Substrate Characterization of Quinault & Nitinat Submarine Canyons of the Washington Continental Margin

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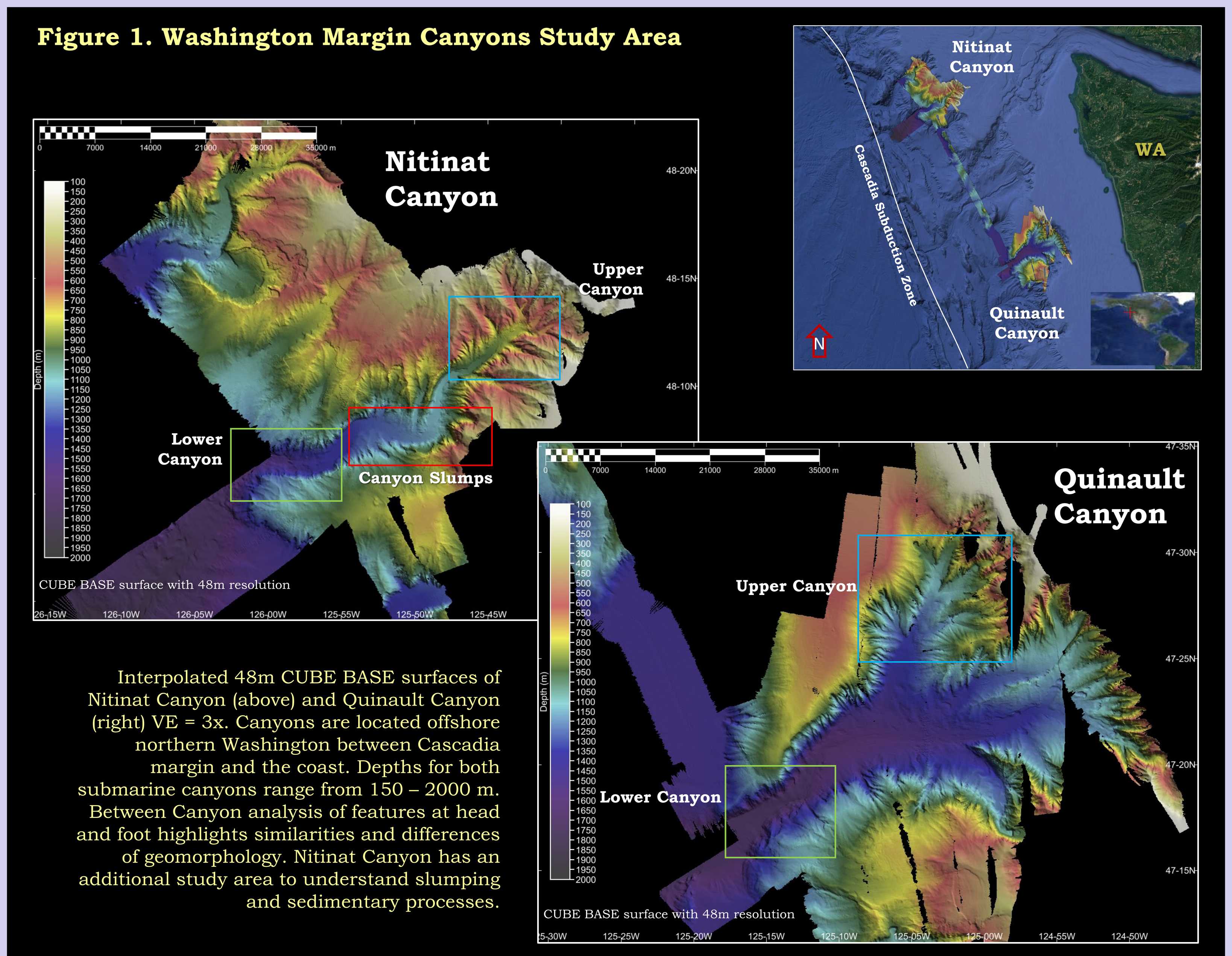
NOAA Ship *Okeanos Explorer*

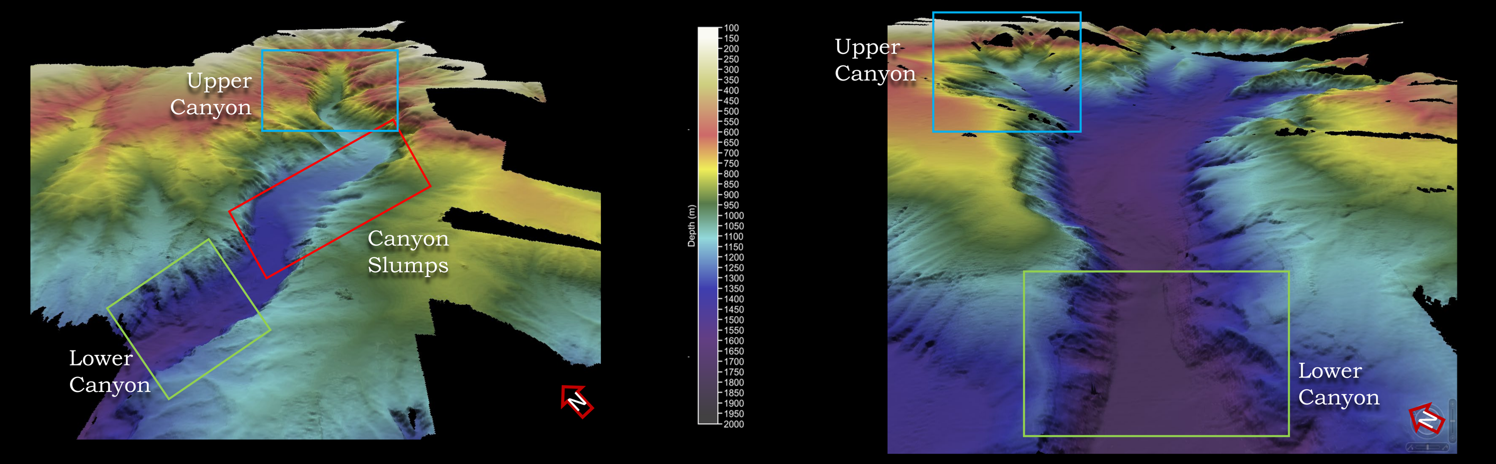
Figure 1. Washington Margin Canyons Study Area



Interpolated 48m CUBE BASE surfaces of Nitinat Canyon (above) and Quinault Canyon (right) VE = 3x. Canyons are located offshore northern Washington between Cascadia margin and the coast. Depths for both submarine canyons range from 150 – 2000 m. Between Canyon analysis of features at head and foot highlights similarities and differences of geomorphology. Nitinat Canyon has an additional study area to understand slumping and sedimentary processes.

3D Views Looking Up Nitinat & Quinault Canyons

VE = 2.6x. Facing Northeast



Nitinat Canyon — Quinault Canyon

Introduction

Quinault and Nitinat Canyons lie on the continental margin approximately 75 km offshore of Washington State, where depths range from 150 to 2000 m. These submarine canyons are located at the western edge of the North American Tectonic Plate along the Cascadia Margin with the subducting Juan de Fuca Plate (NOAA, 2002). Multibeam sonar surveys were conducted in this region from May-June 2011 aboard the University of Washington R/V *Thomas G. Thompson* (TN265) and in April 2023 aboard the NOAA Ship *Okeanos Explorer* (EX2301) as part of NOAA Ocean Exploration's (OE) 2023 Shakedown and EXPRESS West Coast Expedition. In addition to sonar data collection, HD video footage of canyon features was collected in 2023 by NOAA's ROV *Deep Discoverer*. NOAA OE's primary objective was to enhance geomorphologic understanding of unexplored and poorly mapped deepwater areas of the U.S. West Coast. Data collected were used to visualize and ground-truth previous bathymetric maps. ROV dives at both Quinault and Nitinat Canyons encountered areas with semi-consolidated sandstone and siltstone outcrops and unconsolidated clay and silt sediment floors (*Cliffs, Currents, and Corals of Quinault Canyon*). Additionally, Nitinat Canyon had evidence of embedded glacial erratics and bioturbation from native benthic organisms. Sea level was reduced by 400 m during the last glacial maximum approximately 17,000 years ago, which left eroded, unconsolidated sediments and protruding outcrops consistent with Pleistocene glaciation (NOAA Ocean Explorer, 2023). The role these canyons play as repositories for lithogenic sediment transport and deposition seaward is essential for habitat formation (Bührig et al., 2023). With climate change threatening the distribution of benthic organisms and accelerating release of gas hydrates, understanding the sedimentary processes of these canyons is essential for informing future decisions regarding biodiversity and resource management (Hautala et al., 2014).

Methods

- Multibeam sonar data were collected on expeditions EX2301, TN265, and EM302 aboard the NOAA Ship *Okeanos Explorer*, the R/V *Thomas G. Thompson*, and E/V *Nautilus* using Kongsberg EM304 and EM302 echosounders.
- HD videos of benthic habitats were collected by ROV *Deep Discoverer* during EX2301 as part of the NOAA Ocean Exploration's (OE) 2023 Shakedown and EXPRESS West Coast Expedition; EX2301_DIVE07, EX2301_DIVE08, and EX2301_DIVE09.
- Sonar data were post-processed using CARIS HIPS and SIPS 11.4 software to generate bathymetry & slope surfaces and classified backscatter intensity mosaics in 2D & 3D.
- Canyon axis symmetry was analyzed by measuring horizontal distance from thalweg to canyon wall at 100 m depth above the thalweg.

Figure 3. Comparative Canyon ROV Dive Gallery

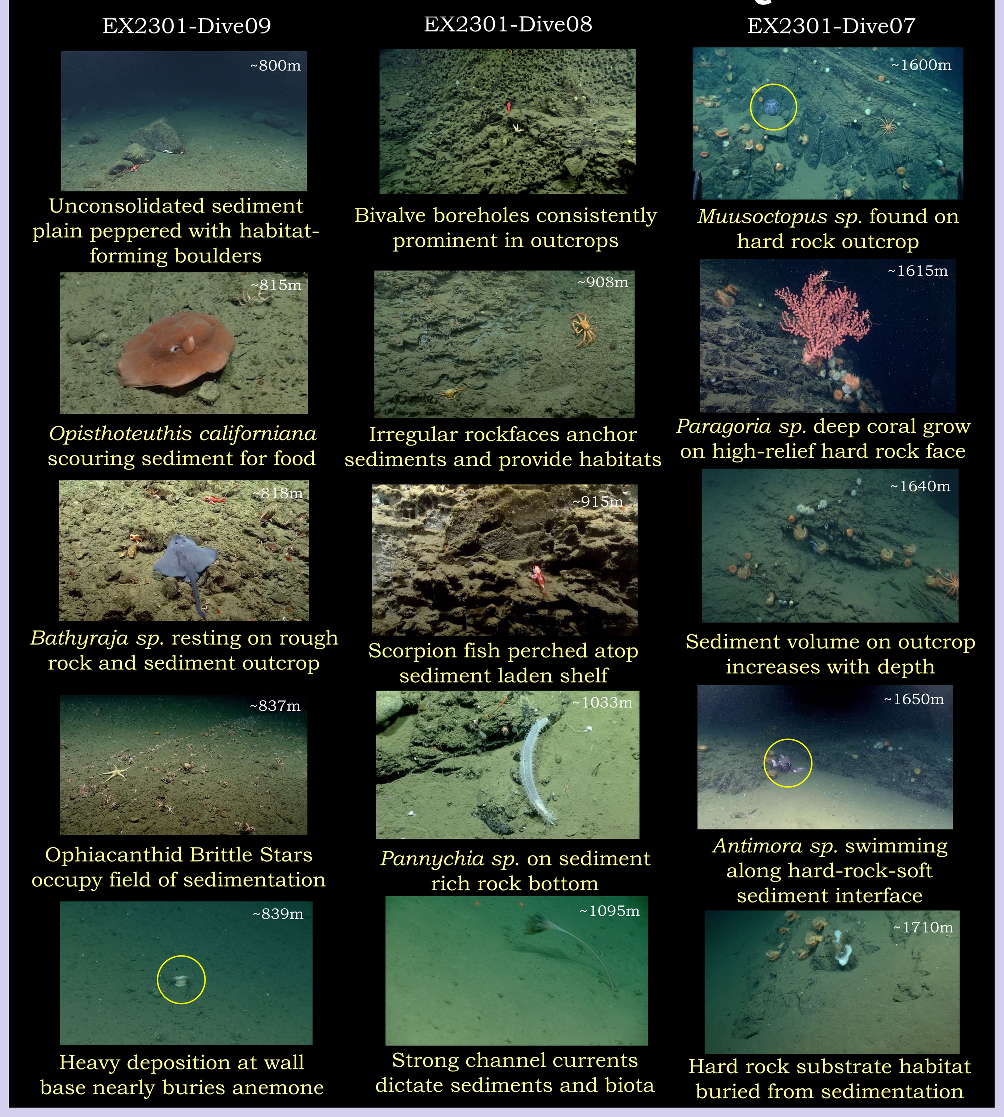
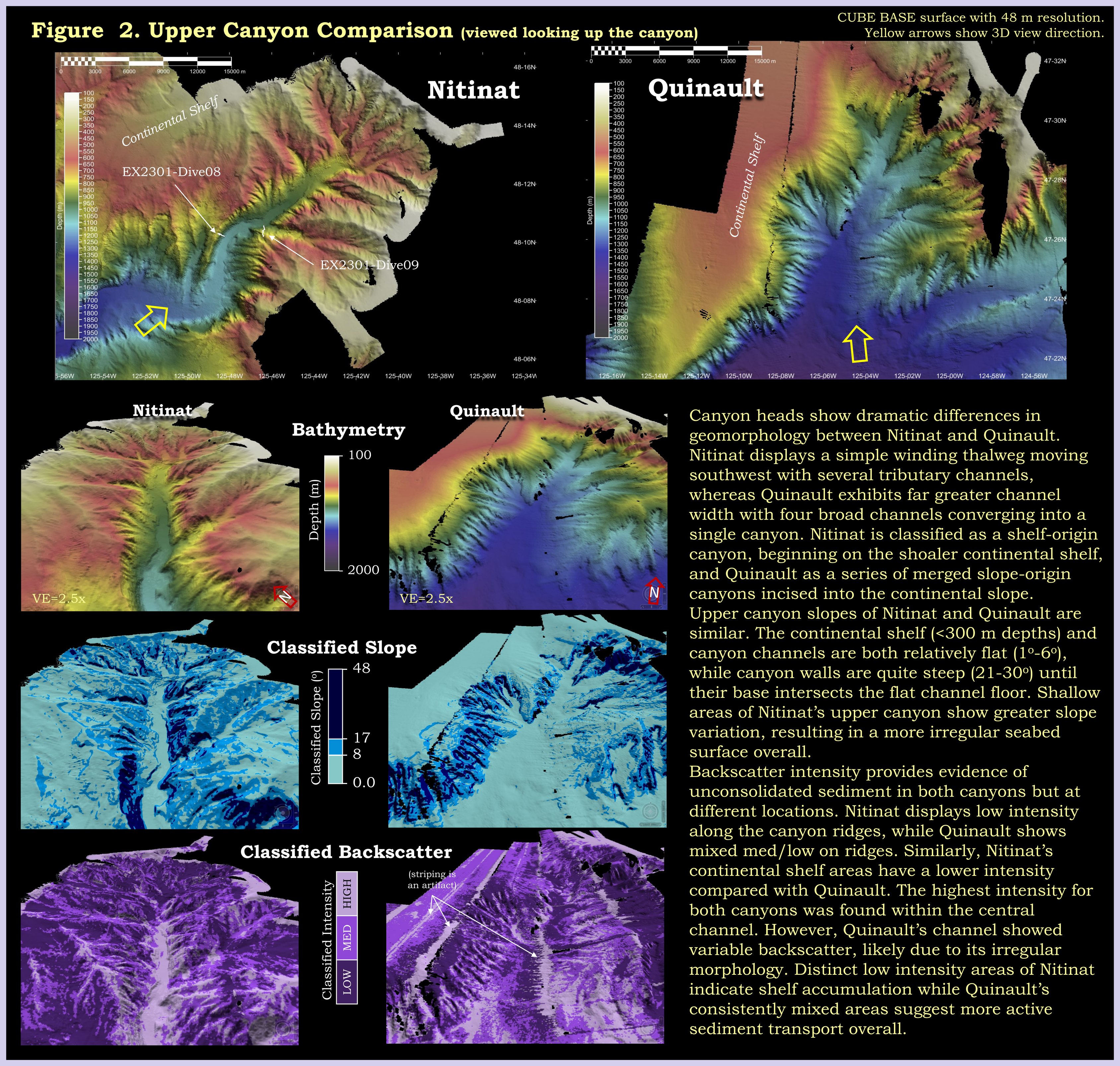


Figure 2. Upper Canyon Comparison (viewed looking up the canyon)

CUBE BASE surface with 48 m resolution. Yellow arrows show 3D view direction.



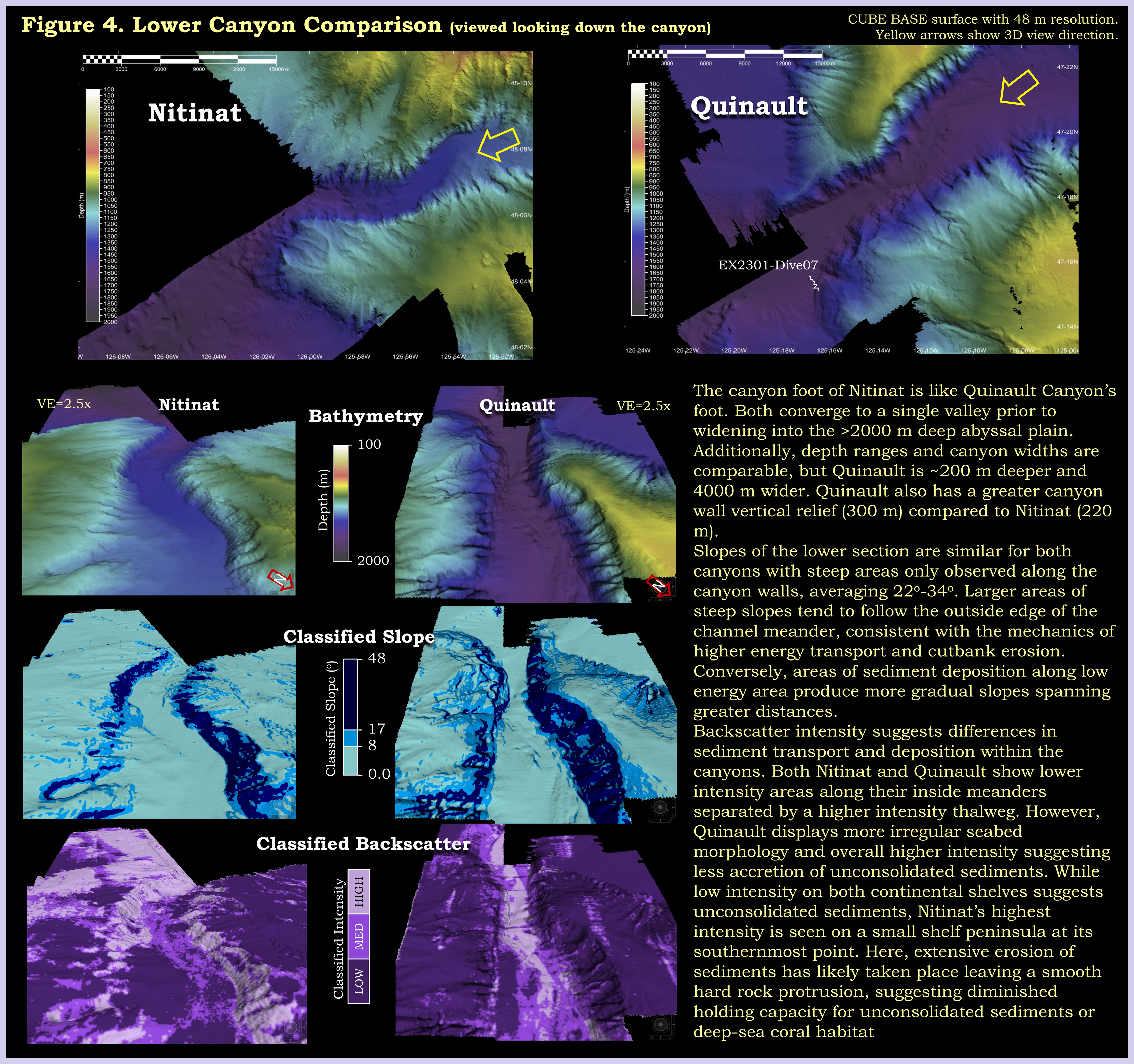
Canyon heads show dramatic differences in geomorphology between Nitinat and Quinault. Nitinat displays a simple winding thalweg moving southwest with several tributary channels, whereas Quinault exhibits far greater channel width with four broad channels converging into a single canyon. Nitinat is classified as a shelf-origin canyon, beginning on the shoaler continental shelf, and Quinault as a series of merged slope-origin canyons incised into the continental slope.

Upper canyon slopes of Nitinat and Quinault are similar. The continental shelf (<300 m depths) and canyon channels are both relatively flat (1°-6°), while canyon walls are quite steep (21-30°) until their base intersects the flat channel floor. Shallow areas of Nitinat's upper canyon show greater slope variation, resulting in a more irregular seabed surface overall.

Backscatter intensity provides evidence of unconsolidated sediment in both canyons but at different locations. Nitinat displays low intensity along the canyon ridges, while Quinault shows mixed med/low on ridges. Similarly, Nitinat's continental shelf areas have a lower intensity compared with Quinault. The highest intensity for both canyons was found within the central channel. However, Quinault's channel showed variable backscatter, likely due to its irregular morphology. Distinct low intensity areas of Nitinat indicate shelf accumulation while Quinault's consistently mixed areas suggest more active sediment transport overall.

Figure 4. Lower Canyon Comparison (viewed looking down the canyon)

CUBE BASE surface with 48 m resolution. Yellow arrows show 3D view direction.

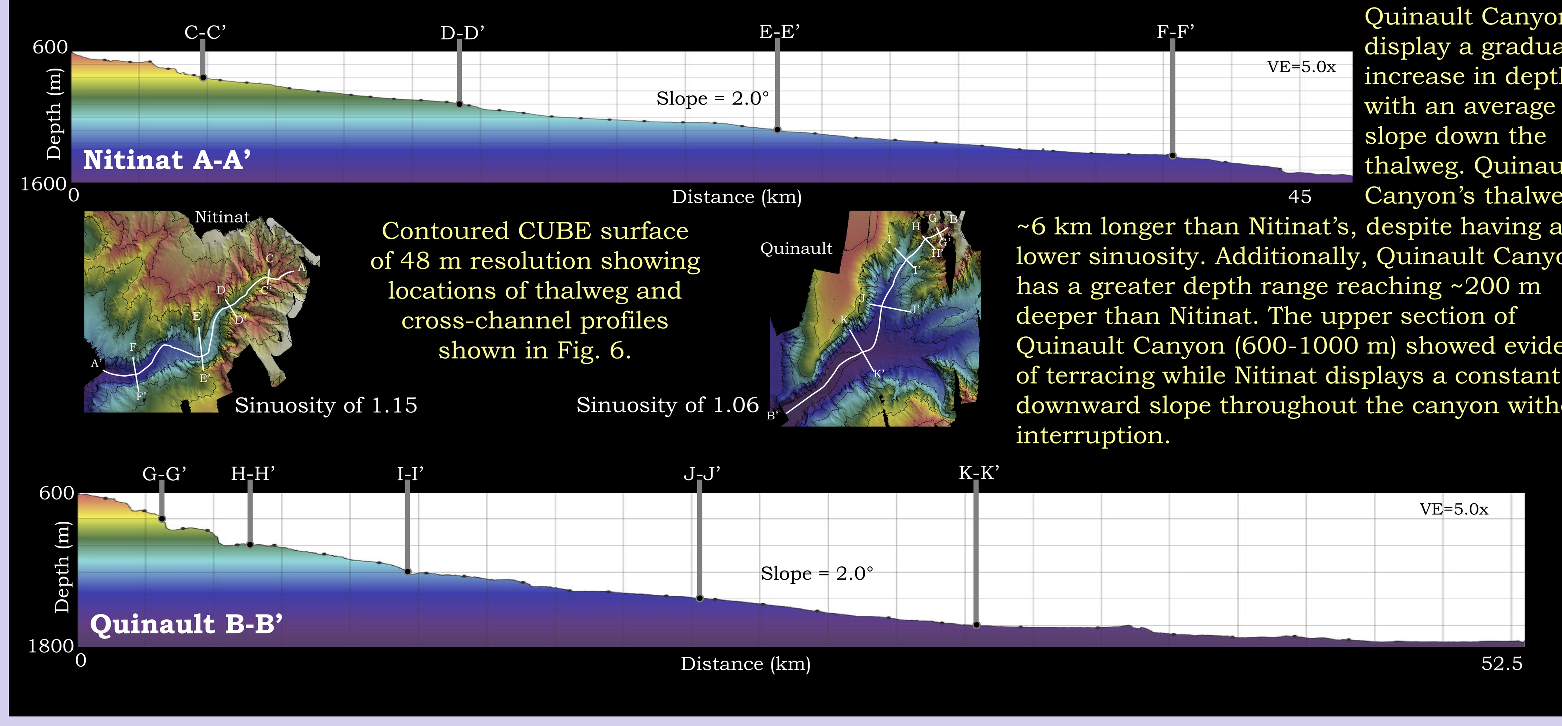


The canyon foot of Nitinat is like Quinault Canyon's foot. Both converge to a single valley prior to widening into the ~2000 m deep abyssal plain. Additionally, depth ranges and canyon widths are comparable, but Quinault is ~200 m deeper and 4000 m wider. Quinault also has a greater canyon wall vertical relief (300 m) compared to Nitinat (220 m).

Slopes of the lower section are similar for both canyons with steep areas only observed along the canyon walls, averaging 22°-34°. Larger areas of steep slopes tend to follow the outside edge of the channel meander, consistent with the mechanics of higher energy transport and cutbank erosion. Conversely, areas of sediment deposition along low energy areas produce more gradual slopes spanning greater distances.

Backscatter intensity suggests differences in sediment transport and deposition within the canyons. Both Nitinat and Quinault show lower intensity areas along their inside meanders separated by a higher intensity thalweg. However, Quinault displays more irregular seabed morphology and overall higher intensity suggesting less accretion of unconsolidated sediments. While low intensity on both continental shelves suggests unconsolidated sediments, Nitinat's highest intensity is seen on a small shelf peninsula at its southernmost point. Here, extensive erosion of sediments has likely taken place leaving a smooth hard rock protrusion, suggesting diminished holding capacity for unconsolidated sediments or deep-sea coral habitat

Figure 5. Canyon Thalweg Profile Comparison

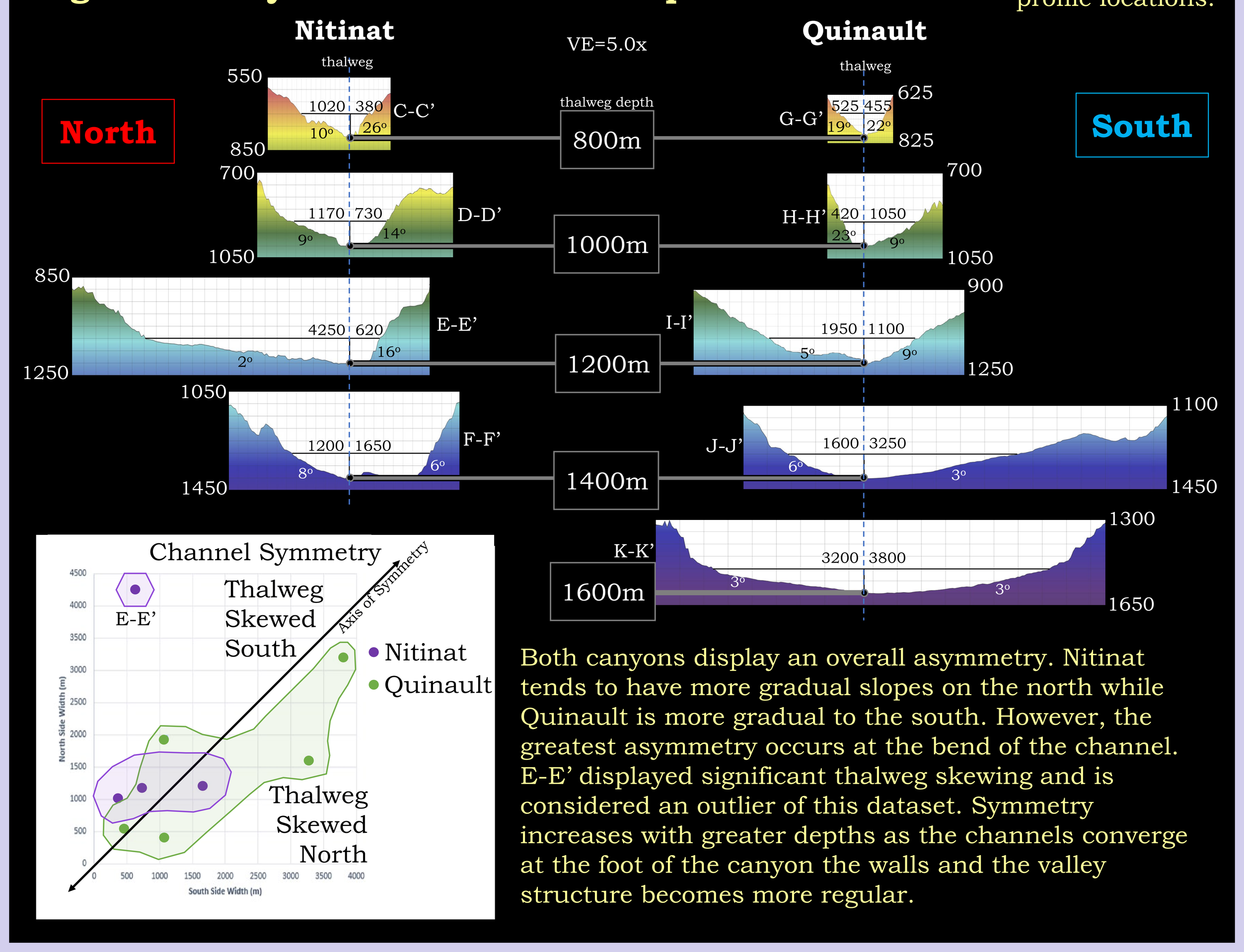


Contoured CUBE surface of 48 m resolution showing locations of thalweg and cross-channel profiles shown in Fig. 6.

Both Nitinat & Quinault Canyons display a gradual increase in depth with an average 2° slope down the thalweg. Quinault Canyon's thalweg is ~6 km longer than Nitinat's, despite having a lower sinuosity. Additionally, Quinault Canyon has a greater depth range ~200 m deeper than Nitinat. The upper section of Quinault Canyon (600-1000 m) showed evidence of terracing while Nitinat displays a constant downward slope throughout the canyon without interruption.

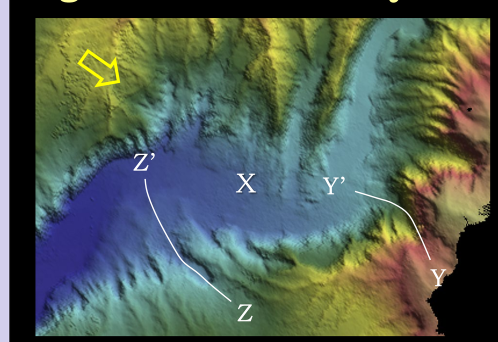
Figure 6. Canyon Cross-Section Comparison

Refer to Fig. 5 for profile locations.



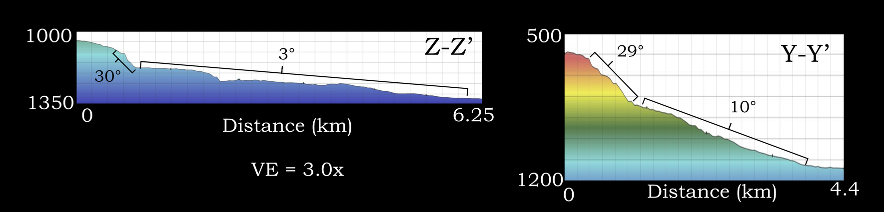
Both canyons display an overall asymmetry. Nitinat tends to have more gradual slopes on the north while Quinault is more gradual to the south. However, the greatest asymmetry occurs at the bend of the channel. E-E' displayed significant thalweg skewing and is considered an outlier of this dataset. Symmetry increases with greater depths as the channels converge at the foot of the canyon the walls and the valley structure becomes more regular.

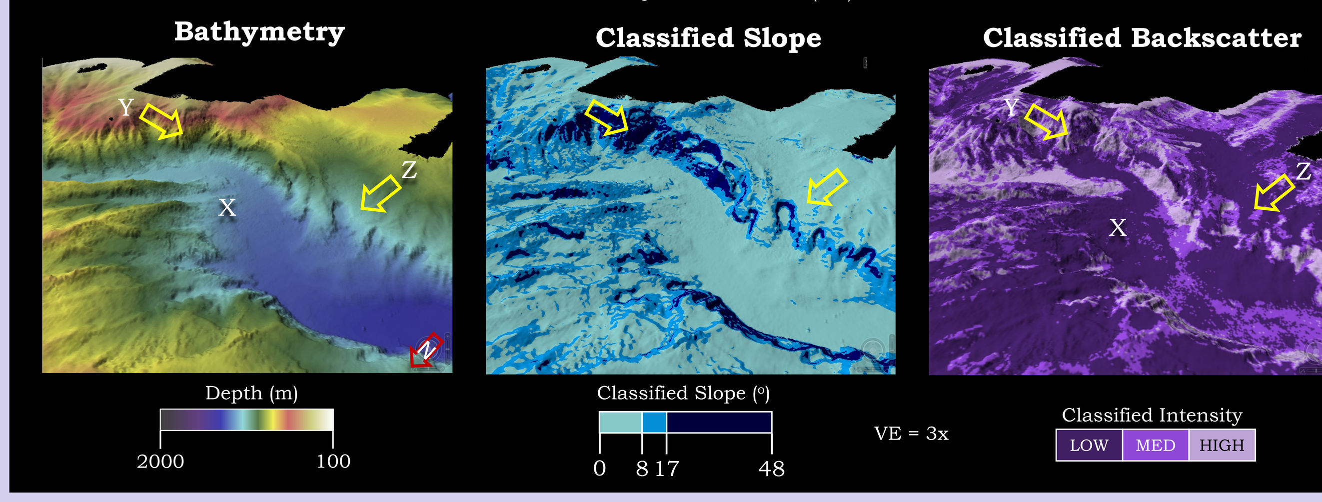
Figure 7. Nitinat Canyon Slumps



Heavy sedimentation along Nitinat Canyon walls observed on ROV footage suggests morphological features associated with significant unconsolidated sediment accumulation. Profiles Z-Z' and Y-Y' display active erosion of these unstable canyon walls and deposition in lower energy regions of the canyon channel. The canyon's outside meander (Y-Y'), experiences faster moving erosive bottom currents which cause canyon wall sediments to slump and be transported down the channel. These slump deposits then accrete along the lower energy, inside meander of the canyon at location X. Profile Z-Z' shows additional slump deposits that may have originated from passive sediment accumulation rather than active channel erosion.

At this profile, volumes of unconsolidated sediments atop the continental shelf may have become too great, causing them to spill into the channel trough. This profile falls on the lower-energy meander of the channel where deposition is dominant. While the two profiles both show an increase in depth, the slopes of each section reveal differences in seabed formation from opposite sides of the channel meander. Z-Z' and Y-Y' both have steep slopes of ~30° at the scarped canyon walls. Along the depositional side, slump deposits remain proximal creating a gradual slope averaging ~3°. The erosional side however quickly loses its sediments, resulting in steeper slopes averaging ~10°. Slumped deposits of unconsolidated sediments in these locations are indicated by patches of low backscatter intensity separated by the canyon channel.





Discussion

As these canyons receive vast quantities of lithogenic sediments, they become rich in unconsolidated sediments at their low-slope areas and within portions of their channels. Far greater volumes of soft, unconsolidated seabed at Nitinat Canyon were corroborated by ROV footage. The walls here show extensive evidence of boring from benthic organism causing sediment release and accretion. Moreover, this shelf-origin canyon displays walls that are more "textured" allowing for greater retention of *in-situ* erosional products. Conversely, Quinault Canyon contains more intact outcrops with collections of unconsolidated sediments only found on small terraces throughout the continental slope and canyon floor. Canyon morphologies become more similar in the lower canyon region. Despite Quinault having a canyon head of four branches, both canyons possess a broad, sinuous thalweg at greater depths.

Both canyons hosted a wide variety of marine organisms with significant taxa overlap. However, due to greater abundance of hard-rock substrate, Quinault had more corals in areas with substantial vertical relief. Conversely, Nitinat hosted many benthic organisms which bore holes in outcrops, thriving in heavily sedimented environments.

Since both canyons fall within the Olympic Coast National Marine Sanctuary (OCNMS), preservation of the seabed and associated marine life is essential. These expeditions, in conjunction with the epicontinental sea tectonic setting, help to illustrate the geologic phenomena of the offshore Pacific Northwest region. Despite its proximity to Juan De Fuca Plate's subduction zone, neither canyon experiences significant earthquakes, and water currents appear to be the main drivers of seabed changes. Moreover, the prevalence of embedded methane hydrates in these canyons' sediments means that release is ongoing. Exacerbated by anthropogenic warming trends, dissociation of these hydrates causes gradual changes in seabed morphology and water chemistry (Hautala et al., 2014). Since both canyons show evidence of erosion and have historical records of submarine landslides, tracking morphological changes is important for understanding how these canyons have implications for global climate.

Acknowledgements

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