Actividad tectónica reciente en el borde sur de la depresión del Guadalquivir entre Cabra y Quesada (provincias de Jaén y Córdoba)

Recent tectonic activity on the south margin of the Guadalquivir basin, between Cabra and Quesada towns (provinces of Jaén and Córdoba, Spain)

Mario Sánchez Gómez[1] and Federico Torcal Medina[2, 3]

[1] Departamento de Geología. Universidad de Jaén, 23071-Jaén (Spain).
e-mail: msgomez@ujaen.es

[2] Departamento de Ciencias Ambientales, Universidad Pablo de Olavide, Crta. de Utrera Km. 1, 41013-Sevilla (Spain).
e-mail: ftormed@dex.upo.es

[3] Instituto Andaluz de Geofísica y Prevención de Desastres Sísmicos. Observatorio de Cartuja, Calle del Observatorio nº 1, Campus Universitario de Cartuja. 18071-Granada (Spain).
e-mail: fede@iag.ugr.es

Summary

The eastern zone of the Guadalquivir river basin has been considered in a traditional way as a zone of a low degree of seismic activity, congruent with a reduced tectonic activity since the Late Miocene. Accordingly, very few efforts have been focused on neotectonics research into this area. However, there are some indications of tectonic movement ratios that can be considered as important as the ones found in the zones contemplated usually as active into the Betic Cordilleras, like the Granada Basin, the southern flank of the Sierra Nevada-Sierra de Filabres mountains, and the lower Segura river basin, all studied intensely since 1980.

The Guadalquivir basin is delimited to the south by the front of thrusts of the South-Iberian Domain sedimentary cover, forming an apparently non-continuous mountain chain front. The front is bounded to the north by the so-called Olistostromic Unit, originated by the gravitational collapse of the former Middle Miocene nappe pile towards the center of the basin. Thus, the Guadalquivir basin constitutes a foreland basin, formed by flexure of the South-Iberian lithosphere as consequence of the thin-skinned thrust thickening and/or the overweight that implies the thrusting of the Alborán-Domain over the South-Iberian margin.

Several observations suggest that a relative tectonic activity continued from the Middle Miocene until nowadays. These are:

-There are a moderate number of earthquakes recorded in the area through the time, although in most of them the magnitude is low. Also some seismic series has been developed in the area, like the one occurred near Alcaudete (Jaén) in 1951, with two main earthquakes of magnitude over 5.

-There are prominent reliefs, limited by faults showing linear topographic shape.

-Some tributary rivers of the Guadalquivir are strongly incised into the mountain front, forming narrow canyons with cliffs over 200 m in high.

- The Guadalquivir and tributary rivers have few terrace levels, some of them separated from the present floodplain tens of meters suggesting a tectonic origin.

Focal mechanisms from several earthquakes illustrate the actual stress field of the upper crust in the area. Our research is in an initial stage of study, but we found a good correlation between the geophysical, geomorphologic and structural data observed until now. The preliminary results show a complex tectonic state with orthogonal movement senses. Future investigations could enlighten us about features of the present tectonic activity, its spatial

distribution and importance. Also some geologic and seismic hazards related with the tectonic activity could be revealed in this "non active" area.

Introduction

The Betic Cordillera is considered as a zone with a significant present tectonic activity inside (Galindo-Zaldívar *et al*., 1999) and there are a few areas showing a moderate to intense seismicity. Earthquakes of low magnitude are common in the so-called Alborán Domain (De Miguel *et al*., 1989), a "terrane" that groups the Internal Zones of the Betics and Rif, and also the Alborán Sea basement (García Dueñas *et al*., 1992). The Alborán Domain is superimposed over the hypothetical limit between Africa and Iberia plates, which are converging in the region at a rate of 5 mm/y (DeMets *et al*., 1994). Paradoxically the main observed structures correspond to large crustal extension (v.g. Jabaloy *et al*., 1993; Crespo-Blanc *et al*., 1994; Martínez-Martínez and Azañón, 1997), as well as a large number of calculated focal mechanisms also show extensional component (Galindo-Zaldívar *et al*., 2001). The Alborán Domain was emplaced over the South Iberian and Magrebian margins since the early Miocene (Balanyá and García-Dueñas, 1988), with a west directed movement. Thus, the present tectonic state in the Alborán Domain is a complex mixture of plate convergence, orogen collapse and back-arc extension, that difficult the geologic analysis of the seismicity.

Nevertheless, seismicity is not restricted to the Alborán Domain. Towards the north, the South Iberian cover is deformed in an up-to 100 km wide mountain belt, where there are evidences of present tectonic activity. This area, called External Zones, have a more simple crustal structure, with a well-layered crust of typical thickness (Banda and Ansorge, 1980, Galindo-Zaldívar *et al*., 1997). Although earthquakes are less frequent and intense than on the Alborán Domain, geomorphologic evidences suggest surface movement rates remaining relatively high. We focus in the South Iberian Domain of the Central Betics, from Cabra to Quesada towns, south to the Guadalquivir River (Figs.1 and 2), trying to relate seismic, geologic and geomorphologic observations. We present here the preliminary results of this research line.

Geological setting

The collision of the Alborán Domain with the South Iberian Margin during the Miocene, results in a thin-skinned thrust belt (Fig. 1). The sedimentary cover of the Iberian plate was detached, imbricated and folded to the north and/or to the west. Two tectono-stratigraphic sub zones are recognized in the External Zones corresponding with the two principal paleogeographic domains (Prebetic and Subbetic; v.g. García-Hernández *et al*., 1980;Vera, 1986). The Prebetic Zone corresponds to the inner shelf of the margin, generally less subsident. The Subbetic Zone corresponds to the outer shelf and is characterized by the prevalence of pelagic sedimentation that produced usually thicker units.

In the Central Betics (Figs. 1 and 2) Prebetic and mainly Subbetic thrusts constitute a coherent mountain chain, bounded towards the northwest by the Guadalquivir basin. Trusting and folding started during the early Burdigalian and the main horizontal shortening stopped on early Tortonian (Molina-Cámara, 1987; Sanz de Galdeano and Vera, 1992). Low-angle faults with NW hanging wall displacement sense have been described on the mountain front after the basal Tortonian (Galindo-Zaldívar *et al.*, 2000), but any upper limit age has been found for this faults. During the middle Miocene, the mountain front, partially bellow the sea level, fell down as olistostromic masses towards the Guadalquivir foreland basin depocentre (Pérez-López and Sanz de Galdeano, 1994), forming a parallel front of olistostrome emplacement (Fig. 2). From middle Tortonian to present is considered a "post-tectonic" period, however deformation should not have stopped yet, as the local presence of striated pebble in Quaternary conglomerates suggest (Ruano and Galindo-Zaldívar, personal communication, 2002). General topographic rise start at that time, controlled by normal faults, and it cannot be excluded a sort of tectonic collapse as it has been observed on other areas of the Betics.

In this way, Guadalquivir basin is a typical foreland basin formed by the flexure of the Iberian crust, because the Miocene tectonic overload (García-Castellanos, 2002). Three main explanations can be invoked to justify the flexion of the entire lithosphere: the thrust of the Alborán Domain, the thickening of the Prebetic and Subbetic zones, and the lower crust and the lithosphere mantle thickness changes. A recent numeric modeling rejects the possibility of isostatic influence of the Alborán Domain kinematics over the Guadalquivir basin (García-Castellanos *et al*, 2002), but scarce geologic evidences are presented.

Thus, the south margin of the Guadalquivir basin displays a relatively simple well-known crustal structure on the contact of the Alborán Domain with the Iberian crust, where tectonic components of the current geologic activity should be easier elucidate.

Structure and geomorphologic description of the area

The most significant feature of the region is the morphologic manifestation of the Subbetic and Prebetic front over the Guadalquivir Units (Fig. 2), although there is not a topographic continuity. Three main massifs (Sierra Alcaide, Jabalcuz and Mágina) have a northern sudden face that can be connected by a straight line. Fault bounded depressions of varied shape separate the sierras on the NNE-SSW direction. Between Sierra Alcaide and Jabalcuz, a large area of Triassic rocks remains relatively lower, except a kilometric klippe of Subbetic units. Nevertheless, two narrow valleys (Guadalbullón and Quiebrajano rivers) filled by upper Miocene to Quaternary sediments split up Jabalcuz from Mágina. Both depressions and valleys are limited by NNW-SSW normal faults with variable intensity topographic manifestation as escarpments or triangular facets. Evidences of Holocene activity of this kind of faults has been found east of Sierra Mágina, where a buried calcrete soil yields an ^{14}C age of 5.2 ±1.5 ka (Jiménez-Espinosa and Jiménez-Millán, 2003). Moreover, deep canyons occur associated to the NNW-SSW faults, as can be observed for example in the confluence of Quiebrajano and Río Frío (Fig. 2), where there are canyons over Jurassic limestone until 300 m deep.

If a hypothetically continuous line is drawn following the north end mountain front (Fig. 2), in general, rivers incised the previous geomorphologic peneplains to south of this line, even on relatively depressed areas as on Alcaudete Triassic neighbourhood. Likewise, Quaternary terrace deposits are strongly incised (Figure 3). On the other hand, lacustrine sediments, now also completely incised (García-García and Sánchez-Gómez, in press), occur on specific segment of the fluvial valleys, suggesting the possibility of relative subsidence (Figure 4). More exhaustive and quantitative analysis of these features is going to be carried out, in order to determine if the topographic rise is homogeneous or there are fault-controlled blocks of different behaviour.

No clear paleoseismic evidences has been observed until now, however the area shows a moderate seismicity (see next section) thus sporadic large earthquakes cannot be refused.

Seismic data

The studied area shows a gentle to moderate seismic activity. Comparatively with the area of the Granada basin located just to the south, the deformation energy released by earthquakes is near two orders of magnitude less. However as it is showed in Figure 5 the area can be discriminated from the north and east adjacent areas by a larger number of earthquakes.

The Figure 5 illustrates the epicentres of the earthquakes between June 1910 and June 2002, considering only the ones which the magnitude m_b is greater to 3, to avoid quarry explosions. The area registered 536 earthquakes of m_b >2.5 (144 of m_b >3), since 1983 when a regional seismograph network has been established (Alguacil *et al*., 1986). Most than 70% of the earthquakes occur above 20 km depth and 60% above 15 km. Data before 1983 only recorded the larger earthquakes, thus temporal distribution cannot be made properly. Some seismic series has been developed in the area, like the one occurred near Alcaudete (Figures 2 and 5) in 1951, with two main earthquakes of magnitude over 5 (Bernal *et al*, 1991; Peláez y López-Casado, 1995). Maximum magnitude documented is about 5.5.

In order to test the relationship between seismicity and geological context, we selected a small area south of Jaén, where we were able to calculate three focal mechanisms (Figure 6) from earthquakes of m_b >3. The focal mechanism noted A and B correspond to successive events (separated 6 hours) with a similar solution on very close coordinates. The A and B focal mechanism indicate reverse ENE-WSW faults, which fit well with the orientation of the Subbetic and Prebetic thrusts. On the other hand, C focal mechanism point to a normal fault of NNW-SSE, similar to the faults that cut the mountain front and bound the transverse valleys.

Discussion and conclusion

The studied area shows a moderate seismic activity that can be related with the structures detected on the area. Nevertheless geomorphologic observations suggest a more intense tectonic activity, although in this preliminary research it cannot be established what is the role of the asesimic deformation.

Overall the area shows a patent elevation inside of the mountain front. This general topographic rise could be compartimentalized in blocks of different rate of movement limited by NNW-SSE normal faults. Some of these faults should be seismic or at least related with seismic sources in depth. Other seismic sources seem to be caused by a roughly N-S compression.

The origin of this tectonic instability could be an isostatic rebound after the nappe thickening in the middle Miocene, or the N-S directed approach between Africa and Iberia. In the second case, normal faults should be explained by extension orthogonal to the main compression direction, after reactivation of Miocene thrust. Further studies must be carried out to characterize the tectonic process predominant and the relationship with the intense tectonic activity present just south of the area, in the Granada basin.

Although seismicity is moderate, it cannot be rejected the seismic risk associated to some faults or local areas, as happened on Alcaudete in 1951. The combination of geologic, geomorphologic and seismic studies became indispensable on areas of relative low activity to determine the diffuse risk and the subsequent hazard of the region.

Acknowledgements: This work has been supported by the projects the MICYT REN2001-3868-CO3-01/MAR and REN2001-3378/RIES

References

Alguacil, G., 1986. *Los instrumentos de una red telemétrica para microterremotos. La red sísmica de la Universidad de Granada*. Tesis doctoral, 228 pp., Univ. Granada, Granada.

Balanyá, J. C. & García-Dueñas, V. 1988. El Cabalgamiento cortical de Gibraltar y la tectónica de las Béticas y Rif. *II Congreso Geológico de España.* Simposium sobre Cinturones Orogénicos, 35-44.

Banda, E. & Ansorge, J. 1980. Crustal structure under the central and eastern part of the Betic Cordillera. *Geophysical Journal of the Royal Astronomical Society* **63**, 515-532.

Bernal, A., Barrera, T. and Santiago, J.L. 1991. The earthquakes of march 10th and may 19th, 1951 occurred in the province of Jaén, Spain. In *Sesimicity, seismotectonics and seismic risk of the Ibero-Maghrebian region*. Instituto Geográfico Nacional, Madrid.

Crespo-Blanc, A., Orozco, M. & García-Dueñas, V. 1994. Extension versus compression during the Miocene tectonic evolution of the Betic chain. Late folding of normal fault systems. *Tectonics* **13**, 78-88.

Demets, C., Gordon, R. G., Argus, D. F. & Stein, S. 1994. Effect of Recent Revisions to the Geomagnetic Reversal Time-Scale on Estimates of Current Plate Motions. *Geophysical Research Letters* **21**, 2191-2194.

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

García-García, F. and Sánchez-Gómez, M. in press. Relleno sedimentario y destrucción de una pequeña cuenca fluvio-lacustre en la Sierra Sur de Jaén (Cordilleras Béticas). *Geogaceta*.

Galindo-Zaldívar, J., Jabaloy, A., González-Lodeiro, F. & Aldaya, F. 1997. Crustal structure of the central sector of the Betic Cordillera (SE Spain). *Tectonics* **16**, 18-37.

Galindo-Zaldívar, J., A. Jabaloy, I. Serrano, J. Morales, F. González-Lodeiro and F. Torcal. 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, 1999. *Tectonics*, vol. 18, no. 4, 686-702.

Galindo-Zaldívar, J., Ruano, P., Jabaloy, A. & Lopez-Chicano, M. 2000. Kinematics of faults between Subbetic Units during the Miocene (central sector of the Betic Cordillera). *Comptes Rendus de L'Academie des Sciences Série II a- Sciences De la Terre et des Planetes* **331**, 811-816.

Galindo-Zaldívar, J., Jabaloy, A., Morales, J., Ruano, P. & Serrano, I. 2001. Estructura y evolución tectónica de la Depresión de Granada en el marco de las Cordilleras Béticas. In: *La Cuenca de Granada: Estructura, Tectónica activa, Sismicidad, Geomorfología y dataciones existentes* (edited by Sanz de Galdeano, C., Peláez Montilla, J. A. & López Garrido, A. C.). CSIC-Universidad de Granada, Granada, 89-108.

García-Castellanos, D. 2002. Interplay between lithospheric flexure and river transport in foreland basins. *Basin Research* **14**, 89-104.

García-Castellanos, D., Fernández, M. & Torné, M. 2002. Modeling the evolution of the Guadalquivir foreland basin (southern Spain). *Tectonics* **21**, art. no.-1018.

García-Dueñas, V., Balanyá, J. C. & Martínez-Martínez, J. M. 1992. Miocene Extensional Detachments in the Outcropping Basement of the Northern Alboran Basin (Betics) and their Tectonic Implications. *Geo-Marine Letters* **12**, 88-95.

García-Hernández, M., López Garrido, A. C., Rivas, P., Sanz de Galdeano, C. & Vera, J. A. 1980. Mesozoic Paleogeographic evolution in the Externes Zones of the Betic Cordillera (Spain). *Geologie En Mijnbouw* **59**, 155-168.

Jabaloy, A., Galindo-Zaldívar, J. & González- Lodeiro, F. 1993. The Alpujárride-Nevado-Filábride extensional shear zone, Betic Cordillera, SE Spain. *Journal of Structural Geology* **15**, 555-569.

Jiménez-Espinosa, R. & Jiménez-Millán, J. 2003. Calcrete development in mediterranean colluvial carbonate systems from SE Spain. *Journal of Arid Environments* **In Press**.

Martínez-Martínez, J. M. & Azañón, J. M. 1997. Mode of extensional tectonics in the southeastern Betics (SE Spain). Implications for the tectonic evolution of the peri-Alborán orogenic system. *Tectonics* **16**, 205-225.

Molina Cámara, J. M. 1987. Análisis de Facies en el Mesozoico en el Subbético Externo (Provincias de Córdoba y Sur de Jaén). Unpublished Ph. D. Thesis, Universidad de Granada.

Peláez, J.A. y López Casado, C. 1995. Sismicidad y peligrosidad sísmica en la provincia de Jaén. *Boletín del Instituto de Estudios Jienenses* **155**, 187-214.

Pérez-López, A. and Sanz de Galdeano, C. 1994. Tectónica de los materiales triásicos en el sector central de la Zona Subbética (Cordillera Bética*). Revista de la Sociedad Geológica de España* 7, 141-153.
Sanz de Galdeano, C. & Vera, J. A. 1992. Stratigraphic record and paleogeographical context of the Neogene basins in the Betic Cordillera, Spain. *Basin Research* **4**, 155-181.
Vera, J. A. 1986. Las Zonas Externas de las Cordilleras Béticas. In: *Libro Jubilar J.M. Rios* **II**. IGME, Madrid, 218-237.

Figures

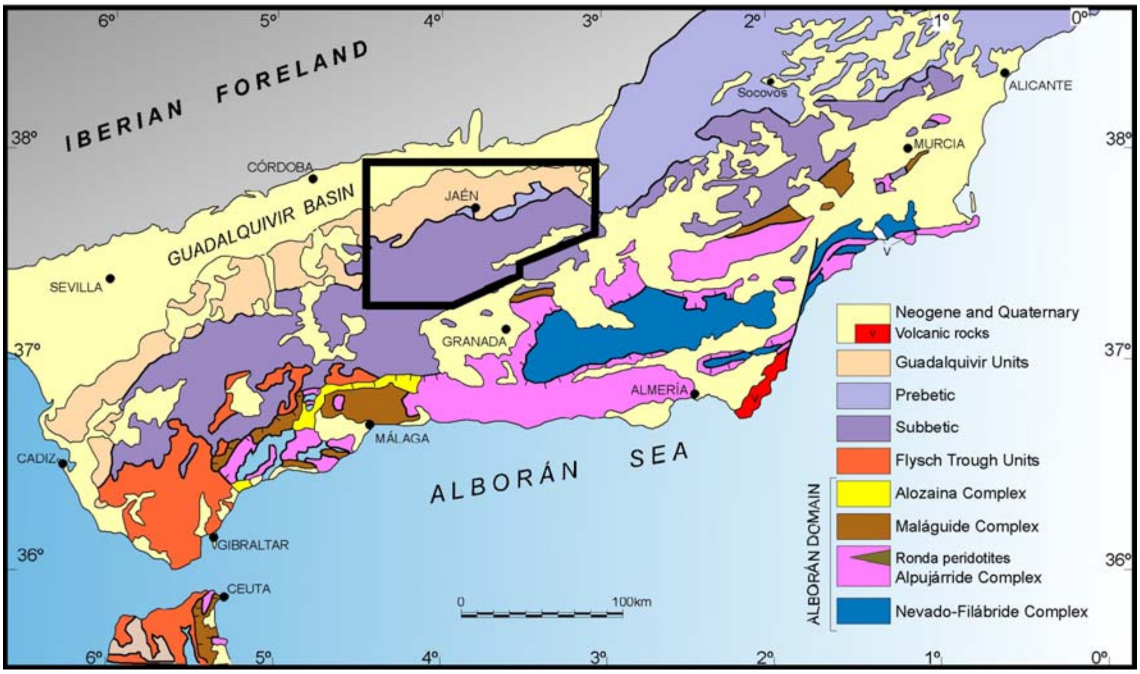

Figure 1. General map of the Betics showing the studied area.

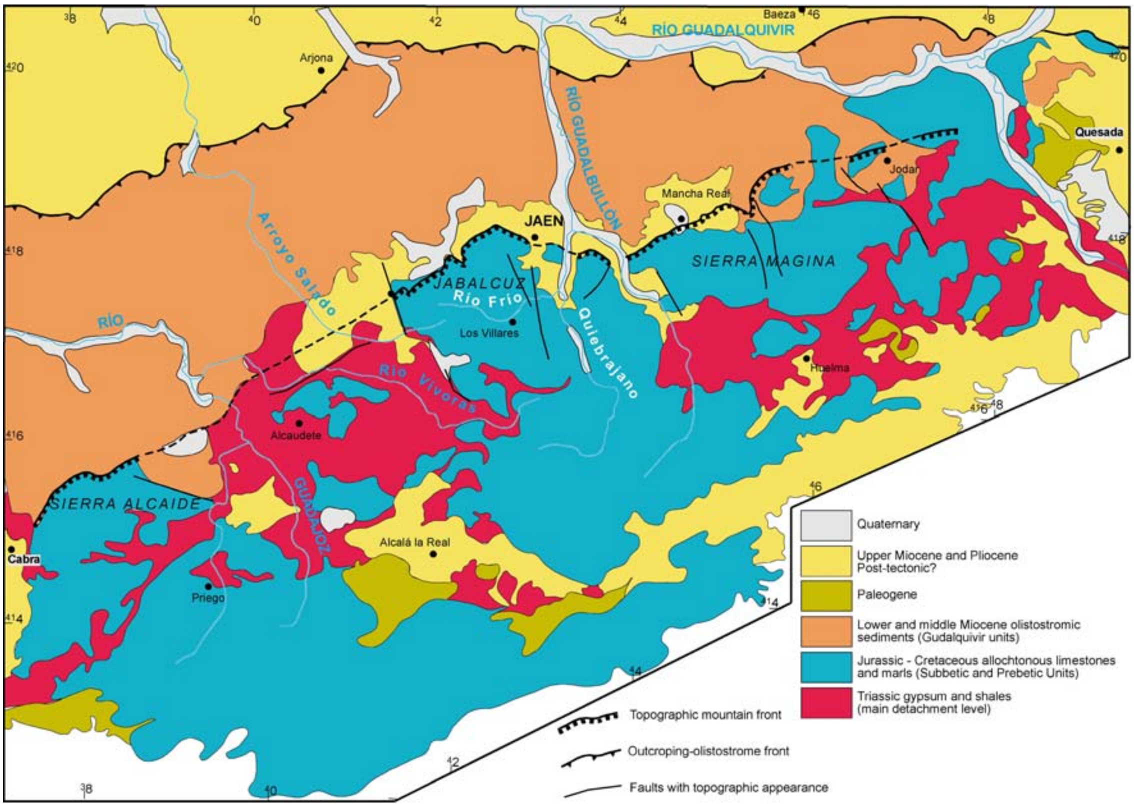

Figure 2. Simplified geological map of the South margin of the Guadalquivir basin and the Central Betics.

Figure 3. A Guadalbullón river terrace, south of Jaén, largely incised respect to the current stream bed (at the bottom of the picture), nowadays separated more than 50 m.

Figure 4. Fluvio-lacustrine sediments on the Quiebrajano valley, showing several abandoned terrace levels. Note the meandering shape of the terraces but the near straight present stream, incised near 30 m on lacustrine sediments bellow the terraces, indicating discrete changes of the base level.

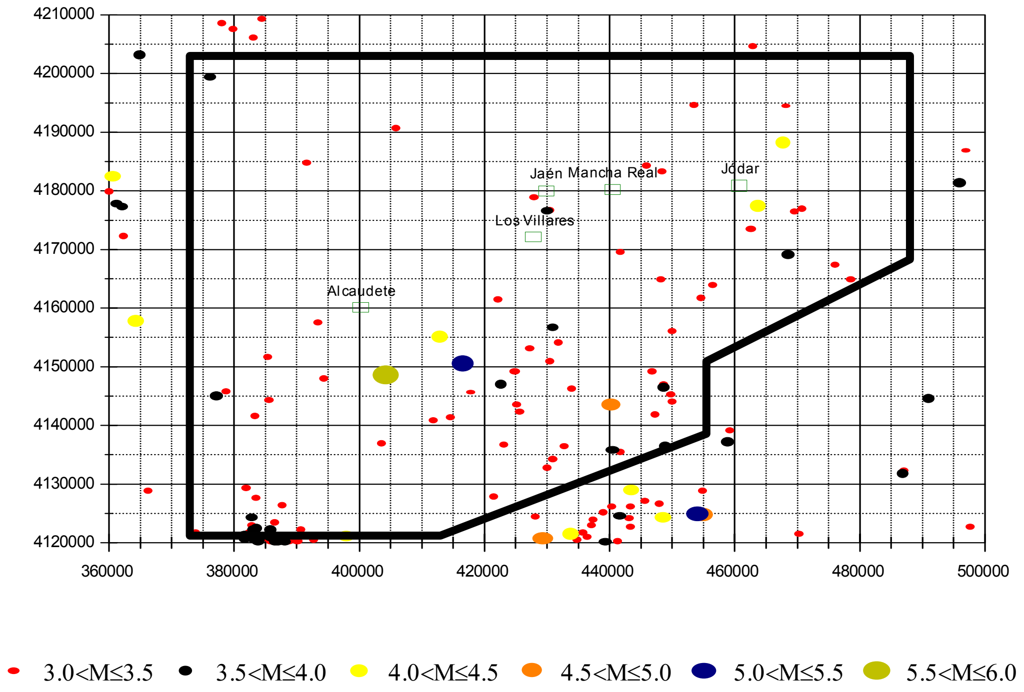

Figure 5. Seismicity of the studied area. The drawn towns outline roughly the Betic mountain front. Note the practically absence of earthquakes NW of this imaginary line.

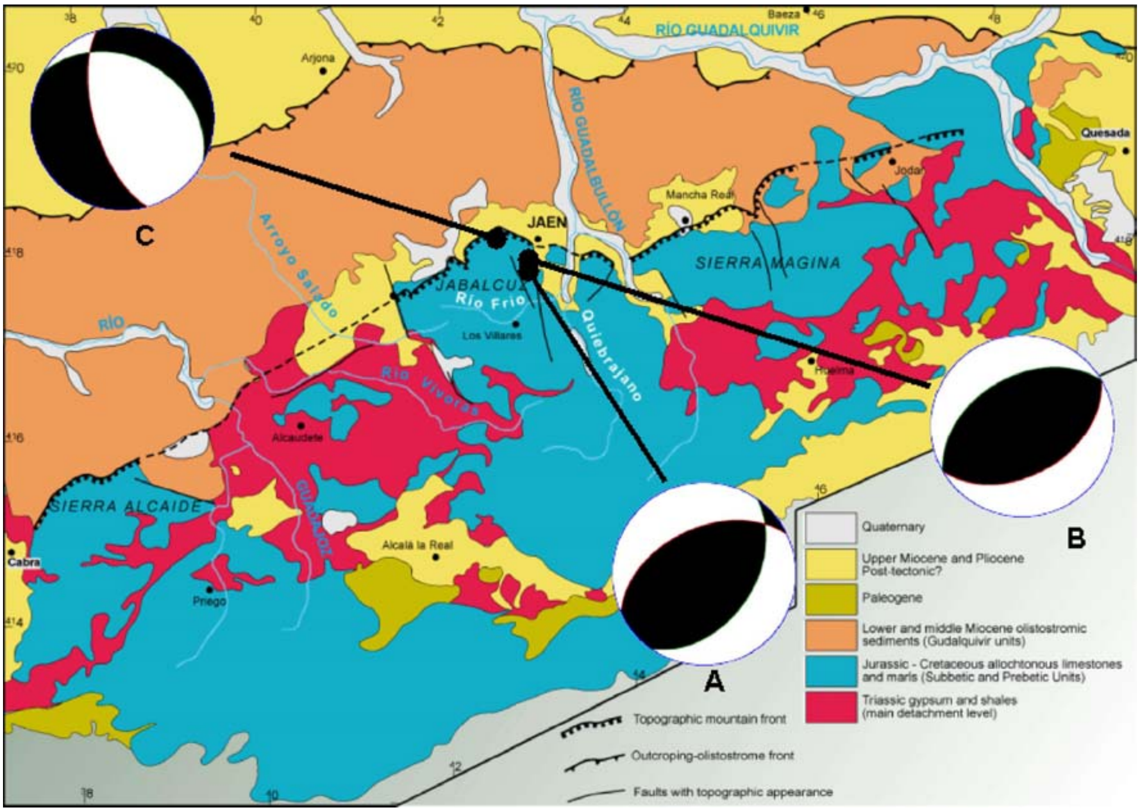

Figure 6. Focal mechanism of three earthquakes SW of Jaén town. A) Earthquake occurred the 24/06/2001 at 04:26:52 GMT, coordinates 37º43'58"N, - 3º47'38"E, 2 km deep and m_b=3.7. B) Earthquake occurred the same day that "A" at 10:50:06 GMT, coordinates 37º43'58"N, - 3º47'20"E, 2.5 km deep and m_b=3.4. C) Earthquake occurred the 09/11/1985 at: 21:36:26 GMT, 37º45'28"N, -3º51'39"S, 38 km deep and m_b=3.