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Improving the Seismic Hazard Evaluation of the Lisbon and Lower Tagus Valley Area

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SUMMARY

The Lisbon and surrounding area of the Lower Tagus Valley has experienced in the past the effects of several moderate sized earthquakes that caused significant damage and destruction. They have been attributed to local sources, though in some cases the source remains to be located. The lack of outcrops in the flat lying Quaternary terrains, the low slip-rates of the area in connection with sedimentation and erosion rates that erase surface ruptures are among the causes of a poor association between faults and seismicty, which has opened way to geophysical studies. Seismic, potential-field and seismicity data have been recently used to improve the seismic hazard evaluation of the area. In this work we complement these studies with DTM and PSInSAR data with the purpose of obtaining an accurate evaluation of the seismic hazard of the study area. The correlation of improved epicentre locations with major fault zones located from the above mentioned data shows that we have progressed in the understanding of the earthquake sources in the region. Some structures show no apparent relationship with present-day seismicity but some are known to be active into the Quaternary. Further geophysical and geological studies are required to understand the causes.

1. Introduction

The Lisbon and Lower Tagus Valley area (Fig. 1) has suffered the effect of moderate local earthquakes throughout its history, such as in 1344, 1531, 1909 that caused important damage (Moreira, 1985). Local seismicity has been recently considered of great importance (Vilanova and Fonseca, 2004; Peláez et al., 2002). However, instrumental seismicity and known geological faults match poorly and the sources of local historical earthquakes are still under debate (e.g. Stich et al., 2005).

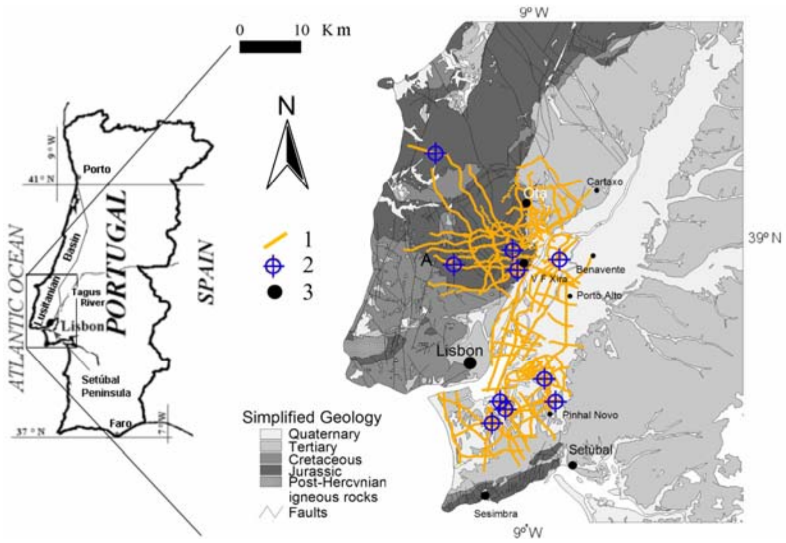

Fig. 1 – Location map and simplified geology of the study area (after Oliveira et al., 1992). 1-oil-industry seismic reflection profiles used for structural mapping of the basin; 2- deep wells; 3-localities discussed in the text.

Though some active faults are known in the area, like e.g. the Azambuja (AZF, Rasmussen et al., 1998; Cabral et al., 2003; 2004) and Pinhal Novo–Setúbal faults (PNSF; Ribeiro et al., 1990; Rasmussen, 1998; Cabral et al, 2003) and Montejunto thrust (MT, Cabral and Ribeiro, 1988; Curtis, 1999), the lack of outcrops in the flat lying Quaternary terrains, the low slip-rates of the area in connection with sedimentation and erosion rates that erase surface ruptures are one of the major causes of this poor association between faults and seismicty. The other important factor for this poor correlation between earthquakes and their sources are deficient hypocenters locations and a moderate seismicity. For this reason several very probably active faults have recently been known due to the use of geophysical data, like the Ota-V. F. Xira-Lisbon-Sesimbra fault (OVLS; Carvalho et al., *in press*) and the Porto Alto fault (PAF; Carvalho et al., 2006).

The integration of seismic, potential-field, seismicity and geological data have recently been used to locate possible earthquake sources and to estimate source parameters (Carvalho et al., 2006; 2007; *in press*). In this work, we complement this data with Digital Terrain Models (DTM) and Permanent Scatterers Interferometry Synthetic Aperture Radar (PSInSAR) data to improve our knowledge of the major geological structures of the study area.

2. Data set and methodology

2.1 Digital Terrain Models

A shaded relief map of the study area was used to correlate with other sources of data, since it is well known that geological structures often produce topographic features, some other topographic features can be attributed to differential erosion, transgressive/regressive episodes, hydrographical network and others. This product was obtained from a Digital Terrain Model (DTM), with a ground sample distance of 25m. The DTM was constructed using altimetry information from the national map M7810, at a 1:50 000 scale. The result is presented in Fig. 2, with major faults affecting the Upper Miocene (after Carvalho et al., 2007) overlaid.

2.2 PSInSAR Data

The Permanent Scatterers Interferometry (PSI) processing was done with the Stable Point Network software (SPN, Duro et al., 2005) in the scope of ESA-GMES Terrafirma Service,

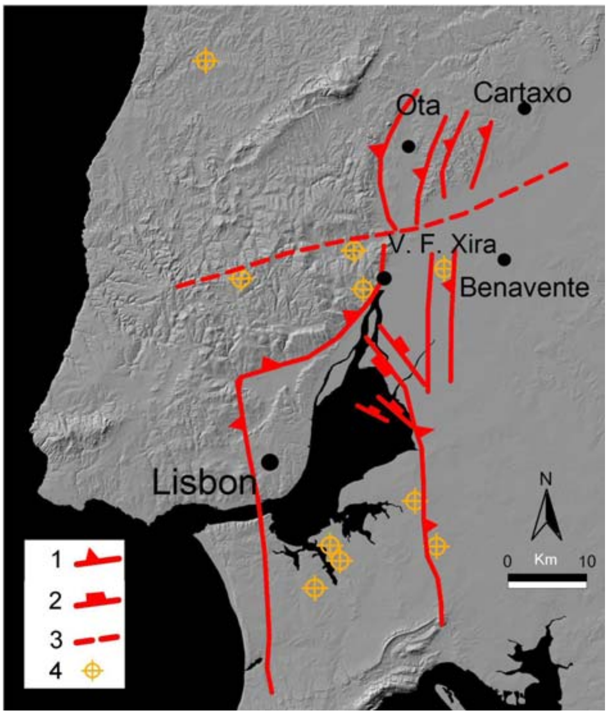

Fig. 2 – DTM model and major faults affecting the Upper Miocene (after Carvalho et al., 2007) in the study area. 1- reverse fault (marks on upper block); 2- normal fault (marks on lower block); 3- inferred fault; 4 oil wells.

spanning the period 1992-2006, were used from both ERS1/2 and ENVISAT satellites (orbital track 223, descending pass), resulting in two PSI maps, for the northern and southern regions of Greater Lisbon. The PSI maps give, for the spanned period, the mean velocity (in the line of sight of the satellite) for surface points behaving as stable radar phase scatterers in these areas. The North and South PSI maps, separated by the Tagus River, are independent from each other, in the sense that the velocities are given in relation to 2 distinct reference points. A subgroup of permanent scatterers with higher stability of phase (coherence >=0.5) was selected for kriging interpolation, resulting in two datasets of over 240.000 points in the North and over 100.000 points in the South. Ordinary kriging of the north points was performed with ArcGIS 9.2 geostatistical Analyst. The same software was used to apply universal kriging to the southern PSI map, accounting explicitly in this way for the NE-SW first order trend present in the data. The comparison, for all points, of the measured and model predicted values (cross-validation) gave root mean square estimation errors of 0.4 mm/year, for both datasets. Figure 3 shows non-krigged data with Upper Miocene faults (Carvalho et al., 2007) overlaid.

2.3 Integrated interpretation

The above data sets (DTM and PSInSAR) were overlaid with the results of the integrated interpretation of seismic reflection, aeromagnetic, gravimetric, geological and seismicity data (Carvalho et al; 2006; 2007; *in press*). All data sets were geo-referenced and integrated in a GIS environment to allow the analysis and correlation between the different sources of informations. From this work resulted a more accurate location of the faults were no seismic data was available and they had been deduced from potential-field data (see Fig 1 for available

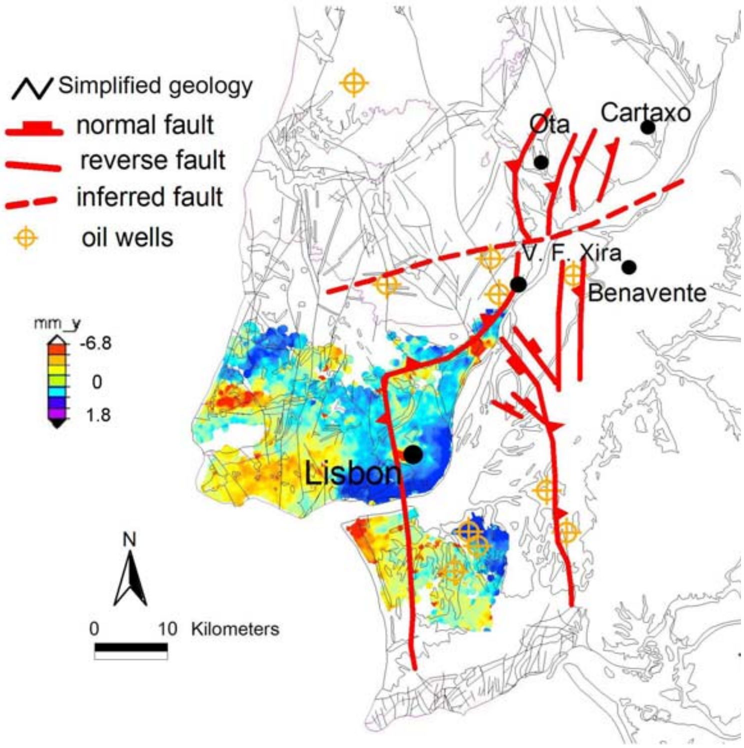

Fig. 3 – PSInSAR krigged map overlaid with the same fault interpretation affecting the approximate top of Upper Miocene (see legend of Fig. 2) and simplified geology also shown in Fig. 1.

seismic reflection profiles location). We also used geological data published by other authors (e.g. Cabral and Ribeiro, 1988; Curtis, 1999; Cabral et al., 2003) to produce a map of active faults in the study area, which is presented in Figure 4.

In this figure we also present the seismicity from the period 1970-2000 (Carrilho et al., 2004). The events were relocated using updated software and velocity models (Carvalho et al., in press). All epicentre errors are below 8 km, while the average error is about 5 km (id.).

3. Results and discussion

From the observation of Figure 4 we can conclude that many major geological structures resulting from this and previous studies can be associated with the instrumental seismicity. Though the horizontal error margins of epicentre locations prevent the association between seismic events and a particular fault, a relationship with major faults systems is evident. This is the case for a few known active faults: MT and OVLSF. The latter controls the earthquake distribution in the study area. Carvalho et al. (*in press*) have shown that most seismicity around V.F. Xira is associated with this large crustal structure at depth.
The E-W trending probable fault named A in Fig. 4 (in Carvalho et al., *in press*) deduced from geological evidences has signature on the PSInSAR and DTM data and can be associated with some earthquakes. The fault zone named B was unknown until this study. Its correlation between PSInSAR and DTM data is very clear. It cannot be correlated with any litholo-stratigraphic contrast but its course is accompanied by several small magmatic outcrops, which might be indicative of a fault at depth. The fact that is has several earthquakes associated along its course suggests it is an active fault.
However, other faults known to be active into the Quaternary show no seismicty associated. Among these are: the AZF, the PNSF and PAF. The Azambuja fault zone southward prolongation across the River Tagus (fault C), proposed by Rasmussen (1998) also shows no associated seismicity in the studied period.

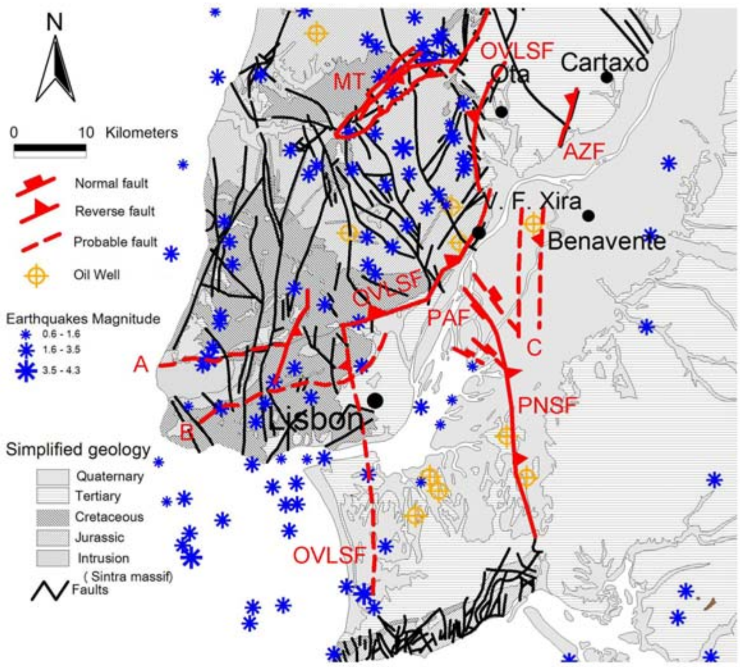

Fig. 4– Map of active faults based on PSInSAR, DTM, seismic reflection, potential-field, geological outcrop and well data and simplified geology also shown in Fig. 1 & 3. The seismicity for the period 1970-2000 is also plotted by magnitude. OVLSF: Ota-V.F.Xira-Lisbon-Sesimbra fault; AZF: Azambuja fault; MT: Montejunto thrust; PAF: Porto Alto fault; PNSF- Pinhal Novo-Setúbal fault; A, B, C- see text.

4. Conclusions

Integrated interpretation of seismic reflection, potential-field, DTM, PSInSAR, geological outcrop and well data have allowed an identification of major active fault zones in the study area, some of them were until very recently unknown. However, some local strong subsidence areas in PSInSAR data remain to be explained.
A more detailed analysis of the present data, in particular DTM and PSInSAR, together with the interpretation of recently available reprocessed oil-industry seismic reflection data, complemented with existent potential-filed data, will certainly identify and locate more hidden geological structures. Acquisition of shallow geophysical data and trench opening will confirm if these faults are

active into the Quaternary. Together with the determination of the faults segments length and vertical offsets this data will allow estimating return periods, maximum expected magnitude and contribute to improve the seismic hazard of the area.

The correlation of improved epicentre locations with major fault zones located as explained above shows that we have progressed in the understanding of the earthquake sources in the region. However, some structures show no apparent relationship with present-day seismicity. Some of these are known to be active into the Quaternary from geological outcrop studies. More geophysical and geological studies are required to determine whether these faults are aseismic or we are presently facing a period of seismic quiescence in these structures or their rate of deformation is too low for the seismicity period studied.

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