THE GEOPHYSICAL ARCHITECTURE OF THE AZORES FROM MAGNETIC DATA

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Abstract

The Azores attracted the interest of geoscientists since the beginning of the XX century. In the late 60's, when plate tectonics was established as the basic geodynamic framework, the peculiar morphology of the Azores Islands and the surrounding plateau, located close to the Mid-Atlantic ridge, early interpreted as the separation between the Eurasian and the North-America plate, was seen as a challenge for the application and the development of plate tectonics. A number of particular geological features were targeted for explanation: the long active fault going from Gibraltar to the Azores (now called Gloria Fault), the existence of a large but inactive large fracture in the North-American plate, offset several tenths of kilometers to the north, the curvilinear succession of islands marked by pervasive volcanic and seismic activity, the development of a plateau, partially split by the Mid-Atlantic Ridge. The interpretation of most of these questions remained elusive for a long time, in spite of the large amount of geological and geophysical data available, as most of the conventional approaches were not as fruitful as expected, and new features were identified, raising new unknowns or revealing uncommon geological environments.

We present here a review of the progresses made in the geophysical research of the Azores, based on geophysical observations and numerical modeling. We expect to provide a global view of this magnificent natural laboratory for earth sciences, the recent advances on the understanding of the basic processes, and we present an updated interpretative scheme for the genesis and evolution of the Azores triple junction.

1. Triggering of the Azores Triple Junction

The geological evolution of the North Atlantic postpones the rise and fall of the Iberian plate. The current interpretation was established by Srivastava *et al*. (1990) for the period after chron M0 (~125 Ma) mainly based on the analysis of a large magnetic compilation of the North Atlantic and on an hypothesis put forward by Schouten et al. (1984) that the Iberian plate could be considered either attached to Africa or to Eurasia in different periods. They showed that (i) Iberia was mostly attached to Africa from the late Cretaceous to middle Eocene; (ii) between the middle Eocene to late Oligocene it behaved almost as an independent plate with slight motion relative to Africa, while most of the deformation was concentrated along its northern border, which corresponds now to a morphological feature known as King's Trough and Azores-Biscay Rise; (iii) since the late Oligocene Iberia became part of the Eurasia plate (Srivastava *et al*., 1990), ultimately leading to the development of a plate boundary south of the Iberian plate.

The structure and geometry of this plate boundary had been studied in the early seventies by Laughton and Whitmarsh (1974) and Laughton *et al*. (1975). They made bathymetric and side-scan sonar surveys between Gibraltar and the Mid-Atlantic Ridge, mapping a major scarp now called Gloria Fault, where several large magnitude strike-slip earthquakes were known to occur. Gloria Fault was interpreted as a segment of the plate boundary separating Eurasia from Africa and it was confirmed that close to the Azores, west of 25ºW there is no continuity between fracture and a marked topographic linear depression that corresponds to the now called East Azores Fracture Zone (EAFZ) strictly speaking, earlier interpreted by Morgan (1971) also as part of the plate boundary. East of Gloria fault, the geometry of the plate boundary up to the Mediterranean Sea is still nowadays controversial.

Luis and Miranda (2008) refined the magnetic compilation of the North Atlantic and re-interpreted the magnetic chrons of the Eurasia-North America plate pair. They confirmed most of the interpretation made by concluded that the establishment of the EU-AF-NA triple junction south of the Azores occurred between chrons C6c (ca. 24 Ma) and C11-C12 (ca. 30 Ma) following the welding of Iberia to Eurasia, at ~27 Ma ago. The main phases can be simply summarized as:

(i) The split of Iberia w.r.t. North-America led to oceanic spreading after ~125 Ma; Spreading pursued during cretaceous times, leading to the opening of Biscay Gulf and the development of a plate boundary along the Azores-Biscay Rise and King's Trough;

(ii) At ~27 Ma Iberia became welded to Eurasia and its northern plate boundary became inactive. Extension developed south of the Iberian plate leading to the onset of a new triple junction, presently known as the Azores Triple Junction (ATJ).

2. Extension and Internal Deformation of the Azores Domain

The new magnetic compilations of the North-Atlantic (e.g. Luis and Miranda, 2008) allowed a better interpretation of magnetic chrons and indirectly the computation of Euler rotations that can reconstruct the past locations of the plate boundaries, particularly when the lithospheric block is rotated and not only the magnetic “picks”. In this case, significant overlaps or gaps correspond to extensional or compressional processes respectively. In figure 2 we present the reconstitutions for chrons C13 (before the development of the ATJ), C6, C5 and the present configuration. The delimitation of the lithospheric blocks (dashed lines in figure 2) is based on the interpretation of magnetic anomalies and transform faults. In the case of Terceira Rift (TR) the lithospheric blocks follow the basin rift shoulders, as depicted by the swath bathymetry data: the southern limit of the Eurasian plate correspond to the northern TR basin flank, while the northern limit of the Nubia plate follows the southern TR basin flanks.

The Euler rotation parameters are taken from Luis and Miranda (2008) for Eurasia-North America and from Klitgord and Schouten (1986) for Nubia-North America. The Azores domain was rotated as Nubia thus creating overlaps to the north and angular mismatch to the west. This choice is a consequence of the fact that so much internal deformation exists in the Azores domain that it cannot be considered as a rigid block.

The main conclusions can be summarized as:

(i) There is an overlap between Nubia and Eurasia past reconstructions at C13 and C6. This quantifies the integrated extension in the Azores domain that took place off Terceira Rift (~30 km in the NNE direction).

(ii) There is an angular mismatch in the MAR segment (~12º). This corresponds to the integrated internal deformation of the Azores domain after chron C5.

(iii) After chron C5 the integrated extension is close to the present width of Terceira Rift.

3. The internal configuration of the Azores domain

The succession of basins and volcanoes between Graciosa Island and Formigas Islets is known since the works of Agostinho (1927), and was early interpreted as a tectonic rift (Machado, 1959), even if misattributed to compressive tectonics. Krause and Watkins (1970) developed the first kinematic interpretation of the Azores based on the pioneering works of Heirtzler *et al*. (1968) on marine magnetic anomalies, and the first sea-floor spreading models (Le Pichon, 1968). They were particularly puzzled by a number of “unique” features: (i) the seismically active East Azores Fracture Zone

(EAFZ) extending from Gibraltar to the Mid-Atlantic Ridge; (ii) the seismically inactive West Azores Fracture Zone (WAFZ, often misleadingly called "Pico Fracture Zone") offset northwards from the trend of EAFZ; (iii) the transverse island chain of the Azores, almost linear, but oblique to the EAFZ; (iv) the change in direction of the Mid-Atlantic Ridge (MAR) from northeast-southwest to north-south across the Azores; and (v) the broadening of the Mid-Atlantic Ridge (Krause and Watkins, 1970).

Most of these interrogations were early explained by Krause and Watkins (1970) as consequences of a difference between spreading directions and velocities, north and south of the East Azores Fracture Zone. Using simple geometric considerations, Krause and Watkins (1970) concluded that the establishment of the abovementioned velocity contrast was older than 45 Ma BP. This would have originated the development of a secondary spreading axis, within a "leaky transform" environment, and creating a triple junction between the Eurasian, African and North America plates. The change in spreading directions was also interpreted as the responsible for the latitudinal offset between the EAFZ and the West Azores Fracture Zone. Krause and Watkins (1970) considered EAFZ as an active feature, in opposition to WAFZ, considered a fossil structure within the single North-American plate. Using 13.3 mm/yr as the half-spreading rate between the Eurasian and North American plates immediately north of the Azores, and 11.0 mm/yr for the African and North American plate pair, south of the Azores, they predicted a 2.5 mm/yr of half-spreading rate for Terceira Rift and partially checked this computation with the direct modeling of three magnetic profiles across almost perpendicular to the new rift. Complementary geophysical surveys were made by Krause and Schilling (Schilling and Krause, 1970; Krause and Schilling, 1970) in the following years to test their interpretation but no new conclusions were presented afterwards.

Searle (1980) densified the bathymetric and the magnetic compilations and acquired a large set of side-scan sonar between the Azores islands and the Mid-Atlantic ridge to understand the geometry of the triple junction; he confirmed several of the Krause and Watkins (1970) interpretations, and proposed a last configuration change corresponding to a northward jump of the Eurasia-Africa plate boundary from the latitude of the East Azores Fracture Zones, to the vicinity of the North Azores Fracture Zone, which would then connect the western tip of Terceira Rift to the MAR (Searle, 1980) and would correspond to its present day location. This northward jump was compatible with the method developed by McKenzie (1972) to judge the stability of triple junctions. In the case of the Azores, McKenzie’s criterion implies that the location of the triple junction is not stable and must migrate northward.

The location and northward motion of the Azores triple junction was re-analyzed by Luis *et al.* (1994) at the segment scale. Their study was based on a detailed Azores Aeromagnetic Survey covering mostly the area close to the MAR, up to chron C5 (~10 Ma) on both plates. They concluded that the Eurasia-Nubia-North America triple junction was located north of the East Azores Fracture Zone between chron C4 and chron C3a, approximately at 38º20’N, 30º15’W (Eurasia fixed co-ordinates) and proposed a present-day location close to 38º55´N, 30º00’W (Eurasia fixed co-ordinates), after chron C2a, approximately 2.45 Ma ago, and not to the North-Azores Fracture Zone as predicted by Searle (1980).

Gente *et al.* (2003) also analysed the topographic anomaly associate with the Azores plateau, concluding that its development showed two different phases: The first one between 20 Ma and 7 Ma, which they attributed to enhanced magmatism, and the second one, after 7 Ma, when rifting dominated magmatism. This led in particular, to the split between the western plateau, where two of the Azorean islands (Corvo and Flores) lie, and the eastern plateau, where the other seven islands developed. This shift matched the determination made by Merkouriev and DeMets (2008) and Miranda and Luis (submitted), of a sudden change of spreading velocity at the Mid-Atlantic ridge.

Recently, new geophysical and bathymetric data were acquired within the Portuguese survey program in the scope of UNCLOS. For the first time both the Triple Junction area and the Terceira Rift were covered by marine magnetic profiles with GPS quality, dense enough to allow a good description of magnetic anomalies over the entire plateau and to provide magnetic chrons. In Figure 3 we present the magnetic anomaly grid reduced to the pole, with a resolution of 30” covering the area 36ºN-41ºN and 32ºW-24ºW. Its interpretation is straightforward: between the Mid-Atlantic Ridge and chrons C4a-C5 magnetic striping is normally developed. Magnetic anomalies are continuous between the North Azores Fracture Zone and Princess Alice Basin and spreading is mostly regular since chron C4a. South of 38º30’N there is evidence of a jump to the west of the ridge axis in the segment 38ºN-38º30’N at chron C3, associated with the northward progression of the triple junction (Luis *et al.*, 1994).

The northward migration of the Azores triple junction attaches Eurasian lithosphere to Africa. However, only two major rift features can be found in the plateau: Terceira Rift that corresponds to the present-day main location of rifting in the Azores, and Princesa

Alice basin and bank, now located south of the triple junction area, and that probably corresponds to a previous location of the rift (see figure 3).

It is now relatively straightforward to picture the evolution of the Azores domain after chron C6c, using the set of rotation parameters deduced for the large plates (Eurasia, Nubia and North-America):

(i) The first phase of extension in the Azores triple junction focused the previously continuous WAFZ-EAFZ transform fault, probably within a "leaky transform" environment. The morphology of the western segment of the EAFZ reflects this extensional phase, as well as the gap that is found between the magnetic anomalies north and south of EAFZ (see figure 3).

(ii) At approximately 8 Ma, there is a major shift in the development of the Azores plateau, between a "magmatic phase" and a "tectonic phase". After this period, the MAR spreading splits the preexisting plateau into an "eastern" and a "western" units.

(iii) As extension progressed with time, rift basins were developed on the Azores plateau. From the morphological data we can conclude that Terceira Rift accommodates most of this interplate extension but other rift basins, like Princess Alice can also be considered as intermediate features before the present ay configuration

4. Spreading and segmentation of the Terceira Rift

The magnetic map used by Krause and Watkins (1970) to search for oceanic spreading related with Terceira rift was based on a few profiles where chron picking could not be robustly accomplished. Miranda *et al.* (1991) and Luis *et al.* (1994) analyses of the Azores Aeromagnetic Survey showed no stable magnetic striping parallel to Terceira rift (see figure 3), in disagreement with the original interpretation of Krause and Watkins (1970). They also concluded that a few high amplitude magnetic stripes, which could be interpreted as young chrons, are not strictly confined to the Terceira Rift: S. Jorge and the Pico-Faial Islands also show large positive magnetic anomalies with the same trend and linear prolongation on the plateau. The linear magnetic anomalies that match the volcanic highs of S. Jorge, Pico and Faial islands with strikes ~N110º-N120º are not a topographic effect as shown by inversion (Luis, 1996). Miranda *et al.* (1991) also showed that the abovementioned young chrons could be interpreted as Brunhes and Matuyama, because their prolongation on-shore, in the island of Faial, was confirmed by both a refined aeromagnetic survey (Miranda *et al.*, 1991) and by radiometric dating

(Féraud *et al.*, 1980, 1981). This was interpreted as a demonstration that the Azores islands are mostly young and do not show any age progression either as a function of the distance to the MAR or a function of the distance to Terceira Rift (Miranda *et al.*, 1991).

Hildenbrand *et al.* (2012) confirmed this assumption with a new set of radiometric ages of volcanic outcrops in the main units of Faial, concluding for the existence of widespread volcanism older than 800 ka, but within Matuyama times. The interpretation of an aeromagnetic survey covering the island of S. Miguel was published only recently (Miranda *et al.*, submitted); it shows magnetization lows associated with hydrothermal alteration above the main volcanic systems, and evidence of the Bruhnes-Matuyama transition on-shore, matching the radiometric ages determined by Johnson *et al.* (1998) in surface outcrops. A similar situation was found in the island of S. Jorge (Silva *et al.*, 2012) reinforcing the interpretation that the Matuyama-Brunhes transition is found almost everywhere in the Azores islands and that Azorean magnetic anomalies are younger than ~2 Ma. The exception is Santa Maria Island, believed to have formed between 5.2 Ma and 4.6 Ma (Féraud *et al.*, 1981), and the only island of the Azores archipelago where fossiliferous sediments of Zanclean age (5.3Ma-3.6Ma) were found (Abdel-Monem *et al*. 1974; Janssen *et al.*, 2008).

The only place where magnetic stripping seems better developed corresponds to the East Graciosa Basin close to Terceira Island, where a succession of normal and reversed anomalies can be found. The two anomalies with normal magnetic polarity that follow the southern and northern flanks of the rift basin are the oldest magnetic signature associated with the development of the Terceira Rift. Princesa Alice basin also disrupts the MAR-related magnetic pattern and its western limit follows chron C2a (~3 Ma) at 38º30’N.

The main conclusions can be summarized as:

(i) Terceira rift is a relatively young feature, and the same occurs with the main volcanic islands that separate the individual basins: Graciosa, Terceira and S. Miguel. Available magnetic and radiometric data point to ~3Ma as an upper limit;

(ii) Spreading is discontinuous, with a number of linear magnetic anomalies that can be interpreted as the signature of linear neovolcanic ridges, sub-parallel to the rift direction;

(iii) The progressive change of the interplate extension across the Azores led to the abandon of the previous RFF configuration, to the formation of a RRR triple junction, present located along Terceira Rift, and to the development of the large volcanic units along Terceira Rift, which correspond to Azores islands.

(iv) Princess Alice can be interpreted as a remanent of a previous RRR configuration;

(v) Lithospheric rifting is focused on Terceira Rift at least after C3. So, the whole EAFZ becomes fossil, and the western Eurasia-Nubia plate boundary started to follow Terceira Rift and Gloria Fault, corresponding to the present day situation. The abandon of Princess Alice as an active axis, led to the subsidence of Princess Alice bank.

This is sketched in figure 4.

5. Off-rift intraplate deformation

Terceira rift accommodates most of the interplate deformation field. This can be confirmed by the morphological signature of the rift, by the effects of rifting on the previous Eurasian lithosphere and even by the analysis of the present day surface displacement field, as measured by space geodesy (e.g. Miranda *et al*., 2012). However, there is a significant amount of off-rift intraplate deformation as described by Lourenço et al. (1998), who distinguish two types of volcanism in the Azores plateau expressed as Point Source Volcanism (PSV) or Linear Volcanic Ridges (LVR). The LVR, or elongated seamounts, develop along fissure systems and are the most pervasive form of volcanism. Islands like S. Jorge, Pico and Faial are extreme cases of LVR development. The PSV consist of circular edifices believed to originate at the intersection of tectonic structures with both directions. The LVRs have been classified into three different categories (Lourenço et al., 1998). The first encompasses the S. Jorge, Faial and Pico islands and two volcanic ridges designated as “Condor Mar” and “Condor Terra”, all showing a nearly uniform axial orientation of N120° and consistently positive magnetic anomalies along their strike (Miranda *et al*., 2012). Tectonic activity concentrates in this sector, as demonstrated by graben development west of S. Jorge tip, submarine prolongation of the fissural system in Faial, more robust volcanic activity on the western tip of Condor ridge and widespread earthquake activity. The second LVR category comprises the East Pico Volcanic Ridge (EPVR), the South Terceira Volcanic Ridge (STVR) and several other volcanic ridge further south, all showing axial orientations of ~N135°-N140° and complex magnetic signatures, occasionally masked by MAR generated magnetic anomalies. Finally, the third is found south of the S. Miguel Island, and shows predominantly N150E orientations.

Nearly 90% of all mapped fault scarps, and elongated seamounts, widespread along the Azores plateau, have azimuths between N100E and N160E. Within this range the two most frequent strikes are N110E-N120E, at west, and N140E-N150E, at east, in agreement with the arcuate form of the Terceira axis itself. This pattern was used by Lourenço *et al*. (1998) as a marker of the tectonic near surface stress field. They qualitatively interpreted it as a result of the prevalence of co-axial oblique extension, focalized within the Terceira axis, and a stress field with minimum compressive axis sub-parallel to the opening directions predicted by geological and geodetic kinematic models.

The mechanism beyond the development of LVR in the Azores plateau was discussed by Vogt and Jung (2003), interpreting them as traces of failed rifts either spreading obliquely (west of Terceira island) or normal (east of Terceira island) to the relative motion between the Eurasian and the Nubian plates. They also suggested that the arcuate shape of the TR may result from the relocation of active spreading in response to the emplacement of massive volcanic loads or tectonic piles. Such a mechanism seems valid at a broad scale and coherent with the northward migration of the Triple Junction. However, the age progression it implies for the LVR, progressively younger towards NE, is not supported by magnetic or geochronology data.

Recently Neves *et al*. (2013) suggested an alternative explanation for the development of LVRs. They assumed that the crustal deformation is driven by plate boundary forces applied at the edges, as describe by global plate kinematic models. Using a 3D numerical model where the brittle layer is described by an elasto-plastic rheology and the mantle underneath is modeled as a viscoelastic layer. Assuming also that fractures are analogous to localized shear bands, they show that lithospheric processes alone can justify the spatial distribution of most of the linear volcanic ridges.

6. Main steps of ATJ evolution

After more than four decades of research a number of questions have been clarified concerning the different phases of development of the Azores triple junction, allowing the design of the following evolution sketch:

> ~27 Ma ago there was a major rearrangement of plate tectonics in the Atlantic attaching the small Iberian plate to Eurasia and developing a new plate boundary close

to a previous transform fault. This was early realized by Krause and Watkins (1970), and confirmed by latter kinematic studies covering the evolution of the North Atlantic since the Cretaceous (e.g. Srivastava et al., 1990, Luis and Miranda, 2008).

> 20 Ma ago the EAFZ was abandoned either as a plate boundary or a transform fault. This corresponded to a northward jump of the ATJ and to beginning of rifting in the Azores. It is predicted by McKenzie TJ stability model, as a consequence of the velocity triangle;

> 20-8 Ma: Extension across the Azores is maintained at the rate of 3.7mm/yr in the N220E direction. The plateau is in the "magmatic phase": the topographic anomaly develops slightly east of the MAR but close to it. Significant surface reshape takes place but the MAR abyssal hill morphology is not destroyed, this meaning that most of the "bump" is sub-crustal. The topographic anomaly associated with the plateau can be found between the EAFZ and Kurchatov FZ while the associated geochemical signal is wider (Dosso et al., 1999, Goslin et al., 1999). The connection between the two concepts is unclear. The contribution of the TJ geometry exists (Georgen et al., 2010) but does not justify the whole topographic excess; most of it being of dynamic origin (Adam et al., 2013). The northern limit of Nubia plate is displaced to the north of the EAFZ: the previous single 200km segment immediately north of EAFZ is split into a number of smaller en-echelon segments at the time of chron 5 (~10 Ma), when spreading had a significant obliquity, similar to what can be observed now in the Reykjanes ridge. This matches the period of maximum magmatic productivity. The topographic signature of this period can be found both east and west of the MAR and even south of EAFZ;

> 8 Ma: major rearrangement at the Atlantic corresponding to a sudden decrease of spreading velocity in the MAR and acceleration of the stretching rate across the Azores (Merkouriev S. and DeMets C., 2008, and Miranda and Luis, submitted), with a change of azimuth of the stretching direction; this corresponds also to the end of the magmatic phase of the plateau, and its split by the MAR (Gente et al., 2003) into the "eastern" and the "western" plateaus;

> 8-3 Ma: extension at the rate 4.5mm/yr in the N240E direction (Miranda and Luis, submitted), corresponding to the rifting phase of the plateau. In this phase Santa Maria Island developed. Rifting started probably at Princess Alice Rift into a RRR configuration.

> 3 Ma: Abandon of Princess Alice Rift and rifting starting at Terceira Rift close to the northern limb of the plateau. Rifting is controlled by boundary kinematic conditions (McKenzie, 1972) and mantle heterogeneities (Vogt et al., 2003, Yang et al, 2006, Adam et al., 2013), associated with the two well know families of surface faults (Miranda et al., 1998): N120E associated with magmatic processes and N150E associated with brittle tectonics.

> 3-0 Ma: extension at the rate 4.5 mm/yr in the N240 direction. Opening of all TR basins, and accommodation of interplate extension into the ATA, with the development of mesoscale blocks, almost deprived of volcanism. Development of most of the Azores islands in both pre-existing Azores plateaus, by a combination of buoyancy and tectonics; island volcanos drifted away of the TR to the EU or the NU plates, with the exception of S. Miguel Island internally stretched by TR, and Flores and Corvo trapped in the North-America plate; development of off-ridge extension controlled by mantle dynamics.

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FIGURE CAPTIONS

Figure 1: General framework of the Azores triple junction. Main morphological structures are sketched below: FZ: Fracture Zone. The plate boundary between Eurasia and Nubia is supposed to presently follow Terceira Rift up to S. Miguel Island, Gloria Fault up to Tore-Madeira Rise. Close to Iberia the plate boundary becomes more complex and its geometry within the Southwest Iberian transpressive area is controversial.

Figure 2: Magnetic reconstruction of Eurasia, Iberia and Nubia at the time of chrons C13, C6, C5 and C0, in fixed Eurasian coordinates. Euler rotation parameters are taken from Luis and Miranda (2008) for Eurasia-North America and from Klitgord and Schouten (1986) for Nubia-North America. Dashed lines delimit the lithospheric blocks based on the interpretation o magnetic anomalies. In the case of Terceira Rift they follow the shoulders of the basins as depicted in the swath bathymetry data. The Azores domain was rotated as Nubia and so, the reconstitution at C13 and C6 times shows an overlap of Nubia and Eurasia that quantifies the integrated extension that took place south of Terceira rift; the angular mismatch in the MAR segment that corresponds to the Azores plateau quantifies the integrated shear deformation that is applied to the Azores domain by the difference in velocity north and south of that segment; after chron C5 the extension is focused on Terceira Rift.

Figure 3: Morphotectonic sketch and main magnetic chrons. Magnetic chrons 5, 6, 13, 18, 20 and 21 are interpreted according to Luis and Miranda (2008). Younger chrons 2, 2A, 3, 3A, 4 and 4A are also interpreted close to the Mid-Atlantic Ridge. Along Terceira spreading axis magnetic lineations corresponding to the Brunhes epoch (red) and Matuyama (blue) are also plotted.

Figure 4: Sketch of the main phases of the evolution of the Azores domain. At the time of chron C6 the western and the eastern Azores fracture zones form a single transform boundary; at the time of chron C5 the extensional component of the motion between Eurasia and Nubia is mainly accommodates as transtension close to the East Azores Fracture Zone; at the time of chron C3 there is a new RRR triple junction with an active rift incorporating the Princess Alice basin; after chron C3, the rift moves to the NE, leading to the development of Terceira rift, ~100 km away from the Mid-Atlantic Ridge. The area between Terceira rift and the MAR (ATA, Azores triple area) is marked by significant internal deformation.

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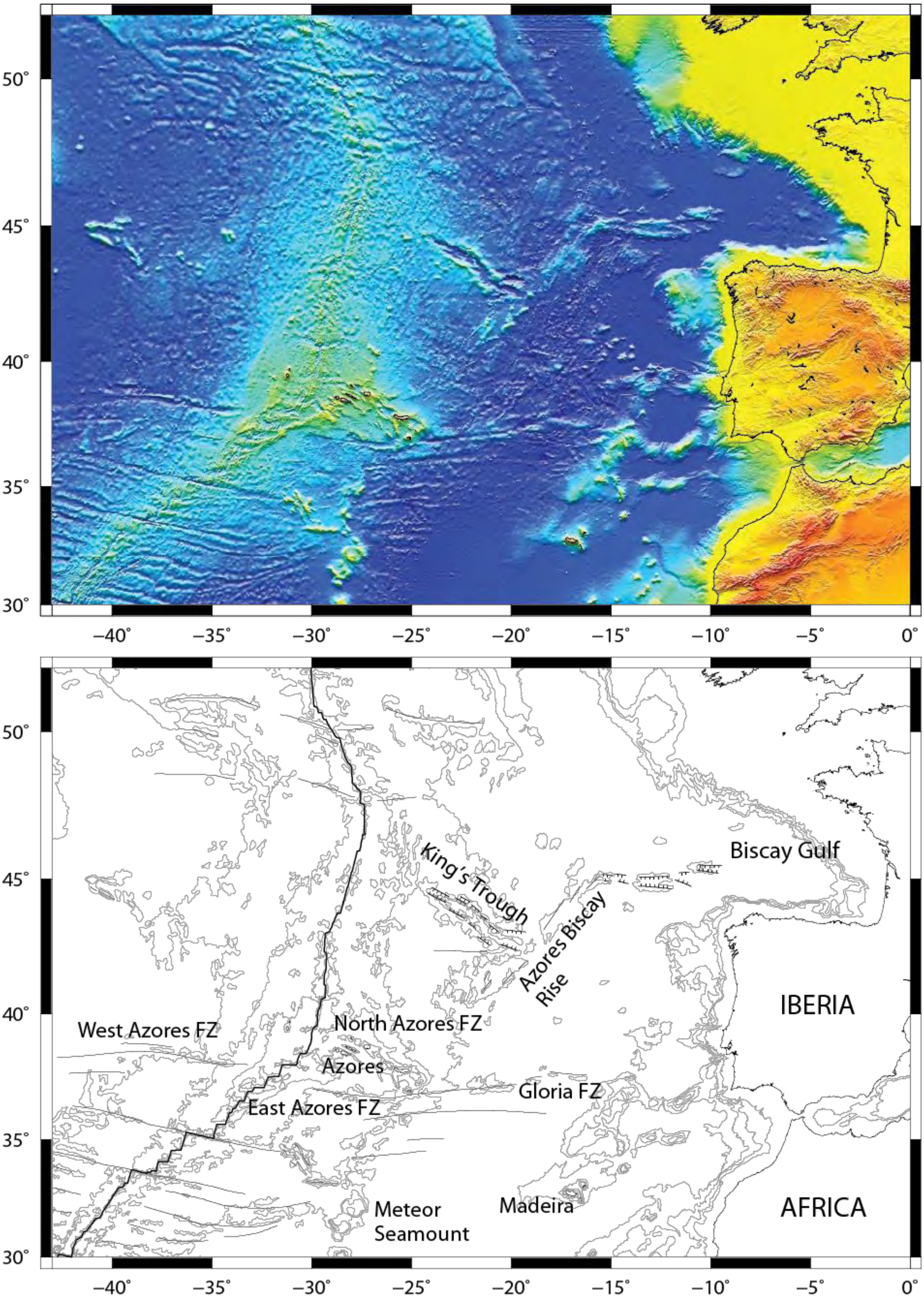

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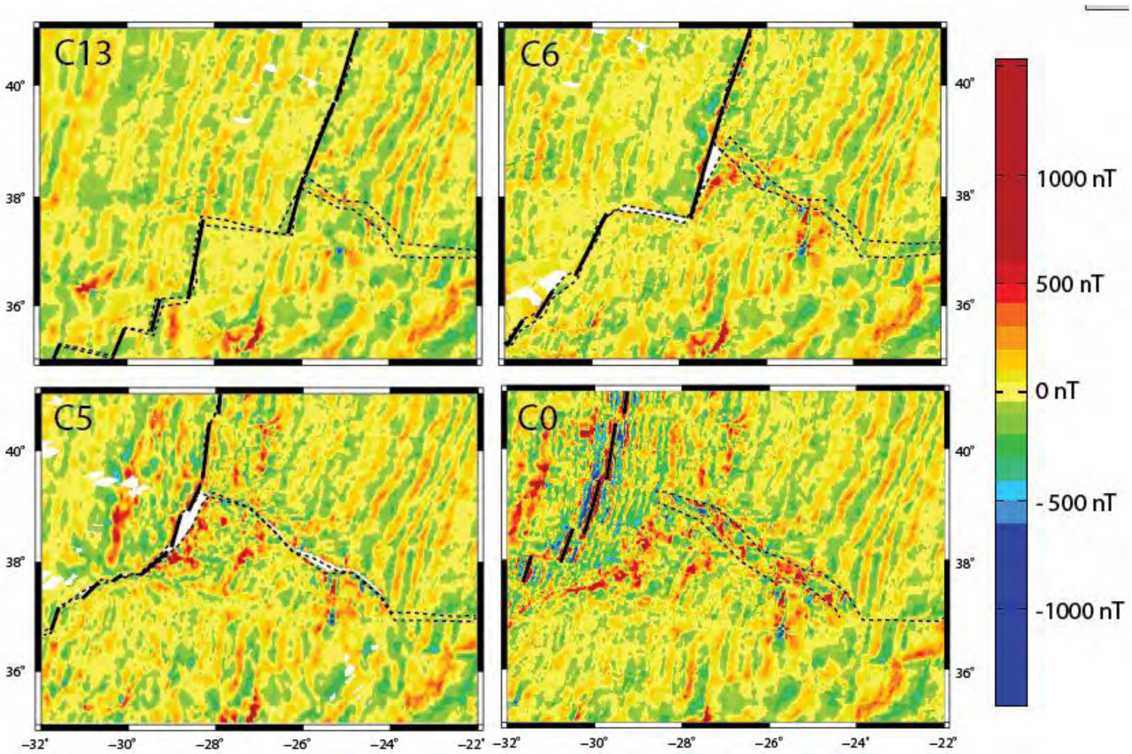

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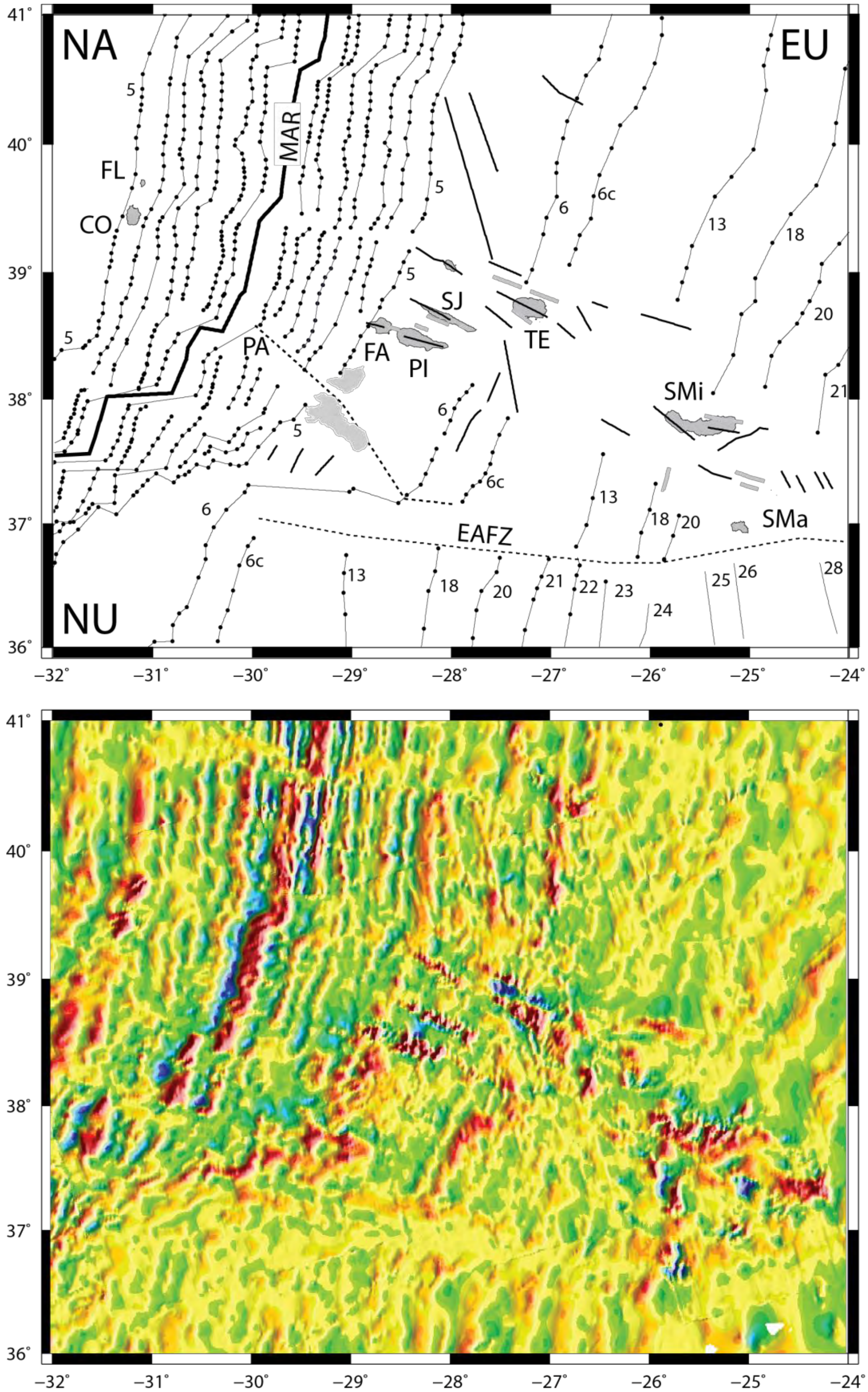

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