Comparing Seabed Geomorphology at Several Methane Seeps Found Along the North Carolina – Virginia Margin

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ABSTRACT

NOAA Office of Ocean Exploration and Research conducted multibeam bathymetric surveys of the Southeast U.S. continental margin aboard the NOAA Ship *Okeanos Explorer* from May 30th through July 12th, 2019. The goal of the *Windows to the Deep 2019* expedition (EX1903) was to collect information about previously unknown or poorly understood deep water habitats along the southeastern United States. A number of the expedition's dives were conducted to investigate active methane seeps previously identified using multibeam analysis of the water column. The remotely operated vehicle (ROV) *Deep Discoverer* investigated two seep sites along intra-canyon ridges of different depths at Bodie Island Seep (360-415 m) and Norfolk Deep Seep (1,600 m). ROV dive videos revealed some active methane seeps, previously unknown chemosynthetic habitats with the presence of seep-associated bacterial mats, and sizable beds of the chemosynthetic mussel *Bathymodiolus childressi*. These mussels were observed growing on and around authigenic carbonate outcrops. Multibeam sonar data collected during EX1903L1 and previous *Okeanos Explorer* mapping cruises were used to generate high resolution bathymetry, slope, and classified backscatter intensity surfaces to investigate the geomorphology, and characterize the methane seep sites at different depths. A negative correlation between slope and backscatter intensity was found at both Norfolk Deep Seep (R^2 = 0.5179) and Bodie Island Seep (R^2 = 0.4893), suggesting that methane seeps can be identified by areas exhibiting low slope and high intensity of backscatter return.

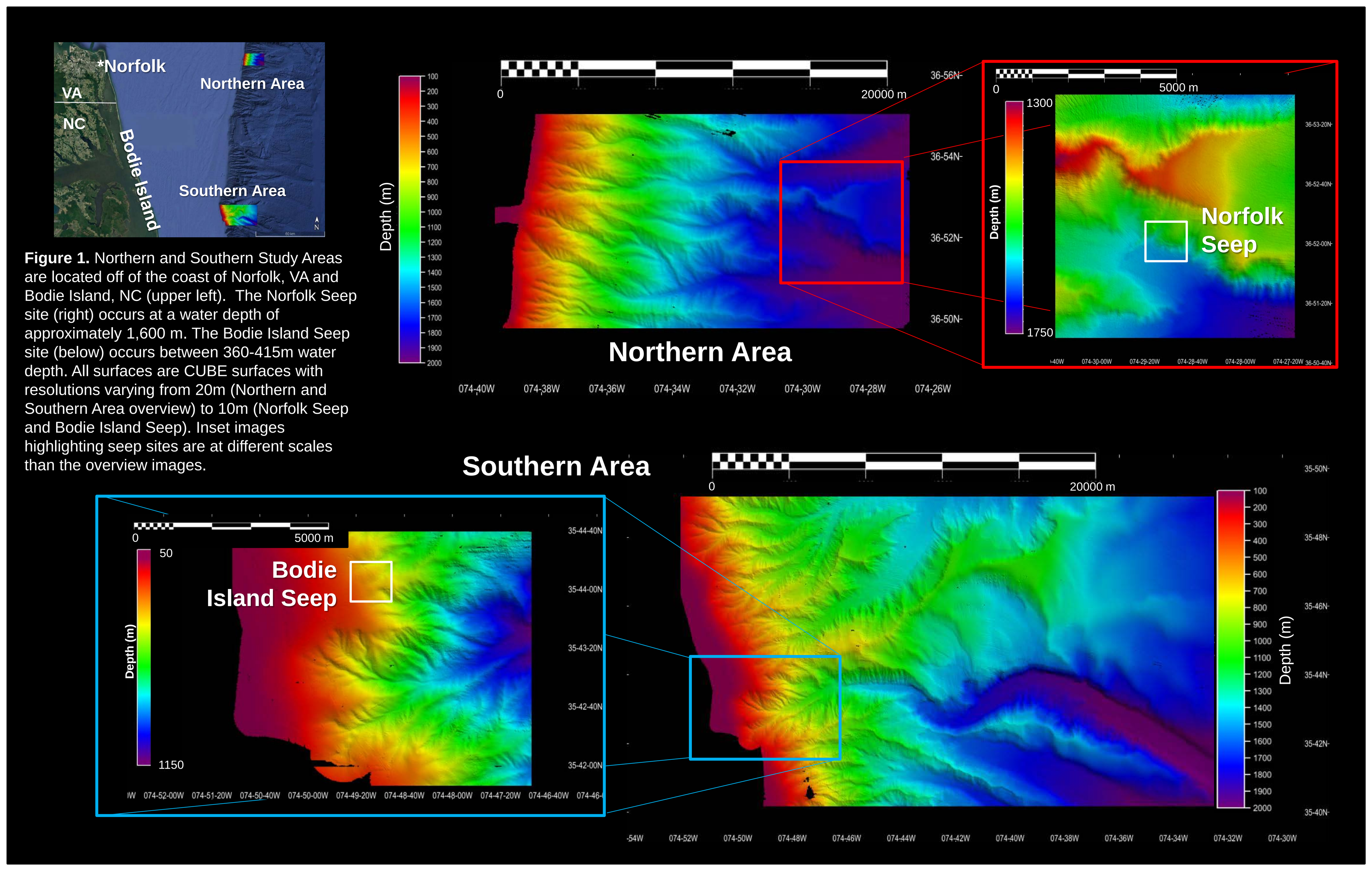

Figure 1. Northern and Southern Study Areas are located off of the coast of Norfolk, VA and Bodie Island, NC (upper left). The Norfolk Seep site (right) occurs at a water depth of approximately 1,600 m. The Bodie Island Seep site (below) occurs between 360-415m water depth. All surfaces are CUBE surfaces with resolutions varying from 20m (Northern and Southern Area overview) to 10m (Norfolk Seep and Bodie Island Seep). Inset images highlighting seep sites are at different scales than the overview images.

BACKGROUND

NOAA's *Windows to the Deep 2019* expedition, conducted on the NOAA Ship *Okeanos Explorer* was performed to better understand various deep-sea habitats along the U.S. continental margin that were identified by the ocean management and scientific communities. Two of the nineteen dives were conducted to view and characterize cold methane seep sites: Bodie Island Seep (360-415 m) off the North Carolina coast and a previously unexplored portion of the Norfolk Deep Seep (1,530-1,625 m) (Fig. 1). Methane seeps along the Atlantic margin were first identified by the *Okeanos Explorer* in November 2012, and since then over 570 sites have been identified between Cape Hatteras and Cape Cod using sonar data provided by the ship (Skarke et al., 2014). Methane emissions from seeps contribute to atmospheric input and ocean acidification, provide habitats for chemosynthetic communities, and affect distribution of energy resources (Skarke et al., 2014). These seeps are biogenic, produced by microbes as a byproduct of the degradation of organic matter in the shallow sediments. Sites explored by NOAA's ROV *Deep Discoverer* during EX1903L2 included communities of filamentous bacteria *Beggiatoa* and *Bathymodiouls* mussels, both of which are dependent on the methane or its hydrogen sulfide byproduct (NOAA OER, Sautter et al., 2019, Skarke et al., 2014). Active bubbling was seen intermittently on ROV dive video at Bodie Seeps, and not at all during the Norfolk Deep Seeps dive, an occurrence common even among active seeps. A physical byproduct of biogenic methane production also observed is production of authigenic carbonate rocks beneath the sediment and subsequent exposure at the surface by erosion (NOAA OER, 2019). The aim of this research is to characterize methane seep site geomorphology by comparing slope values against backscatter intensity values near verified seeps to find possible correlations. Using profiles of bathymetry, slope, and backscatter of some intra-canyon ridges along the dive track further help visualize regions of correlation.

Norfolk Deep Seeps

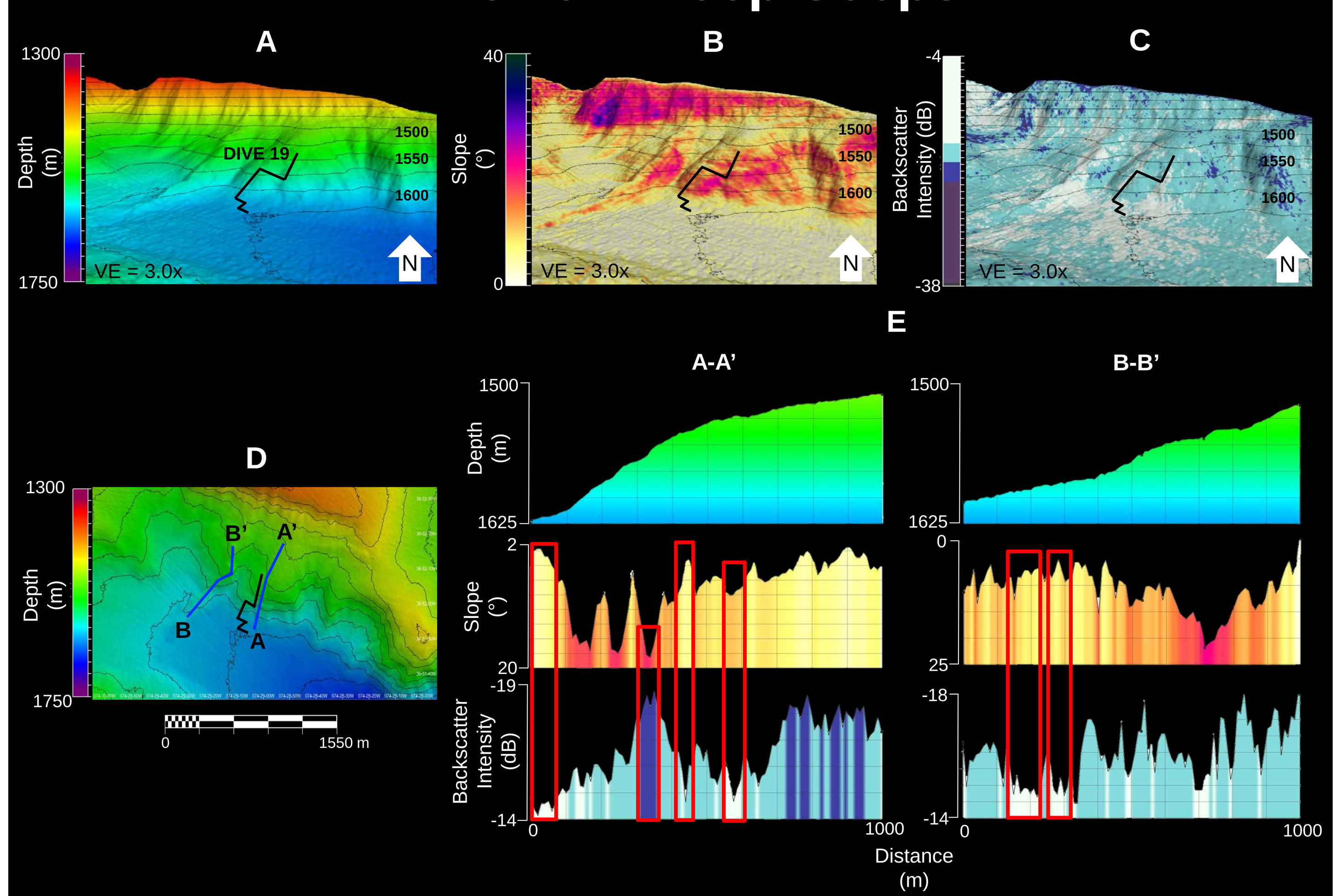

Figure 2. 3D images of the Norfolk Canyon Seep site showing **A)** depth, **B)** slope, and **C)** classified backscatter intensity with the dive track depicted as a black line. Pinks and purples in B represent higher sloped areas. In C, white areas indicate high intensity backscatter returns. **D)** Locations of profiles A-A' and B-B' are depicted by blue lines within the study area and the ROV dive track is represented by the black line. **E)** Bathymetric, slope, and backscatter intensity profiles are shown at the same scale, with negatively associated regions outlined with a red box (VE = 2.9x).

Bodie Island Seeps

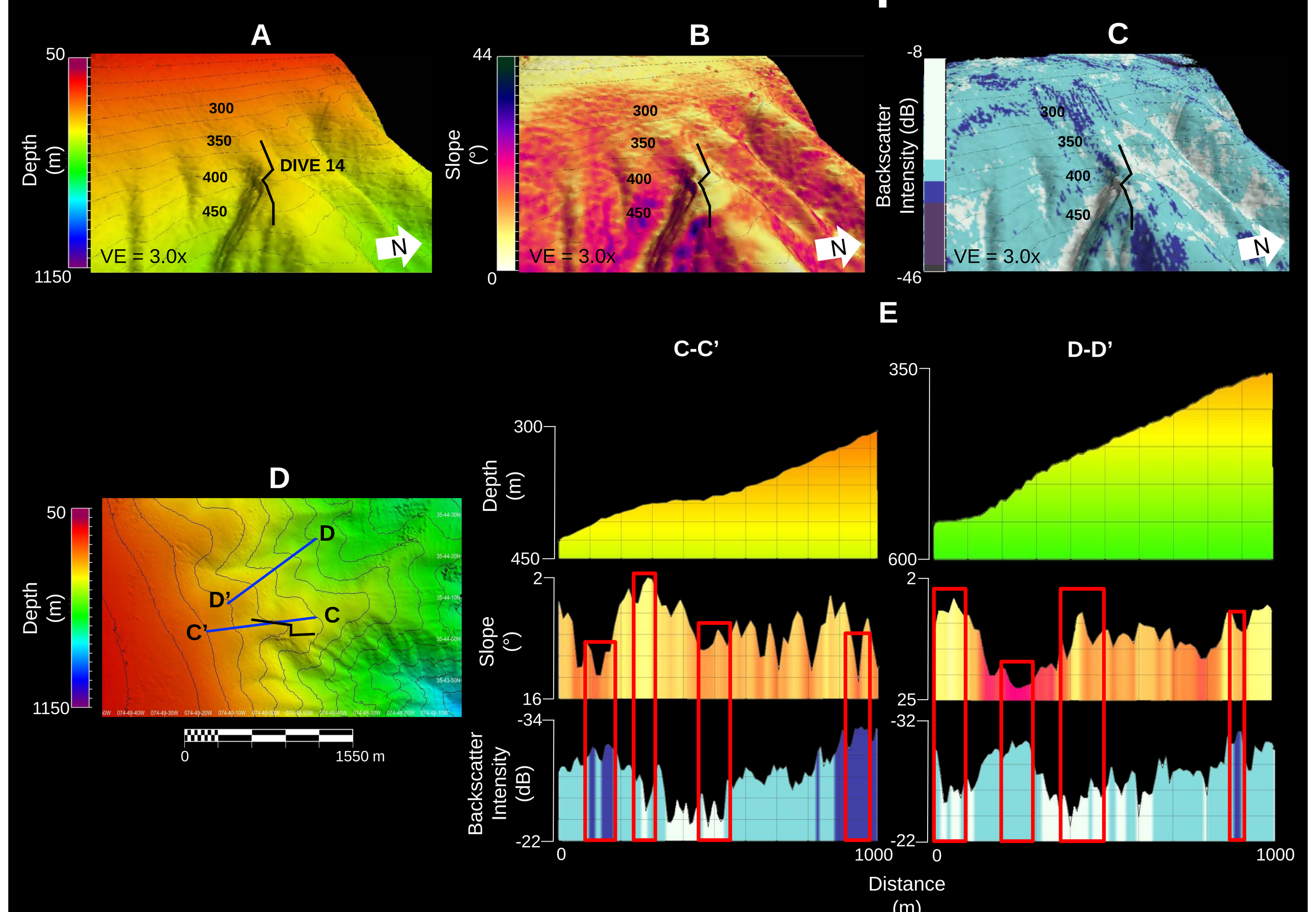

Figure 3. 3D images of the Bodie Island Seep site showing **A)** depth, **B)** slope, and **C)** classified backscatter intensity with the dive track depicted as a black line. Pinks and purples in B represent higher sloped areas. In C, white areas indicate high intensity backscatter returns. **D)** Locations of profiles C-C' and D-D' are depicted by blue lines within the study area and ROV dive track are represented as a black line. **E)** Bathymetric, slope, and backscatter intensity profiles are shown at the same scale, with negatively associations regions outlined with a red box. (VE = 2.2x)

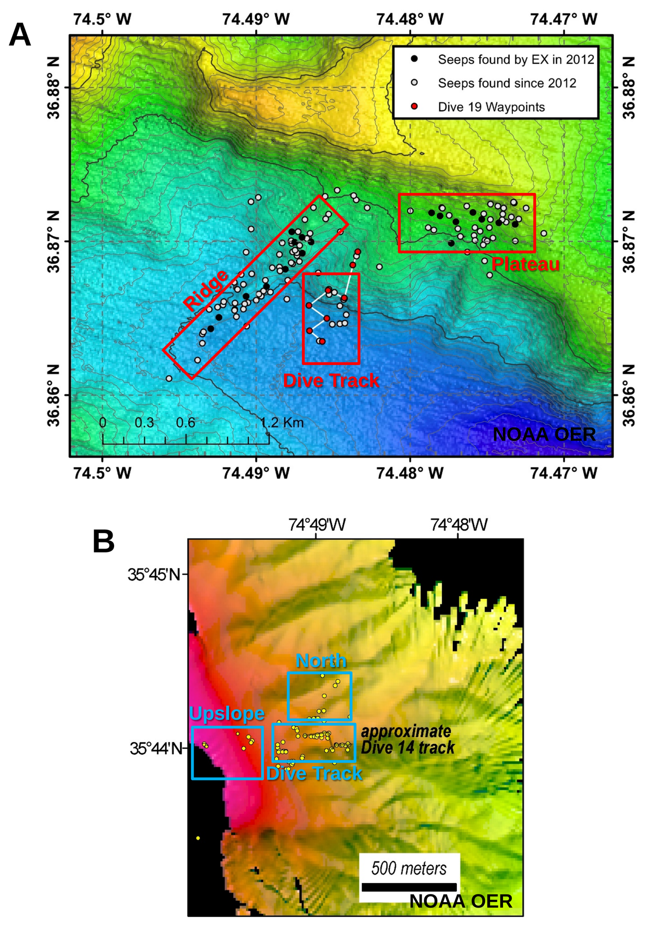

Figure 4. A) Approximate track of dive 19 (Norfolk Deep) with focus areas highlighted in red. **B)** Approximate track of dive 14 (Bodie Island) with focus areas highlighted in blue (Image credits: NOAA OER).

Table 1. Average slope and Backscatter intensity values from study areas around the Norfolk Deep dive site.

Norfolk Seeps Averages				
Area	Avg. Slope (°)	St. Dev.	Avg. Backscatter Intensity (dB)	St. Dev
Plateau	7.756	3.459	-16.506	1.301
Dive Track	8.836	5.905	-16.483	1.765
Ridge	9.229	4.397	-16.278	1.515
All Samples	8.607	4.686	-16.422	1.525

Table 2. Average slope and Backscatter intensity values from study areas around the Bodie Island dive site.

Bodie Island Seeps Averages				
Area	Avg. Slope (°)	St. Dev.	Avg. Backscatter Intensity (dB)	St. Dev
Dive Track	10.827	4.860	-27.611	2.972
North	12.717	6.009	-27.855	2.365
Upslope	8.786	3.091	-28.492	2.509
All Samples	10.777	5.018	-27.986	2.625

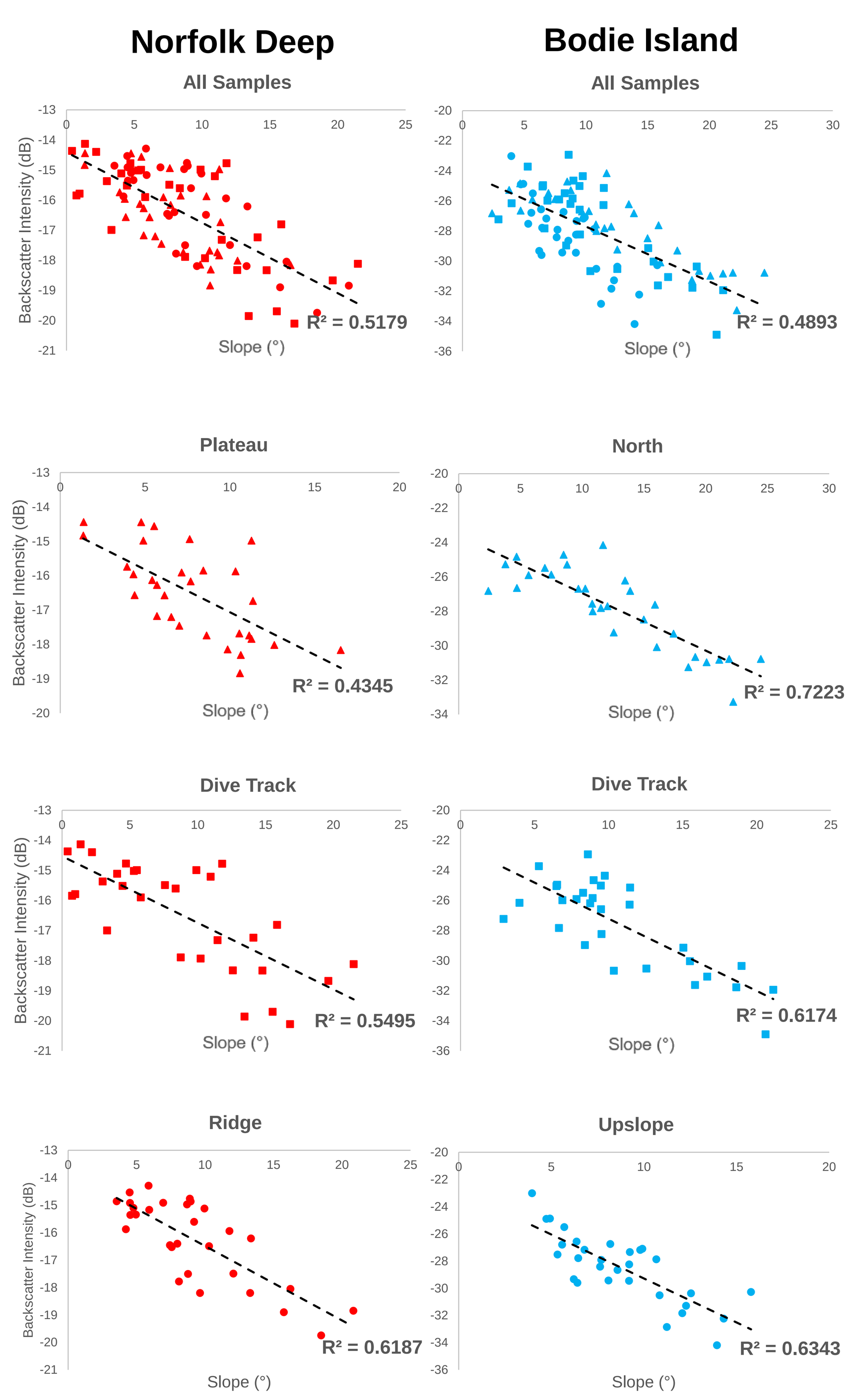

Figure 5. Scatterplots of slope values vs. backscatter intensity values for Norfolk Deep focus areas (Fig. 4A) in red and Bodie Island focus areas in blue (Fig. 4B).

METHODS

- NOAA OER conducted bathymetric surveys aboard the *Okeanos Explorer* using a hull-mounted 30kHz Kongsberg EM302 during the *2019 Windows to the Deep* expedition EX1903L2.
- Overview surfaces of Northern and Southern areas used lines of data from primarily EX1903, EX1806, and EX1206 with single lines from other *Okeanos Explorer* expeditions to fill holes.
- Study areas were identified through high definition video provided by the ROV *Deep Discoverer*.
- CARIS HIPS and SIPS 11.2 was used to process raw multibeam data and create CUBE BASE 2D and 3D surfaces as well as slope and classified backscatter intensity surfaces and profiles.
- Study sites were separated into three focus areas based on known seep locations.
- Profiles of depth, slope, and classified backscatter intensities generated along the intra-canyon ridges near ROV dives aid in visualization of the correlation of slope and backscatter. Using the CARIS HIPS tooltip function, slope and backscatter intensities were recorded (n=30) randomly within the area near to each profile. A linear regression was then performed.

ACKNOWLEDGEMENTS

This research would not have been possible without NOAA OER and the hardworking crew of the NOAA Ship *Okeanos Explorer* that participated in the *Windows to the Deep* 2019 expedition. Special thank you to Dr. Leslie Sautter who's continued feedback and guidance was instrumental, and my fellow BEAMers who helped and supported me throughout this process. Many thanks to CARIS for Academic Partnership, the College of Charleston School of Sciences and Mathematics, and eTrac inc. along with other industrial partners for travel assistance to this meeting. This project was conducted as a part of College of Charleston's BEAMS program.

Dive Images

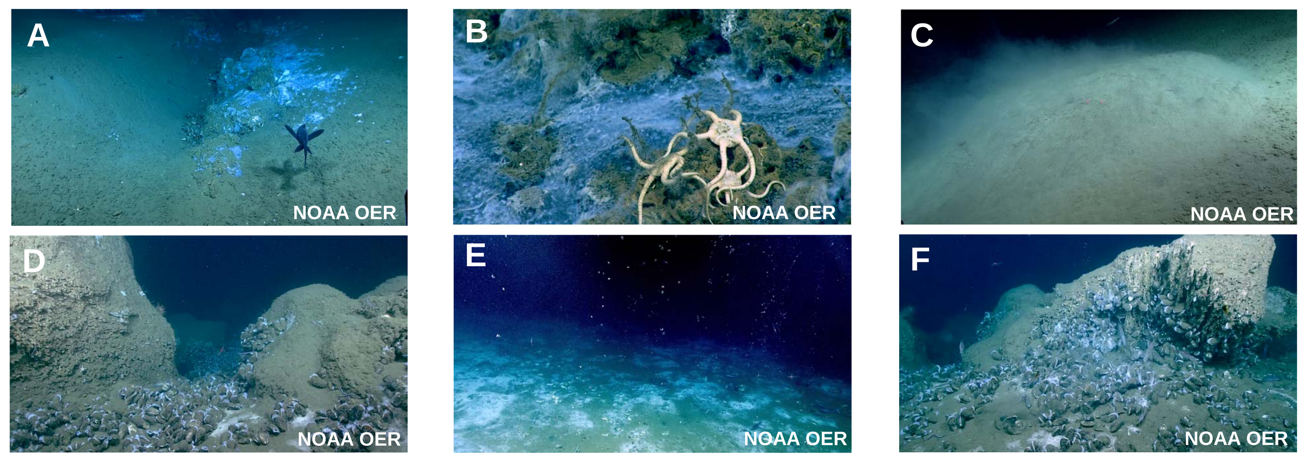

Figure 6. ROV Deep Discoverer video screen grabs from Norfolk Deep seeps **(A, B, C)** and Bodie Island seeps **(D, E, F)**. **A)** Bacterial mats and chemosynthetic mussels clustered around outcropping authigenic carbonate. **B)** Close up of a bacterial mat with brittle stars in the foreground. **C)** A low relief mound that was discharging an unknown fluid that was denser to the water column. **D and F)** A colony of *Bathymodiouls* mussels near large outcropping carbonate. **E)** Bubbling due to active seeping from the seafloor, with white bacterial mats (Image credits: NOAA OER).

RESULTS

Norfolk Deep Seeps

- A negative correlation exists between backscatter intensity and slope (R^2=0.5179) for all sites analyzed, with slope ranging from 0 to 21° (Fig. 5A).
- The strongest negative correlation existed along the ridge (R^2=0.6187) and the weakest occurred on the plateau (R^2=0.4345) (Fig. 5A).
- Profiles of selected ridges (A-A', B-B') show negative associations between slope and backscatter in areas of mild slopes, and little relationship in areas of low relief (Fig. 2E).
- ROV video shows multiple sites of authigenic carbonate outcropping from unconsolidated sediments, a low relief mound discharging brine, microbial mats, and colonies of *Bathymodiouls* mussels (Fig. 6).

Bodie Island Seeps

- A negative correlation exists between backscatter intensity and slope (R^2=0.4893), with slope ranging from 2 to 24° (Fig. 5B).
- The strongest negative correlation existed in the north study area (R^2=0.7223), while the weakest existed in the area of the dive track (R^2=0.6174) (Fig. 5B).
- Slope and backscatter profiles from selected ridges (C-C', D-D') displayed multiple sections negative association (Fig. 3E).
- ROV video displayed areas of active bubbling, large authigenic carbonate outcrops, microbial mats, and the first observed colonies of *Bathymodiolus* mussels at a cold seep site between Norfolk Canyon deepwater (~1,400 m) and Blake Ridge diapir deep seep (~2,100 m) off of South Carolina (NOAA OER, 2019)(Fig. 6).

DISCUSSION

Despite differences in depth and location along the Southeast US continental margin, substrates at both Norfolk Deep and Bodie Island study areas exhibited significant moderate to strong negative correlations between backscatter intensity and slope in the vicinity of known seeps, indicating lower slopes had higher intensity of acoustic signal return. Areas of high backscatter intensity likely are due to the authigenic carbonate byproduct of anaerobic oxidation of methane occurring just beneath the surface sediments (Skarke et al., 2014), providing a harder surface for acoustic signal reflection. Outcropping carbonate observed during ROV dives was surrounded by colonies of the chemosynthetic *Bathymodiolus* mussels (Fig. 6A, D, F), with their patchy distribution possibly indicating spatial variation of methane hydrate supply beneath the seafloor (NOAA OER, 2019). ROV dive video showed that areas of lower slope exhibited less outcropping carbonate and more visible bacterial mats (Fig. 6E), but these areas still had colonies of chemosynthetic bivalves near and on top of the mats. The significant negative correlation between slope and backscatter intensity exhibited at seep sites could be used in conjunction with water column analysis to better pinpoint methane seep dive sites for future expeditions.

REFERENCES

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