RECENT SEISMIC ACTIVITY IN THE AZORES REGION

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SUMMARY

This seismic activity in the Azores Region is characterized by sequences of low-magnitude events, usually with epicenter off-shore. These seismic sequences are sometimes triggered by larger events, felt by the population, that could produce significant material and human losses. This characteristic is confirmed by the historical and instrumental seismicity, in particular by the recent earthquakes occurred on 1980 (Mw=6.8), 1997 (Mw=6.2), 1998 (Mw=6.2) and 2007 (Mw=6.3, Mw=6.1). The mechanism responsible for this spatial and temporal seismic pattern still yet not very well known.

In this work we discuss the recent (2007) seismic activity of the Azores region by analyzing the spatial and temporal distribution of seismic events associated with two sequences with different characteristics. The fisrt one is a seismic swarm started on April 21st 2007, centered at about 40 kilometers west of the Faial Island (maximum magnitude mb=4.0). The second one corresponds to an aftershock sequence associated to the events of 2007/04/05 (Mw=6.3) and 2007/04/07 (Mw=6.1), both with epicenter in the Formigas Islets and felt (I=V/VI in Mercali scale) in S. Miguel.

We calculate the static Coulomb stress change for both events using focal mechanisms derived from the inversion of body waves. We find that the static stress change caused by the April 5 event is higher, about 2 bar at the location of the second event (April 7), triggering the second rupture. Locations of aftershocks do not agree well with areas of increased Coulomb failure stress.

1. INTRODUTION

The Azores archipelago is located at a lateral branch of the Mid-Atlantic ridge near the Azores triple junction (ATJ), a region where the American, Eurasian and African lithospheric plates meet. The ATJ is located in the western part of the Eurasian-African (EU) plate boundary. The region is a zone of anomalously shallow topography, with an approximately triangular form limited by the bathymetric line of 2000 m, known as the Azores Plateau (AP) (Lourenço et al., 1998). The islands of the Azores Archipelago are located in the AP, with the exception of Flores and Corvo islands that are located in the American plate.

The Terceira Ridge (TR) is commonly considered as the limit between EU and AF plates. Different explanations have been proposed for the origin of the TR: normal to the ridge (Krause et al, 1970; Udías, 1980; Buforn et al, 1988); oblique extension (McKenzie, 1972; Searle, 1980); leaky transform model (Madeira and Ribeiro, 1980) and diffuse boundary that is acting simultaneously as an ultra slow spreading centre Lourenço et al (1998). Understanding the dynamic of the ATJ is difficult because the very slow sea floor spreading rates at the TR (< 1cm/yr) and the nature and location of the TR are still in debate. Nevertheless, the high level of seismicity along the MAR and the TR (Fig. 1) is strongly associated with the seafloor spreading, origin of the northeasterward motion of the Eurasian plate with respect to Africa plate (Buforn et al., 2004).

The seismicity of the Azores region is associated with the boundary between the Eurasian, African and American plates and is characterized by events of moderate magnitude of shallow depth (maximum depth of about 10 km). Since 1920 only two earthquakes have had $M_s \sim 7$, one on 8 May 1939, with its epicentre east of Santa Maria Island, and the other on 1 January 1980, with its epicentre between Terceira and Graciosa Islands. Most seismic activity is located on the Mid-Atlantic Ridge (MAR) and on the North Azores fracture zone (NAFZ) continuing into the Terceira Ridge (TR), while the East Azores fracture zone (EAFZ) is practically inactive (Fig. 1). From historical seismicity, we know that large shocks have occurred in the Azores with maximum intensities of X (modified Mercalli - MM) (Nunes and Ribeiro, 2001). We observe that the seismicity follow the same trend as the islands: approximately ENE from the MAR to Terceira Island (where the 1980 and

1998 shocks were located) and SE from Terceira Island to San Miguel Island (the 1997 earthquake was located SE of Terceira Island) (Borges et al., 2007; Matias et al., 2007). Seismicity stops at 24ºW where the TR joins with the Gloria fault, which is considered seismically inactive (Fig. 1).

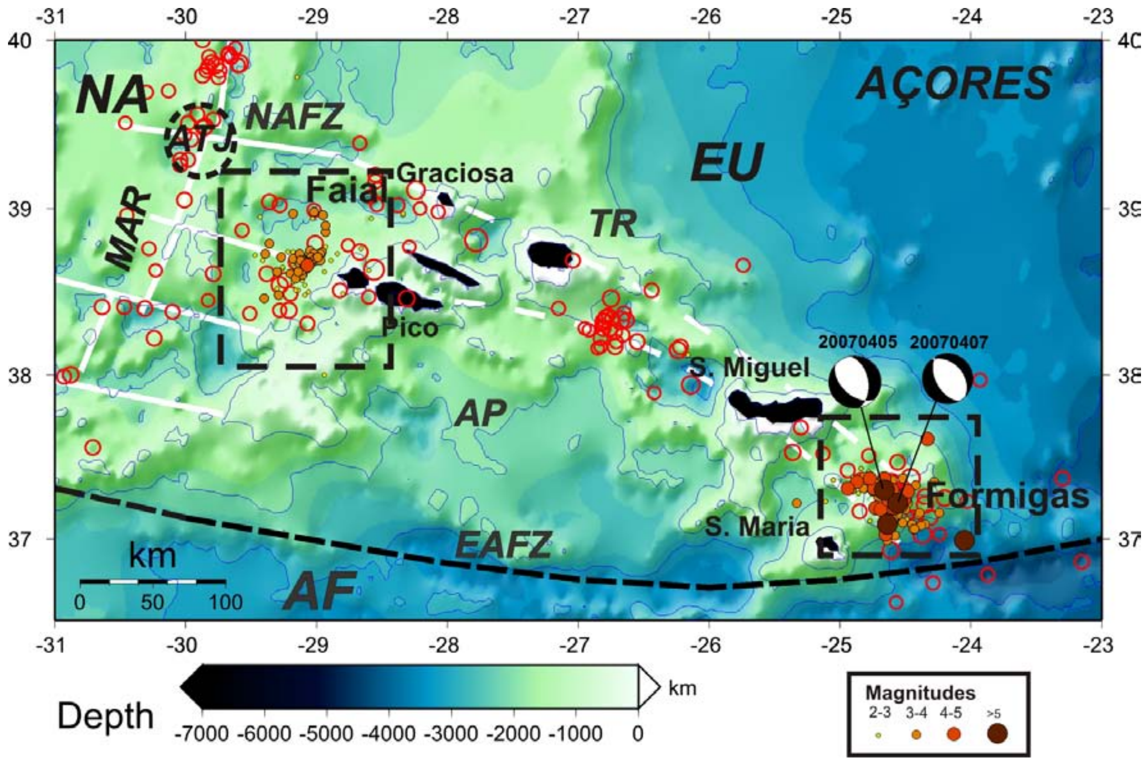


Figure 1: Seismicity of the Azores region: Open circles represent the seismicity with magnitude M>4 and fill circles represents the 2007 seismic activity (IM data base) witch correspond to both main studied seismic sequences. NAP=North American plate, EP=Eurasian plate, AF=African plate, AP=Azores Plateau, TR= Terceira Ridge, AJT=Azores Triple Junction.

In this work we discuss the recent (2007) seismic activity of the Azores region by analysing the spatial and temporal distribution of seismic events associated with two sequences with different characteristics: a seismic swarm started on April 21st 2007, centred at about 40 kilometres West of the Faial Island (maximum magnitude mb=4.0) and the aftershock sequence associated to the main events of 2007/04/05 (Mw=6.3) and 2007/04/07 (Mw=6.1), with epicenter located in the Formigas area (Figura 1).

2. THE SW FAIAL SEISMIC SEQUENCE

The earthquake sequence of April 21st 2007, centred at about 40 kilometres west of the Faial island, started with a small number of low magnitude events (m~2.0). Analysing the time histogram (Fig 2a) we recognize that the number of events increases, reaching a peak on April 23 (Fig. 2a), when occurred the larger shock (M=4.0). In the figure 2b the cumulative number of events distribution is not regular and not associated to a main event. We conclude that this typical swarm sequence suggests that the seismicity is not generated by a tectonic main shock/aftershock mechanism.

3. THE FORMIGAS SEISMIC SEQUENCE

The recent seismicity located at SE of S. Miguel (Formigas) is associated to the main event, which occurred on 05-04-2007 by 03:56, Mw = 6.3 (Figure 1). This event was not preceded by any foreshock, but followed by a series of aftershocks of between magnitude 3 and 4, whose number decreases until two days latter, on 7, at 20h:30m when a new earthquake occurs (mb = 6.1). From this date, despite some periods increase, the daily frequency of earthquakes has been gradually decreasing (Figure 2c and d). This is not a typical aftershock sequence because there are two main shocks with similar magnitude in a time interval of 3 days.

We estimated the focal mechanism from body wave inversion at teleseismic distances using broadband records (IRIS and GEOFON seismic stations). Our results showed, for both events, normal faulting with the fault plane oriented NW–SE (132/49/-117 - Mw=6.3 - for the 2007/04/05 event and 125/52/-81 – Mw=6.1- for the 2007/04/07 event).

In order to investigate the effect of the larger shock of the 2007/04/05 on the adjacent faults, we calculated static co-seismic Coulomb stress change induced by the earthquake. According to Coulomb failure criterion, the Coulomb failure stress change ($\Delta \sigma_f$) on a receiving fault resulting from an earthquake on the source fault takes the form of $\Delta \sigma_f = \Delta t + \mu' \Delta \sigma_n$, Δt is the shear stress change, $\Delta \sigma$ represent the normal stress change on the receiving fault and the $\mu'$is the apparent friction coefficient, which includes the effect of pore pressure.

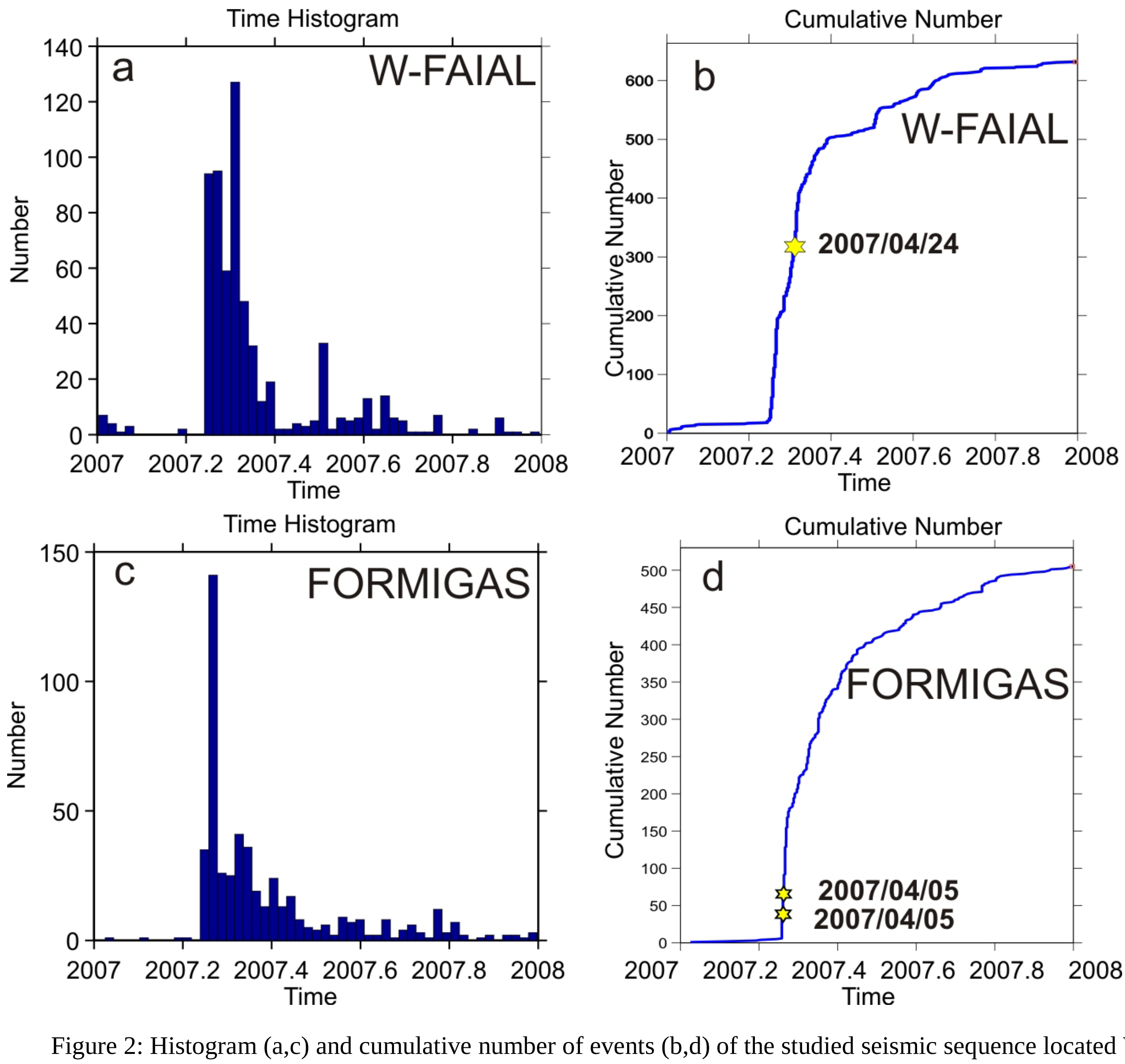
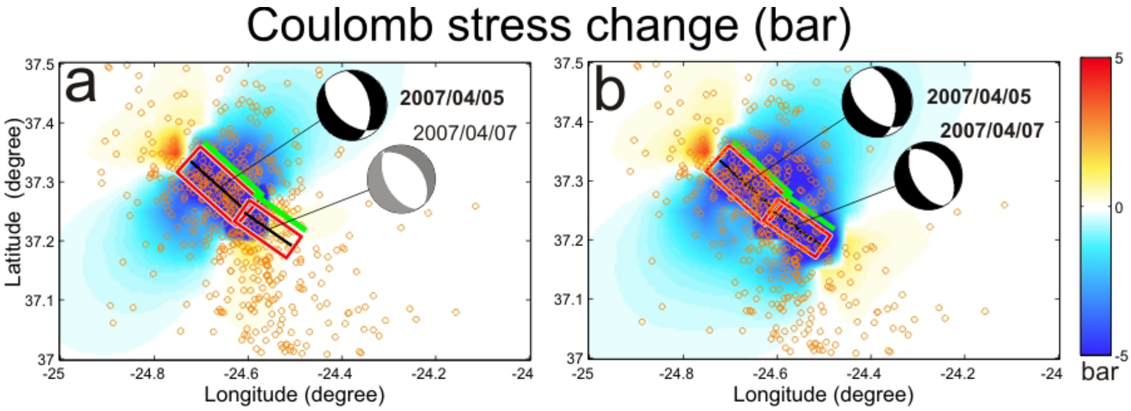


Figure 2: Histogram (a,c) and cumulative number of events (b,d) of the studied seismic sequence located W Faial (a,b) and at Fromigas area (c,d). Stars represent the most energetic events of those sequences (Time in decimal-year format).

Applying this methodology to our area we conclude that Coulomb Stress change in the nucleation point of the second event is greater than 1 bar (Figure 3a) witch is sufficient to trigger this event.



Figures 3: Correlation between Coulomb Stress change (CSC) and aftershock distribution; a) CSC produced by the 2007/04/05 (black focal mechanism) in a receptor fault with a focal mechanism of the 2nd event (grey focal mechanism) ; b) CSC produced by both events in the area. Apparent friction coefficient μ ′=0.4.

If we compare the distribution of the aftershock sequence with the Coulomb stress change for both faults (Figure 3b), we conclude that there are a lot of earthquakes in regions of Coulomb stress decrease and that contrary the Coulomb hypothesis. Generally, the best correlations of Coulomb stress change to aftershock distribution are at distances greater than a few kilometres from the fault. Many of the inconsistencies may be explained by the details of the slip distribution and rupture geometry influence near-fault stress changes that are not accounted for in the Coulomb stress calculations(Harris and Simpson 1996).

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4. CONCLUSIONS

In this work we discuss the recent (2007) seismic activity of the Azores region by analyzing the spatial and temporal distribution of seismic events associated with two sequences. We conclude, by analyzing the spatio-temporal evolution of the seismic activity that those two sequences present different characteristics. The seismic activity at West of Faial Island is a typical swarm sequence, not related to a prominent event; the seismic activity at Formigas region is a typical aftershock sequence associated to two main events (2007/04/05, Mw=6.3 and 2007/04/07, Mw=6.1).

We calculate the static Coulomb stress change for both events using focal mechanisms derived from the inversion of body waves (King et al., 1994). We find that the static stress change caused by the April 5 is larger than 2 bars at the epicentre of the second event, promoting their failure. Locations of aftershocks do not agree well with areas of increased Coulomb failure stress which can be explained by the complexities of the rupture process or errors on the hypocentral determination

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6. REFERENCES

Buforn, E., Bezzeghoud, M., Udías, A. and Pro, C. (2004). Seismic sources on the Iberia-African plate boundary and their tectonic implications. *Pure Appl. Geophys*. 161, 623-646.

Buforn, E., Udías, A. and Colombás, M.A. (1988). Seismicity, source mechanisms and seismotectonics of the Azores-Gibraltar plate boundary. *Tectonophysics*, 152, 89-118

Borges J. F., M. Bezzeghoud, E. Buforn, C. Pro and A. Fitas, 2007. The 1980, 1997 and 1998 Azores earthquakes and its seismotectonic implications. *Tectonophysics*, 435, 37-54.

Harris RA, Simpson RW. 1996. In the shadow of 1857: the effect of the great Ft.Tejon earthquake on subsequent earthquakes in southern California. Geophys. Res. Lett. 23:229–32.

King G C P, Stein R S, Lin J. Static stress changes and the triggering of earthquakes. Bull Seismol Soc Am, 1994, 84: 935－953.

Lourenço, N., Miranda, J.M., Luis, J.F., Ribeiro, A., Mendes Victor, L., Madeira, J. and Needham, D. (1998). Morpho-tectonic analysis of the Azores Volcanic Plateau from a new bathymetric compilation of the area. *Marine Geophy. Res*. 20, 141-156.

Matias, L., N. Dias, , I. Morais, D. Vales, F Carrilho, Madeira F. J.L. Gaspar, L. Senos and A. B. Silveira. (2007) - The 9th of July 1998 Faial Island (Azores, North Atlantic) seismic sequence. Journal of Seismology, 11, p. 275 - 298.

McKenzie, D. (1972) Active tectonics of the Mediterranean region. *Geophys. J. R. Astron. Soc*. 30, 109-185.

Nunes, J.C. and Ribeiro, E. (2001). Caracterizaçao da sismicidade instrumental dos Açores no periodo 1950-1980. *SISMICA, Encontro Nacional de Sismología e Enghenaria Sísmica, Açores*.

Searle, R. (1980). Tectonic pattern of the Azores spreading centre and triple junction. *Earth Plan. Sci. Lett*. 51, 415-434.

Udías, A. (1980). Seismic stresses in the region Azores-Spain-Western Mediterranean. *Rock Mechanics* 9, 75-84.