

EARTHQUAKE
ARCHAEOLOGYINQUA PALEOSEISMOLOGY
AND ACTIVE TECTONICS

NEOTECTONIC ACTIVITY OF THE GRANADA BASIN – NEW EVIDENCE FROM THE PADUL-NIGÜELAS FAULT ZONE

Rudersdorf, Andreas, Jochen Hürtgen, Christoph Grützner, Klaus Reicherter

Lehr- und Forschungsgebiet Neotektonik und Georisiken, RWTH Aachen, Lochnerstraße 4-20, 52056 Aachen (Germany).

E-Mail: andreas.rudersdorf@rwth-aachen.de, jochen.huertgen@rwth-aachen.de

Abstract (Neotectonic activity of the Granada Basin – New evidence from the Padul – Nigüelas fault zones): The Padul-Nigüelas Fault Zone (PNFZ) is situated at the south-western mountain front of the Sierra Nevada (Spain) in an extensive regime and belongs to the internal zone of the Betic Cordilleras. The aim of this study is a collection of new evidence for neotectonic activity of the fault zone with classical geological field work and modern geophysical methods, such as ground penetrating radar (GPR). Among an apparently existing bed rock fault scarp with triangular facets, other evidences, such as deeply incised valleys and faults in the colluvial wedges, are present in the PNFZ. The preliminary results of our recent field work have shown that the synsedimentary faults within the colluvial sediments seem to propagate basinwards and the bed rock fault is only exhumed due to erosion for the studied segment (west of Marchena). We will use further GPR data and geomorphologic indices to gather further evidences of neotectonic activity of the PNFZ.

Key words: Active faulting, ground penetrating radar (GPR), neotectonics, Granada Basin

INTRODUCTION

The Granada Basin is a seismically active intramontane basin in the Betic Cordillera of Andalucía, Southern Spain. Earthquakes have been documented both in the historic and the instrumental record (Reicherter (2001) among others). Situated in an extensive regime, normal faults delimit basins of Neogene and Quaternary ages. In this study, modern geophysical methods like ground penetrating radar (GPR) have been combined with classical geologic field work to gain new insight into neotectonic activity of the Padul-Nigüelas Fault Zone.

GEOLOGY

The convergence of the Eurasian and African plates resulted in coupled extension and compression during the Oligocene and Miocene whereas recent stress fields designate a NW-SE oblique convergence with a velocity of 4 mm/a (McClusky et al., 2003). As a result the Betic Cordillera orogeny formed a highly folded mountain belt simultaneously with associated normal faults. Uplift and exhumation resulted in erosion of stacked lithological units (Galindo-Zaldívar et al., 2003). The Betic Cordilleras are subdivided into an External Zone and an Internal Zone, which is subdivided into the Malaguide-Complex, the Alpujárride-Complex and the Nevado-Filábride-Complex because of different metamorphic facies.

The Padul-Nigüelas Fault Zone (PNFZ), situated in the internal zone of the Betic Cordilleras, is part of a NW-SE trending system of normal faults adjacent to sedimentary basins. They usually show a

sedimentary succession from Tortonian ages (11.6 - 7.2 Ma BP) on and consist of calcarenites, evaporites, terrigenous clastics as well as carbonate intercalations. The youngest sequences are composed of Quaternary colluvial and alluvial deposits. The footwall, the Alpujárride complex, comprises several units, such as metapelites, metapsammities and quartzites at the base and carbonate rocks as uppermost formation. (Azañón et al., 2002)

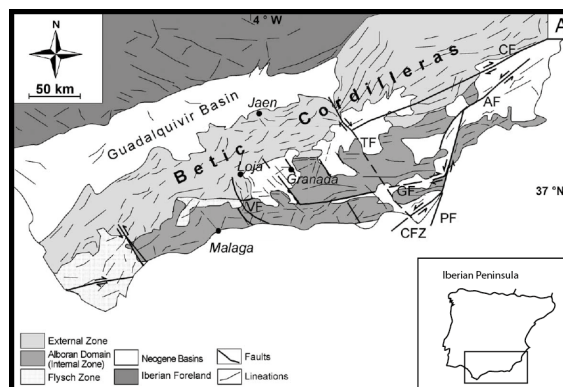


Fig. 1: Geological Map of the southern Iberian region (after Reicherter & Peters, 2005).

The PNFZ (Fig. 2) is well documented in the westernmost and easternmost parts whereas faults are circumspectly indicated in the central part north of Dúrcal. Due to the hard-rock carbonate lithology of the Alpujarrian basement, active faults in this segment are commonly preserved as bedrock fault-scarps.

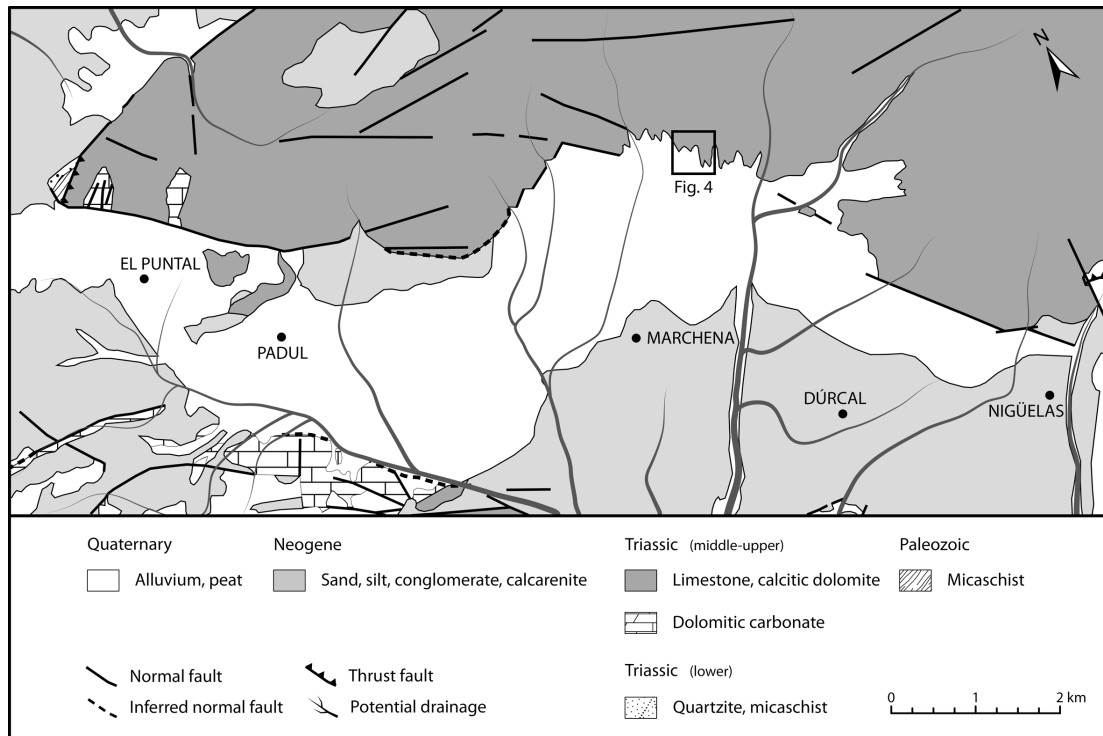


Fig. 2: Geological Map of the Padul-Nigüelas Fault Zone, simplified and composed from Sanz de Galdeano et al. (1975) and González Donoso et al. (1978).

METHODS

Apart from classical field methods, such as geological mapping, we used geophysical survey methods like ground penetrating radar and laser distance measurements to get a detailed image of both subsurface and outcropping structures in order to give evidence for historic and recent seismic



Fig. 3: Illustration of a laser distance measurement. Exhumed scarp near the natural monument "Nigüelas Fault".

activities in the Padul-Nigüelas Fault Zone.

Laser distance measurements

Laser distance measurements (LDM) have been done with a compact rangefinder (LTI TruPulse 360) with an integrated tilt sensor and compass to measure slope, horizontal distance, vertical distance, inclination and azimuth of points in outcrops. LDM was used (1) to describe undulating scarp geometries and their dimensions and (2) to get exact relationships between several faults in outcrops of colluvial wedges and alluvial fans. The method of LDM is illustrated in Fig. 3. The rangefinder is mounted on a tripod and the position of the tripod is stationary during a measurement. With a narrow grid, it is possible to get detailed information about exhumed scarp planes or faults in colluvial wedges. We have recorded these measurements at several sites in the PNFZ.

Ground penetrating radar

Ground penetrating radar is a non-invasive geophysical method which uses electromagnetic waves for shallow subsurface surveys. Due to changing magnetic and electric properties in the underground, reflections of transmitted waves can be registered and the two way travel time (TWT, in ns) of the waves gives information about the depth of a reflector. We used a 270 MHz antenna to record the raw data, which have to be interpreted by various filtering and correction tools. According to subsurface conditions (permittivity, conductivity, presence of water-saturated or clay-rich sediments), the penetration depth varies between 5 and 10 m with high-resolution data. In our study area, we especially



EARTHQUAKE
ARCHAEOLOGY

INQUA PALEOSEISMOLOGY
AND ACTIVE TECTONICS



investigated the colluvial wedges and alluvial fans of the Padul-Nigüelas Fault Zone with the aim to find basinwards trending faults in the subsurface.

PRELIMINARY RESULTS

The 3-week field work for this study has just been completed in the end of April 2011 and the evaluation and processing of recorded data is still in progress. Therefore, we present some preliminary results, especially from the central part of the Padul-Nigüelas Fault Zone on the Marchena fan.

During our field work, we have found several obvious evidences which suggest geologically recent fault activity in the PNFZ, such as triangular facets, deeply incised channels, faultward dipping layers and faults in both colluvial wedges and alluvial fans at numerous sites within the PNFZ. These features were also observed and documented by other authors (e.g. Alfaro et al. (2001), Galindo-Zaldívar (2003)).

The morphology of the PNFZ is characterized by the exhumed fault scarp, developed on the Alpujarrian bedrock. We could confirm the observations from Alfaro et al. (2001), who has already mentioned that the scarp is exhumed due to erosion and not due to fault activity. The exhumed fault scarps of the PNFZ are specified by lateral as well as downslope undulations of the main fault plane surface in a widespread range. The dip angle varies in a range from 20° to 65° and the dip direction from 190° to 260°. These undulations were documented and combined with laser distance measurements on several sites along the exhumed fault scarp of the entire fault zone.

Due to the apparently inactive main fault, our investigations in the field brought the colluvial wedges and alluvial fans in front of the PNFZ into focus. We gathered multiple profiles of faults in the colluvium and alluvium by classical field methods and by laser distance measurements. We have found active as well as buried faults in the sediments (see also Hamdouni et al. (2008)). Most of the outcrops are created naturally by strong river incision into the sediments and are situated adjacent to the bedrock fault scarp.

For this state of our study, we have concentrated the field-work on the widespread alluvial fan deposits located between the two segments of the Padul-Nigüelas Fault Zone developed on the Alpujarrian bedrock north of Marchena, which is axially dissected

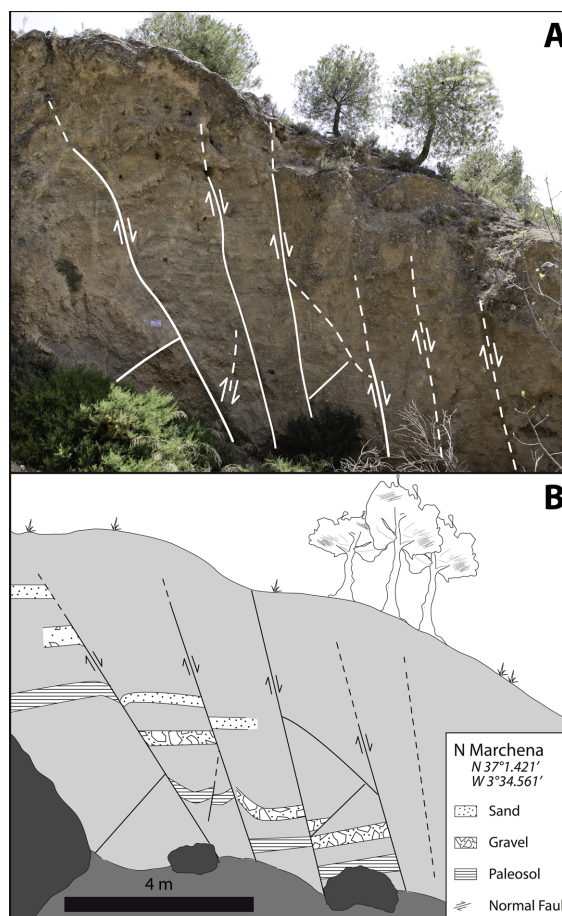


Fig. 4: Outcrop of an incised channel in the alluvial and colluvial fan in the north of Marchena. A: Photograph of the colluvial sediments and existing faults. B: Sketch of the same outcrop with a few traceable layers.

by the river Dúrcal. We collected several GPR profiles and documented several outcrop profiles in the proximal colluvial wedges developed at fault-fan contacts. One example is located in the northern part of the Marchena fan (Fig. 2). Fig. 4 shows a photograph of the outcrop (A) with interpreted faults in the sediments and a sketch (B) with the simplified geometry and certain marker horizons. On the basis of these horizons, we can preliminary determine the offset of the larger faults between a few cm and 1.8 m. Noticeable features in the faults are aligned clasts with their longitudinal axis along slip direction and carbonate-coated clasts, which indicate water circulation on the faults. Some of the faults are traceable up to the surface and build small scarps in the topography.

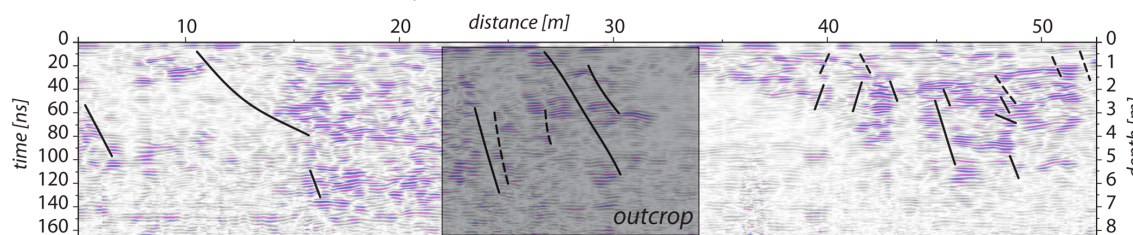


Fig. 5: GPR profile on the upper surface of the outcrop (Fig. 4). The profile is not topographically corrected and a velocity of 0.1 m/ns is assumed for the time-depth conversion. Grey box: excerpt of the outcrop. Black lines: interpreted faults.

EARTHQUAKE
ARCHAEOLOGYINQUA PALEOSEISMOLOGY
AND ACTIVE TECTONICS

In addition to the documentation of the faults in the colluvial wedge, we achieved a GPR profile on the upper surface of the outcrop (Fig. 5). The processed data is not topographically corrected, but first interpretations allow inferring a few faults in the profile. An exact correlation between the outcrop and the radar profile was not done so far. This profile as well as profiles in other studies (Reicherter et al. (2001)) demonstrates that GPR surveys are a useful method to locate faults and faultward dipping layers within colluvial wedges along presumably active range-front faults, such as the case of the Padul-Nigüelas Fault Zone.

The above mentioned features also occur at sites NW of El Puntal, Padul and Nigüelas which points to similar fault activity in this stage of our research.

DISCUSSION & OUTLOOK

The Padul-Nigüelas Fault Zone has been examined extensively for decades and is considered as active since instrumental and historical seismicity indicate several earthquakes in the Granada Basin. In our field study we found the fault scarps exposed because of erosion instead of fault activity. The colluvial wedges are not undisturbed, they show both buried and active faults, therefore we consider basinwards trending fault activities for this sector, as well as for the entire PNFZ.

Since our study is not finished, GPR data and geomorphologic indices will be used to give further evidence for either active or inactive faults in the Padul-Nigüelas Fault Zone.

References

- Alfaro, P., J. Galindo-Zaldívar, A. Jabaloy, A.C. López-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), 283-295.
- Azañón, J.M., J. Galindo-Zaldívar, V. García-Dueñas and A. Jabaloy (2002). Alpine tectonics II. Betic Cordillera and Balearic Islands. In: W. Gibbons and T. Moreno (eds.), *The Geology of Spain* 16, 401-416.
- Galindo-Zaldívar, J., A.J. Gil, M.J. Borque, F. González-Lodeiro, A. Jabaloy, C. Marín-Lechado, P. Ruano, C. Sanz de Galdeano (2003). Active faulting in the internal zones of the central Betic Cordilleras (SE, Spain). *Jornal of Geodynamics* 36, 239-250.
- González Donoso, J.M., V. García-Dueñas, J.A. Gallegos, J. Avidad Castañeda (1978). Mapa Geológico de España - 1041 Dúrcal. Instituto Geológico y Minero de España.
- Hamdouni, R., Irigaray, C., Fernández, T., Chacón, J., Keller, E.A. (2008). Assessment of relative active tectonics, southwest border of the Sierra Nevada (southern Spain). *Geomorphology* 96, 150-173.
- McClusky, S., R. Reilinger, S. Mahmoud, D. Ben Sari, A. Tealeb (2003). GPS constraints on Africa (Nubia) and Arabia plate motions. *Geophysical Journal International* 155 (1), 126-138.
- Reicherter, K.R. (2001). Paleoseismologic advances in the Granada basin (Betic Cordilleras, southern Spain). *Acta Geologica Hispanica* 36 (3-4), 267-281.
- Reicherter, K., G. Peters (2005). Neotectonic evolution of the Central Betic Cordilleras (Southern Spain). *Tectonophysics* 405, 191-212.
- Sanz de Galdeano, C., J.M. González Donoso, J.A. Gallegos (1975). Mapa Geológico de España - 1026 Padul. Instituto Geológico y Minero de España.