P45

Looking for Earthquake Sources in the Lisbon Area

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SUMMARY

The Lisbon and surrounding areas have suffered the effect of historical earthquakes that caused important damages and loss of lives. Some of these earthquake sources are local but they are still poorly known. The knowledge of these sources is important for seismic hazard studies. The use of geophysical methods in the area is required due to the difficulty in finding geological outcrops, together with low-slip rates and erosion/sedimentation processes that erase surface ruptures. Furthermore, most of earthquake occurs at great depth, emphasizing the need for the application of the latter methods. In this paper we present a revised structural interpretation of the area using newly reprocessed and reinterpreted seismic reflection and potential-field data, relocated epicentres, geological outcrop and well data. This interpretation differs in some aspects from previous ones. Well known active faults zones like the Azambuja fault and the Pinhal Novo-Setúbal fault have new interpretations, while other previously unknown structures, like the Ota-V. F. de Xira-Lisbon-Sesimbra fault zone, for example, have been interpreted. These studies, together with shallow geophysical data, which has been and will be acquired over selected targets from this work, will constitute an improvement to the seismic hazard evaluation of the area.

1. Introduction

The Lisbon area has suffered the effect of large and moderate earthquakes throughout its history, such as in 1344, 1531, 1755, 1909 and 1969 (Moreira, 1985). Besides offshore sources connected to the Eurasia-Africa plate boundary such as in the 1755 Lisbon earthquake and in 1969, local seismicity has been responsible for moderate earthquakes that caused important damage such as in 1531 and 1909 (Moreira, id.). Local seismicity has been recently considered of great importance (Vilanova and Fonseca, 2004; Peláez et al., 2002). However, the sources of local historical earthquakes are still under debate (e.g. Stich et al., 2005). Instrumental seismicity and known geological faults also match poorly.

Though some active faults are known in the area, like the Azambuja and Pinhal Novo faults (Cabral et al., 2003), 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 (OVFXLS; Carvalho et al., 2006b) and the Porto Alto fault (Carvalho et al., 2006a). 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 this poor association between faults and seismicty. On the other hand, deficient hypocenters locations and a moderate seismicity do not allow a clear relationship between earthquakes and their sources.

For the above reasons, available geophysical data and geological data have been used to locate possible earthquake sources. This information has been (Carvalho et al., 2006a; b) and will continue to be complemented with near surface data to confirm if faults are active and to estimate source parameters. Considering that most of the earthquakes are generated at crustal depths, the study of those structures at depth is of great importance.

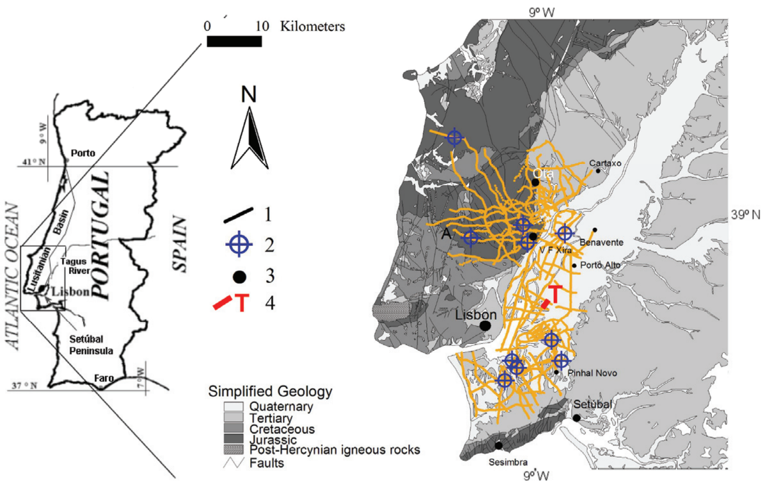

Fig. 1 – Location map and simplified geology of the study area. 1-oil-industry seismic reflection profiles used for structural mapping of the basin; 2- deep wells; 3-localities discussed in the text; 4-part of profile T17, shown in Fig.2.

Data from seismic reflection, potential-field, well, geological outcrop and seismicity are used in this paper to improve our knowledge on several recently known geological structures based on seismic reflection data. These are the Porto Alto fault (Carvalho et al., 2006a), the Pinhal Novo fault (Rasmussen et al., 1998; Cabral et al., 2003; Kullberg, 2000) and Azambuja fault (Rasmussen et al., 1998; Cabral et al., 2004). Except for the papers from Carvalho et al. (2006a; b), the previous work was based on paper stacked sections. Here, we present recently reprocessed and reinterpreted digital seismic reflection data, well, geological outcrop, reinterpreted magnetic and gravimetric data, together with relocated hypocenter data to present new enlightenments in the study area major tectonic structures.

2. Data sets

2.1 Seismic reflection

Several thousands kilometres of seismic reflection profiles have been acquired fot the oil-industry in the study area from the midst 1950's till 1981. Studies of part of these data have been realised with paper migrated stacked sections (Rasmussen, 1998; Kullberg, 2000; Cabral et al., 2003). Reprocessing and reinterpretation of several thousand kilometres of these profiles in digital format has been carried out (Carvalho et al., 2006a; b).

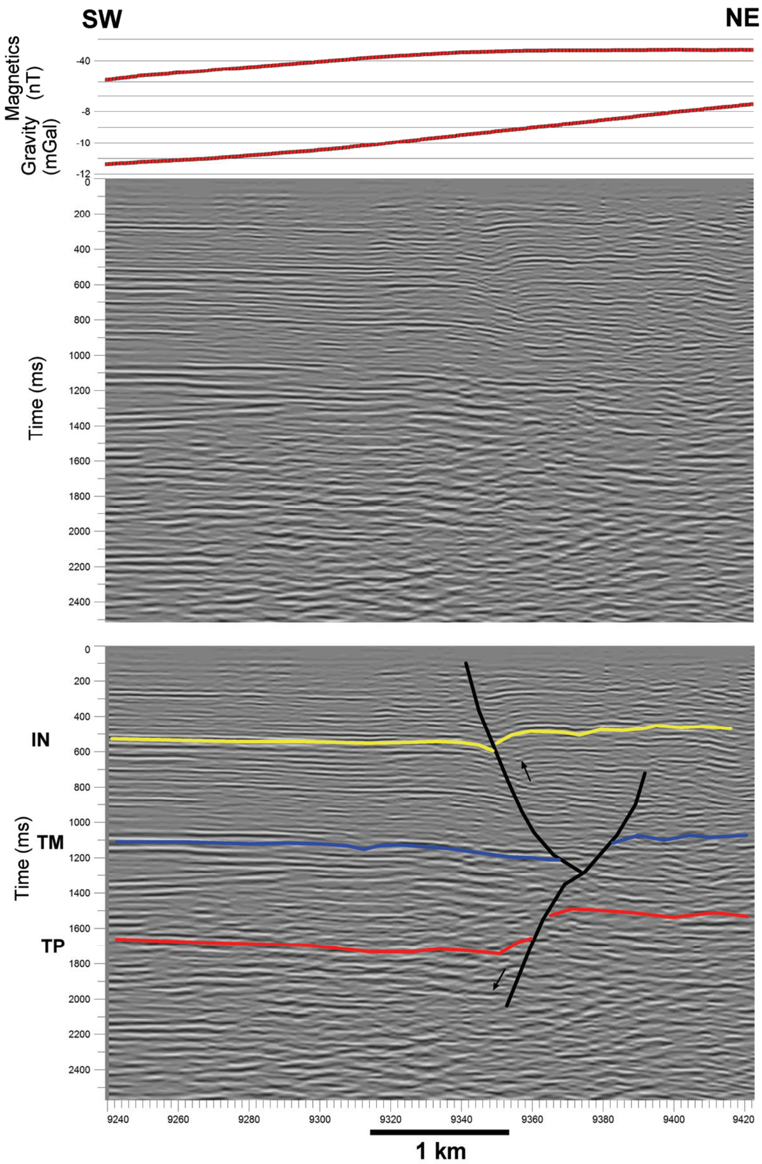

Fig. 2 – Migrated stack showing the Pinhal Novo-Setúbal fault zone in its central sector, where transition from reverse to normal geometry is occurring. Top: raw section with gravimetric and magnetic anomalies plotted. Bottom: interpreted section. IN- intra-Neogene horizon; TM- top of Mesozoic; TP- top of Paleozoic..

For this study, we have added about 1 000 kilometres of profiles in the southern margin of the Tagus River (Fig. 1). The data have been reprocessed by different companies and by the authors. In this interpretation, several wells were used (Fig. 1) to tie the seismic horizons to the geological formations while aeromagnetic and gravimetric data were used for picking the basement (top of Paleozoic) and locate salt and igneous structures (Fig. 2).

2.2 Potential-field

Besides its utility in interpreting seismic data, potential-field data were also reinterpreted to provide independent information and also to cover areas where no seismic information is available. An aeromagnetic survey flown in 1969 at a flight altitude of 0.6 km and with a 2km north-south flight line spacing was reprocessed (Carvalho et al., 1995). Gravimetric data from different surveys were compiled, homogenised and a Bouguer anomaly map computed (Torres, *in press*), from which a second degree polynomial was extracted.

Both sets of data were interpreted using trend, 2D Euler deconvolution, analytical signal and 2.5D modelling techniques. The modelling was performed for each data set and was calibrated using geological outcrop and, where available, well and seismic reflection data.

2.3 Epicentre relocation

Events from the period 1970-2000 were relocated using updated software and velocity models (Carrilho et al., 2004). All epicentre errors are below 8 km, while the average error is about 5 km. These error margins prevent the association between seismic events and a particular fault but the relationship with major faults systems is possible. Concerning hypocenters, the depth errors are larger due to the lack of an adequate azimuthal coverage and accurate regional velocity models. The location of faults at crustal depths is therefore not possible from seismicity studies.

3. Results and discussion

A map with the geological structures affecting the Neogene is presented in Fig. 3. This map shows some new aspects of some already known geological structures: i) the Azambuja fault (Rasmussen et al., 1998; Cabral et al., 2003); the Pinhal Novo-Setúbal fault (Ribeiro et al., 1990; Rasmussen, 1998; Kullberg, 2000; Cabral et al, 2003). Our interpretation, using the above geophysical data, shows that the Pinhal Novo-Setúbal fault zone has a clear gravimetric signature along its full length and in the southernmost sector it also has magnetic signature. In this area, seismic data shows the structure is a major reverse fault zone associated with salt movements and, as it continues northwest, gradually changes to a normal geometry, with a strike-slip component. This interpretation differs from previous ones of Ribeiro et al. (1990), Fonseca and Long (1991, *in* Vilanova and Fonseca, 2004), Kullberg (2000) and is similar to the interpretation of Cabral et al. (2003), who have only analysed part of the fault's trace.

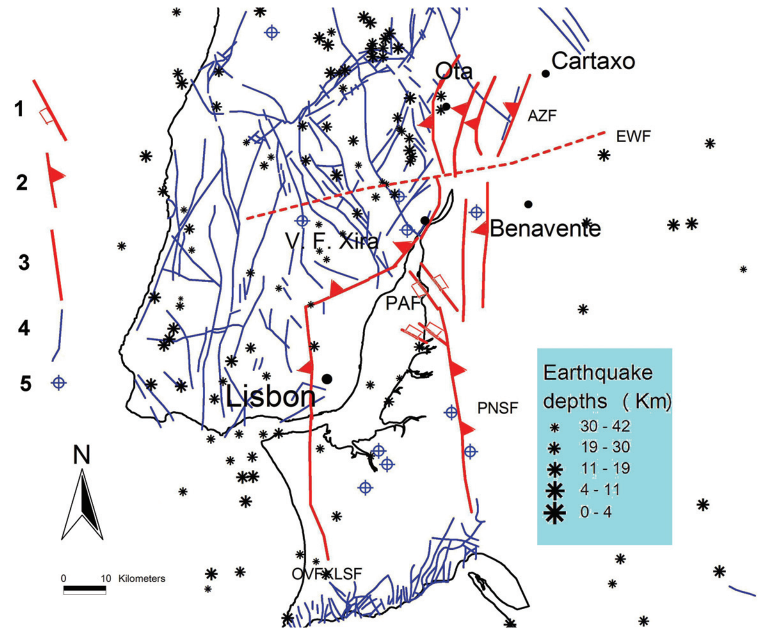

Fig. 3 – Final map with fault interpretation affecting an intra-Neogene horizon (approximate top of Upper Miocene). 1- normal fault (marks on lower block); 2- reverse fault (marks on upper block); 3- strike-slip or unknown movement fault. PNSF-Pinhal Novo-Setúbal fault; AZF-Azambuja fault; PAF- Porto Alto fault; OVFXLS- Ota-V.F. Xira-Lisbon-Sesimbra fault; EWF- E-W postulated fault (see text); 4- outcropping faults (after Oliveira et al., 1992); 5- wells.

The Azambuja fault zone southward extension across the River Tagus, proposed by Rasmussen (1998) has also been interpreted differently by the authors. In our interpretation, the prolongation southwards of the Tagus River is in fact another structure with similar geometry but very distinct in their geological setting. North of the Tagus River, the western side of the fault is marked by a reduced Cenozoic thickness with a significant increase in thickness across the fault. South of the River, the Cenozoic thickness of sediments on both sides of the faults is similar and the style of deformation, while still reverse, is different. The very different depths of the base of the Cenozoic on both sides of the Tagus suggest that the two structures are offset by a predominantly W-E fault system.

No seismicity is associated with both structures during the period covered by the catalogue (1970-2000). The OVFXLS fault zone controls earthquake distribution in the study area.

4. Conclusions

The Pinhal Novo-Setúbal fault was a major extensional fault zone during the Mesozoic though it did not constitute the eastern the limit of Lusitanian Mesozoic Basin. During the Cenozoic it has suffered positive reactivation in its southern sector and very probably this reactivation is propagating towards the northwest. Its northern sector still presents normal geometry (Porto Alto fault zone). The Azambuja fault does not propagate southwards across the River Tagus as some authors have hypothesized. South of the River, another approximate N-S trending thrust fault (slightly to the E of Benavente) presents different seismic characteristics and appears to be an independent structure. Due to the difference in depth of the base of the Cenozoic in the western block of both faults, we suggest an E-W fault zone to separate the two structures. Both structures have been active during the Quaternary and therefore, the faults total length has important implications for seismic hazard studies. Together with the acquisition of shallow geophysical data in a near future, which will help to determine fault parameters like vertical offsets, this data will allow to estimate return periods and contribute to improve the seismic hazard of the area.

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