The most well-recognized area of the Mariana region is undoubtedly Challenger Deep, the deepest point in our ocean at over 10,900 m. As a result, most Mariana deep-sea research has been focused on this tiny spot in the subduction zone’s trench or in the volcanic back arc; however, much of the deepwater habitats of this diverse and dynamic region remain poorly understood.

As part of the CAPSTONE effort, NOAA and partners conducted the Deepwater Exploration of the Marianas expedition on NOAA Ship Okeanos Explorer. The primary goal of this three-leg, 59-day expedition was to collect baseline biological and geological information from a variety of deepwater habitats in and around the Marianas Trench Marine National Monument (MTMNM), Guam, and the Commonwealth of the Northern Mariana Islands (CNMI). Baseline characterizations expand our understanding of the diversity and distribution of benthic and pelagic habitats, as well as their geologic underpinnings, and contribute to better management of this unique environment.

Prior to commencing the expedition, science priorities were identified through 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: (1) locating and assessing commercial bottomfish and precious coral habitats; (2) identifying vulnerable marine habitats, particularly high-density deep-sea coral and sponge communities; (3) surveying the communities that exist on ferromanganese-encrusted guyots; (4) mapping and conducting ROV transects over a variety of geologic structures within the region, including hydrothermal vents, volcanic areas, and ridges; (5) investigating subduction zone areas and the habitats within the abyssal-hadal transition zone of the trench; (6) exploring life in the water column; and (7) searching for submerged cultural heritage sites in an area that played a critical role in World War II. Operations were designed to target these priorities during 41 ROV dives that ranged from 240 m to 6,000 m depth, including 18 within the MTMNM, and the equivalent of ~35 days of mapping over 73,800 km² of seafloor (Figure 1). During ROV dives, 58 biological samples (plus 102 commensals) were collected, many of which may be undescribed species, and 73 rock samples were collected for use in age dating and geochemical composition analysis. The expedition accumulated more than 48 terabytes of data that include video and still imagery, multibeam sonar and single-beam echosounder recordings, subbottom profiles, current profiles, CTD and dissolved-oxygen measurements, and surface oceanographic and meteorological information.

Exploration for Commercial Species and High-Density Biological Communities

To address fisheries priorities identified by expedition partners, 12 ROV dives targeted depths where bottomfish and precious corals exist. A number of commercially viable bottomfish species were observed, including pale snapper (Etelis radiosus), deepwater longtail red snapper (E. coruscans), deepwater red snapper (E. carbunculus), eightbar grouper (Hyporthodus octofasciatus), amberjack (Seriola sp.), dogtooth tuna (Gymnosarda unicolor), monchong or sickle pomfret (Taractichthys steindachneri), roughy (Hoplostethus sp.), oblique-banded snapper (Pristipomoides zonatus), ornate jobfish (P. argyrogrammicus), goldflag jobfish (P. auricilla), and golden grouper (Saloptia powelli). Despite precious coral being listed as a managed fishery in Guam and the CNMI, no
precious coral beds had been identified prior to this expedition, and accounts of their presence in this region were only anecdotal. The search for precious corals was successful with observations of *Corallium* spp., *Hemicorallium* spp., *Leiopathes* spp., *Acanella* spp., and *Kulamanamana* sp. (Figure 2), although there were fewer than expected. There appeared to be little overlap between bottomfish and precious coral habitats, as bottomfish were found at shallower depths, though there was overlap between bottomfish and non-precious coral habitat.

Aside from documenting precious corals, this expedition was the first to specifically explore for deep-sea coral and sponge communities in the Mariana region. Ten high-density and several medium-density communities were identified. Many of them were highly diverse and included corals such as primnoids, isidids, chrysogorgiids, paragorgiids, stylasterids, desmophyllids, and plexaurids, as well as a combination of hexactinellid and demosponge sponges. Some of the corals and sponges, especially at Vogt Seamount, were very large (over one meter in width) indicating healthy and stable communities (Figure 3). These high-density communities are extremely important; as in shallow coral reefs, they provide habitat and shelter to many different animals (e.g., commensal echinoderms and crustaceans, and also commercial fish species). A notable rare find never before observed in the Mariana region was a high-density community of gorgonocephalid basket stars and stalked crinoids at Zealandia Bank (Figure 4).

**Volcanically Active Areas**

As part of this expedition, three hydrothermal vent sites were characterized for the first time. The most spectacular was an active vent field on the Mariana back-arc spreading center, imaged for the first time since its discovery by the NOAA Pacific Marine Environmental Laboratory’s Vents Program in 2015. There were at least two large chimney sites, plus multiple areas of diffuse flow, and a circular crater (origin as yet undetermined) surrounded by sulfide deposits. A 30 m tall black smoker discovered at 3,292 m depth emitted fluid at 339°C and hosted large communities of *Chorocaris* shrimp, *Gandalfus* crabs, actiniarians, barnacles, *Bathymodiolus* mussels, *Alviniconcha* snails, *Paralvinella* tubeworms, and many other species known from other active sites in the region (Kojima and Watanabe, 2015; Figure 5). The fauna showed clear zonation consistent with distance from the vent fluids. A second new vent field was discovered at approximately 980 m depth on Chamorro Seamount, an area with no known history of hydrothermal activity. Chimneys were 1–2 m tall, with fluid temperatures as high as 31°C, and were dominated by stylasterid corals, *Alviniconcha* snails, *Chorocaris* shrimp, and *Gandalfus* crabs. Other fauna documented included amphipods, polychelid lobsters, unidentified demosponges, synaphobranchids, and macrourids. New areas of hydrothermal
activity were also discovered on the southeast side of Eifuku Seamount, with much of the area exhibiting diffuse low-level hydrothermal activity at temperatures reaching 16°C.

Dives were also conducted at Ahyi Seamount, at Daikoku Seamount, at an area of fresh lava flows in order to document change in areas with evidence of recent eruptions, and at extinct calderas (Fina Nagu volcanic chain) in order to evaluate the geologic progression of volcanic activity. The seafloor and slope of Daikoku Seamount were covered with volcanic ash and volcaniclastics. Many tubeworms, barnacles, and anemones were also observed, as well as a high density of flatfish specialized for living on the sulfur-rich seafloor. Gas plumes of likely carbon dioxide and sulfur were emanating from cracks and orifices near the crater rim and along the lower wall of the crater. Very few sessile animals were observed at Ahyi Seamount, and it was speculated that recent volcanic activity might be the cause. Recent lava flows, including some that were less than two years old (as indicated by bathymetric surveys and ROV images) were observed at a site known as “Young Lava Flows.” This site also had very little faunal colonization, as the basalt was likely too new. There were also extinct hydrothermal chimneys noted at Fina Nagu A and extinct iron-oxide chimneys in Esmeralda Crater.

Acoustic Mapping
In pursuit of the NOAA OER strategic objective to collect modern sonar data over previously unmapped or poorly mapped areas of seafloor, acoustic mapping operations focused on the northernmost section of the MTMNM Island and Trench Units, in priority areas identified by expedition partners, and were also conducted during transits between ROV dive sites. Execution of this plan resulted in collection of 60 m resolution (or better) bathymetric data over several key features, including complex folded ridges, a crescent ridge, mud volcanoes, sites of hydrothermal venting, and the definition of the 6,000 m isobath on the west side of the trench. Additionally, a large volume of split-beam, subbottom, and ADCP sonar data was collected and deposited in the national data archives.

ROV dive plans were refined based on the high-resolution bathymetric data collected, and in some cases, dives revealed correlations between anomalies observed in acoustic water-column data and hydrothermal venting. At the site called “New Vent Field at 17°N,” a dive to 3,292 m depth on a relatively flat area of the Mariana back-arc spreading center located several high-temperature black smokers. Simrad EK60 split-beam data collected at this site showed a distinct water-column anomaly likely associated with the venting activity, which was observed over several hundred meters of seafloor during the dive (Figure 6). The dive at Esmeralda Crater within the MTMNM, another site with previous evidence of hydrothermal venting, was conducted in relatively shallow water (~350 m; Figure 7). While only a single extinct chimney was found by the ROV during the dive, several strong persistent scattering layers were repeatedly detected with multiple EK60 frequencies. The acoustic scattering layers could be due to the chemical, physical, and thermal composition of the particulate-laden fluid emitted during venting, or to biomass associated with the vent communities.
The initial findings from these two dives demonstrate the potential for use of acoustic split-beam data, when interpreted within the local geological context, to determine the presence and extent of vent fields. Use of this technique may increase the ability and efficiency of detecting hydrothermal vents, and would complement traditional chemical-sensing methods such as CTDs. Additionally, because split-beam echosounders can be calibrated for acoustic target strength, there is potential for these data to provide insights into flux rates of gas and particulates emanating from vents, a complex phenomenon whose study currently requires direct measurements with ROVs.

Forearc Exploration
The forearc region, from the trench axis westward to the active island-arc volcanoes, contains the oldest rocks (~52 million years) in the region and tells the history of subduction in the Mariana Trench. ROV imagery and multibeam mapping from this expedition provide improved geologic context for the forearc region, which includes extensive and complex faulting. Mapping operations identified several new features, including a crescent-shaped ridge along the western wall of the Mariana Trench (not evident in satellite altimetry), several potential mud volcanoes, and a ridge with tiered platforms that was anecdotally named “Explorer Ridge.” Two subsequent ROV dives conducted at Explorer Ridge revealed a large coral community and documented the first-ever live sighting of a fish from the family Aphyonidae (ghost fish). It was observed at a depth of ~2,500 m, was about 10 cm in length, and had transparent gelatinous skin that lacked scales and had highly reduced, unpigmented eyes (Figure 8).

The eastern half of the Mariana forearc is host to numerous mud volcanoes that have been periodically erupting since subduction began. As the Pacific Plate descends into the subduction zone, increases in pressure and temperature squeeze out fluids from the sediments and rocks being subducted. These fluids rise into the overriding Philippine Sea Plate and hydrate rocks within its many forearc fault zones. Particularly where faults intersect, the fluids can find escape routes to the seafloor. Because fluids rise along the faults, any rock material ground up by movement within the fault zones can be remobilized. The hydrated material is less dense than surrounding rock and tends to rise with the fluids in a slurry of “mud” (Fryer, 2012). Two of the potential mud volcanoes mapped during this expedition were confirmed during ROV dives through collection of imagery and serpentine samples. Serpentine is a product of the hydration of mantle rock (peridotite) and comprises >90% of a mud volcano. No active seepage (typically associated with mud volcanoes) was found on the crest of either the Kunnapo Hulo mud volcano or the “unnamed forearc mud volcano.” Instead, sedimented seafloor inhabited by deposit feeders was observed. Also, several suspension-feeding sponges with Relicanthus sp. (a cnidarian similar to an anemone) living on their stalks were documented, an association rarely seen, but common among those observed (Figure 9).

Figure 7. Simrad EK60 water-column data shows acoustic evidence for potential hydrothermal vent activity as green “clouds” in the Esmeralda Bank crater. The trackline of an ROV dive there is shown in red, and the dark blue point marks the location of an extinct chimney discovered during the dive.

Figure 8. This “ghost fish” is the first specimen from the family Aphyonidae ever seen alive. Observed on “Explorer Ridge” at a depth of ~2,500 m, the 10 cm long fish had transparent, gelatinous skin that lacked scales and had highly reduced eyes without pigment.

Figure 9. This Relicanthus sp., a cnidarian resembling a sea anemone, was seen on an unnamed forearc seamount in the northern part of the Trench Unit of MTMNM.
**Exploration of the Mariana Trench and Subducting Areas**

Nine dives were conducted along the west slope of the trench and an additional three along the trench axis or within the MTMNM Trench Unit. Because the Mariana Trench lacks a thick wedge of sediment off-scraped from the subducting plate or derived from nearby land masses, Earth’s upper mantle is exposed at depths near 6 km. Three dives to 6,000 m examined the deep architecture of the overriding Philippine Sea Plate near the trench axis (Figure 10) and cataloged the diversity of organisms at the hadal-abyssal transition zones. A high diversity of species was observed—including many potential new species or new records. Several species of holothurians, crinoids, swimming polychaetes, enteropneusts, cladorhizid sponges, brisingid asteroids, and actiniarians were observed. Most fish observed in the trench were ophidiid cusk eels, including a *Penopus* sp. seen over 1,000 m deeper than previously recorded for the genus. A bamboo coral (Isididae) observed during the dive at “Subducting Guyot 2” at a depth of 4,300 m expanded the known depth range for this family by approximately 100 m, making it the deepest known Isidid ever observed.

At Sirena Canyon, baseline information was collected on the abyssal fauna, starting in a fault-controlled canyon south of Guam at ~5,000 m depth on a steep slope that exposed fractured, partially sedimented, volcanic rock below a layered sediment sequence. This supports the hypothesis that canyons act as funnels to the deep sea, enabling accumulation of high concentrations of organic material. This was also shown to be true of marine debris, with many pieces of trash observed at this site.

Just inside the MTMNM boundaries, west of Fryer Guyot, a dive was conducted on a small (1 km in diameter and 141 m in height) volcanic edifice—a potential petit-spot volcano—to determine if it was located on a fracture in the Pacific Plate that formed prior to subduction. This type of young intraplate volcano was previously discovered east of the Japan Trench (Hirano et al., 2008). In addition to documenting this for the first time in US waters, the dive helped to determine that such occurrences might be a common feature of subducting plates as they fracture while bending.

**Cretaceous Guyots**

Five dives took place on Pacific Plate guyots—large, flat-topped, submarine volcanoes that formed 80 to 100 million years ago. Because of their age, these guyots have thick crusts of economically valuable metal oxides that are potential sources of cobalt, copper, manganese, platinum, and other metals (Figure 11). The guyots visited (Vogt, Pigafetta, Del Cano, Fryer, and Enrique) are located in the Prime Crust Zone, the region with the most valuable, and therefore the most vulnerable, ferromanganese crusts on the planet (Hein, 2004). In international waters east of the CNMI, three exploratory mining licenses have been granted at present. The guyots investigated can be used as proxies to better understand habitats in international waters that are vulnerable to deep-sea mining. The ROV dives highlighted a high diversity of both geology and biology at each location, suggesting that guyots can host a range of communities and may need to be considered individually, versus as a group, from a management perspective. However, only a small area of each guyot was surveyed, so broad conclusions cannot yet be drawn.

Three additional unnamed Pacific Plate guyots were also explored. These guyots are being subducted beneath the Philippine Sea Plate and have “broken open” to reveal their underlying structures. The edge of Subducting Guyot 1 can still be seen on the inner trench slope as it burrows its way under the edge of the overriding Philippine Sea Plate, exposing fossil reef-building rudist bivalves (Figure 12) along near-vertical fault scarps. Rudists dominated the seas 65 to 100 million years ago, and this was the first time they were observed in today’s ocean.
Expedition Highlights

Hundreds of different species were observed during the ROV surveys, including sponges, molluscs, tunicates, ctenophores, fishes, bryozoans, cnidarians, echinoderms, and arthropods (Figure 13). Dozens that were not collected were suspected to be new species, including several species of jellyfish, a nudibranch, a slit shell gastropod (a living fossil; Figure 14), holothurians, cladorhizid (carnivorous) sponges, and an electric-blue tilefish. Several new species of hexactinellid sponges were also observed. Additionally, there were new range and depth records for the Mariana region. These included the first records for the region of the family Atelopodidae (jellynose eels), a slit shell gastropod (cf. Bayerotrochus teramachii), a gorgonocephalid basket star, several cusk eels, a large blind lobster (Acanthocaris tenuimana), two nudibranchs, and Relicanthus sp. Even if an organism was not a new species, new record, or rare, many were still extremely strange—from the numerous walking fishes to candelabra-shaped carnivorous sponges and hermit crabs with actinarians replacing their shells.

Other highlights included locating a B-29 Superfortress long-range heavy bomber from World War II in the channel between Tinian and Saipan (see pages 72–73). This expedition also featured the deepest ever (4,000 m) water-column exploration and spent a significant portion of four dives collecting critical information in this vast biome (see pages 66–67). The majority of organisms identified during these transects were new records for the Mariana region, rare observations, or potential new species, indicating an active, but largely unknown pelagic community.

This expedition also set several records for an OER telepresence-enabled expedition. Throughout the three cruises, 100 shoreside scientists, student researchers, and managers participated, with the science team representing 16 US states and six foreign countries. Around the world, members of the general public watched as the expedition unfolded in real time. The live video feeds received a record-breaking 3.1 million views, which stands as a testament to the public’s interest in learning about and exploring the deep sea. This was one of the longest ROV missions that Okeanos Explorer has ever undertaken, and the value of the work completed leaves a legacy of publicly available data that will be used to catalyze future research efforts and inform management decisions.