Mid-Atlantic Ridge Geomorphology at Kurchatov Fracture Zone

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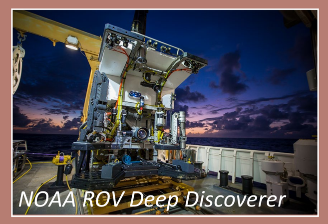
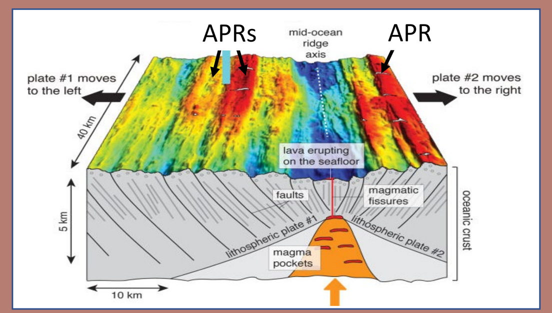


BACKGROUND

The Mid-Atlantic Ridge (MAR) spans from the Arctic Ocean to the South Atlantic. The Kurchatov Fracture Zone lies in an east-west orientation at ~40.5°N and runs perpendicular to the MAR just west of the Azores. Searle and Laughton (1977) concluded that this fracture zone did not have similar features to other transform plate boundaries. They found that the fracture zone had a sawtooth shape that is most likely caused by crustal mountains emerging from the seafloor, causing numerous normal fault scarps. In 2022, NOAA Ship *Okeanos Explorer* conducted an expedition, *Voyage to the Ridge*, with the goal to map in high resolution a large portion of the MAR, including the Kurchatov Fracture Zone area (NOAA Ocean Exploration 2022, EX-2205).

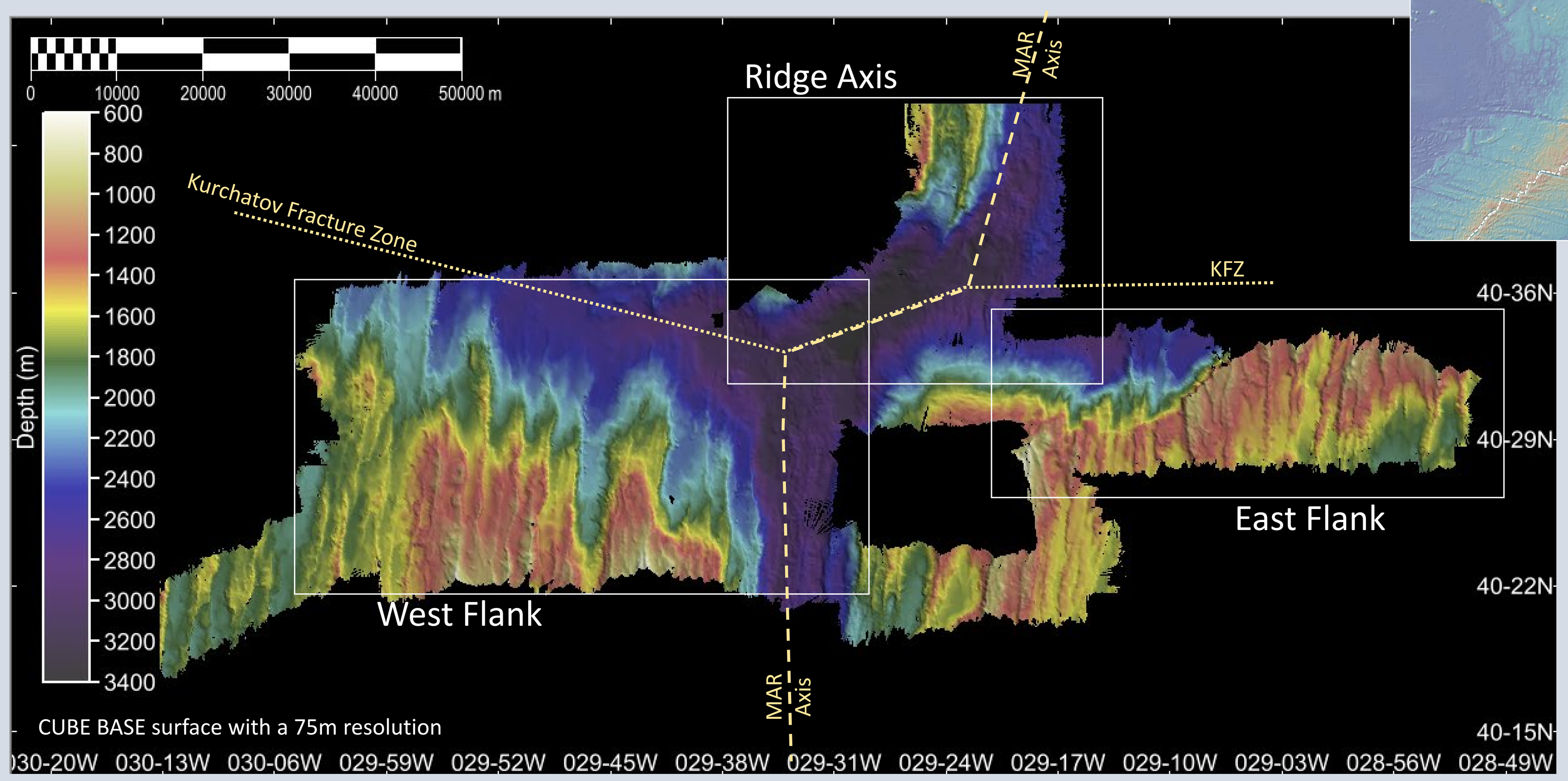
Common features along mid-ocean ridge sites include hydrothermal vents, pillow basalts, and consecutive axis-parallel peaks that result from seafloor spreading. The diagram shown below (from Olive et al., 2015) demonstrates how pockets of magma form within a lithospheric plate, rise upward towards the seafloor through elongate fissures at the ridge axis, then cool, generating new seafloor. Expansion due to the plates' diverging causes these new vertical slabs of seafloor to fault and tip away from the axis. The resultant seafloor features are here referred to as axis-parallel ridges (APRs), also known as abyssal hills. Usually, these sites lack benthic organisms due to their fairly new substrate. Typical MAR ridge segments have many APRs, as shown in the figure below.

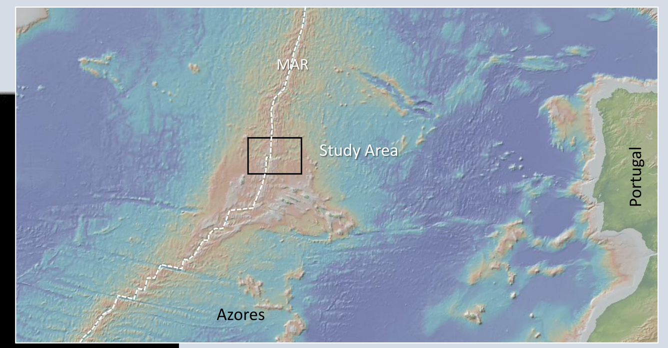
The purpose of this study is to examine seafloor geomorphology on either side of the MAR, and to compare tectonic features on both plates. Sonar data were used to generate bathymetry, slope, aspect and backscatter surfaces, as well as depth profiles. This expedition also included multiple ROV dives, with photographs and footage from three different sites within the study area. ROV images are used to ground-truth sonar data to describe benthic habitats.



The image above (modified from Olive et al., 2015) illustrates numerous faults on each side of and tilting away from the axis, resulting in several uniform axis-parallel ridges (APRs).

Figure 1. Kurchatov Fracture Zone and 3 Site Locations





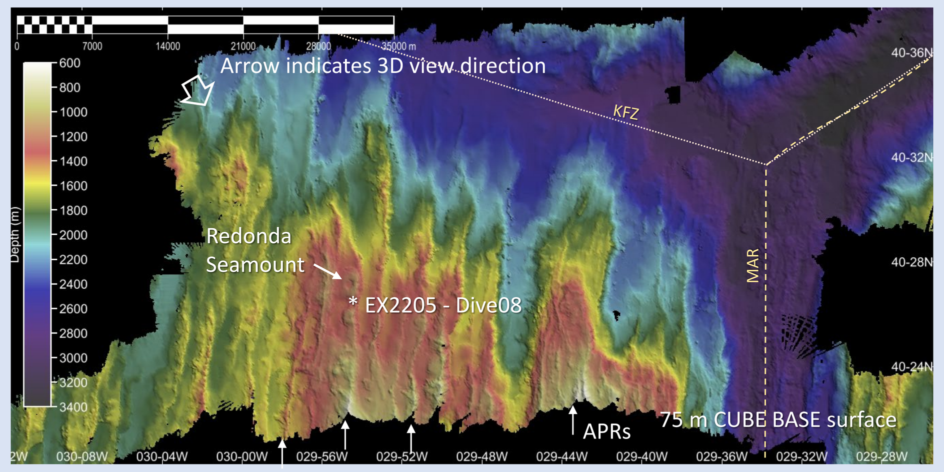
Kurchatov Fracture Zone (KFZ) is a large offset of two Mid-Atlantic Ridge (MAR) ridge segments, approximately 1,600 km west of Portugal and north of the Azores.

The study area includes the KFZ and portions of two ridge segments, where depths range 600 to 3400 m. Three sites were examined: East Flank, West Flank and Ridge Axis Sites. Ridge Axis site includes the area where the MAR is offset by the KFZ.

METHODS

- The NOAA Ship *Okeanos Explorer* conducted multibeam sonar surveys of the MAR on expedition EX2205 equipped with a Kongsberg EM304 multibeam echosounder.
- Sonar data were processed using CARIS HIPS and SIPS 11.4 to produce surfaces of bathymetry, classified slope and classified backscatter intensity mosaics.
- Several depth profiles were made to compare slopes and vertical relief of axis-parallel ridges of similar features.
- ROV *Deep Discoverer* conducted three separate dives (EX2202-06,07,08), to examine geomorphology and collected biological samples.

Figure 2. West Flank

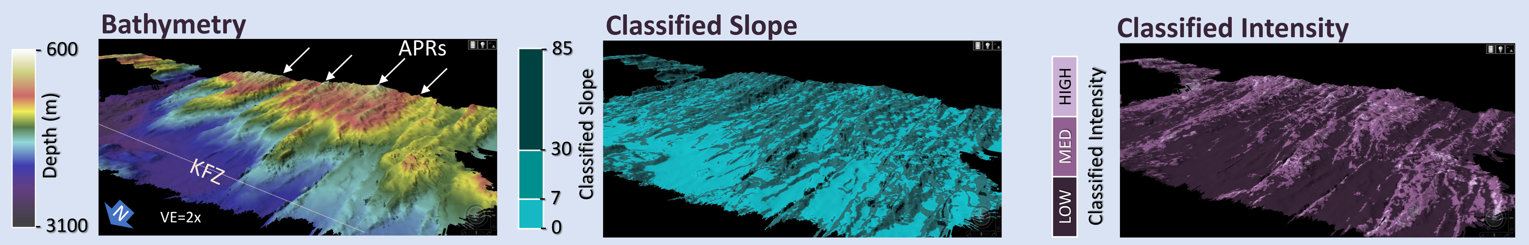


(right) ROV images show the *Deep Discoverer* surveying the basaltic substrate in detail (top). The fish species *Hoplostethus atlanticus* has a large population in this area, and is a vulnerable, overfished game fish (bottom).

EX2205-Dive 08 (1,235 m)

EX2205-Dive 08 (1,205 m)

West Flank, on the North American Plate moving westward, has depths ranging 620 to 3100 m. A large volcanic seamount named the Redonda lies on the western portion of the site and was explored during EX2205-Dive08. The substrate mainly consists of jagged pieces of basalt with many deep-sea corals and sponges growing on the hard substrate.

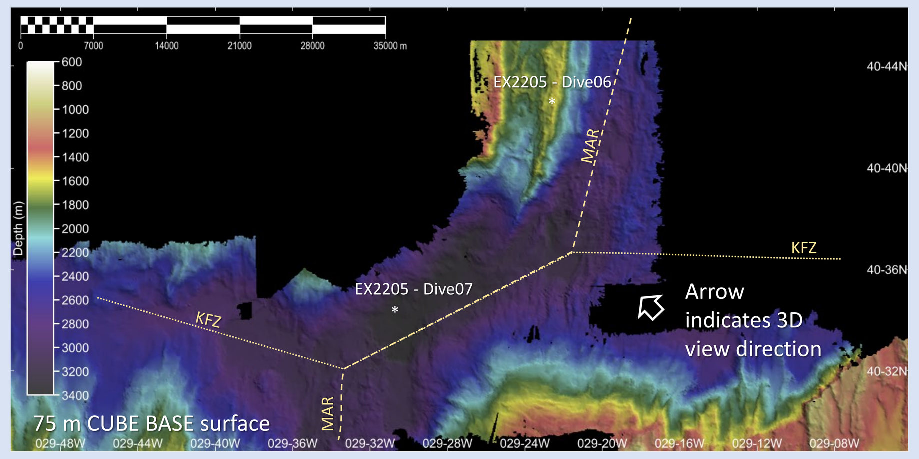


Many uniform axis-parallel ridges are present along the West Flank. The KFZ depth is 3100 m, and APRs crest at 600 m.

Slopes within the KFZ are low (2-5°). APRs however, have a slope of ~40° due to the steep crests that were created during faulting.

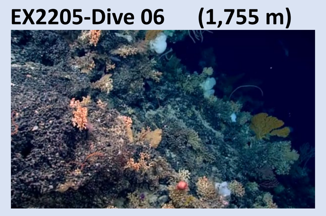
Low backscatter intensity is associated with lowest slopes. Highest intensities occur at the crest of each fault.

Figure 3. Ridge Axis

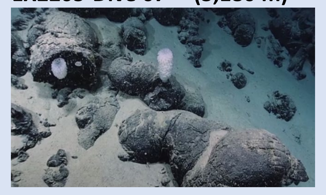


(right) ROV images are from two separate dives: 06 and 07 (locations on map). Dive 06 revealed a large community of deep-sea corals and sponges. Dive 07 reached the deepest part of the axial valley, revealing many pillow basalts with some glass sponges.

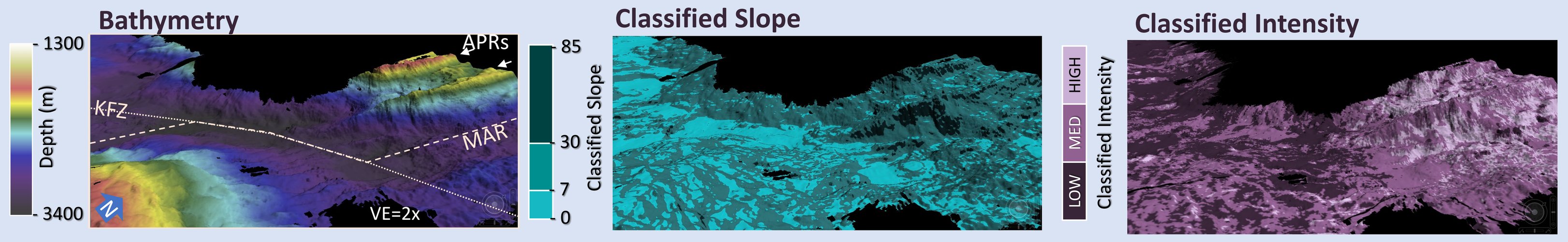
EX2205-Dive 06 (1,755 m)



EX2205-Dive 07 (3,180 m)



The ridge axis is the cross section between the MAR and the Kurchatov Fracture Zone, with a maximum depth of ~ 3400 m at the intersection. A large cliff lies at the north end of the site, with a shoalest depth of about 1300 m.



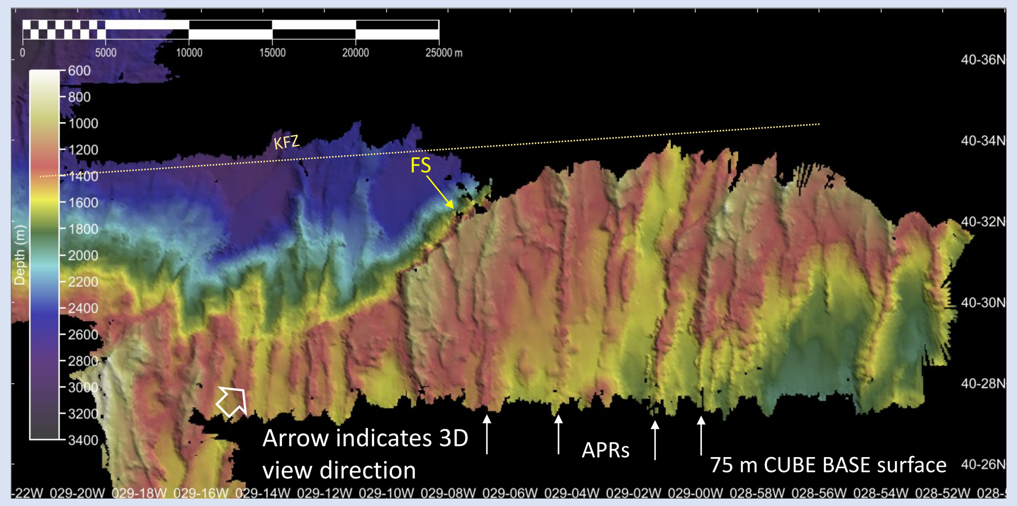
This intersection of the KFZ and MAR axis at ~ 3400 m is the deepest point, creating a broad trough-like valley, with the youngest APRs acting as valley walls.

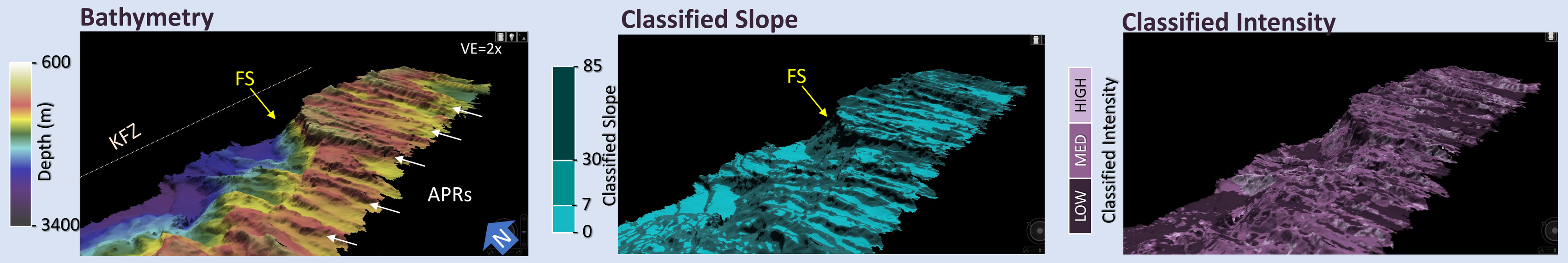
Highest slope of ~50° occurs along the northern fault leading down into the axial valley, and lowest slopes of ~2° are present at the bottom of the cross section.

Lowest intensities occupy the greatest depths are within 0° to 5°. Highest intensities occur on the northern fault where slopes are greatest.

Figure 4. East Flank

East Flank lies on the Eurasian plate and spreads in an eastward direction. When comparing this site to West Flank, the APRs are truncated by the fracture zone, which generated a fault. Along the fault lies a steep cliff, or fault scarp (FS) that in some parts drops from 900 to 2400 m.



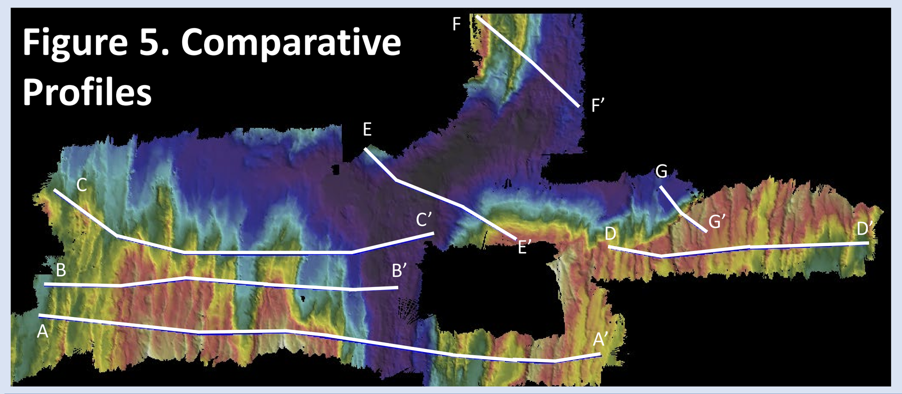


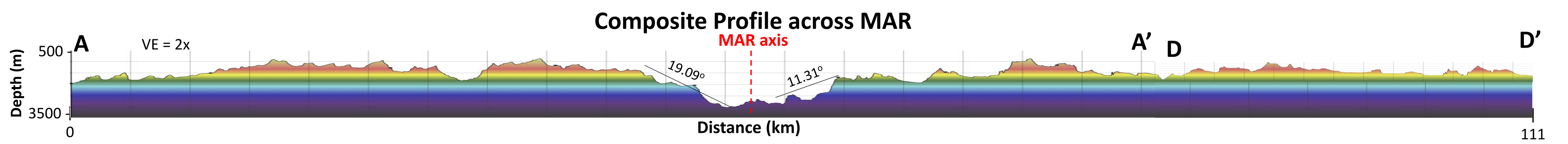
East Flank is another uniform region of axis-parallel ridges, all with defined valleys and crests. A major fault scarp (FS) is shown by the yellow arrow.

Slopes are similar to those of the West Flank, but the study area's greatest slope of 85° occurs on the FS.

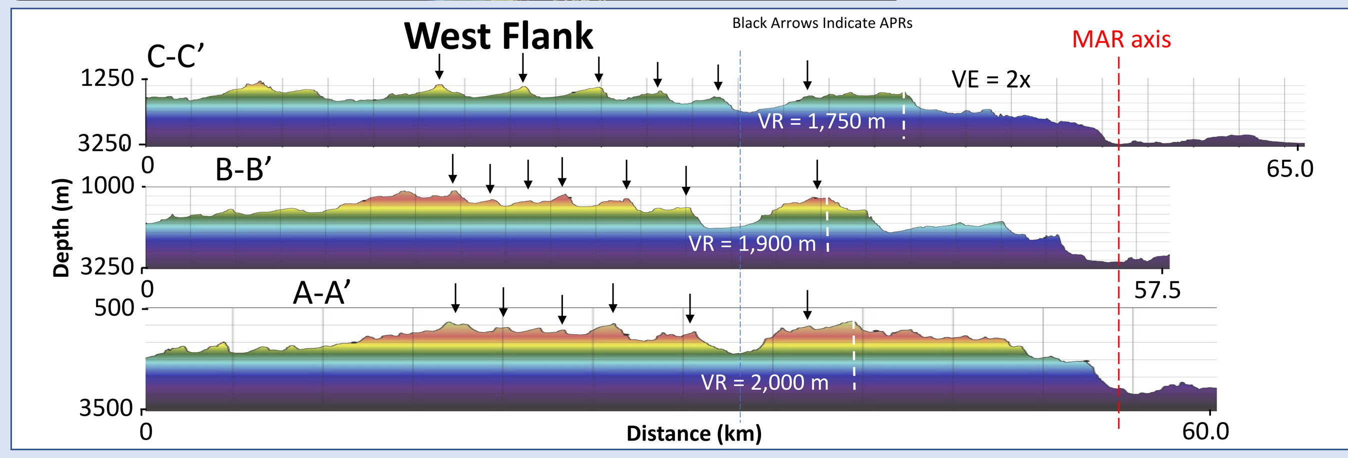
Medium intensity occupies most of the site, with high intensities at the APR crests and FS, and low intensities in the valleys.

Figure 5. Comparative Profiles





A-A' spans the southern region of West Flank, across the MAR axis and onto the opposite side of the ridge at D-D', which spans the length of East Flank. The two are combined to give a hypothetical look at the axis-parallel ridges on either side of the ridge.



Profiles are aligned to compare axis-parallel ridges (APRs), centered around a large valley between ridges (at dashed blue line). Vertical relief (VR) increases south-ward from 1,750 to 2,000 m at the APR closest to the MAR axis (red dashed line).

Profiles are aligned to the ridge axis, and axis valley wall slopes were measured. G-G' is located on the fault scarp (FS) (Fig. 4), and has the greatest overall slope (27.55°) with some portions as steep as 85°. Valley walls at F-F' and E-E' are less steep, at 12.99° and 7.43°, respectively.

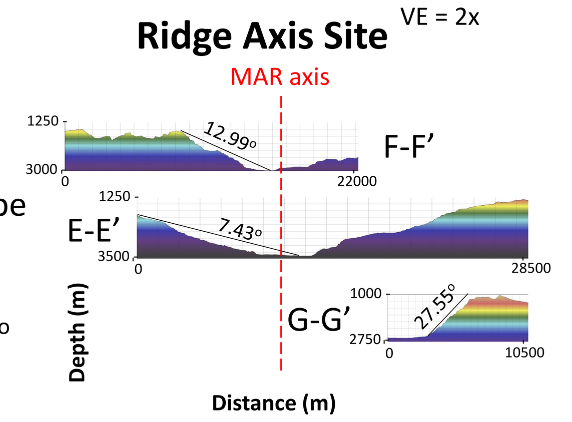
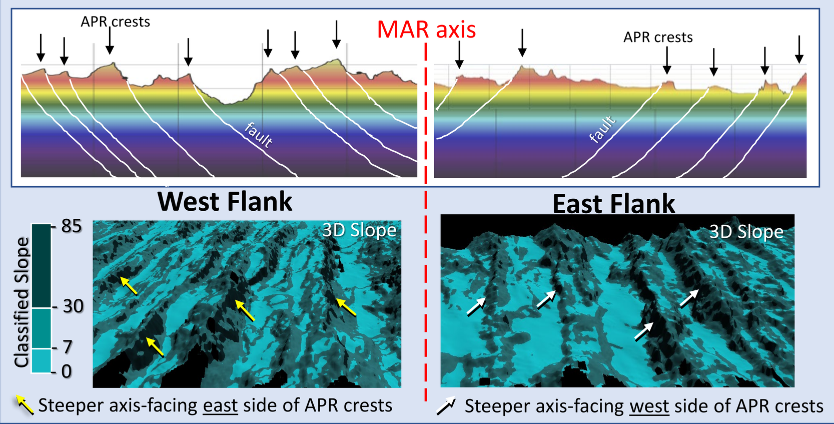


Figure 6. Axis-Parallel Ridges



APRs are shown with their hypothesized faults extending into the crust on each flank of the MAR axis, similar to those depicted by Olive et al. (2015). Slopes of both sides of each APR were measured. The west sides of **West Flank** range 7.6° to 28.9° (mean: 16.6°), whereas steeper slopes occur on the axis-facing east side ranging 20.2° to 49.7° (mean: 34.7°)(yellow arrows). Similarly, **East Flank's** axis-facing APR sides are steeper (10.1° to 49.2°, mean: 29. 4°)(white arrows) than the outer sides (4.8° to 35.4°, mean: 18.6°).

DISCUSSION and CONCLUSIONS

Across the study area there are multiple locations of certain features common to other mid-ocean ridges. Both East and West Flanks display uniform axis-parallel ridges (APRs) that result from spreading of new seafloor formed at the axis over the last 5 million years (Mueller, 2008). At each APR crest, slope is usually greater on the fault, the side facing the MAR axis (Fig. 6). Faults occur on the east side of APR crests on the West Flank, and are a mirror image on the East Flank. Backscatter intensity shows an equally high intensity on each side of most APR crests, suggesting the basaltic rock is exposed without sediment cover on each side. Lower intensities found within troughs between APRs, and within the broad valley at the intersection of MAR and KFZ may be due to a substrate with unconsolidated sediments.

Two ROV dives in the study area (EX2205-06 and -08) revealed a collection of deep-sea corals and sponges. During Dive EX2205-06 on the northern ridge of the study area, the deep reef ecosystem discovered was exceptionally large. This habitat corresponds with an area of high backscatter intensity indicating rocky substrate. On the Redonda Seamount (Dive EX2205-08) deep-sea corals were found growing on the inner walls of the volcano. A crucial *Hoplostethus atlanticus* population was also observed. This species of fish is important, as it has been overfished and has a slow sexual maturity rate.

Further deep-sea coral research should be conducted within the northern most ridge of this study area to locate other benthic ecosystems. Additional bathymetric sonar data to fill in the large data gap between East and West Flanks would allow for improving our understanding of spreading patterns between both sides of the MAR associated with a fracture zone.

ACKNOWLEDGEMENTS

Many thanks to BEAMS alumni and the Matt Christie BEAMS Student Support Fund for sponsoring student registration to this meeting. We are grateful to the CofC Dept. of Geology and Environmental Geosciences, the School of Sciences, Mathematics, and Engineering, and eTrac/Woolpert for support of the BEAMS Program.

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