Characterizing Canyon Geomorphologies within Currituck Submarine Landslide Complex, Mid-Atlantic U.S. Continental Margin

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NOAA Ship *Okeanos Explorer*

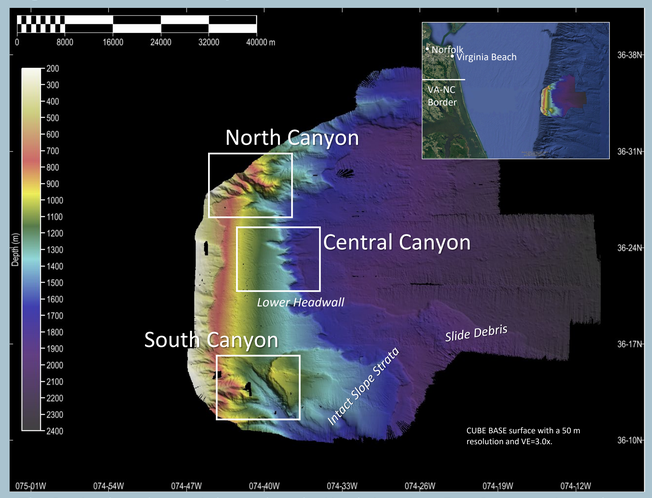
BACKGROUND

Submarine canyons represent important geological features that have the ability to both support and threaten life above and below the sea surface. Steeply sloped canyon walls can provide underwater habitats for corals and other marine life, but unstable slopes can also fail, creating underwater landslides that have the potential to generate tsunamis (Driscoll et al., 2000). The formation of submarine canyons is thought to be linked to slope failures that create sediment slumps and carve away at rock scarps (Hill et al., 2014). However, the causes of these slope failures remain largely uncertain, but links to high sedimentation rates have been hypothesized (Hill et al., 2014; Hill et al., 2017).

Currituck, located approximately 93 km east of the North Carolina coast, is a submarine canyon and landslide complex on the continental slope (Fig.1). The study area ranges from 200 to 2400 m in depth, with the upper section having a gentle slope. Towards the middle of the study area, there is a steeper section before advancing towards the abyssal plain. Located within the study area are multiple examples of submarine landslides that appear to be developing into submarine canyons. Currituck, therefore, is an integral study area to further investigate the origins of submarine canyons (Hoy, 2021).

Recent NOAA Ship *Okeanos Explorer* missions, including EX1903L2 and EX2103 conducted along the mid-Atlantic continental margin have expanded bathymetric sonar ROV data for Currituck. Utilizing bathymetric data, three study sites have been identified, consisting of two submarine canyons and a lower headwall pocketed with past submarine landslides. The sites are here referred to as North Canyon, Central Canyon, and South Canyon, and have depths ranging from 200-1600 m, 1100-1900 m, and 600-1500 m, respectively. ROV HD video from EX1903L2 – Dive 15 was utilized to ground-truth bathymetric data and visualize seafloor habitats and biota. The purpose of this study is to understand the geomorphology of the Currituck region to provide insight into the occurrence of submarine landslides and the formation of submarine canyons.

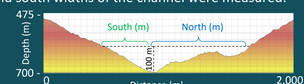
Figure 1. Currituck Study Area and Site Locations



The Currituck study area is located on the North American East Coast continental margin approximately 93 km from the North Carolina coast. The depth of the study area ranges from 200 to 2400 m. Within the study area are three study sites that feature submarine canyons. The sites here are referred to as North Canyon, Central Canyon, and South Canyon.

METHODS

- Multibeam sonar data were collected on expeditions EX1903L2 and EX2103 aboard the NOAA Ship *Okeanos Explorer* using a Kongsberg EM 302 and EM 304, respectively.
- HD video of benthic habitats was collected with ROV *Deep Discoverer* during EX1903L2 - Dive 15.
- CARIS HIPS & SIPS 11.4 was used to process raw multibeam sonar data and produce 20 m, 25 m, and 50 m resolution CUBE bathymetric and slope surfaces, contour layers and depth profiles.
- Geomorphology of submarine canyons was compared using vertical relief and channel symmetry.
- Canyon axis depth profiles and cross-channel profiles were generated along the thalweg of each canyon at the intersection of the main channel axis profile and contour lines.
  - At 100 m above the canyon thalweg, the north and south widths of the channel were measured.
  - A ratio of **South(m):North(m)** was used as a Channel Symmetry Index (CSI), where:
    CSI = 1 is a symmetric canyon channel,
    CSI < 1 is an asymmetric channel with the thalweg skewed to the south (see diagram at right), and
    CSI > 1 is an asymmetric channel with the thalweg skewed to the north.



ACKNOWLEDGEMENTS

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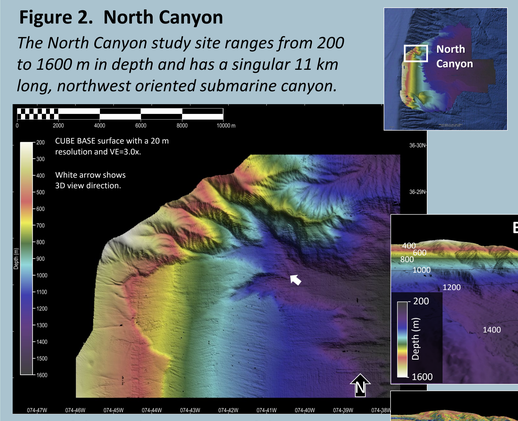
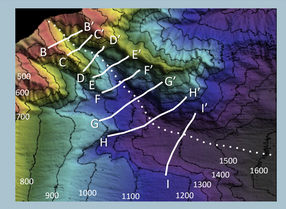
Figure 2. North Canyon

The North Canyon study site ranges from 200 to 1600 m in depth and has a singular 11 km long, northwest oriented submarine canyon.

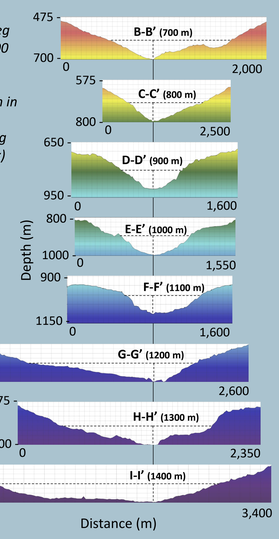


Much of the southwest section of this site is comprised of substrate sloping at <5°. North Canyon, however, has slopes as high as 45° with multiple intra-canyon ridges and channels converging into a larger feature.

Note different depth ranges for study sites



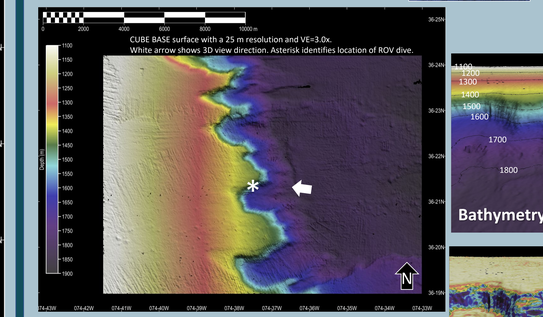
8 cross-channel profiles (at thalweg depths 700 to 1400 m) along North Canyon's axis illustrate variation in canyon channel shape and thalweg location. (VE=2.0x)



(right) Cross-channel profiles throughout this canyon are V-shaped, suggesting a younger canyon age or more resistant substrate. At shallower depths (700-800 m) the thalweg is skewed to the south, but at depths between 900 and 1000 m the channel is more symmetric. The thalweg is skewed north between 1200 and 1400 m water depth. Channel widths are quite variable, ranging from 660 to 2250 m.

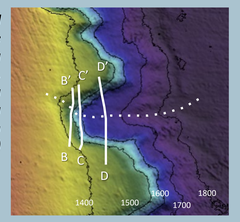
Figure 3. Central Canyon

The lower headwall of Central Canyon study site features slumped areas of potential submarine canyon formation with a depth range of 1100 to 1900 m.

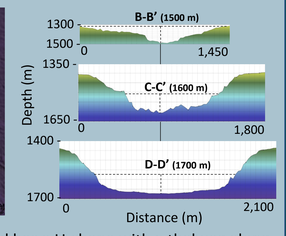


Along the slumped areas, the upper scarp exhibits a steeper range of slopes from 20° to 45°. The lower sections have a lower slope of 5° to 15°. Young canyons from slumping carve away the lower headwall.

Note different depth ranges for study sites

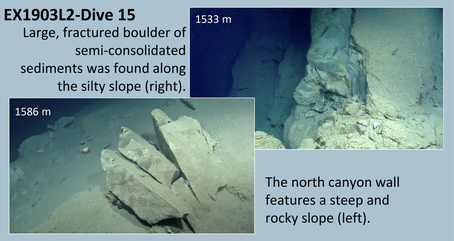


Three cross-channel depth profiles were generated at thalweg depths of 1500, 1600, and 1700 m for a single slumped area within Central Canyon study site. (VE=2.0x)



(above) The canyon channel has a U-shape with a thalweg along the channel's center at depths ranging from 1500 to 1700 m. Cross-channel profile widths vary from 900 to 1360 m.

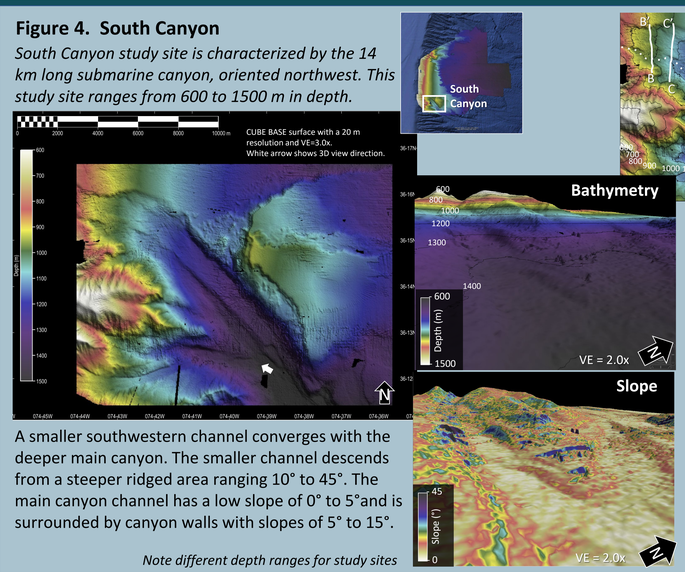
EX1903L2-Dive 15
Large, fractured boulder of semi-consolidated sediments was found along the silty slope (right).



The north canyon wall features a steep and rocky slope (left).

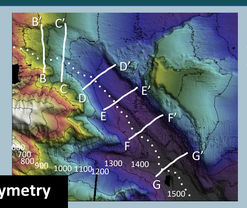
Figure 4. South Canyon

South Canyon study site is characterized by the 14 km long submarine canyon, oriented northwest. This study site ranges from 600 to 1500 m in depth.



A smaller southwestern channel converges with the deeper main canyon. The smaller channel descends from a steeper ridged area ranging 10° to 45°. The main canyon channel has a low slope of 0° to 5°and is surrounded by canyon walls with slopes of 5° to 15°.

Note different depth ranges for study sites



Variations in geomorphology along South Canyon were analyzed using six cross-channel profiles at thalweg depths between 1000 and 1500 m. (VE = 2.0x)

(below) South Canyon's channel displays consistent vertical relief of only 100 m. Its south-skewed thalweg is due to a shallower secondary channel to the north. Because of the secondary channel, the width of the cross-channel profiles was much greater and ranged from 2300 to 3460 m.

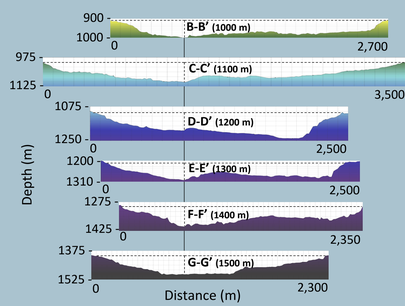
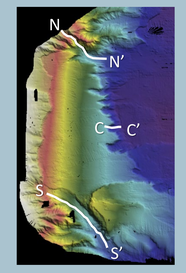
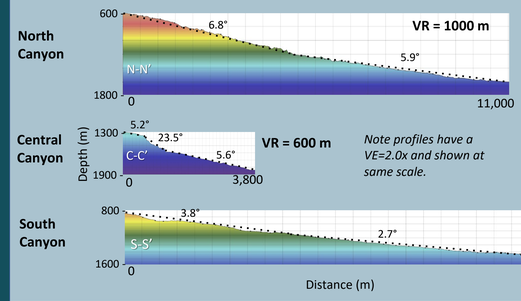


Figure 5. Comparative channel axis profiles

Canyon axis profiles were drawn from the canyon head to where the slope flattened. Axis lengths ranged from 3800 at Central Canyon, to 15,000 m at South Canyon.



The **North Canyon** axis has the greatest vertical relief (VR) of the 3 canyons (1000 m) and displays a consistent low slope of 5.9 to 6.8 ° over a depth range of 600 to 1600 m.
Central Canyon features a VR of 600 m, and a variable gradient with 5.2 ° slope in the upper 100 m, then steepens to 23.5 ° between depths of 1400 and 1600 m, returning to 5.6 ° from 1600 to 1900 m.
South Canyon has lowest VR (530 m), the lowest sloping channel axis (0.6-3.8 °).

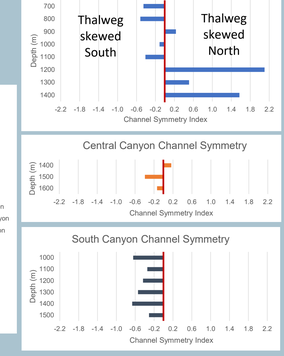


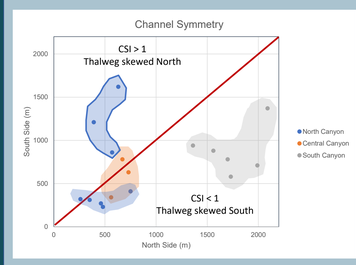
Note profiles have a VE=2.0x and shown at same scale.

As canyons develop and grow longer with age, their slopes decrease in magnitude.

Figure 6. Comparative cross-channel profiles

Channels were quantitatively analyzed in terms of their symmetry at 100 m above the thalweg using a Channel Symmetry Index (CSI, see Methods). The thalweg is the deepest point of a cross-canyon profile. Red lines represent symmetry (CSI = 1).





Canyons formed distinctive groupings in terms of symmetry, with **Central Canyon** being the most symmetric. **South Canyon's** cross-channel profiles display the least variance, with channels skewed to the south. **North Canyon** is split into two groupings, with the three deepest profiles outlined in dark blue being asymmetrical to the north, whereas the shallower profiles appear more symmetrical. This suggests that as canyons develop, they become less symmetric.

SUMMARY

Three study sites were chosen within the Currituck submarine landslide complex, and canyon geomorphology was characterized using canyon axis and cross-channel depth profiles. North and South Canyons are longer, more asymmetric, and display low-sloping axes, whereas Central Canyon has the shortest and steepest axis with more symmetric and U-shaped cross-channel profiles.
Geomorphology results suggest that as canyons develop over time, they become less symmetric. Central Canyon's study indicates that possibly younger, less developed canyons contain more symmetric, U-shaped canyon features. Older, more established canyons, such as North and South Canyons, have longer, lower axis slopes and higher geomorphologic cross-channel variation. Over time, canyons develop this variation through repeated slope failures and sediment transport. As an area filled with past submarine landslides, Central Canyon's morphology suggests that submarine canyons form through repeated slope failures that later result in canyons carving upslope into headwalls and scarps.

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