Comparison of Seabed Features within the Azores and Nearby Mid-Atlantic Ridge

Kate Leturgez and Dr. Leslie R. Sautter

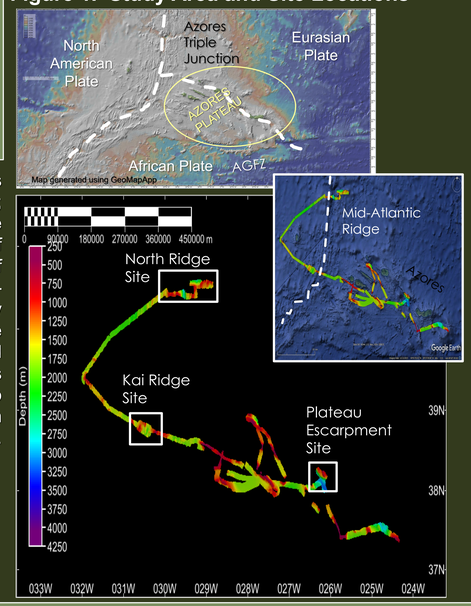
Department of Geology and Environmental Geosciences, College of Charleston

leturgezkh@g.cofc.edu and SautterL@cofc.edu

BACKGROUND

From May 11 through August 18, 2022, NOAA Ocean Exploration and numerous partners conducted a series of three telepresence-enabled ocean exploration cruises on the NOAA Ship *Okeanos Explorer.* The *Voyage to the Ridge* expedition's mission was to collect critical baseline information and improve knowledge about unexplored deep-water areas of the Charlie-Gibbs Fracture Zone, the Mid-Atlantic Ridge, and the Azores Plateau in the North Atlantic Ocean (NOAA Ocean Exploration 2022d). This information was used to inform management needs for sensitive habitats, geological features, and potential resources, as well as to collect data to enhance predictive capabilities for vulnerable marine habitats, seafloor composition, island formation, plate tectonics, hydrothermal vents, critical minerals, and submarine geohazards (NOAA Ocean Exploration 2022b). During the expedition's third and final cruise (EX2206, July 22-August 18), ROV dives and seabed mapping (NOAA Ocean Exploration 2022a) were conducted in the region of Azores, Portugal exploring the Azores Plateau and Mid-Atlantic Ridge (MAR) northwest of the Azores.

Figure 1. Study Area and Site Locations



Shown at right are the three sites that have been studied in depth; North Ridge is located along the Mid-Atlantic Ridge, northwest of Azores, Kai Ridge; located south of North Site also lies along the Mid-Atlantic Ridge, approximately 160km west of Azores, and the Plateau Escarpment; located southeast of both the ridges', falls along a third ridge that makes up the Azores Triple Junction, ~340 km from the MAR.

The Azores, an autonomous region of Portugal, is an archipelago of nine volcanic islands in the Micronesia region of the North Atlantic located roughly 1,610 km west of the Portuguese mainland. The islands are situated on a basaltic submarine plateau that is subdivided by the Mid-Atlantic Ridge (MAR), and falls along a triple junction – a place where three mid-ocean ridges intersect, separating the North American, Eurasian, and African Plates. Portions of the plateau formed by enhanced melt production close to the MAR between 10 and 4 mya (Storch et al. 2020). Several geomorphological features appear on the plateau and ridge including a range of escarpments and deep axial valleys.

The Azores Plateau sits along the Azores Triple Junction (ATJ) which has an elevated seafloor from an underlying mantle plume (Marques et al. 2013). This triple junction is marked by a ~15% decrease in MAR seafloor spreading rates (Marques et al. 2013). The plateau lies directly north of the Azores-Gibraltar Transform Fault (AGFZ); a major seismic zone.

The purpose of this study is to use bathymetry, slope, and classified backscatter intensity data to characterize the seafloor geomorphology and interpret the regional impact of plate tectonics

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BEAMS


NOAA Ship *Okeanos Explorer*

METHODS

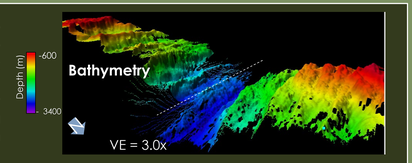
- The NOAA Ship *Okeanos Explorer* collected raw multibeam sonar data utilizing the ship's deep-water Kongsberg EM304 multibeam sonar.
- Sonar data were processed using CARIS HIPS and SIPS 11.4.
- 2D and 3D bathymetry, slope, and classified backscatter intensity mosaics were generated with 35 and 18 m resolutions. Depth profiles were made to better compare geomorphological features.
- A classified backscatter intensity mosaic was generated for each study area in order to compare intensity values among locations.
- ROV *Deep Discoverer* was used during NOAA Ocean Exploration expedition EX2206-Dive10 to collect critical information about the dive site substrate and benthic biodiversity (NOAA Ocean Exploration 2022a).
- For each study area slope and classified backscatter intensity data were collected using the Tooltips function, along profiles generated.

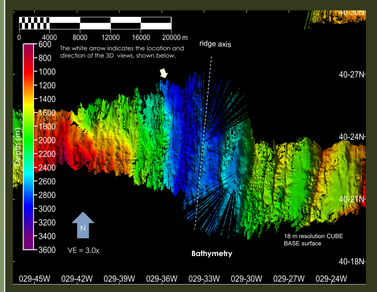

ROV *Deep Discoverer* (*D2*)

Figure 2. North Ridge Site

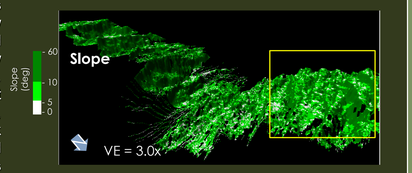
The North Ridge displays an axial valley, located along the Mid-Atlantic Ridge northwest of Azores, about 1,710 km from the Portuguese mainland.

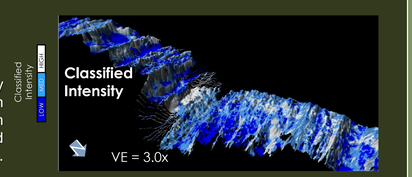
The axial valley bathymetry appears to be fairly symmetric, with the deepest region at about 3000 m. Towards the axial valley ridges becomes increasing shallow to less than 1000 m





Lowest slopes (represented below in white) are found on top of shallow axial valley ridges. Areas with highest slope (58°), represented in dark green, are situated on sides of ridges (see yellow box).

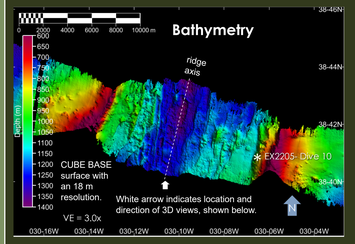




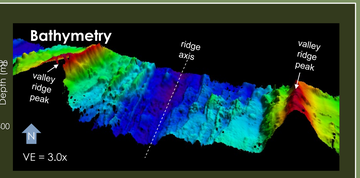
Areas with low intensity (shown in dark blue) are likely regions of irregular rocky outcrop, where as areas with highest intensities; shown above in white, are found within steepest areas of the axial valley. Representing exposed featureless basaltic outcrop.

Figure 3. Kai Ridge Site

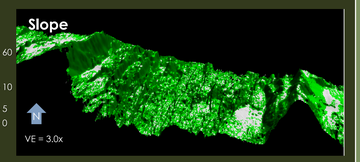
Kai Ridge lies south of North Site along the Mid-Atlantic Ridge approximately 160 km west of the Azores.



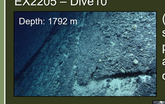
Kai Ridge is generally a symmetric axial valley with a ridge axis depth of ~1300 m. The axial valley ridges rise from the axis to a depth of ~500 m at the prominent valley ridge peaks.



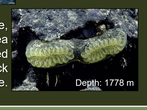
Areas with low slope (right, in white) are located on east and west bases of axial valley ridges. While areas of highest slope (dark green) are on rising side of ridges.



ROV Dive Images
EX2205 – Dive10



(left) The basaltic substrate of this area is part of the exposed fault and has a steep angle of approximately 40°.



(right) A delicate tunicate, commonly called a sea squirt was observed attached to a rock surface during the dive.

The western region of the valley has highest intensity, (right, in white), indicating an area of flat-lying basaltic outcrop. While eastern region of the valley, has low intensity (dark blue), as well as low slope, suggesting an irregular or rough seabed.

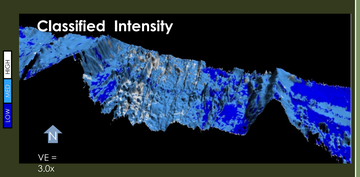
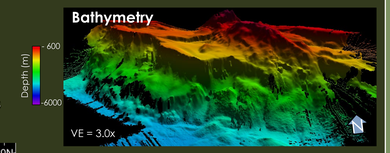
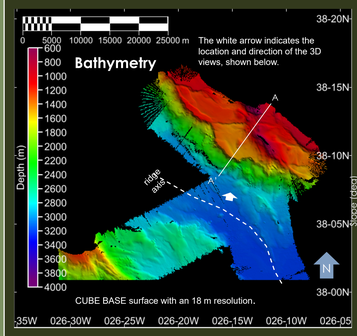


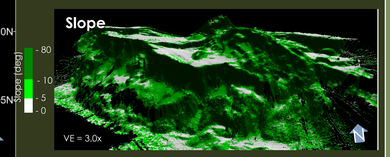
Figure 4. Plateau Escarpment Site

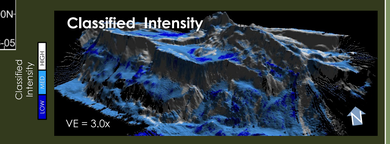
This site is located directly north of the triple junction's eastern ridges axis, about 1,535 km from the Portuguese mainland, and includes a large escarpment, with overall vertical relief of ~2,250 m. The escarpment lies on the eastern side of a low valley (3,000 m depth), which rises to the west.



Faulting during seafloor spreading of the MAR likely caused the scarp (above), which has a range of slopes; steepest being on the feature's side (80°). Below the overhang is a depth of ~3,200 m while the top of the scarp is nearly flat (1.5°) and ~1000 m in depth with a vertical relief of 2,250 m.







The exposed sides of the scarp exhibit highest intensity (right, in white), suggesting an area of flat-lying basaltic outcrop.

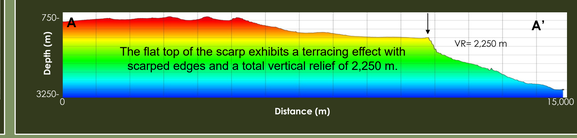
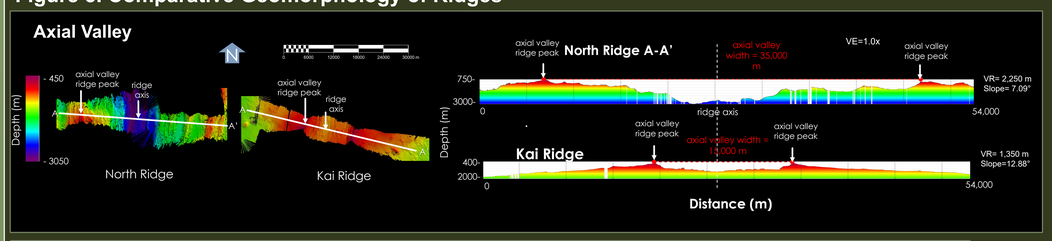
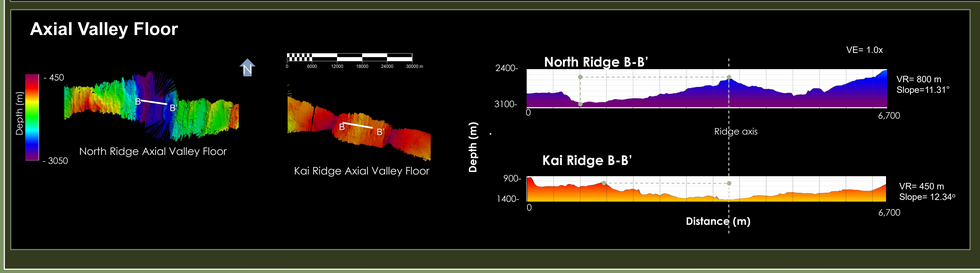


Figure 5. Comparative Geomorphology of Ridges



North and Kai Ridge axial valleys have very different geomorphologies. North Ridge's axis lies at greater depth (2700 m) than the axis of Kai Ridge (1250 m), and has an axial valley width of approximately 35 km, compared to Kai Ridge's valley width of ~15 km. Additionally, North Ridge has numerous intermediate ridges between each axial valley peak and has nearly twice the vertical relief from the axial valley ridge peak to ridge axis; 2,250 m compared to Kai Ridge's 1,350 m, which has several smaller ridges between each peak.



North Ridge and Kai Ridge have significantly different axial valley floor geomorphologies. North Ridge has a prominent ridge with vertical relief of 800 m directly on the axis, flanked by two deeper valleys with depths of 2900-3000 m. This area has a gradual slope from the ridge axis crest to adjacent valley (11.31°). In contrast, Kai Ridge has no axis-centered ridge but instead shows a broad, pronounced valley with a depth of ~1300 m. The seafloor is irregular and has a smaller ridge approximately 2350 m from the axis with a vertical relief of 450 m and 12.34° slope.

DISCUSSION

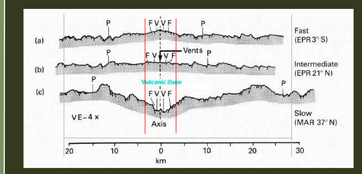
High-resolution bathymetric surveys and ground-truth from video surveys were used to identify geological and biological seafloor habitats. The lack of prior research and sample material from the seafloor of the Azores' geographic area made interpretation limited regarding the regional impact of Plate Tectonics.

Ridge Sites (North and Kai)

Axial valley geomorphology at North Ridge and Kai Ridge Site differs greatly; features on each valley floor vary in depth, size, and distance to the ridge axis. North Ridge has three elongated axis valley ridges that lie at depths of 2850, 2600, and 2400 m, with a gradual shoaling (Fig. 5), while Kai Ridge appears to have several smaller ridges on the valley floor with a more abrupt shoal and depths of ~1,000 m (Fig. 6). The features seen at each ridge are likely the result of rising and diverging convection currents from within the Earth moving the plates apart along a spreading center known as Terceira Rift. Rising magma creates new oceanic crust along the boundary (i.e., the ridge axis), solidifying and forming unique features at each site. Kai Ridge, located just west of the plateau lies at shallower depths than other ridge segments and has an axial valley similar to Fig.10b (Kennett, 1982), which represents a ridge axis with an intermediate spreading rate. North Ridge's axial valley has greater depths and a prominent valley ridge at its axis. The axis geomorphology is similar to Fig.10a which represents a relatively fast spreading rate- possibly due to its distance from the junction and lower degree of uplift from convection. Kai Ridge is located on the ATJ which is marked by a ~15% decrease in MAR seafloor spreading rates (Marques et al. 2013). This ridge's location potentially explains the different geomorphology from the faster-spreading North Ridge area.

Plateau Escarpment Site

The Plateau Escarpment Site exhibits numerous terraces with exposed scarps comprised of basaltic substrate with a significant variance of slopes from 1.5° to 80° (Fig. 4). This escarpment lies adjacent to the spreading ridge of the ATJ, just northwest of the Azores-Gibraltar Transform Fault (AGFZ); a major seismic zone. These scarps and terracing are likely the result of seismic tectonic activity and seafloor spreading associated with the Azores rifting. Due to increased tectonic activity and other geological disturbances, many of these rock outcrops have dropped and tilted at the fault scarps; creating a terraced geomorphology north of the valley. This effect would explain why the area's seabed has been transformed into a number of flat leveled areas with high-slope scarps, resembling a series of steps.



Spreading Rates and geomorphology along mid-ocean ridges (from Kennett,1982.)

ACKNOWLEDGEMENTS

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