Geomorphologic Characterization of the Northern Tonga Ridge

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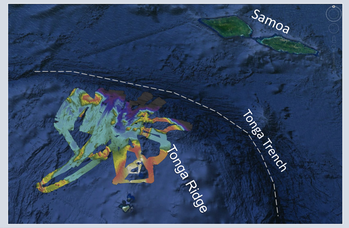
BACKGROUND

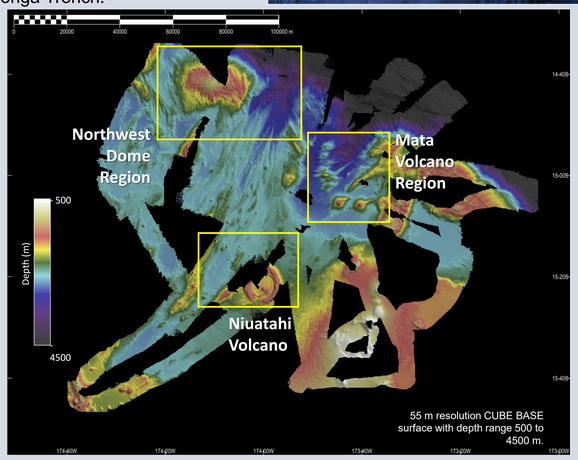
From November 2017 through January 2018 a team of scientists from several universities and NOAA studied the Tonga Ridge Region from on board the R/V *Falkor* on the northwestern side of the Tonga Trench to examine submarine volcanism. The goal of the expedition was to better understand the role submarine volcanism and tectonics play in shaping the seabed. Multibeam sonar data were used to determine the region's geomorphology. The area revealed a unique set of characteristics ranging from a 30 km broad domed feature that may be a shield volcano or a mud volcano, a chain of deformed active volcanoes, as well as a young volcano forming within an older caldera. Remotely operated vehicle dives were conducted by the Schmidt Ocean Institute to provide ground truth of the Mata Volcanoes revealing active hydrothermal vents as well as old lava flows. A variety of marine organisms were observed taking advantage of the unique seabed habitat.

The purpose of this study was to better understand the geomorphologic features created by submarine volcanism. The Tonga Ridge is located along a subduction zone where the Pacific Plate subducts beneath the Australian Plate, resulting in the formation of the Tonga Trench and a variety of volcanoes on the overriding Australian Plate. The Study Area is located on the overriding Australian Plate along the northwest-southeast bend of the Tonga Trench, and consists of a chain of up to 30 active and inactive submarine volcanoes, or seamounts, as well as a series of parallel, faulted ridges. The nearest land masses are Samoa to the northeast (200 km) and Fiji to the southwest (745 km) (Fig. 1). This area is one of many with active submarine volcanism and provides habitat for many organisms. Dr. Ken Rubin (Schmidt Ocean Institute) along with a team of scientists collected multibeam sonar data on the R/V *Falkor* from November 10 to December 17, 2017. Images, video, and samples were collected by Schmidt Ocean Institute's ROV *SuBastian*. Three areas studied reveal how tectonic activity has generated a range of volcanoes with completely different geomorphologies.

Figure 1. Study Area and Site Locations

The Tonga Ridge is a very complex area of the sea floor. Its bathymetry varies from broad domed features to chains of active volcanoes. Three regions within the mapped area were examined in this study, all of which are located within 200 km of the Tonga Trench.





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METHODS

- Raw multibeam sonar data were collected on the R/V *Falkor* by a team of scientists from U. of Hawaii, Oregon State U., U. Washington, and NOAA, as well as others, using a Kongsberg EM302 multibeam echosounder.
- The ROV *SuBastian* was used to collect all images and samples.
- Raw sonar data were converted using CARIS HIPS & SIPS 11.3.
- Bathymetry, slope, and classified backscatter surfaces along with several profiles were created for each site through CARIS HIPS & SIPS 11.3.
- Backscatter intensity and slope values were collected from mapped surfaces along profiles and compared for correlation analysis.

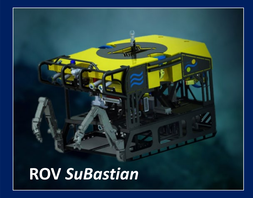
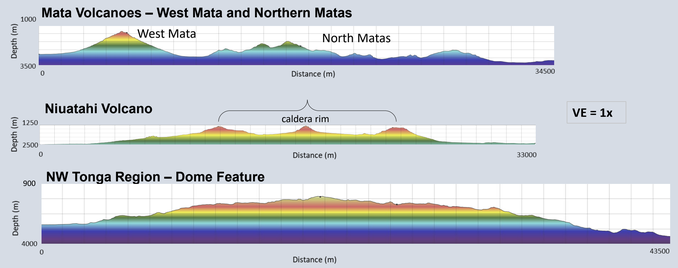
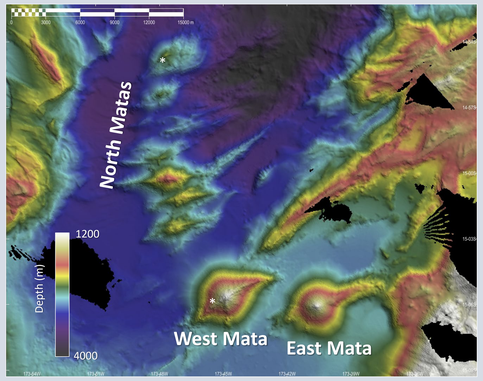


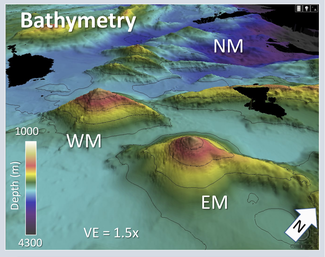
Figure 5. Comparative profiles

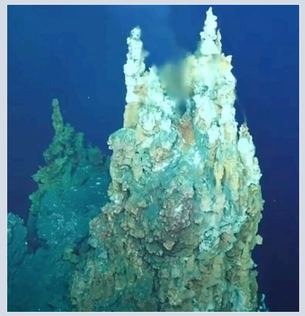


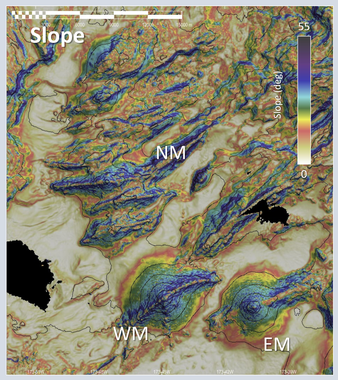
A representative profile was selected from each site. All profiles are shown at the same scale with no vertical exaggeration. All three locations vary dramatically in geomorphology. The Mata Volcanoes are a chain while both the Niuatahi Volcano and the domed feature are individual features. The profiles also reveal how distinct the Mata Volcanoes are from the Niuatahi Volcano. The Matas are significantly greater in vertical relief (300 to 1,350 m) as compared to the Niuatahi Volcano (1,200 m), however Niuatahi's caldera is much broader (13.81 km) than any of the individual Matas. The Northwest Tonga Region profile has the greatest vertical relief (3 km) and length (43.5 km).

Figure 2. Mata Volcano Region

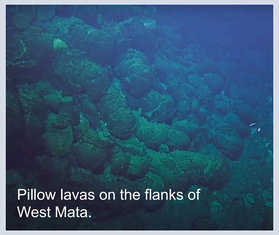






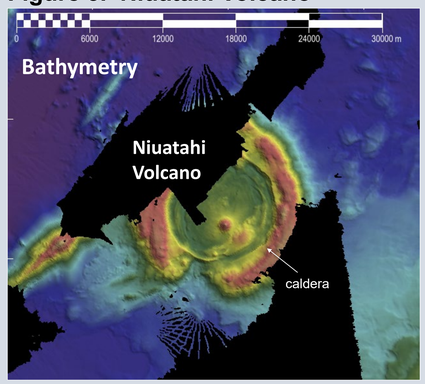


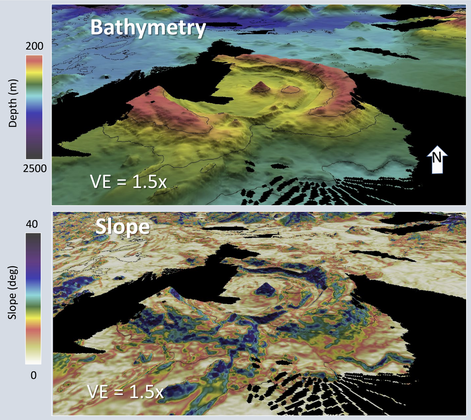
ROV dive footage showed areas with hydrothermal vents (right). Some were colonized by corals (below).



All the Mata Volcanoes have an unusual elongated, eye-like morphology. However, the West and East Matas (labeled as WM, EM) are more rounded and significantly larger than the chain of North Matas (NM). The slope surface shows increasing slope up to 55° on the flanks of West and East Matas. The North Matas also have areas of high slope, particularly along their ridges.

Figure 3. Niuatahi Volcano



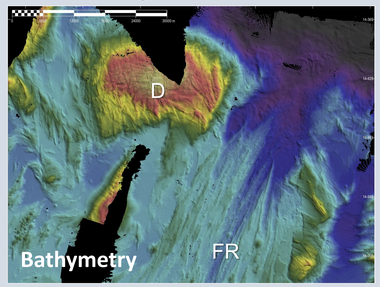


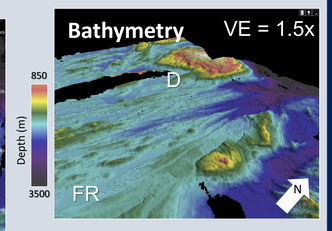
The Southern Tonga Region includes a small volcano growing inside a larger inactive Niuatahi Volcano caldera. The peak of a smaller, younger volcano within Niuatahi is approximately as shallow as the larger volcano's caldera. The Niuatahi Volcano has slopes reaching as high as 40°. 3D views of bathymetry and slope for Niuatahi Volcano show the younger seamount within the older caldera.

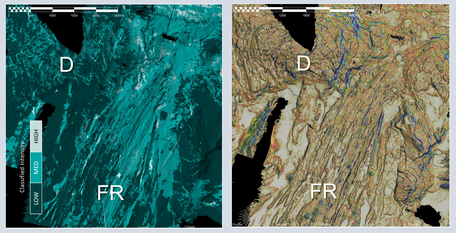
Figure 4. Northwest Dome Region

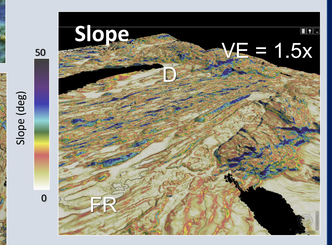
The Northwest Tonga Region is dominated by a large, 30 km wide domed feature (D) in the north with a depth range of 850 to 3,500 m. Its eastern side has the greatest slope (50°). Parallel faulted ridges (FR) are found in the southeast section with slopes reaching up to 50°.

The high-sloped eastern dome region and faults in the FR have higher backscatter intensity, suggesting it is composed of consolidated sediment.









DISCUSSION and CONCLUSIONS

Seamounts within the **Mata Volcano Region's** chain (Fig. 2) have a very distinct eye-like shape. The North Matas are very similar in geomorphology, with high slopes (ranging up to 55°) defining elongate ridges that extend their full diameter (ranging 4.48 to 15.09 km). Each volcano's ridge is oriented northeast-southwest. These features indicate either northwest-southeast compression or extension from the northeast and southwest. The volcanic chain likely formed early in the subduction of the Pacific Plate, and the volcanoes may have been deformed as a result of plate warping due to extended subduction. In comparison, a previous study of seamounts located near the Mariana Trench documents similar eye-shaped, pinched morphology observed for the East and West Matas (Alpert and Sautter, 2018).

The **Niuatahi Volcano Region** (Fig. 3) includes a smaller, presumably younger volcano within a larger caldera, indicating the larger volcano was once active and collapsed, followed by the smaller seamount's formation. The presence of the caldera suggests it was an explosive eruption. This caldera's diameter (13.81 km) is significantly larger than the Mata Volcanoes' diameter and does not show any signs of compression or extension, suggesting this location has not been as impacted by the subducting Pacific Plate as the Mata Region to the north, and was likely formed more recently than the Matas.

The **Northwest Tonga Region** (Fig. 4) includes the largest feature in the study area, with a dome shape. Unlike the Mata Volcanoes and volcanoes found in the Southern Tonga Region, it does not have a cone shape, but instead has the distinctive broad, convex shape of a shield volcano. This feature is significantly larger than the other volcanoes at nearly 3,000 m in relief and 43.5 km in diameter (Fig. 5). Comparatively, the northern Mariana Trench region contains a smaller but similar feature that has been identified as a serpentinite mud mound but is only 17 km in diameter and 2 km in relief (McCuen and Sautter, 2021). The large domed feature in the Northwest Tonga Region could potentially be a mud mound, although high backscatter intensity returns suggest it may be composed of more consolidated sediment or have rock exposures (Valentine, 2019).

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