Regional Environmental Assessment for the Northwest Pacific Ocean


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Background document prepared for the workshop on the development of a regional environmental management plan for the Area of the Northwest Pacific

26 October - 6 November, 2020
Online workshop

Contents

Contributors

Chapters 1 – 3 of this report were prepared by the Secretariat of the International Seabed Authority.

Chapters 4 – 6 were prepared by experts. The expert contributors to the three chapters on the geology, oceanography and biology of the Northwest Pacific Ocean are detailed below and their names are arranged in alphabetical order:

Chapter 4: Geology of the Northwest Pacific Ocean
- Tatyana M. Khulapova
- Maria V. Kruglyakova
- Huaiming Li
- Irina Ponomareva
- Phil Weaver
- Kyoko Yamaoka
- Hyung Jeek Kim

Chapter 5: Oceanography of the Northwest Pacific Ocean
- Masayuki Nagao
- Ayumi Tsukasaki
- Yeping Yuan

Chapter 6: Biology of the Northwest Pacific Ocean
- Rachel Boschen-Rose
- Amy Baco
- Cherisse Du Preez
- Akira Iguchi
- Eri Ikeuchi
- Tina Molodtsova
- Miyuki Nishijima
- Viacheslav Melnik
- Xue-Wei Xu

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- China Ocean Mineral Resources Research and Development Association
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- National Institute of Advanced Industrial Science and Technology, Japan
- P. P. Shirshov Institute of Oceanology, Russian Academy of Sciences
- Second Institute of Oceanography, Ministry of Nature Resources, China

1 Background

In accordance with the UN Convention on the Law of the Sea ("the Convention") and the 1994 Agreement relating to the implementation of Part XI of the Convention, the International Seabed Authority (ISA), on behalf of the States Parties to the Convention, is mandated to administer the mineral resources in the Area. In so doing, the ISA is responsible for regulating and controlling seabed activities in the Area for the benefit of mankind as a whole. As of today, this exclusively covers exploration activities but will apply to exploitation activities in the future. At the core of the ISA's mandate lies its duty to take all necessary measures to ensure effective protection for the marine environment from harmful effects which may arise from seabed activities. To that end, the ISA is required to adopt appropriate rules, regulations and procedures for, *inter alia*, the prevention, reduction and control of pollution and other hazards to the marine environment, the protection and conservation of the natural resources of the Area, and the prevention of damage to the flora and fauna of the marine environment[1].

In pursuance of this mandate, the Council of the ISA, during its 17th session in 2012, on the basis of the recommendation of the Legal and Technical Commission of the ISA, approved an Environmental Management Plan (EMP) for the Clarion-Clipperton Zone (CCZ)[2]. This included the designation of a network of nine "Areas of Particular Environmental Interest" (APEIs).

At its 24th session, in March 2018, the Council took note of a preliminary strategy proposed by the Secretary-General of the ISA for the development of Regional Environmental Management Plans (REMPs) for key provinces where exploration activities are carried out under contracts[3]. The Council agreed with the priority areas that had been identified on a preliminary basis as the Mid-Atlantic Ridge, the Indian Ocean triple junction ridge and nodule-bearing province, and the Northwest Pacific and South Atlantic for seamounts. The Council also noted that the preliminary strategy laid out a coherent and coordinated approach to the process and considered it essential that REMPs be developed in a transparent manner under the auspices of ISA.

The implementation of this preliminary strategy started with the organization of two workshops, including one organised in Qingdao, China, in May 2018, which addressed the design of a REMP for cobalt-rich ferromanganese crusts in the Northwest Pacific Ocean.

At its 25th session, in 2019, the Council took note of and welcomed the programme of work of the Secretariat to implement the preliminary strategy for the development of regional environmental management plans for the period 2019–2020.[4] At the same session, the ISA Assembly adopted the Strategic Plan of the ISA for the period 2019–2023, and invited members of the ISA and observers, as well as the organs of the ISA, to support the implementation of the strategic plan and the high-level action plan. As reflected in Strategic Direction 3.2, efforts are to be made to "*develop, implement and keep under review regional environmental assessments and management plans for all mineral provinces in the Area where exploration or exploitation is taking place to ensure sufficient protection of the marine environment as required by, inter alia, article 145 and part XII of the Convention*".

Subsequently, in 2019, the Secretariat prepared a guidance document to facilitate the development of REMPs. This document clarified the roles and responsibilities of ISA organs and built upon the preliminary strategy presented in 2018, envisaging a series of workshops to be convened by the Secretariat with a view to organise

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[1] United Nations Convention on the Law of the Sea, art.145.

[2] ISBA/17/LTC/7 ; ISBA/17/C/19 and ISBA/18/C/22.

[3] ISBA/24/C/3.

[4] ISBA/25/C/13.

the scientific and technical process needed to prepare draft elements for inclusion in the REMPs. Steps are being undertaken to further develop the REMP guidance document, in accordance with the decision of the Council as contained in ISBA/26/C/10.

In this context, during October and November 2019, two workshops were convened on deep sea biodiversity of the CCZ and on the development of a REMP for the Area of the northern Mid-Atlantic Ridge. The outcomes of these workshops support the ongoing review of the environmental management plan for the CCZ and the development of a REMP in the northern Mid-Atlantic Ridge.

With the above background, the ISA will convene the virtual workshop on the development of a REMP for the Area of the Northwest Pacific from 26 October to 6 November 2020, in collaboration with the Ministry of Oceans and Fisheries of the Republic of Korea and the Korea Institute of Ocean Science and Technology (KIOST). This workshop builds on the results of the workshop convened in Qingdao, China, in May 2018. Since the Qingdao workshop, a new contract for exploration of polymetallic nodules was approved for this region, providing additional environmental and resource settings for consideration under the REMP.

In preparation for the virtual Northwest Pacific workshop, a Regional Environmental Assessment (REA) report was developed to summarise the available scientific information to support workshop deliberations and subsequent development of a REMP in the Northwest Pacific region.

2 Purpose and scope of the document

The deep ocean in the Northwest Pacific has a complex geophysical setting. It is bordered by the Mariana Trench to the east, and hosts some of the oldest seamounts in the world. A diverse array of ecosystems, habitats and species can be found in the deep waters of this region.

This document represents a compilation of background information to support the development of a REMP by the ISA for the Area in the Northwest Pacific. This document provides an overview and synthesis of existing scientific information relating to the Northwest Pacific region, including geology, oceanography, and biological communities. The information forms the basis for regional environmental assessment, as well as for the discussions on area-based management tools and assessment of cumulative impacts in the region. This document also facilitates the identification of knowledge gaps, which informs the design of future research and monitoring efforts, as part of the development of the REMP. This document will be a living document, which will be updated and improved over time as more information becomes available.

To guide the collection and organization of information, a detailed outline for the document (Annex 1) was developed at an early stage of preparation for this document. The document outline was based on the parameters and categories of information required for environmental baseline studies, as set out in the ISA recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area (ISBA/25/LTC/6/Rev.1).

The information presented in this document was collated from multiple sources and includes both published and unpublished information. The document also combines literature with results from on-going surveys and environmental baseline studies conducted by contractors in this region. The information summarised in this document is focused on, but not limited to, the ISA exploration areas and their surroundings (see Figure 3.1).

The document is divided into the following chapters:

- Chapter 3 provides an overview of the contract areas in the Northwest Pacific region.
- Chapter 4 provides an introduction to the geological setting of the Northwest Pacific region, including bathymetry, geomorphological features and sediment distribution and fluxes in both seamount and abyssal plain areas.
- Chapter 5 reviews the oceanographical setting of the region, including water circulation at the regional and local (individual seamounts) scales, net primary productivity and chemistry of seawater.
- Chapter 6 provides information on biological communities in the region and is further divided into the pelagic (surface and mid-water) and benthic environments. Where possible, information is provided for both seamount and abyssal plain communities. The grouping of organisms into different size categories (microorganisms, meiofauna, macrofauna and megafauna) is based on ISA recommendations ISBA/25/LTC/6/Rev.1.

3 Overview of contract areas for exploration of mineral resources in the Northwest Pacific Ocean

The ISA has entered into 15-year contracts with twenty-one contractors for exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts in the international seabed area (the Area). The areas being explored are in the Clarion-Clipperton Zone, the Indian Ocean, Mid Atlantic Ridge, South Atlantic Ocean, and the Pacific Ocean.

For polymetallic nodules, the entitled exploration area allocated to each contractor is 75,000 square kilometres. For polymetallic sulphides, the entitled exploration area allocated to each contractor is 10,000 square kilometres and consists of 100 blocks. Each block is no greater than 100 square kilometres. For cobalt-rich ferromanganese crusts, the entitled exploration area allocated to each contractor is 3,000 kilometres and consists of 150 blocks. Each block is no greater than 20 square kilometres.

The mechanism of so-called 'reserved areas' is a key component of the system of access to the Area and its mineral resources under the convention. It is one of the means by which the Convention ensures that developing countries can access deep sea mineral resources. Reserved areas are contributed by developed States when they apply to ISA for exploration rights. They are then held in a 'site bank' which is reserved for access by developing countries or for the Enterprise (UNCLOS, Article 170, Annex IV and 1994 Agreement, Annex, Section 2)[5].

In the Northwest Pacific, ISA has granted a total of five exploration contracts (Table 3.1). In accordance with exploration regulations, contractors are required to collect environmental baseline data within contract areas, and report annually to ISA on the implementation and results of their monitoring programmes.[6]

Table 3.1. ISA exploration contracts in the Northwest Pacific Ocean.

Contractor	Mineral resource	Date of entry into force	Date of expiry	Sponsoring State
Japan Oil, Gas and Metals National Corporation (JOGMEC)	Cobalt-rich ferromanganese crusts	27 Jan 2014	26 Jan 2029	Japan
China Ocean Mineral Resources Research and Development Association (COMRA)	Cobalt-rich ferromanganese crusts	29 Apr 2014	28 Apr 2029	China
Ministry of Natural Resources and Environment of the Russian Federation (MNRE)	Cobalt-rich ferromanganese crusts	10 Mar 2015	09 Mar 2030	Russia
The Republic of Korea (RoK)	Cobalt-rich ferromanganese crusts	27 Mar 2018	26 Mar 2033	Republic of Korea
Beijing Pioneer High-tech Development Corporation (BPHDC)	Polymetallic nodules	18 October 2019	17 October 2034	China

Contractors may be required to relinquish a portion of their contract area in accordance with ISA exploration regulations. The relinquished area will revert to the Area.

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[5] For more information on reserved areas, please refer to the ISA Policy Brief on Current Status of the Reserved Areas with the International Seabed Authority. https://isa.org.jm/files/files/documents/statusofreservedareas-01-2019-a_1.pdf

[6] Regulation 34, ISBA/18/A/11; Regulation 32, ISBA/19/C/17.

Regulation 25 of ISBA/19/C/17 states that:

> *1. The total area allocated to the contractor under the contract shall not exceed 150,000 square kilometres. The contractor shall relinquish portions of the area allocated to it to revert to the Area. By the end of the third year from the date of the contract, the contractor shall have relinquished 20 per cent of the area allocated to it; by the end of the fifth year from the date of the contract, the contractor shall have relinquished an additional 10 per cent of the area allocated to it; and, after eight years from the date of the contract, the contractor shall have relinquished an additional 20 per cent of the area allocated to it, or such larger amount as would exceed the exploitation area decided upon by the Authority, provided that a contractor shall not be required to relinquish any portion of such area when the total area allocated to it does not exceed 75,000 square kilometres.*
>
> *2. The Council may, at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, inter alia, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the contractor.*

Regulation 27 of ISBA/18/A/11 states that:

> *1. The contractor shall relinquish the area allocated to it in accordance with paragraph 1 of this regulation. Areas to be relinquished need not be contiguous and shall be defined by the contractor in the form of sub-blocks comprising one or more cells of a grid as provided by the Authority. By the end of the eighth year from the date of the contract, the contractor shall have relinquished at least one third of the original area allocated to it; by the end of the tenth year from the date of the contract, the contractor shall have relinquished at least two thirds of the original area allocated to it; or, at the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate an area from the remaining area allocated to it to be retained for exploitation.*
>
> *2. Notwithstanding the provisions in paragraph 1, a contractor shall not be required to relinquish any additional part of such area when the remaining area allocated to it after relinquishment does not exceed 1,000 square kilometres.*
>
> *3. The contractor may at any time relinquish parts of the area allocated to it in advance of the schedule set out in paragraph 1.*
>
> *4. Relinquished areas shall revert to the Area.*
>
> *5. The Council may, at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, inter alia, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the contractor.*

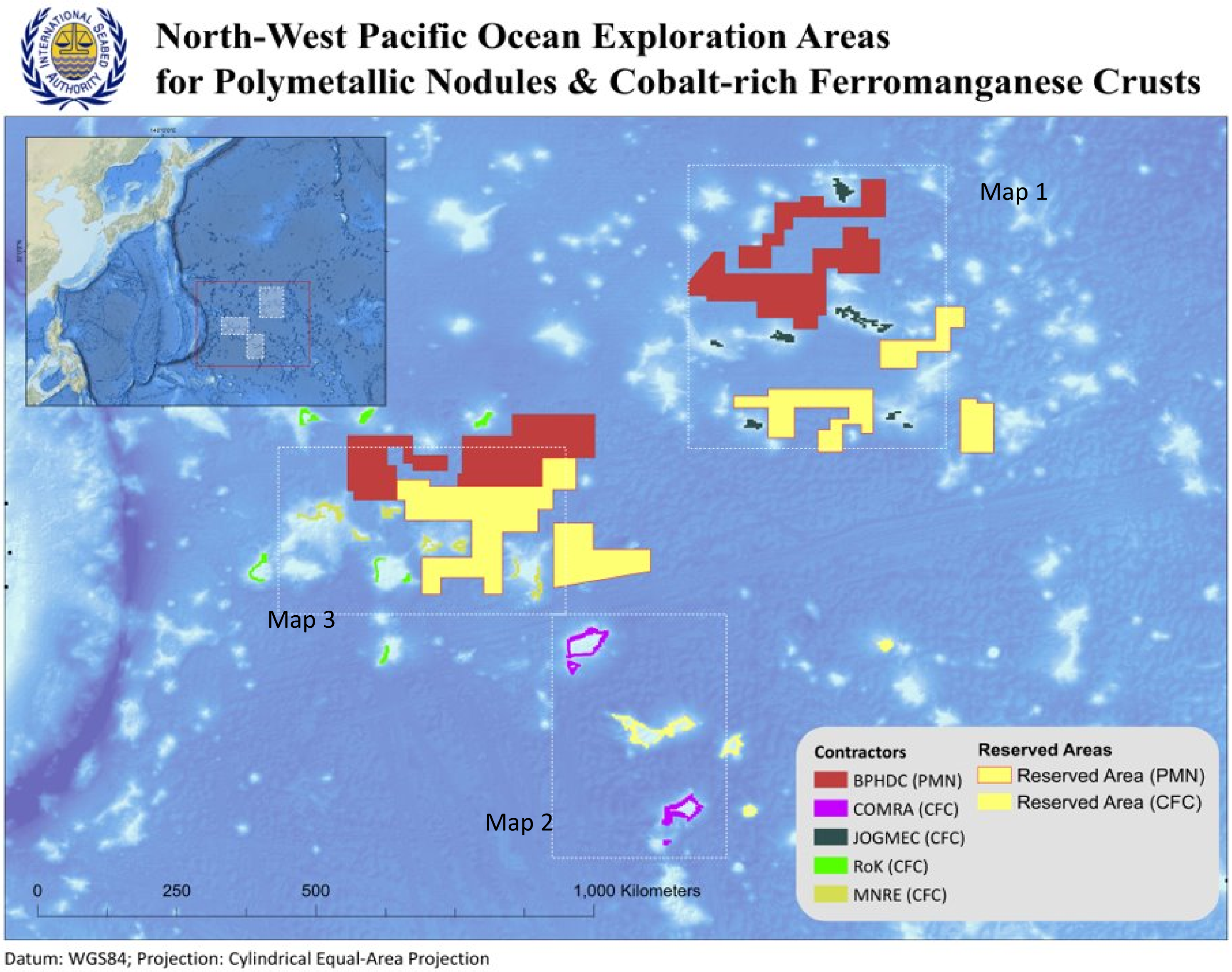
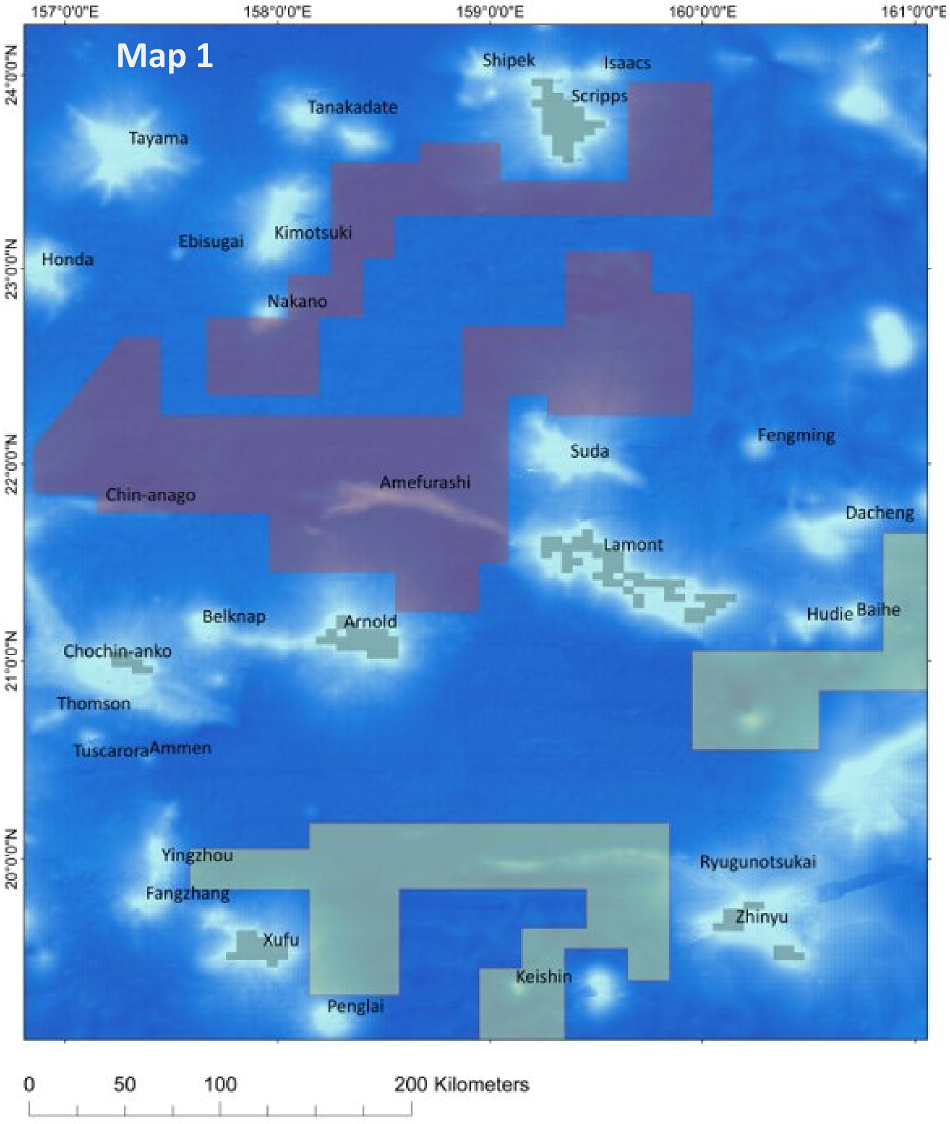


Figure 3.1. Exploration areas for polymetallic nodules and cobalt-rich ferromanganese crusts in the Northwest Pacific. The boxes show the areas detailed in the maps in Figure 3.2. Abbreviations for contractors are detailed in Table 3.1.



Datum: WGS84; Projection: Cylindrical Equal-Area Projection

Figure 3.2a

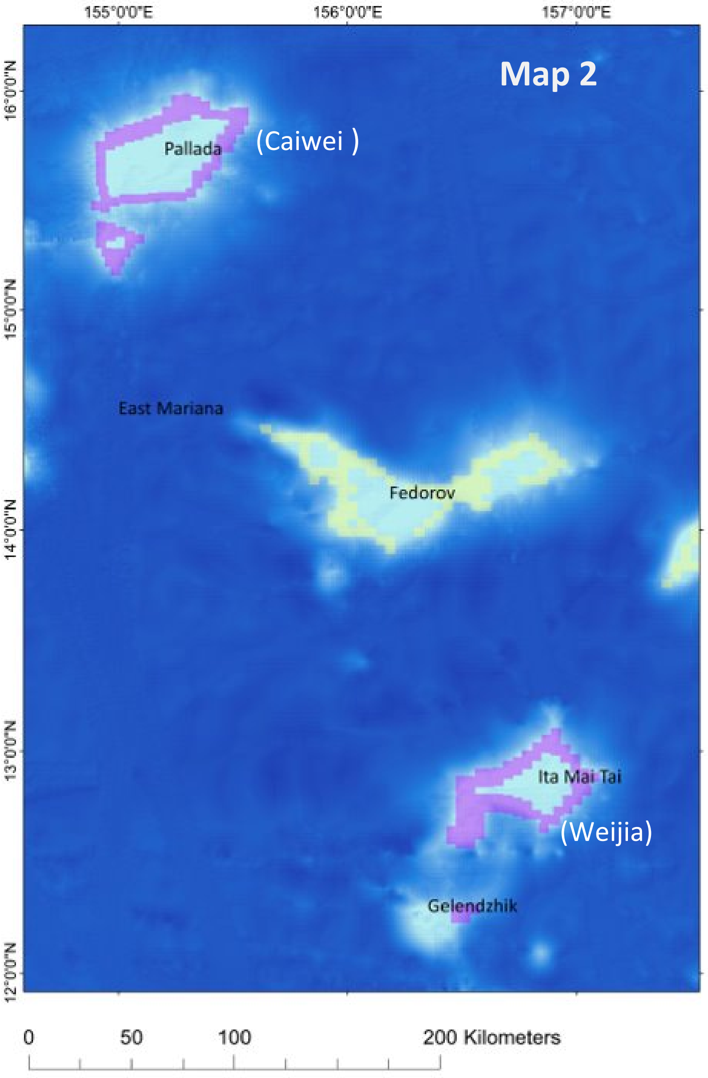


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Figure 3.2b

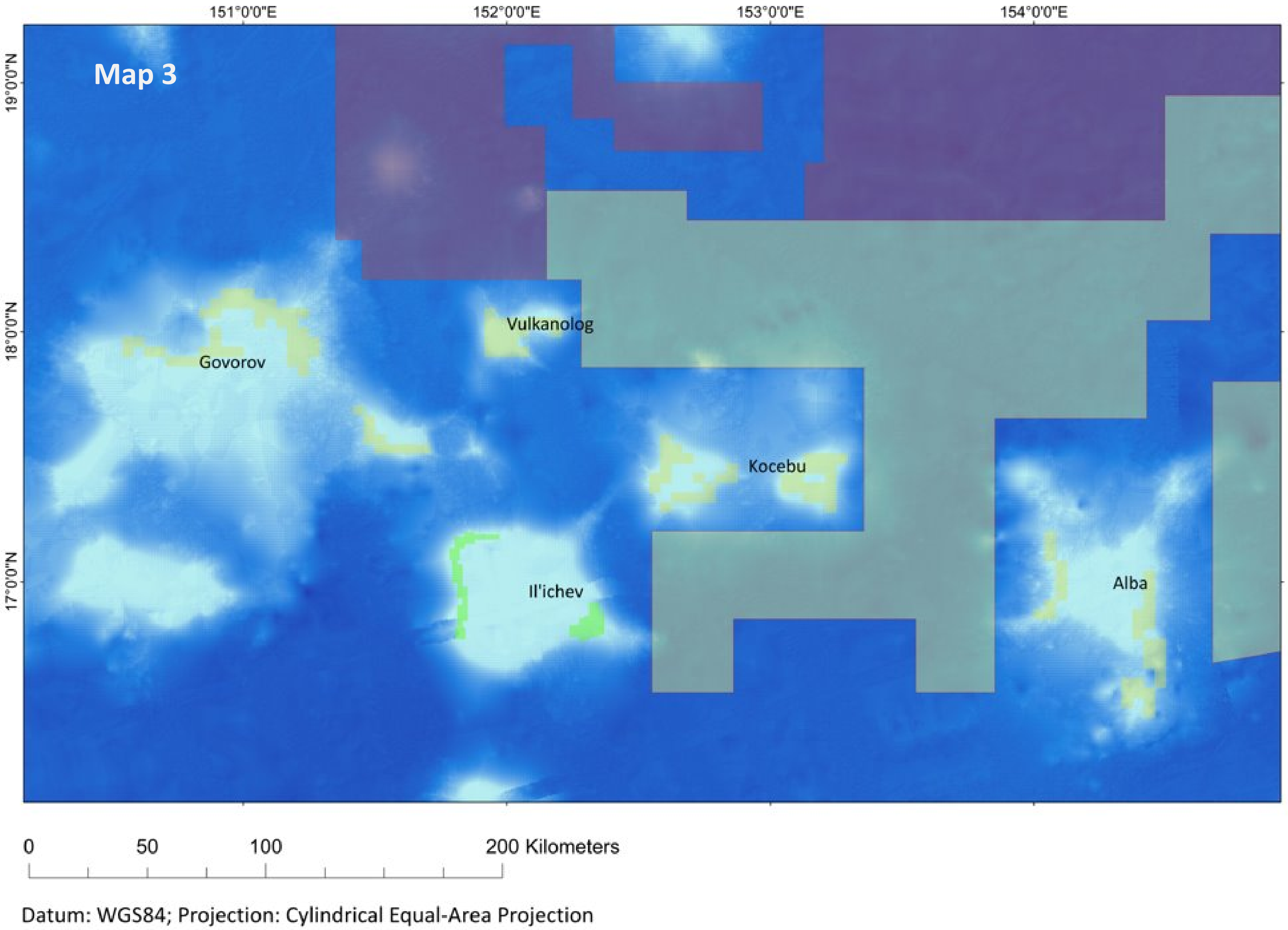


Figure 3.2c

Figures 3.2 a-c. Detailed maps of the distribution of seamounts and contract areas in selected areas (areas inside the boxes in Figure 3.1).

4 Geology of the Northwest Pacific Ocean

4.1 Overview

The geographic extent examined in this chapter includes the vast area east of the Mariana Trench, west of the Central Pacific Seamounts, and north of the Caroline Seamounts (Figure 4.1). The complex geography of the Northwest Pacific is a result of tectonic and magmatic activity during the Mesozoic. Seamount chains and inter-mountain basins that formed at different times are distributed irregularly, and include three major seamount chains (i.e., the Marcus–Wake, Magellan, and Marshall Island chains), and deep ocean basins including the Nadezhda, Kartagraf, Pigafetta, East Mariana, and Nauru basins (Figure 4.1). This region includes the Magellan Mountains and the Markus Wake Rise, where the contract areas of Japan, China, Russia, and Republic of Korea are located.

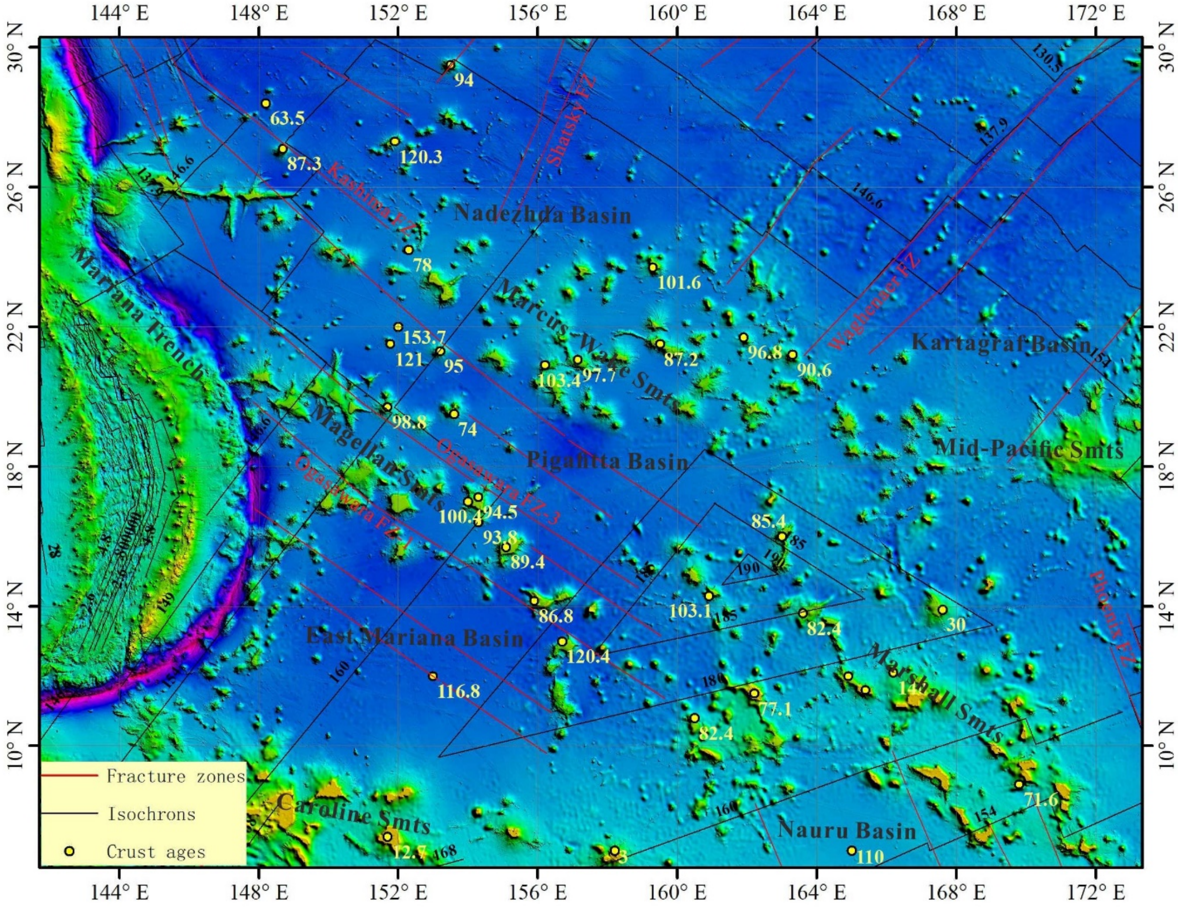


Figure 4.1. Geological map of the study area in the Northwest Pacific. Isochronal age data for the Pacific Ocean crust are from Müller et al. (2016); age data for intraplate seamounts are from Clouard and Bonneville (2005); fracture-zone data are from Nakanishi et al. (1993). Credit Huaiming Li and Zhenggang Li.

The Northwest Pacific preserves the oldest oceanic crust and intraplate seamounts on earth. The region has broad topographic relief, with a maximum depth in the Mariana Trench of ~11,000 m and some islands reaching 2,000 m above sea level. Studies have shown that the bathymetry and topography of the Magellan seamounts and the Markus-Wake Rise are complex and diverse in terms of geological and morphological characteristics.

Seamounts can be classified into different types based on their tectonic position and formation mechanisms, slope variation and other geomorphological features. Studies in other regions suggest that flatness and height are the two key factors determining seamount shape. The geomorphological features of several guyots and seamounts in this region have been studied in detail.

The patterns of cobalt-rich ferromanganese crust (CFC) occurrences on the seamounts are primarily determined by the common features of their relief. In general, CFC occurrences are confined to single structures – a guyot or a needle. As a consequence, the expansion of CFC is concentric-zonal. The zone center is the vertex surface. Cobalt-bearing manganese crusts are distributed mainly on the top surfaces and slopes of mountain structures. On the slopes there is an alternation of zones with different thickness of mineralization, confined to bathymetric intervals of 1,500—3,000 m and the specific geomorphological situation. The main factor controlling the distribution of crust mineralization along the seamount slopes is the slope inclination. The maximum thickness of crusts — 10 to 15 cm or even more – are found on gentle surfaces devoid of loose sediments along the periphery of vertex plateaus, and on weakly inclined surfaces of stepped slopes. On steep slopes (inclination of 35—40°), the thickness of crusts decreases considerably to few millimeters in thickness.

In the oligotrophic Northwest Pacific Ocean, seamount biological communities are largely dependent on sinking organic matter. Based on sediment trap observations around three seamounts (Lamont, Maloney, and Xufu) in the Northwest Pacific, sinking particles mainly consist of biogenic carbonate, and total mass fluxes are very low, consistent with the characteristics of oligotrophic areas in the ocean (Yamaoka et al., 2020). Total mass fluxes showed seasonality with a sharp peak in late summer, although satellite data indicated the lowest primary production in summer season. Yamaoka et al. (2020) suggest that this discrepancy could be explained by short-lived or subsurface blooms induced by passing typhoons. During the vertical transport of particles from depths of 1,000 to 4,700 m, half of the organic matter was decomposed, suggesting less food is available for the benthic habitats in deeper abyssal plains compared to seamounts. Based on the elemental analyses of sinking particles, more than 85% of total Mn, Co, Ni, Cu, Zn, Cd, and Pb fluxes were attributable to scavenging (biogenic uptake) processes. Such scavenging-dominant metal flux seems to be ubiquitous in the oligotrophic open ocean.

4.2 Tectonics and magmatism

The Northwest Pacific preserves the oldest oceanic crust and intraplate seamounts on Earth. According to the global plate-motion model of Seton et al. (2012), the Pacific Plate formed at ~15°S, in the middle of the Pan-Pacific Ocean, 190 million years ago (Ma). Seafloor spreading at the ancient ridge-ridge-ridge triple junction formed the Farallon, Izanagi, and Phoenix plates. At about 43 Ma, the Pacific Plate underwent an abrupt rotation of ~60°, from a NNW orientation to WNW, indicated by bends in the seamount chains, such as the Hawaii–Emperor and Louisville bends (Koppers and Staudigel, 2005). Since 20 Ma, the tectonic environment of the Pacific Plate has remained relatively stable, maintaining the pattern of old crust in the west and new crust in the east. The oldest oceanic crust in the Northwest Pacific occurred beneath the Marshall seamounts (Müller et al., 2016), and the age of the crust decreases gradually from the triangular centre of the Pacific Plate to its periphery (Figure 4.1). Results of the Oceanic Drilling Project (ODP) indicated that the age of the oceanic crust near the Izu–Bonin–Mariana Trench is 127.0 ± 1.5 Ma and younger than that of the Pigafetta Basin (167.4 ± 1.4 Ma: Koppers et al., 2003), confirming that the oldest region of the Pacific Plate does not occur close to the subduction zone.

Abyssal seamounts and plateaus of the Northwest Pacific, including the Central Pacific, Marshall, Magellan, and Marcus–Wake seamount chains, as well as the Ontong Java Plateau and Shatsky Rise, formed mainly during magmatic intervals at 140–120 and 100–80 Ma due to the emplacement of a sequence of large igneous provinces (Müller et al., 2016). However, the superposition of multiple magmatic events on old basement during a later stage is also discussed (Castillo et al., 1992; Pilet et al., 2016). The Shatsky Rise exhibits symmetrical magnetic stripes and tholeiitic basalt oceanic crust, which could result from ridge–plume interaction (Sager et al., 2019). Ocean-island alkaline basalts (OIBs) mostly occur on the Magellan and Marcus–Wake seamounts and indicate mantle sources similar to those of young seamount groups in French Polynesia and the Southern Pacific Ocean, including the Marquesas, Society, Cook–Austral, and Pitcairn–Tuamotu seamounts (W. H. F. Smith et al., 1989; Staudigel et al., 1991; Janney and Castillo, 1999). Large-scale magmatic episodes during the Mesozoic were therefore most likely related to the South Pacific Isotopic and Thermal Anomaly (SOPITA) or a mantle superplume currently located in the South Pacific Ocean. These ancient seamounts and plateaus moved away from the SOPITA region to their current positions through seafloor spreading.

4.3 Bathymetry and topography

4.3.1 Depth profile at the regional scale

Gridded bathymetric data of the General Bathymetric Chart of the Oceans (GEBCO) were used with Surfer and ArcGIS software to construct a topographic map (Figure 4.2). The region has large and variable topographic relief, with a maximum depth in the Mariana Trench of ~11,000 m and some islands reaching 2,000 m above sea level. Basements of the Marshall and Caroline seamounts are at ~4,000 m depth, with a considerable number of seamounts protruding above sea level. The Marcus–Wake and Magellan seamount basements, for example, are at 5,000–6,000 m depths. The Marcus and Wake islands rise above sea level, whereas other seamount peaks in these areas are below sea level.

Depth profiles (Figure 4.3) indicate that (1) Marcus–Wake and Magellan seamounts peaks are generally at >1,000 m depth, and (2) Marcus–Wake seamounts basement are mainly at shallower levels than those of the Magellan seamounts, which are generally at >6,000 m depth.

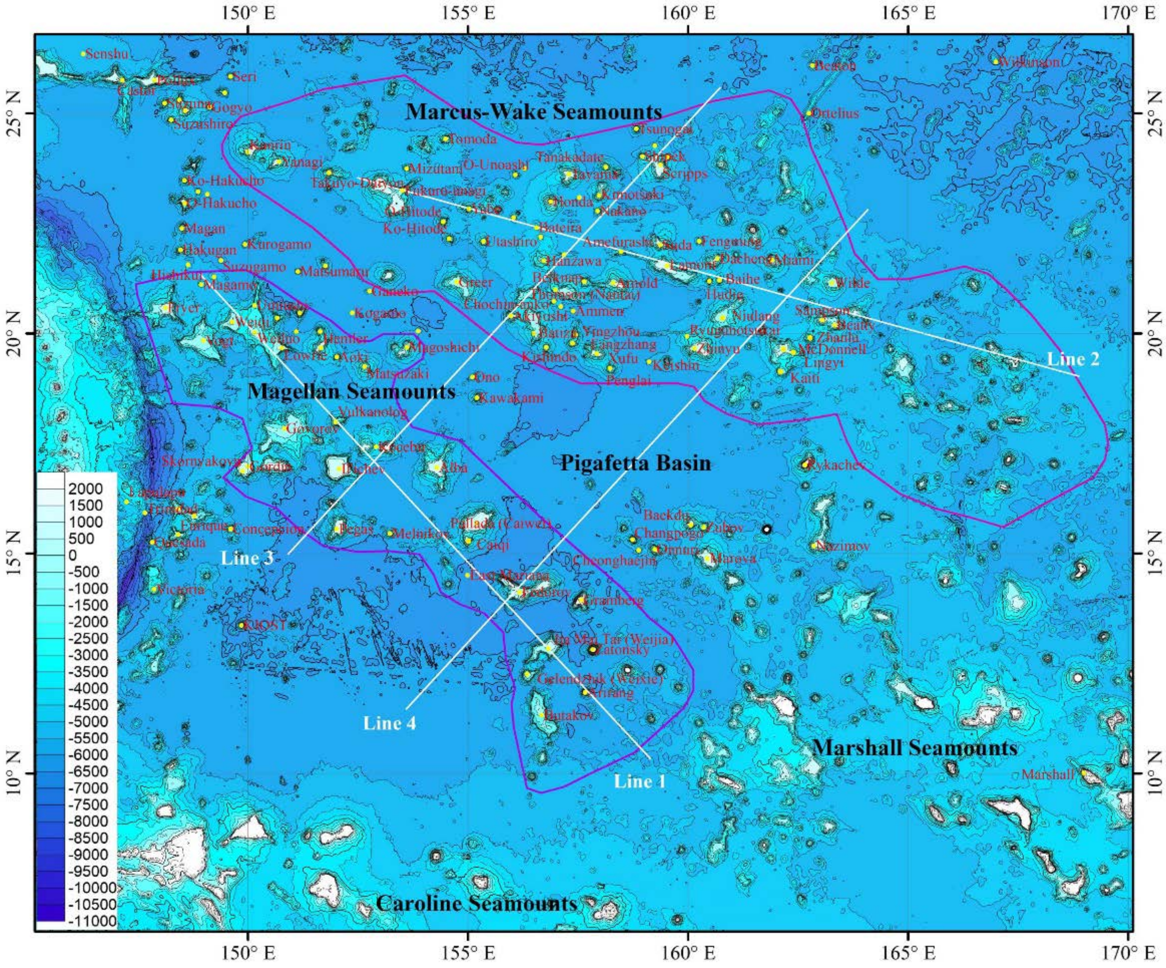


Figure 4.2. Regional and bathymetric map of the examined area. Depth profiles along lines 1–4 are plotted in Figure 4.3. Dark purple and dark pink outlines indicate the Magellan and Marcus–Wake seamount regions, respectively. Terrain data are from GEBCO 15″ grid data, and seamount names are from the Scufn database. Credit Huaiming Li and Zhenggang Li.

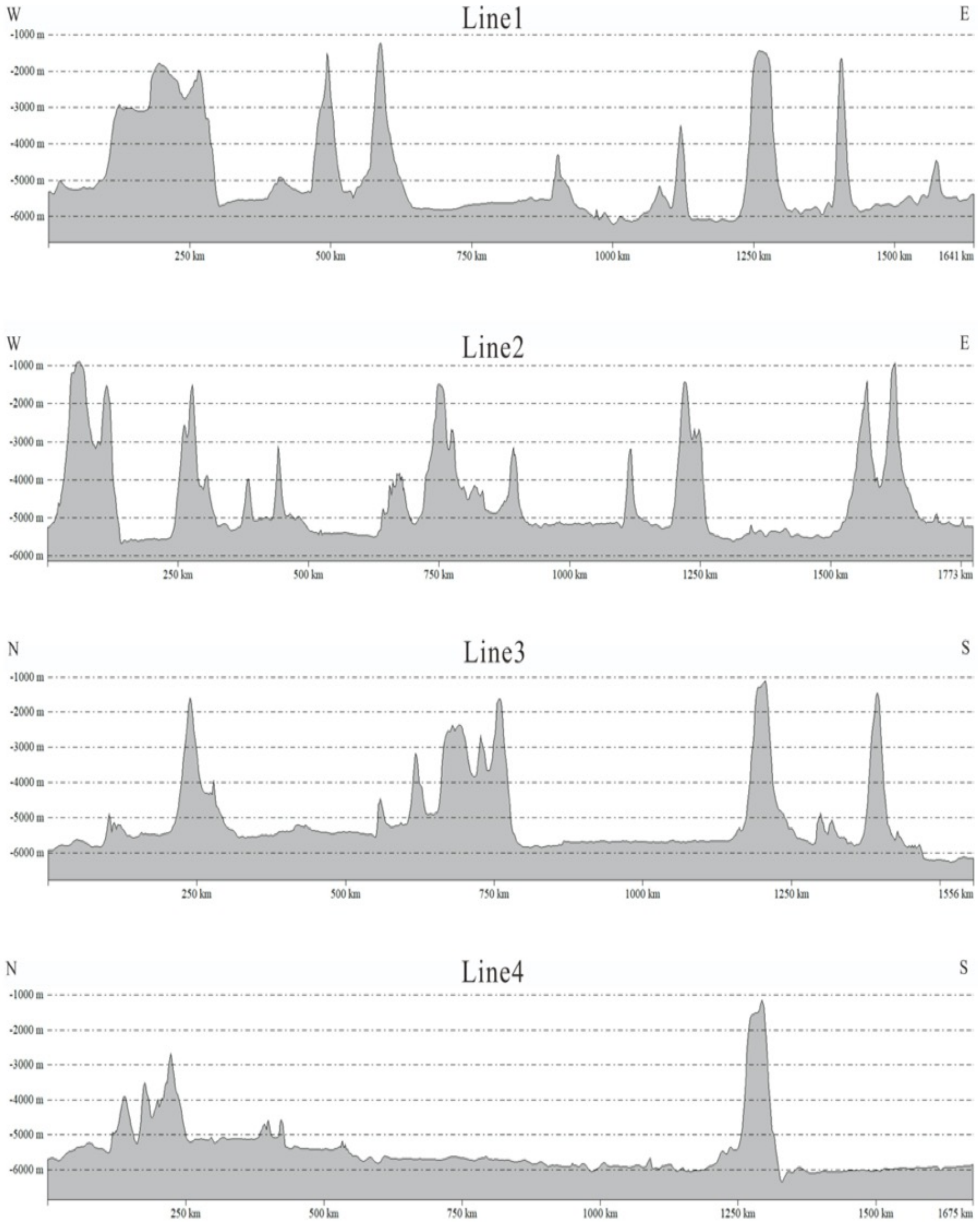


Figure 4.3. Water depth profiles (meters below sea level) of the Marcus–Wake and Magellan seamount chains. Section locations (lines 1–4) are shown in Figure 4.2. Credit Huaiming Li and Zhenggang Li.

The Marcus–Wake and Magellan seamount chains are delineated in Figure 4.2, and a statistical analysis of water depths and slopes was undertaken for the two areas (cell numbers 4688860 and 2939567, respectively). The total area of the Marcus–Wake Seamount chain is 942,000 km^2, including an area occupied by seamounts (above 5,000 m depth) of 351,000 km^2. The total area of the Magellan Seamount chain is 610,000 km^2, including a seamount area of 227,000 km^2. Notably, the two seamount chains regions have similar seamount distribution densities.

Depth distribution frequencies (Figure 4.4) of the two seamount chains are positively skewed. First-quartile, median, and third-quartile values for the Magellan and Marcus–Wake seamount chains are 5,781 and 5,501 m, 5,486 and 5,284 m, and 4,894 and 4,816 m, respectively. The depth of the Magellan seamount chain is thus greater overall than that of the Marcus–Wake seamount chain. Fourth-quartile bathymetric data of the Marcus–Wake seamount chain indicate a gradual decrease in frequency with decreasing water depth, and a sudden increase at 1,350 m in the Magellan seamount chain (Figure 4.4). As the area of each grid is identical, we infer that (1) the proportion of spire seamounts relative to guyots is higher in the Marcus–Wake seamount chain, and (2) the depths of guyot summits are clustered at around 1,350 m in the Magellan seamount chain.

The slope frequency distributions (Figure 4.5) of both seamount chains are non-normal and positively skewed. First-quartile, median, and third-quartile values for the Magellan and Marcus–Wake regions are 0.48° and 0.45°, 1.17° and 1.1°, and 3.67° and 3.48°, respectively. Most of the area (75%) in both regions is fairly flat (<5°). Although the maximum slopes in the two seamount chains are in the range of 39°–49°, high-slope (>5°) areas occupy <1% of the total areas.

The bathymetry and topography of the Magellan and the Markus-Wake seamount chains are complex and diverse, with each seamount chain displaying individual characteristics.

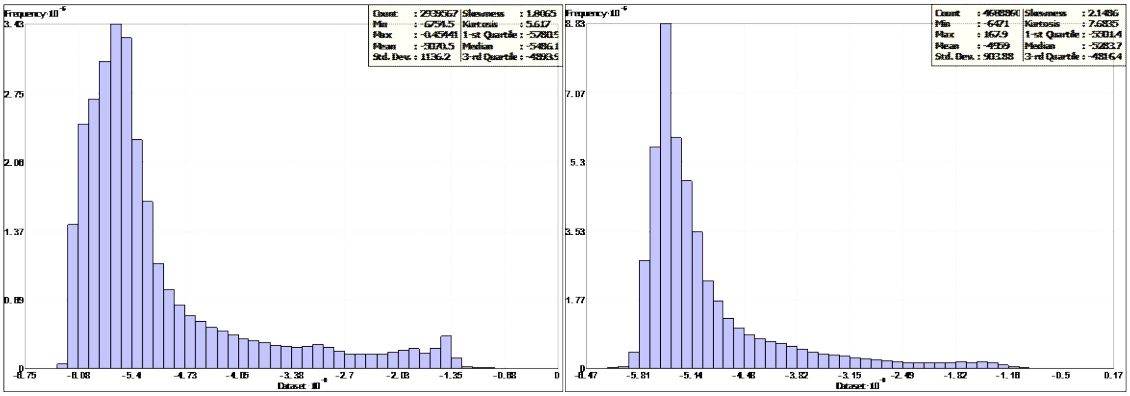


Figure 4.4. Depth frequency distributions for the Magellan (left) and Marcus–Wake (right) seamount chains. Credit Huaiming Li and Zhenggang Li.

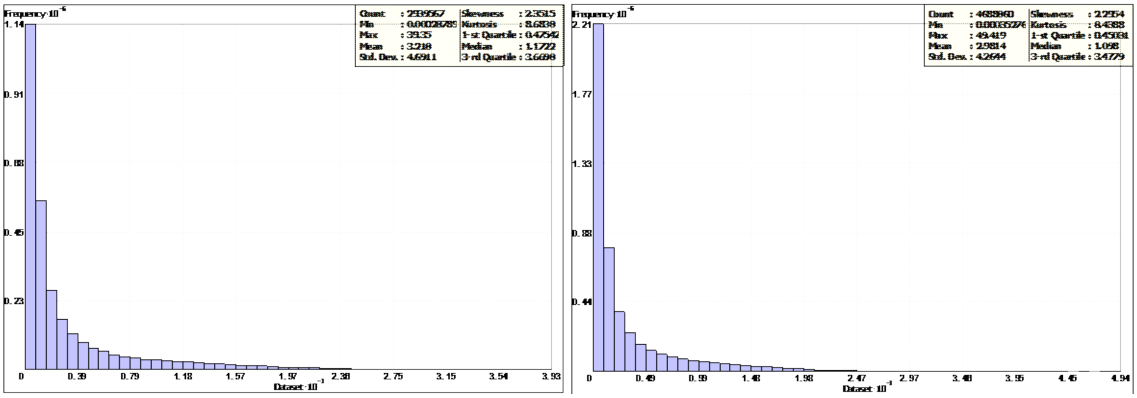


Figure 4.5. Slope frequency distributions for the Magellan (left) and Marcus–Wake (right) seamount chains. Credit Huaiming Li and Zhenggang Li.

4.3.2 Bathymetry and topography of the Magellan Mountains

The Magellan seamount chain is the arching chain of volcanic edifices more than 1,200 km long, dividing the East Mariana Basin into two smaller parts: the northeastern Pigafetta and the southwestern Saipan basins. In the west, the chain is bounded by the Mariana system of trenches and uplifts, in the southeast by the uplifts of the Greater Caroline and Marshall Islands (Figure 4.6).

The relief of the seabed in the area of the Magellan seamount chain was studied in the years 2000 to 2010. For each prospective guyot with cobalt-rich ferromanganese emplacement, a bathymetric survey at a scale of 1: 200,000 was performed using multi-beam echo sounder to obtain maps of the bottom relief, distribution of bottom slopes, and amplitudes of the backscattered signal. These data made it possible to study the depths of the seabed, slopes, and all morphostructural features of the Magellan seamounts. Since 2015, the study of the seabed topography has continued within the Russian Exploration Area of cobalt-rich ferromanganese crusts with a degree of detail that enables the compilation of bathymetric maps at a scale of 1: 50 000. With these newly available data, it is possible to better define the depths, slopes, and complex morphology determining the mesoforms of the seamount topographies.

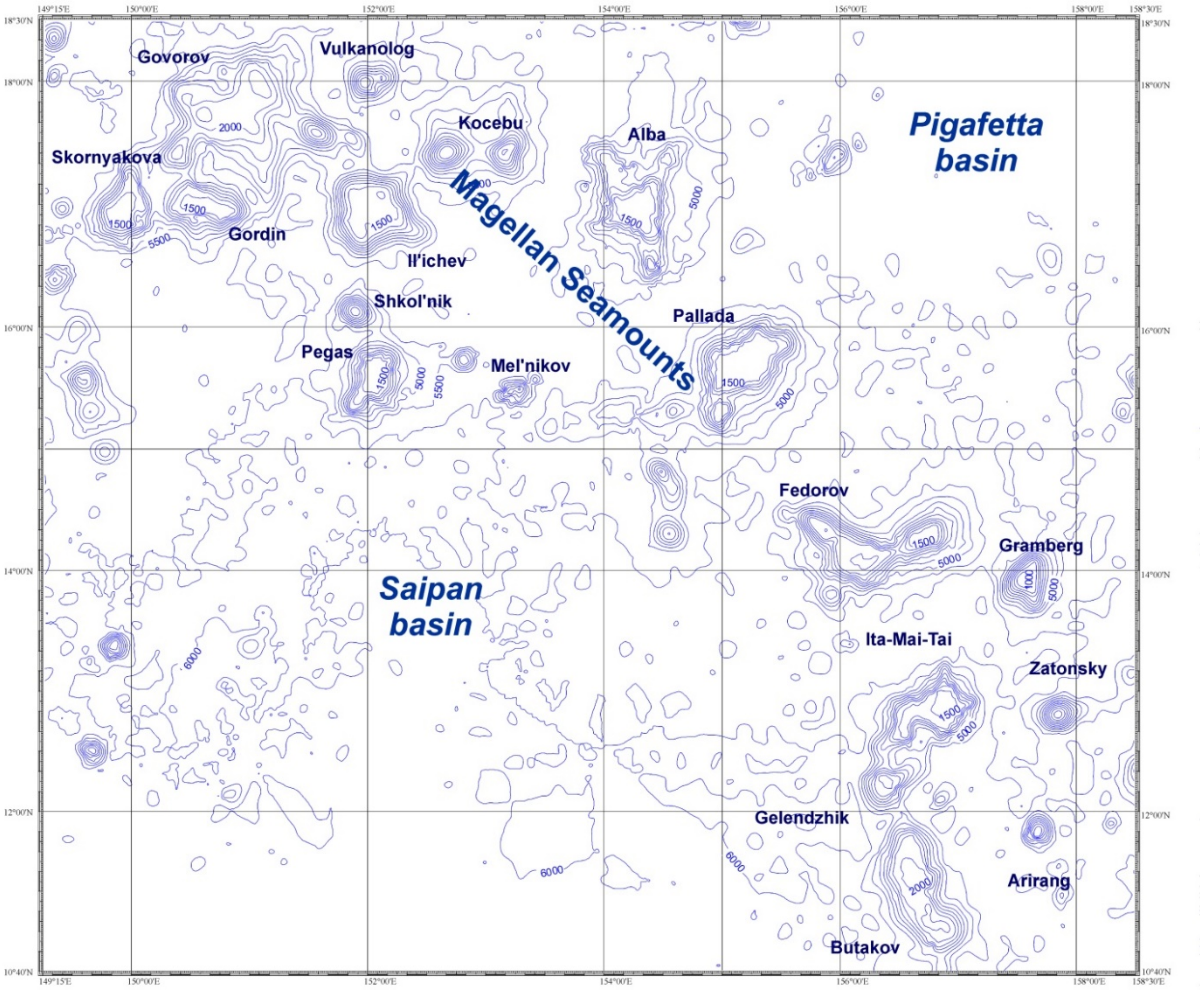


Figure 4.6. Bathymetric map of the Magellan seamounts. Isobaths every 500 m. Credit Yuzhmorgeology.

The Magellan seamount chain consists of single mountain and volcanotectonic massifs, which represent several edifices located on a single base. Guyots are outlined by isobaths from 5,100 to 5,600 m below the sea surface, and in the southeastern part down to 6,000 m. The largest transverse dimensions of the bases vary from 70 to 130 km, sometimes up to 180 km, the area of these bases is up to 15,000 km^2. The summit plateaus are located between 1,300 and 2,600 m water depth, with relative elevations from 2,500 m to 4,700 m. The individual plateau is represented by sub-horizontal or gently sloping surfaces with slopes from 0˚ to 2˚. The contours of the plateau generally follow the shape of the bases, and the transverse dimensions vary from 15x10 km to 80x30 km, with areas up to 3,650 km^2. The central parts of the plateau are more often level and covered by loose carbonate sediments. Slight slopes up to 5˚ occur along the periphery of the vertex surfaces. Here, the rocky outcrops are practically devoid of sedimentary cover. The minimum water depth of 551 m is recorded on a cone-shaped structure located on the summit surface of the Alba Guyot (Melnikov 2005; Anokhin 2018; The World Ocean, 2018).

The slopes of the guyots have a convex-concave profile. The upper parts of the slopes below the edge of the summit surface are convex. They are confined to the depth interval between 1,800 and 2,600 m and are characterised by slopes from 15˚ to 20˚ or more. In the central parts (depth interval 2,600 – 4,000 m), the steepness decreases and is between 10˚ and 12˚. At the base of the guyots (depth interval 4,000 – 5,600 m), the slopes are gentle, between 2˚ and 8˚. The tops of guyots are usually covered with loose carbonate sediments (foraminiferal sands), the bases are covered with argillaceous and slightly carbonate argillaceous sediments, and the slopes are outcrops of limestones, breccias and basalts. The transition of the slopes to the basal plain is characterised by an arch bend at depths of 5,000 to 5,600 m. The slopes of the guyots are complicated by extended spurs and satellite volcanic edifices.

There are fewer conical seamounts in the chain than guyots with summit plateaus, and the area of the conical seamount bases is much smaller (less than 2,000 km^2). Like guyots, conical seamounts are delineated by isobaths between 5,400 and 5,600 m, and the bases are mostly isometric or elongated with the largest dimensions not exceeding 55 km. The minimum water depth reaches 1,800 m, rarely to 1,500 m, and the overall seamount height is 2,500 to 3,500 m.

The foothills of the conical seamounts and guyots can be (1) traced quite clearly (Pegas), (2) appear shortened (Pallada, Ilyichev), or (3) are not clearly pronounced (Skornyakova, Gordin). In the first case, their length from the bend of the slope to the surface of intermontane plains or abyssal basins is up to 50 km, in the depth interval from 5,000 to 5,900 m. The relief of the base surface is undulating, intruded by numerous hills and small mountain features, with a general slope of 1˚ to 3˚. In the second case, the length of the base trace is about 25 km in the same depth interval. The surface relief is also undulating, but there are practically no significant morphological features to be noticed. The slope of the surface varies between 2˚ and 5˚. In the third case, relatively steep slopes (7˚ - 12˚) with a sharp bend are associated with the subhorizontal surface of the depressions (Melnikov, 2005).

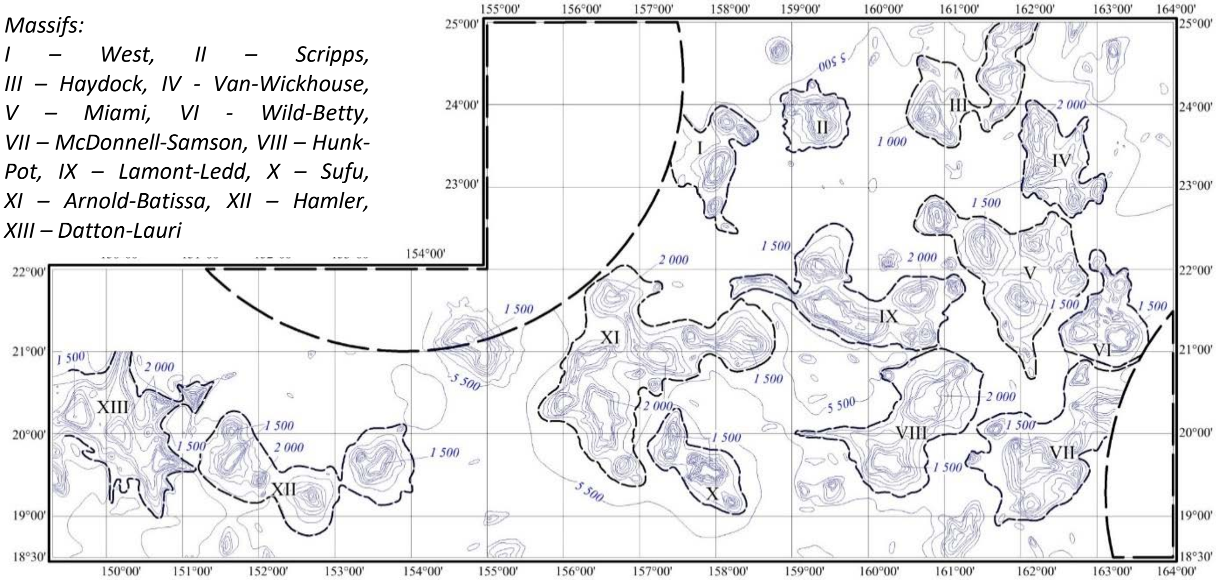
Seamounts show complex morphologies. There are round-shaped formations, satellite structures, volcanic domes, cones and terraces, and linear features like spurs, ridges, hollows, and ledges. The length of the spurs can be tens of kilometers, as is the diameter of the base of the satellite structures, and the transverse dimensions of the volcanic cones and domes vary from hundreds of meters to few kilometers. The latter can be present on guyots in large numbers including several dozens and even more than a hundred on a single seamount, ranging from 2 to 24 structures per 1,000 km^2. The height of structures in most cases varies from 50 to 350 m, and on the largest cones it can reach 750 m e.g., a cone on the summit surface of the Alba guyot (Melnikov, 2017).

4.3.3 Bathymetry and topography of the Markus Wake Rise

The Markus-Wake seamount chain is the western branch of the extensive Markus-Necker volcanic system. The length of the uplift is about 2,200 km, with a width between 300 and 600 km. The uplift separates the Northwestern and the East Mariana Basins. There are two islands within the uplift, namely Markus or Minamitori in the west and Wake in the east (Figure 4.7).

Studies of the bottom topography of the Markus-Wake seamount chain was carried out in the late 1970s and 1980s using conventional single-beam echo sounders. The resulting bathymetric maps provide an overview of the seabed topography, slopes, and morphology of seamounts. The results of investigations of the bottom relief by multi-beam echo sounders made it possible to obtain more detailed information about the morphology of the seamounts. These data indicated that the Markus-Wake seamounts do not have the rounded outlines, as previously thought. Instead, their contours are angular, and their outlines are close to irregular polygons.

The Markus-Wake seamount chain is characterised by numerous seamount edifices, grouped into volcanotectonic massifs located on similar crustal bases. The surface of the basement is elevated relative to the bottom of the surrounding abyssal depressions by 200 to 400 m and is outlined by the 5,600 m water depth isobath. A total of 13 massifs were identified in the area under consideration (Melnikov 2005; The World Ocean, 2018).



Massifs:
I – West, II – Scripps, III – Haydock, IV - Van-Wickhouse, V – Miami, VI - Wild-Betty, VII – McDonnell-Samson, VIII – Hunk-Pot, IX – Lamont-Ledd, X – Sufu, XI – Arnold-Batissa, XII – Hamler, XIII – Datton-Lauri

Figure 4.7. Bathymetric map of the western parts of the Markus-Wake seamount chain, modified from The World Ocean (2018). Credit Yuzhmorgeology.

For a large number of massifs, the delineating isobaths are in the depth range between 5,000 m and 5,100 m whilst several massifs are in the range of 5,000 m to 5,400 m. The extension areas of the massifs vary between 7, 000 km^2 to 33, 000 km^2, with an average of approximately 20, 000 km^2.

The largest guyots are represented by Scripps, Lamont, Arnold, Pot, Hunk, and McDonnell. The height of most of these seamounts varies from 1,500 m to 3,500 m and in only one case does the height reach 4,300 m. The highest seamounts are found in the Miami massif (the minimum depth is 938 m), and the shallowest in the Wild-Betty massif.

The summit plateaus of guyots generally fall into three depth ranges: (1) 1,150 m – 1,350 m, (2) 1,550 m – 1,850 m, and (3) deeper than 2,300 m. The first includes the Lamont, Arnold, Pot, Scripps, and a number of other seamounts; the second includes Batissa, Smoot, Maloney, Jennings and Hunk seamounts; the third includes Wild, Haydock and Taylor seamounts.

Summit plateaus of seamounts can be table-like (Maloney, Betty, Pot) or be irregular by rampart, domed uplifts (e.g., Batissa, Arnold, Jennings), large (Hunk), and small (Van-Wickhouse). The Lamont Guyot has a stepped summit collapse feature in the southeast at depths between 1,250 m and 2,000 m, also pierced by domes and outliers.

The profile of the seamount slopes is generally convex to concave. The convex part, as a rule, falls on the upper parts of the slopes with steepness of 15˚ to 20˚ or more. The concave part corresponds to the lower parts of the slopes with steepness is 6˚ to 9˚. In places where the slopes meet with the base of the seamount, the steepness decreases to 3˚ to 6˚. Slopes can be up to 40˚ on the upper parts of seamounts. The slopes are stepped, with an alternation of slightly inclined steps and steeply dipping ledges.

Many seamounts are characterised by spurs, the length of which can reach tens of kilometers (e.g., Batissa, Hunk, Maloney, Dixie-Jane), and additional domes, the tops of which can be plateau-like (e.g., Arnold, South, Scripps).

Between the seamounts the seafloor is very flat, with undulations not exceeding heights of 100 m for tens, and even hundreds of kilometers. The general trend of the relief is a smooth slope from the base of the seamounts to the central parts of the basins. In the described area, there are four morphological depressions or basins, the areas of which vary from 13 ,000 km^2 to 38, 000 km^2. The largest basin, located in the south and opening in the southeastern part towards the Pigafetta basin, is surrounded by the largest seamount massifs, such as Arnold - Batissa and Lamond - Ladd, as well as Hunk - Pot and South (Melnikov, 2005).

4.3.4 Bathymetry and topography of other seamounts

In addition to the Markus Wake and Magellan seamounts, there are other seamounts in the region, most of which are distributed within the exclusive economic zones (EEZ) of the Republic of the Marshall Islands and Federated States of Micronesia.

The bathymetry of Marshall Islands seamounts has been surveyed by the United States Geological Survey (USGS) since the 1980s and bathymetry maps are available through the USGS database.[7] The USGS survey results from the 1980s indicate that seamounts in the waters of the Marshall Islands did not show simple or uniform morphologies and structures, but rather vary significantly, even between adjacent seamounts. The summit platforms are complex, often rugged, and may be tilted (Hein et al., 1990). Bathymetric surveys were conducted by the Japan/SOPAC programme in the late 1990s over 13 seamounts in the EEZ of Marshall Islands, and results revealed that eleven of them have flat summits (guyots) and 2 have peaked summits (conical seamounts). The tops of the surveyed seamounts had a depth ranging from 950 to 1750m, and the relative height of these seamounts was 2700 – 4300m (Kojima, 1999).

4.4 Seamounts

There are as many as 25 million seamounts with heights of >100 m on the seafloor globally, according to the Global Digital Elevation Model (ETOPO2) (Wessel et al., 2010). Seamount here refers to the conical or ridge-like

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[7] https://ngmdb.usgs.gov/Prodesc/proddesc_33349.htm

volcanos with elevations of >1,000 m. Based on their tectonic and formation mechanism, seamounts can be divided roughly into three categories: intraplate (hotspot origin), off-axis (mid-ocean ridge magmatism), and island-arc seamounts. Off-axis seamounts are by far the most common, but they are often small, with peaks below sea level. Island-arc seamounts are less common, but most are exposed above sea level due to enhanced magmatism. There are ~12,000 intraplate seamounts worldwide, and they often have mantle plume-related, chain-like distribution patterns and are medium to large in size (Wessel et al., 2010). As plates move away from mantle plumes, exposed seamounts are eroded and morphologically flattened leading to the formation of guyots (Staudigel and Clague, 2010).

By considering the statistics of the shapes of ~70 seamounts in the East Pacific Rise and South Pacific Ocean, D. K. Smith (1988) concluded that flatness and height are the two key factors determining seamount shape and classified them as guyots and spire/conical seamounts with flatness values of >0.25 and <0.25, respectively. The top platform of guyots is usually smooth, whereas conical seamounts are more steep-sided. High-resolution multi-beam bathymetric data indicate that geomorphology varies strongly, often showing complex topographical features.

Based on their slope variation and other geomorphologic features, seamounts can be further subdivided into the following types:

- The shape of the seamount base:
    - Isometric
    - Elongated
    - Irregular shape
- Number of tops:
    - Single
    - Multiple
- The presence or absence of satellites
- The presence or absence of volcanic edifices
- Type of vertex surface:
    - Conical
    - Flat (plateau-like)
    - Table-shape

4.4.1 Geomorphological features of studied seamounts in the Northwest Pacific

Four guyots within the **Russian exploration area** were studied in detail and classified by geomorphological features (Table 4.1): Alba, Vulcanolog, Govorova, and Kocebu.

Table 4.1. Geomorphological features of guyots within the **Russian exploration area.** Credit Yuzhmorgeology.

Geomorphological feature	***Alba***	***Vulcanolog***	***Govorova***	***Kocebu***	
				West structure	East structure
Minimum water depth (m)	551	1192	1301	1298	1174

Water depth of the brow (m)	1400 to -1500	1300 to 1400	2000 to 2400	1500 to 1600	1400 to 1600
Water depth of the base (m)	5100	5175	4700	3700	3700
Area of the base (km^2)	10000	2600	15000	1400	1000
Base morphology	Elongated, tetragonal	Isometric	Irregular shape, trapezoidal	Irregular shape, angular	Triangular
Number of tops	1	1	1	2	
Number of satellite cones	2	1	3	no	
Volcanic edifices (number of structures per 1,000 km^2)	14.5	13.5	22.1	22.3	
Type of vertex surface	Table-shape	Table-shape	Dome, near to flat	Dome, near to flat	Table-shape

Seamount evolution is often accompanied by flank collapse and mass transportation to different extents. Magmatism (especially dike intrusion), overpressure, and erosion are the three main causes of flank–slope instability (McGuire et al., 1996). Mass transportation is inevitable during the evolution of intraplate seamounts, with direction and scale being related to regional tectonic stress and seismic activity. For example, topographic features of the **Suda Seamount** in the Marcus–Wake seamount chain indicate that the northern flank collapsed significantly, forming a depression in the seamount top, resulting in a wider and less-steep slope in the north than in other directions (Figure 4.8). The fan-shaped formation extending more than 50 km indicates the scale of the mass transportation (Figure 4.8).

Three-dimensional geomorphic features of this collapse feature (Figure 4.9) indicate that the upper part of the slope developed a high-angle normal fault constituting the slip plane, resulting in mass collapse and formation of steep topography. The slope decreases sharply in the middle flank where large quantities of the collapse rocks (debris avalanche) were deposited (Masson et al., 1998). The lower part of the slope is characterised by radial lineaments (alluvial valley and ridges), indicating the direction of the mass transportation. The pediment is relatively flat (slope <5°), with accumulation of banded sediments generated by the debris flow. There are small-scale fault scarps between the banded sediments, perpendicular to the direction of the mass deposits, which formed during the transport of unconsolidated sediments (Masson et al., 1998). Such sediment often carries large volumes of rafted rocks and may cover areas up to several kilometres in diameter. The rocks are probably sourced from the collapse of the seamount flank and transported in the debris avalanche (Masson et al., 1998).

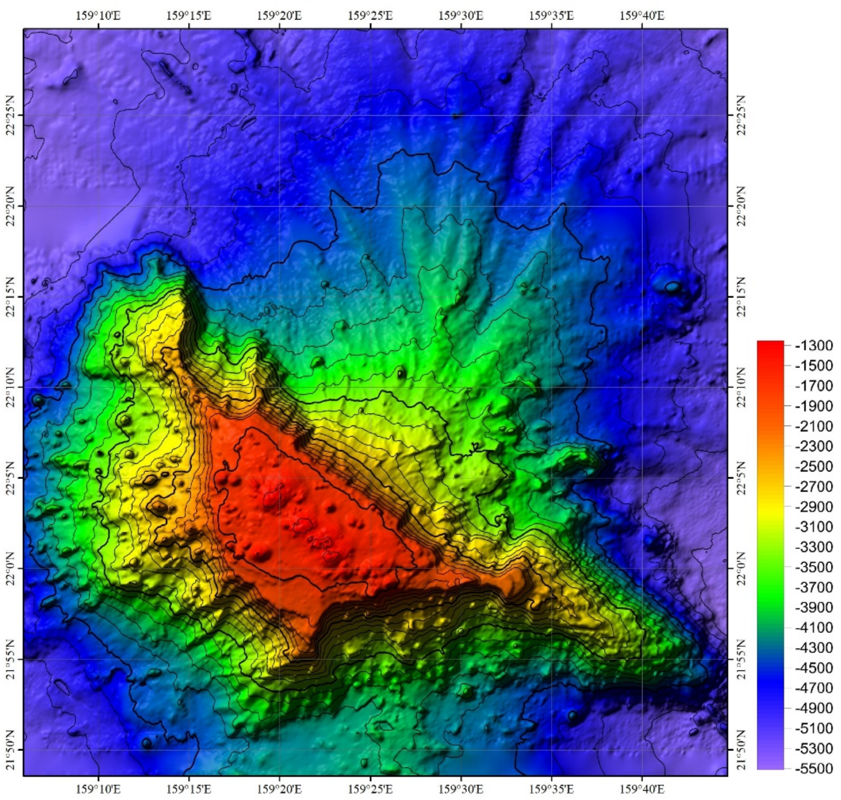

Figure 4.8. Topographic map of Suda Seamount. Data from China Ocean Voyage Survey (unpublished data). Credit Huaiming Li and Zhenggang Li.

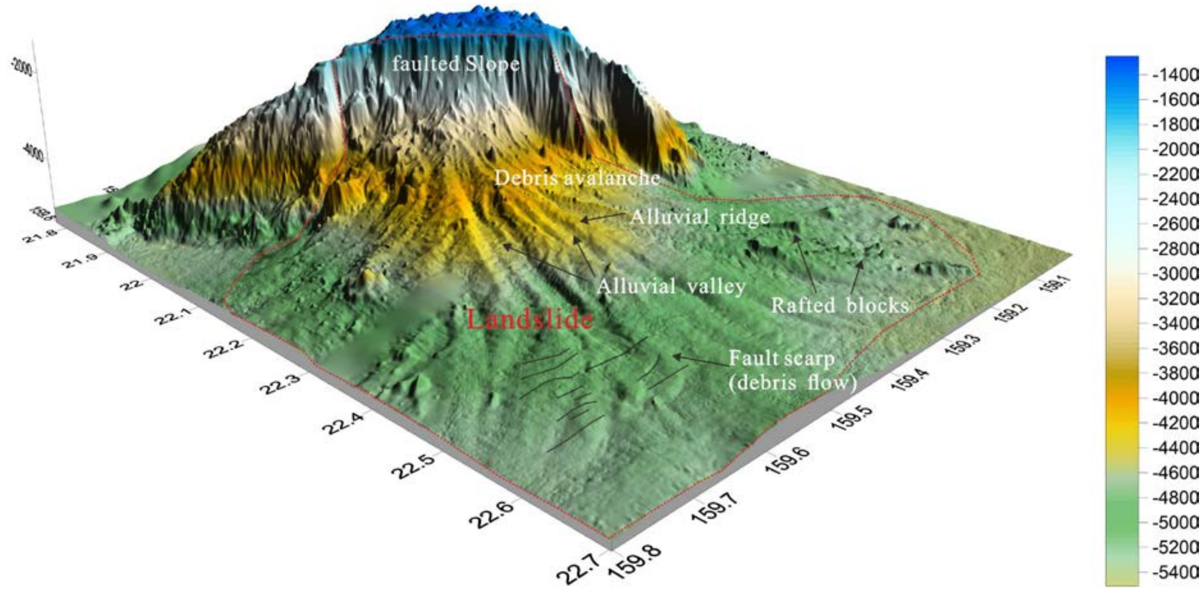

Figure 4.9. Three-dimensional representation of geomorphologic features of the north flank of the Suda Seamount. Credit Huaiming Li and Zhenggang Li.

4.3.1 Distribution of sediment

In general, the guyots of **the Magellan seamount chain** consist of volcanic and sediment formations from Mesozoic to Cenozoic times. In their geological architecture, three different compositional evolutionary stages can be distinguished. The first stage is composed mainly of volcanics that are characteristic of plume-related ocean islands and uplifts. This forms the guyot bases to a water depth of about 3,000 m and consists of tholeiites and plagiobasalts. The second stage is composed of subalkaline and alkaline basalts, amongst which are picrites, olivine basalts, and trachybasalts. Rocks of both levels belong to the tholeiite-alkali basalt association of the Hawaiian type (Frey et al., 1983). The time interval of their formation is the second half of the Early Cretaceous. The third stage is composed of lower and upper Cretaceous sedimentary rocks, Cenozoic rocks, and loose sediments. Four time intervals of sedimentary rock formation can be distinguished, i.e., Aptian–Turonian, Santonian-Maastrichian, Late Paleocene-Eocene, and Miocene. The first three formed similar rock sequences, including reef and planktonic limestone, breccias and fine-grained detrital rocks. The Miocene is characterised by deep-sea carbonatic facies. During the Pliocene-Quaternary period, unlithified detrital carbonatic sediments were formed (Figures 4.10 and 4.11).

Volcanic and sedimentary rocks of the Mesozoic-Cenozoic period form the seamounts of the **Marcus-Wake seamount chain**. The majority of seamounts are composed of ankaramite and trachybasalt associations, in which ankaramite basalts and dolerites as well as trachybasalts, phonolites, and volcanic ashes tuffs can be distinguished. The age of the oceanic crust which forms the base of the guyots is Late Jurassic to Early Cretaceous. The sedimentary cap of the guyots is formed by the same formations as on the Magellan seamounts but in narrower time intervals of Albian-Cenomanian and Campanian-Maastrichtian.

The distribution of CFC on the guyots is primarily determined by morphology and relief. In general, the CFC are confined to a single structure of a guyot or a needle. The structure of the CFC area is concentric-zonal. The central zone is the vertex surface. Cobalt-bearing manganese crusts are distributed mainly on the top surfaces and slopes of the seamounts. On the slopes there is an alternation of zones with different extents of mineralization, largely confined to uniform bathymetric intervals between 1,500 and 3,000 m and depending on the morphology. The slope of the seamount is the main factor controlling the distribution of CFC mineralization. The maximum thickness of crusts is determined at 10 to 15 cm or more on gentle surfaces devoid of loose sediment coverages along the periphery of vertex plateaus and on weakly inclined surfaces of stepped slopes. On steeper slopes (35—40°), the thickness of crusts decreases significantly (Anokhin et al., 2018). Figure 4.12 shows the thickness of CFC on various guyots of the Magellan seamounts.

Survey results show that most of the seamounts in the waters of the **Marshall Islands** were capped by various amounts of sediment, predominantly foraminiferal sand and ooze. In the Ujlan seamount complex, outcrops on the upper flanks of the seamounts might be dusted with sediment or covered with a thin layer of sediment. Exposed outcrops appear to alternate with sections of sediment-covered outcrops. The exposed outcrops commonly include one or more nearly vertical cliffs several meters to tens of meters high. Outcrops commonly contain sediment ponds (Hein et al., 1990).

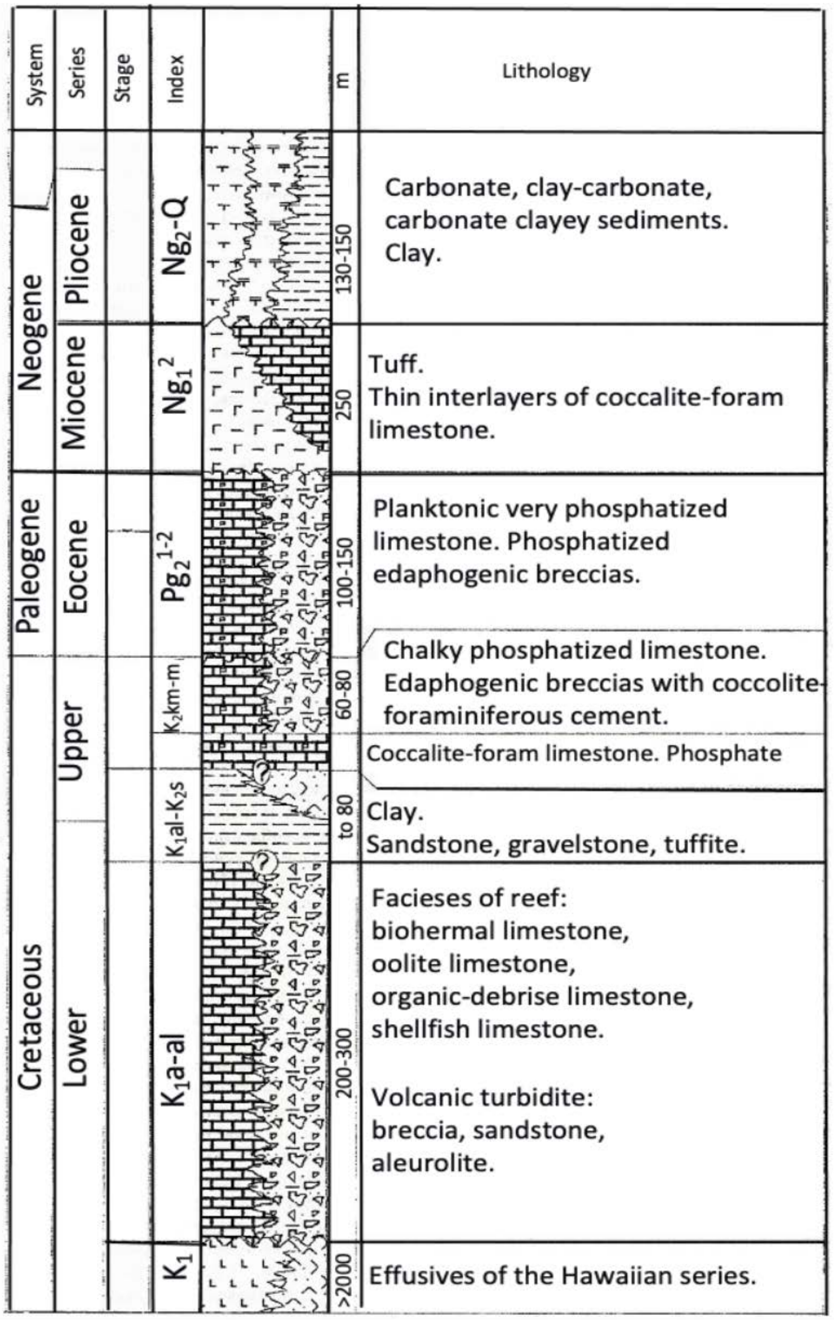

Figure 4.10. Total stratigraphic section of the Magellan Seamounts. Credit Yuzhmorgeology.

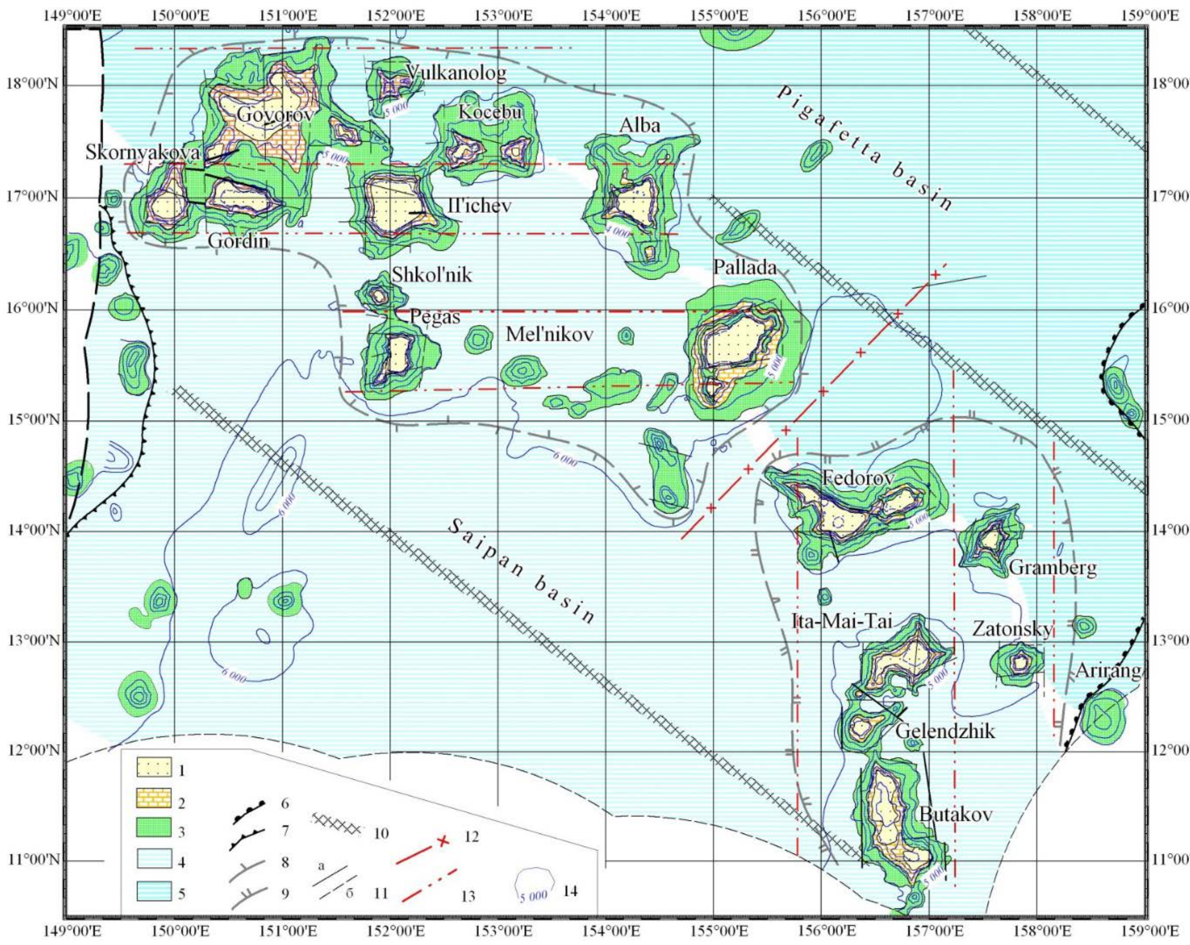

Figure 4.11. Map of stratigraphy, morphological distribution, and tectonic control structural and tectonic of the Magellan Seamounts. Credit Yuzhmorgeology.

Legend: 1 – Pliocene-Quaternary unlithified carbonate sediments; 2 – Sedimentary formations (limestones, breccias, clays, sandstones) of Cretaceous-Neogene; 3 – Tholeiite and alkali-basalt igneous rocks of the lower Cretaceous; 4 - 5 – Tholeyites overlain by Mesozoic-Cenozoic sedimentary cover (4 - Upper Jurassic, 5 - Middle Jurassic); 6 – 9 - Boundaries (6 - Marshall Islands uplifts, 7 - Mariana trench and uplifts system, 8 - Western branch of the Magellan seamounts, 9 - Eastern branch of the Magellan seamounts); 10 - Assumed fault zones of transform nature; 11 – Faults expressed in an anomalous magnetic field (a - negative anomalies, b - positive anomalies); 12 - The centreline of the passage between the Saipan basin and the Pigafetta basin (the structural boundary of the Western and Eastern branches of the Magellan seamounts); 13 – Area of guyot location within the Western and Eastern branches of the Magellan seamounts; 14 - Isobaths every 1000 m.

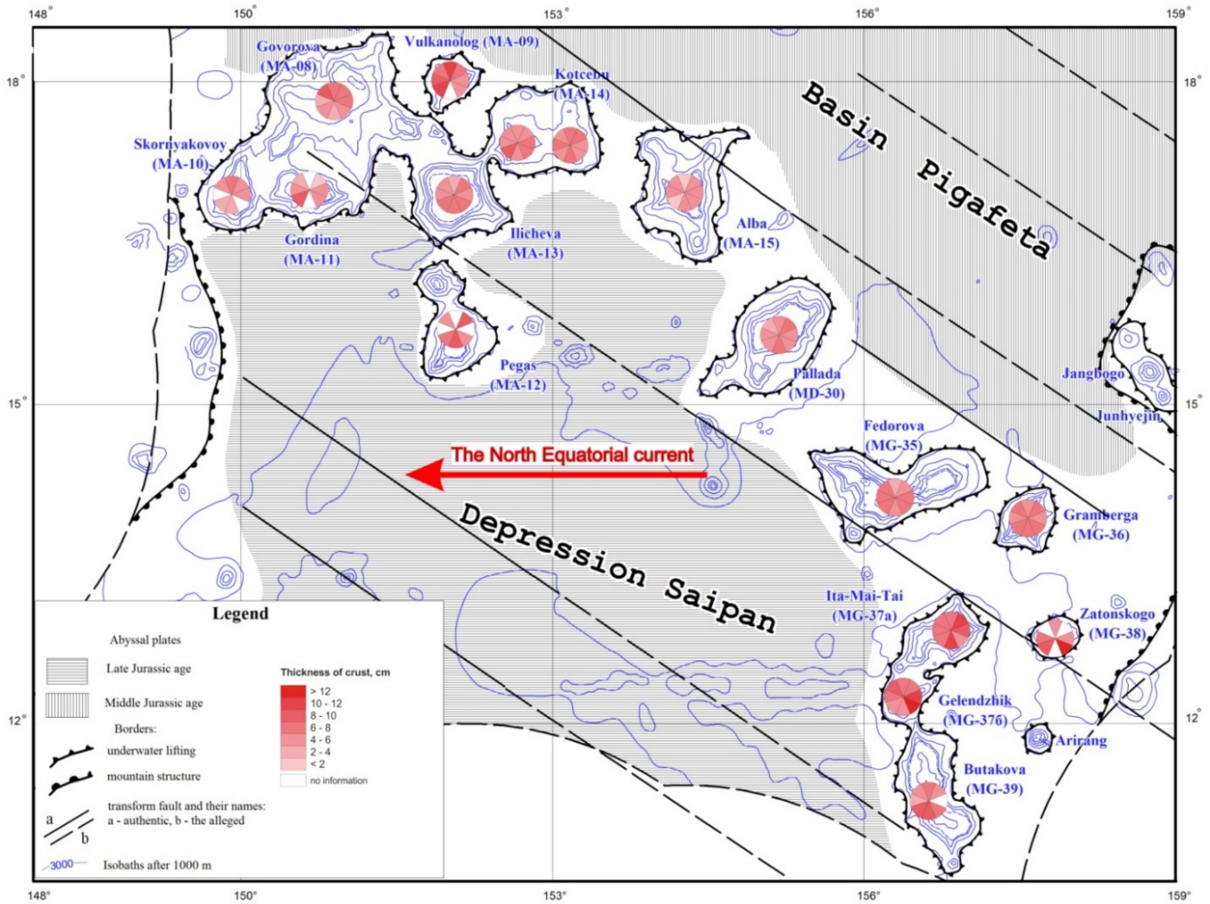

Figure 4.12. Scheme of the thickness of CFC on conical seamounts and guyots of the Magellan Seamounts. Modified from Kruglyakova et al. (2018). Credit Yuzhmorgeology.

4.5 Abyssal plains

The Pacific has the longest oceanic sedimentary record on Earth, spanning from the Jurassic to the Quaternary (Karl et al., 1992). Apart from carbonate deposits on the East Pacific Rise and on top of platforms of guyots and shallow oceanic plateaus in the West Pacific, the North and South Pacific and Pacific gyres form a vast sedimentary basin with slow accumulation of pelagic clay. The rim of the basin is dominated by semi-pelagic clastic sediments, whereas glacial silt deposits predominate in the southern part of the basin. The main sedimentary species are pelagic oozes, clays, and volcaniclastic sediments. GlobSed data from Straume et al. (2019) indicate a heterogeneous distribution of sediment thickness in the Northwest Pacific Ocean (Figure 4.13). For example, sediment thickness in the Pigafetta Basin has a depth of 300–500 m, and sedimentary layers in some basins of the Magellan Seamount region can be ~750 m thick. Deep Sea Drilling Project (DSDP) seismic reflection data for the East Mariana Basin have revealed a sedimentary section at least 1,200 m thick (Whitman, 1986). Dominant surface sediments in the Northwest Pacific Ocean are pelagic clay, calcareous ooze, and siliceous ooze. Pelagic clay is distributed in most areas of the abyssal basin, whereas calcareous ooze is distributed mainly around the Caroline and Marshall Islands (Figure 4.14). The siliceous ooze in the northern part of the East Marina Basin is 100–150 m thick, with a basal middle to late Miocene sedimentary age and an average deposition rate of 1.5–6.0 cm kyr^{-1} (John et al., 1983).

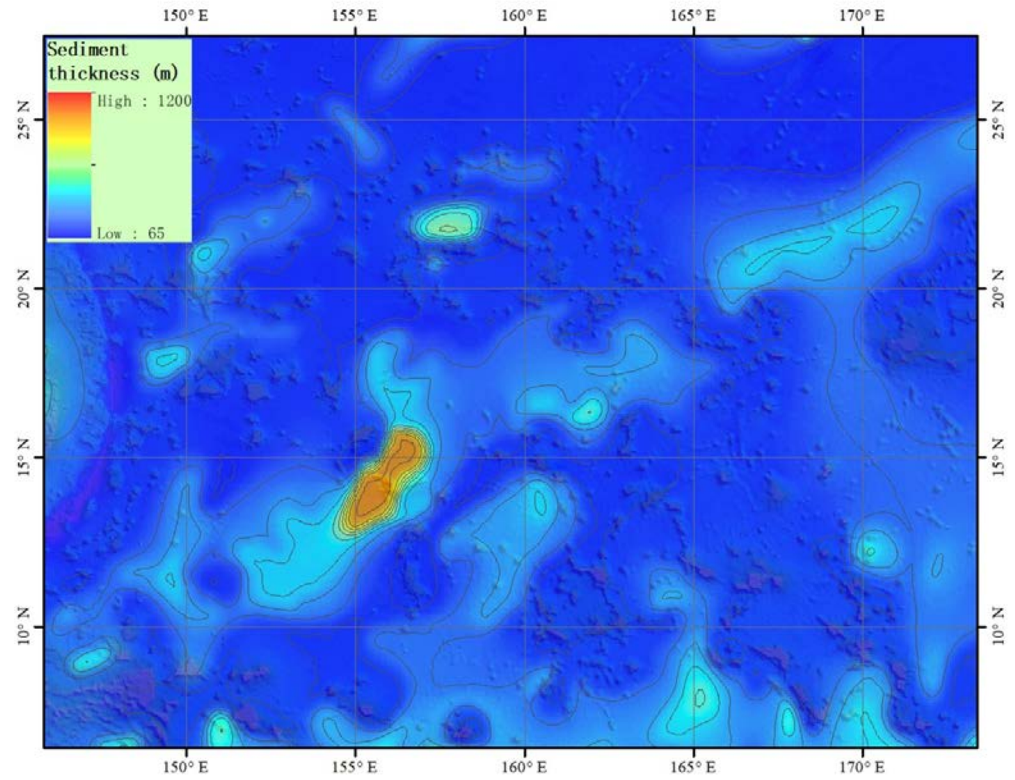

Figure 4.13. Sediment thickness in the Northwest Pacific Basin produced using GlobSed data from Straume et al. (2019). Credit Huaiming Li and Zhenggang Li.

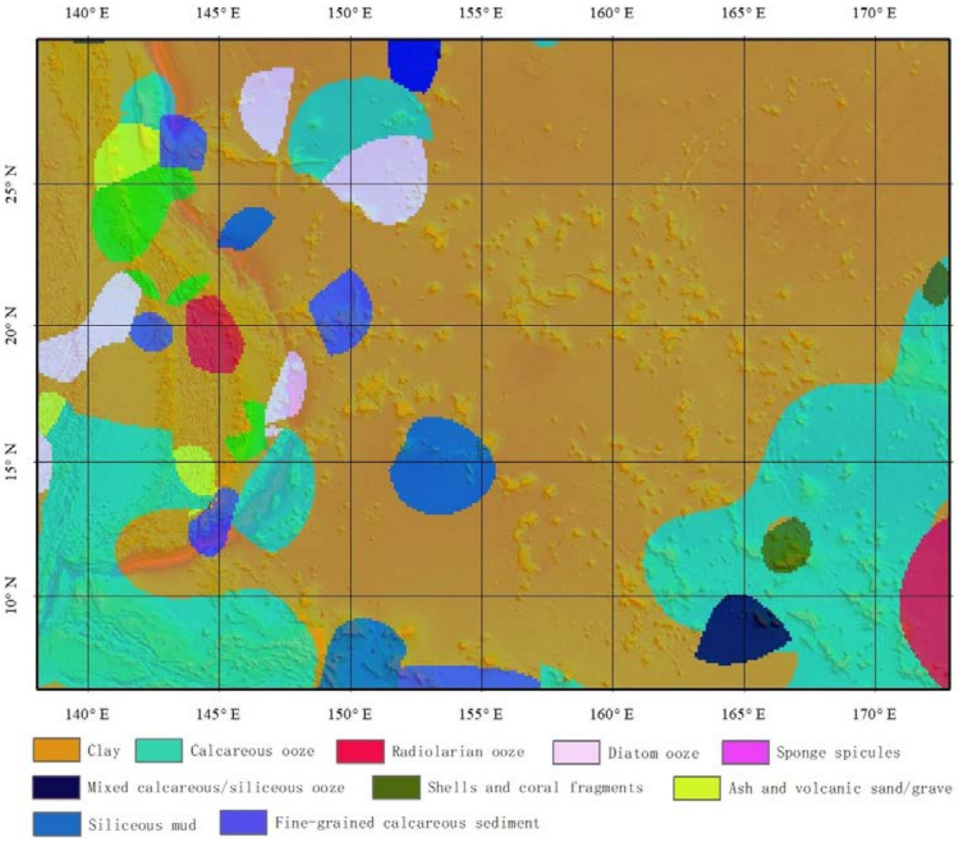

Figure 4.14. Sediment types in abyssal basins of the Northwest Pacific Ocean produced using data from Dutkiewicz et al. (2015). Credit Huaiming Li and Zhenggang Li.

Early Jurassic–Cretaceous sedimentary records are available for many ODP/DSDP drill holes in the Northwest Pacific Ocean, with ODP Leg 129 sites 800, 801, and 802 having penetrated through the sedimentary layer and reached the oceanic crust basement (Karl et al., 1992). Core data of ODP site 801 indicate that Bathonian and Callovian basalts are intermixed with carbonate and metalliferous radiolarian clay, thin lenses of flint, and thick layers of hydrothermal metalliferous quartz. The basalt layer is unconformably overlain by brown radiolarian rocks rich in manganese oxides and of Oxfordian–Valanginian age, including tilted Kimmeridgian strata, bedded middle Tithonian radiolarian chert, and late Berriasian volcaniclastic turbidites. An upper Valanginian hardground terminates the main episode of radiolarite deposition and is overlain by a thick accumulation of volcaniclastic turbidites and breccia of Aptian–Albian age associated with the formation of adjacent seamounts. Cenomanian–Campanian brown chert and porcellanite comprise opals and diagenetic quartz. The top of the core is a 63-m-thick pelagic-clay deposit, comprising mainly clays (smectites), iron oxides/hydroxides, and zeolites (phillipsite) (Karl et al., 1992).

In summary, several stages of sedimentation were involved in the abyssal basins of the Northwest Pacific Ocean. The earliest deep-sea deposition can be traced back to the Callovian–Bathonian (Middle Jurassic), and comprises mainly pelagic clay followed by siliceous ooze. During the Oxfordian to Campanian, the area was dominated by abundant biogenic silica, with volcaniclastic sedimentary discontinuities. From the Cenozoic to the present, pelagic clay has been widely deposited, with relatively small amounts of radiolarian siliceous ooze (Karpoff, 1992). The inclusion of pyroclastic, zeolite, chert, and calcareous sediments in pelagic clay and siliceous ooze indicates a complex sedimentary history. The occurrence of pyroclastic, volcanic ash, and zeolite sediments provides evidence of multi-stage volcanic activity in the region, whilst calcareous sediments indicate that some basin areas have been uplifted (as in intraplate seamount formation) and experienced carbonate deposition over neritic facies.

4.6 Sediment fluxes

According to the ISA environmental guidelines (ISA, 2019: ISBA/25/LTC/6.Rev.1), ‘fluxes to the sediment’ need to be addressed as part of environmental baseline data gathering. In the oligotrophic Northwest Pacific Ocean, the seamount communities are largely dependent on sinking organic matter. Understanding fluxes and composition of sinking particles is fundamental to elucidate how primary production in the surface ocean affects the productivity and biodiversity in seamount communities. Another important aspect is the environmental effect of suspended materials derived from mining activity. For quantitative assessments of sediment plumes and discharge water, natural spatial and temporal variation in sinking particles should be obtained as environmental baseline data. Sediment trap observations are limited in the oligotrophic oceans. It is generally known that the fluxes and seasonal variation of sinking particles in the western North Pacific subtropical gyre are low, reflecting limited primary production throughout the year. However, many basic issues, such as influence of large seamounts, relationships between primary production and particulate fluxes, and export processes from shallow to deep water, have not yet been fully investigated.

Yamaoka et al. (2020) reported the results of sediment trap deployments around three seamounts (Lamont: JA02; Maloney: JA04; and Xufu: JA06) in the Area of the Northwest Pacific (Figure 4.15). At JA04 Seamount a single sediment trap was deployed 23 m above the flat top (water depth 2,257 m) from 8 April 2001 to 18 May 2002. Similarly, a single sediment trap was deployed 23 m above the flat top (water depth 1,600 m) of JA02 Seamount from 5 August 2006 to 31 July 2007. At JA06 Seamount, the sediment trap experiments were conducted on the flat top and the northeastern base of the seamount from 7 June 2016 to 21 April 2017. Each mooring system had double sediment traps. On the flat top, traps were deployed at water depths of 900 and 1,000 m, whereas they were deployed at water depths of 1,000 and 4,720 m at the base. Figure 4.16 shows seasonal variation in the total mass fluxes at shallow traps from these three seamounts. The results showed similar low total mass fluxes (4.3 to 9.3 mg m^{-2} d^{-1} on annual average) with a strong peak in late summer (August – September). These total mass fluxes were the lowest level amongst reported sediment trap observations in the global ocean, reflecting oligotrophic conditions.

At OSM07 seamount, the Korea Institute of Ocean Science and Technology has operated a mooring station at 16°50′N, 152°20′E (Kim et al., 2018). Time-series sediment traps were operated at three depths (400 m, 690 m, and 1,710 m) from August 11 to September 30 in 2015 at Station CR15 (water depth 2,210 m). Kim et al. (2018) reported that total mass flux at the 400 m water depth varied between 4 and 16 mg m^{-2} d^{-1}, with an average of 9.1 mg m^{-2} d^{-1}. A mean total mass flux of 4.8 mg m^{-2} d^{-1} was reported from the western Pacific below the North Equatorial Current (Kempe and Knaack, 1996), and is comparable to mass fluxes reported by Yamaoka et al (2020) and Kim et al. (2018). Kawahata et al. (2000) also observed a similar mean total mass flux of 13.2 mg m^{-2} d^{-1} in the western Pacific under influence of the Equatorial Counter Current. However, seasonality was not observed in these previous wester Pacific studies (Kempe and Knaack, 1996; Kawahata et al., 2000).

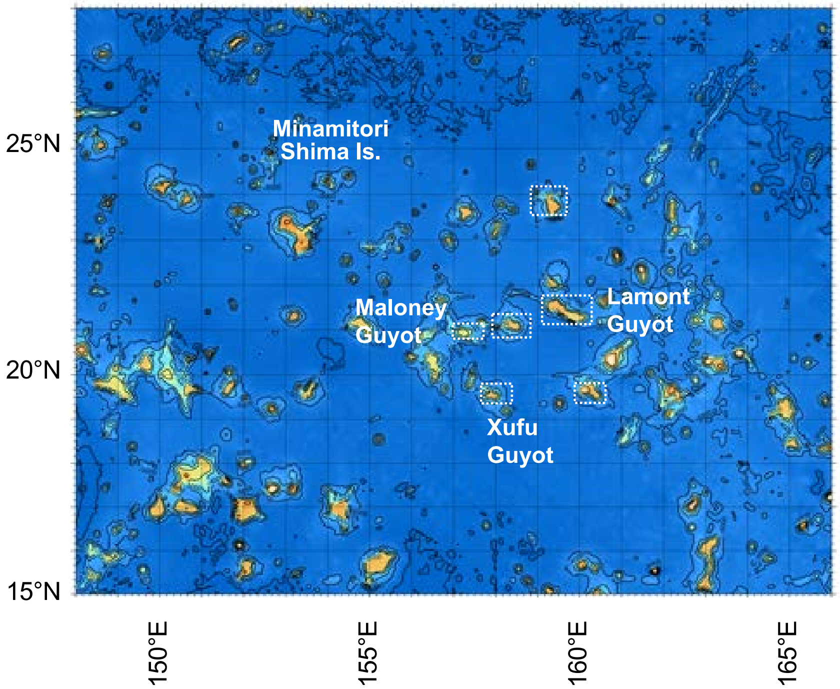

Figure 4.15. Map of Japan's exploration area for cobalt-rich ferromanganese crusts. Modified from Yamaoka et al. (2020).

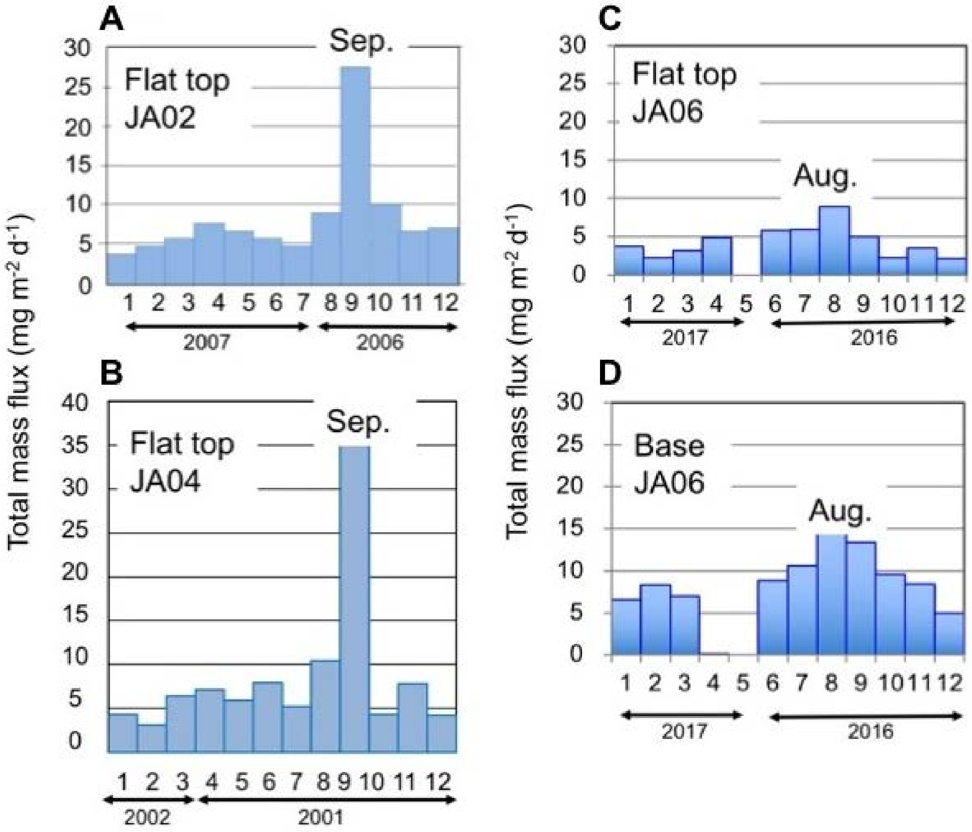

Figure 4.16. Seasonal variations in total mass fluxes at shallow sediment traps on the (A) JA02: Lamont Seamount; (B) JA04: Maloney Seamount; and (C, D) JA06: Xufu Seamount. Reproduced from Yamaoka et al. (2020).

Analyses of chemical composition was carried out for the sinking particles at JA06 Seamount by Yamaoka et al. (2020). Figure 4.17 demonstrates the constituents of particulate fluxes collected at four sediment traps from the flat top and the base of JA06 Seamount. The sinking particles mainly consisted of carbonate, which is characteristics for a warm open ocean setting. The mean fluxes of organic matter, carbonate, biogenic opal, and lithogenic matter ranged from 0.5–1.7, 3.7–5.7, 0.1–1.5, and 0.4–1.4 mg m^{-2} d^{-1}, respectively. The seasonal variations of organic matter fluxes corresponded to those of total mass fluxes, suggesting enhanced primary productivity in late summer. In contrast, the seasonal variation of satellite-based net primary production (NPP) was at a minimum during summer (See section 5.2.5.1: Satellite-data analysis of sea surface productivity).

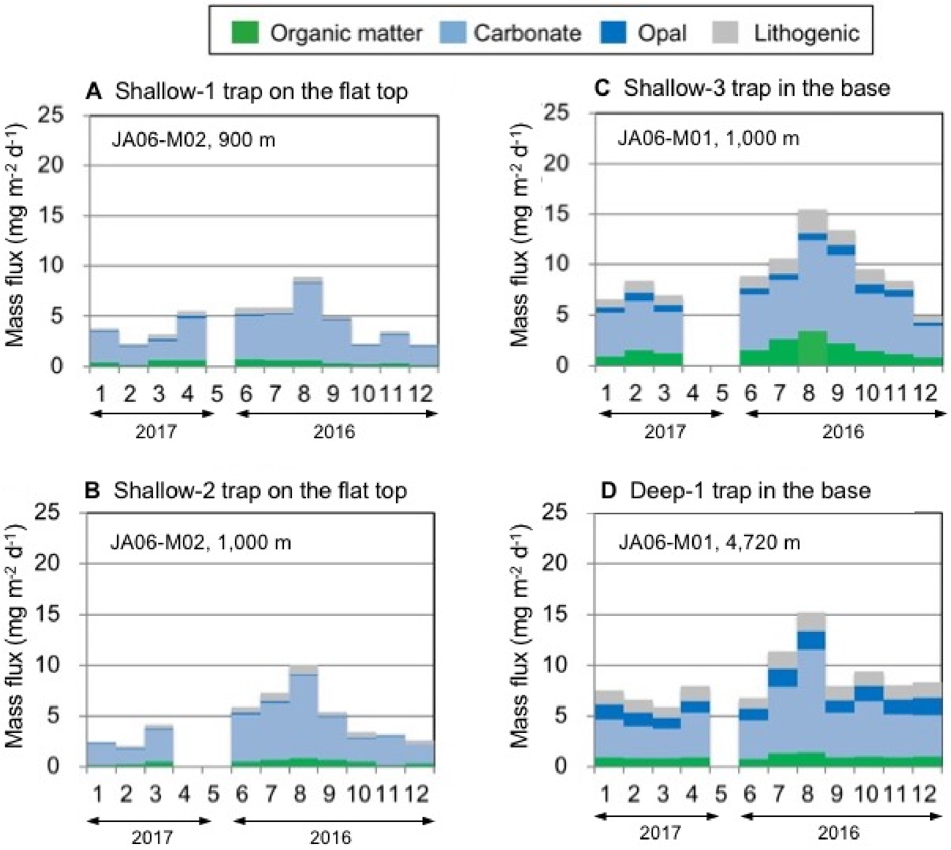

Figure 4.17. Fluxes of organic matter, carbonate, opal, and lithogenic elements from June 2016 to April 2017 at four sediment traps around JA06 (Xufu) Seamount. Reproduced from Yamaoka et al. (2020).

Yamaoka et al. (2020) interpreted the discrepancy between organic matter fluxes and NPP to result from short-lived or subsurface blooms induced by passing typhoons. Typhoon-induced phytoplankton blooms have been well studied, especially in the South China Sea (Sun et al., 2010; Lin, 2012; Ye et al., 2013; Zhao et al., 2015; Liu and Tang, 2018; Wang et al., 2020). The intense winds of a typhoon are thought to lead to strong vertical mixing and upwelling of nutrients, although some additional factors (e.g., transient time, ocean eddies) are needed. According to the National Oceanic and Atmospheric Administration (NOAA) historical hurricane track records, typhoons frequently pass through the studied area in late summer. In addition to the local and short-lived nature of typhoon-induced blooms, the heavy cloud cover would make it difficult to detect the ocean surface data by satellite. Another possible cause for the discrepancy is subsurface phytoplankton blooms. In the studied area, a subsurface chlorophyll *a* maximum (SCM) was observed at 125 m water depth (See section 5.3.2.1: Ocean chemistry at seamounts). Such subsurface blooms may be stronger and last longer than the surface blooms occurring after the passage of a typhoon (Ye et al., 2013; Pan et al., 2017). Such subsurface responses would not be visible via satellite.

The total mass flux at the base of JA06 Seamount was approximately twice the size of that occurring at the top of the seamount, and the sinking particles at the base of the seamount had elevated Opal/carbonate and C_{org}/C_{inorg} ratios. These observations suggest differences in the primary production systems (both activity and community) between the top and base of the seamount. However, it is still unclear whether this is representative of typical conditions. Previous studies have proposed a ‘seamount effect’, in which local upwelling caused by circular currents at the seamount summit can boost primary production, which is contrary to the observations of Yamaoka et al. (2020). Further studies are needed to elucidate the patchy productivity and export fluxes around seamounts in the oligotrophic ocean.

Yamaoka et al. (2020) investigated the vertical transport of sinking particles at the base site of JA06 Seamount. From depths of 1,000 to 4,720 m, the flux of organic matter declined from 1.7 to 0.9 mg m^{-2} d^{-1}, whereas the flux of carbonates decreased from 5.7 to 4.9 mg m^{-2} d^{-1}. Assuming settling speeds of 160–200 m d^{-1} (e.g., Takahashi, 1986), half of the organic matter was decomposed within 19–23 days. In contrast, more than 85% of carbonate was transported without dissolution, despite the local carbonate compensation depth occurring at 4,000–4,500 m (Pälike et al., 2012). This outcome would result from slower dissolution rates of carbonate minerals relative to the sinking speed of settling particles. However, seabed samples from the base of the seamount consist of pelagic clay with low carbonate content, suggesting that most of the biogenic materials in sinking particles should be dissolved and/or decomposed mainly near or on the sediment surface.

Elemental analyses of sinking particles demonstrated that elemental fluxes in the area are controlled by four major processes: lithogenic (Al, Ti, Fe), carbonate (Mg, Ca, Sr), biogenic (+scavenging) (Ni, Zn, Cd, Pb), and scavenging (V, Mn, Co, Cu, rare earth elements). To separate from lithogenic origin, the relationships between Al and trace element fluxes are plotted and compared to the average composition of the upper continental crust (Figure 4.18). Amongst the elements that deviated from the slope of upper continental crust, Ni, Zn, Cd, and Pb in the shallow traps showed large variations resembling P. These observations are consistent with the previous studies suggesting nutrient-like behavior for these elements and their association with fluxes of organic materials (Schüßler et al., 1997; Kuss and Kremling, 1999; Pohl et al., 2004; Kuss et al., 2010). On the other hand, the regressions of V, Mn, Co, Cu, and ΣREE showed continuous correlations with Al in the shallow and deep traps. This suggests that scavenging onto lithogenic materials is the primary process for these elements. Although scavenging behaviors of these elements are well known, excess fluxes in sinking particles have never been detected except for Mn due to significant input of lithogenic materials. In the pelagic ocean, these metals in seawater would be scavenged onto suspended fine aluminosilicate (i.e., clay minerals) and then incorporated into sinking particles. Based on the estimated excess fluxes, more than 85% of total Mn, Co, Ni, Cu, Zn, Cd, and Pb fluxes were attributable to scavenging (+biogenic uptake) processes. Such scavenging-dominant metal flux seems to be ubiquitous in the oligotrophic open ocean.

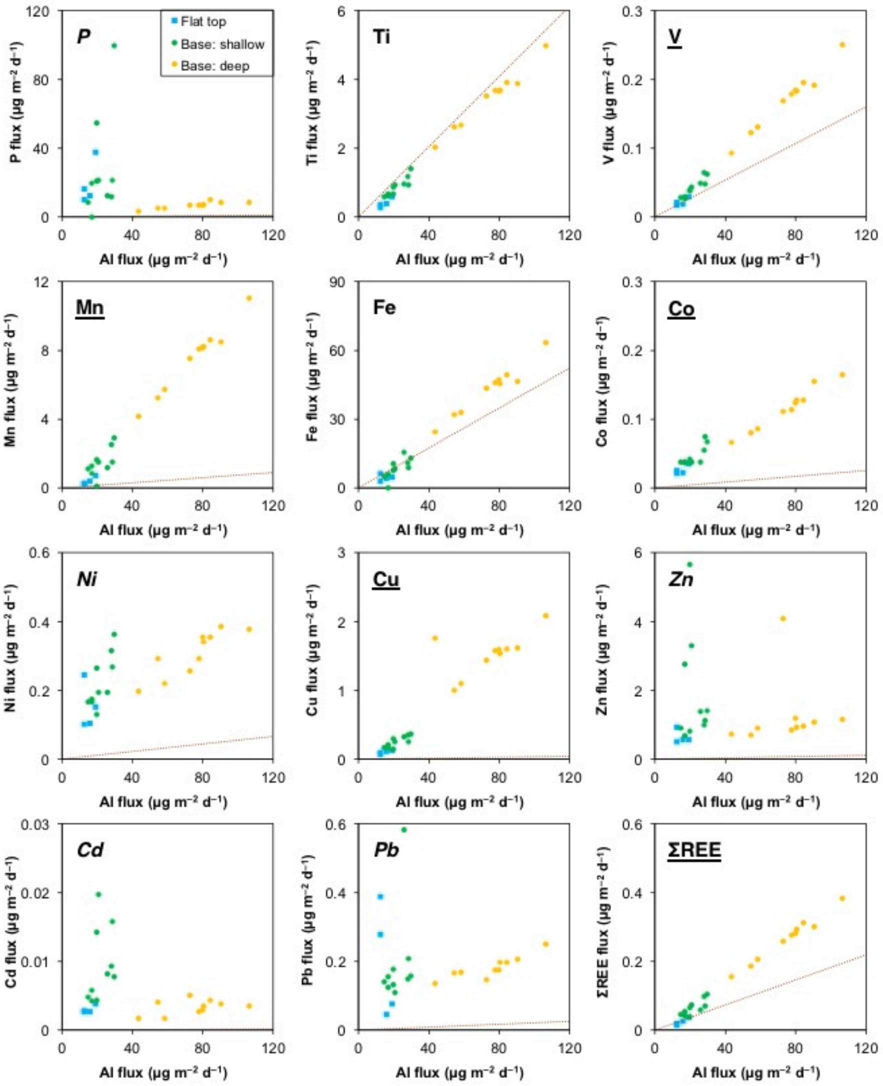

Figure 4.18. Correlations between trace element and Al fluxes in the sinking particles from JA06 (Xufu) Seamount. Dashed lines indicate average ratios of upper continental crust from McLennan (2001). Bold, italic, and underlined element names indicate the classifications of lithogenic, biogenic, and scavenging, respectively. Reproduced from Yamaoka et al. (2020).

4.7 Other geomorphological features

The Magellan seamount chain consists of a western and an eastern province. The boundary between the provinces is drawn between the Pallada and Fedorov guyots. The guyots of the western province have mainly isometric or oval bases, the guyots of the eastern part are angular in shape, with numerous variable morphologies. In the eastern province, there is a gradual increase in the depths of the vertex plateau of the guyots from north to south. The edge plateau of the Fedorov guyot on the western peak has an average water depth of 1,750 m, Ita-May-Tay of 2,000 m, Gelendzhik of 2,300 m and Butakov of 2,700 m. On the Gramberg guyot, as well as in the eastern area of the Fedorov seamount, the tip occurs at depth of 1,500 m. This feature can be a reflection of the isostatic equilibrium of the position of the guyots. There is a distinct division of the western and eastern provinces according to the depths of the intervening basins. In the area of the western province the depths of the basins range from 5,700 to 5,850 m, and in the eastern province from 5,800 to 6,000 m. The forms of the individual guyots are diverse ranging from simple, in the form of a truncated cone, to very complex edifices, including multiple constructive events. The most complex form is exhibited by Govorov guyot, which combines the main body, large satellite structures, and numerous complicating large spurs and protrusions. Dual forms also exist that combine two similar structures (Kocebu, Fedorov).

The bases of the guyots are located at depths between 5,100 and 5,600 m, in the southeast part down to 5,900 m. The morphology of the base is different ranging from relatively regular (Pegas) to irregular rugged shapes (Govorov, Fedorov, Ita-Mai-Tai). The area of the bases covers 1,600 to 15, 000 km^2. The vertex plateaus of the guyots of the Magellan seamount chain are located at depths between 1,400 and 2,600 m. The plateaus are represented by subhorizontal and flat-inclined surfaces (0-2°), the contours of which generally reflect the shape of the base. The areas of the vertex surfaces are from 37 km^2 (Vulcanolog) to 3,650 km^2 (Govorov) in size. The central parts of the peaks are more often aligned and covered by a continuous cover of loose carbonate sediments. Slopes up to 5° are marked along the periphery of the vertex surfaces, where the bedrock is exposed. The vertex surfaces locally show a dome-shaped profile. The vertex plateaus and domes are often modified by ramparts and hollows, ledges, and groups of volcanic conical or dome-shaped edifices. The relative heights of the semounts are 3,900 to 5,000 m. The slopes of the guyots have the greatest steepness with 20°to25° or even more in its upper part, near the edge of the vertex plateaus (depth from 1,600 to 2,600 m). In the central parts (depth between– 2,600 and – 4,000 m) the steepness decreases to 10—15°. At the base of the guyot, at depths between– 4,000 and– 5,600 m, the slopes are shallow (2°—8°). The transition to the regional plain is defined by arch bends at depth from 5,000 to 5,600 m. All the seamounts show complex morphologies including spurs, collapse areas, satellites, and volcanic edifices. The largest satellite edifices were observed at the Govorov, Pallada, Alba and Fedorov guyots. Spurs are defined as narrow ridges that extend 10 to 40 km from the slopes of the seamounts. The collapse areas are 1-2 km to 10-15 km in length and have incisions of 25 – 50 m. Most of the troughs are formed by bottom water currents. Slopes are often complex and show multidirectional ledges with a length from 1 – 2 km up to 15 – 30 km, with amplitudes of 25 to 350 m, sometimes clearly of tectonic origin. Slopes show radial grabens, which are trapezoidal subsidence structures 3-6 km × 0.6-0.8 km in size. These structures are formed due to the slipping of blocks from the edge portions of the vertex plateau. Volcanic edifices are developed on vertex plateaus and slopes; sometimes their number reaches several tens and even hundreds on one mountain. They often form straight lines and shafts (Govorov, Fedorov, and Ita-Mai-Tai guyots). The age of these edifices ranges from the Santonian to the Middle Miocene and Pliocene (Anokhin et al., 2018).

Fracture zones (FZs) have a complex distribution in the Northwest Pacific, with most lying perpendicular to isochronous or magnetic lineation, oriented mainly NW–SE and NE–SW (Figure 4.1), subparallel to the Marcus–Wake, Magellan, and Marshall Island seamount chains reflecting the complex tectonic evolution of the region. The FZs in the eastern Pacific are regularly distributed due to effects of seafloor spreading and spatial distribution of the FZs could be identified using satellite altimetry and gravity-anomaly data (Wessel et al., 2015). However, the FZs in the Northwest Pacific could only be inferred from striped magnetic anomalies or high-resolution bathymetric data owing to the thick sediment overlay. Nakanishi et al. (1992) identified 61 FZs in the Northwest Pacific, including the Ogasawara, Kashima, South Shatsky, Waghenaer, and Phoenix FZs, which reflected major tectonic events, such as changes in seafloor spreading direction and lithospheric subsidence. For example, the difference of the fault strike in the Kashima FZ indicated spreading direction of the ancient Pacific–Izanagi Ridge changing from N45°E to N70°E. The strike of the South Shatsky FZ is oblique rather than perpendicular to the striped magnetic anomaly, which indicates that the FZ is not a transformation fault, but an oceanic trough formed by ridge propagation (Nakanishi, 1993). Since the FZs were formed prior to intraplate volcanism, weakening of the lithosphere along a FZ could promote eruption of mantle-derived magma, thus controlling seamount distribution to an extent. There are many seamounts between Ogasawara FZ-1 and FZ-3 with more consistent ages than that of the oceanic crust, possibly due to eruptions along the FZ over a limited timescale. This may also explain why the Northwest Pacific seamounts do not display age-progressive features observed elsewhere, such as those of the Hawaiian Islands.

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5 Oceanography of the Northwest Pacific Ocean

5.1 Overview

This chapter aims to provide an overview of oceanography of the Northwest Pacific region. Information compiled in this chapter covers the following topics:

- **Regional circulation pattern** (section 5.2.1), including at the surface, in the intermediate layer and deep water.
- **Spatial distribution of mesoscale eddies** (section 5.2.2), based on satellite altimeter data.
- **Distribution of physical water properties** (section 5.2.3), based on studies conducted on individual seamounts.
- **Local flow environment** (section 5.2.4) based on detailed field and modelling studies conducted at the Lamont and Caiwei seamounts.
- **Temporal and spatial variability** (section 5.2.5) in sea surface productivity based on satellite measurements.
- **Distribution of chemical water properties** (section 5.3.1) with a focus on nutrients.
- **Local chemical environment** (section 5.3.2) based on studies conducted on an individual seamount.

Considering that there is a long history of oceanographical studies in the North Pacific Ocean, significant information gaps remain in this chapter, in particular for physical and chemical water properties, and temporal and spatial variability in oceanographical conditions. These oceanographic properties affect ecosystem processes and the distribution of biodiversity in the Northwest Pacific region (See Chapter 6: Biology of the Northwest Pacific Ocean).

5.2 Physical oceanography

5.2.1 Regional circulation

Surface currents can link to form gyres, which are large areas defined by the currents flowing in a circular pattern. The Northwest Pacific Subtropical Gyre is the one of the largest biomes on earth, covering a semi-enclosed surface area of about 2×10^7 km^2 (Karl and Church, 2017). The gyre moves clockwise and comprises four prevailing ocean currents: the North Pacific Current to the north, the California Current to the east, the North Equatorial Current to the south, and the Kuroshio Current to the west (Yu et al., 2019; Figure 5.2.1).

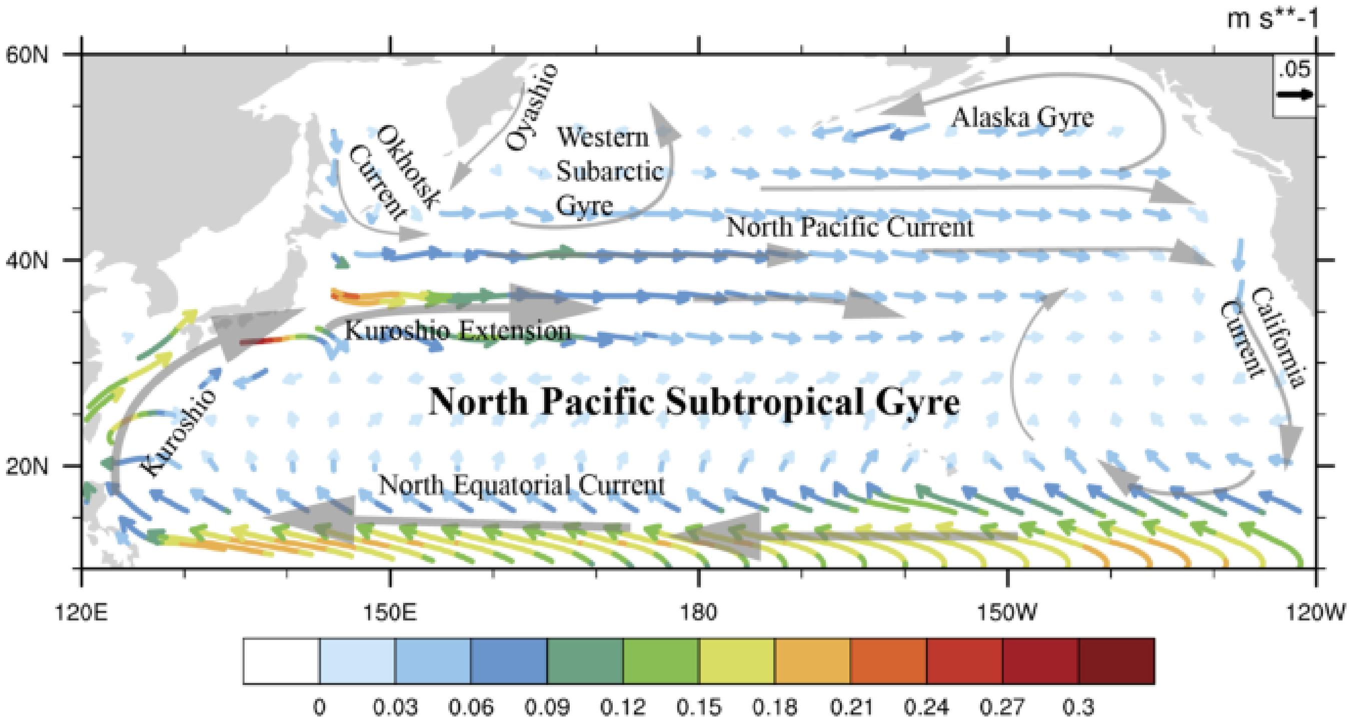

Figure 5.2.1. General circulation in the North Pacific showing the North Equatorial Current, Kuroshio, Kuroshio Extension, California Current, Alaska Gyre and Western Subarctic Gyre. The coloured arrows denote the climatology of the surface ocean current velocity over the period 2003–2017, using data from the European Centre for Medium-range Weather Forecasts Ocean Reanalysis System 4 (ORAS4, http://icdc.cen.uni-hamburg.de/thredds/aggregationOras4Catalog.html). This figure was generated using the NCAR Command Language (version 6.4.0) [Software]. (2017). Boulder, Colorado: UCAR/NCAR/CISL/TDD. https://doi.org/10.5065/D6WD3XH5. Reproduced from Yu et al., (2019).

Nutrient-poor, well-ventilated North Pacific Intermediate Water (NPIW) occupies depths of 300–2000 m in the northwest Pacific (Korff et al., 2016), and is sourced from the Okhotsk Sea outflow and western subpolar gyre (You, 2003). Below the NPIW is the North Pacific Deep Water (NPDW), which is sourced from cold water from the Lower Circumpolar Deep Water (LCDW) supplied by the Southwest Pacific Deep Western Boundary Current (DWBC). The DWBC reaches the North Pacific through the Samoan Passage (Korff et al., 2016). There are two branches of deep circulation in the topographically complex Northwest Pacific region: an eastern branch flowing northward through Wake Island Passage, and a western branch flowing through the East Mariana Basin at low latitudes (Figure 5.2.2).

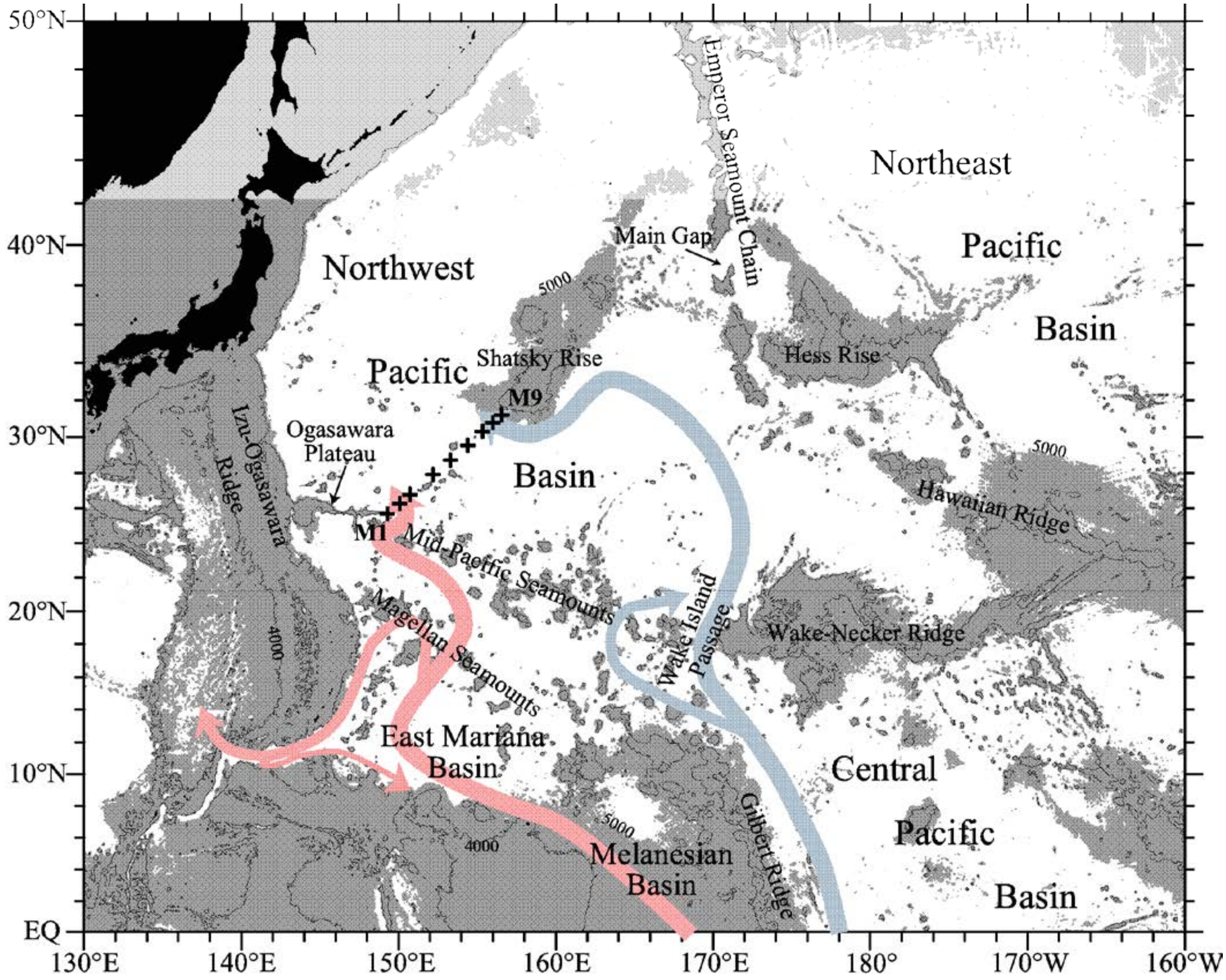

Figure 5.2.2. Deep water circulation in the Northwest Pacific. The red arrow indicates the eastern branch, and the blue indicates the western branch of deep-water circulation. Reproduced from Yanagimoto et al. (2010).

5.2.2 Spatial distribution of mesoscale eddies in the Northwest Pacific region

Based on satellite altimeter data from 1993 to 2017, the temporal and spatial distribution of mesoscale eddies in the seamount areas in the Northwest Pacific is shown in Figure 5.2.3. Based on the analysis of satellite data, there were more mesoscale eddies (both cyclone and anti-cyclone) in the northern part of the region. The mesoscale eddies influenced the northern and southern part of the study area on 60% and 20% of the total number of days, respectively.

Results of the statistical analysis of long-term cyclone and anti-cyclone eddies are shown in Figure 5.2.4, with a similar band distribution in latitude, also showing a greater number of eddies in the northern part of the region. Based on the data provided at the AVISO website[8] for the period 1 January 1993 – 18 January 2018, mesoscale eddies in western Pacific seamounts have low activity, with a frequency of only 10-20%. The polarity of mesoscale

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[8] www.aviso.sltimetry.fr

eddies reached a maximum at around 18°N, indicating that there are more active anti-cyclone eddies in this part of the region. Theoretically, the anti-cyclone eddies can influence the deeper ocean, thus, the deep flat-topped seamounts are more likely to be affected by anti-cyclone eddies. Considering the amplitudes and orbitial velocities of cyclone and anti-cyclone eddies, there is a similar latitudinal band of distribution, with all amplitudes in the range of 4-10 cm and orbital velocities of 16-28 cm s^{-1}. The spatial distribution pattern of mesoscale eddies is unclear, and the influence of mesoscale eddies on the seamounts is still unknown.

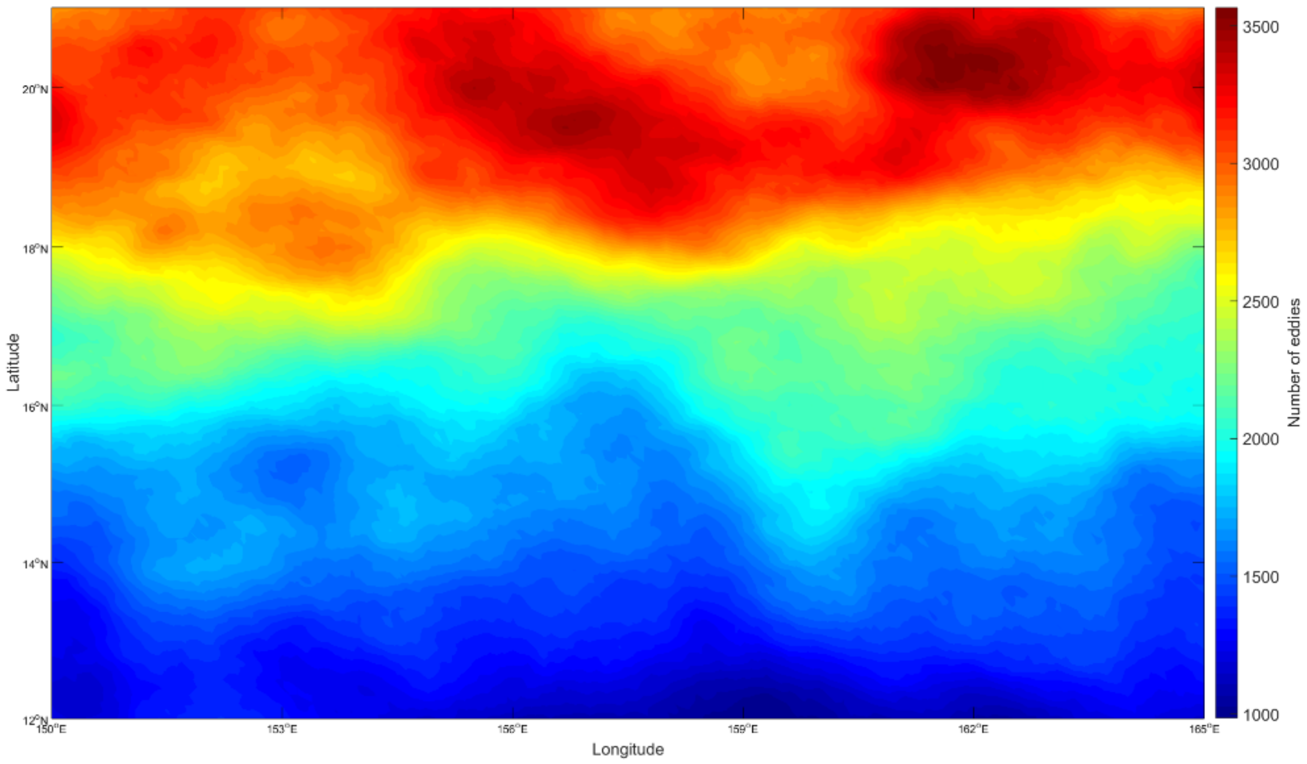

Figure 5.2.3. Statistical analysis of mesoscale eddies occurrence in the Northwest Pacific seamount region.

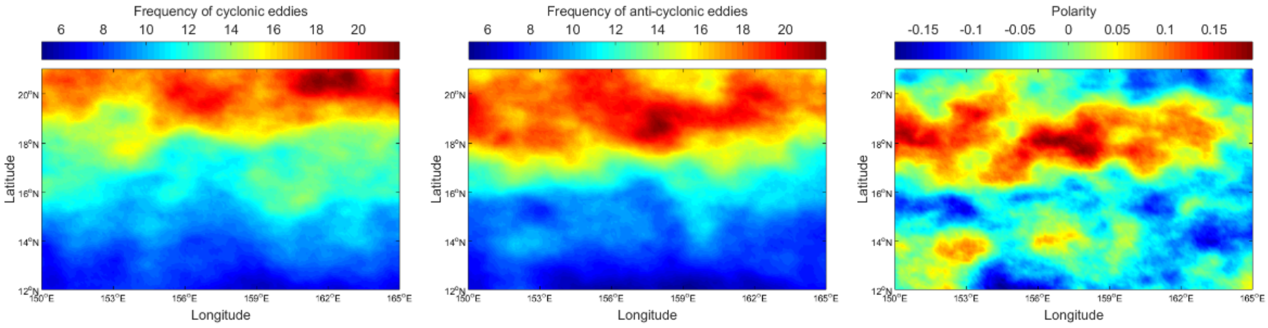

Figure 5.2.4. Frequency of cyclone (fc; left) and anticyclone (fa; centre) occurrence and its polarity (defined as (fa-fc)/(fa+fc); right).

5.2.3 Distribution of physical water properties

Detailed studies have been conducted within exploration areas on physical water properties. The following section provides results from the Caiwei seamount; further information on temperature and salinity from other seamounts is also provided under section 5.3.

At Caiwei seamount, as shown in Figure 5.2.5, water temperature near the sea surface is relatively high, with a single thermocline structure. Below the mixing layer to a depth of about 400 m, there is a large vertical temperature gradient. The temperature profile in the middle and deep layers is affected by ocean circulation. From the lower boundary of the climatic layer to the depth of 2000 m, the temperature decreases rapidly with depth to 2.17 ~ 2.30 ℃. Below 2000m depth, the temperature remained low.

The mean salinity of the surface seawater is around 35.0 psu, high-salinity water (35.2-35.3 psu) appeared in the subsurface within the depth of 200 m; a negative halocline appears at a depth of 200 m, and medium-low salinity water (34.2 psu) appears at about 450 m depth. A second positive halocline is present, with the salinity gradually increasing to 34.7 psu around 2000m depth.

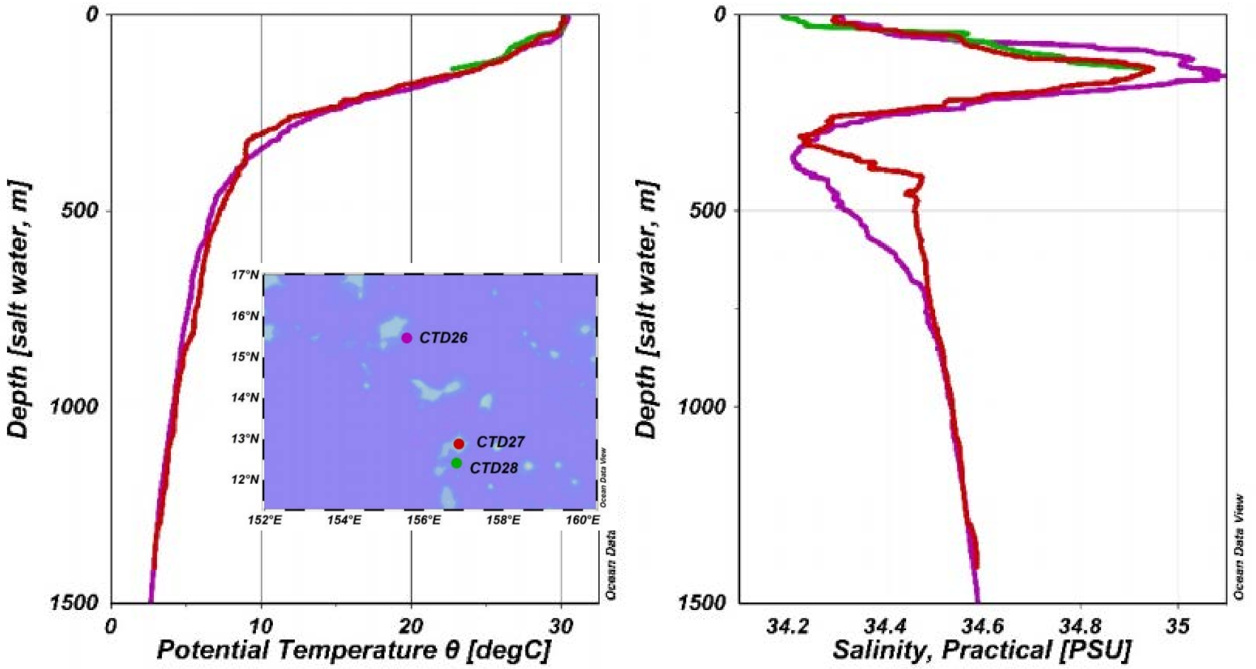

Figure 5.2.5. Typical vertical profile of temperature (left) and salinity (right) near Caiwei Seamount obtained by CTD (COMRA DY56 cruise report). Credit Jun Wang.

5.2.4 Local flow environment

5.2.4.1 Current flow at the **Lamont seamount** in the JOGMEC exploration area

The ISA environmental guidelines (ISA, 2019: ISBA/25/LTC/6.Rev.1) require the collection of physical oceanographic data in order to assess natural baseline conditions and evaluate the potential extent and influence of any operational and discharge plumes. Thus, current velocity is measured in exploration areas to support environmental impact assessments. Acoustic doppler current profiler (ADCP) instruments are commonly used for this purpose. For example, Furushima and Yamamoto (2015) found periodic behaviour of deep-sea currents using a bottom-mounted ADCP with the frequency of 300 kHz in the Hatoma Knoll hydrothermal vent field in the Okinawa Trough. ADCP measurements are more difficult to obtain in the abyssal zone compared with coastal areas because of insufficient acoustic backscatter due to low density of suspended matter. As Furushima and Yamamoto (2015) described, measuring currents with the ADCP was impossible 60 m above the seafloor due to the extremely clear and low-turbidity seawater, except in the case when high backscatter was observed. According to Furushima and Yamamoto (2015), the detection of this high backscatter by the ADCP indicates the movement of a water mass with a high concentration of particles, possibly originating from the hydrothermal vent field.

ADCP measurements of velocity need to be validated through an appropriate method. The following section discusses a case study of ADCP measurements on a seamount, including subsequent validation of ADCP data.

Nagao et al. (2018) conducted velocity measurements using a mooring system with ADCPs mounted near the seafloor on the flat top of Lamont seamount (also known as JA02 seamount) in the Northwest Pacific Ocean (159° 48´ E; 21° 19´ N; water depth, 1583 m), within Japan’s contract area for cobalt-rich ferromanganese crusts (ISA, 2013). The period of observation was from 5 October 2011 to 22 November 2012. Four Workhorse (WH) ADCPs (Teledyne RD instruments) were mounted on the mooring system to measure the current above the flat top of the seamount: three WH 300 kHz and one WH 1200 kHz ADCP. One 300 kHz ADCP failed to record data because of equipment failure; therefore, data were retrieved from the other two 300 kHz and the 1200 kHz ADCPs. The 300 kHz ADCPs were deployed at 73 m and 13 m above the seafloor facing upwards. The 1200 kHz ADCP was deployed at 13 m above the sea bottom facing downwards. The 300 kHz ADCPs had 20 depth cells, each with a size of 4 m, and the 1200 kHz ADCP had 15 depth cells, each 1 m in size. The lengths of deployment for the 300 kHz ADCPs were 9 and 8 months, and that of the 1200 kHz ADCP was approximately 400 days (13 months). The following discussion is based on the data of first to fourth layers of WH 1200 kHz ADCP acquired from 5 October 2011 to 22 November 2012.

To check the status of data acquisition, Nagao et al. (2018) defined the data acquisition rate (P_i) as follows:

$$P_i = m_i/N_\mathrm{i},$$

where i is the layer number, and P_i, m, and N_i are the acquisition rate, the number of non-zero velocity data, and total number of velocity data, respectively, in the i-th layer. The resultant data acquisition rates varied widely amongst the observation layers (Table 5.2.1). Additionally, there were significant differences in the acquisition rate, even amongst adjacent layers. Thus, there were concerns about the reliability of the ADCP data, even when the acquisition rate exceeded 50 %.

Table 5.2.1. ADCP data acquisition rate for WH 1200 kHz. Layers with data acquisition rate > 50 % are shaded in grey, the depth of the mooring system with ADCP was 1583 m. Adapted from Nagao et al. (2018).

Observation condition	**Height from bottom (m)**	**Layer number**	**Layer depth (m)**	**Data number**	**Data acquisition rate (%)**
Expected data number: 20153 Depth: 1529.8 m Installation direction: down	11.64	1	1571.4	19882	98.7
	10.64	2	1572.4	19883	98.7
	9.64	3	1573.4	19882	98.7
	8.64	4	1574.4	13113	65.1
	7.64	5	1575.4	2360	11.7
	6.64	6	1576.4	522	2.6
	5.64	7	1577.4	19822	98.4
	4.64	8	1578.4	1529	7.6
	3.64	9	1579.4	16	0.1
	2.64	10	1580.4	4	0.0
	1.64	11	1581.4	4	0.0
	0.64	12	1582.4	1018	5.1
	-0.36	13	1583.4	12424	61.6
	-1.36	14	1584.4	19768	98.1
	-2.36	15	1585.4	197	1.0

The magnitudes of horizontal velocities (Figure 5.2.6) decreased with increasing distance from the ADCP. However, the magnitudes of velocity in the first layer did not always appear reasonable. This problem could be attributed to insufficient blanking distance of the ADCP, where measurements can be influenced by ultrasonic signal interference.

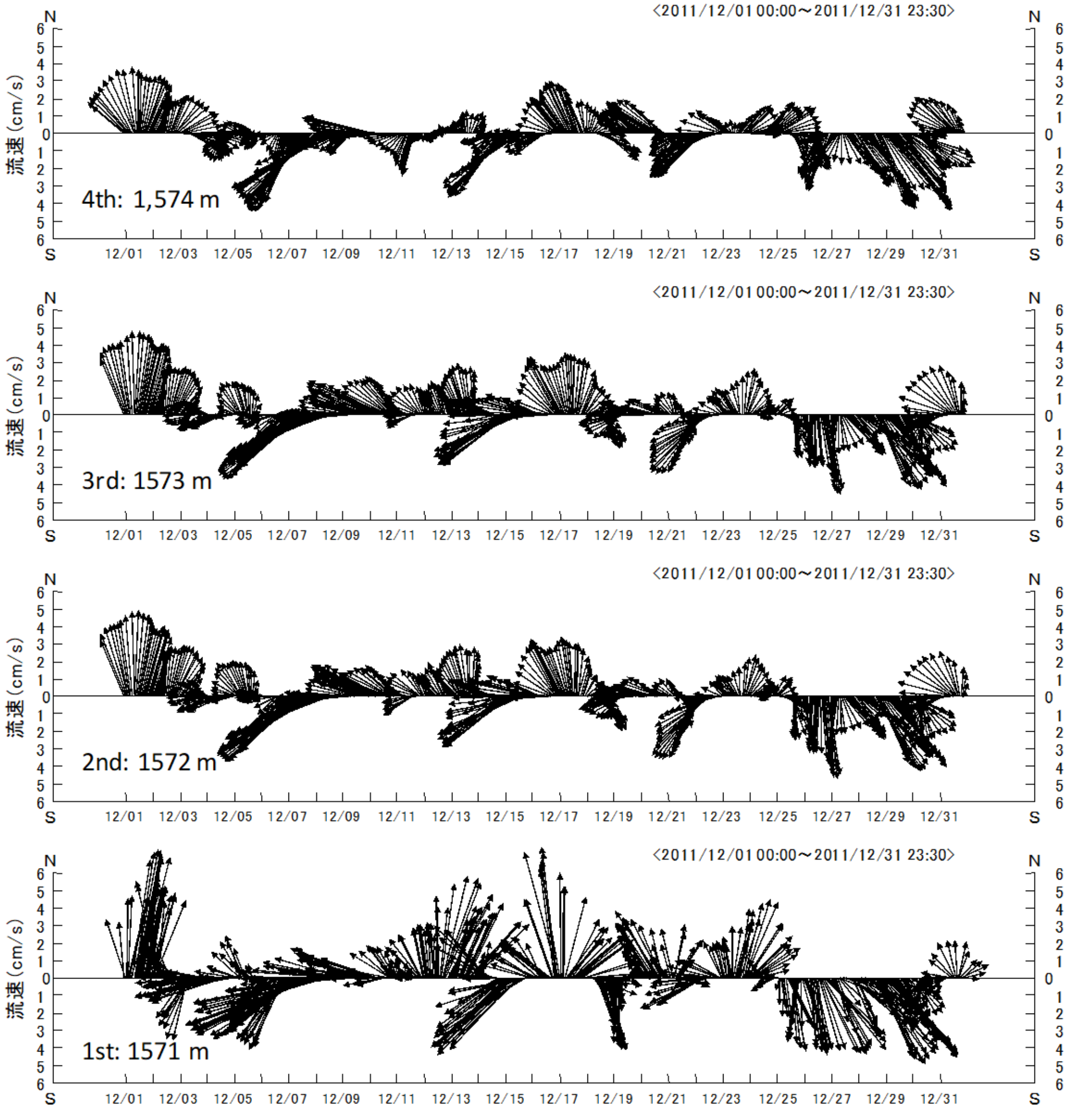

Figure 5.2.6. Time series of velocity of WH 1200 kHz ADCP in December 2011. The velocity is the 25 hours moving average to remove tidal components. Reproduced from Nagao et al. (2018).

The problems mentioned above are related mainly to differences in the velocity tendency amongst adjacent layers. To examine these velocity tendency differences, Nagao et al. (2018) calculated power spectra for each layer (Figure 5.2.7). The results revealed that power spectrum differences did not appear in the low-frequency (long-period, including tidal periodicity) zone, but did appear in the high-frequency (short-period) zone.

Because there were no significant differences in the low-frequency zone amongst the observation layers, Nagao et al. (2018) concluded that the low-frequency velocity component detected by the ADCPs was reliable. Accordingly, they examined rotary spectra of horizontal velocity to confirm the presence of a Coriolis effect; it is thought that rotary spectra should be dominantly clockwise rather than anticlockwise in the Northwest Pacific, because the Coriolis effect causes water masses to rotate clockwise in the open ocean in the Northern Hemisphere. The clockwise rotary spectrum of the WH 1200 kHz ADCP data (2nd layer) (Figure 5.2.8) was clearly dominant over all frequency bands. This result indicates that the Coriolis effect caused water masses to rotate clockwise and confirmed the validity of ADCP velocity data.

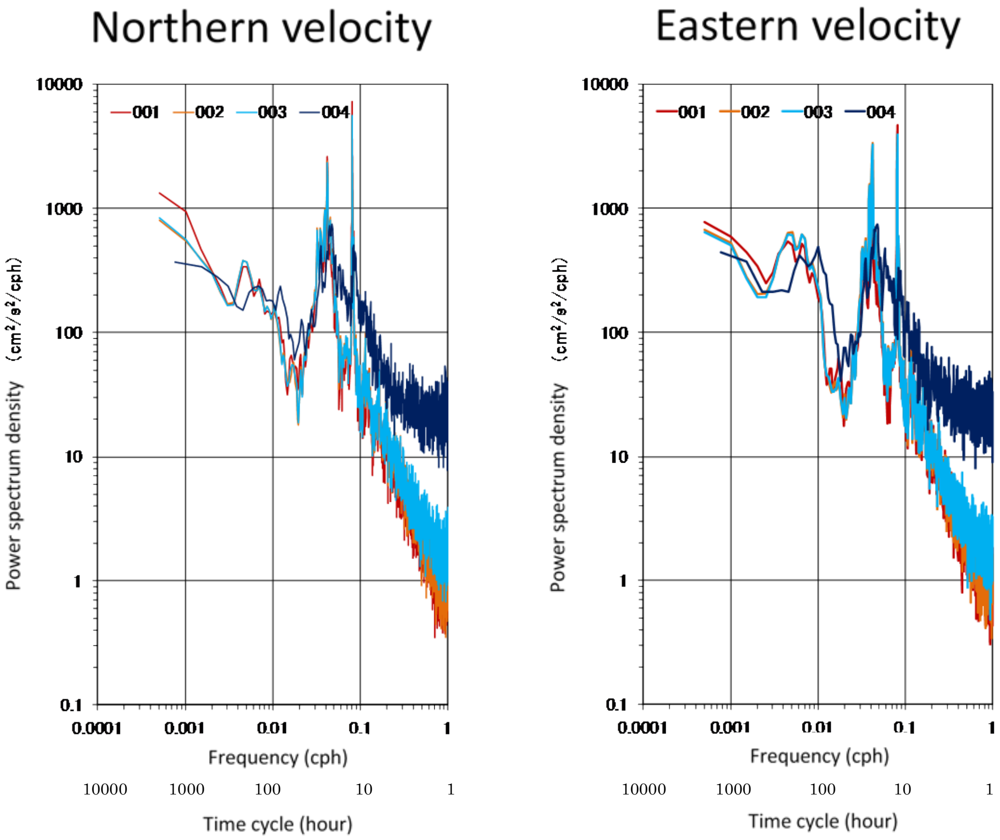

Figure 5.2.7. Power spectra of velocity of 1200 kHz WH ADCP (left: northern velocity; right: eastern velocity). The spectra are colour-coded according to layer number. Reproduced from Nagao et al. (2018).

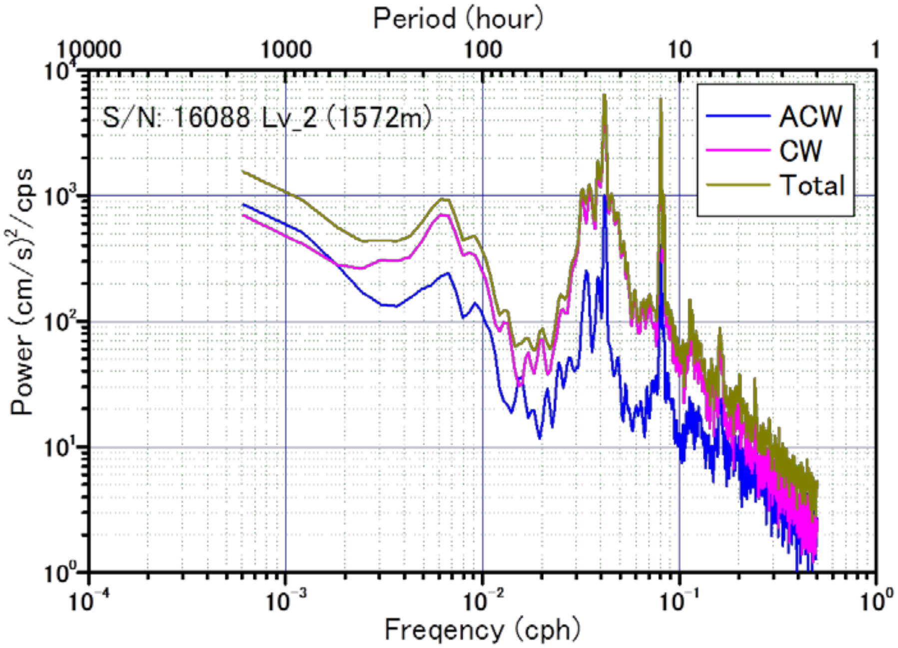

Figure 5.2.8. Rotary spectra of velocity in the 2nd layer of WH 1200 kHz ADCP. ACW: anticlockwise; CW: clockwise; cph: cycle per hour; cps: cycle per second. Reproduced from Nagao et al. (2018).

Nagao et al. (2018) also validated the data from ADCP measurements by comparing these data with the second version of Japan Coastal Ocean Predictability Experiment (JCOPE2) reanalysis dataset, which shows the variability of water mass properties and currents in the western North Pacific (Miyazawa and Yamagata, 2003; Miyazawa et al., 2008). The JCOPE2 dataset has a high horizontal resolution of 1/12° for describing the oceanic variability associated with the Kuroshio, the Kuroshio Extension, and the Oyashio currents; therefore, mesoscale eddies in JOGMEC's contract area should also be detectable.

Overall, the ADCP velocity data in the second layer (1572 m) obtained by the WH 1200 kHz ADCP corresponded reasonably well to those in the JCOPE2 reanalysis at the same depth; with differences in average magnitude of velocity ranging from 0.02 to 0.03 m/s (Figure 5.2.9). Additionally, a scatter plot of northern and eastern velocity components (Figure 5.2.10) shows that the average direction and magnitude of velocity are generally consistent between the ADCP and the JCOPE2 data, although velocities varied widely.

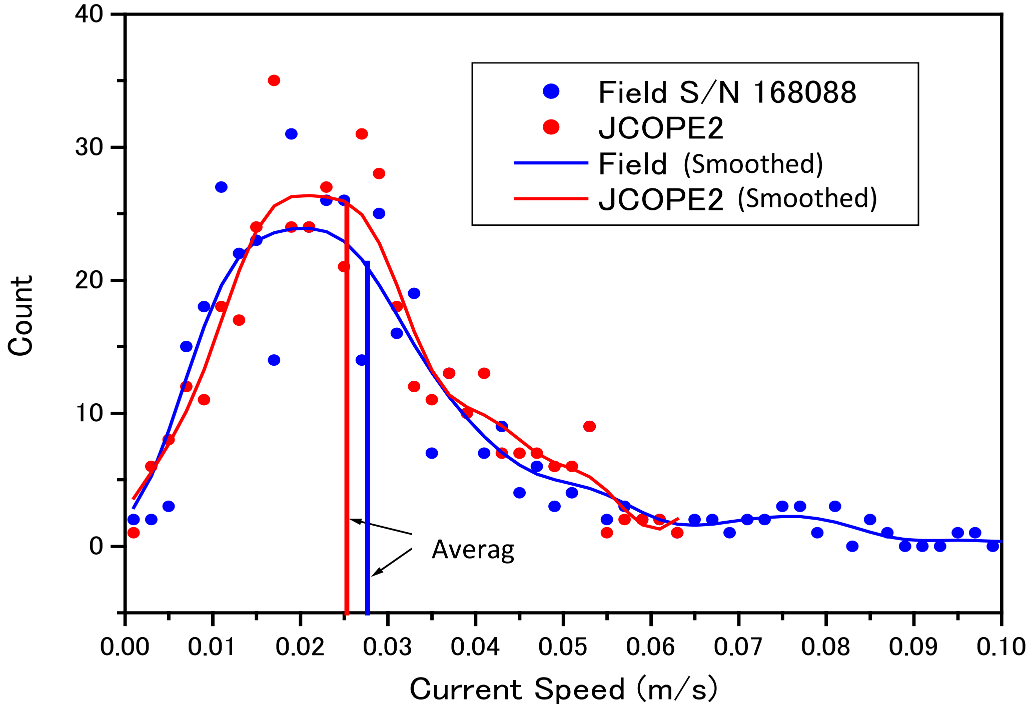

Figure 5.2.9. Comparison of ADCP velocity data (2nd layer, WH 1200 kHz ADCP) with JCOPE2 velocity reanalysis data. Reproduced from Nagao et al. (2018).

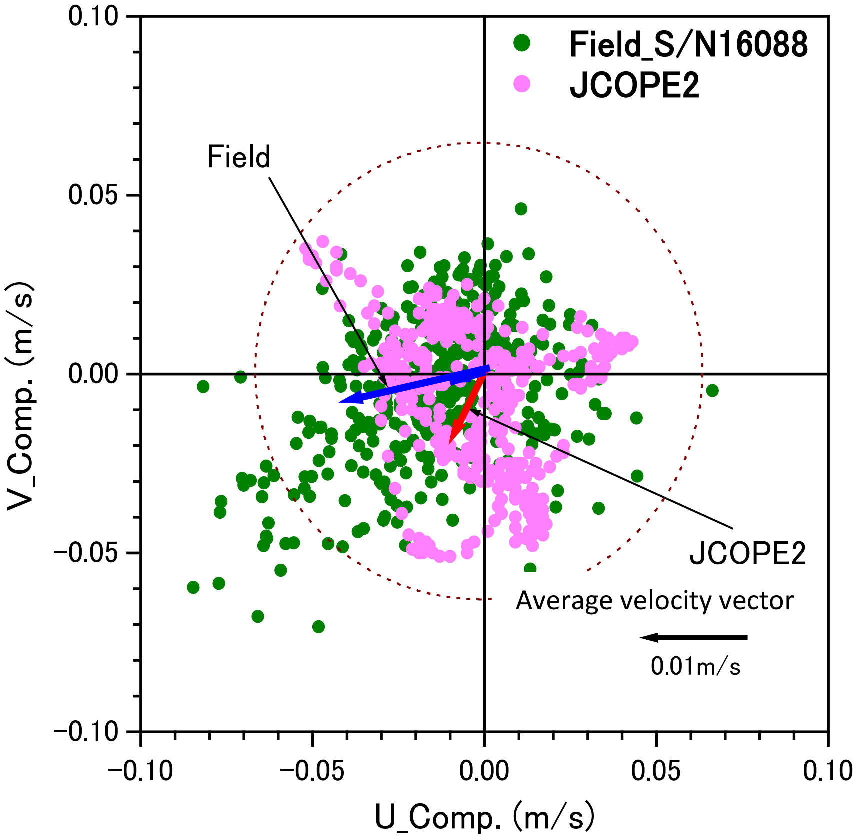

Figure 5.2.10. Scatter plot of northern and eastern ADCP and JCOPE2 velocity components. The dotted circle outline denotes the range of the JCOPE2 data. Vectors show the mean ADCP (blue) and JCOPE2 (red) velocities. Note that the scale of the unit velocity vector shown in the bottom right corner is not the same as the scale of horizontal and vertical axes. Reproduced from Nagao et al. (2018).

In conclusion, Nagao et al. (2018) conducted ADCP measurements on the flat top of Lamont seamount for 1 year and verified the data by confirming the presence of a Coriolis effect. Comparing the velocity data from ADCP measurements with JCOPE2 reanalysis showed that the average velocities between the two were almost identical in terms of magnitude and direction. However, from the viewpoint of environmental impact assessments it would not be appropriate to replace velocity measurement with reanalysis data, as the latter has a lower spatial resolution of 1/12°. High resolution current profile data will still be needed to predict the physical impacts of disturbance experiments, and in the future, exploitation activities.

5.2.4.2 Current flow at Caiwei Seamount

Numerical modelling methods are commonly used to study hydrodynamic patterns at seamounts. The regional ocean model (ROM) utilises oceanographical and meteorological data for modelling long-term patterns. Results from this model are generally consistent with field measurements (Liu et al. 2019), from the surface to the depth of the thermocline and halocline. However, the variation of temperature and salinity near the thermocline and halocline predicted by the model is not as significant as measured data. However, in deep waters below the thermocline and halocline, the results from the model are in agreement with field measurements.

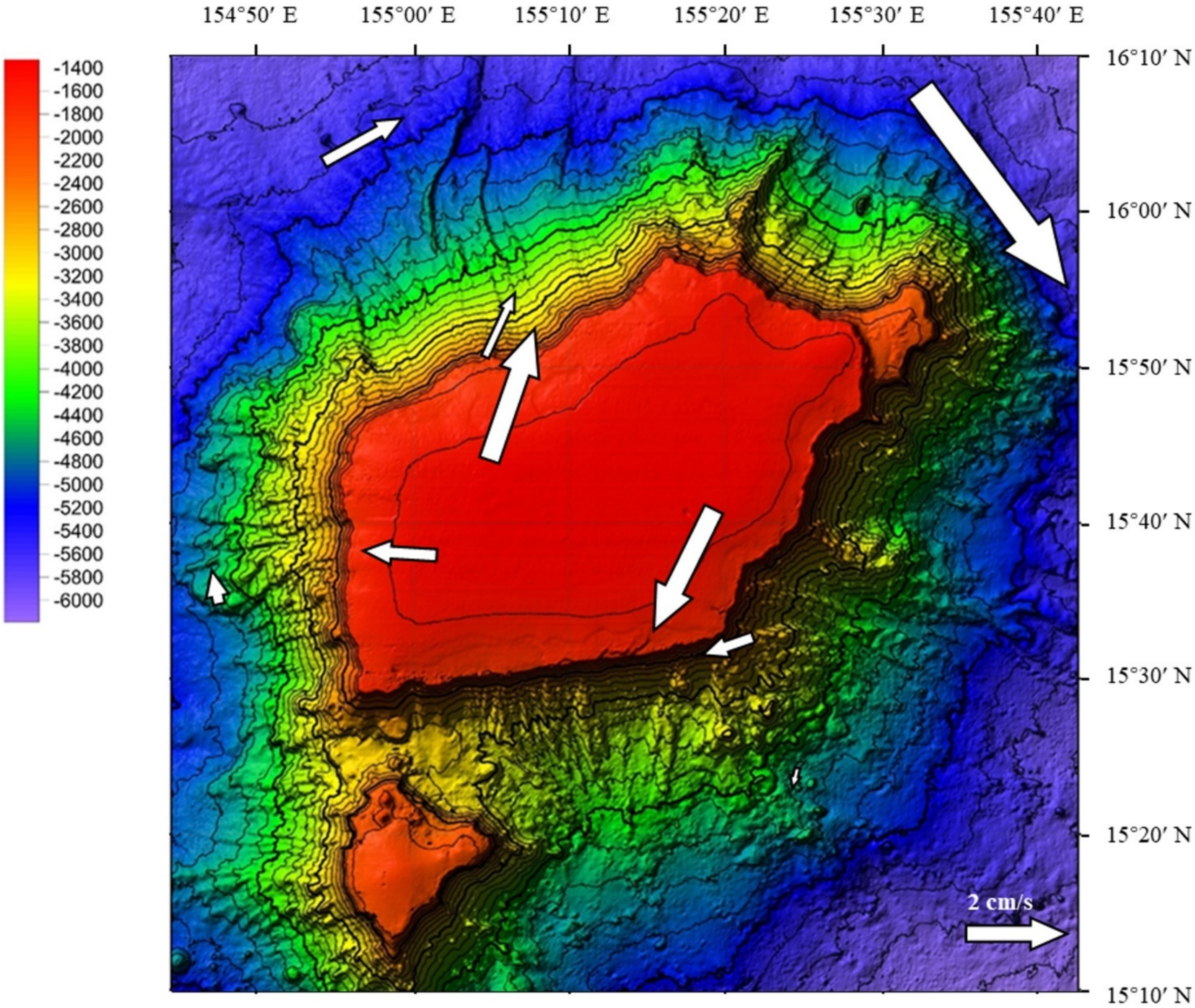

Figure 5.2.11. Long-term mean velocity near Caiwei Seamount obtained by current moorings. The placement of the arrows indicates the directions of the currents, and the size of the black arrows is proportionate to the magnitude of mean velocity. Modified from Liu et al. (2019).

Caiwei seamount is in the northeast trade wind belt, and as a result, the annual average surface current shows a westward current entering from the eastern boundary (Figure 5.2.12). At a depth of 1000 m, anticyclones are formed continually above the seamounts, and propagate or dissipate downstream due to background currents. At the depth of 3000 m and below, it mainly appears as a clockwise circulation around the seamount, and the intensity gradually strengthens from 3000-5000 m, which is mainly caused by potential vortices.

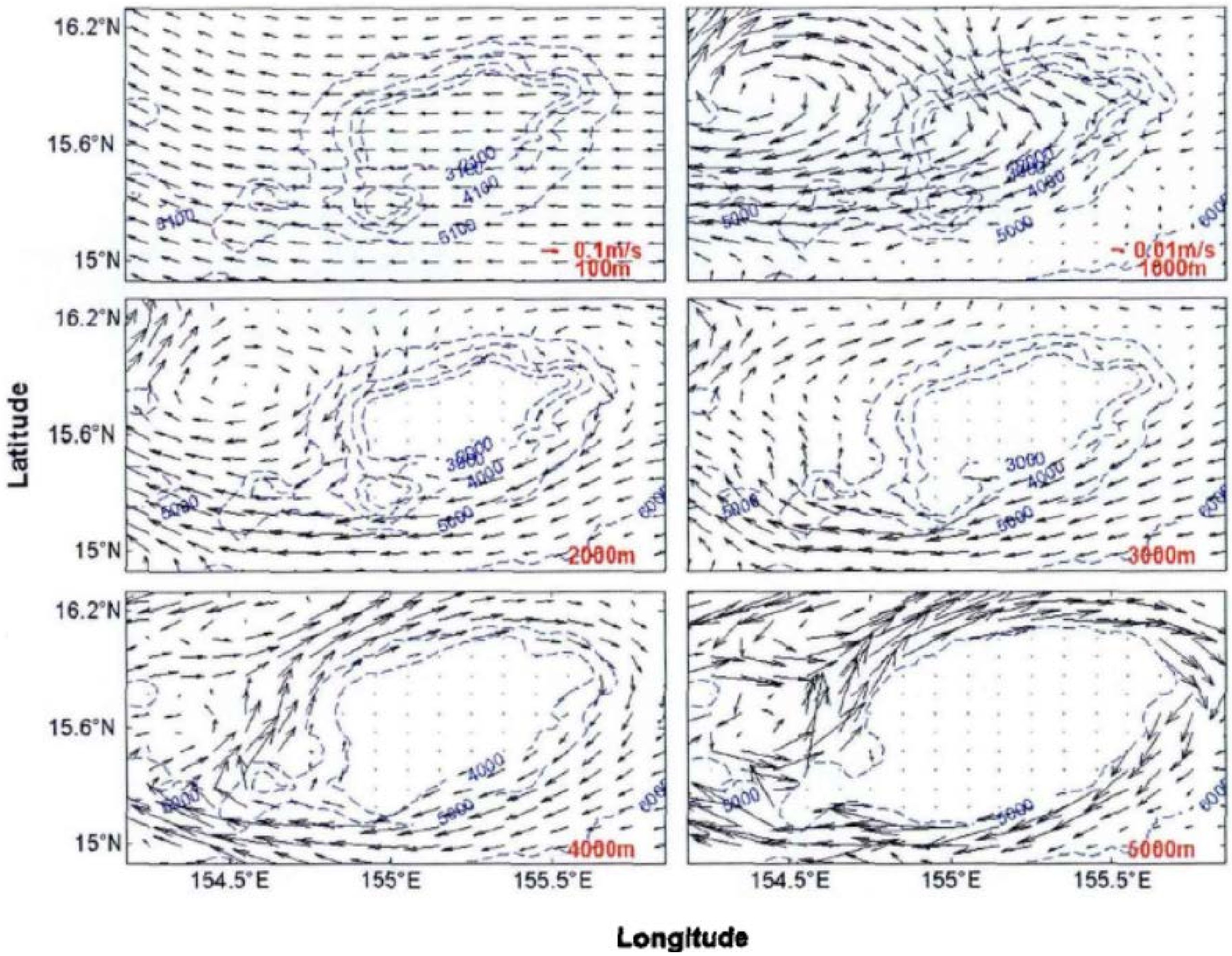

Figure 5.2.12. ROMS simulation of Caiwei Seamount showing the three-year mean velocity at different depths. Credit Dong-Feng Xu and Chang-Ming Dong.

5.2.5 Temporal and spatial variability

5.2.5.1 Satellite-data analysis of sea surface productivity

Satellite-based remote sensing is a promising option for large-scale and long-term environmental baseline monitoring, particularly in the open ocean where the distance from land may limit the frequency of measurements that can be obtained by ship-based research expeditions. Various sensors deployed on satellites can monitor parameters related to phytoplankton ecology and dynamics, including sea surface temperature (SST), water colour, and photosynthetically active radiation (PAR). Satellite observation datasets can also be useful for estimating the spatial distribution of phytoplankton biomass and primary production.

Net primary production (NPP), defined as the difference between gross photosynthetic production rate and respiration rate, was estimated at four locations around three seamounts of the JOGMEC contract area for cobalt-rich crusts in the Northwest Pacific Ocean (Yamaoka et al., 2020). Ocean colour data, including chlorophyll *a* concentration, PAR, and SST was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) mounted on the Aqua satellite through the National Aeronautics and Space Administration (NASA) OceanColor Web. Aqua MODIS views the entire surface of the Earth every 1 to 2 days, acquiring data in 36 spectral bands or wavelength groups. To estimate depth-integrated NPP, the Vertically Generalised Production Model (Behrenfeld and Falkowski, 1997) was used in combination with the two-phytoplankton community model of Kameda and Ishizaka (2005).

Monthly average NPP over a 17-year period at four locations was estimated using the long-term datasets of daily NPP for the period between July 2002 and October 2018 (Figure 5.2.13). The estimated NPP varied seasonally at all stations. The seasonal fluctuation, range, and pattern were almost identical between the four locations. NPP maximums (234-262 mg C/m^2/day) were observed during early spring blooms from February to May, and NPP minimums (131-139 mg C/m^2/day) were observed during summer and autumn (August to October). The values were consistent with the range of NPP estimated around the North Pacific subtropical gyre using the satellite data (Longhurst et al., 1995; Gregg et al., 2003).

Yamaoka et al. (2020) also conducted sediment trap observations (See Section 4.6 - Sediment fluxes) at the same locations where NPP was estimated using satellite dataset. The early spring bloom by satellite observation may be related to broader and lower-amplitude peaks in total mass fluxes of sinking particles observed around April in sediment traps at JA02 Seamount (Figure 4.17). Kawahata (2006) also reported one broad maximum from January through March in total mass fluxes obtained from a sediment trap in the western North Pacific Ocean (30°N, 175°E; water depth 3873 m). As well as the broad peaks during the spring bloom, Yamaoka et al. (2020) observed a distinctive sharp peak of sinking particle fluxes in late summer at all trap experiments at the JA02, 04 and 06 seamounts. This seasonal pattern of particle flux was inconsistent with the results from satellite data analysis where the NPP minimums were found in late summer. Phytoplankton booms and subsequent particle export pulses in late summer appear to be a recurring phenomenon in the oligotrophic eastern North Pacific, especially to the northeast of the Hawaiian Islands (Karl et al., 2001; Wilson, 2003). The blooms are fuelled by N_2 fixation by *Trichodesmium* and/or diatom–cyanobacteria symbiosis assemblages and nitrogen influx to the euphotic zone via vertical diatom migrations (Wilson and Qiu, 2008; Church et al., 2009; Karl et al., 2012). Summer blooms are not always detected by satellites and do not always reach the arbitrary 0.15 mg m^{-3} chlorophyll threshold (White et al., 2007; Villareal et al., 2011). It is possible that the late summer peak of total mass fluxes observed in this study reflects blooms supported by N_2 fixation that are invisible to satellite observation, although the trigger for these blooms is not well understood.

Alternatively, an episodic climate event might cause unusual seasonal peaks in sedimentation fluxes. In late summer, the area of the JA seamounts is frequently influenced by hurricanes and tropical depressions. According to historical hurricane tracks obtained from NOAA, tropical depressions and storms slowly moved around JA Seamounts in late summer. It has been suggested that stronger upwelling and vertical mixing (Shibano et al., 2011; Lin, 2012) and heavy rainfall (Lin and Oey, 2016) induced by typhoons could enhance plankton blooms. The local and short-lived nature of these blooms may hinder their detection in monthly average NPP data. In fact, some sporadic high values of NPP were observed in late summer from a detailed analysis of shorter-term satellite observation data, although the data acquisition rate was low due to cloud cover. It is also important to consider the possibility that a subsurface phytoplankton bloom may have been responsible for these observations. Subsurface chlorophyll *a* maximum (SCM) has been observed frequently in tropical and subtropical oceans and would likely be invisible from satellite. Considering the low acquisition rate of satellite data during summer and the invisibility of subsurface chlorophyll *a*, additional methods for monitoring local and episodic blooms may be needed.

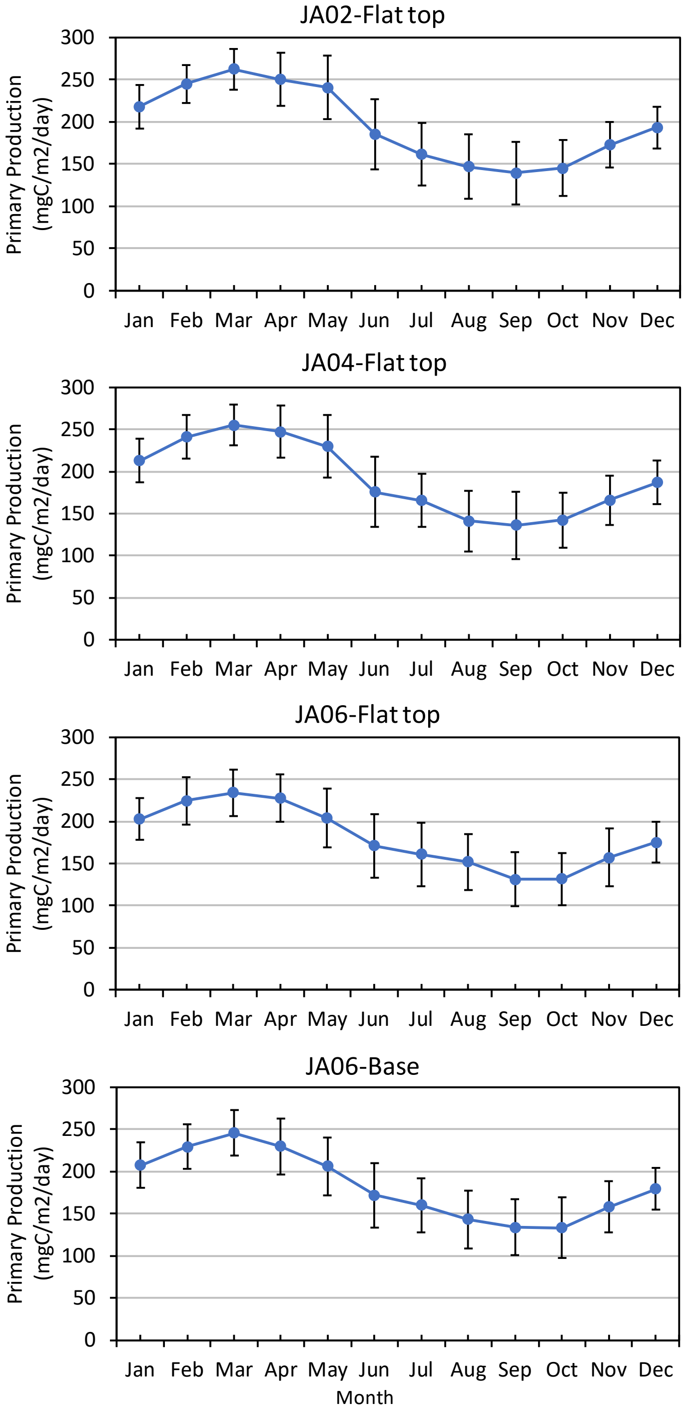

Figure 5.2.13. Annual climatology of satellite-based net primary production for the period 2002–2018 around JA02: Lamont Seamount (top); JA04: Maloney Seamount (second from top); and JA06: Xufu Seamount (second from bottom and bottom). Reproduced from Yamaoka et al. (2020).

5.3 Chemical oceanography

5.3.1 Distribution of chemical water properties

5.3.1.1 Nutrients

PACIFICA (PACIFic ocean Interior CArbon) was an international collaborative project for the data synthesis of ocean interior carbon and its related parameters in the Pacific Ocean (PACIFICA Group, 2013). Hydrographic/hydrochemical data taken over the entire Pacific Ocean were assembled from 272 cruises. The PACIFICA Group data were extracted for an area covering the six seamounts in the JOGMEC contract area for winter (January–March) and summer (July–September) for the period 1991–2008. In total, these data included more than 1500 data points from 61 locations (Figure 5.3.1).

There were considerable differences in seasonal vertical mixing between the area north and south of 23°N of the JOGMEC contract area (Figure 5.3.2). In subsurface layers around 100 m depth, seasonal changes in water density were greater in the north than in the south. These differences suggest that winter vertical mixing extends to the subsurface layers, supplying dense nutrient-rich water to the surface euphotic zone in the north and resulting in enhanced phytoplankton growth and increased chlorophyll content. The vertical profiles of nutrients showed different degrees of depletion amongst nutrient species and between seasons. Nitrate was strongly depleted in both winter and summer in the upper water layers in both the north and south. Hashihama et al. (2009) also found an overall depletion of surface nitrates (<5 nM) around this area in both winter and summer. Phosphate and silicate were only depleted in summer and in the north, respectively. The community structure of primary producers (e.g., the abundance of diatoms that selectively utilise silicates and cyanobacteria that fix dinitrogen with phosphate consumption) and nutrients supplied amongst atmospheric dust deposition (e.g., Iron: Sohm et al., 2011) also appear to be essential components affecting nutrient distributions of surface water in the Northwest Pacific.

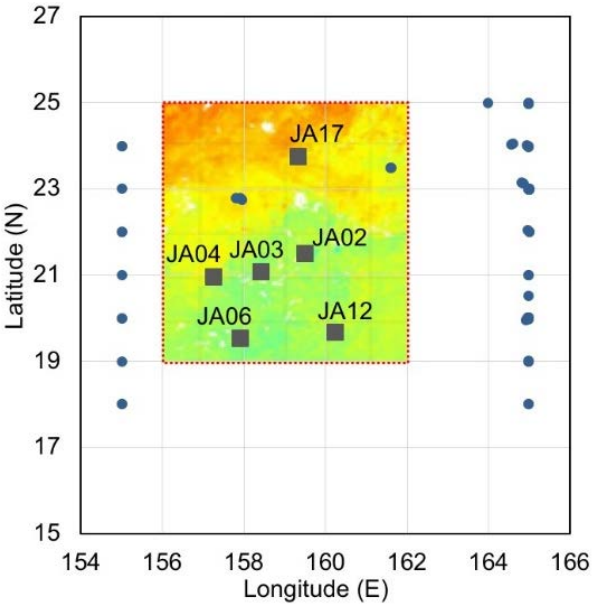

Figure 5.3.1. Locations of sampling stations in the PACIFICA Group (2013) data set (blue dots) that are adjacent to the seamounts in JOGMEC contract area. Credit Ayumi Tsukasaki.

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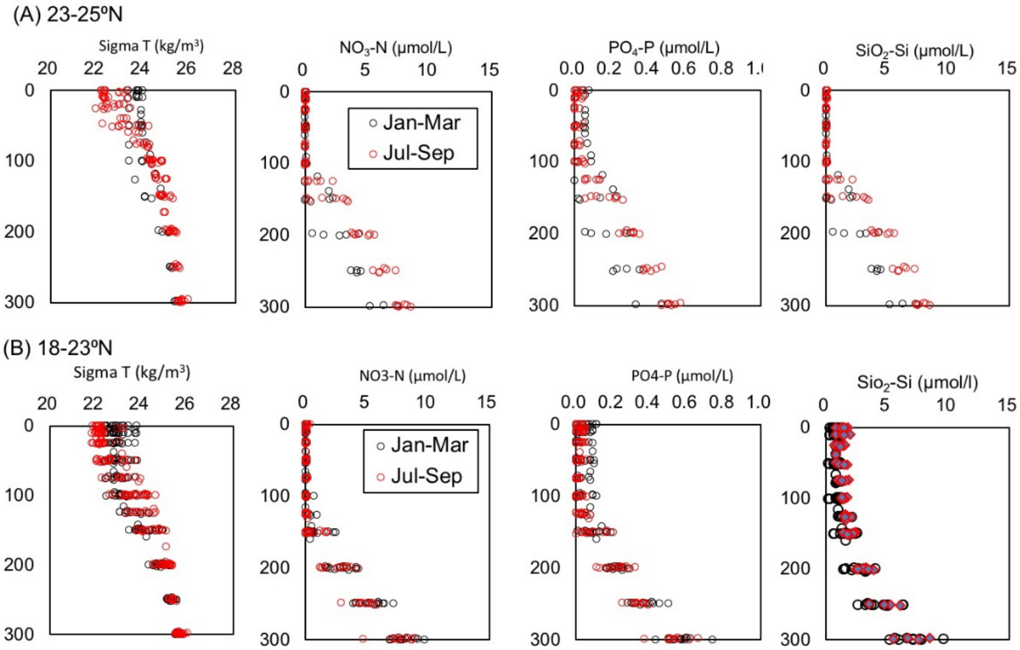


Figure 5.3.2. Profiles of water density and nutrient concentrations in winter (Black dots: Jan – Mar) and summer (Red dots: Jul – Sep) at the stations showed in Figure 5.3.1. Data were obtained from the PACIFICA dataset (PACIFICA Group, 2013). (A) Data from the stations located between 23°N and 25°N (northern area); (B) data from the stations located between 18°N and 23°N (southern area). Credit Ayumi Tsukasaki.

5.3.2 Local chemical environment

5.3.2.1 Ocean chemistry at seamounts in the JOGMEC contract area

The JOGMEC contract area for cobalt-rich ferromanganese crusts in the Northwest Pacific is located in the western North Pacific subtropical gyre. To obtain the environmental baseline data in accordance with ISA recommendations (ISBA/25/LTC/6.Rev.1), water column profiles were determined using a conductivity temperature depth (CTD) sensor and water sampling over several seamounts. In 2018, the oceanographic survey was conducted around the JA03 seamount (Figure 5.3.3). Water column profile data were collected at two stations: one above the flat top (St. JA03-T01, water depth 1,429 m) and another above the seamount's base (St. JA03-B01, water depth 5,089 m). The CTD instrument was also equipped with *in situ* sensors for fluorescence, dissolved oxygen (DO), and turbidity. Seawater samples were collected using a multiple-bottle rosette sampler and analysed for salinity, DO, pH, dissolved inorganic nutrients [including nitrate (NO3-N), nitrite (NO2-N), ammonium (NH4-N), phosphate (PO4-P), and silicate (SiO2-Si)], dissolved metals, total alkalinity (TA), total organic carbon (TOC), chlorophyll *a* (Chl. *a*) and particulate organic carbon (POC). DO and pH were analyzed on board the ship; then samples were pretreated, preserved, and brought back to land-based laboratories for further analyses.

Vertical profiles of the various parameters obtained by chemical analyses of the seawater samples around the JA03 seamount are shown in Figure 5.3.3. There were no marked differences between the profiles taken on the flat top and at the base of the seamount. The profiles of DO and pH were similar; both decreased rapidly from the surface to 750 m water depth and then gradually increased with depth below 750 m. An oxygen minimum zone (OMZ) was observed at 700-800 m water depth, consistent with the feature of the subtropical North Pacific Gyre (Popp et al., 2002; Cartisano et al., 2018). Vertical profiles of total alkalinity were similar to those of salinity obtained by CTD sensor (data not shown), and total alkalinity values were consistent with those in the subtropical North Pacific region extracted from the PACIFICA dataset (PACIFICA Group, 2013). Concentrations of dissolved inorganic nutrients in the top 100 m water layer were quite low and close to the detection limits. The low concentrations of nutrients suggest that waters in the euphotic zone in the area around the JA03 seamount are depleted in inorganic nutrients, which limits primary production. TOC concentrations were consistent with previously reported values in the North Pacific Subtropical Gyre (Abell et al., 2000; Cartisano et al., 2018). POC was a minor component of organic carbon throughout the water column, accounting for only 0.5–2.5% of TOC. In other words, the bulk of organic matter in the seawater was composed of dissolved organic matter. The relative abundance of POC in TOC observed in the JA03 seamount area is consistent with abundances reported previously in the North Pacific (Loh and Bauer, 2000). Although POC was analysed in five depth layers in this study (at the surface, 100 m, 500 m, 1000 m depth, and at 50 m above the seafloor), POC is not typically determined as frequently as other parameters such as TOC, nutrients, and Chl. *a*, which are routinely measured as part of marine chemistry observations. Measuring POC requires a large amount of seawater followed by a time-consuming filtration procedure on board. However, through obtaining POC abundance data as well as carbon isotopic ratios in POC, it should be possible to obtain important insights for understanding biogeochemical cycles around Northwest Pacific seamounts. The vertical profiles of TOC, POC, and Particulate Organic Nitrogen (PON) show high concentrations in the surface zone. Concentrations of these organic components decreased with depth, likely owing to the decomposition of dissolved and particulate organic matter in the deep sea. The rapid decreases in pH and DO as well as the rapid increases in dissolved inorganic nutrient concentrations between the surface and 800 m depth can be ascribed to the production of CO_2, the utilization of DO, and nutrient remineralization through organic matter decomposition processes.

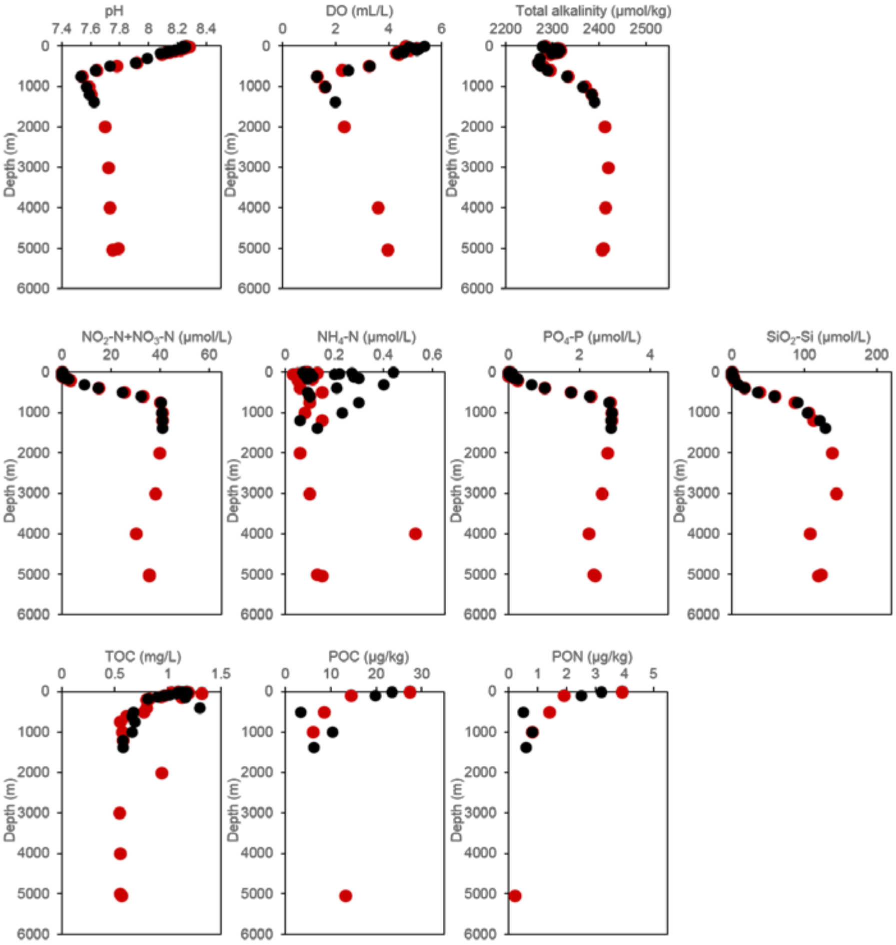
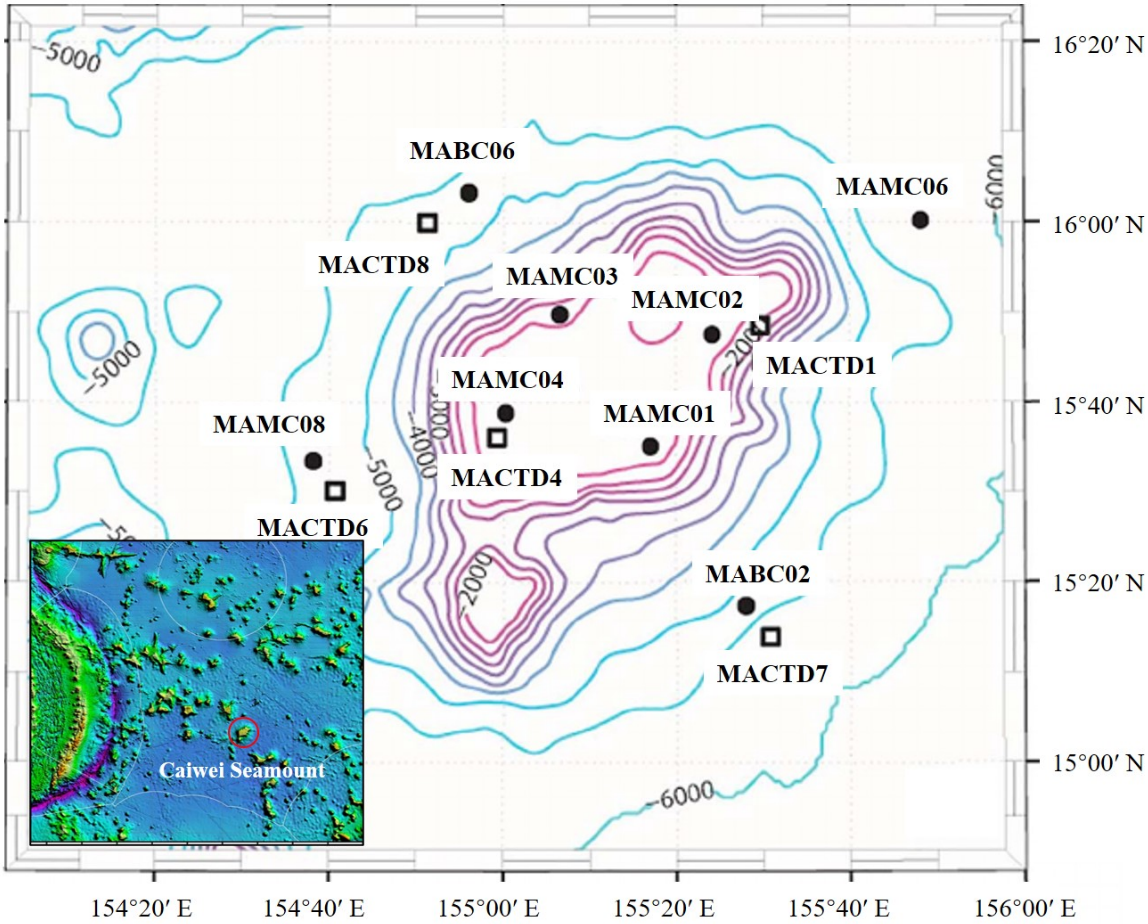


Figure 5.3.3. Vertical profiles of physicochemical parameters in the water column determined by chemical analyses of seawater samples at two stations around the JA03 seamount: above the flat top (black points) and at the seamount's base (red points). Credit Ayumi Tsukasaki.

To examine the euphotic zone in more detail, the portion of the vertical profiles between the surface and 250 m depth was enlarged including temperature and salinity data obtained with a CTD sensor. The surface mixed layer depth was at around 50 m, and above this depth, both water temperature and salinity were constant. A chlorophyll maximum layer (CML) was observed at 125 m depth at both the flat top and the base. Nutrient concentrations were quite low between the surface and 100 m depth, but below the CML, nutrient concentrations rapidly increased with depth. These results strongly suggest that phytoplankton biomass as well as primary productivity in this oligotrophic seamount region is regulated largely by the availability of inorganic nutrients supplied from the subsurface zone. Under such nutrient-depleted conditions, biochemical processes related to the efficient uptake and recycling of nutrients are responsible for sustaining oligotrophic subtropical ecosystems (Parsons et al., 2012; Suzumura et al., 2012; Moore et al., 2013). No considerable differences were found in the vertical profiles in the euphotic zone between the flat top and the base, except for ammonium and phosphate, both of which exhibited slightly higher concentrations at the flat top than at the base. No reasonable explanation can be provided for the spatial differences in vertical profiles of ammonium and phosphate, which can contribute to regenerated production in the surface euphotic zone. Bottom topography of the seamounts, as well as various biological and ecological parameters including community structure, could be contributing factors. Limited data collection opportunities make it challenging to examine temporal and spatial differences in water chemistry around the Northwest Pacific seamounts. More sensitive methods could be used to measure nutrients where concentrations are close to the detection limits of conventional analytical methods. In the past decade, analytical methods for seawater nutrients have improved and are increasingly applied to oligotrophic ocean environments, which will enable future studies to examine nano-molar level dynamics of nutrients in the euphotic layer of seamount areas.

5.3.2.2 Ocean chemistry at Caiwei seamounts in the COMRA contract area

Research was conducted on hydrochemical characteristics of seawater surrounding Caiwei seamount (Figure 5.3.4). Seawater at the top and the base of the seamount have similar salinity, pH, and concentrations of ammonia, nitrite, nitrate, and phosphate. Temperature was higher in seawater overlying the top of the seamount, whilst dissolved oxygen concentrations were greater at the base of the seamount (Liu et al. 2019).



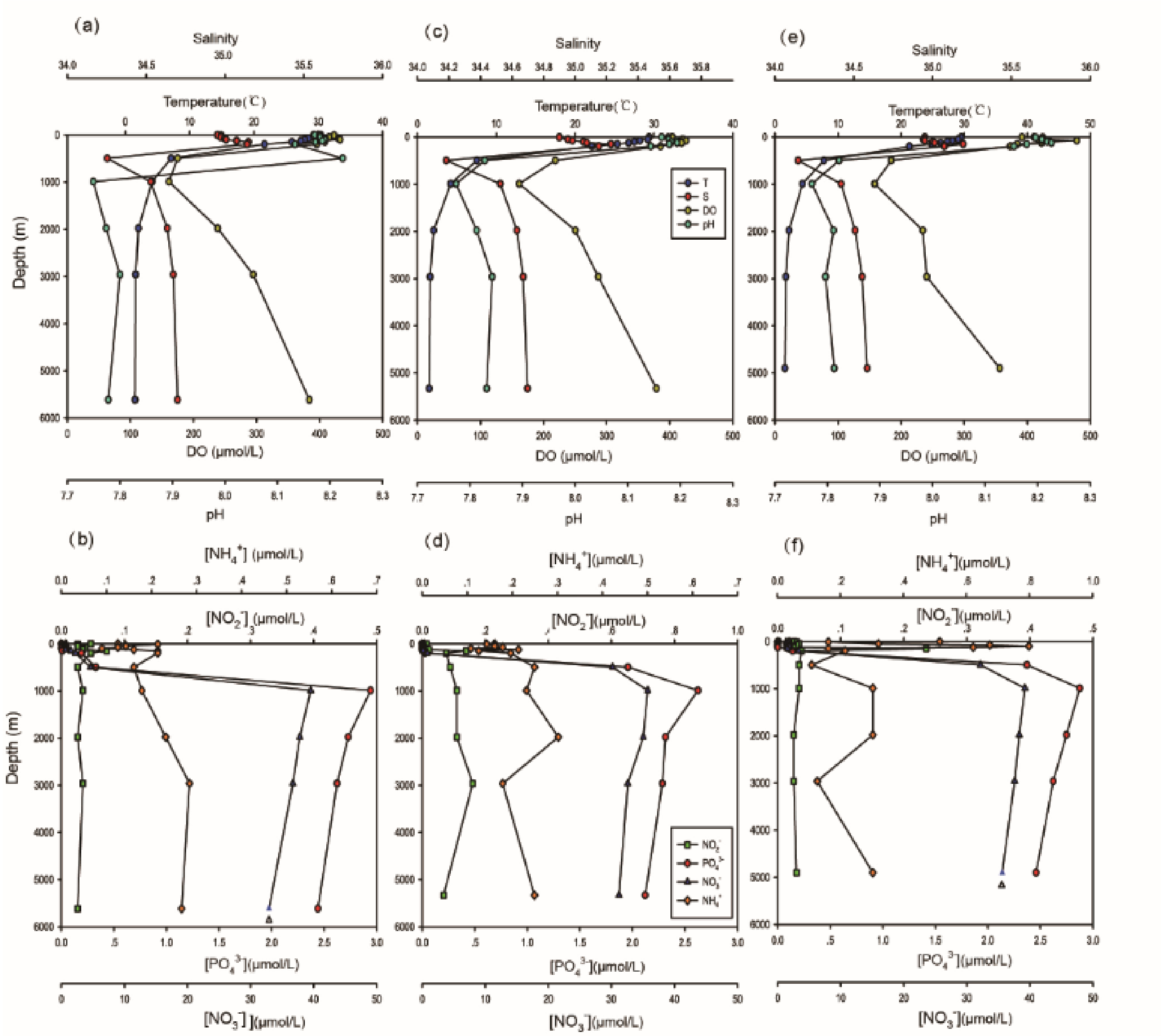


Figure **5.3.4.** Top: Sampling stations at Caiwei seamount. Bottom: Temperature, salinity, dissolved oxygen concentration (DO), pH, [NH4+], [NO2-], [NO3-] and [PO43-] measured at stations MACTD7 (a, b), MACTD8 (c, d) and MACTD6 (e, f) shown in map above. Modified from Liu et al. (2019).

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6 Biology of the Northwest Pacific Ocean

6.1 Overview

The chapter on the Biology of the Northwest Pacific Ocean presents a wide range of information on the biology of the surface and mid-water environment, and the benthic environment. This chapter aims to provide a regional overview of biological patterns and processes in the Northwest Pacific region, including biological linkages to other regions, and complemented by site-specific studies conducted within exploration contract areas where possible. Historically, the Northwest Pacific Ocean has not been as extensively studied as other ocean regions but there is a growing body of literature to support the establishment of an environmental baseline for the region. This document is a first step in collating and presenting the available biological information for the Area of the Northwest Pacific region. As further scientific expeditions and surveys are conducted within the region, the new information gathered during these activities can be used be to update future versions of this document.

The combined surface and mid-water environment of the Northwest Pacific (surface to 50 m above seafloor) is a vast environment spanning thousands of meters' water depth. Within the **Biology of the surface and mid-water environment** (Section 6.2), information is presented on the following topics:

- **Spatial distribution** (Section 6.2.1), including biogeography, and the distribution of microorganisms, zooplankton, mid-water fishes, sharks and commercially important fishes, seabirds, sea turtles, and marine mammals.
- **Temporal variability** (Section 6.2.2), including diel (daily) vertical migration.
- **Ecosystem function** (Section 6.2.3).
- **Connectivity** (Section 6.2.4), including the connectivity of zooplankton.
- **Resilience and recovery** (Section 6.2.5), including general concepts and potential impacts from future mineral exploitation activities.

Future versions of this document may be able to address further scales of temporal variability, for example seasonal variation and multidecadal variability. Trophic relationships were not addressed for the surface and mid-water environment but should be considered in future versions of this document.

The benthic environment of the Northwest Pacific (seafloor to 50 m above seafloor) spans a wide range of benthic habitats, including the seamounts and abyssal plains that are the focus of this document. Within the **Biology of the benthic environment** (Section 6.3), information is presented on the following topics:

- **Spatial distribution** (Section 6.3.1), including biogeography, the distribution of seamount and abyssal plain biological communities (microorganisms, benthic invertebrates, benthic and demersal nekton), and local distribution patterns for seamount communities.
- **Temporal variability** (Section 6.3.2) of seamount communities.
- **Trophic relationships** (6.3.3) for seamount and abyssal plain communities.
- **Ecosystem function** (6.3.4) for seamount communities.
- **Connectivity** (Section 6.3.5) for seamount and abyssal plain communities.
- **Resilience and recovery** (Section 6.3.6), including impacts from climate change, bottom trawling, and future mineral exploitation activities.

For the benthic environment, there is more information available for the seamount communities than for the abyssal plain communities in the Northwest Pacific region, reflecting a longer history of scientific expeditions on seamounts in this region. When more information becomes available, future versions of this document may be able to address the local distribution patterns, temporal variability, and ecosystem function for abyssal plain communities. For both seamount and abyssal plain communities, the most information is available for spatial distribution patterns, with larger organisms that are identifiable using imagery being the most comprehensively surveyed. One group that was not addressed within this document for either seamount of abyssal plain communities was the benthic and demersal zooplankton. This group typically lives within the benthic boundary layer (BBL) and provides an important linkage between the benthic and pelagic environments, although it can be challenging to sample. Future versions of this document may be able to address this group as more information becomes available.

6.2 Biology of the surface and midwater environment

The combined surface and mid-water environment of the Northwest Pacific (surface to 50 m above seafloor) is a vast environment spanning thousands of meters' water depth. The pelagic environment is one of the least understood habitats globally, and there is often little information about the pelagic biota. In general, life in the deep sea decreases logarithmically with depth, with biomass declining roughly ten-fold for every 2000 m increase in depth (Priede, 2017), in both the benthic and pelagic realms. Few studies have been conducted on the biology of the pelagic environment overlying Northwest Pacific seamounts, although fisheries and scientific research surveys have been conducted at seamounts in other parts of the Pacific Ocean and the Atlantic Ocean. During these surveys, diverse and specialised biological communities were recorded from both the pelagic and benthic environments of seamounts. One of the common findings of seamount surveys is the greater biomass, abundance and diversity of plankton, nekton, and benthic biota on and around seamounts, compared to the pelagic and benthic habitats of the surrounding ocean. These phenomena are generally summarised as 'Seamount effects' (Boehlert and Genin, 1987; Rogers, 1993).

A series of hypotheses have been put forward to explain these 'Seamount effects', based on physical oceanography, ecological theory, geology, and animal behaviour. Some of these hypotheses include upwelling and enhanced primary productivity (Uda and Ishino, 1958); topographic trapping of daily vertical migration (Genin et al., 1994); enhancement of surrounding food supply (Hirch et al., 2009); and the retention of upwelling and downwelling circulation (Franks, 1992). Survey data and observations rarely follow just one of these hypotheses, with repeat surveys of the same seamount at different time periods indicating complex patterns in the spatial and temporal variation of biological communities at seamounts (Dower et al., 1992; Comeau et al., 1995; Dower and Mackas, 1996; Martin and Christiansen, 2009).

Seamounts with different depths have different hydrological and ecological characteristics, which influence the biological communities that occur in the surface and midwater environment overlying the seamount (Genin, 2004). Seamounts are classified as 'shallow' when the summit is within the photic layer; 'intermediate' when the summit is below the photic layer but shallower than 400m water depth; and 'deep' when the summit is below 400 m water depth (Genin, 2004). Different biological communities also occur in the deep-pelagic, with distinct communities occurring in the abyssal-pelagic waters below 3000m depth. Little is known about the biota colonising the deep-pelagic waters overlying abyssal polymetallic nodule fields in the Northwest Pacific.

6.2.1 Spatial distribution

6.2.1.1 Biogeography

The distribution, density, and community structure of pelagic and benthic organisms normally responds to patterns in surface primary productivity and particle flux from the surface to the seabed. According to early biogeographic studies, the portion of the Norwest Pacific where exploration contracts have been awarded by the ISA is located in the western part of the Northern oligotrophic zone (Sokolova, 1997). The upper ocean in this region was considered to be largely within the North Pacific Tropical Gyre Province, with the southernmost part of the region belonging to the Western Pacific Warm Pool Province (Longhurst, 2007); both of these provinces are characterised by relatively oligotrophic conditions. A recent study demonstrated that these two provinces determined by Longhurst (2007) show different patterns of diel vertical migration (Sun, 2019), which in turn may result in different efficiencies of the carbon pump and the proportion of active carbon flux to the deep sea in the northern and southern parts of this region.

More recent biogeographic studies have addressed the surface (epipelagic: 0 – 200m) and mid-water (mesopelagic: 200m - seafloor) parts of the pelagic environment separately and proposed revised global biogeographic province allocation. According to the epipelagic biogeography proposed by Spalding et al. (2012), the portion of the Norwest Pacific where exploration contracts have been awarded by the ISA is located in the North Central Pacific province, although the more southern part of the region may be influenced by the Equatorial Pacific province. Similar results were obtained by Sutton et al. (2017) who also placed the mesopelagic environment for this region within the North Central Pacific, with potential influences from the Equatorial Pacific in the southern parts of the region.

According to Spalding et al. (2012), the North Central Pacific epipelagic province is a Gyre biome, located between the equator and 50° North, comprising most of the North Pacific Ocean. The Gyre has a clockwise circulation pattern and is bounded by four major ocean currents: the North Pacific current, California current, North equatorial Current and Kuroshio current (Spalding et al., 2012). According to Sutton et al. (2017), the North Central Pacific mesopelagic province largely corresponds to the same North Pacific Gyre system, with high mesopelagic fish species diversity (Barnett, 1983) and copepod species diversity (McGowan and Walker, 1979).

6.2.1.2 Microorganisms

The Northwest Pacific is an oligotrophic marine region, and most of the area is nitrogen limited (Polovina et al., 2008). Biological nitrogen fixation is often an important metabolic function for microorganisms in nitrogen-limited waters (Montoya et al., 2004) but at present, there are few studies on microorganisms in the pelagic environment of the Northwest Pacific Ocean.

6.2.1.2.1 Studies from the COMRA cruise

Microorganisms in the surface waters were sampled as part of an environmental baseline survey conducted during the DY54 cruise in 2018. In this survey, microorganisms in the surface waters belonged primarily to Proteobacteria, Cyanobacteria, Bacteroidetes and Actinobacteria, and the microbial community was similar amongst different stations. Proteobacteria accounted for approximately 50% of the total taxonomic richness, dominated by α-Proteobacteria (mainly the SAR11 group) and γ-Proteobacteria (mainly the SAR86 group) (data from DY54 research cruise, unpublished). The SAR11 and SAR86 groups have simplified genomes (~1.2-1.7Mb), and can reduce energy and material consumption through reducing metabolic pathways, as an adaptation to oligotrophic waters. Under nutrient and carbon limited conditions, SAR11 and SAR86 groups can use rhodopsin to produce adenosine triphosphate (ATP: DuPont et al., 2012; Grote et al., 2012).

Prochlorococcus was the most abundant cyanobacteria sampled in surface waters, followed by *Synechococcus*. *Prochlorococcus* is broadly distributed in oligotrophic waters from 40°N to 40°S and is the most abundant photoautotrophic bacteria on the earth, largely occurring in the euphotic zone of oligotrophic seawater (Moore et al., 2002). *Prochlorococcus* uses inorganic nitrogen to produce organic carbon and is the main source of organic carbon in oligotrophic waters, playing an important role in the carbon cycle (Szul et al., 2019). The results of the

DY54 research cruise indicated that the relative abundance of *Prochlorococcus* in the surface seawater overlying cobalt-rich crust seamounts in the Northwest Pacific is much higher than abundances recorded in waters overlying the continental shelf.

6.2.1.3 Plankton

6.2.1.3.1 Phytoplankton

Historically, most surveys on plankton ecology of seamounts were conducted around shallow seamounts. These investigations found that the primary productivity and biomass of phytoplankton and zooplankton in the photic layer around the summit and slope of seamounts were significantly higher than those in the surrounding ocean waters (e.g., Comeau et al., 1995; Dower and Mackas, 1996).

The Northwest Pacific Ocean that overlies exploration contracts issued by the ISA is typical of tropical and subtropical oligotrophic oceans. The phytoplankton biomass is dominated by nano- and pico-phytoplankton, with a low proportion of micro-phytoplankton (> 20 µm) within the total phytoplankton standing stock (Figure 6.2.1).

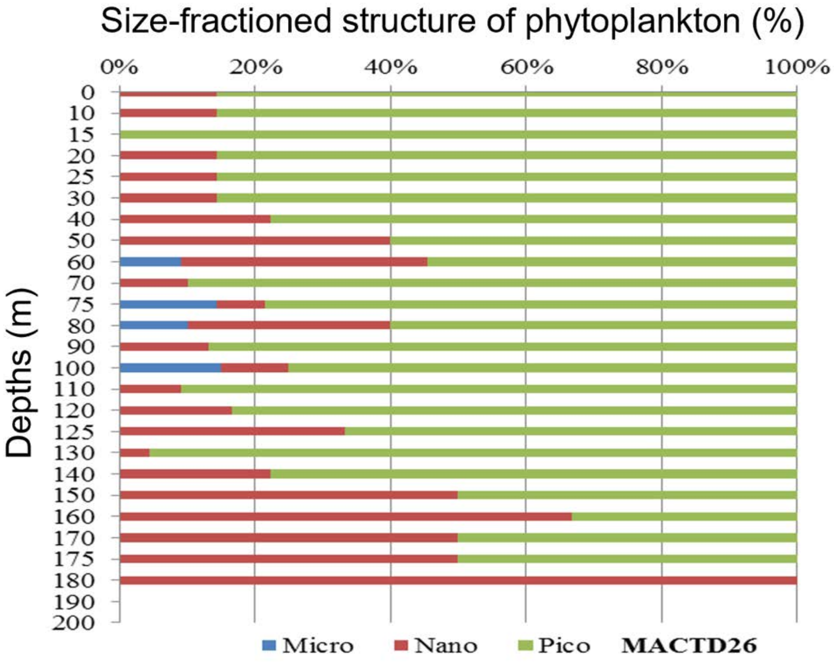

Figure 6.2.1. Size-fractioned structure of phytoplankton biomass with water depth at Caiwei Seamount in the Norwest Pacific. Data source: Cruise report DY29, unpublished. Credit COMRA.

Along a latitudinal gradient (longitude of 175°E), the main biomass of phytoplankton was dominated by coccolithophores and photosynthetic autotrophic prokaryotes, with little spatial difference in community structure in the vast area between 10°N and 24°N (Suzuki et al., 1997).

Along a longitudinal gradient in the subtropical Western Pacific, the region overlying the seabed where exploration contracts have been awarded by the ISA is more oligotrophic, compared to the nearby Philippine Sea. The chlorophyll *a* concentration of 0-75 m depth in the east of the region was significantly lower than that of Philippine Sea (Figure 6.2.2; D. Zhang et al., 2012).

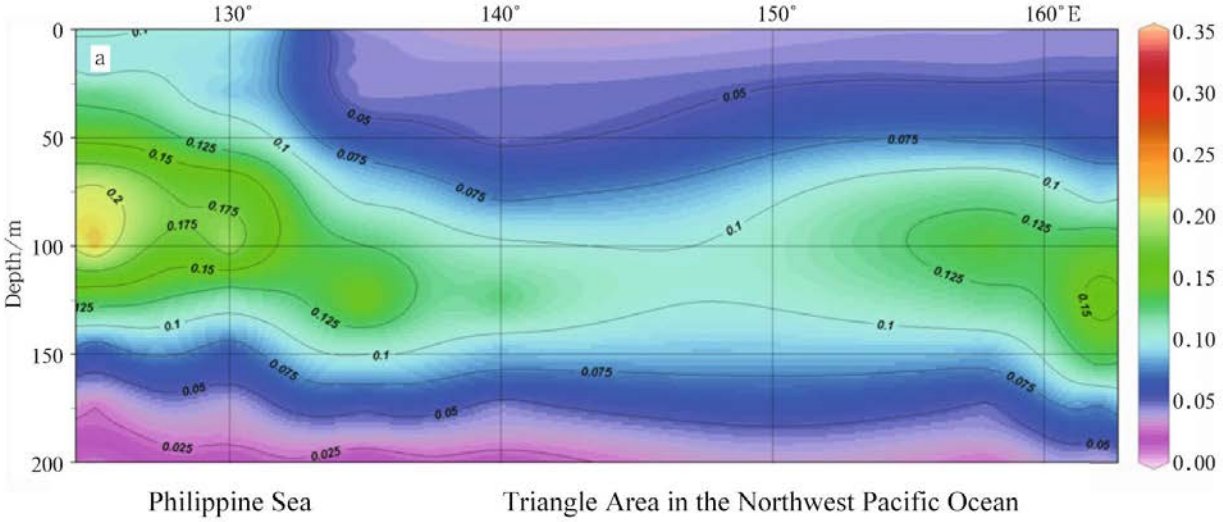

Figure 6.2.2. Profile of chlorophyll *a* concentration in the upper ocean of the subtropical Western Pacific along a longitudinal gradient, showing the difference between the Philippine Sea and the water column overlying the seabed where exploration contracts have been awarded by the ISA. Reproduced from D. Zhang et al. (2012).

Chlorophyll *a* concentration in the Northwest Pacific also exhibits strong temporal and spatial variations. Since most field-measurements in this region are taken during the summer and autumn seasons, satellite remote sensing data were used to study the seasonal variation in chlorophyll a concentration in the upper ocean. The central and southern parts of this region experience highly oligotrophic conditions throughout the year, whilst the northern parts have seasonal phytoplankton blooms in winter and spring. These seasonal blooms may be due to the enhanced mixing conditions of the upper ocean and increased nutrient supply to the photic layer in winter (Figure 6.2.3). Seasonal blooms may provide more biological material and energy, leading to a higher carrying capacity of pelagic ecosystems and fishery production in the northern parts of the region compared to the south.

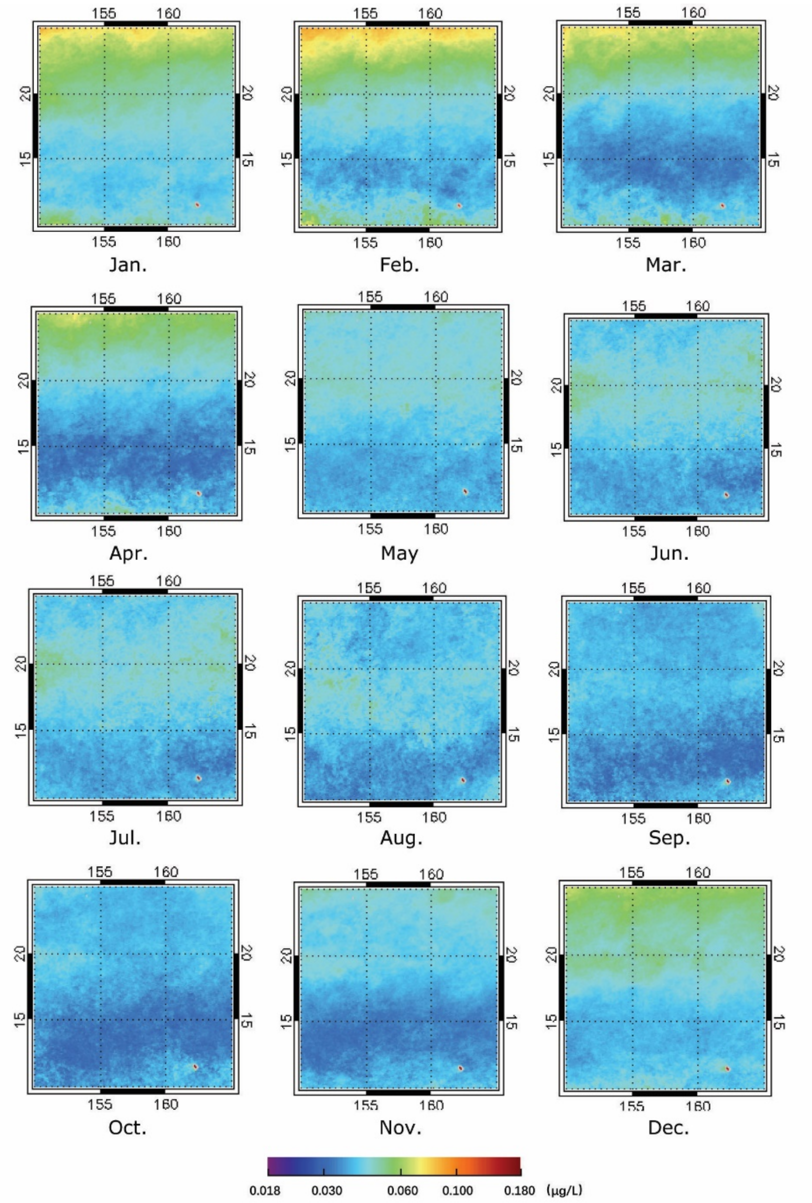

Figure 6.2.3. Temporal and spatial variation in chlorophyll *a* concentration in the surface waters overlying the seabed where exploration contracts have been awarded by the ISA in the Northwest Pacific Ocean. Based on data from 2012-2018, data source: SeaWiFS. Credit Shu-Jie Yu.

6.2.1.3.2 Zooplankton

Studies of the mesopelagic and deep-water zooplankton communities around deep-sea seamounts are generally scarce and very few have been conducted in the Northwest Pacific. In one study conducted at a deep-sea seamount in the East Pacific Ocean, a secondary peak in zooplankton biomass and copepod abundance was found between 600 to 1000 m, close to the summit depth of the seamount, although similar peaks in abundance have not always been found in other studies (Saltzman and Wishner, 1997). Genin (2004) suggested that the classical upwelling and enhanced primary productivity hypothesis at seamounts could be only used to explain the higher zooplankton biomass around shallower seamounts. At shallower seamounts, a more persistent and stronger upwelling occurs, enabling nutrient-rich deep-sea water to rise into and remain in the photic layer, stimulating phytoplankton blooms.

6.2.1.3.2.1 Studies from the COMRA contract area

The zooplankton community sampled from the COMRA contract area had high species diversity. Based on samples collected by plankton net, 252 species of mesozooplankton and six phyla were identified. Some of the taxonomic groups that were sampled included copepods, cnidarians, ostracods, chaetognaths, urochordates, euphausiids, pteropods, polychaetes, amphipods, *Sergestes* sp. shrimp and planktonic larvae. Copepods were the most diverse taxa, comprising 160 species and constituting 63% of total zooplankton community diversity. Other dominant groups include cnidarians, ostracods and chaetognaths (Figure 6.2.4).

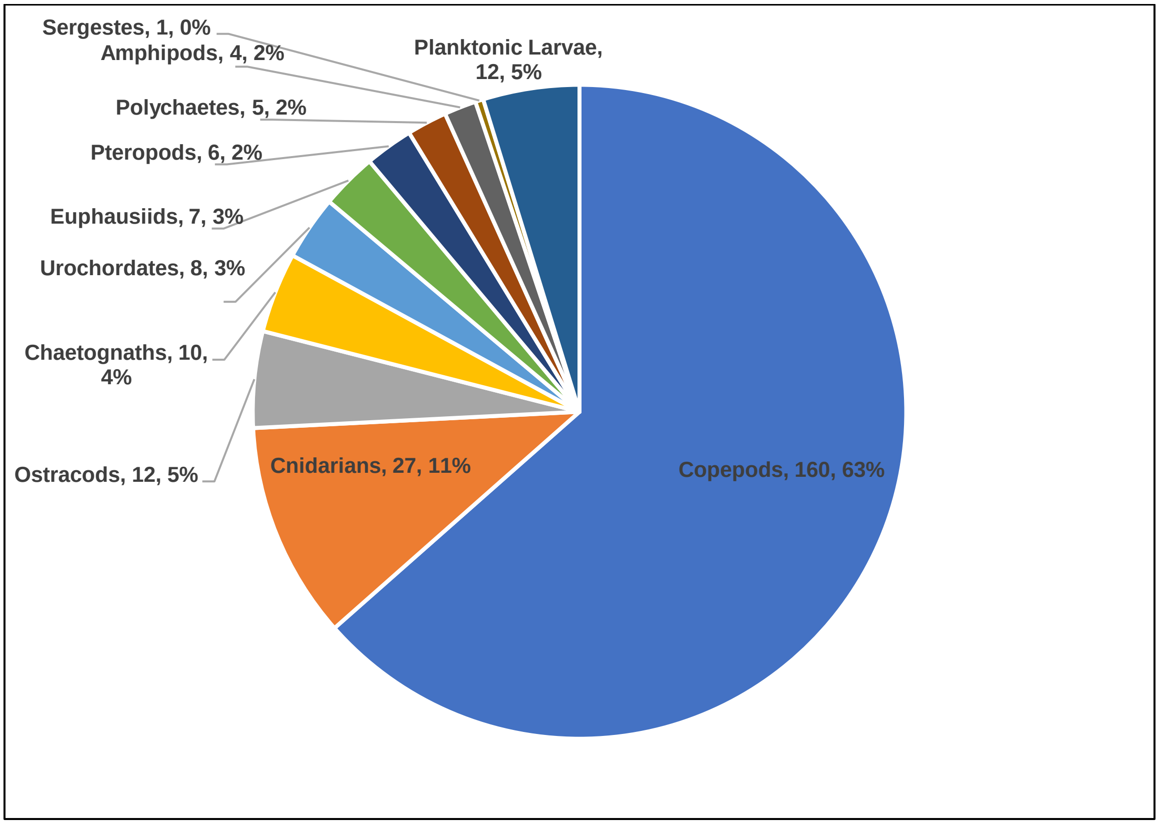

Figure 6.2.4. Taxonomic diversity of the zooplankton community in the surface waters overlying the seabed where exploration contracts have been awarded by the ISA in the Northwest Pacific Ocean. Data source: Cruise report DY48, unpublished. Credit Dong Sun.

Zooplankton biomass overlying the COMRA contract area is low and shows a marked decline from surface to mesopelagic depths. The average biomass was 5.14 mg m^{-3}, 1.43 mg m^{-3} and 0.88 mg m^{-3} at water depths of 0-200 m, 200-500m and 500-1000 m, respectively. Species diversity of the zooplankton community was also closely related to water depth, with the highest zooplankton diversity in the surface and subsurface layers, and significantly lower diversity below 500 m depth (Figure 6.2.5).

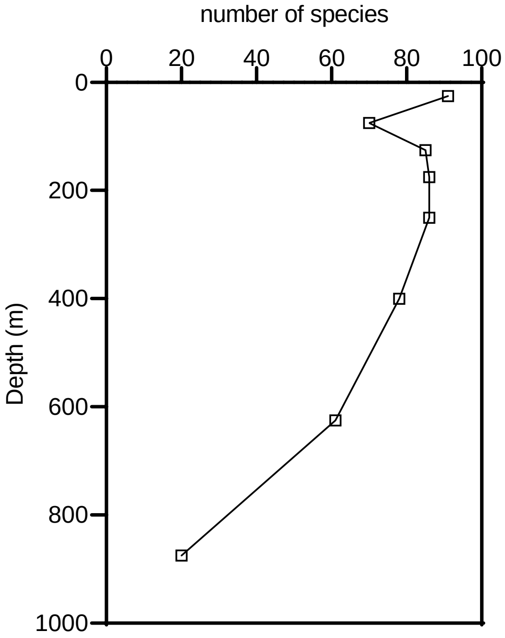

Figure 6.2.5. The relationship between species diversity of zooplankton community and water depth in the water column overlying the seabed where exploration contracts have been awarded by the ISA in the Northwest Pacific Ocean. Data source: Cruise report DY48, unpublished. Credit Dong Sun.

Along a latitudinal gradient, the Northwest Pacific region can be divided into two parts at 19°N based on the spatial differences in chlorophyll *a* concentration over the past seven years. The zooplankton biomass in the upper layer of the northern part of the region was higher than that in the southern part, whereas there was no significant difference between the northern and southern parts of the region at mesopelagic depths. The average zooplankton biomass at 0-200 m was 5.73 mg m^{-3} in the northern part and 4.46 mg m^{-3} in the southern part. The average biomass at 200-500 m was 1.43 mg m^{-3} and 1.44 mg m^{-3} in the northern and southern parts, respectively. The average biomass of 500-1000 m was 0.87 mg m^{-3} in the northern part and 0.90 mg m^{-3} in the southern part of the region (Figure 6.2.6). These results indicate that the vertical energy transfer efficiency is likely to be higher in the more oligotrophic southern region.

The pelagic environment around Weijia Seamount, located at the southernmost part of the cobalt-rich ferromanganese crusts seamount region (13°N), is affected by persistent oligotrophic conditions, and had lower zooplankton biomass. The average biomass at 0-200 m depth was 3.33 mg m^{-3}, decreasing to approximately 10% of the biomass of the upper layer at a depth of 500 – 1000 m, with an average biomass of 0.30 mg m^{-3}. Zooplankton abundance also decreased with increasing depth. The average zooplankton abundance at 0-200 m depth was 21.67 individuals m^{-3}, decreasing to approximately 5% of the abundance in the upper layer at 500-1000 m, with an average abundance of 1.03 individuals m^{-3}.

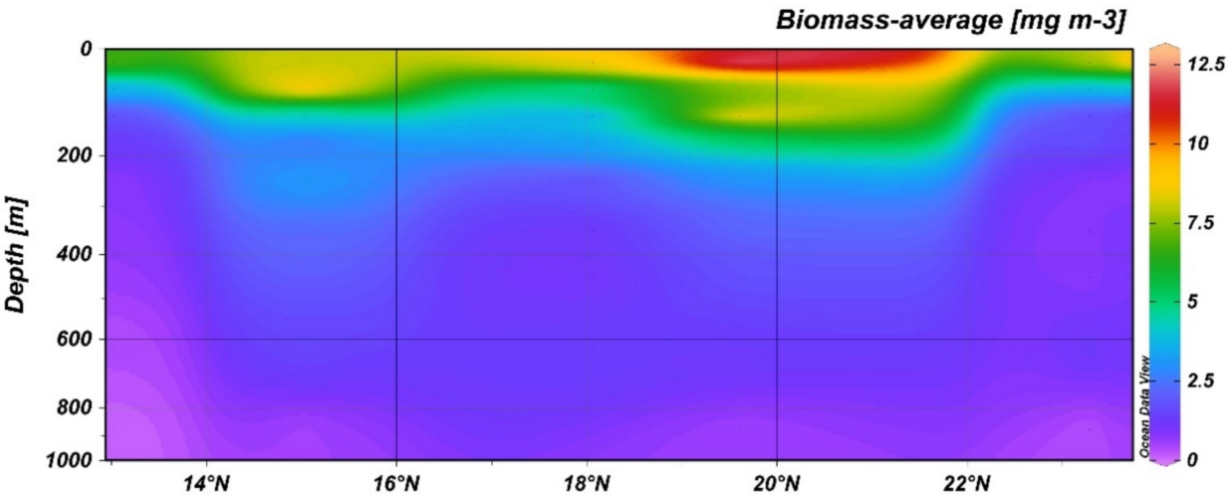

Figure 6.2.6 Profile of zooplankton biomass in the water column at 0-1000 m depth, along a latitudinal gradient in the water column overlying the seabed where exploration contracts have been awarded by the ISA in the Northwest Pacific Ocean. Data source: Cruise report DY48, unpublished. Credit Dong Sun.

6.2.1.4 Mid-water nekton

6.2.1.4.1 Fishes

Recent estimates suggest the majority of global fish biomass inhabits the mid-water zone between 200 – 1000m depth (Irigoien et al., 2014), however there have been few studies conducted on the spatial distribution of mid-water fishes in the Northwest Pacific region where mineral exploration contracts have been granted by the ISA. One of the few studies conducted was reported by Orlov (1991). Pelagic fish were surveyed in January-February 1983 between 15-25°N and 148°E – 179°W across 14 seamounts, all located on the seabed beyond national jurisdiction. Twelve of these seamounts were in the Northwest Pacific region where mineral exploration contracts have been granted by the ISA, or near this region (Figure 6.2.7). The sound-scattering layer (SSL) was reported as a continuous ribbon at 100-700 m for up to 5 nautical miles. Pelagic trawling in the SSL resulted in as many as 53 species per trawl represented by juvenile and small species of squids, decapods, pyrosomes, Leptocephali eels and, also Myctophidae, Sternoptychidae, Gonostomatidae, Chauliodontidae, Astronesthidae and Melastomiatidae fishes.

In pelagic trawls, species of Bramidae, Pteraclidae, and Nomeidae fishes were collected and *Carcharhinus longimanus* were recorded from visual observations. The absence of epipelagic top predators, such as tuna, xiphiids, and coryphena was explained by virtual absence of flying fish (Orlov, 1991). Meropelagic fish were represented by Myctophidae, *Vinciguirria* sp. (Photiochthydae), *Gempylus serpens* (Gempylidae) and other diurnal migrants. Mesopelagic fish were represented by Alepisauridae, Gempylidae, Paralepidae, Myctophydae, Sternoptychidae, Astronesthidae, Melanostomatidae, Chauliodontidae, Stomiatidae, Malacosteidae, Idiacanthidae, Omosudidae, Evermannelidae, and Nemichthydae. Myctophidae was the most diverse fish family (approximately 25 species) and the most numerous (up to 250-300 specimens per haul). Bathypelagic fish were poorly sampled, represented by a few specimens of Cetomimidae, Eurypharyngidae, and Ceratoidei. Serrivomeridae and Melampheidae within the bathypelagic were more numerous with up to 60 and 20-30 specimens per haul, respectively.

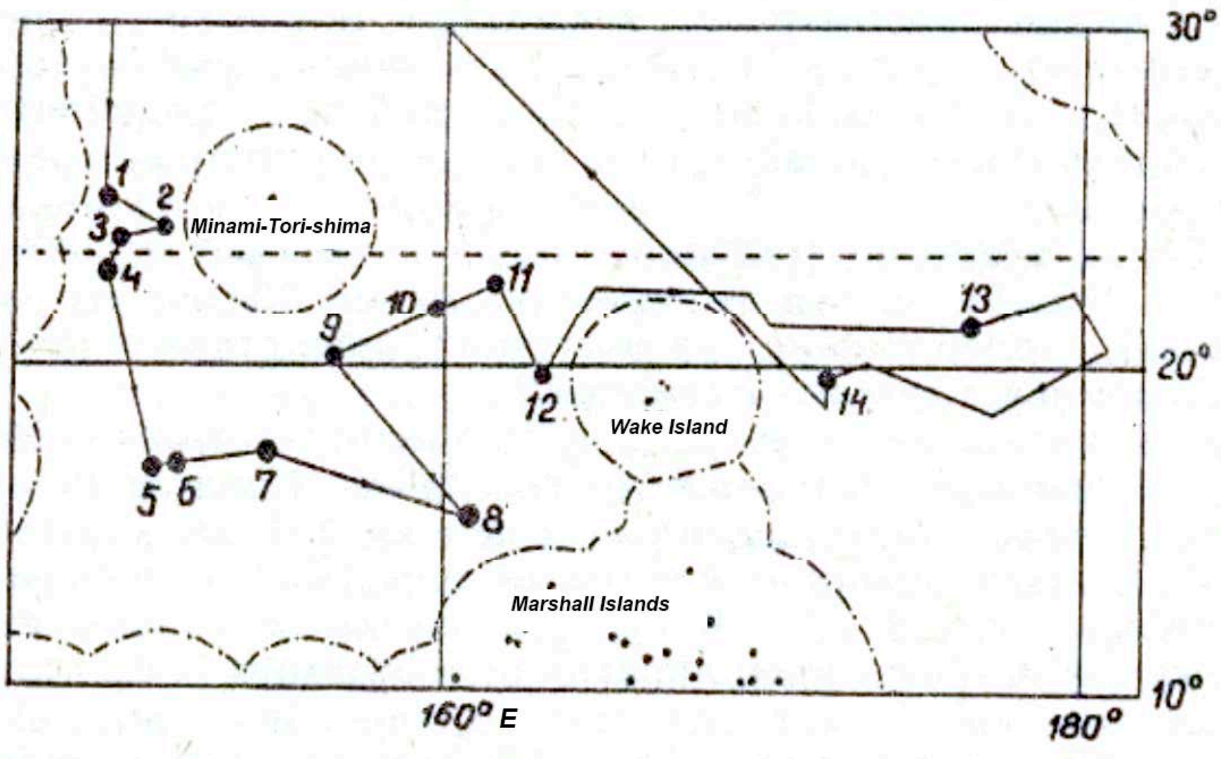

Figure 6.2.7. Seamounts studied in Jan-Feb 1983 by TINRO (FV Novoulyanovsk, midwater and benthic fish fauna). Modified from Orlov (1991) by Tina Molodtsova.

6.2.1.4.1.1 Studies from the COMRA contract area

The micronekton dwelling in mesopelagic zones are an important ecological group in oligotrophic oceans, playing a key role in the transfer of energy to the deep sea. Environmental baselines surveys conducted within the COMRA contract area included a survey of the micronekton community in the Northwest Pacific region using acoustic methods. The main targets of this survey were the deep sound scattering layers (DSLs), which were distributed at a depth of 200-1000 m. This survey demonstrated that the biomass of micronekton in the northern part of the region was higher than that in the southern part of the region, and that the boundary for the two parts of the region occurred at 19°N. In the northern part of the region, the nautical area scattering coefficient (NASC, a proxy of mesopelagic biomass) for the DSLs was 50-200 m^2 per square nautical mile, with an average value of 104 m^2 per square nautical mile. In the southern part of the region, the NASC of DSLs was 10-50 m^2 per square nautical mile and the average value was 28 m^2 per square nautical mile. The occurrence depth of micronekton in the mesopelagic exhibited a tendency to deepen with latitude (Figure 6.2.8; Song et al., in review).

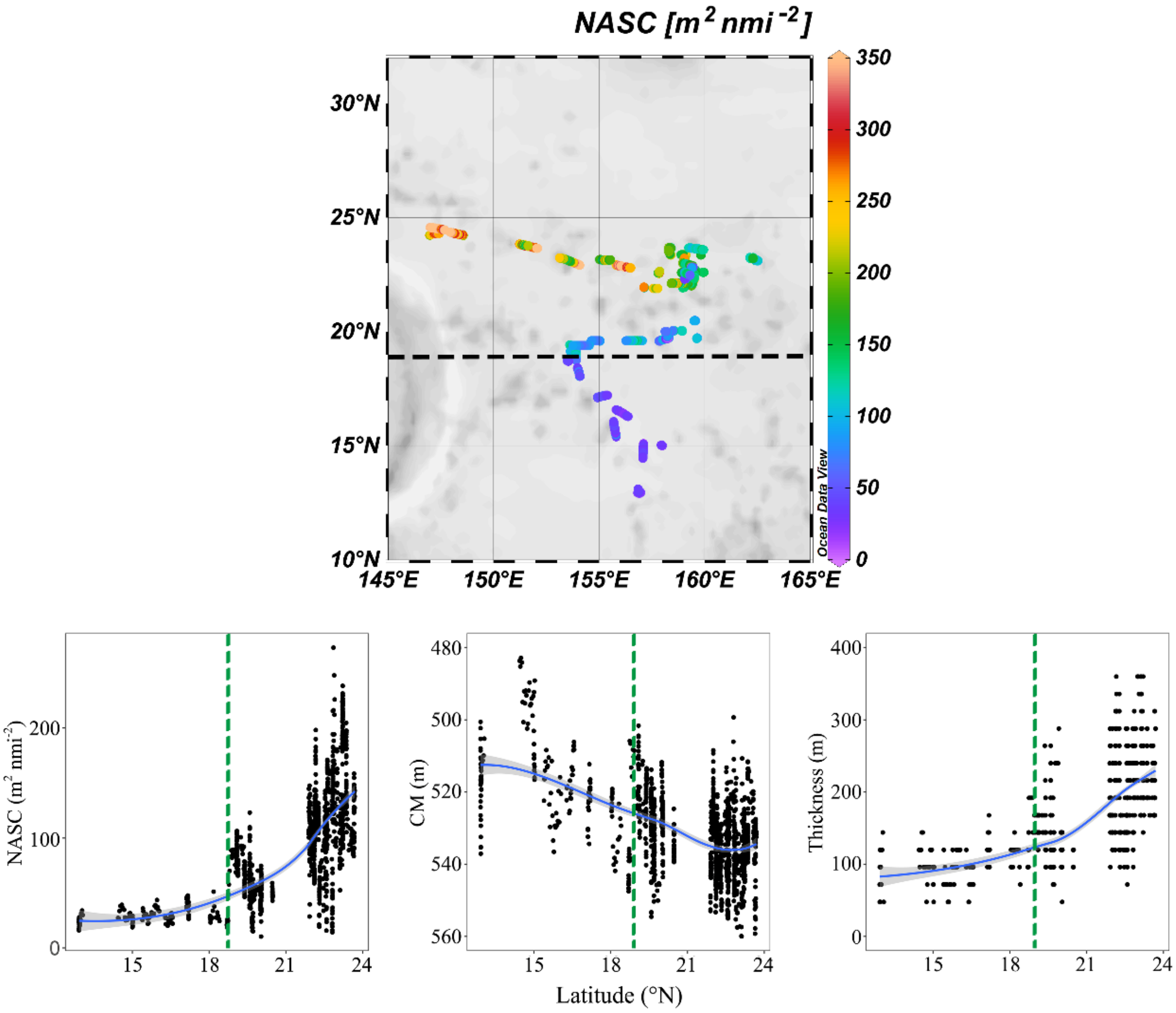

Figure 6.2.8. Latitudinal variation of deep sound scattering layers (DSLs) in the water column overlying the seabed where exploration contracts have been awarded by the ISA in the Northwest Pacific Ocean (Song et al., in review). Top: horizontal distribution of the nautical area scattering coefficient (NASC); bottom-left: latitudinal variation of NASC; bottom-middle: latitudinal variation of centre of mass (CM) of DSLs; bottom-right: latitudinal variation of DSLs thickness. Credit Dong Sun.

6.2.1.5 Sharks and commercially important fishes

According to the Food and Agriculture Organization (FAO) of the United Nations, the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA overlaps the Western and Central Pacific Fisheries Commission (WCPFC) and the North Pacific Fisheries Commission (NPFC) convention areas and is located close to the southwest corner of the North Pacific Anadromous Fish Commission (NPAFC) convention area (Løbach et al., 2020). These Regional Fisheries Management Organizations (RFMOs) are good sources of baseline information on the spatial distribution and temporal variability of commercially important fishes in the Northwest Pacific, as well as information on the current and historic fisheries activities, other stressors, and stock and conservation status (Løbach et al., 2020). The WCPFC is also a potential source of information for various shark species, having adopted binding measures for the prevention of bycatch and for the conservation of non-target species, including sharks, in 2006 (Løbach et al., 2020). Within its convention area, the WCPFC (with its 26 members) regularly assesses up to ten highly migratory fish stocks and manages up to ten fisheries, authorizing between 3,000 and 7,000 vessels to fish in 2017 (Løbach et al., 2020). There are currently 19 WCPFC stocks of interest, 14 of which have distributions that overlap the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA (Table 6.2.1; WCPFC, 2019).

Table 6.2.1. Overview of stocks of interest to the Western and Central Pacific Fisheries Commission (WCPFC, 2019). The last column indicates the potential overlap with the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA, derived from the Food and Agriculture Organization of the United Nations aquatic species distribution records (FAO, 2020). Credit Cherisse Du Preez.

Stock	Latest Assessment	Overfished[1]	Overfishing[1]	Potential overlap with exploration contracts issued by the ISA[2]
WCPO Tuna				
Bigeye tuna (*Thunnus obesus*)	UPDATE 2018 (SC14)	No (100%)	No (94%)	Yes
Yellowfin tuna (*Thunnus albacares*)	2017 (SC13)	No (92%)	No (96%)	Yes
Skipjack tuna (*Katsuwonus pelamis*)	2019 (SC15)	No	No	Yes
South Pacific albacore tuna (*Thunnus alalunga*)	2018 (SC14)	No	No	No
Northern Stocks				
North Pacific albacore (*Thunnus alalunga*)	2017 (SC13)	No	No	Yes
Pacific bluefin tuna (*Thunnus orientalis*)	UPDATE 2018 (SC14)	Yes	Yes	Yes
North Pacific swordfish (*Xiphias gladius*)	2018 (SC14)	No	No	Yes
WCPO Billfish				
Southwest Pacific swordfish (*Xiphias gladius*)	2017 (SC13)	No (100%)	No (68%)	No
Southwest Pacific striped marlin (*Kajikia audax*)	2019 (SC15)	Likely (50%)	No (56%)	No
North Pacific striped marlin (*Kajikia audax*) (*Tetrapturus audax*)	2019 (SC15)	Yes	Yes	Yes
Pacific blue marlin (*Makaira nigricans*)	2016 (SC12)	No	No	Yes
WCPO Sharks				
Oceanic Whitetip shark (*Carcharhinus longimanus*)	2019 (SC15)	Yes	Yes	Yes
Silky shark (*Carcharhinus falciformis*)	2018 (SC14)	No (indicative)	Yes (indicative	Yes
South Pacific blue shark (*Prionace glauca*)	2016 (SC12)	N/A	N/A	No
North Pacific blue shark (*Prionace glauca*)	2017 (SC13)	No	No	Yes
North Pacific shortfin mako (*Isurus oxyrinchus*)	2018 (SC14)	No (>50%)	No (50%)	Yes

Pacific bigeye thresher shark (*Alopias superciliosus*)	2017 (SC13)	N/A	N/A	Yes
Southern Hemisphere Porbeagle shark (*Lamna nasus*)	2017 (SC13)	N/A	Very low	No
Whale Shark (*Rhincodon typus*)	'PS Risk' 2018 (SC14)	N/A	N/A	Yes

[1] The determination of overfished and overfishing is a likelihood not a firm statement – where a percentage is provided that indicates probability.

[2] Potential overlap with with the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA is based on the regional specificity of the stock, not the species distribution.

Within its convention area, the NPFC (with its eight contracting parties) regularly monitors fisheries targeting more than ten fish stocks, authorizing between 1,000 and 3,000 vessels to fish in 2017 (Løbach et al., 2020). In the Northwest Pacific, these include fisheries targeting bottom fish stocks on the Emperor seamounts (primarily North Pacific armorhead, *Pentaceros wheeleri*; splendid alfonsino, *Beryx splendens*; oreo, *Allocyttus verrucosus*; and mirror dory, *Zenopsis nebulosa*) and pelagic fish stocks that range widely across the convention and adjacent areas (Pacific saury, *Cololabis saira*; chub mackerel, *Scomber japonicus*; spotted mackerel, *Scomber australasicus*; Japanese sardine, *Sardinops melanostictus*; neon flying squid, *Ommastrephes bartramii*; and Japanese flying squid, *Todarodes pacificus*) (NPFC, 2020). Three of the contracting parties actively target commercially important bottom fish stocks and six target commercial pelagic fish stocks in the convention area. Data collected by members of the NPFC on commercial fisheries include spatially explicit catch and effort by species, life history information (such as length, weight, sex ratios, and age structure), bycatch of non-target fishes and invertebrates, and fisheries independent survey data. More information on the bottom fish stock species is provided in Section 6.3.1.2.3.1: Benthic and demersal nekton – fishes.

Whilst Pacific salmon (*Oncorhynchus* spp.) migrate over considerable distances and their open ocean distributions, migration routes, and timings are not well known (e.g., Myers et al., 2007) it is unlikely their spatial distributions overlap the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA. That said, oceanic fishes such as Pacific salmon may be vulnerable to indirect mining effects that occur beyond the scale of the mining sites (e.g., large-scale oceanic food web perturbation; Drazen et al., 2019). Salmon are valuable species within Pacific rim nations (Vierros et al., 2020), for their ecological importance, economic value, and cultural and social significance (e.g., NPAFC current members: Canada, Japan, the Republic of Korea, the Russian Federation, and the United States of America). Chum (*O. keta*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon are the most abundant of the salmon species inhabiting the open Pacific Ocean, Chinook (*O. tshawytscha*), Coho (*O. kisutch*), Masu (*O. masou*) and Steelhead (*O. mykiss*) are less abundant (Myers et al., 2007 and the references therein; Ruggerone and Irvine 2018). Low returns of many salmon populations are the result of multiple factors including stressors facing salmon in the North Pacific open ocean phase of their lives, such as climate change induced environmental shifts and competition for limited prey resources (Myers et al., 2007; Holt et al., 2008; NPAFC, 2019), but not all populations and species are in decline.

The Northwest Pacific has high fisheries production, with 25% of the global catch landed in 2017. Based on the recent report of the Food and Agriculture Organization (FAO, 2020), in the 1980s and 1990s, the total catch in the Northwest Pacific fluctuated between 17 and 24 million tons and was recorded as 22.2 million tons in 2017. Historical data show that the Japanese sardine (*Sardinops melanostictus*) and Alaska cod (*Theragra* *chalcogramma*) are the main species caught in this region, with peak production of 5.4 and 5.1 million tons respectively, although catches have declined sharply in the past 25 years. Conversely, the catch of squid, cuttlefish, octopus, and shrimp has increased significantly since the 1990s. Monitoring data from 2017 showed that two populations of Japanese anchovies (*Engraulis japonicus*) and one population of Alaskan cod were overfished. As of 2017, of the fish stocks monitored in the Northwest Pacific, approximately 65.4% were caught within the limits of biological sustainability and 34.6% were beyond sustainable limits (FAO, 2020).

The succession of fish species and patterns in fishery exploitation in the Northwest Pacific can reflect the dynamics of the ecosystem. Japanese fishing data show fluctuations in peak production and target species every ten years. This period is related to changes in environmental parameters, such as Sea Surface Temperature (Yasunaka and Hanawa, 2002), and the path of the Kuroshio Current and the Pacific Decadal Oscillation Index (PDO: Mantua and Hare, 2002).

The Northwest Pacific has the highest density of seamounts in the world (Kitchingman et al., 2007). Generally, seamount fish stocks are mostly composed of deep-sea fish, although many shallow water species also gather at seamounts (Rogers, 2018). Seamounts can have highly diverse fish communities, for example in one study of the 535 species of seamount fish, 62 species occurred on the same seamount (Froese and Sampang, 2004). Many pelagic predators of commercial interest also gather near or at the top of seamounts, such as the blue shark (*Prionace glauca*), tunas, and billfishes. Some fishes associated with coral reefs also gather to spawn at shallow water seamounts where the seamount peak is less than 200 m from the sea surface (Rogers, 2018).

The blue shark (*Prionace glauca*) is widely distributed in temperate and tropical Pacific waters and is the most abundant shark species in the North Pacific (King et al. 2015). Although the blue shark is not listed as ‘overfished’ or subject to ‘overfishing’ by the WCPFC (Table 6.2.1), this species is listed as ‘near threatened’ (Rigby et al., 2019), with multiple characteristics that make the species vulnerable to environmental changes and anthropogenic impacts (e.g., King et al., 2015). In the North Pacific, the distribution of the blue shark exhibits spatial and temporal variation according to individual size and gender. Tagging data also indicates that the blue shark can migrate for long distances with a highly mixed population in the North Pacific (WCPFC, 2017). Research suggests that there is a single population of blue shark in the North Pacific. Blue shark individuals less than 50 cm long are usually distributed in the 35-40°N breeding area. Juvenile (length 100 – 150 cm) females are distributed at 35-50°N, with the males occurring in the 30-40°N range. The distribution of adult blue shark is more southerly (Nakano, 1994). Generally, the mating period for blue sharks is from June to August, and the juveniles in the Northwest Pacific (15-112 cm length, 35.5 cm average) are longer than those in other parts of the North Pacific (1-62 cm length, 25.6 cm average) (Nakano, 1994; Fujinami et al., 2017). Other shark species known to occur within the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA include those listed as stocks of interest to the WCPFC (Table 6.2.2), as well as the great white shark (*Carcharodon carcharias*; FAO, 2020).

The Northwest Pacific is an important source of tuna and billfish, such as swordfish. These large predatory fish account for more than 70% of the total high sea fishery production in the region (FAO, 2020). According to the data from Fisheries and Resources Monitoring System (FIRMS), tuna can travel long distances, and migrate between different regions. For example, bluefin tuna tagged offshore of southern California have been recorded as migrating into the Northwest Pacific (Block et al., 2011). Pacific bluefin tuna, yellowfin tuna and bigeye tuna are mainly distributed in the Northwest Pacific. In the Northwest Pacific region where exploration contracts have been awarded by the ISA longline fishing is the most common fishing method. The potential of fishery resources and current catch is higher in the northern and western part of this region, resulting from higher primary productivity (Figure 6.2.9).

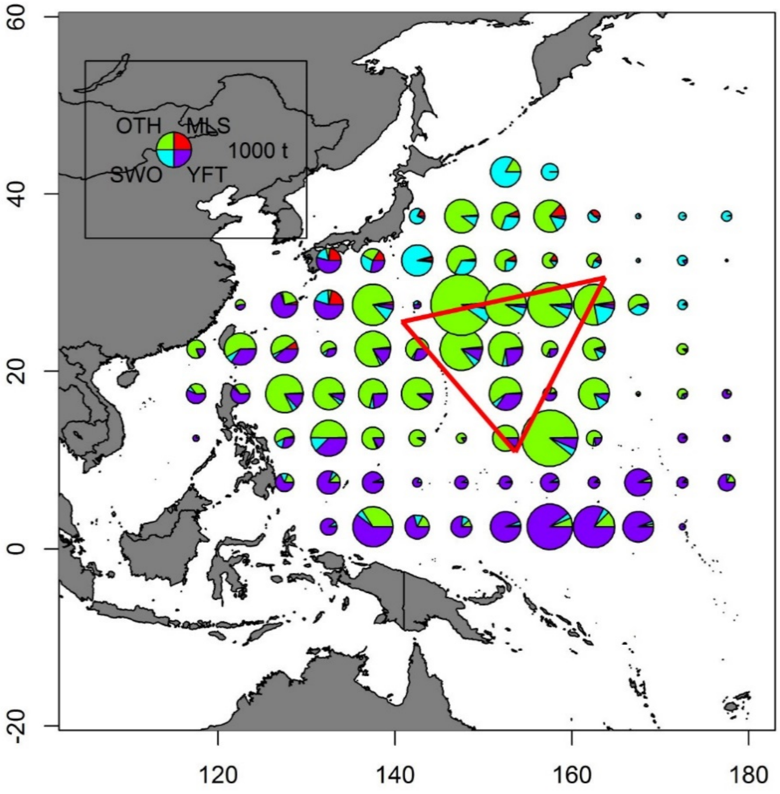

Figure 6.2.9. Distribution of the main fishing catches in the Northwest Pacific Ocean, including where exploration contracts have been awarded by the ISA (red triangle). MLS: striped marlin; OTH: other fishes; SWO: swordfish; YFT: yellowfin tuna. Based on WCPFC 2014 open data. Credit Li-Bin Dai.

6.2.1.6 Air-breathing fauna

6.2.1.6.1 Seabirds

As top predators in the marine food web, seabirds can be used as indicators of primary productivity and general ecosystem health. Seabirds are one of the most threatened groups of vertebrates in the world. Of the 346 seabird species, 97 (28%) are globally threatened (IUCN, 2020). Almost half of seabird populations are currently in decline, and a third of the world's seabird species are threatened with extinction. Researchers estimates that more than 170 million individual birds (approximately 20% of all seabirds) are currently exposed to the combined impacts of bycatch, invasive species, and climate change/severe weather, with more than 380 million individuals (approximately 45% of all seabirds) exposed to at least one of these three threats (Dias et al., 2019).

A diverse array of seabird species is widespread in the Northwest Pacific Ocean. The main groups belong to Procellariiformes, Charadriiformes and Pelicaniformes, amongst which the Procellariiformes are the most threatened. Approximately 65% of the species in the Northwest Pacific Ocean are under a degree of threat. Albatross, petrels, and storm-petrels are the most typical oceanic seabirds living in the Northwest Pacific Ocean.

Table 6.2.2 lists the major seabird groups in the Northwest Pacific Ocean and their threatened status according to the International Union for Conservation of Nature (IUCN) Red List, with 27 out of the 61 species classified above ‘near threatened’.

Table 6.2.2. The status of seabirds in the Northwest Pacific Ocean according to the IUCN Red List. IUCN level: least concern, LC; near threatened, NT; vulnerable, VU; endangered, EN; and critically endangered, CR. Credit Hong-Chang Zhai.

Taxonomy	**English name**	**scientific name**	IUCN Red List
Procellariiformes/Diomedeidae	Short-tailed Albatross	*Phoebastria albatrus*	VU
	Laysan Albatross	*Phoebastria immutabilis*	NT
	Black-footed Albatross	*Phoebastria nigripes*	NT
Procellariiformes/Procellariidae	Tahiti Petrel	*Pseudobulweria rostrata*	NT
	Providence Petrel	*Pterodroma solandri*	VU
	Kermadec Petrel	*Pterodroma neglecta*	LC
	Juan Fernandez Petrel	*Pterodroma externa*	VU
	White-necked Petrel	*Pterodroma cervicalis*	VU
	Bonin Petrel	*Pterodroma hypoleuca*	LC
	Black-winged Petrel	*Pterodroma nigripennis*	LC
	Stejneger's Petrel	*Pterodroma longirostris*	VU
	Bulwer's Petrel	*Bulweria bulwerii*	LC
	Cook's Petrel	*Pterodroma cookii*	VU
	Collared Petrel	*Pterodroma brevipes*	VU
	Phoenix Petrel	*Pterodroma alba*	EN
	Mottled Petrel	*Pterodroma inexpectata*	NT
	Hawaiian Petrel	*Pterodroma sandwichensis*	EN
	White-winged Petrel	*Pterodroma leucoptera*	VU
	Herald Petrel	*Pterodroma heraldica*	LC
	Pycroft's Petrel	*Pterodroma pycrofti*	VU

	Streaked Shearwater	*Calonectris leucomelas*	NT
	Flesh-footed Shearwater	*Ardenna carneipes*	NT
	Pink-footed Shearwater	*Ardenna creatopus*	VU
	Wedge-tailed Shearwater	*Ardenna pacifica*	LC
	Buller's Shearwater	*Ardenna bulleri*	VU
	Sooty Shearwater	*Ardenna grisea*	NT
	Short-tailed Shearwater	*Ardenna tenuirostris*	LC
	Christmas Shearwater	*Puffinus nativitatis*	LC
	Tropical Shearwater	*Puffinus bailloni*	LC
	Heinroth's Shearwater	*Puffinus heinrothi*	VU
Procellariiformes/Oceanitidae	Wilson's Storm-petrel	*Oceanites oceanicus*	LC
	White-faced Storm-petrel	*Pelagodroma marina*	LC
	Polynesian Storm-petrel	*Nesofregetta fuliginosa*	EN
	Leach's Storm-petrel	*Hydrobates leucorhous*	VU
	Band-rumped Storm-petrel	*Hydrobates castro*	LC
	Matsudaira's Storm-petrel	*Hydrobates matsudairae*	VU
	Tristram's Storm-petrel	*Hydrobates tristrami*	NT
	Black-bellied Storm-petrel	*Fregetta tropica*	LC
	White-bellied Storm-petrel	*Fregetta grallaria*	LC
	Swinhoe's Storm-petrel	*Hydrobates monorhis*	NT
Suliformes/Fregatidae	Lesser Frigatebird	*Fregata ariel*	LC
	Great Frigatebird	*Fregata minor*	LC
Phaethontiformes/Phaethontidae	Red-billed Tropicbird	*Phaethon aethereus*	LC
	Red-tailed Tropicbird	*Phaethon rubricauda*	LC
	White-tailed Tropicbird	*Phaethon lepturus*	LC

Suliformes/Sulidae	Red-footed Booby	*Sula sula*	LC
	Brown Booby	*Sula leucogaster*	LC
	Masked Booby	*Sula dactylatra*	LC
Charadriiformes /Laridae	Brown Noddy	*Anous stolidus*	LC
	Black Noddy	*Anous minutus*	LC
	Blue-gray Noddy	*Procelsterna cerulea*	LC
	Common White Tern	*Gygis alba*	LC
	Grey-backed Tern	*Onychoprion lunatus*	LC
	Little Tern	*Sternula albifrons*	LC
	Common Gull-billed Tern	*Gelochelidon nilotica*	LC
	White-winged Tern	*Chlidonias leucopterus*	LC
	Bridled Tern	*Onychoprion anaethetus*	LC
	Greater Crested Tern	*Thalasseus bergii*	LC

The seabirds in the Northwest Pacific Ocean have strong migratory habits, with some species undertaking long-distance migrations across the Equator. Pacific Ocean Basin migration routes can be grouped into ‘flyways’, with the Central Pacific Flyway and Asian-Australian Flyway crossing the Northwest Pacific Ocean (Figure 6.2.10). An example migratory bird using the Asian-Australasian Flyway is the flesh-footed shearwater, whose distribution encompasses almost all of the Northwest Pacific Ocean (BirdLife, 2018). The flesh-footed shearwater migrates northwards from New Zealand in April to May every year, with most non-breeding populations located in the Kuroshio-Oyashio Transition Area. In May to June, the main distribution area of the flesh-footed shearwater is in the range of 25-35°N, from June to September this distribution shifts North of 40°N. The southward migration back towards New Zealand occurs from October to November every year. When returning South towards the New Zealand colonies, there is some indication that birds pass further East than on the northward migration (Rayner et al., 2011; Reid et al., 2013).

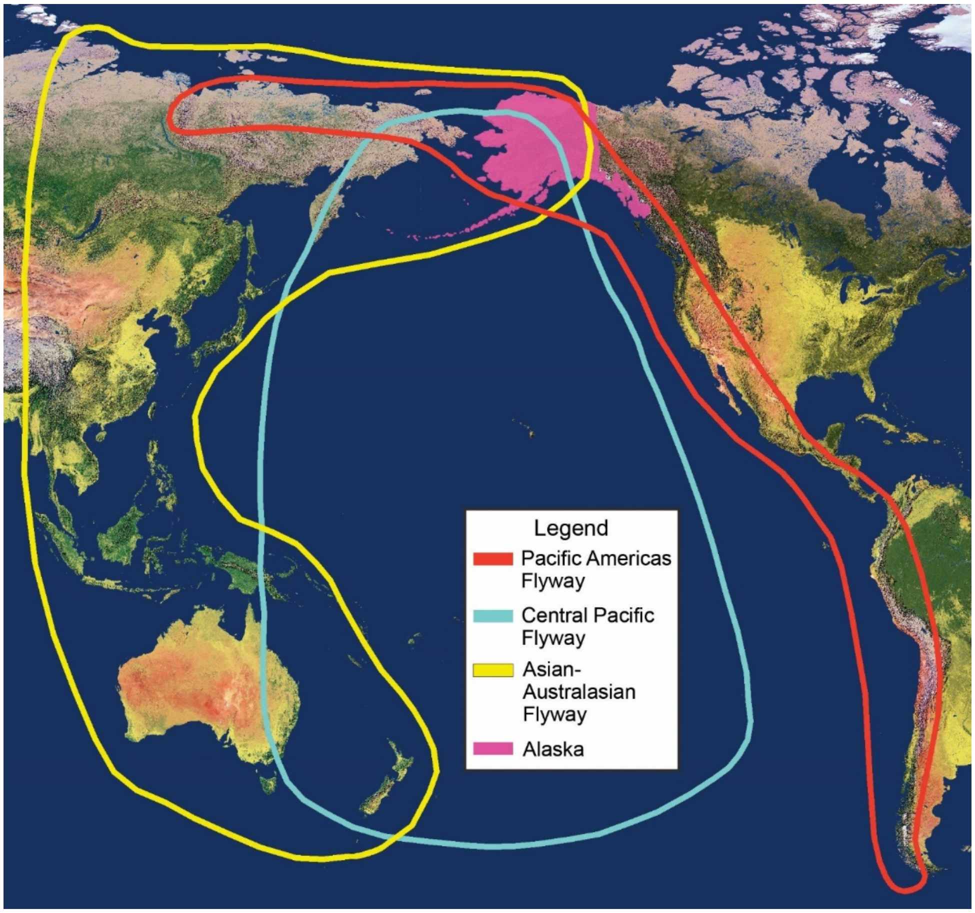

Figure 6.2.10. Graphic depicting five bird migration flyways of the Pacific Ocean basin. Credit Mary Whalen, USGS, Alaska Science Center.

6.2.1.6.2 Sea turtles

Several species of sea turtles occur in the Northwest Pacific Ocean (FAO, 2020; Lewison et al., 2014). The Tagging of Pacific Predators, a field program of the Census of Marine Life, documented the migration pathways of vulnerable leatherback (*Dermochelys coriacea*) and endangered loggerhead (*Caretta caretta*) sea turtles. Both these turtle species were recorded crossing the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA (Block et al., 2011; Vierros et al., 2020). Leatherback turtles also have considerable cultural significance to communities in Pacific Island Countries and Territories (Figure 6.2.11. Vierros et al., 2020). Other Pacific Ocean turtles known to migrate through this region include the green turtle (*Chelonia mydas*), the hawksbill turtle (*Eretmochelys imbricata*), and possibly the olive ridley turtle (*Lepidochelys olivacea*) (FAO, 2020).

Fisheries bycatch has been identified as a primary driver of population declines in Pacific Ocean turtles (Wallace et al., 2010). For instance, unsustainable levels of fishery bycatch mortality have decimated populations of the Pacific loggerhead turtles (Peckham et al., 2007). As a result, sea turtle bycatch prevention measures were adopted by the WCPFC in 2008. The WCPFC may provide an additional source of baseline information on the spatial distribution and temporal variability of sea turtles, and other air-breathing taxa, such as seabirds.

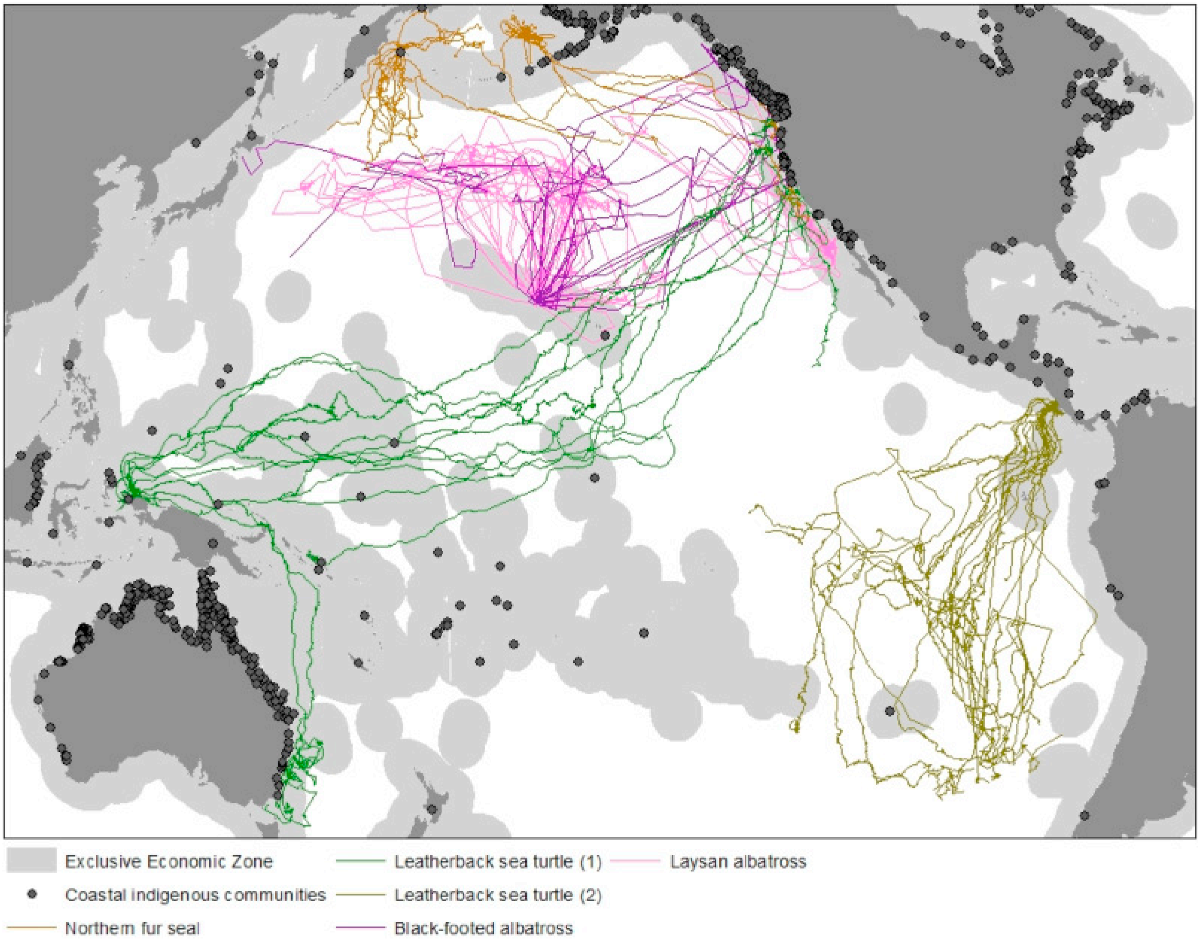

Figure 6.2.11. Selected migration paths of culturally important migratory species crossing jurisdictional boundaries in the Pacific Ocean. Reproduced from Vierros et. al (2020).

6.2.1.6.3 Marine mammals

Cetaceans occur in all major oceans, with many species of whales and dolphins recorded within the region of the Northwest Pacific Ocean where mineral exploration contracts have been granted by the ISA (Rice, 1998; Kaschner et al., 2011). Populations of large whales in the Pacific Ocean are still recovering from a long history of commercial exploitation (Magera et al., 2013) and populations of smaller cetaceans are currently under pressure from fisheries bycatch (Read et al., 2006). Cetaceans are also susceptible to contaminants because of their high trophic level (Cossaboon et al., 2019) and anthropogenic activities that degrade their habitat by significantly altering the natural ambient soundscape (NRC, 2005; Warner et al., 2019). The region of the Northwest Pacific Ocean where mineral exploration contracts have been granted by the ISA overlaps the International Whaling Commission (IWC) convention area (Løbach et al., 2020). The IWC may provide an additional source of baseline information on the spatial distribution and temporal variability of marine mammals in the region, as well as information on the historic fisheries activities, other stressors, and current conservation status. The IWC currently lists data for 21 species of interest, 16 of which have known primary or secondary ranges that overlapping the region of the Northwest Pacific Ocean where mineral exploration contracts have been granted by the ISA (Table 6.2.3). Historically, the primary focus of the IWC was the 'Great Whale' species heavily depleted by commercial whaling; more recently the organization has started to include small cetaceans within their conservation concerns and species of interest (IWC, 2020). In 2011 the WCPFC adopted binding measures for the prevention of bycatch and for the conservation of non-target species, including cetaceans (Løbach et al., 2020), thus the WCPFC may provide an additional source of baseline information on the spatial distribution and temporal variability of cetaceans within the region.

Table 6.2.3. Overview of the primary and secondary ranges for 16 whale species of interest to the International Whaling Commission, and the overlap between these ranges and the region of the Northwest Pacific where mineral exploration contracts have been granted by the ISA. Summary of information provided by IWC (2020) and the references therein. The International Union for Conservation of Nature (IUCN) conservation status is also provided. Credit Cherisse Du Preez.

Marine mammal	Scientific name	IUCN Conservation status	Potential overlap between primary or secondary ranges and the region where exploration contracts have been issued by the ISA
Blue whale	*Balaenoptera musculus*	Endangered	Yes, primary range
Bottlenose dolphin	*Tursiops truncatus* & *T. aduncus*	Data deficient	Yes, secondary range
Bryde's whale	*Balaenoptera edeni*	Data deficient	Yes, primary range
Common dolphin	*Delphinus delphis*	Least Concern	Yes, at least partially with its primary range
False killer whale	*Pseudorca crassidens*	Data deficient	Yes, primary range
Fin whale	*Balaenoptera physalus*	Vulnerable	Yes, at least partially with its primary range
Humpback whale	*Megaptera novaeangliae*	Vulnerable to least concern	Yes, at least partially with its primary & secondary range
Killer whale	*Orcinus orca*	Data deficient	Yes, at least partially with its primary & secondary range
Minke whale	*Balaenoptera acutorostrata* & *B. bonaerensis*	Least concern	Yes, primary range of *B. acutorostrata*
Pilot whale	*Globicephala melas* & *G. macrorhynchus*	Data Deficient	Yes, primary range of *G. macrorhynchus*
Right whale	*Eubalaena glacialis, E. japonica,* & *E. australis*	Endangered	Potential slight overlap with primary range
Sei whale	*Balaenoptera borealis*	Endangered	Yes, at least partially with its primary & secondary range
Sperm whale	*Physeter marcrocephalus*	Endangered	Yes, primary range

Spinner dolphin	*Stenella longirostris*	Data Deficient	Yes, primary range
Spotted dolphin	*Stenella attenuata* & *S. frontalis*	Least concern	Yes, primary range of *Stenella attenuata*
Striped dolphin	*Stenella coeruleoalba*	Least concern	Yes, primary range

6.2.2 Temporal variability

6.2.2.1 Diel (daily) vertical migration

The diel or daily vertical migration (DVM) of zooplankton, fishes, and other mobile species forms a fundamental component of the biological pump, the mechanism by which carbon-containing compounds are exported from the surface to the deep ocean (Sarmiento and Gruber 2006). The sound or deep scattering layer (SSL or DSL) is a dense aggregation of living organisms that undergoes DVM in response to changes in light intensity between the surface and roughly 1000 m depth (Proud et al., 2017). Where the seafloor rises to depths shallower than the SSL (e.g., seamount summits), the DVM of these mesopelagic organisms directly delivers nutrients from the surface to the benthic biota, providing input to the benthic food web (e.g., productivity and biomass), especially if the DSL is advected and retained by the local circulation (Pitcher and Bulman 2007). See Section 6.3.3.1 Trophic relationships – Seamount communities for further information on these trophic linkages. Deep-sea fishes and other species can display large DVMs to forage on the SSL (Afonso et al., 2014).

The average body size of zooplankton in the Northwest Pacific Ocean region is relatively small, and as a result there is only weak vertical migration of zooplankton. The average coefficient of DVM is only 0.9-1.1 (Sun et al., 2019), which is lower than the coefficient for the North Pacific or Tropical East Pacific (Steinberg et al., 2008). In terms of the different taxa, those with strong vertical migration patterns include copepods, ostracods and chaetognaths, whilst appendicularians have a patchier distribution (Figure 6.2.12).

As reported in the mid-water nekton fishes section (6.2.1.4.1), pelagic tows through the SSL in the Northwest Pacific region (Figure 6.2.10) landed Myctophidae, Sternoptychidae, Gonostomatidae, Chauliodontidae, Astronesthidae, Melastomiatidae, and other DVM fishes. Myctophidae or ‘lanternfish’ are amongst the most abundant group of mesopelagic fishes in the world and are both central consumers and prey items in open ocean food webs (e.g., Beamish et al., 1999).

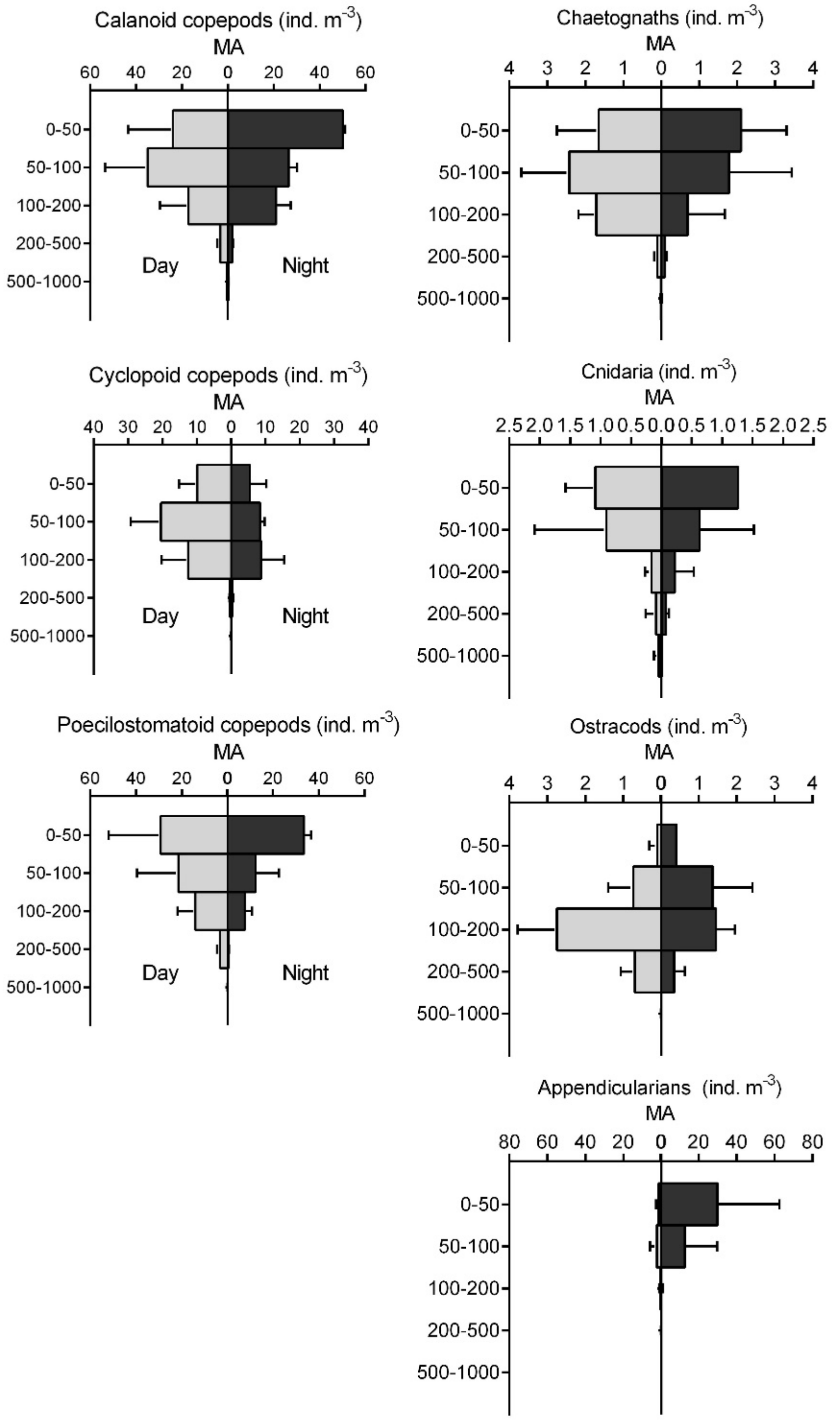

Figure 6.2.12. The day and night vertical abundance distribution of mesozooplankton, illustrating the patterns of vertical migration for different taxa at Caiweii Seamount. Reproduced from Sun et al. (2019).

6.2.3 Ecosystem function

Ecosystem functions can broadly be defined as the natural processes and components that contribute to the self-maintenance of the biological community and their physical environment (de Groot et al., 2002). These functions often translate into provisioning, regulating, supporting, and cultural services that are important for human survival and well-being (de Groot et al., 2002; Palumbi et al., 2008; Lindegren et al., 2016). Examples of pelagic ecosystem functions include biogeochemical cycling, biological production, energy transfer in food webs, and niche, refuge, or habitat provision (Griffiths et al., 2017).

Ocean biodiversity helps to increase, maintain, and promote the provision of marine ecosystem functions (Palumbi et al., 2008). Using a globally standardised, data-driven approach, new research on marine conservation and sustainable use planning identified 23.7% of areas beyond national jurisdiction (ABNJ) as biodiversity priority regions (Visalli et al., 2020). The study algorithm integrated global ecological data layers whilst avoiding areas of high fishing effort. Several of these proposed biodiversity priority regions are within or adjacent to the region of the Northwest Pacific where exploration contracts have been awarded by the ISA (Figure 6.2.13). Adding information on climate change had a minor influence on the study results, suggesting the proposed biodiversity regions identified by the study will remain important regions for maintaining marine ecosystem functions in the foreseeable future.

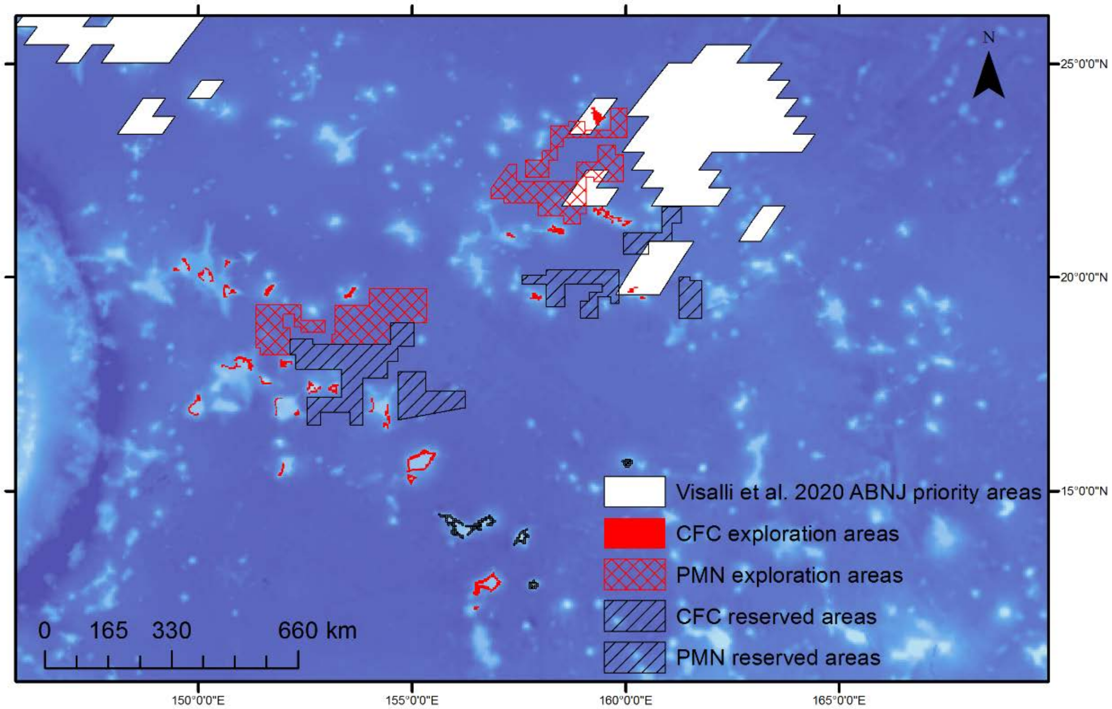

Figure 6.2.13. Locations of proposed priority regions for the conservation of marine biodiversity (Visalli et al., 2020) and therefore associated marine ecosystem function (*sensu* Palumbi et al., 2008) in areas beyond national jurisdiction (ABNJ) (white polygons) within and adjacent to the region of the Northwest Pacific where exploration contracts have been awarded by the ISA. Produced by Cherisse Du Preez using data from Visalli et al. (2020).

6.2.4 Connectivity

6.2.4.1 Zooplankton

Planktonic organisms have weak swimming abilities and are not considered to have the capability for active swimming over long distances. Connectivity for the plankton community is largely determined by physical and biological oceanographic factors, such as water mass structure, ocean currents, temperature and salinity gradients, and primary productivity gradients (Villarino et al., 2018). Amongst these, transport though ocean currents is considered the main mechanism for connecting zooplankton communities (Villarino et al., 2018).

A study on the connectivity of zooplankton communities in the upper layers of the Pacific Ocean identified significant differences between the zooplankton communities in the Equatorial Pacific and those in the Subtropical Pacific (Sun and Wang, 2017). Zooplankton communities in the upper layers of the Northwest Pacific Ocean overlying cobalt-rich ferromanganese crust seamounts were not significantly different, across 9°N-30°N in latitude. These results indicated high levels of connectivity amongst zooplankton communities in the region (Figure 6.2.16; Sun and Wang, 2017). A further large-scale study of the North Pacific identified high levels of connectivity amongst zooplankton communities based on data from 0-1000 m depth across the whole North Pacific Ocean, with high levels of connectivity along the latitudinal gradient between 10°N and 30°N (Sun and Wang 2017; Hirai et al. 2020).

6.2.5 Resilience and recovery

Little is known about the specific resilience of Northwest Pacific pelagic biota to the commercial phase of seabed mining (exploitation). Given that deep-sea mineral exploitation has not yet happened anywhere in the world, and there have been few experimental disturbances at spatial and temporal scales that approximate the disturbances anticipated from mineral exploitation, the recovery of Northwest Pacific pelagic biota from these disturbances remains largely unknown.

However, understanding how ecological systems may withstand the disturbances and stressors associated with mineral exploitation is key to the development of suitable environmental management measures as part of regional environmental management planning. It is beyond the scope of this document to provide a detailed account of the resilience of all Northwest Pacific pelagic biota to mineral exploitation, especially given the current paucity of region- and activity-specific information. Instead, the following sections introduce some of the key concepts in resilience and recovery, summarise existing information relevant to anticipated activities and disturbances, and draw on studies from other regions and research on different disturbances and stressors.

6.2.5.1 Concepts in resilience and recovery

To facilitate discussion of resilience and recovery within both pelagic (surface and midwater) and benthic environments, this section introduces and defines ecological terms and concepts that can be applied throughout the document (Figure 6.2.14). The following glossary draws from terms defined in published literature (Crain et al., 2008; Lotze et al., 2011; Borics et al., 2013; Hodgson et al., 2015; O'Leary et al., 2017; Capdevila et al., 2020).

- **Resilience** describes the ability of a natural system to resist and recover from a disturbance.
- A **system** may be any component of the ecosystem (e.g., a species, specific population, community, ecosystem function).
- **Resistance** describes the amount of change occurring for a system in response to a disturbance where more resistance reflects less change.
- A **response** can be degradation and depletion, or it can be growth and compensation.
- **Recovery** captures the capacity of a system to return to pre-disturbed state following a disturbance.
- A **disturbance** is an outside discrete, temporary, or infrequent event that alters the structure of a system. In contrast, a **stress** is frequent, chronic, or ongoing and prevents return to pre-disturbance state.
- **Cumulative effects** result from multiple sources of disturbances or stresses. The overall system response is dependent on the interaction type of the disturbances (additive, synergistic, or antagonistic).

- A **tipping point** is the threshold past which a disturbed system becomes too unstable and transitions into a new, persistent post-disturbance state. The natural variability of a system may indicate its tipping point.
- **Recovery time** is the time needed for a disturbed system to settle into one of the multiple possible persistent post-disturbance states (Figure 6.2.14). Recovery time is known to vary with the generation time of the system.

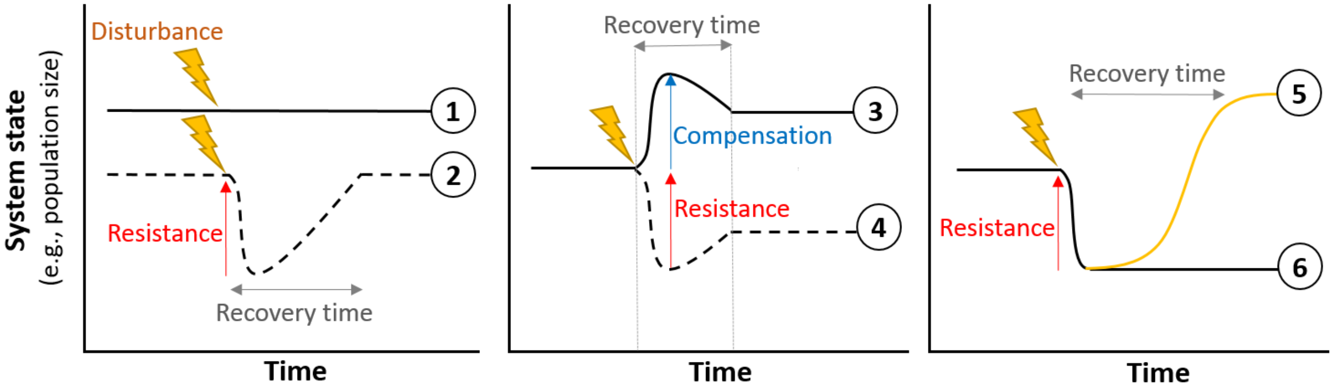

Figure 6.2.14. Comparison between six disturbance responses and the elements of resilience. After a disturbance, the system state changes according to the initial state, tipping point, and response creating a range of possible system states and defining the resistance to being disturbed. Note that resistance is the inverse of the amount of change, more resistance reflects less change. The time needed to settle into one of the multiple possible post-disturbance state outcomes establishes the recovery time. Post-disturbance system states include: (**1**) same initial pre-disturbance state (resistant), (**2**) full recovery to initial state, (**3**) partial recovery to a compensation state, (**4**) partial recovery to a reduced state, (**5**) recovery to an alternative state, and (**6**) no recovery with potential continued degradation. Modified by Cherisse Du Preez from figures in Lotze et al. (2011) and Capedevile et al. (2020).

Lotze et al. (2011) and Capedvila et al. (2020) together describe six post-disturbance state outcomes (Figure 6.2.14). (1) When the disturbance does not exceed the tipping point, the system is resistant and will remain in the initial pre-disturbance state, for example, organisms retain the same abundance, populations have the same size structure, or the diversity of a community stays the same. When the disturbance passes the tipping point, the system is partially or non-resistant and will change (defining the resistance or compensation) for a disturbed period (the recovery time). Following the recovery time, a system will either (2) make a full recovery to the initial pre-disturbance state, (3) a partial recovery to an increased or compensation state, (4) a partial recovery to a depleted, degraded, or reduced state, (5) a recovery to a new, altered, or alternative state, or (6) no recovery with or without the potential for further decline or degradation.

Information on growth rates, life histories, and tolerance to disturbance (both acute and chronic) for biota are needed to understand and predict the spatial and temporal scales of resilience (Smith et al., 2020). However, there are general system characteristics believed to promote resistance and recovery, such as adequate recruitment or connectivity, high levels of beneficial species interactions, favourable physical setting, adequate remaining habitat, functional diversity or redundancy, remoteness or low human accessibility, and conservation and management measures (e.g., O'Leary et al., 2017).

To document the resilience of a system, state metrics need to be identified. Table 6.2.4 provides examples of system parameters, indicators, and measurable characteristics (metrics) from a Canadian seamount risk-assessment (Thornborough et al. 2016). Spatial and temporal data collected for studies on resilience predominantly use iterations of these metrics, for example, fish density as number per unit volume, plankton size structure as frequency distribution. The example parameters, indicators, and metrics in Table 6.2.4 are standard, quantitative, and repeatable, and comparable across ecosystems (Thornborough et al. 2016).

Table 6.2.4. Examples of ecological system state parameters, indicators, and metrics, where a system can be any component of the ecosystem. Modified from a Canadian seamount assessment (Thornborough at al., 2016) by Cherisse Du Preez.

Parameter	**Indicator**	**State metric(s)**
System size	Abundance or density	Area coverage (% or patch area or volume), number per unit area or volume, catch per unit effort, average density, count within a given range, frequency of occurrence, habitat suitability model
	Size or age structure	Size-frequency distribution, age-frequency distribution
	Diversity	Population delineations, richness, and diversity indexes
System condition	Biomass	Weight per unit area or volume, catch per unit effort
	Condition or health	Proportion of population (%) displaying signs of disease, damage, injury, behavioural indicator, weight as a function of length, age, stomach contents, parasitic load, growth rate, reproductive success
	Genetic diversity	Allele frequency, polymorphism, population delineation
	Species range	Spatial distribution, spatial extent

The presented information on resilience and recovery draws on studies from other regions and research on various disturbances and stressors (e.g., simulated mining impacts, bottom-contact fishing, oil spills, drilling). The resilience of a system will be dependent on the nature of the disturbance and its spatial extent, temporal duration and frequency, and intensity or magnitude, as well as the cumulative effects of all disturbances or stressors (Hodgson et al., 2015; Levin et al., 2016). Existing general large-scale stressors in the Northwest Pacific include climate-related changes, such as ocean warming (Woodworth-Jefcoats et al., 2017), deoxygenation (Breitburg et al., 2018; Schmidtko et al., 2017; Li et al., 2020), and ocean acidification (Bopp et al., 2013), as well as commercial fishing (Kroodsma et al., 2018) and shipping traffic (e.g., ship strikes; Pirotta et al., 2019).

Seabed mineral exploitation has not yet taken place in the deep-sea, making it challenging to determine resilience to and recovery from exploitation activities. Whilst multiple studies have investigated the impacts small-scale benthic disturbance experiments or test mining, these have not occurred at spatial or temporal scales that are comparable to what is expected for full-scale commercial exploitation (K. A. Miller et al., 2018). Conditions in deep-sea pelagic and benthic environments are typically stable over geological time scales, and the associated biological communities adapted to these stable conditions are expected to be highly susceptible to changes in disturbance regimes (Ross et al., 2020). The negative impact of bottom trawling on deep-sea biological communities, including those at seamounts, is relatively well studied, although it has been suggested that biota will be less resilient to mining because the removal of substrata will be complete (K. A. Miller et al., 2018). Where recovery is possible, predicted recovery times for biological communities from mineral exploitation range from decades to centuries, or even millennia (Levin et al., 2016; MIDAS, 2016; Gollner et al., 2017; K. A. Miller et al., 2018).

6.2.5.2 Impacts from future exploitation of cobalt-rich ferromanganese crusts and polymetallic nodules

Little is known about the specific resilience of Northwest Pacific pelagic biota to mineral exploitation, partially because full-scale mining machinery and associated technology for mining the seafloor have not yet been developed, and the impacts on the marine environment from this equipment are not yet known. The following section summarises the potential resilience and recovery of biological communities in the surface and mid-water environments, based on existing information relevant to anticipated activities and disturbances. These potential disturbances may include artificial light and introduced noise from the surface vessel and mining vehicle, increased particle load or toxins from mining plumes, localised changes in temperature or nutrients, and other disturbances related to the activities of the surface vessel or mining vehicle (e.g., Levin et al., 2016; Gollner et al., 2017; K. A. Miller et al., 2018; Drazen et al., 2019).

Pelagic organisms, from microbes to whales, demonstrate a range of responses to anthropogenic disturbances and stressors depending on the nature of the event (Table 6.2.5). In general, the existing information describes partially resistant systems, with no records of fully resistant systems or of extinction events. Estimated recovery times relate to the natural variability of the system and its mobility, size, and generation time. Existing information reported in Table 6.2.5 is primarily based on ecological principles and reasonable expectations, with a few empirical studies on resilience to anthropogenic noise and light, but none at the scale of a commercial operation or specific to seabed mineral exploitation. There are many knowledge gaps concerning resilience to anticipated mineral exploitation disturbances, which may be addressed in future versions of this document as new information becomes available.

Table 6.2.5. Information on the potential resilience of Northwest Pacific surface and mid-water biological communities to anthropogenic disturbances. The systems listed represent components of a generalised pelagic ecosystem overlying seamounts and abyssal plains. Resistance and recovery are primarily reported in terms of individuals and local populations, not communities, metapopulations, or whole species. Credit Cherisse Du Preez.

System	Information on resilience: resistance, recovery, and recovery time
Microbes	Resilience to **plumes**: Communities expected to be quite resilient, likely to respond quickly to change with low resistance, but will also recover quickly once the disturbance is gone if individuals are advected from outside plume. (Drazen et al., 2019)
Phyto-plankton	Response to **plumes**: Increased sediment load in surface waters may affect planktonic primary productivity by reducing light penetration, altering nutrient availability, or even introducing toxins. Responses are variable depending on the environmental requirements and limiting factors of individual taxa. Changes to phytoplankton biomass production has the potential for a cascade of consequences. Reduced primary productivity of phytoplankton would impact trophic interactions throughout the marine food web. An increase in the primary productivity of certain phytoplankton species may result in Harmful Algae Blooms (HABs), which are often associated with enhanced nutrient supply. (Häder and Gao, 2015)
Zooplankton	Resilience to **plumes**: Damage to feeding structures and the masking of biologically significant cues may compromise fitness, communication, settling, feeding, breeding, predator avoidance, habitat avoidance, and other visual interactions. Individuals expected to suffer reduced fitness, with potential mortality if they cannot escape the scale of plume. Recovery time reliant on advection of individuals from outside. (Drazen et al., 2019; Drazen et al., 2020)

Nekton	Resilience to **anthropogenic noise**: Reduced fitness and survivorship of fish offspring (Nedelec et al., 2017) and mature fish (Popper and Hawkins, 2019) up to hundreds or even thousands of metres from a sound source (Hawkins and Popper, 2018). Severe physical damaged to swim bladders (e.g., Halvorsen et al., 2012) and to hearing structures, in fishes (e.g., McCauley et al., 2003; with no evidence of physical recovery after two months) and invertebrates (Carroll et al., 2017 and references therein). Many species display avoidance behaviour, which could lead to interruption of key behaviours and compromised fitness (e.g., sea turtles; DeRuiter and Doukara, 2012). Resilience to **plumes**: Individual organisms expected to suffer reduced prey availability and fitness, possible suffocation, and mortality, if they cannot move away from the plume (Levin et al., 2016; Drazen et al., 2019). Mass die-offs or severely reduced fitness of fishes and other nekton caused by rapid ocean deoxygenation or "dead zones" is evidence that even highly mobile species can be vulnerable to sudden changes in environmental conditions, with examples including commercial stocks (Limburg et al., 2020). Recovery times are expected to be relatively long for species inhabiting greater depths, based on longevity, slow growth, later sexual maturation, and low fecundity (Gordon, 2001; Morato et al., 2006; Levin et al., 2016; Drazen et al., 2019).
Marine mammals	Resilience to **anthropogenic noise**: Changed behaviour, masking of biological sounds, physiological effects, injuries—can be temporary or permanent—and mass stranding (Richardson et al., 1995; Gomez et al., 2016). For example, shipping noise has been linked to reduced foraging time (Joy et al., 2019) and sonar has been linked to internal acoustic trauma and atypical mass strandings (Cox et al., 2006). Resilience to **plumes**: Individuals expected to suffer food web perturbation but with high potential for resistance and recovery given that habitat scales can be large in comparison to the plume (Drazen et al., 2019). Resilience to **physical disturbance**: Cetaceans of all sizes are currently under pressure due to mortalities associated with fisheries bycatch (Read et al., 2006), gear entanglement (Johnson et al., 2005), and ship strikes (Pirotta et al., 2019). Resilience to **toxins** and **anthropogenic debris:** Cetaceans are particularly vulnerable to contaminants because of their high trophic level and the progressive increase in chemical concentrations with increasing trophic status, 'biomagnification' (Cossaboon et al., 2019). Beaked whales are particularly vulnerable to ingesting anthropogenic debris (e.g., plastics and fishing gear), resulting in stomach obstructions and mortality (e.g., De Stephanis et al., 2013). Recovery from **perturbation**: Large whale populations worldwide are still recovering from a long history of commercial exploitation that ended almost 40 years ago, with many endangered species still decreasing in abundance (Magera et al., 2013).
Marine birds	Resilience to **artificial lighting**: Reduced fitness and mortality of seabirds caused by lighting on vessels (Troy et al., 2013), recovery from non-fatal impacts unknown. Resilience to **anthropogenic noise**: Lack of information available for diving seabirds but, if similar to above water, diving seabirds exposed to underwater noise pollution are expected to suffer implications for survival and fitness (CBD, in review, and the references therein). Resilience to **plumes**: Some evidence of behavioral resilience when facing shifted food availability (Paiva et al., 2013).
All pelagic fauna	Resilience to **anthropogenic noise**: Injury, tissue damage, physiological change, and the masking of biologically significant sounds may compromise fitness, communication, settling, foraging, and feeding, bonding, schooling, breeding, predator avoidance, habitat avoidance, and a myriad of other acoustical

	interactions, with long-term impacts or unknown recovery (summarised by de Soto and Kight, 2016; Gomez et al., 2016; CBD, in review;). Resilience to **anthropogenic debris**: Pelagic surface feeders—including fish, turtles, birds, whales, etc.—are particularly vulnerable to fatal ingestion of floating debris (e.g., Roman et al., 2019). Resilience to **increased temperatures**: Individuals of some deep-sea species expected to suffer impeded growth, metabolism, reproductive success, and survival (summarised by K. A. Miller et al., 2018). Resilience to **toxins:** If released, toxins can progressively increase in chemical concentration with increasing trophic status (biomagnification), with lethal results (e.g., Cossaboon et al., 2019). **Trophic cascade**: Each altered ecosystem component has the potential to trigger reciprocal changes to their predators and prey, affecting the resilience of other local or distant systems. For example, a degraded zooplankton community could trigger a decline in fish abundance, reducing prey availability for top predators, potentially impacting commercial fishes intended for human consumption.

The same characteristics attributed to potentially promoting resilience in the pelagic environment—the spatial extent and fluidity of the pelagic—make studying the resilience of biological communities in this environment challenging and are at least partially responsible for the current knowledge gaps. A great deal of uncertainty surrounds the potential impacts from the dewatering plume associated with mineral exploitation (Drazen et al., 2019). Depending on ocean currents, discharge volume and vertical ocean stratification, sediment-laden (potentially toxic) plumes could travel tens to hundreds of kilometres, potentially affecting distant ecosystems (Levin et al., 2016; K. A. Miller et al., 2018). In the Northwest Pacific, passive loads in the surface waters are known to travel from the region where contracts have been awarded for mineral exploration West via the North Equatorial current towards the Mariana Archipelago (Kendall and Poti, 2014). This pathway of transport and ecological connectivity suggests the need to consider the potential impact to—and resilience of—surrounding environments, beyond the immediate exploration contract areas. Understanding the temporal and spatial extent of the anticipated plumes is key to addressing knowledge gaps concerning the resilience of surface and mid-water environments to deep-sea mineral exploitation.

Whilst this section discussed surface and mid-water environments without spatial distinctions, the pelagic biota in these environments could each respond differently to disturbances due to their evolutionary history and environmental differences which lead to differences in community composition and the relative importance of taxa that might be more susceptible to effects from mineral exploitation activities (Drazen et al., 2019). There will be differences in the surface and mid-water environments overlying abyssal plains and seamounts. For example, a key characteristic of seamounts is their large-scale influence on the surrounding surface and mid-water environments and communities—known as the ‘seamount effect’ (e.g., Boehlert, 1988; Dower and Mackas, 1996; Rowden et al., 2010). This ‘seamount effect’ may play a role in the disturbance and resilience of pelagic communities above and downstream from seabed mineral exploitation activities on seamounts.

6.3 Benthic biology

There are many deep-water seamounts covered by cobalt-rich crust (CRC) in the Northwest Pacific Ocean. The summits for most of these seamounts occur at approximately 1500 m water depth, with the seamount bases surrounded by vast deep-sea basins with an average water depth greater than 5000 m. The physical projection of these seamounts into the water column alters the localised characteristics of ocean currents and nutrient levels, potentially leading to these seamounts acting as deep-sea biological hot spots. Together, the seamounts and deep-sea basins of the Northwest Pacific provide an array of deep-sea habitats that support diverse seafloor biological communities. However, the benthic communities of the Northwest Pacific seafloor are also some of the least studied. To better understand the benthic biota of CRC seamounts in the Northwest Pacific, the available published (and some unpublished) data were collected and reviewed, alongside published papers and reports from the north-central and Northwest Pacific areas where appropriate.

In line with the template for Environmental Impact Statements (EIS) as detailed in the ISA Draft Regulations for Exploitation document (ISA, 2018: ISBA/24/LTC/WP.1/Rev.1, Annex IV), the benthic environment is considered here to include the seafloor itself and the 50 m of water column immediately overlying the seafloor.

6.3.1 Spatial distribution

6.3.1.1 Biogeography

The seamounts and guyots in the Northwest Pacific are generally deeper than 800 m, thus fall within the lower bathyal zone. From the perspective of global biogeographical provinces, the Northwest Pacific Ocean may be in the transition zone between the Western Pacific Province and the North Pacific Province (Watling et al., 2013; Costello et al., 2017). Different methods have been used to define these global biogeographical provinces, resulting in delineation of slightly different boundaries. The provinces determined by Watling et al. (2013) are based on the evaluation of environmental parameters such as temperature, dissolved oxygen, and organic flux, whilst the provinces determined by Costello et al. (2017) are based on the analysis of species information. According to Watling et al. (2013), most of the seamounts and guyots in this region belong to the West-Pacific lower bathyal province, although the easternmost part of the region may have closer affinity with the North Pacific lower bathyal province (UNESCO, 2009; Watling et al. 2013; Figure 6.3.1). The deeper basins in this region are located within the North Pacific and the North Central Pacific provinces (UNESCO, 2009; Watling et al. 2013; Figure 6.3.2), although an earlier classification by Vinogradova (1997) considered the abyssal seafloor in this region to be part of the West-Pacific Abyssal province. In general, there is limited information on the benthic communities of the Northwest Pacific region and the current interpretation of biogeography may change when more data become available.

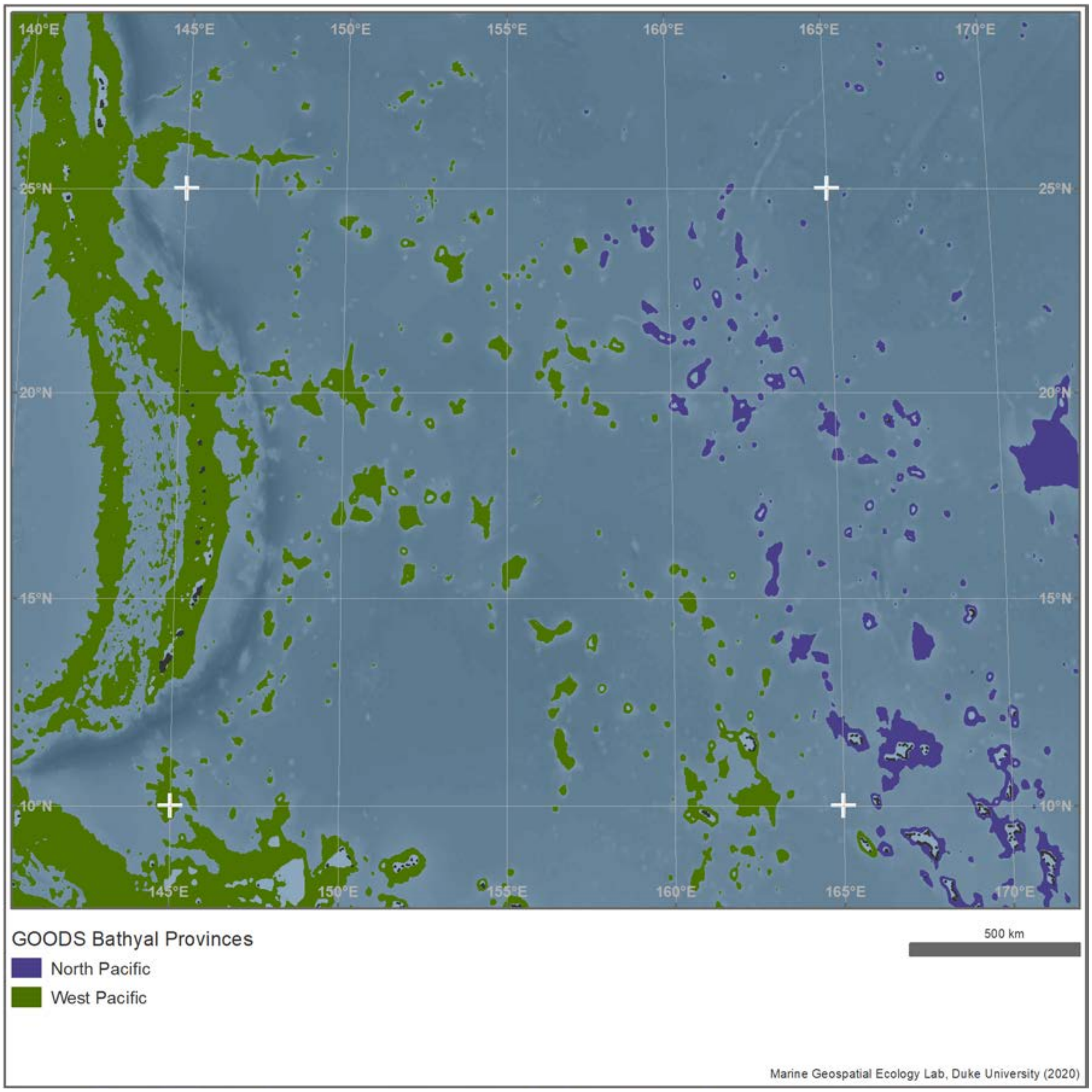

Figure 6.3.1. Global Open Oceans and Deep Seabed (GOODS) biogeographic classification lower bathyal provinces. Reproduced from the Data Report for the Workshop on the Development of a Regional Environmental Plan for the Area of the Northwest Pacific. Credit Marine Geospatial Ecology Lab, Duke University (2020).

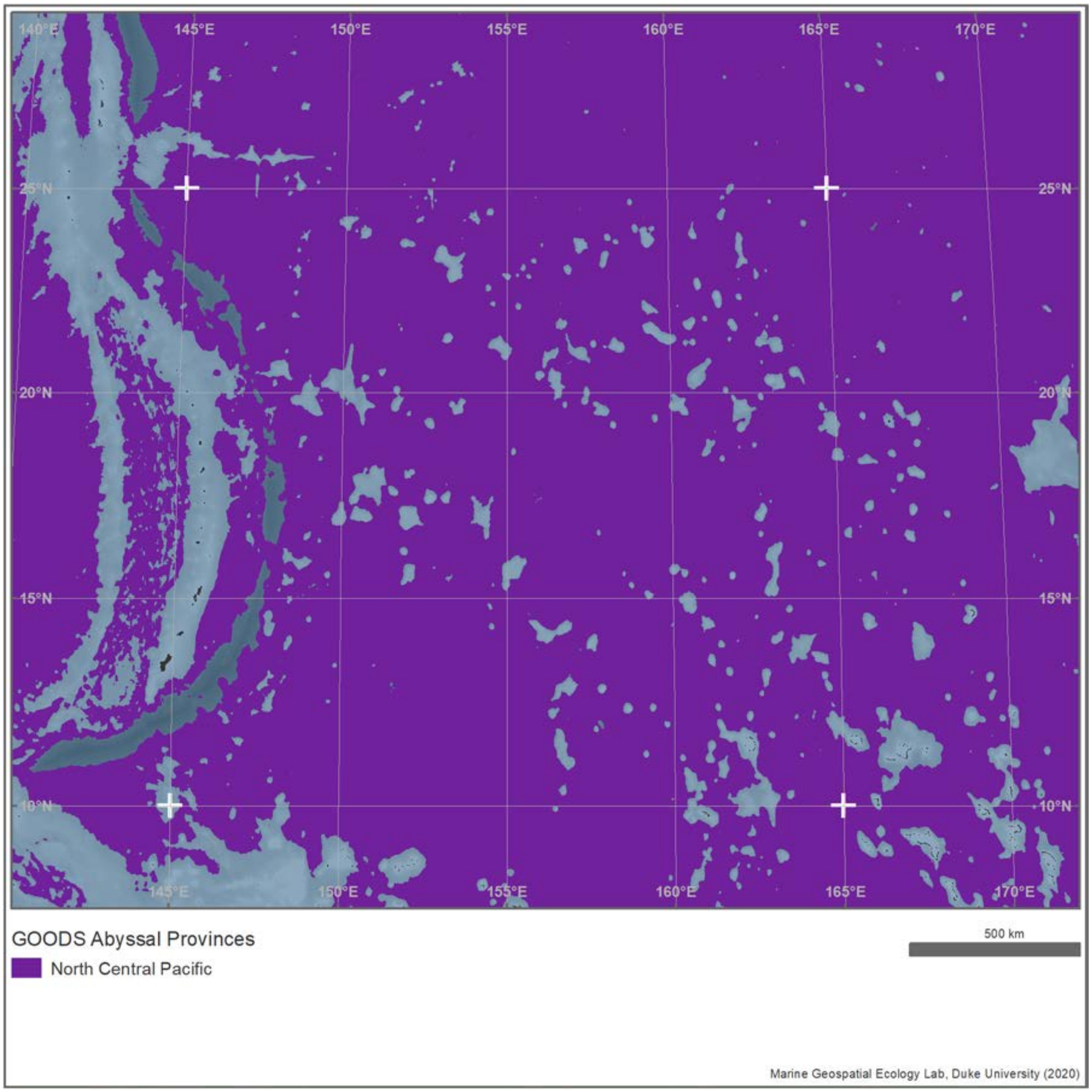

Figure 6.3.2. Global Open Oceans and Deep Seabed (GOODS) biogeographic classification abyssal provinces. Reproduced from the Data Report for the Workshop on the Development of a Regional Environmental Plan for the Area of the Northwest Pacific. Credit Marine Geospatial Ecology Lab, Duke University (2020).

Understanding how productivity affects biodiversity at seamounts has been a question of interest to deep-sea biologists for more than a decade (Clark et al., 2010a; McClain and Rex, 2015). In general, the distribution, density and community structure of deep-sea benthic organisms tends to respond to variations in surface primary productivity and particle flux to the seabed (Thistle, 2003). The Northwest Pacific is in the western part of the Northern oligotrophic zone (Sokolova, 1997), where the overlying upper-ocean biogeographic provinces are the North Pacific Tropical Gyre Province and the Western Pacific Warm Pool Province for the southernmost part of the region (Longhurst, 2007). Both provinces are characterised by relatively oligotrophic conditions, however, according to a recent study (Sun et al., 2019), these two provinces show different patterns of diel vertical migration that may result in differing degrees of efficiency for the carbon pump and the active proportion of carbon flux to deep sea.

On a global scale, deep-sea biodiversity can also exhibit significant latitudinal changes. For example, deep-sea ophiuroid biodiversity below 2000 m is often greatest at mid-latitudes, and gradually decreases toward high and low latitudes (Woolley et al., 2016). Studies in the Northwest Pacific (Sea of Japan and Sea of Okhotsk) also show that both the abundance and diversity of deep-sea biota tends to gradually decrease toward low and high latitudes (Saeedi et al., 2020). The cobalt-rich crust area in the Northwest Pacific spans approximately 15 degrees of latitude (10°N – 25°N); it is possible that the abundance and diversity of deep-sea biota in this area may also change with latitude. There have been few benthic biota surveys in this region to date and further information is needed to strengthen the study of large-scale spatial distribution patterns in this region.

6.3.1.2 Seamount communities

6.3.1.2.1 Microorganisms

The role of seamount microbes in ecology and biogeochemistry is still not clear. The limited research conducted to date indicates that there is high diversity and metabolic potential for the microorganisms at seamounts, and that these microorganisms are adapted to complex and heterogenous seamount environments. Seamounts in the Northwest Pacific Ocean are mostly guyots with concentrations of ferro-manganese (Fe-Mn) crusts on the top and slopes of these seamounts. The concentrations of metals such as Fe (iron), Mn (manganese), Co (cobalt), Mo (molybdenum), and W (tungsten), are an order of magnitude higher in these crusts than in seawaters or even in the crustal rocks. The Fe-Mn oxides absorb dissolved ions, forming substratum with unique geological characteristics. Some studies have demonstrated that the microorganisms sampled from these crusts have higher richness and diversity than those sampled from non-crust locations (Tully and Heidelberg, 2013; Shulse et al., 2017).

Liao et al. (2011) reported microbial communities of three layers of sediments around cobalt-rich ferromanganese crusts in the North Pacific, indicating that diversity of Bacteria was higher than the diversity of Archaea, and that Bacteria and Archaea were mainly involved in sulphur oxidation and nitrogen cycling, respectively. Nitahara et al. (2011) collected sediments, Fe-Mn crusts, and surrounding seawaters to compare the microbial biomass and community diversity in different locations and habitats on Takuyo-Daigo Seamount, using molecular biological approaches. The results showed that Archaea is the major group inhabiting the crusts and sediments, whilst Bacteria is the primary group in seawater. The relative abundances of Thaumarchaeota in Archaea and γ-proteobacteria in Bacteria were high in crusts and sediments, and α-proteobacteria was abundant in seawater. Based on microbial diversity in crusts, sediments, and seawaters at Takuyo-Daigo Seamount in the Northwest Pacific Ocean, and Daito Seamount (25°40’N, 133°15’E) and Ryusei Seamount (25°32’N, 135°34’E) in Philippine Sea, overlap between the microbial communities within crust and sediment was ~20%, with the remainder of the microbial community unique to the crust habitat. Microbial community structure of Takuyo Daigo, Daito, and Ryusei seamounts demonstrates that the microbial community at cobalt rich seamounts is related to the sample type (crust, sediment, seawater), but not to seamount location (Nitahara et al., 2011; Nitahara et al., 2017). The ammonia-oxidizing ß-proteobacteria Nitrosospira and Thaumarchaeota were detected in Fe-Mn crusts, suggesting that autotrophy by ammonia-oxidization could be the major carbon and energy sources in crust micro-ecosystems (Nitahara et al., 2011; Nitahara et al., 2017). Application of metagenomics to analyse the metabolic potentials of the microbes on Fe-Mn crusts at Takuyo-Daigo Seamount also discovered that microbes participated in the biogeochemical cycling of C (carbon), N (nitrogen), S (sulphur), Fe (iron) and Mn (manganese), and play a key role in the growth of Fe-Mn crusts (Kato et al., 2019).

Liu et al. (2019) analysed community composition, diversity, and potential functions of Bacteria on the top and bottom of the Caiwei Seamount, a guyot in the Northwest Pacific Ocean, to study the spatial distribution characteristics of seamount microorganisms. The bacterial community at the top of the seamount was distinct from the community at the seamount base (Figure 6.3.3). The surface sediment on the top of the guyot harboured bacterial communities with greater diversity and evenness, represented by Gamma- and Deltaproteobacteria involved in sulphur cycling. At the base of the guyot, Gammaproteobacteria and Chloroflexi were dominant, the former plays a role in sulphur-oxidizing and the latter is involved in the decomposition of refractory organic material. These results suggested that the redox state at the interface of the sediment and the water can influence bacteria-mediated elemental cycling, over time shaping the physicochemical and geological characteristics of a guyot. Differences in depth and physicochemical properties of the surrounding environment (e.g., concentrations of dissolved oxygen and geochemical elements) between the top and the base of the guyot may contribute to this partition of bacterial communities. The typical anticyclonic current flow around the guyot may influence bacterial dispersal and maintain environmental homogeneity at the same depth, resulting in similar bacterial community structure at sampling stations within each feature (the top or the base of the seamount: Figure 6.3.4).

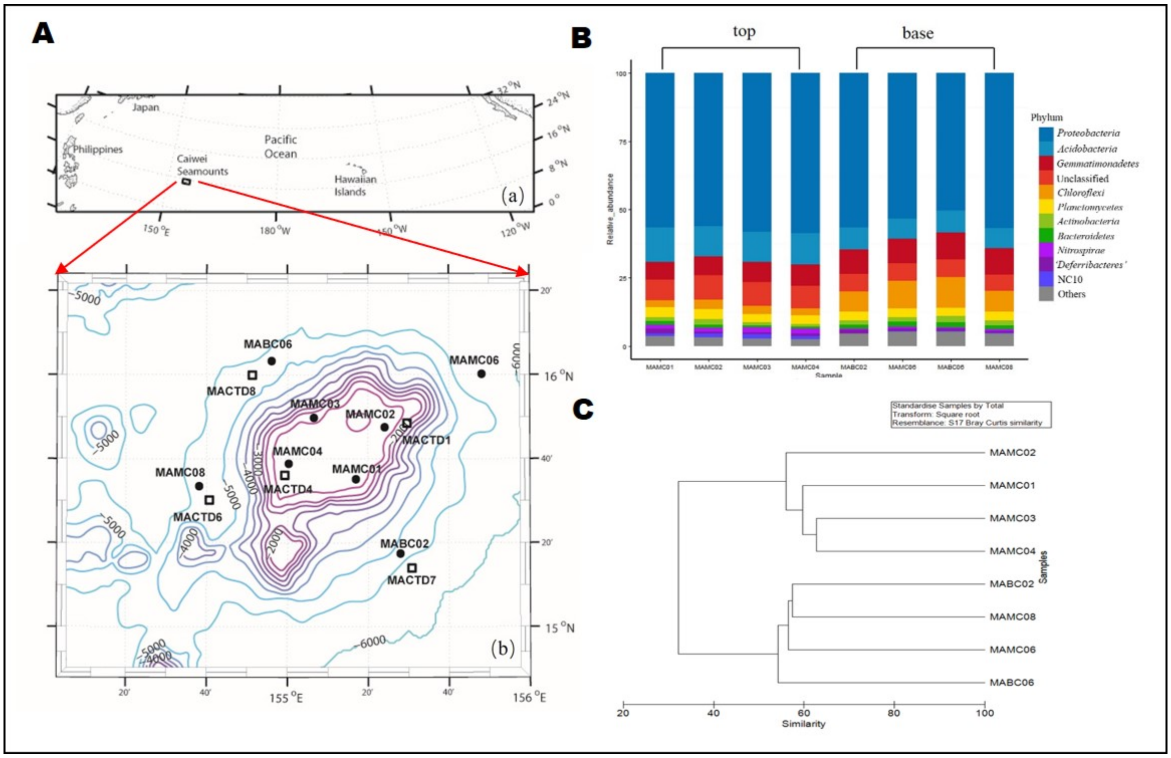

Figure 6.3.3. A: Location of Caiwei Seamount and sampling sites (stations at the seamount top: MAMC01-MAMC04; stations at the seamount base: MABC02, MAMC08, MAMC06, MABC06); B: bacterial composition at the top and base of the seamount; C: microbial clustering analysis in sediments from the top and base of the seamount. Modified from Liu et al. (2019).

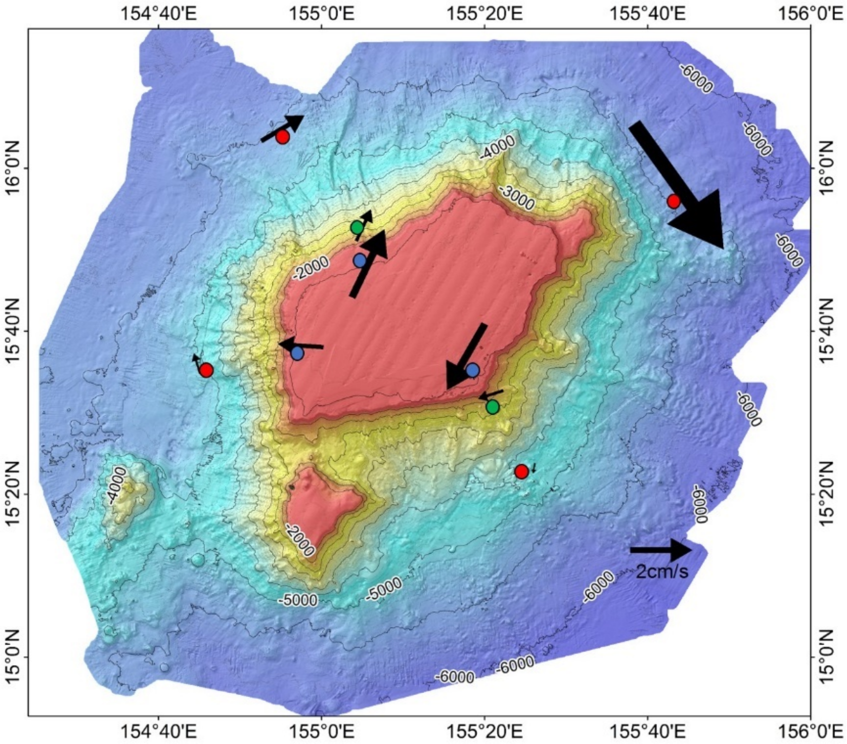

Figure 6.3.4. The time-averaged observed bottom current vector of the Caiwei Seamount from nine seafloor mooring stations (15 m above the bottom) identified anticyclonic circulation around the seamount. Modified from Liu et al. (2019).

There is limited information available on the Fungi of the benthic environment in the Northwest Pacific. Pioneering studies of fungal diversity and abundance at the Magellan seamount chain and adjacent locations using DNA barcoding suggested high involvement and importance of fungi in deep-sea environments (Xu et al., 2014). Most recently, Luo et al. (2020) used *ITS2* metabarcoding to assess the fungal community within 18 samples from the Magellan seamounts at 3531-5496 m depth. This study recovered 1,979 fungal operational taxonomic units (OTUs), which were taxonomically assigned to seven phyla, 17 classes, 43 orders, 7 families, and 98 genera. Basidiomycota and Ascomycota represented 44.11% and 24.56% of the total OTUs, respectively.

6.3.1.2.1.1 Studies from the JOGMEC contract area

In the environmental baseline surveys of Xufu Guyot (JA06 seamount) within the JOGMEC exploration contract area, sediment samples were collected around Xufu Guyot. To characterise spatial patterns in microbial communities from different locations on the seamount, Iguchi et al. (2018) conducted metabarcoding analyses on sediment samples from the top and base of the seamount, and on one sample from the digestive tract of a fish collected during biological sampling. Iguchi et al. (2018) extracted DNA from the samples, targeting the *16S* rRNA gene sequence in metabarcoding analysis using Illumina MiSeq. Microbial community composition of the sample from the fish stomach was significantly different from the microbial community of the sediment samples. Cluster analysis of the gene sequences from the sediment samples identified two main clusters corresponding to the top and base of the seamount. Network analysis also supported the existence of two distinct groups, suggesting that microbial community composition may be influenced by water depth. Iguchi et al. (2018) also identified microbial types that bridge these two groups based on betweenness centrality.

6.3.1.2.2 Benthic invertebrates

The benthic invertebrates of the seamounts and guyots within and adjacent to the exploration area in the Northwest Pacific were studied in several sampling programs conducted by the P.P.Shirshov Institute of Oceanology RAS including several cruises of *RV Vityaz* (1957-1970), the 21st cruise of *RV Dmitry Mendeleev* (1978) (Kuznetsov and Mironov, 1981), and the 9th cruise of *RV Akademik Mstislav Keldysh* (Moskalev and Galkin, 1986). The latter two cruises in 1981 and 1986 collected samples using the manned submersibles Pisces VI and Pisces XI, in addition to sampling using benthic trawls and grabs.

More recently, the benthic invertebrates at cobalt-rich crust bearing seamounts in the region have been studied using a range of sampling and surveying techniques during environmental baseline surveys conducted within the COMRA, JOGMEC, and the Ministry of Natural Resources and Environment of the Russian Federation exploration contract areas. More information regarding the benthic invertebrate communities at these seamounts will become available as further environmental baseline studies are conducted.

The National Oceanic and Atmospheric Administration (NOAA) organised and implemented a Pacific-wide field campaign entitled CAPSTONE (Campaign to Address Pacific monument Science, Technology, and Ocean Needs) from 2015 to 2017. As part of this field campaign, >347,000 individual organisms were recorded across a subset of 168 dives, and more than 597,230 km^2 of seafloor was mapped, with the Okeanos Explorer vessel mapping 10 atolls, 7 banks, 148 conical seamounts, 114 guyots, 24 islands, and 61 ridge seamounts (Kennedy et al. 2019).

The records of deep-sea invertebrates and fishes from video imagery collected during CAPSTONE were catalogued and characterised alongside *in situ* environmental conditions including habitat, substratum, water chemistry, and geographic location. Animals were identified using a deep-water identification guide[9], with 1,700 reference images prepared with taxonomic assistance from experts; this identification guide is freely available and could support the generation of comparable datasets during environmental baseline gathering as part of mineral exploration in the Northwest Pacific. Video annotations made as part of the CAPSTONE are also freely available[10], whilst the data generated by CAPSTONE are also available via the OER Digital Atlas discoverability tool[11].

6.3.1.2.2.1 Megafauna

The spatial distribution of deep-sea benthic megafauna has traditionally been studied using benthic trawls and grabs. Increasingly, benthic megafauna are studied using underwater photogrammetry and systematic visual surveys based on direct observation with deep-sea survey cameras mounted on remotely operated vehicles (ROVs) (Lundsten et al., 2009; Henry et al., 2014; Amon et al., 2016; Boschen et al., 2016; Sugishima et al., 2018b; Victorero et al., 2018; Trotter et al., 2019) and autonomous underwater vehicles (AUVs) (Durden et al., 2016; Morris et al., 2014, 2016; Milligan et al., 2016; Simon-Lledó et al., 2019a). Deep-sea survey cameras towed behind research vessels are also used for obtaining observation of spatial distribution for deep-sea benthic megafauna (Shortis et al., 2008; Clark and Rowden, 2009; Williams et al., 2010Boschen et al., 2015; Rowden et al., 2016).

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[9] https://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html

[10] https://www.ncei.noaa.gov/maps/deep-sea-corals/mapSites.htm

[11] https://service.ncddc.noaa.gov/website/google_maps/OE/mapsOE.htm

Using imagery data from CAPSTONE surveys in the Pacific, Kennedy et al. (2019) determined preliminary patterns in diversity and abundance of seafloor megafaunal taxa and any relationships in these patterns with depth, benthic feature, and geographic region. Patterns in the distribution of megafaunal taxa were compared across five geographic regions: Hawaii, Marianas, American Samoa, South Central Pacific, and Western Pacific. Multiple feature types were surveyed including islands, atolls, banks, guyots, conical seamounts, ridge seamounts, and abyssal areas. The focus of the CAPSTONE field campaign was on seabed areas within national jurisdictions; only one ROV dive was conducted on a guyot within the Area of the Northwest Pacific, with a further nine guyot dives and two dives on banks conducted within national jurisdictions in the Western Pacific region of the CAPSTONE project (Figure 6.3.5).

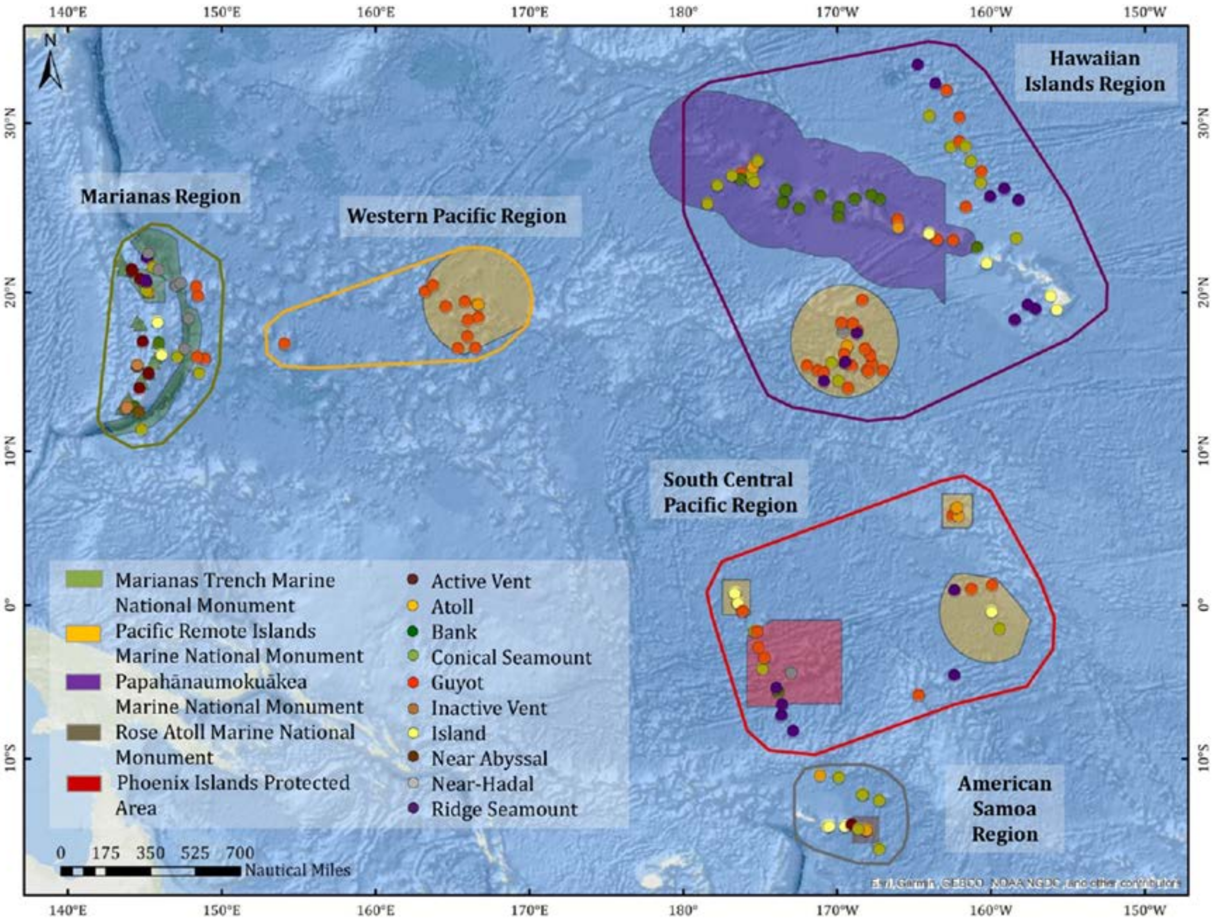

Figure 6.3.5. CAPSTONE ROV dive sites organised by region (Marianas, Western Pacific, Hawaiian Islands, South-Central Pacific, American Samoa). Marine Protected Area boundaries are indicated by polygons. Dive site markers are colour coded by feature type. Reproduced from Supplementary Material of Kennedy et al. (2019).

General patterns from CAPSTONE surveys indicate that the best characterised seafloor depth is 2000 – 2500 m, where 90% of all taxa were identifiable at the family level (Kennedy et al. 2019). Some taxa appeared to have distribution patterns associated with depth, for example echinoderm genera (sea stars, brittle stars, sea lilies, sea urchins, and sea cucumbers) were highly specific at shallow depths (200 – 500 m), with each taxon only observed in a narrow depth range. Conversely, deep water echinoderm genera (3000 – 6000 m) were observed across a much broader depth range. Similar patters were observed for anthozoans (corals and anemones), with distinct anthozoan assemblages at shallower depths and anthozoan genera being more widely distributed across depths exceeding 800 m. Conversely, poriferan (sponges) genera were more widely tolerant of depth changes than echinoderms and anthozoans.

Patterns associated with seafloor feature were also observed by Kennedy et al. (2019). In general, Porifera were the most abundant on banks, guyots, and ridges, although some taxa occurred almost exclusively on a single feature type. Poriferan assemblages were generally similar on guyots, conical seamounts, and ridge seamounts, whereas assemblages found on banks, islands, and atolls were more unique. Echinoderm assemblages were similar across ridge and conical seamounts, banks, guyots, atolls, and islands, with abyssal locations having distinct echinoderm assemblages at the genus level. Anthozoans occurred in higher abundance on atolls compared to islands, with higher abundance on banks compared to guyots. Some anthozoan genera had higher abundances on specific feature types or were only found on certain types of features.

Based on surveys conducted on the plateau and upper slopes of Ita Mai Tai (Weijia) and IOAN guyots using different sampling methods and observation protocols (Figure 6.3.6), Moskalev and Galkin (1986) reported at least 49 morphotypes of benthic megafauna. The megafauna sampled from these guyots included individuals from Xenophyophorea, Hydrozoa, Scyphozoa, Actiniaria, Pennatularia, Caudofoveata, Gastropoda, Cephalopoda, Pantopoda and Sipunculoidea (Moskalev and Galkin, 1986). Sponges, cnidarians, and echinoderms were the most diverse groups in terms of number of species reported. Sponges were mostly represented by Hexactinellida (glass sponges). Cnidarians were dominated by octocorals of families Chrysogorgiidae, Primnoidae and Isididae; Scleractinia were represented primarily by solitary cup-corals. One small colony of the framework-building species *Enallopsammia rostrata* was observed on the Mussau underwater ridge at approximately 2°N, South of the Northwest Pacific region where exploration contracts for mineral exploration have been awarded (Keller and Shcherba, 2006).

Additional sources of information on the spatial distribution of seamount megafauna could be considered in future version of this document. Potential additional resources include taxonomic records within the Ocean Biogeographic Information System (OBIS), Ex 1606 *Okeanos Explorer* imagery obtained during the CAPSTONE expedition, and species inventories from other nearby regions including records available through the University of Hawaiʻi Undersea Research Laboratory (HURL) Deep-sea Animal Identification Guide[12].

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[12] http://www.soest.hawaii.edu/HURL/HURLarchive/guide.php

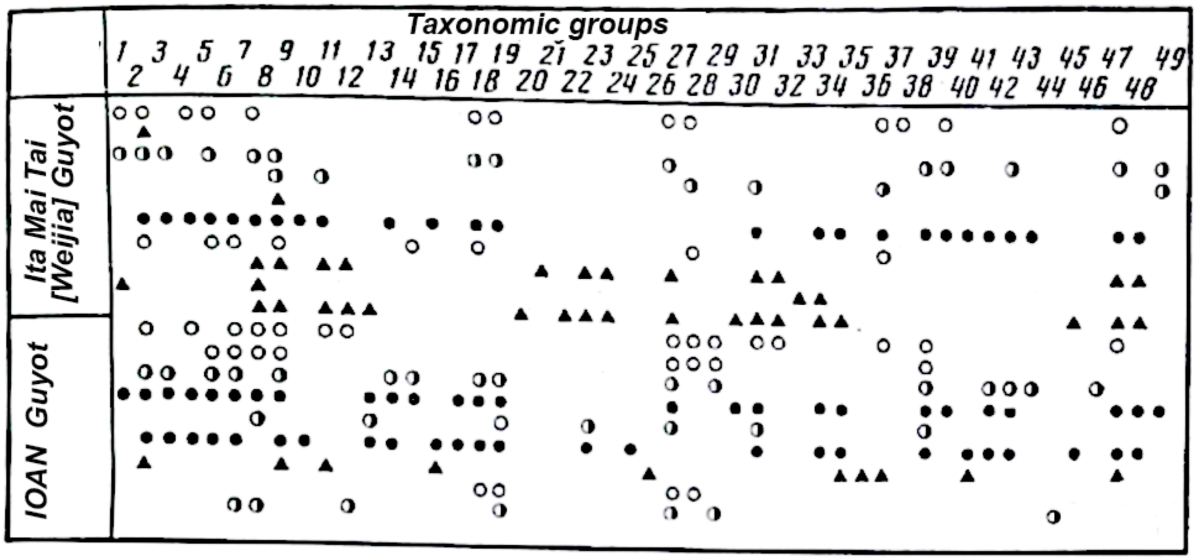


Figure 6.3.6. Occurrence of different taxonomic groups recorded using different sampling methods and observation protocols. Open circle – Pisces dive, no biologist, no sampling; Half-filled circle – Pisces dive, no biologist, sampling; Filled circle – Pisces dive, with biologist and sampling; Triangle- Sigsbee trawl. Taxonomic groups: 1 – Xenophyophorea; 2 – Hexactinellida_1; 3 – Hexactinellida_2; 4 – Hexactinellida_3; 5 – Hexactinellida_4; 6 – Hexactinellida_5; 7 – Hexactinellida varia; 8 – Hexactinellida_subfossil; 9 – Hydrozoa; 10 – Scyphozoa; 11 – Scleractinia; 12 – Actiniaria_1; 13 – Actiniaria_2; 14 – Antipatharia_1; 15 – Antipatharia_2; 16 – Antipatharia_3; 17 – Gorgonaria_1; 18 – Gorgonaria_2; 19 – Pennatularia; 20 – Solenogastres; 21 – Caudofoveata; 22 – Gastropoda Prosobranchia; 23 – Bivalvia; 24 – Cephalopoda Octopoda; 25 – Polychaeta_1; 26 – Polychaeta_2; 27 – Polychaeta_3; 28 – Polychaeta varia; 29 – Pantopoda; 30 – Cirripadia Lepadomorpha; 31 – Cirripedia Verrucomorpha; 32 – Amphipoda; 33 – Decapoda Natantia; 34 – Decapoda Reptantia; 35 – Sipunculoidea; 36 – Bryozoa; 37 – Ascidiacea; 38 – Crinoidea; 39 – Holothuroidea Psolidae; 40 – Holothuroidea_1; 41 – Holothuroidea_2; 42 – Asteroidea Brisingidae; 43 – Asteroidea Asteropectinidae; 44- Asteroidea_1; 45 – Asteroidea_2; 46 – Asteroidea_3; 47 – Ophiuroidea; 48 – Echinoidea Aspidodiadematidae; 49 – Echinoidea. Reproduced from Moskalev and Galkin (1986) with translation by Tina Molodtsova.

6.3.1.2.2.1.1 Corals

Cold-water corals are cornerstone species in the benthic biological community at seamounts. Research on seamounts near the Hawaiian seamount chain in the North Pacific identified Alcyonacea as the dominant group within deep-water seamount coral communities, including Primnoidae, Coralliidae, Isididae, Chrysogorgiidae, Acanthogorgiidae, and Paramurideidae, along with an abundance of Antipatharian corals (Baco, 2007; Parrish and Baco, 2007; ISA, 2011; Long and Baco, 2014; Schlacher et al., 2014; Parrish et al., 2015; Morgan et al., 2019). A study at Necker Ridge in the North Central Pacific Ocean reported that of nearly 8,000 coral records, Isididae and Chrysogorgiidae accounted for 41.8% and 38.2% of these records respectively, with these two families also exhibiting the greatest number of species (Morgan et al., 2015).

A preliminary species list for the corals recorded during surveys conducted at the seamounts and guyots within and adjacent to the exploration area in the Northwest Pacific was compiled from the available literature (Table 6.3.1). To date, surveys in the region have identified 10 species of Alcyonaria, one species of Antipatharia (black corals) and eight species of Scleractinia (stony corals). Two new Chrysogorgiidae corals from Kocebu Guyot in the Magellan Seamount chain are some of the most recently described new coral species in the Northwest Pacific region (Xu et al. 2019).

Table 6.3.1. Preliminary species list for corals recorded from seamounts and guyots within the Northwest Pacific. Credit Tina Molodtsova.

Order	Family	Species	Reference
Alcyonaria	Alcyonidae	*Pseudoanthomastus pacificus*	Kuznetsov and Mironov (1981); Y. Xu et al. (2020)
	Chrysogorgiidae	*Chrysogorgia binata*	
		Chrysogorgia dendritica	
		Chrysogorgia fragilis	
		Chrysogorgia ramificans	
		Metallogorgia melanotrichos	
	Primnoidae	*Narella grandiflora*	
		Pterostenella plumatilis	
	Isididae	*Keratoisis paucispinosa*	
		Lepidisis sp.	
Antipatharia	Cladopathidae	*Trissopathes tristicha*	Pasternak (1976); Kuznetsov and Mironov (1981)
Scleractinia	Caryophylliidae	*Caryophyllia pacifica*	Keller and Shcherba (2006)
		Vaughanella oreophila	
	Deltocyathidae	*Deltocyathus lens*	
	Flabellidae	*Flabellum marcus*	
		Flabellum trapezoideum	
	Fungiacyathidae	*Fungiacyathus pliciseptus*	
	Turbinoliidae	*Peponocyathus australiensis*	
	Dendrophylliidae	*Enallopsammia rostrata*	

As these Northwest Pacific sites are beginning to be explored, additional data on potential distributions of coral species could be gleaned from global habitat suitability models for deep-sea corals. Davies and Guinotte (2011) determined habitat suitability for five species of framework forming scleractinian corals. They found generally low habitat suitability for scleractinians in the North Pacific, but closer examination of the maps from this study indicates that there is high habitat suitability in the Northwest Pacific areas for *Enallopsammia rostrata* and low to moderate habitat suitability for *Madrepora oculata*. Both *Solenosmilia variabilis* and *Lophelia* (now *Desmophyllum*) *pertusa* had low habitat suitability on Northwest Pacific seamounts (Davies and Guinotte et al., 2011). Yesson et al. (2012) found extremely high habitat suitability for all octocoral groups on the Northwest Pacific seamounts, whilst Yesson et al. (2017) found very high habitat suitability for antipatharian corals at these sites. There are many caveats to habitat suitability modelling, but these results provide insights into the potential distributions of key taxa until further exploration can be undertaken.

6.3.1.2.2.1.2 Sponges

Sponges are frequently observed on the slopes and tops of seamounts and, being almost exclusively filter feeders, tend to occur in higher densities where topography and currents combine to enhance the availability of suspended particles. Eighty-two sponge species were reported from the Hawaiian seamount chain in the central

North Pacific, including areas with cobalt-rich manganese crusts (ISA, 2011). This extensive taxonomic listing was composed of 70 species of Hexactinellida (33% of which were Euplectellidae), 6 species of Demospongiae, and 6 unidentified species (ISA, 2011). On the Necker Ridge, sponge assemblages were also dominated by Hexactinellida, with Euplectellidae and Farreidae identified as major groups in northern and southern pinnacles of the Ridge, respectively (Morgan et al., 2015). Further studies on the Emperor seamounts suggested that hard substratum is also dominated by two Hexactinellida families (Euplectellidae and Rossellidae) (Downey et al., 2020).

A preliminary species list for the sponges recorded during surveys conducted at the seamounts and guyots within and adjacent to the exploration area in the Northwest Pacific was compiled from the available literature (Table 6.3.2). To date, surveys in the region have identified three species of Demospongia and 16 species of Hexactinellida. Amongst the Hexacitnellid species, three genera belong to the family Pheronematidae, which is widely distributed in the deep-sea (Tabachnick and Menshenina, 2002). *Caulophacus variens variens* within the family Uncinateridae primarily occurs in the Pacific, including the cobalt-rich crust seamounts in the Northwest Pacific, tropical western Pacific, and Hawaiian seamounts in the North Pacific (Reiswig, 2002; Dohrmann et al., 2017; Shen et al., 2020). Two new species and one new genus of Pheronematidae sponges within Hexactinellida have also been described from the Yap and Caroline Seamounts in the Northwest Pacific (Gong et al. 2017, 2018).

Table 6.3.2. Preliminary species list for sponges recorded from seamounts and guyots within the Northwest Pacific. Credit Tina Molodtsova.

Class	Family	Species	Reference
Demospongiae	Axinellidae	*Axinella* sp.	Kuznetsov and Mironov (1981)
	Biemnidae	*Biemna* sp	
	Cladorhizidae	*Abyssocladia bruuni*	
Hexactinellida	Uncinateridae	*Caulophacus variens variens*	Tabachnick (1988); Tabachnick et al. (2011); Wang et al. (2016); Castello-Branco et al. (2020)
	Rosselidae	*Tretopleura stylophormis*	
	Euretidae	*Lefroyella ceramensis*	
	Farreidae	*Farrea occa polyclavula*,	
		Farrea sp.	
		Aspidoscopulia sp.	
	Pheronematidae	*Poliopogon canaliculatus*	
		Poliopogon matai	
		Platylistrum subviridum	
		Semperella alba	
		Semperella retrospinella	
	Hyalonematidae	*Tabachnickia polybasalia*	
	Euplectellidae	*Advhena magnifica*	
		Euplectella aspera	
		Walteria leucarti longina	
		Trachycaulus sp.	

6.3.1.2.2.1.3 Other megafauna

Other benthic invertebrate megafaunal taxa found at cobalt-rich crust seamounts in the Northwest Pacific are often found attached to or in association with corals and sponges. These attached organisms include ophiuroids (brittlestars), sea stars, crinoids (sea lilies) and crustaceans (Figure 6.3.7; Xu et al., 2017; Zhang et al., 2018; Zhang et al., 2020; Na et al., 2021). Some of these associated organisms can have complex relationships with corals and sponges. For example, some ophiuroids have an obligate attachment relationship with specific corals, whilst others do not have selectivity for their hosts (Cho and Shank, 2010). A study in the Northwest Pacific found that *Ophioplinthaca defensor* had a strong preference for sponge hosts, but *O. defensor* did not appear to have an obligate epiphytic relationship with a specific sponge species (Na et al., 2021).

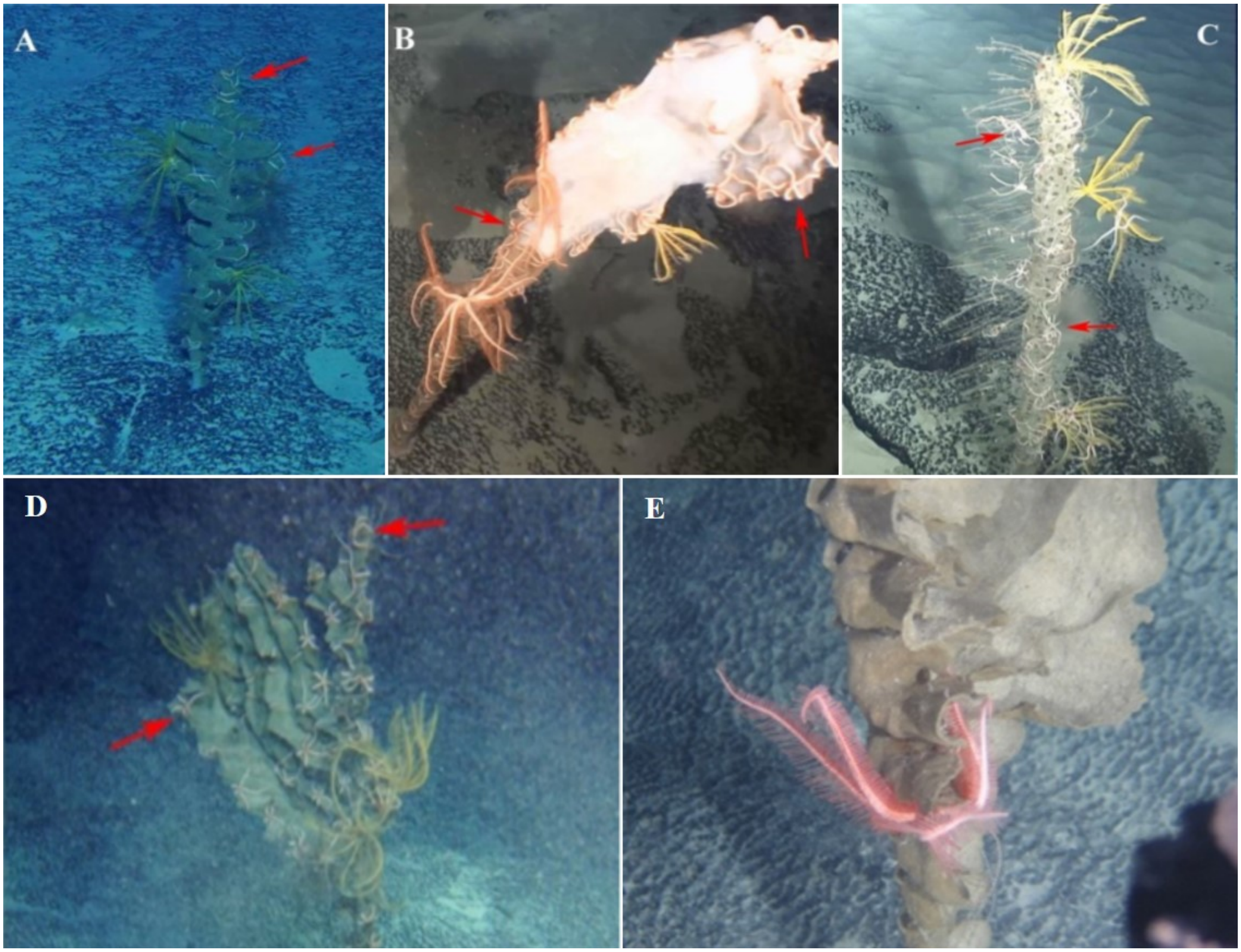


Figure 6.3.7. *Ophioplinthaca defensor* (A – D) and *Astrolirus patricki* (E) on sponges. Images A – D are modified from Na et al. (2021) and image E is modified from R. Zhang et al. (2020).

A preliminary species list for the additional megafaunal taxa (excluding corals and sponges) recorded during surveys conducted at the seamounts and guyots within and adjacent to the exploration area in the Northwest

Pacific was compiled from the available literature (Table 6.3.3). To date, surveys in the region have identified three species of Polychaeta worms, two species of Cirripedia (barnacles), nine species of Decapoda crustacean, one species of Solenogastres mollusc, one species of Bivalvia mollusc, one species of Crinoidea, at least 13 species of Ophiuroidea (brittlestars), three species of Holothuroidea (sea cucumbers), two species of Echinoidea (sea urchins), more than four species of Asteriodea (sea stars) and one species of Brachiopoda (lamp shells).

Table 6.3.3. Preliminary species list for additional benthic invertebrate megafauna recorded from seamounts and guyots within the northwest Pacific. Credit Tina Molodtsova.

Class	**Family**	**Species**	**Reference**
Polychaeta	Eunicidae	*Eunice* sp.	Britaev (1981); Kuznetsov and Mironov (1981)
	Onuphidae	*Rhamphobrachium diversosetosum*	
	Polynoidae	*Gorgoniapolynoe uschakovi*	
Cirripedia	Poecilasmatidae	*Megalasma orientalis*	Kuznetsov and Mironov (1981)
	Calanticidae	*Calantica* sp.	
Decapoda	Homoloidea	*Homologenus asper*	Kuznetsov and Mironov (1981); Dong et al. (2017); Dong et al. (2019); Kou et al. (2020)
	Pandalidae	*Heterocarpus facetus*	
	Axiidae	*Eiconaxius serratus*	
	Chirostylidae	*Gastroptychus investigatoris*	
		Uroptychus soyomaruae	
		Uroptychus inaequipes	
	Munidopsidae	*Munidopsis albatrossae*	
		Munidopsis bairdii	
		Munidopsis spinifrons	
Solenogastres	Strophomeniidae	*Anamenia* sp.	Kuznetsov and Mironov (1981)
Bivalvia	Arcidae	*Acar asperula*	Kuznetsov and Mironov (1981)
Crinoidea	Hyocrinidae	*Thalassocrinus clausus*	Mironov and Sorokina (1998)
Ophiuroidea	Ophiacanthidae	*Ophiacantha cf. cuspidata*	Belyaev and Litvinova (1972); Kuznetsov & Mironov (1981); Litvinova (1991, 2010); D. Zhang et al. (2018)
		Ophiomitrella sp.	
		Ophioplinthaca vicina	
	Ophiacanthida incertae sedis	*Ophiacanthella* sp.	
	Ophiothamnidae	*Ophiothamnus* sp. (*aff vemestrus*)	
		Ophiothamnus (?) sp.	
		Histampica duplicata	
		Ophioleila elegans	
	Ophiohelidae	*Ophiohelus densispinus*	

	Ophiomusaidae	*Ophiomusa granosa*	
	Ophiopyrgidae	*Ophiophyllum concinnus*	
		Amphiophiura radiata	
	Euryalidae	*Asteroschema* sp.	
Holothuroidea	Synallactidae	*Paelopatides* sp.	Kuznetsov and Mironov (1981); Moskalev and Galkin (1986)
	Psychropotidae	*Benthodites* sp.	
	Psolidae	*Psolus* sp.	
Echinoidea	Aspidodiadematidade	*Aspidodiadema montanum*	Kuznetsov and Mironov (1981)
	Fibulariidae	*Echinocyamus scaber*	
Asteroidea	Astropectinidae	Astropectinidae gen.sp	Moskalev and Galkin (1986); R. Zhang et al. (2020)
	Brisingidae	Brisingidae gen.sp	
		Astrolirus patricki	
		Brisinga sp.	
		Hymenodiscus cf. fragilis	
Brachiopoda	Discinidae	*Pelagodiscus atlanticus*	Kuznetsov and Mironov (1981)

6.3.1.2.2.1.4 Studies from the COMRA contract area

During the cruise DY56 organised by COMRA, several cold-water corals were collected by ROV from five seamounts in the Northwest Pacific Ocean (Figure 6.3.8) and identified onboard using stereoscopic microscope. The cruise report for DY56 reported that octocorals accounted for 90% of the coral samples collected from these five seamounts. The octocorals collected during DY56 were dominated by the families Primnoidae, Isididae, Victorgorgiidae, Halipteridae, Chrysogorgiidae and Gorgoniidae (Figure 6.3.9). Primnoidae was collected from four seamounts whilst Isididae and Chrysogorgiidae were collected from two seamounts. Pending further analysis, the coral communities in the seamount areas of the Northwest Pacific appear (at least at the family level) to be similar to those of the Central Pacific.

Sponge specimens collected by ROV during two COMRA cruises from Caiwei and Weijia guyots have also been identified. These results indicate that the sponge fauna was mostly composed of Hexactinellids (glass sponges), dominated by the families Euplectellidae, Rosellidae and Pheronematidae (unpublished data). Euplectellidae, Rosellidae and Pheronematidae are common sponge families in the deep sea (Tabachnick, 1988) and these early results suggest that the sponge fauna at cobalt-rich crust seamounts in the Northwest Pacific is potentially similar (at least at the family level) to that at seamounts in the North Pacific and tropical West Pacific. More samples would be needed to further explore the similarities in sponge and coral fauna from seamounts in the Northwest, North and tropical West Pacific.

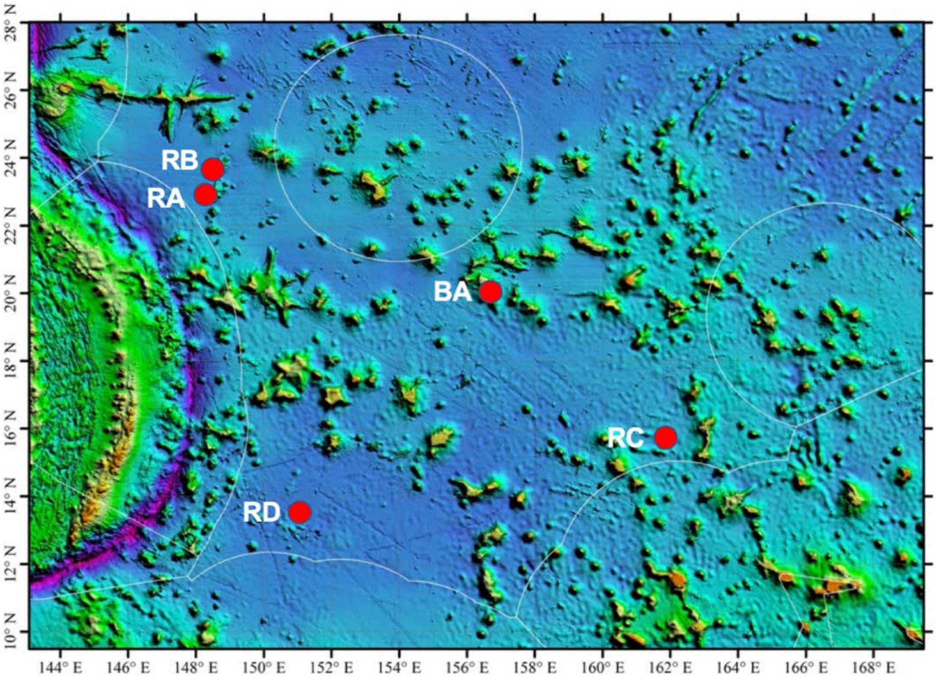


Figure 6.3.8. Sampling sites for corals during cruise DY56 to the Norwest Pacific seamounts. RA, RB, BA, RC, and RD represent different sites sampled during cruise DY56. Credit COMRA.

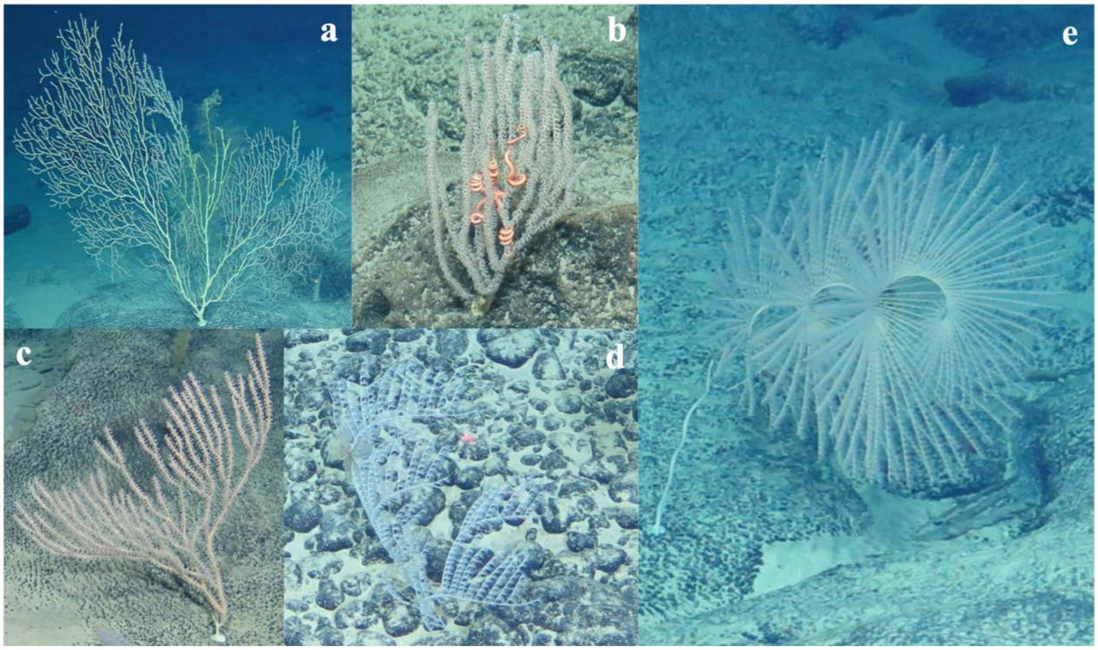


Figure 6.3.9. Selected *in-situ* photos of corals on the seafloor. From top left a: *Isidella* sp.; b: *Calyptrophora* sp.; c: *Keratosis* sp.; d: *Pleurogorgia* sp.; e: *Iridogorgia* sp. Source: unpublished data from the cruise report of DY56. Credit COMRA.

6.3.1.2.2.1.5 Studies from the JOGMEC contract area

Sugishima et al. (2018a) analysed the occurrence data of representative benthic megafaunal taxa obtained with the Finder installed Deep-sea Camera (FDC) from four seamounts (JA02, JA03, JA06, JA12) in the Northwest Pacific within the JOGMEC exploration contract area. The study by Sugishima et al. (2018a) indicated that the composition and abundance of benthic megafaunal taxa was different amongst seamounts, although the detailed spatial distributions of benthic megafaunal taxa within a seamount was not determined. To map benthic habitats for cobalt-rich ferromanganese crusts, Japanese researchers identified substratum types and the megafauna around Xufu Guyot (JA06 seamount) and analysed the spatial distribution pattern of substrata and the megafauna using FDC (Yorisue et al., 2019). The study by Yorisue et al. (2019) recorded a wide range of taxa at Xufu Gyout, including sessile (e.g., sponges, crinoids) and mobile (e.g., deep-sea fishes) organisms. Substratum types were mapped using three categories according to the ratio of hard rocks and these substratum types were correlated with megafaunal distribution patterns. Substratum type and water depth were important environmental factors explaining the spatial distribution of deep-sea benthic megafauna at Xufu Guyot. Previous studies have also demonstrated that substratum type and depth influence the distribution of benthic megafaunal taxa on seamounts (O'Hara, 2007; Rogers et al., 2007; Clark and Rowden, 2009; McClain et al., 2010; Long and Baco, 2014; Schlacher et al., 2014; Boschen et al., 2015; Morgan et al., 2015, 2019; Rowden et al., 2016; Mejia-Mercado et al., 2019). Yorisue et al. (2019) also detected significant aggregation patterns for many benthic taxa at Xufu Guyot, in particular for sessile organisms, where multiple aggregations were observed.

To improve the quality of imagery obtained from cobalt-rich ferromanganese crust environments, habitat mapping was conducted, visualising distribution patterns of benthic organisms using a state-of-the-art 3-D mapping SeaXerocks system (Thornton et al., 2012, 2016; Bodenmann et al., 2017). The SeaXerocks system was mounted on the skid of the ROV along a survey line on the flat top of the Arnold Guyot (Iguchi et al., 2019). Through the SeaXerocks system, researchers were able to determine the distributions of microtopography and benthic organisms from a 'whale's eye view' of the seafloor. Sessile organisms, such as sponges and octocorals, were aggregated on the surface of hard substrata providing further evidence that the availability of hard substrata restricts the distribution of benthic megafauna. The pattern of sand ripples on the seafloor was also characterised, indicating that the dominant seafloor current travelled from the northeast to southwest or vice versa. Through the SeaXerocks system, the relationship between benthic megafaunal spatial distribution and environmental factors was explored in greater detail than was possible using alternative methods.

To provide additional observations on the benthic megafauna, the Edokko Mark I free-fall deep-sea camera lander was deployed (Furushima et al., 2019). The first trial of Edokko Mark I was conducted at Xufu Guyot (the JA06 Seamount), where many deep-sea organisms were attracted to the baited trap and observed (Sugishima et al., 2018b). From the Arnold and Scripps guyots (JA03 and JA17 seamounts), 32 taxa were observed using Edokko Mark I including Cnidaria, Annelida, Arthropoda, Echinodermata, and Vertebrata (Sugishima et al., 2020). There were distinct differences in benthic megafaunal assemblage structure at different depths.

6.3.1.2.2.1.6 Studies from the Ministry of Natural Resources and Environment of the Russian Federation contract area

To study species composition and distribution of megafaunal taxa, an imagery survey was conducted using the towed camera platform Neptune. The camera platform was towed at an average height of 5 m above the seafloor at an average speed of 1 knot. The seafloor area in the photographs ranged from 4.5 m^2 to 10 m^2, averaging 6.7

m^2. A Canon EOS 60D digital camera was used to obtain images with an image size of 5184 × 3456 pixels. Additional megafaunal taxa were also sampled by rock dredges and telegrabs.

The highest densities of benthic megafaunal taxa were recorded on the slopes of the studied seamounts, represented by aggregations of colonies of corals, sea lilies, and sponges. Most of the observed benthic megafaunal taxa were recorded between 1200 and 2500 m, where faunal distribution density averaged from 472 to 1706 individuals per hectare. Downslope at greater depths, the megafaunal density decreased to 128 individuals per hectare. Megafaunal density was much higher in areas with hard substrata, with an average of 406 to 909 individuals per hectare. In sedimented areas, the megafaunal density decreased to an average of 196 individuals per hectare. A complete list of benthic megafaunal invertebrate groups found on the seamounts within the Ministry of Natural Resources and Environment of the Russian Federation exploration contract area is provided in Table 6.3.4.

The most numerous animals on the slopes of the Govorov, Kotsebu, and Vulcanolog guyots were corals of the class Anthozoa. From the photographs collected, six orders were identified within the Anthozoa: Alcyonacea, Actiniaria, Antipatharia, Pennatulacea, Penicillaria and Zoantharia. Of these six orders, actinians and penicillarians are solitary organisms, the other four orders are exclusively colonial forms.

Most of the coral types observed were alcyonacean colonies. Alcyonacea is a diverse group of corals which includes both branching forms and colonies that form long flexible stems covered with numerous polyps. Both soft coral colony forms attach to the hard substratum through the extended stem base. The most common alcyonaceans on the slopes of Govorov Guyot slopes were coral colonies belonging to the *Keratoisis* genus (family *Isididae*) (Figure 6.3.10.A). *Keratosis* attaches to a solid substratum with a rounded expanded base, from which several main trunks of varying thicknesses extend. Subsequently, numerous thinner branches extend from the main trunks, which are covered with small polyps on all sides. Adult colonies of *Keratosis* can reach a height of more than one meter and acquire a bushy shape.

On some sites of the seamount slopes, *Keratosis* corals sometimes form coral gardens where the branches of one colony reach the branches of another colony. Such gardens of coral colonies are places of increased biological activity, where many species of benthic organisms live in the habitat provided by these corals. Of the megafaunal taxa, crinoids (sea lilies), ophiuroids (brittle stars), sea stars, sea spiders and crustaceans are often found on the branches of alcyonacean corals. These coral gardens serve as an ecological niche not only for megafaunal taxa, but also for smaller benthic organisms within the macrofauna and meiofauna. In some areas of Govorov Guyot slopes, the density of alcyonaceans can reach more than 2200 individuals per hectare.

Large aggregations of crinoids (sea lilies) can also occur on the seamount slopes within the Ministry of Natural Resources and Environment of the Russian Federation exploration contract area. On Alba Guyot, sea lilies are the most numerous megafaunal group. Most of the individuals identified in photographs are unstalked sea lilies belonging to the family Thalassometridae (Comatulida order). These comatulid sea lilies are relatively small with a body span of less than 20 cm (Figure 6.3.10.B). Comatulids attach to the seabed through their articulated roots (cirri), which are equipped with terminal claws. These cirri form a temporary attachment with the substratum, enabling comatulids to detach and swim short distances to find a new attachment site. The ability of unstalked sea lilies to disperse and occupy new habitats is much higher than that of stalked sea lilies with permanent attachment to the seafloor. Stalked sea lilies are rarer than comatulids on the studied seamounts but can reach a larger size. For example, a stalked sea lily from the genus *Guillecrinus* (family Guillecrinidae) had a stem height of 6 cm and an arm length of 41 cm (Figure 6.3.10.C). Almost all sea lilies were found in the depth range of 1500 to 2000 m, with only a few individuals found at other depths. The abundance of sea lilies at some locations on Alba Guyot reached 3800 individuals per hectare.

At Kotsebu Guyot, large aggregations of ascidians of the genus *Culeolus* (family Pyuridae, order Stolidobranchia) were observed. Outwardly, these ascidians resemble small round translucent sacs, tapering at the bottom where they join a thin short stalk. The body size of these ascidians is small, ranging from 5 to 10 cm (Figure 6.3.10.D). At some locations on the slopes of Kotcebu Guyot, the ascidian density reached 2600 individuals per hectare, with up to 35 ascidians in a 7 m^2 portion of seabed.

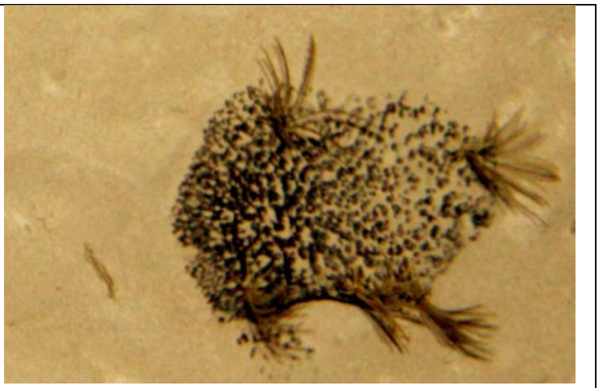
Glass sponges are an important habitat-forming group of organisms within the seamount benthic megafauna. Numerous small macrofaunal organisms can be found on the stems and within the bodies of glass sponges. Multiple glass sponges were recorded during the imagery survey of the seamounts within the Ministry of Natural Resources and Environment of the Russian Federation exploration contract area. These sponges included individuals from the genus *Hyalonema* (family Hyalonematidae, order Amphidiscosida) and individuals from the *Tretopleura* genus (family Uncinateridae, order Sceptrulophora). *Hyalonema* individuals have long stems that are anchored to the seamount hard substratum (Figure 6.3.13.E). *Tretopleura* individuals have a flattened body with a distinctive tree-like shape and can be large, such as the individual in Figure 6.3.10.E, which has a height of 1.5 m. The slopes of Vulcanolog Guyot had the greatest number of sponges, where average sponge density reached 148 individuals per hectare.

Table 6.3.4. Benthic megafaunal invertebrate groups observed on the seamounts within the Ministry of Natural Resources and Environment of the Russian Federation cobalt-rich ferromanganese crust exploration contract area. Credit Yuzhmorgeology.

Phylum	Class	Order	Family
Porifera (sponges)	Hexactinellida (glass sponges)	Amphidiscosida	Hyalonematidae
		Sceptrulophora	Uncinateridae
Cnidaria	Scyphozoa (jelly fishes)	Coronate	Periphyllidae
	Anthozoa (corals)	Actiniaria (actinians)	Actinostolidae
		Antipatharia (black corals)	Schizopathidae
		Penicillaria	Arachnactidae
		Pennatulacea (sea pens)	Umbellulidae
		Alcyonacea	Isididae
Annelida (annelid worms)	Polychaeta (bristle worms)	Phyllodocida	-
Arthropoda	Pycnogonida	Pantopoda (sea spiders)	-
	Malacostraca (higher crustaceans)	Decapoda	Aristeidae
			Nematocarcinidae
			Galatheidae
	Hexanauplia	Scalpelliformes (barnacles)	Scalpellidae
Mollusca	Cephalopoda	Octopoda	Opisthoteuthidae
Echinodermata	Crinoidea (sea lilies)	Comatulida	Thalassometridae
			Guillecrinidae

	Asteroidea (sea stars)	Brisingida	Brisingidae
		Paxillosida	-
	Ophiuroidea (brittle stars)	Ophiurida	Ophiolepididae
	Holothuroidea (sea cucumbers)	Aspidochirotida	Synallactidae
		Elasipodida	Laetmogonidae
	Echinoidea (sea urchins)	Aspidodiadematoida	Aspidodiadematidae
		Holasteroida	Urechinidae
Hemichordata	Enteropneusta (acorn worms)	Enteropneusta	-
Chordata	Ascidiacea	Stolidobranchia	Pyuridae

A



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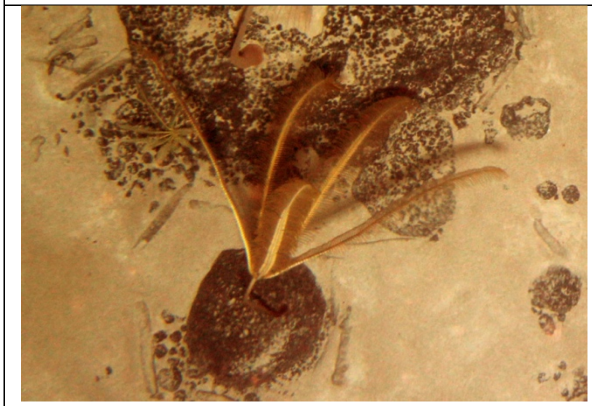

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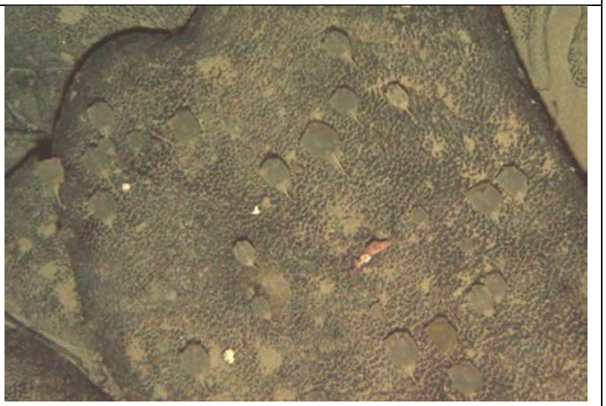

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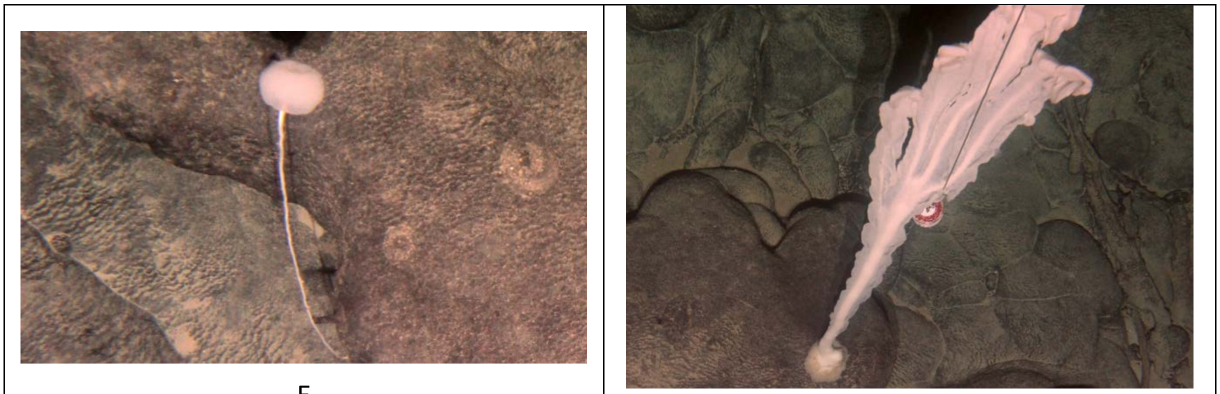

E

F

Figure 6.3.10. A) Aggregation of coral colonies from the genus *Keratoisis* on Govorov Guyot; B) an aggregation of sea lilies from the Comatulida order on Alba Guyot; C) stalked sea lily from the *Guillecrinus* genus on Alba Guyot; D) aggregation of ascidians of the genus *Culeolus* on the surface of crusts at Kotcebu Guyot; E) glass sponge of the *Hyalonema* genus on Govorov Guyot; F) glass sponge of the *Tretopleura* genus on Govorov Guyot. Credit Yuzhmorgeology.

In addition to those observed through image surveys, several megafaunal taxa were sampled by rock dredges and telegrabs on Govorov Guyot (Figure 6.3.11.A – H). These megafaunal taxa included shrimps of the Palaemonidae family; squat lobsters of the *Munida* genus (family Munididae, order Decapoda) and *Acanthephyra* genus (family *Acanthephyridae*); ophiuroids from the *Ophioplinthaca* genus (family Ophiacanthidae, order Ophiacanthida); coral polyps of the *Iridogorgia* genus (family Chrysogorgiidae, order Alcyonacea); fragments of coral branches from the *Paragorgia* genus (family Paragorgiidae, order Alcyonacea), a sea star of the *Henricia* genus*,* and a soft coral colony of the *Clavularia* genus. A small fish belonging to the species *Brama orcini* (family *Bramidae*, order *Perciformes*) was also collected.

A

B

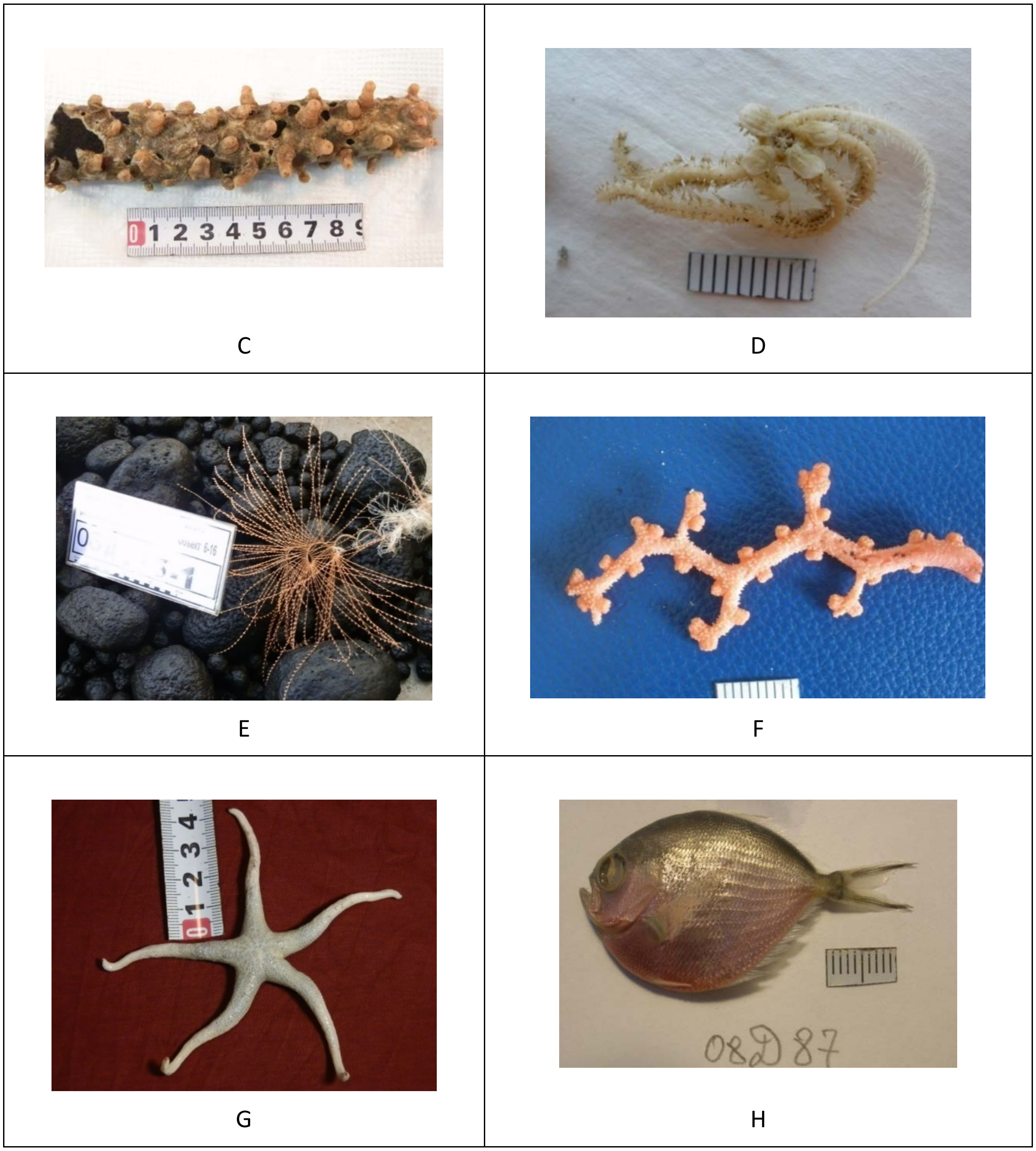
C D E F G H

Figure 6.3.11. Megafaunal taxa sampled by rock dredges and telegrabs on Govorov Guyot. A) Deep-sea shrimp from the Palaemonidae family; B) decapod crustacean of the *Munida* genus; C) coral colony of the *Clavularia* genus; D) ophiuroid of the *Ophioplinthaca* genus; E) coral of the *Iridogorgia* genus; F) single branch of coral of the *Paragorgia* genus; G) sea star of the *Henricia* genus; H) ray-finned fish *Brama orcini*. Scale bar division is 1 mm. Credit Yuzhmorgeology.

6.3.1.2.2.2 Macrofauna

Benthic macrofauna are smaller organisms that can occur within the sediment or attached to hard substrata. Most macrofaunal taxa are too small to be identified by imagery (photos and videos), and as a result, there is often less information available regarding these taxa. To date, there have been few studies characterising the benthic macrofauna at cobalt-rich crust seamounts, and little is known about the macrofauna at Northwest Pacific seamounts.

From the limited information available, the common macrofaunal taxa recorded from Northwest Pacific seamounts appear to be similar to those found in other deep-sea environments, including Annelida (e.g., Polychaeta), Arthropoda (e.g., Arachnida, Brachipoda, Malacostraca and Ostracoda), Chaetognatha (e.g., Sagittoidea) and Mollusca (e.g., Gastropoda and Bivalvia).

6.3.1.2.2.2.1 Studies from the Ministry of Natural Resources and Environment of the Russian Federation contract area

The macrofaunal taxa were studied through analysing biological samples of bottom sediments collected with a boxcorer sampler and dredges. The boxcorer sampler had a sampling area of 0.25 m^2 and samples were taken from within the boxcorer in three layers: 0 – 2, 2 – 5, and 5 – 10 cm. The samples were washed on a sieve with a mesh size of 0.25 mm. The material remaining on the sieve was sequentially fixed with 4 % formalin and 80 % ethanol.

The macrofauna was studied at locations where sediments overlaid hard substratum. The sediment on seamounts within the Ministry of Natural Resources and Environment of the Russian Federation exploration contract area was very dense and consisted of calcareous foraminiferal shells and their fragments (Figure 6.3.12.A). This type of sediment is not favorable for burrowing organisms or detritus feeders, therefore, these locations tended to have low macrofaunal abundance and taxonomic diversity. The most numerous macrofaunal group were the polychaetes; however, due to the hardness of the sediment, almost all specimens were severely damaged during sampling and washing of samples. The best-preserved taxa were the other worm-like animals - priapulids (phylum Priapulida), with their absence of segmentation and dense body tissues making them more robust to sampling and sample treatment (Figure 6.3.12.B). The full list of sampled macrofaunal taxa and their average density on the surface of sediments on Vulcanolog Guyot is given in Table 6.3.5.

Figure 6.3.12. A) Photograph of a sediment sample from Govorov Guyot, image taken using a microscope; B) priapulids in sediments from Vulcanolog Guyot. Scale bar division in both images is 1 mm. Credit Yuzhmorgeology.

Table 6.3.5. Taxonomic composition and average abundance of macrofaunal taxa in sediment samples recovered from Vulcanolog Guyot. Credit Yuzhmorgeology.

Phylum	**Class**
Annelida	Polychaeta
Priapulida	-
Mollusca	Bivalvia
Mollusca	Gastropoda
Mollusca	Scaphopoda
Echinodermata	Holothuroidea
Arthropoda	Malacostraca

6.3.1.2.2.3 Meiofauna

Despite the increasing number of studies being conducted on the benthic fauna of seamounts, there is limited information about benthic meiofaunal taxa. Whilst it has been suggested that some species may be restricted to certain seamounts or regions, it is often unclear whether these species are truly endemic or whether the meiofauna are chronically under-sampled. To gain a regional appreciation for meiofaunal taxa, including potentially endemic species, there would need to be comprehensive surveys conducted at different seamounts and adjacent deep-sea sediments at the same depths.

Obtaining quantitative meiofauna samples from seamounts can be challenging due to seamount topography, which may be uneven with steep slopes. Obtaining quantitative meiofaunal samples across the full range of seafloor types, including hard or rocky substrata and soft sand or mud, can also present challenges. As a result, many studies on seamount fauna are qualitative, and may include samples collected using different sampling devices (e.g., Multi-corer, Box corer, Epibenthic sledges), which hinders comparison between samples (George and Schminke, 2002).

6.3.1.2.2.3.1 Studies from the COMRA contract area

The studies conducted to date have identified numerous meiofaunal groups from seamounts in the Northwest Pacific. The taxa sampled during COMRA surveys DY27 and DY36 include Nematoda, Harpacticoida, Copepoda, Sarcomastigophora, Polychaeta, Aplacophora, Gnathostomulida, Priapulida, Acari, Tardigrada, Ostracoda, Isopoda, Gastropoda, Amphipoda and Heteropoda (unpublished data).

From the published literature, meiofaunal taxa recorded from this region include Bivalvia, Bryozoa, Cnidaria, Cumacea, Entoprocta, Gastrotricha, Halacarida, Kinorhyncha, Leptostraca, Loricifera, Oligochaeta, Pantopoda, Rotaria, Sipuncula, Solenogastres, Tanaidacea, Tantulocarida and Turbellaria (George, 2013). Nematoda is the most dominant meiofaunal group, with nematodes typically accounting for more than 80% of the total benthic abundance, followed by Harpacticoida.

6.3.1.2.2.3.2 Studies from the Ministry of Natural Resources and Environment of the Russian Federation contract area

Meiofaunal communities were characterised through analysing biological samples of seafloor sediments collected with a boxcorer sampler and dredges. Samples for the study of meiofauna were taken from a boxcorer sample using a plastic tube 9.5 cm in diameter. Sub-samples of meiofauna were taken from this tube in the following layers: 0 – 0.5, 0.5 – 1, 1 – 1.15, 1.5 – 2, 2 – 3, 3 – 4, 4 – 5 cm. Samples were fixed on the research vessel with 10 % formalin, without washing. Later in the laboratory, samples were washed with running water over a sieve with a mesh size of 0.032 mm.

Compared to other size classes of deep-sea benthic fauna, meiofauna organisms are often the most numerous, with abundances reaching almost three thousand individuals per 0.25 m^2. The majority of meiofaunal individuals are found in the upper layer of the sediment above the 5 cm horizon, whereas some macrofaunal individuals can be found at up to 10 cm depth within the sediment. The most numerous meiofaunal individuals in the 0 – 5 cm sediment layer collected from Alba Guyot were worm-like animals from the phylum Nematoda (nematodes), which made up 72% of the average abundance of meiofaunal individuals. Small copepod crustaceans from the order Harpacticoida were the second most abundant, comprising 23% of the collected meiofaunal individuals. The remaining 5% of individuals were comprised of ostracods and gnatostomulids (Table 6.3.6).

Table 6.3.6. Meiofaunal taxa found in the sediments on Alba Guyot, and their average abundance in the sediment layer from 0 to 5 cm. Credit Yuzhmorgeology.

Phylum	**Class**	**Order**	**Abundance (individuals 0.25 m^{-2})**
Nematoda	-	-	1682
Arthropoda	Hexanauplia	Harpacticoida	534
Arthropoda	Ostracoda		6
Gnathostomulida	-	-	3

Deep-sea nematodes can be challenging to differentiate based on morphological features. Their small, worm-like bodies are covered with a strong elastic cuticle that can be either smooth or ringed. Individuals belonging to the family Desmoscolecidae are more readily distinguished based on morphological features, including their short and fusiform body, visible segments, and adornment with spines, needles, warts, or sticky mucus that adheres to particles. Some of the nematodes sampled from the sediments on Alba Guyot were identified as members of the Desmoscolecidae family (Figure 6.3.13).

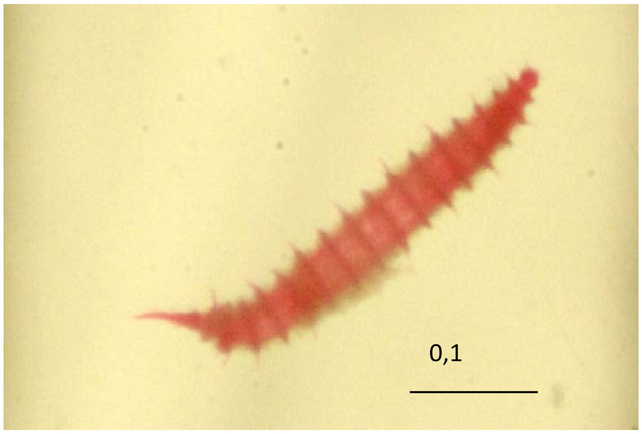

Figure 6.3.13. A nematode individual from the Desmoscolecidae family collected from the sediments of Alba Guyot. Scale bar is 0.1 mm. Credit Yuzhmorgeology.

6.3.1.2.3 Benthic and demersal nekton

Due to natural depth-related gradients in water properties, seamounts transition through a considerable range of environmental conditions (Ross et al., 2020). As a result, depth can act as a proxy for other environmental variables that play a significant role in determining the spatial distribution of benthic seamount fauna (e.g., Boschen et al., 2015; Ross et al., 2020). Seamount species are generally found in stratified bands, the depths of which are determined by both environmental (e.g., temperature, oxygen) and biological (e.g., predation, competition) factors (Wishner et al., 1990; Du Preez et al., 2016; Victorero et al., 2018). Generalists tolerant of a broad range of depth-related conditions can be widespread over a seamount, particularly highly mobile species that undertake ontogenetic or diel vertical migrations. However, a narrower depth-stratified distribution holds true for many nekton species on seamounts (e.g., Ross et al., 2020), which, despite their ability to swim over the seafloor, display high habitat fidelity. The Northwest Pacific seamounts in the exploration area rise from the abyssal plains of the East-Marianas Deep, through the lower and upper bathyal zones, to summits as shallow as 550 m depth (e.g., Alba Guyot; Mel'nikov et al., 2016), transecting roughly 5.5 vertical kilometres of the ocean. The combination of depth bands, habitat fidelity, and depth range suggest there is likely highly depth-related, and therefore spatial, turnover in nekton species distributions (i.e., seamount beta-diversity).

Whilst many benthic and demersal nekton species aggregate on seamounts, few, if any, are thought to be seamount obligates (Clark et al., 2007). More commonly, the distribution of these species also includes adjacent continental shelf and slope habitats in addition to the small, scattered seamount populations. Yet, spatially isolated seamount populations may not necessarily be genetically isolated if they produce larvae or migrating adults capable of long-distance dispersal (Samadi et al., 2007). Although it may not represent a dispersal boundary, the area of the Northwest Pacific where contracts for exploration of cobalt-rich crusts have been awarded spans two ecologically defined deep-sea biogeographic provinces; the West Pacific, and North Pacific lower bathyal zones (UNESCO, 2009; Watling et al., 2013) (See Section 6.3.1.1 – Spatial distribution, biogeography). Each of these two provinces has 16 biologically meaningful classes of seamounts (32 in total) (Clark et al., 2011) where each class is defined by a unique suite of ecological parameters that would influence the type of habitats the seamounts provide and so the potential spatial distribution of benthic species within the region.

In general, there is less information available on the spatial distribution of benthic and demersal nekton at Northwest Pacific seamounts compared to the information available for the benthic invertebrates in the same region. To potentially address the limited information available for benthic and demersal nekton, a future approach could be to extrapolate the known spatial distribution of species inhabiting similar depths along the Marianas and other nearby island groups as well as the distant but relatively well studied Central-West Pacific seamounts to ascertain 'presence probability' or 'density' (e.g., species distribution or habitat suitability models or predictions) for Northwest Pacific seamounts. The following sections review the information that is currently available for benthic and demersal nekton at Northwest Pacific seamounts.

6.3.1.2.3.1 Fishes

Benthic fishes have played a major role in the storied history of seamounts (Brewin et al., 2007) and much of the existing knowledge on seamount benthic and demersal nekton often originates from fisheries data on commercially valuable species. Despite there being at least 15 peaks above 1500 m within the Magellan seamounts alone (i.e., within fishable depths) (Clark et al., 2007), historically there are no major seamount fisheries in the part of the Northwest Pacific where mineral exploration contracts have been awarded by the ISA

(UNEP, 2006; Clark et al., 2007). Due to the absence of fisheries data and few dedicated biological surveys (ISA, 2006), there is limited information available on the benthic and demersal nekton in the region.

A limited number of studies have been conducted on the benthic and demersal fishes at the Northwest Pacific seamounts by Russian scientists. In 1979, *FV Mys Yunony* (TINRO) sampled nine seamounts in the region, recording 37 species from 27 families including Macrouridae, Alepocephalidae, Brotulidae and Anguilloidea (Borets and Kulikov, 1986). The TINRO bottom sampling program conducted at seamounts in the region during January and February 1983 was severely limited due to challenges posed by the rough seafloor topography (Orlov, 1991). From the few successful bottom trawls, several specimens from families characteristic of seamount fishes were identified, including Alepocephalidae, Derichthydae, Nettestomidae, Synaphobranchidae, Haulosauridae and Macrouridae (Orlov, 1991). The most numerous fishes from the successful trawls were from the Alepocephalidae family. These early surveys indicated that there were considerable differences between the fish fauna from the Northwest Pacific seamounts and the Hawaiian ridge (Orlov, 1991), although more recent data collections suggest that there are also similarities in the fish fauna from these locations (see Table 6.3.8).

In 2016, eleven remotely operated vehicle (ROV) dives were conducted between Guam and Wake Monument from the NOAA Ship *Okeanos Explorer* (Kelley et al., 2016). One of these dives was conducted on Alba Seamount (maximum depth of 2319 m) within the exploration contract area held by the Ministry of Natural Resources and Environment of the Russian Federation. The remaining dives were in the Wake Monument Boundary (dive depths 3135 to 766 m), East of the region of the Northwest Pacific where exploration contracts have been issued by the ISA. Provisional identifications of 61 fish taxa were made during the expedition (Table 6.3.7; Figure 6.3.14). For information on the imagery (e.g., high-resolution imagery readily available online), faunal observations (e.g., corals, sponges, other invertebrates, and fishes), and biological sample inventories, see the Ex 1606 cruise report (Kelley et al., 2016).

Table 6.3.7. A list of fishes observed during the EX 1606 *Okeanos Explorer* expedition (provisional identifications) (Appendix C, Kelley et al., 2016). All dives were conducted in the in the Wake Monument Boundary, apart from Dive 1, which was on Alba Seamount within the exploration contract area held by the Ministry of Natural Resources and Environment of the Russian Federation. [1]Fish taxon observed during the dive on Alba Seamount. Credit Cherisse Du Preez.

Group	**Taxon**	**Dive Number**
Eels	*Bathyconger* sp.	8
	Bathyuroconger sp.	8,14
	?*Ilyophis* sp.	2,3,6
	Nettastoma parviceps	11
	?*Synaphobranchus affinis*	14
	Synaphobranchus brevidorsalis/oregoni[1]	1,2,3,6,7,10
	Synaphobranchus sp.	7,14
	Synaphobranchidae	2,7,9,12,13,14
	Venefica sp.	12
	Unidentified eel	9
Halosauridae	*Aldrovandia phalacra*	14
	Aldrovandia sp.	8,10

	Halosauridae	12
Macrouridae	*Coryphaenoides* sp.	12
	Kumba sp.	2,5,6,10,12
	Luciobrotula sp.	8
	?*Malacocephalus boretzi*	8,9
	Malacocephalus sp., *Nezumia* sp., or *Ventrifossa* sp.	8
	Nezumia sp.	8
	Ventrifossa sp.	8
	Unidentified macrouridae	9
Moridae	*Gadella* sp.	11
	?*Laemonema robustum*	8
Myctophidae	Myctophidae	3
Ophidiidae	*Bassogigas* sp.	5,6,12
	Bassozetus sp.	3,5,6,7,14
	Lamprogrammus sp.	12
	Ophidiidae	8,9,12
	Porogadus sp.[1]	1
Other fishes	Alepocephalidae	12
	Apristurus sp.	9
	Argyripnus sp.	11
	Astronesthes sp.	11
	Barbourisia sp.	12
	Bathypterois tricolor	12
	Bathytyphlops sp.	9
	Beryx decadactylus	11
	Pyramodon sp.	8,9
	Chaunacops coloratus	6
	Chlorophthalmus sp	11
	Chrionema chryseres	11
	Diplacanthopoma sp.	8
	Epigonus sp.	11
	Glossanodon sp?	11
	Grammicolepis brachiusculus	11
	Hexanchus griseus	11
	Hollardia sp.	11
	Lophiodes miacanthus	11
	Neoscopelus sp.	8,9

	Odontaspis ferox	8
	Plectranthias sp.	11
	Plesiobatis daviesi	8
	Polymixia berndti	11
	?*Pontinus* sp.	11
	Randallichthys filamentosus	11
	Rexea sp.	9
	Ruvettus pretiosus	8
	Scopelarchus sp.	8
	Setarches sp.	11
	Sladenia sp.	8,9
	Stethopristis eos	11

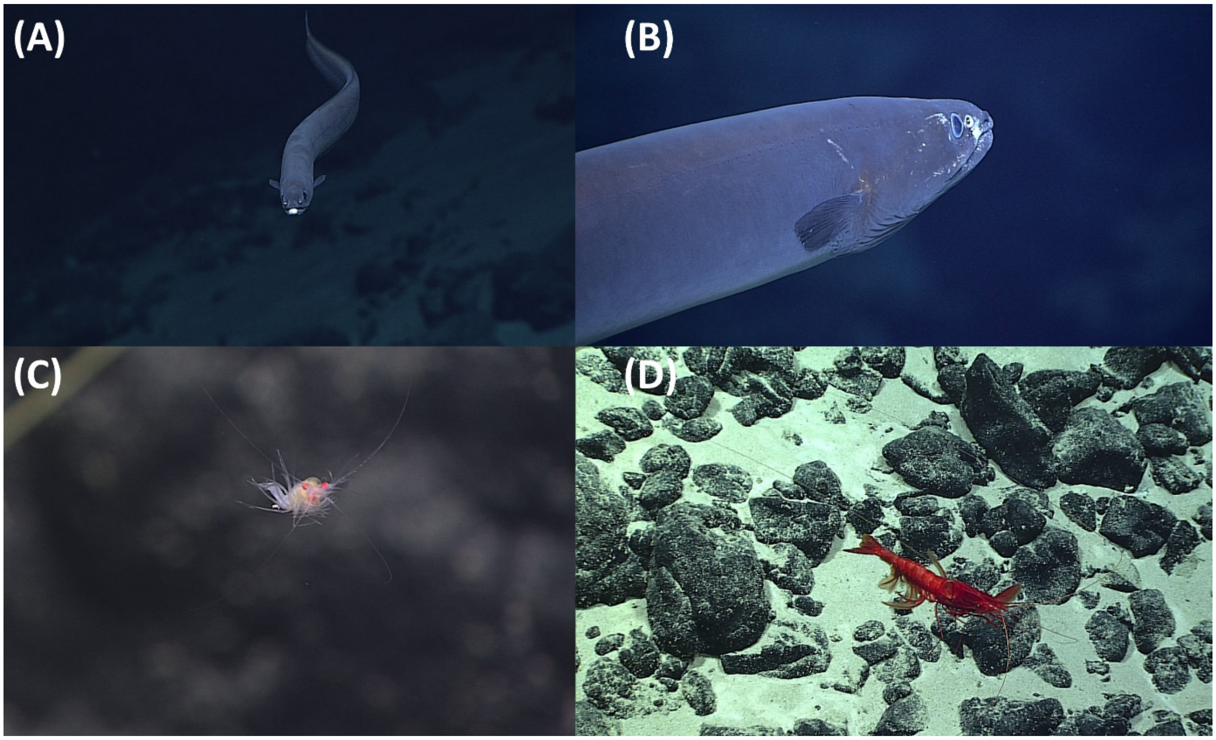

Figure 6.3.14. Representative images of benthic nekton observed swimming over Alba Seamount within the exploration contract area held by the Ministry of Natural Resources and Environment of the Russian Federation (EX 1606 *Okeanos Explorer* expedition; Kelley et al., 2016): (A, B) cutthroat eels (*Synaphobranchus* sp.), (C) a copepod, and (D) a shrimp.

To supplement the limited information available in the published literature regarding the benthic and demersal fishes in the region, the Ocean Biodiversity Information System (OBIS) was queried for seamount specific datasets (i.e., Seamounts Online version 2005-1-European data) within the region of the Northwest Pacific where exploration contracts have been awarded by the ISA. The OBIS search returned 86 records of 55 taxa, 38 of which were identified to species. Of these taxa, 25 were fishes (Table 6.3.8). All of the 25 fish taxa were within the class

Actinopterygii and were collected during the 1972 JAMARC benthic trawl survey between 1520 and 1300 m depth (Japan Marine Fishery Resource Research Centre, 1973). Whilst it is possible that the trawl net caught pelagic fishes during deployment and retrieval, the assumption is that the fishes collected were in association with the seafloor. The distribution of fishes in Table 6.3.8 was further refined using additional references (Mundy, 2005; ISA, 2011).

Table 6.3.8. The benthic and demersal fish taxa queried from the Ocean Biodiversity Information System (OBIS) for the Northwest Pacific exploration area (dataset: Seamounts Online version 2005-1-European data). Six taxa[1] were recorded from seamounts in the Hawaii region by Mundy (2005). A further nine taxa[2] were listed in the species inventory for the Hawaiian Archipelago and nearby seamounts, developed as part of an ISA workshop (ISA, 2011). Credit Cherisse Du Preez and Amy Baco.

Order	**Family**	**Scientific name**	**Depth (m)**	
			Max.	**Min.**
Anguilliformes	Congridae	Congridae	1440	1300
Anguilliformes	Nemichthyidae	*Nemichthys scolopaceus*[1]	1440	1440
Anguilliformes	Serrivomeridae	Serrivomeridae	1520	1300
Anguilliformes	Synaphobranchidae	*Synaphobranchus affinis*[2]	1440	1300
Anguilliformes	Synaphobranchidae	*Synaphobranchus kaupii*[2]	1420	1420
Aulopiformes	Alepisauridae	*Alepisaurus ferox*[1]	1420	1420
Aulopiformes	Ipnopidae	*Bathytyphlops marionae*[2]	1440	1440
Aulopiformes	Paralepididae	Paralepididae[2]	1420	1420
Beryciformes	Anoplogastridae	*Anoplogaster cornuta*[1]	1420	1420
Cetomimiformes	Barbourisiidae	*Barbourisia rufa*[2]	1420	1420
Gadiformes	Macrouridae	Macrouridae[2]	1440	1300
Lophiiformes		Lophiiformes	1440	1440
Myctophiformes	Myctophidae	Myctophidae[2]	1520	1300
Notacanthiformes	Halosauridae	Halosauropsis	1520	1300
Ophidiiformes	Ophidiidae	*Xyelacyba myersi*[1]	1520	1300
Osmeriformes	Alepocephalidae	Alepocephalidae[2]	1440	1300
Perciformes	Chiasmodontidae	Kali	1300	1300
Saccopharyngiformes	Eurypharyngidae	Eurypharyngidae	1440	1440
Stomiiformes	Gonostomatidae	Gonostomatidae[2]	1440	1440
Stomiiformes	Sternoptychidae	Argyropelecus	1300	1300
Stomiiformes	Stomiidae	*Chauliodus sloani*[1]	1440	1300
Stomiiformes	Stomiidae	Idiacanthinae	1420	1420
Stomiiformes	Stomiidae	Malacosteinae	1420	1300
Stomiiformes	Stomiidae	Melanostomias	1440	1440
Stomiiformes	Stomiidae	*Photonectes albipennis*[1]	1520	1520

The 25 fish OBIS records represent data from 21 sample stations on nine seamounts between 1180 and 1520 m depth (Table 6.3.9; Figure 6.3.15). This depth range only covers a fraction of the full depth range within which seamounts occur in the Northwest Pacific region. Future assessments of spatial distribution could consider expanding the OBIS search to include non-specific seamount datasets or inclusion of species inventories from nearby regions, such as a post-expedition annotation of the Ex 1606 *Okeanos Explorer* imagery (Kelley et al., 2016), the list developed as part of a previous ISA workshop (see shared species in Table 6.3.8; ISA, 2011) or species records available through the University of Hawaiʻi Undersea Research Laboratory (HURL) Deep-sea Animal Identification Guide[13].

Table 6.3.9. Summary information on the Ocean Biodiversity Information System (OBIS) records for the Northwest Pacific exploration area (dataset: Seamounts Online version 2005-1-European data). M-P Seamount = Mid-Pacific Seamount. The seamount name used in the dataset and the GEBCO Undersea Feature Names Gazetteer name (based on latitude and longitude) are both provided. Seamount locations are mapped in Figure 6.3.18. Credit Cherisse Du Preez.

Number of stations	**Name (survey)**	**Name (GEBCO)**	**Latitude**	**Longitude**	**Depth (m)**	
					Max.	**Min.**
5	Guyot IOAN	Fedorov Guyot	14.188334465	155.993331909	2000	1485
6	Ita Mai Tai Guyot	Ita Mai Tai Guyot	12.9600000381	156.795829773	2005	1422
1	M-P Seamount 7	Tayama Guyot	23.5333328247	157.393325806		1420
1	M-P Seamount 8	na	22.6583328247	160.869995117		1900
1	M-P Seamount 9	na	22.3333339691	161.526672363	1334	1296
2	Wilde Guyot	Wilde Guyot	21.0916671753	163.27166748	2400	1350
1	Seamount B	Sampson Guyot	20.3116664886	163.016662598	1300	1300
3	Seamount C	na	19.296667099	164.886672974	1520	1420
1	Sylvania Tablemount	na	11.9499998093	164.850006104	1353	1353

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[13] http://www.soest.hawaii.edu/HURL/HURLarchive/guide.php

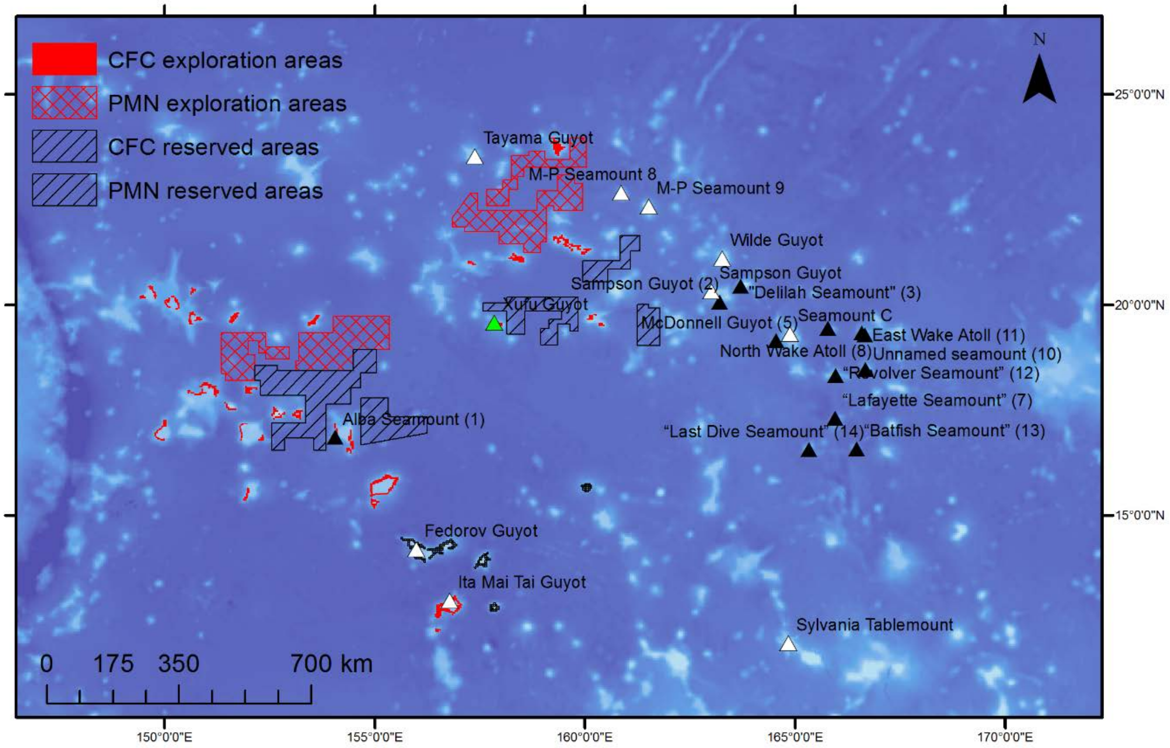

Figure 6.3.15. Locations of survey data on seamounts and guyots in and around the region of the Northwest Pacific where exploration contracts have been awarded by the ISA. Black triangles: surveyed during the Ex 1606 *Okeanos Explorer* expedition (site name followed by bracketed dive number); white triangles: from the Ocean Biodiversity Information System (OBIS) records (dataset: Seamounts Online version 2005-1-European data); and green triangles: from recent benthic spatial distribution research (in review). Exploration and reserved areas shapefiles from https://www.isa.org.jm/minerals/maps. Base map courtesy of the Global Multi-Resolution Topography synthesis (Ryan et al., 2009). Credit Cherisse Du Preez.

6.3.1.2.3.2 Crustaceans and cephalopods

Benthic and demersal nekton of the Northwest Pacific seamounts are expected to consist of a diverse assemblage of fishes, crustaceans (e.g., amphipods and shrimp), and cephalopods (squid and octopus). There is limited information on the spatial distribution of benthic and demersal nekton, other than fishes, at Northwest Pacific seamounts. Photographic observations will continue to be a valuable source of species distribution information as exploration continues within the region (e.g., the presence of a nektonic shrimp confirmed by photographic observations taken from the seafloor of a Magellan Seamount, courtesy of Dr V Yubko; ISA, 2006).

In 2016, an ROV deployed from the *Okeanos Explorer* captured high-resolution still and video imagery of the benthos on Alba Seamount and nearby seamounts in the Wake Monument (Kelley et al., 2016). Provisional identifications made on Alba Seamount include two isopod taxa and 14 shrimp taxa, but further annotation of the imagery would likely resolve many more benthic and demersal nekton taxa. In a new study, images from towed cameras and remotely operated vehicles were used to document the spatial distribution of both nekton and sessile taxa for Xufu Guyot (the JA06 Seamount). In a different study also on Xufu Guyot, scientists collected 17 amphipod species using baited traps, all belonging to the superfamily Lysianassoidea (Iguchi et al., 2020).

Deep-sea amphipods are a diversified group of mobile scavengers in the epibenthic. The diversity and high abundance of amphipods means they can provide useful information for evaluation biodiversity at seamounts. Deep-sea amphipods are suitable study organisms for understanding adaptive evolution of deep-sea organisms (Ritchie et al., 2017a, 2018) and have the potential to be used as test subjects in future deep-sea mining ecotoxicological studies (Kwan et al., 2019).

Where sufficient deep-sea amphipod individuals are collected by baited traps, these samples can be used to determine patterns in both diversity and connectivity at seamounts. Previous studies have used this approach with deep-sea amphipods to conduct population and assemblage structure analyses, clarify species diversity, and determine patterns in assemblage structure associated with depth (Duffy et al., 2013; Fujii et al., 2013; Horton et al., 2013; Jamieson et al., 2011a). Jamieson et al. (2011a) characterised the ecotone of the amphipod assemblage at 6000 m depth using deep-sea amphipods collected with baited traps from the Southwest Pacific. Fujii et al. (2013) conducted assemblage analysis using deep-sea amphipods collected across the abyssal and hadal zones in the South Pacific, categorizing amphipod assemblages into four groups that could be explained by depth and longitude reflecting geographic distances. Through analysing deep-sea amphipods collected by baited trap from the Mid-Atlantic Ridge, Horton et al. (2013) identified 39 species, dominated by *Abyssorchomene abyssorum*. A further study analysing the population structure of *A. abyssorum* indicated that amphipod size and morphology were different between males and females (Duffy et al., 2013). The types of studies conducted using samples with abundant deep-sea amphipods in other regions could also be conducted at seamounts in the Northwest Pacific.

To supplement the limited information available in the published literature regarding the benthic and demersal crustaceans and cephalopods in the region, OBIS was queried for seamount specific datasets (i.e., Seamounts Online version 2005-1-European data) within the Northwest Pacific exploration area. Although the OBIS search returned 86 records of 55 taxa, this dataset did not include any nektonic amphipods, shrimp, squid, or octopus. Future assessments of spatial distribution could consider expanding the OBIS search to include non-specific seamount datasets, or inclusion of species inventories from nearby regions, such as a post-expedition annotation of the Ex 1606 *Okeanos Explorer* imagery (Kelley et al. 2016) or species records available through the University of Hawaiʻi Undersea Research Laboratory (HURL) Deep-sea Animal Identification Guide[14]. Representative images of ten deep-sea octopus and squid observed on Hawaiian seamounts and nearby island slopes photo-documented within the HURL Deep-sea Animal Identification Guide are available from http://www.soest.hawaii.edu/HURL/HURLarchive/guide.php.

6.3.1.2.3.3 Studies from the JOGMEC contract area

To determine the spatial distribution and diversity of amphipods at seamounts within the JOGMEC contract area, a baited trap was mounted on Edokko Mark I, which was deployed at Arnold and Scripps guyots. These baited trap deployments succeeded in collecting many amphipod specimens including several species groups with different life history characteristics (Sugishima et al. 2018b, 2020). Through DNA barcoding and molecular operation taxonomic unit (MOTU) community analysis of the sampled amphipods, researchers determined that amphipod assemblage structure was different amongst depths and seamounts. Historically, ecological studies using deep-sea amphipods have been based on morphological identification, however convergent evolution and intraspecific variations complicate the ability to provide robust identifications (Ritchie et al., 2015). DNA

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[14] http://www.soest.hawaii.edu/HURL/HURLarchive/guide.php

barcoding, as used by Sugishima et al. (2018b, 2020), could help to address challenges with morphological identification and contribute to better understanding of population and community structure for amphipods and other deep-sea organisms (Janssen et al., 2015).

Further studies targeting deep-sea amphipod assemblages from multiple seamounts, including information on local environmental conditions, would enable biodiversity patterns amongst seamounts to be better characterised. As part of the environmental baseline surveys being conducted on cobalt-rich crust seamounts South and West of Marcus Island (Minamitorishima Island), an international joint cruise was carried out on *RV Da Yong Yi Hao* (DY56), which collected many samples of deep-sea amphipods. Genetic analysis targeting these amphipods and others collected in the region could enable species diversity and population and assemblage structure to be evaluated with high resolution amongst seamounts in the Northwest Pacific.

6.3.1.2.4 Local distribution patterns

The composition and spatial distribution of seamount biological communities are affected by numerous environmental factors, including primary productivity, hydrodynamic conditions, chemical characteristics, seamount topography, side of a seamount, and substratum. Some of these influencing factors are closely related to water depth, for example as the water depth increases, available light, temperature, dissolved oxygen, and labile organic matter tend to decrease, whilst pressure increases (Thistle 2003). Therefore, water depth is often used as a key indicator or proxy to explain variation in seamount biological communities (O'Hara, 2007; Rogers et al. 2007; Clark and Rowden 2009; McClain et al. 2010; Long and Baco 2014; Schlacher et al. 2014; Boschen et al. 2015; Rowden et al. 2016; Mejia-Mercado et al. 2019; Morgan et al. 2019). McClain et al. (2010) studied the seamounts in the Northeast Pacific Ocean and found that benthic species change across the seamount slope, with species composition changing by approximately 50% for every 1500m of water depth gradient. The community similarity between the seamount top and the base was only 20-30%. Long and Baco (2014) studied a deep-sea coral bed in the Main Hawaiian Islands and found 93% dissimilarity amongst the six distinct deep-sea coral communities that occurred across a relatively narrow depth band of 320-530m. Morgan et al. (2019) found a similarly high turnover rate on a seamount in the Northwestern Hawaiian Islands. Substrata can also play an important role in shaping the spatial distribution of seamount benthic megafauna (Clark et al., 2011; Morgan et al., 2015, 2019). For example, Narayanaswamy et al. (2013) studied the benthic communities at seamounts in the Northeast Atlantic Ocean and determined that fish and crustaceans with strong mobility were dominant in sedimented areas, whilst filter feeders were mostly located on hard substratum.

In the Northwest Pacific, faunal distribution patterns were described based on visual observations obtained during a series of human-occupied submersible dives using Pisces VI and Pisces XI on the Ita Mai Tai (Weijia) and IOAN guyots (Figure 6.3.16; Moskalev and Galkin, 1986). Benthic assemblage structure along the 1500 – 2000 m depth gradient was similar at Ita Mai Tai and IOAN guyots. The hard outcrops at the margins of the plateau and escarpments had a higher density and greater abundance of benthic organisms (particularly sessile suspension-feeders) compared to the sedimented plateau and slopes with shallow gradients. This pattern of higher density and greater abundance of sessile suspension-feeders, such as corals and sponges, in elevated areas with hard substrata is common in seamount ecosystems (e.g., Genin et al., 1986). Many of the taxonomic groups (such as Crinoidea, Asteroidea, and Ophiroidea) reported from localised elevations on these seamounts utilise biological substrata such as coral frameworks and sponges (Moskalev and Galkin, 1986; Zhang et al., 2020). Obligate symbiotic taxa have also been reported from seamounts, including certain polynoid (e.g., Britaev, 1981) and chyrostylid (e.g., Dong et al., 2017) species.

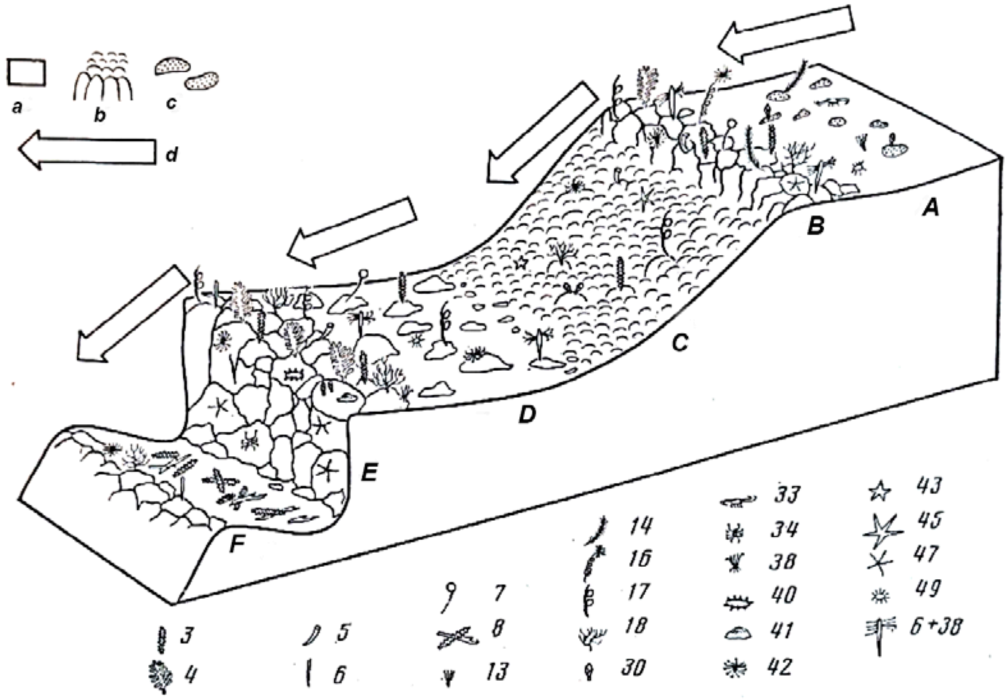

Figure 6.3.16. Patterns of benthic faunal distribution as observed at Ita Mai Tai and IOAN guyots (depth 1500-2000m). For A-F forms of topography: A – plateau, B – ledge, C – low gradient slope; D – terrace, E – cliff, F – sediment accumulation pocket. For a-c substratum types: a – soft sediment (foraminifera sand), b – bedrock with cobalt-rich crust, c – pumice. For d: predominant current directions. Taxonomic groups (numbers): same as in Figure 6.3.6. Reproduced from Moskalev and Galkin (1986) with translation by Tina Molodtsova.

Similar patterns of benthic faunal assemblage structure have been reported from other cobalt-rich crust areas. A survey conducted by Morgan et al. (2015) at Necker Ridge used 27 high definition video transects from 1400 to 2000m depth to determine benthic assemblage structure. Significant differences in assemblage structure were observed between northern and southern pinnacles, with northern pinnacles dominated by octocorals largely from the families Isididae and Chrysogorgidae, and southern pinnacles dominated by crinoids from the family Charitometridae (Morgan et al., 2015). Observed patchiness in species distribution did not correlate with depth, however assemblage structure did correlate with six other environmental variables, including latitude, sediment cover, and oxygen concentration, illustrating that cobalt-rich seamounts are highly heterogeneous habitats (Morgan et al., 2015). A later study was conducted by Morgan et al. (2019) across a shallower depth range of 200-700 m at Mokumanana Seamount (Necker Island), another cobalt-rich crust seamount in the North Pacific. This finer-scale assessment of benthic assemblage distribution patterns determined that there was high Beta-diversity between all depths sampled, as well as amongst sides of the seamount at a given depth (Morgan et al., 2019). Although topography and substratum type were considered important in structuring benthic assemblages at Mokumanana Seamount, these environmental factors were unable to fully explain faunal distribution patterns and assemblage structure. Even when hydrographic, productivity, and water column data were included in the analyses, a large part of the variation in assemblage structure remained unexplained. Other explanatory factors that are more challenging to measure, such as community interactions, reproductive and recruitment methods, and near-bottom hydrodynamics, were hypothesised to influence the observed fine-scale assemblage structure

(Morgan et al., 2019). Mejia-Mercado et al. (2019) studied fishes across the same seamount from the same AUV survey transects and similarly found significant variation in fish abundance, species richness, and assemblage structure with depth and side of the seamount. They found assemblage structure was most strongly correlated with the environmental variables of dissolved oxygen, salinity, percentage of sand, rugosity, slope, particulate organic carbon (POC), and current vectors u and v.

The presence of polymetallic crust can also be a major structuring factor for benthic invertebrate communities at seamounts. Analysis of distribution patterns for 471 species of Mollusca, Crustacea, Brachiopoda, and Crinoidea collected in different programs in the Southwest and Central Pacific indicated that deep-sea benthic assemblages are structured by depth, habitat, geography, and also the presence of polymetallic crust (Delavenne et al., 2019). Similarly, based on spatial analysis of seamount benthic taxa from a large biological dataset (> 600 taxa) obtained from 144 submersible dives (depth range: 113–1985 m) on 27 seamounts, Schlacher et al. (2014) determined that benthic invertebrate assemblages are structurally different between seamounts located inside and outside a region with cobalt-rich crusts. Modern visual data obtained using human-occupied submersibles, ROVs, and AUVs, continue to challenge the historical notion of an impoverished cobalt-rich crust fauna (Schlacher et al., 2014; Morgan et al., 2015, 2019; Kennedy et al., 2019).

6.3.1.2.4.1 Studies from the COMRA contract area

Several video surveys using ROVs have been conducted at the Weijia Guyot (Figure 6.3.17). Benthic taxa were identified and quantified from ROV video; these data were subsequently used to generate a rank-abundance curve for the identified morpho-species (Figure 6.3.18). The abundance distribution visualised in the rank-abundance curve suggests an uneven distribution of morpho-species at Weijia Guyot. Two crinoid morpho-species were the most dominant (Crinoidea sp2 and sp4), followed by two ophiuroid species (*Ophioplinthaca* sp1 and sp2). Within the top nine most abundant morphospeices, *Tretopleura* sponges and Primnoidae gen sp1 soft corals were densely distributed on the northwest slope of Weijia Guyot. Crinoidea sp2 was largely observed attached to *Tretopleura* sponges. Crinoidea sp4 and sp3, and *Ophioplinthaca* sp1 and sp2, were all observed living on sponges, whereas Crinoidea sp2 and sp1 lived solitarily.

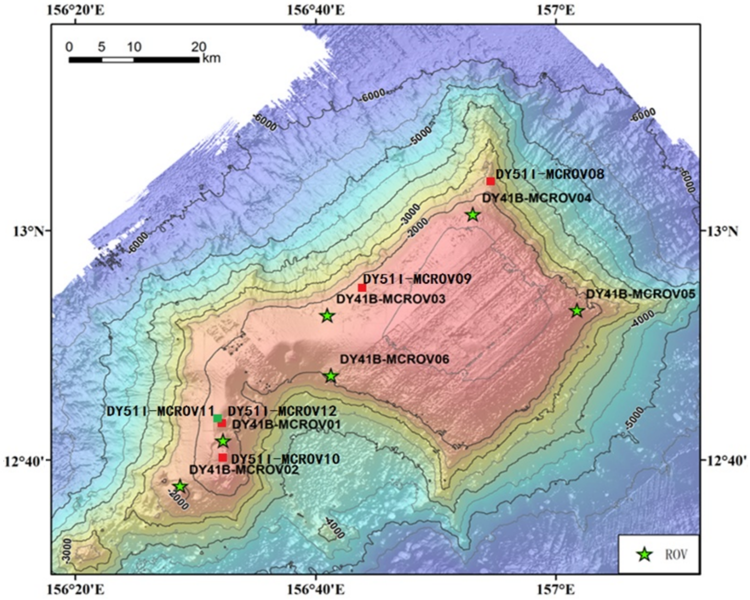

Figure 6.3.17. ROV dive locations on Weijia Guyot. Credit Cheng-Cheng Shen and Dong-Sheng Zhang.

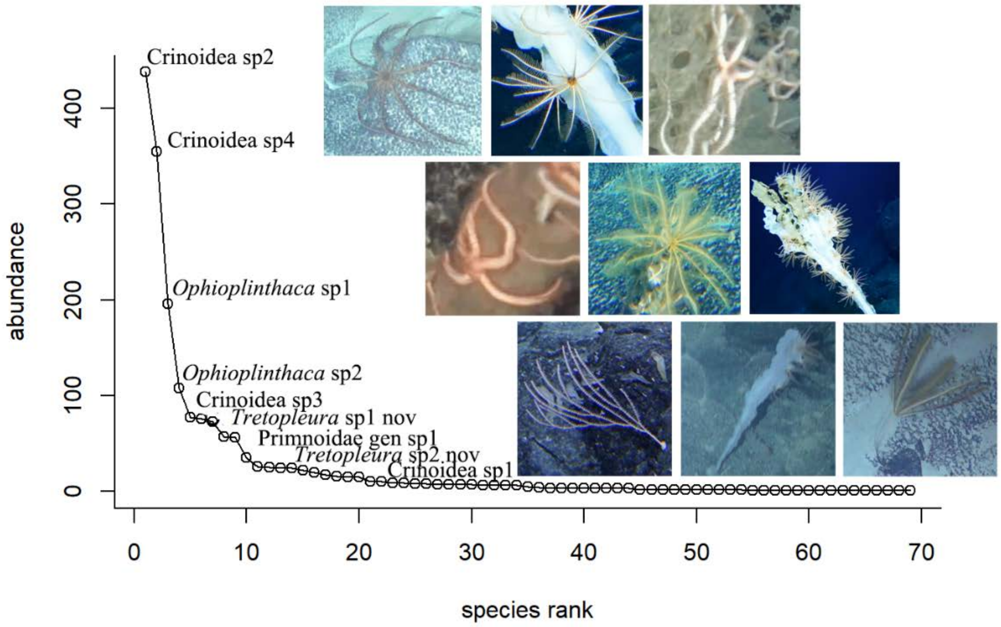

Figure 6.3.18. Rank-abundance curve of megafaunal morpho-species recorded from ROV dives on Weijia Guyot. Credit Cheng-Cheng Shen and Dong-Sheng Zhang.

The composition, abundance, and richness of megafaunal taxa observed on each of the ROV dives are presented in Figure 6.3.19. The MCROV09 dive on the northwest slope (1740 m approximate water depth) had higher morpho-species abundance and higher morpho-species richness than was observed at other locations on Weijia Guyot. Sponges (*Tretopleura* sp1 nov and sp2 nov) and bamboo corals (Isididae gen sp1), as well as Crinoidea sp4 attached to sponges, were dominant taxa on this dive. The MCROV08 dive on the northern slope (2340 m approximate water depth) had lower morpho-species abundance but relatively high morpho-species richness. The MCROV03 dive near the seamount top on the northwest (1800 m approximate water depth) had low morpho-species abundance and morpho-species richness, with only 1 sponge and 1 small blackfish (Rossellidae gen sp2 and Fish2) observed during the ROV dive.

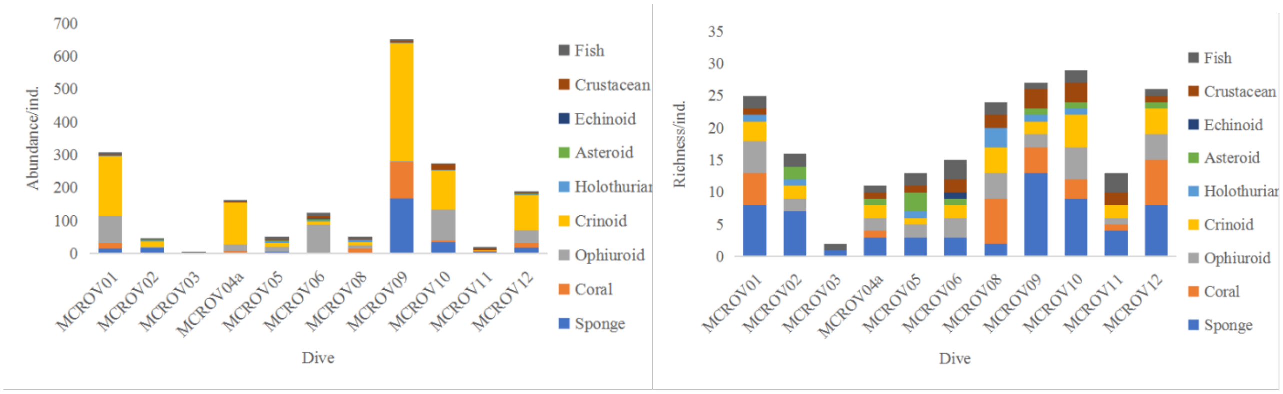

Figure 6.3.19. Megafauna observed during the ROV dives conducted on Weijia Guyot. Left: composition and abundance of megafauna, right: composition and richness. Credit Cheng-Cheng Shen and Dong-Sheng Zhang.

6.3.1.3 Abyssal plain communities

6.3.1.3.1 Microorganisms

Most of the research conducted on abyssal plain microorganisms has focused on communities associated with cobalt-rich crusts or nodules. Molari et al. (2020) surveyed microbial communities from samples of nodules and sediments obtained from the Peru Basin. Microorganisms in the abyssal Peru Basin were typical deep-sea groups, including the classes *Gammaproteobacteria*, *Alphaproteobacteria*, *Deltaproteobacteria*, and *Acidimicrobiia* (Molari et al., 2020). Bacterial and archaeal community composition were distinct between nodule and sediment samples, with low microbial diversity. Metal-cycling bacteria were dominant, and nitrifiers were also detected in nodules (Molari et al., 2020).

Wu et al. (2013) compared microbial communities of nodules and the surrounding non-nodule areas at three nodule sites across the Pacific, including one site in the Northwest Pacific and two sites in the Clarion-Clipperton Zone (CCZ). High bacterial diversity was discovered within nodules and in the sediments, but archaeal diversity was relatively low. Nodules and sediments also contained different microbial communities and different phylotype compositions (Wu et al., 2013). A study of bacterial communities at Caiwei Guyot (Liu et al., 2019) demonstrated that bacterial community structure and composition was strongly associated with depth and environmental variables, such as dissolved oxygen concentrations, concentrations of metals, and availability of organic matter. This study also determined that a large proportion of the bacterial community were unknown with uncharacterised functions.

6.3.1.3.2 Benthic invertebrates

6.3.1.3.2.1 Megafauna

There have been few studies on the benthic invertebrates colonising abyssal plains in the tropical Northwest Pacific Ocean, particularly in the region where the ISA has issued an exploration contract for polymetallic nodules. A few distributional records for benthic megafauna are available from historical oceanographic expeditions. Four stations deeper than 3000 m were sampled in the *HMS Challenger* expedition (1873-1876), however only one these (Station 224: 7°45’N, 144°20’E, 3383 m) revealed any benthic biota apart from foraminifera. Benthic megafaunal taxa recorded from this station included *Styracaster armatus* (Asteroidea: Porcellanasteridae) and *Ophiosphalma corticosum* (Ophiuroidea: Ophiosphalmidae). During the voyage of *RV Vityaz* (1957-1970, IORAS), benthic megafaunal taxa were reported from at least 20 stations below 3000 m near the Northwest Pacific region where exploration contracts have been awarded, however most of these stations were located North of 24°N and East of 162°E (Kuznetsov and Mironov, 1981). Only two stations were located within this region, with an additional station in the near vicinity. At Station 6364-2 on the lower slope of a guyot, *Bathoxiphus soymaruae* (Scaphopoda) and *Propeamussium* sp. (Bivalvia) were recorded. For the two stations on an abyssal plain with nodules, *Janirella eximia* and *Macrostylus longissima* (Isopoda) and *Bathycrinus* sp. (Crinoidea) were recorded from Station 4455, 6043-6051 m; *Nannoniscus acanthurus* (Isopoda) was recorded from Station 4362 at 3941 m. Some data are available on Mariana and Yap trench fauna (e.g., Linley et al., 2017; Zhang et.al., 2019), however, most of these works were concentrated within national jurisdictions, on the fore arc or trench axis.

There is limited knowledge regarding abyssal filter-feeders in region of the Northwest Pacific where exploration contracts have been awarded by the ISA. Historical photo and video- transects in this region were restricted to 800 – 3100 m depth (Kuznetsov and Mironov, 1981; Moskalev and Galkin, 1986), focussing on the polymetallic crusts of seamounts. The closest set of visual megafauna observations at abyssal depths is from within Kiribati

Basin (Simon-Lledó et al., 2019b), where there was clear evidence of spatial variation between the assemblages in the three areas studied, despite all areas sharing a relatively large pool of morpho-species.

In the review by Tabachnick (1988) detailing the glass sponges (Hexactinellida) of Magellan seamounts and the adjacent area, at least four species of Hexactinellida were reported from abyssal depths: *Polyopogon amadou pacifica* (Pheronematidae), *Caulophacus variens*, *Caulophacus variens juvinilis* (Rosselidae) and *Farrea microclavula* (Farreidae) (14°09 N, 155°54E, 3800 - 4270 m). Based on collections taken during the CAPSTONE expedition (Kennedy et al., 2019), the diversity of carnivorous sponges (Cladorhizidae) of Mariana Island and the adjacent area was reported by Hestetun et al. (2019). Seven new species were described, six of which were sampled from depths exceeding 3000 m, including two new species collected in close vicinity of the Northwest Dutton Ridge (*Abyssocladia fryerae*: 20.62°N, 147.3°E, 5565 m; *Abyssocladia kellyae*: 20.45°N, 147.1E, 4770m).

Two new species of brisingid sea stars from the family Freyellidae have been recorded from guyots in the region and from slopes of nearby trenches (R. Zhang et al., 2019). *Freyastera delicata* was collected near Caiwei Guyot (15.94°N, 137.85°E, 4322 m), whilst *Freyastera basketa* was collected from near Lamont Guyot (15.94°N, 159.13°E, 4832 m) and from the slopes of the Mariana (11.82°N 141.96°E, 4798m) and Yap (8°06°N 137.55°E 4991m) trenches (Zhang et al., 2019).

Also from near Lamont Guyot, within the nodule field (159.1322°E, 21.7298°N, depth 4833 m), *Munidopsis kensmithi* (Crustacea: Decapoda: Anomura) was recorded on top of an empty *Argonauta* sp. shell, alongside a Cladorhizid sponge (Dong et al., 2017). Another species of the same genus, *Munidopsis albatrossae*, was reported from an experimental carcass fall site off Weijia Guyot (12°43.0149' N, 156°27.2057'E, 3225 m) (Dong et al., 2019).

6.3.1.3.2.2 Meiofauna

The meiofauna from abyssal plains in the Northwest Pacific region have not been extensively characterised. Meiofauna have been collected from four abyssal stations (B02, B02-2, B03, B04) near Xifu Guyot (Kitahashi et al., 2020) and one abyssal station (MAMC07) near Caiwei Guyot (Zhao et al., 2020). All stations had low densities of meiofauna with the dominant groups being Nematoda and Harpacticoida copepods. Comparison of meiofaunal community structure from abyssal and bathyal stations near Cawei Guyot and samples from a polymetallic nodule field South of Hawai'i could not detect any significant differences between locations, largely due to low meiofaunal abundancies (Zhao et al., 2020). Similarly, traditional sampling methods did not show significant differences in community structure and diversity of meiobenthos collected at the base and plateau of Xifu Guyot, also due to low meiofaunal abundances (Kitahashi et al., 2020).

The same sampling stations near Xifu Guyot were also analysed using eDNA- and eRNA-based metabarcoding (Kitahashi et al., 2020). These analyses revealed significant differences in the spatial distribution of meiofaunal diversity and assemblage structure between the plateau and base of Xifu Guyot. Several meiofauna taxa, such as Gastrotricha, Platyhelminthes, Rotifera, and Xenacoelomorpha, were not identified from traditional sampling but were detected by metabarcoding. Almost half of the total operational taxonomic units (OTUs) were assigned to Cnidaria (both using eDNA- and eRNA-based metabarcoding), despite cnidarians being rarely recorded in deep-sea meiofaunal assemblages. The most abundant class amongst the cnidarian OTUs was Siphonophorae, which comprises largely planktonic organisms, suggesting that this biological material originated from carcasses deposited on the deep-sea floor.

6.3.1.3.3 Benthic and demersal nekton

6.3.1.3.3.1 Fishes

There is limited information available on the abyssal benthic and demersal fishes in the Northwest Pacific region. Bait-attending fishes have been reported from 4506-6189 m within the Mariana Trench (Linley et al., 2017) and were represented by Abyssal Hadal Transition Zone species, such as *Coryphaenoides yaquinae* (Macrouridae), *Bassozetus* spp. and *Barathrites iris* (Ophididae), and unidentified Zoarcidae. Within the Mariana Trench, *C. yaquinae* and *Bassozetus* spp. accounted for more than 99% of the similarity between baited lander deployments in this depth range (Linley et al., 2017).

Two baited landers in the East Mariana Basin deployed in 2007 outside of the nodule area (at 18.8°N, 149.8° E) revealed the presence of *Coryphaenoides yaquinae* (Macrouridae), *Histiobranchus* (Sinaphbranchidae), and *Bassozetus* (Ophidiidae), in very low numbers (A. Jamieson, personal communication). *Ipnops* sp. individuals were collected at two stations (14°09 N, 155°54E, 3800 – 4270 m; and 14°09 N, 155°54E, 3800 – 4270 m) at the base of Ita-Matai and IOAN Guyots (IORAS, unpublished report).

6.3.1.3.3.2 Cephalopods and crustaceans

There have been few studies on the abyssal cephalopods and crustacean in the Northwest Pacific region. The list of scavenging amphipods reported from 4506 – 6189 m in the southern Mariana Trench (Chan et al., 2020; Weston et al., 2020) includes *Alicella gigantea*, *Paralicella caperesca*, *Paralicella tenuipes* and *Valettietta anacantha* (Alicalllidae); *Hirondellea dubia*, and *Hirondellea gigas* (Hirondelleidae); and the recently described *Eurythenes plasticus* (Eurytheneidae).

6.3.2 Temporal variability

6.3.2.1 Seamount communities

Seamount communities exhibit considerable spatial and temporal variation. The variability of fish can correspond with oceanographic and anthropogenic temporal factors (e.g., Menezes and Giacomello, 2013). Deep-sea fishes and other species that aggregate over seamount summits can also display large diel vertical migrations (DVMs) to forage within the sound or deep scattering layer (SSL or DSL) (Afonso et al., 2014). Ontogenetic changes in the vertical distributions of species may alter the assemblages over longer time scales (Boehlert and Mundy, 1993). The presence of transient animals also changes over time. There is some evidence that seamounts are used as navigation waypoints during ontogenetic or seasonal migrations or as a 'foraging base' by way of signals in the magnetic field or by odours—this has been put forward for sharks and fish such as tunas and swordfish, as well as for turtles, seabirds, and whales (Rogers, 2018 and the references therein).

6.3.3 Trophic relationships

6.3.3.1 Seamount communities

Seamounts are generally considered to be hotspots of biomass and diversity, although other seamount paradigms, such as higher incidences of species endemism, are more widely debated (Rowden et al., 2010). Apart from shallow-water seamounts that have their summit in the photic layer and may support algal growth on the seafloor, the greater part of seamount ecosystems depends on the productivity of overlying waters, with seamount food webs being based upon retention or local enhancement of primary and secondary production of plankton (Pitcher and Bulman, 2007).

Seamounts are complex prominent structures on the oceanic floor and can significantly influence hydrodynamic patterns (see Section 5.2.4: Local flow environment). In some cases, hydrodynamics at seamounts can generate isopycnal doming due to Taylor Cone formation. The formation of a Taylor Cone over a particular seamount depends on the seamount width, current regime, and the height and intensity of the Coriolis force, which varies by latitude. Where a Taylor Cone forms, this can bring deeper nutrient-rich waters up to a shallower depth where they can be used by phytoplankton. Such an increase in nutrient flux, especially in oligotrophic low-nutrient waters, may result in a localised increase in primary productivity. Isopycnal doming can also generate localised regions of high-density stratification over the seamount, which may stabilise the water column, helping to promote local productivity (White et al., 2007). Although elevated chlorophyll concentrations have been occasionally observed above seamounts, they generally do not remain over a seamount long enough to affect the growth of local zooplankton stocks (Genin and Dower, 2007).

Trophic enrichment over seamounts may also occur due to allochthonous input via topographic trapping of the vertically migrating biota with the deep-scattering layer (DSL) during diurnal descent (Genin and Dower, 2007). The summits of many seamounts are well within the vertical range crossed by zooplankton in their daily migration. During the night, zooplankton foraging near the surface are carried by currents to the surface waters above the seamount summit. If the seamount summit is shallower than the depth to which they descend to avoid visual predators, these animals would be become trapped above the summit and be vulnerable to predation (Clark et al., 2010a). As most diel migrations are restricted to the upper few hundred meters, bottom trapping of migrating zooplankton is a major trophic mechanism at shallow and intermediate depth seamounts.

The summits and upper slopes of seamounts are typically exposed to stronger currents, which enhance the supply of suspended prey resources. For deeper seamounts that are out of the reach of vertical migrators, the proposed mechanism for supporting higher biomass of benthic invertebrate and demersal fish communities is enhanced horizontal fluxes of suspended food, resulting from strong interactions between amplified currents, internal waves, and the seamount topography (Genin and Dower, 2007). Cyclonic mid-ocean eddies may also aggregate micronekton at seamounts, these micronekton then feed on the enhanced secondary productivity (Drazen et al., 2011).

Benthic invertebrate and demersal fish communities at seamounts can be strongly influenced by a wide range of factors including local water column productivity, overlying water masses, depth, substratum type, and topographic variability (Pitcher and Bulman, 2007). Together, these ecological and oceanographic factors determine the trophic relationships within seamount communities, forming a biological community with complex trophic interactions between pelagic and benthic realms (Fulton et al., 2007). The increased supply of particles to seamounts, in combination with steep topography and an abundance of hard substrata, can support dense assemblages of suspension feeders, such as corals and sponges, which often dominate the seamount benthic megafauna. Where the summit of relatively shallow seamounts occurs within the photic layer, these seamounts can also attract seabirds, top predator fishes, marine mammals, and sea turtles.

Dedicated trophic studies have not yet been conducted at seamounts in the portion of the Northwest Pacific where exploration contracts have been granted by the ISA. Trophic studies on the New Caledonian seamounts on the Norfolk Ridge revealed complex food-chains in seamount benthic biota, as determined by stable nitrogen isotope ratios (δ15N) (Samadi et al., 2007). The benthic food web on Norfolk Ridge seamounts (200 – 900 m water depth) had a diverse trophic architecture, with food-chain length broadly comparable to other aquatic systems (Samadi et al., 2007). Compared with other aquatic food webs, food-chain lengths for seamount benthic biota (4 – 5 trophic levels) lie towards the upper end of reported values (Samadi et al., 2007).

The results from Norfolk Ridge seamounts are broadly comparable to those reported for Condor Seamount in the North Atlantic, where five trophic levels were reported based on the analysis of stable isotopes δ13C and δ15N in collected organisms (Colaço et al., 2013). Condor Seamount is relatively shallow, with the summit occurring at approximately 180 m water depth, which may contribute to the importance of mesopelagic organisms in linking the epipelagic environment to the benthic and benthopelagic organisms, effectively bridging the gap between primary consumers in the surface waters and the fourth and fifth levels of the trophic web at the seafloor (Colaço et al., 2013).

6.3.3.1.1 Studies from the Ministry of Natural Resources and Environment of the Russian Federation contract area

The abundance of different feeding types within the benthic megafauna, macrofauna, and meiofauna were determined from surveys on four guyots within the Ministry of Natural Resources and Environment of the Russian Federation contract area. For megafaunal taxa, suspension feeders were the most abundant, accounting for approximately 60% of the observed megafaunal individuals, followed by detritivores and carnivores with 25% and 15% of individuals respectively (Table 6.3.10). Most of the suspension feeders and deposit feeders were observed at locations with hard substratum, with lower densities of these groups observed at sedimented sites. Conversely, the density of carnivores was higher at sedimented sites, although this was not statistically significant.

Table 6.3.10. Average density of megafauna from the studied seamounts by feeding and substratum type. Credit Yuzhmorgeology.

Feeding type	**Average density of megafaunal (individuals per hectare)**	
	Hard substratum	**Sediment**
Suspension feeders	476	55
Deposit feeders	159	98
Carnivores	87	121

For macrofaunal taxa collected from sediments on Vulcanolog Guyot, deposit feeders/carnivores represented by polychaete worms were the most abundant, accounting for 57% of the macrofaunal individuals. Deposit feeders, represented by priapulids, gastropods, scaphopods, holothurians, and malacostraca, comprised 32% of macrofaunal individuals. The suspension feeders, comprised of bivalves, were the least abundant group, accounting for 11% of macrofaunal individuals (Table 6.3.11).

Table 6.3.11. Average density of macrofaunal taxa identified in sediment samples from Vulcanolog Guyot by feeding type. Credit Yuzhmorgeology.

Feeding type	**Phylum**	**Class**	**Abundance (individuals m^{-2})**
Suspension feeders	Mollusca	Bivalvia	14
Deposit feeders	Priapulida	-	24
	Mollusca	Gastropoda	4

	Mollusca	Scaphopoda	4
	Echinodermata	Holothuroidea	4
	Arthropoda	Malacostraca	4
Deposit feeders/Carnivores	Annelida	Polychaeta	72

Within the meiofaunal taxa collected from the top 5 cm of sediment on Alba Guyot, deposit feeders/carnivores represented by nematode worms were the most abundant, accounting for 97% of the meiofaunal individuals. Deposit feeders, represented by harpacticoid copepods, ostracods, and gnathostomulids, comprised the remaining 3% of meiofaunal individuals (Table 6.3.12).

Table 6.3.12. Average density of meiofaunal taxa by feeding type identified in the 0 – 5 cm layer of sediment samples taken from Alba Guyot. Credit Yuzhmorgeology.

Feeding type	**Phylum**	**Class**	**Order**	**Abundance (individuals 0.25 m^{-2})**
Deposit feeders	Arthropoda	Hexanauplia	Harpacticoida	45
		Ostracoda	-	6
	Gnathostomulida	-	-	3
Deposit feeders/Carnivores	Nematoda	-	-	1682

6.3.3.2 *Abyssal plain communities*

Abyssal ecosystems are characterised by the absence of *in situ* primary production, well-oxygenated waters, and low temperatures of less than 3°C (Smith and Demoupolos, 2003). Primary production in the surface waters is the only source of organic matter for abyssal plain communities. Benthic production in abyssal ecosystems depends exclusively on the input of detrital organic material derived from the euphotic zone. Most of the organic flux to the seafloor arrives as an attenuated rain of small particles (typically, only 0.5–2% of net primary production in the euphotic zone), with the occasional input from carcasses of large zooplankton (e.g., salps), fish, and marine mammals (Smith et al., 2008; Kuhnz et al., 2020).

In abyssal plain ecosystems, the meiofauna plays an important role in ecosystem functions such as nutrient cycling and energy transfer to higher trophic levels (Woodward, 2010). The majority of macrofaunal species appear to be surface deposit feeders that consume a very thin veneer of labile organic material deposited at the sediment-water interface (Paterson et al., 1998; Smith and Demopoulos, 2003; Smith et al., 2008; Bonifacio et al., 2019). Subsurface deposit feeders (such as paraonid polychaete worms) can be abundant in abyssal plain habitats, whilst other trophic types, including predators and omnivores, have also been recorded within the macrofauna (Smith et al., 2008; Bonifacio et al., 2019). Megafaunal deposit-feeders (such as holothurians) may play an important role in decomposing seasonal falls of salps and phytodetritus in abyssal plain habitats (Jamieson et al., 2011b).

The abyssal plain in the Northwest Pacific region is in the western part of the Northern oligotrophic zone (Sokolova, 1997). Little is known about the trophic structure of the abyssal benthic communities in this region. Moskalev and Galkin (1986) described abyssal communities of the lower slope of Ita-Mai Tai (Weijia) and IOAN (Fedorov) Guyots as being soft-sediment communities dominated by sessile filter-feeders, existing in conditions of extremely limited food supply.

6.3.4 Ecosystem function

6.3.4.1 Seamount communities

The benthic megafauna at seamounts is often dominated by sessile filter-feeders, such as corals, sponges, and crinoids (e.g., Morgan et al., 2015; Watling and Auster, 2017; Du Preez et al., 2020). Some of these sessile organisms are vulnerable marine ecosystem (VME) indicator species for bottom contact fisheries, typically because of their slow growth rates, high longevity, and slow recovery. Many of these organisms are also habitat-forming species, providing habitat and refuge for other invertebrates and small fish, thereby increasing the biodiversity of seamounts (Buhl-Mortensen et al., 2010; Watling and Auster, 2017; Du Preez et al., 2020).

Macrofaunal taxa play an important role in seamount ecosystems through feeding and burrowing activities, which can modify, ameliorate, or change the habitat and food supply for other organisms (Snelgrove and Smith, 2002; Chivers et al., 2013; Baldrighi and Manini, 2015; Narayanaswamy et al., 2017). Benthic macrofaunal taxa can play an important role in the early stages of organic matter diagenesis and recycling (Witte et al., 2003; Hunter et al., 2012), and the biodiversity and activities of benthic macrofauna are closely related to the cycling of organic matter and the regeneration of nutrients in the seabed. For example, echiurans (spoon worms), polychaetes (bristle worms), and sipunculans (peanut worms) are key groups that provide easily degradable organic substances for other organisms through their feeding and foraging activities (Levin et al., 1991). In addition, macrofaunal taxa can provide important food sources for benthic and demersal fishes (Drazen, 2002; Jones, 2008).

The meiofauna is an important part of the benthic community, and is typically characterised by high abundance, diversity, and turnover rate (Giere, 2009; Baldrighi and Manini, 2015). The relative contribution of meiofauna to overall faunal abundance and biomass typically increases with water depth (Tietjen, 1992; Giere, 2009). In many deep-sea habitats, nematodes are often the dominant meiofaunal taxa (Lambshead and Boucher, 2003; Grove et al., 2006; Baldrighi and Manini, 2015; Rosli et al., 2018), however for some seamounts, such as those in the Atlantic, the most frequently recorded group is Harpacticoida copepods, followed by Tardigrada and Nematoda (George, 2013).

6.3.5 Connectivity

6.3.5.1 Seamount communities

Connectivity amongst seamounts is complicated and affected by multiple biotic and abiotic factors. Previous studies suggest that some deep-sea animals can disperse long distances during their larval stages, resulting in high connectivity and gene flow amongst seamounts (Miller et al., 2010; Clague et al., 2011; Castelin et al., 2012; Varela et al., 2013; O'Hara et al., 2014). Conversely, some organisms display distinct genetic structure within seamounts, between seamounts, between seamounts and similar proximal non-seamount habitats, or show patterns that suggest individual seamounts may have isolated populations (Aboim et al., 2005; Baco and Shank, 2005; Rogers et al., 2006; Cho and Shank, 2010; Miller and Gunasekera, 2017; Zeng et al., 2017).

Very few connectivity studies have been conducted on the seamount benthic fauna in the Northwest Pacific. The only two connectivity studies available to date (detailed below) are both limited in sample size, and each focus on only one species. Further studies would be needed encompassing more taxa, such as sponges and corals, to obtain a better understanding of megafaunal connectivity in the Northwest Pacific. There no studies currently available on the connectivity of macrofaunal or meiofaunal species at seamounts in the Northwest Pacific. It has been suggested that some meiofaunal species may be well-connected amongst seamounts, given the variety of mechanisms proposed for their dispersal (Yeatman, 1962; Sterrer, 1973; Gerlach, 1977; Hagerman and Rieger, 1981; Stock, 1994; Gad and Schminke, 2004; Fontaneto, 2011). Whilst some meiofaunal groups can disperse in the water column through passive resuspension or active movement (Sedlacek and Thistle, 2006; Boeckner et al., 2009), dedicated connectivity studies would be needed to determine the connectivity of meiofaunal species at seamounts in the Northwest Pacific region.

In the recent study on the connectivity of the ophiuroid *Ophioplinthaca defensor* collected from Northwest Pacific seamounts (Figure 6.3.20), sequencing of two mitochondrial gene markers (*COI* gene and *16S* gene) revealed 20 haplotypes from 32 *COI* gene sequences, and eight haplotypes from 37 *16S* gene sequences (Na et al., 2021). The star-shaped haplotype network and an absence of significant pairings between populations have been interpreted to mean that there was no significant population structure between or within seamounts, suggesting that *O. defensor* may have long-distance dispersal capability (Figure 6.3.21; Na et al., 2021). In general, star-shaped haplotype networks are often considered to be indicators that a recent colonisation or founder event has occurred, potentially following a population bottleneck. As an example, star-shaped haplotype networks occur for many hydrothermal vent taxa (Vrijenhoeck, 2010).

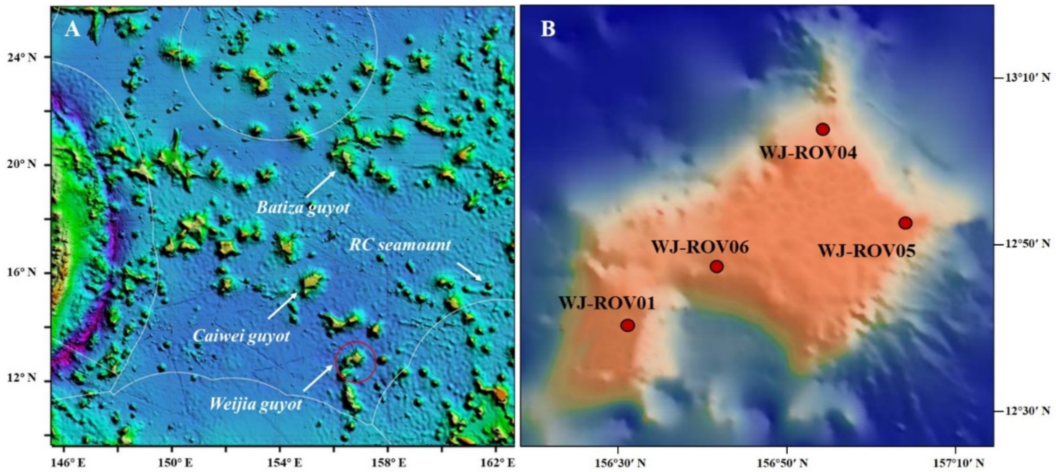

Figure 6.3.20. Map of the Northwest Pacific study seamounts (A) and sampling sites at Weijia guyot (B) for samples used to determine population genetic connectivity of the ophiuroid *Ophioplinthaca defensor.* Modified from Na et al. (2021).

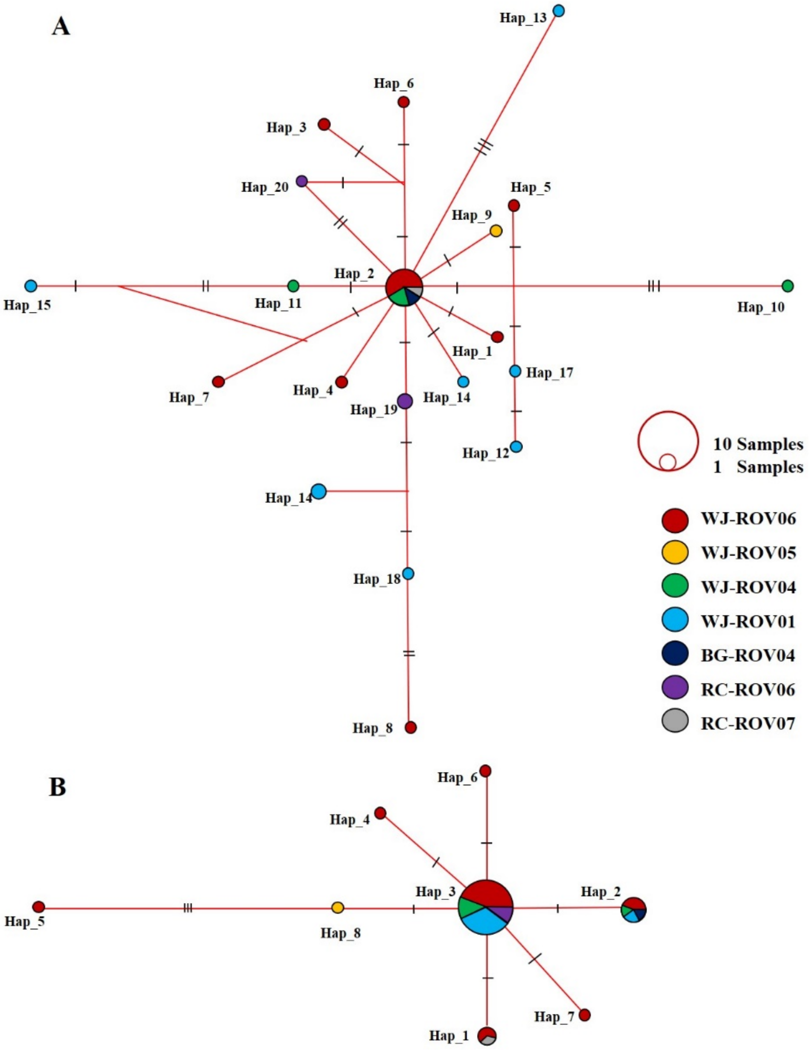

Figure 6.3.21. *COI* (A) and *16S* (B) haplotype networks for the ophiuroid *Ophioplinthaca defensor* sampled from Northwest Pacific seamounts. Each circle represents a haplotype, and its diameter is proportional to the haplotypic frequency. Median vectors (black circles, which represent missing intermediate haplotypes) were added to the network. Modified from Na et al. (2021).

Amphipods have also been proposed as suitable candidates for studying the genetic connectivity of deep-sea organisms at Northwest Pacific seamounts. In a recent study, Iguchi et al. (2020) analysed 37 amphipods collected from different water depths (1300 m – 3800 m) on Xufu Guyot near Minami-Torishima Island. From the 37 sequences, 18 were clustered in a single clade belonging to *Abyssorchomene*, which has also been reported from the New Hebrides Trench in the South Pacific. Further details on the genetic connectivity of amphipods studied from seamounts in the Northwest Pacific are provided in Section 6.3.5.1.1 below.

6.3.5.1.1 Studies from the JOGMEC contract area

To determine the evolutionary history of amphipods at seamounts in the Northwest Pacific, and to inform choices on target species for future population genetic connectivity studies, Iguchi et al. (2020) used baited traps to collect amphipods from three sampling sites around Xufu Guyot (JA06 Seamount). Total genomic DNA was extracted from the pleopods of each specimen and the cytochrome oxidase I (*COI*) gene was sequenced according to the method described in the ISA Technical Study No. 13 (ISA, 2015). To estimate the degree of fidelity that specimens had to different amphipod taxa, molecular phylogenetic analysis was conducted using sequences from the Xufu Guyot specimens and sequences from closely related species in public DNA databases. Based on the phylogenetic results, the Xufu Guyot specimens were separated into several groups, and Molecular Operational Taxonomic Units (MOTUs) were extracted based on Automatic Barcode Gap Discovery (Puillandre et al., 2012) and Bayesian Poisson Tree Process (Zhang et al., 2013) (Figure 6.3.22). One of the groups included specimens collected from all three sampling sites on Xufu Guyot. This group was included in a similar lineage to specimens collected from New Hebrides Trench, from genus *Abyssorchomene*. Haplotype network analysis using *COI* was conducted to derive the genetic connectivity pattern of the *Abyssorchomene* group sampled from Xufu Guyot. From the haplotype network analysis of the *Abyssorchomene* group, individuals formed one cluster, suggesting that these haplotypes belong to a single species. Analysis of Molecular Variance of this putative species of *Abyssorchomene* did not detect significant genetic structure, suggesting that genetic connectivity was maintained amongst sites. New microsatellite markers are now being developed for this *Abyssorchomene* sp. using the next-generation sequencing technology methods of Nakajima et al. (2018), which will enable a more detailed view of population genetic connectivity amongst seamounts to be determined.

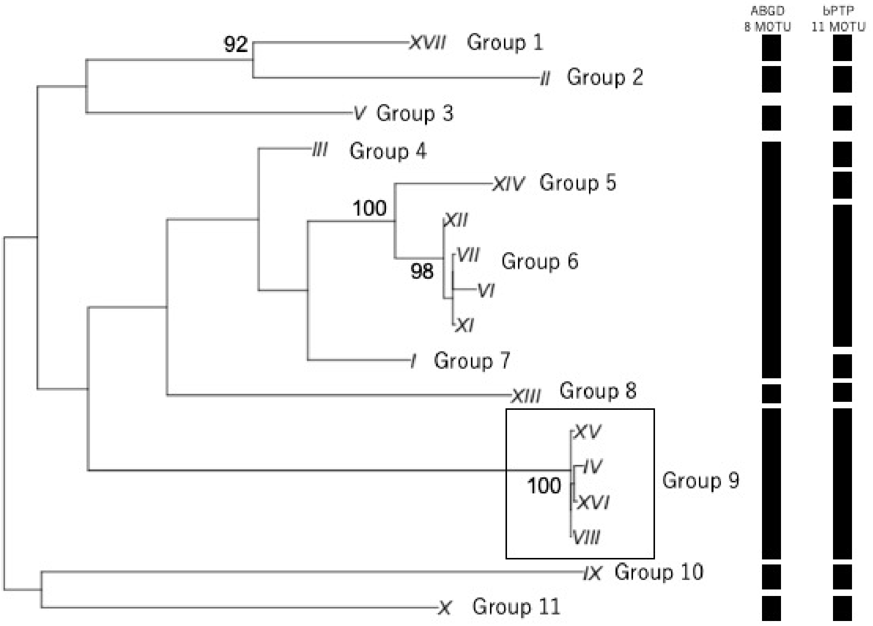

Figure 6.3.22. Molecular tree of the 17 amphipod species haplotypes obtained from Xufu Guyot (the JA06 Seamount). Numbers indicate bootstrap values (1,000 replicates). One clade (Group 9, in the box) is composed of haplotypes inferred to represent a putative species. Reproduced from Iguchi et al. (2020).

6.3.5.2 Abyssal plain communities

There have been few genetic connectivity studies conducted on abyssal plain biota to date, with none conducted in the portion of the Northwest Pacific where exploration contracts have been awarded by the ISA. According to Taylor and Roterman (2017), deep-sea benthic invertebrate population genetics studies are scarce compared to the available studies for shallow water groups, making it difficult to determine general patterns of genetic connectivity in deep-sea populations. The same authors also highlighted the utility of next-generation sequencing techniques for deep-sea populations.

The techniques used in population genetics studies from other regions could be utilised in future population genetics studies conducted on the Northwest Pacific abyssal plains. For example, Ritchie et al. (2016) developed microsatellite markers for the deep-sea amphipod *Paralicella tenuipes* using the next-generation sequencing technique MiSeq. Using these microsatellite markers, Ritchie et al. (2017b) were able to present the detailed connectivity pattern of two genetically different groups of *P. tenuipes* across a large area of the Pacific Ocean. Also in the Pacific Ocean, Taboada et al. (2018) conducted detailed population genetic analysis on a dominant Porifera species in the Clarion-Clipperton Zone (CCZ) using microsatellite markers. Taboada et al. (2018) also used a combination of genetic connectivity patterns and hydrodynamic modelling to discuss the effectiveness of Area of Particular Environmental Interest (APEI) placement within CCZ.

Future genetic connectivity analyses in the Northwest Pacific region could consider using additional molecular methods, such as Single Nucleotide Polymorphisms (SNPs). Using SNPs can enable detailed population genetic analyses to be conducted with high resolution, even where the number of individual specimens collected is small. The most common SNPs method, RAD-seq, has been little used in deep-sea studies to date (Xu et al., 2017, 2018; Iguchi et al., 2020). The newest method using SNPs, multiplexed Inter-Simple Sequence Repeat genotyping by sequencing (MIG-seq: Suyama and Matsuki, 2015) is another promising approach because this method can obtain SNP loci from samples with low DNA concentrations. Utilising these, and other emerging genetic methods, in future studies could help to resolve patterns of genetic connectivity amongst deep-sea populations on abyssal plains and seamounts.

6.3.6 Resilience and recovery

Little is known about the specific resilience of Northwest Pacific benthic biota to the commercial phase of seabed mining (exploitation). Given that deep-sea mineral exploitation has not yet happened in any ocean, and there have been few experimental disturbances at spatial and temporal scales that approximate the disturbances anticipated from mineral exploitation, the recovery of Northwest Pacific benthic biota from these disturbances remains largely unknown.

However, understanding the ways is which ecological systems may withstand the disturbances and stressors associated with mineral exploitation is key to the development of suitable environmental management measures as part of regional environmental management planning. It is beyond the scope of this document to provide a detailed account of the resilience of all Northwest Pacific benthic biota to mineral exploitation, especially given the current paucity of region- and activity-specific information. Instead, the following sections summarise existing information relevant to anticipated activities and disturbances and draw on studies from other regions and research on different disturbances and stressors.

6.3.6.1 Concepts in resilience and recovery

For an overview of ‘resilience and recovery’ including a glossary of terms, post-disturbance state outcomes, and examples of system state parameters, indicators, and metrics, see Section 6.2.5.1 - Concepts in resilience and recovery.

The following sections discuss some of the general concepts and studies addressing resilience and recovery of the benthic biota, with focus on impacts from climate change, bottom trawling, and mineral exploitation. To address the potential resilience and recovery of benthic biota to mineral exploitation, which has not yet occurred, existing information from the impacts of other sectors is summarised.

6.3.6.2 Impacts from climate change

The benthic environment is affected by multiple processes, including periodic irregular changes in the surface environment (Frigstad et al., 2015; Thomsen et al., 2017) and longer-term shifts due to climate change such as rising ocean temperatures, ocean acidification, and deoxygenation (Bindoff et al., 2019). These environmental disturbances and stresses can result in complex changes in marine environmental baselines, which can make it challenging to assess the impacts of human activities on the benthic environment (Soltwedel et al., 2016; Thomsen et al., 2017).

The responses of the benthic biota in the Northwest Pacific to climate-induced changes in the marine environment is not well-known. Negative responses to these changes could occur across a large range of ecosystem components and may compromise the resilience of some biota to additional environmental disturbances and stressors associated with mineral exploitation. These potential interactions and responses could be explored through cumulative impact modelling and assessment.

With respect to the seamounts in the Northwest Pacific, it is anticipated that seamounts in general will experience climate change-induced warming, decreases in pH, deoxygenation, and a decline in POC flux, which is expected to lead to a reduction in seamount biomass, with especially deleterious impacts for cold-water corals (Bindoff et al., 2019). For abyssal plain biota, one of the most abundant groups on polymetallic nodule fields is benthic foraminifera. Dedicated studies on benthic forams indicated that short-term exposure to low pH did not have a significant impact on the survival of many species (Dissard et al., 2010; McIntyre-Wressnig et al., 2014) and even that hypoxia and elevated pCO_2 may be beneficial to the survival of some foraminifera (Wit et al., 2016). However, other studies have demonstrated that lower pH increased the sensitivity of shallow foraminifera to higher ocean temperatures (Webster et al., 2016). There is also evidence that the combined effects of ocean acidification and hypoxia may lead to the decreased abundance of carbonate-producing foraminifera but an increase in the abundance of other groups (van Dijk et al., 2017). Whilst adverse impacts to carbonate-producing animals are often the focus of ocean acidification studies, the impacts of hypercapnia (excessive internal CO_2 levels) on the physiological processes of marine organisms are often overlooked, for example the impacts to fish documented by Heuer and Grosell (2014). For benthic meiofauna, the reported responses of this group to climate change are also inconsistent, but it is agreed that meiofauna are sensitive to changes in environmental parameters and food supply, and further studies on how hypoxia and pH affect all taxa are needed (Gobler and Baumann, 2016). Larger organisms, such as benthic megafaunal taxa, may experience a more pronounced impact from decreased oxygen, as their individual oxygen demand would be higher. A recent study using deep-sea observations and oceanographic time series data determined that if climate change chemical trends in the Northeast Pacific continue, within decades the benthic seamount taxa will suffer the compounding effects of impacts on faunal distribution, respiration, metabolism, growth, dissolution, feeding, behaviour, and reproduction, ultimately impacting their survival (Ross et al., 2020).

6.3.6.3 Impacts from bottom trawling

Impacts from fishery associated bottom trawling in the Northwest Pacific would be restricted to seamounts where there is an active bottom trawling fishery. Seamount ecosystems can support rich fishery resources and are often target areas for deep-sea trawling (Clark, 2009). Trawling can cause long-term damage to seamount biota and habitats, especially where fragile and slow-growing organisms (such as corals and sponges) occur.

Many deep-sea seamounts are over-fished, with limited recovery once overfishing occurs (Clark and Rowden, 2009). The combined characteristics of seamount biota and fishing methods explain why many seamount taxa have low resilience to bottom trawling and why recovery of habitats, populations, and communities is extremely slow:

1. **Biological characteristics**: seamount fishes typically have a long lifespan, late maturity, slow growth, low fecundity and discontinuous population growth. These characteristics mean that recruitment to the fishery is low, and recovery is slow after being affected, reducing the resilience of populations to overfishing.
2. **Habitat preference**: seamount fishes usually gather on ridges or at the top of the seamount, where fishing effort is focused. If fishes are caught when spawning, the success rate of reproduction will be reduced, which will further reduce the resilience of the population to fishing.
3. **Fishing methods**: most fishing on seamounts is conducted through bottom trawling, with some mid-water trawling and longline fishing. Heavy bottom trawlers are used where the seabed is rough with predominantly hard substrata, causing considerable disturbance to the seabed environment. Slow-growing and long-lived benthos will be particularly affected (Clark, 2009; Clark and Rowden, 2009; Clark and Dunn, 2012). A study on seamounts in the South Pacific demonstrated that there are clear differences in benthic habitats, species number and abundance, and community composition and structure between seamounts with fishing activities and those without fishing activities (Koslow et al., 2001). Degradation of fish habitat will further reduce resilience of the population to fishing (e.g., Du Preez and Tunnicliffe, 2011).

The most severely damaged species by bottom trawling are attached benthic megafaunal taxa, such as sponges and cold-water corals (e.g., Buhl-Mortensen et al., 2008; Clark et al., 2010b). These species have a long lifespan, slow growth, extremely slow recovery, preference for ridges and the tops of seamount where fishing effort is focussed, and fragile attached bodies susceptible to damage by bottom trawling. Researchers have conducted a comparative survey of seamounts in New Zealand and Australia on a time scale of 5 and 10 years after the trawling operation stopped (Althaus et al., 2009; Williams et al., 2010). The recoverability of coral-dominated seamount ecosystems disturbed by seabed trawling was less than that of other marine ecosystems, and the disturbance led to dramatic changes in the distribution, density, diversity, and composition of benthic communities on seamounts, including a significant reduction in the coverage of habitat-forming stony corals (such as *Solenosmilia variabilis*) (Williams et al., 2010). Seamount corals create habitats for many organisms (e.g., Wilson and Kaufmann, 1987; Etnoyer et al., 2010) and where coral habitat is damaged or destroyed, the abundance and diversity of associated organisms will also decrease.

6.3.6.4 Impacts from future exploitation of cobalt-rich ferromanganese crusts

The habitat provided by cobalt-rich crusts was formed over geological time scales (1-6 millimetre per million years: Hein and Koschinsky, 2014) and will take millions of years to reform. Although the commercial exploitation phase for these minerals has not yet started, future exploitation has the potential for wide-ranging impacts on the seamount biota (Vanreusel et al., 2016). Little is known about the specific resilience of Northwest Pacific benthic seamount biota to mineral exploitation, partially because full-scale mining machinery and associated technology for mining the seafloor have not yet been developed and the impacts on the marine environment from this equipment are not yet known.

It is beyond the scope of this document to provide a comprehensive review of potential impacts from cobalt-rich crust exploitation, this has been addressed in several comprehensive reviews. However, given the general properties of benthic biota at seamounts in the Northwest Pacific, some general statements can be made on their potential resilience and recovery. For example, cobalt-rich crust seamounts can support highly diverse communities of sessile filter-feeders, such as sponges and deep-sea corals, which have long lifespans and slow recovery rates (Schlacher et al., 2014 and references within). The cobalt-rich crust seamounts near Hawai'i host some of the largest recorded specimens of Hexactinellida sponge (Wagner and Kelley, 2017) and octocoral family Chrysogorgiidae (Watling and Guinotte, 2013), which would take centuries to regrow to a similar size, if recovery is possible following mineral exploitation. In cases where suitable habitat is available for recolonization following mineral exploitation, it is also important to note that benthic biota rely almost entirely on surface water primary productivity and its delivery through the mid-water column (See section 6.3.3.1: Trophic relationships – Seamount communities). The resilience of benthic biota is, therefore, linked to the condition and resilience of the surface and mid-water environments through bentho-pelagic coupling.

To address the potential resilience and recovery of seamount benthic biota to cobalt-rich crust exploitation, this section summarises the potential resilience and recovery of biological communities in the benthic environment, based on existing information relevant to anticipated activities and disturbances. These potential disturbances may include removal or modification of substrata through mineral extraction, artificial light and introduced noise from the mining vehicle, increased particle load or toxins from mining plumes, localised changes in temperature, and other disturbances related to the activities of the surface vessel or mining vehicle (e.g., Levin et al., 2016; Gollner et al., 2017; K. A. Miller et al., 2018; Drazen et al., 2019). Exploitation of cobalt-rich crusts at seamounts is expected to cause direct mortality to many local benthic organisms—sessile species or species with limited mobility are expected to be especially vulnerable (Table 6.3.14). In general, the existing information describes non- or partially resistant systems, depending on the scale of the study (i.e., individual organisms to communities). Estimated recovery times range from decades to centuries, if at all, and are related to the natural variability of the system and its generation time, as well as the fragmented nature of seamount habitats. The loss or alteration of hard substrata may cause substantial community shifts, or complete loss of hard substratum communities, with these impacts potentially persisting over geological timescales at mined sites.

Whilst multiple studies have investigated the impacts of small-scale benthic disturbance experiments or test mining, these have not occurred on seamounts or at spatial or temporal scales that are comparable to what is expected for full-scale commercial exploitation (K. A. Miller et al., 2018). There are many knowledge gaps concerning resilience to anticipated mineral exploitation disturbances, which may be addressed in future versions of this document as new information becomes available. As a result, existing information reported in Table 6.3.14 is primarily based on empirical studies investigating the resistance and recovery of benthic systems to bottom-contact fisheries and to the Deep-Water Horizon oil spill, and on ecological principles, with many studies focused on habitat-forming cold-water corals.

Table 6.3.13. Information on the potential resilience of Northwest Pacific seamount benthic communities to anthropogenic disturbances. The systems listed represent components of a generalised benthic ecosystem on seamounts. Resistance and recovery are primarily reported in terms of individuals and local populations, not communities, metapopulations, or whole species. Credit Cherisse Du Preez.

System	Information on resilience: resistance, recovery, and recovery time
Microbes	Largely unknown, represents a knowledge gap. May have resilience similar to microbes on abyssal plains. See Table 6.3.14 for further details.

Infauna	Resilience to **physical disturbance**: Disturbance to the physical structure of hard substratum habitats on seamounts was still visible decades after the disturbance (Baco et al., 2019). Resilience to **anthropogenic noise**: Physiological and behavioural responses with potential for cascading ecosystem consequences (Solan et al., 2016). See Table 6.3.14 for further details on the resilience of infauna.
Cold-water corals & sponges	Resilience to **physical disturbance**: Mortality or severely reduced fitness with low recovery potential estimated to take centuries if recovery occurs. Cold-water corals and sponges are fragile, long-lived, and slow-growing; life-history traits that make them extremely vulnerable to physical disturbances (Levin et al., 2016; Gollner et al., 2017; and references cited therein). Timescales in years are proving too short to detect recovery (e.g., Althaus et al., 2009; Williams et al., 2010; Huvenne et al., 2016;). After 30 to 40 years coral recovery seeded by broken fragments was initiated (Baco et al., 2019). However, if mineral exploitation results in the compelte removal of attached organisms, regrowth is an unlikely mechanism of recovery. Recovery through recolonization is expected to be delayed or potentially prevented due to the removal of the surficial hard substrata and altered larval dispersal, mortality of larvae, and decreased settlement success (Gollner et al., 2017). It is not yet known if exploitation of cobalt-rich crusts would release toxins into the benthic environment, and what the response of benthic biota may be to these toxins. Resilience to **toxins** (if applicable): Mortality or severely reduced fitness with potential for sublethal impacts to persist for years causing continued degradation (Fisher et al., 2014; Girard et al., 2018; Girard and Fisher, 2018). Depending on the toxins considered, there is the potential for large-scale coral die-off tens of kilometers away from the source (Fisher et al., 2014). Recovery time of impacted corals to a pre-disturbance health state is estimated to take up to 30 years, albeit with reduced biomass (Girard and Fisher, 2018). Recovery time for coral communities to pre-disturbance biomass is estimated to take hundreds of years (Girard et al., 2018). The information on toxins is based on coral research following the Deep Horizon oil spill—it is uncertain if sponges respond similarly to corals.
Other epibenthic fauna	Resilience to **physical disturbance**: Mortality or severely reduced fitness with low recovery potential estimated to take decades to centuries. As with cold-water corals and sponges, recovery is expected to be exceedingly slow since deep-sea invertebrate and fish species are typically long-lived and have slow growth rates (Levin et al., 2016; Gollner et al., 2017; and references cited therein). Recovery may be delayed or potentially prevented due to the removal of the surficial substratum (Gollner et al., 2017). Seamount benthic megafaunal assemblages failed to recover to their initial state 5 to 10 years post-trawling, with systems temporarily or permanently degraded, or shifting to alternative states (Williams et al., 2010). In addition to epibenthic fauna directly on the hard substrata of the seamount, a high diversity of invertebrate fauna are associated with deep-sea corals and sponges (e.g. Husebø et al., 2002; Krieger and Wing, 2002; Roberts et al., 2006; Baco, 2007; Parrish and Baco, 2007; Buhl-Mortenson et al., 2010; Beazley et al., 2013). These relationships can by obligate or facultative, ranging from suspension feeding invertebrates using the corals and sponges as a structure to climb up above the benthic boundary layer for better feeding (e.g., O'Hara et al., 2008; Buhl-Mortensen et al. 2017), to obligate relationships of invertebrates to specific species of corals (e.g. Buhl-Mortensen and Buhl-Mortensen, 2004; Mosher and Watling, 2009; Baillon et al., 2014; Girard et al., 2016). Removal of corals and sponges will therefore have significant impacts on the overall benthic biological diversity of the region as a highly diverse array of invertebrates will lose their habitat or critical structures to reach optimal feeding locations. For associated organisms to recover after removal by mining, corals and sponges will first need to return to the area and reclaim their roles as foundation species.

	Response to **artificial lighting**: Reduced fitness of deep-sea shrimp, with the potential for permanent vision damaged caused by submersible vehicle floodlight (Herring et al., 1999).
Fishes	Resistance to **physical disturbance**: Mortality or severely reduced fitness (Levin et al., 2016; Gollner et al., 2017) if unable to escape physical disturbance. Resistance to **plumes**: Resilience of benthic fishes may be similar to that of pelagic nekton, with the caveat that the migration of benthic seamount fishes can be restricted by their high habitat fidelity (Ross et al., 2020). Individual fishes are expected to suffer reduced prey availability and fitness, possible suffocation, and mortality, if they cannot move away from the plume (Levin et al., 2016; Drazen et al., 2019). Recovery from **perturbation**: recovery time expected to be relatively long for seamount-aggregating fishes, based on adaptations to the stability of the deep ocean, longevity, slow growth, later sexual maturation, and low fecundity (Gordon, 2001; Morato et al., 2006; Levin et al., 2016). These characteristics are probably most accentuated in species such as the benthopelagic North Pacific armourhead (*Psuedopentaceros wheeleri*) and the orange roughy (*Hoplostethus atlanticus*) where much of their energy may be expended in maintaining position around seamounts (Gordon, 2001). The orange roughy have a centenarian lifespan (Andrews et al., 2009). After fishing ceased for the orange roughy in the South Pacific, some signs of recovery were detected after 20 years, but some still consider the future of the stock difficult to predict (Rogers, 2019; and references therein). Even relatively short-lived benthic fishes can demonstrate long recovery timelines. For example, the North Pacific armourhead usually lives for less than a decade (Yanagimoto and Humphreys, 2005) and was overfished in the 1980s in the waters off Hawaii (NOAA, 2018). The U.S. seamount armourhead fishery collapsed and has been closed since 1987 with no signs of recovery, potentially linked to the continued stock condition deterioration in the surrounding area where the fishery is ongoing. Whilst the nature of the relationship of many fish species that co-occur with deep-sea corals and sponges is still being elucidated, a number of species have been found to use corals as nursery habitat for their eggs (e.g. Etnoyer and Warrenchuk, 2007; Baillon et al., 2012; Cau et al., 2017), and many commercially important fishes have been observed in deep-sea coral beds (e.g. Krieger and Wing, 2002; Auster et al., 2005; Parrish and Baco, 2007). It is also highly probable that fishes take advantage of the high diversity and biomass of invertebrates associated with corals and sponges to use these areas for feeding. For example, Capezutto et al. (2020) showed *Helicolenus dactylopterus* had a more specialised diet in deep-sea coral areas than in general muddy bottom areas. Similar to the effect on invertebrates, removal of the corals and sponges will remove this nursery and potentially feeding habitat for these fish species, and recovery of corals and sponges will be a prerequisite for return of any fishes that are dependent upon them.
All benthic fauna (including other nekton)	Resistance to **physical disturbance**: Mortality or severely reduced fitness (Levin et al., 2016; Gollner et al., 2017). The loss of hard substrata or alteration of substrata composition or structure may cause substantial community shifts that persist over geological timescales at mined sites (Gollner et al., 2017). The recovery potential of seamount ecosystems is thought to be low compared to other marine ecosystems because of the lack of alternative nearby habitats (Williams et al., 2010; Ross et al., 2020). In terms of physical disturbance caused by bottom-contact fisheries, seamounts meet the Food and Agriculture Organization of the United Nations criteria as Vulnerable Marine Ecosystems (VMEs: Watling and Auster, 2017). Resilience to the collector and dewatering **plumes**: Benthic and benthopelagic organisms may suffer impacts to their settlement, colonisation, respiration, feeding, communication, buoyancy, and biochemistry, with reduced fitness and a growing probability of mortality if they cannot escape the extent of plume (Levin et al., 2016; Gollner et al., 2017; Drazen et al., 2019). High sedimentation rates following sediment resuspension and redistribution, or the fallout from the dewatering plume, is expected to

	exceed the natural sedimentation rates of seamounts and abyssal plains, which are thought to be only a few millimeters per 1,000 years (reported in Millier et al., 2018). Deep-sea oil and gas industry assessments indicate that sedimentation and toxin exposure have significantly negative effects that can extend kilometers from the source and for years after the event (see Cordes et al., 2016 and the references therein). Resilience to **anthropogenic noise**, **increased temperatures,** and potential **trophic cascade**: resilience expected to be similar to that of 'all pelagic fauna' and other sections in Table 6.2.5.

6.3.6.5 Impacts from future exploitation of polymetallic nodules

The results from small-scale benthic disturbance experiments or test mining of polymetallic nodules on abyssal plains indicate that these activities had a negative impact on population density and species diversity for most of the benthic fauna, and that few taxa were able to recover to pre-disturbance states, even after multiple decades post-disturbance (Vanreusel et al., 2016; Gollner et al., 2017; D. O. B. Jones et al., 2017). Disturbance studies have not yet occurred at spatial or temporal scales that are comparable to what is expected for full-scale commercial exploitation (K. A. Miller et al., 2018), making it challenging to determine the specific resilience to and recovery from exploitation activities in the abyssal Northwest Pacific.

It is beyond the scope of this document to provide a comprehensive review of potential impacts from polymetallic nodule exploitation, this has been addressed in several comprehensive reviews. Instead, to address the potential resilience and recovery of benthic biota to polymetallic nodule exploitation, this section summarises the potential resilience and recovery of biological communities in the abyssal benthic environment, based on existing information relevant to anticipated activities and disturbances. These potential disturbances may include removal or modification of substrata through mineral extraction, artificial light and introduced noise from the mining vehicle, increased particle load or toxins from mining plumes, localised changes in temperature, and other disturbances related to the activities of the surface vessel or mining vehicle (e.g., Levin et al., 2016; Gollner et al., 2017; Miller et al., 2018; Drazen et al., 2019). Exploitation of polymetallic nodules from abyssal plains is expected to cause direct mortality to many local benthic organisms, particularly sessile species or species with limited mobility (Table 6.3.15). In general, the existing information describes non-resistant or partially resistant systems, depending on the habitat type. Estimated recovery times range from years to centuries, if recovery occurs at all, with recovery times related to the natural variability of the system and its generation time, as well as habitat and taxa morphology. The loss of nodule hard substratum is expected to cause substantial community shifts that persist over geological timescales at mined sites. Existing information reported in Table 6.3.14 is primarily based on empirical studies investigating the resistance and recovery of benthic systems to small-scale benthic disturbance experiments or test mining, and on ecological principles.

Ultimately, exploitation of polymetallic nodules has not yet taken place in the deep-sea, making it challenging to determine the resilience of Northwest Pacific abyssal plain biota to future exploitation activities. There are many knowledge gaps concerning resilience to and recovery from anticipated mineral exploitation disturbances, which may be addressed in future versions of this document as new information becomes available.

Table 6.3.14. Information on the potential resilience of Northwest Pacific abyssal plain communities to anthropogenic disturbances. The systems listed represent components of a generalised benthic ecosystem on abyssal plains. Resistance and recovery are primarily reported in terms of individuals and local populations, not communities, metapopulations, or whole species. Credit Cherisse Du Preez.

System	Information on resilience: resistance, recovery, and recovery time
Microbes	Resilience to **physical disturbance**: Reduced abundance and activity with only partial recovery after almost three decades (Vonnahme et al., 2020). Based on growth estimates, soft-sediment microbially mediated biogeochemical functions may need >50 years to recover to pre-disturbance state if the bioreactive surface layer is removed (Vonnahme et al., 2020). Where bioreactive organic matter is redistributed by exploitation instead of being completely removed, recovery of geochemical gradients may be restored to near their pre-disturbance state in as little as one year (Haffert et al., 2020). The loss of the hard substratum provided by nodules is expected to cause substantial community shifts that may persist over geological timescales at mined sites (Gollner et al., 2017).
Infauna	Resilience to **physical disturbance** and **increased sedimentation**: Cases of population depletion or compensation, with soft-sediment community shifts and a range of recovery outcomes based on habitat and morphology that can last decades (Smith et al., 2013; Cordes et al., 2016; Gollner et al., 2017; Vonnahme et al., 2020). Disturbance to the physical structure of sediment habitats is still visible decades later (Miljutin et al., 2011; Vonnahme et al., 2020). Reduced infaunal abundance (albeit non-significant; Radziejewska, 2002), biological activity (Vonnahme et al., 2020), and diversity and biomass of nematode worms (Miljutin et al., 2011) following the physical disturbance of abyssal plain sites (with and without nodules). Examples of compensation responses to disturbance include community respiration recovery after less than 26 years (Khripounoff et al., 2006) and increased meiobenthic abundance after 22 months in sites that received increased resuspended sediment settlement and detrital inputs (Radziejewska, 2002).
Cold-water corals & sponges	Resilience to **physical disturbance**: Mortality or severely reduced fitness with low recovery potential estimated to take centuries, where recovery is possible (Levin et al., 2016). Most cold-water corals and sponges attach to hard substrata, alcyonacean and antipatharian corals were virtually absent from nodule-free areas of an abyssal plain site (Vanreusel et al., 2016). Most of these habitat-forming taxa are expected to be removed with the nodules. Nodules have accretion rates of millimeters to centimeters over millennia (Levin et al., 2016) and in the absence of alternative hard substratum habitat post-mining, there would be little to no recovery potential. If suitable alternative habitat is available, recovery is estimated on the order of decades to centuries, owing to extremely slow growth rates and long generation times (e.g., Leys et al., 2007; Sherwood and Edinger, 2009). The potential for surrounding populations to support the recovery of a mined site would be reduced if these populations are indirectly impacted by increased sedimentation (Gollner et al., 2017). Other aspects of resilience to **physical disturbance** and resilience to **toxins**: see the 'cold-water corals & sponges' section in Table 6.3.13 for information that could be applied to corals and sponges on abyssal plains.
Other epibenthic fauna	Resilience to **physical disturbance**: Mortality or severely reduced fitness with low recovery potential estimated to take decades if not more depending on the ability of taxa to escape disturbance. As with cold-water corals and sponges, there may be little to no survival of other hard substratum attached fauna where nodules are removed from the seafloor, with little to no recovery potential for millennia in the absence of hard substratum habitat. Mobile animals are the most likely to display behavioural resilience; however, both mobile and sessile megabenthic epifauna (excluding fish, crustaceans, and large protozoans) were severely reduced in nodule field plough tracks 37 years after an experimental disturbance (Vanreusel et al., 2016). Whilst the resilience of abyssal plain fish and other demersal or benthopelagic megafauna represent a knowledge gap, nodule ecosystems are considered a unique habitat for these animals (Tilot, 2006).
All benthic fauna	See the 'fishes' and 'all benthic fauna' sections in Table 6.3.13 for information that could be applied to all of the benthic fauna on abyssal plains.

(including nekton)	

6.4 References

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Annex 1: Detailed document outline used to prepare the REA report

This detailed outline was prepared to guide the development of the regional environmental assessment (REA) report. The structure and content of this outline was based on the parameters and categories of information required for environmental baseline studies, as set out in the ISA recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area (ISBA/25/LTC/6/Rev.1).

1. Background

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- *4.3 Seamounts*
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        - 5.2.2.1 Temperature and salinity
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    - 5.2.3 Local flow environment
        - 5.2.3.1 Current flow at seamounts
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- *5.3 Chemical oceanography*

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            - 6.3.1.2.3 Benthic and demersal zooplankton
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