Geomorphological Analysis and Substrate Classification of Seafloor Features on a Northern Slope Segment of the Aleutian Trench

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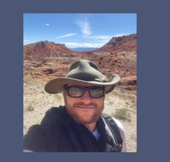

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INTRODUCTION AND BACKGROUND

In June 2023, the NOAA Ship *Okeanos Explorer* initiated Seascape Alaska 2: Aleutians Deepwater Mapping Expedition (EX2303) to increase mapping coverage of previously unexplored deep-water regions near Alaska's Aleutian Islands and the Aleutian Trench, and to identify potential geological hazards (NOAA 2023). High-resolution multibeam sonar data were used for a 95 by 88 km portion of the Aleutian Trench's northern slope. This study area is located approximately 130 km south of Unimak Island and has depths ranging from 1050 to 7020 m, gradually descending to the trench. The area is part of the Alaska-Aleutian subduction zone where the Pacific Plate is actively subducting below the North American Plate resulting in regular seismic activity (NOAA OE 2023).

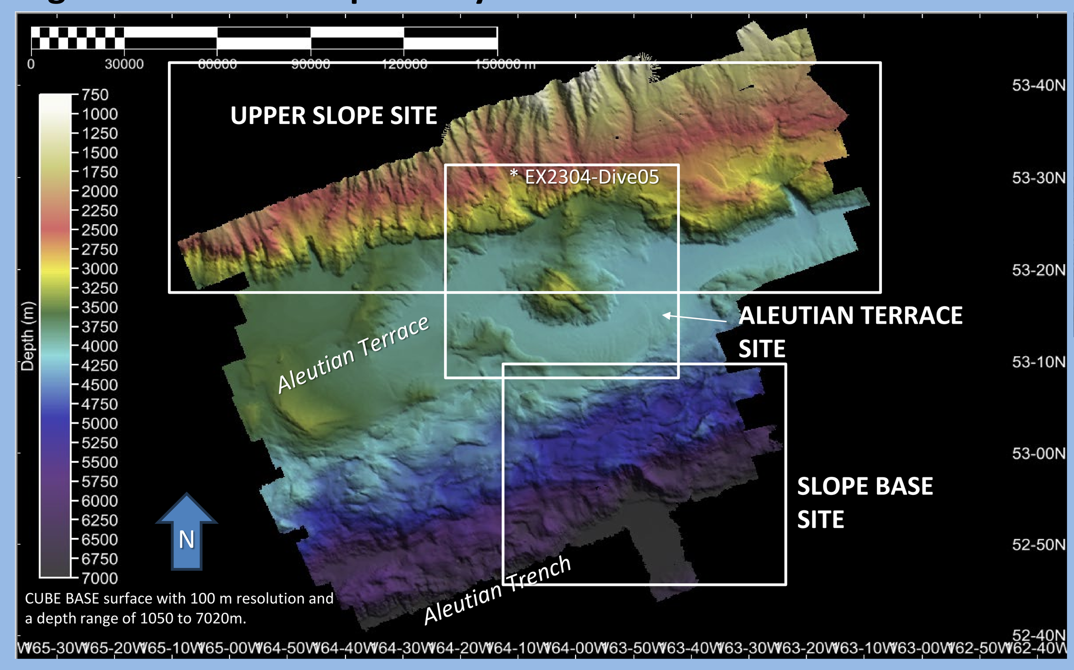
In July 2023, during EX2304, ROV *Deep Discoverer* explored a segment of Lone Knoll Scarp at depths of 2100-2800 m on the upper slope. This scarp likely resulted from a submarine landslide caused by the M8.6 1946 Aleutian Islands interpolate thrust earthquake and resulting Pacific-wide M9.3 tsunami (USGS, Accessed 2023). The earthquake was caused by subduction at the Aleutian Trench (Miller, 2014) and its epicenter was extremely close to our study area. HD video of the seafloor substrate collected by ROV *Deep Discoverer* revealed large mudstone blocks at the scarp's base surrounded by unconsolidated sediments. A diverse benthic community was observed which included several species of echinoderms and cnidarians.

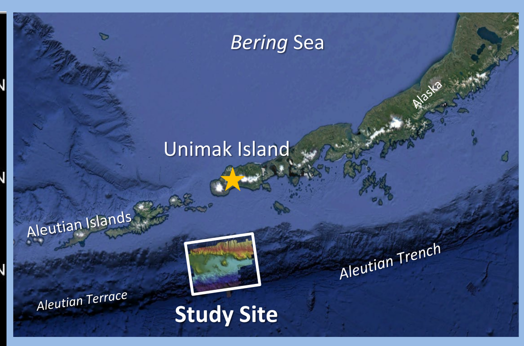
Three highlighted regions of the study area are presented in detail: 1) Numerous scarps associated with slope-origin canyons occur along the area's upper slope just above the Aleutian Terrace, where depth ranges are 1200-4200 m. 2) A 1000 m relief feature named Lone Hill lies at a depth of approximately 3100 m on the broad, flat Aleutian Terrace. 3) A significant slump scarp is present just above the Aleutian Trench, where depth ranges from approximately 4,800 - 7,000 m.

Some of these scarped features are likely to have formed due to landslide activity resulting from earthquakes. Since the terrace area is generally an accumulation zone for volcaniclastic and glaciomarine deposits Lone Hill is thought to have resulted from sediment accumulation (Dobson et al., 1996).

Video footage used as ground-truthing coupled with bathymetric and backscatter intensity data allows for analyses of Lone Knoll Scarp and other geomorphological features throughout the study area to predict substrate character and potential deep-sea coral habitats. These analyses will greatly enhance our knowledge of geological hazard impacts and deep-sea subduction zone environments.

Figure 1. Unimak Slope Study Area and Site Locations

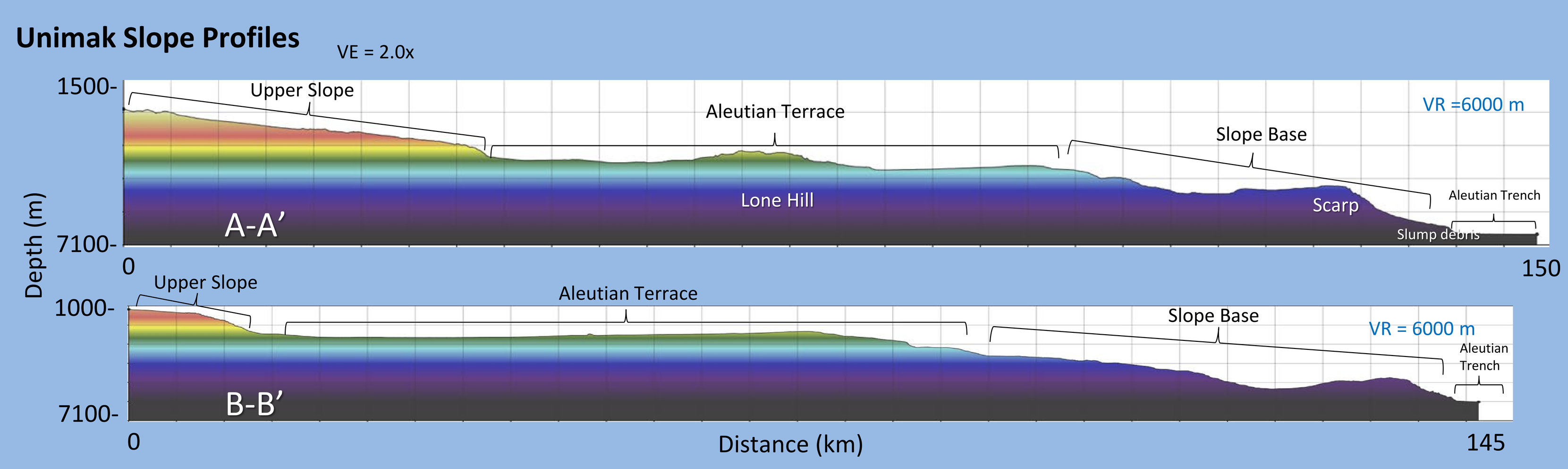


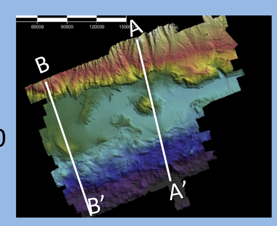


(left) The study area is located off the coast of the Aleutian Islands in Alaska approximately 130 km south of Unimak Island, and includes the Aleutian Terrace as well as a small section of the Aleutian Trench.

(left and below) The study area has a vertical relief of 6000 m.

The Upper Slope Site includes three slope-origin canyons formed along the northern slope of the Aleutian Terrace with a depth range of 1200-4200 m. The Aleutian Terrace Site is near the center of the study area with a depth range of (3150-4150 m) and includes Lone Hill. The Slope Base Site descends from 4300 to 7020 m to the Aleutian Trench and features a slump just above the trench at 4800 m.



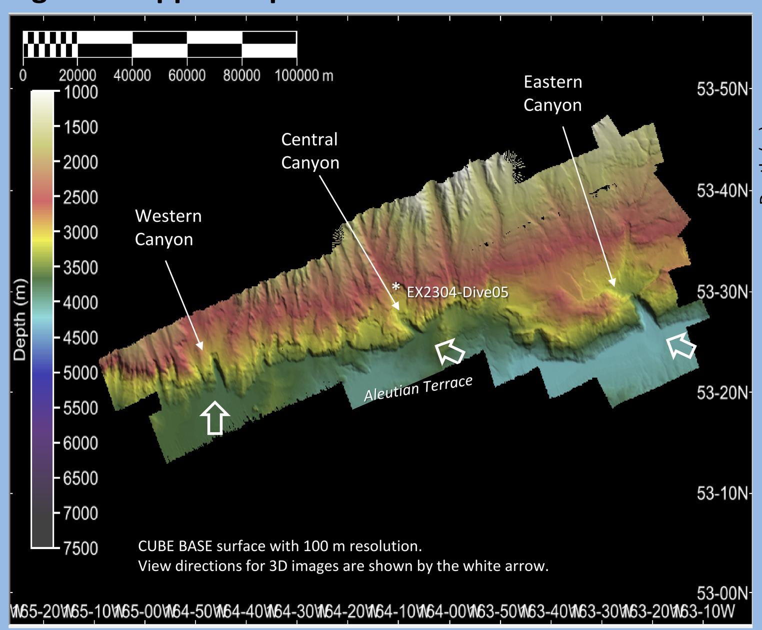


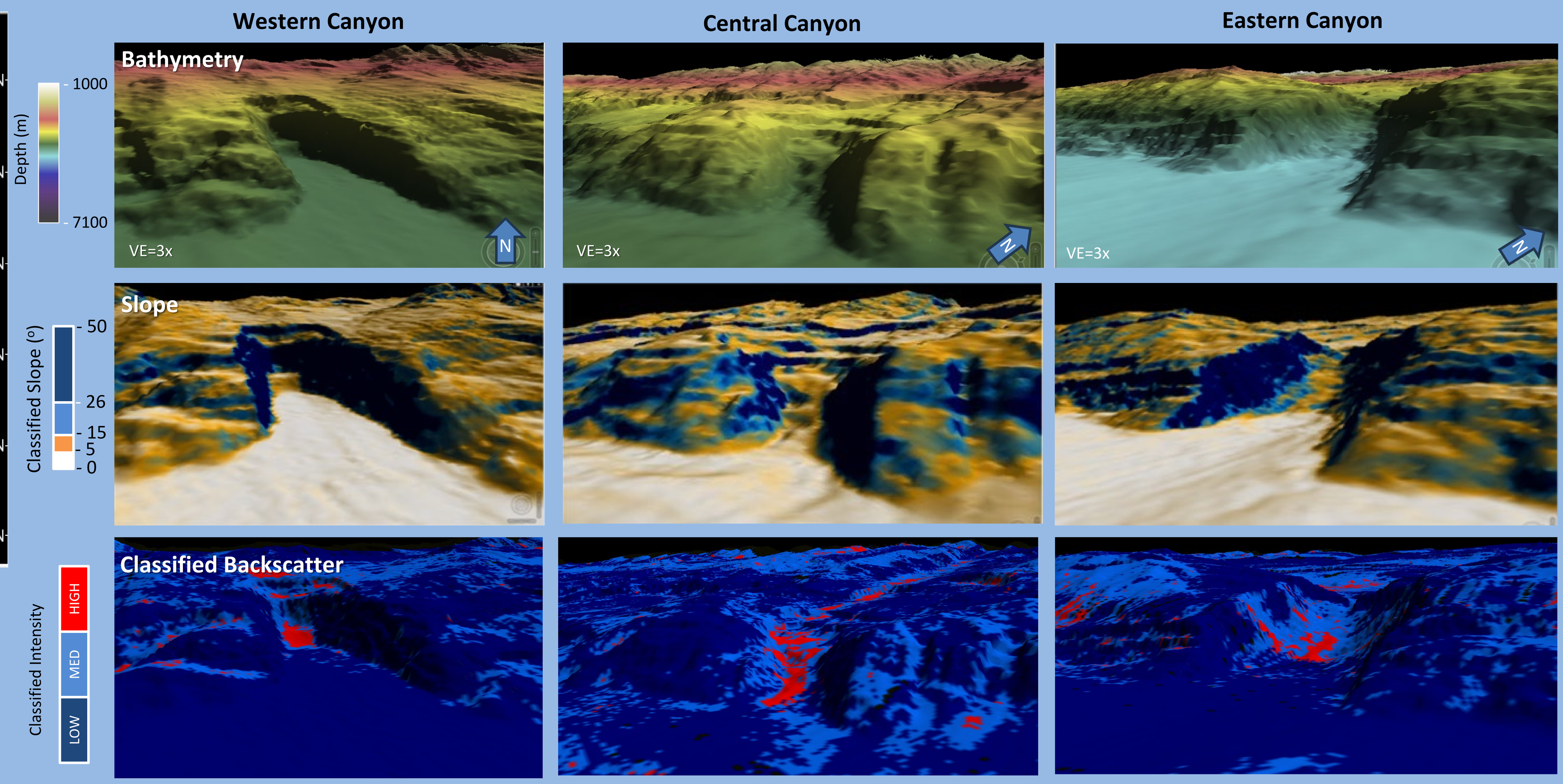
METHODS

- NOAA Ship *Okeanos Explorer* collected multibeam sonar data during expedition EX2303- Seascape Alaska 2: Aleutians Deepwater Mapping. The data was collected using EM304 multibeam echosounder.
- High-definition video recorded by the ROV *Deep Discoverer* during EX2304- Dive 05: Lone Knoll Scarp was used for ground truth of sonar data.
- High resolution bathymetric CUBE surfaces were created using CARIS HIPS & SIPS 11.4 software.
- Each study site was analyzed using backscatter intensity mosaics, along with depth and slope surfaces. All had a 75 m resolution except the slope origin canyons site, which had a 100 m resolution.
- Depth profiles of each site were generated along with and cross canyon profiles within the Upper Slope Site to compare slope origin canyon geomorphology.
- Slopes of prominent features of the canyons were compared.

NOAA Ship *Okeanos Explorer*

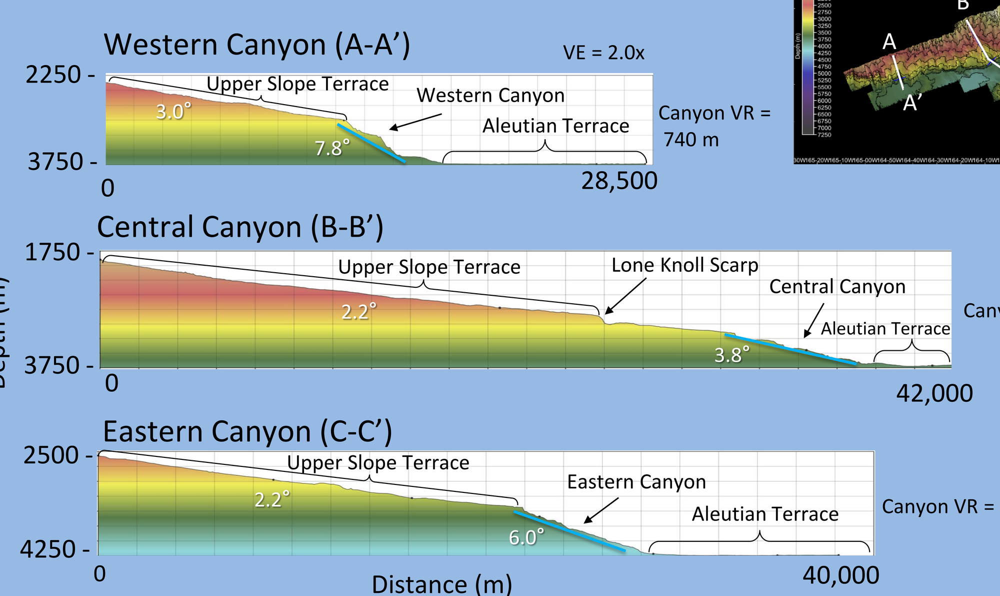
Figure 2. Upper Slope Site

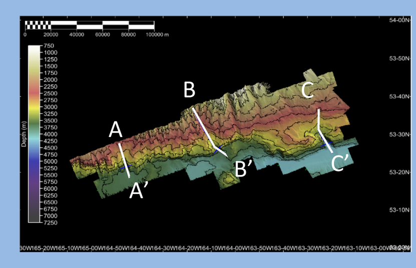


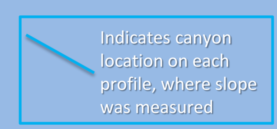


Upper Slope Site highlights three slope-origin canyons immediately adjacent to the Aleutian Terrace with a depth range of 1200-4200 m. Slopes range from 10-38° within the canyon walls that lead to the extremely flat (<5°) terrace floor. High intensity areas along the canyon channels appear to be scarps of exposed rock suggesting erosion activity within the canyons. There is no apparent association between higher slopes and high intensities.

Along-Canyon Depth Profiles

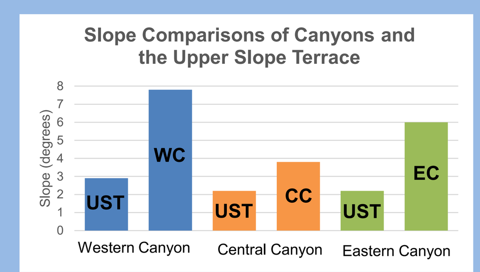




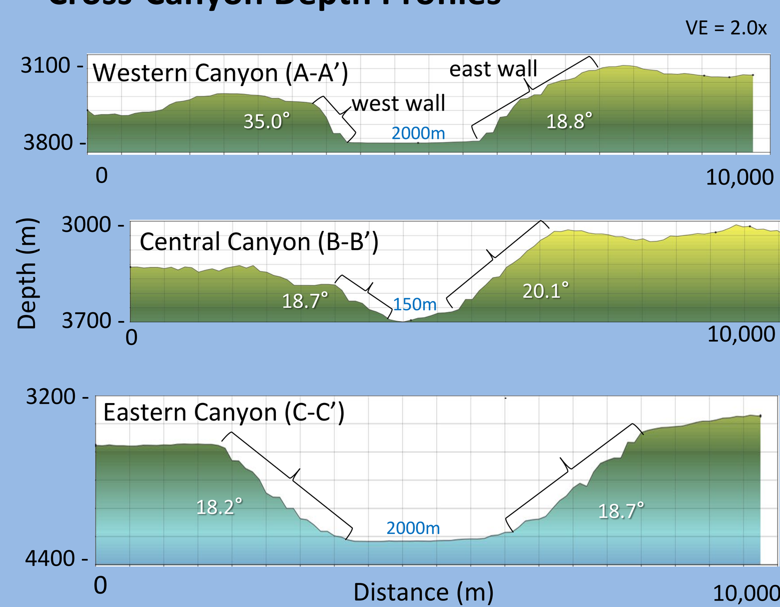


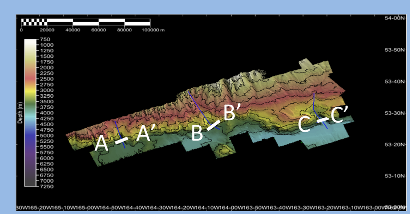
Blue lines on along-canyon profiles indicate canyon locations with slopes identified. Upper slope terrace portions of each profile are indicated by brackets. Each upper slope terrace just above the canyon has similar slopes between 2.2° and 3.0°. Western and Eastern Canyons have larger vertical reliefs of 740 and 790 m while Central Canyon's vertical relief is 540 m.

(below) Western Canyon has the steepest slope of 7.8° while Central Canyon has the lowest slope of 3.8°. Eastern Canyon is similar to Western Canyon with a slope of 6.0°.



Cross-Canyon Depth Profiles





(left) Slopes of east and west walls of each canyon were examined, and approximate length of the flat canyon floor was recorded.

In both Western and Eastern Canyons, the floor is approximately 2000 m, whereas Central Canyon's floor is 150 m.

(below) Slopes of the west walls show Western Canyon has the steepest slope (35.0°), whereas, Central and Eastern Canyon have similarly lower slopes of 18.7° and 18.2°. Slopes of east walls show Central Canyon has the steepest slope of 20.1°, while Western and Eastern Canyon's east walls have similar slopes of 18.8° and 18.7°. These similar slope patterns within the walls of each canyon could suggest that these canyons may have formed in similar ways; likely earthquake or landslide activity.

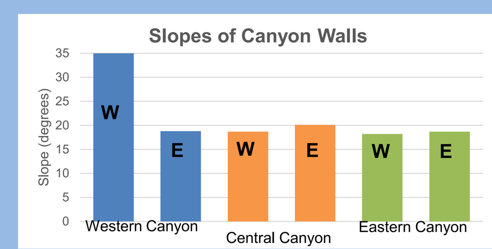
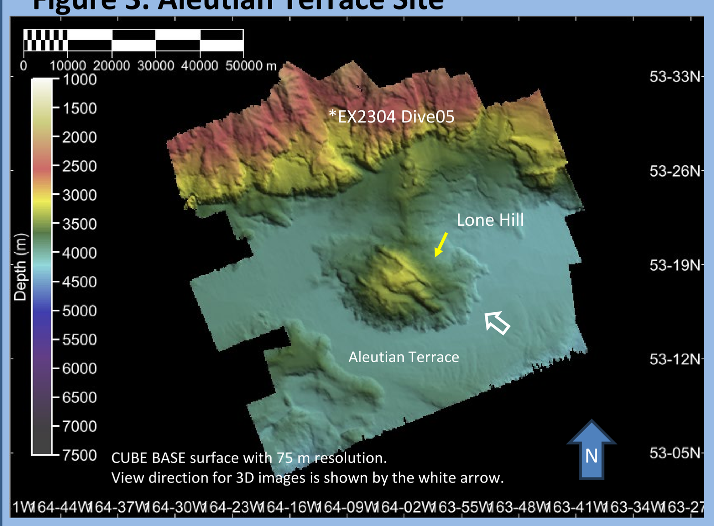
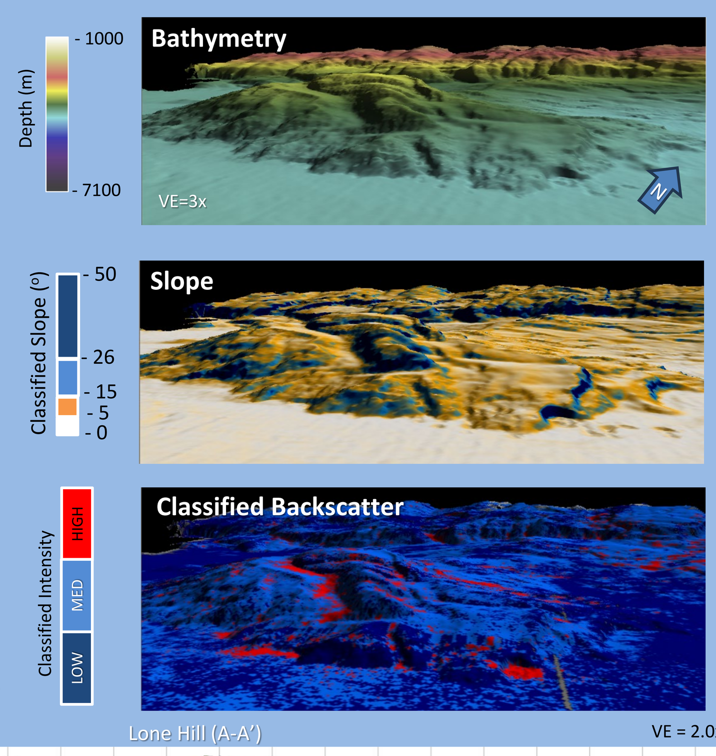
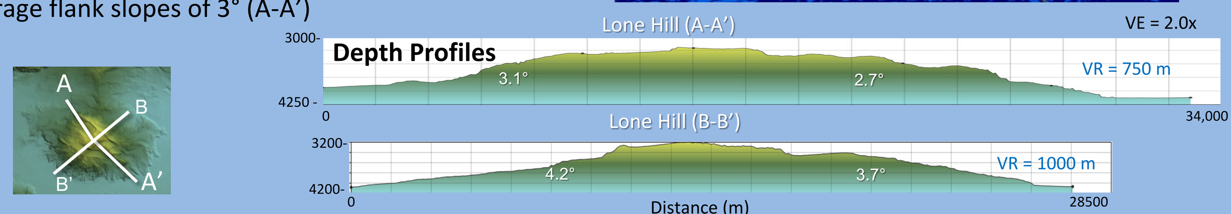


Figure 3. Aleutian Terrace Site



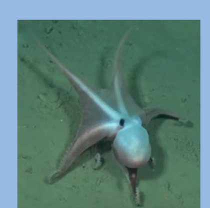


The Aleutian Terrace Site (depth range 3150-4250 m) highlights Lone Hill near the terrace's center (yellow arrow) with a debris trail connecting the hill to Upper Slope Site's edge. Steepest slopes on Lone Hill range from 22-26°, surrounded by the flat terrace floor (<1°). High-intensity areas of classified backscatter suggest exposed sedimentary rock. (below) Profiles of Lone Hill show average flank slopes of 3° (A-A') to 4° degrees (B-B').



ROV EX2304-DIVE05 FOOTAGE

Several species of biota were found while the ROV *Deep Discoverer* was exploring Lone Knoll Scarp and the surrounding submarine landslide areas. At the deeper depth, less rubble and blocks were encountered. Large angular mudstone boulders were seen surrounded by muddy unconsolidated sediment, but closer to the scarp there were many more rounded mudstone boulders in what seemed to be a debris cone from landslide activity. This gradual change in the amount and shape of rock near to the scarp can be seen in the pictures below on the right. The depth range of this dive was 2,820- 2100 m.

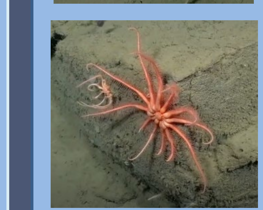


This deep-sea *Muusoctopus* was showing hunting and or defensive behavior. (Depth: 2806 m)

The Venus Flytrap Anemone feeding on the muddy, hummocky seafloor at a depth of 2802 m.

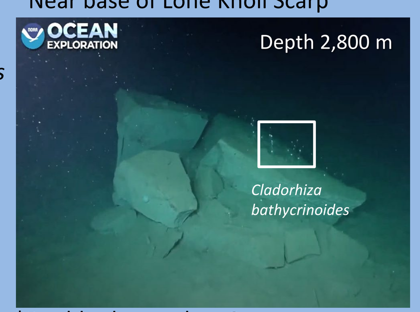
Several sea cucumbers were observed during the dive, one of which was the *Amperima*, better known at a Sea Pig. (Depth: 2803 m)

This species of *Virgularia* sea pen may be new to science! (Depth: 2804 m)

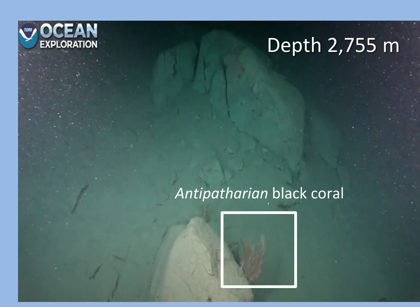


While Brisingid Sea Stars are well-known, this is the first time it has been recorded in the Aleutian area. (Depth: 2803 m)

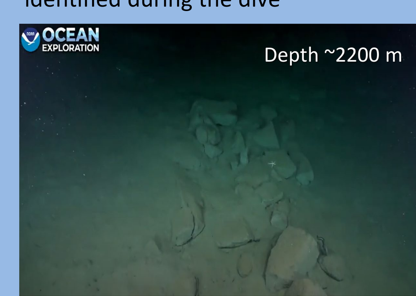
Near base of Lone Knoll Scarp



*Boulder larger than 2m

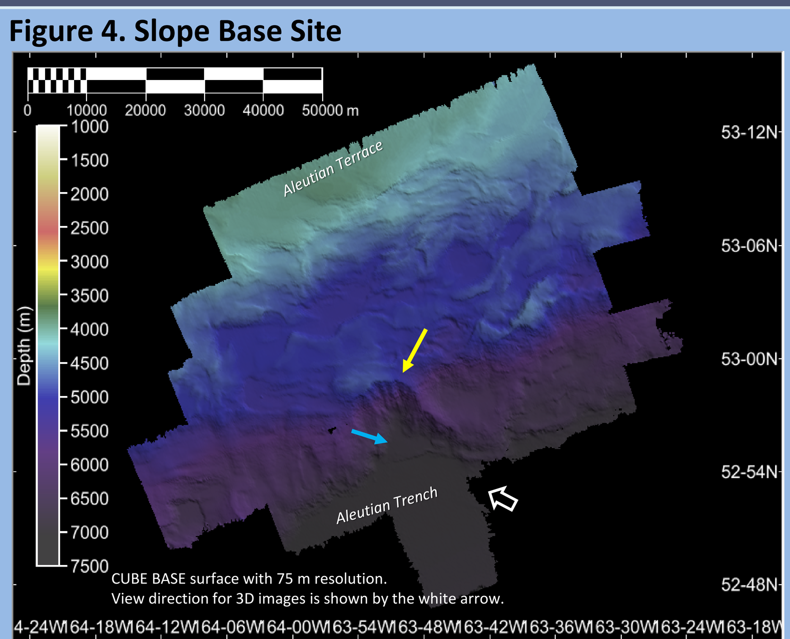


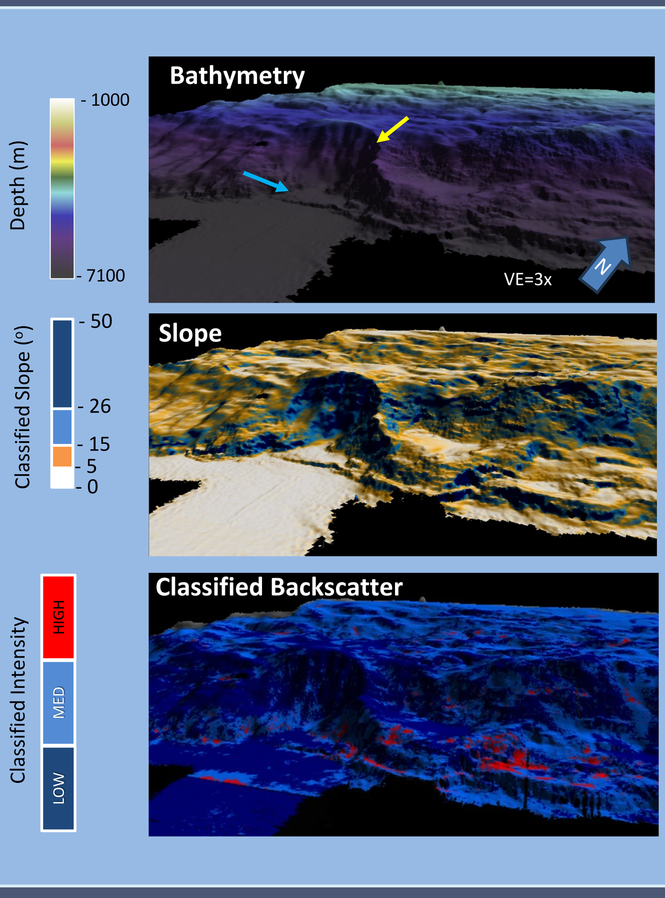
* At least 4 species of black coral were identified during the dive



Close to scarp site of Lone Knoll Scarp

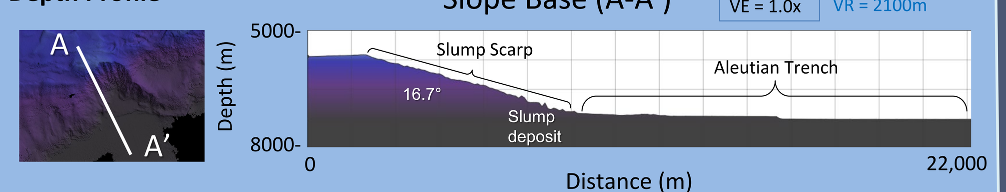
Figure 4. Slope Base Site





Slope Base Site highlights a slump scarp (yellow arrow) with a small debris pile (blue arrow) just above the Aleutian Trench. The depth range is 4300-7020 m and 35–46° slopes were the steepest found at the scarp and sloped area leading into the trench. High intensity areas suggest exposed rock or consolidated sediment near the base of the sloped area and east and west ends of the slump scarp.

Depth Profile



(above) Slope Base (A-A') is shown with no vertical exaggeration. The slump scarp to the north of the Aleutian Trench has a slope of 16.7°. The slump scarp exhibits a small debris deposit at its base, indicated on the profile. Further south, the Aleutian Trench section maintains a slope of less than 1°.

DISCUSSION and CONCLUSIONS

The Unimak Slope study area includes several different geomorphological features spread across a small portion of the North American continental slope at the Aleutian Trench. There are several slope-origin canyons across the upper slope region, with depths ranging 1200-4200 m (Fig.2). All three canyons observed exhibit similar backscatter patterns, with highest intensities in canyon channels and lower intensities on canyon ridges and walls. High intensities within channels suggest exposed rock, possibly due to scouring by active bottom currents moving low-density organic sediments covering this area (NOAA OE, 2023). Intensity patterns may indicate similarities in sediment distribution off the continental slope among all three areas. West and east walls of the canyons had very similar slopes (18-20º) except for Western Canyon's east wall (35º) (Fig. 2). This could be due to turbidity currents; the steeper side may experience higher velocity and allowing sediment deposition to be much higher on the eastern side of the canyon.

In the Aleutian Terrace Site, Lone Hill shows a vertical relief of 1000 m at a depth of 3150-4150 m (Fig. 3). The feature appears connected to the upper slope terrace, suggesting sediments transported from the upper slope may have been deposited here. The hill's composition is primarily sedimentary rock covered in bio-organic sediments which can be attributed to the terrace's back-tilted nature causing an interception of sediment sloughing from slopes above (Fryer, 2004). Additionally, Lone Hill's geomorphology may be explained by catastrophic sliding of a detached block onto the Aleutian Terrace, resulting from subduction activity of the Pacific plate beneath the North American plate (Miller, 2014).

*S*carp and slump features highlighted within Figures 2, 3 and 4 are potentially the result of the historic M8.6 Unimak Earthquake that created a tsunami; killing 167 people (Fryer, 2004). The scarp featured on the upper continental slope (Figs. 2 and 3) and slump scarp in Figure 4 both display evidence of relation to this marine catastrophe.

Slope Base Site shows a slump scarp located on the lower slope at approximately 4800 m that descends into the 7000 m deep trench (Fig. 4). Submarine slopes, prone to instability and landslides, pose tsunami risks for coastal areas (Masson et al. 2009). Given the slump scarp's proximity to the epicenter of Unimak Earthquake and Aleutian Trench, this slump site could have contributed to dangerous conditions in 1946 (Fryer, 2004), however, the scarp's time of origin is unknown.

ROV footage from EX2304-Dive05 provided ground truth for classified backscatter intensities at each site. The dive explored a Lone Knoll Scarp (2100-2800 m depth), a submarine landslide scarp. Dive footage revealed a seafloor covered mostly in low-density, muddy sediment, and a few exposed large mudstone boulders. As the Aleutian Terrace accumulates volcaniclastic and glaciomarine deposits, the source of these sediments may come from past volcanic or glacial activity (Dobson et al. 1996). Angular boulders at the scarp's base, hosting diverse biota, suggest longer placement than the rounder rubble near the top, likely from recent landslide activity (Fig. 3).

Analyzing these geological features near the Alaska-Aleutian subduction zone enhances abilities to predict and safeguard against future marine hazards, deepening our understanding of other deep-sea subduction zones.

REFERENCES

- Dobson, M.R., et al. (1996) Sedimentation along the fore-arc region of the Aleutian Island arc, Alaska. *Geology of the United States' Seafloor*, pages 219-304.
- Fryer, G.J., et al. (2004) Source of the great tsunami of 1 April 1946: a landslide in the upper Aleutian forearc. *Marine Geology*, 203, 201-218. ISSN 0025-3227.
- Masson, D.G., et al. 2006. Submarine Landslides: Processes, Triggers and Hazard Prediction. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, 364(1845), 2009–39. JSTOR.
- Miller, John, et al. (2014) The 1946 Unimak Tsunami Earthquake Area: Revised Tectonic Structure in Reprocessed Seismic Images and a Suspect Near-Field Tsunami Source. *U.S. Geological Survey Open-File Report 2014–1024*, 19 p., http://dx.doi.org/10.3133/ofr20141024
- NOAA. 2023. *Seascape Alaska 3: Aleutians Remotely Operated Vehicle Exploration and Mapping (EX2304).* NOAA Ocean Exploration, 22 June 2023. https://oceanexplorer.noaa.gov/okeanos/explorations/seascape-alaska/ex2304/welcome.html#dives
- NOAA. 2023. *Seascape Alaska 2: Aleutians Deepwater Mapping (EX2303).* NOAA Ocean Exploration. https://oceanexplorer.noaa.gov/okeanos/explorations/seascape-alaska/ex2303/welcome.html
- USGS. "M 8.6 - 1946 Aleutian Islands (Unimak Island) Earthquake, Alaska." Earthquake Hazards Program. Accessed 15 October 2023.

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