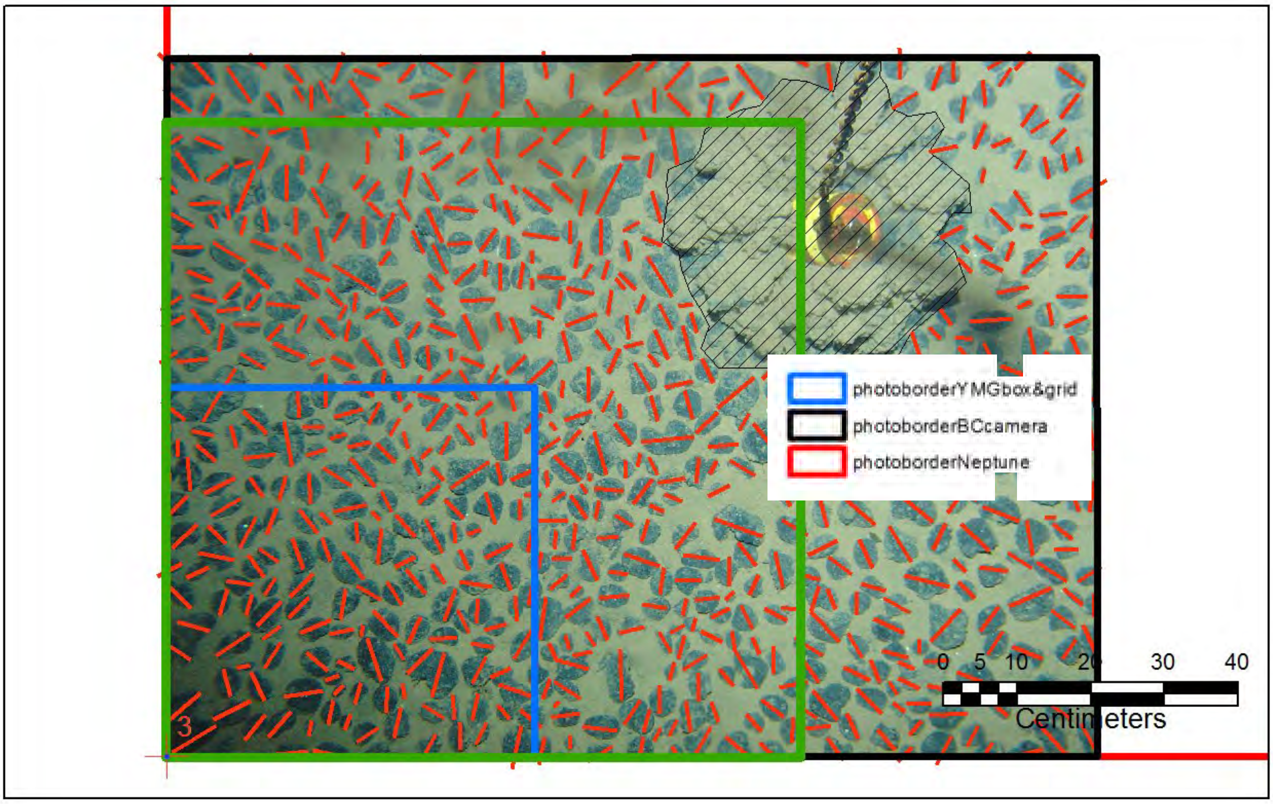
Values from Table 9.2

9.2.3.1 Photo-based estimates in the TOML Area

During 2015 TOML collected seabed photos using a box core mounted camera system to collect seabed photos from areas B, C, D and F (bottom shots) and a towed camera system (called the Neptune) to collect seabed photos from areas B, C and D.

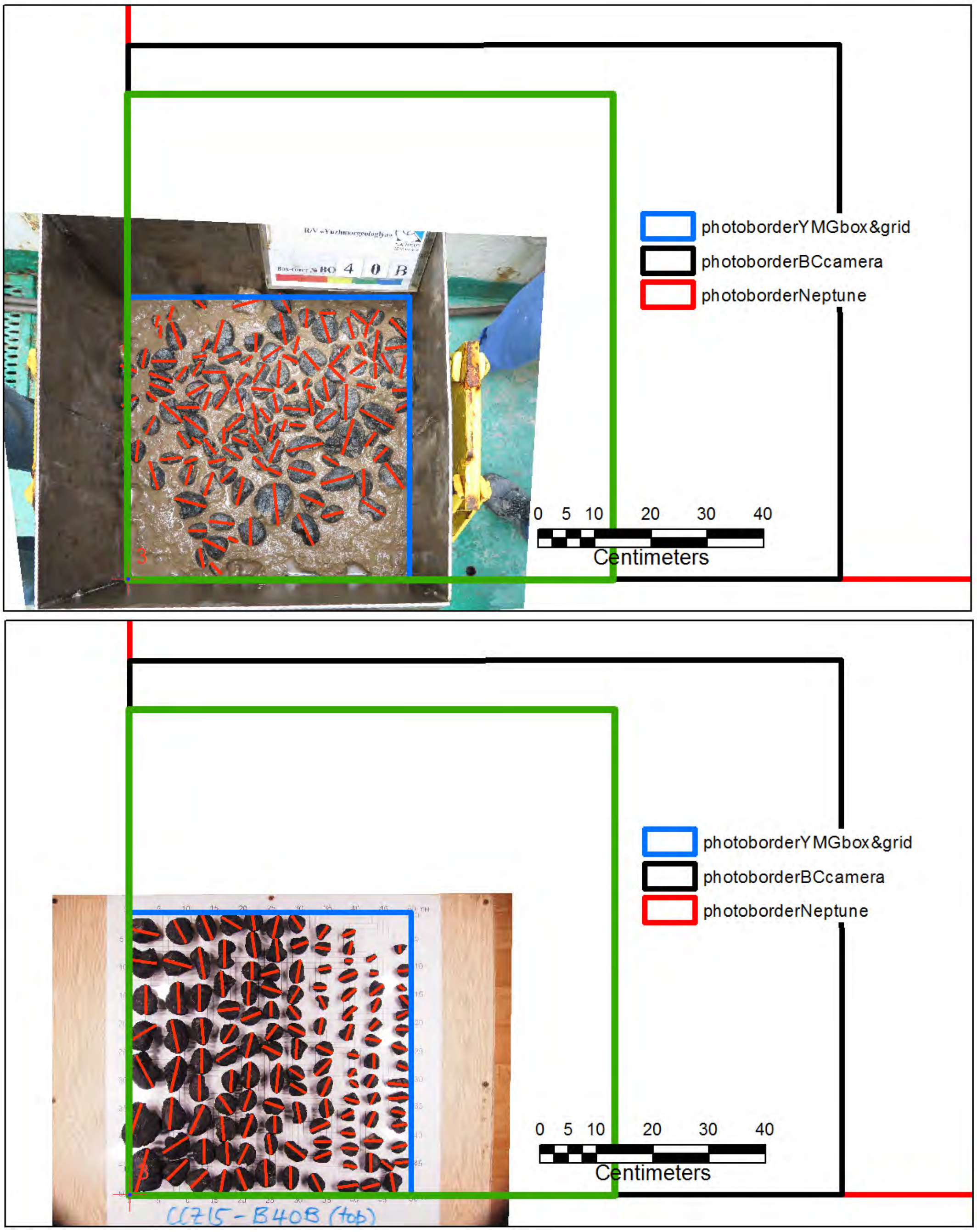
In areas B and C, it proved possible to use the bottom shots (e.g., Figure 9.3) as well as photos of the box-core samples taken on the vessel to calibrate and modify the Felix (1980) formula (above) to accurately estimate the weighed abundance of each box-core. The photos taken on the vessel included topshots of the sample in the box-core as it landed on deck and grid photos of the nodules from the box-core after washing off mud (e.g., Figure 9.4).

Figure 9.3 Example LAE measurement – bottom photo



Green frame is the area sampled by the KC box-corer

Figure 9.4 Example LAE measurement – top shot (YMG box) and grid photo

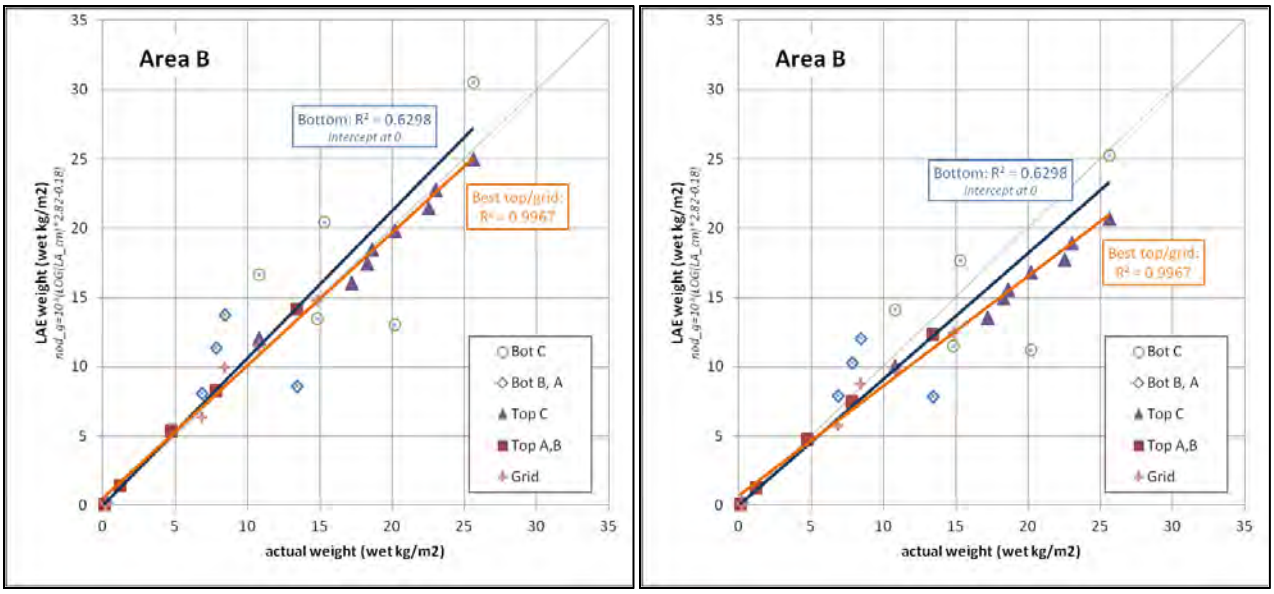


Green frame is the area sampled by the KC box-corer

The process involved referencing the photos to scale in a GIS package, using an average field of view based on a variety of images of the trigger weight-scale. Then a line was digitised along the long axis of each nodule before recording the length of each line into a database. The line measurements were then analysed in MS Excel, comparing the total calculated weight with the total actual sample weight. Accurate weighing of individual nodules was not possible due to the heave of the vessel, but a motion compensated scale could accurately weigh entire box-core samples (±50 g).

Initially the formula of Felix (1980) was used but a much better fit was achieved if the factors were modified (Figure 9.5). The need to modify the factors probably relates to difference in nodule's thickness:area aspect ratios between areas, that in turn could relate to differences in the thickness of the geochemically active layer.

Figure 9.5 Area B correlations with best fit factors (L) and Felix 1980 factors (R)



In Area B, long-axis estimates made use of box-core seafloor photos, topshots and, where needed, sample grid photos, as in some cases the camera on the box-corer didn't work, and in other cases the sample arrived on deck scrambled into the sediment. Area B was compared by type of nodule (Contractor Yuzhmorgeologiya facies A, B, C) as well as combined types with no noticeable difference in relationship.

The calibrated relationship stood up very well (Figure 9.5); better than some nodule by nodule point counting that was also tried and so the formula was applied to the Neptune photos (approximately every 100th) with results broadly agreeing with the box coring (Figure 9.6) but providing much more detail.

The processing involving the Neptune towed camera sled photos was broadly similar to the calibration work done with the box-core bottom photos except that the Neptune images were referenced to an average field of view from images that clearly showed two centrally located laser pointers (30 cm spacing) carried on the towed camera sled. Although an electronic altimeter triggered the camera at near identical heights above the seafloor, each image varied slightly in terms of field of view due to flare and rocking of the sled in response to vessel motion.

Due to the very large volume of readings (>90,000) the digitised nodule lengths were compiled into and reported from a MS Access database. They were also studied using the statistical program R.

The process was then extended to Area C, and with agreement of the mineral resource Qualified Person only half the box-cores were taken (for calibration and grade estimation) as the Neptune photos were seen to be the better dataset due to area covered in each shot and frequency of photos available for measurement-interpretation. Again, the factors in the Felix (1980) formula were adjusted to improve accuracy (Figure 9.7).

In Area C the correlations between bottom photos based estimates and actual weights show less scatter – this might be due to a slightly different camera with a wider field of view being used.

Figure 9.6 Comparison of physical samples and LAE in Areas B and C

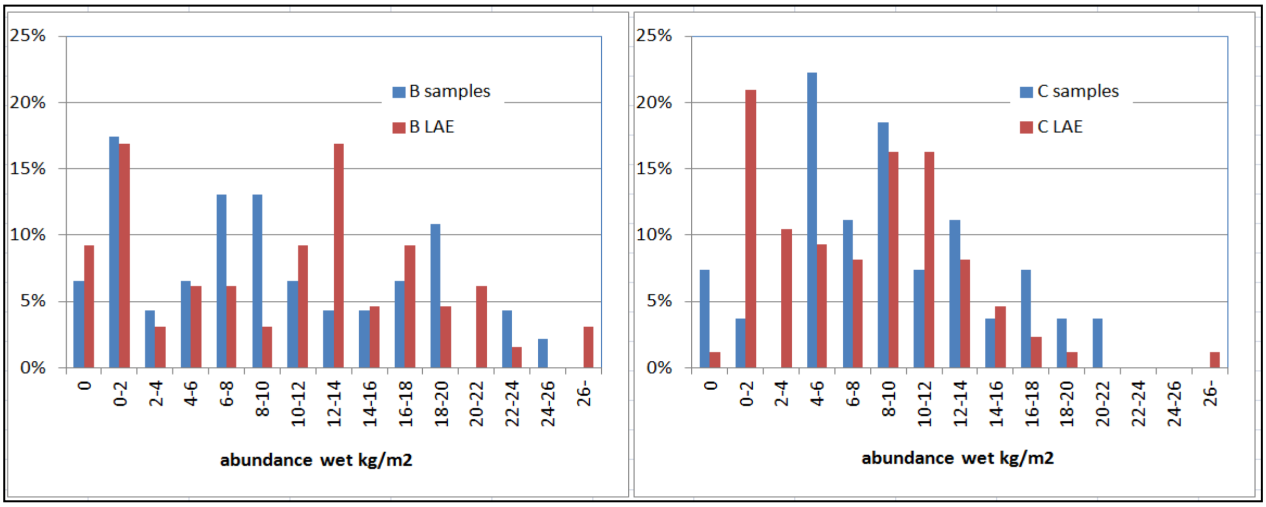
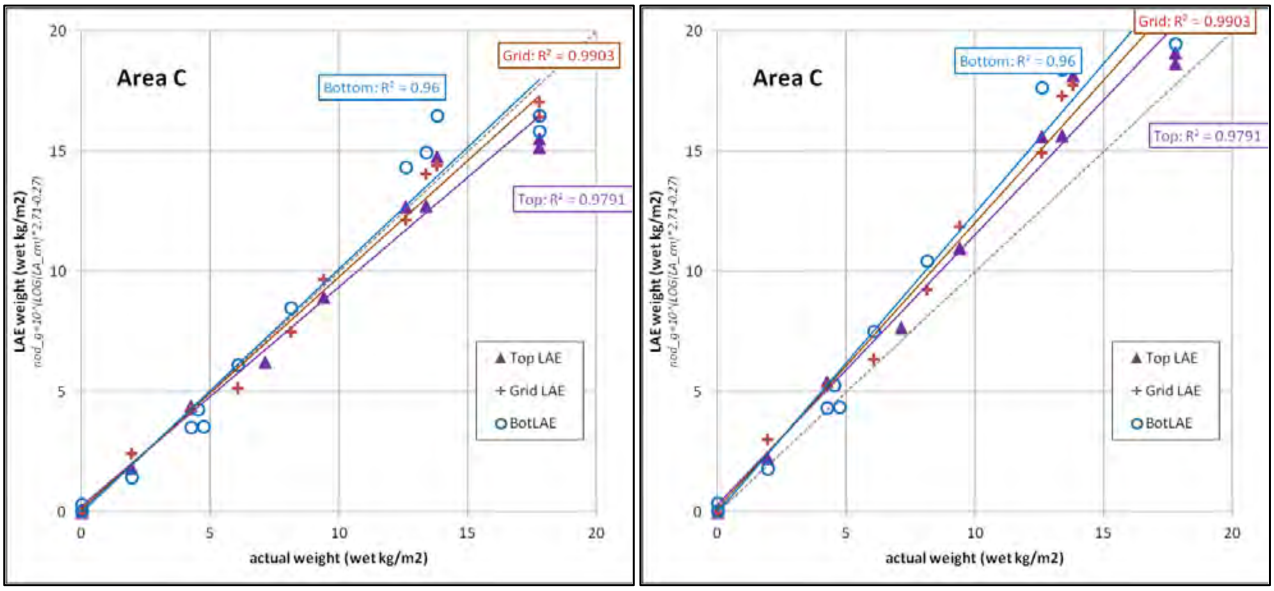
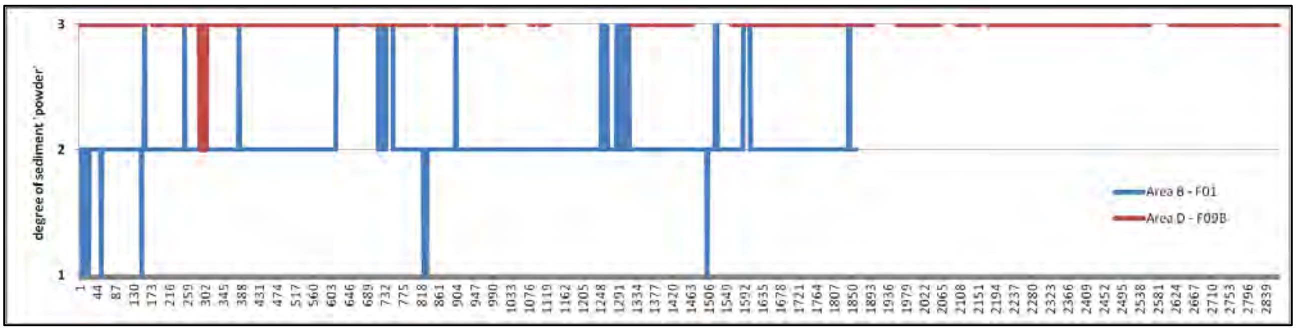


Figure 9.7 Area C correlations with best fit factors (L) and Felix 1980 factors (R)



In Area D however, the degree of cover (Figure 9.8, Figure 9.9, Figure 9.10) confounded the process. This possibility of this had been warned by Felix (1980), so after the orientation Neptune lines were complete, the survey focused on box-cores and there is no Neptune LAE data from this area for mineral resource estimation purposes.

Figure 9.8 Degree of powder on visible nodules in Area D vs Area B



Note that level 3 cover is the highest possible per the logging schema used during the CCZ15 campaign.

Figure 9.9 High degree of sediment "powder" and cover in Area D

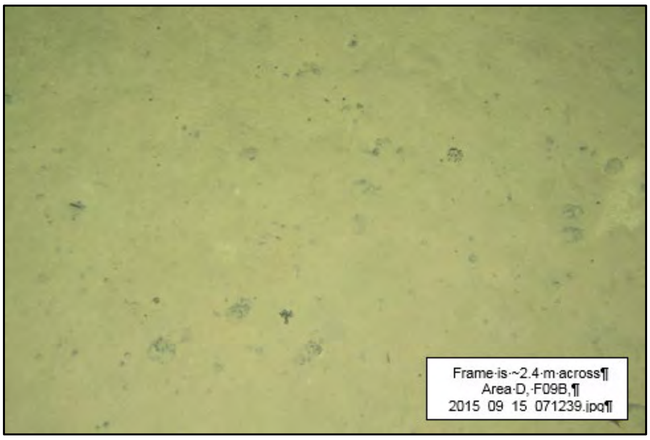


Figure 9.10 Covered nodules B75, Area D2

In Area F, no towed camera survey was done but a visual comparison between bottom photos, topshots and grid photos reveals good exposure of nodules.

Abundance variance for both box-core samples and LAE estimates are summarised and compared in Table 9.3. Area B1 and Area C1 have higher box-core based global coefficients of variation than Area D1 and Area D2, while Area F and Area F2 are especially continuous. Thus, the Neptune LAE results are helping in the two more variable areas and would probably have been less critical in the others.

Table 9.3 Summary statistics of abundance between box-cores and LAE

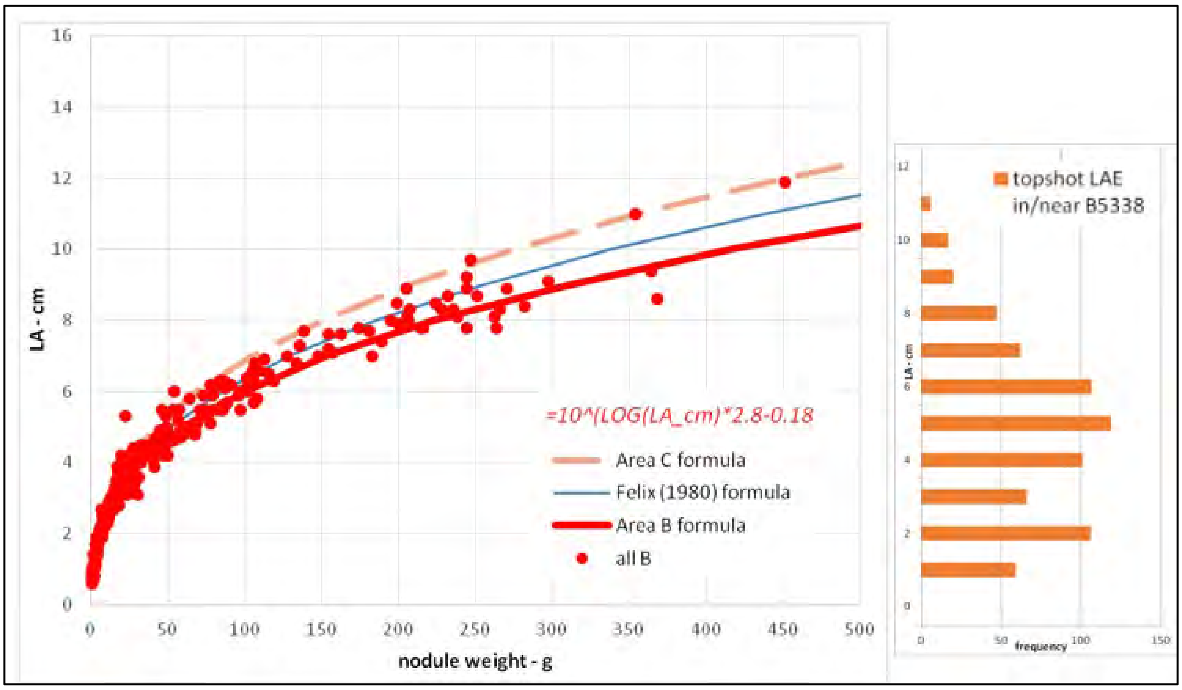
Area	Type	Count	Stdev	Average	CV
B1	BC	30	8.25	9.35	0.88
B1	NeptLAE	75	7.74	10.16	0.76
C1	BC	16	5.54	7.80	0.71
C1	NeptLAE	86	5.40	7.34	0.74
D2	BC	26	6.86	11.59	0.59
D1	BC	16	8.20	13.84	0.59
F	BC	15	6.81	15.80	0.43
F1	BC	10	4.63	21.65	0.21
Historical data used in 2012 NI43-101 Inferred estimate (count = 255)					0.62

9.2.3.2 Confirmation Study

In April 2016 individual nodules were weighed on shore to check the relationships obtained and applied at sea. More accurate weighing of individual nodules was possible, now that the work could be done on land without the influence of vessel heave, but the samples used were necessarily residues of the collected samples that had already been split and sub-sampled for grade, reference and mineragraphy. Also, the samples had been transported several times and were then more 6 months old and so were often comprised mostly of broken nodules which could not be measured. Nevertheless, some 390 nodules were each weighed and measured with results as follows:

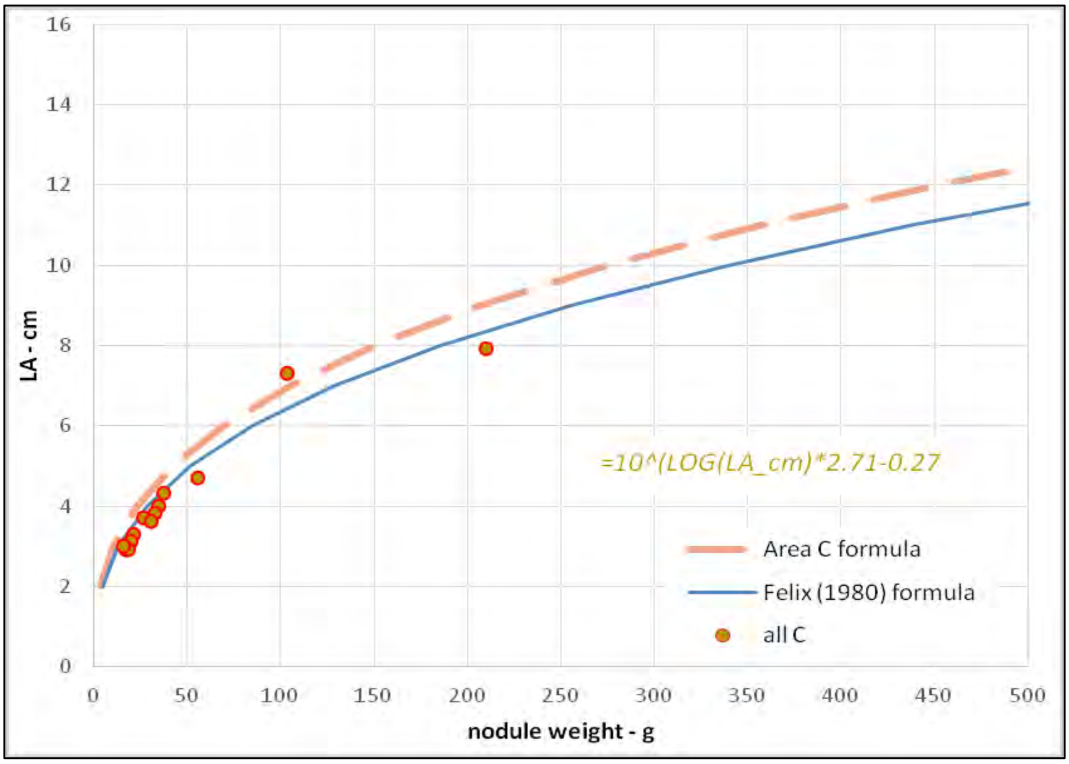
In TOML Area B1 there was a good fit between the formula used at sea and individual nodules weighed (Figure 9.11) confirming a valid relationship. While a slightly better visual fit might have been possible regarding the larger nodules it is likely that the unbiased correlation in Figure 9.7 would be adversely impacted (e.g., using Felix's factors in Figure 9.5). Large nodules are uncommon and it is not clear how representative the individuals weighed actually are (irregular nodules might be more prone to breakage).

Figure 9.11 Confirmation nodules weights Area B and histogram of nodules by long-axis length



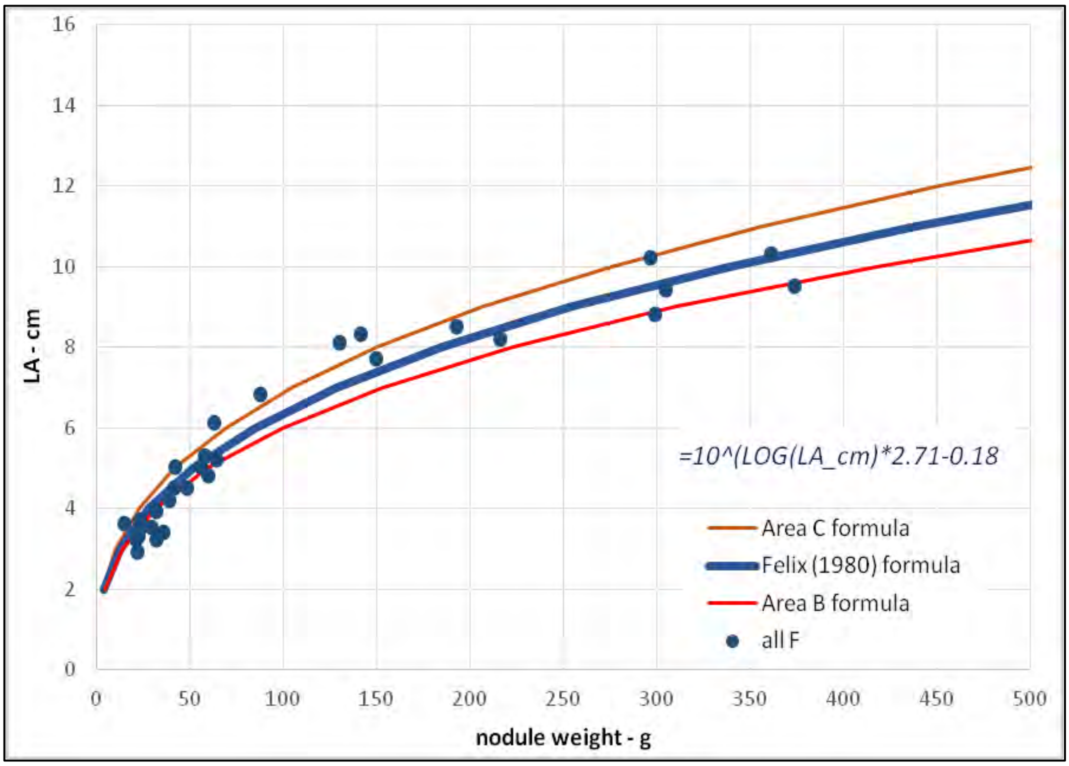
For Area C there was a shortage of whole nodules especially larger ones (which are naturally rare in Area C; Figure 9.12) but the relationship and formula was confirmed. There is a chance that the formula is a little conservative (i.e., factors a little closer to Felix's or Area B's could have been used), but again care needs to be taken considering the strong correlation obtained using the best fit factors versus the imparted bias using Felix's factors in Figure 9.7.

Figure 9.12 Confirmation nodules weights Area C



For TOML Area F, if LAE is used in the future, then the factors published by Felix look to be potentially suitable (Figure 9.13). It is worth noting that TOML Area F is near the southern side of the Kennecott "Frigate Bird" exploration area, and that the larger nodules there are known to be distinctly thinner in aspect (Section 6).

Figure 9.13 Confirmation nodules weights Area F



9.3 Adequacy of data

The historical nodule sample data is considered suitable for the purpose of estimating Mineral Resources to an Inferred level of confidence. The QP also considers that the combination of the TOML and historical nodule sample data (physical samples and photo based long axis estimates) combined with detailed backscatter, photo profiling and geological interpretation is sufficient to estimate polymetallic nodule Indicated Mineral Resources and, in one small especially data rich area, Measured Mineral Resources.

The primary characteristic of the polymetallic nodule deposit that separates this deposit from typical terrestrial manganese, nickel and copper deposits is that the nodules themselves can be accurately mapped through photo-profiles and backscatter acoustic response. The bulk of the polymetallic nodules sit on top of the seabed allowing them to be photographed. However, in some areas such as TOML Area D some nodules are partially covered by sediment making it more difficult to detect the presence and abundance of the nodules. The most accurate method for determining nodule abundance is through physical sampling by box-core or free fall-grab sampling. However, these methods are costly and result in wide sample spacing. Due to the fact that nodules are visible, photography can be used in many areas to estimate nodule abundance directly. The two methods for doing this are estimating the nodule percent coverage (percent of exposed nodule surface area within the photo) and measuring each individual nodule long-axis and then using these measurements to calculate abundance using variants of the formula defined by Felix (1980). The long-axis estimation (LAE) method is the most accurate and preferred method but comes at a cost in the time to manually process each photo - limiting the number of photos that can be used for estimating abundance. The benefit of using photographs is being able to demonstrate continuity between physical sample location and accurately quantify nodule abundance. TOML is developing an automated method of doing these measurements for future application.

The QP considers the abundance estimates derived from photographs to date from TOML Areas B and C, to be suitable for estimating nodule abundance for the Mineral Resource.

10 Mineral Processing and Metallurgical Testing

Considerable mineral evaluation and metallurgical testwork on nodules from the CCZ has been reported. This was predominantly at a laboratory scale, with some test work at a pilot plant scale (Sen, 2010). All published historical work indicates that processing of nodules is technically feasible. To maximise recoveries of valuable metals the manganese lattice has to be broken down, either through pyrometallurgical or hydrometallurgical/biohydrometallurgical action.

Haynes et al (1985), in a NOAA funded US Bureau of Mines managed study, examined in detail the chemistry, morphology, and mineralogy of the nodules as well as five discrete processing routes. The processing routes are either hydrometallurgical or combinations of pyrometallurgical and hydrometallurgical processes, and were investigated at the bench scale with nodule feed, with a specific focus on tailing and slag composition (Haynes et al, 1985). The potential process routes (Figure 10.1) include:

- Gas reduction and ammoniacal leach process (Caron process).
- Cuprion ammoniacal leach process (as developed by Kennecott in their nodule studies in 1970s and 80s).
- High temperature and high pressure sulfuric acid leach process (HPAL).
- Reduction and hydrochloric acid leach process.
- Smelting and sulfuric acid leach process.

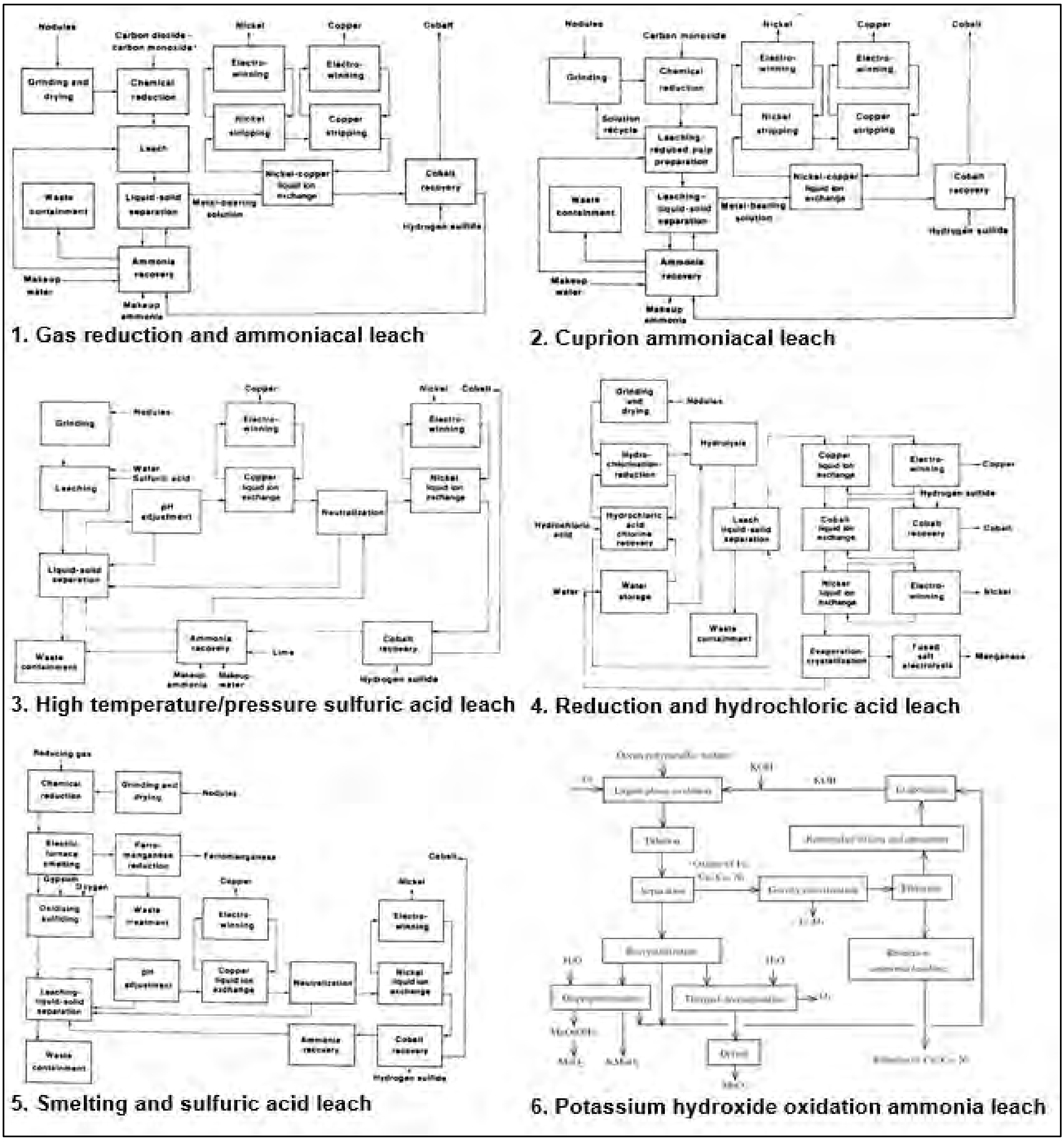
The first three processes are three-metal recovery systems with manganese reporting to a waste stream, with the last two also recovering manganese. The cuprion process operates at atmospheric pressure and temperature and flotation of the tailings can produce commercial grade manganese concentrates (NIOT, 2008).

Additional process routes, including biohydrometallurgy and alternative reducing agents, have been studied, e.g., Wang and Li (2005, Figure 10.1) and general reviews by Mukherjee et al. (2004) and Sen (2010).

Haynes et al (1985) and Wang and Li (2005) both conclude that the studied flow sheets for nodules are technically feasible. At the laboratory (bench top) scale Ni, Cu and Co recoveries vary but for the processes not using ammonia leach generally exceeded 90%. For the ammonia leach type processes recoveries vary with Haynes et al (1985) achieving greater than 90% for Ni and less for Co and Cu and Wang et al. (2005) achieving 95% for Cu, 65% for Co and 84% for Ni.

Neither Haynes et al (1985) nor Wang and Li (2005) reported Mn recovery, although the smelting process produced Mn rich tailings and a ferro-manganese product, and the hydrochloric acid leach process could also produce manganese. Sen (2010) reports process options with manganese recoveries of 85%. In NIOT (2008) COMRA reports that pilot tests on ‘smelting — oxidative leaching-SX’ returned metal recoveries of Ni, Cu and Fe of greater than 90%, Co of 89%, and Mn of 82%, while IOM, who studied both hydrometallurgical and pyrometallurgical process routes, report extraction efficiencies via sulphur-dioxide leaching of greater than 98% for Ni and Mn and greater than 90% for Co.

Figure 10.1 Potential process flow-sheets for seafloor nodules. 1-5 studied by Haynes et al. (1985) and 6 by Wang and Li (2005)



Recovery methods that could be employed for commercial development of polymetallic nodule deposits in the CCZ were studied in an IA for NORI Area D (AMC, 2021). The commonality between the polymetallic nodule deposits in NORI Area D and TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. This is discussed further in Section 11.9.

11 Mineral Resources

Estimation of tonnage and grade for TOML Exploration Areas A, B, C, D, E, and F within the CCZ was undertaken in the second quarter of 2016. The estimates are based on the historical box-core and free fall-grab nodule sampling (262 samples) supplemented with recently acquired TOML nodule box core (113 samples) and photo-profile data (20,857 frames over 587 line km). Only sample data within the TOML tenement Area was used to inform the estimates.

The Mineral Resource estimate reported here follows and supersedes a maiden NI 43-101 Inferred Mineral Resource estimates reported by Golder Associates (2013). Differences between the two estimates are consistent and explicable.

The modelling methodology used for estimating the Mineral Resource was determined through careful consideration of the scale of deposit, geological mechanism and controls behind nodule formation and nature of the sampling method. The approach involved estimating nodule abundance and grades into a two-dimensional block model. Abundance, in wet kg/m^2, was used for calculating tonnage. Abundance and grades were estimated using ordinary kriging (OK). Inverse distance weighting (IDW) and nearest neighbour (NN) estimates were used to validate the OK estimates.

The QP has assessed the available geological, mining and processing information regarding the manganese nodules and concluded that there are reasonable prospects of economic extraction (see additional explanation in Sections 10, 13, and 16).

11.1 Mineral Resource domains

The occurrence of polymetallic nodules within the CCZ is influenced on a regional scale by two large scale geological features: the boundary of the CCZ deposit and the presence of seamounts.

The boundary limits of the CCZ defining the region where nodules have been found to occur is bracketed by the Clarion and Clipperton Fracture Zones to the north and south respectively. The deposit extends to the west and east between the two fracture zones. The limits to the CCZ occur well outside the boundaries of the TOML Exploration Areas. Accordingly, 100% of the TOML Exploration Area fall within the CCZ polymetallic nodule deposit.

Bathymetric features only play a role in distribution of polymetallic nodules at a regional scale. There are principally two regional scale bathymetric domains: sea mount ranges and abyssal hill province. Based on interpretation of the GEBCO bathymetry data from the ISA, and TOML's own bathymetry, less than 2% of the TOML Exploration Area is covered by isolated sea mounts. Effectively, the entire TOML Exploration Area falls within the abyssal hill domain.

Within the TOML Area there are small, disconnected zones where there are no polymetallic nodules present or the polymetallic nodule abundance is very low. These zones are controlled by local geology (presence of basalt or carbonate ooze) and bathymetry.

The TOML Area has been split into two domains. Areas with polymetallic nodules and areas predominately without polymetallic nodules. The MBES bathymetry and the backscatter data was used to interpret the parts of TOML Area B through F with no polymetallic nodules. For the Mineral Resource estimate two broad domains have been interpreted from the data. These are:

1. NOD – polymetallic nodule domain. This domain exists almost everywhere and extends beyond the boundaries of the TOML Exploration Areas.
2. NON – areas with no or low nodule abundance of polymetallic nodules. This domain includes the No Nodules on Ooze (Nnoo), seamounts and areas with basalt. Nodule abundance in the NON areas was set to zero in the block model. It is not defined in Area A as that area has not been surveyed by MBES.

Figure 11.1 through to Figure 11.5 show the TOML Exploration geological domains used for the Mineral Resource estimate. Sample locations are indicated by white circles.

Figure 11.1 TOML Exploration Area A geological domains

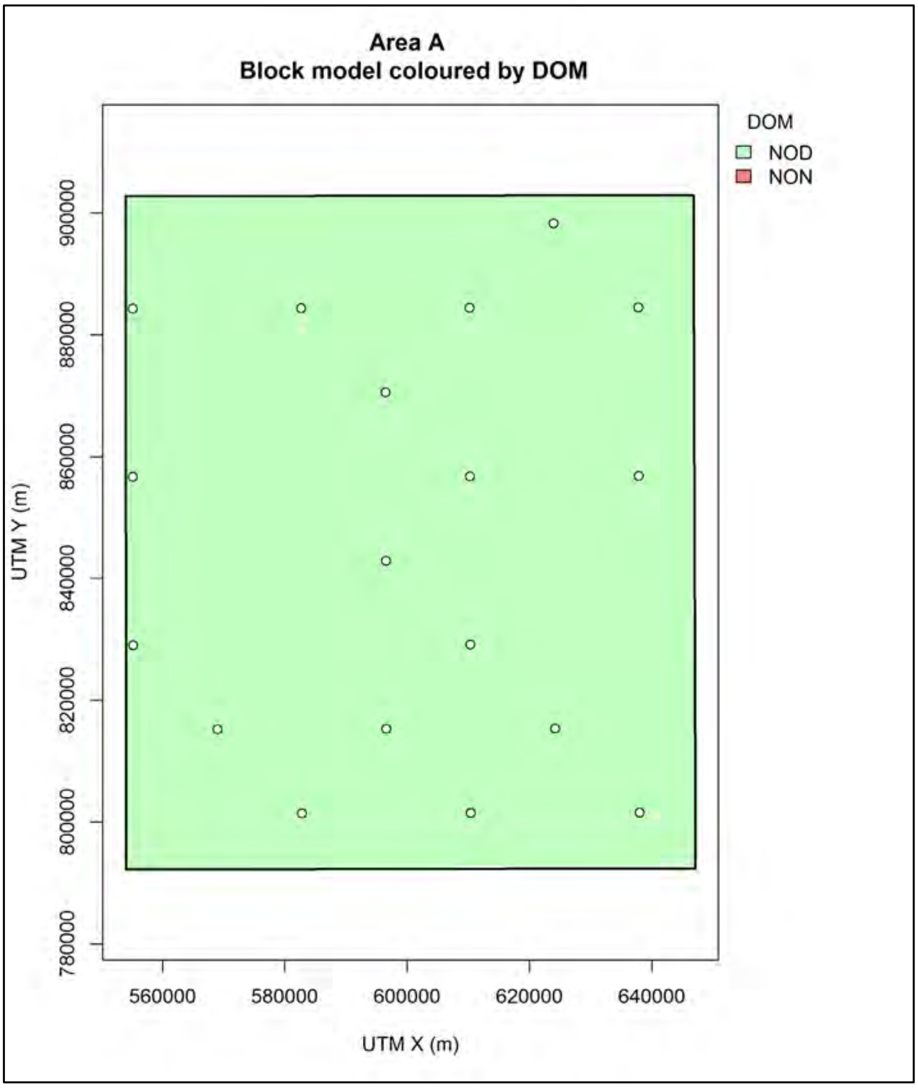


Figure 11.2 TOML Exploration Area B geological domains

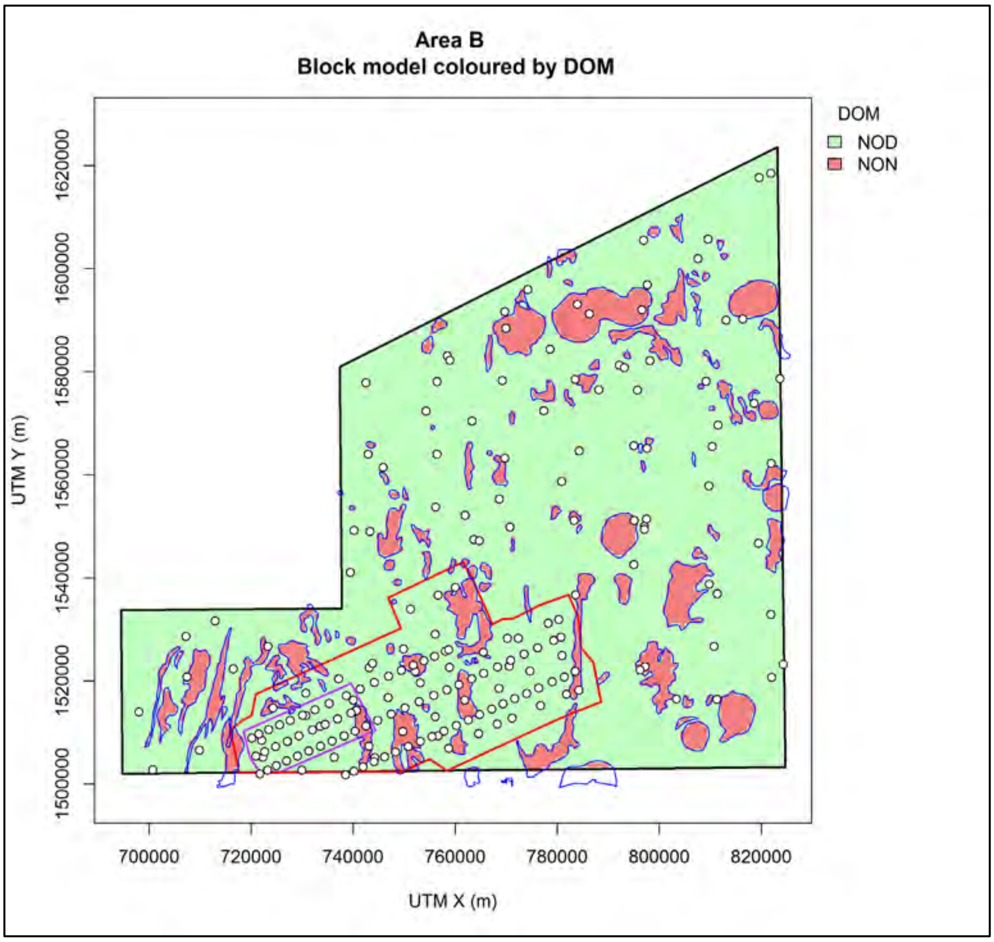


Figure 11.3 TOML Exploration Area C geological domains

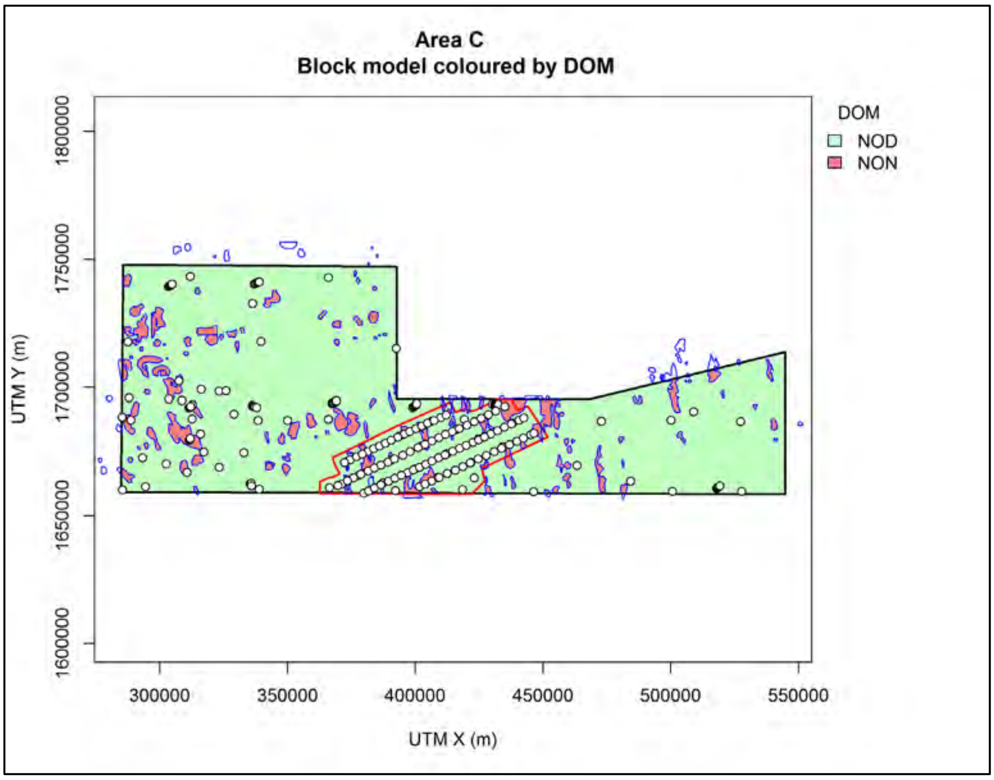


Figure 11.4 TOML Exploration Area D and E geological domains

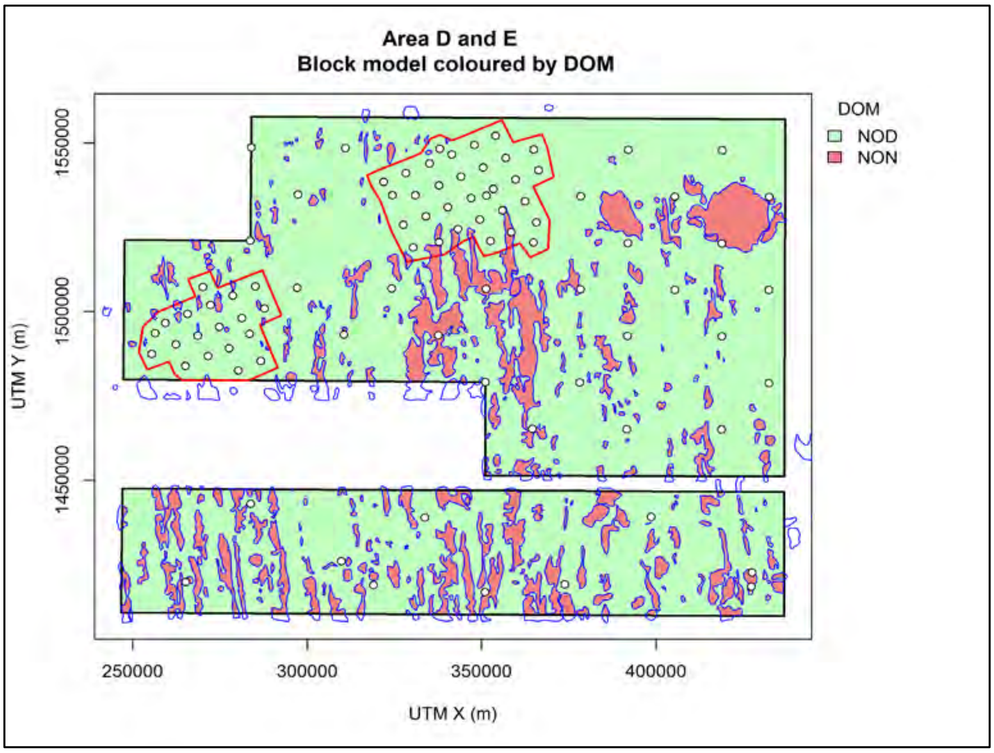
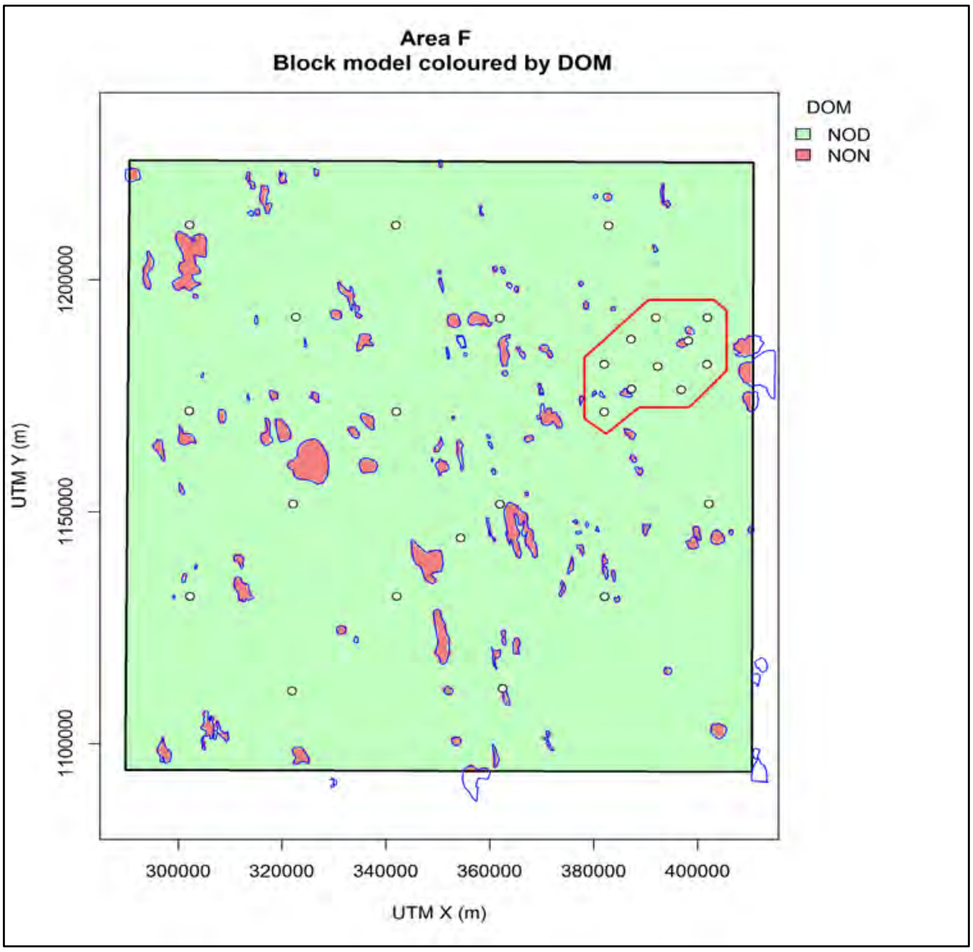


Figure 11.5 TOML Exploration Area F geological domains



11.2 Manganese Nodule Data used for the Mineral Resource Estimate

11.2.1 Description of data

Historical box-core and free fall grab sampling data was initially provided by Dr Vijay Kodagali, Senior Scientific Officer of the International Seabed Authority (Email: vkodagali@isa.org.jm) who sent the data by email in Microsoft Excel format on June 22 2012. This data included samples for TOML Exploration Areas A, B, C, D, E and F (Figure 11.6). An additional eight samples within Area E were provided by Tomasz Abramowski from Interoceanmetal Joint Organization (IOM) on 21 November 2014. The data were provided in comma delimited format.

The historical polymetallic nodule sample data consists of 2211 records of which only 268 of the nodule samples fall within the TOML Exploration Area.

Polymetallic nodule samples collected during the TOML 2015 campaign within the TOML Exploration Areas B, C, D, and F were analysed by ALS Laboratories and provided to the QP on 17 March 2016 in a single text file. A total of 104 box-core samples were collected and sampled.

A separate data set containing the manganese nodule abundance for the 113 TOML box-core samples and calculated abundance for 536 sea floor photos was provided by TOML. The calculated abundance was derived from every 100th photo of the TOML 2015 sea floor photo-profiling, providing an average spacing of 2.7 km between photo observation points. The photos were processed manually by measuring the long axis of every nodule within the photo or within a subset of the photo. This enabled an accurate estimate of the nodule abundance in each photo.

The spatial coordinates of the data were in digital latitude and longitude. For spatial modelling and Mineral Resource estimation the coordinates were transformed into Universal Transverse Mercator (UTM) using the World Geodetic System (WGS 84) spatial reference system. Table 11.1 lists the minimum and maximum UTM coordinates for each TOML Exploration Area.

Figure 11.6 Location of the historical sample data provided by the ISA and IOM and the TOML data

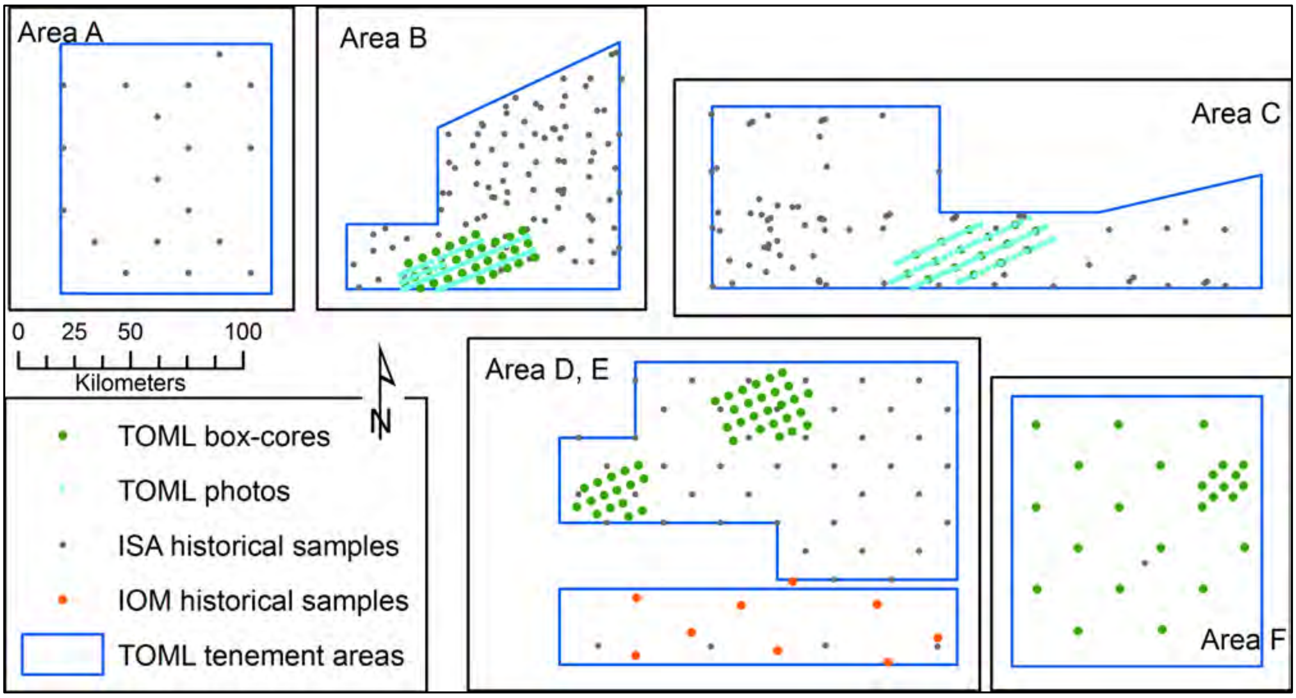


Table 11.1 Minimum and maximum UTM coordinates for each TOML Exploration Area

TOML Exploration Area	Easting		Northing		UTM Zone
	Min (m)	Max (m)	Min (m)	Max (m)	
A	553 976.1	647 191.3	792 205.9	902 969.6	5
B	694 523.4	824 684.8	1 502 007	1 623 606	8
C	284 947.0	544 795.5	1 658 368	1 747 831	9
D	247 296.3	437 027.2	1 451 032	1 557 860	10
E	246 691.9	436 798.9	1 409 560	1 447 514	10
F	289 837.4	410 806.1	1 093 913	1 225 830	11

The historical and recent TOML data were combined into a single data set and checked for anomalous or erroneous values. The 0 assay values in the historical data represent absent data and were reset to absent value where abundance is recorded as 0, and to 0.01 where abundance is greater than 0.

11.2.2 Sample statistics

The descriptive statistics of the nodule sample data are listed in Table 11.2 to Table 11.6. Comparison of the historical nodule samples within the TOML Exploration Area (Table 11.4) and the recently acquired TOML nodule samples (Table 11.5) indicate slightly higher mean grades for Abundance, Mn, Ni and Cu, and slightly lower Co for the TOML samples.

Table 11.2 Statistics of all samples within the TOML Exploration Areas

Variable	Samples	Missing	Min (%)	Max (%)	Mean (%)	Var	CV	Median
Abundance	527	9	0	30.77	9.50	43.088	0.69	8.79
Mn	338	198	6.54	33.79	27.91	13.426	0.13	28.9
Ni	338	198	0.33	1.55	1.26	0.034	0.15	1.31
Cu	338	198	0.22	1.51	1.09	0.046	0.2	1.16
Co	338	198	0.02	0.35	0.23	0.002	0.21	0.23

Var = variance; CV = coefficient of variation

Declustering weights were calculated and applied to the nodule sample data to assess the potential bias in the descriptive statistics that can arise from clustering of sample data. Table 11.3 lists the declustered nodule descriptive statistics for all samples within the TOML Exploration Area. Declustering the data resulted in a slight increase in the mean of Abundance, but no significant change for Mn, Cu and Co indicating that the statistics are not significantly affected by clustering.

Table 11.3 Declustered statistics of all polymetallic nodule samples within TOML Exploration Area

Variable	Samples	Missing	Min (%)	Max (%)	Mean (%)	Var	CV	Median
Abundance	527	9	0	30.77	10.20	39.35	0.61	9.16
Mn	338	198	6.54	33.79	28.09	10.414	0.11	28.71
Ni	338	198	0.33	1.55	1.26	0.03	0.14	1.31
Cu	338	198	0.22	1.51	1.11	0.045	0.19	1.16
Co	338	198	0.02	0.35	0.22	0.003	0.24	0.22

Var = variance; CV = coefficient of variation

Table 11.4 Statistics of historical samples within the TOML Exploration Areas

Variable	Samples	Missing	Min (%)	Max (%)	Mean (%)	Var	CV	Median
Abundance	253	9	0.03	26.0	8.82	27.134	0.59	8.09
Mn	234	28	10.3	32.4	26.88	11.097	0.12	27.67
Ni	234	28	0.53	1.51	1.22	0.034	0.15	1.27
Cu	234	28	0.4	1.51	1.06	0.053	0.22	1.13
Co	234	28	0.02	0.35	0.24	0.002	0.18	0.24

Var = variance; CV = coefficient of variation

Table 11.5 Statistics of TOML samples within the TOML Exploration Areas

Variable	Samples	Missing	Min (%)	Max (%)	Mean (%)	Var	CV	Median
Abundance	113	0	0.0	29.13	12.23	66.384	0.67	12.6
Mn	104	9	6.54	33.79	30.23	11.006	0.11	30.84
Ni	104	9	0.33	1.55	1.34	0.025	0.12	1.37
Cu	104	9	0.22	1.43	1.18	0.019	0.12	1.2
Co	104	9	0.08	0.31	0.21	0.003	0.24	0.22

Var = variance; CV = coefficient of variation

Table 11.6 Statistics of TOML photo samples within the TOML Exploration Areas

Variable	Samples	Missing	Min (%)	Max (%)	Mean (%)	Var	CV	Median
Abundance	161	0	0	30.77	8.65	45.745	0.78	8.78

Var = variance; CV = coefficient of variation

Figure 11.7 Histogram and log-probability plot of Abundance for all samples within TOML Exploration Areas

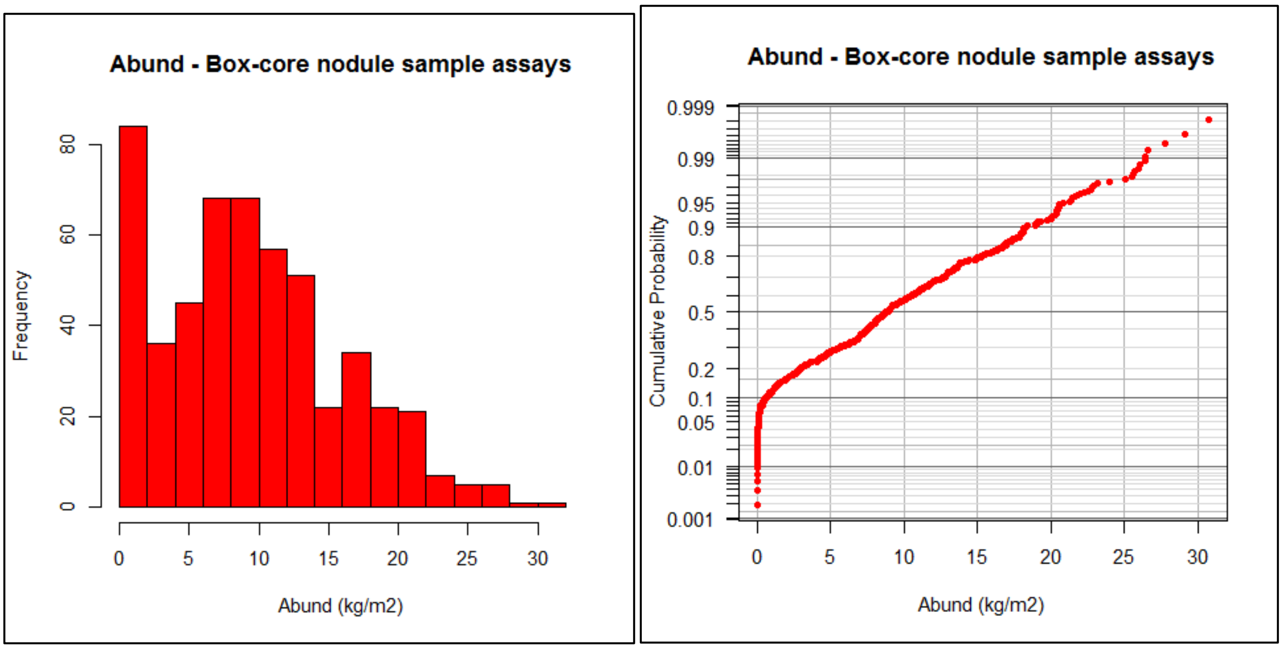


Figure 11.8 Histogram and log-probability plot of Mn for all samples within TOML Exploration Areas

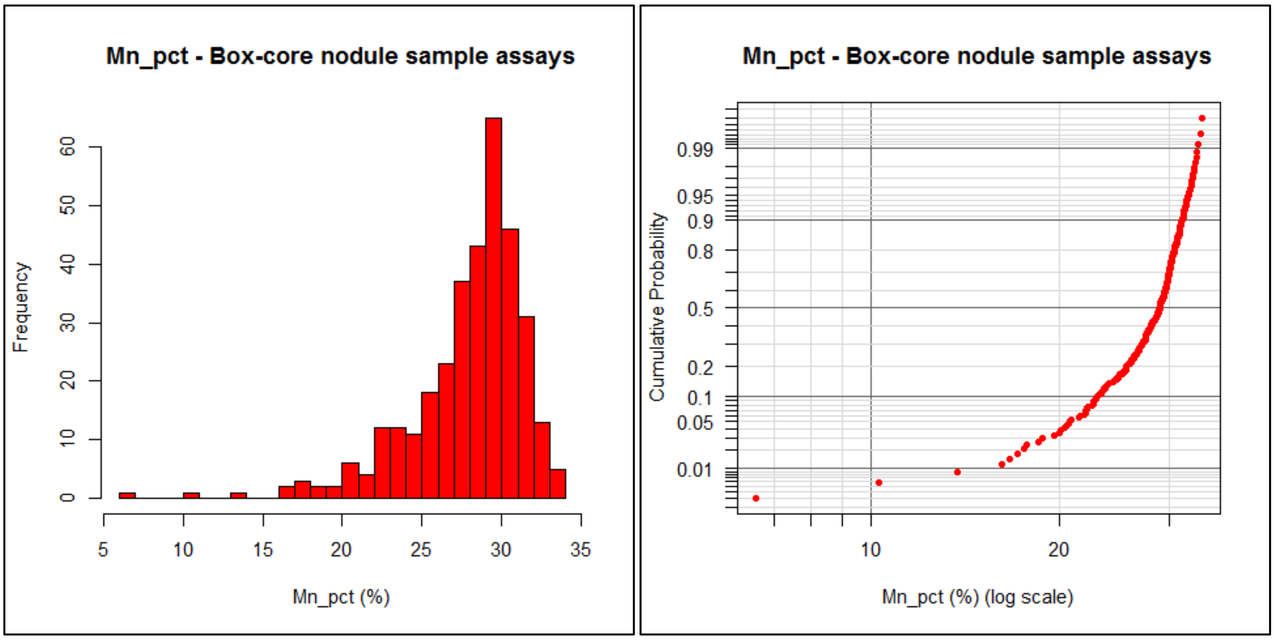


Figure 11.9 Histogram and log-probability plot of Ni for all samples within TOML Exploration Areas

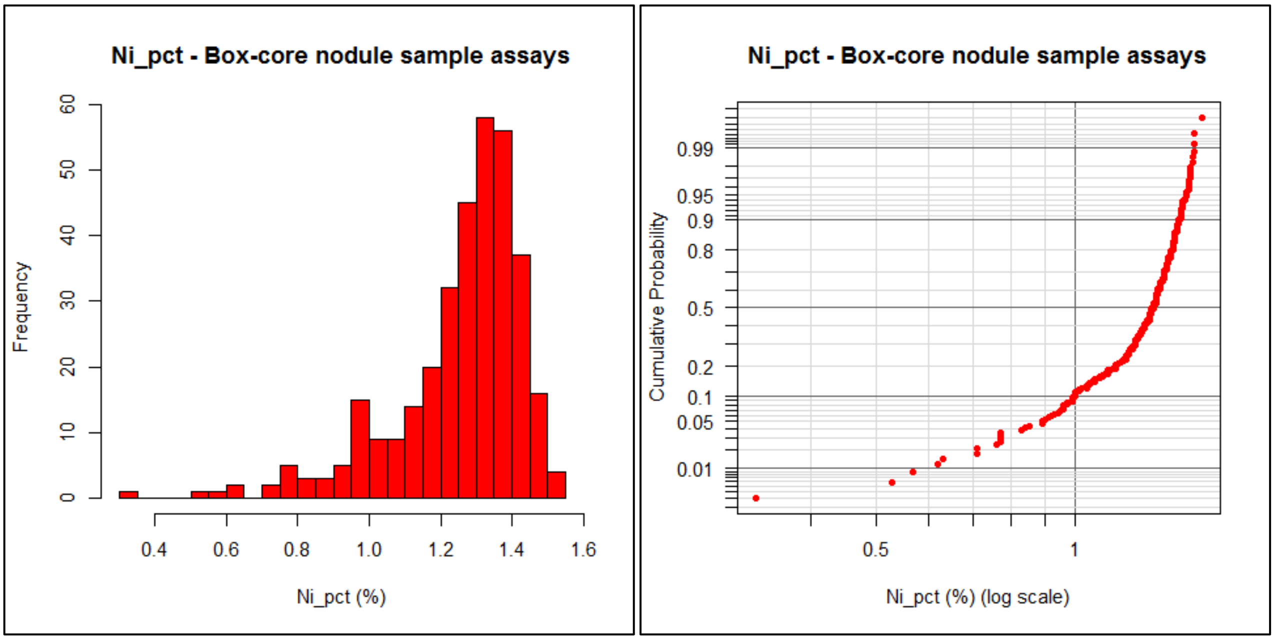


Figure 11.10 Histogram and log-probability plot of Cu for all samples within TOML Exploration Areas

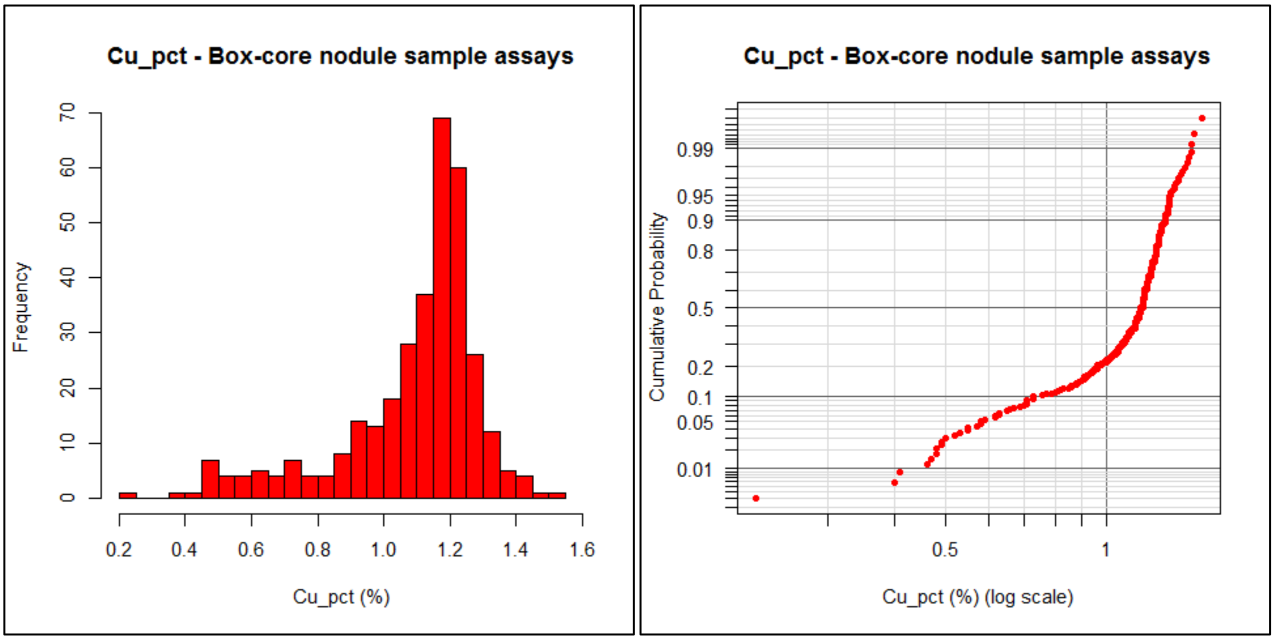
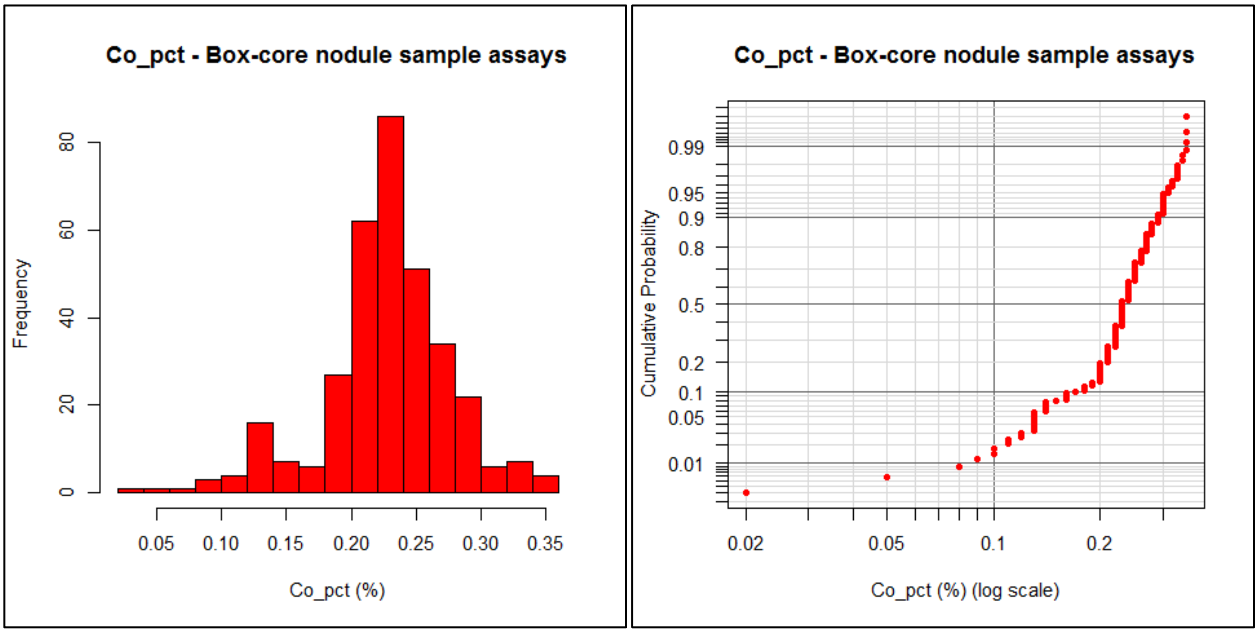
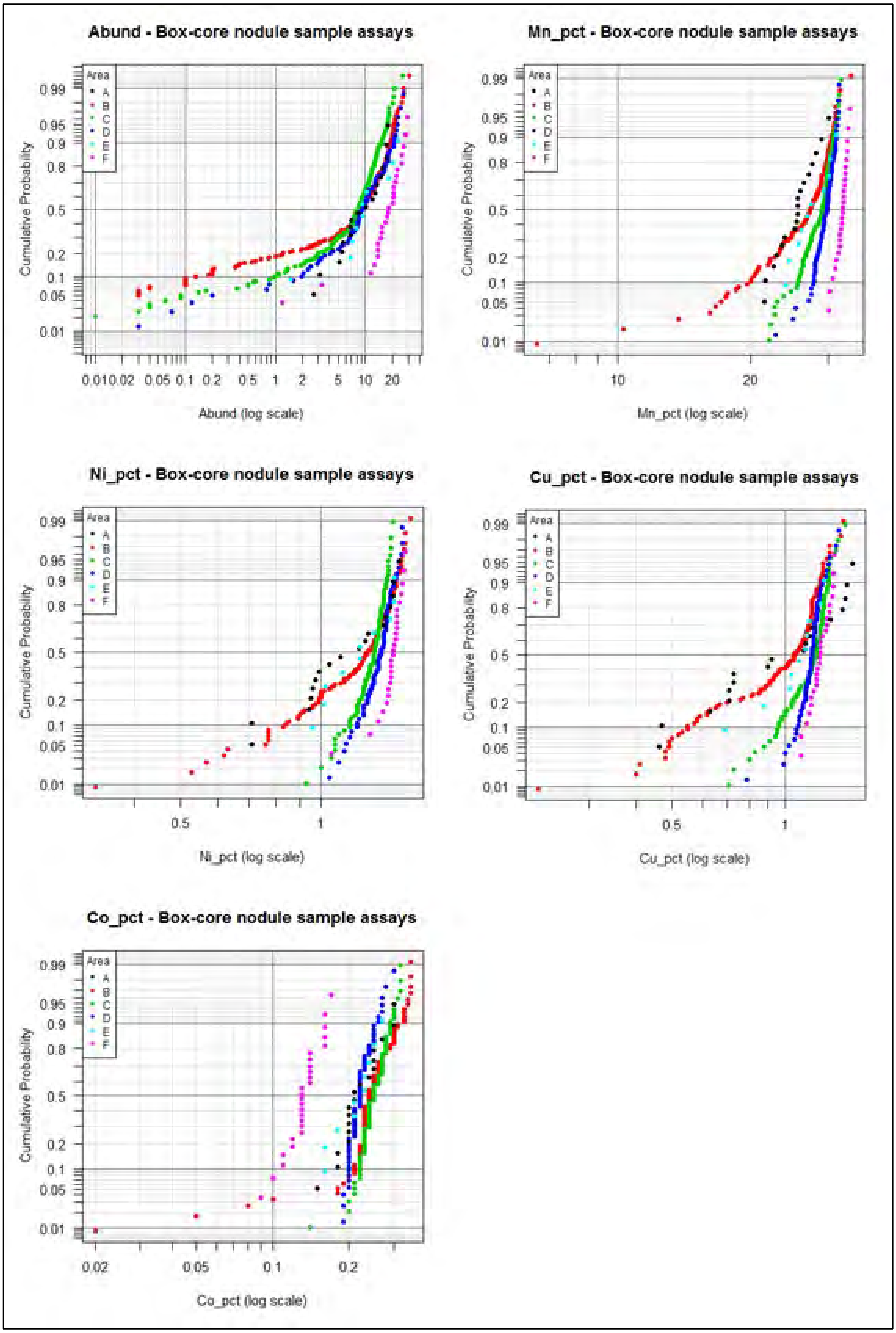


Figure 11.11 Histogram and log-probability plot of Co for all samples within TOML Exploration Areas



The log-probability plots (Figure 11.12) for Abundance, Mn, Ni, Cu and Co by TOML Exploration Area indicate variations in the grade distributions between the areas (note regional grade variations illustrated in Section 6). The distributions for Ni and Cu for samples in TOML Exploration Areas A, B and E are different than the samples in Areas C, D and F. This feature is also present in the full CCZ data set and is interpreted to be due to regional-scale geological differences. Nodule samples from Area F show significantly lower Co than samples from all the other areas while Mn shows a gradual increase from Areas A and B through to Area F.

Figure 11.12 Log-probability plots for Abundance, Mn, Ni, Cu and Co by TOML Exploration Areas



Box plots provided in Figure 11.12 clarify the differences in assays between TOML Exploration Areas. These plots also reveal that the variance in Ni and Cu is higher for TOML Exploration Areas A and B then the other areas. Also, Area E shows higher Ni variance similar to Area A and B. Area F appears to have anomalously high Mn with a much lower variance then all other areas. Area F appears to also have higher median Ni and Cu and significantly lower Co values.

Box-plots summarising molybdenum and the light and heavy rare earth elements are provided in Figure 11.14 to Figure 11.16. At this stage reasonable prospects of economic extraction have not been demonstrated for these elements and so they have not been estimated as part of the Mineral Resource.

Figure 11.13 Box-plots for Abundance, Mn, Ni, Cu and Co by TOML Exploration Areas

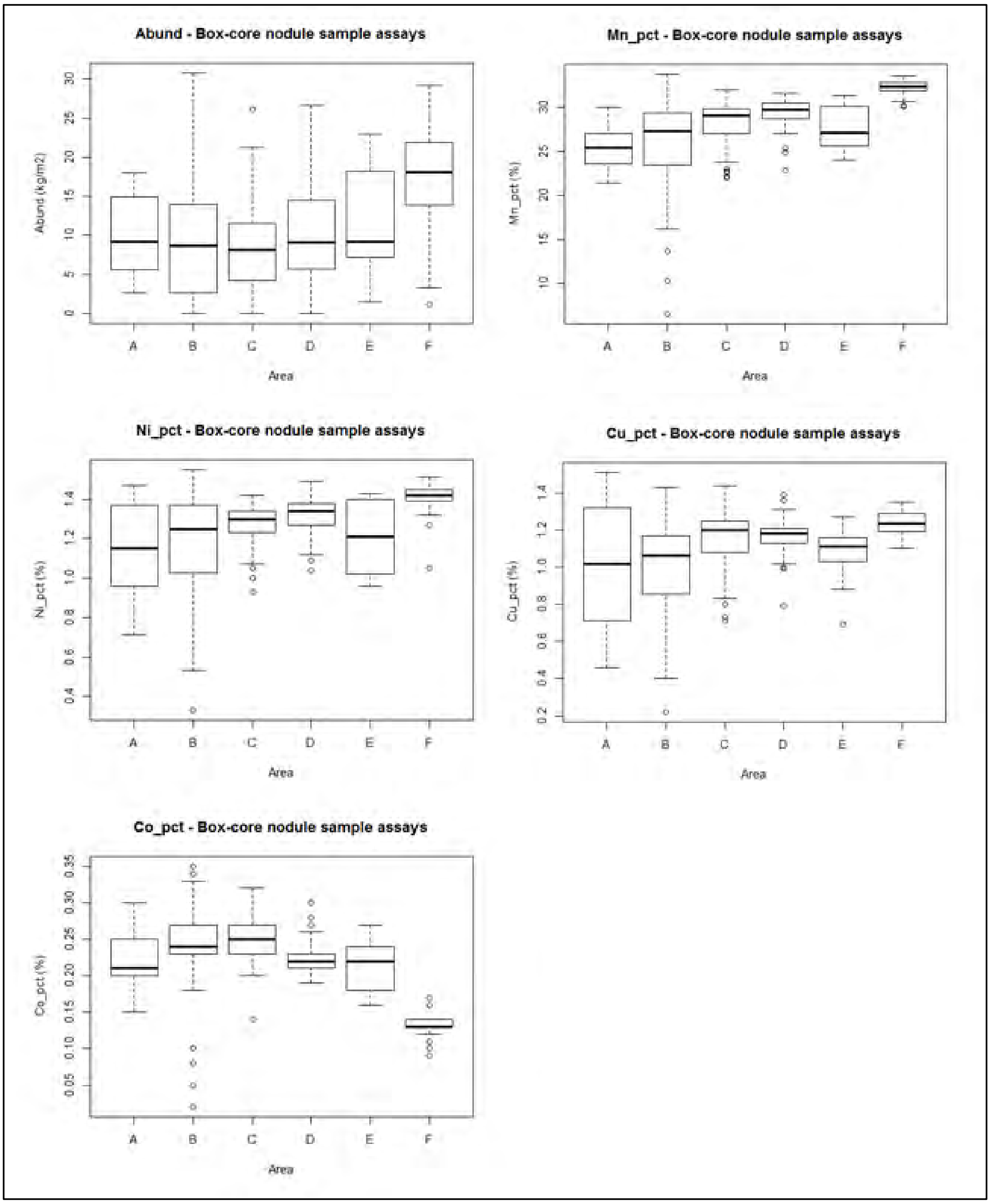


Figure 11.14 Box-plot of Mo for sample data within the TOML Exploration Areas

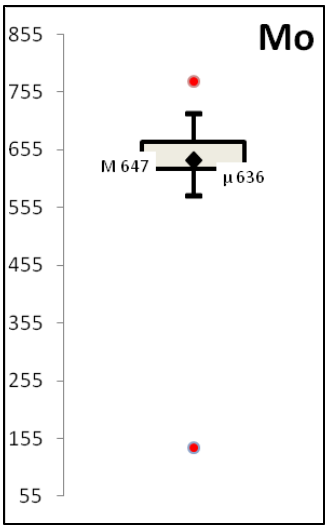


Figure 11.15 Box-plot of light rare earth elements for sample data within the TOML Exploration Areas

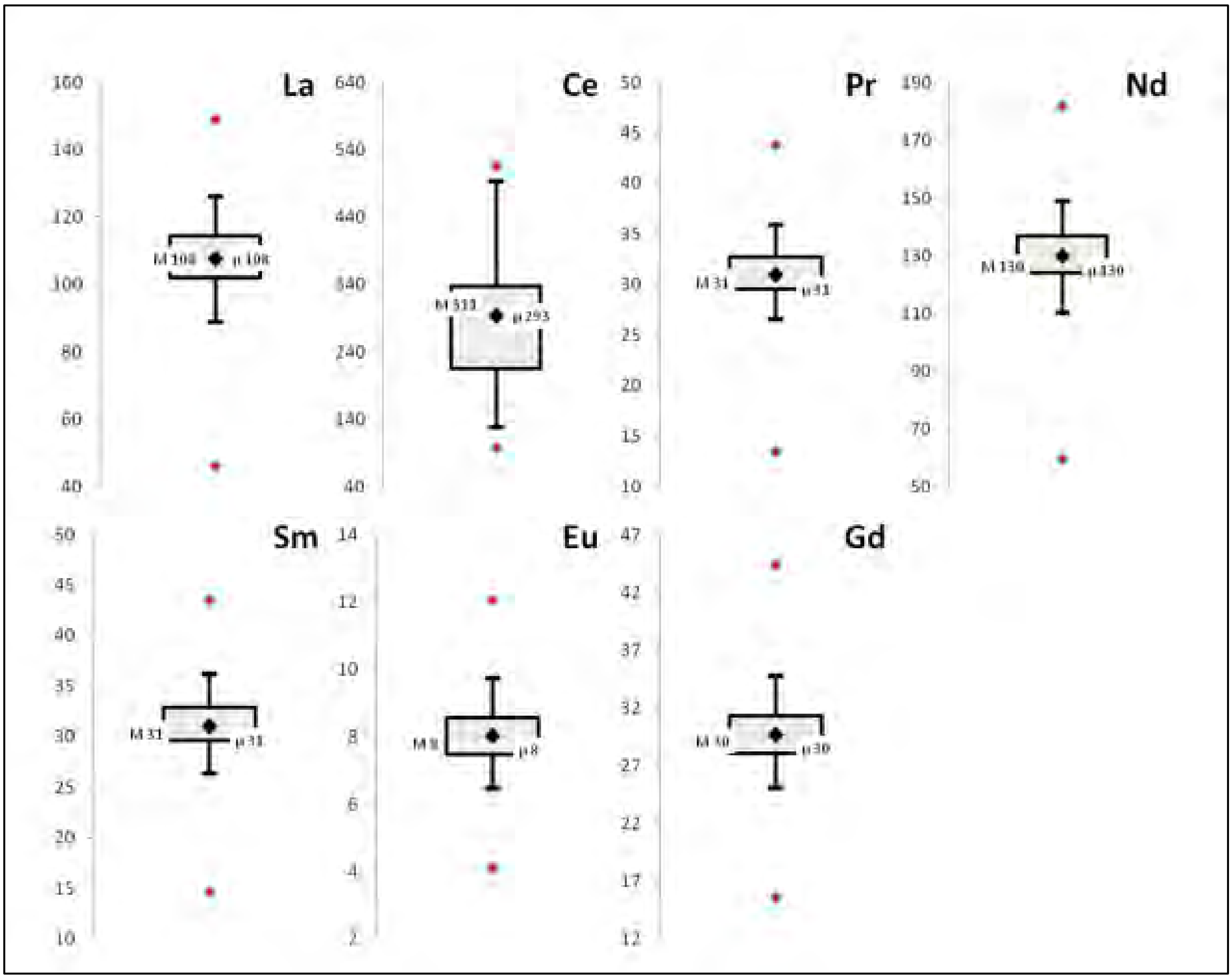
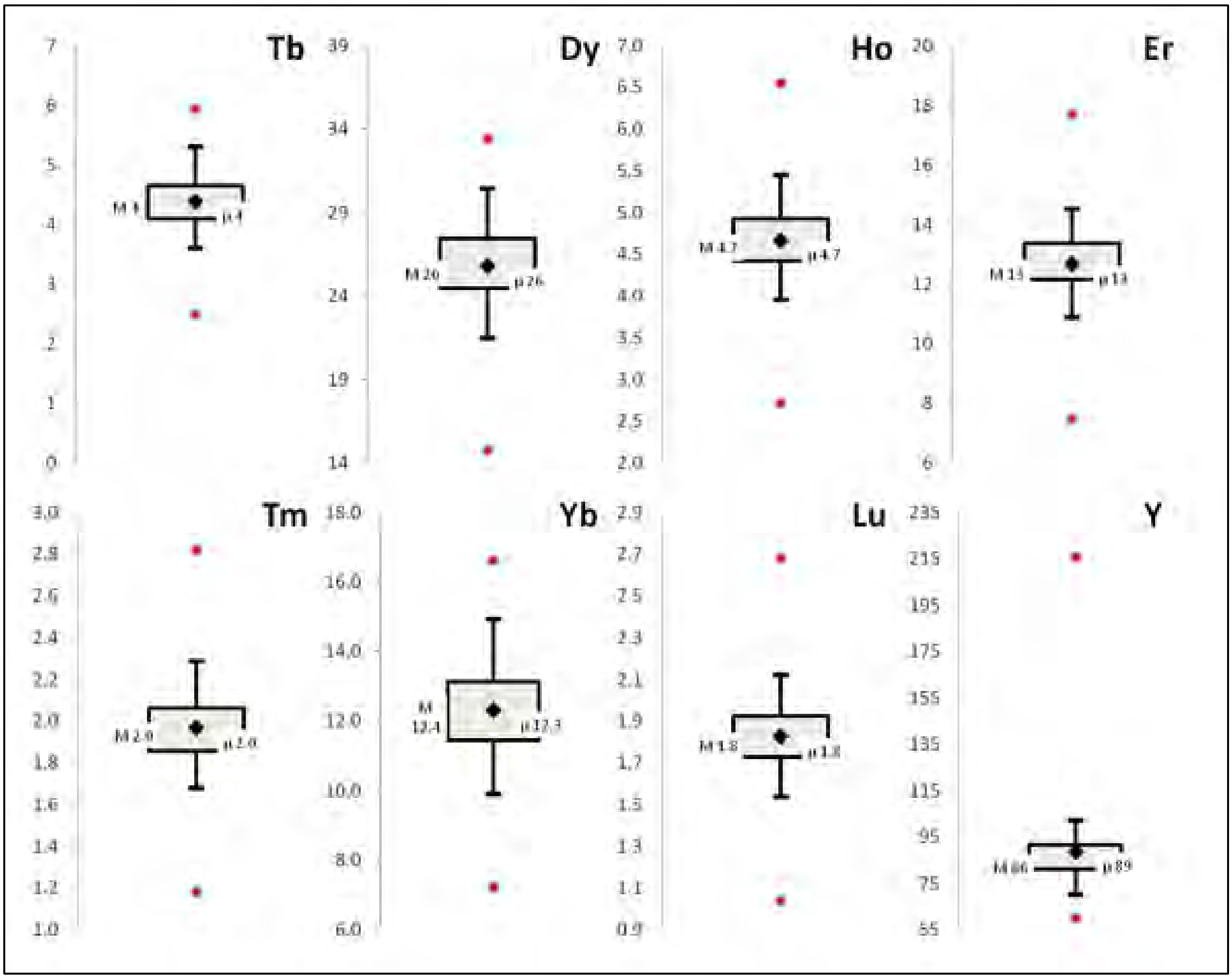


Figure 11.16 Box-plot of heavy rare earth elements for sample data within the TOML Exploration Areas



The coefficients of variation are very small for nodule Abundance, Mn, Ni, Cu and Co suggesting that the application of top-cuts is not necessary. Also, the approximate natural limits for absorption of the Ni (~6.02%), Cu (~8.03) and Co (~6.60%) metals, suggested in the study by Novikov and Bogdanova (2007), are significantly higher than the maximum values (Ni=1.55%, Cu=1.51%, Co=0.35%) in the data. This suggests that all the Ni, Cu and Co values are within natural limits.

The presence of outliers (or 'extreme' values) was assessed by examining the summary statistics and probability plots. No outliers were detected.

Top cuts were not applied to the data prior to grade estimation.

11.2.3 Representativeness of sampling

In-fill box core sampling by TOML in 2015 confirmed the presence of nodules at similar grade and abundance to the wider spaced historical sampling. A comparison between the mineral resource estimates is further below.

TOML also collected continuous sea floor photo profiles along three (3) lines in Area B and four (4) lines in Area C.

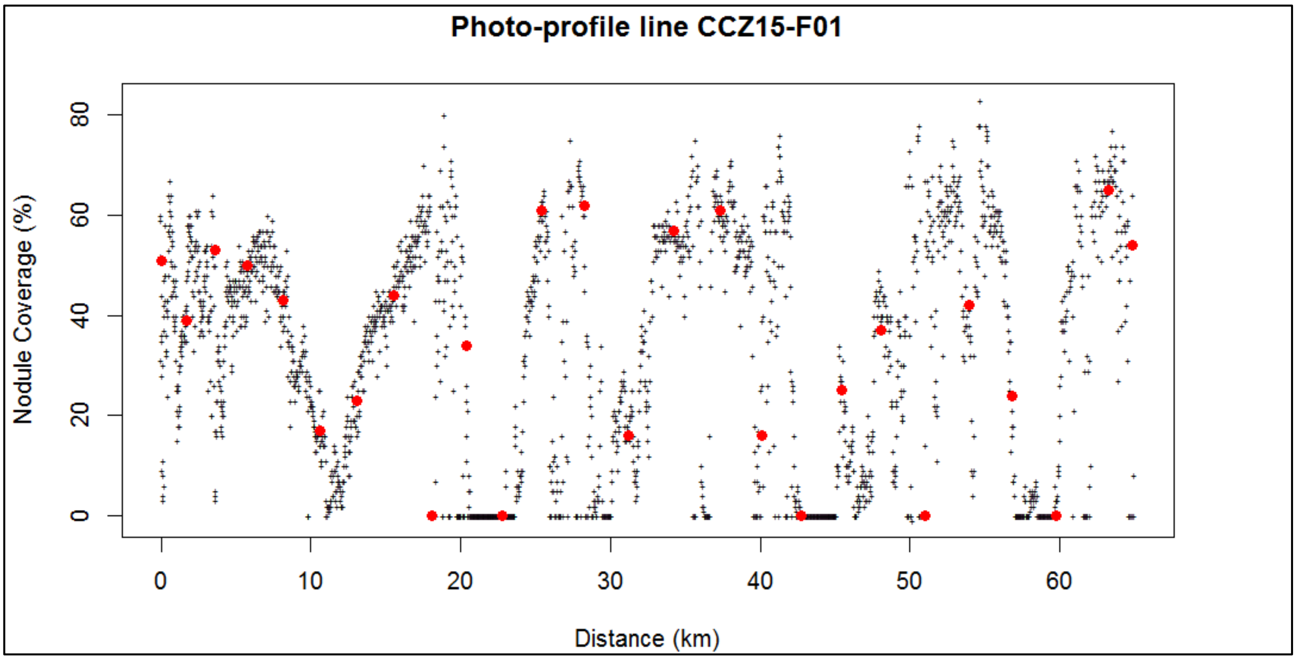
From these photos it is possible to derive the percent of nodule coverage using automated image processing techniques. The percent nodule coverage is the amount of image pixels identified as nodules divided by the total number of pixels in the photo. It is also possible to use the long-axis estimation method for determining nodule abundance. However, this method is time consuming to process a single image as the long axis of every nodule is picked manually. An accurate, repeatable and robust automated computer implementation of LAE is being developed by a Nautilus contractor and is currently in the prototype stage.

The nodule percent coverage estimated from the sea floor photos shows a positive correlation with nodule abundance (Figure 11.20). Nodule percent coverage can be used as a proxy for nodule abundance although it is at best a moderate estimator (Figure 11.20).

Plots of the nodule percent coverage for the three lines that cross the TOML Exploration sub-area B1 are shown in Figure 11.17 to Figure 11.19.

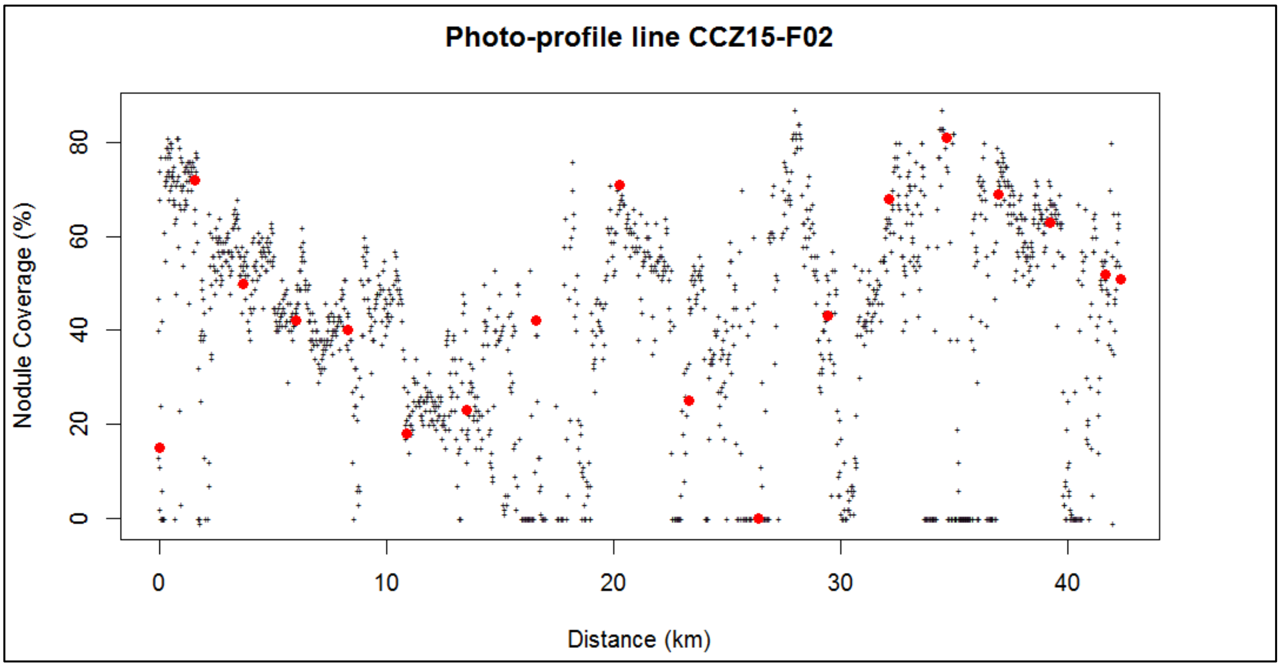
These plots show the presence of nodules between box-core locations. Note that the average distance between each photo is approximately 25 m and ranges from 5 m to 79 m.

Figure 11.17 Photo-profile line CCZ15-F01 that crosses Area B1 Mineral Resource



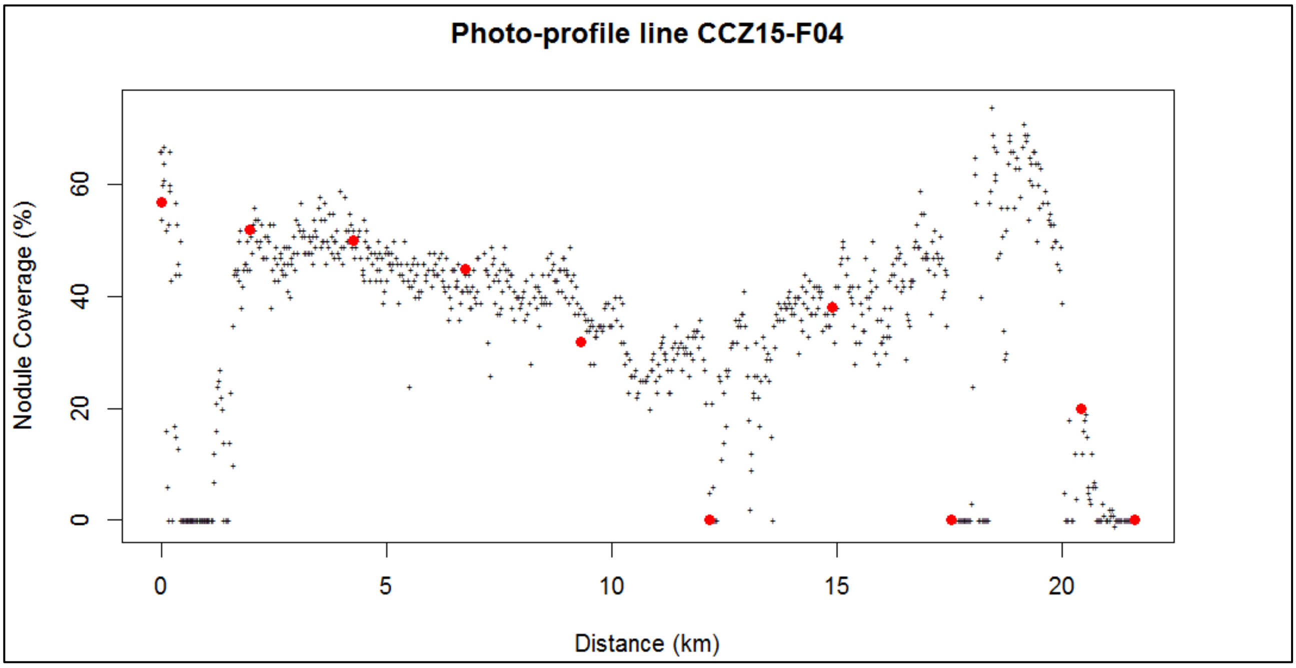
Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate. Black dots – nodule abundance for all other seafloor photos.

Figure 11.18 Photo-profile line CCZ15-F02 that crosses Area B1 Mineral Resource



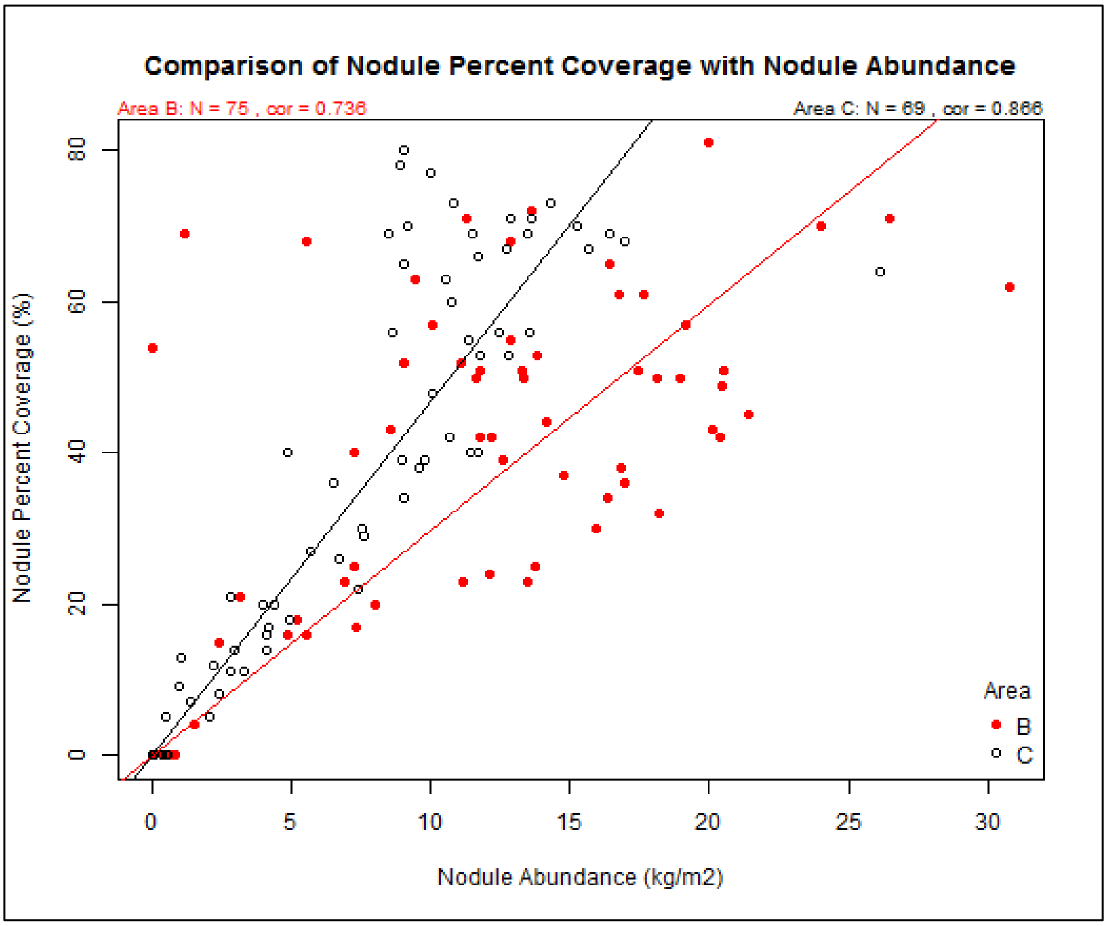
Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate. Black dots – nodule abundance for all other seafloor photos.

Figure 11.19 Photo-profile line CCZ15-F04 that crosses Area B1 Mineral Resource



Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate. Black dots – nodule abundance for all other seafloor photos.

Figure 11.20 Comparison of nodule percent coverage against nodule abundance

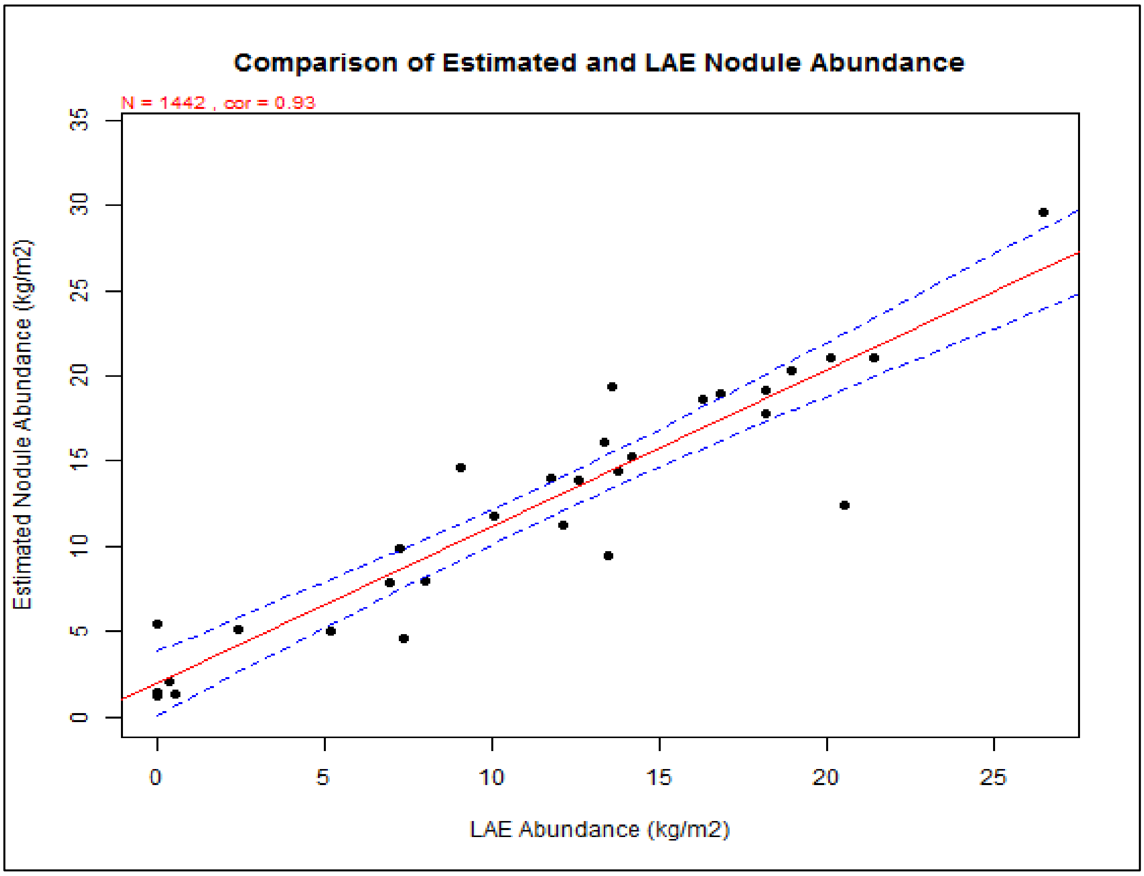


A total of 2754 seafloor photos from the photo profile lines CCZ15-F01, CCZ15-F02 and CCZ15-F04, using an image analysis program to estimate the long axis dimensions of nodules in the photos. These photo-profile lines cover the Measured Mineral Resource area within TOML sub-area B1. The long axis estimates were then used to estimate the nodule abundance for each photo. This data was not required or used in estimation of the Mineral Resource, but they do support it.

There is very good agreement between the nodule abundance estimated from automated analysis of the seafloor photos and the nodule abundance estimated from manual measurement of the nodule long-axis (Figure 11.21). Refinement of the automated method is likely to result in even better correlation with the manual method. The benefit of the automated method is reduced time in processing each image which enables more images to be processed. This will enable almost complete mapping of nodule abundance within selected areas prior to nodule harvesting and can be used in a grade control system.

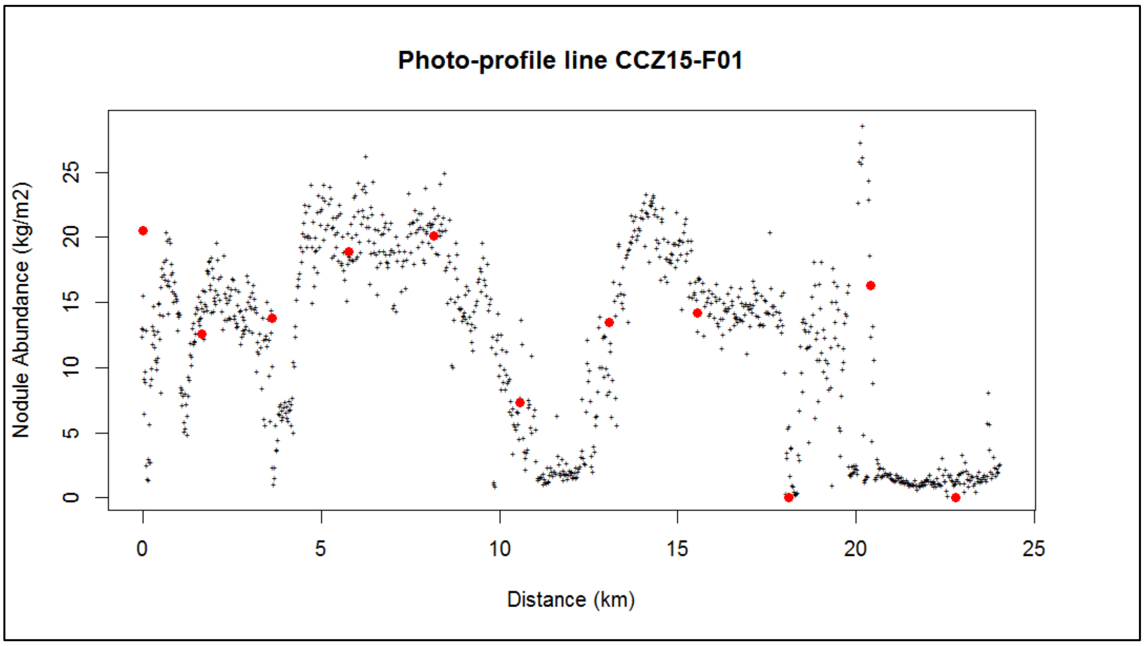
Figure 11.22 to Figure 11.24 show plots of the nodule abundance estimated from the seafloor photos. Note that the distance between each photo is approximately 30 m.

Figure 11.21 Comparison of nodule abundance estimated from photos against nodule abundance estimated manually using the long-axis estimation method



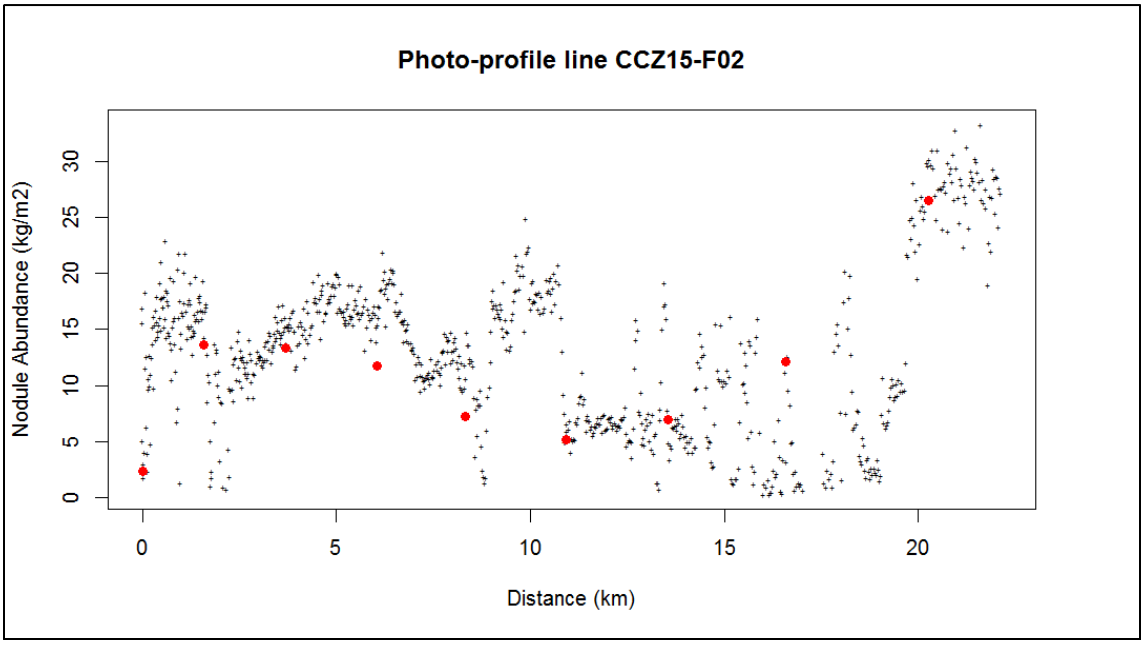
The red line is the fitted linear regression. The blue dashed lines are the 95% confidence intervals for the linear regression model.

Figure 11.22 Nodule abundance photo-profile line CCZ15-F01 that crosses sub-area B1 Measured Mineral Resource



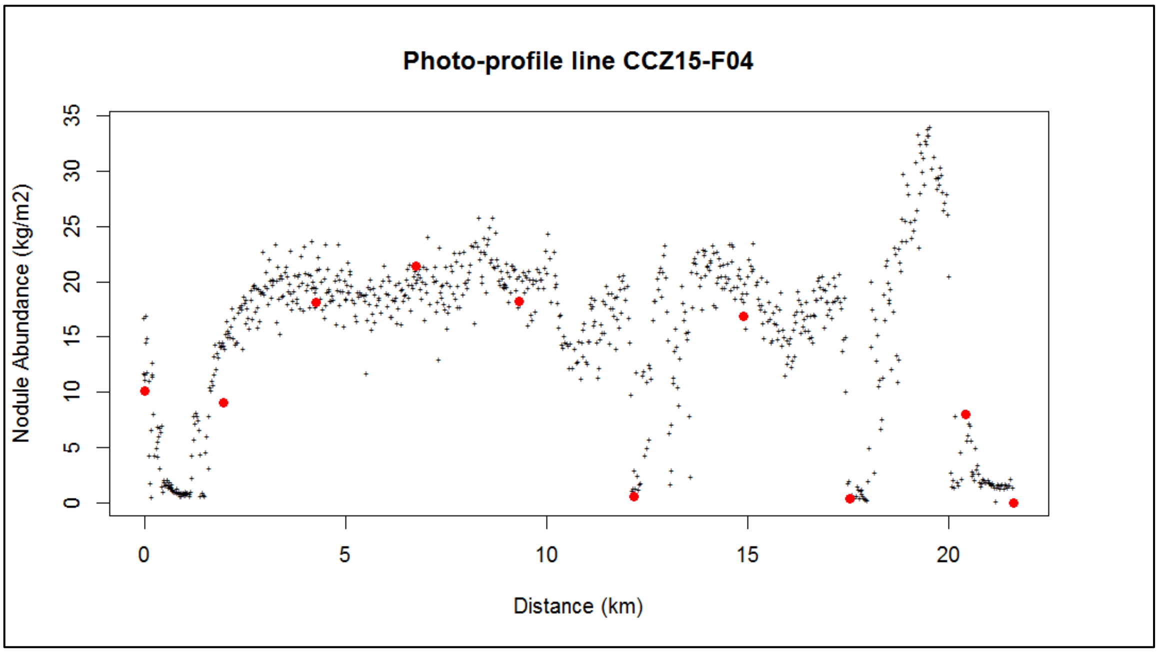
Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate. Black dots – nodule abundance for all other seafloor photos.

Figure 11.23 Nodule abundance photo-profile line CCZ15-F02 that crosses sub-area B1 Measured Mineral Resource



Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate. Black dots – nodule abundance for all other seafloor photos.

Figure 11.24 Nodule abundance photo-profile line CCZ15-F04 that crosses sub-area B1 Measured Mineral Resource



Red dots – nodule coverage for seafloor photos which were used in the manual estimate of abundance using the long-axis estimation method and used in the Mineral Resource estimate.

Black dots – nodule abundance for all other seafloor photos.

Polymetallic nodule grades (Table 11.2) within the CCZ have very low coefficients of variation which indicate a low risk in estimating grades and that ordinary kriging is an appropriate technique to use for estimation. The dredge sampling programme conducted by TOML on polymetallic nodules during their 2013 campaign, included analysis of multiple individual nodules taken from each dredge sample. It confirmed the very low variance in the nodule grades at the local scale.

Variograms of the polymetallic nodule grades of Mn, Ni, Cu and Co within the TOML Exploration Area show reasonable spatial continuity with ranges greater than the average sample spacing. The long variogram ranges for the nodule grades reflect the very large-scale diffuse distribution of metals within the ocean water column and that the manganese acts like a sponge absorbing the metals. The variogram for abundance, on the other hand, has significantly shorter ranges. This reflects the mechanism of nodule formation and the less continuous distribution of nodules.

The Qualified Person considers that the box-core and free fall grab sample spacing within the TOML Exploration Areas A to F are sufficient to demonstrate continuity of Mn, Ni, Cu and Co. The addition of photo profiling enables confidence in the continuity of nodule abundance and can be reasonably assumed on the basis of the scale of the deposit and the mechanisms of nodule formation.

11.3 Geostatistics

11.3.1 Nodule sample variography

All manganese nodule samples (historical box-core and free fall-grabs, TOML box-core and photos) within the TOML Exploration Area were combined and used for analysis of spatial continuity (autocorrelation). The experimental semi-variograms were scaled to the population variance. Variogram maps (Figure 11.30) were calculated for the purpose of determining the direction of greatest continuity.

Spherical semi-variogram models were fitted to the experimental variograms using two structures (Table 11.7). Where possible, consistent parameters were used between the fitted variogram models for each direction and each of the variables. This was done to ensure element relationships or correlations evident between samples are respected implicitly during estimation and reflected in the resource estimate. Also, the same type of variogram model was fitted to the experimental semi-variograms.

The directions of greatest continuity deduced from the variogram maps appears to be approximately 150° and 060°. Abundance and Cu show no anisotropy in the variogram ranges while Mn and Ni appear to show greater continuity in the 150° and Co shows greater continuity in the 060° direction. The 060° direction is roughly parallel to the broad regional trend of the CCZ and the 150° direction is parallel to the abyssal hills. Smaller scale local trends oriented parallel with bathymetry ridges are not visible in the wide spaced data.

The variogram models listed in Table 11.7 were used in estimating the values for nodule abundance, Mn, Ni, Cu and Co.

Table 11.7 Variogram models

Variable	Nugget	Spherical Structure 1			Spherical Structure 2			Anisotropy Ratio
			Range H1			Range H2		
	C0	C1	060° (km)	150° (km)	C1	060° (km)	150° (km)	
Abundance	0.40	0.60	5	5	–	–	–	1.0
Mn	0.21	0.37	5	10	0.42	15	30	0.5
Ni	0.21	0.37	5	10	0.42	15	30	0.5
Cu	0.21	0.37	22	22	0.42	70	70	1.0
Co	0.21	0.37	22	16	0.42	70	50	0.714

Figure 11.25 Abundance omni-directional, 060° and 150° directional variograms

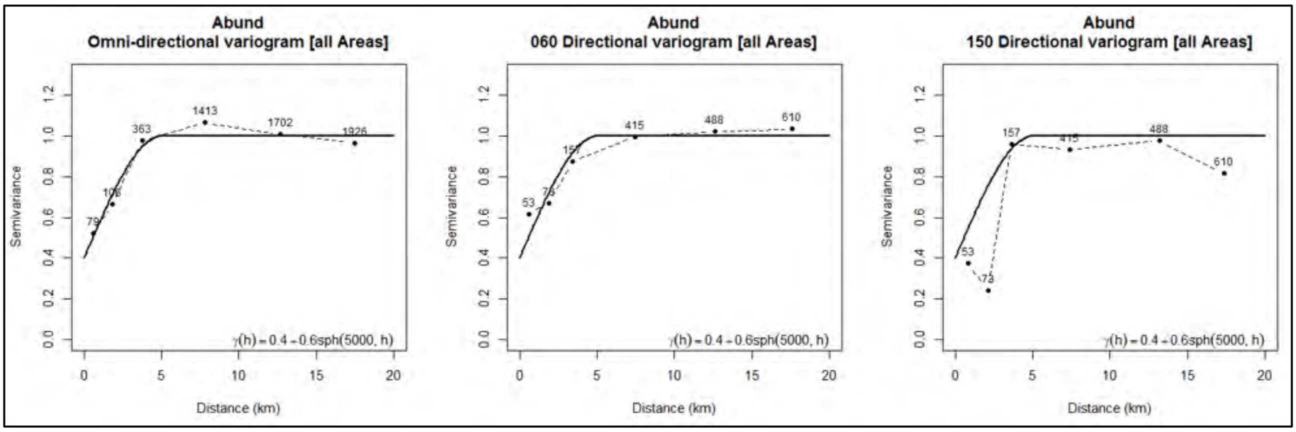


Figure 11.26 Mn omni-directional, 060° and 150° directional variograms

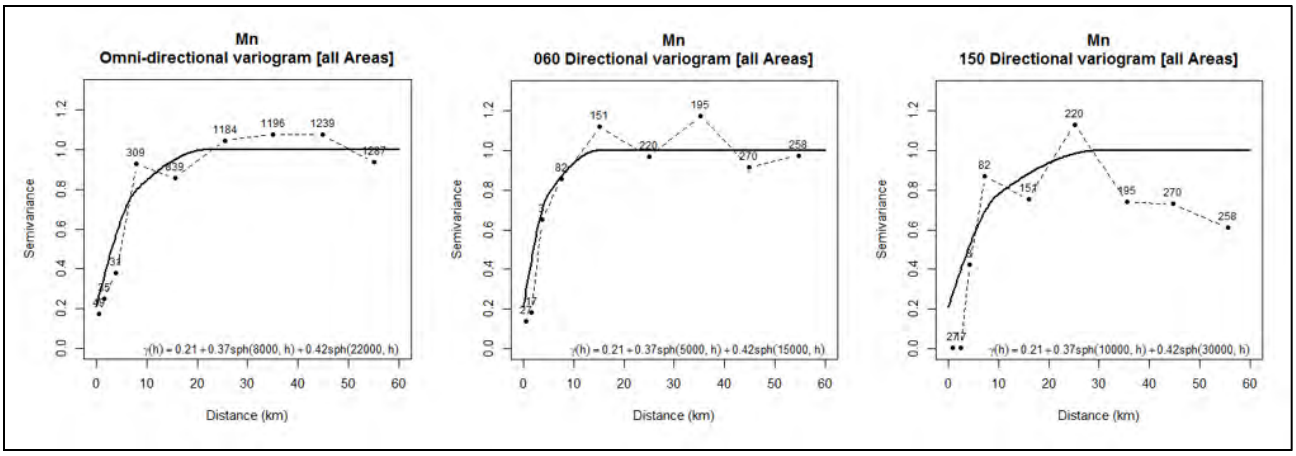


Figure 11.27 Ni omni-directional, 060° and 150° directional variograms

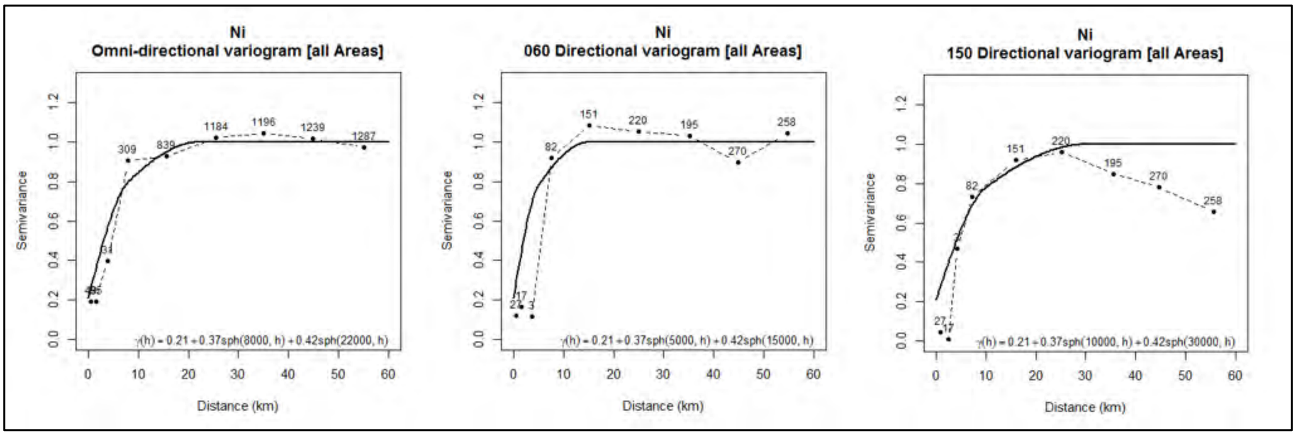


Figure 11.28 Cu omni-directional, 060° and 150° directional variograms

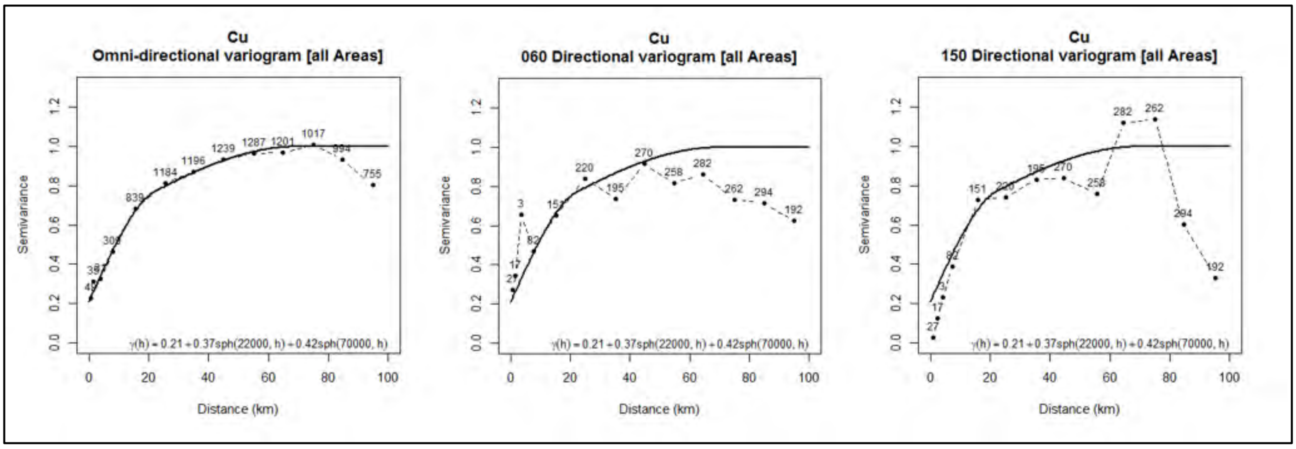


Figure 11.29 Co omni-directional, 060° and 150° directional variograms

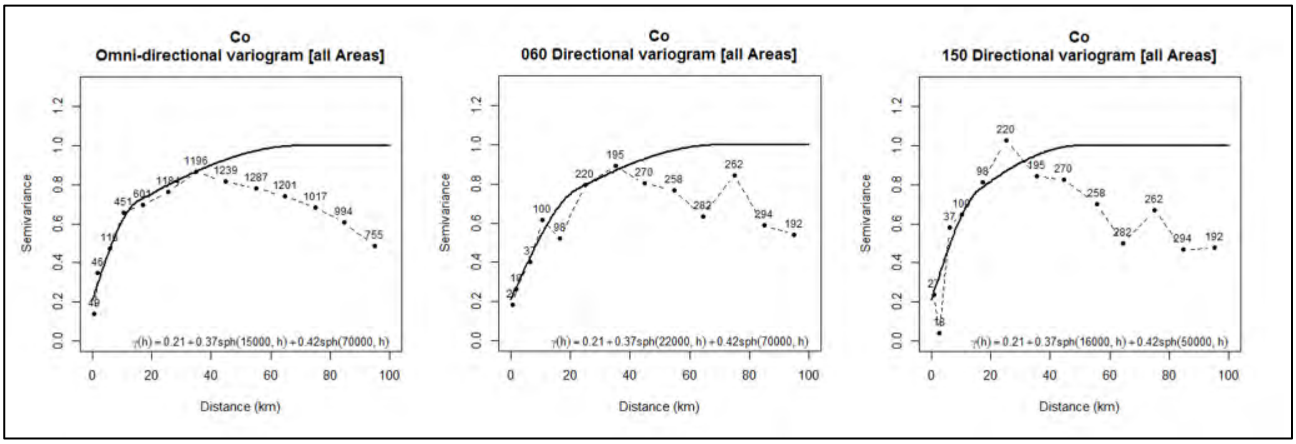
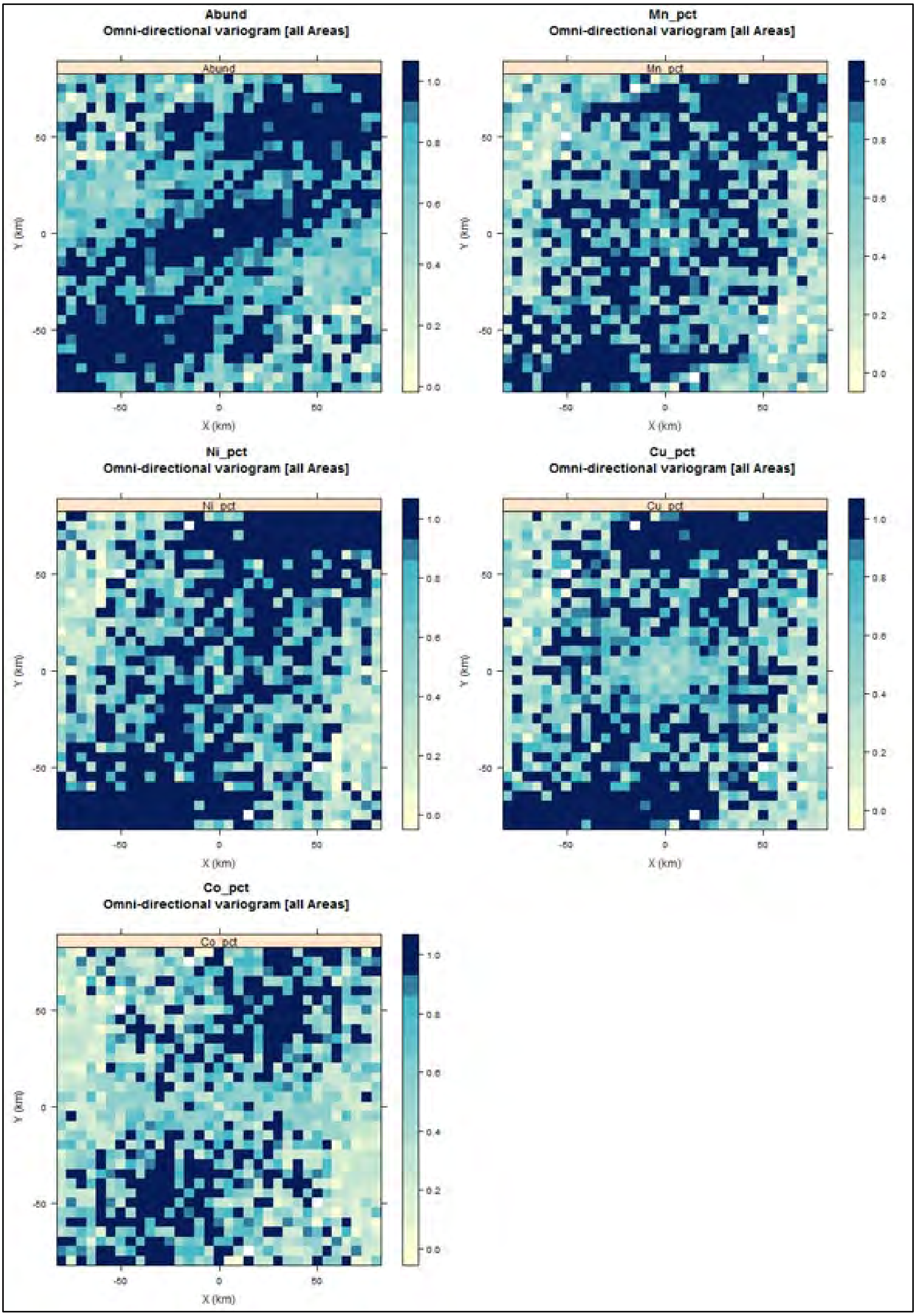


Figure 11.30 Semi-variogram maps for Abundance, Mn, Ni, Cu and Co



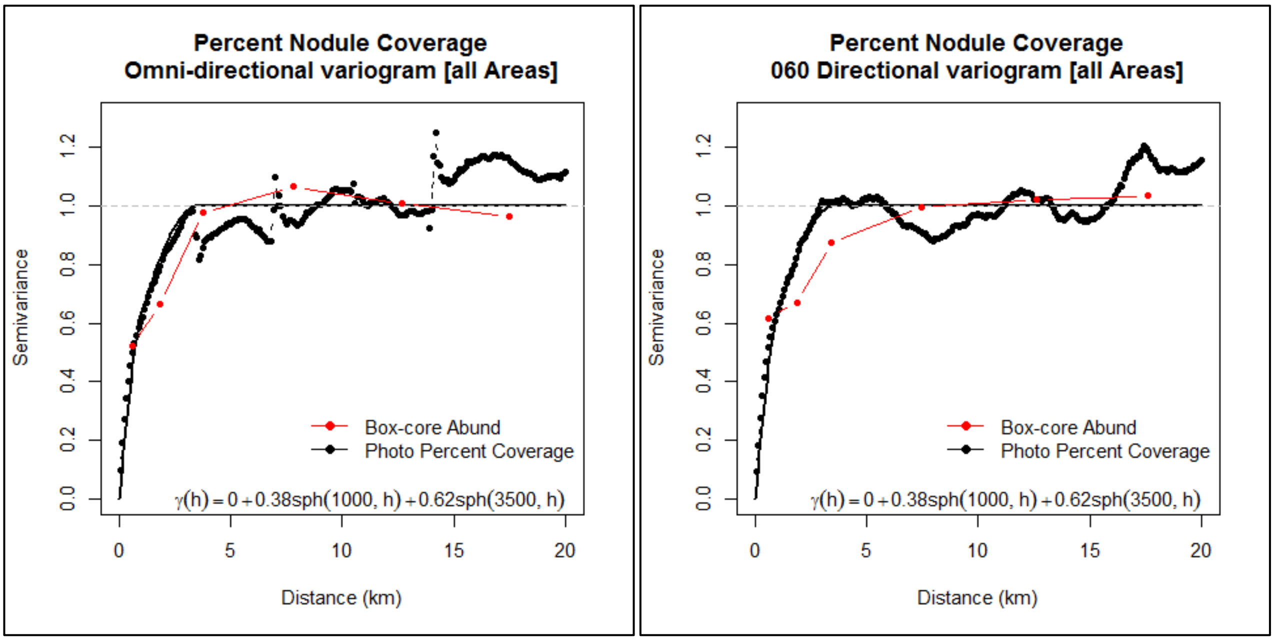
11.3.2 Variography of nodule coverage estimated from photo profiles

The continuity of nodule abundance as measured by the abundance variograms was checked by using the photo profile data.

The omni-directional and 060° directional variograms (Figure 11.31) for the percent nodule coverage estimated from the sea floor photos are similar to the box-core variograms. The range of percent nodule coverage is slightly shorter than the box-core samples. The large number of close spaced photos allows for a better estimate of the very short-range spatial variability and nugget. The percent nodule coverage semivariance starts at 0 (nugget) and quickly rises to the same semivariance value (between 0.5 and 0.6) as the first point on the box-core nodule abundance variogram. This suggests that the nugget for nodule abundance is close to 0 and that the first variogram structure has a sill of approximately 0.38 at a range of 1,000 m.

Also interesting is the periodic effect (hole effect) evident in the sill at ranges of approximately 7.5 km and 15 km which may be related to the spacing between the abyssal hills.

Figure 11.31 Omni-directional and 060° directional variograms for percent nodule coverage estimated from sea floor photos

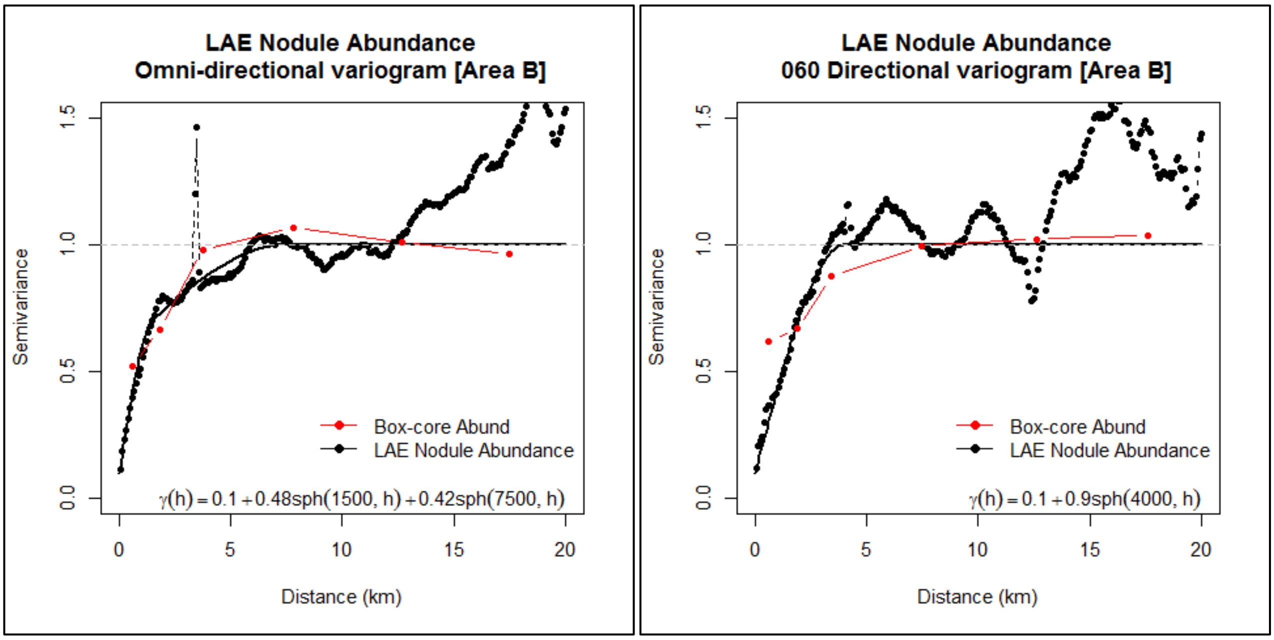


11.3.3 Variography of the estimated nodule abundance from the photo profile lines

The nodule abundance data automatically estimated from the seafloor photos using the LAE method were used to check the continuity of nodule abundance and compared with the variograms from the exploration sample data.

Compared with the nodule percent coverage variograms (Figure 11.31), the LAE nodule abundance omni-directional variograms show a slightly longer range of 7500 m. The same periodic effect (hole effect) evident in the percent nodule coverage variograms is also present in the 060° directional variogram while the omni-directional variogram hints at the presence of a long-range trend in the data. The omni-directional variogram is very similar to the nodule sample variogram but again shows a very low nugget variance.

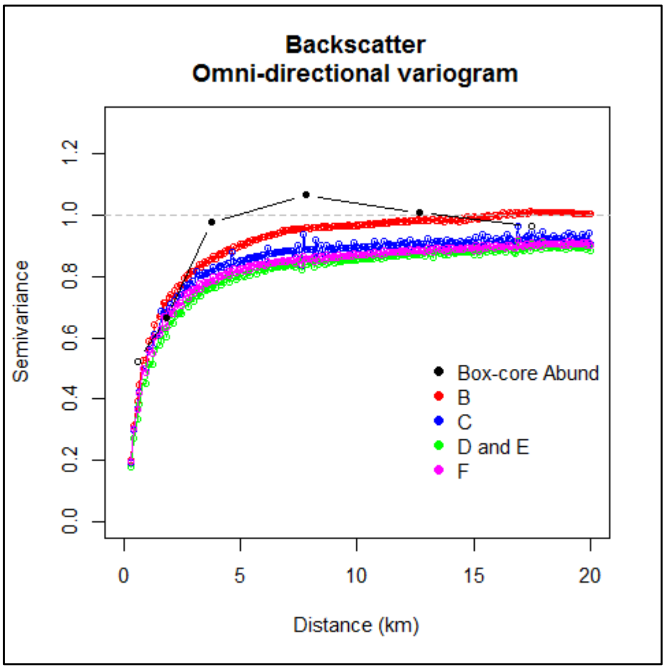
Figure 11.32 Omni-directional and 060° directional variograms for nodule abundance estimated using the LAE method from sea floor photos



11.3.4 Variography of the backscatter data

The backscatter data shows limited correlation with abundance but, in a broad sense, can be used to delineate zones of nodules from zones with very low to no nodules (the no nodule (NON) domain). Omni-directional variography (Figure 11.33) of the backscatter values indicate spatial variability that is consistent with the nodule sample data. The omni-directional variogram of the nodule sample data has a shorter range than the backscatter variograms but with similar very short range spatial variability. Interestingly Area B has the shortest range of the backscatter variograms and Area D and E have the longest.

Figure 11.33 Omni-directional variograms for backscatter values



11.4 Geological block model

Six block models were constructed, one for each TOML Exploration Area (A through to F). Each model was blocked according to the data spacing. Blocks of 1.75 km by 1.75 km were used to fill the areas tested by box core and photo profiles on a 3.5 km by 3.0 km grid (Measured Mineral Resource). Blocks of 3.5 km by 3.5 km were used to fill areas tested by box core sampling on a nominal spacing of approximately 7 km by 7 km (Indicated Mineral Resources), while the remainder were filled with blocks of 7.0 km by 7.0 km (Inferred Mineral Resources). Sub-cells with dimensions of 0.875 km by 0.875 km were used to accurately represent the boundaries of the TOML Exploration Areas, the areas interpreted to contain no nodules and the boundaries between Measured and Indicated.

The total area of the block model is 74 683 km^2 which is 99.96% of the actual total area of the TOML Licence Areas of 74 713 km^2 (Table 11.8). This indicates that the sub-blocks were adequate for approximating the licence boundaries.

Table 11.8 Comparison of model areas and actual licence areas

Area	Actual Area (m^2)	Model Area (m^2)	Percent Difference
A	10 280.560	10 309.141	0.278
B	9 966.266	9 950.062	–0.163
C	15 763.385	15 785.656	0.141
D and E	22 882.804	22 843.953	–0.170
F	15 819.900	15 794.078	–0.163
All	74 712.915	74 682.891	–0.04

11.5 Mineral Resource estimation

Ordinary Kriging (OK) was used to estimate Abundance, Mn, Ni, Cu and Co into the block model. Grades were estimated on a parent block basis using block discretisation of 5 by 5 by 1. Grades were also estimated using Nearest Neighbour (NN) and Inverse Distance (IDW) to the power of 2 for validation of the OK estimates. Blocks and sub-blocks within the NON domain were set to zero.

Three separate estimation passes were run, one for each parent cell size (Mineral Resource classification). The estimates for Measured and Indicated Mineral Resource used a search range of 30 km while for Indicated and Inferred a search range of 70km was used. A minimum of 1 and a maximum of 3 samples were allowed per octant search with a maximum of 8 samples per estimate.

The global Mineral Resource estimate is listed in Table 11.9 and the grade tonnage curves are shown in Figure 11.34. At abundance cut-offs of 7 kg/m^2 or less the tonnage and grade are relatively insensitive. Above 7 kg/m^2, global tonnage declines rapidly.

Figure 11.35 through to Figure 11.39 show sample locations on estimated block grades for Ni, Cu, Co, Mn and Abundance within the TOML Exploration Areas A to F. The figures indicate that for Ni, Cu, Co, Mn and Abundance there is continuity at ranges (40 to 80 km) several times greater than the average sample spacing. The patterns in distribution appear consistent between Ni, Cu, Co, and Mn reflecting the homogenous nature of the nodule chemistry across the TOML Exploration Area.

11.6 Cut-off grade

Due to the extremely low variance in the grades and the high metal content of the nodules, a conventional cut-off based on grades is not relevant to definition of the Mineral Resources. A cut-off based on abundance is a more effective basis for determining the limits of economic exploitation. A cut-off of 4 kg/m^2 abundance was chosen for the TOML Area, based on the estimates of costs and revenues presented in the Initial Assessment (IA) of the Mineral Resource contained in NORI Area D (AMC, 2021). The polymetallic nodule deposits in NORI Area D are similar to those in TOML Areas A through F and the QP considers that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas. Further details are presented in Section 11.9 of this report.

The method of calculation for the cut-off determined the minimum average nodule abundance needed during steady state operations such that the revenue minus costs (excluding capital) is greater than zero. Revenue includes metal pricing and metallurgical processing recoveries, and the costs include the collection, transport, processing, corporate costs, and royalties.

The metal prices assumed in the calculation of the cut-off were: nickel metal US$16,472/t; nickel in nickel sulphate US$18,807/t Ni; copper metal US$6,872/t; cobalt metal US$46,333/t; cobalt in cobalt sulphate US$56,920/t Co; manganese in manganese silicate US$4.50/dmtu. The price estimates are long term (2034–2046) forecasts provided in a report by CRU International Limited (CRU report, dated October 23, 2020). Section 16 summarizes the issues CRU considered in arriving at these price estimates. The QP considers that this timeframe is reasonable in view of the likely time required to bring the majority of the TOML Mineral Resources into production.

11.7 Mineral Resource classification

Classification of the Mineral Resource into Measured, Indicated and Inferred categories, in accordance with SEC Regulation S-K (subpart 1300), considered: the nodule sample quality, uncertainty in the nodule sample abundance and grades, continuity of nodule abundance and grade and scale of the deposit.

- Inferred Mineral Resource classification was based on sampling by Pioneer Contractors on a nominal spacing of 20 km, the variation and uncertainty in the sample quality, and the likely presence of short-range variation to nodule abundance.
- Indicated Mineral Resource classification was based on box core sampling by TOML on a nominal spacing of approximately 7 km by 7 km (including photo profiling in some cases at 7 km by 3 km), supplemented by sampling by Pioneer Contractors.
- Measured Mineral Resource was based on box core sampling by TOML on a nominal spacing of approximately 7 km by 7 km plus photo-profiling on a nominal spacing of 3.5 km by 3.0 km, supplemented by sampling by Pioneer Contractors.

Table 11.9 Mineral Resource estimate, in situ, for the TOML Exploration Area within the CCZ at a 4 kg/m^2 nodule abundance cut-off

TOML Area	Classification	Tonnes (x10^6 wet t)	Abundance (wet kg/m^2)	Ni (%)	Cu (%)	Co (%)	Mn (%)
A	Inferred	114	11.0	1.1	1.0	0.2	25.0
B	Measured	3	11.8	1.3	1.0	0.2	27.6
B	Indicated	14	11.1	1.3	1.1	0.2	28.6
B	Inferred	63	9.1	1.2	1.0	0.3	25.9
C	Indicated	15	8.6	1.3	1.2	0.2	30.5
C	Inferred	115	9.0	1.3	1.1	0.2	28.2
D	Indicated	29	12.2	1.3	1.2	0.2	30.1
D	Inferred	102	9.0	1.3	1.2	0.2	28.8
E	Inferred	58	10.6	1.3	1.1	0.2	28.7
F	Indicated	12	21.6	1.5	1.2	0.1	32.5
F	Inferred	244	16.6	1.4	1.2	0.1	32.2
Total	**Measured**	**2.6**	**11.8**	**1.3**	**1.0**	**0.2**	**27.6**
Total	**Indicated**	**69.6**	**11.8**	**1.3**	**1.2**	**0.2**	**30.3**
Total	**Inferred**	**696**	**11.3**	**1.3**	**1.1**	**0.2**	**29.0**

Note: Tonnes are quoted on a wet basis and grades are quoted on a dry basis, which is common practice for bulk commodities. Moisture content was estimated to be 28% w/w. These estimates are presented on an undiluted basis without adjustment for resource recovery.

Figure 11.34 Nodule Abundance – Tonnage Curve

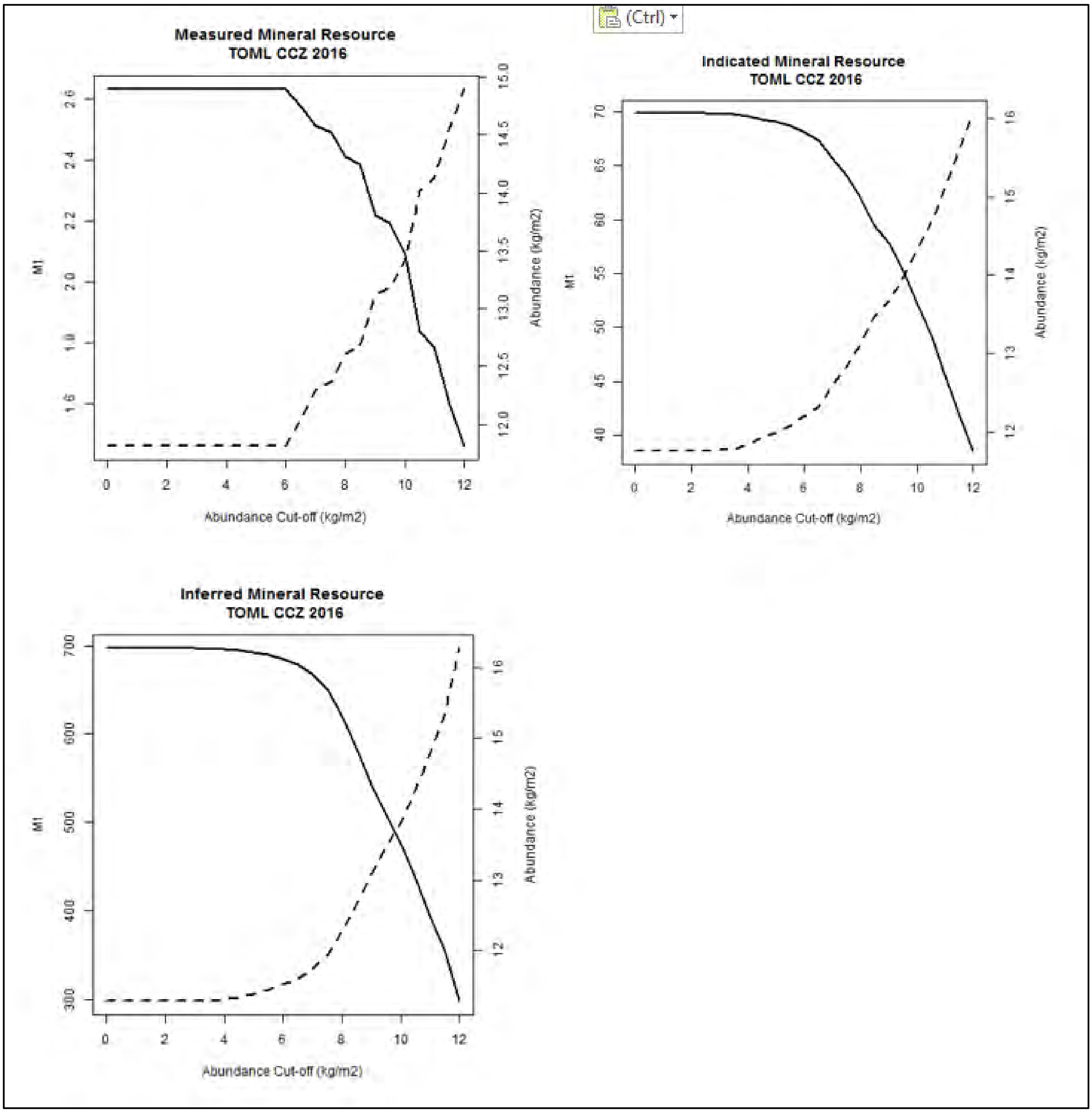


Figure 11.35 Map showing block model and sample distribution for Abundance Mn, Ni, Cu and Co in TOML Area A

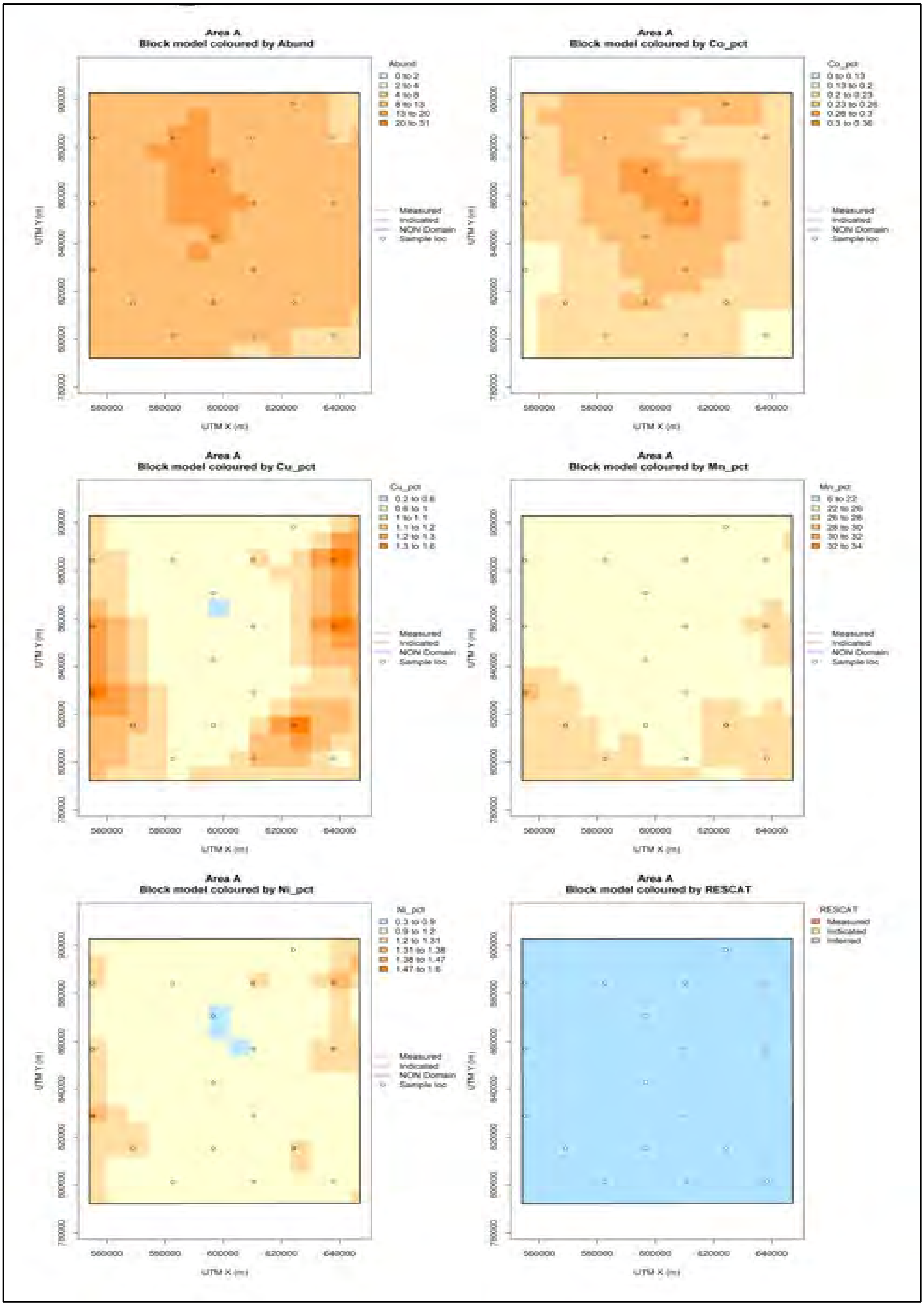


Figure 11.36 Map showing block model and sample distribution for Abundance Mn, Ni, Cu and Co in TOML Area B

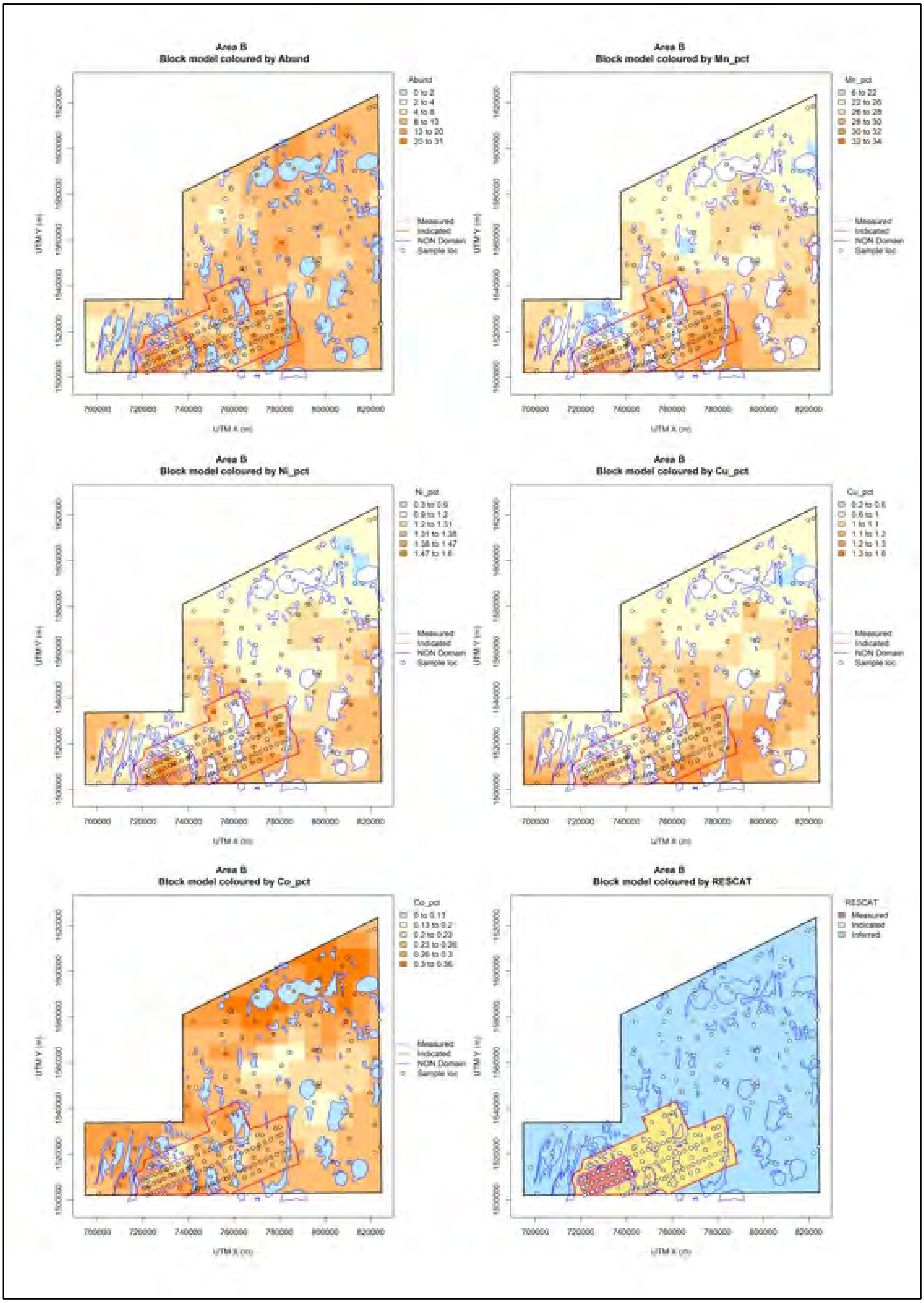


Figure 11.37 Map showing block model and sample distribution for Abundance Mn, Ni, Cu and Co in TOML Area C

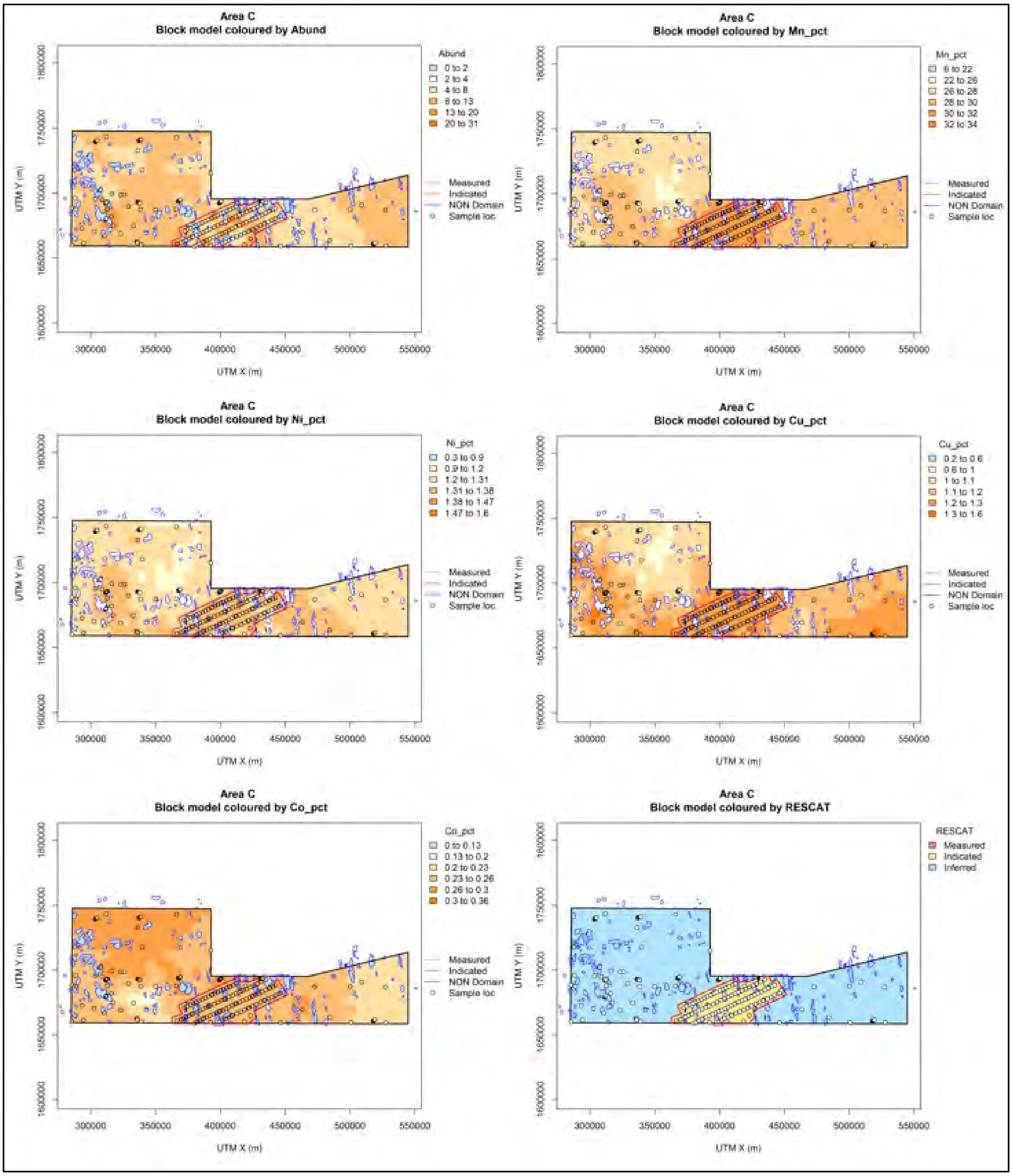


Figure 11.38 Map showing block model and sample distribution for Abundance Mn, Ni, Cu and Co in TOML Area D and Area E

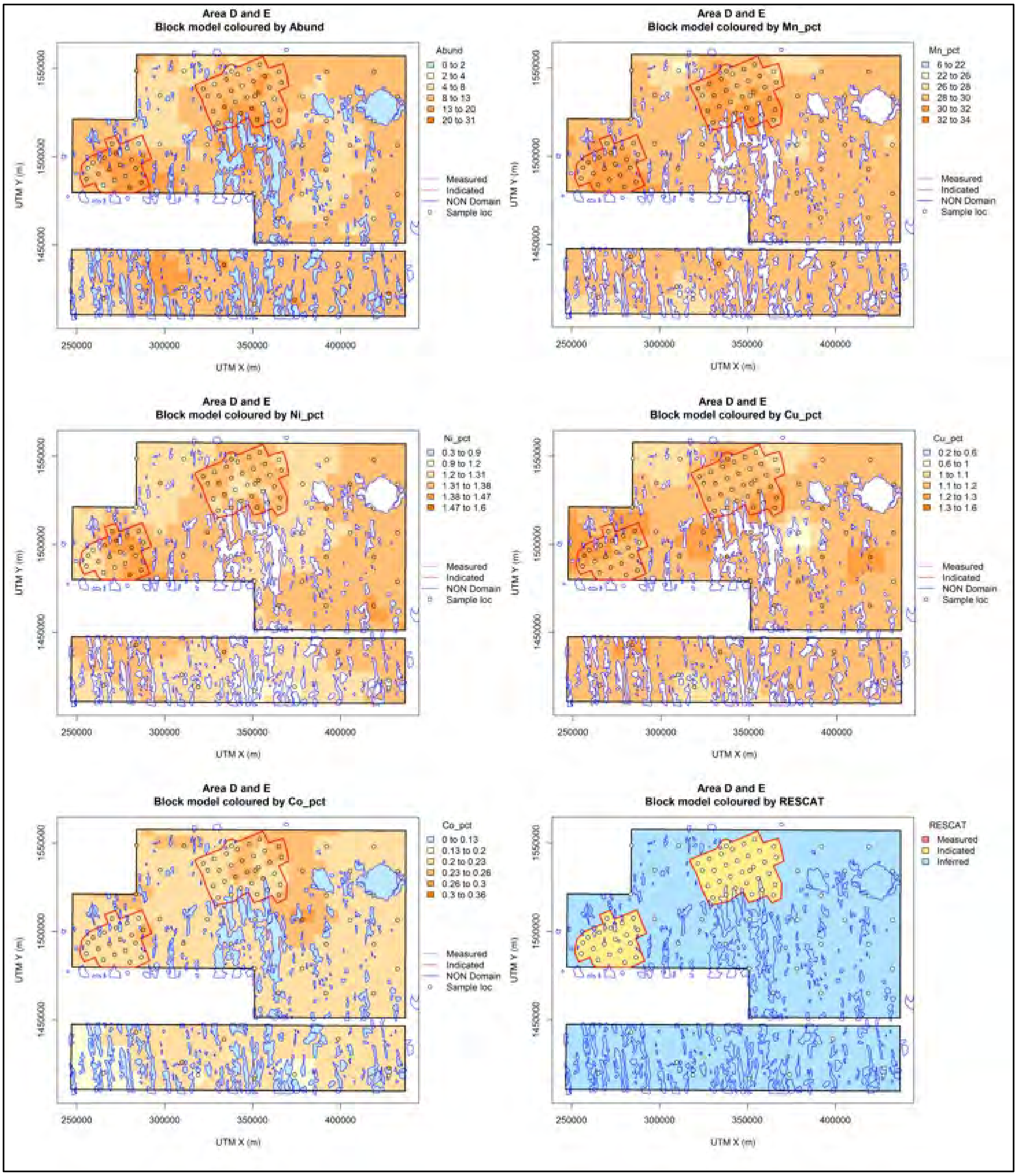
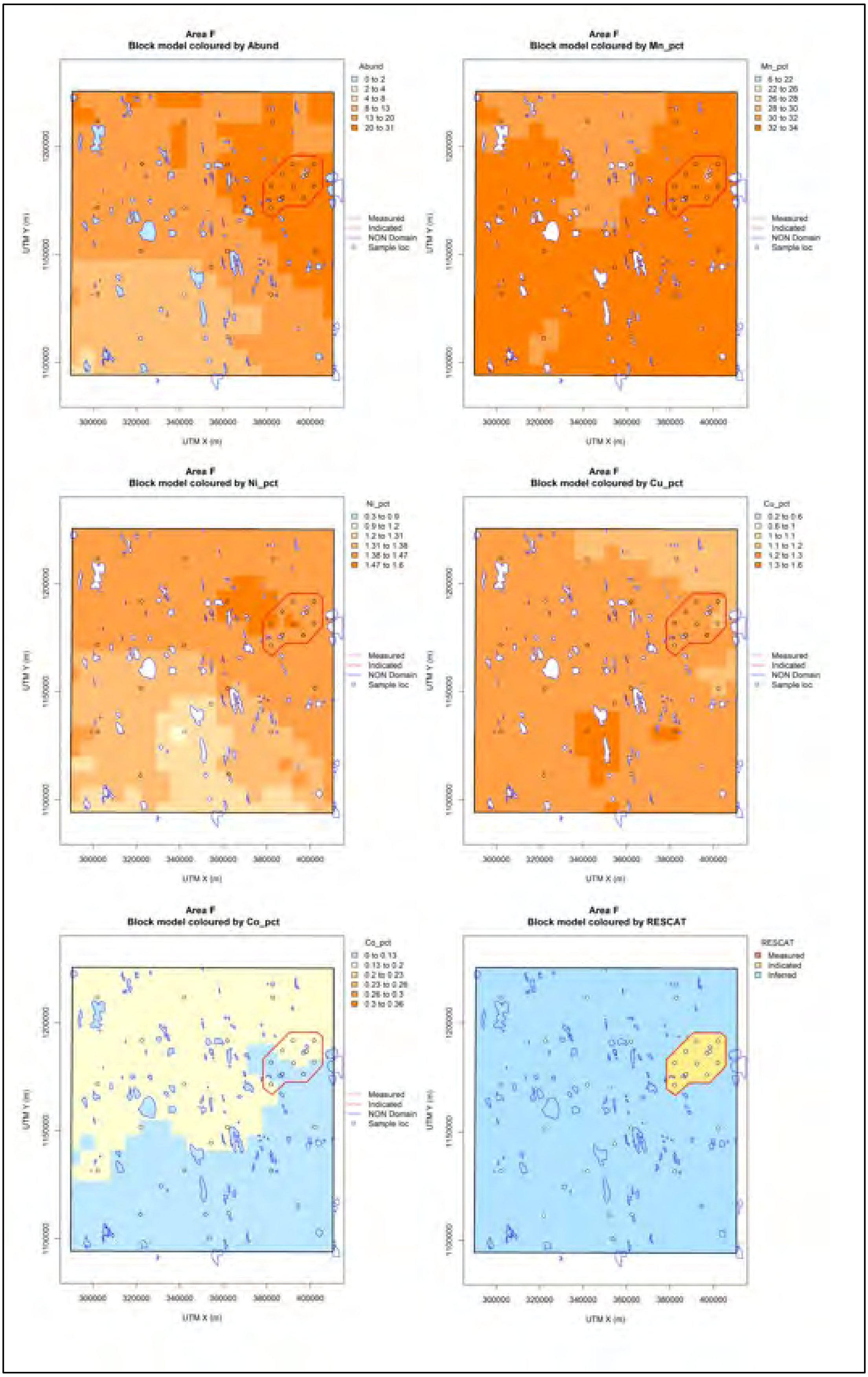


Figure 11.39 Map showing block model and sample distribution for Abundance Mn, Ni, Cu and Co in TOML Area F



The Mineral Resource model was validated by comparing the global mean and variance of the model against alternative nearest neighbour and inverse distance weighting estimates and the declustered samples. The comparative data for abundance, Mn, Ni, Cu and Co are presented in Table 11.10. The mean grades compare favourably and the expected variance reduction is observed, indicating that the estimate is satisfactory.

Table 11.10 Global mean and variance comparison (excluding NON domain, model cells weighted by volume)

		Declustered Samples (N=476 Abund) (N=315 Metals)	Model (N=14939)		
			NN	IDW	OK
Abundance (wet kg/m^2)	Mean	10.39	10.78	10.98	11.33
	Variance	38.19	36.29	26.86	16.56
Mn (%)	Mean	28.19	28.57	28.60	28.65
	Variance	9.652	9.100	7.895	6.887
Ni (%)	Mean	1.27	1.28	1.28	1.28
	Variance	0.028	0.024	0.018	0.018
Cu (%)	Mean	1.12	1.13	1.13	1.13
	Variance	0.043	0.037	0.028	0.020
Co (%)	Mean	0.220	0.210	0.210	0.210
	Variance	0.003	0.003	0.003	0.002

11.8 Comparison with previous Mineral Resource estimate

The initial global Inferred Mineral Resource for the TOML Exploration Areas was reported on 20 March 2013 by Golder Associates (Golder Associates, 2013). Table 11.11 shows the 2013 Mineral Resource estimate at a 4 kg/m^2 abundance cut-off.

The changes in the 2020 Mineral Resource estimate for the TOML CCZ Exploration Areas are due to:

- Inclusion of Areas E and F for the first time. High abundances and grades in Area F.
- Additional nodule abundance sample information (from box core and photo profile) collected during the 2015 Campaign.
- Setting the abundance estimates within the NON (no nodule) domain to zero in areas covered by MBES (TOML Areas B, C, D, E, F).
- Use of ordinary kriging (rather than inverse distance weighting) supported by short-range variogram to estimate abundance.
- Changes in block model parent cell size related to improved sample spacing.

The biggest change to the estimate is the inclusion of Areas E and F. In order to understand the impact of the other changes, the 2020 Mineral Resource estimate only for TOML Areas A to D, is shown in Table 11.12. The change from inverse distance weighting to ordinary kriging and the changes to block model parent cell size are unlikely to have any significant impact on the overall estimates. The differences between the 2013 and 2020 estimates for Area A to D are therefore likely to be mainly due to the additional sampling in 2015 and excising the NON domain from the estimates.

Comparison of Table 11.11 and Table 11.12 shows that the additional data has increased the total Mineral Resource tonnage by 3%. In the areas with the most new data (the Indicated and Measured areas), abundance and grades are all higher in the new model than the 2013 model. These changes show that it is reasonable to expect that the majority of Inferred Mineral Resources could be upgraded to Indicated or Measured Resources with further exploration.

Table 11.11 2013 Mineral Resource Estimate for the TOML Areas A to D at a 4 kg/m² abundance cut-off

Mineral Resource Classification	Tonnes (x10⁶ wet t)	Abundance (wet kg/m²)	Ni (%)	Cu (%)	Co (%)	Mn (%)
Inferred	440	8.9	1.2	1.1	0.24	26.9

Table 11.12 Current (2020) Mineral Resource Estimate for the TOML Areas A-D at a 4 kg/m² abundance cut-off

Mineral Resource Classification	Tonnes (x10⁶ wet t)	Abundance (wet kg/m²)	Ni (%)	Cu (%)	Co (%)	Mn (%)
Measured	2.6	11.8	1.33	1.05	0.23	27.6
Indicated	57.5	11.0	1.33	1.17	0.23	29.8
Measured + Indicated	60.1	11.1	1.33	1.16	0.23	29.7
Inferred	393.6	9.6	1.22	1.07	0.24	27.1

Additional more-detailed comparisons of the data available in 2013 and the data gathered by TOML in 2015 are provided in Table 11.13 to Table 11.18.

Table 11.13 Mean Abundance of historical and 2015 campaign nodule samples (including NON domain)

Sub-Area	Historical Abundance (wet kg/m²)		2015 Abundance (wet kg/m²)		All Abundance (wet kg/m²)	
	N	Mean	N	Mean	N	Mean
B1	16	8.91	105	9.93	121	9.79
C1	11	11.26	102	7.41	113	7.78
D1	4	7.12	16	13.84	20	12.49
D2	6	9.42	26	11.59	32	11.19
F1	–	–	10	21.65	10	21.65

Table 11.14 Mean Abundance of historical and 2015 campaign nodule samples (excluding NON domain)

Sub-Area	Historical Abundance (wet kg/m²)		2015 Abundance (wet kg/m²)		All Abundance (wet kg/m²)	
	N	Mean	N	Mean	N	Mean
B1	15	8.88	89	11.45	104	11.08
C1	11	11.26	92	8.08	103	8.42
D1	4	7.12	16	13.84	20	12.49
D2	5	9.21	25	12.05	30	11.58
F1	–	–	10	21.65	10	21.65

Table 11.15 Mean Ni grades of historical and 2015 campaign nodule samples (excluding NON domain).

Sub-Area	Historic % Ni		2015 % Ni		All % Ni	
	N	Mean	N	Mean	N	Mean
B1	14	1.31	23	1.32	37	1.31
C1	11	1.31	13	1.33	24	1.32
D1	3	1.31	14	1.36	17	1.35
D2	5	1.34	24	1.33	29	1.33
F1	–	–	10	1.46	14	1.38

Table 11.16 Mean Cu grades of historical and 2015 campaign nodule samples (excluding NON domain).

Sub-Area	Historic % Ni		2015 % Ni		All % Ni	
	N	Mean	N	Mean	N	Mean
B1	15	1.07	23	1.09	37	1.08
C1	11	1.23	13	1.24	24	1.24
D1	4	1.20	14	1.19	17	1.19
D2	5	1.15	24	1.17	29	1.17
F1	–	–	10	1.23	14	1.25

Table 11.17 Mean Co grades of historical and 2015 campaign nodule samples (excluding NON domain).

Sub-Area	Historic % Ni		2015 % Ni		All % Ni	
	N	Mean	N	Mean	N	Mean
B1	15	0.240	23	0.238	37	0.239
C1	11	0.248	13	0.243	24	0.245
D1	4	0.210	14	0.221	17	0.219
D2	5	0.232	24	0.224	29	0.226
F1	–	–	10	0.131	14	0.133

Table 11.18 Mean Mn grades of historical and 2015 campaign nodule samples (excluding NON domain).

Sub-Area	Historic % Ni		2015 % Ni		All % Ni	
	N	Mean	N	Mean	N	Mean
B1	15	28.0	23	28.6	37	28.4
C1	11	29.4	13	31.1	24	30.3
D1	4	29.3	14	30.5	17	30.3
D2	5	28.0	24	30.3	29	29.9
F1	–	–	10	32.5	14	32.1

11.9 Initial Assessment

The TOML Mineral Resource estimates are supported by an Initial Assessment carried out on behalf of DeepGreen for the NORI Property (AMC, 2021). The polymetallic nodule deposits in NORI Area D are similar to those in TOML Areas A through F and the QP considers that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas. The NORI Property IA is directly relevant and applicable to the TOML Property for the reasons set out below.

11.9.1 Geological setting and mineralisation

The TOML area and the NORI Property occur within the vast polymetallic nodule field in the Clarion Clipperton Zone of the Pacific Ocean. This mineral field is essentially a single mineral deposit almost 5,000 km in length and up to 600 km wide. The size and level of uniformity of mineralization is unmatched by any mineral deposit of similar value on land. The mechanism of formation of the nodules is interpreted to be essentially identical across the entire CCZ, with only minor local variations. Consequently, there is relatively little difference between the size, shape or metal content of the nodules from one area to another. Figure 6.9 to Figure 6.11 illustrate the remarkable continuity of grades and abundances across the whole of the CCZ.

The morphological features of the seafloor are similar in the TOML and the NORI Areas, which all lie within the Abyssal Plains and are characterized by sub-parallel basaltic lava ridges called abyssal hills. The Areas are punctuated by typically extinct volcanic knolls and seamounts and scattered sediment drifts in which few nodules are preserved at the seafloor.

Figure 11.40 compares nodule shapes, nodule abundance on the seafloor and backscatter imagery from TOML and NORI Areas.

11.9.2 Exploration methods

The exploration methods used to explore and delineate the Mineral Resources in the TOML and NORI areas were essentially the same. MBES was used to determine the depth of water (bathymetry) and the acoustic reflectance (backscatter) of the seabed. Nodule coverage was interpreted using the backscatter data. Physical sampling of the nodules was carried out initially using FFG samplers and in more recent years by BC samplers which provide a better-quality sample. Measurements of nodule abundance obtained from physical samples were supplemented with estimates of abundance made using the LAE method and high-resolution photographs of the seafloor.

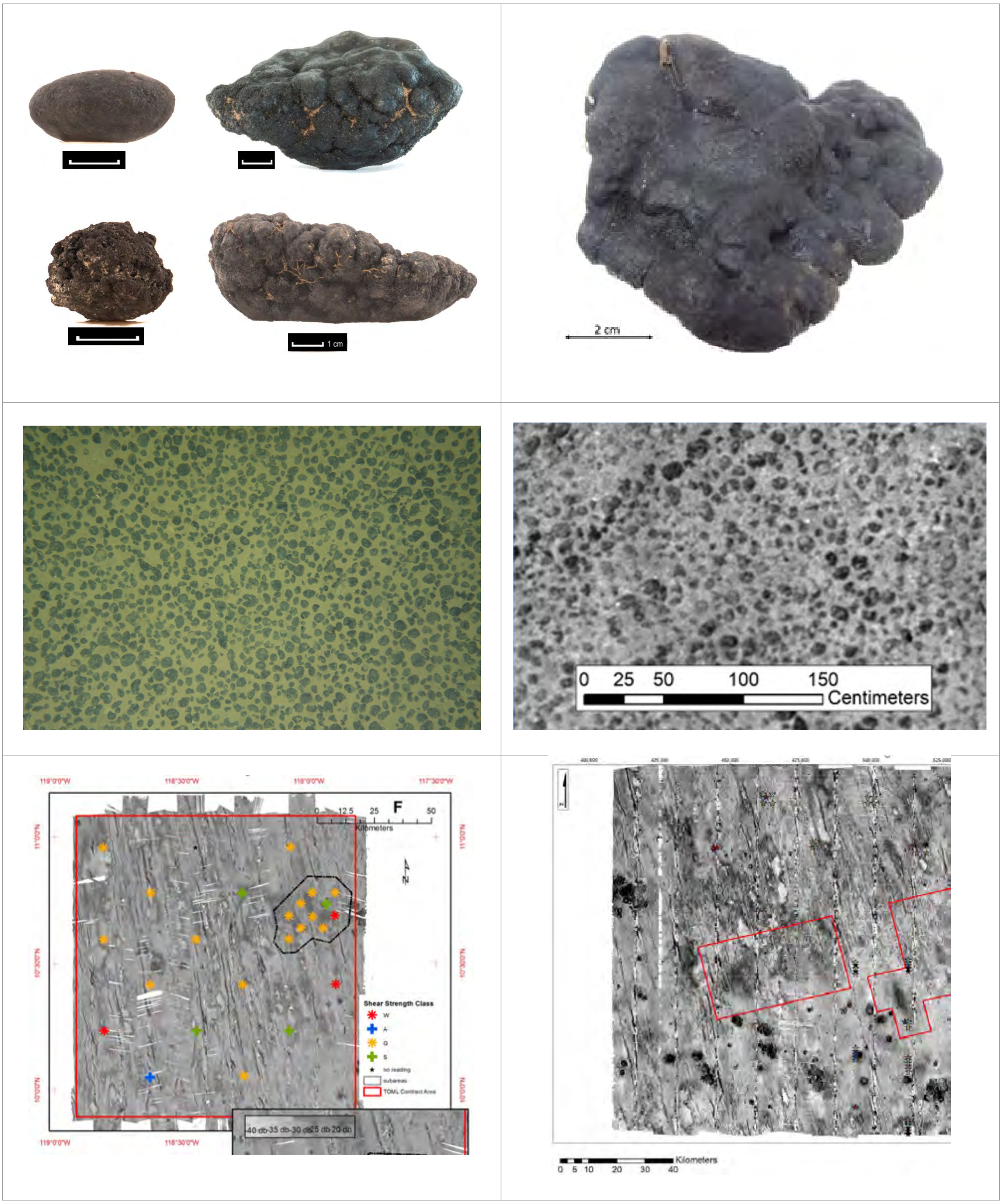
11.9.3 Sample preparation analysis and security

The sample preparation and assaying procedures used in the TOML and NORI areas were essentially the same. The Pioneer Investor data lacks some supporting information but all studies to date indicate that the Pioneer Investor data is reliable. In both Areas, high standards of QAQC were applied to the exploration programmes that were carried out by TOML and NORI. The assay data are supported by the results of certified reference materials, duplicate samples, blank samples, and duplicate analyses at a second laboratory. Sample security was of a high standard and the QPs consider that there was negligible risk of interference with the samples.

11.9.4 Mineral Resources

The Mineral Resources in the TOML and NORI areas were estimated using similar methods. Although the average abundances in the TOML Areas are lower than in NORI Area D, they are still well above the 4 kg/m^2 abundance cut-off derived in the IA. Furthermore, as discussed in Sections 7.1.2 and 11.8, the FFG samples tend to underestimate abundance and it is likely that, as the FFG data is progressively replaced with BC data, the estimated abundances in the Mineral Resource will increase.

Figure 11.40 Comparison of nodule shapes, nodule abundance and backscatter imagery from TOML Areas (left and NORI Areas (right)



11.9.5 Mining methods

The commonality between the polymetallic nodule deposits in NORI Area D and the TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. The Technical Report Summary for NORI Area D assessed the following mining development scenario:

"The main items of off-shore infrastructure are the nodule collector vehicles, the riser, and… production support vessels (PSV).

The nodules will be collected from the seafloor by self-propelled, tracked, collector vehicles. No rock cutting, digging, drill-and-blast, or other breakage will be required at the point of collection. The collectors will be remotely controlled and supplied with electric power via umbilical cables from the PSV. Suction dredge heads on each collector will recover a dilute slurry of nodules, sediment, and water from the seafloor. A hopper on each vehicle will separate sediment and excess water, which will pass out of the hopper overflow, from the nodules, which will be pumped as a higher concentration slurry via flexible hoses to a riser.

The riser is a steel pipe through which nodules will be transferred to the surface by means of an airlift. The riser will consist of three main sections. The lower section will carry the two-phase slurry of nodules and water from the collectors to the airlift injection point. The mid-section will carry a three-phase mixture of slurry and air. This section will also include two auxiliary pipes: one to carry the compressed air for the airlift system, and one to return water from dewatering of the slurry to its subsea discharge point. The upper section of riser will have a larger diameter to account for the expansion of air in the airlift.

The airlift works by lowering the average density of the slurry inside the riser to a level lower than seawater. The difference between the hydrostatic pressure of the seawater at depth and the pressure caused by the weight of the low-density three-phase slurry column inside the riser forces the slurry column to rise. The energy to achieve the lift will be supplied by compressors housed on the PSV, which will be capable of generating very high air pressures.

The PSVs will each support a riser and lift system (RALS) and its handling equipment, and will house the airlift compressors, collector vehicle control stations, and material handling equipment. All power for off-shore equipment, including the nodule collecting vehicles, will be generated on the PSVs. The PSVs will be equipped with controllable thrusters and will be capable of dynamic positioning (DP), which will allow the vessels and risers to track the collectors. Nodules will be discharged from the RALS to the PSVs, where they will be dewatered and temporarily stored or transferred directly to a transport vessel."

The QP considers that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

11.9.6 Mineral Processing and metallurgical testing

The polymetallic nodules in the TOML and NORI Areas have similar morphological, mineralogical, and grade characteristics. As noted in Section 10, all published historical work indicates that processing of nodules is technically feasible.

The commonality between the polymetallic nodule deposits in NORI Area D and TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. The Technical Report Summary for NORI Area D (AMC, 2021) assessed the following mineral processing scenario:

"The first part of the pyrometallurgical process is the Rotary Kiln Electric Furnace (RKEF) process that is widely used in the nickel laterite industry. The second pyrometallurgical step (sulphidisation of the alloy produced in the first step to form a matte and then partially conversion in a Peirce-Smith converter to remove iron), while not widely practiced, also has commercial precedent at the Doniambo plant of Societe Le Nickel in New Caledonia.

Sulphuric acid leaching of matte from the pyrometallurgical process has precedent in the platinum group minerals (PGM) industry. Although copper producers typically have a solvent *extraction step before electrowinning of their copper, direct copper electrowinning is done in most PGM refineries, where nickel and cobalt are also significant pay-metals. This is to maximise nickel recovery and minimise operating expenses. The nickel and cobalt are purified using solvent extraction, ion exchange and precipitation, which are all commercially proven hydrometallurgical processes. Battery grade nickel and cobalt sulphate are then crystallised from the purified solutions.*

The pyrometallurgical process forms two by-products as well as the matte for the hydrometallurgical refinery:

- *Electric furnace slag containing silica and 53% MnO that is intended to be sold as feed to the Si-Mn industry.*
- *A converter aisle slag that could be used for aggregate in road construction or other applications.*

The hydrometallurgical refinery generates iron residues that would, for a stand-alone plant, require disposal. However, these streams can be recycled back to the pyrometallurgical plant for re-treatment and recovery of entrained pay metals.

Selection of ammonia as a principal reagent in the hydrometallurgical refinery means that an additional by-product—ammonium sulphate—is generated. This could be sold into the fertiliser industry.

The copper cathode quality from direct electrowinning, without a solvent extraction step, is expected to be ≥99.9% Cu. Quality of the matte produced in the pyrometallurgical plant will have an impact on this, including the potential carryover of impurities beyond values assumed for the purpose of the IA.

The production of battery-grade nickel and cobalt sulphates is targeted instead of nickel or cobalt cathodes or other intermediate products.

In summary:

- *All parts of the proposed process have commercial precedents in similar or analogous industries, however not as a whole continuous flowsheet.*
- *Pay-metals are recovered in the following forms:*
  - *Copper cathodes with an expected quality of ≥99.9% Cu.*
  - *Battery-grade nickel sulphate.*
  - *Battery-grade cobalt sulphate.*
- *Rather than generating large waste streams, the process produces by-products including high manganese content furnace slag and ammonium sulphate.*

The process assumptions used in this study will need to be verified as the project proceeds."

The QP considers that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

11.9.7 Infrastructure

The infrastructure requirements for the development of commercial production in the TOML Areas, apart from the minerals processing facility, will be modest compared to terrestrial resources projects of similar production capacities.

The site and host country for the minerals processing facility has not yet been confirmed. The site must be serviced by grid power, reticulated water, and natural gas. A location will be selected that is close to an industrial port, and near an existing municipality from which labour can be sourced.

As part of the IA for the NORI Area D Project, a preliminary assessment of the transportation fleet for transfer of nodules from the CCZ to an existing deep-water industrial port equipped with bulk offloading facilities was examined (AMC, 2021). The IA assumed that chartered vessels would be used to transport the dewatered nodules to the port of Lazaro Cardenas, Michoacan, Mexico, 960 nm from the NORI Area D reference site. The vessels would be converted bulk mineral carriers with dynamic positioning (DP) to allow tracking behind the production support vessels during operations. The method of offloading, known as tandem offloading, is well established for offloading of oil production vessels in remote areas of the world.

There are no physical or logistical barriers between the TOML and NORI Areas. Their location may simply influence shipping costs.

The QP considers that establishing on-shore infrastructure and transportation of nodules from the TOML Areas to suitable ports are unlikely to be impediments to commercial production from the TOML Areas.

11.9.8 Market studies

AMC has considered the market for the nickel, copper, cobalt and manganese products that might be recovered from the polymetallic nodules in the TOML Areas.

CRU International Limited (CRU) was commissioned by NORI to provide market overviews for the four main products from the NORI Area D Project: nickel sulphate ($NiSO_4$), cobalt sulphate ($CoSO_4$), copper, and a manganese product (CRU, 2020).

CRU expects $NiSO_4$ and $CoSO_4$ markets to undergo extreme growth from a relatively small current level of 181 kt nickel in sulphate and 35 kt of cobalt in sulphate in 2019, with markets to increase to 138 and 178 times their 2018 sizes respectively to 1.6 Mt nickel in sulphate and 500kt cobalt in sulphate by 2035, with much of this growth occurring post-2025. Electric vehicle production is the driver of this forecast growth.

Copper and manganese markets are forecast to grow by 25% and 20% of their 2020 sizes by 2035 respectively. Copper and manganese demand will benefit from electric vehicle penetration, however the primary driver of growth for manganese ore will be steelmaking, and a variety of end use applications generally related to economic health for copper.

CRU expects copper and $NiSO_4$ prices to rise in real terms by 2035, while manganese ore and $CoSO_4$ prices are forecast to remain flat, due to current prices being at or near a high point in the cycle, recent fall in prices, and expected modest growth in the global steel industry after the COVID 19 epidemic. The long-term cost of production is expected to rise for both copper and $NiSO_4$, helping to support prices.

11.9.9 Environmental compliance and permitting

The ISA is mandated through UNCLOS to organize, regulate, and control all mineral related activities in the international seabed Area whilst preserving and protecting the marine environment. As the TOML Areas are in the international seabed Area, the ISA is responsible for assessing any Environmental and Social Impact Assessment prepared by TOML and for granting the relevant contracts. Further details are provided in Section 17.

Between 1998 and 2014, the ISA held workshops and developed a number of documents to provide guidance to contractors with respect to its expectations for responsible environmental management during the exploration and exploitation phases of mineral development. The ISA held a workshop “Towards an ISA environmental management strategy for the Area” over 20-24 March 2017 in Berlin Germany. The results of the workshop were published as ISA Technical Study 17 (ISA 2017).

The ISA has issued Regulations on Prospecting and Exploration for Polymetallic Nodules (adopted on 13 July 2000, updated on 25 July 2013). The regulations were complemented by the Legal and Technical Commission (LTC) recommendations for the guidance of contractors on assessing the environmental impacts of exploration (ISBA/25/LTC/6/Rev.1) which was most recently updated on 30 March, 2020. The draft exploitation regulations on deep-seabed mining were discussed at the 25th Session of the ISA (25 February to 1 March 2019 in Kingston Jamaica). The ISA had declared a target of 2020 to have the regulations approved but the COVID-19 pandemic disrupted the ISA program.

Although the environmental impact review process has not yet been finalised, the draft regulations outline the application process and the conditions that Contractors would need to implement during operations. All contractors have been made aware that the ISA requires the completion of the Environmental and Social Impact Assessment (ESIA) studies, culminating in an Environmental Impact Statement (EIS), in support of their applications for an exploitation license. Guidance for contractors in terms of what will be expected in the EIS has been provided in ISA Technical Study No. 10 (ISA 2012a). Further guidance will be provided with the completion of Standards and Guidelines for exploitation activities. The LTC has prioritized the development of six Standards and Guidelines, with three released for public comment in 2020 and the remaining three expected to be released in early 2021. The EIS, along with an Environmental Management System with subordinate Environmental Management and Monitoring Plans (EMMP), will be required as part of the application for an exploitation license within the Contract Area.

The environmental permitting process for the Area has been developed through a consultation program initiated by the ISA in 2013 and includes feedback obtained from multiple stakeholder groups. It is expected to involve a series of checks and balances, with reviews being conducted by the LTC with input from independent experts, as required. The recommendations of the LTC will then go before the ISA Council, which will then review the information provided and decide whether to approve the license application and, if so, what conditions should be applied.

The LTC has recommended seven key areas of information for the development of EIAs. These are physical oceanography, chemical oceanography, sediment properties, biological communities, bioturbation, sedimentation, and geological properties. These will form the key investigation topics for surveys within the Area, including the TOML Areas.

The social impacts of the off-shore operation are expected to be positive. The CCZ is uninhabited by people, and there are no landowners associated with the TOML Areas. No significant commercial fishing is carried out in the area. The Project will provide a source of revenue to the sponsor country, Tonga, and to the ISA.

The on-shore environmental and social impacts have not yet been assessed because the process plant has not been designed in detail, and the location and host country (and hence regulatory regime) not confirmed.

As sponsoring state, Tonga has a responsibility to ensure that TOML's activities in the international seabed area are carried out in conformity with Part XI of UNCLOS.

Under ISA requirements contractors are required to submit five-year work programs. The first TOML five-year work program was completed in 2016 and reviewed and accepted by the ISA in late 2016.

For the second five-year period ending in 2022 TOML proposed the following program.

- Continue environmental baseline work;
- Complete pilot testing;
- Complete geotechnical studies;
- Complete feasibility studies;

- First draft EIA/EMP;
- Continue training.

TOML noted that the program was:

- Dependent on success at each stage;
- Subject to change based on findings at hand at any particular time; and
- Reliant on funding which in turn is dependent to some extent on macro-economic conditions and development with regards to the Authority and its stakeholders.

As a result of the financial state of the company, TOML did not progress at the rate intended until TOML was purchased by DeepGreen in March 2020. TOML currently plans an aggressive program of offshore campaigns in 2021–2023 focussing on resource assessment and environmental base line studies with the objective of upgrading the TOML F resource area to Indicated Mineral Resource status and completing environmental baseline studies and ESIA for the TOML F resource area.

12 Mineral Reserve Estimates

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

13 Mining Methods

Mining methods that could be employed for commercial development of polymetallic nodule deposits in the CCZ were studied in an IA for NORI Area D (AMC, 2021). The commonality between the polymetallic nodule deposits in NORI Area D and TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. This is discussed further in Section 11.9.

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

14 Recovery Methods

Recovery methods that could be employed for commercial development of polymetallic nodule deposits in the CCZ were studied in an IA for NORI Area D (AMC, 2021). The commonality between the polymetallic nodule deposits in NORI Area D and TOML Areas indicates that the methods proposed for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. This is discussed further in Section 11.9.

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

15 Project Infrastructure

The project infrastructure that would be required for commercial development of polymetallic nodule deposits in the CCZ was studied in an IA for NORI Area D (AMC, 2021). The commonality between the polymetallic nodule deposits in NORI Area D and TOML Areas indicates that the requirements for the development of NORI Area D can reasonably be assumed to be equally relevant for future development in the TOML Areas. This is discussed further in Section 11.9.

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

16 Market Studies and Contracts

For initial assessment of the prospects for economic extraction of the Mineral Resource, AMC has considered the market for the nickel, copper, cobalt and manganese products that might be recovered from the polymetallic nodules in the TOML Areas.

CRU International Limited (CRU) was commissioned by NORI to provide market overviews for the four main products from the NORI Area D Project: nickel sulphate ($NiSO_4$), cobalt sulphate ($CoSO_4$), copper, and a manganese product (CRU report dated October 23, 2020).

Over a five year horizon, CRU's price forecasts are based primarily on supply and demand fundamentals. These are established from CRU's detailed bottom-up analysis of supply by individual mine and finished product producer, and in-depth analysis of demand from individual applications. CRU also considers operating costs and inventories in its forecasts, as well as various other factors where relevant.

For the forecast beyond a five year horizon, cyclical supply-demand balances become hard to predict. Therefore, CRU's longer term price forecasts are based on the Long Run Marginal Cost (LRMC) concept. That is, that prices in the long term will trend towards, and fluctuate around, the full economic costs (i.e., operating costs including an allowance for a return on capital) of the marginal tonne required to meet long term demand. For example, when prices are above the LRMC, CRU would assume that supply would be added and prices would subside. Assets selected for the LRMC analysis are a representative sample that are likely to be in production to satisfy future demand. CRU uses its Project Gateway classification system to select projects. It is important to consider where these new assets will be located, how large they will be and what processing technology they will adapt. The composition of future capacity and accompanying demand levels will have a significant impact not just on the LRMC assessment, but also the upside and downside risk associated with that assessment.

One exception to this long term price forecasting methodology is the cobalt market. Since the majority of cobalt is produced as a by-product of copper or nickel mining, supply is inelastic to the cobalt price, with supply decisions instead more likely to be driven by the market environment for the operations' main copper or nickel product. This means that the Long Run Marginal Cost concept cannot readily be applied. Instead, CRU refers to historic pricing trends to establish a long term equilibrium price, taking into account longer term factors, such as the increasing importance of batteries as a cobalt end use, that might result in cobalt prices and product premia differing with historical trends.

Taking into account the foregoing assumptions and analysis, CRU expects $NiSO_4$ and $CoSO_4$ markets to undergo extreme growth from a relatively small current level of 181 kt nickel in sulphate and 35 kt of cobalt in sulphate in 2019, with markets to increase to 138 and 178 times their 2018 sizes respectively to 1.6 Mt nickel in sulphate and 500kt cobalt in sulphate by 2035, with much of this growth occurring post-2025. Electric vehicle production is the driver of this forecast growth.

Copper and manganese markets are forecast to grow by 25% and 20% of their 2020 sizes by 2035 respectively. Copper and manganese demand will benefit from electric vehicle penetration, however the primary driver of growth for manganese ore will be steelmaking, and a variety of end use applications generally related to economic health for copper. A significant copper supply gap of around 5 Mtpa is expected by 2030 in the absence of new mine capacity, indicating that inducement pricing of > US$ 3.10/ lb Cu will be required to bring on new copper supply.

CRU expects copper and $NiSO_4$ prices to rise in real terms by 2035, while manganese ore and $CoSO_4$ prices are forecast to remain flat, due to current prices being at or near a high point in the cycle, recent fall in prices, and expected modest growth in the global steel industry after the COVID 19 epidemic. The long-term cost of production is expected to rise for both copper and $NiSO_4$, helping to support prices.

The $NiSO_4$, $CoSO_4$ and copper to be produced by NORI are expected to be chemically and physically standard products and no marketability issues are expected. The sulphate forms ($NiSO_4$, $CoSO_4$) of these products are expected to be premium products and attract premia over pure nickel and cobalt.

The manganese silicate product differs in both physical and chemical specifications from standard forms of ore found in the market. NORI's manganese silicate is expected to have a manganese grade of around 40%, which matches neither the high grade (44% Mn) or low-grade (36–38% Mn) ore benchmarks. The product is expected to have SiO_2 and Al_2O_3 contents exceeding the most desirable levels for manganese products but a desirable high Mn to Fe ratio. NORI's processing route also reduces the oxidation state of the manganese oxide from MnO_2 to MnO, which will reduce the energy requirements for customers' downstream processing. On balance, CRU recommended adopting a small premium of 1- 3% of the 44% Mn ore benchmark price.

17 Environmental Studies, Permitting, and Social or Community Impact

The ISA is mandated through UNCLOS to organize, regulate, and control all mineral related activities in the international seabed Area whilst preserving and protecting the marine environment. As the TOML Areas are in the international seabed Area, the ISA is responsible for assessing any Environmental and Social Impact Assessment prepared by TOML and for granting the relevant contracts.

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The ISA has issued Regulations on Prospecting and Exploration for Polymetallic Nodules (adopted on 13 July 2000, updated on 25 July 2013). The regulations were complemented by the Legal and Technical Commission (LTC) recommendations for the guidance of contractors on assessing the environmental impacts of exploration (ISBA/25/LTC/6/Rev.1) which was most recently updated on 30 March, 2020. The draft exploitation regulations on deep-seabed mining were discussed at the 25th Session of the ISA (25 February to 1 March 2019 in Kingston Jamaica). The ISA had declared a target of 2020 to have the regulations approved but the COVID-19 pandemic disrupted the ISA program.

Although the environmental impact review process has not yet been finalised, the draft regulations outline the application process and the conditions that Contractors would need to implement during operations. All contractors have been made aware that the ISA requires the completion of the Environmental and Social Impact Assessment (ESIA) studies, culminating in an Environmental Impact Statement (EIS), in support of their applications for an exploitation license. Guidance for contractors in terms of what will be expected in the EIS has been provided in ISA Technical Study No. 10 (ISA 2012a). Further guidance will be provided with the completion of Standards and Guidelines for exploitation activities. The LTC has prioritized the development of six Standards and Guidelines, with three released for public comment in 2020 and the remaining three expected to be released in early 2021. The EIS, along with an Environmental Management System with subordinate Environmental Management and Monitoring Plans (EMMP), will be required as part of the application for an exploitation license within the Contract Area.

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The LTC has recommended seven key areas of information for the development of EIAs. These are physical oceanography, chemical oceanography, sediment properties, biological communities, bioturbation, sedimentation, and geological properties. These will form the key investigation topics for surveys within the Area, including the TOML Areas.

As sponsoring state, Tonga has a responsibility to ensure that TOML's activities in the international seabed area are carried out in conformity with Part XI of UNCLOS.

Under ISA requirements contractors are required to submit five-year work programs. The first TOML five-year work program was completed in 2016 and reviewed and accepted by the ISA in late 2016.

For the second five-year period ending in 2022 TOML proposed the following program.

- Continue environmental baseline work;
- Complete pilot testing;
- Complete geotechnical studies;
- Complete feasibility studies;
- First draft EIA/EMP;
- Continue training.

TOML noted that the program was:

- Dependent on success at each stage;
- Subject to change based on findings at hand at any particular time; and
- Reliant on funding which in turn is dependent to some extent on macro-economic conditions and development with regards to the Authority and its stakeholders.

As a result of the financial state of the company, TOML did not progress at the rate intended until TOML was purchased by DeepGreen in March 2020. TOML currently plans an aggressive program of offshore campaigns in 2021–2023 focussing on resource assessment and environmental base line studies with the objective of upgrading the TOML F resource area to Indicated Mineral Resource status and completing environmental baseline studies and ESIA for the TOML F resource area.

18 Capital and Operating Cost

Capital and operating costs have not been estimated for the TOML Areas.

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

19 Economic Analysis

A cash flow analysis has not been developed for the TOML Areas.

There are no Mineral Reserve estimates for the TOML Exploration Area of the CCZ and the potential viability of the Mineral Resources has not yet been supported by a pre-feasibility study or a feasibility study.

20 Adjacent Properties

Nauru Ocean Resources Inc (NORI), a wholly-owned subsidiary of DeepGreen, holds exploration rights to four areas (NORI Area A, B, C, and D, the Property) in the CCZ that were granted by the International Seabed Authority (ISA) in 2011. NORI is sponsored to carry out its mineral exploration activities in the Property by the Republic of Nauru, pursuant to a certificate of sponsorship signed by the Government of Nauru on 11 April 2011.

Several other contractors have rights in the CCZ under the ISA, as described in Section 5 and summarized in Figure 3.1.

Lockheed Martin Systems Co (LMS) or Ocean Minerals Company (OMCO; GPO, 2011, Spickermann, 2012) is recognised to have two US licenses granted by NOAA (Section 5).

To date, no commercial production of polymetallic nodules has taken place in the CCZ.

21 Other Relevant Data and Information

As part of the eighteenth session of the ISA in July 2012, (ISA 2012b). Nine APEIs within the CCZ were designated by the Council of the ISA as part of an environmental management plan. None of the nine areas impact the TOML Exploration Area.

The APEIs are an important part of the ISA's EMP for the CCZ (ISA, 2012b; Smith et al, 2010) they aim to:

- Protect large enough areas to maximise both conservation benefits and exploitation benefits (at present they are more extensive than areas granted by the ISA to contractors for development;
- Be arranged to provide representative cover of different subregions as defined by productivity gradients and faunal turnover and as many seamounts as possible;
- Each APEI is large enough to ensure a core area is remote from even pessimistic estimates of impact from deep-sea mining;
- Complement ecosystem based management strategies for the area.

The APEIs were reviewed as required by policy in 2014 for the purposes of forthcoming review of the ISA's EMP and the decision (or not) to extend their location and validity. Independent consultants Seascape (Seascape Consultants, 2014) found no reason to change the APEI.

22 Interpretation and Conclusions

TOML holds tenement over a significant part (74 713 km^2) of the CCZ polymetallic nodule deposit in six areas (Areas A to F). These licences are under a contract for exploration of polymetallic nodules signed with the International Seabed Authority which has its remit from the United Nations Convention on the Law of the Sea.

Historical work over the last four decades has shown the deposit to be widespread and of very consistent grades. Exploration and development have progressed over this period, including scientific discovery and characterisation, successful efforts at trial mining, and bench scale metallurgical processing.

Work by TOML confirmed the historical data available for Mineral Resource estimation and furthermore provides significant additional detail and evidence for continuity such that Mineral Resource estimates of higher confidence can be determined. TOML also completed sampling of environmental and geotechnical data that is still being analysed. To date results complement, but have not revealed anything fundamentally different from, available historical work.

TOML Exploration Areas A to F have sufficient samples of adequate quality to define a Mineral Resource for Mn, Ni, Cu and Co. The estimate of abundance and hence tonnage for the Inferred Mineral Resource for the TOML Exploration Areas A to F may be biased low due to reliance on free fall grab samples in places.

The 2020 Mineral Resource estimate (Measured, Indicated and Inferred Mineral Resources), which was informed by data collected by TOML in 2013 and 2015, is presented in Table 11.9.

Due to the extremely low variance in the grades and the high metal content of the nodules, a cut-off based on abundance is appropriate for determining the limits of economic exploitation. A cut-off of 4 kg/m^2 abundance was chosen for the TOML Area, based on the estimates of costs and revenues presented in the Initial Assessment (IA) of the Mineral Resource contained in NORI Area D (AMC, 2021). The metal prices assumed in the calculation of the cut-off were: nickel metal US$16,472/t; nickel in nickel sulphate US$18,807/t Ni; copper metal US$6,872/t; cobalt metal US$46,333/t; cobalt in cobalt sulphate US$56,920/t Co; manganese in manganese silicate US$4.50/dmtu. The price estimates are long term (2034–2046) forecasts provided in a report by CRU International Limited (CRU, 2020). The QP considers that this timeframe is reasonable in view of the likely time required to bring the majority of the TOML Mineral Resources into production.

Comparison of the 2013 Inferred Mineral Resource estimate and the 2020 estimate shows that the additional data has increased the total Mineral Resource tonnage by 3%. In the areas with the most new data (the Indicated and Measured areas), abundance and grades are all higher in the new model than the 2013 model. These changes show that it is reasonable to expect that the majority of Inferred Mineral Resources could be upgraded to Indicated or Measured Resources with further exploration.

The ISA is mandated through UNCLOS to organize, regulate, and control all mineral related activities in the international seabed Area whilst preserving and protecting the marine environment. As the TOML Areas are in the international seabed Area, the ISA is responsible for assessing any Environmental and Social Impact Assessment prepared by TOML and for granting the relevant contracts.

The ISA has issued Regulations on Prospecting and Exploration for Polymetallic Nodules. Draft exploitation regulations on deep-seabed mining were discussed at the 25th Session of the ISA (25 February to 1 March 2019 in Kingston Jamaica). The ISA had declared a target of 2020 to have the regulations approved but the COVID-19 pandemic disrupted the ISA program.

Although the environmental impact review process has not yet been finalised, the draft regulations outline the application process and the conditions that Contractors would need to implement during operations. All contractors have been made aware that the ISA requires the completion of the Environmental and Social Impact Assessment (ESIA) studies, culminating in an Environmental Impact Statement (EIS), in support of their applications for an exploitation license. Guidance for contractors in terms of what will be expected in the EIS has been provided in ISA Technical Study No. 10 (ISA 2012a). Further guidance will be provided with the completion of Standards and Guidelines for exploitation activities.

The TOML area and the NORI Property occur within the vast polymetallic nodule field in the Clarion Clipperton Zone of the Pacific Ocean. This mineral field is essentially a single mineral deposit almost 5,000 km in length and up to 600 km wide. The size and level of uniformity of mineralization is unmatched by any mineral deposit of similar value on land. The mechanism of formation of the nodules is interpreted to be essentially identical across the entire CCZ, with only minor local variations. Consequently, there is relatively little difference between the size, shape or metal content of the nodules from one area to another.

The morphological features of the seafloor are similar in the TOML and the NORI Areas, which all lie within the Abyssal Plains and are characterized by sub-parallel basaltic lava ridges called abyssal hills. The Areas are punctuated by typically extinct volcanic knolls and seamounts and scattered sediment drifts in which few nodules are preserved at the seafloor.

The polymetallic nodules in the TOML and NORI Areas have similar morphological, mineralogical, and grade characteristics. All published historical work indicates that processing of nodules is technically feasible.

The TOML Mineral Resource estimates are supported by an Initial Assessment carried out on behalf of DeepGreen for the NORI Property (AMC, 2021).

The IA proposes that nodules will be collected from the seafloor by self-propelled, tracked, collector vehicles. No rock cutting, digging, drill-and-blast, or other breakage will be required at the point of collection. The collectors will be remotely controlled and supplied with electric power via umbilical cables from production support vessel (PSV). Suction dredge heads on each collector will recover a dilute slurry of nodules, sediment, and water from the seafloor. A hopper on each vehicle will separate sediment and excess water, which will pass out of the hopper overflow, from the nodules, which will be pumped as a higher concentration slurry via flexible hoses to a riser. The riser is a steel pipe through which nodules will be transferred to the surface by means of an airlift.

The PSV will support a riser and lift system (RALS) and its handling equipment, and will house the airlift compressors, collector vehicle control stations, and material handling equipment. All power for off-shore equipment, including the nodule collecting vehicles, will be generated on the PSV. The PSVs will be equipped with controllable thrusters and will be capable of dynamic positioning (DP), which will allow the vessels and risers to track the collectors. Nodules will be discharged from the RALS to the PSVs, where they will be dewatered and temporarily stored or transferred directly to a transport vessel."

The polymetallic nodules in the TOML and NORI Areas have similar morphological, mineralogical, and grade characteristics. The IA for NORI Area D assessed a combine pyrometallurgical and hydrometallurgical mineral processing scenario. The first part of the pyrometallurgical process is the Rotary Kiln Electric Furnace (RKEF) process that is widely used in the nickel laterite industry. The second pyrometallurgical step (sulphidisation of the alloy produced in the first step to form a matte and then partially conversion in a Peirce-Smith converter to remove iron), while not widely practiced, also has commercial precedent at the Doniambo plant of Societe Le Nickel in New Caledonia.

Sulphuric acid leaching of matte from the pyrometallurgical process has precedent in the platinum group minerals (PGM) industry. Although copper producers typically have a solvent extraction step before electrowinning of their copper, direct copper electrowinning is done in most PGM refineries, where nickel and cobalt are also significant pay-metals. This is to maximise nickel recovery and minimise operating expenses. The nickel and cobalt are purified using solvent extraction, ion exchange and precipitation, which are all commercially proven hydrometallurgical processes. Battery grade nickel and cobalt sulphate are then crystallised from the purified solutions.

The pyrometallurgical process forms two by-products as well as the matte for the hydrometallurgical refinery:

- Electric furnace slag containing silica and 53% MnO that is intended to be sold as feed to the Si-Mn industry.
- A converter aisle slag that could be used for aggregate in road construction or other applications.

The hydrometallurgical refinery generates iron residues that would, for a stand-alone plant, require disposal. However, these streams can be recycled back to the pyrometallurgical plant for re-treatment and recovery of entrained pay metals.

Selection of ammonia as a principal reagent in the hydrometallurgical refinery means that an additional by-product—ammonium sulphate—is generated. This could be sold into the fertiliser industry.

The copper cathode quality from direct electrowinning, without a solvent extraction step, is expected to be ≥99.9% Cu. Quality of the matte produced in the pyrometallurgical plant will have an impact on this, including the potential carryover of impurities beyond values assumed for the purpose of the IA.

The production of battery-grade nickel and cobalt sulphates is targeted instead of nickel or cobalt cathodes or other intermediate products.

In summary:

- All parts of the proposed process have commercial precedents in similar or analogous industries, however not as a whole continuous flowsheet.
- Pay-metals are recovered in the following forms:
  - Copper cathodes with an expected quality of ≥99.9% Cu.
  - Battery-grade nickel sulphate.
  - Battery-grade cobalt sulphate.
- Rather than generating large waste streams, the process produces by-products including high manganese content furnace slag and ammonium sulphate.

The process assumptions used in this study will need to be verified as the project proceeds.

The QP considers that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

The infrastructure requirements for the development of commercial production in the TOML Areas, apart from the minerals processing facility, will be modest compared to terrestrial resources projects of similar production capacities.

The site and host country for the minerals processing facility has not yet been confirmed. The site must be serviced by grid power, reticulated water, and natural gas. A location will be selected that is close to an industrial port, and near an existing municipality from which labour can be sourced.

A preliminary assessment of the transportation fleet for transfer of nodules from the CCZ to an existing deep-water industrial port equipped with bulk offloading facilities was examined (AMC, 2021). The IA assumed that chartered vessels would be used to transport the dewatered nodules to the port of Lazaro Cardenas, Michoacan, Mexico, 960 nm from the NORI Area D reference site. The vessels would be converted bulk mineral carriers with dynamic positioning (DP) to allow tracking behind the production support vessels during operations. The method of offloading, known as tandem offloading, is well established for offloading of oil production vessels in remote areas of the world.

AMC has considered the market for the nickel, copper, cobalt and manganese products that might be recovered from the polymetallic nodules in the TOML Areas.

CRU International Limited (CRU) was commissioned by NORI to provide market overviews for the four main products from the NORI Area D Project: nickel sulphate ($NiSO_4$), cobalt sulphate ($CoSO_4$), copper, and a manganese product (CRU, 2020). CRU expects growth in these markets.

CRU expects copper and $NiSO_4$ prices to rise in real terms by 2035, while manganese ore and $CoSO_4$ prices are forecast to remain flat, due to current prices being at or near a high point in the cycle, recent fall in prices, and expected modest growth in the global steel industry after the COVID 19 epidemic. The long-term cost of production is expected to rise for both copper and $NiSO_4$, helping to support prices.

The QPs consider that the proposed development of NORI Area D is a reasonable analogue for future development in the TOML Areas and the IA completed for the NORI Property is directly relevant and applicable to the TOML Property. The QPs consider that this IA supports the view that there are reasonable prospects of economic extraction of polymetallic nodule Mineral Resources in the TOML Areas.

23 Recommendations

It is recommended that future work on the TOML Area focus on determining the viability of mining systems through trial nodule mining and appropriate methods for predicting, monitoring and controlling production rates during mining. Additionally, key modifying factors need to be constrained to a point where a Mineral Reserve could potentially be estimated for the TOML Exploration Areas.

Exploration

- Undertake additional box core sampling campaigns to raise the Inferred Mineral Resources to Indicated and Measured status. The proximity of TOML Area F to NORI Area D suggests that TOML Area F should be a priority.
- Undertake additional photo profiling in areas categorized as Indicated Mineral Resource to increase the Measured Mineral Resource.
- Investigate automated processing of nodule photographs to estimate nodule abundance using the long-axis method. This will allow very detailed short-range determination of abundance along photo-profile lines informing a simulation study regarding variability during mining.
- Undertake a conditional simulation study to quantify the uncertainty and risk in nodule abundance. This will likely help provide production bounds for the operating system(s).
- Undertake additional photo profiling in areas categorized as Indicated Mineral Resource to increase the Measured Mineral Resource well ahead of commercial extraction of the existing Measured Mineral Resource.

Environment

- Complete analysis of data collected during the TOML CCZ13 and CCZ15 campaigns, including analysis of oceanographic information, taxonomy of collected samples, habitat mapping from photo profiles, collection of moorings to enable:
  - Integration with CCZ-wide published data.
  - Environmental baseline conditions to be documented.
- Complete new environmental baseline studies and ESIA for TOML Area F.
- Develop a monitoring programme to accompany future work, including trial mining.

Engineering and Commercial Concept

- Complete analysis of geotechnical data collected during the TOML CCZ15 campaign.
- Complete system concept design and options and risking exercises.
- Prepare economic and commercial studies to provide scoping estimates for CAPEX and OPEX for mining, transportation and processing options.
- Complete metallurgical research and pilot testing of nodules.
- Advance engineering design.

Trial Mining

- Conduct a trial mining operation within the TOML Area, which will inform a commercial mining feasibility study. This should include:
  - Fabrication of pilot scale equipment;
  - Appropriate permitting;
  - Selection of a candidate site(s).
- Include an environmental monitoring programme, which will inform a commercial mining EIS.

Possible budgets required for this work over the next two to three years may total $US30–50 million.

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25 Reliance on information provided by the registrant

AMC has relied upon information provided by the registrant in preparing its findings and conclusions regarding the following aspects of modifying factors:

(i) Macroeconomic trends, data, and assumptions, and market studies as, for example, presented in Section 16;

(ii) Legal matters outside the expertise of the qualified person, such as statutory and regulatory interpretations affecting the Project as, for example, described in Section 3 and 17;

(iii) Environmental matters outside the expertise of the qualified person as, for example, described in Section 17;

(iv) Governmental factors outside the expertise of the qualified person as, for example, described in Section 3, 17.

Date

The effective date of this Technical Report Summary is 31 December 2020.

Signature

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