PALAEOSEISMOLOGICAL FEATURES OF THE GRANADA FAULT

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Abstract: *This paper presents preliminary results of a palaeoseismic study of the Granada Fault, a NW-SE active normal fault that produces a Plio-Quaternary throw of 300 m. According to these data, slip rate has been estimated in 0.38 mm/y (Sanz de Galdeano et al., 2003). Several palaeosols, Pleistocene in age, have been affected by this fault. Three different events can be recognized from the accumulative throw. The vertical slip per event ranges from 5 to 7 cm. Following the empirical relationship between moment magnitude and average displacement proposed by Wells and Coppersmith (1994), a magnitude between 5.9 and 6.0 can be preliminary assessed for these events. The palaeosols were sampled and dated using the thermoluminiscence method to constrain these estimates.*

Key words*: Palaeoseismicity, slip ranges, seismic hazard, Central Betics*

ACTIVE FAULTS IN THE GRANADA TOWN

The present-day relief of the margins of the Granada depression is strongly conditioned by the activity of some faults, together with the incision produced by several rivers that drain the area. The faults produce large steps in the relief (Fig. 1). The most important topographic step corresponds to the faults bounding the basement of the basin; these faults are characterised by metre- to hectometre-scale scarps with associated slicken-surfaces and striations; the footwalls of these faults are uplifted blocks with strong relief and deeply incised by rivers. Several steps are found between the flat area of the Granada basin and the ranges where the basement outcrops, which could represent fault scarps variably degraded by erosion of the soft sediments. These steps show NW-SE orientations, in accordance with the orientation of the majority of the normal faults mapped in the margin of the basin (Fig. 2).

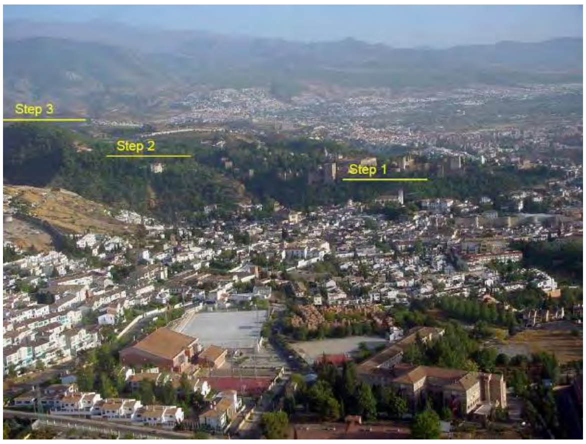

Fig. 1: Topographic steps produced by the NW-SE normal faults.

The seismic activity in the Granada depression is high, with a large number of earthquakes, all of them with a moderate to low magnitude ($m_b \leq 5.5$) (De Miguel et al., 1989). The seismicity has its origin mostly at depths between 5 and 17 km (Morales et al., 1997; Serrano et al., 2002) and the focal mechanisms indicate a present-day stress state dominated by a NE-SW extensional axis. This extensional stress field coincides with palaeo-stress determinations from Tortonian and younger sediments, and is perfectly compatible with NW-SE striking normal faults and NE-SW directed extensional transport (Galindo-Zaldívar et al., 1999; Martínez-Martínez et al., 2002).

Fig. 2: NW-SE normal faults outcropping in the northeastern border of the Granada basin near the Granada city. The red square shows the location of the fault shown in Fig. 3.

Taking into account the length of the seismic faults in the area (approximately 17 km) the "realistic" maximum magnitude of an earthquake would be 5.1 (De Miguel et al., 1989; Peláez Montilla et al., 2002). An earthquake of this magnitude at depths of 5 km would produce maximum vertical displacements of 3 mm in the vertical of its focus (Peláez Montilla et al., 2002).

A detailed study about the longitude and segmentation of the NW-SE active faults outcropping in the surrounding areas of the Granada Town is critical to evaluate the seismic hazard in this place. In a previous analysis, Sanz de Galdeano et al., 2003 attributed a maximum longitude to the Granada fault of 17 km. However, deformation induced by the Granada fault is distributed in a wide area of several kilometres. In this area, it can be appreciated that the fault is segmented in multiple discontinuous planes. By instance, in the Alhambra hill and surrounding areas, the outcropping rocks are affected by several faults with centimetre throws. The lateral continuity of these faults is less than 10 km.

PALAEOSEISMOLOGICAL ASSESSMENT

The seismic capability of the NW-SE faults of the Granada City is assessed studying one of these faults affecting several paleosoils. The studied fault has been located in a vertical urban talus at the suburb of Granada (UTM30N: X-445083; Y-4117927).

The fault, with strike N125ºE and dipping 86º southwards, affects some horizontal levels of silty sand that present pedogenic development (Fig. 2). The dark horizons have been taking as markers to estimate the accumulative displacement of the fault. We took into account the top and the bottom of these dark horizons because their diffuse limits. In addition, we took three samples (Table 1) for thermoluminescence dating (TL) in order to estimate some recurrence of the seismic events and the slip rate of the fault. The result of the accumulative slip, coseismic slip and mean coseismic slip of the fault is presented in the Table 2.

Table 1: TL dating

Sample	Age (ka BP)	X (UTM30N)	Y (UTM30N)
TL-4	> 150	445083	4117927
TL-5	> 150	445083	4117927
TL-6	> 80	445083	4117927

With such a mean coseismic slip of 5.86 cm within a range of 4.8 to 7.0 cm, this fault would be capable to generate events with magnitude 5.9-6.0 following the relationships between moment magnitude and average displacement of Wells and Coppersmith (1994). The accumulative displacement remaining of 50.0 cm of the level D might be generated by 8-9 events considering the mean coseismic slip. Unfortunately, the ages of the samples TL-4, TL-5 and TL-6 are all beyond the age range of the dating technique that is 150 ka. In any case we can estimate some extreme values of recurrence period and slip rate of the fault. In this way, considering the youngest material affected by the fault (Level D) like older than 150 ka, we estimate a seismic recurrence period longer than 16.7 ka. On the other hand, the slip rate of the fault should be considered as a maximum value of 0.003 mm/y, which is remarkable lower than that given by Sanz de Galdeano et al. (2003) as 0.38 mm/y in these faults since the mid-Pleistocene (800 ka). The difference of these two values should be understood as a distribution of the deformation in a complex set of faults that limit the Granada Basin at this edge. Nevertheless, we can not discard a deceleration of the rate during the Upper Pleistocene.

Table 2: Coseismic slip and mean coseismic slip of the fault

Level	Accumulative slip (cm)	Coseismic slip (cm)
D	50.0	
		5.8
C	55.8	
		7.0
B	62.8	
		4.8
A	67.6	
	Mean coseismic slip (cm)	**5.86**

IMPLICATIONS IN SEISMIC HAZARD

Sanz de Galdeano et al. (2003) assessed the seismic potential of the Granada Fault. They estimated a 6.3-6.6 maximum moment magnitude (M_w), and a recurrence time of less than 510 years for a M_w=6.0 earthquake. Recurrence time was obtained using a 0.38 mm/yr slip rate, which results from considering 300 m accumulated vertical offset since the mid-Pleistocene (800 ka). According to these data, the authors classified the Granada Fault as the most active one in the whole Granada Basin. Even though their observations could be regarded as very interesting at the time they were produced, the absence of absolute dating and precise measurements of coseismic deformation, makes their conclusions very arguable.

According to the results obtained in our palaeoseismological analysis, the interest in modelling the Granada Fault as a particular seismogenic source is very limited. A M_w=6.0 maximum magnitude does not represent a particular large value in the tectonic and/or historical seismicity context in the Granada Basin. Furthermore, a minimum mean recurrence time of 16.7 ka means a very low frequency when compared to the extrapolation of the Gutenberg-Richter law of the area (~100 years in Morales et al., 1996).

Nevertheless, these results agree with a model of distributed deformation at this border of the Granada Basin. In this model, the Granada Fault represents a shear band composed of multiple small faults, in contrast to a single large fault which accumulates most of the deformation. In this context, elastic energy is released preferentially by small earthquakes and, exceptionally, by moderate size ones ($M_{w\ máx}$≈6.0).

DISCUSSION AND CONCLUSION

According to the palaeoseismological results obtained from TL dating and direct measurement of coseismic deformation, we regard the seismic hazard of the Granada Fault preliminary as low. However, these results shall be confirmed in following studies. Our study remarks the importance of performing absolute dating and direct measurement of coseismic deformation in recent sediments (Upper Pleistocene, at least) in order to evaluate properly the current activity and, subsequently, the seismic hazard of particular faults. In this context, the actual activity of many faults in the Granada Basin –which have been assessed based on Plio-Quaternary markers (ca. 5 Ma), could be much lower than it is currently believed.

Finally, the Granada Fault is capable of producing earthquakes as large as 6.0 (±0.3). Whether these earthquakes will be catastrophic or not depends much more on the observance of seismic code provisions by builders and on Civil Protection Plans, rather than on the seismic potential of the Granada Fault. If we consider the rupture of the total length of this fault (<10 km), the maximum magnitude estimated with the relationships between moment magnitude and surface rupture length of Wells and Coppersmith (1994) would be between 6.1-6.2. This magnitude is quite similar to that obtained in our paleoseismological assessment attending to the average displacement (M_w=5.9-6.0). This value is much higher than that given by De Miguel et al. (1989) or Peláez Montilla et al. (2002) as the "realistic" maximum magnitude of 5.1.

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References

De Miguel, F., Vidal, F., Alguacil, G., and Guirao, J.M. (1989). Spatial and energic trends of the microearthquakes activity in the Central Betics. Geodinamica Acta, 3, 87-94.

Galindo-Zaldívar, J., Jabaloy, A., Serrano, I., Morales, J., González Lodeiro, F., and Torcal, F. (1999). Recent and present-day stresses in the Granada Basin (Betic Cordilleras): example of a late Miocene - present-day extensional basin in a convergent plate boundary. Tectonics, 18, 686-702.

Martínez-Martínez, J.M., Soto, J.I., Balanyá, J.C. (2002). Orthogonal folding of extensional detachments: structure and origin of the Sierra Nevada elongated dome (Betics, SE Spain). Tectonics, 21, 1-20.

Morales, J., Serrano, I., Vidal, F., and Torcal, F. (1997). The depth of the earthquake activity in the Central Betics (Southern Spain). Geophysical Research Letters, 24, 3289-3292.

Peláez Montilla, J.A., Gil, A.J., Sanz de Galdeano, C., and Rodríguez Caderot, G. (2002). Condicionantes en el diseño de una red geodésica para el control de una falla normal: aplicación a la falla de Granada. Proceedings of the 3ª Asamblea Hispano Portuguesa de Geodesia y Geofísica. Valencia (Spain), 51-55.

Sanz de Galdeano, C., Peláez Montilla, J.A., and López Casado, C. (2003). Seismic potential of the Main Active Faults in the Granada Basin (Southern Spain). Pure and Applied Geophysics, 160, 1537-1556.

Serrano, I., Zhao, D., and Morales, J. (2002). 3-D crustal structure of the extensional Granada Basin in the convergent boundary between the Eurasian and African plates. Tectonophysics, 344, 61-79.

Wells, D. L. and K.J. Coppersmith (1994). New empirical relationships among magnitude, rupture length, rupture area, and surface displacement. Bulletin of the Seismological Society of America, 84(4), 974-1002.

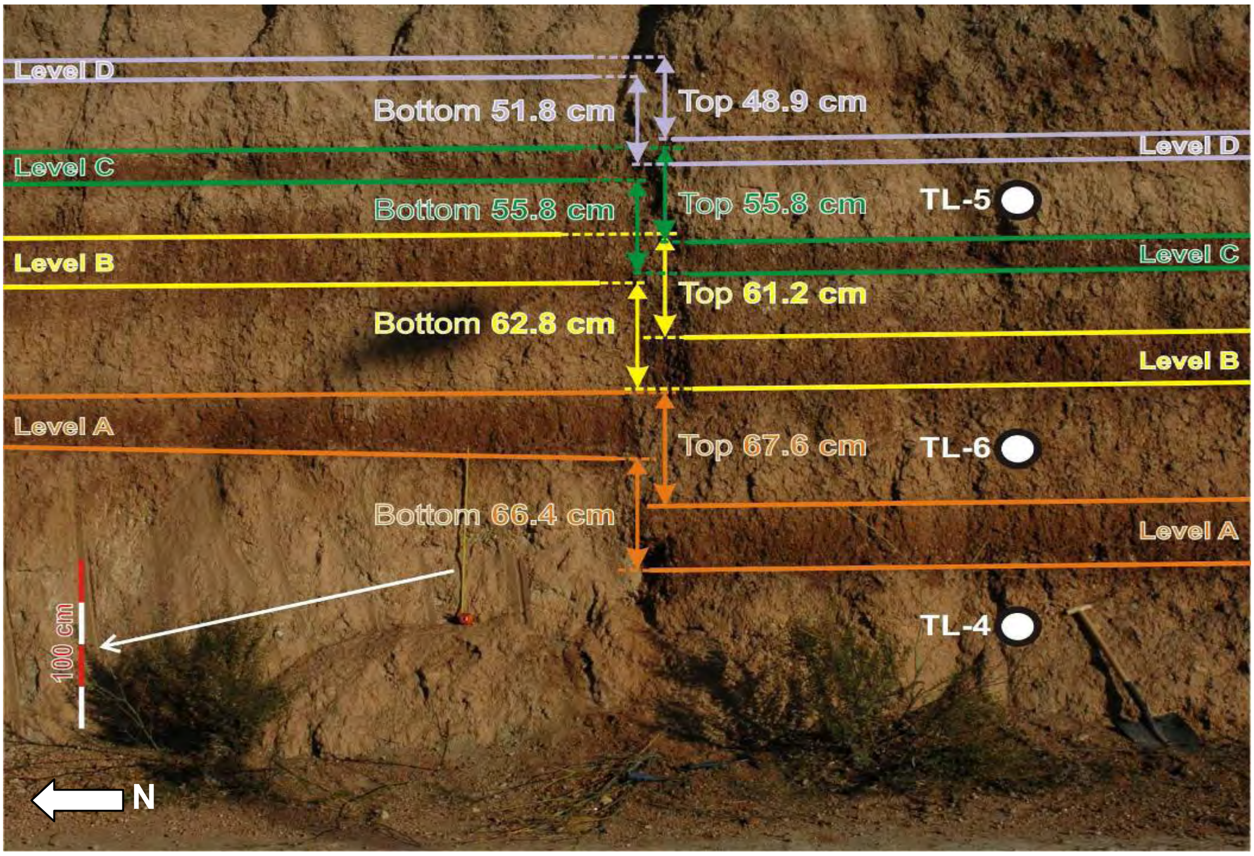

Fig. 3: Palaeoseismological analysis of the Granada Fault. TL-4 and TL-6 are the selected points for thermoluminescence dating