Insights about St. Peter peridotitic ridge in the Equatorial Atlantic tectonic setting: Deep upper-mantle structure with ductile and brittle deformation

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Abstract

The St Peter peridotitic ridge (SPPR) is a large structure in the Equatorial Atlantic Ocean, located at southern side of the intersection of the Mid Atlantic Ridge (MAR) with the St. Paul´s Transform Fault (SPTF); It is composed for upper-mantle derivate lherzolitic and harzburgitic rocks with serpentinitic and mylonitic processes superimposed. Basaltic rocks and sediments are presents in less proportion.

The sigmoid structure of the SPPR is elevated 4000 m above the ocean bottom and it´s northern side protrudes above the sea level forming the St. Peter and St. Paul´s Archipelago (SPSPA) in the geographical coordinates 0° 55'.1 N and 29° 20'.7 W. This segment ridge corresponds to the wall of the active SPTF, for this reason is the more intensity deformed and mylonitized, that constitute a excellent outcrop of the mantle related rocks with accessible structural elements of the ductile and brittle deformation.

Introduction

The existence of three, (and possibly four) intra-transform segments is a special tectonic setting as is showing in the figure 1.That situation in SPTZ system is the example in a low spreading ridge.

The area were mapped and dredged since 1970 (Bonatti & Honnorez, 1970; Gorini, 1981; Bonatti, 1990; Bonatti, et al., 1993, Schilling et al., 1995).

Two of the intra-transform segments were surveyed by Nautile dives (Hékinian et. al., 2000). The results show that the flanks of the MAR are mainly formed by serpentinized peridotites, with thin basaltic layers on top of the rift walls. A few gabbros were observed on the flanks, suggesting that melt supply is low. On the bottom of the rift valley, fresh basalts were sampled (Hékinian et al., 2000). Results from basalt chemistry show that they are related to low degrees of partial melt and to low potential mantle temperatures. Thus, the SPTZ represents a discontinuity in the depth, crustal thickness and basalt composition profiles, between a cold equatorial mantle and a more "normal" mantle at the northern MAR (Schilling et al., 1995). Cold barrier effects of the exceptionally long transform faults (Fox and Gallo, 1984) could be partially responsible for the low mantle temperature and consequent low melting rates (Sichel. et. al. 2002).

Those results are compatible with asthenospheric deformation as consequence of relative displacement of the lithosphere on the upper-mantle generating shear asymmetry at variant scales for the Equatorial Atlantic and for the SPPR as is show in figures 2 and 5.

Stress indicators for tectonic characterization

In the way for determinate the transform fault effects over the upper-mantle exposure in the out-side corner of the major fracture intersection (MAR and SPTF). This study pretend to establish the main stress indicators which provide absolute or relative stress magnitudes the tectonic regime across to regional and local geological tools.

Different types of stress indicators are used to determine the tectonic stress orientation. They are grouped into four categories: Earthquake focal mechanisms well bore breakouts and drilling-induced fractures, in-situ stress measurements (overcoring, hydraulic fracturing, borehole slotter) and young geologic data (from fault-slip analysis and volcanic vent alignments).

The figure 2 shows the stress vector in the MAR, all of them are product of earthquake focal mechanism analyses. For the SPTZ there are NW-SE dextral strike slip vectors that are explained by the extension perpendicular to the main ridge (MAR) and the E-W orientation of the St. Paul fracture zone. The sum of those processes and displacements produced a dextral shear deformation and consequent tectonic uplift in the out-side corner of that geographic setting.

Other stress indicator comes from the structural analyses of ductile and brittle deformation across the measurement of foliation, faults and fractures mainly.

Detailed study

The SPSPA is showing in the figure 3, which contains photographs of the morphological aspect. Those islands are composed of mylonitized abyssal mantle rocks with serpentinization superimposed. The mylonitization obliterated all primary textures of these rocks. Concomitantly, the serpentinization, through pervasive hydrothermal fluids and/or seawater actions during late tectonic movements, fractured even more the rocks. The emerged part of some islets still show a sedimentary covering of quaternary age, that are constituted of clastic sediments derived from the biogenic activity and basement, cemented by calcium carbonate.

The SPSPA give an excellent opportunity for measure different structural elements for the tectonic approximate. The field structural data included elements of ductile and brittle deformation. For the ductile deformation is sampled the ultramylonitic foliation S1 N040 related to a foliation S2 N149 in a conjugate system.

The brittle deformation generates different types of fractures, including the Riedel-type fractures showing a N080-N110 orientation (figure 4a), which is the main trend of the SPFZ. The mylonitization is a process in the ductile state present in the archipelago rocks due to partial recristalization of olivine, pyroxene and spinel with amphibole in the matrix (aqueous presence) (Simões et. al, in press) which generates a high foliated rock parallel to the compositional variance, in the figure 4b is possible to see the strong lineation product of the shear belts action. The first foliation S1 controls the serpentinization and the second foliation S2 is characterized by veins filled with carbonates as is showing in the figure 4c, probably related to low-temperature hydrothermal fluids.

The figure 5 shows the structural map of the Belmonte Island, the major island that conform the archipelago. In that figure are mapped major shear belts with a thickness greater than 0.5 m and include the measuring stations with the stereographic projections of structural planes (faults, foliations and fractures). The stereographic analysis produces the orientation of the principal contraction vector for each data set, for the SPSPA the N140 is the orientation of the stress generates the dextral shear deformation that coincide with the regional effort for the SPTZ (figure 2).

Results

It is therefore highly probable that the SPSP peridotite ridge is linked to the starved accretion process taking place at the MAR segments inside the SPTZ system, although the extremely high position of the islets, above the sea level, which is unique in the area, cannot be simply explained by the peridotitic nature of the rocks themselves.

Thick petrologic crust, with basaltic layers and dikes, is formed at the center of the accreting segments, while peridotites and gabbros are frequently exposed at segments ends and discontinuities. In a first order, this variability is attributed to focusing of melt at the segments centers, while at segments ends less melt availability results in thinner upper crust (e.g., Cannat et al., 1995). Additional complexity in the structure of the crust arises from asymmetric spreading processes, with low angle detachment faults at segments ends exposing gabbroic bodies and peridotites at one flank of the ridge (e.g. Ildefonse et al., 2007). These structures, known as core complexes or “megamullions”, are common along the MAR flanks and, although frequently associated with transform faults (e.g. Atlantis and Kane fracture zones). However, low-angle fault structures have not been studied in the SPPR because the abrupt morphology and the low resolution of geophysical methods. The sigmoidal shape of the massif suggesting that the processes operating is the dextral shear in the out-side corner of the MAR and SPTZ intersection, generating a NW-SE contraction vectors (Figure 2) that forces upwelling, deforming the lithosphere and probably the upper-mantle and the asthenosphere like a plume upwelling event.

The oriented deformation is reflected in the SPSPA which constitute an accessible outcrop of mylonitized peridotites. There, is possible to measure structural elements (mylonitic foliation, faults and fractures) that suggesting a NW-SE contraction, the same direction for regional scale. (Fig. Y)

Although global tomographic models have generally low resolution at the surface (half-wavelength of ~1000 km), both the S and P models show high velocities in the upper mantle near the equatorial area. A notable characteristic of these whole-mantle seismological models is that the high velocity zone observed for the upper mantle apparently continues into the lower mantle. That phenomenon is attributed to the presence of could subducted slab during the assembly of Pangaea (460-300 Ma) that effectively reduce the average mantle temperature, thus yielding low melting rates and high seismic velocities at higher levels in the mantle or less probably by delamination and downwelling of large blocks of subcontinental lithosphere. (Sichel et. al. 2002).

Conclusions

Extension linked to the opening of the Atlantic is mainly accommodated by tectonic processes with low magma supply (amagmatic accretion processes), resulting in the exposure at the ocean floor of deep mantle rocks.
The probable reasons are active processes that include N140 dextral shear contraction in the SPTZ and MAR intersection, and asthenospheric deformation for cause of the relative displacement of the lithosphere over the upper-mantle generating an asymmetric disturbance of the magma supply.

Although detailed studies were carried on at some of the intra-transform MAR segments, bathymetric and geophysical data on the area is still very sparse and of low resolution.

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The world stress map was obtained from UNAVCO Boulder (Colorado, USA), it developed the Jules Verne Voyager interactive map tool, where images are produced using the Generic Mapping Tools (GMT).

The Marine Geoscience Data System (MGDS; www.marine-geo.org) designed of GeoMapApp© for both public and academic use.

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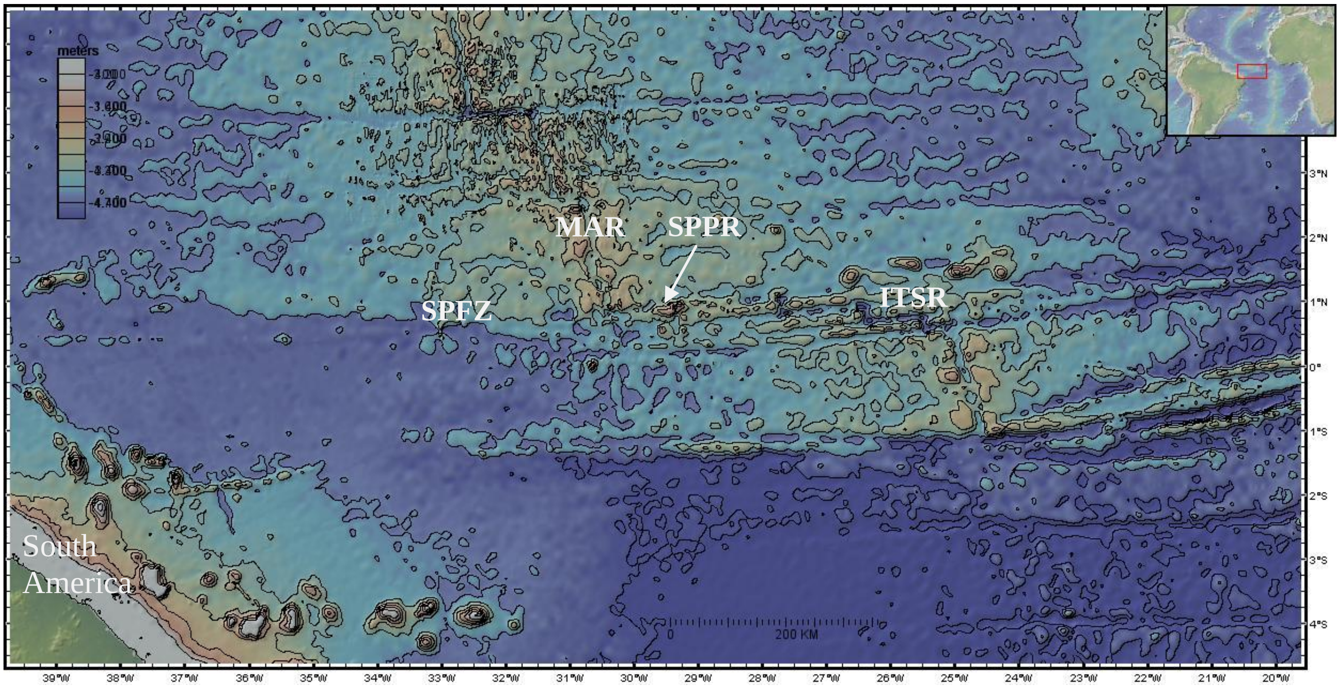

Figure 1: Bathymetry of the Equatorial Atlantic zone showing the bottom geomorphology and the location of the St. Peter St. Paul Archipelago in the St. Paul fracture zone influence. The SPFZ is characterized by the Intra-transform segment ridges. MAR Mid Atlantic Ridge; SPFZ St. Paul fracture zone; ITSR Intra-Transform Segment Ridges; SPPR St. Paul Peridotitic Ridge. http://www.marine-geo.org.

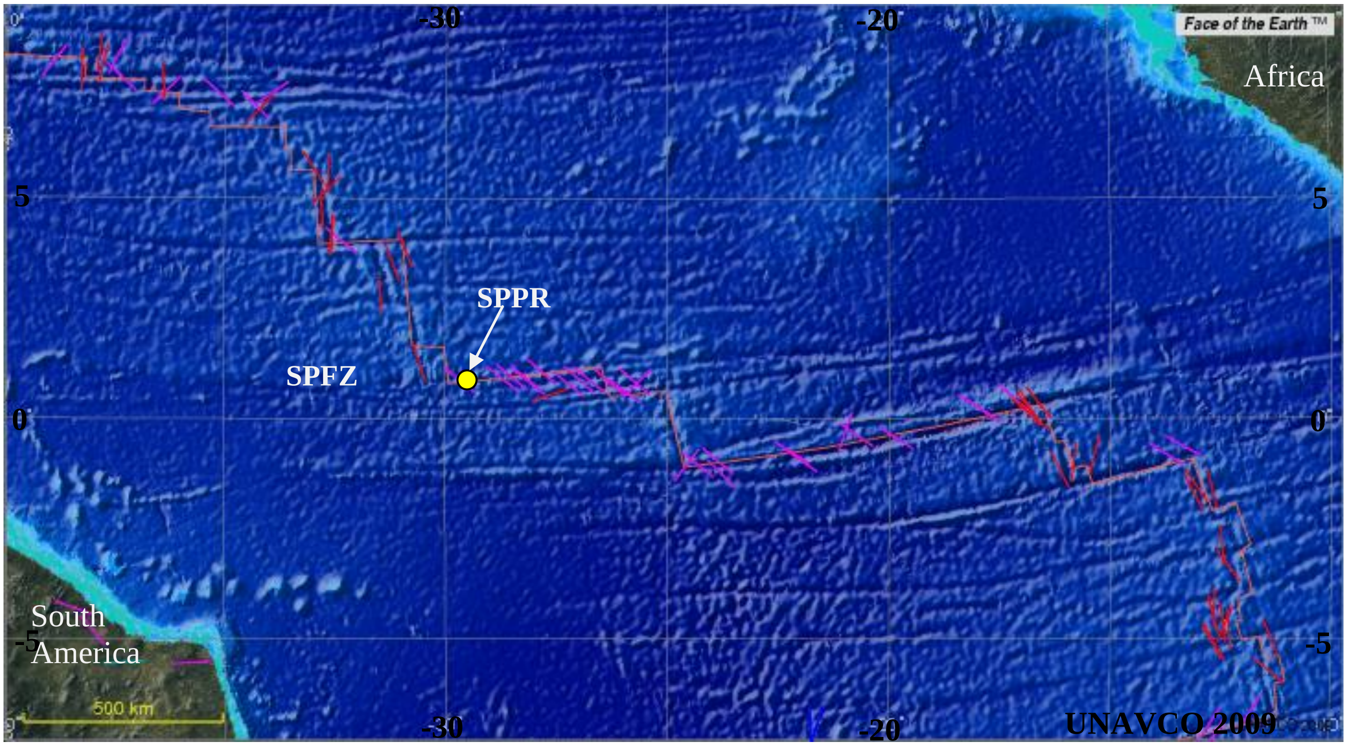

Figure 2: The World Stress map released for 2004, from the UNAVCO Voyager interactive map tools. SPFZ St. Paul´s Fracture Zone; SPPR St. Peter Peridotitic Ridge. Stress Vectors: Red color Normal fault and Purple color dextral strike slip fault. The vectors of contraction were derivate from focal mechanism of the Mid Atlantic Ridge Earthquakes obtained from NEIC/USGS and Harvard sources. Face of the Earth is a registered trademark, ARC Science Simulations © 1999. http://jules.unavco.org/.

Figure 3: Photographs of the geomorphological aspect of the St. Peter St. Paul Archipelago. A. General view; B. Detailed in the St. Paul minor island.

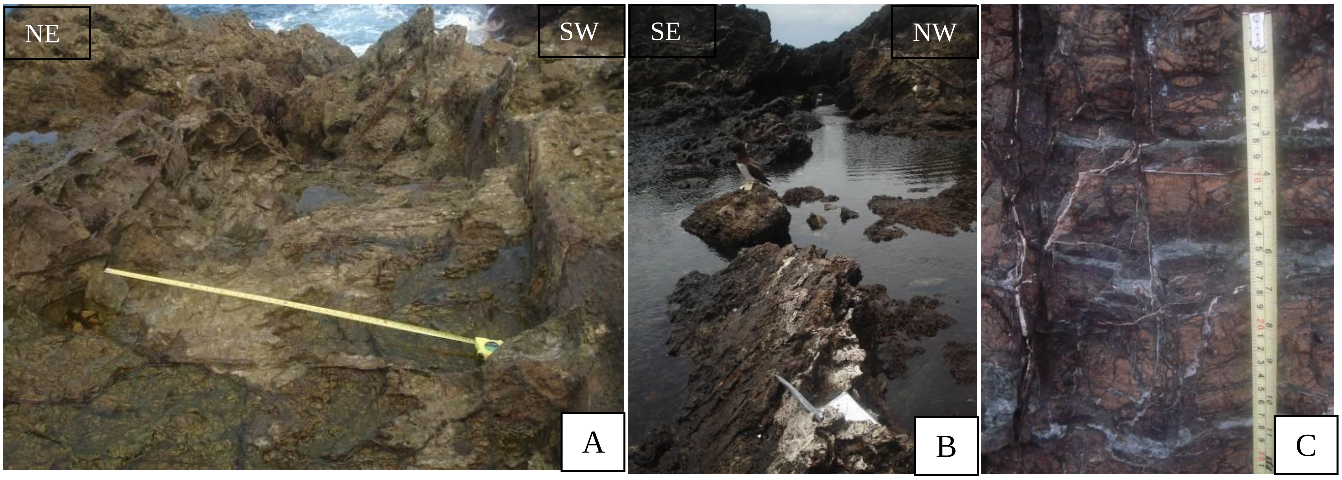

Figure 4: Photographs of different outcrops in the Belmonte Island showing the main structural elements. A. Riedel-type fractures N80-N110 oriented, that complement the main shear belts; B. Strong mylonitic lineation product of the local shear faults action; C. The two different foliations, S1 (N40) controls the serpentinization and S2 (N149) is filled with white hydrothermal carbonates.

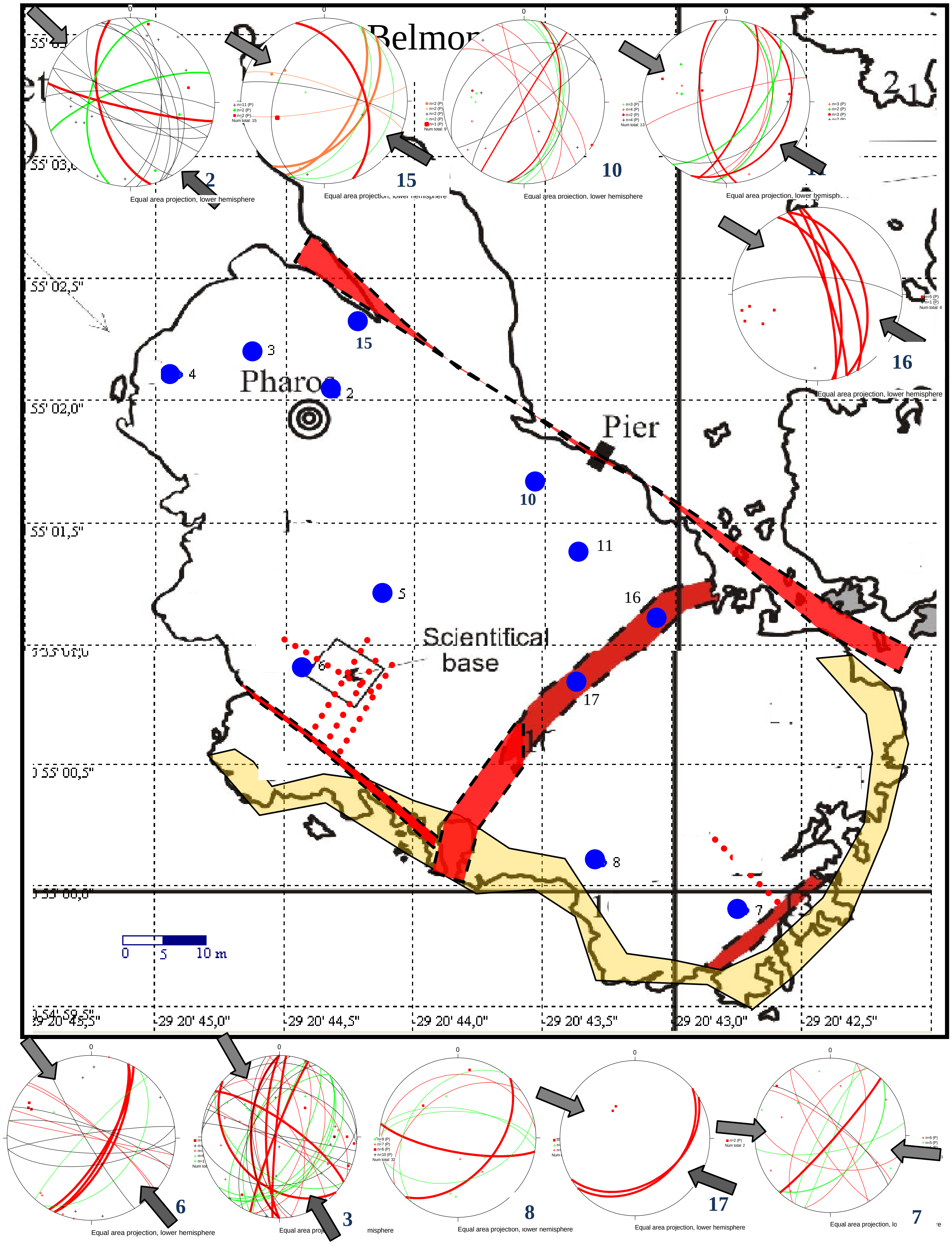

Figure 5: Structural map of the Belmonte island, in the SPSPA showing the main shear zones (red belts) and the stereographic representations of the structural elements for each measuring station (blue points). **Green**: mylonitic foliation, **Dark red**: fault zones with thickness >0,5 m, **Light red**: fault zones with thickness <0,5 m, **Black**: fractures, Filled arrow: vectors of contraction.