Hadal Zones of the Northwest Pacific Ocean

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Abstract

Understanding the extent of the hadal ecosystem (habitats exceeding 6000 metres water depth) is convoluted due to the complexity of seafloor geomorphology that accounts for 45% of the total ocean depth range. Furthermore, at such great depths, features such as fracture zones and basins, although numerous, are less prominent and therefore have drawn less focus compared to the conspicuous subduction trenches that are typically associated with hadal science. Here we focus on the Northwest Pacific Ocean, where the majority of hadal features are located, to evaluate the true extent of the deepest marine ecosystem. This analysis has highlighted that the Mariana Trench, in terms of continuous hadal habitat, is in fact five isolated areas, with the most northern being what Russian scientists used to call the Volcano Trench. Conversely, we identified that there are no physical partitions either north or south of the Japan Trench to isolate it from the neighbouring Kuril-Kamchatka or Izu-Bonin trenches respectively, thus it forms one continuous hadal habitat. By evaluating the frequency and distribution of smaller features, such as basins and fracture zones, we conclude that in the northwest Pacific, the total area occupied by depths >6000 m is 2,793,011 km^2, which is considerably larger than the 686,114 km^2 accounted for by subduction trenches alone. These results demonstrate not only that the hadal ecosystem may be far larger than previously anticipated but that the geomorphology is crucial in understanding the distribution and genetic connectivity of endemic hadal species that inhabit these great depths.

1. Introduction

The official geomorphological definition of a trench, according to the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission of UNESCO (IOC), is "a long, narrow, characteristically very deep and asymmetrical depression of the seafloor, with relatively steep sides (e.g. the Mariana Trench, Tonga Trench)" (Holcombe 1977; Bouma 1990). These trenches are formed by the process of subduction at tectonic convergence zones (Stern 2002). The biological definition of the hadal zone is where water depths exceed 6000 m (Wolff 1960, 1970; Jamieson et al. 2010), with the deepest point on Earth accepted to be 10,925 m ± 12 in the Mariana Trench (van Haren et al. 2017). The term 'hadal' as an ecological biozone is in line with the shallower marine environments: littoral (0–200 m), bathyal (200–3000 m) and abyssal zones (3000–6000 m). Although a number of different geomorphological features can exceed 6000 m depth (e.g. basins, fracture zones and transform faults), the largest, deepest and most conspicuous of the ocean's hadal zones are comprised of these subduction trenches, of which most are situated in the western Pacific Ocean (Jamieson 2015).

One of the main characteristics of hadal ecosystems is the high degree of species endemism. This is thought to be a result of physical isolation driven by geomorphological complexity and increased seismic activity compared to the surrounding abyssal plains, as well as increased hydrostatic pressure and reduced food supply. Indeed the continuum from the coast to the abyssal plain is disrupted at the 6000 m contour where the remaining bathymetric space comprises these disjunct array of isolated trenches (and other deep features) of varying size, shape and depth, with no correlation to latitude or longitude, partitioned by abyssal plains and fore-arcs (Stewart and Jamieson 2018). Therefore the hadal zones of the world can be treated as large inverted islands bounded by the 6000 m contour, where extrapolation from the surrounding areas is unreliable.

Given the disparate nature of areas exceeding 6000 m depth, collating a comprehensive list of the world's hadal zones is complex as it largely depends on whether the criteria includes just the subduction trenches, or whether it includes defined troughs, basins, fracture zones and transform faults. For instance, the number of hadal trenches reported ranges from 14 (Smith and Demopolous 2003), 22 (Angel 1982, one of which is <6000 m), 32 (Vinogradova et al. 1993, two of which are <6000 m), and 37 (Herring 2002). Including other geomorphological features exceeding 6000 m in depth, Belyaev (1989) listed a total of 55 trenches and troughs, whereas Jamieson et al. (2010) listed 22 trenches and 15 troughs, that was revised to 46 individual hadal habitats in total (27 subduction trenches, 13 troughs and six trench faults comprising both transform faults and fracture zones) (Jamieson 2015), with an additional trench fault added in Stewart and Jamieson (2018). Priede (2018) defines the hadal zones as "deeper than 6000 m in which there is a depth of 7000 m or more" and concluded there were 95 hadal zones of which 16 were trenches and seven are 'basins'. The remaining 72 'hadal zones' comprise fracture zones, smaller basins and depressions but inexplicably omits reasonably well known trenches such as New Hebrides (7156 m), and Palau (8021 m) (Jamieson 2015), and interestingly splits the Java Trench into two features ('Java East' and 'Java West') and again in the Mariana Trench ('Mariana North' and 'Mariana South').

In pursuit of an inventory of ecologically significant geomorphological structures that are useful in hadal science, and refining undersea features, it is apparent that there are a number of inconsistencies, ambiguities and new insights emerging into trench connectivity and the significance of non-trench hadal features. The impetus for this study was driven by confusion surrounding a subduction trench known as either the 'Volcano Trench' (Belyaev 1989), 'Bonin Trench' (Smoot 1983a, 1983b) or 'Mariana North Trench' (Priede 2018). Likewise there have been discussions on whether or not the Japan Trench is an isolated habitat or is simply an extension of the Kuril-Kamchatka Trench to the north (Jamieson 2015; Priede 2018). The significance of other non-trench hadal systems such as fracture zones, troughs and basins has recently been highlighted as endemic hadal species have been recovered from a relatively small and isolated fracture zone that barely exceeds 6500 m water depth (Wallaby-Zenith Fracture Zone, Indian Ocean; Weston et al. in press) and the largely isolated Diamantina Fracture Zone in the Indian Ocean (A. J. Jamieson personal observation). While these non-trench systems are often less conspicuous and often much shallower than the large trenches, their overall global footprint appears significant, and may offer connecting corridors or stepping stone habitats linking other apparently isolated hadal zones together. However, information regarding the location, depth and area of these potentially important habitats are lacking. The site specific rationale for three study areas are detailed below.

1.1 The Volcano Trench ambiguity

In both 1955 and 1975, Soviet deep-sea research expeditions on board the RV *Vityaz* performed four bottom trawls and one sediment grab from depths ranging from 6330 to 8540 m, in, among many other locations, what was thought to be a 9156 m deep subduction trench in the northwest Pacific Ocean. These samples recovered a total 27 species of diverse hadal fauna (Porifera = 1, Annelida = 3, Arthropoda = 11, Chordata = 1, Cnidaria = 1, Echinodermata = 3, Echuira =1, and Mollusca = 6; Belyaev 1989). This volume and diversity was not uncommon during these early hadal bottom sampling campaigns, and indeed, the entire inventory of samples taken by the RV *Vityaz*, and the Danish RV *Galathea* expeditions, were collated and published in Belyaev (1966), revised in Belyaev (1989), and updated in Jamieson (2015). The aforementioned species inventory sits consistently alongside many other trench communities sampled during those decades and in part provided the baseline biodiversity data for all future hadal science. This particular data set is mentioned here because it was obtained from the 'Volcano Trench' which is part of a deep subduction zone forming a chain of trenches that run from Palau in the south to the Kuril Islands of Eastern Russia in the northwest Pacific. The emphasis here is that Volcano Trench is a large, ultra-deep geological feature that for reasons unresolved has been almost entirely ignored in Western literature. Contrary to the official definition of a trench or a hadal zone, this trench that was clearly well known by Soviet Scientists has inexplicably been incorporated into the Mariana Trench. To add further confusion, some geological literature from the 1970s and 80s refer to the 'Volcano Trench' as the 'Bonin Trench', differentiating the 'Bonin Trench' from the 'Izu Trench' to the north, which is now known as the Izu-Bonin Trench (Fukao et al. 2018). For example, Smoot (1983a) stated that the Michelson Ridge "lies at the intersection between the Izu and Bonin trenches", which means the 'Bonin Trench' in this case, is the Russian 'Volcano Trench' which is now merged with the Mariana Trench. Adding even more confusion, Priede (2018) list two separate trenches as the Mariana North and the Mariana South, the former inferring the existence of the Russian Volcano Trench/geologist's Bonin Trench, albeit a name not formally recognised. Regardless of the name, one common detail in all these instances is that these studies all show at least two isolated trenches making up what is now the 'Mariana Trench'. The Volcano (Bonin) Trench assimilation into the Mariana Trench is also evident in the official boundaries of the Marianas Trench Marine National Monument making no mention of isolated components within the designated trench unit (Tossato 2009; Iverson 2010).

1.2 The Japan-Kamchatka continuum

In addition to the example of two trenches now being considered one when they are perhaps not, there are instances of two or more trenches being considered isolated when they are possibly not. The confusion arises when considering the geological and biological perspectives. For example, the Tonga and Kermadec trenches in the Southwest Pacific are clearly the same tectonic convergence zone in geophysical applications (Tonga-Kermadec Trench; e.g. Castillo et al. 2009), but the subducting Osborn Seamount in the middle results in two isolated habitats from a biological perspective (Jamieson et al. 2020). Similarly, the Peru-Chile Trench, intersected by the Nazca Ridge, is often separated into the Milne-Edwards Trench to the north and the Atacama Trench to the south, depending on which context it is being used. The New Britain Trench and the Bougainville Trench have, historically, been referred to as two separate trenches but there is no shallow water partition between the two; the only 'boundary' is a near 90˚ bend in the same trench. In the case of the Japan Trench, biological and geological literature typically refer to this as an individual trench, yet despite the differentiation of a separate trench to the south and north (Izu-Bonin and Kuril-Kamchatka trenches respectively), there are reports that the join between the Japan and Kuril-Kamchatka trenches being >6000 m deep and thus forming a continuous hadal (biological) corridor between them (Jamieson 2015). Priede (2018) also merged the Japan Trench with the Kuril-Kamchatka Trench on the grounds there is no bathymetric division <6000 m deep between them. If this is indeed correct then the Japan-Kamchatka Trench continuum would represent one of the largest continual hadal habitats in the world.

1.3 Non-Trench hadal significance

Most of our understanding of endemic hadal species and biogeographic connectivity is based on the large subduction trenches, and has to date largely ignored other hadal ecosystems such as basins, transform faults and fracture zones. This is in part because they are often much shallower than trenches and appear less conspicuous on bathymetric maps. However, recent studies have shown that some common and endemic species are present in lesser appreciated geomorphological features, such as the Wallaby-Zenith Fracture Zone (Indian Ocean) that is small (4150 km^2) and relatively shallow (6625 m) compared to other trenches (Weston et al. 2019; in press). The surprise finding of the endemic hadal species *Bathycallisoma schellenbergi* (Birstein and Vinogradov 1958), highlighted that a population that would normally occupy several thousand metres of trench >6400 m – and exhibit depth related ontogenetic stratification – were found, non-stratified in high numbers occupying a very narrow depth range (<300 m) at the bottom of a relatively small feature located 1500 km from the nearest hadal trench. This infers that potentially a lot of the seemingly more insignificant morphological features on the seafloor, often located between the larger subduction trenches, are harbouring quintessentially hadal species and perhaps even providing deep-corridors for gene flow between large populations. If, indeed, this is the case — where are these corridors? which trenches are they potentially connecting? and do they significantly increase the global footprint of hadal ecosystems?

1.4 Objectives

Given the complexity and expanse of global hadal zones, it is perhaps more beneficial to closely examine the bathymetry of particularly complex areas to resolve or clarify such issues. There are perhaps two large areas globally where this type of analysis is required the most; the trenches spanning the Indo-Pacific from the Java Trench to the New Hebrides Trench, and the Northwest Pacific Ocean, from the Palau Trench to the Kuril-Kamchatka Trench. This study will focus on the latter, and for completeness and context will expand to the entire northwest Pacific Ocean. The objectives are to describe and define each distinct hadal feature, whether trench or non-trench, and resolve the issues of the potential Japan-Kamchatka continuum and to prove or refute the existence of the Volcano Trench. The aim of the study is not to suggest or change the names of any undersea feature, but to use the best available global bathymetric datasets to describe and scrutinise discreet hadal zones of the northwest Pacific Ocean that could harbour isolated populations of hadal species.

2. Materials and methods

Publically available bathymetry derived from the Global Multi-Resolution Topography (GMRT Synthesis; www.marine-geo.org) were used in this study. These data comprise tiled, multiresolution, bathymetric datasets with source citations (Ryan et al. 2009). Each gridded tile set involves computing weighted averages of depth estimates at the nodes for each grid tile, designed to ensure preservation of the data whilst avoiding introduction of data artefacts in the resultant Digital Elevation Model (DEM) (Ryan et al., 2009). Where no better resolution data are available, the GMRT Synthesis includes gridded seafloor depths from the global compilation GEBCO_2014 (30 arc-second resolution which equates to approximately 1 km) (Weatherall et al. 2015). GEBCO_2014 utilises satellite altimetry in areas where data are sparse (e.g. the Shuttle Radar Topography Mapping 30 arc seconds database (SRTM30_PLUS) altimetry-derived bathymetry (Becker et al. 2009)). An in depth analysis of the errors and limitations associated with DEMs generated from datasets of vastly differing resolution, and indeed derived from different sensors (e.g. multibeam echosounder, single-beam echosounders, and satellite altimetry) is beyond the scope of this study (see instead Smith and Sandwell 1997; Becker et al. 2009; Weatherall et al. 2015; Mayer et al. 2018). However, it should be acknowledged that as technology improves and more high-resolution data are uploaded to global repositories, some areas may be host to higher resolution datasets (e.g. Kuril-Kamchatka Trench as reported in Dreutter et al. 2020), which may not be reflected in the regional grid utilised here to ensure geographic coverage of the study area.

ArcGIS grids of the bathymetry data were produced at the resolution of the dataset with additional layers of comprising bathymetric contours and slope generated in ArcGIS using the 3D analyst extension. Polygons of areas exceeding 6000 m water depth were generated using the relevant contour and checked manually. All polygons smaller than 1.5 km^2 were deleted as they were deemed to result from spurious depth soundings. Surface area, and maximum and minimum water depths were calculated for each polygon using Functional Surface within 3D analyst.

2.1 Study areas

The northwest Pacific area of interest (Fig. 1) was analysed and described in five main components, starting with the two areas that require the greatest scrutiny and clarification: Area A, the Palau to Izu Bonin chain of trenches, with emphasis on the Mariana and Volcano trench relationship, and Area B, the links between the Japan Trench and the Izu-Bonin and Kuril-Kamchatka trenches. The following areas of interest (Fig. 1) were also considered: Area C, the Philippine and Ryukyu trenches, and the Philippine Basin; Area D, the Emperor Fracture Zone; Area E, the Northwest Pacific Basin; and Areas F and G, East Mariana Basin and the Central Pacific Basin.

3. RESULTS

3.1 Area A: The Mariana and its surrounding trenches.

The Palau Trench runs east of the Island of Palau, in a northeast by southwest direction (Fig. 2A). At the southern end of the trench there are four small depressions of ~6000 m depth at just 16.1, 9.6, 9.6 and 11.5 km in length, that together cover a surface area of 231 km^2. The main trench covers 4121 km^2 and comprises two sections separated by a topographic high 2-20 km wide that shoals at between 5980 and ~5000 m water depth. The southerly part is an elongated trough, ~73 km long by ~14 km wide, up to ~6800 m deep, separated by as little as ~2 km or less from the larger, northern part of the Palau Trench. The topographic high, albeit very narrow is ~5980 m deep. The larger trench section to the north is ~210 km long and includes two primary depressions: The southern depression is ~50 x ~15 km and 7183 m deep at 06.708° N / 134.538° E, whereas the northern depression is ~91 x ~30 km and 8027 m deep at 07.797° N / 134.995° E.

The Yap Trench (Fig. 2A) is located 100 km to the east of the Palau Trench, from south west of the island of Yap, it is oriented broadly parallel to the east coast of the island for a further 244 km to 11.684° N / 138.870° E before turning south-southeast for a further 140 km. The 100 km gap between the Palau and Yap trenches comprises a series of isolated depressions up to between 5500 and 5800 m deep and seamounts rising to a minimum depth of 3200 m. The trench is ~720 km long, covers a surface area of 18,388 km^2, and reaches a maximum of 8487 m deep at the deepest point at 08.395° N / 137.924° E. Technically the trench is in fact two separate trenches, partitioned at 09.000° N / 138.287° E by a 5460 m sill that separates the 6000 m contours of the north and south areas by just 11 km. The southern trench is 357 km long (8681 km^2) and the northern area is 347 km long (9707 km^2). The southern area has two distinct depressions to the north (the most northern being the deepest point) and the northern area has four main depressions and a smaller one adjacent to the right angle bend.

95 km east of the eastern most tip of the Yap Trench is the southernmost tip of the Mariana Trench at 10.851°N / 140.675° E, near the intersection with the Caroline Ridge (Fig. 2A). The two trenches are separated by a minimum depth of around 5330 m. The main trench is approximately 1050 km long, has a surface area of 85,475 km^2, and extends in a crescent shape oriented roughly E-W directly south of Guam before switching orientation to broadly northeast-southwest approximately parallel to the Mariana Islands to its most northern point at 15.967° N / 147.732° E.

The deepest point of the Mariana Trench is known as Challenger Deep at 11.332° N / 142.202° E with a depth of 10,925 ± 12 m located within the western depression of a double-depression that forms the overall deep (van Haren et al. 2017). To the east, at 12.017° N / 144.487° E is Sirena Deep, located due south of Guam at the base of the Santa Rosa Bank with a depth of ~10,700 m (Tarn et al. 2016). Following the trench axis north-westerly there are a series of deep depressions at 12.888° N / 146.080° E (10,590 m; Nero Deep), 13.301° N / 146.591° E (9848 m), 13.867° N / 146.983° E (9600 m), 14.323°N / 147.234° E (9435 m at the base of the Victoria Guyot), and two smaller ones at the northern tip of the trench at 15.165° N / 147.547° E (8300 m) and 15.614° N / 147.722° E (7836 m) at the base of the Quesada Seamount. There is a continuous hadal corridor along the entire trench axis, with a topographic high between Sirena and Nero deeps that shallows at 8440 m water depth at 12.575° N / 145.569° E. The end of the hadal corridor, and thus the boundary of the trench is instead located at 15.967° N / 147.732° E and not at the intersection of the Izu-Bonin Trench to the north as is commonly documented (Fig. 3).

The Volcano Trench lies between the Mariana and Izu-Bonin trenches between 16.248° N / 148.143° E and 25.294° N / 143.267° E (Fig. 2B). The 34 km long bathymetric high between the Mariana and Volcano trenches is approximately 5180 m water depth at its shallowest between the Trinidad Seamount and Del Cano Guyot, with the high between the Volcano and Izu-Bonin trenches (the Izu-Ogasawara Plateau) significantly larger in size and more prominent, with a minimum depth of 3373 m. The Izu-Ogasawara Plateau spans 142 km between the 6000 m contours of these neighbouring trenches.

The Volcano Trench trends north westerly north of 17˚ N following the crescent shaped archipelago of the Mariana Islands. In total it is 1180 km in length following the 6000 m contour with the deepest point at 24.303° N / 143.633° E in 8822 m water depth in a confined deep located at the very north of the trench. However, this section of the subduction zone, known to the Russian scientists as the Volcano Trench, is actually a series of four disparate areas each exceeding 6000 m water depth (Fig. 2B, 2C).

From south to north, the first intermediate hadal area (for clarity, 'MV3' meaning 'Mariana-Volcano') is located immediately north of the Mariana Trench. It is 250 km long, has a surface area of 20,772 km^2, is around 110 km at its widest point with a maximum depth of 8761 m (16.903° N / 147.839° E). At 18.568° N / 147.694° E there is 19 km long bathymetric high, rising to 5359 m deep separating MV3 from the second hadal area (MV2). MV2 is 93 km long, has a surface area of 3638 km^2, and is around 68 km at its widest point delineated by the 6000 m contour. This section has a maximum depth of 7161 m at 18.929° N / 147.674° E. At 19.496° N / 147.504° E there is an 12 km long topographic high, formed by the subduction of the most western Dutton Guyot (Smoot 1983a). This high rises to 5519 m water depth separating MV2 from a third isolated trench (MV1) to the north. MV1 is 96 km long, covers a surface area of 1989 km^2, and is around 43 km at its widest point. This section has a maximum depth of 7292 m at 20.005° N / 147.331° E. The westernmost extent of the Fryer Guyot (Smoot 1983a) at 20.438° N / 147.137° E divides MV1 from the Volcano Trench to the north by 23 km. This high between these hadal zones rises to around 4600 m depth at its shallowest. The northernmost, and largest, hadal area of the Volcano Trench covers a surface area of 47,864 km^2, is 669 km long and 195 km at its widest point, and hosts the a maximum water depth of 8822 m for the entire trench (24.303° N / 143.633° E). There is a small enclosed hadal basin a mere 11 km to the north which in only 34 km^2 and attains a maximum water depth of 6291 m at 25.243° N / 143.274° E.

This chain of hadal areas that collectively form the 'Volcano Trench' is separated from the Izu-Bonin Trench by the Izu-Ogasawara Plateau and the Minami, Imotojima and Anejima Knolls. The physical partition is the subduction of the Hahajima seamount, a tectonic block in a large shelf like structure (Fujioka et al. 2011), and the wider region is referred to as the Izu-Ogasawara Plateau (Smoot 1983b)

Within the Palau to Izu-Bonin Trench subduction zone, there are 26 depressions running due north from the northern tip of the Yap Trench, exceeding >6000 m depth, extending for ~1080 km up the middle of the West Mariana Basin (also known as the Parece Vela Basin; Kasuga and Ohara 1997). Located in the Philippine Sea, the West Mariana Basin is bounded by the Kyushu-Palau Ridge to the west and the West Mariana Ridge to the east. Nineteen of these appear to be between 6000-6500 m deep, but seven of these defined hadal areas exceed this depth at 12.783° N (7124 m), 13.469° N (7435 m), 13.993° N (6516 m), 14.599° N (6516 m), 16.899° N (6723 m), 17.997° N (7259 m), 19.805° N (6761 m) and 20.604° N (6585 m). In total these 26 hadal areas account for 3230 km^2 of seafloor. Additionally there is a small 687 km^2 isolated depression at 6715 m deep north of the Palau and west of the Yap trenches at 10.188° N / 136.109° E.

3.2 Area B: Partitions of the Izu-Bonin–Japan–Kuril-Kamchatka trenches

The Japan Trench is typically considered bounded by the subducting Erimo Seamount that shallows to 3729 m at 40.947 N / 144.971 E in the north at its juncture with the Kuril-Kamchatka Trench and the subduction of the most western seamount of the Joban Seamount Chain at the junction with the Izu-Bonin Trench (Cadet et al. 1987; Yamazaki and Okamura 1989; Nishizawa et al. 2009; Watts et al. 2010; Nakata et al. 2011) (Fig. 4A). If taking these features as bounding a single trench, then the Japan Trench is 611 km long, has a surface area of 37,854 km^2 with a maximum depth of 8046 m at 36.065° N / 142.725° E. To the south lies the Izu-Bonin Trench that sits at the triple junction of the Pacific, Eurasian and Philippine tectonic plates which extends south of the Japan Trench to the Izu-Ogasawara Plateau. The trench is 1122 km long, covers 105,328 km^{-2} with a maximum depth of 10,011 m at 29.220° N / 142.774° E. This depth should be treated with caution as visual examination of the bathymetric data suggests this may comprise spurious depth records, a more realistic maximum water depth may be around 9990 m at a location slightly further south at 29.057° N / 142.847° E. The Kuril-Kamchatka Trench is 2089 km long and attains a maximum published depth of 9604 m at 45.164° N / 152.680° E (Dreutter et al. 2020), has a surface area of 130,985 km^2, and trends north east from the intersection with the Japan Trench at the Erimo Seamount to 54.311° N / 163.528° E where it intersects the subducting Emperor Seamount Chain. There is a small depression 58 km long, covering 306 km^2, coincident with the intersection with the Emperor Seamount Chain that reaches a maximum depth of 6061 m which follows the same trend as the rest of the Kuril-Kamchatka Trench. The Emperor Seamount Chain is around 200 km wide where it enters the subduction zone at the juncture between the Kuril-Kamchatka and Aleutian trenches at the Meiji Seamount (Keigwin et al. 1992). This juncture shallows to ~5570 m on the Aleutian side of the intersection and around 5720 m depth on the Kuril-Kamchatka side. The Aleutian Trench is 2902 km long, covering a surface area of 107,782 km^2, forming an easterly arc, running parallel to the Aleutian Islands towards the Alaskan mainland in the northeast Pacific Ocean.

However, in terms of biologically significant boundaries at the 6000 m bathymetric contour it appears that the Japan Trench is actually not separated from the Kuril-Kamchatka Trench to the north, and Izu-Bonin Trench to the south. Rather, the data confirm that at depths >6000 m there are two connecting corridors with both neighbouring trenches (Fig. 5).

The southern boundary to the Japan Trench is formed by the westernmost three seamounts of the Joban Seamount Chain (Masulu et al. 2001) (Fig. 4C), the western two of which reside in the trench axis off the coast of Cape Inubō. From west to east these three seamounts are named the Daiiti-Kashima Seamount, Katori Seamount and the Daini-Kashima Seamount with only the Katori Seamount surrounded on all sides by water depths exceeding 6000 m. The Katori Seamount shoals at 4139 m, descending to 6483 m deep to the east in a hadal pathway 16 km wide, and to the southwest the seamount descends to 7271 m in a pathway 17 km wide. The Daiiti-Kashima Seamount, located around 46 km to the southwest of Katori Seamount shallows to a depth of 3526 m at 35.804° N / 142.665° E.

The northern boundary to the Japan Trench is the Erimo Seamount (shoaling at 3729 m depth), currently being subducted into the trench axis leaving two deep-water pathways between the Japan and Kuril-Kamchatka trenches exceeding >6000 m depth on each side of the feature (Fig. 4B). To the east the passage is ~6080 m at its shallowest (6130 m maximum depth) and just 6 km wide but to the west it is around 6280 m at its shallowest (6738 m maximum depth) and 10 km wide.

3.3 Area C: Philippine and Ryukyu trenches

The Philippine Trench trends north-south for 1571 km parallel to the east coast of the Philippines from 3.7° N to 15° N comprising one large hadal area with a surface area of 82,845 km^2 with two smaller confined basins from 3.7° N to 4° N with surface areas of 367 and 38 km^2 (Fig. 6). The deepest point of the Philippine Trench is 10,025 m residing within a narrow 23 km long by ~2 km depression located at 10.336° N / 126.665° E. Around 1060 km north of the northern most tip of the Philippine Trench is the Ryukyu Trench that trends southwest to northeast parallel to the Japanese Nansei-Shotō Islands (Okinawa) between Taiwan and Kyūshū in southern Japan from 123° E to 130° E. This trench is 1012 km long, covering a surface area of 39,073 km^{-2}. The deepest point of the Ryukyu Trench is 7447 m at 24.880° N / 128.076° E at the southwestern end of an elongated depression ~108 km long delineated by the 7300 m bathymetric contour. Between 90 and 173 km northeast of the northeastern tip of the Ryukyu Trench there are three depressions >6500 m deep, each of them roughly 40 x 20 km in size, with a combined surface area of 1613 km^2.

Within the Philippine Basin, east of the Philippine Trench, there are depressions scattered all over the region, with the vast majority only slightly exceeding 6000 m. There is one slightly deeper hadal area parallel to the Oki-Daito Ridge (Keenan and Encarnación 2016), about around 211 km long, between 15.96° N / 131.765° E and 17.214° N / 129.575° E that attains a maximum depth of 7779 m at 16.933° N / 129.744° E in an elongated feature known as the Central Basin Trough or the Central Basin Fault Rift. The majority of the ~6000 m depressions are between 21.76° N and 8.08° N between 134.32° E and 128.06° E with some addition features extending from the Ryukyu Trench, perpendicular to its axis. The Oki-Daito Ridge effectively divides the Philippine Basin into northern and southern sub-basins with the total area, together comprising 127,754 km^2 of hadal habitat.

3.4 Area D: The Emperor Fracture Zone

The Emperor Fracture Zone (occasionally referred to as the Emperor Trough) extends from approximately 36.6° N / 173.4° W in the southeast to 49.3° N / 170.1° E in the northwest, and stretches roughly in a straight line over a distance of 2100 km with an eastward bend in the most southern 300 km (Fig. 7) terminating at the eastern end of the Hess Rise (Davies et al. 1972). The total surface area of the fracture zone is 44,208 km^2 and comprises a number of disjunct hadal corridors separated by stretches of seafloor <6000 m water depth. The majority of the fracture zone is between 6000 and 7000 m with just 5 narrow areas exceeding 7000 m depth. From north to south these deeps >7000 m are located at: 45.158° N / 174.140° E (8163 m); 39.804° N / 178.868° W (8629 m); 39.128° N / 177.950° W (7325 m), 38.669° N / 177.240° W (8523 m), and 37.905° N / 176.629° W (7828 m).

The wider area surrounding the Emperor Fracture Zone and Emperor Seamount Chain comprises extensive hadal areas (Fig. 7). The northernmost two hadal areas discussed here are located west and east of the northern part of the Emperor Seamount Chain (the Tenji, Jinmu and the Suiko Seamounts; Kodama et al. 1978). To the west of the seamounts there is an extensive hadal area within the Kruzenstern Fracture Zone as it widens at its southern end where it intersects the Hokkaido Trough (Mammerickx and Sharman 1988). This 35,889 km^2 feature reaches a maximum depth of 6895 m at 45.594° N / 168.759° E.

Between the Tenji, Jinmu and Suiko Seamounts, and the Emperor Fracture Zone, north of 43.9° N, three large basins and nine smaller discreet deeps that exceed 6000 m water depth covering a region of around 600 x 120 km (Fig. 7), informally named in this study the "Emperor Basin Complex" to distinguish between the Emperor Fracture Zone and mirroring the Hokkaido Trough on the western side of the Emperor Seamount Chain. In total the three largest basins cover a surface area of 36,937 km^2 and reach maximum depths of 6565 m, 6162 m and 6759 m from north to south, with the deepest located at 44.970° N / 170.776° E. The remaining nine, hadal areas in this region account for a further 312 km^2 with none of these discreet areas exceeding 6120 m depth.

In the southerly section of the Emperor Seamount Chain, the Jingū Basin (Smoot 1998) is located in a gap between the Ninigi and Nintoku guyots and the double Ōjin and Jingū Guyots (Smoot 1982) and is approximately 284 x 120 km at the 6000 m bathymetric contour (24,351 km^2, maximum depth of 6556 m at 38.851° N / 170.654° E). Two further depressions >6000 m are located to the east of the Jingū Guyot accounting for a further 11,301 km^2 of hadal zone although neither of these exceed 6400 m water depth (6285 and 6378 m). All these basins are all relatively flat bottomed.

Running perpendicular to the axis of the Emperor Fracture Zone, at a latitude of around 41.4° N and extending for approximately 1200 km east, is another complex series of hundreds of small depressions exceeding the 6000 m in the region known as the Chinook Trough (Smoot 1998), where the total area exceeding 6000 m depth is 117,561 km^{-2}. A number of zones within the axis of the Chinook Trough exceed 6500 m water depth with a maximum depth of 8045 m recorded at 43.440° N / 174.748° W. South of the Chinook Trough region, three fracture zones trend approximately west-east. These are the Surveyor Fracture Zone, the Pioneer Fracture Zone and the Mendocino Fracture Zone (Menard 1967) with the latter two trending due east of the eastern edge of the Hess Rise. Note that these fracture zones extend to the east, beyond the study area, and are also known collectively as the Mendocino–Pioneer Fracture Zone System (Rea and Dixon 1983). However, the sections of these fracture zones within the area of interest comprise sections of the Mendocino and Surveyor fracture zones that exceed 6500 m depth. The deepest point of the Surveyor Fracture Zone is at 39.346° N / 169.679° W (7659 m) with another 3 points exceeding 7000 m depth, furthermore there are 4 very small areas that exceed 7000 m within the Mendocino Fracture Zone. The largest and deepest of these is located at 36.798° N / 166.247° W with a maximum depth of 7082 m. The deepest point in the Pioneer Fracture Zone is 6505 m at 38.173° N / 166.929° W. There are a number of small, confined basins that exceed 6000 m depth scattered across the abyssal plain and do not cluster to form a coherent group of hadal areas but rather simply form disparate deeps.

3.5 Area E: The North West Pacific Basin

The North West Pacific Basin (as it is collectively known; e.g. Den et al. 1969) is a series of named basins centred around 30˚ N by 160˚ E, with a combined area of 1,218,643 km^{-2} (comprising 792 individual features exceeding >1.5 km^2 in area) exceeding 6000 m water depth (Fig. 8). It is located to the west, east and south of the Shatsky Rise, and south and west of the Kōko Seamount (Davies et al. 1972; Sager et al. 2016) and is bounded by the Marcus-Wake Seamount Group to the south (Smoot 1989). The North West Pacific Basin is comprises five major basins (Kalaniopuu, Mercator, Cipangu, Nedezhda and Ptolemy) along with scattered topographic lows >6000 m, although the depth rarely exceeds 6400 m.

The most eastern basin (71,671 km^{-2}) is the Kalaniopuu Basin, which is intersected by the Waghenaer Fracture Zone (Nakanishi et al. 1989) that runs northeast, and parallel to that, to the west is the shorter Ortelius Fracture Zone (Nakanishi et al. 1989). Immediately north, between the Shatsky Rise and Kōko Seamount is the Mercator Basin (166,102 km^2). The most north-westerly basin is the Cipangu Basin (Nagihara et al. 1996) which is 125,453 km^2 and separated from the 185,622 km^2 Nedezhda Basin (Bartolini 2003) immediately south by the Japanese Guyot Group (Matthews et al. 1974). The Nedezhda Basin terminates to the west by the Fujibakama and Kaede Escarpments (Ishihara and

Fujioka 2015). The basin immediately south of the Shatsky Rise, separated from the Nedezhda Basin by the MIT Guyot and Makarov Seamount, is the Ptolemy Basin (Lancelot et al. 1990) which is 95,386 km^2. The maximum depth (and locations) of the Kalaniopuu, Mercator, Cipangu, Nedezhda and Ptolemy basins are: 6315 (27.215˚ N / 171.127˚ E), 6582 (31.816˚ N / 165.902˚ E), 6455 (33.292˚ N / 148.278˚ E), 6448 (29.104˚ N / 146.488˚ E) and 6525 m (28.713˚ N / 156.804˚ E) respectively.

3.6 Area F and G the East Mariana and Central Basins.

The East Mariana Basin (Castillo et al. 1994) is located east of the Mariana Trench centred on a latitude of ~13.75˚ N (Fig. 9). It comprises 138 depressions of predominant depths of between 6000-6300 m, with an area exceeding 6000 m depth of 182,256 km^2, and is bounded by the Magellan Seamount Chain in a northern and eastern arc (Koppers et al. 1998) and by the Caroline Ridge to the south. Its western boundary is delineated by a series of seamounts on the subducting plate of the Mariana Trench. The deepest point is 6539 m is located at 14.625˚ N / 155.678˚ E.

Central Pacific Basin (Fig. 10) is centred around 10˚ N / 180˚ E south of the Mid-Pacific Mountains (Winterer and Metzler 1984). The basin comprises 171 discreet areas >6000 m totalling 126,266 km^2 bounded by the 6000 m contour, with a maximum depth of 6870 m at 8.400˚ N / 176.130˚ E. The eastern edge of the basin lies between the Magellan Rise and North Magellan Rise (Zakharov et al. 2007). The western edge is bounded by the Victoria Fracture Zone oriented approximately north–south, perpendicular to the southern Marshall Islands and the Gilbert Islands (Nakanishi and Winterer 1998).

4. Discussion

Examination of the best available bathymetric datasets from the northwest Pacific Ocean revealed that the potential area occupied by depth exceeding 6000 m to be 2,793,011 km^2. If, as is often done, it is only the large subduction trenches that are taken into account, the total hadal area is only 686,114 km^2. Furthermore, basins account for almost double the hadal area (1,318,123 km^2) occupied by subduction zones with fracture zones accounting for significantly less hadal habitat. It should be noted that if all excursions to hadal depths are accounted for across the wider area, including those discreet areas that do not cluster to form a 'named' feature, the total surface area of hadal habitat in the northwest Pacific Ocean is 2,793,011 km^2.

The first salient finding of this study is that the Mariana-Volcano chain of trenches is more complex than expected. It is more convoluted than just the fact that what the Russians referred to as the Volcano Trench does exist as a bathymetric feature delineated by the 6000 m contour, as opposed to simply being the northern sector of the Marianas Trench Marine National Monument. This study proves that there are actually four topographic highs that partition the hadal areas of this subduction zone within what is has previously been considered by some to be a single feature: the Mariana Trench. Therefore from a habitat perspective, it means there are multiple areas of physically isolated hadal habitat, and the Mariana Trench as we know it, actually comprises five separate hadal zones. These five hadal habitats are spread across a 1050 km long Mariana Trench in the south with a maximum depth of 10,925 m (van Haren et al. 2017), a 669 km long and 8822 m deep Volcano Trench in the north, and three smaller habitats (from south to north) of 250 km (8761 m), 93 km (7161m), and 96 km (7292 m) long in between. The partitions between these areas (5180 m, 5359 m, 5519 m, and 4600 m deep from south to north) indicates that there are no hadal corridors connecting these habitats and thus are highly likely to negate genetic flow between population of species endemic to hadal depths.

The second salient finding of this study is that, converse to the previous example, there are no true biologically significant abyssal partitions between the hadal zones of the (from south to north) Izu-Bonin, Japan and Kuril-Kamchatka trenches. Rather, the data confirm that at depths >6000 m there are connecting corridors between all three trenches. While Priede (2018) had raised the issue of the hadal continuum at the Japan and Kuril-Kamchatka Trench juncture with the Erimo Seamount, there is also evidence for connectivity at the southern end of the Japan Trench at the intersection with the Joban Seamount Chain. Both these ends have hadal pathways flowing on either flank of the respective seamounts.

One of the results of this study is that there is no ambiguity regarding the hadal boundaries of the Ryukyu, Philippine and Aleutian trenches. The large basins (North West Pacific Basin, West and East Mariana Basins, Central Basin, Chinook Trough and the Philippine Basins) and to some degree the Emperor Fracture Zone, and its wider surrounding features, are defined by reasonably poor resolution data, and often only represent very small excursions to hadal depths. They do however warrant further study through both biological sampling and high-resolution bathymetric mapping to establish whether these relatively shallow, but geographically extensive areas are indeed forming significant biological corridors for hadal species connectivity between larger subduction trenches.

Finally, with regard to abyssal partitioning, this study has found that the Yap Trench actually comprises two separate hadal areas, one in the south (357 km long and 8487 m deep) and one in the north (347 km long and 8472 m deep) separated by an 11 km wide sill that shallows to a depth of 5460 m.

Similarly, albeit to a lesser extent, the Palau Trench is also formed of two depressions, but separated by just 2 km.

The significance of these findings are dependent on whether they are being considered in a geological or biological context. For example, the Peru-Chile Trench is clearly one long subduction zone and is often referred to in this way in geological contexts (e.g. Omiria et al. 2016) and has been for a long time (Hayes 1966). However, the Peru-Chile Trench is partitioned at ~15° S by the Nazca Ridge forming two isolated trenches from a biological perspective. The trench to the north is typically abyssal in depth (i.e. <6000 m water depth), but the southern section comprises a hadal trench, often referred to as the Atacama Trench (e.g. Danovaro et al. 2002). Likewise in the southwest Pacific, the Kermadec and Tonga trenches form one subduction zone, often referred to in geological contexts as the Tonga–Kermadec Trench (e.g. Billen et al. 2003). However, within this convergence zone the Louisville Seamount Chain intersects the subduction zone at ~25˚40'S (Vanderkluysen et al. 2013) creating a topographic high that fluctuates between 5500 and 6000 m water depth, therefore isolating the two >6000 m habitats (Jamieson *et al*. 2020). Therefore, in biological or hadal contexts, these are referred to individually as the Tonga and Kermadec trenches (e.g. Blankenship et al. 2006). Inconsistencies arise when referring to the trenches included in this study whereby the northern Mariana Trench, once referred to as the Volcano Trench is merged with the Mariana Trench regardless of the multiple partitions therein (e.g. Tosatto 2009). Conversely, the Izu-Bonin, Japan and Kuril-Kamchatka trenches are generally considered different trenches when in fact they form one continuous hadal corridor >6000 m deep.

In the most recent studies, two main organisms have been used to study hadal endemism: amphipods and fishes. Amphipods are typically collected consistently in large numbers using baited traps (Fujii et al. 2013; Lacey et al. 2016), with fish more often observed on baited cameras (Linley et al. 2016; 2017). Of the hadal amphipods, the genera *Hirondellea* Chevreaux 1889, and *Bathycallisoma,* Dahl 1959 (formally *Scopelocheirus;* Kilgallen and Lowry 2015) are the most frequently found. In the northwest Pacific trenches, the *Hirondellea* species is *H. gigas* (Birstein and Vinogradov 1955; Eustace et al. 2013) and in the southwest Pacific it is *H. dubia* (Dahl 1959; Jamieson et al. 2011). To examine genetic homogeneity in *H. gigas* using morphological variance from specimens found in the Mariana, Palau and Philippine trenches, France (1993) concluded they were geographically isolated populations that may have reduced levels of gene flow between them, causing them to diverge morphologically. The shallowest record of *H. gigas* is from the Mariana Trench at 6142 m (Unpublished data, A.J. Jamieson) suggesting that indeed they cannot cross the abyssal partitions. Likewise, in the Kermadec and Tonga trenches, the shallowest *H. dubia* records are from 6000 m (Fujii et al. 2013), 6709 m (Lacey et al.

2016) and 7349 m (Blankenship et al. 2006) depth with only the latter collected in the Tonga Trench. In the New Hebrides Trench, Lacey et al. (2016) did however recover three specimens of *H. dubia* from 4700 m, albeit the other 582 specimens were found >6000 m.

There is a similar trend for *Bathycallisoma* sp. whereby Lacey et al. (2016) recovered 13 specimens at 5600 m and another 779 at depths >6000 m. In other trenches, this species has a shallower depth record of 6252 m in the Tonga Trench (Blankenship et al. 20006), 6007 and 6097 m in the Kermadec Trench (Fujii et al. 2013; Lacey et al. 2016 respectively). Again, this supports the theory that *Bathycallisoma* sp. forms isolated populations that cannot readily cross abyssal partitions.

The influence of hadal depths on species endemism may also extend further. Eustace et al. (2016) studied a population of, otherwise cosmopolitan, abyssal *Eurythenes* sp. from 4600 to 8000 m from the Peru-Chile Trench and concluded that the population separated at 6173 m into two genetically and morphologically distinct species.

With regards to hadal fishes, Jamieson et al. (2009, 2011) observed the endemic snailfish *Notoliparis kermadecensis* (Nielsen 1964) in the Kermadec Trench to be abundant at depths between 7000 and 7600 m. Further studies increased the depth limit to 7669 m but did however observe just one individual at a non-hadal depth of 5879 m (Linley 2016). A second species *Notoliparis stewarti*, Stein 2016, was also described from the Kermadec Trench between 7000 and 7261 m. In the Mariana Trench, a similar species *Pseudoliparis swirei* Gerringer et al. 2017 is known from 6198 to 8078 m, with a second less abundant species dubbed the 'Ethereal snailfish' at 8007 to 8145 m (Linley et al. 2016). A similar species, *Pseudoliparis belyaevi*, Andriashev and Pitruk 1993, is known from the Japan Trench at 6945-7703 m and 7565-7587 m (Jamieson et al. 2009). However, *Pseudoliparis amblystomopsis* (Andriashev 1955) is known from the Japan and Kuril-Kamchatka Trenches, at depths of 7210-7230 m and 7420-7450 m respectively (Fujii et al. 2010; Horikoshi et al. 1990). The latter is the only hadal snailfish currently known from more than one trench and happens to be found in two of the trenches that this study has confirmed are not partitioned by abyssal depths.

The above examples indicate that, with a few rare exceptions of often single or very few individuals sampled from depths <6000 m, the otherwise largely dominant trench species would be unable to cross the abyssal partitions described in this study. This would explain, for example, why some trenches, or trench clusters are host to species endemic to that area and why some speciation appears between neighbouring trenches which is more pronounced with increasing distance between trenches (Ritchie et al. 2015).

5. Conclusion

In deep-sea biology, the complex interplay between genetic connectivity, population structure and biogeography with underlying geological phenomenon has long been studied. Perhaps the more conspicuous examples are from hydrothermal vent, submarine canyon and seamount communities (e.g. Grassle 1987; De Leo et al. 2010; de Forges et al. 2000 respectively). Similar interplays, and indeed very similar biological and ecological questions can be posed relating to the hadal fauna, but by comparison with the aforementioned examples, the hadal questions are perhaps on a much grander scale. Hadal trenches often host seamounts, chemosynthetic communities and geological features on the scale of submarine canyons within their interior, coupled with isolating distances of thousands of kilometres (Stewart and Jamieson 2018; Jamieson et al. 2020). One of the first steps to unravelling what drives and influences biodiversity in the deepest 45% of the oceans is to examine the boundaries in which all other processes take place. Molecular adaptation to high pressure is simply a prerequisite to colonisation of the great depths, but once isolated within a trench the seafloor geomorphology influenced by the process of subduction must play a significant role thereafter. Therefore studies like this must be taken into account during the interpretation of future results at such depths.

Figures

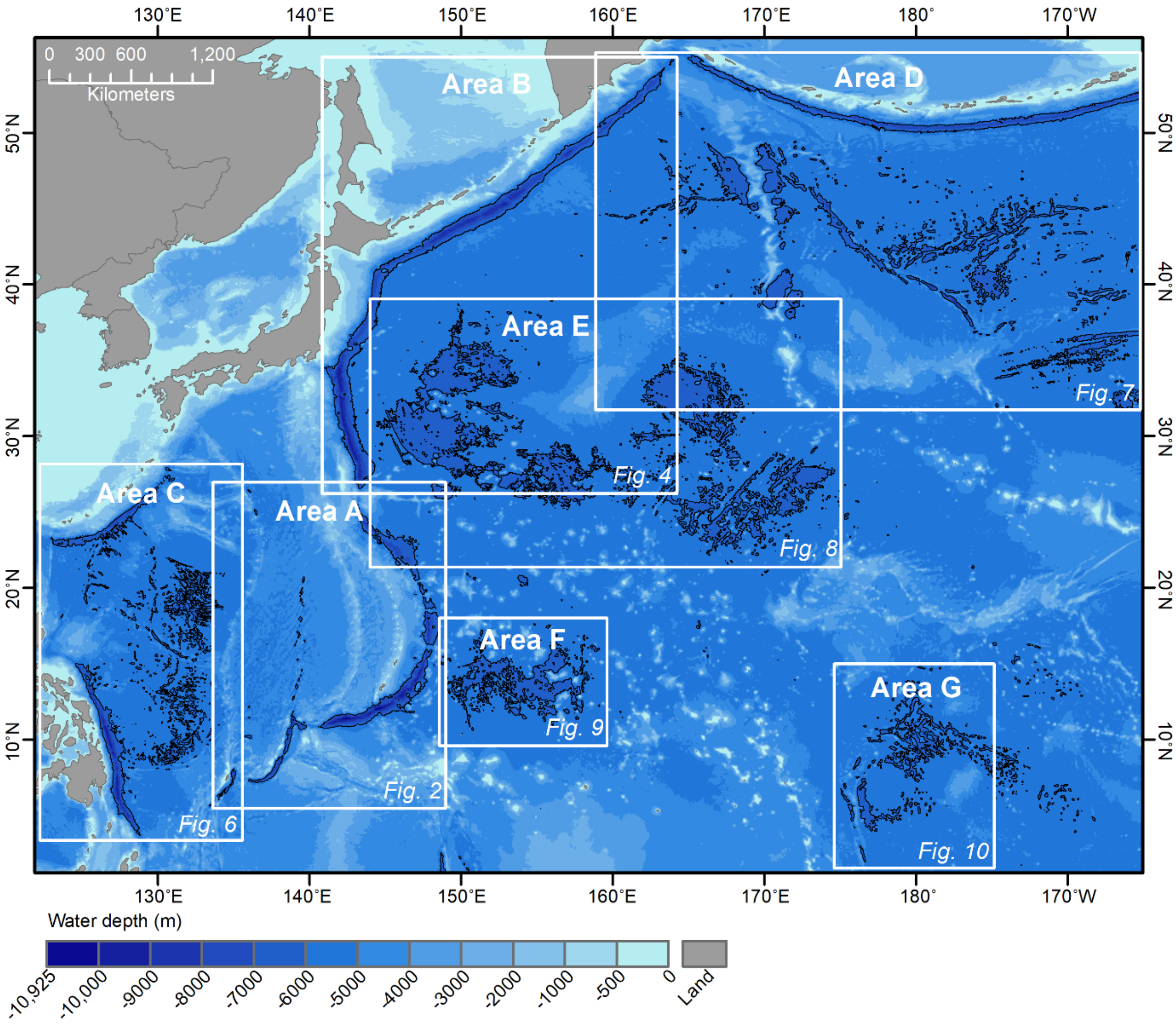


Figure 1. Bathymetry of the Northwest Pacific Ocean, white boxes relate to specific study areas described herein. Area A, the Palau, Yap, Mariana and Volcano trenches, Area B, the Izu-Bonin, Japan and Kuril-Kamchatka trenches, Area C, the Philippine and Ryukyu trenches, and the Philippine Basin, Area D, the Emperor Fracture Zone, Area E, the Northwest Pacific Basin, Area F, the East Mariana Basin, and Area G, the Central Pacific Basin. The black line represents the 6000 m depth contour. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

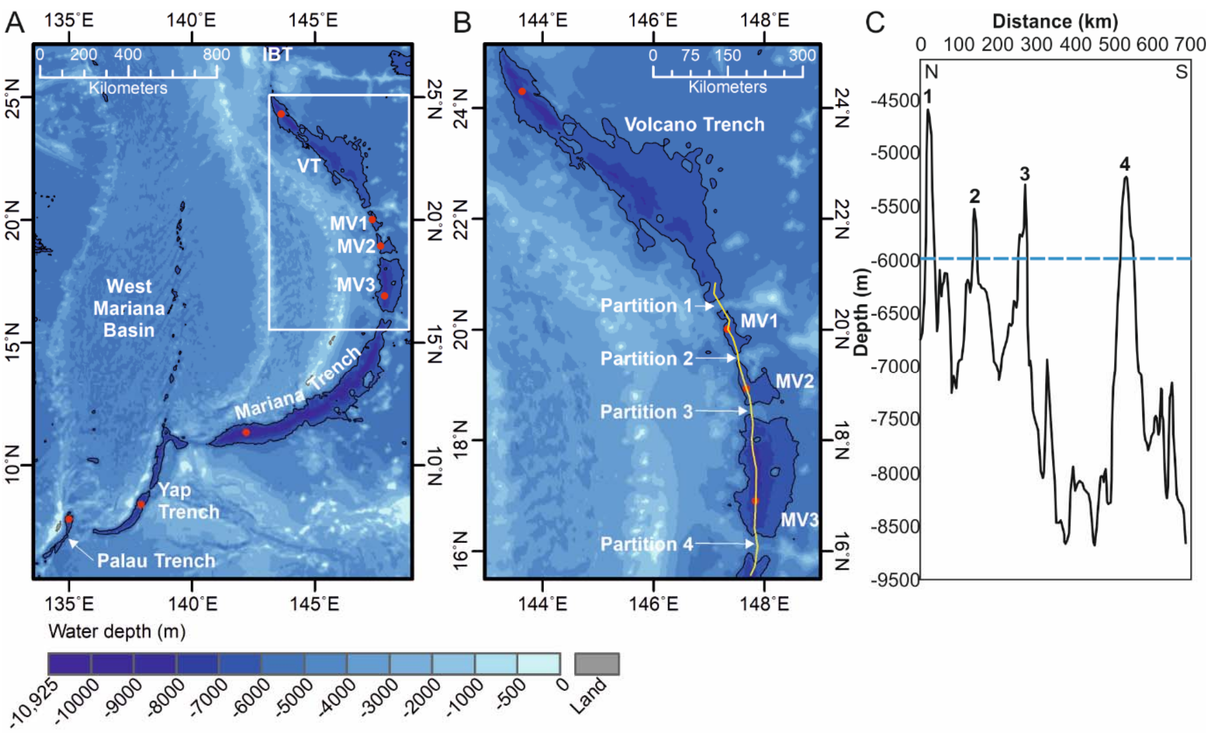


Figure 2. A - Bathymetry of Area A, the northwest Pacific subduction zones from the Palau Trench to the Izu-Bonin Trench (IBT) where MV1-3 indicates the intermediate 'Mariana–Volcano' hadal areas. VT = Volcano Trench. The red dot marks the deepest point in each feature discussed and the white box indicates the area shown in B. B – Close up of the four partitions between the Mariana and Volcano trenches. C is the cross sectional depth profile (yellow line in B) showing the partitions against the 6000 m abyssal–hadal boundary (dashed blue line). The black lines in A and B represent the 6000 m depth contour. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

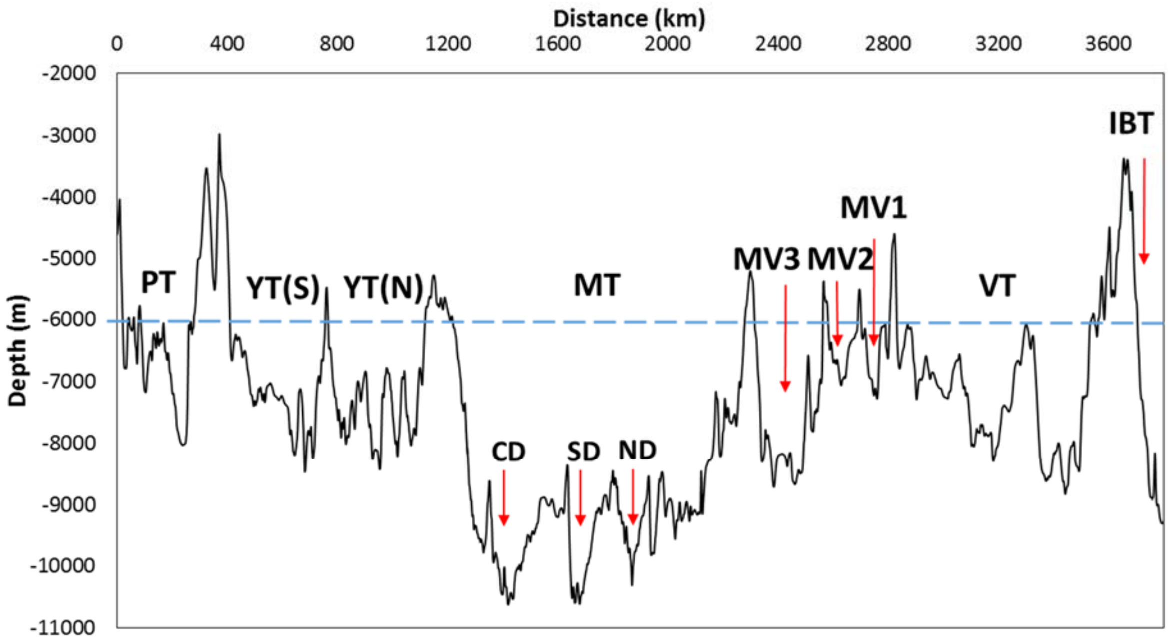
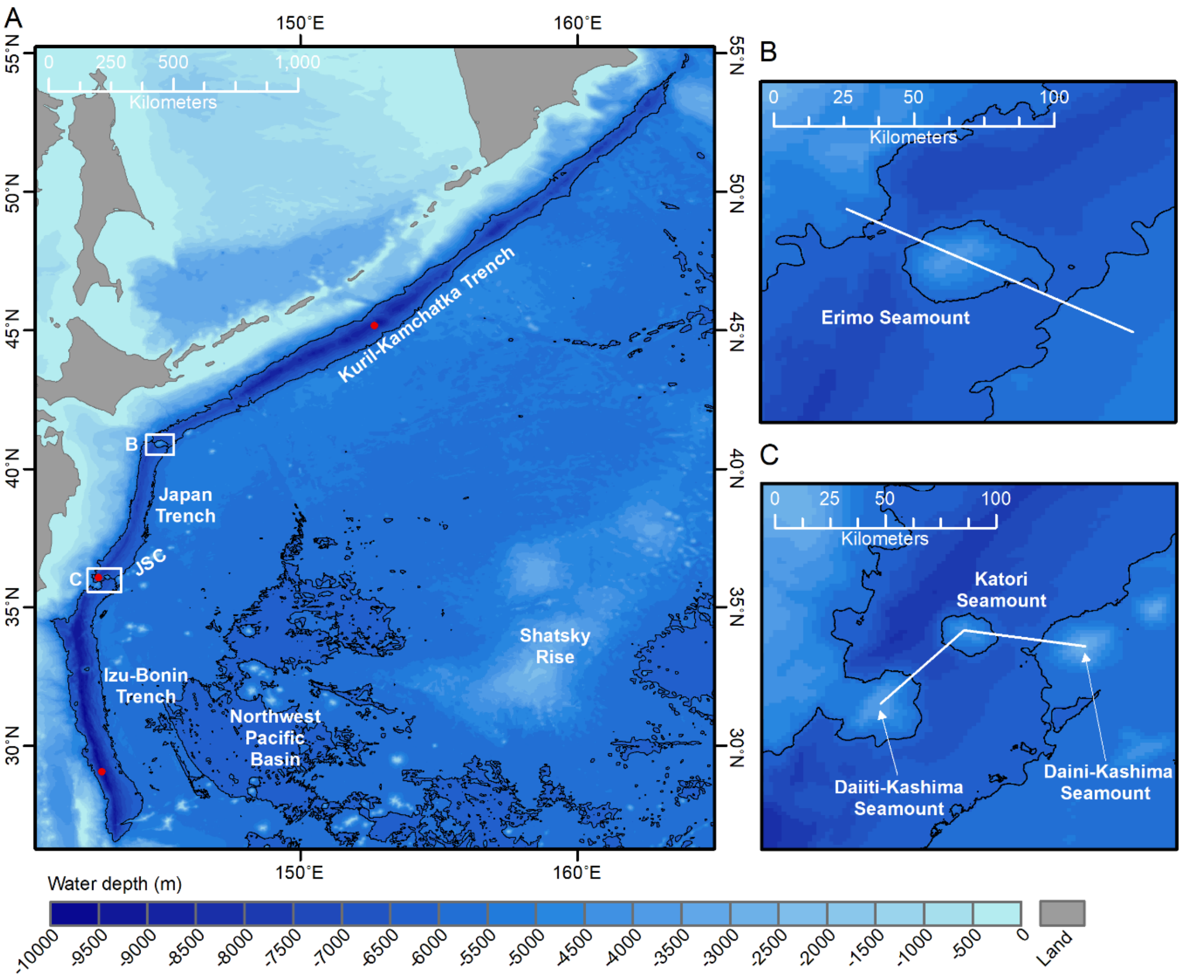


Figure 3. Cross section of the bathymetry along the trench axis of Area A, running from south to north: PT = Palau Trench, YT(S) = Yap Trench (southern depression), YT (N) = Yap Trench (northern depression), MT = Mariana Trench (CD, SD and ND = Challenger, Sirena and Nero deeps respectively), MV3, MV2 and MV1 are the unnamed 'Mariana–Volcano' hadal areas, VT = Volcano Trench and IBT = Izu-Bonin Trench. The dashed blue line represents the abyssal–hadal 6000 m depth boundary.

578 

579 **Figure 4.** A - Bathymetry of Area B comprising the Izu-Bonin, Japan and Kuril-Kamchatka trenches, and
580 the North West Pacific Basin to the east. The white boxes indicate the location of inset maps B and C.
581 B and C show the bathymetry of the trench partitions in greater detail, where the white line
582 corresponds to the cross sections in Figure 5 A and B respectively. The red dots mark the deepest point
583 of each feature discussed. The black lines represent the 6000 m depth contour. JSC = Joban Seamount
584 Chain. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al.
585 2009). Copyright British Geological Survey © UKRI 2020.

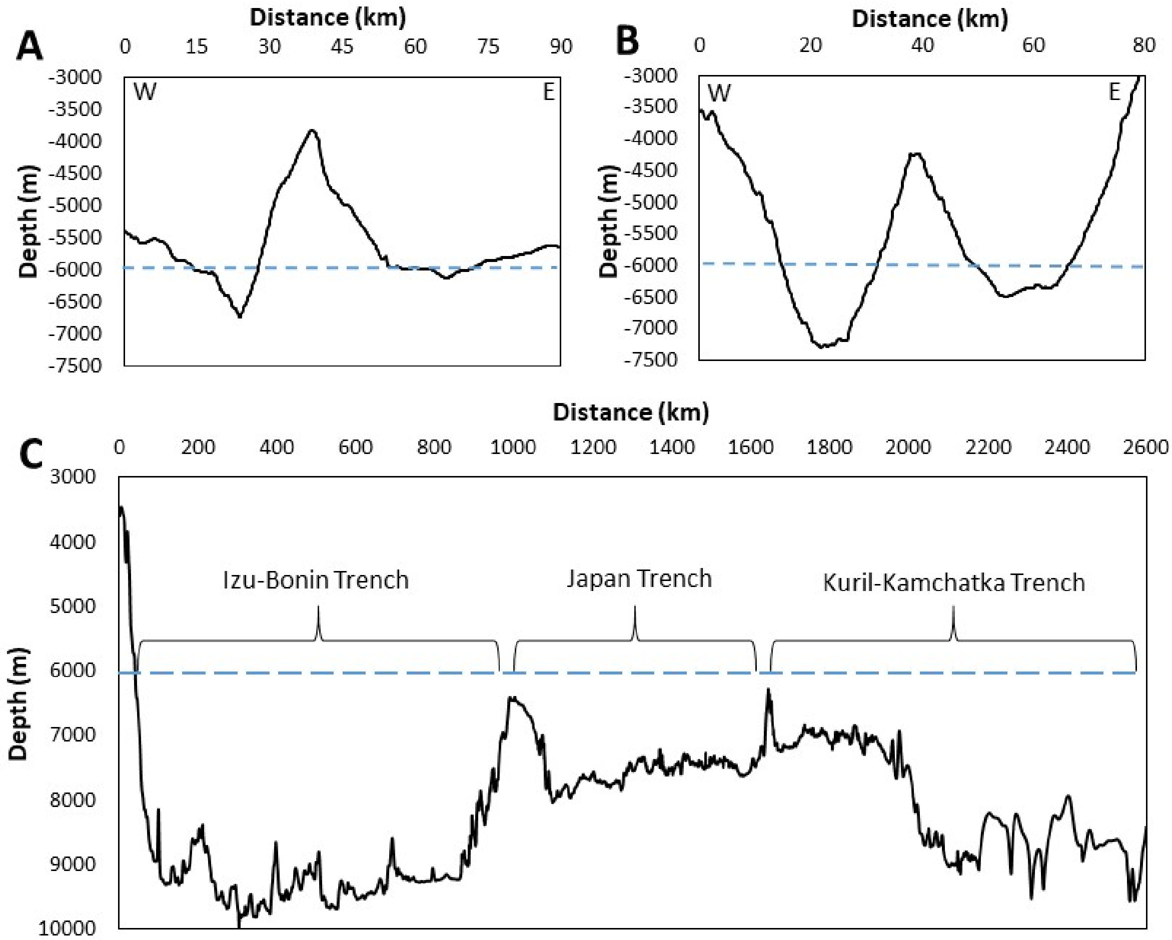


Figure 5. Cross section of the bathymetry along the partitions between the Japan and Kuril-Kamchatka trenches comprising the Erimo Seamount (A) and the Japan and Izu-Bonin trenches where the Joban Seamount Chain intersects the subduction zone (B). C shows the regional bathymetric cross section from south to north along the trench axis of the Izu-Bonin, Japan and the Kuril-Kamchatka trenches. The dashed blue line represents the abyssal–hadal 6000 m depth boundary. See Figure 4 for location.

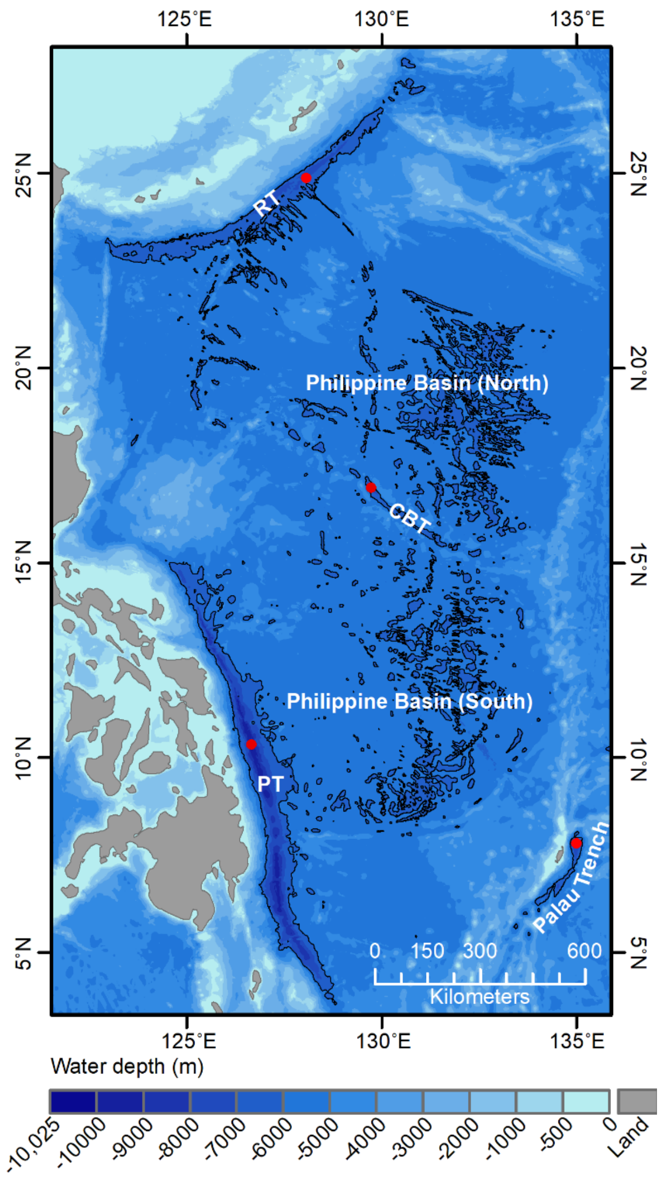


Figure 6. Bathymetry of Area C, the Philippine (PT) and Ryukyu (RT) trenches and the Philippine Basin. CBT = Central Basin Trough. The black lines represents the 6000 m depth contour, the red dots represent the deepest point in each feature discussed. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

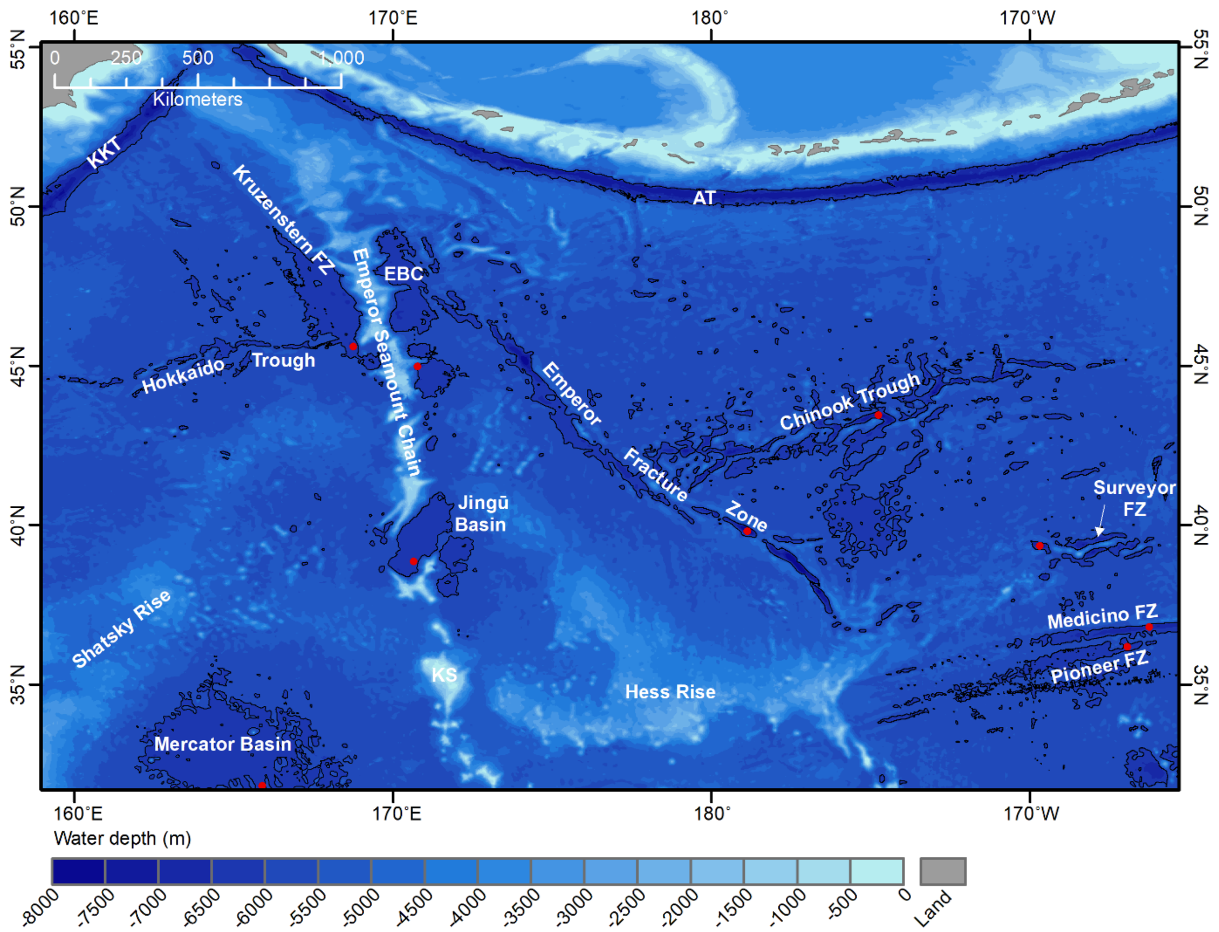


Figure 7. Bathymetry of Area D comprising the Emperor Fracture Zone and surrounding features; Emperor Seamount Chain, and the Emperor Basin Complex (EBC) with the red dots mark the deepest spot in each feature discussed. The black lines represent the 6000 m depth contour. FZ= Fracture Zone, AT =Aleutian Trench and KKT = Kuril–Kamchatka Trench. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

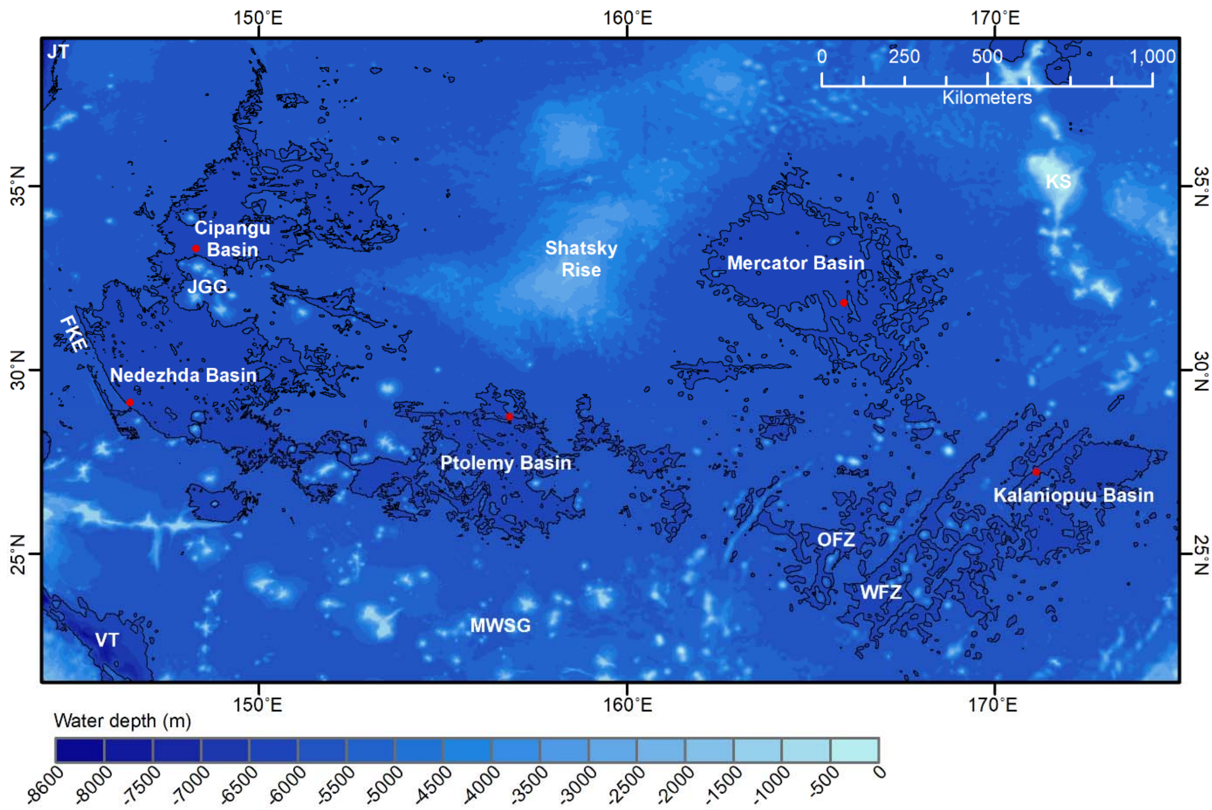


Figure 8. Bathymetry of Area E, the North West Pacific Basin, comprised of five basins: The Kalaniopuu, Mercator, Cipangu, Nedezhda and Ptolemy basins. Also marked are the Volcano Trench (VT), Japan Trench (JT), Kōko Seamount (KS), Waghenaer and Ortelius Fracture Zones (WFZ and OFZ), the Japanese Guyot Group (JGG), Marcus-Wake Seamount Group (MWSG) and the Fujibakama and Kaede Escarpments (FKE). The black lines represent the 6000 m depth contour, the red dots represent the deepest point in each of the five basins. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

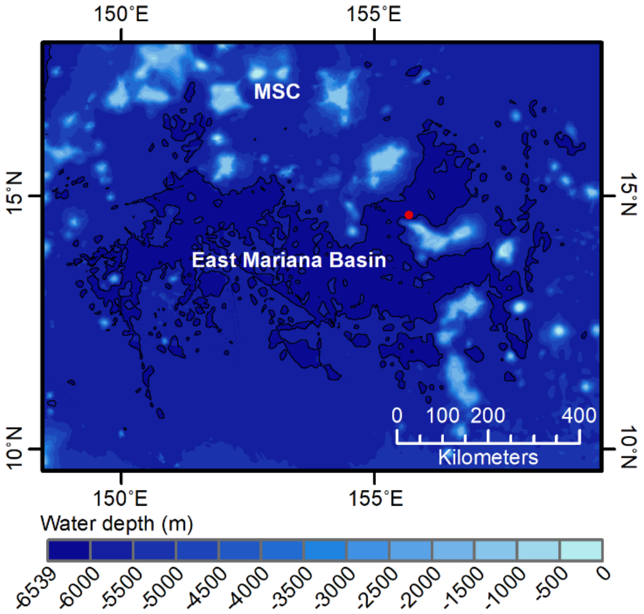


Figure 9. The East Mariana Basin and Magellan Seamount Chain (MSC) (Area F). The black lines represent the 6000 m depth contour the red dot indicates the deepest point. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

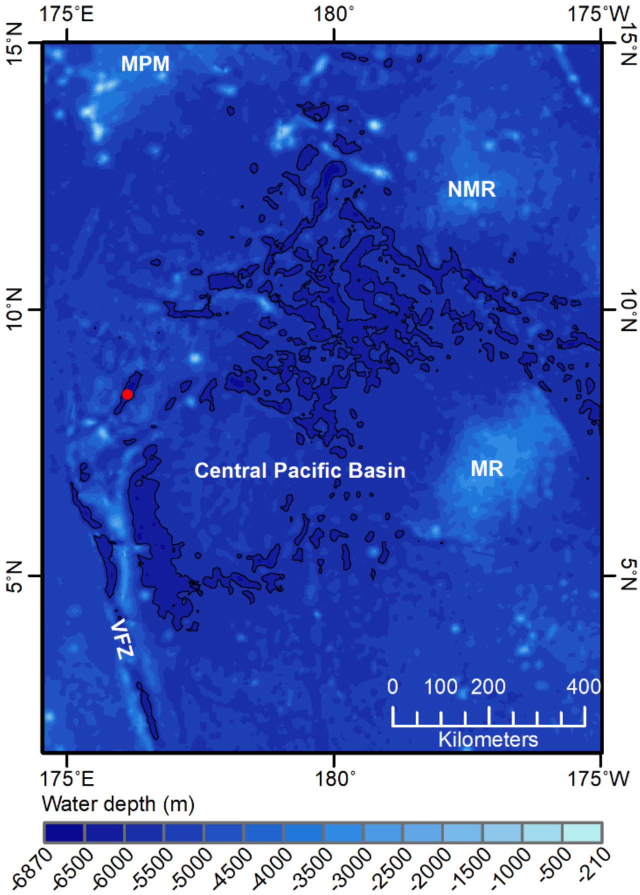


Figure 10. The Central Pacific Basin, showing the Mid-Pacific Mountains (MPM), the Magellan and North Magellan Rises (MR and NMR) and the Victoria Fracture Zone (VFZ) (Area G). The black lines represent the 6000 m depth contour and the red dot indicates the deepest point. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al. 2009). Copyright British Geological Survey © UKRI 2020.

Table 1 – Depth, length and area of each of the trenches and partitioning sills in Area A. *Depth from van Haren et al. (2017). **Depth from Dreutter et al. (2020).

Name/Feature	Depth (m)	Length (km)	Area (km^2)
Palau Trench	8027	276	4121
Palau-Yap Sill	5500	100	-
(South) Yap Trench	8487	357	8681
(South) Yap-(North) Yap Sill	5460	11	-
(North) Yap Trench	8472	347	9707
(North) Yap-Mariana Sill	5330	95	-
Mariana Trench	10925*	1050	85,475
Mariana-MV3 Sill	5180	34	-
MV3 Trench	8761	250	20,772
MV3-MV2 Sill	5359	19	-
MV2 Trench	7161	93	3638
Dutton Guyot	5519	12	-
MV1 Trench	7292	96	1989
Fryer Guyot	4600	23	-
Volcano Trench	8822	669	47,864
Izu-Ogasawara Plateau	3373	142	-
Izu-Bonin Trench	9990	1122	105,328
Katori Seamount	4139	22	-
Japan Trench	8046	611	37,854
Erimo Seamount	3729	32	-
Kuril-Kamchatka Trench	9604**	2089	130,985
Aleutian Trench	7834	2902	107,782
Philippine Trench	10025	1571	82,845
Ryukyu Trench	7447	1012	39,073

Table 2. Area >6000 m deep (km^{-2}) and maximum depth (m) of the hadal basins of the northwest Pacific. *Denotes feature that extends beyond the study area, therefore total surface area may be larger than stated here.

Location	Sub-Feature	Area >6000 m (km^{-2})	Max. Depth (m)
North West Pacific Basin	Kalaniopuu Basin	71,671	6315
	Mercator Basin	166,102	6582
	Cipangu Basin	125,453	6455
	Nedezhda Basin	185,622	6448
	Ptolemy Basin	95,386	6525
Emperor Fracture Zone	Emperor Fracture Zone	44,210	8629
	Hokkaido Trough	35,889	6895
	Emperor Basin Complex	37,247	6759
	Jingū Basin	35,652	6556
	Chinook Trough	117,561	8045
	Surveyor Fracture Zone	12,496*	7659
	Mendocino–Pioneer Fracture Zone System	52,734*	7082
Central Basin	Central Basin	126,266	6870
	Victoria Fracture Zone	5664	6539
East Mariana Basin	East Mariana Basin	182,256	6539
West Mariana Basin	West Mariana Basin	3230	7435
Philippine Basin	North Philippine Basin	70,745	6721
	South Philippine Basin	57,009	6911
	Central Basin Trough	8032	7779

Table 3. Total number of individual habitats >6000 m deep, categorised as trench, basin or fracture zone and the total area >6000 m (km^{-2}) of each.

Feature	Number of isolated habitats	Total Area (km^{-2})
Subduction Trench	14	686,114
Basins	15	1,318,123
Fracture Zones	4	115,104
Total	**33**	**2,119,341**

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