Quaternary faulting in Granada Basin, Southern Spain

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Introduction

The Granada Basin is located in the central part of the Betic Cordillera, southern Spain. The intermountain basin is filled in with Upper Miocene marine and continental deposits and Pliocene, Pleistocene and Holocene continental deposits. Many faults at the basin boundary and inside the basin affect the young deposits including the Pleistocene and Holocene strata. Thirty five faults longer than 5 km are considered as active or probably active (Sanz de Galdeano et al., 2003). The faults are normal and oblique. Most of the faults in the basin and some at the mountain front strike NW-SE (fig. 1) reflecting

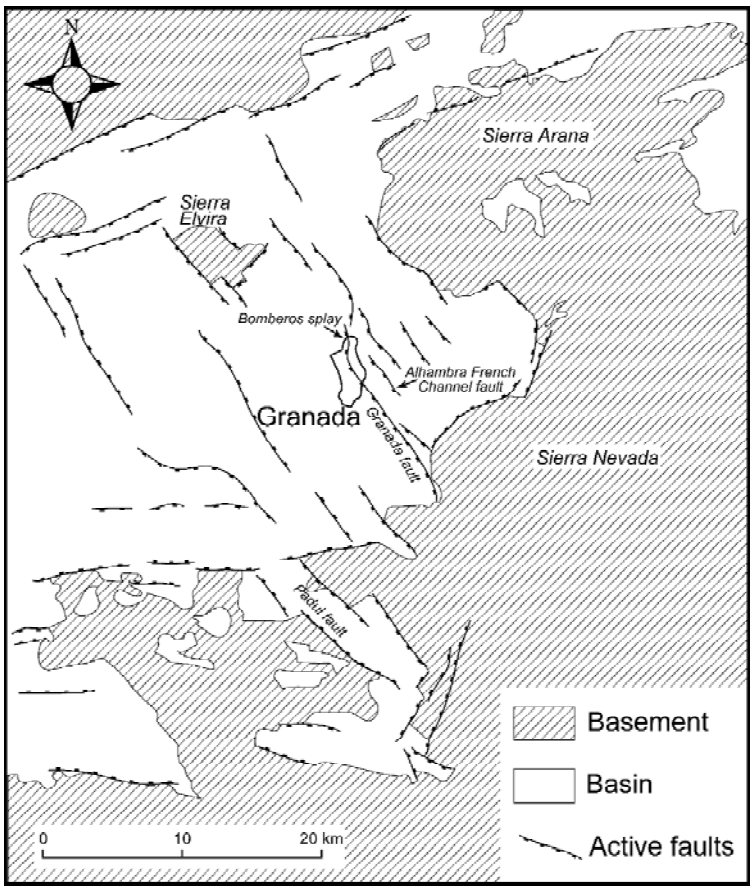

Fig. 1. Active faults in Granada basin (modified from Sanz de Galdeano, Lopez-Garrido, 2000)

a general NE-SW extension (Galindo-Zaldivar et al., 1999). NNE-SSW striking faults also show evidence for recent activity. Faults of E-W direction are considered to be the oldest faults activated in early and middle Miocene. Long-term slip rate of the active faults varies between 0.03 mm/yr and 0.5 mm/yr for the last 5 Ma (Sanz de Galdeano et al., 2003). Very limited data about historical strong earthquakes do not allow recognizing of any individual surface-rupturing event except the December 25, 1884 M 6.7 event on Ventas de Zaffarraya Fault (Reicherter, 2001). The existing paleoseismological data in the Granada basin are very scarce, and recurrence intervals of the surface rupturing events and displacement are unknown (Pelaez Montilla et al., 2003; Sanz de Galdeano et al., 2003). Deterministic seismic hazard assessment requires paleoseismological data for the active faults in this intensively populated region.

In this study we present evidence for young fault activity and data for recent coseismic displacement on some of the active faults in the Granada basin.

Paleoseismic records

Granada Fault, Bomberos splay

The Granada Fault runs through the Granada city (fig. 1). The Bomberos splay is not really the main fault line here but it is one of the few lines parallel to the main scarp in this area. The length of the main fault segment calculated from the fault trace on the surface is 16.8 km. The fault affects Pleistocene deposits. The slip rate for the last 0.8 Ma is 0.38 mm/yr (Sanz de Galdeano et al., 2003). A single normal fault in an outcrop in Bomberos, Granada, displaces a Pleistocene sequence of alluvial sediments and paleosols (fig. 2). The offset of 0.7 m presents a single faulting event near the surface. Unfortunately, the top sediments have been eroded and any deposits younger than the event have not been observed in the cross-section. Observed offset of 0.7 m is the only known single offset along the Granada Fault and we do not know if it is the maximum offset or not. Following empirical relationship between moment magnitude and displacement proposed by Wells and Coppersmith (1994), we calculate M between 6.5 and 6.8 for that event, which is a little bit more than expected M 6.3—6.6 proposed by Sanz de Galdeano et al. (2003) based on fault segment length. Average recurrence interval of seismic events is equal to long term slip rate divided into slip per event (Wallace, 1970). Using observed displacement of 0.7 m and slip rate of 0.38 (Sanz de Galdeano et al., 2003), recurrence interval should be 1842 yr. Calculated recurrence interval should be tentative because it is based on a single offset and the long term slip rate is not accurate enough.

The absence of repeated fault activity on the observed Bomberos splay leads to a conclusion that the individual surface faulting events along the Granada Fault likely occurred on different fault splays.

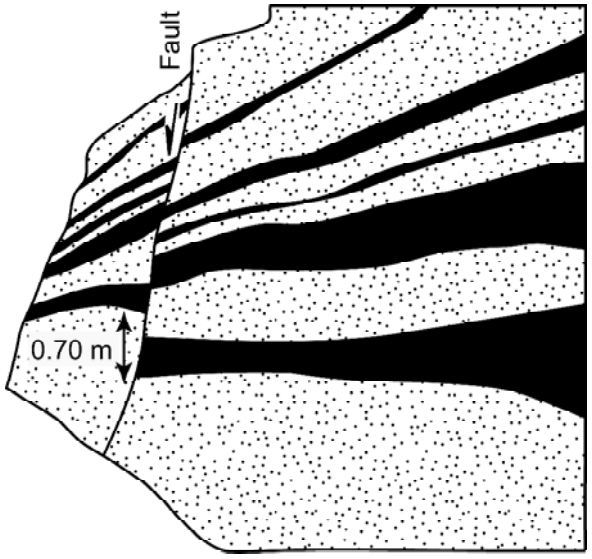

Fig. 2. Oblique view to the Bomberos splay of the Granada fault showing 0.70 m offset of alluvium (dot pattern) and paleosols (black)

Alhambra French Channel Fault

The Alhambra French Channel Fault is one of the normal faults in Pliocene — Pleistocene alluvium striking NW-SE through the Alhambra hill (Azanon at al., 2004) northward of Granada (fig. 1). A discontinuous scarp less than 0.5 m traces the fault on the surface. We studied in details deformed sediments and fault zone in a cross section along a road construction in order to prove or disprove young fault activity. A fault zone about 1 m wide is almost entirely filled in with infiltrated carbonates (fig. 3). The fault zone separates gray alluvial conglomerate in the footwall from reddish alluvial deposits in hanging wall. Three couplets of a lower pebbly layer and an upper silty layer build up the hanging wall alluvium. Primary sub-horizontal layers in hanging wall have progressively been tilted toward the fault zone. Tilt starts 8 meters away from the fault and reaches maximum value of 1.0—1.2 m at the fault where the layers are warped. Subsidence of hanging wall causes tilting and warping of the layers. The tilting indicates the minimum cumulative displacement along the fault after deposition. Topsoil developed in both fault walls has not been affected by the fault. The fault was active during Pleistocene and no faulting event occurred since the modern soil formation.

Padul Fault

The Padul Fault is a normal fault at the boundary of Sierra Nevada and the Pliocene — Holocene ba-

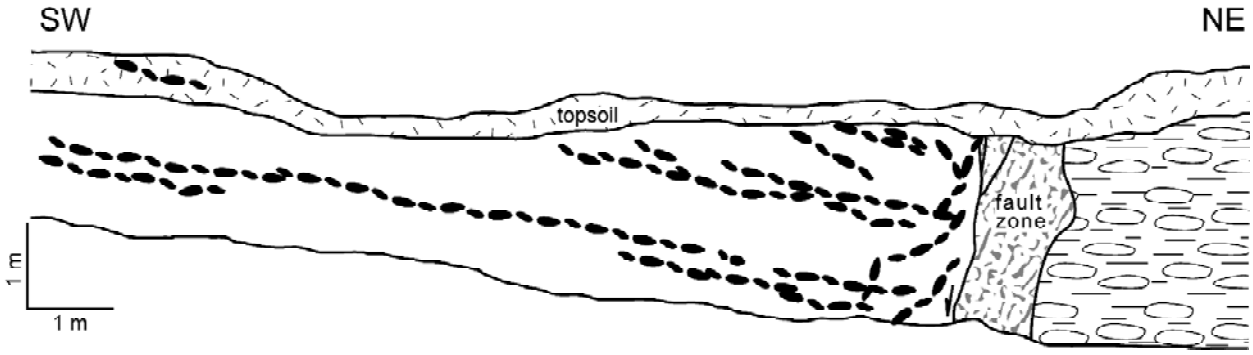

Fig. 3. Log of the Alhambra French Channel Fault. Alluvial layers in the hanging wall are tilted toward the fault zone. The fault does not affect the topsoil.

sin (fig. 1). A young fault scarp runs across the Quaternary alluvial fans parallel to a fault on the contact between Triassic carbonates from the mountain and the Neogene basin (Alfaro et al., 2001). The scarp face is vertical and fresh along several hundred meters. The mean height of the scarp face along this section is 0.7 m. Most probably the scarp was formed in a very recent surface faulting event because scarp degradation is at primary stage. The morphology of the Ventas de Zafarraya scarp originated in 1884 event is analogue to the Padul scarp. Assuming that the Padul Fault height resulted in one event and taking the long term slip rate of 0.35 mm/yr for the last 1 Ma (Sanz de Galdeano et al., 2003), the mean recurrence interval should be about 2000 years.

Conclusion

Paleoseismic records exist despite the high erosion rate in the Granada basin. The Bomberos splay of the Granada Fault and the Padul Fault have experienced faulting events of similar offsets. According to empirical relationship between moment magnitude and displacement (Wells, Coppersmith, 1994) both earthquakes should be of M between 6.5 and 6.8. Due to uncertainties in the long term slip rate used for calculation of the mean recurrence interval (Sanz de Galdeano et al., 2003) and limited data for the individual offsets presented in this study, the mean recurrence interval of 1842 years for the Granada Fault and 2000 years for the Padul Fault should be perceived as tentative values.

References

Alfaro, P., J. Galindo-Zaldivar, A. Jabaloy, A. C. Lopez-Garrido, C. Sanz de Galdeano. 2001. Evidence for the activity and paleoseismicity of the Padul fault (Betic Cordillera, Southern Spain). – *Acta Geologica Hispanica, 36,* 3—4, 283—297.

Azanon J. M., A. Azor, G. Booth-Rea, F. Torcal. 2004. Small-scale faulting, topographic steps and seismic ruptures in the Alhambra (Granada, southeast Spain). – *Journal of Quaternary Science*, *19,* 219—227.

Galindo-Zaldivar, J., A. Jabaloy, F. Gonzalez-Lodeiro, I. Serrano, J. Morales, F. Torcal. 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,* 4, 686—702.

Pelaez Montilla, J. A., C. Sanz de Galdeano, C. Lopez Casado. 2003. Use of active fault data versus seismicity data in the evaluation of seismic hazard in the Granada Basin (southern Spain). – *Bulletin of the Seismological Society of America, 93,* 4, 1670—1678.

Reicherter, K. R. 2001. Paleoseismologic advances in the Granada basin (Betic Cordilleras, Southern Spain). – *Acta Geologica Hispanica, 36,* 3—4, 267—282.

Sanz de Galdeano, C., A. C. Lopez-Garrido. 2000. Las fallas tortonienses a cuaternarias entre Granada y la costa:el límite occidental del Nevado-Filábride y de las unidades alpujárrides inferiores. – *Revista de la Sociedad Geológica de España, 13,* 3—4, 519—528.

Sanz de Galdeano, C., J. A. Pelaez Montilla, C. Lopez Casado. 2003. Seismic potential of the main active faults in the Granada Basin (Southern Spain). – *Pure and Applied Geophysics, 160,* 8, 1537—1556.

Wallace, R. E. 1970. Earthquake recurrence intervals on the San Andreas fault. – *Geol. Soc. America Bull., 81,* 2875—2890.

Wells, D. L., K. J. Coppersmith. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. – *Bull. Seismological Soc. America, 84,* 4, 974—1002.

Кватернерно разломяване в Гранадския басейн, Южна Испания

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Резюме. Гранадският басейн се намира в централната част на Бетските кордилиери, южна Испания. Множество разломи по границите му и в неговите предели засягат млади седименти, включително плейстоценските и холоценските хоризонти. Дължините и дългосрочните скорости на движение на активните и потенциално активните разломи са добре изучени, но необходимите за детерминистична оценка на сеизмичната опасност палеосеизмоложки данни са оскъдни. В настоящето проучване описваме палеосеизмоложки следи в три от считаните за активни разломи.

Разклонението Бомберос на Гранадския разлом е претърпяло едно разломяващо събитие с разместване на едновъзрастни пластове от 0,70 m. Анализът на разломния откос на Падулският разлом показва, че той е претърпял едно сравнително скорошно събитие с разместване около 0,70 m. Според емпиричните зависимости между преместване и моментен магнитуд (Wells, Coppersmith, 1994), силата на двете земетресения е аналогична и варира между 6,5 и 6,8. Приблизителният период на възвръщаемост на сеизмичните събития на Гранадския разлом и Падулския разлом е изчислен по данни за дългосрочната скорост на разломите (Sanz de Galdeano et al., 2003) и установените косеизмични премествания. Средният период на възвръщаемост на Гранадския разлом е 1842 години, а на Падулския разлом е 2000 години. Получените стойности са ориентировъчни, поради недостатъчната точност на изчисление на дългосрочната скорост (Sanz de Galdeano et al., 2003) и оскъдните данни за косеизмични премествания.

Разломът „Алхамбра френски канал“ асоциира със сравнително запазен разломен откос, което предполага неговата сравнително млада активност. Детайлното описание на разломната зона в разкритието показва, че разломът е активен през плейстоцена с минимално кумулативно разместване 1,0—1,2 m. Съвременната почва не е засегната от разломяване.