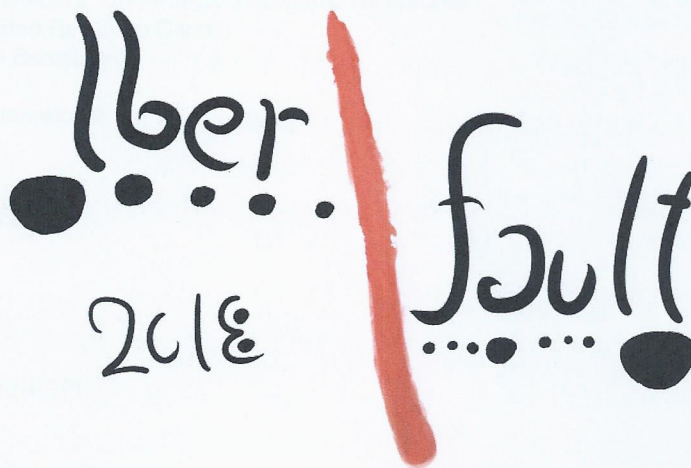


**AVANCES EN EL ESTUDIO DE FALLAS ACTIVAS,
TERREMOTOS Y PELIGROSIDAD SÍSMICA DE IBERIA**



Alicante · 11 al 13 de junio de 2018

**III Reunión Ibérica sobre Fallas Activas y Paleosismología
VOLUMEN DE RESÚMENES**

editora

Carolina Canora Catalán

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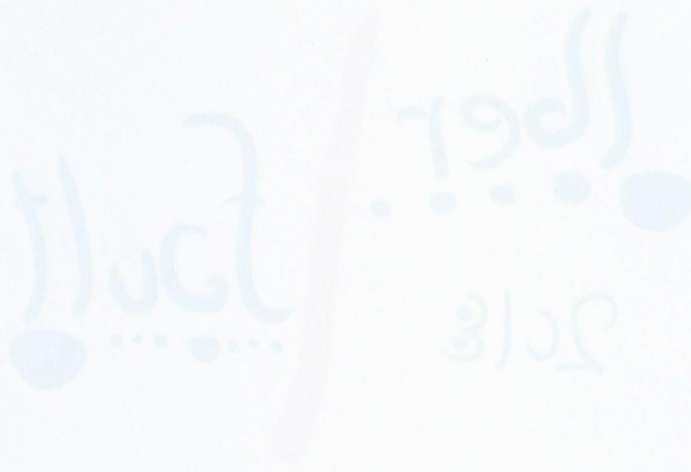
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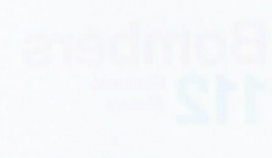
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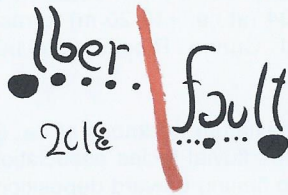
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Faulted Middle Pleistocene fluvial terrace deposits at Leiria, central Portugal

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Abstract: *Folded and faulted Middle Pleistocene terrace deposits of the Rio Lis were identified at Capuchos-Quinta de Santa Clara site, located in the city of Leiria (central-western region of mainland Portugal). These deformed sediments present a relevant assemblage of Acheulean lithic industry making them an unequivocal marker of neotectonic deformation. A detailed study of the brittle and ductile structures revealed a strong relationship with two major regional seismogenic faults that cross the site and also with the diapiric structure of Leiria. The age, intensity, and location, of this tectonic deformation is particularly relevant because it may potentially increase the seismic hazard for Leiria region.*

Key words: *Active Faults, Diapir, Fluvial Terrace, Acheulean*

Introduction

Intensely faulted and folded Middle Pleistocene terrace deposits of the Rio Lis were identified at Quinta de Santa Clara, in the city of Leiria (central-western region of mainland Portugal). These deformed sediments were exposed during the execution of new road works (“Variante dos Capuchos”) and presented a relevant content of an Acheulean lithic assemblage. Because of the ephemeral nature of the outcrops, a rescue archaeological excavation was carried out as well as a detailed study of the brittle and ductile structures affecting these fluvial deposits. These deformed sediments are located at a diapiric structure developed on ductile Upper Triassic-Lower Jurassic marls and silty clays, which may induce aseismic creep. The age, intensity and location of this tectonic deformation is particularly relevant because it potentially increases the regional seismic hazard, depending on whether the studied deformation is aseismic or related with major regional seismogenic faults that cross the site. If so, it significantly impacts the seismic risk assessment of Leiria city, with its 127,000 inhabitants.

Regional geological setting

The Leiria region is located in the Lusitanian Basin (LB), on the Western Iberian Atlantic Margin. This basin evolved under a predominately E-W extensional regime (Late Triassic to Early Cretaceous) by continental lithosphere thinning of the Variscan basement. The main extensional structures were controlled by pre-existent late-Variscan fault zones (NNE-SSW and NNW-SSE trending wrench faults), being reactivated as normal faults. Of particular relevance for the present work is the NE-SW trending Pombal – Leiria – Caldas da Rainha fault (PLCF), which worked as a major transfer zone

during the Mesozoic extensional regime, separating the LB northern sector from the LB central sector (e.g. Alves et al. 2003; Carvalho et al. 2005) (Fig. 1).

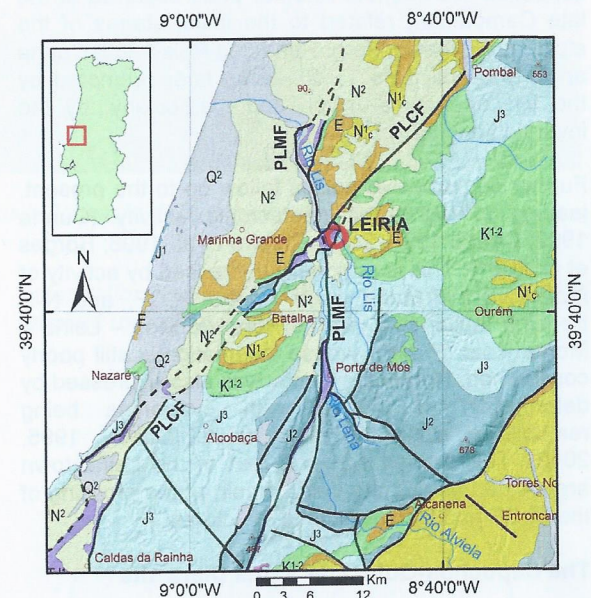


Figure 1: Geologic map of Leiria region (adapted from Carta Geológica de Portugal à escala 1:1 000 000, edição 2010, LNEG-LGM). J1, J2 – Jurassic; K1-2 – Cretaceous; E – Eocene; N1c, N2 – Neogene; Q2 – Quaternary. PLCF – Pombal – Leiria – Caldas da Rainha Fault; PLMF – Porto de Mós – Leiria – Monte Real Fault. Red Circle: city of Leiria

Since the middle Campanian (Late Cretaceous) there was a significant change in the interaction between adjacent lithosphere plates, with the onset of Eurasia-Nubia convergence in a roughly N-S direction leading to the development of the circum-Mediterranean Alpine Belt. In Iberia, the Alpine

orogeny is marked by a dominant compressive regime with the maximum compressive stress rotating from an approximately N-S direction, during Late Campanian to early Tortonian times, to a NW-SE direction after the middle Tortonian (e.g. Ribeiro et al. 1990; Srivastava et al. 1990; Cloetingh et al. 2002; De Vicente and Vegas 2009; De Vicente et al. 2011). The compressive stresses acted upon cratonic Iberia causing positive inversion of the Mesozoic rifted basins. In the LB, the NW-SE Miocene compression took place with particular intensity, leading to the tectonic inversion of previous extensional structures. (Ribeiro et al. 1990; Rasmussen et al. 1998). Some newly created thrusts were formed, trending ENE-WSW to NE-SW, sometimes cross cutting earlier faults, as it happened with the NW verging inverse reactivation of the PLCF (Ribeiro et al. 1990; Rasmussen et al. 1998).

In the LB, several salt diapirs occur associated with the lateral migration and rising of the Dagorda Formation (Upper Triassic to Hettangian), predominately composed of evaporite deposits (marls and silty clays). The diapiric structures exhibit different geometries, from simple salt pillows and anticlines to extruded diapirs, generally located over major fault zones of the Mesozoic extensional structuring. The relationship between salt tectonics and fault activity was already recognized by Zbyszewski (1959) and later confirmed in regional seismic reflection profiles acquired for oil exploration (e.g. Rasmussen et al. 1998). Halokinesis has started in the Early Jurassic, with a peak in the Late Jurassic – Early Cretaceous, associated with fault-controlled subsidence. Another peak occurred at the late Campanian, related to the initial stages of the alpine compression (e.g. Pena dos Reis 1983; Cunha and Pena dos Reis 1995), being later promoted by the Miocene compression and, particularly, by the inversion tectonics.

Further compressive pulses follow up to the present, leading to significant neotectonic activity (Cunha 1992; Cabral 1995, 2012; Ribeiro et al. 1996; Borges et al. 2001). This is regionally expressed by activity of major NE-SW faults, such as the PLCF, and N-S trending faults, such as the Porto de Mós – Leiria – Monte Real (PLMF), whose kinematics is still poorly constrained. Neotectonic activity is also expressed by deformation of diapirs, with evaporites being remobilized along the major faults (Cabral, 1995, 2012). The studied site and part of the Leiria town are located astride the Leiria diapir, at the crossing of the PLCF and PMLF tectonic structures.

The Capuchos-Quinta de Santa Clara site

The Capuchos-Quinta de Santa Clara site is located in Leiria, on the left bank of the Rio Lis (N39°44'41.7"; W008°49'007", WGS84) and comprises several outcrops of Middle Pleistocene fluvial terrace deposits and Upper Triassic to Hettangian marls (Dagorda Formation - DF). The terrace surface is located ca. 25-30 m above the modern river bed which is here at an elevation of ca. 27 m. According to the local 1/50 000 geological map (Teixeira et al. 1968) these fluvial deposits belong to

a Pleistocene Q3 terrace (+30-45 m) in between Q2 (at ca. +60-75 m) and Q4 (at ca. +10-20 m) terraces (see also, Texier and Cunha Ribeiro, 1991/92, Ramos, 2008).

The Q3 terrace has a maximum thickness of ca. 6.5 m at the site. It comprises fluvial facies associations that are organized in two fining upward depositional sequences, corresponding to channel infills. The lower one (1.5 m thick) comprises a basal gravel bed (ca. 0,2 m thick) and upper coarse sands showing through crossbed lamination. The upper sequence is 4.7 m thick and comprises a basal bed of gravel (up to 0,6 m thick; clasts up to 30 cm in size; quartzite – 90%, quartz – 10%) and an upper bed of brown reddish medium sand with a local intercalation of brown silt.

These fluvial deposits unconformably overlie massive reddish to dark-grey clayey marls of the Dagorda Formation, related to the Leiria diapir. In the basal gravel bed and in interbedded pebbly layers (mostly of the lower depositional sequence) it was collected an abundant lithic assemblage, mainly made in quartzite cobbles. This assemblage is composed mainly of large and small cores, some of the latest with centripetal technique, and a few large cutting tools. Among these tools were identified several pics, handaxes and bifaces, in general with the edges rounded and sometimes with a very balanced volumetric configuration. Such characteristics suggest the correlation of these lithic assemblage with the older Acheulean industry, also present in the base of correlative sedimentary formations known nearby (Texier and Cunha Ribeiro, 1991/92) (Fig. 2).



Figure 2: Some large cutting tools collected during the archaeological work carried out in the Capuchos-Quinta de Santa Clara site. Scale in centimeters.



Figure 3: Severely deformed (faulted and folded) Middle Pleistocene fluvial deposits overlying unconformably massive reddish to dark-grey clayey marls of the Dagorda Formation (Upper Triassic to Hettangian) related to the Leiria Diapir, at Capuchos-Quinta de Santa Clara site.



Figure 4: Reverse fault in Middle Pleistocene fluvial deposits that roots in Formação da Dagorda marls, at the same site.

In order to better constrain the age of the fluvial deposits and of the observed deformation, samples have been collected for absolute dating, namely by OSL (samples of coarse sands under measurement by the Nordic Laboratory for Luminescence Dating) and CRN (quartzite cobbles from a gravel level, not yet processed).

The local Quaternary deformation and seismotectonic implications

The fluvial deposits are intensely deformed, showing several faulted contacts with the Jurassic bedrock and an irregular folded pattern on top of buckled DF marls, which behave as highly ductile material under low strain rates (Fig. 3 and 4). Folding is evidenced by the tilting and warping of the fluvial sediments, that reach high dips (Fig. 3, white arrow), and, together with the effect of faulting, by the varying height at which the terrace basal surface occurs.

Faulting may be explained as a shortening mechanism associated to the buckling of the DF marls inside the Leiria diapir, with aseismic creep on superficial faults, and/or may represent brittle

deformation episodes at high strain rates, possibly induced (or transmitted) by faulting at depth.

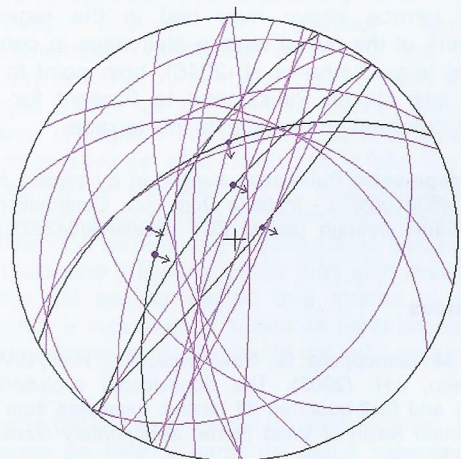


Figure 5: Stereographic projection (lower hemisphere) of measured fault planes (20) and striated slickensides (5), totaling 25 measurements.

The length of both regional faults that may be correlated with the studied local deformation, over several tens of kilometers long, implies a potential for generating Mw >6.5 earthquakes, representing a significant regional seismic hazard, particularly to the city of Leiria. Further active tectonics research around the studied site is thus considered very important for the characterization of the regional seismic risk.

The identified faulting of the fluvial sediments may in fact be the surface rupture expression of a deeply rooted major fault at the regional scale, with two potential candidates, namely the NE-SW trending Pombal – Leiria – Caldas da Rainha fault (PLCF) and the N-S trending Porto de Mós – Leiria – Monte Real fault (PLMF), which cross each other at the Leiria diapir and near the Quinta de Santa Clara site (Fig. 1).

The observed faults comprise high dipping faults showing vertical offsets, and lower dipping faults evidencing reverse movement component. The orientation of the measured fault surfaces shows significant dispersion (Fig. 5), although with a preferential NNE trend which is more compatible with the PLC fault. The few striated slickensides that were measured all show high pitch striae supporting a predominance of dip slip movement component, although mismatch of sediments facies across faulted contacts also suggests significant strike-slip in some of these.

Conclusions

The studied faulting may be explained as a local, superficial shortening mechanism after the amplification and verticalization of fold limbs inhibit further ductile deformation, and/or may represent brittle deformation episodes at high strain rates, possibly induced (or transmitted) by faulting at depth. It is interpreted a compressive regime with the maximum compressive stress in an approximately NW-SE direction.

Considering that the deformed fluvial deposits contain an Acheulean industry that has been dated as ca. 340 to 200 ka in other Portuguese sites (e.g. Cunha et al. 2017), as well as the height of the studied terrace above river bed in the regional framework of the fluvial terrace staircases in central Portugal (e.g. Cunha et al. 2016), both point to an age of late Middle Pleistocene to Present for the tectonic deformation that affects this terrace.

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References

- Alves, T.M., Manuppella, G., Gawthorpe, R.L., Hunt, D.W. & Monteiro, J.H. (2003). The depositional evolution of diapir- and fault-bounded rift basins: examples from the Lusitanian Basin of West Iberia. *Sedimentary Geology*, 162, 273-303.
- Borges, J.F., Fitas, A.J.S., Bezzeghoud, M. & Teves-Costa, P. (2001). Seismotectonics of Portugal and its adjacent Atlantic area. *Tectonophysics*, 337, 373-387.
- Cabral, J. (1995). Neotectónica em Portugal Continental. *Memórias do Instituto Geológico e Mineiro*, 31, 265 pp.
- Cabral, J. (2012). Neotectonics of mainland Portugal: state of the art and future perspectives. *Journal of Iberian Geology*, 38 (1), 71-74.
- Carvalho, J., Matias, H., Torres, L., Manuppella, G., Pereira, R. & Mendes-Victor, L. (2005). The structural and sedimentary evolution of the Arruda and Lower Tagus sub-basins, Portugal. *Marine and Petroleum Geology*, 22, 427-453.
- Carta Geológica de Portugal à escala 1:1 000 000, edição 2010, LNEG-LGM, Lisboa. ISBN: 978-989-675-005-3
- Cloetingh, S., Burov, E., Beekman, F., Andeweg, B., Adriessen, P.A.M., García-Castellanos, D., De Vicente, G. & Vegas, R. (2002). Lithospheric folding in Iberia. *Tectonics*, 21, 1041-1067.
- Cunha, P.P. (1992). *Estratigrafia e sedimentologia dos depósitos do Cretácico Superior e Terciário de Portugal Central, a leste de Coimbra*. Ph.D. Thesis, Univ. Coimbra, 262 pp.
- Cunha, P.P. & Pena dos Reis, R. (1995). Cretaceous sedimentary and tectonic evolution of the northern sector of the Lusitanian Basin. *Cretaceous Research*, 16, 155-170.
- Cunha, P.P., Martins, A.A. & Gouveia, M.P. (2016). As escadarias de terraços do Ródão à Chamusca (Baixo Tejo) – caracterização e interpretação de dados sedimentares, tectónicos, climáticos e do Paleolítico. *Estudos do Quaternário*, 14, 1-24.
- Cunha, P.P., Martins, A.A., Buylaert, J.-P., Murray, A.S., Raposo, L., Mozzi, P. & Stokes, M. (2017). New data on the chronology of the Vale do Forno sedimentary sequence (Lower Tejo River terrace staircase) and its relevance as a fluvial archive of the Middle Pleistocene in western Iberia. *Quaternary Science Reviews*, 166, 204-226.
- De Vicente, G. & Vegas, R. (2009). Large-scale distributed deformation controlled topography along the western Africa–Eurasia limit: tectonic constraints. *Tectonophysics*, 474, 124-143.
- De Vicente, G., Cloetingh, S., Van Wees, J.D. & Cunha, P.P. (2011). Tectonic classification of Cenozoic Iberian foreland basins. *Tectonophysics*, 502, 1-2, 38-61.
- Ribeiro, A., Cabral, J.; Baptista, R.; Matias, L. (1996). Stress pattern in Portugal mainland and the adjacent Atlantic region, West Iberia. *Tectonics*, 15, (2), 641-659.
- Pena dos Reis, R. (1983). *A sedimentologia de depósitos continentais. Dois exemplos do Cretácico Superior - Miocénico de Portugal*. Ph.D. Thesis, Univ. Coimbra, 404 pp.
- Ramos, A. (2008). *O Pliocénico e o Plistocénico da plataforma litoral entre o Cabo Mondego e a Nazaré*. Ph.D. Thesis, Univ. Coimbra, 329 pp.
- Rasmussen, E.S., Lomholt, S., Andersen, C. & Vejbaek, O.V. (1998). Aspects of the structural evolution of the Lusitanian Basin in Portugal and the shelf and slope area offshore Portugal. *Tectonophysics*, 300, 199-255.
- Ribeiro, A., Kullberg, M.C., Kullberg, J.C., Manuppella, G. & Phipps, S. (1990). A review of Alpine tectonics in Portugal: Foreland detachment in basement and cover rocks. *Tectonophysics*, 184, 357-366.
- Srivastava, S.P., Roest, W.R., Kovacs, L.C., Oakey, G., Le'vesque, S., Verhoef, J. & Macnab, R. (1990). Motion of Iberia since the Late Jurassic: Results from detailed aeromagnetic measurements in the Newfoundland Basin. *Tectonophysics*, 184, 229-260.
- Teixeira, C., Zbyszewski, G., Assunção, C.F.T. & Manuppella, G. (1968). Carta geológica de Portugal na escala de 1/50.000 e Notícia explicativa da folha 23-C (Leiria). Serviços Geológicos de Portugal, Lisboa.
- Texier, J-P. & Cunha Ribeiro, J-P. (1991/92). Les formations quaternaires du bassin du Lis: leur importance pour la chronostratigraphie de l'acheuléen portugais. *Cadernos de Arqueologia*, Série II, 8-9, Braga, 7-30.
- Zbyszewski, G. (1959). Étude Structurel de L'Aire Typhonique de Caldas da Rainha. *Serv. Geol. Portugal*, Mem. 3, 184 pp.