Comparative Geomorphology of Mid-Ocean Ridge Segments in the Central North Atlantic

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BACKGROUND

Mid-Ocean Ridge rift zones provide a detailed presentation of Earth's tectonic processes. The study area is a section of the Mid-Atlantic Ridge located approximately 480 km southwest of the Azores Islands, Portugal. In this area, the North American and European Plates diverge, generating new oceanic crust as a result of lower pressure of the near-surface rocks and allowing molten basaltic magma to rise to the crust's surface. (Chadwick 2022) This magma then cools, becoming new oceanic crust and forms the ridge axis. The selected study area reveals volcanic, tectonic, and hydrothermal systems, with hydrothermal vents, volcanoes, and exposed igneous plutons located in basins on either side of the ridge axis. The rift itself has rugged topography of cliffs, ridges, and basins that run like a spine down the middle of the spreading zone, with blocky and uneven terrain composed exposed basalt. Fracture zones have shifted the axial valley, staggering the mid-ocean ridge axis. (Chadwick 2022)

The purpose of this study is to compare bathymetry, slope, and classified backscatter intensity data of three adjacent ridge segment sites to identify different tectonic features. Very little is known about mid-ocean-ridge environments, so this study aims to reveal specific examples of mid-ocean ridge features, such as underwater volcanoes, rift valleys, lava flows, and ridge basins. Using bathymetric profiles and 3D mapping to compare and contrast different features across the study site, comparative geomorphologies can be analyzed. These geomorphologies then correlate to the long-term processes of mid-ocean ridges and how they evolve over time. Classified Backscatter intensity is used to examine the substrate character along and perpendicular to the ridge axis, to investigate and to classify the mid-ocean ridge's substrate geomorphology.

METHODS

- The Research Vessel *Marcus G. Langseth* collected raw multibeam data using the Kongsberg EM122 multibeam echosounder during EX1305 (April to May 2013).
- CARIS HIPS and SIPS 11.4 software was used to process raw sonar data, which was collected by chief scientist onboard, Dr. Juan Pablo Canales of the Woods Hole Oceanographic Institution (WHOI).
- 2D and 3D Bathymetric CUBE surfaces were generated using CARIS, as well as 2D & 3D slope and surfaces, 2 & 3D aspect surfaces, and classified backscatter intensity mosaics.
- Depth profiles were constructed to examine and compare mid-ocean ridge bathymetry and geomorphologic features.

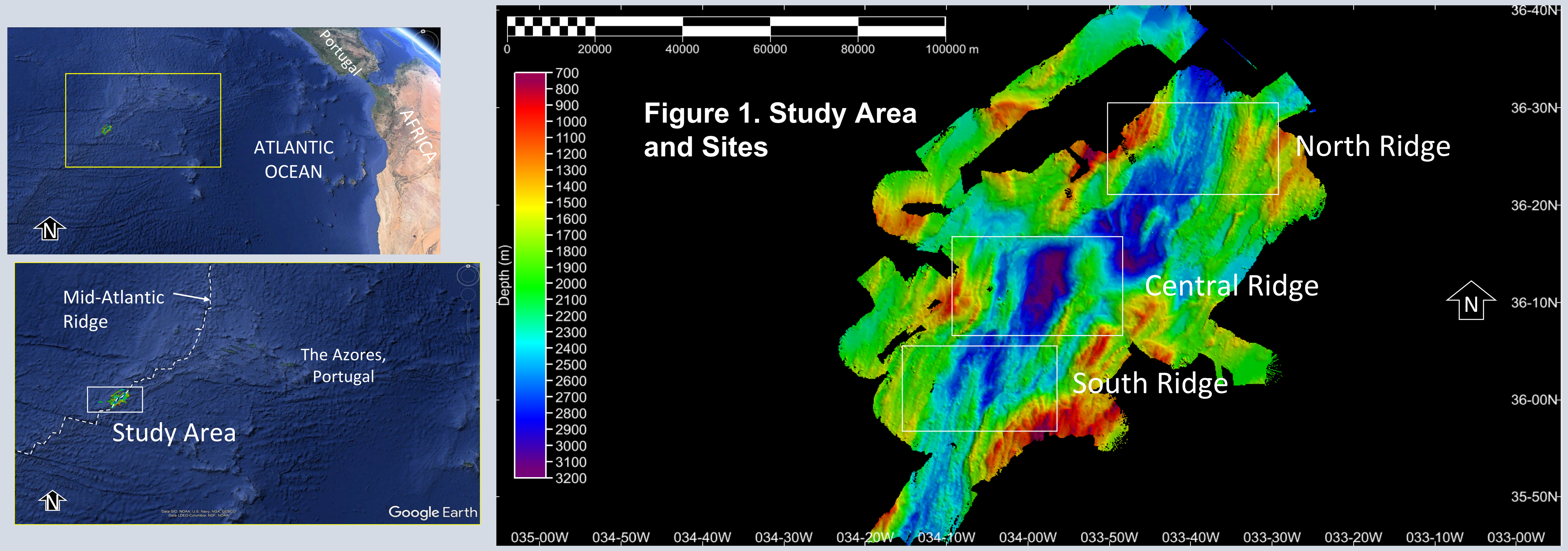
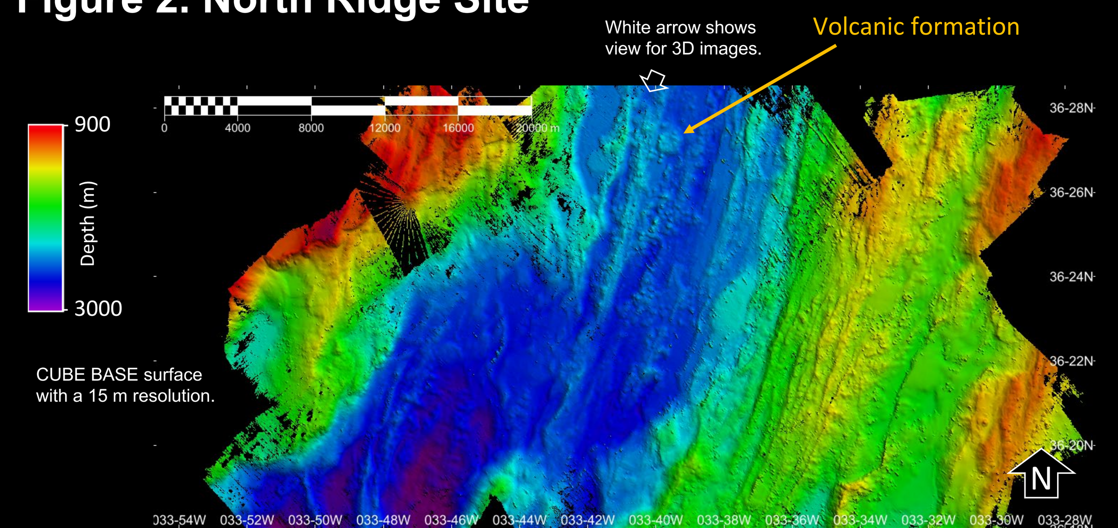
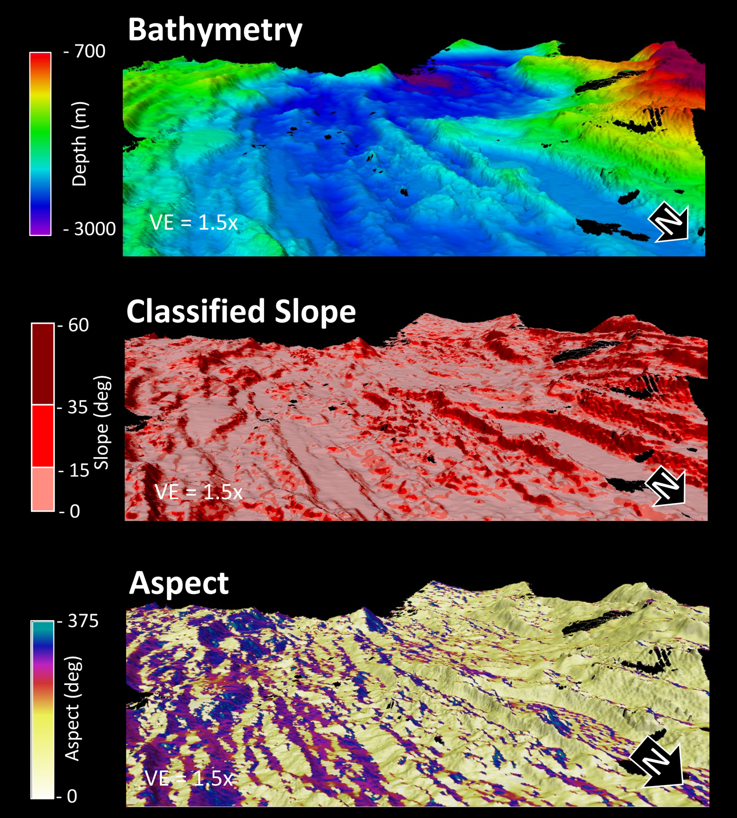


Figure 1. Study Area and Sites

Figure 2. North Ridge Site

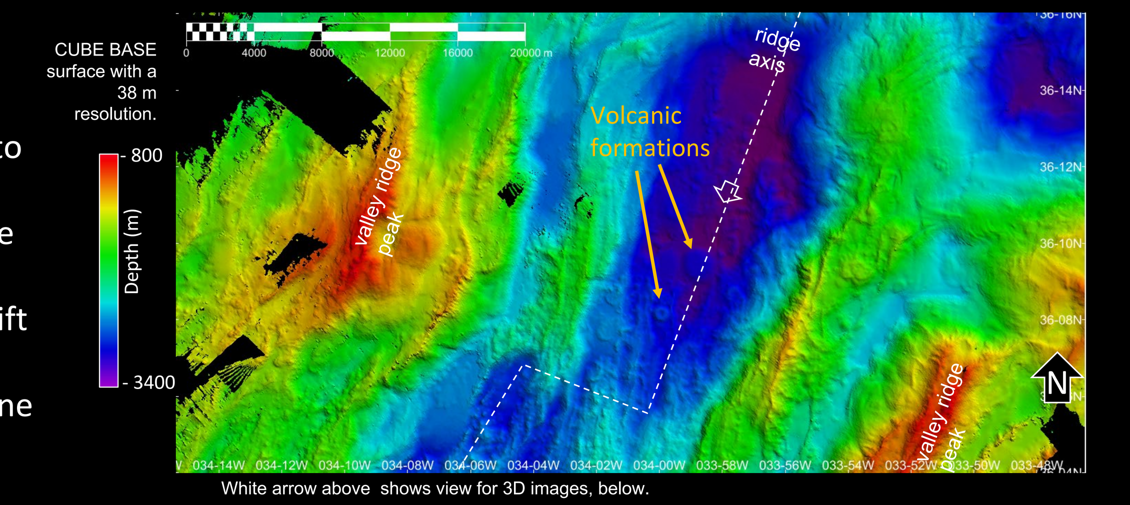




An abrupt rise is observed on the western axial valley rim, with vertical relief of over 2000 m, and cliffs with slopes reaching 75°, whereas the easternmost valley rim shows vertical relief of only ~1600 m, and significantly lower slope. Circular volcanic formations are scattered along the northernmost ridge axis section.

Figure 3. Central Ridge Site

This study site has high vertical relief and multiple volcanic features, but no defined axial ridge compared to other study sites. Two ancient axial ridges are found on either side of the basin-like valley floor. The width of the Rift Valley is approximately 25 km. 3D image (below), shows detail of effusive rift basin volcanoes and steep rift valley walls lining the basin. Circular formations are exposed batholiths with volcanic rims (Canales 2022), one with a 750 m diameter.



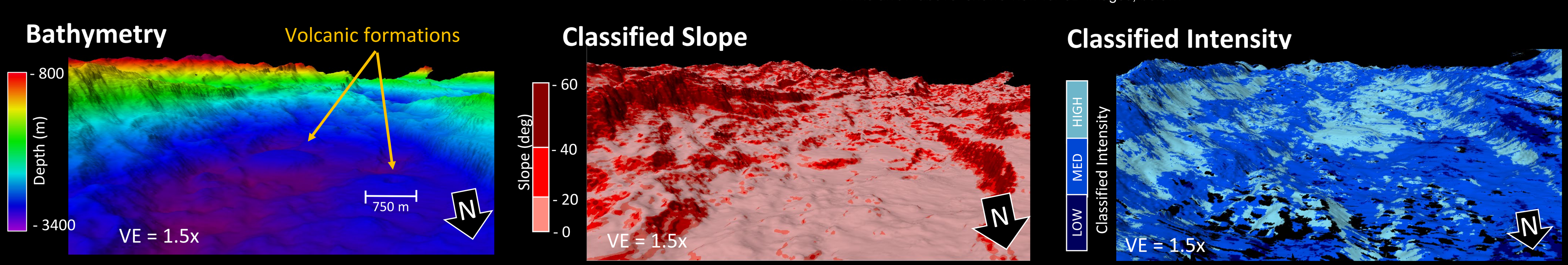
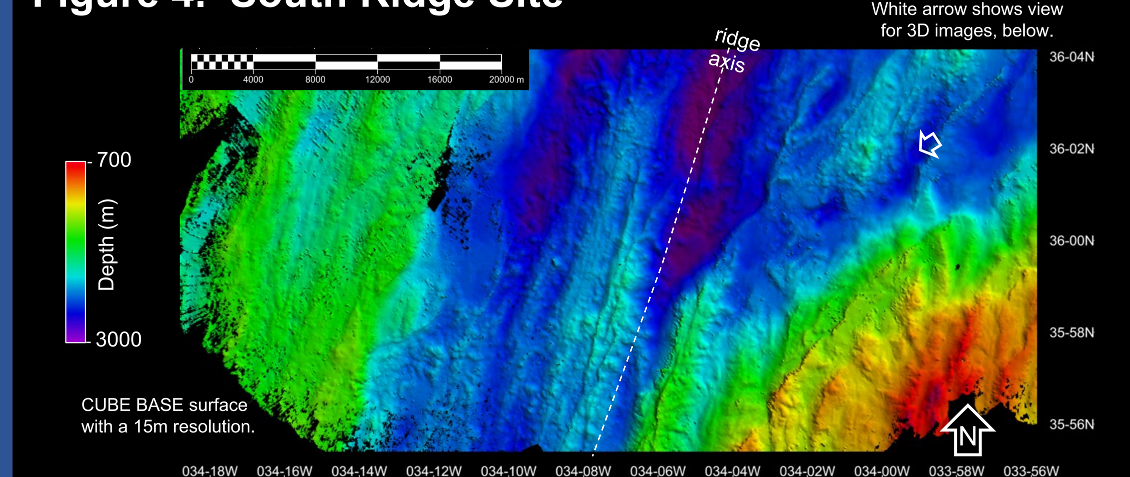


Figure 4. South Ridge Site



High intensity is found on the exposed ridge segments and areas of generally steeper slope, as well as along the ridge axis. Low intensity is observed at the more gradual slope areas, where unconsolidated sediments may have deposited over the mid-ocean ridge basalts.

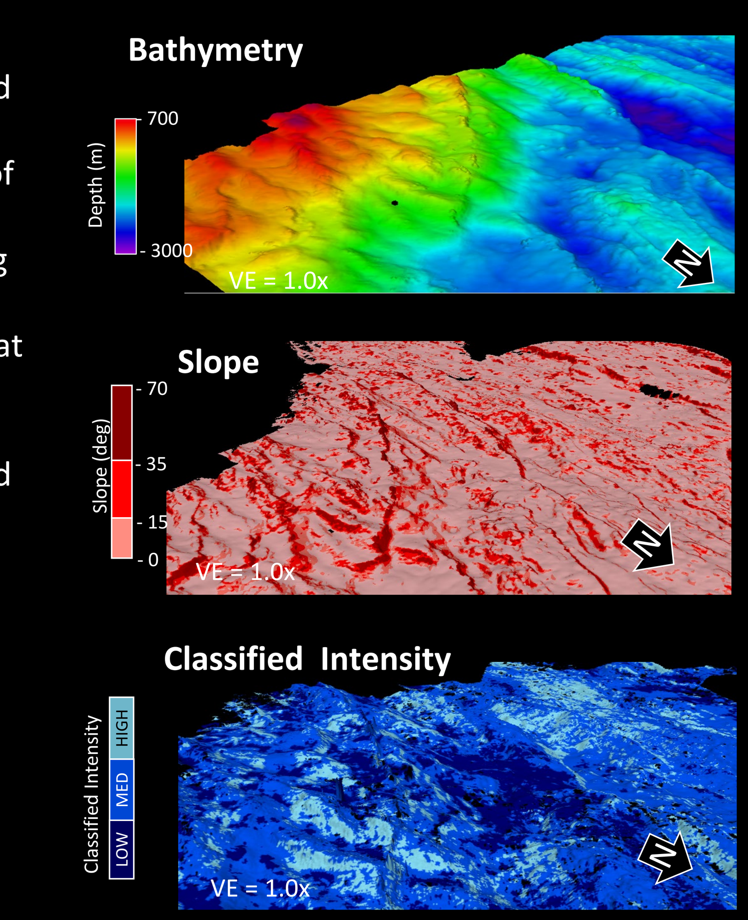
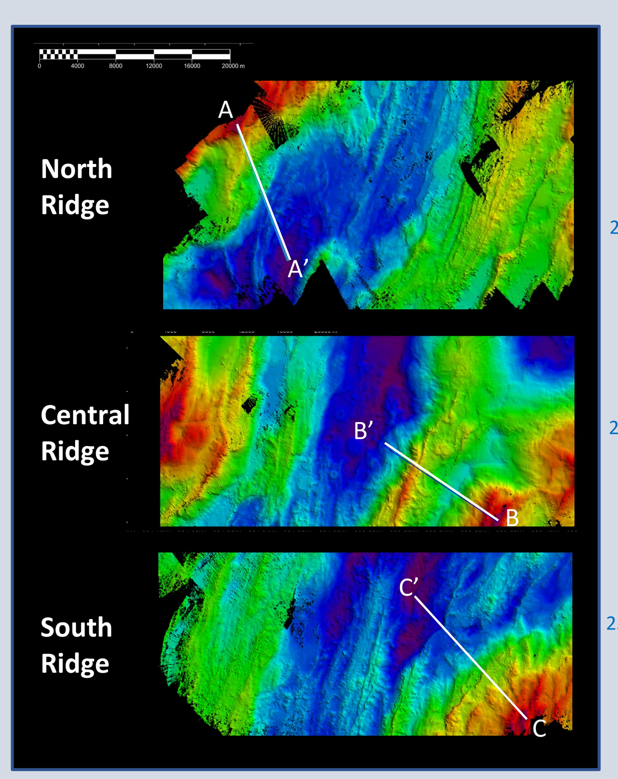


Figure 5. Comparative Vertical Relief Profiles

Depth profiles were made from shallowest point to axial ridge valley. North and South Ridge sites are very similar in morphology and slope. Central Ridge has a secondary valley ridge east of the ridge axis, whereas North and South sites lack secondary valley ridges. South Ridge has the highest vertical relief of 2500 m compared to 2200 and 2300 m for the north and central sites, respectively.



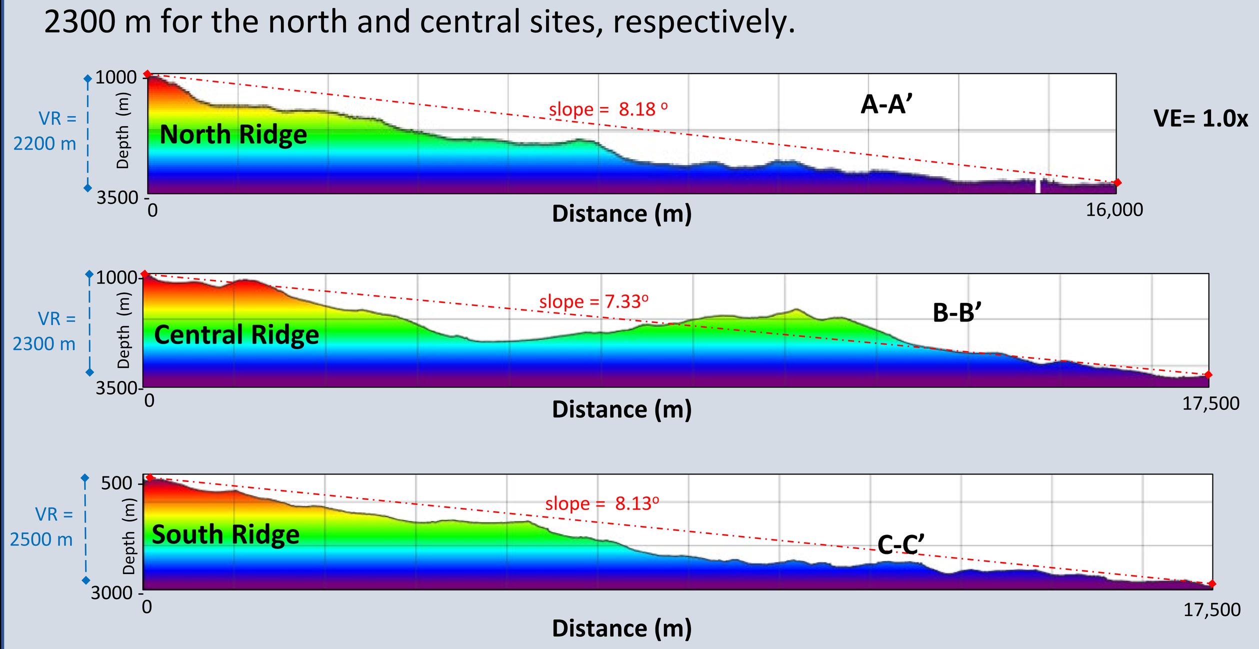
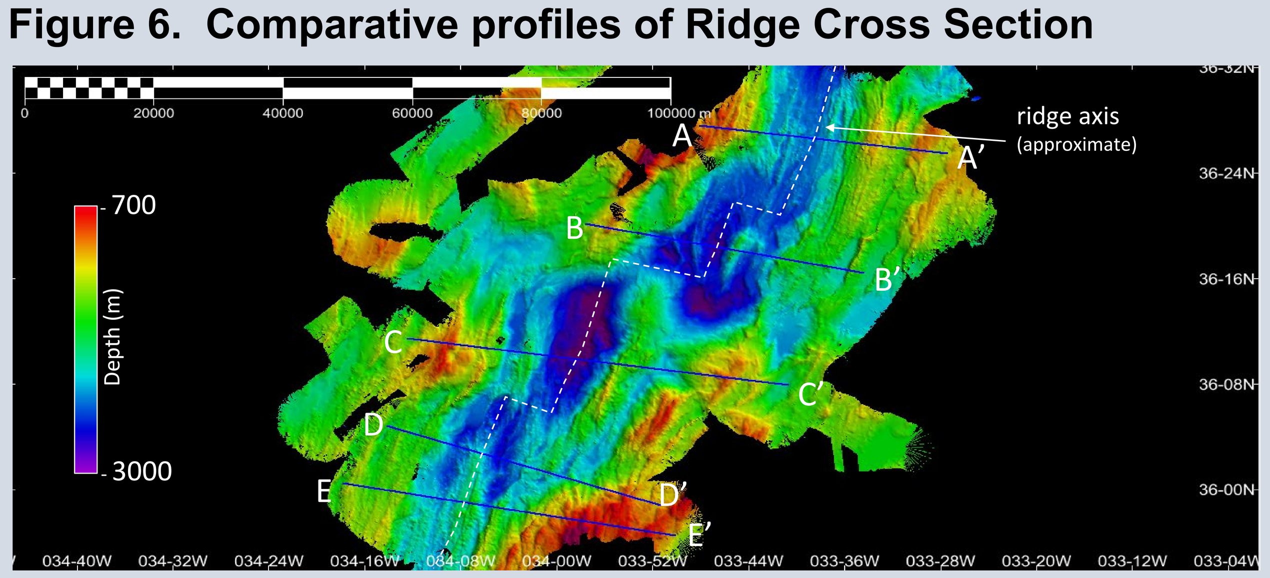
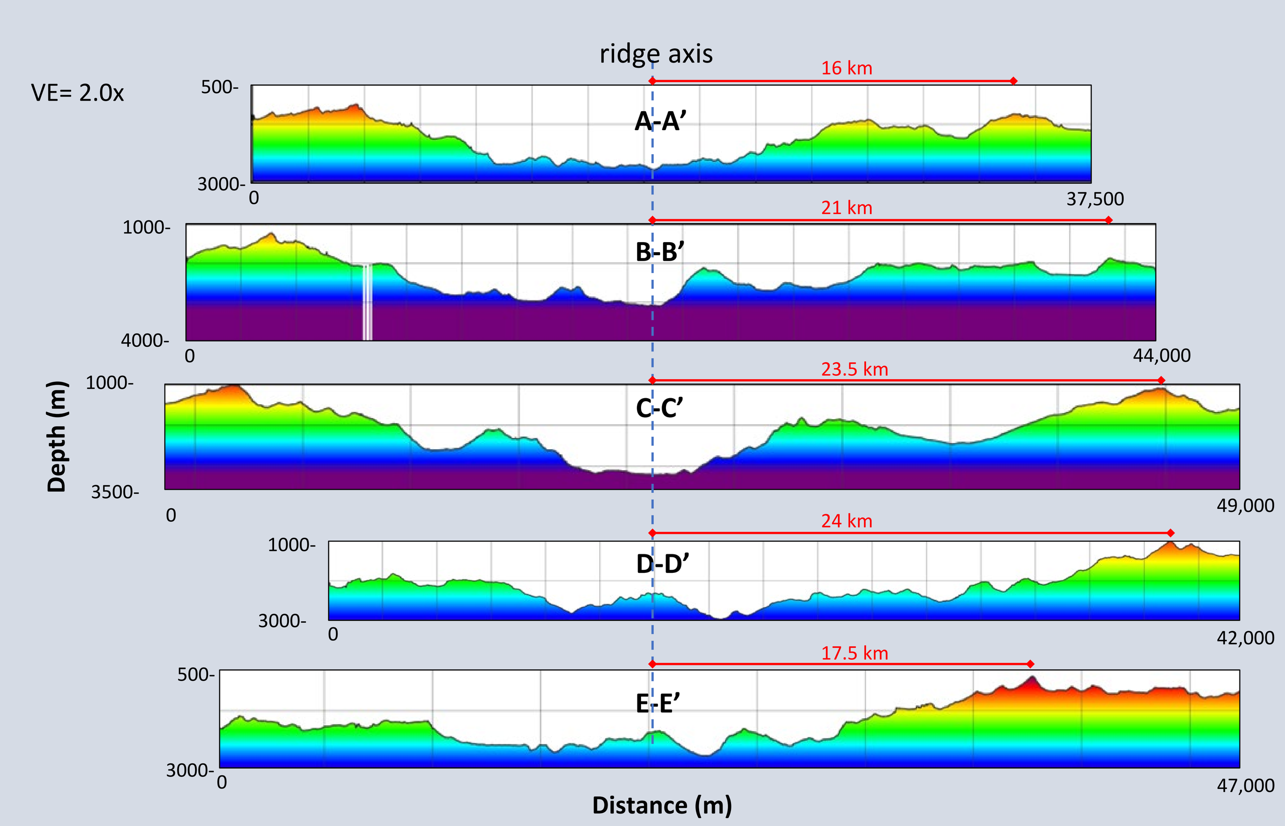


Figure 6. Comparative profiles of Ridge Cross Section





Axial Valley cross-section profiles are arranged north to south. Axis ridge geomorphology transitions from a steeper, more symmetric axial valley with greater vertical relief in the north, to a more gradual and asymmetrical axial valley in the south. An additional ridge is seen on the D-D' and E-E' profiles on the ridge axis.

DISCUSSION and CONCLUSIONS

The study area has been tectonically stretched, diverging two tectonic plates, for tens of millions of years. The active low pressure melting right beneath the axis means the youngest crust is found on the ridge axis. Substrate of exposed, freshly cooled basaltic rock on the surface here shows evidence of mid-ocean ridge features and tectonic activity.

Due to the volcanic activity along the axial ridge and the presence of water, the crust has heated and partially melted, and over time, forming the observed low slope valley wall and causing the crust to appear rugged and uneven.

If this laterally spread area of seafloor could be analyzed by its magnetic signature, on would find evidence of plate tectonics and active seafloor spreading due to the magnetically aligned iron phenocrysts in the freshly cooled basalt.

Aspect maps give a perfect representation of this tectonic spreading and the rugged, exposed oceanic crust. Geomorphology at North Ridge and South Ridge sites (Figures 2 & 4), reveal bands of alternating mini-ridges facing east then west repeatedly, spreading outwards from the ridge axis. This similarity between sites and its consistency over tens of miles is direct evidence of active seafloor spreading.

New oceanic crust gets created from rising, melted mantle peridotite , resulting in basaltic magma erupting along the rift basin floor. This magma is hydrothermally metamorphosed in a process called metasomatism, in which heated water brings new ions into rapidly cooling basaltic magma, causing new minerals to from and changing its chemistry. Because the ridge axis is the area with the youngest, most-recently erupted basalt, these processes cause the axis to have extremely rugged vertical relief.

Analyzing axial valley profiles and seeing similarities to a cross section of a rift valley, the valley's symmetry is evidence for seafloor spreading and plate tectonics. The deepest point is typically at the axis center, where terrain is most rugged, and may be a rift basin walled by symmetrical ridges. Extending outwards from the ridge basin, symmetrical periods of low-slope terrain lead to the rise of the shoalest area, an axial valley mountain ridge, bordering the edges of the study area on east and west sides. Total vertical relief from rift basin floor to shoalest axial valley peak is approximately 2900 m. Faulting and fracturing has created the Rift Valley and mid-ocean ridge. Strike slip faulting has affected the study area, offsetting the valley ridge to the east as the mid-ocean ridge goes northwards.

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