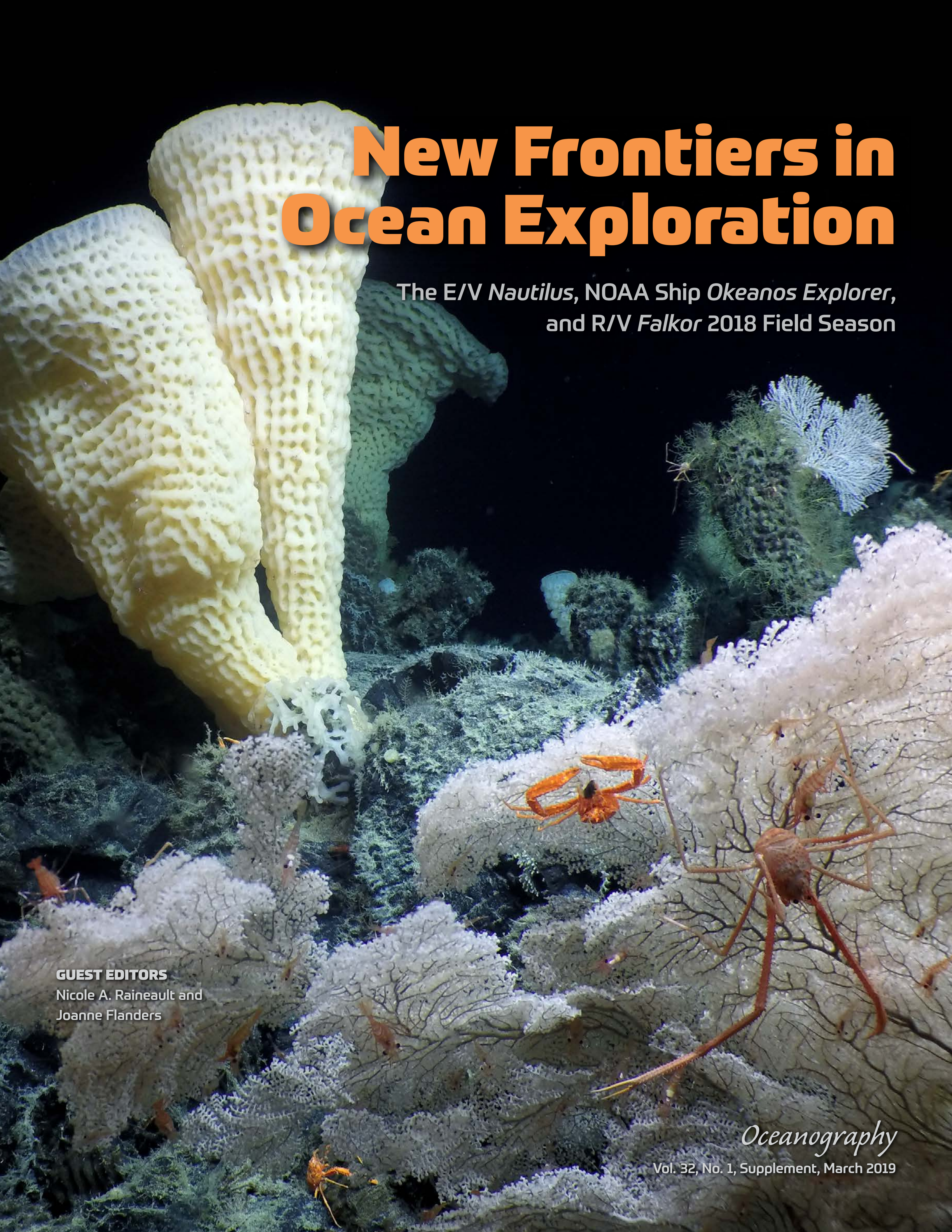
New Frontiers in Ocean Exploration

The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2018 Field Season



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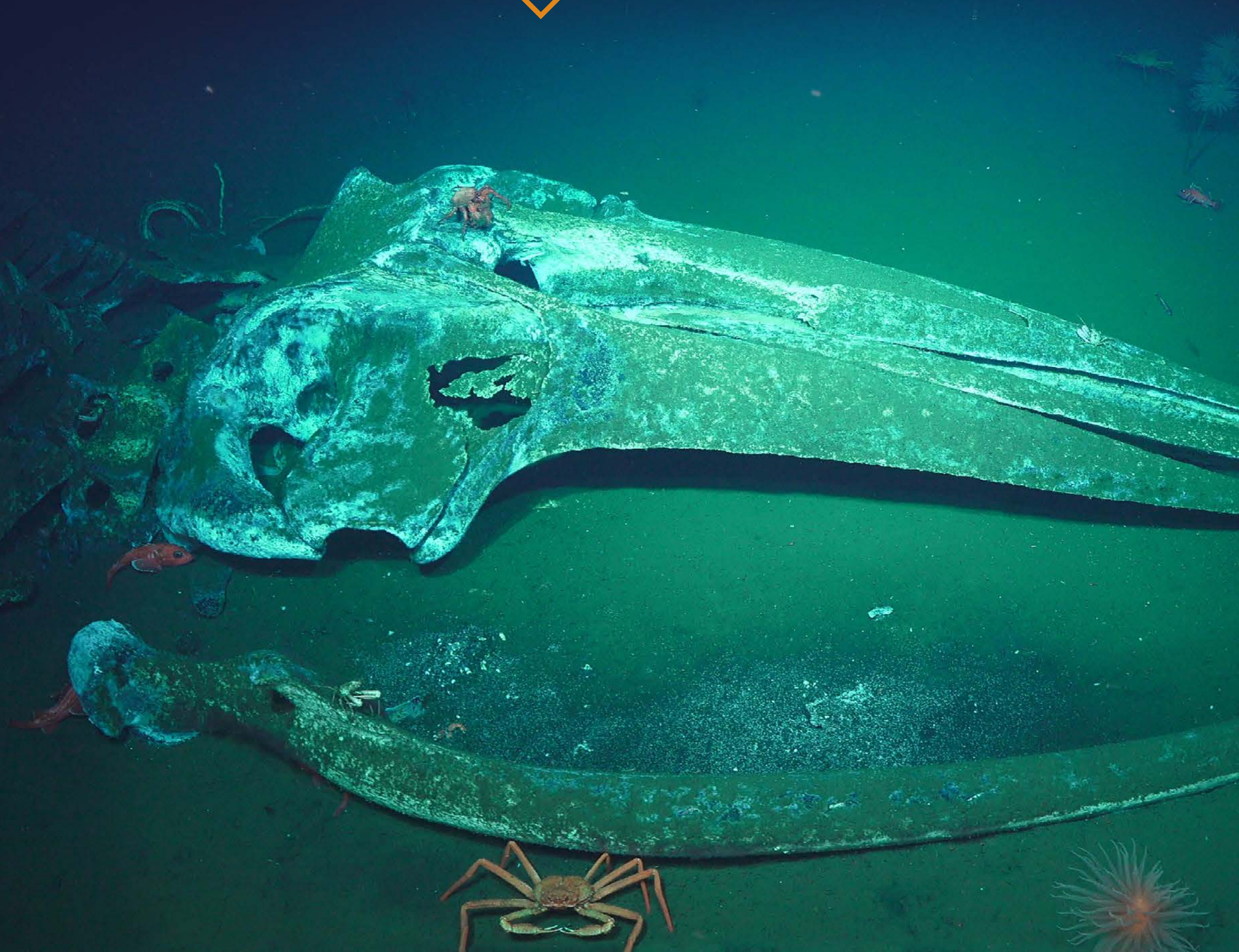
FRONT COVER
A high-density habitat consisting of deep-sea sponge, coral, and squat lobsters on a previously unmapped and unexplored seamount in Papahānaumokuākea Marine National Monument. The photo was taken during E/V *Nautilus* cruise NA101. *Image credit: D. Fornari (WHOI-MISO Facility) and OET*

The R/V *Falkor* team dove on “Rosebud,” a whale fall that was placed by researchers off San Diego, California, in La Jolla Canyon. Researchers noted changes in composition and life forms around the location in a beautiful, exciting dive investigating ecosystems unique to whale falls. *Image credit: SOI*



Windows to the Deep 2018: Exploration of the Southeast US Continental Margin

By Leslie R. Sautter, Cheryl L. Morrison, Kasey Cantwell, Derek Sowers, and Elizabeth Lobecker

INTRODUCTION

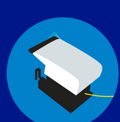
Windows to the Deep 2018: Exploration of the Southeast US Continental Margin was a 36-day expedition aboard NOAA Ship *Okeanos Explorer* to acquire data on priority exploration areas identified by the ocean management and scientific communities. This expedition involved high-resolution multibeam sonar mapping and ROV dives, ranging from 340 m to 3,400 m depth, across the southeast US continental margin (Figure 1). Operations primarily targeted areas with potential to host deep-sea coral and sponge communities, including mounds, ridges, and terraced features on the continental slope. Dive sites also included maritime heritage sites, a submarine landslide feature, and several submarine canyon slopes, some of which exhibited evidence of active cold seeps. High biological abundance was noted at six of 17 dive sites, three of which also had high biological diversity. Additionally, deep-sea corals or sponges were observed on every dive except one, which was dedicated to gas seep exploration.

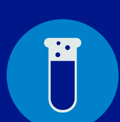
MAPPING HIGHLIGHTS

Mapping data collected during this expedition filled data gaps in the region and contributed to Seabed 2030 goals to map unexplored regions of Earth's ocean. More than 29,700 km^2 of seafloor (an area larger than the State of Maryland) were mapped at high resolution, providing new insights into this region. Although not all areas were explored using the ROV, newly mapped areas revealed interesting features on Blake Plateau, including intraslope terraces along the plateau's eastern edge, karstic features and scarps, and numerous likely biogenic ridges and mounds on the plateau's western edge in areas significantly influenced by the Gulf Stream. Due to their sizes, these biogenic features cannot be resolved from satellite data and were only revealed in detail using the ship-mounted multibeam sonar. Finding numerous and previously unknown features has implications for habitat modeling, given that similar features may occur elsewhere in the region.

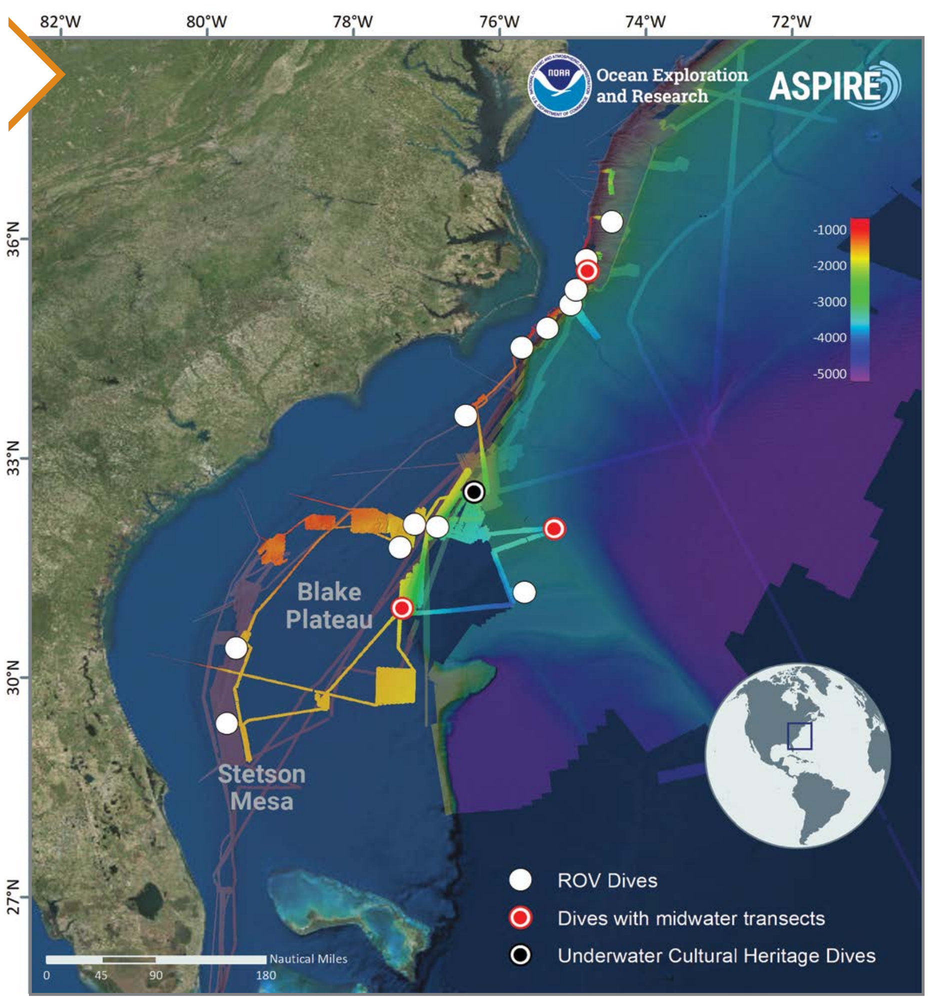
Figure 1. Summary map of the Windows to the Deep 2018 expedition.


29,700+ km^2 of seafloor mapped


17 ROV dives at a depth range of 325 to 3,436 meters


175 biological and 38 geological samples collected


140+ participating scientists, resource managers, and students



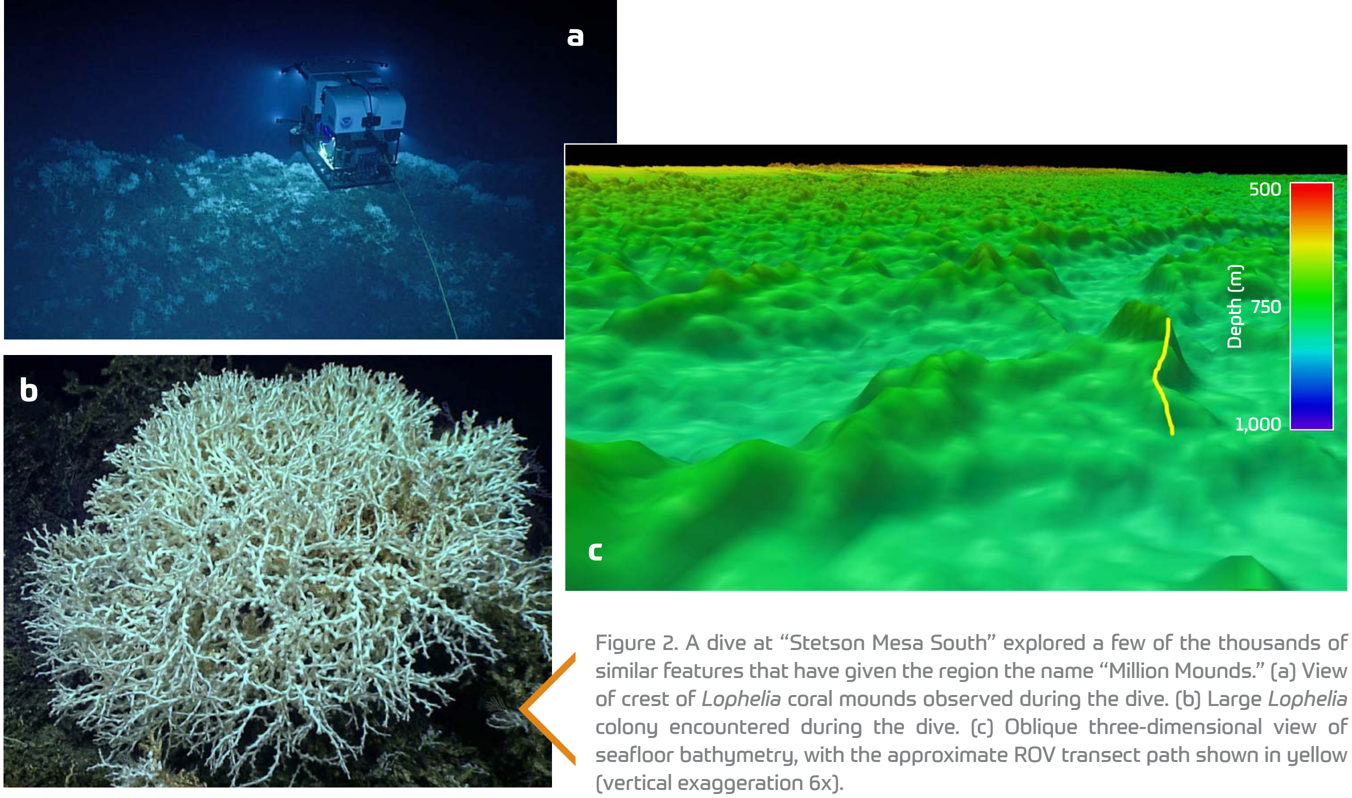


Figure 2. A dive at "Stetson Mesa South" explored a few of the thousands of similar features that have given the region the name "Million Mounds." (a) View of crest of *Lophelia* coral mounds observed during the dive. (b) Large *Lophelia* colony encountered during the dive. (c) Oblique three-dimensional view of seafloor bathymetry, with the approximate ROV transect path shown in yellow (vertical exaggeration 6x).

DEEP CORAL MOUNDS

Through both mapping and visual surveys, this expedition added substantial evidence that the numerous mounds on Stetson Mesa offshore of Florida and Georgia are comprised of thick accumulations of dead coral rubble, the remaining skeletal framework of old colonies of the stony coral *Lophelia pertusa* (Figure 2). Documenting the biogenic nature of the coral mounds along Stetson Mesa (600–780 m depth) and at Richardson Ridge (660–870 m depth) was a highlight of the expedition. Though the expedition only explored three Blake Plateau mounds, all were rich with live coral stands at their crests. The Stetson Mesa mounds are representative of thousands of similar features mapped during previous *Okeanos Explorer* expeditions, revealing one of the largest areas of potential deep-sea coral reef habitat discovered to date in US waters. These mounds range in size from 10 m to 75 m of vertical relief, with crests at depths between 600 m and 700 m, and exhibit gradual to steep slopes ranging from 15° to 30°. Skeletal framework provided the complex, hard substrate that is ideal habitat for a high diversity of organisms such as sponges, echinoderms, solitary corals, crabs, and octocorals that live both attached to the framework and within cave-like areas beneath. At the shallowest points of the Blake Plateau mounds, in areas with the strongest current velocities, thriving communities of *L. pertusa* were encountered. However, on the mound flanks and swales between crests, few living colonies were observed, and only moderate currents were encountered. The new data collected on the expedition highlights the vastness of potential deep-sea coral habitat in this region.

The Gulf Stream strongly influences all coral mounds explored. Even Richardson Ridge, located well east of the current's usual path, is affected by significant flow due to the eastward bending of the stream axis. Differences in mound distribution were noted between the Stetson Mesa and Richardson Ridge areas. While the coral mounds in the Stetson Mesa region are rounded and fairly evenly distributed, Richardson Ridge is composed of a series of mounds in a chain-like arrangement, shaped by significant erosion from slumping, resulting in steep (>30°) walls and a narrow ridge crest. The northernmost coral mound visited, within the Cape Fear Lophelia Banks Deepwater Coral Habitat Area of Particular Concern, is significantly shallower than the other mounds and resembles the Stetson Mesa mounds, although live coral coverage is lower.

INTRASLOPE TERRACES

Several ROV dives along the Blake Escarpment revealed a high diversity of deep-sea corals and sponges on low relief, intraslope terraces (Figure 3). Dives were conducted along the outer reaches of Blake Plateau, where the relatively flat-lying rock-layers (strata) are exposed as depths increase toward the Blake Escarpment. The edges of these strata form step-like areas, often resulting in rock surfaces where invertebrates settled. Dives at Blake Escarpment North (1,675–1,740 m depth), Blake Escarpment South (1,246–1,310 m), and Richardson Scarp (868–1,006 m) each began at the foot of a terraced feature identified in the high-resolution multibeam maps. Backscatter imagery for these dive sites showed high-intensity returns, indicating

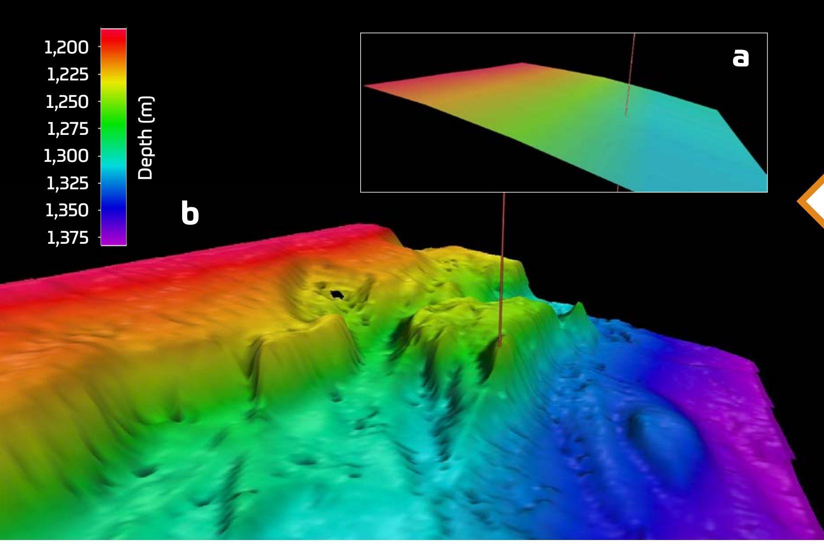
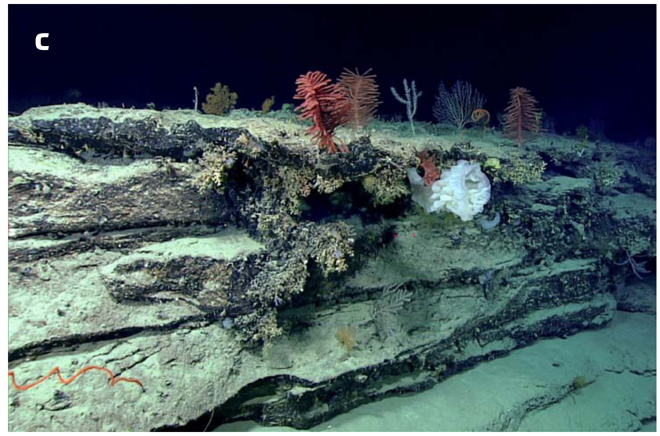


Figure 3. Prior to the Windows to the Deep 2018 expedition, based on satellite altimetry (V18.1 of Smith and Sandwell, 1997), this section of the Blake Escarpment appeared to exhibit a low slope with no distinct features. (a) Satellite altimetry at the Blake Escarpment South location (red vertical line in b). (b) During the mapping leg of this expedition, multibeam data revealed a series of terraced features. (c) ROV exploration documented highly diverse, dense communities of deep-sea corals and sponges throughout the dive.



relatively hard substrate, and potentially suitable habitat for deep-sea corals and sponges. The seafloor at the base of these features was very low-sloped pelagic mud seafloor, with intermittent rock slab outcrops at the terrace steps. Generally, echinoderms such as brittle stars, sea stars, and pancake urchins, along with sea pens and cerianthid tube anemones, were observed in the mud habitat, though bamboo corals and sea pens were present at Blake Escarpment North as well.

Exposed rocks were sometimes observed on steep slopes at the edges of the terraces, most commonly composed of interbedded indurated/semi-lithified pelagic muds, likely of biogenic origin. Many surfaces were coated with what appears to be ferromanganese crust. In nearly all areas, rock slabs served as excellent substrate for numerous species of corals, sponges, and many mobile organisms. The highest diversity of black corals and octocorals occurred at the southern portion of the Blake Escarpment, making this dive a highlight of the expedition.

DEEP TERRACE, SEDIMENT PLAINS, AND GIANT BEDFORMS

Three ROV dives were completed over mostly sedimented benthic environments in deeper waters (> 2,500 m). These sites each exhibited unique geomorphology. The Blake Ridge site (3,360–3,420 m) had the highest coverage of hard substrate, consisting of tabular mudstones and gravel that was colonized by demosponges (e.g., *Phakellia* and *Geodia*) and glass sponges, as well as several unbranched octocorals (*Convexella* spp.) and a stalked tunicate. High-resolution bathymetry indicated a gently sloped landscape with minimal terracing. Although backscatter surfaces showed this dive was positioned within a large area of high-intensity backscatter, much of the site was covered with mud that often included large areas of gravel that appeared to have a ferromanganese crust. Occasional outcrops of tabular mudstones that tilted beneath the muds supported numerous large sponges throughout these sites. It is likely that the seabed mud was underlain by this hard substrate and the sonar penetrated the mud sediment veneer, generating the observed high-intensity return. Gravel was often concentrated in the lee of large sponges, indicating episodes of significantly high current velocities.

The third dive of the expedition (3,330–3,350 m) explored an area of Blake Ridge characterized by enormous undulating dune-like bedforms where crest-to-crest lengths exceed 800 m. Sediments collected were stiff and cohesive and were dominated by clay-sized particles (likely calcium carbonate nannofossils). Planktonic foraminifera were the primary component of the silt-size fraction. One portion of a bedform sloped at least 70° and exhibited ripples from horizontal currents moving along the wall. No rock outcrops were present. A few of the sessile organisms documented during the dive were entwined with *Sargassum*, likely a result of the macroalgae drifting in the current after sinking from the surface.

SUBMARINE CANYON SLOPES

Five dives were located on steep slopes within and between submarine canyons along the North Carolina continental slope, with dives ranging from 340 m to 1,700 m depth. Substrate throughout these dives was consistently clay/silt particles (mud), comprised mostly of calcareous microfossils and an increasing fraction of terrigenous material in shallower areas. No rock or hard substrate was encountered. However, some areas showed significant mud compaction that facilitated the formation of the steeply sloped seabed. Bacterial mats indicative of methane gas seeps were seen at Hatteras Canyon (310–520 m depth), Keller Canyon

(510–720 m), and Pea Island (340–520 m). Active methane seep bubbling was observed at both Hatteras Canyon and Pea Island, although gases were not venting vigorously. Pea Island appeared to be the most active of the sites visited, as evidenced by the high density of white bacterial mats, with underlying black, anoxic sediments. No evidence of methane seepage was seen during the other canyon dives.

The biota observed at these five submarine canyon slope areas were typical of sedimented habitats, including anemones, gastropods, and echinoderms. Squid and octopus were commonly observed, along with eelpouts and rattail fishes. Although some taxa were common across the canyon slope sites, each site also had unique benthic biota. For example, brittle stars dominated at the South of Pamlico site, whereas high abundances of mud stars (*Plutonaster* sp.) were observed on the seafloor at Intercanyon Ridge and Hatteras Canyon, and quill worms were common at the Pea Island site. Numerous pycnogonids (sea spiders) were seen on the compacted mud walls of Keller Canyon. Exploration at Pea Island revealed an active water column, with instances of bentho-pelagic coupling, where benthic organisms were observed preying upon midwater organisms.

SHELF-EDGE ROCKY LEDGES

Initially, a dive was planned to explore and identify a potential World War II wreck off the North Carolina coast. Previously mapped high backscatter returns were coincident with a large, high-relief structure at the edge of the continental shelf (Figure 4). Additional multibeam tracklines verified the presence of a structure and enhanced bathymetry available for this site. Anomalous sonar returns were also observed in the water column immediately above the site. However, no wreck was discovered. Instead, the ROV encountered a steep scarp with slopes ranging from 20° to 50°, exhibiting many layers of outcropping sedimentary rocks. This rock feature—subsequently named Wreckless Scarp—provides habitat for a rich diversity of fishes and invertebrates. The close proximity to the Gulf Stream undoubtedly helps this community thrive on the hardbottom substrate.

MUD CLIFFS

The final dive (1,760–1,880 m depth) of the expedition explored the lower portion of the Currituck Landslide feature (1,760–1,880 m depth). A large 100 m vertical wall of cohesive mud was explored. Meter-high mud blocks were strewn at the wall's base, having detached from the sheer cliff. Despite the lack of hard rock substrate, the mud cliffs and consolidated mud blocks created habitat for corals, sponges, and numerous echinoderms. The most conspicuous echinoderm was the brisingid sea star that inhabited many surfaces, including the sheer cliff face. Corals encountered included the stony solitary coral *Desmophyllum dianthus*, plus *Chrysogorgia*, *Anthomastus*, and *Paramuricea*, as well as bamboo corals *Acanella* and *Keratoisis*. The only black coral observed was *Bathypathes*, which grew on the sheer wall. Fishes included halosaurs, *Bathysaurus*, synaphobranchid eels, and the flatnose codling (*Antimora rostrata*).

LEGACY OF DATA

During the Windows to the Deep 2018 Expedition, we were able to observe a variety of seafloor features identified by both the expedition's mapping efforts and previous expeditions conducted by NOAA and the US Geological Survey. High-resolution bathymetry is sparse across this region, and important discoveries are made with each new survey. Many exciting biological observations were made, including high-density and high-diversity coral and sponge communities, commercially important species in areas where they have not been previously observed (e.g., *Chaceon fenneri* documented in newly explored areas of the Blake Plateau), dramatic predation events, mating, juveniles utilizing habitat, species at deeper depths or wider geographic distributions than previously known, associations between corals and/or sponges with other species, sightings of rare species, and marine debris at most dive sites. Expedition data are now publicly available and have already been used to guide additional discoveries (pages 104–105).

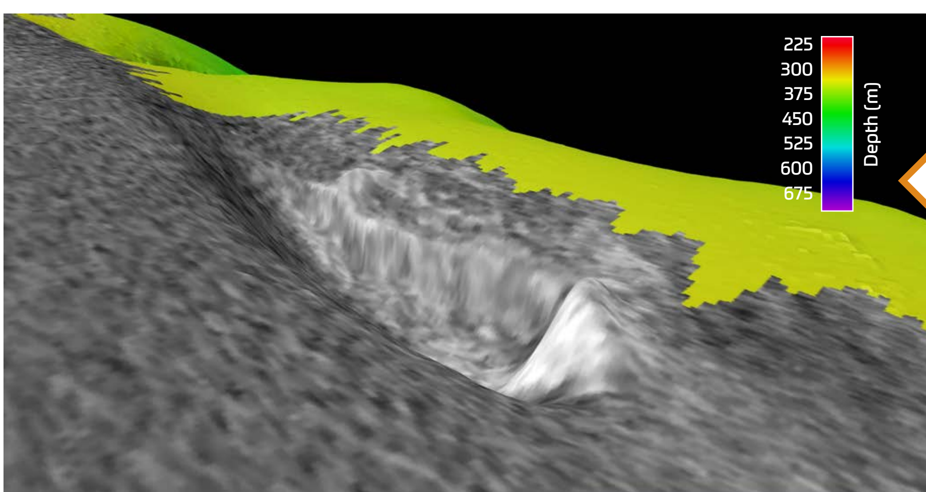


Figure 4. Three-dimensional view of the Wreckless Scarp sonar anomaly, with multibeam sonar backscatter intensity draped on bathymetry (3x vertical exaggeration). Brighter areas are stronger return echo intensities, which turned out to be rocky reef habitat and not a shipwreck.