Geomorphological Comparison of Seamounts in a Deepwater Area of the Northeast Pacific

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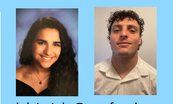
NOAA Ship *Okeanos Explorer*



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Introduction/ Background

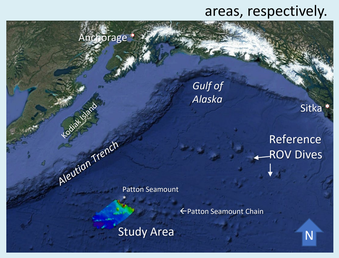
During the *Seascape Alaska 4: Gulf of Alaska Deepwater Mapping Expedition* (cruise EX2305), NOAA Ocean Exploration mapped a deep ocean area of the northeast Pacific, 530 km off the coast of Alaska's mainland, and 470 km southeast of Alaska's Aleutian Islands. Multibeam sonar data were collected in August 2023 with the primary objective of providing initial characterization of unexplored areas to support further exploration and priority NOAA science and management needs (NOAA 2023). The surveyed study area is approximately 130 by 85 km with much of the area being a 5000 m deep abyssal plain.

The region's abyssal plain includes several volcanic features at varying depths. First, the study area includes a seamount informally known as Codman Seamount which has a summit depth of 450 m. Codman Seamount lies adjacent to the southeast perimeter of Patton Seamount, connected by a low saddle. Codman's flanks are comprised of volcanic ridges and interridge chutes radiating from the small summit. The missing southern half of the caldera rim gives way to a prominent chute down the southern flank leading to a bulbous debris pile (Chaytor et al. 2007). Second, a smaller unnamed seamount, here referred to as "Conical Seamount", is located 12 km southwest of Patton Seamount. This smaller seamount has a summit depth of 1600 m and a distinctive slump scarp on its southwestern flank. Lastly, two 50-80 km chains of flat-topped, disk-like seamounts are southwest of the cone-shaped seamounts, and have summit depths of ~3050-3300 m. Some of the domes are modified by one or more calderas either centrally located or offset near their edges. Formation of these igneous domed seamounts is the result of the moderate-high pressure conditions during their formation at such a great depth (Clague et al. 2000).

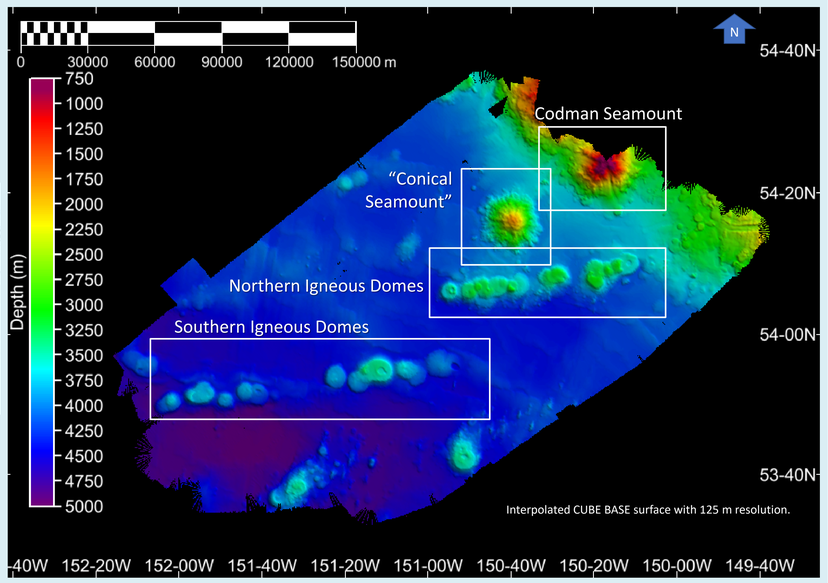
HD video acquired by ROV *Deep Discoverer* during Seascape Alaska 5 in August-September 2023 (EX2306-Dive06 and EX2306-Dive07) was used to ground-truth similar geomorphological features also found at a depth of 3100 m approximately 600 km to the northeast of Codman Seamount. The main focus of this study is to compare the geomorphology of these unique volcanic features using bathymetric surfaces, backscatter, and flank profiles of each site.

Figure 1. Northeast Pacific Deep Seamounts

(right). The overall surveyed Northeast Pacific Deep study area features depths of 450-5000 m. Sites studied contain numerous primary volcanic features. Codman Seamount has the shallowest depth range of 450-3800 m, whereas "Conical Seamount" features a depth range of 1700-4000 m. Two 50-80 km chains of flat-topped, igneous seamount domes have depths ranging 3050-4400 m and 3300-4800 m in the north and south areas, respectively.



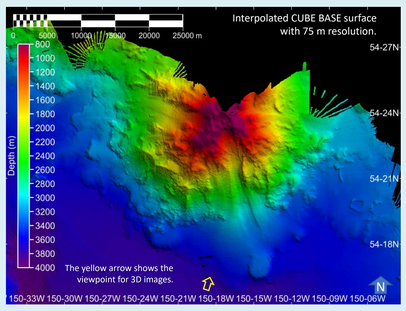
(above) The study area is located in a deep-sea region of the Northeast Pacific approximately 300 km southeast of Kodiak Island, AK and 175 km southeast of the Aleutian Trench. The area is notably close to the Patton Seamount and the Patton Seamount Chain. 600 km to the northeast, another leg of the Seascape Alaska expedition featured ROV dives on similar features to those of the study area.

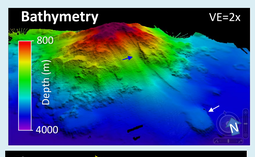


METHODS

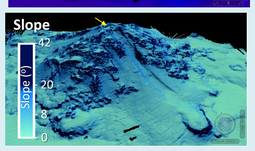
- Bathymetric surveys were conducted on the NOAA Ship *Okeanos Explorer* with a Kongsberg EM304 multibeam sonar echosounder during EX2305 (August 1 – 17, 2023).
- High-definition video collected by ROV *Deep Discoverer* during EX2306-Dive06 and EX2306-Dive07 was used for ground truth comparisons.
- CARIS HIPS & SIPS 11.4 software was used to post-process all raw multibeam sonar data, generating all 2D and 3D bathymetric surfaces, slope bands, classified backscatter intensity mosaics, and depth profiles.
- Flank slopes and vertical relief were measured from depth profiles of each site and compared graphically along with a two-way ANOVA.

Figure 2. Codman Seamount

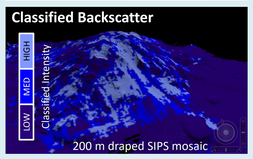




Codman Seamount has a significant scarp (blue arrow, left) on its southeast flank with a visible slump deposit (white arrow) at its base. The overall depth range is 450 - 3650 m. This seamount is located 12 km to the southwest of Patton Seamount.

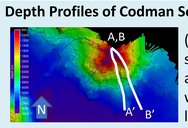


This seamount has lowest slopes of <1° at the caldera (yellow arrow, left) where the scarp originates. Highest slopes of 25-42° occur on the scarp's eastern side and at the south end of the slump. The surrounding seabed is nearly flat with slopes of <2° .



High intensity areas tend to be on the seamount's steeper flank, while low intensity areas occur around the low-sloped surrounding abyssal plane and western flank. The scarp exhibits high intensity suggesting exposed volcanic rock from erosion, while the slump has low intensity possibly due to unconsolidated sediment.

Depth Profiles of Codman Seamount



(below) Flanks A-A' and B-B' have similar slopes of ~10°. Profile A-A' has a slightly lower slope due to the scarp which smoothed that flank making it less steep.

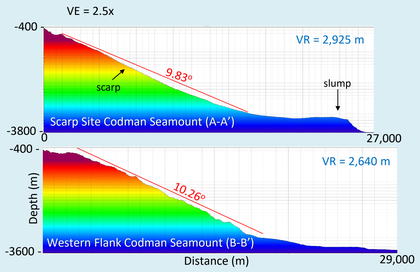
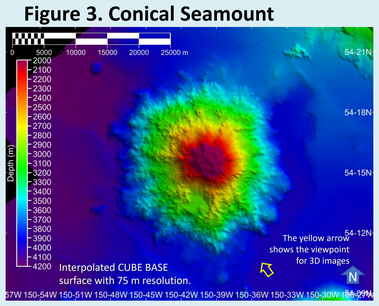
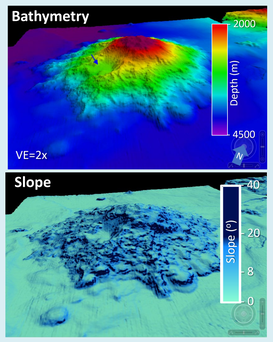


Figure 3. Conical Seamount

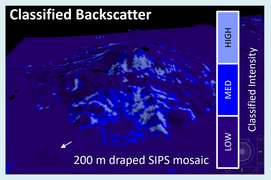


Conical Seamount has a depth range of 1600 to 4,000 m. This seamount features a scarp on the southwest flank (blue arrow) smaller than the Codman Seamount scarp (Fig. 2).

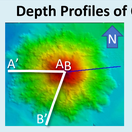


Conical Seamount has a low slope of <1° at the scarp origin. The steepest slope present is 40°.

Highest intensity occurs along the southeast flank and at the volcano's summit, indicating volcanic rock exposure. The lower intensity areas cutting through the center portion of the seamount and slump area (white arrow) indicate unconsolidated sediments.



Depth Profiles of Conical Seamount



The southwest flank (B-B') has a greater overall slope of 10° than the west flank (A-A', 7°). The southwest flank includes a scarp (14°) and flat terrace that alters the profile.

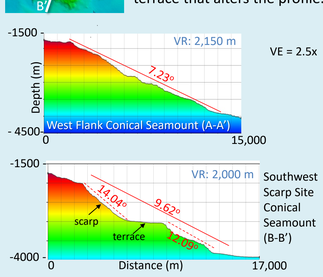
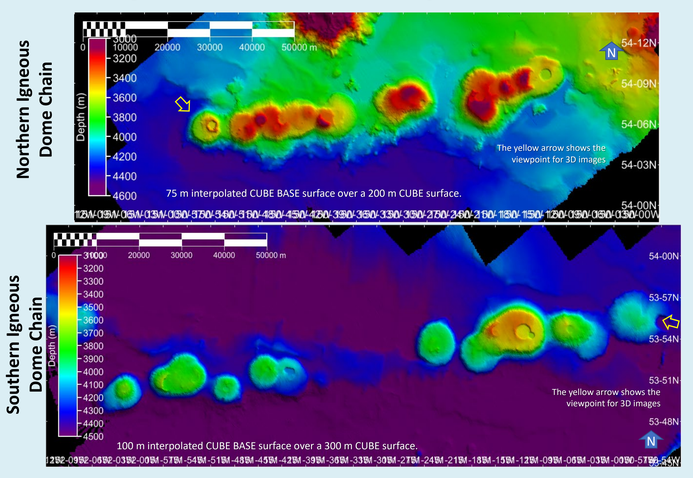
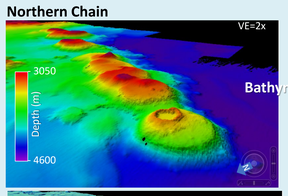


Figure 4. Northern and Southern Igneous Domes

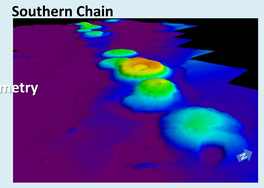


The Northern and Southern Igneous Domes comprise two chains of volcanic seamounts with flattened tops (slopes of ~ <1°). The northern chain is 90 km long with at least 10 volcanoes, many of which are overlapping. The southern chain contains two segments of 55 and 60 km, and numerous distinct calderas. These flattened dome-like formations were determined to be of igneous nature, rather than mud volcanoes due to reference ROV footage from a similar feature in the Gulf of Alaska. See ROV dive images, Fig. 5.

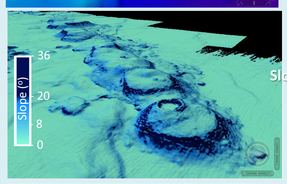
Northern Chain

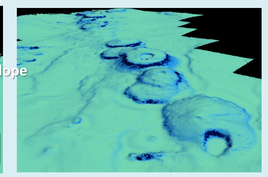


Southern Chain

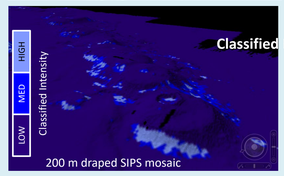


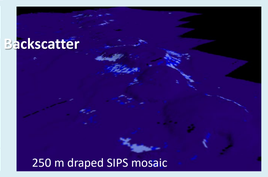
The Northern chain is shallower, having a depth range from 3050 – 4400 m compared to 3300 - 4800 m of the southern domes. Both igneous dome chains share a very similar scale.





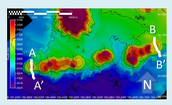
Both chains have lowest slopes of <2° on their flattened tops, and both contain steeper slopes of 15-35° along the flanks and within the calderas.



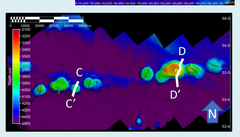


Few high intensity areas occur. Those present are highlighted along the northern and southern flanks, as well as within the calderas indicating basalt outcrops. Low intensity areas indicating unconsolidated sediment, cover most of these features.

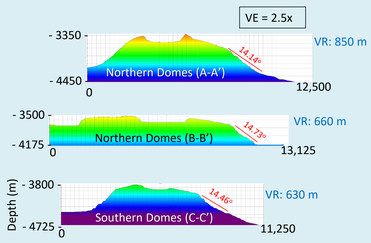
Depth Profiles of Igneous Domes



Northern Chain



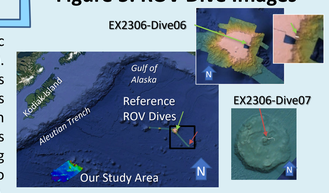
Southern Chain



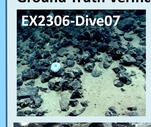
Depth profiles of select igneous domes from each chain show very similar slopes and vertical relief. Slopes range from 14° (A-A') to 16° (D-D'), and vertical relief ranges from 630 (C-C') to 1,025 m (D-D').

Figure 5. ROV Dive Images

ROV *Deep Discoverer* dove on two similar volcanic features to the study sites during EX2306 (right). EX2306-Dive07 investigated dome-like features resembling the Northern and Southern Igneous domes. Videos revealed basaltic rocks with manganese crusts, confirming these features as igneous volcanic seamounts (red arrow). During EX2306 the ROV dove on a seamount similar to Codman and Conical Seamounts (green arrow).

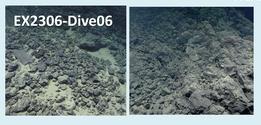


Ground Truth Verification from reference sites



(above and left) Basalt rubble and pillow formations on igneous domes, depth range: 3,171 - 3,290 m

(right) exposed volcanic rock and basalt rubble on a reference site for Conical/ Codman Seamounts: depth range 1,003 - 1,270 m

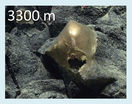


Images courtesy of NOAA Ocean Exploration, Seascape Alaska.

Biota on EX2306- Dive07

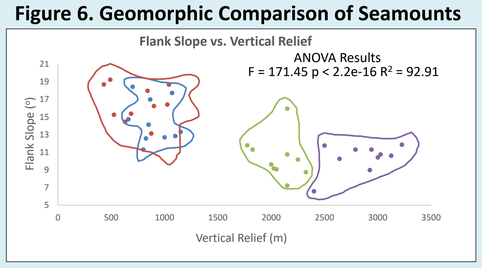
(above) Black coral Order Antipatharia, Deep sea anemone Family *Actiniidae*

(above) Glass sponge Class Hexactinellida, Genus *Muusoctopus*



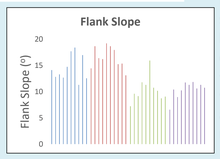
(right) Unidentified 'golden orb' specimen, collected for genetic testing

Figure 6. Geomorphic Comparison of Seamounts



Northern Domes · Southern Domes · Conical · Codman Seamount

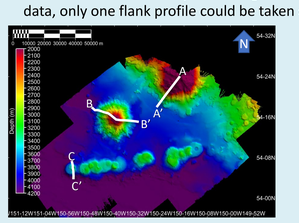
(right) Codman Seamount and Conical Seamount both had lower slopes measured from numerous profiles (means of 10°), whereas the Southern and Northern domes had higher slopes with means of 17° and 14°. The Southern Igneous Domes included the highest flank slope of 19°.

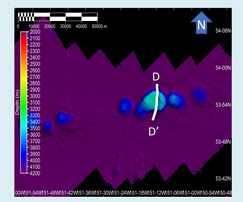


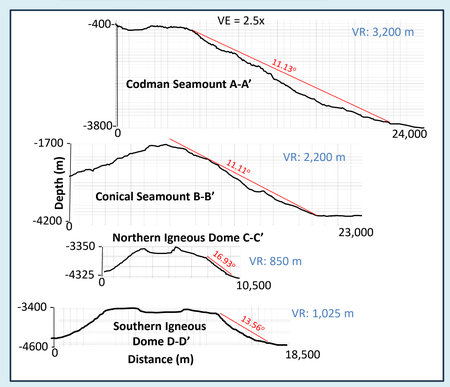
Slope and vertical relief data collected along various profiles from each site's prominent flank show significantly different geomorphologies between the igneous domes (red and blue) and the Conical Seamounts (green and purple). Codman Seamount displayed lower slopes associated with higher vertical relief, whereas the Southern and Northern Igneous Domes have higher slopes associated with lower vertical relief. The difference in slope and vertical relief between sites was statistically significant as shown by ANOVA results.

Figure 7. Study Sites Depth Profile Comparison

All four features are compared using flank slope depth profiles. Due to lack of data, only one flank profile could be taken of the Codman Seamount.







Codman Seamount has the greatest vertical relief of 3,200 m, ranging in depth 450 to 3650 m. In comparison the Northern Igneous Domes have the smallest vertical relief of 850 m. Codman Seamount also has a smoother flank than the other study sites. The Conical Seamount has the roughest flank.

The Northern and Southern Igneous Domes display the greatest average slopes of 17° and 14° with greatest values of 35° being found along the flank. Codman and Conical Seamounts have more gradual slopes of 11°.

DISCUSSION and CONCLUSIONS

This study area contains seamounts with significantly different geomorphology. Comparing seamounts from the Codman Seamount, Conical Seamount, and Northern and Southern Igneous Domes sites can provide insight on their formation and depth environments.

Codman Seamount displayed the lowest flank slopes (min 6°) and highest vertical relief (3225 m) between sites (Fig 6). Codman was formed ~30 mya during the formation of the Patton-Murray Seamount chain as the Pacific Plate passed over the Cobb hotspot (Chaytor et al. 2007). Multiple chute formations are common in older seamounts due to slope failures over time. These failures are likely responsible for the deformed cone and scarp formation on the southeast flank of Codman Seamount. Codman also has multiple U-shaped chutes on the flanks where sonar data were collected previously (Chaytor et al. 2007). The low intensity backscatter of the bulbous pile at the base of the scarp suggests that this is debris from flank failure.

Conical Seamount has intermediate flank slopes and vertical relief (10° and 2000 m) (Fig 6), and displays certain features similar to Codman, such as its shape and the presence of a clearly scarped site (Fig 3). The lack of additional U-shaped chutes and slope failures may indicate that Conical Seamount is younger than the Codman Seamount (Chaytor et al. 2007). Codman Seamount and Conical Seamount have the classic cone shape known to most seamounts that are formed over hotspots with summits at a shallow depth. Relatively low water pressure allows summits to remain conical, since lava erupts and flows down the sides of the seamount. ROV footage from EX2306-Dive06 provides ground truth verification of basaltic outcrops and exposed volcanic rock on a feature similar to Codman and Conical Seamounts 600 km to the northeast.

The **Northern and Southern Igneous Domes** displayed the greatest flank slopes (max 20°) and lowest vertical relief (490 m) (Fig 6). These separate chains have extremely similar characteristics of shape, slope, and backscatter (Fig 4), implying that they formed under the same conditions. These flat-topped volcanoes are not guyots formed by erosion, but instead likely form from continuously overflowing submarine lava ponds (Clague et al. 2000). Their flattened tops can be attributed to low-to-moderate effusion rates, steady eruption, low lava viscosities, and high confining pressure (Clague et al. 2000). The increased water pressure at the great depths of the igneous domes formation (3050-4800 m) can explain their flattened tops, lower vertical relief, and steeper flanks. ROV Footage from EX2306-Dive07 provides ground-truth verification from a similar feature 600 km northeast in the Gulf of Alaska. The lava pillows identified in these videos align with the hypothesized lava pond formation of the domes. As the domes grow, repeated overflows allow spillage of pillow lava to flow down the flanks (Clague et al. 2000). These videos display diverse biota mainly concentrated around the pillow domes and basalt rubble outcrops. The Northern and Southern Igneous domes would make an interesting dive spot on future expeditions for identifying potential deep-sea habitat.

ACKNOWLEDGEMENTS

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Clague, D., Moore, J., & Reynolds, J. (2000). Formation of submarine flat-topped volcanic cones in Hawai'i. Bull Volcanol, 62, 214–233. https://doi.org/10.1007/s004450000088

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