doi: 10.25923/xy0q-0f35

Cruise Report: EX-16-05 Leg 3, 2016 Deepwater Exploration of the Marianas (ROV/Mapping)

Remotely Operated Vehicle (ROV) and Mapping Exploration of the Marianas Trench Marine National Monument and the Deepwater Areas in and around Guam and the Commonwealth of the Northern Mariana Islands

June 17 to July 10, 2016

Santa Rita, Guam, to Santa Rita, Guam

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Report Completed
June 2, 2021

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Abstract:

The *2016 Deepwater Exploration of the Marianas* expedition (EX-16-05), conducted by NOAA and partners, was a combined mapping and remotely operated vehicle (ROV) expedition conducted as part of NOAA's Campaign to Address Pacific monument Science and Technology NEeds (CAPSTONE), a multi-year foundational science effort to collect critical data and information in unknown and poorly-known deepwater areas in U.S. marine protected areas (MPAs) in the central and western Pacific Ocean. The final leg (EX-16-05-L3) in this three-part expedition commenced on June 17, 2016, and continued through July 10, 2016, focusing on areas in and around the Marianas Trench Marine National Monument (MTMNM) and the Commonwealth of the Northern Mariana Islands (CNMI). The main objective of EX-16-05 Leg 3 was to focus primarily on the northern half of the Marianas region—where past research cruises identified hydrothermal vents, but did no investigation of bottomfish, deep-sea coral habitats, or a number of submarine volcanoes. Before this expedition, many of the flanks of islands in the Marinas Arc remained unexplored and unmapped within the Monument. The expedition used the ship's deepwater mapping systems to map over 27,700 km^2 of seafloor. In addition, 22 ROV dives were conducted with over 120 hours dedicated to seafloor and midwater communities at depths 250 m to 6,000 m. During these dives, over 300 different organisms were observed, many of which could be new species or records for the region, and several high-density coral and sponge communities were examined. In total, 113 samples (45 geological samples, and 68 biological samples) were collected for further analysis. This report summarizes operations conducted during EX-16-05 Leg 3, presents data collected, and provides an overview of initial findings.

This report can be cited as follows:
Cantwell, K., Pomponi, S., Fryer, P., Sowers, D., Cantelas, F., Netburn, A., Ford, M., & Bowman, A.. (2020). EX-16-05 Leg 3 Expedition Report: 2016 Deepwater Exploration of the Marianas (ROV/Mapping). Office of Ocean Exploration and Research, Office of Oceanic and Atmospheric Research, NOAA, Silver Spring, MD 20910. OER Expedition Cruise Report 16-05-03 71 p.71. doi: https://doi.org/10.25923/xy0q-0f35

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1. Introduction

The NOAA Office of Ocean Exploration and Research (OER) is the only U.S. federal program dedicated to exploring our deep ocean, closing the prominent gap in our basic understanding of U.S. deep waters and seafloor, and delivering the ocean information needed to strengthen the economy, health, and security of our nation.

Using the latest tools and technology, OER explores previously unknown areas of our deep ocean, making discoveries of scientific, economic, and cultural value. Through live video streams, online coverage, training opportunities, and real-time events, OER allows scientists, resource managers, students, members of the general public, and others to actively experience ocean exploration—expanding available expertise, cultivating the next generation of ocean explorers, and engaging the public in exploration activities. From this exploration, OER makes the collected data needed to understand our ocean publicly available, so we can maintain the health of our ocean, sustainably manage our marine resources, accelerate our national economy, and build a better appreciation of the value and importance of the ocean in our everyday lives.

NOAA Ship *Okeanos Explorer* is the only U.S. federal vessel dedicated to exploring our largely unknown ocean for the purpose of discovery and the advancement of knowledge. America's future depends on understanding the ocean. Exploration supports NOAA mission priorities and national objectives by providing a broad diversity of data and information about the deep ocean to anyone who needs it.

In close collaboration with government agencies, academic institutions, and other partners, OER conducts deep-sea exploration expeditions using advanced technologies on NOAA Ship *Okeanos Explorer*. From mapping and characterizing previously unseen seafloor to collecting and disseminating information about deep waters and seafloor—and the resources they hold—this work establishes a foundation of information and fills data gaps. Data collected on the ship adhere to federal open-access data standards and are publicly available shortly after an expedition ends. This ensures the delivery of reliable scientific data needed to identify, understand, and manage key elements of the ocean environment. As the only federal program dedicated to ocean exploration, OER is uniquely situated to lead partners in delivering critical deep-ocean information to managers, decision makers, scientists, and the public—leveraging federal investments to meet national priorities.

2. Expedition Overview

2.1 Rationale for Exploration

The Campaign to Address Pacific Monument Science, Technology, and Ocean Needs (CAPSTONE), was a three-year effort designed to provide critical new information about the deepwater resources within the U.S. National Marine Monuments and Sanctuaries located throughout the Pacific. The primary goal of all NOAA Ship *Okeanos Explorer* expeditions during this campaign was to obtain baseline data and information of the poorly known deepwater areas and resources in these extensive marine protected areas (MPAs). From 2015 to 2017, CAPSTONE expeditions focused on collecting baseline information in and around the MTMNM, Papahānaumokuākea Marine National Monument (PMNM), Pacific Remote Islands Marine National Monument (PRIMNM), Rose Atoll Marine National Monument (RAMNM), National Marine Sanctuary of American Sāmoa (NMSAS), Phoenix Islands Protected Area (PIPA), and Marae Moana, the Cook Islands Marine Park. The *2016 Deepwater Exploration of the Marianas* expedition was the fourth in a series of expeditions that comprised CAPSTONE.

NOAA and partners conducted the third and final cruise (EX-16-05 Leg 3) of the *2016 Deepwater Exploration of the Marianas* expedition (EX-16-05 Legs 1, 2, & 3) from June 17, 2016, through July 10, 2016. To meet the CAPSTONE objectives, this expedition collected critical data and information about unknown and poorly understood areas in and around the Marianas Trench Marine National Monument (MTMNM) and the Commonwealth of the Northern Mariana Islands (CNMI). The primary goal of the expedition was to acquire baseline information to understand the diversity and distribution of deepwater habitats in and around the CNMI and MTMNM to support emerging science and management needs.

The Marianas region is tectonically complex and biologically diverse. Despite decades of previous work in the region, much of the Monument and surrounding areas remain unexplored. During the 23-day cruise, EX-16-05 Leg 3 characterized bottomfish habitats, documented new hydrothermal vent sites and mud volcanoes, explored deep-sea coral and sponge communities, peered deep into subduction zone and trench areas, and discovered the resting place of a lost World War II (WWII) B-29 Superfortress aircraft. Data collected provided the first observations of these habitats and will help managers and researchers, for years to come, to better understand this region.

EX-16-05 Leg 1 of this expedition focused on exploration targets in the southern portion of this region, conducting ROV dives and mapping operations at hydrothermal vents and extinct calderas within the Mariana Trench, as well as at bottomfish, precious coral, and deep-sea coral habitats (Glickson et al., 2017). EX-16-05 Leg 2 mapped over 29,000 km^2 of seafloor within the MTMNM, revealing potential mud volcanoes and an unusual fragmented flat top ridge, and defined the 6,000 m contour along the western wall of the Mariana Trench (Lobecker et al, 2016; **Figure 1**).

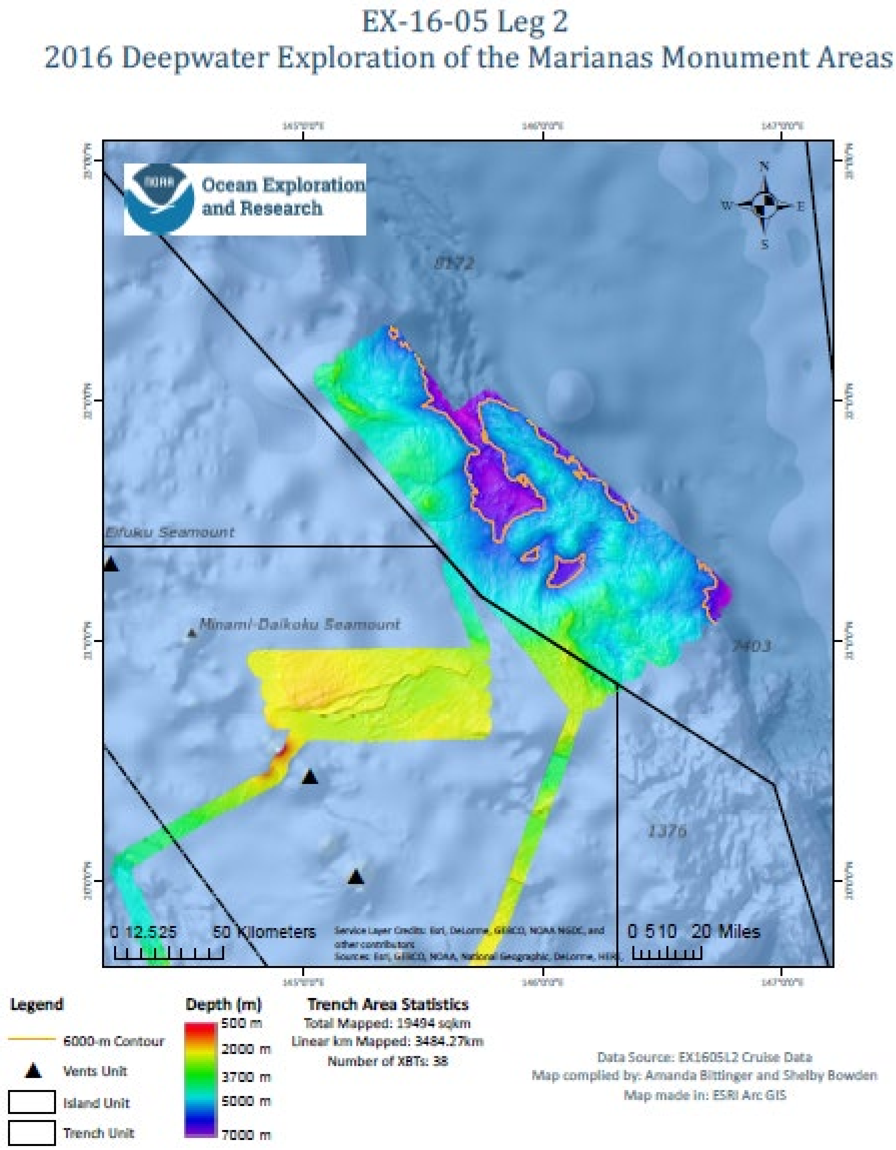

Figure 1: *EX-16-05 Leg 2 collected a significant amount of multibeam data within the MTMNM and revealed a number of features of interest that were investigated on ROV dives during EX-16-05 Leg 3, including mud volcanoes and "Explorer Ridge". (Figure adapted from Lobecker, 2016)*

EX-16-05 Leg 3 focused primarily on the northern half of the Marianas region. While there had been some past research cruises to the back arc in this area to investigate hydrothermal vents, their scope was limited and only targeted a few sites. Prior to EX-16-05 Leg 3, there had been no targeted efforts to investigate bottomfish or deep-sea coral habitats. Additionally, a number of submarine volcanoes and the flanks of islands in the back arc were still unexplored, large swaths of the Monument remained unmapped, and there had been very little deep submergence work in the northern part of the Mariana Trench. Basic questions about what was down there and how these communities and environments were connected remained unanswered, as this region lacked primary baseline data.

Monument Background

The MTMNM **(Figure 2)** was established in January 2009 through Presidential Proclamation 8335 under the authority of the Antiquities Act of 1906. The Monument was established for the purpose of protecting objects of interest such as the subduction system in the trench, submerged volcanoes, hydrothermal vents, coral reef ecosystems, and biologically diverse ecosystems where chemosynthetic and photosynthetic organisms exist side by side.

The Monument consists of three units: the Islands Unit, the Volcanic Unit, and the Trench Unit. The Volcanic Unit and the Trench Unit are additionally designated as National Wildlife Refuges https://www.fws.gov/refuge/mariana_trench_marine_national_monument/ , last accessed: August 28, 2020), the "Mariana Trench National Wildlife Refuge" (aka "Trench Unit/Refuge") and "Mariana Arc of Fire National Wildlife Refuge" (aka "Volcanic Unit/Arc of Fire Refuge").

The Islands Unit includes the waters and submerged lands of the three northernmost Mariana Islands (Farallon de Pajaros, Maug, and Asuncion) from the mean low water line to approximately 50 nautical miles offshore. The Volcanic Unit/Arc of Fire Refuge includes the submerged lands within a 2.3 nautical mile diameter around 21 undersea mud volcanoes and hydrothermal vents along the Mariana Arc. The Trench Unit/Refuge is almost 1,100 miles long and 44 miles wide and includes the submerged lands within the Mariana Trench, extending from the northern limit of the U.S. exclusive economic zone (EEZ) of the CNMI to the southern limit of the EEZ adjacent to the U.S. Territory of Guam.

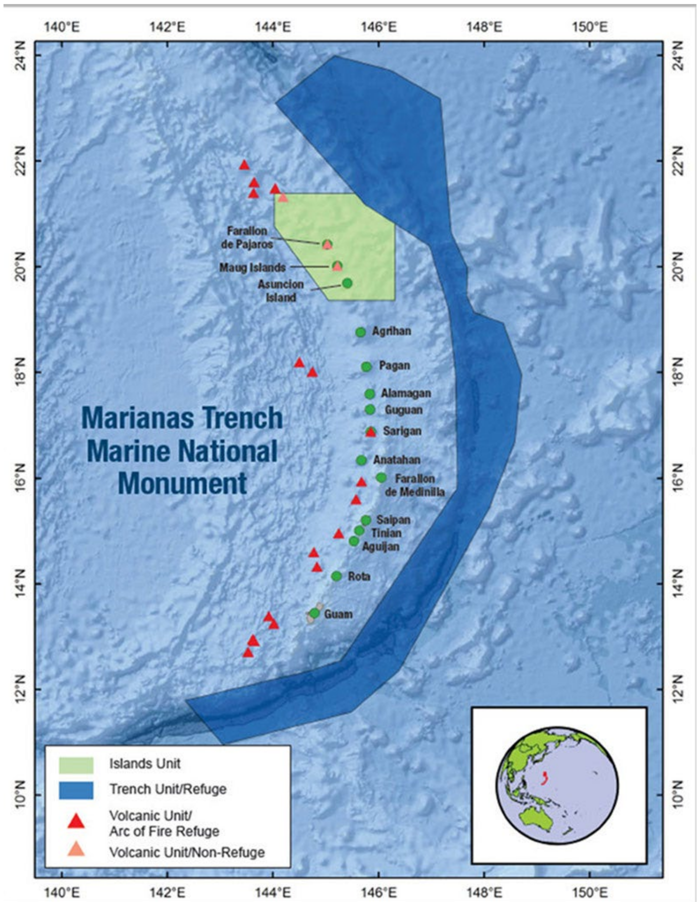

Figure 2*: Management designations within the Marianas Trench Marine National Monument. The green points denote islands. Figure courtesy of the Marianas Trench Marine National Monument.*

2.2 Objectives

NOAA Ship *Okeanos Explorer* cruises, in general, have a large number of objectives that can be categorized as being either scientific or programmatic in nature. Typically, scientific objectives are specific to a particular cruise or set of cruises, whereas programmatic objectives (i.e., operations, telepresence, data management, education, and outreach) are common to all cruises. Below are brief descriptions of the science and programmatic objectives for EX-16-05 Leg 3.

2.2.1 Science Objectives

EX-16-05 Leg 3 operations covered a wide area of the U.S. EEZ in and around the CNMI, Guam, and the MTMNM. Prior to commencing the expedition, science priorities were identified through extensive interactions between NOAA, CNMI and MTMNM managers, and the science community. This planning process identified several key exploration objectives to address current knowledge gaps in the region: locating and assessing commercial bottomfish and precious coral habitats; identifying high-density biological communities, with deep-sea corals and sponges of particular interest; surveying the communities that exist on ferromanganese-encrusted guyots; mapping and conducting transects over a variety of geological structures within the region, including hydrothermal vents, volcanic areas, and ridges; investigating subducting areas and the habitats within the abyssal-hadal transition zone of the trench; exploring life in the water column; and searching for Underwater Cultural Heritage (UCH) sites in an area that played a critical role in WWII.

2.2.2 Programmatic Objectives

a) *Mapping and ROV and Operations*

Mapping objectives during each NOAA Ship *Okeanos Explorer* cruise are to collect high-resolution acoustic data. At the time of the EX-16-05 Leg 3 expedition, data were collected from all three types of sonars: EM 302 multibeam, EK60 echo sounder, and 3.5 kHz subbottom profiler (SBP). Mapping data were acquired during transits, as well as on specific targets identified by the science team. Data from these systems were processed as quickly as possible in order to generate daily mapping products that supported ROV operations. Data quality was expected to be high, as a result of proper instrument maintenance, careful planning of the surveys, and appropriate calibration of the instruments. For example, standard operating procedure for the multibeam sonar is to obtain sound velocity profiles at regular intervals,no longer than three to six hours, using expendable bathythermographs (XBTs).

ROV objectives were to obtain high-quality video and sensor data on exploration targets to achieve the science objectives. This most often involved surveying benthic habitats and features in priority areas (e.g., deep corals and related benthic ecosystems, canyons, and seamounts), as well as occasionally surveying in midwater for water column organisms. Benthic surveys were not only used to characterize the habitats in each target area but also to ground-truth the acoustic data with visual data (i.e., video). In 2015, the ROV was fitted with hydraulically-activated sample boxes that permitted ROV pilots to collect limited geological and biological specimens.

b) *Telepresence*

Telepresence objectives were to provide real-time, high-quality video and audio during ROV dives to as wide a shoreside audience as possible. This audience included the general public, students, and researchers—the latter of whom were either passively watching or actively participating in the dives via teleconference or instant messaging. Telepresence was used to help achieve the science objectives by extending the science team well beyond those actually onboard the ship. Telepresence objectives also included the establishment of a two new Exploration Command Center (ECCs) in Guam—at the University of Guam and at UnderwaterWorld Guam—that helped to achieve the expedition's education and outreach objectives through live ship-to-shore events.

c) *Data Management*

Data management objectives were to collect, process, distribute, and archive cruise data as quickly and efficiently as possible. Effective data management provided a foundation of publicly accessible information products to spur further exploration, research, and management activities; it also stimulated interest in the deep-sea environment and the excitement of exploration. Each year, new methods and new equipment, such as video encoders, are tried and tested in an effort to improve data management activities. Additional details can be found in Appendix A.

d) *Education and Outreach*

Education and outreach objectives included the engagement of the general public in ocean exploration through live video and a variety of other web-based products, both during and after each cruise. Web content included topical essays written before the cruise, daily updates, mission logs, highlight videos, still imagery and mapping products—all of which are posted on the OER website (http://oceanexplorer.noaa.gov/okeanos/welcome.html). Additional activities, including live telepresence events and an in-port event that included ship tours, presentations, workshops, and other events, helped to expand the reach of this expedition.

3. Participants

Participation on EX-16-05 Leg 3 involved 21 at-sea mission personnel (Table 1) and 69 shore-based scientists (Table 2), the latter of whom engaged either by audio commentary or instant messaging via the expedition chat room on a regular basis. At-sea personnel included the expedition coordinator, mapping specialists, ROV engineers, video engineers, data specialists, and on-board scientists. Shore-based science team members participated from remote Exploration Command Centers (ECCs) and from their home locations. In addition to these participants, all NOAA Ship *Okeanos Explorer* expeditions are made possible with the work of the ship's dedicated crew and the shoreside operations team.

Table 1: *At-sea mission personnel*

Name	Role	Affiliation
Kasey Cantwell	Expedition Coordinator	NOAA OER
Derek Sowers	Mapping Team Lead	NOAA OER
Shirley Pomponi	Science Team Co-Lead	Florida Atlantic University (FAU)

Patricia Fryer	Science Team Co-Lead	University Corporation for Atmospheric Research (UCAR)/University of Hawaiʻi at Mānoa (UH)
Jason Meyer	Mapping Watch Lead	UCAR
Joshua Carlson	Data Management	Global Foundation for Ocean Exploration (GFOE)
Jim Newman	ROV Engineer Lead	GFOE
Don Liberatore	ROV Engineer	GFOE
Fernando Aragon	ROV Engineer	GFOE
Levi Unema	ROV Engineer	GFOE
Jeff Williams	ROV Engineer	GFOE
Andy Lister	ROV Engineer	GFOE
Roland Brian	Video Engineer	GFOE
Dan Rogers	ROV Engineer	GFOE
David Casagrande	ROV Engineer	GFOE
Sean Kennison	ROV Engineer	GFOE
Richard Stoner	ROV Engineer	North Atlantic Treaty Organization (NATO) Centre for Maritime Research & Experimentation (CMRE)
Tara Smithee	Video Engineer	GFOE
Annie White	Video Engineer	GFOE
Karl McLetchie	ROV Engineer	GFOE
Matt Dornback	Sample Data Manager	National Centers for Environmental Information (NCEI)

Table 2: *Shore-based science team members participated from remote exploration command centers (ECCs) and from their home institutions at various locations around the world.*

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4. Methods

4.1 Equipment

The two types of equipment typically used during NOAA Ship *Okeanos Explorer* cruises are ROVs and sonars. The equipment and methods are detailed below.

All environmental data collected during this expedition have been archived with NOAA archives and are publicly accessible. The data management plan for EX-1605L3 can be found in Appendix A.

4.1.1 ROVs

NOAA Ship *Okeanos Explorer* conducts high-resolution visual surveys to obtain critical deep-sea data and information using NOAA's custom-built, dual-body, 6,000-meter-rated ROV system that is comprised of two interconnected vehicles: *Deep Discoverer* (*D2*) and *Seirios*. *Seirios* is directly cabled to the ship and is, therefore, subjected to the vertical movements of the ship from surface swell. *D2* is laterally tethered to *Seirios* and is, therefore, largely isolated from surface conditions. This is a fundamental purpose of a dual-body design system.

D2 has five high-definition (HD) cameras, five standard-definition cameras, and 24 light-emitting diode (LED) lights that bring 144,000 lumens to the seafloor—resulting in some of the highest quality deep-sea footage in the industry. *D2* also has four custom-built lighting swing arms that allow for the position and angle of the light to be adjusted for optimal imaging. *Seirios* has one HD camera, five standard-definition cameras, and 18 LED lights that add 108,000 lumens to *D2*'s lighting. The vehicles work in tandem, with *D2* surveying the seafloor, and *Seirios* providing additional lighting and situational awareness, as well as dampening the movement of the ship. *D2* also has two manipulator arms, a Schillings Orion arm and a Kraft Predator arm. The Kraft arm is more dexterous and is outfitted with custom-built jaws that allow for delicate work, like sample collection, detaching small fragments, and equipment deployment or recovery. The Orion arm is used as a backup; this arm is also outfitted with the color calibration card. At the beginning of every dive, the HD video cameras on *D2* are color-corrected and white-balanced. In terms of oceanographic sensors, both vehicles have a Sea Bird 9/11+ CTD with dissolved oxygen (DO) sensors and *D2* also has a temperature probe.

4.1.2 Sonars

At the time of this expedition, NOAA Ship *Okeanos Explorer* had three scientific sonars that were operated simultaneously during mapping operations: a Kongsberg 30 kHz (EM 302) multibeam system, a Kongsberg 18 kHz (EK60) split-beam fisheries sonar, and a Knudsen 3.5 kHz chirp SBP sonar, and the. Mapping operations onboard NOAA Ship *Okeanos Explorer* occur continuously, throughout the day and night, except when the ROV is deployed.

EM 302

NOAA Ship *Okeanos Explorer*'s EM 302 (30 kHz) multibeam sonar was used to collect seafloor bathymetry, seafloor backscatter, and water column backscatter. Backscatter represents the strength of the acoustic signal reflected from some target, whether that's the seafloor or bubbles in the water column. The EM 302 is a deepwater multibeam system designed to map in depths ranging from approximately 200 -7,000 meters.

Single Beam Sonar

The Kongsberg EK60 (18 kHz) single beam was used to collect information about the water column, such as gas plume or seep sites, and to obtain information about biomass. The EK60 split-beam sonar is used as a quantitative scientific echosounder to identify water column acoustic reflectors —typically biological scattering layers, fish, or gas bubbles—providing additional information about water column characteristics and anomalies.

Sub Bottom Profiler

The primary purpose of the Knudsen Chirp 3260 (3.5 kHz) SBP sonar is to provide echogram images of surficial geological sediment layers underneath the seafloor to a maximum depth of about 80 meters below the seafloor. The SBP is normally operated to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the multibeam sonar. The data generated by this sonar was fundamental in helping geologists interpret the shallow geology of the seafloor.

XBTs

The Lockheed Martin Sippican Deep Blue XBT probe was deployed to obtain sound velocity profiles to help calibrate the multibeam system and ensure accurate bathymetric mapping. XBTs were collected every three to six hours at an interval defined by prevailing oceanographic conditions to correct multibeam data for changes in sound speed in the water column, and were applied in real time using Seafloor Information Software (SIS). Sound speed at the sonar head was determined using a Reson sound velocity probe (SVP)-70, and salinity measurements near the transducers were taken using the ship's flow-through thermosalinograph (TSG).

4.2. Operations

During all CAPSTONE expeditions, NOAA Ship *Okeanos Explorer* operations were conducted continuously around-the-clock and involved sonar mapping (i.e., mapping only cruises) or both sonar mapping and ROV dives. For dive planning purposes, existing gridded bathymetry data were viewed in collaboration with the onshore science team as the ROV was being recovered each day. Dive tracks for the next day were then planned, plotted in 3D, and shared with the at-sea and shore-based teams prior to the next dive.

4.2.1. ROV Survey Operations

ROV dive operations were conducted during daylight hours to support the expedition objectives. Dive sites were chosen using high-resolution bathymetry data from previous NOAA Ship *Okeanos Explorer*, Schmidt Ocean Institute R/V *Falkor*, or Pacific Marine Environmental Laboratory expeditions, or data obtained from other the NOAA National archives. Additional information about the general process of site selection, collaborative dive planning, scientific equipment on the ROVs, and the approach to benthic exploration can be found in Kennedy et al. (2019). A record of the ROV dive codes used during this cruise can be found in Appendix B. ROV survey operations targeted areas with no previous deep submergence dives and unknown areas of previously explored features, with the exception of the dive at Daikoku Seamount, which had the objective of surveying for any changes since a recent eruption. Data Access information can be found in Section 7.

During each dive, the ROV descended onto the seafloor and then moved up the slope, from waypoint to waypoint, documenting the geology and biology of the area. At-sea and shore-based scientists identified each encountered organism to the lowest possible taxon. For this purpose, scientists used the OER Benthic Animal Identification guide (http://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html, last accessed August 27, 2020) to augment their expertise and that of the participating shore-based science team. Additionally, at-sea and shore-based scientists provided geological interpretations of the observed substrate throughout each ROV seafloor survey.

During ROV Dives 03, 09, 16, and 18, midwater transects were conducted. A variety of depths from 4,000-340 m were explored and the expedition team experimented with a few different approaches to water column transects. More information about midwater exploration is in Section 6.8.

ROV operations also allowed for limited biological and geological sample collection by using *D2*s manipulators. Samples were placed into the sample boxes and retrieved by the at-sea science team after the ROV had been secured on deck. Samples were processed immediately in the ship's lab, the protocol for which is described in Section 4.3.3.

4.2.2 Seafloor Mapping

Mapping operations included EM 302 multibeam, EK60 single beam, and Knudsen subbottom profiler data collection. The schedule of operations included overnight transit mapping and mapping whenever the ROV was on deck. Lines were planned to maximize either edge matching of existing data or data gap filling in areas where existing bathymetry coverage existed. In regions with no existing data, exploration transit lines were planned to optimize potential discoveries. All mapping operations were completed within the United States EEZ. Much of the mapping work was done during transits between daily ROV dive operations. **Figures 3, 9, 10,** and **11** highlight a few of the larger continuous seafloor bathymetry surveys that were able to be completed without long distance transits between ROV dives. Data Access information can be found in Section 7.

4.2.3 Shoreside Operations

The current operating model for NOAA Ship *Okeanos Explorer* cruises is based on telepresence-enabled participation whereby the small at-sea science team is augmented by a significantly larger shore-based science team located around the world (Cantwell et al., 2020). Shore-based scientists help to plan and execute dives from Exploration Command Centers (ECCs), their home institutions, or even their homes. Those in ECCs benefit from the advantages of having higher Internet2 speeds, the means to simultaneously display all of the video feeds being sent from the ship, and direct interaction between other scientists who were stationed together in those facilities. The team also benefited from the wider expertise made possible through digital communications (e.g., email and instant messaging) that facilitated idea exchanges across this geographically-distributed team in real time.

Additional information about the operating model and how OER conducts community-driven exploration can be found in Cantwell et al., 2020.

4.3 Data acquisition and processing

The categories of data collected during all CAPSTONE expeditions included 1) sonar data from all three types of sonars, 2) video data from the various cameras mounted on *D2* and *Seirios*, 3) samples collected during the dives and sample data recorded while the samples were being processed, 4) environmental and tracking data from the CTDs and Tracklink system on *D2* and *Seirios*, and 5) biological and geological observations from participants that were captured on the dive audio or in the Eventlog. When time and resources allowed, Survey of Opportunity data were also collected in order to maximize the scientific benefit of the cruise to NOAA and the nation. Additional details about Surveys of Opportunity supported during EX-16-05 Leg 3 are provided in Section 4.3.6 and Appendix C.

4.3.1 Sonar Data

Throughout the cruise, multibeam data quality was monitored in real time by acquisition watch standers. Line spacing was planned to ensure 25-30% overlap between adjacent lines of multibeam sonar swaths. Cutoff angles in SIS were generally set between 60° and 70° on both the port and starboard sides. Ship speed was adjusted to maintain data quality as necessary and as transit time to the next dive site allowed.

All multibeam sonar data collected during the expedition were fully processed according to established onboard procedures and was archived with the National Center for Environmental Intelligence [NCEI, formerly National Geophysical Data Center (NGDC)]. Additional details about data archival can be found in Section 6 of this report. Raw multibeam bathymetry data files were acquired by SIS, and were imported into Teledyne Computer Aided Resource Information System (CARIS.) In CARIS, attitude and navigation data stored in each file were checked, and erroneous soundings were removed using CARIS Swath Editor and Subset Editor. Once per day, cleaned, gridded bathymetric data were exported to American Standard Code for Information Interchange (ASCII) text files (y,x,z) at 50-meter cell size in World Geodetic System 1984 (WGS84) datum. The ASCII files were then used to create Fledermaus Scientific Data (SD) objects. These SD objects were then exported to geotiff and Google Earth Keyhole Markup language Zipped (KMZ) files, which were copied to the shoreside file transfer protocol (FTP) on a daily basis to support shoreside scientist participation. For more detailed information about the sonar systems, see Sowers, 2019.

4.3.2 Video Data

The primary data set collected by the ROVs is HD video. The video is recorded and archived in several different formats and resolutions. The dives are recorded in their entirety at 720p, five megabit per second (Mbps) and in ProRes 4.2.2. 1080i, 145 Mbps. In addition to the full dive recording, a subset of the video collected is preserved in ProRes 4.2.2. 1080i, 145 Mbps. These clips represent the vast majority of the major events of the dives and capture nearly all of the geological formations and organisms that are observed. The video clips are time coded to Universal Time Coordinated (UTC) to coordinate with all data products collected on the ship. In addition to the video itself, at least one frame grab was taken from each ProRes clip that was representative of that video segment for the purpose of discoverability.

4.3.3 Samples and Sample Data

A limited number of geological and biological samples were collected from the seafloor using the manipulator arms and biological and geological collection boxes on *D2*. For each collected specimen, the date, time, latitude, longitude, depth, salinity, temperature, and DO content were recorded at the time of collection. Geological specimen collections targeted samples for age dating and geochemical composition. Biological specimen collections targeted samples that represented potential new species, range extensions of animals not previously known to occur in the region, or dominant species in the area.

Once specimens were brought back onto the deck of the ship, they were examined for commensal organisms, labeled, photographed, and inventoried into a database containing all relevant metadata. Any commensal organisms found were separated from the sample and processed separately. Geological samples were air dried and placed in rock bags. The geological samples were shipped to the Marine Geology Repository (MGR) at Oregon State University (OSU) after the 2016 expeditions, where they were analyzed in the laboratory for their chemical composition and geologic age. Additionally, biological samples were processed for DNA extractions using a kit provided by the Ocean Genome Legacy (OGL). For this purpose, a small subsample, consisting of ~1 cm^2 of tissue, was removed from the original sample and processed using the OGL DNA extraction kit. The remainder of the biological sample was preserved in 95% ethanoland were sent to the National Museum of Natural History (USNM), Smithsonian Institution (SI), for taxonomic identification and permanent storage. Some of these specimens were also frozen. Some corals and sponges were also subsampled, preserved in 10% buffered formalin for future histological examinations, with some of the subsamples transferred to 70% ethanol after three days; these subsamples were provided to the Bernice Pauahi Bishop Museum (BM) in Honolulu, Hawaiʻi. Data Access information can be found in Appendix C. Full details of the preservation of each biological sample was noted in the metadata record and is available through the sample repository as well as through NOAA OER's Digital Atlas (https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm).

The OER data management team at the National Center for Environmental Information created a Microsoft Access database specifically for recording the collection data for each of these biological and geological samples. EX-16-05 Leg 3 was the sixth deployment of this database and significant time was spent by the onboard Sample Data Manager to continue to troubleshoot bugs and on developmental improvements during the cruise. The database is named the Sampling Operations Database Application (SODA), and its fields were populated for each sample as it was being processed in the ship's lab. Using SODA, collection data is automatically pulled from the ROV systems and shipboard computer system (SCS). Additional, metadata and documentation generated through SODA include cruise and dive numbers, sample condition, subsample identifications including OGL vial numbers, commensal organisms that were removed from each sample, weight of the rock samples, and sample photo numbers.

4.3.4 Environmental and Tracking Data

The *D2* environmental data collected during each dive were provided to the OER archive as raw Seabird HEX files. The *D2* tracking data were exported from Tracklink as text files. In order to make these data types more accessible to interested researchers, the science team processed all CTD and tracking data and merged them together in simple to use comma-separated-values (CSV) files that can be opened in Microsoft Excel. These files were provided to both OER and NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) for distribution.

4.3.5 Eventlog

During ROV dives, participating researchers communicate between ship and shore using the Eventlog. The Eventlog is a persistent chat room where all comments, discussions, and requests are logged and provided a UTC timestamp that can later be correlated to the operations, location, and data feeds collected by the ship. The chat server facilitates the first-order annotation of cruise activities, serving as a digital version of scientists' daily logs and enabling input from multiple users. Eventlog users were encouraged to use "dive codes", which are three-to-five letter shorthand codes that are used to standardize and speed the recording of observations in the Eventlog. The dive codes can be found online (https://oceanexplorer.noaa.gov/okeanos/collaboration-tools/im-eventlog/dive-codes.html, last accessed August 27, 2020) and are included in Appendix B

4.3.6 Post-cruise Scientific Annotations

At the conclusion of EX16-05 Leg 3, a detailed analysis and quality assurance/ quality control of the ROV video collected was carried out at the University of Hawai'i's Hawaii Undersea Research Laboratory, under the direction of Dr. Christopher Kelley (supported by NOAA's Deep Sea Coral Research and Technology Program). The annotation creation process analyzed video from benthic exploration using Video Annotation and Reference System (VARS), created by the Monterey Bay Aquarium Research Institute and customized for the University of Hawai'i. VARS was used to generate records of animals from ROV dive video captured while on the seafloor. Animal records were catalogued and characterized with their in situ environmental data including habitat, substrate, water chemistry, and geographic location. Animals were identified using the OER Benthic Deepwater Animal Identification Guide (https://oceanexplorer.noaa.gov/okeanos/animal_guide/animal_guide.html, last accessed August 27, 2020).

Additional information about the annotations collected during CAPSTONE expeditions can be found in Kennedy et al., 2019.

4.3.7 Survey of Opportunity Data

During both EX-16-05 combined ROV and mapping cruises (Legs 1 and 3), data were collected as time allowed for the NASA-led, long-term Maritime Aerosol Network (MAN) research effort. Observations were made by mission personnel (as time allowed) with a sun photometer instrument provided by the NASA MAN program. Resulting data were delivered to the NASA MAN primary investigator, Alexander Smirnov, by the expedition coordinator. All collected data were archived and made publically available at: http://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html (last accessed August 27, 2020)

The full Survey of Opportunity description is available in Appendix C.

5. Clearances and Permits

A Scientific Research License application to conduct work on the submerged lands extending 3 nm surrounding the Northern Marianas Island was approved and received from the CNMI Department of Lands and Natural Resources, Division of Fish and Wildlife on April 15, 2016. This license was effective from April 20 to July 27, 2016. The expedition also received a CNMI Fish and Game License (license number 03345-2016), which covers sample collections, effective from April 20 to July 27, 2016. Both licenses can be found in Appendix D.

The expedition was planned and conducted by NOAA, as an agency of the U.S. federal government, in partnership with NOAA NMFS Pacific Islands Regional Office (PIRO) Marine National Monument Program. OER did not require a permit to work in the MTMNM. Additional information can be found in the EX-16-05 Leg 3 Project Instructions (Cantwell, 2016).

In order to support or conduct Marine Scientific Research within the U.S. EEZ, work funded, authorized and/or conducted by NOAA must be compliant with the National Environmental Policy Act (NEPA). The NOAA Administrative Order (NAO) 216-6 (link to the Companion Manual: https://www.nepa.noaa.gov/docs/NOAA-NAO-216-6A-Companion-Manual-03012018.pdf, last accessed August 27, 2020) describes NOAA's specific obligations with regard to NEPA compliance. Among these is the need to review all NOAA-supported projects with respect to their environmental consequences. In compliance with NAO 216-6 and NEPA, a memorandum describing the project's scientific sensors' possible effects on the environment was submitted for the project. As expected with ocean research with limited time or presence in the marine environment, the project was determined not to have the potential to result in any lasting changes to the environment. As defined in Sections 5.05 and 6.03.c.3 (a) of NAO 216-6, this is a research project of limited size or magnitude or with only short-term effects on the environment and for which any cumulative effects are negligible; and, as such, the project is categorically excluded from the need to prepare a full-scale NEPA environmental assessment. The categorical exclusion met the requirements of NAO 216-6 and NEPA, and authorizes the Marine Scientific Research conducted for the project.

Additionally, an informal consultation was initiated under Section 7 of the Endangered Species Act (ESA) of 1973, requesting NOAA NMFS Protected Resources Division concurrence with OER's biological evaluation determining that the *2016 Deepwater Exploration of the Marianas* expedition—and all other planned NOAA Ship *Okeanos Explorer* 2016-2017 cruise operations—may affect, but are not likely to adversely affect, ESA-listed marine species. The informal consultation was completed on February 3, 2016, when NOAA OER received a signed letter from the Regional Administrator of NMFS PIRO, stating that NMFS concurred with OER's determination that the proposed NOAA Ship *Okeanos Explorer* cruises were not likely to have an adverse effect on ESA-listed marine species.

6. Results

Below is a brief summary of the finding from this cruise. This section is further broken into two broad categories: ROV Findings and Sonar Findings.

During 24 days at sea (DAS), EX-16-05 Leg 3 conducted 22 ROV dives, usually eight or ten hours long, at depths ranging from 250-6000 m. The ROVs spent a total of 188 hours in the water, resulting in approximately 117 hours dedicated to exploring the seafloor and 5 hours dedicated to exploring midwater. ROV operations were conducted during the daylight hours, with mapping operations conducted during non-ROV hours, opportunistically filling data holidays as time allowed. The expedition mapped a total area of 27,764 km^2. **Figure 3** shows a summary map of EX-16-05 Leg 3 operations. A total of 25.29 TB of data were collected, including EM 302 multibeam, EK60 single beam, subbottom, XBT, ROV CTD and DO profiles, surface oceanographic and meteorological sensor data, video, imagery, and associated dive and video products. No CTD rosette casts were conducted during this cruise. A summary of operations can be found in Table 3.

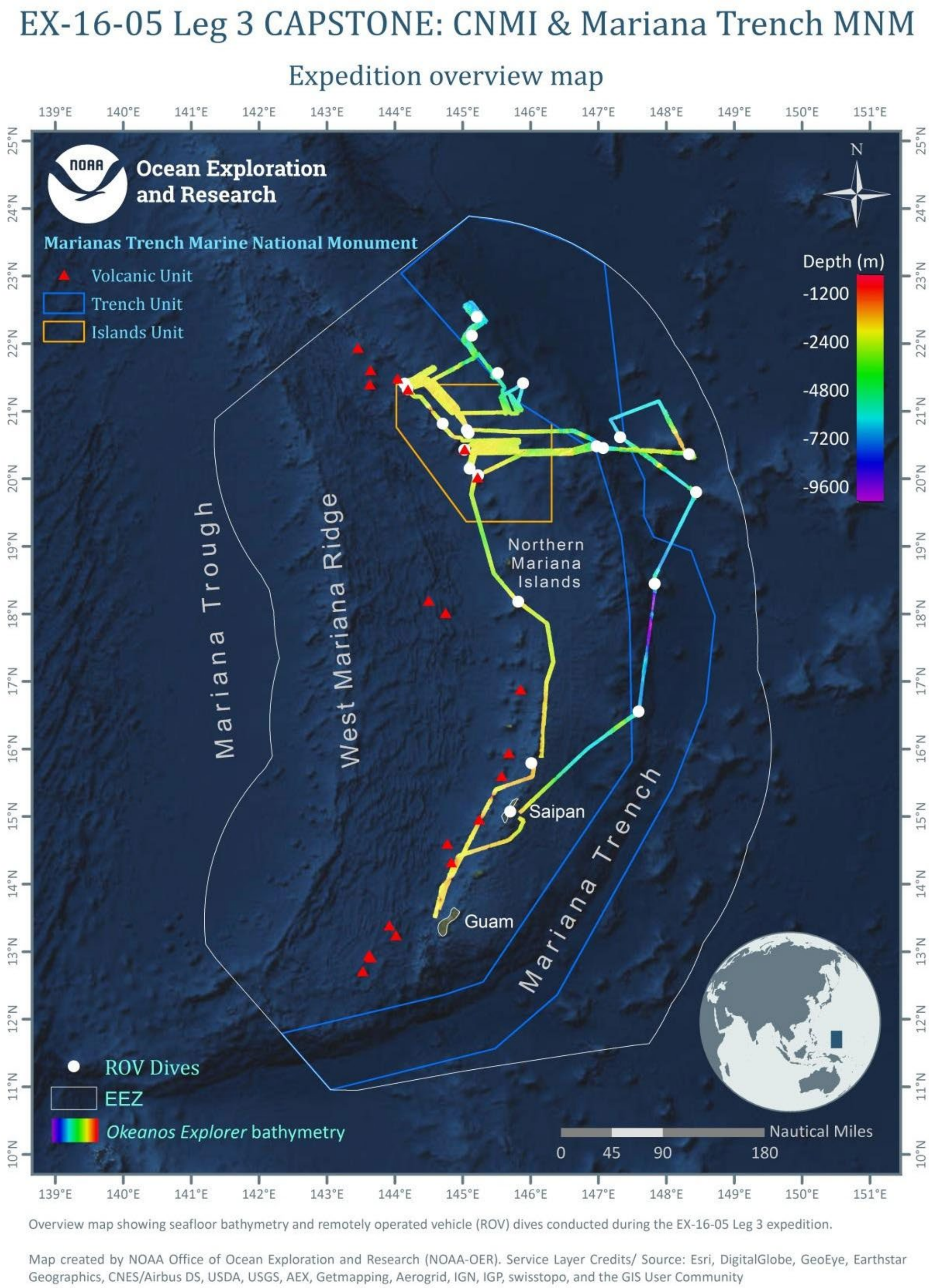

Figure 3. *Summary map of EX16-05 Leg 3 operations.*

Table 3: Expedition Schedule

Date	Dive	Activities	Operational Details
6/13/2016	-	Mission personnel arrive.	
6/14/2016	-	Mobilization.	

6/15/2016	-	Mobilization. Ship tours	
6/16/2016	-	Mobilization. Final mission personnel arrive. Media Interview with KUAM.	
6/17/2016	-	Depart Guam. Mapping operations conducted during transit.	~0900 Departure from Guam **1st time zone change overnight (+1 hr).**
6/18/2016	Dive 01	Dive 01–"Farallon de Medinilla (FDM 2)" Overnight mapping operations	6 hour ROV dive. Ship operated on UTC +11.
6/19/2016	Dive 02	Dive 02–"Pagan" Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/20/2016	Dive 03	Dive 03–"Maug" Overnight mapping operations	Normal 8 hour ROV dive. Benthic survey and midwater transects. Mapping operations during transit to the next dive site. **2nd time zone change overnight (+1 hr)**
6/21/2016	Dive 04	Dive 04–Hadal Ridge Overnight mapping operations	Ship will operate on UTC +12 for the duration of the cruise. 10 hour ROV dive. Mapping operations during transit to the next dive site.
6/22/2016	Dive 05	Dive 05–"Ahyi Seamount" Overnight mapping operations	Normal 8 hour dive. Mapping operations during transit to the next dive site.
6/23/2016	Dive 06	Dive 06–"Supply Reef" Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/24/2016	Dive 07	Dive 07–"Chamorro Seamount" Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/25/2016	Dive 08	Dive 08–Eifuku Seamount Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/26/2016	Dive 09	Dive 09–Daikoku Seamount Overnight mapping operations	10 hour ROV dive. Benthic survey and midwater transects. Mapping operations during transit to the next dive site.
6/27/2016	Dive 10	Dive 10–"Stegosaurus Ridge" Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/28/2016	Dive 11	Dive 11–"Northern Forearc Ridge" Overnight mapping operations	10 hour ROV dive. Mapping operations during transit to the next dive site.
6/29/2016	Dive 12	Dive 12–Unnamed Forearc Seamount Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
6/30/2016	Dive 13	Dive 13–"Twin Peaks" Overnight mapping operations	10 hour ROV dive. Mapping operations during transit to the next dive site.
7/1/2016	Dive 14	Dive 14–"Explorer Ridge" Deep Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.

7/2/2016	Dive 15	Dive 15–"Explorer Ridge" Shallow Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
7/3/2016	Dive 16	Dive 16–"Subducting Guyot 1" Overnight mapping operations	10 hour ROV dive. Benthic survey and midwater transects. Mapping operations during transit to the next dive site.
7/4/2016	Dive 17	Dive 17–Fryer Guyot Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
7/5/2016	Dive 18	Dive 18–Petite-Spot Volcano Overnight mapping operations	10 hour ROV dive. Benthic survey and midwater transects. Mapping operations during transit to the next dive site.
7/6/2016	Dive 19	Dive 19–Vogt Guyot Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
7/7/2016	Dive 20	Dive 20–"Subducting Guyot 2" Overnight mapping operations	Normal 8 hour ROV dive. Mapping operations during transit to the next dive site.
7/8/2016	Dive 21	Dive 21–Hadal Wall Overnight mapping operations	10 hour ROV dive. Mapping operations during transit to the next dive site.
7/9/2016	Dive 22	Dive 22–"Romeo and Juliet" (B-29 Superfortress) Overnight mapping operations	Dive to investigate potential crash sites of B-29 Superfortresses from WWII. OER UCH procedures in effect while within a 5 nm buffer of the site.
7/10/2016	-	Mapping operations conducted during transit. Pulled into port in Guam	~1200 Arrival into Guam
7/11/2016	-	Cruise demobilization and ship tours.	
7/12/2016	-	Mission personnel depart and ship tours.	
7/13/2016	-	Mission personnel depart	

6.1 ROV Findings

ROV dives conducted during EX16-05 Leg 3 are summarized in Table 4. Note, the location of Dive 22 is withheld from public distribution a s a UCH site, protected under the National Historic Preservation Act. Data users interested in acquiring this information can request data through the OER data request form (https://docs.google.com/forms/d/e/1FAIpQLSdBLvbtStVhGrDO3Ugn_sNJpgR1Yy -e-DaUU3TIqGjg07ITNg/viewform?formkey=dHAycC1MYndJb0hTdGRaYXAzVTVBdWc6MA#gid=0, last accessed August 27, 2020). Full Dive Summaries for each dive conducted during this expedition can be accessed through OER's Digital Atlas, in the ROV Data Access section https://www.ncei.noaa.gov/maps/oer -digital-atlas/mapsOE.htm?cruiseNum=EX1605L3 (last accessed August 27, 2020).

Table 4: Summary data for the 22 ROV dives conducted during EX16-05 Leg 3.

Dive #	Date (local)	Location	Lat. (N)	Lon. (E)	Max. Depth (m)	Dive Duration (h:m)	Bottom Time (h:m)	Midwater Exploration (h:m)	Geo. Samples	Bio. Samples	Commensal Samples
01	6/18/16	"Farallon de Medinilla (FDM 2)"	15° 47.621' N	146° 00.733' E	532.7 m	6:10:36	5:09:46	0:00	2	2	5
02	6/19/16	"Pagan"	18° 10.864' N	145° 49.206' E	396.9 m	7:59:56	7:28:14	0:00	3	2	0
03	6/20/16	"Maug"	20° 03.169' N	145° 13.639' E	532.7 m	8:04:32	5:24:55	0:45	2	2	3
04	6/21/16	Hadal Ridge	20° 28.914' N	146° 58.598' E	5999.8 m	10:08:55	2:51:19	0:00	1	0	0
05	6/22/16	"Ahyi Seamount"	20° 25.927' N	145° 01.671' E	363.4 m	8:03:55	6:54:33	0:00	3	1	2
06	6/23/16	"Supply Reef"	20° 09.243' N	145° 06.266' E	363.6 m	8:08:28	7:25:35	0:00	3	2	6
07	6/24/16	"Chamorro Seamount"	20° 49.002' N	144° 42.449' E	991.2 m	8:16:59	7:04:24	0:00	3	2	4
08	6/25/16	Eifuku Seamount	21° 24.624' N	144° 08.820' E	501.3 m	8:10:11	7:19:03	0:00	2	2	2

09	6/26/16	Daikoku Seamount	21° 19.591' N	144° 11.272' E	436.0 m	9:40:48	6:28:05	2:00	2	2	2
10	6/27/16	"Stegosaurus Ridge"	22° 07.285' N	145° 08.138' E	3218.5 m	7:28:00	3:31:10	0:00	3	2	2
11	6/28/16	"Northern Forearc Ridge"	22° 23.802' N	145° 12.665' E	4428.0 m	10:06:11	5:15:27	0:00	2	2	0
12	6/29/16	Unnamed Forearc Seamount	21° 34.021' N	145° 31.153' E	3321.0 m	8:11:48	4:29:01	0:00	2	1	1
13	6/30/16	"Twin Peaks"	21° 25.062' N	145° 53.416' E	4839.9 m	10:08:13	4:48:21	0:00	2	1	1
14	7/1/16	"Explorer Ridge" Deep	20° 40.779' N	145° 05.211' E	2594.2 m	7:59:28	5:08:51	0:00	2	1	0
15	7/2/16	"Explorer Ridge" Shallow	20° 43.418' N	145° 03.768' E	1915.3 m	8:00:53	5:51:54	0:00	1	2	1
16	7/3/16	"Subducting Guyot 1"	20° 27.374' N	147° 04.248' E	5005.7 m	10:08:53	3:14:28	1:02	3	0	0
17	7/4/16	Fryer Guyot	20° 22.076' N	148° 20.172' E	2128.6 m	8:02:47	5:43:16	0:00	0	2	2
18	7/5/16	Petite-spot Volcano	20° 36.926' N	147° 19.334' E	5702.3 m	10:11:47	3:06:11	0:50	4	1	0

19	7/6/16	Vogt Guyot	19° 48.240' N	148° 26.454' E	1944.9 m	8:13:29	6:07:02	0:00	1	2	1
20	7/7/16	"Subducting Guyot 2"	18° 26.836' N	147° 49.778' E	4438.7 m	8:15:29	3:44:55	0:00	1	1	0
21	7/8/16	Hadal Wall	16° 33.394' N	147° 35.512' E	5924.3 m	10:14:13	3:53:29	0:00	3	1	0
22	7/9/16	"Romeo and Juliet" (B-29 Superfortresses)	FOUO*	FOUO*	FOUO*	6:50:58	6:10:19	0	0	0	0

*Location information from underwater cultural heritage dives (e.g. Dive 22) is for official use only (FOUO).

6.1.1 Shallow Slopes of Four Mariana Volcanic Arc Seamounts (Dives 01, 02, 03, and 05)

The goal of the four dives conducted on the shallow (500 to 250 m) outer slopes of submerged Mariana volcanic arc seamounts addressed the CAPSTONE priorities of: (1) assessing the population density and diversity of bottomfishes, and (2) exploring for high-density communities of deep-sea corals. Precious corals are under the management of NMFS. Whereas the precious coral fishery is listed as a managed fishery in Guam and the CNMI, no precious coral beds had been identified prior to EX-16-05 Leg 1, and only an anecdotal account of their presence in this region of the Pacific had been published. These particular sites were also chosen to survey bottomfish fishery habitat, which has also not been characterized in Guam or the CNMI, and to determine if there was a depth and site overlap between the bottomfish and precious coral fishery habitats.

Dive 01, at the upper slope of Farallon de Medinilla Island, explored a ridge crest that had considerable relief. A series of knolls were present for most of the dive, and the first half of the dive traversed seafloor surfaces (probably volcaniclastics —fragments of volcanic rock) that alternated between rough and smooth. Samples were taken of a layered block (likely volcanic ash) and, from the top of the ridge, a coralline limestone. At least two precious coral species—bamboo coral (Primnoidae) and black coral

(?Schizopathidae)—were observed. Also present, but not abundant, were several species of octocorals (including *Acanthogorgia* spp. and *Paragorgia* spp.), stoloniferans, and stony corals (Dendrophyllidae, ?*Enallopsammia sp.*). The most abundant organism was a demosponge of Astrophorina (?Pachastrellidae). At least two species of lithistid demosponges (Corallistidae) were observed in the area. Other invertebrates observed included squat lobsters (*Eumunida* spp. and *Munida spp.*), shrimps, a stone crab, hermit crabs, comatulid crinoids, brittlestars (attached to sponges and octocorals), sea stars, several different species of urchins, stalked barnacles and an octopus. The green filamentous organisms observed were likely algae that had been swept downslope by currents.

Dive 02, on the upper flank of Pagan Island, was geologically diverse. The depth was shallower than expected, most likely due to the series of pinnacles along the steep ridge at the beginning of the dive. The ridge was covered with subangular, igneous (i.e. lava rock) blocks; a sample was collected. Additionally, there were a few patches of small scorria (volcaniclastics); a vesicular (having many holes produced by expanding volcanic gas as lava erupts) sample was collected. The loose scorria terrain transitioned into a combination of finer ash and blocks of scoriaceous lava, some of them very large boulders, and there were also exposures of bedded volcaniclastics. Toward the end of the dive, the seafloor was covered with finer volcaniclastics. At each transition of these different bottom compositions, the biological communities changed. At the start of the dive, by the pinnacles, numerous organisms were revealed as the depths changed.

Stoloniferous octocorals in three different colors—white, pink, and yellow, presumably different species—were abundant, encrusting on more than 75% of the rocks. There were also numerous dead branches of octocorals, possibly killed off during the volcanic activity in the 1980's. Numerous live stony corals (*Enallopsammia* sp.), several types of octocorals (*Narella* cf. *muzikae*, *Chrysogorgia* sp., *Callogorgia* sp., *Paracalyptrophora* sp.), and black corals were observed. Other organisms present were yellow anemones, and several different species of hydroids, yellow Dendrophylliidae, demosponges (astrophorid, encrusting, and possibly dendroceratid), and spherical sponges (similar to the demosponge halichondrid *Spongosorites siliquaria*) with vermetid snails. At least two live slit shells, a sea star (*Coronaster* sp.), solitary ascidians covered with epibionts, and numerous fish (long-tailed red snapper—onaga or *Etelis coruscans*, scorpaenids, frogfish, eels, amberjacks, and a shark) were also video-documented. A brown pom pom anemone (?*Liponema* sp.) was collected.

Dive 03 followed a short, curved ridge—concave to the southwest—on the northwest flank of the Maug Islands. The side of a steep wall at the beginning of the dive appeared to be massive lava. For most of the dive, however, it was difficult to tell what the ridge face was made of, because it was covered with so many benthic animals. There were some fractures and irregular, pockmarked surfaces along the track. The edge of the ridge had some vertical walls, creating 2-3 m ledges that down-dropped to the southwest. Toward the end of the dive, there were some thin layers of fine volcaniclastics (ash or lapilli); some ash layers had larger, rounded boulders resting on them and pebble- to cobble-sized volcaniclastics. The entire dive was dominated by biology, not geology, as this feature was on the slope of a volcano that has not erupted in historic time, so there has been plenty of time for colonization to occur. The biggest challenge on the dive, in terms of choosing biological samples, was deciding which to collect, as there were many new and different organisms. Observations at the beginning of the dive included different species of bamboo corals, "gold coral" (*Kulamanamana haumeaae*), deepwater cardinalfish, and sea stars (*Coronaster* sp.). At 400 m, there was a different assemblage of organisms along the ledge of the ridge: stalked crinoids, scorpaenids, dead skeletons of a pseudocolonial coral (*Eguchipsammia* sp.), basket stars, crinoids, unusual sea stars, live slit shells, thousands of small knobby lithistid sponges, and a "pregnant" female deepwater sand tiger shark. A halichondrid demosponge (*Spongosorites* ?siliquaria) was observed and collected. Midwater exploration was conducted at the end of this dive, more information can be found in Section 6.1.8.

Dive 05 explored an area of recent eruption near the summit of "Ahyi" Seamount. The descent for this dive was marked by cloudy water on most of the way to the bottom, and the dive began on a slope covered with fine- to medium-sized volcaniclastics with larger rocks scattered about the slope. One of the larger rocks, a black and rough-surfaced piece of lava, was recovered. The ROV transited toward the base of a scarp near the summit of the seamount, where the volcaniclastics were larger and rested against a steep rock wall of columnar igneous rock (huge through-going cracks formed as hot lava cools and shrinks). A block of dark gray lava rock was collected from an area of the cliff covered with small (~5 to 10 mm) barnacles. As the ROV moved up the slope of volcaniclastics, patches of a white surface coating, likely bacterial, were encountered; eventually, the flocculant white coating nearly completely covered the seafloor. Farther up the slope, the white surface coating turned to yellow until the top, where there was a sharp break in slope, and the nearly horizontal seafloor was covered again with the white coating. A piece of volcanic rock, yellow-brown on the exposed surface and medium-gray (with a glassy groundmass) on the underside, with a strong sulfur smell, was recovered in this area. As the ROV traversed eastward to the bounding wall, massive igneous rocks were again encountered. The team initially thought there was a paucity of fauna at this site, but many of the usual deep-sea inhabitants (e.g., brittlestars, squat lobsters, a few crinoids, urchins, etc.), were observed, as well as some very unusual invertebrates and behaviors. An octopus was observed with (probably eating) numerous squat lobsters, and unusual snails (?*Oenopota* sp.) were grazing on the substrate covered by white and yellow bacterial mats. Two unidentified crustaceans (possibly crab or squat lobster) buried themselves in the rubble. Siphonostome copepods were found living in bacterial filaments on the rocks, and were also found to be on the adjacent seafloor. Other organisms observed included a benthic platyctenid ctenophore, an Aliciidae anemone with yellow nematocyst batteries, a Pleurobranchidae sea slug, aggregations of the shrimp *Plesionika* cf. *edwardsii* in some of the crevices of the outcrops, and numerous limpets on the rock outcrops. In general, the environment could be characterized as unstable, since most of the animals we observed were mobile. There was some discussion about how long the attached fauna (e.g., the rare black coral and primnoid octocoral) had been there, and if they had survived the volcanic eruption in 2014. The fish fauna included scorpionfish, deepwater cardinalfish, oblique-banded snapper, soldierfish, and epigonids, a cusk eel, duckbill, flatfish, and a snake mackerel (*Rexea* sp.)—a new record of occurrence in the Mariana region.

6.1.2. The Inner Slope of the Mariana Trench (Dives 04 and 21)

The main goals of the two dives performed—near the maximum depth-capability of the ROV—on the lower part of the western slope of the trench were to examine the deep architecture of the overriding Philippine Sea Plate near the trench axis and to catalogue the diversity of organisms at the transition between abyssal and hadal depth zones. Hadal regions are defined as those areas of the ocean below 6,000 m; the Mariana Trench, at over 11,000 m deep, is the world's deepest ocean trench. The first of the two dives dive was located in the northern part of the trench, a location chosen, in part, to try to determine whether the shallow parts of the trench axis, along its length, act as barriers to the distribution of deep pelagic fish or other fauna. The southern part of the trench had been previously studied to characterize the types of deep-sea fish south of Guam, and Dive 04 provided a contrasting northern view. The second hadal dive, Dive 21, was planned for near the mid-latitude of the trench axis to examine a location between the two.

Dive 04 on the informally named "Hadal Ridge" gave a glimpse of the complexity of the trench's inner slope. The ROV reached bottom at ~6,000 m on fine sediment covered with ripple marks. This area contained a rock, possibly peridotite (mantle rock), and calcium carbonate white rocks of varying sizes, one of which was collected. The lower part of the slope was composed of loose talus with tongues of pebble- to cobble-sized, mixed composition (mostly carbonate) debris. At a depth of 5898 m, a stratified, light-colored (possibly carbonate or serpentinite mudflow material), ~53 m high outcrop topped by a darker "polymict" (many rock types) was encountered. Toward the end of the dive there was a series of knife-edge ridges and troughs, exposing some stratified layers of light-colored material in multiple colors, and alternating with dark brown sediment layers. The dive ended at 5,750 m, and although not much of the vertical extent of the inner trench slope was covered, it was found to be a fascinating, variable, and unexpected set of exposures. The sparse fauna observed at this site included brisingid sea stars, cladorhizid (carnivorous) sponges, shrimp, amphipods, a holothurian (*Enypniastes* sp.), and what might have been a cusk eel.

Dive 21 on the informally named "Hadal Wall" explored a bathymetrically steep part of the inner wall of the trench on the northern slope of a regional "horst" (uplifted footwall block of crust surrounded by normal faults) that had at least three large, serpentinite mud volcanoes on it, one just west of our dive location. Most of the dive covered what appeared to be a talus slope with intermittent, completely sedimented, shallower slopes. There were numerous spiral and zigzag trails of benthic animals on the darker sediment, as well as areas where the sediment had a fluffy (biotic?) surface texture.The dive began on a pale, undulatory, sedimented surface strewn with sparse cobbles of angular to rounded rock with dark to white surfaces and some channels that appeared to be eroded. Three very green rocks (mantle peridotite?) were present, as well as a small white cobble (carbonate) with a pale pinkish surface in the upper right side of the rock (manganocalcite?). The ROV traversed patches of rock rubble, and small rubble outcrops enclosed in a fine, clay-like matrix. The few small exposures of outcropping layers beneath the surface sediment were all light colored and contained rubble, suggestive of serpentinite mudflows. There were also linear trails of large cobbles and small boulders that appeared at the edges of narrow ridges. The ROV documented a 1-m-thick, light, clay-rich sediment (mudflow?) sequence overlying another that seemed to contain fewer rock fragments, an almost entirely unsedimented area that appeared to be a recent serpentinite mud or debris flow, more pink carbonate boulders in a ridge of mud and rubble, and a heavily sedimented slope with ripple marks generally oriented perpendicular to slope that was a prime grazing area for several different species of holothurians. Spiral fecal trails of acorn worms were of interest to the paleontologists. There were a few sea stars, a narcomedusa jellyfish, long-legged isopods with very long antennae, cusk eels (*Penopus* sp.), and a stephanoberycid *Malacosarcus* sp. The dive ended with the collection of a sunburst-shaped carnivorous sponge—likely another new species—attached by a long stalk to a rock (which was also collected).

6.1.3 Mariana Island Arc Active Submarine Volcanoes (Dives 06, 07, 08, and 09)

The objectives for these dives on several of the known or suspected active submarine volcanoes of the Mariana volcanic arc were to examine and sample lavas—especially glass, in order to determine magmatic volatiles—as shallow as possible (the maximum depths of these four dives ranged between 363 and 991 m), and to determine whether or not life is significantly affected by being on the shallow flanks of an active submarine volcano. These submarine volcanoes are part of the Vents Unit and are also within the area of the Islands Unit of the MTMNM. Dive 9 at Daikoku Seamount also included a mid-water transect to characterize mid-water fauna during recovery.

Dive 06 was on “Supply Reef” and examined a small- to medium-sized stratovolcano (~150 km^3) that had confirmed eruptions in 1969 and 1989, but had never been explored with an ROV. There were only two types of rock seen on the dive: dark gray, coarse-grained, strikingly layered sections of volcaniclastics (some of which had large “bombs”) and a very fine-grained, brown ash with rounded holes that led the team to question if they represented burrows from animals “disturbing" the rocks. The ridge crest was generally covered with the brown ash. At the shallowest part of the ridge, what appeared to be a slump scar (curved wall, concave southeastward on the bathymetry) was examined. The slope was covered with loose rubble and there were numerous large boulders further upslope. At the top of the scarp, coarse volcaniclastic masses were cracked with surfaces that fit close to one another. The benthic fauna were abundant. Large, rock-hard "lithistid" demosponges were the dominant fauna at the start of the dive, and several different species of smaller demosponges were abundant along the entire dive track. The fish included grouper aggregations, onaga, at least two species of moray eels, a flounder that may not have been previously documented in the Mariana region, and thousands of smaller fish. Invertebrates included many corals, octocorals, and at least three *Rhipidaster* sp. sea stars that have not previously been observed alive.

Dive 07 was on "Chamorro Seamount" and climbed the outer southeast slope of the seamount's summit, traversing fragmented volcanic ash, cobbles (a white pumice fragment with black phenocrysts was collected) and boulders until small, black, active hydrothermal vents producing 10.5°C fluid were found. The top of the crater rim had jagged boulders and a steep drop. There were more hydrothermal structures, including chimneys, on the smooth and ash-covered crater floor, as well as on the northern wall of the crater, where there was what appeared to be a heavily fractured dike structure. A couple of pieces of the top of a chimney structure near the crater rim close to an active vent were collected (as well as some Alvinoconcha snails and polynoid polychaetes). There was some unusual fauna on the outer slope of the crater, including amphipod families on "sticks" they had constructed; at least 10 rarely seen polychelid lobsters), two species of demosponges, and alvinocaridid shrimps. It was hypothesized that several fish, including cutthroat eels and rattails, swimming near the vents may have been feeding on the high density of potential food items in the water column near those vents. Hydrothermal activity disappeared about halfway up the crater, and the rubble substrate was increasingly populated with stylasterid hydrocorals; one was collected along with the rock on which it was growing.

Dive 08, on Eifuku Seamount, descended into a crater on the southeast side of the volcano summit area. A lava dome in the center of the crater was composed of many large, jagged boulders with striated (grooved) surfaces. Near the top of the dome was a tall, striated lava spine leaning to the side and heavily fractured. The dive track traversed a ridge on the northwest side of the crater that was likely centered on a dike exposed in the wall of the crater. Much of the ridge had diffuse, low-level hydrothermal activity with temperatures reaching about 16°C. Midway along the ridge, an old hydrothermal chimney structure still produced some shimmering water, but no obvious active growth or characteristic vent fauna. Above this point, there were additional chimney structures, outcrops of columnar jointed rock, and talus piles of blocks broken from the dike walls. There were pillow lava fragments at the top of the cone.At least two species of barnacles (typically the early settlers) were the dominant fauna in the crater. Nudibranchs, although rare, were also seen. The fish fauna were unexpectedly diverse, including several Randall's snappers (as deep as 476 m—a depth range extension) and two large groupers. The octocoral fauna was very diverse, including a (sampled) bamboo coral that appeared to be different from any described genera. Echinoderms included many *Coronaster* sp. sea stars, unusual long-spined urchins, and basket stars. A biological sample was taken of a demosponge (possibly a petrosiid haplosclerid).

Dive 09, on Daikoku Seamount, was previously surveyed in 2004-2006. The data collected showed active hydrothermal venting near the summit, and pools of molten sulfur surrounded by dense chemosynthetic communities, including a new species of flatfish. In 2014, the seamount was apparently erupting (based on high hydrogen in CTD water samples over the summit), but the expedition was unable to make a dive there to confirm. However, a repeat multibeam bathymetric survey of the summit showed a large new crater. Dive 09 hoped to investigate whether the sulfur pond and flatfish communities still exist, to explore the new crater and its surroundings, to search for evidence that an eruption indeed occurred in 2014, and to assess the impacts of these changes on the local chemosynthetic ecosystem. The upper northwest flank seafloor of Daikoku Seamount exposed large broken blocks of what appeared to be consolidated volcaniclastics. The ROV had to reposition out of the thick plume of sulfur "smoke" that made visibility impossible for maneuvering. After resettling at ~410 m, the seafloor was covered with volcanic ash and lapilli-sized (pea- to grape-sized) volcaniclastics, sulfur splatter covered with bacterial mats, blebs of sulfur with trailing threads, and a general white patina of sulfur with bacterial mat. Where patches of darker ash were uncovered, there were abundant tongue fish. Up the slope to the southeast, the team encountered a plume, which had been mapped over the previous two days. The plume was centered above a small crater near the rim, where there were bubbles of CO_2 gas and sulfur "smoke" emanating from a series of small depressions, some of which were surrounded by encrustations of solid sulfur stained by dark minerals. A rock was collected here from a part of the crust. Moving along a contour to the south, the slope was covered mostly with ash and small volcaniclastic fragments. Tongue fish (*Symphurus thermophilus*) were almost everywhere. The "yunohana" crab (*Gandalfus yunohana*) was also present. Near the summit crater, the rim fell away into nearly vertical outcrops of the bacterially-encrusted volcaniclastics. Around the rim of the crater, there were barnacles with "fuzzy" cirri underneath overhangs of the rocks. Tube worms (*Lamellibrachia sp.*) and anemones (never before reported from this site) were present. The scarps had numerous fractures. At the bottom of the crater, there were angular cobbles and boulders, as well as some irregular-shaped pieces of solid sulfur. One rock was recovered. Toward the northern part of the crater, there were numerous plumes of sulfur and CO_2 bubbles emanating from cracks, orifices, and diffuse regions along the lower wall of the crater. At the end of the dive, midwater transects were conducted (see section 6.1.8).

6.1.4 Forearc Scarps (Dives 10, 14, and 15)

These three dives on the forearc scarps all began on what appeared to be talus (broken rock fragments) slopes, with varying degrees of sediment covering. Outcrops were present on all dives, although outcropping on Dives 10 and 15 appeared to be sedimentary, while there was columnar jointing on Dive 14, which is suggestive of volcanic rock. Carnivorous sponges were observed on all three dives.

"Stegosaurus Ridge"

Dive 10 explored "Stegosaurus Ridge" in the Trench Unit of the Monument, assessing a newly discovered steep ridge feature—to the west of the Mariana Trench axis and on the eastern edge of the overriding Philippine Sea Plate—that was mapped during EX-16-05 Leg 2. This dive examined the architecture of the forearc region between the trench and the active volcanic arc at shallower depths than the inner trench wall, an area thought likely to be inhabited by deep-sea corals and sponges. This was the only feature to have similar characteristics to previously studied coral habitats within the Trench Unit that also represented uncharacterized Monument habitat. The ROV landed on a talus slope and rose up the eastern face of the ridge.Vertical or near vertical outcrops of dark fractured rock—with both vertical and horizontal fractures and a rough blocky surface made up this layered accumulation of sediment. Contorted bedding in the light sediment in this area was reminiscent of turbidite flow channeling. Pebble-sized, sub-rounded, volcaniclastic fragments were present. The seafloor at the top of the ridge was covered with mostly fine to coarse sediment and pebble-sized, sub-rounded rock fragments, as well as some flattened cobbles and large boulders. Interestingly, only some of the rocks had a dark (MnO) coating. The team had anticipated that volcanic sequences might be revealed, but the dive was surprising in that it only exposed sedimentary sequences, which was consistent with what was observed during Deep Sea Drilling Program Leg 60 (http://deepseadrilling.org/60/dsdp_toc.htm, last accessed August 27, 2020), in which a drill hole—at 18°N, at about the same distance from the trench—recovered hundreds of meters of forearc sediments. The slope was surprisingly sparse in sponges and octocorals; however, hydroids, stalked barnacles, and representatives of each class of echinoderms were present (including a "mudstar"). Several individuals of the hexactinellid sponge, *Semperella* sp., were observed; a sample was collected. At least three different species of carnivorous (cladorhizid) demosponges were observed. Perhaps the biggest surprise was a baby bamboo coral at the top of the ridge; while it was still too young to see the characteristic segmented "stalk" sclerites in the tissue of the four small polyps were visible.

"Explorer Ridge"

Dives 14 and 15 at "Explorer Ridge" examined this east-west trending feature about 80 km east of the active volcanic arc, and presented an opportunity to explore the internal architecture of the forearc region. The inner part of the forearc region east of the volcanoes in the Islands Unit of the MTMNM had never been studied previously. The region was mapped during EX-16-05 Leg 2 and revealed a complex series of faulted blocks down-dropping to the south along steep scarps (walls) and forming a "graben" that is bounded to the south by a set of fault blocks that are down-dropping to the north. These dives were on the south-facing fault scarps; Dive 14 was on the deeper scarp and Dive 15 was on the shallower one.

Dive 14 ascended the deeper, fault-controlled scarp. Most of the beginning of the dive was on what appeared to be a steep talus slope covered by sediment. The talus pile had occasional chutes (large or small furrows), likely caused by debris moving downslope and eroding the surface of the pile, some of which contained rocks that varied in size from pebbles to boulders. A well-indurated (hardened) siltstone rock was collected; the sediment adhering to it showed many fragments of foraminiferal tests, a green olivine grain, cleavage fragments of the minerals plagioclase-feldspar and pyroxene, and a lot of black volcanic glass fragments—all enclosed in fine clay-sized particles, which are common components of forearc sediment (volcanic ash and pelagic sediment). Higher up the slope, outcrops were present. One small (~1-m-thick) outcropping appeared to have columnar jointing (suggesting volcanic rock), while other exposed rock surfaces were rough (rubbly) and dusted with fine sediment. At 2,318 m, there was an interesting hard surface, very lightly dusted with sediment, that had linear scratch marks running downslope. At 2,253 m a definite outcropping of blocky rocks with columnar jointing (fractures) was exposed in cross-section, the joints were diving into the face of the wall. This extended nearly 25 m upward until a smooth, nearly vertical wall was present for the remainder of the dive. An aphyonid fish was documented on this dive; according to the experts, this is the first time that a fish in this family has ever been seen alive. Other findings included a benthic-sweeper black coral (*Schizopathes* sp.), tiny polynoid polychaetes riding on elasipod holothurians, mounds of possibly echiuran feeding traces, *Paleodictyon nodosum* burrows, a tripod fish (*Ipnops* sp.), carnivorous sponges, hexactinellid sponges, and bamboo corals.

Dive 15 started on a pile of talus on the shallower fault-controlled scarp above and slightly to the west of the Dive 14 location. The talus pile was sediment-covered on the left side of the field of view and entirely comprised of sub-angular boulders on the right side. Near the base of a steep outcrop of angular fractured rock, a sample of layered sedimentary rock was collected. The entire dive consisted of multiple layers of sedimentary sequences that changed in texture and degree of fracturing. Faulted layers with normal faults (upper rocks having slid down the fault faces) were near the top of the wall, and there appeared to be a decrease in the degree of induration (hardening) of the sediment layers as the ROV rose up the scarp. Near the top of the scarp, the layers were very thin and had crumbled into slabs that lay on a more heavily sedimented surface. Corals were common on this dive, the most abundant taxa were chrysogorgiid octocorals and antipatharians; two corals (*Chrysogorgia* sp. and *Stauropathes* sp.) were collected.r *Metallogorgia* sp. were especially abundant—along with the associated brittlestar, *Ophiocreas oedipus*. Other cnidarians observed included *Iridigorgia* sp., a lyrate bamboo coral(likely a range extension), "rock pens," and sea pens (*Umbellula* sp.). Other observations included an isopod (likely a *Thylakogaster* sp.), small carnivorous sponges, several species of hexactinellids, thinly encrusting demosponges (white and blue), and some more lobate species on a large piece of debris (potentially a part of a boat). There were not many fishes on this dive; those documented included a sorcerer eel, a halosaur, and a rattail (*Kumba sp.*).

6.1.5 Forearc Mud Volcanoes (Dives 11, 12, and 13)

Three seamounts in the northern Mariana forearc (the 200-km-wide region between the Mariana Trench axis and the active volcanoes of the island arc) were targeted for dives on this leg of the expedition. These edifices were mapped on EX-16-05 Leg 2 and found to be similar in morphology to mud volcanoes well-known in the southern Mariana forearc region, south of 18°N. The mud volcanoes are important because they provide windows into processes active along the boundary between the subducting Pacific Plate and the overriding Philippine Sea Plate. At the collision zone between these two tectonic plates, large earthquakes occur that can result in devastating tsunamis. The mud volcanoes occur where deep faults in the forearc intersect the contact region between the two plates (Fryer, 1992). When earthquakes occur on these forearc faults, movement along the faults forms fault gouge (ground-up rock fragments). When this gouge mixes with fluids squeezed out of (or "distilled") from the subducting Pacific Plate—by increases in temperature and pressure as it descends—the fluid reacts with the gouge and mobilizes it. The mixture rises because the fluids hydrate the gouge, changing its composition and making it lighter than the surrounding rock. Thus, the "mud" mixture of fluid and gouge rises to the seafloor and erupts as mudflows (Fryer et al, 2020). Over millions of years, these actions produce enormous volcanoes of mud, mostly (~95%) composed of gouge derived from hydrated mantle rock (peridotite hydrated to "serpentine") Fryer, 2012). This process permits scientists to determine the physical and compositional characteristics of the zone of earthquake genesis along the contact between the subducting and overriding plates, and to assess the degree to which the constituents of the subducting plate are recycled into the deep mantle.

Dive 11, on the informally named "Northern Forearc Ridge" approached the seafloor at ~4,422 m on a steep wall of highly fractured, pale-brown to pale-gray rock. The slope had a series of ridges with narrow channels between them. The face of the wall was cut by numerous thin white veins snaking across the exposed surface at a variety of angles. A mafic, medium-grained rock in the wall was collected. The ridge was ~20 to 30 m wide, although the width was quite variable, narrowing to "knife-edged" in some places. Small patches of red staining were present in one location on the wall, while at a shallower depth there was a distinct white layer, roughly 20 to 30 cm thick, containing pebbles and cobbles that covered the top of the ridge. The entire eastern-facing wall of the ridge was intermittently covered with talus and/or finer unconsolidated sediment. Along the ridge crest, down the side of the ridge wall, was a steep face with layers of varying thicknesses of clay-like sequences interlayered with darker, brown sediments. The biology was sparse; very few benthic (or even midwater) organisms were observed, including a few squat lobsters, a tiny stalked crinoid and a comatulid (unstalked) crinoid with long cirri (both likely new species), two species of sponges—one hexactinellid and one demosponge (both new species), pelagic polychaetes, cusk eels, an anemone living on a pagurid crab, and a shrimp with very long antennae with attached leeches. This paucity prompted a discussion about the potential scarcity of food.

Dive 12 was on an unnamed forearc seamount, which was the site of a previously sampled serpentinite mud volcano. At a depth of 3,315 m, the sedimented seafloor had a scattering of numerous small pebbles and a few patches of larger cobble-to boulder-sized rocks. There were numerous small, white, rounded specks that were likely foraminiferal tests scattered among the sediments and pebbles. The seafloor surface was very similar throughout most of the dive. In some areas, however, there were clusters of cobbles and boulders resting on the flat seafloor. A highly- serpentinized block, likely peridotite (mantle), rock sample was collected . Near the end of the dive, in another cluster, a second, also highly serpentinized, likely mantle rock sample was collected. No active spring sites were visible to the team on this mud volcano, and the degree of sedimentation on the seamount suggested that it has not been active for a long time, but blocks of serpentinized mantle rocks were exposed on the surface. A number of furrows were present and there was some speculation that these were made by some deep-diving marine animal., Observed organisms included xenophyophores, holothurians, small unusual urchins, brittle stars, a pregnant mysid shrimp hanging onto a glass sponge spicule stalk, numerous pairs of *Relicanthus* sp. (one of which was collected) attached to the spicule stalk of a Caulophacidae hexactinellid sponge. and a benthic ctenophore on a sponge stalk. The few fish observed were all cusk eels, but it is possible that one with an unusual scaly head is a new species.

Dive 13 examined a seamount informally named "Twin Peaks" that had two prominent summits; this dive explored the southwestern, more conical one. The seafloor at the beginning of the dive, at ~4,839 m, was a nearly featureless, sedimented bottom made of very small, pale-brown particles. The sediment was clay-like, and there were fewer of the tiny, white foraminifera "tests" (shells) here than were observed on Dive 12, which could be due to the increased depth of this dive.The dive track was nearly due north, and slabby exposures of mantled rock with a black (likely MnO) coating were aligned in linear rows parallel to one another. At the base of some of the slabs, there was an exposure of a pale-tan to yellow-orange surface with a rough, rubbly texture. There were also a few large boulders of similar material associated with the linear outcrops. A medium-brown, loosely consolidated sedimentary ,rock was collected at the base of a linear outcropping. A similar rock was recovered near the end of the dive on the summit of the seamount. The seafloor remained thickly sedimented throughout most of the dive. Based on the prevalence of the small outcroppings of sedimentary rocks throughout the dive, it is unlikely that the seamount is a mud volcano; it appeared to be a fault block of forearc sedimentary sequences. One of the more obvious and common features in the sediment was the large spiral tracks made by acorn worms. Organisms observed included swimming holothurians, a shrimp with pincers that were modified for suspension feeding, long-legged isopods, quite a few crabs with commensal anemones, many "pregnant" mysids attached to the stalks of glass sponges (Caulophacidae), at least four different species of carnivorous sponges (one was collected that was similar to *Chondrocladia lyra*), and several deep-sea lizardfish (*Bathysaurus* cf. *molis*).

6.1.6 The Large Pacific Plate Guyots (Dives 16, 17, 19, and 20)

East of the Mariana Trench within the U.S. EEZ, resides a number of large (100-km-diameter) flat-topped, ancient undersea volcanoes, called guyots. These ancient volcanoes are now considered seamounts, formed during the Cretaceous geologic period between 120 and 80 million years ago. At that time, the area of the Pacific Ocean where these volcanoes formed was shallower than today, in part because of an updoming of the lithosphere caused by a localized thermal anomaly from the mantle beneath this part of the Pacific. Over time, the exposed part of these seamounts eroded, creating the flat-topped features seen today.

The guyots surveyed during EX-16-05 Leg 3 fall within the Prime Crust Zone (PCZ), an area of the Pacific with the highest concentration of commercially valuable deep-sea minerals (Hein, 2002). As part of the overarching CAPSTONE efforts, NOAA targeted ridge tops and summit margins of guyots to better understand the communities that occur on these manganese (Mn)-encrusted habitats. Dives 16 and 20 investigated a different portion of the geologic history of two subducting Cretaceous guyots. This period in Earth's history had a very warm climate, which is attributed to the intense volcanic activity resulting in warmer seas, which then promoted a vigorous growth of reef communities. One of the goals of these four dives on the guyots was to explore the exposure of millions of years of Cretaceous reef growth. Dives 17 and 19 were chosen, in part, to examine the occurrence and habitats related to Mn crust deposits on the flanks of Fryer and Vogt Guyots. These crusts are sources of important metals and elements with a high economic value, but there remains a poor understanding of what living resources and organisms are associated with these areas.

Subducting Guyots

As two of the expedition's deeper dives, Dive 16 explored "Subducting Guyot 1" at a maximum depth of 5,005 m, while Dive 20 on "Subducting Guyot 2" reached a maximum depth of 4,438 m. Both dives encountered Mn-crusted rock, although it was observed that the Mn crusting at the Dive 20 location was thin. Neither location had abundant fauna, and it was hypothesized that this may have had to do with limited food availability at this depth range, or perhaps it was due to the substrate, as the deeper fauna may not prefer to settle on carbonate. Of the organisms observed at the Dive 20 site, it was noted that many of those documented could be novel observations (e.g., species, depths, records, etc).

Dive 16 addressed both the expedition and CAPSTONE objective to explore the Pacific Plate Seamounts as well as gain a better understanding of what was thought to be exposures of millions of years of Cretaceous reef growth. The dive site chosen was on a nearly vertical fault scarp that cut through a ridge on part of a Pacific Plate seamount close to the Mariana Trench. The steep bathymetry data indicated this area was a likely place to view the sequences of reef growth through time. Samples were collected at the start of the dive that had elongated shell fragments in a white carbonate matrix.The wall revealed a fascinating sequence of layered accumulations of varying texture and fossil types. Bivalve fossils dominated the darker layers and were generally thinner than the more massive white layers between. Further up the wall, an offset in the layers was overtopped by continuous lineation of horizontal layers, which indicated an unconformity, or hiatus, in deposition of the upper layer after a faulting event. At the shallower elevations of the wall, distinct vertical ridges with chutes between them gave the wall a unique texture and variation in structure, with dark, bivalve-rich, more resistant layers and the thin, vertical outcrops and gently sloping "steps" composed of white, less-resistant layers. Two additional rock samples were collected, one about halfway through the dive that was a single coiled fossil, and another near the end of the dive that was a boulder-sized limestone from one of the bivalve layers. In addition to the fossils, observed animals included one fish, a few shrimp, a couple of anemones, and a possible carnivorous sponge. When the deepwater portion of the dive was completed, the team began midwater exploration; more information can be found in Section 6.1.8.

Dive 20 started out on a talus slope with enormous boulders that were present for the entire beginning half of the dive. Many were "massive" in terms of texture, but some were breccias with rock fragments embedded in an enclosing matrix. On some boulders, the matrix looked sheared and were likely composed of fault gouge (rock that is ground up between the faces of a fault trace when movement on the fault takes place at greater depth), while others looked more sedimentary, which may indicate a shallower fault gouge (brittle ductile transition does occur in deep-penetrating faults). An angular pillow rock fragment—with a glassy surface and only a thin MnO coating—was collected. On the second half of the dive, the steep wall had many fractures and was cut by near vertical, columnar-jointed, side-by-side dikes. Much of the exposed rock surface only had a thin MnO coating; however, in some places, the MnO had been removed—presumably by collision with falling boulders. The exposed rock underneath was a lighter color. At the top of the wall, the entire sedimentary sequence looked to be only a couple of meters thick, while the uppermost surface sediment was only about 20 cm thick and ripple-marked. The non-abundant fauna included a hexactinellid sponge, several unusual glass sponges, one huge bamboo coral (a small portion of this was collected), arthropods, brisingid sea stars, crinoids, holothurians, a hooded sea slug (Nudibranchia), and an undescribed species of eelpout (*Pachycara* sp.).

Guyots

Dive 17 on Fryer Guyot, to a depth of 2128.6 m, and Dive 19 on Vogt Guyot, to a depth of 1944.6 m, both focused on the Mn crust and habitat. While Mn crust was present at both sites, there were different geological and biological observations in these two locations. The Mn coating appeared more botryoidal (shaped like grape clusters) on the Fryer Guyot site than on the Vogt Guyot site, while the fauna abundance and diversity was more prevalent on the Vogt Guyot site than the Fryer Guyot site.

Dive 17 began in front of a boulder that permitted to conduct close-up observations of the crust and make a rough estimate regarding its thickness, which varied between 7 and 10 cm. Many boulders at the beginning of the dive were covered with a thick MnO crust, botryoidal in texture, which appeared to cement them to the seafloor and one another. There were scattered clumps of boulder- to cobble-sized, Mn-crusted rocks set among ripple-marked sediment ponds along the track for most of the dive. The slope alternated between steep and relatively flat; layering was only observed once. There was a ~60 m fault scarp on the flat part of the guyot surface above and to the south of the dive track. Short, vertical stumps, as well as long, broken stalks of dead hexactinellid sponges—coated with MnO —suggested that the sundering of the northern half of the plateau above the dive track may have affected the environment of the slope for any animals living there. Thelarger, barrel-shaped, Mn-encrusted forms stumped the team; some team members wondered if these ancient barrel sponges were from a much shallower environment. Bubblegum coral (Paragorgiidae) was observed throughout the dive, as were numerous species of antipatharians, chyrsogorgiids, primnoids, isidids (including the lyrate bamboos that are a new genus), and some rare sightings of sea pens. Some bamboo corals appeared to be partially eaten, and one of their predators—an aplacophoran—was observed eating its way up a bamboo coral stalk; the pair were collected. A sample was also collected of a cnidarian (either an anemone or a zoanthid) living within a hexactinellid sponge (possibly *Tretopleura* sp.). Other observed organisms included giant tunicates, brittlestars (mostly on octocorals), crinoids, holothurians, sea stars (including a brisingid growing 4 new arms), halosaurs, and cusk eels.

Dive 19 on Vogt Seamount was planned to document biodiversity at a site that might be a target for deep-sea mining activities. On this site, Mn-crusted boulders with a thin sediment cover were prevalent. The large lumps of rounded blocks and boulders were typical for seafloor surfaces covered with a heavy MnO crust, although the surface of the Mn coating was apparently not as thick as the team had observed elsewhere. Some large boulders, unattached to the lumpy surface, were heavily populated with sponges, corals, and crinoids along the track. Up the slope, there were sediment patches covered with small manganese nodules; the larger ones were suggestive of piles of talus beneath the Mn coating. Small vertical steps (~ 1.5 m high) were near the edge of the steep wall and toward the edge of the steepest part of a nearly vertical fault scarp, there were numerous fractures in the seafloor that paralleled the edge of the scarp. At the top edge of the scarp, the seafloor dropped away precipitously, and a few thick MnO ledges projected out over the edge of the wall; some exposures of light-colored (suggestive of reef material) outcropping sequences beneath the FeMn coating were visible. However, fossil shapes did not appear to be preserved in the wall. Some fractures toward the end point of the dive had caused separations of a meter or more between blocks of the wall itself, and provided a variety of surfaces for a rich diversity of fauna to take hold and flourish. This dive had high abundance and diversity of both cnidarians (primnoids, isidids, chryosogorgiids, plexaurids, coralliids, and antipatharians, as well as cup corals, zoanthids, and hydrozoans) and sponges (mostly hexactinellids including pheronematids, *Tretopleura* sp., and euplectellids). Many MnOencrusted stalks of dead sponges were present; based on the abundance of *Walteria* cf. *leuckarti* at this site, it is possible that these stalks were the remains of that species. The density and variability of organisms increased closer to the edge, perhaps these organisms were better able to survive in the stronger currents. Both the corals and sponges were very large in size, including gigantic bamboo corals (possibly *Eknomisis* n. sp. and the relatively smaller ?*Isidella* n. sp.) and 1- to 2 m diameter *Poliopogon* sp. sponges (also a new species). Few fish were observed.

6.1.7. "Petite-Spot Volcano" (Dive 18)

The dive on "Petite-Spot Volcano" was chosen to address the possibility that a small (1 km in diameter and 141 m high) and geologically young volcanic edifice, located on one of the fractures in the Pacific Plate, formed as the plate bent prior to subduction. Small, young (1 to 5 My old) volcanoes have been discovered east of the Japan Trench. Such occurrences may be a common feature of subducting plates as they near the trench axis. This dive started at 5,692 m on a sedimented surface with numerous subangular to angular rocks scattered on the surface; an angular rock with a thin coating of MnO crust was collected. This igneous rock likely had a shorter period of seawater exposure than the thickly-encrusted rocks on the large guyots nearby and may give a good radiometric age. Further up the slope, many large, angular blocks had a thin MnO coating and the areas of sedimented seafloor also had pebble- and cobble-sized rocks scattered over the surface, suggesting that the rocks were recently (geologically) deposited there. A second rock was collected from a large, broken boulder. Some white staining (possibly hydrothermal) was observed on the rocks at 5,848 m. Other observed rocks looked platy. Some larger boulders had portions of their surfaces more heavily coated with MnO. Tongues of talus, mainly cobble-sized, and smaller rock fragments were seen toward the upper flank of the edifice; much of this material showed white staining and thin white veins in interstices between the rubble. About 30 m from the summit were layered, graded beds that included pebble-sized angular fragments (possibly volcaniclastic deposits in ash layers). During an attempt to collect a rock sample from this location, the rock crumbled in the ROV manipulator arm. A different sedimentary rock (possibly volcaniclastic) from the same area, that appeared to be a partially indurated sedimentary rock with a thin MnO coating, was collected. Many of the animals documented on this dive were mobile fauna, with the exception of some carnivorous (likely new records) and hexactinellid (including a lavender Corbitellinae) sponges, a few anemones, some tube-dwelling polychaetes, a scaleworm, and a translucent holothurian. Other documented organisms included a brisingid sea star with parasites (gastropods and perhaps barnacles), abyssopelagic crustaceans (mysids, shrimp, and long-legged isopods), polynoid polychaetes, a chaetognath (possibly a new depth record), cusk eels (including a *Penopus* sp., possibly a new depth record), and an acorn worm (possibly a new depth record). Midwater transects were conducted at the end of the dive, see Section 6.1.8.

6.1.8 Exploring the Water Column (Dives 03, 09, 16, and 18)

Despite being the largest biome on earth, the water column remains one of the most poorly explored regions throughout the globe, especially in remote parts of the ocean such as the Mariana Islands. EX-16-05 Leg 3 presented a unique opportunity to conduct midwater exploration in this critical region. During the cruise, the team investigated water masses above seamounts and an active hydrothermal vent, developing what is perhaps the first characterization of these sites. At the four sites selected for midwater exploration, nature presented interesting and diverse assemblages of organisms living in unique and unexplored environments. In some instances, these were the first occasions humans were able to image this realm. As exploration of the midwater biome continues, the development of an ecological understanding emerges as a future goal.

Maug Volcano (Dive 03)

The water column surrounding the Maug Volcano is protected within the MTMNM. This was the first midwater exploration of this kind at this location; a single transect was conducted at 340 m to target the deep scattering layer observed in the EK60 sonars. The team encountered numerous chaetognaths, a solitary salp, a polychaete (Tomopteridae), and two siphonophores: a physonect (Physonectae), and a calycophoran (Calycophorae). Several copepods were visible with the HD cameras.

In addition, observations of Cestid ctenophores (Phylum Ctenophora: Class Tentaculata: Order Cestida) captivated the team. Ctene rows in this unusual ctenophore body plan form two rows along the trailing edge of its wing-like body. During the dive, animals were observed exhibiting both population modes known for these ctenophores—the typical slow propulsion mode and the faster escape propulsion mode (Matsumoto, 1991; Stretch, 1982).

While the primary objective was to discover what fauna were present in the midwater, the team glimpsed into some aspects of the trophic ecology present in this system. For example, Cestid ctenophores suggest the presence of small copepods (Haddock, 2007). The presence of chaetognaths support the potential for copepod prey.

Daikoku Seamount (Dive 09)

The objective of the midwater portion of the Daikoku Seamount hydrothermal vent site was to explore the water column macrofauna associated with the vent plume. Little is known about the associations between hydrothermal fluids and pelagic animals (Levin et al., 2016). The team was interested to see if there was any evidence of an association (or avoidance) of animals, either within or at the edge of the Daikoku plume, which extended from the seafloor at 408 m to approximately 350 m. Nine short (10-15 m), vertically-stacked transects were conducted through the plume at depths from 2 m above the seafloor to 275 m depth. Within the plume, there was high turbulence and particulate concentrations, presumably from the hydrothermal venting. Almost no visible life within this plume was observed; it was speculated that this could be a result of either high turbulence or toxicity of hydrothermal vent fluids and/or associated particles. In contrast, numerous organisms were observed at the plume's edge, including salps, siphonophores, chaetognaths, larvaceans, and an abundant amphipod aggregation coincident with a peak in acoustic backscatter observed with a Simrad EK60 echosounder (Burd & Thomson, 1994). As part of the MTMNM, understanding the role of the hydrothermal vents on surrounding productivity is essential to understanding the ecosystem of these protected regions.

"Subducting Guyot 1" (Dive 16) and "PetiteSpot Volcano" (Dive 18)
At "Subducting Guyot 1", six 10-minute transects were conducted at large depth intervals, ranging between 800-4,000 m. The final set of transects were conducted at "Petite Spot Volcano" where the vehicles conducted 10-minute transects at 100-meter intervals between depths of 800-1,200 m. The fauna near the "Maug" volcano, as well as the fauna over the "Petite-Spot Volcano" and "Subducting Guyot 1", indicated diverse midwater communities. Numerous medusae were observed during these last two midwater dives including coronate scyphomedusae, narcomedusae, and trachymedusae. It was interesting that an assortment of body forms, and their associated assortment of foraging strategies, were found within the limited volume of these dives. Some observations suggest an ambush foraging mode, while other species observed suggest predation while on the move. The different types of gelatinous animals give us a sense of the potential complexity of the food web dynamics that might be occurring in these little-known habitats.

6.1.8 Underwater Cultural Heritage (Dive 22)

Between 1941 and 1945, U.S. and Japanese forces confronted each other across many remote Pacific locations. Physical remains of WWII are found on the islands, atolls, and underwater, which now contains an extensive archaeological record. Dive 22, on the site informally called "Romeo and Juliet" investigated two sonar anomalies near Tinian Island and discovered the first of a collection of a dozen U.S. B-29 Superfortresses lost in the area while flying missions against Japan during WWII. The sites represent the final stages of the war, a historically significant time in U.S. history

Tinian Island, located in the Northern Mariana Islands, was captured in August 1944 and became one of the largest air bases in the world. In November 1944, the U.S. Twentieth Air Force initiated strategic bombing of Japan from Tinian Island using the B-29 Superfortress. The new aircraft featured many advanced technologies, including pressurized cabin space, making it capable of long-range missions—often traveling more than 3,000 miles round trip. With a wingspan measuring just over 141 feet, the B-29 was one of the largest aircraft flown by the U.S. in WWII. Between late 1944 and to the end of 1945, several B-29s flying from Tinian Island's North Field, and from fields on Saipan, suffered mechanical difficulties or other problems, ultimately crashing in the channel (J. Mayer, pers. comm.).

The deep floor of the Saipan Channel, where many of the crashes reportedly occurred, is characterized by strong tidal currents and a relatively flat and sandy bottom ranging in depth from 350 to 400 m. Several nondescript sonar anomalies found in this area correspond to the expected signature of fragmented aircraft wreckage. Missing Air Crew Reports for aircraft lost in this area describe how most of the planes broke apart or even exploded (Missing Air Crew Reports).

One anomaly with relatively high backscatter became the subject for closer investigation (G. Fabian, pers. comm. 2016). As the ROV reached the seafloor, a ghostly reminder of WWII quickly came into view when the wing and engines of a B-29 Superfortress were revealed. The wing assembly was upside-down with the landing gear retracted. Three of the four radial engines were still mounted. Debris was observed aft of the wing, likely associated with the fuselage, and contained a parachute, oxygen cylinder, and the fourth engine. Following a debris trail northeast for several hundred meters led to the discovery of the forward gun turret and part of the flight engineer’s station. On the B-29, both features were located forward of the wing. The search for debris ended with the discovery of the tail’s horizontal stabilizer. The debris field was strewn along a roughly linear 500-m long path.

The aircraft broke apart, perhaps caused by an explosion when airborne, but more likely, as indicated by the length of the debris field, on contact with the water, either during an attempt to ditch or a crash. A final determination as to the identity of the aircraft remains unknown as there were several potential candidates.

6.2 Mapping Summary

Mapping Statistics

Dates	6/17/16 - 7/10/16
Line kilometers of survey	4,878
Square kilometers mapped	27,764
Number / Data Volume of EM 302 raw bathymetric / bottom backscatter multibeam files	369 files / 21.2 GB
Number / Data Volume of EM 302 water column multibeam files	369 files / 82 GB
Number / Data Volume of EK60 water column single beam files	480 files / 33.7 GB
Number / Data Volume of subbottom sonar files	409 files / 3.89 GB
Number of XBT casts	48
Number of CTD casts (including test casts)	0

Beginning draft	Forward: 15'3"; Aft: 14'0"
Ending draft	Forward: 14'4"; Aft: 14'3"

Background data used to guide this expedition's exploration mapping included multibeam data collected on previous NOAA Ship *Okeanos Explorer* cruises, R/V *Falkor* expeditions, the Extended Continental Shelf (ECS) project, and Sandwell and Smith satellite altimetry bathymetric data. Some dive planning was conducted using bathymetry grids created by using all available bathymetry achieved with NCEI and using NCEI's AutoGrid online tool.

Mapping operations were conducted whenever the ROV was on deck, and included overnight transit mapping. Lines were planned to maximize bathymetry coverage and to optimize potential discoveries. The expedition shiptrack is shown in **Figure 4**. Long transits were completed at the beginning and end of the cruise. Clustering of ROV dive sites in the middle of the cruise enabled focused survey operations in several priority areas within, and adjacent to, the MTMNM (within both the Trench and Islands Units—see Fig. 2).

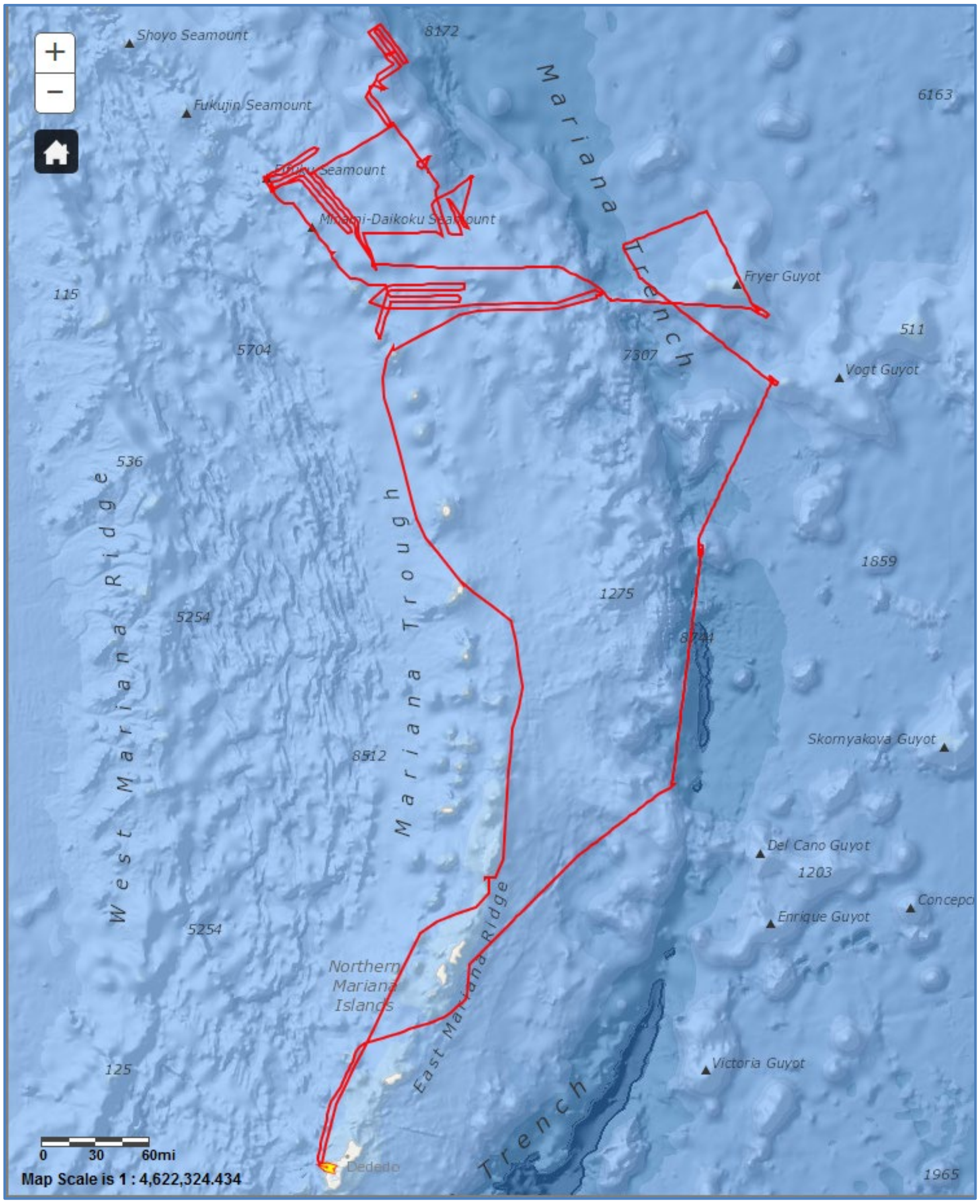

Figure 4. *Shiptrack of NOAA Ship* Okeanos Explorer *during EX-16-05 Leg 3. Map generated by the Okeanos Explorer Atlas online mapping service, maintained by the National Center for Environmental Information (NCEI). Beginning and ending port was in Santa Rita, Guam.*

During normal mapping operations, data were collected with the EM 302, EK60s, and subbottom profiler. During daytime ROV operations, the 38 and 300 kHz ADCPs were turned on to provide information on currents in the vicinity of the dive site. EK60s were also run on several dives where midwater exploration transits with the ROVs were conducted (**Figure 5**).

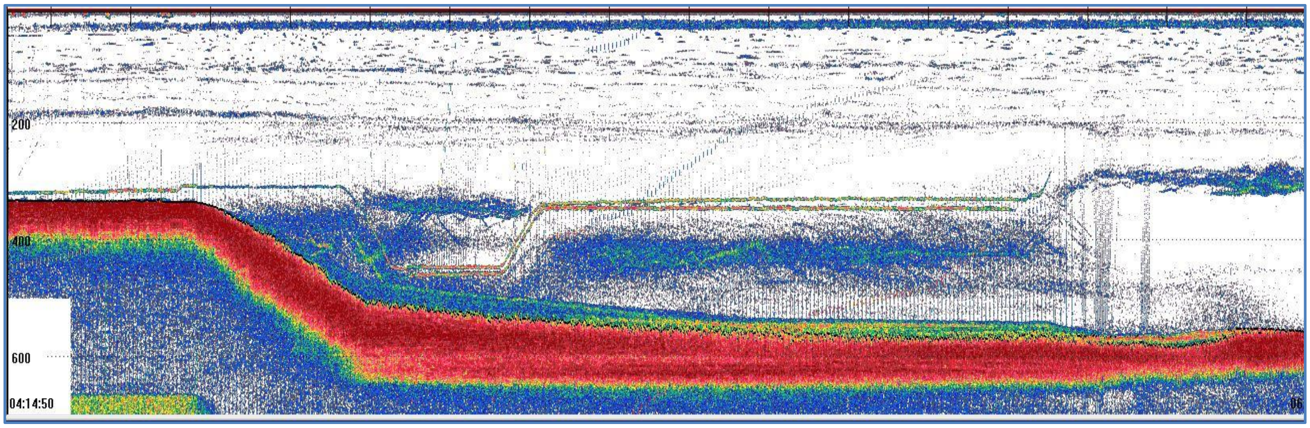

Figure 5. *EK60 18 kHz echogram from the Maug ROV dive site showing apparent avoidance by organisms to the presence of the ROVs. Red area is the seafloor. Solid lines in the water column represent the dual-body ROVs conducting transects.*

The ROV dive site at Daikoku Seamount had active hydrothermal vents at a depth of 410 m. Prior to the dive, two lines of sonar data were collected over the summit of the volcano. Data were analyzed for signs of bubble plumes, since this site had previously been documented to release CO_2 bubbles associated with sulfur pools (OER-funded *Submarine Ring of Fire 2014–Ironman* expedition). EK60 and EM 302 water column data clearly showed the bubble plume (**Figure 6 and 7**). The active bubble plumes were well documented with video footage during the ROV dive at this site (**Figure 8**).

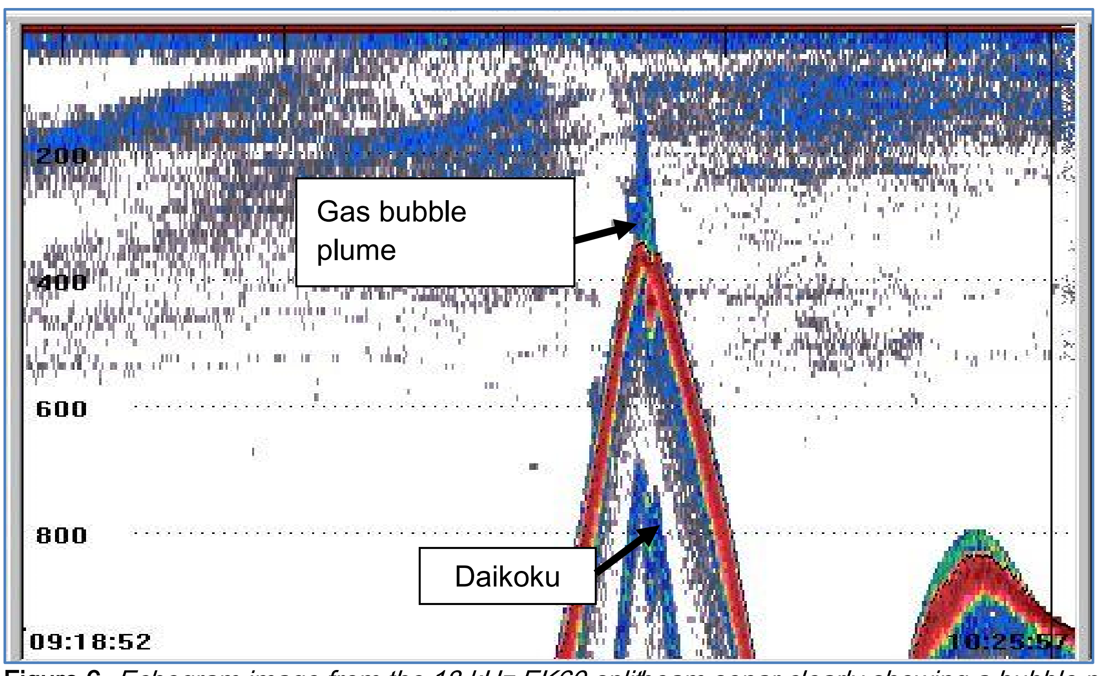

Figure 6. *Echogram image from the 18 kHz EK60 split-beam sonar clearly showing a bubble plume emanating from near the summit of Daikoku Seamount. The red color represents the seafloor, while blue represents strong sound scatterers in the water column.*

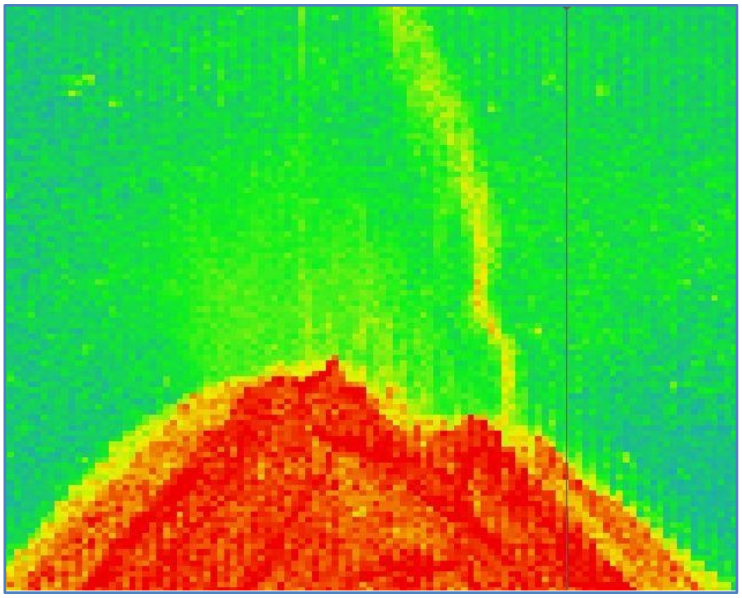

Figure 7. *Image showing EM 302 mulitibeam water column data processed with QPS Fledermaus Midwater software showing the bubble plume (yellow) coming from an areabelow the summit of Daikoku Seamount (red feature). Data processing and imagery by Jason Meyer.*

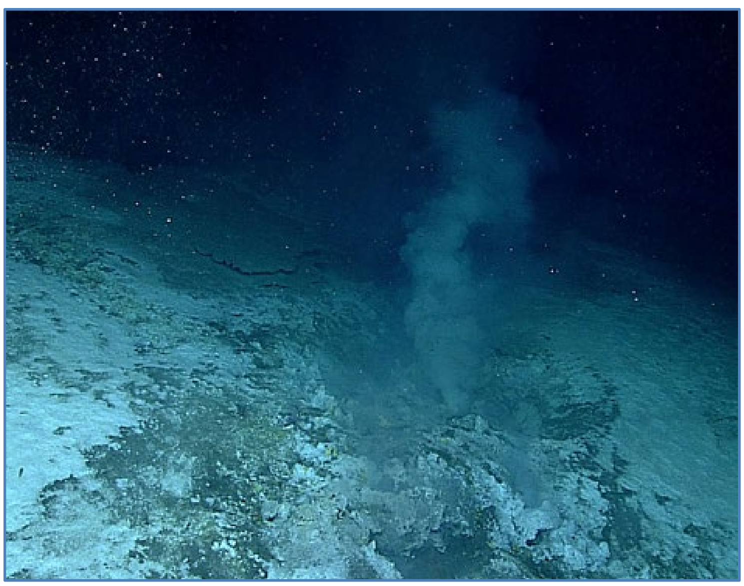

Figure 8. *Example image from ROV* Deep Discoverer *showing one of many sources of bubble and fluid expulsion from the seafloor in the vicinity of the Daikoku Seamount sulfur pools at approximately 410 m depth.*

Closer to Tinian Island and Saipan, focused surveys were conducted nearshore in support of UCH assessment work. The ROV dive completed in this area discovered a B-29 Superfortress resting upside-down on the seafloor. This is the first B-29 crash site found of over a dozen U.S. B-29s that were lost in the area while flying missions during WWII.

Figures **9, 10**, and **11** depict areas of focused mapping during EX-16-05 Leg 3. At "Explorer Ridge" (**Figure 9)**, a focused mapping survey complemented survey coverage collected during EX-16-05 Leg 2 and highlighted the extensive distinct fault patterns in the seafloor of the area. Two ROV dives (Dives 15 and 16) further explored the exposed fault features and collected rock samples to provide additional geological information about the area. At Eifuku (Dive 8) and Daikoku (Dive 9) Seamounts new data revealed distinct fault patterns in the seafloor of the area **(Figure 10**). Mapping data (**Figure 7)** collected over Daikoku Seamount confirmed the presence of an active bubble blume in both the EM302 and EK60 data. Additionally, new multibeam data and in situ exploration (**Figure 8)** confirmed that the seafloor near the summit of Daikoku Seamount had changed since the last mapping survey, and analysis of water column data confirmed the presence of active bubble plumes. **Figure 11** details the northernmost extent of focused mapping surveys during this expedition. The "Northern Forearc Ridge" dive site (Dive 11) was originally thought to be a potential site of a mud volcano, but mapping data and ROV investigations during Dive 11 confirmed that it was not.

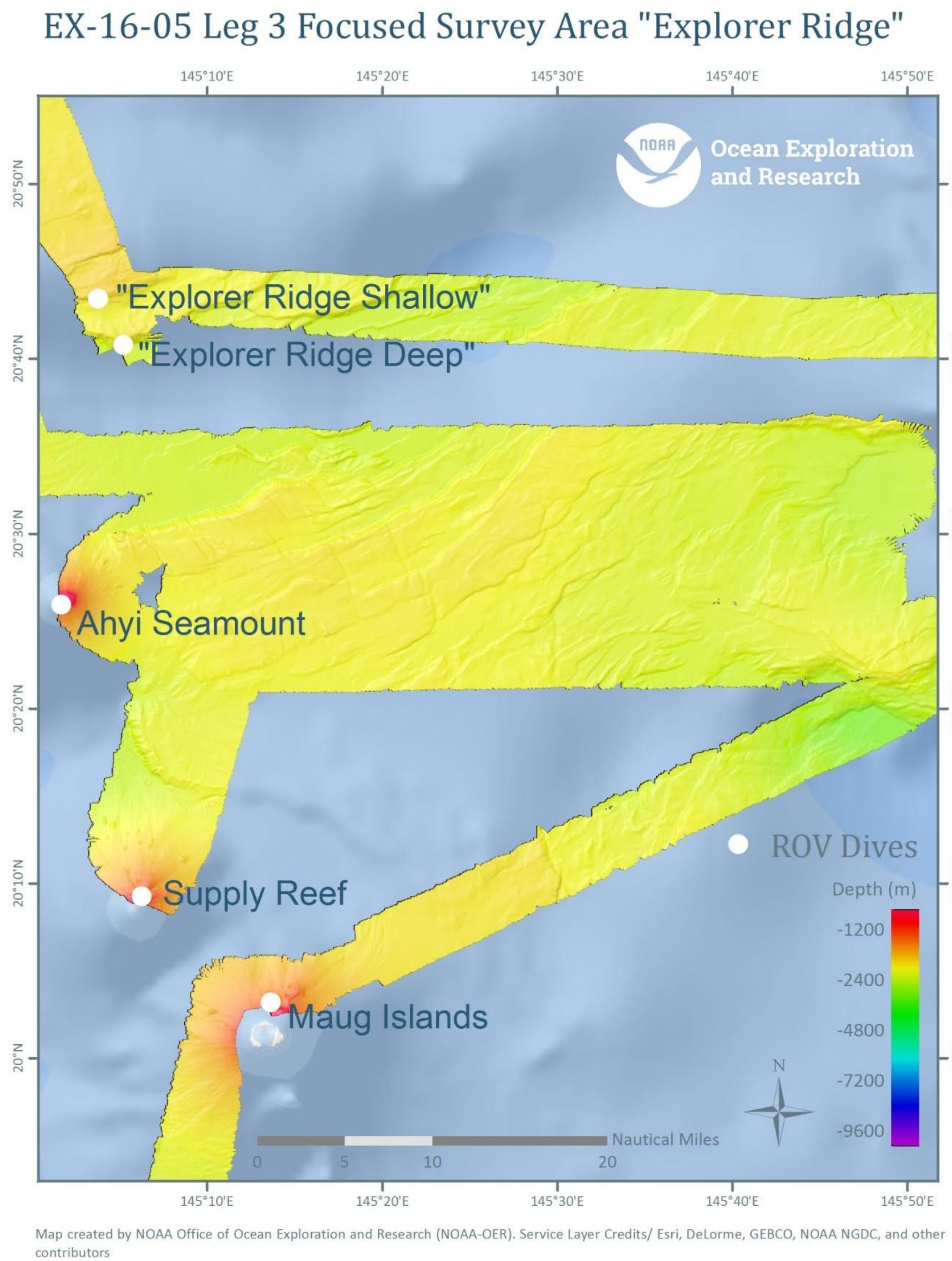

Figure 9. *Map showing new multibeam sonar data collected in the vicinity of five ROV dives sites near an area informally dubbed "Explorer Ridge".*

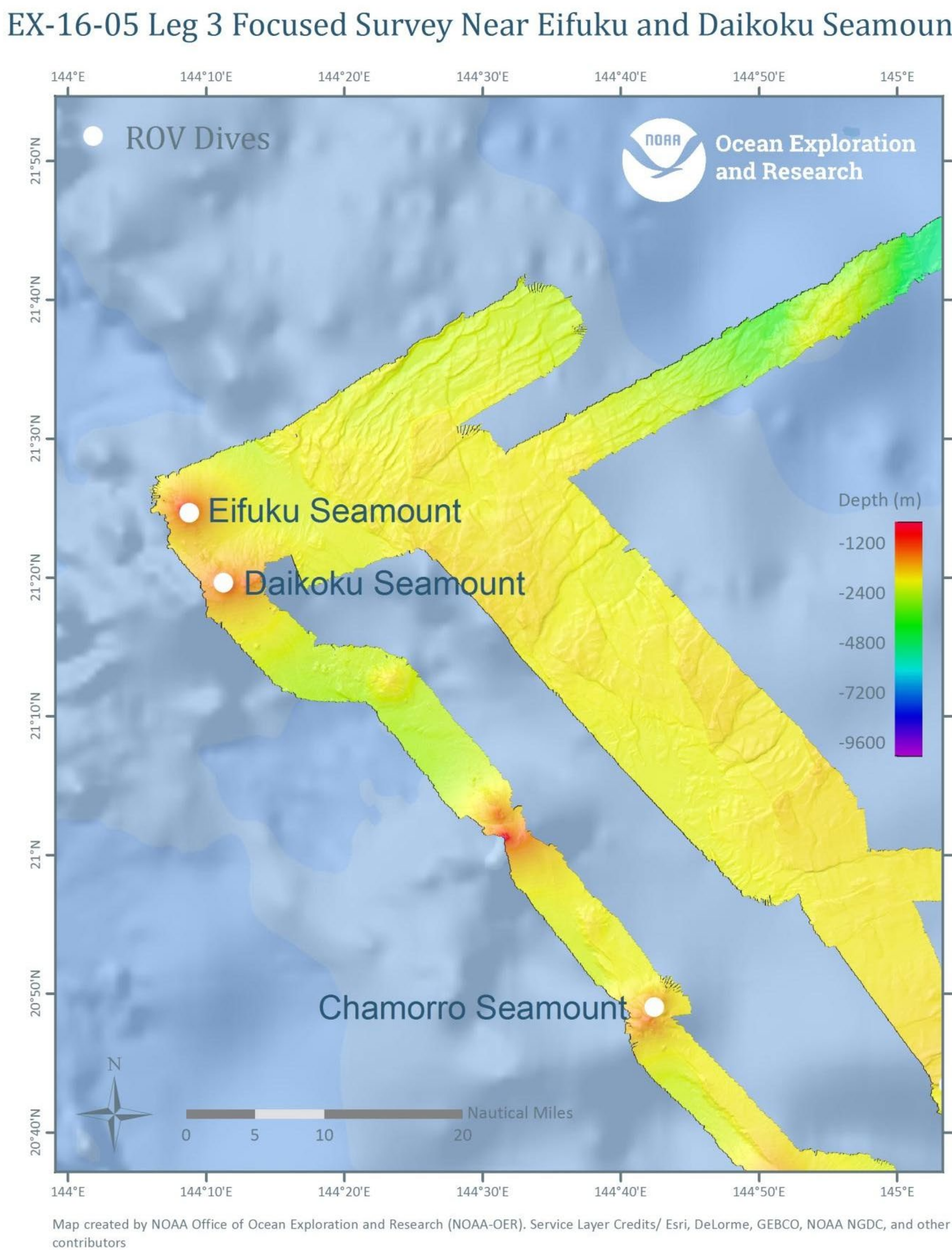

Figure 10. *Map showing new multibeam sonar data collected in the vicinity of Eifuku and Daikoku Seamounts.*

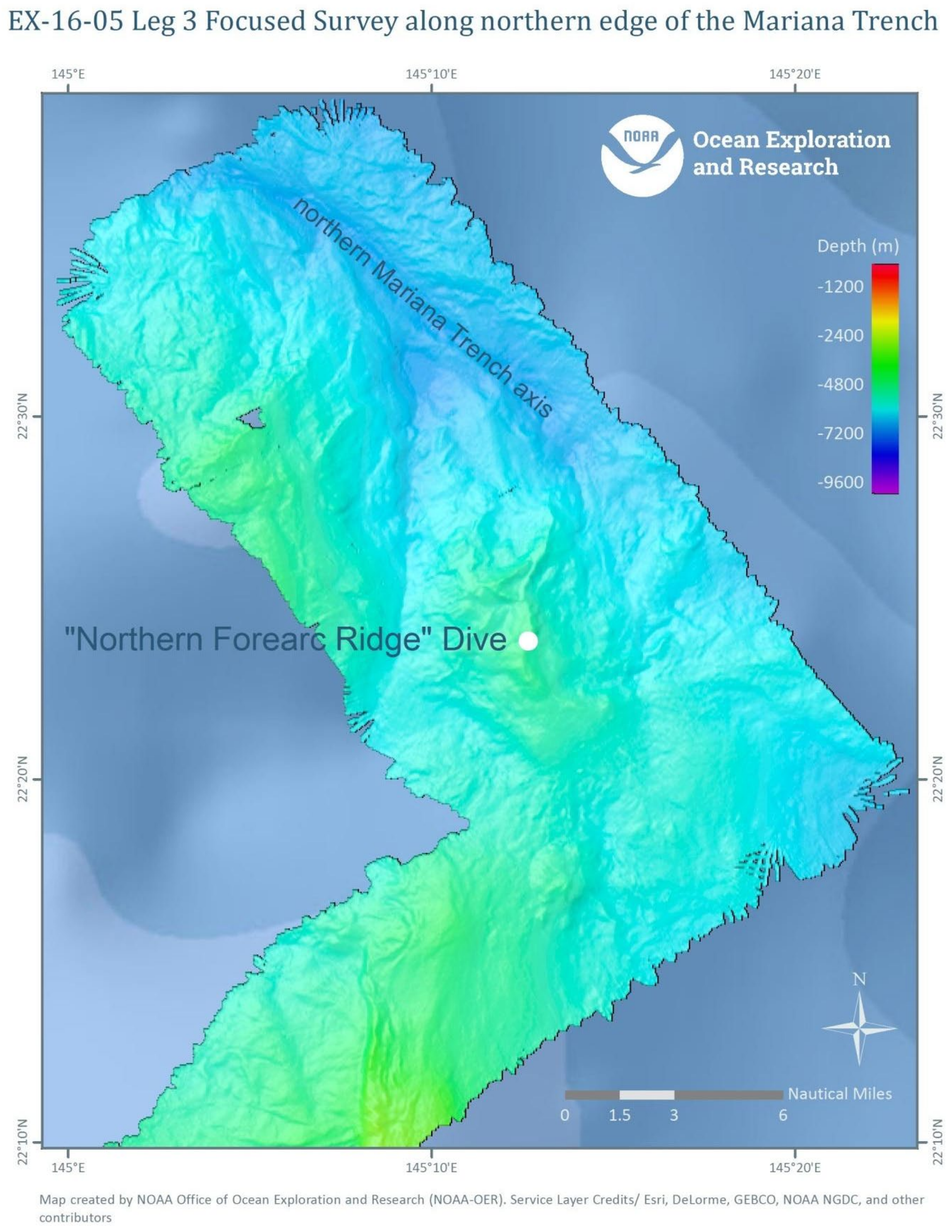

Figure 11. *Map showing new multibeam sonar data collected along the northern edge of the Mariana Trench axis.*

All sonar data and sound velocity data files collected, and products created during the cruise, have been provided to the National Archives. Additional summary of mapping data acquisition and processing can be found in the EX-16-05 Leg 3 Mapping Data Acquisition and Processing Summary Report:

Sowers, D. (2019).Mapping Data Acquisition and Processing Summary Report, Cruise EX16-05 Leg 3: 2016 Deepwater Exploration of the Marianas.NOAA OER Expedition Report. NOAA Institutional Repository. Retrieved from https://repository.library.noaa.gov/view/noaa/21363 .

7. Data Access

Below is a list of access points and archival location for data collected during EX-16-05 Leg 3. All links in this section were last accessed 8/27/2020.

Multibeam Sonar (Kongsberg EM 302)
The multibeam dataset for the expedition is archived at NCEI and accessible through their Bathymetric Data Viewer (https://maps.ngdc.noaa.gov/viewers/bathymetry/). To access these data, click on the Search Bathymetric Surveys button, select "NOAA Ship *Okeanos Explorer*" from the Platform Name dropdown menu, and "EX1605L3" from the Survey ID dropdown menu. Click OK, and the ship track for the cruise will appear on the map. Click the ship track for options to download data.

Subbottom Profiler (Knudsen Chirp 3260)
The subbottom profiler was not run during any of EX-16-05 Leg 3's ROV dive operations, but generally was operated during multibeam mapping operations. These data are archived at NCEI and accessible through their Trackline Geophysical Data Viewer (https://maps.ngdc.noaa.gov/viewers/geophysics/). To access these data, select "Subbottom Profile" under Marine Surveys and click on Search Marine Surveys. In the pop-up window, select "EX1605_3" in the Filter by Survey IDs dropdown menu. Click OK, and the ship track for the cruise will appear on the map. Click the ship track for options to download data.

Split-beam Sonars (Simrad EK60 and EK80)
EK60 and EK80 water column data for EX-16-05 Leg 3 are archived at NCEI and available through their Water Column Sonar Data Viewer (https://www.ngdc.noaa.gov/maps/water_column_sonar/index.html). To access these data, click on the Additional Filters button, deselect "All" next to Survey ID, and select "EX1605L3" from the Survey ID list. Click OK, and the ship track for the cruise will appear on the map. Click on the ship track for options to download data.

Acoustic Doppler Current Profilers (Teledyne Marine Workhorse Mariner and Teledyne Ocean Surveyor ADCPs)
ADCP data collected at each ROV dive location are archived at NCEI and available through their Global Ocean Currents Database (https://www.nodc.noaa.gov/gocd/sadcp_oer_inv.html). Access these data by searching the table for the Expedition identifier "EX1605L3."

Conductivity, Temperature, and Depth Measurements
CTD profile data from EX-16-05 Leg 3 are archived at NCEI and available through OER's Digital Atlas (https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm). To access these data, click on the Search tab, enter "EX1605L3" in the Enter Search Text field, and click Search. Click on the point that represents EX1605L3 to access data options. In the pop-up window, select the Data Access tab for a link to download the CTD profile data.

ROV CTD data can also be found with the dive summaries on the *Okeanos Explorer* website (https://service.ncddc.noaa.gov/rdn/oer-rov-cruises/ex1605l3).

OER Digital Atlas

ROV data from EX-16-05 Leg 3 are archived at NCEI and available through OER's Digital Atlas (https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm). To access these data, click on the Search tab, enter "EX1605L3" in the Enter Search Text field, and click Search. Click on the point that represents EX1605L3 to access data options. In the pop-up window, select the ROV Data Access tab for links to the ROV dive data, which is organized by dive.

ROV Dive Summaries

Individual ROV dive summaries and associated ROV dive data are archived at NCEI and available here: https://service.ncddc.noaa.gov/rdn/oer-rov-cruises/ex1605l3

ROV Dive Video

To search, preview, and download dive video for NOAA Ship *Okeanos Explorer* dives, go to the OER Video Portal (https://www.nodc.noaa.gov/oer/video/). Under Cruises, select "CAPSTONE CNMI and Mariana Trench ROV and Mapping (EX1605L3)" and click Search to pull up video data from this cruise.

Sample Repositories

The following repositories archive samples collected during expeditions on NOAA Ship *Okeanos Explorer*.

- Invertebrate Zoology Collections, National Museum of Natural History, Smithsonian Institution, Museum Support Center, MRC 534, 4210 Silver Hill Road, Suitland, MD 20746
  Contact: Abigail Reft, ReftAJ@si.edu
  Website: https://invertebrates.si.edu/LoanPolicy.html
- Biorepository, National Museum of Natural History, Smithsonian Institution, Museum Support Center, 4210 Silver Hill Road, Suitland, MD 20746
  Contact: Chris Huddleston, HuddlestonC@si.edu
  Website: https://naturalhistory.si.edu/research/biorepository
- Marine and Geology Repository, Oregon State University, Burt Hall 346, Corvallis, OR 97331-5503
  Contact: Kevin Konrad, konradke@geo.oregonstate.edu
  Website: http://osu-mgr.org/noaa-ex/
- Ocean Genome Legacy Center, Northeastern University, 430 Nahant Road, Nahant, MA 01908
  Contact: Hannah Appiah-Madson, h.appiah-madson@northeastern.edu
  Website: https://www.northeastern.edu/ogl/
- Bishop Museum, Natural Sciences Collections, 1525 Bernice Street, Honolulu, HI 96817
  Request access: https://www.bishopmuseum.org/collections-access/

Sun Photometer Measurements

Sun photometer measurements are available through NASA's MAN (https://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html). Access these data by searching the table for "2016", "Okeanos Explorer," and "North Pacific Ocean." Click on the links to download the data. (Note: There may be more than one entry for NOAA Ship *Okeanos Explorer* in a region in a given year.)

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9. Appendices

APPENDIX A: Data Management Plan

NOAA Ship *Okeanos Explorer* (EX-16-05 Leg 3): Campaign to Address Pacific monument Science, Technology, and Ocean NEeds: *2016 Deepwater Exploration of the Marianas, Leg* 3 (ROV & Mapping)

OER Data Management Objectives

Standard Operating Procedures onboard the ship and throughout the ship's established data pipelines will be followed to ensure the data from this mission is organized, documented and archived within 30-90 days of cruise end.

1. General Description of Data to be Managed

1.1 Name and Purpose of the Data Collection Project

NOAA Ship *Okeanos Explorer* (EX-16-05 Leg 3): CAPSTONE: 2016 Deepwater Exploration of the Marianas, Leg 3 (ROV & Mapping)

1.2 Summary description of the data to be collected.

The ship will conduct 24-hour operations consisting of daytime ROV dives and evening/nighttime mapping operations including during transit. During this cruise, the team will conduct primarily eight-hour ROV dives with occasional 10- or 12-hour dives on particularly interesting or deep water dive sites, as staffing allows. ROV operations will focus in depths between 250 and 6,000 meters and will include high-resolution visual surveys and limited sample collection. Mapping operations will be conducted in 250 m of water and deeper, and include transit and overnight multibeam, water column backscatter, and subbottom data collection. CTD rosette operations are requested at several sites to inform ROV dives, and may be requested opportunistically at selected sites where collecting the data is considered important to understanding the physical or chemical properties of the overlying water column.

1.3 Keywords or phrases that could be used to enable users to find the data.

expedition, deep sea corals, coral communities, hydrothermal vent communities, mud volcanoes, trench habitats, subduction zone habitats, Prime Crust Zone, telepresence enabled exploration, Pacific seamounts, exploration, explorer, marine education, noaa, ocean, ocean discovery, ocean education, ocean exploration, ocean exploration and research, ocean literacy, ocean research, OER, science, scientific mission, scientific research, sea, stewardship, systematic exploration, technology, transformational research, undersea, underwater, Davisville, mapping survey, multibeam, multibeam backscatter, multibeam sonar, multi-beam sonar, noaa fleet, okeanos, okeanos explorer, R337, Rhode Island, scientific computing system, SCS, single beam sonar, singlebeam sonar, single-beam sonar, subbottom profile, water column backscatter, oceans, Commonwealth of the Northern Marianas Islands, CNMI, Marianas Trench Marine National Monument, MTMNM, benthic habitats, bottomfish habitats

1.4 If this mission is part of a series of missions, what is the series name?

NOAA Ship *Okeanos Explorer* ROV Cruises

1.5 Planned or actual temporal coverage of the data.

Dates: 6/17/2016 to 7/10/2016

1.6 Planned or actual geographic coverage of the data.

Latitude Boundaries: 11.63 to 17.51
Longitude Boundaries: 143.2 to 149.5

1.7 What data types will you be creating or capturing and submitting for archive?

Cruise Plan, Cruise Summary, Data Management Plan, Highlight Images, Quick Look Report, CTD (processed), CTD (product), CTD (raw), Dive Summaries, EK60 Singlebeam Data, Expedition Cruise Report, Highlight Video, Images, Multibeam (image), Multibeam (processed), Multibeam (product), Multibeam (raw), NetCDF, Raw Video (digital), Sample Analysis Reports, Sample Logs, SCS Output (compressed), SCS Output (native), Selected Raw Video, SBP data, Water Column Backscatter, XBT (raw)

1.8 What platforms will be employed during this mission?

NOAA Ship *Okeanos Explorer*, ROV *Deep Discoverer*, Camera Sled *Seirios*

2. Point of Contact for this Data Producing Project

Overall POC: Ms. Kasey Cantwell, Field Operations Specialist, NOAA Office of Ocean Exploration and Research, kasey.cantwell@noaa.gov

Title: Field Operations Specialist

Affiliation/Dept: NOAA Office of Ocean Exploration
E-Mail: kasey.cantwell@noaa.gov
Phone:301-734-1050

3. Point of Contact for Managing the Data

Data POC Name: Joshua Carlson, Andy O'Brien, Matt Dornback, Susan Gottfried

Title: Onboard operational data management, shoreside data management, sampling operations data management, data stewardship and archive

E-Mail: joshocar@gmail.com, andrew.parson.obrien@gmail.com, matt.dornback@noaa.gov, susan.gottfried@noaa.gov

4. Resources

4.1 Have resources for management of these data been identified?

True

4.2 Approximate percentage of the budget devoted to data management. (specify % or "unknown")
unknown

5. Data Lineage and Quality

5.1 What is the processing workflow from collection to public release?
SCS data shall be delivered in its native format as well as an archive-ready, documented, and compressed NetCDF3 format to NCEI-MD; multibeam data and metadata will be compressed and delivered in a Bagit format to NCEI-CO

5.2 What quality control procedures will be employed?
Quality control procedures for the data from the Kongsberg EM 302 are handled at the University of New Hampshire (UNH) Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC). Raw (level-0) bathymetry files are cleaned/edited into new data files (level-1) and converted to a variety of products (level-2). Data from sensors monitored through the SCS are archived in their native format and are not quality controlled. Data from CTD casts and XBT firings are archived in their native format. CTDs are post-processed by the data management team as a quality control measure and customized CTD profiles are generated for display on the Okeanos Explorer Atlas (explore.noaa.gov/okeanosatlas)*.

*NOTE- at time of report completion, December 2020, the Okeanos Explorer Atlas has been decommissioned in favor of publicly available services on ArcOnline.

6. Data Documentation

6.1 Does the metadata comply with the Data Documentation Directive?
True

6.1.1 If metadata are non-existent or non-compliant, please explain:

6.2 Where will the metadata be hosted?

Organization: An International Organization for Standardization (ISO) format collection-level metadata record will be generated during pre-cruise planning and published in an OER catalog and Web Accessible Folder (WAF) hosted at NCEI-MS for public discovery and access. The record will be harvested by data.gov.

URL: http://www.ncddc.noaa.gov/oer-waf/ISO/Resolved/2016/

Metadata Standard: ISO 19115-2 Geographic Information with Extensions for Imagery and Gridded Data will be the metadata standard employed; a NetCDF3 standard for oceanographic data will be employed for the SCS data; the Library of Congressstandard, MAchine Readable Catalog (MARC), will be employed for NOAA Central Library records.

6.3 Process for producing and maintaining metadata:

Metadata will be generated via xml editors or metadata generation tools.

7. Data Access

7.1 Do the data comply with the Data Access Directive?

True

7.1.1 If the data will not be available to the public, or with limitations, provide a valid reason.

Not Applicable

7.1.2 If there are limitations, describe how data are protected from unauthorized access.

Account access to mission systems are maintained and controlled by the Program. Data access prior to public accessibility is documented through the use of Data Request forms and standard operating procedures.

7.2 Name and URL of organization or facility providing data access.

Org: National Centers for Environmental Information (NCEI)
URL: https://www.ncei.noaa.gov/maps/oer-digital-atlas/mapsOE.htm

7.3 Approximate delay between data collection and dissemination. By what authority?

Hold Time: no
Authority: not applicable

7.4 Prepare a Data Access Statement

No data access constraints, unless data are protected under the National Historic Preservation Act of 1966.

8. Data Preservation and Protection

8.1 Actual or planned long-term data archive location:

Data from this mission will be preserved and stewarded through the NOAA National Centers for Environmental Information. Refer to the NOAA Ship *Okeanos Explorer* FY16 Data Management Plan at NOAA's Environmental Data Management Committee (EDMC) Data Management Plan (DMP) Repository (EX_FY16_DMP_Final.pdf) for detailed descriptions of the processes, procedures, and partners involved in this collaborative effort.

8.2 If no archive planned, why?

not applicable

8.3 If any delay between data collection and submission to an archive facility, please explain.

30-90 days

8.4 How will data be protected from accidenta l or malicious modification or deletion?
Data management standard operating procedures minimizing accidental or malicious modification or deletion are in place aboard NOAA Ship *Okeanos Explorer* and will be enforced.

8.5 Prepare a Data Use Statement
Data use shall be credited to NOAA Office of Ocean Exploration and Research.

APPENDIX B: Dive Codes

The dive codes listed below are the final list of codes used during EX-16-05 Leg 3, which can be used in conjunction with the Eventlog data, which documents real-time observation.

Taxa

ACN - Actinaria (anemone)
APH - Amphipod
ART - Arthropod
ASR - Asteroid
BAR - Barnacle
BIO - Biology (Unspecified)
BIV - Bivalve
BRA - Brachiopod
BRY – Bryozoan

CER - cerianthid (tube anemone)
CHI - Chiton
CLA - Clams
CNI - Cnidarian
COP - Copepods
COR - Coral
CORA - Antipatharian
CORAC - Acanthogorgiidae
CORC - Coralliidae
CORCH - Chrysogorgiidae
CORI - Isididae
CORL - Lophelia
CORM - Madrepora
CORO - Octocoral
CORP - Paramuricea
CORPA - Paragorgiidae
CORPL - Plexauridae
CORPR - Primnoidae
CORS - Stylasterid
CPEN - Pennatulacean
CORW - Whip coral
CRA - Crab
CRAKC - King crab (family Lithodidae)
CRARED - Red Deep Sea Crab (Chaceon quinquedens)
CRASPI - Spider crabs (family Majoidea)
CRI - Crinoid
CRIHYO - Hyocrinida
CRIBAT - Bathycrinidae
CRIBOU - Bourgeuticrinidae
CRIANT - Antedonidae
CRIZEN - Zenometridae
CRIPNT - Pentametrocinidae
CRIATE - Atelecrinidae
CRITHA - Thalassometridae
CTE - Ctenophore
DAN - Dandelion
ECN - Echiuran
ENT – Enteropneust

EGG - Egg (case)
FEC - Fecal (matter)
FSH - Fish
FCHN - Chondrichthyes
FCOD - Codlets
FREF - Reeffish (grouper, tilefish, AJs, snapper)
FANT - Anthiins (fancy bass)
FELO - Elongate (eels, brotulids)
FOVO - Ovoid (roughys, boarfish, dories)
FLAT – Flatfish
FOR - Foraminiferan
GAS - Gastropods (not limpets)
GRO - Gromiid
HOL - Holutharian
HYD - Hydroid
ISO - Isopod
JFH - Jellyfish
LAR - Larvacean house
LIM - Limpets
LOB - Lobster
MAT - Bacterial (Mat)
MUC - Unidentified mucus structure
MOL - Mollusk
MUS - Mussels
NUD - Nudibranch
OCT - Octopus
OPH - Ophiuroid
PAG - Pagurid (hermit)
POL - Polychaete
PTE - Pteropod
PYC - Pycnogonid
RIF - Riftia
SAL - Salp
SCA - Scale (worm)
SER - Serpulid worm
SHI - Shrimp
SIP- Siphonphores
SPA - Spaghetti worms
SPO - Sponge
SPOAST: Astrophorid sponge
SPODEM - demosponge
SPOGEO - Geodiid sponge
SPOP - Pheronematidae
SPOE - Euplectellidae
SPOR – Rossellidae

SQA - Squat Lobster
SQD - Squid
STR - Mucus string
STY - Stylasterine hydrocoral
TUB - Tubeworms (not Riftia)
TUN - Tunicate
URC - Urchin
USO - Unidentified sessile object
WOD - Wood
WOR - Worm
XEN - Xenophyophoran
ZOA – Zoanthid

Geology

BUR – Burrow
CONG - conglomerate
COB - Cobble
DIKE - Dike
MUD - Mud
ROC – Rock
ROU - rounded
RUB - Rubble
SAD - Sand
SED – Sediment
RIP- Ripples
SUB - subangular
SUL - Sulfide
VNT - Vent
WAL - Wall

Sediment Cover

BLA - Blanket
HEA - Heavy/Coalescent
LIG - Light
POC - Partial/Pockets

Lava Morphology

ENT - Entrail
FOL - Folded
FRAC - Fractured
HAC - Hackly
JUM - Jumbled
LOB - Lobate
PIL - Pillow
ROPY - Ropy lava flow
SHE - Sheet
TAL - Talus
VCL - Volcaniclastics

Feature

ASG - Axial Summit Graben
AVR - Axial Volcanic Ridge
CAR - Carbonate
CLI - Cliff
COL - Collapse
CON - Contact
FAU - Fault
FIS - Fissure
HAY - Haystack
HYX - Hydrothermal
PIL - Pillar
SCP - Scarp
SEP - Seep

Other

ANT - Anthropogenic object (trash, traps lines, etc.)

APPENDIX C: NASA Aerosol Survey of Opportunity

NASA Maritime Aerosols Network Survey of Opportunity

Survey or Project Name

Maritime Aerosol Network

Lead POC or Principle Investigator (PI & Affiliation)

POC: Dr. Alexander Smirnov

Supporting Team Members Ashore

Supporting Team Members Aboard (if required)

Activities Description(s) (Include goals, objectives and tasks)

The Maritime Aerosol Network (MAN) component of the Aerosol Robotic Network (AERONET) provides ship-borne aerosol optical depth measurements from the Microtops II sun photometers. These data provide an alternative to observations from islands as well as establish validation points for satellite and aerosol transport models. Since 2004, these instruments have been deployed periodically on ships of opportunity and research vessels to monitor aerosol properties over the world ocean.

During the cruise the marine aerosol layer observations will be collected for the NASA MAN research effort. Observations were made by mission personnel (as time and weather allowed) with a sun photometer instrument provided by the NASA MAN program. Resulting data were delivered to the NASA MAN principle investigator, Alexander Smirnov, by the expedition coordinator. All collected data were archived and are publicly available at:
http://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html

Equipment resides on the ship and is stewarded by the Expedition Coordinator.

APPENDIX D: Licenses and Permits

DFW
DATE 03/21/16

COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS
DIVISION OF FISH & WILDLIFE
SCIENTIFIC RESEARCH LICENSE APPLICATION

Pursuant to 2 CMC §85.30.1-205, all scientific research, attempts to gain or collect data, and/or exploratory studies for academic or commercial purposes in the CNMI are regulated activities. A permit is therefore required to ensure the integrity and conservation of wildlife, fisheries, and habitat; personal and public safety; the legitimacy of project, best practice methodology, qualifications of participants; due diligence, identification of responsible and liable parties; compliance with local and federal laws, regulations, and customs; and that CNMI's scientific, ecological, cultural, and economic interests are considered, represented, and advanced.

Printed Name and Affiliation of Principal Investigator (PI): Kelley P. Elliott, NOAA Office of Ocean Exploration & Research
Position Title of PI: Expedition Manager
Contact Address for PI: 1315 East-West Hwy, SSMC3 Room 10236, Silver Spring, MD 20910
Printed Names and Affiliations of Co-Investigators:
Shirley Pomponi, *Harbor Branch Oceanographic Institute, Florida Atlantic University*
Deborah Glickson, *Harbor Branch Oceanographic Institute, Florida Atlantic University*
Patty Fryer, *Hawai'i Institute of Geophysics & Planetology, University of Hawai'i*
Diva Amon, *Department of Oceanography, University of Hawai'i*
Chris Kelley, *Department of Oceanography, University of Hawai'i*
Elizabeth "Meme" Lobecker, *NOAA Office of Ocean Exploration and Research (ERT, Inc.)*
Kasey Cantwell, *NOAA Office of Ocean Exploration and Research (Collabralink)*

Name of Project: 2016 CAPSTONE CNMI & Mariana Trench Marine National Monument Exploration

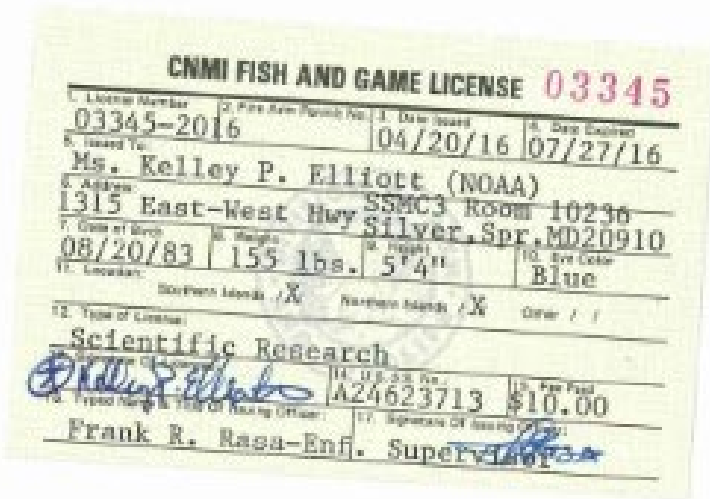
Date Project Will Begin: April 20, 2016

Date Project Will End: July 27, 2016 (when the ship will depart Guam for Kwajalein)

Assurance: Through the voluntary submission of this application, I hereby certify that I am familiar with applicable state and federal regulations pertaining to my research activities. I further certify that the information submitted in this application is complete and accurate to the best of my knowledge and belief. I understand that failure to follow the regulations or any false statement submitted in this application may subject me to penalties under applicable state and federal Laws. Furthermore, I understand that the License I may receive on the basis of this application will be accompanied by conditions that I agree to follow in full. I understand that failure to do so may also subject me to the penalties and/or revocation and non-renewal of the license.

Signature of PI: Kelley P. Elliott **Date:** March 8, 2016

Project Description:



CNMI FISH AND GAME LICENSE 03345

1. License Number: 03345-2016
2. Fire Arm Permit No.:
3. Date Issued: 04/20/16
4. Date Expired: 07/27/16
5. Issued To: Ms. Kelley P. Elliott (NOAA)
6. Address: 1315 East-West Hwy SSMC3 Room 10236 Silver.Spr.MD20910
7. Date of Birth: 08/20/83
8. Weight: 155 lbs.
9. Height: 5'4"
10. Eye Color: Blue
11. Location: Southern Islands /X Northern Islands /X Other / /
12. Type of License: Scientific Research
14. U.S.S.S. No.: A24623713
15. Fee Paid: $10.00
16. Typed Name & Title of Issuing Officer: Frank R. Rasa-Enf. Supervisor
17. Signature Of Issuing Officer:

APPENDIX E: Acronyms

3D—Three-dimensional
ADCP—Acoustic Doppler Current Profiler
AERONET—Aerosol Robotic Network
ASCII—American Standard Code for Information Interchange
CAPSTONE—Campaign to Address Pacific monument Science and Technology NEeds
CARIS—Teledyne Computer Aided Resource Information System
CCOM/JHC—Center for Coastal and Ocean Mapping/Joint Hydrographic Center
CMRE—Centre for Maritime Research & Experimentation
CNMI—Commonwealth of the Northern Mariana Islands
CSV—Comma-separated-values
CTD—Conductivity, temperature, and depth
D2—ROV *Deep Discoverer*
DAS—Days at sea
DMP—Data Management Plan
DNA—Deoxyribonucleic acid
DO—Dissolved oxygen
DPAA—Defense POW/MIA Accounting Agency
DSCRTP—NOAA Deep Sea Coral Research and Technology Program
ECC—Exploration Command Center
ECS—Extended Continental Shelf
EDMC—Environmental Data Management Committee
EEZ—Exclusive Economic Zone
ESA—Endangered Species Act
FAU—Florida Atlantic University
FOUO- For Official Use Only
FSU—Florida State University
FTP—File transfer protocol
GFOE—Global Foundation for Ocean Exploration
HBOI—Harbor Branch Oceanographic Institute
HD—High-definition
IHMC—Institute for Human & Machine Cognition
ISO—International Organization for Standardization
JAMSTEC—Japan Agency for Marine-Earth Science and Technology
KMZ—Keyhole Markup language Zipped
LED—Light-emitting diode
LSU—Louisiana State University
Mbps—Megabit-per-second
MAN—Maritime Aerosol Network
MARC—MAchine Readable Catalog
MGR—Marine Geology Repository
MHP—Marine Heritage Program
MIA—Missing in action

Mn—Manganese
MnO—Manganese oxide
MPA—Marine protected area
MTMNM—Marianas Trench Marine National Monument
NAP—Nautical Archaeology Program
NASA—National Aeronautics and Space Administration
NAO—NOAA Administrative Order
NATO—North Atlantic Treaty Organization
NCEI—NOAA National Centers for Environmental Information
NEPA—National Environmental Protection Act
NGDC—National Geophysical Data Center
NMFS—National Marine Fisheries Service
NMSAS—National Marine Sanctuary of American Samoa
NPS—National Park Service
OER—NOAA Office of Ocean Exploration and Research
OGL—Ocean Genome Legacy
ONMS—Office of National Marine Sanctuaries
OSU—Oregon State University
PCZ—Prime Crust Zone
PERC/CIT—Planetary Exploration Research Center/Chiba Institute of Technology
PIFSC—NOAA Pacific Islands Fisheries Science Center
PIPA—Phoenix Islands Protected Area
PIRO—NOAA Pacific Islands Regional Office
PMEL—NOAA Pacific Marine Environmental Laboratory
PMNM—Papahānaumokuākea Marine National Monument
PPSIO—P.P. Shirshov Institute of Oceanology
PRIMNM—Pacific Remote Islands Marine National Monument
RAMNM—Rose Atoll Marine National Monument
RAS—Russian Academy of Sciences
ROV—Remotely operated vehicle
SBP—Subbottom profiler
SCS—Shipboard computer system
SD—Scientific Data
SI—Smithsonian Institution
SIO—Scripps Institution of Oceanography
SIS—Seafloor Information System
SODA—Sampling Operations Database Application
SVP—Sound velocity probe
TAMU—Texas A&M University
TSG—Thermosalinograph
UCH—Underwater Cultural Heritage
UH—University of Hawai‘i at Mānoa
ULL—University of Louisiana at Lafayette
UNH—University of New Hampshire

USGS—U.S. Geological Survey
USNM—National Museum of Natural History
UT—University of Texas
UTC—Universal Time Coordinated
UVIC—University of Victoria
UW—University of Washington
VARS- Video Annotation and Reference System
WAF—Web accessible folder
WGS84—World Geodetic System 1984
WHOI—Woods Hole Oceanographic Institution
WWII—World War II
XBT—Expendable bathythermographs