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SEISMICITY STUDIES OF THE AZORES ISLANDS - AN APPLICATION TO THE JULY 9, 1998 EARTHQUAKE

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SUMMARY

This paper presents a short review on some seismological aspects of the Azores Islands, exhibiting their important role on the global tectonic process. Special attention was devoted to the study of the July 9, 1998, which produce a MM intensity of VIII for the Faial Island and maximum MM intensities of VII for the Pico and S. Jorge Islands. Aftershock analysis is also presented in order to understand the source mechanism as well as the geodynamical evolution of the region. Seismic lineaments are identified, some of which correspond to already mapped geological faults, showing that the readjustment of the stress field was performed along pre-existent fractured zones. However, different observed lineaments, in the NNE-SSW direction, must be still confirmed with the further analysis of the aftershocks sequence. A preliminary seismic hazard estimation for the Azores Islands was performed, presenting a return period of 413 years for an earthquake with magnitude 7.0, and a return period of 27 years for an earthquake with magnitude 5.8. These return periods seem a little high, but improvement on the seismic hazard estimation could be performed only after the improvement of the seismic catalogue, in order to complete it for a larger period of time. Finally, this study shows the importance to pursue the implementation of geophysycal projects concerning, in particular, research on crust and upper mantle seismic models and on seismic hazard evaluation.

INTRODUCTION

The Azores archipelago, located near the triple junction between the North-American, the Eurasian and the African plates, in North Atlantic Ocean, present a high level of seismicity, long seismic swarms and volcanic activity. Morphologically it is mainly characterised by a shallow and irregularly shaped plateau, approximately 2000 m deep, broadening to the SE the Mid-Atlantic Ridge (MAR) axial zone. The topographic highs that reached the sea surface form three distinct group of islands: the Western Group, located west to the MAR (comprising Flores and Corvo Islands); the Central Group (Terceira, Graciosa, Faial, Pico and S. Jorge Islands) and the Eastern Group (S. Miguel and St. Maria Islands) follow the axis of the plateau approximately in the N110E direction (Krause and Watkins, 1970; Searle, 1980).

Since the fifteenth century, historical reports refer several destructive shocks and volcanic eruptions. Earthquakes such as of those of October 22, 1522, July 9, 1757 and January 1, 1980 resulted in dramatic number of causalities. The recent July 9, 1998 earthquake produced nine victims and hundreds of people remained homeless.

Due to its particular location and all the tectonic activity, the Azores Islands are an important natural field, in the globe, to be “explored” by geophysical studies. In particular, the studies on its seismicity will contribute for the definition of a geodynamical model for the region. Seismic hazard studies, as well as site effects estimations, could be very useful to be introduced in urban planning programs.

This paper presents a short review on some seismological aspects of the Azores Islands, performed following the 1998 earthquake. Special attention was devoted to the study of the July 9, 1998 aftershock sequence, taking into account the manifestations of the tectonic processes of the region. A preliminary seismic hazard estimation was

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also performed for the whole Archipelago. However, due to the amount of reliable data, the results must be carefully interpreted.

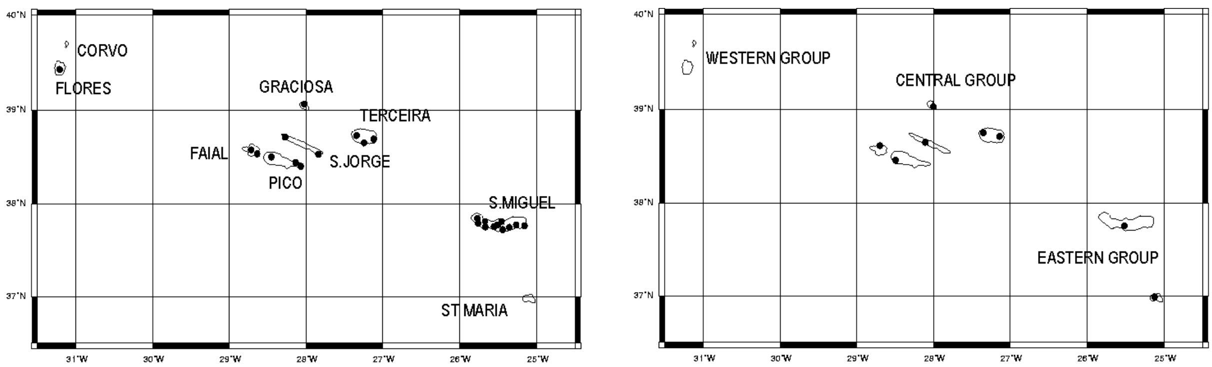
SEISMOLOGICAL HISTORY

Reports on seismic and volcanic events in the Azores Islands are available since the time of its discovery in 1427. Throughout the last five centuries several devastating seismic events occurred. One of the most important was the one on the October 22, 1522, felt in S. Miguel Island, which has destroyed Vila Franca do Campo, the capital by the time, and caused about 5,000 deaths. A second catastrophic earthquake occurred in 1757, it was felt in the central group if islands, and caused deaths to more than one fifth of the population in S. Jorge Island. This last event is considered to be the largest earthquake felt in the region (Nunes, 1999).

During this century, the largest event occurred on January 1, 1980 (with magnitude 7.2). It caused big damage in the Central Group, particularly at Angra do Heroísmo (Terceira Island) and caused a lot of victims.

Precisely due to the Azores Island’s seismicity, the first Portuguese seismological stations were installed there. In 1902, two seismic stations were installed in Horta and Ponta Delgada (Faial and S. Miguel Islands, respectively) and, in 1932, one was installed in Angra do Heroísmo (Terceira Island). These three stations composed the seismic monitoring network in Azores for several decades. When the 1980 earthquake took place only these three stations existed in the archipelago and, this catastrophe clearly showed the necessity of installing a modern monitoring network, which could allow more accurate studies on the seismicity of the region.

In the eighties an analogical network composed by 11 seismographic stations was installed in these islands. The majority of the stations were installed at the central group because it presented the highest level of seismicity. At the same time a seismic network of 16 stations was installed and it was explored independently during 10 years. In this decade these two networks began to be explored together, disposing the monitoring system of about 30 analogical stations (see figure 1a). In 1997, a digital network began to be installed and actually, the monitoring system includes also 12 digital seismic stations (Senos, 1998). Figure 1 presents the location of both analogical and digital seismic stations.



(A) (B)

Figure 1 – Azores seismic network: (A) analogical stations; (B) digital stations.

Figure 2a presents the seismicity of the Azores Islands, recorded between 1980 and 1997. It is possible to observe several clusters, which are associated with different seismic swarms. However, the concentration of events in and near S. Miguel Island must be interpreted carefully, due to the number of stations that exist in this island (information concerning the magnitude is not available for all the events but, with no doubt, they belong to differentiated magnitude ranges). The seismicity in Azores Islands is characterised by the occurrence of seismic swarms, associated with tectonic or volcanic activity. Besides the crises, the Azores Islands present a permanent small magnitude seismic activity.

Two types of seismic swarms were identified: *(i)* in the first one the activity is initiated by small magnitude events, increasing in number and magnitude during the crisis, and ending with a decrease in magnitude and number of events; *(ii)* in the second one, a mainshock occurred, followed by a sequence of a decreasing number of aftershocks (Senos, 1998). As an example of the first type swarms it is possible to refer the 1992 crisis, which occurred northwestern of Faial Island, during about 5 months, and in which the main shock occurred three months after its beginning, with hundreds of events already recorded (see figure 2b). For the second type, it is possible to refer the D. João de Castro Bank crisis, located between Terceira and S. Miguel Islands, which occurred during the second semester of 1997, recording 2400 events in the first month of the crisis. The main shock was a 5.0 magnitude event and, among the recorded events, more than 50 were felt earthquakes.

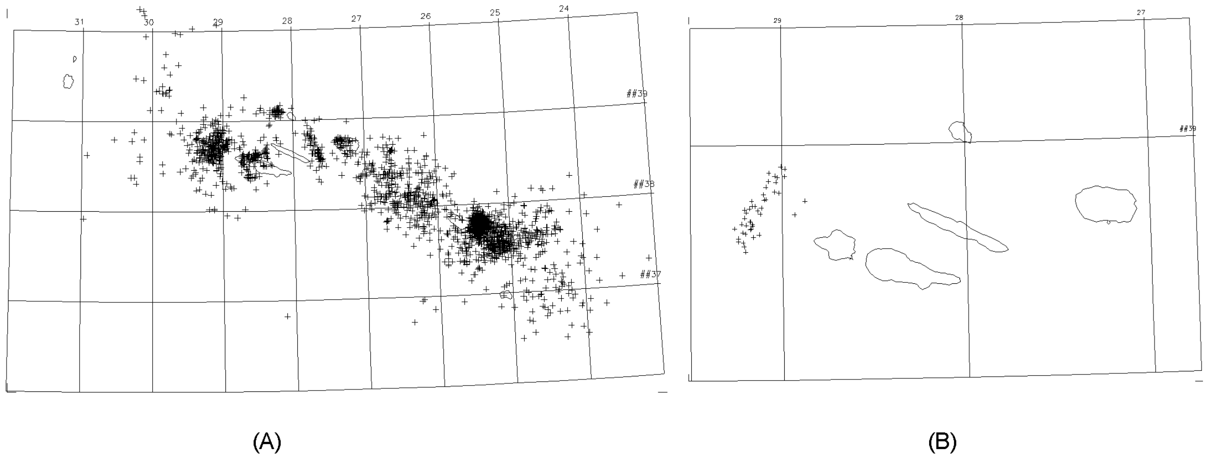


Figure 2 – (A) Instrumental seismicity of Azores Islands, recorded between 1980 and 1997. (B) 1992 crisis: events recorded between 92.11.26 and 92.12.15.

THE JULY 9, 1998 EARTHQUAKE

On July 9, 1998, at 05:19 am, a devastating earthquake occurred in Azores Islands which epicentre was located about 16 km N-NE from Horta (Faial Island). The assigned magnitude was 5.8. As the epicentre occurred in the vicinity of land, it produced a lot of damage in Faial and Pico Islands. Figure 3 presents the isosseismal curves for the Central Group (Senos et al., 1998).

The crisis initiated with this earthquake is still occurring. During the first year, about 12,000 events were recorded, from which 500 were felt. The number of events per day decreased quickly in the first week and afterwards in a slower way. However, during all the time, energy peaks were observed, due to a concentration of events or due to the occurrence of events with higher magnitude.

Due to the large amount of aftershocks, only a few were analysed in the beginning. The first events analysed were the felt ones and those presenting the soil velocity higher than a chosen level in a selected station. After, those events presenting different S-P interval, were also analysed (Senos et al., 1998). The remaining events are being analysed by several teams.

Figure 4a presents the located epicentres. As it is possible to observe, most of these events are located in the Faial-Pico Channel, almost oriented in a north-south direction. Other dominant direction is almost perpendicular to the first one, and is parallel to Pico and S. Jorge Islands. However, during the first 5 days, a different epicentral lineament was observed, in the NE-SW direction (figure 4b).

This crisis present no foreshock, with the probably exception of the 05:01 am event (with 3.3 magnitude). However, due to the seismicity pattern of the Azores Islands, it was not possible to consider it as a foreshock. Also, the analysis of the recent seismicity (figure 2a) did not show the existence of a seismic gap near the epicentre zone.

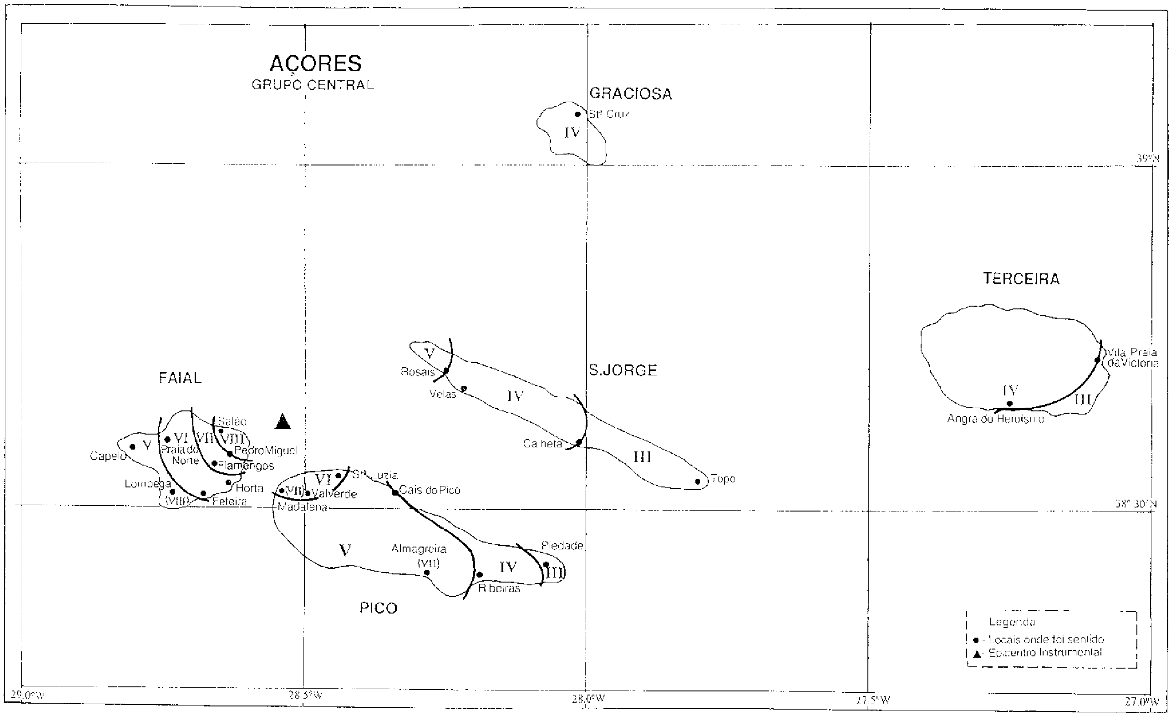
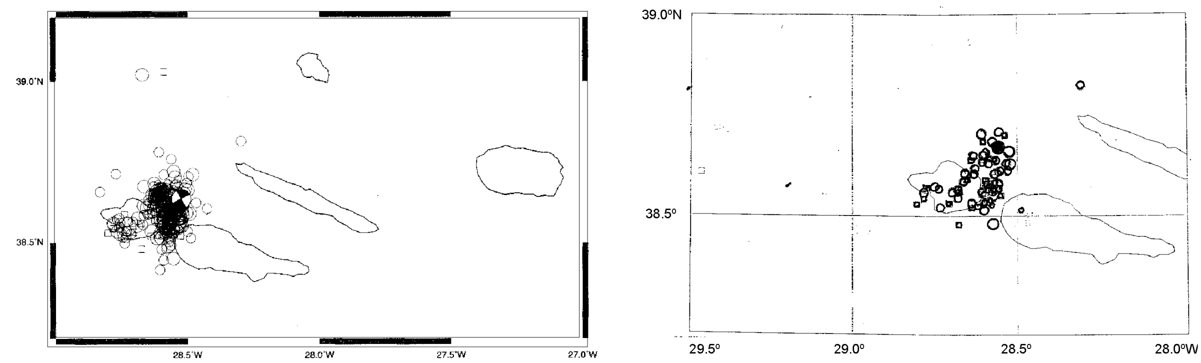


Figure 3 – Isosseismal curves of the July 9, 1998 earthquake (Central Group Islands). The black triangle presents the epicentral location (after Senos et al., 1998).



(A) (B)

Figure 4 – (A) Aftershocks of the July 9, 1998 earthquake, recorded between 1998.07.09 and 1998.07.31. The focal mechanism presented by Harvard (CMT) is also displayed. (B) Aftershocks analysed during the first 5 days.

SEISMIC HAZARD

Using the instrumental seismicity, a study on the regional seismic hazard of the Azores Islands was carried out. However due to the quality of the available data, the results must be carefully considered. Taking into account the seismic network evolution, reliable information on event magnitude is only available after 1980. Before 1980 events location (and magnitude estimation) was usually performed using the worldwide seismic stations and most of the located events were in the MAR. NEIC database (NEIC, 1990) includes only 505 located events between 1900 and 1990, from which only 147 has an assigned magnitude (between 1980 and 1990 there is 195 events from which 40 with assigned magnitude). Taking into account the actual seismicity, is easy to infer that the old catalogues are very incomplete.

It was decided to use the data of the Portuguese Institute of Meteorology, from 1980 to 1998. However, due to the improvement on the regional seismic network in the last decade, these data are necessarily heterogeneous and some previous analysis were performed. First, the events with no information about the magnitude were eliminated; second, the aftershocks were also eliminated; third, the Poissonian behaviour of the data was checked (Gardner and Knopoff, 1974). Finally, the Gutenberg-Richter parameters were estimated, using about 170 events, with magnitude greater than 3.1 and occurred between 1992 and 1998. Figure 5 displays the Gutenberg-Richter law, obtained with these data. This result was introduced in a seismic hazard program, in order to estimate the seismic hazard for the Azores region (Mortgat and Shah, 1979; Patwardhan et al, 1980). According to this procedure, the return period for an earthquake with magnitude 7.0 is 413 years, and the return period for an earthquake with magnitude 5.8 (the same as the July 9, 1998) is 27 years (Matias, 1999).

In order to detect possible seismicity rate changes, the cumulative number of earthquakes (M<3) from 1945 to 1997 is presented in figure 6. It is possible to observe in these figures that, prior to a seismic crisis, the seismicity rate seems to slightly decrease, closing to a horizontal line. However, due to the small time interval during which, this behaviour is observed, it is very difficult to predict a future crisis using this analysis.

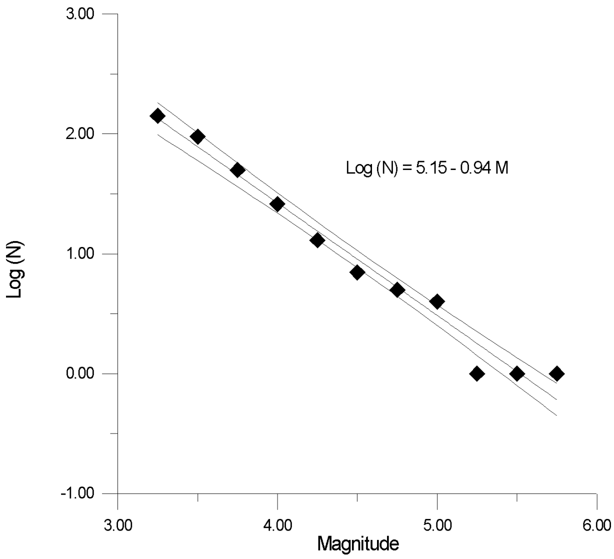


Figure 5 – Gutenber-Richter law for the whole Archipelago. The two external curves correspond the limits of the 90% confidence interval.

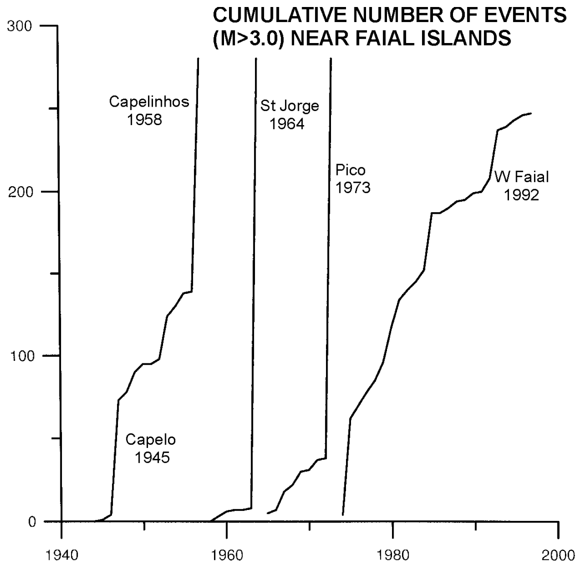


Figure 6 - Cumulative of events (M>3.0) for the Pico-Faial-S.Jorge region. The most important swarms are indicated.

DISCUSSION

The analysis of the aftershock sequence of the 9 July, 1998 earthquake produced some discussion between different authors. At the beginning the aftershocks seem to be oriented in NNE-SSW direction (fig 4b), defining a fracture zone with the same orientation than the one defined during the 1992 crisis (see figure 2b). However, the further analysis of the aftershock sequence put in evidence two main lineaments: one in the Pico-Faial channel in the NNW-SSE direction, and the other northern Faial and parallel to S.Jorge and Pico Islands with a WNW-ESE direction (see figure 2a). These two directions are in agreement with the two dominant fractures families presented in Faial (Madeira, 1998). However, some fractures directions presented in the tectonic map of Faial, could support the first observed lineament.

The seismic hazard estimation was almost performed as an "academic exercise". The time interval used (only 7 years) is very short to considered the obtained results as reliable. As referred by Mendes-Victor and Nunes (1986) and Oliveira et al. (1990), the seismicity pattern of the Azores Islands show a clearly space and time repetition (approximately 50 years). Oliveira et al. (1990) established 42 years as the minimum period of observation for a correct characterisation of the seismicity of this zone; shorter periods observation could underestimate the seismicity, if the sampling period coincide with a quiescent period, or could overestimate the seismicity, if the sampling period coincide with a high activity period.

Even so, it is possible to observe that the obtained return periods may be a little underestimated (in spite of the occurrence of the July 9, 1998 during the observation period), considering the actual knowledge of the seismic activity of the Azores region; however, the "real" values must be not very different from these ones. The b value seems to be low, due to the tectonic environment of the Azores Islands; Oliveira et al. (1990) found a b value of 1.39, for the whole archipelago, which seems more adequate.

However, to estimate the seismic hazard in a more correct approach, it is necessary to define the seismogenic zones and to determine the attenuation laws. But the hard work will be necessarily devoted to complete the seismic catalogue, in order to become it useful for seismic hazard evaluation.

CONCLUSIONS

This study presents a short review of some seismological aspects of the Azores Islands, exhibiting their important role on the global tectonic process.

The 9 July, 1998 event is included in a seismic crisis which follows one of the two typical crisis pattern usually occurred in the Azores. The aftershock analysis allowed the definition of seismic lineaments that confirm some geological fractures already mapped. The observed NNE-SSW lineaments must be confirmed with the analysis of the aftershock sequence. However, in order to locate with more accuracy the recorded events, the seismic crust and upper mantle model must be improved.

Improvement on the seismic hazard estimation could be performed only after the improvement of the seismic catalogue, in order to complete it for a larger period of time. Also, due to the seismicity characteristics of this zone, the numerical method used to estimate it, must be carefully chosen, as well as the definition of the seismogenic zones and the attenuation laws.

This study shows the necessity of pursue the implementation of geophysycal projects concerning, in particular, the research on crust and upper mantle seismic models definition and the seismic hazard evaluation.

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