# Comparative Geomorphology of Axis-Parallel Ridges Along the Mid-Atlantic Ridge, Northwest of the Azores

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### BACKGROUND

The area of study is located on the Mid-Atlantic Ridge (MAR) axis approximately 1100 km off Portugal's coast. In July 2022, NOAA led a cruise to this study area on the NOAA Ship Okeanos Explorer as a part of the expedition *Voyage to the Ridge 2022*. During this expedition, NOAA's primary objective was to gather high resolution bathymetric data and ROV dive footage along the MAR to better understand these previously unexplored regions. On Leg 2, three dives were conducted within the study area, yielding both mapping and videographic data collected by the ROV Deep Discoverer.

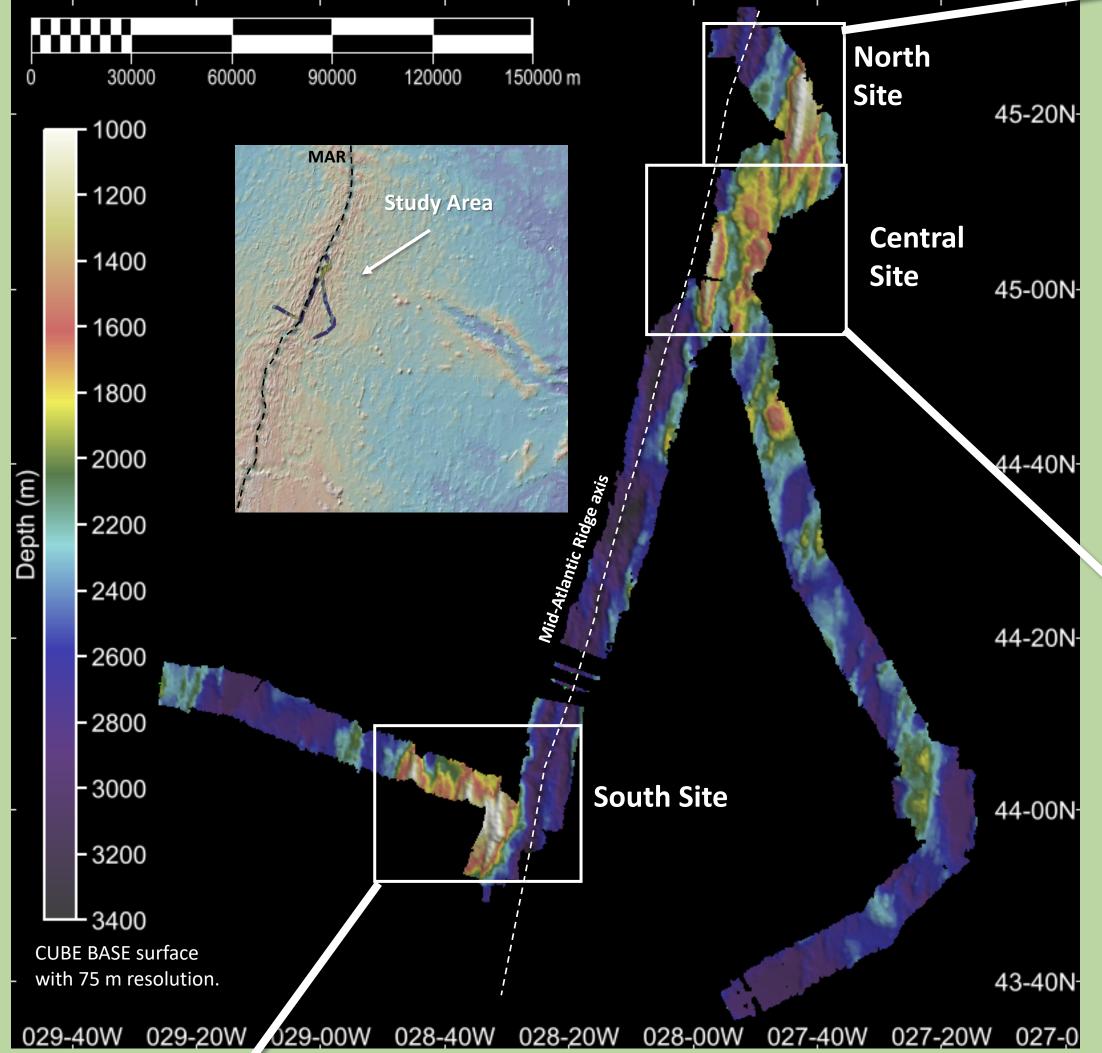
EX2205-Dive 01 explored the area here referred to as South Site and analyzed an unnamed seamount west of the MAR axial valley. Deep-sea corals of *Eguchipsammia* were observed attached to the seamount's slopes, encasing deep layers of skeletal rubble of the same genus. EX2205-Dive 02 was located on the study area's North Site, where the ROV encountered extremophilic life within the Moytirra Vent Field, the only known deep hydrothermal vent located between the Azores and Reykjanes Ridge (NOAA 2022). This vent field was formed on a nearly vertical fault scarp (Wheeler et al., 2013) and is located in the study area's North Site.

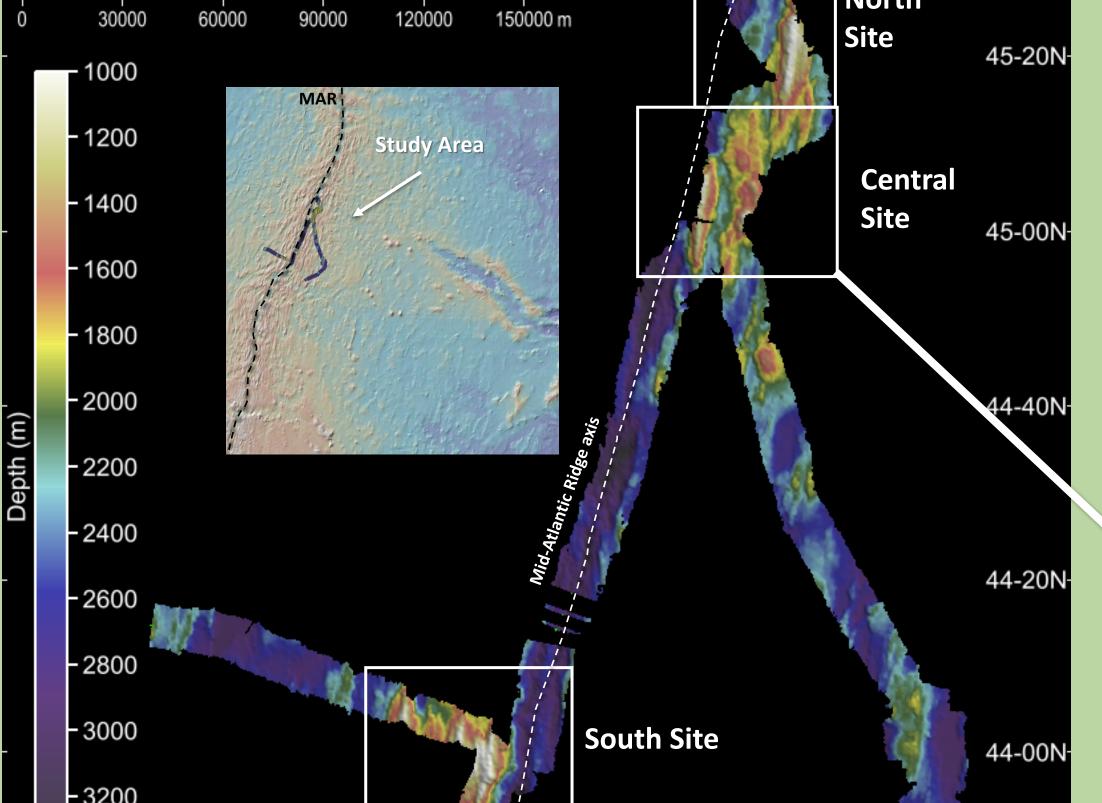
One type of feature is extremely common to most slowspreading mid-ocean ridges: here referred to as axis-parallel ridges (APRs), which are commonly referred to as abyssal hills (Olive et al. 2015; Johnson 2015). APRs result from faulting associated with a divergent plate boundary and form parallel to the axial valley (Escartín et al., 2008). Another mid-ocean ridge feature is axial volcanic ridges (AVRs), which are ridges present within the axial valley itself (Wheeler et al., 2013).

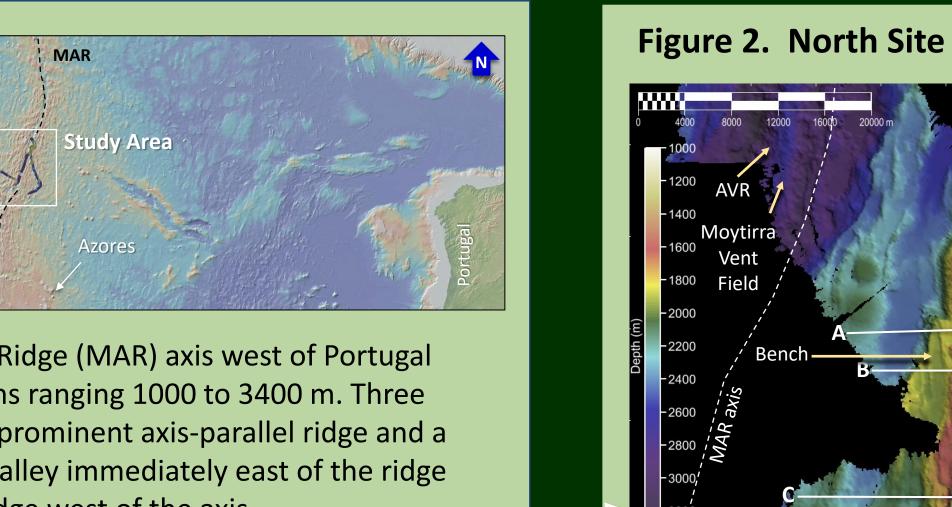
Further analysis of multibeam bathymetry data collected during the expedition can provide more detailed information on the unique geomorphology of this area, including variations in backscatter, slope, and vertical relief as different features and their locations relative to the MAR axis are analyzed and compared.

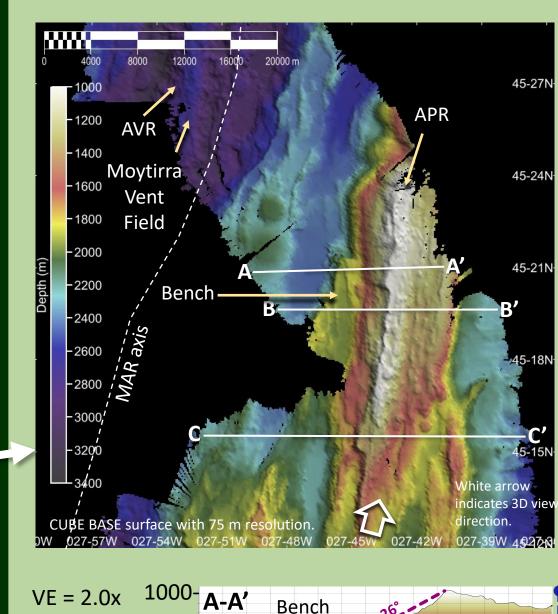
### Figure 1. Study Area and Sites

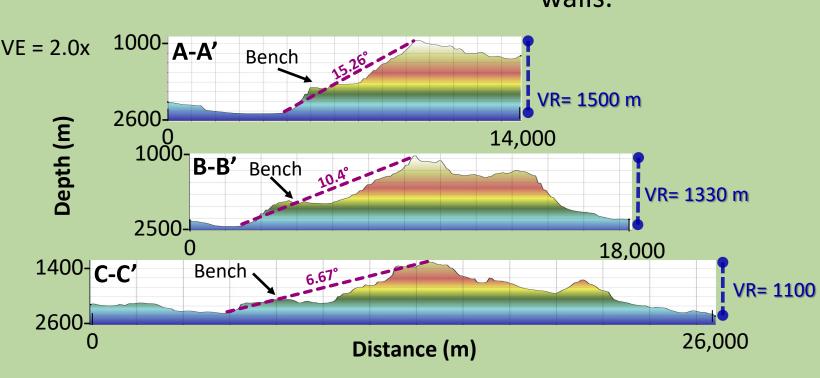
The area of study is located on the Mid-Atlantic Ridge (MAR) axis west of Portugal and north of the Azores. The area features depths ranging 1000 to 3400 m. Three study sites were analyzed: North Site features a prominent axis-parallel ridge and a hydrothermal vent field. Central Site displays a valley immediately east of the ridge axis, and South Site also features a prominent ridge west of the axis.











North Site (800 to 3200 m) features a parallel ridge (APR) volcanic ridge (AVR) lies within the ridge axial valley where the Moytirra Vent Slopes range 0 to 56° with highest slopes Classified Intensity present on the APR

(above) Low slope areas display the lowest intensity, while the APRs display higher intensity return, suggesting exposed rock substrate.

(above) Vertical relief (VR) and overall slope of the prominent APR decreases substantially north to south; 1500 to 1100 m and 15.26 to 6.67°, respectively. A bench occurs to the west of the APR in profiles A-A' and B-B', indicating the presence of an AVR west of the axial valley.

prominent axis-

east of the ridge

Field is located.

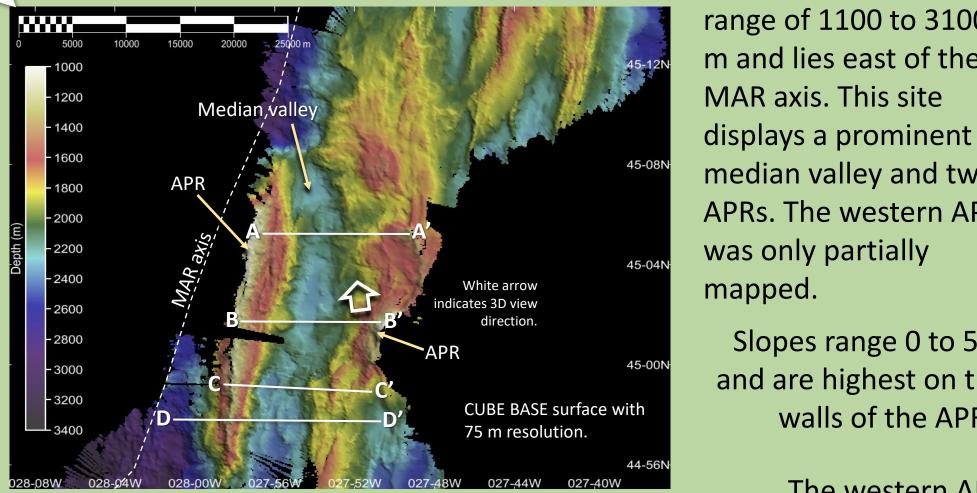
axis. An axial



### **METHODS**

- The NOAA Ship *Okeanos Explorer* collected high resolution multibeam sonar data using the Kongsberg EM304 multibeam echosounder, as well as HD video using the ROV Deep Discoverer during EX2205 (July 20-22, 2022).
- CARIS HIPS and SIPS 11.4 software was used to postprocess raw multibeam data.
- A 2D CUBE BASE bathymetric surface was generated, from which all 2D and 3D bathymetric surfaces, aspect bands, slope bands, and classified backscatter intensity mosaics were created.
- For each site, depth profiles were made in order to measure and further analyze slope and vertical relief (VR) variations within the study site.
- All slopes were graphed for further comparison.

### Figure 3. Central Site



VE = 2.0x 2400

walls of the APRs. The western APR featured high intensity, suggesting the presence of exposed rock. Intensity decreased sharply in the low-slope median valley.

Central Site has a depth

range of 1100 to 3100

m and lies east of the

median valley and two

APRs. The western APR

Slopes range 0 to 54°

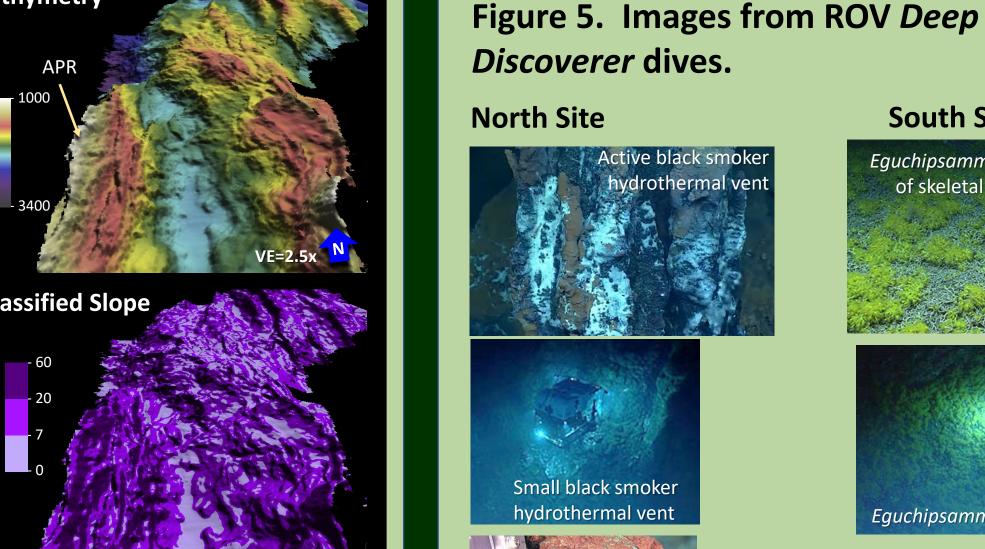
and are highest on the

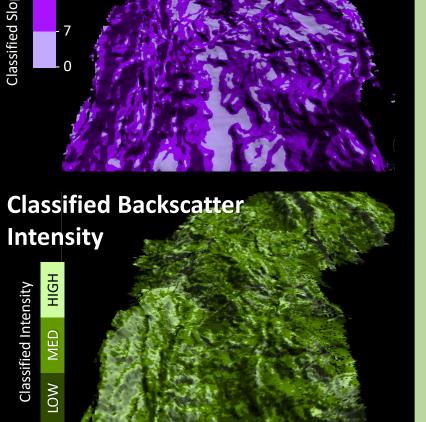
MAR axis. This site

was only partially

(left) North to south, the median valley's slopes gradually increase from

9.76 to 14.93°, while the vertical relief remains fairly consistent at 960 to 1175 m with little variation.





EX2205-Dive02: Black smoker hydrothermal vents were encountered within the Moytirra Vent Field. The substrate was mostly exposed basalt, of which some samples were collected.







of skeletal coral rubble





EX2205-Dive01: An entire deep-sea reef of Eguchipsammia lives on a large seamount's summit, growing on a mix of dead coral rubble and exposed basalt.

# **APR Geomorphology** North Site ■ Central Site South Site

Distance (m)

Figure 7. Comparison of

(above) Data collected from numerous profiles (not shown) of each sites' most prominent APR indicate South Site had the greatest VR and extent (distance). Central Site had the smallest VR and extent. North Site's VR and extent were between South Site's and Central Site's.

### Figure 6. Comparative Geomorphology of **Each Sites' Prominent APR**

South Site ranges in depth from 500 to 3400 m and includes

several prominent APRs west of the ridge axis. An axial valley

and discovered a deep-sea coral reef on both its summit and

Median valley walls display relatively low intensity, while the

ridge axis itself has much higher intensity, suggesting the

of the axis. This APR also displays a bench feature before

median walls.

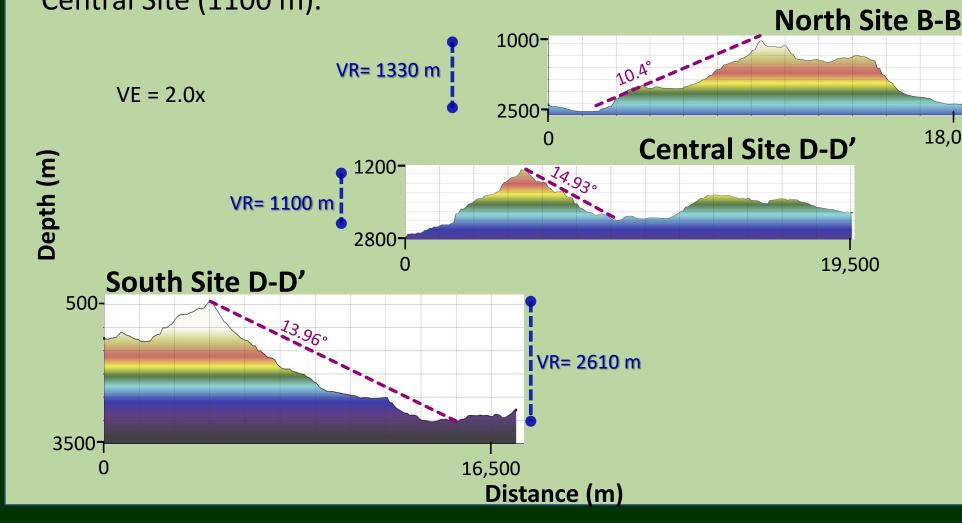
presence of exposed rock.

ridge (AVR) also occurs, with a prominent APR immediately west

descending into the ridge valley. EX2205-Dive01 explored this APR

Slopes range from 0 to 56° and are highest on the prominent APR.

A representative profile at each site was selected for comparison. All are shown at the same scale. North Site has the lowest slope (10.4°), while Central Site and South Site slopes are only somewhat greater at 14.93° and 13.96°, respectively. South Site's VR of 2610 m was double that of North Site (1330 m) and Central Site (1100 m).



## **DISCUSSION and CONCLUSIONS**

North Site and Central Site are located on the Eurasian Plate, east of the MAR axis, while South Site is located west of the MAR axis on the North American Plate. At the MAR axis, the seafloor spreading rate of the Eurasian plate is higher than that of the North American Plate; approximately 18.0 mm/a and 12.0 mm/a, respectively (Müller et al., 2008). North and Central sites are approximately the same age, while South Site is older; ~1.0, ~1.0, and ~3.0 my, respectively (Müller et al., 2008).

High backscatter intensity at each sites' APRs suggest the presence of basaltic outcrops, recently confirmed in North and South Sites by NOAA ROV Deep Discoverer dive footage. The presence of deep-sea coral reefs in South Site as well as black smoker hydrothermal vents in North Site were also confirmed. ROV dive footage of Central Site was not available, but high backscatter intensity was also present on Central Site's easternmost APR, suggesting that this region could also contain exposed basalt substrate.

The confirmed outcrops serve different ecological purposes for each site, as South Site's outcrops host a vibrant deep-sea coral reef, whereas North Site's outcrops were observed to host primarily extremophilic life within the Moytirra hydrothermal vent fields. South Site's reef is located on the summit of the most prominent APR, which displayed South Site's highest slopes and lowest backscatter intensities. Low intensity typically indicates lack of exposed rock outcrops, but in this case, ROV dive footage confirmed the presence of basaltic substrate supporting the coral reef. The coral reef, a rough and uneven surface, is likely responsible for the low intensity. Based on these data, more deepsea coral habitats may be located on APRs west of the MAR axis that are ~3.0 my with high slopes and low backscatter intensities. North Site's hydrothermal vents are located within the AVR. This region displayed moderate slopes, but North Site's highest backscatter intensity, possibly due to the confirmed presence of basalt outcrops. Based on these data, more hydrothermal vent habitats may be located in AVRs east of the MAR axis that are  $^{\sim}1.0$  my with moderate slopes and high backscatter intensity.

Central Site has no AVRs but does contain two APRs with a median valley separating them. Central Site's highest slopes are located where the westernmost APR meets the MAR axis. This APR also contains Central Site's highest backscatter intensities, suggesting that the presence of deep-sea coral reefs is unlikely. The presence of hydrothermal vents is unclear, as data were collected over a relatively small area. To determine what truly may be present in and around this portion of the MAR, more extensive bathymetric and ROV dive data collection must be conducted over a larger ridge segment.

## **ACKNOWLEDGEMENTS**

Figure 4. South Site

1400-A-A'

1200-B-B'

EX2205-Dive01

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Distance (m)

### REFERENCES

in these profiles.

across the MAR axis to the AVR.

doi:10.1126/science.aad0715.

White arrow indicates

**Classified Slope** 

Profiles A-A' and B-B' (approximately

slopes of 19.36 to 12.03°, and vertical

small bench (2300 m depth) adjacent to the axial

Profiles C-C', D-D', and E-E' show the ridge's

western median valley wall which also has a

valley. C-C' is drawn from the prominent APR,

30,000 m west of the MAR) show high

reliefs of 1300 m. Small APRs are displayed

- Escartín, J., Smith, D.K., Cann, J., Schouten, H., Langmuir, C.H., and Escrig, S., 2008, Central role of detachment faults in accretion of slow-spreading oceanic lithosphere: Nature, v. 455, p. 790–794, doi:10.1038/nature07333
- Müller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest, 2008, Age, spreading rates and spreading symmetry of the world's ocean crust: Geochemistry Geophysics Geosystems, v. 9, doi:10.1029/2007GC001743. • NOAA. Voyage to the Ridge 2022. NOAA Ocean Exploration website, https://oceanexplorer.noaa.gov/okeanos/explorations/22voyage-to-the-ridge/dives/dives.html (accessed March 2023).
- Wheeler, A.J., Copley, J., Lim, A., Carlsson, J., and Collins, P., 2013, Moytirra: Discovery of the first known deep-sea hydrothermal vent field on the slow-spreading Mid-Atlantic Ridge north of the Azores: Geochemistry Geophysics Geosystems, v. 14, p. 4170–4184, doi:10.1002/ggge.20243.

• Olive, J.A., Behn, Ito, G., Buck, W.R., Escartín, J., and Howell, S., 2015, Sensitivity of seafloor bathymetry to climate-driven fluctuations in mid-ocean ridge magma supply: Science, v. 350, p. 310–313,