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[1] Seismicity distribution along the Mid-Atlantic Ridge (MAR), monitored with the Autonomous Underwater Hydrophone (AUH) array, shows a band of seismicity ~70 km west of the axis between ~11.9°N and 14.2°N. Available focal mechanisms at the off-axis seismic band show extension directions consistent with the accommodation of the North-American (NA) and South-American (SA) relative plate motion. Axial seismicity shows a gap at ~14°N, coinciding with the 14°N hotspot-like region, and the focal mechanisms near this region are consistent with spreading of the African (AF) and the NA or SA plates. We speculate that the triple junction between the AF, NA and SA plates is close to the 14°N seismic gap. The westward continuation of the NA-SA plate boundary is unconstrained, but could initiate at ~13°N, at the south end of the off-axis seismic band, or be diffuse between ~12°N and ~15°N. *INDEX TERMS:* 3040 Marine Geology and Geophysics: Plate tectonics (8150, 8155, 8157, 8158); 7230 Seismology: Seismicity and seismotectonics; 7220 Seismology: Oceanic crust; 8150 Tectonophysics: Plate boundary—general (3040); 8164 Tectonophysics: Stresses—crust and lithosphere. **Citation:** Escartín, J., D. K. Smith, and M. Cannat, Parallel bands of seismicity at the Mid-Atlantic Ridge, 12–14°N, *Geophys. Res. Lett.*, *30*(12), 1620, doi:10.1029/2003GL017226, 2003.

1. Introduction

[2] Understanding of the distribution of seismicity along the northern MAR has improved by the detection of low-magnitude events (M > 2.5–3) with the North-Atlantic AUH array [*Smith et al.*, 2002, 2003]. These data show an irregular distribution of earthquakes along the ridge, with zones of continuous seismicity and seismic gaps [*Smith et al.*, 2003]. As in the case of 14°N, many gaps coincide with shallow seafloor near segment centers associated with high magma supply, focused melt supply, or elevated mantle temperatures. These seismic gaps may therefore mark ridge sections with a thin lithosphere where seismicity is subdued or of low magnitude. Most of the events (>80%) occur within ~20 km of the axis or along fracture zones, while off-axis seismicity is scattered [*Smith et al.*, 2003]. The one exception is the ~12–14°N area where an axis-parallel band of seismicity is observed ~70 km west of the axis, extending ~100 km along-axis (Figure 1).

[3] Several processes can cause the intraplate seismicity between ~12–14°N, including off-axis magmatism, an incipient westward ridge jump, a recent eastward ridge jump, or the presence in the area of the triple junction between the AF, NA, and SA plates. In this paper we study the nature of seismic activity from both the AUH and teleseismic events, and the direction of extension inferred from the teleseismic focal mechanisms. We compare these results with seafloor morphology from multibeam bathymetry acquired recently (Figure 2). Directions of extension from focal mechanisms are compared with predictions of relative plate motions, and the results are used to propose a possible location and configuration of the NA-SA-AF triple junction in the area (Figure 3).

2. Plate Dynamics and the North-South American Plate Boundary

[4] The Central Equatorial Atlantic accommodates the relative motion between the NA and SA plates, but the location and nature of this boundary is undetermined, as it is not clearly marked by seismicity or prominent tectonic features (Figure 1). The position of the triple junction between the NA, SA and AF plates is also ill defined, and has been placed between ~10°N and ~20°N along the MAR [e.g., *Minster and Jordan*, 1978; *Roest and Collette*, 1986; *Müller and Smith*, 1993]. The nature of the triple junction is unknown, and some models propose a zone of diffuse deformation over a portion of the ridge, or continuous position changes due to the unstable configuration of this triple junction [e.g., *Roest and Collette*, 1986]. While numerous plate models exist, the comparison of the distribution and nature of seismicity with predictions from plate models derived from Global Positioning System (GPS) data is more adequate than using models derived from magnetics or fracture zone orientations (see Figure 1, Table 5 and discussion in *Sella et al.* [2002]); In this paper we use the recent REVEL model, based on 7-year global GPS observations [*Sella et al.*, 2002]. At ~15°N this model predicts NA-SA plate separation at ~1.4 km/my along ~170°, while the predicted NA-AF or SA-AF plate separation is ~23.5 km/my along ~92–95° (Figure 3).

3. Bathymetry and Tectonic Structure

[5] The Mid Atlantic Ridge between the Marathon and the Fifteen-Twenty Fracture zones (MFZ and FTFZ) shallows by >1.5 km towards the segment centered at ~14°N. Geochemical, geological and geophysical data indicate that this segment is magmatically robust: Shallow topography and thick crust at its center; presence of a ≪hot spot≫ geochemical anomaly; regular faulting (Figure 2); no known peridotite or gabbro outcrops; no irregular faults and striated detachments, such as found on the ridge flanks to the north or south of the 14°N segment [e.g., *Escartín and Cannat*, 1999]. Bathymetry in the area south of 14°N

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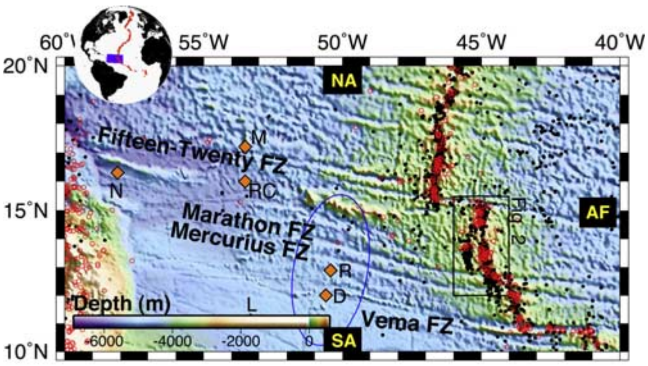

Figure 1. Location map and distribution of seismicity around the study area. Seismic events are from the USGS NEIC catalog (1973–2002, open circles) and the AUH array deployed at the Northern Atlantic (julian day 52/1999–245/2001, solid circles; data available at http://autochart.pmel.noaa.gov:1776/autochart/GetPosit. html). NA, SA and AF are the North-, South American and African plates. Diamonds are rotation poles for the NA-SA plate pair; REVEL model, *Sella et al.* [2002] (annotated R) and corresponding error ellipse); *Dixon and Mao* [1997] (D); *Roest and Collette* [1986] (RC); NUVEL-1 model, *DeMets et al.* [1990] (N); *Müller and Smith* [1993] (M); *Larson et al.* [1997] (L). Bathymetry from *Smith and Sandwell* [1997].

shows a normal subsidence of the oceanic crust over the off-axis seismicity band, with no subsidence anomaly or relict rift valley left (Figure 2). These features would be expected after a recent eastward ridge jump of a now dying or fossil ridge axis [e.g., *Mammerickx and Sandwell*, 1986; *Freed et al.*, 1995] from the off-axis seismicity band to the present-day axis. A large increase in depth (~500 m) is observed at the east edge of the off-axis seismic zone, corresponding to the western limit of the rift shoulders.

[6] The multibeam data show that the seafloor off-axis is characterized by short normal faults with irregular trends, locally oblique, and by irregular massifs that are not delimited by faults. These structures may correspond to tectonically elevated massifs where the fault escarpments have been degraded by mass wasting, or to later volcanic edifices that may cover the pre-existing topography. The deeps between abyssal hills are flat-bottomed sediment ponds that appear undeformed. The seafloor both north and south of the 14°N segment is similar, based on the irregular faulting, the occurrence of detachments (Figure 2), and the peridotite and gabbro outcrops.

4. Seismicity

[7] Numerous seismic events identified in the AUH array data are located along a well-defined, ridge-parallel band of seismicity, ~35 km wide and ~110 km long ~70 km west of the axis. This off-axis zone of seismicity is well constrained, as the error bars associated with the event locations are small (the calculated rms for errors in event location throughout the study area is 0.1° in latitude and 0.03° in longitude, see *Fox et al.* [2001] and *Smith et al.* [2003]). The southern limit corresponds to the MFZ, which may be locked, or deforming aseismically west of the ~45°W ridge-transform intersection. North of 14°N, the number of off-axis events seem to decrease and approach the ridge axis. The ridge-axis seismicity show a marked seismic gap at ~14.1–14.3°N, separating a large number of events that concentrate at ~14.5°N (in proximity to the Logachev hydrothermal site), and a less abundant concentration of events south of 14°N (Figure 2).

[8] While the average acoustic magnitude of events is similar within the three seismic areas (off-axis, and on-axis north and south of the 14°N seismic gap), there are important variations in the rate of events among the areas. The off-axis band of seismicity shows 41 AUH events/100 km, similar to the rate of ~51 events/100 km at the ridge axis zone at the same latitude range (Figure 2). In contrast, the northern section of the axis shows the highest number of events (167/100 km), including several seismic swarms associated with teleseismic events (Figure 2), while the

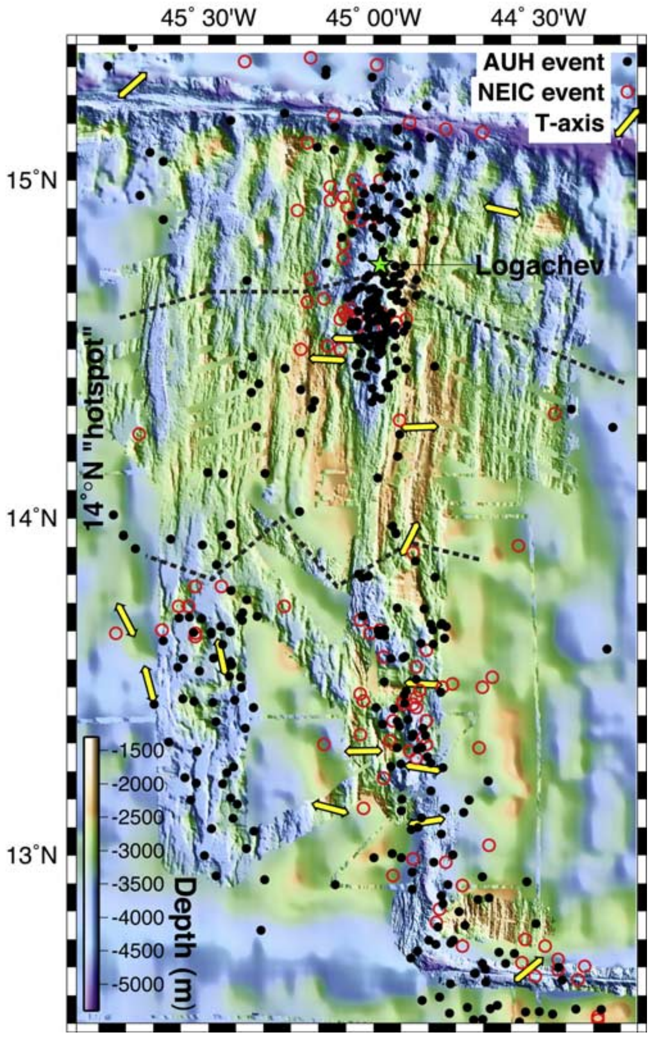

Figure 2. Parallel bands of seismicity and bathymetry between the Marathon and Fifteen-Twenty fracture zones. Solid and open circles correspond to AUH and teleseismic events, and arrows to the direction of extension (T-axis) derived from focal mechanisms (Harvard CMT catalog). Shaded multibeam bathymetry for the ~15°N area [*Escartín and Cannat*, 1999; *Fujiwara et al.*, 2003] is complemented with data from the AT-4-4 (D. Smith, chief Scientist) and the JR63 cruises (C. J. MacLeod and J. Escartín, chief Scientists).

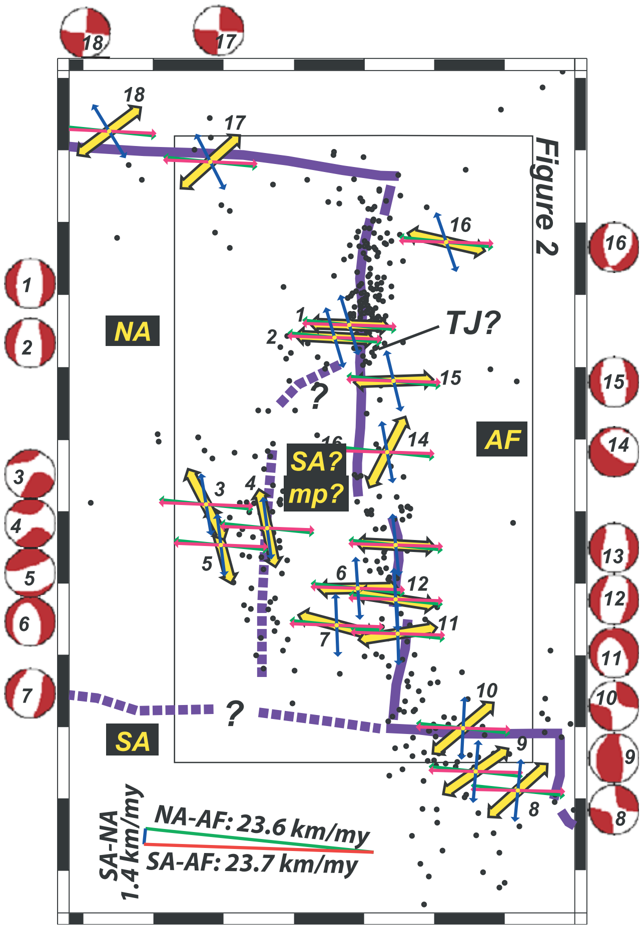

Figure 3. Proposed configuration of the NA-SA-AF plate system at the study area. The T-axes directions from focal mechanisms (thick arrows) are compared with the predicted spreading directions for the NA-SA-AF plate system (thin arrows) from the REVEL model [*Sella et al.*, 2002], and the distribution of AUH events (solid circles). The continuous line indicates the ridge axis and transform faults, and the dashed line the proposed additional plate boundaries. The off-axis seismic band may accommodate NA-SA plate separation, while the zone between the two seismic bands may be part of the SA plate (triple junction, TJ, located at ~14.3°N), or correspond to microplate (mp) associated with the triple junction (TJ extending from ~12.8°N to ~14.3°N).

seismic gap shows only a few events. This overall pattern of distribution of AUH seismicity is also observed in the teleseismic events, although it is less defined due to the lesser number of recorded events. Differences in the epicenter location between the Harvard CMT and the NEIC catalogs, or the NEIC and AUH-recorded events, be >50 km due to the less accurate locations of the teleseismically determined events with respect to AUH determined events, although no systematic shift in the locations of the same event given by the NEIC, AUH, and Harvard CMT catalogs is observed. A cluster of ~10 teleseismic events at the north of the off-axis band may indicate an increase in the intensity of seismicity towards the north of this band.

[9] Available focal mechanisms for some of the teleseismic events (Harvard CMT catalog) show a clear change in stress orientation between the present-day ridge axis and the off-axis seismic band. All but one event at or near the ridge axis show focal mechanisms consistent with extension sub-parallel to spreading. One event at 14°N shows a T-axis highly oblique to spreading (~20°), but it is poorly located as the corresponding AUH and NEIC derived event locations are placed at the off-axis seismicity band (Figure 2). In contrast, the three focal mechanisms at the off-axis seismic band show T-axis directions at ~150–165°, <15° from the ~170° direction of relative NA-SA spreading predicted by the REVEL model [*Sella et al.*, 2002]. Most transform fault events correspond to strike-slip mechanisms (Figure 3).

5. Discussion

[10] Possible explanations for the off-axis seismic band include a recent eastward ridge jump, a westward ridge jump taking place at the present time, and the complex stress and tectonic regime that may be expected from the presence of a NA-SA-AF triple junction in the area.

[11] *Eastward ridge jump*. Ridge jumps are common along the MAR [e.g., *Müller et al.*, 1998; *Allerton et al.*, 2000], and leave behind fossil rift valleys and anomalous seafloor subsidence [e.g., *Mammerickx and Sandwell*, 1986; *Freed et al.*, 1995]. The apparently normal subsidence of the seafloor (Figure 2) seems to be inconsistent with this ridge-jump model, and no magnetic data are available to constrain the spreading history of the area.

[12] *Westward ridge jump and incipient rifting*. The axis-parallel distribution of AUH-derived seismicity (Figure 2) may mark the development of a new ridge segment off-axis due to an active ridge jump. The lack of structures consistent with the development of an incipient rift valley, and the presence of sediment ponds, indicate that such a ridge jump would have initiated very recently, without substantial reshaping of the seafloor. Irregular structures several hundreds of meters high that seem to cover fault-controlled abyssal hills may correspond to recent volcanic edifices associated with off-axis magmatism, but sampling and direct observations are required to determine their nature. High-density magnetic data across the area would constrain the spreading history, and magnetic anomalies may be associated with the off-axis seismic band if it indicates off-axis magmatism. This model of a very recent ridge jump cannot be ruled out based on the existing data, but is not consistent with the direction of extension given by focal mechanisms that parallel the NA-SA separation direction, and that are highly oblique to both NA-AF and SA-AF plate separation at the ridge axis.

[13] *North-, South-American and African triple junction*. The orientations of the T-axes from focal mechanisms of teleseisms are consistent with the presence of a NA-SA boundary in close proximity to the ridge axis, and therefore placing the NA-SA-AF triple junction in the 12°–14°N area (Figures 2 and 3). All but one of the axial events show approximately east-west extension, consistent both with the NA-AF or SA-AF plate separation. The extension directions from events at the off-axis seismic band (155–165°) suggest that this region may correspond to the NA-SA plate boundary, with an extension direction of ~170°. However, the bathymetry does not show structures that may be associated with this plate boundary (i.e., normal faults trending ~80°, or strike

slip faults trending ~170°). Pre-existing normal faults that are parallel to the ridge axis trend could be re-activated mainly as strike-slip faults (events 3 and 4 in Figure 3), although normal faulting is also observed (event 5 in Figure 3).

[14] The link of the off-axis seismic zone with the axis is not well defined, but the scattered seismicity may place it near the ~14°N seismic gap (Figure 2). If the oceanic lithosphere between the seismic bands corresponds to the SA plate, the AF-NA-SA triple junction may be located at ~14.3°N, and the MAR between ~12.9 and ~14.2°N must correspond to the AF-SA plate boundary (Figure 3). There may be a feedback between the position of the triple junction and the thin axial lithosphere at 14°N, as observed at other triple junctions along slow-spreading ridges [e.g., *Ligi et al.*, 1997; *Georgen and Lin*, 2002], but the mechanisms of these interactions are not fully constrained. Alternatively, the lithosphere between the seismic bands may be a ~70 × 110 km microplate associated with the triple junction. The reduced seismicity at the north may be explained by the inferred thin lithosphere at ~14°N, while the south boundary at the MFZ may be locked or deforming aseismically. In both models the triple junction induces an important rotation of stresses, with extension along ~90° at the axis and along ~150°–170° 70-km off-axis at the seismic band.

[15] We cannot provide constraints on the position of the NA-SA plate boundary extending west towards the Caribbean subduction zone (Figure 1). If this boundary were continuous, we expect it to initiate at the southern end of the off-axis seismicity band, coinciding approximately with the trace of the MFZ (Figure 3). Alternatively, the plate boundary may be diffuse along the corridor defined by the FTFZ and MFZ (~12.5°N and ~15.3°).

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