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Revisiting the Seismic Structure of Atlantic Oceanic Fracture Zones

Richard Davy (1), Jenny Collier (1), Tim Henstock (2), and the Volatile in the Lesser Antilles (VoiLA) project, United Kingdom

(1) Department of Earth Science and Engineering, Imperial College London, London, United Kingdom, (2) Ocean and Earth Science, University of Southampton, Southampton, United Kingdom

Much of our current knowledge on the seismic structure of mature oceanic crust comes from studies older than 25 years, which suffer from limited lateral resolution, because receiver spacings at the time were typically on the order of 20 – 25 km. These studies show that fracture zones and non-transform offsets are expressed as varying degrees of thinning of the oceanic crust, while oceanic crustal structure varies little. However, recent high-resolution studies along the Mid-Atlantic Ridge have emphasised the extent of along axis variation in crustal accretion, providing new insights into processes such as the tectonic accommodation of extension at segment ends, through the exhumation of mantle peridotites along large detachment faults. This motivates the re-examination of mature fracture zones and oceanic crust formed at slow-spreading ridges at a comparable along-strike resolution.

We present results from an active seismic experiment, with 54 ocean-bottom seismometers spaced every 4 km, conducted over ~65 Ma central Atlantic crust in 2017. The 225 km long profile crosses three discontinuities, one of which can be seen on satellite gravity data to follow Atlantic spreading flowlines (Marathon FZ) and two which do not. We therefore have an opportunity to compare the structure generated at transform and non-transform offsets. We have developed a 2D compressional velocity model by forward and inverse modelling of wide-angle seismic data.

In the resulting model we observe transform and non-transform offsets as a significant thinning of the oceanic crust from 6.9 $\pm$ 1.5 km thick in the segment centres, to 4.0 – 5.0 km, over lateral distances of 9.0 – 20.0 km. Crustal thickness within the oceanic segments is asymmetric, with a rapid shoaling of the Moho at inside corners (~260 m/km) and a gradual shoaling at outside corners (~75 m/km), with the difference being attributed to enhanced mechanical deformation at the inside corners.

Within the segment centres two clear basement layers are observed; uppermost crustal velocities of 4.6 $\pm$ 0.3 kms ^{1} increase to 6.4 $\pm$ 0.4 kms^{1} in layer 2 (gradient of ~0.9 s^{-1}), and then increase to 7.5 $\pm$ 0.3 kms^{1} at the base of layer 3 (gradient of ~0.2 s^{1}). In contrast, within the offsets the seismic structure is characterised by a single velocity gradient, increasing from uppermost crustal velocities to mantle velocities (~7.8 kms^{-1}) at depths of 4.0 – 5.0 km below top basement. Nowhere within these domains is there a clear velocity structure indicative of oceanic layer 3. These results are consistent with an interpretation that these structures formed through the pervasive hydration and serpentinization during active deformation processes.

However, there are structural and seismic differences between the Marathon FZ and the two non-transform offsets. Nontransform offsets exhibit no clear Moho reflections, velocity gradients of ~0.6 0.7 s^{1}, and one is flanked by significant basement topography. Conversely, the Marathon FZ shows muted basement topography, exhibits Moho reflections and a velocity gradient of ~0.4 s^{1}. This difference in velocity gradient indicates either a differing degree of serpentinization or structural composition, while Moho reflections suggest the presence of a reflective alteration front.