QUANTIFICATION OF TECTONIC DEFORMATION IN SOUTHEASTERN SPAIN BY COMPARING HIGH PRECISION LEVELING DATA

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Abstract

Comparison of high precision leveling data carried out in different epochs is a technique that permits us to quantify recent vertical movements. We used the high precision leveling data from the Instituto Geográfico Nacional to improve our knowledge of the areas in southeastern Spain where major deformation has occurred in this century.

Four major leveling lines have been studied: Alicante-Albacete, Alicante-Almería, Almería-Málaga and Almería-Linares. The results obtained demonstrate that the most important deformation rates are located near major tectonic structures such as the Cádiz-Alicante and the Valldinga-Jumilla faults, the Almería basin faults and the faults that affect the coast of the Alborán sea. Most of the anomalies observed can be related to ENE-WSW faults with a reverse component or to faults oriented NE-SW or NW-SE with a normal component. These movements agree with the Betics stress tensor determined from different methodologies, which indicates the existence of an approximately N-S compression together with an E-W extension. If we regard constant the rate of deformation, an estimate of the return periods for major earthquakes (M=6.0) is possible. The return periods obtained agree with those deduced from the seismic catalogues in areas where there is sufficient information. This confirms the validity of the leveling data we used. The return periods range between 250 and 1000 years depending on the zones.

Introduction

Comparison of high precision leveling data carried out in different epochs has been applied in different areas of the world to quantify recent vertical tectonic deformations. We used the high precision leveling data from the Instituto Geográfico Nacional (IGN) measured between 1872 and today to improve our knowledge about the areas in southeastern Spain where significant deformation has occurred during this century. The precision and quality of the IGN data permit us to carry out this study, as was demonstrated in a previous work in the northeast of Spain (Giménez et al., 1996).

To quantify vertical deformations we used the original data from IGN archives to construct recent vertical movement profiles by adding the vertical movements between each two bench marks along a line. In the profiles the first bench mark is considered stable. The vertical movements are obtained by comparing the height differences between two common bench marks obtained in different epochs and measured along the same path. Kilometric errors for each line were recalculated. In all the profiles we represent two standard deviations related to the previous bench mark (95% of confidence). Vertical movements smaller than the error bar are not considered. Systematic correlation between vertical movements and topography, present in some of the profiles, was corrected, when possible, by a method proposed by Stein (1981) (Giménez et al., 1996).

The analysis of the constructed profiles allows us to determine the faults around which major deformation has accumulated in this century. Nevertheless, the obtained vertical movements can be related to or magnified by superficial (non tectonic) movements as compaction of young sediments or anthropic influences.

Vertical movements profiles

The studied lines Alicante-Albacete, Alicante-Almería, Almería-Málaga and Almería-Linares are represented on a geological sketch of the southeastern Spain (figure 1). The main vertical anomalies obtained in the profiles together with the I=IX historic epicenters (IGN, 1983) are also presented in the same figure.

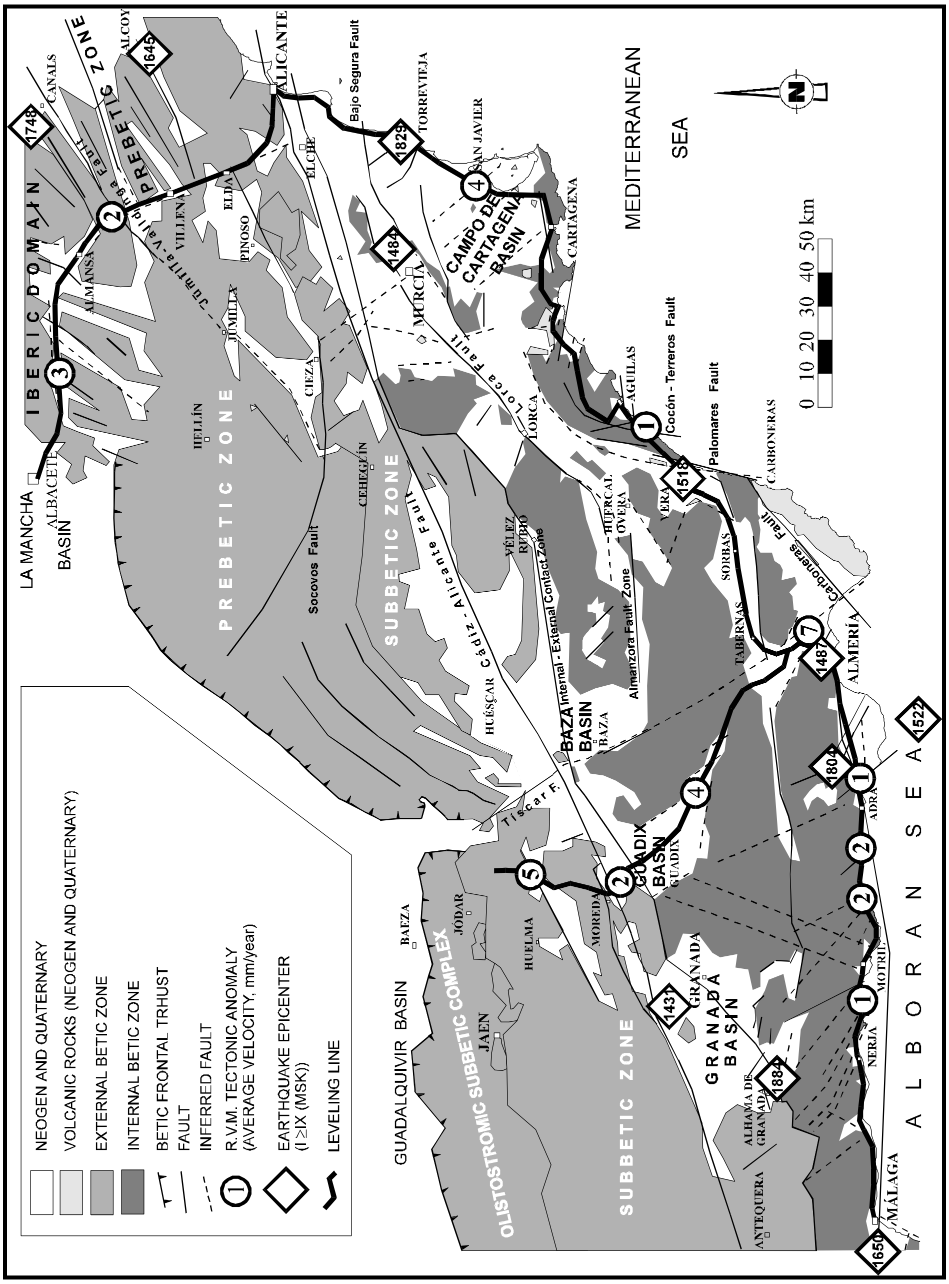

Figure 1: Studied leveling lines of the southeast of the Iberian Peninsula on a geological sketch.

Alicante-Albacete line

This line was leveled 5 times (1872, 1880, 1885, 1925 and 1975). Almost all the recent vertical movements profiles constructed with this data (1872-1880, 1872-1925, 1885-1925 and

1925-1975) show a rise of approximately 2 mm/year of the Prebetic domain in the south respect to the Iberian domain in the north affecting a wide area between Villena and Almansa (figures 1 and 2). We attributed the rise to the recent movement of the ENE-WSW oriented faults affecting the Prebetic zone (Jumilla-Valldinga fault and other faults) (figure 1) (Sanz de Galdeano, 1983; López Casado et al., 1987; Buforn et al., 1995). The activity of these faults can be also associated with historic seismicity (I=IX, Enguera 1748 and Tabernes 1396) and instrumental seismicity (IGN, 1983). The subsidence of Villena related to Sax in the 1925-1975 profile must be associated with superficial movements, as the 1925-1975 bench marks are not located in the same building as the bench marks used in the other profiles.

The subsidence of the northern part (Chinchilla de Montearagón-Albacete) related to El Villar de Chinchilla, observed in some of the profiles should be mainly related to sedimentary compaction of young sediments, given that the seismicity of the area is very low (Giménez, 1997).

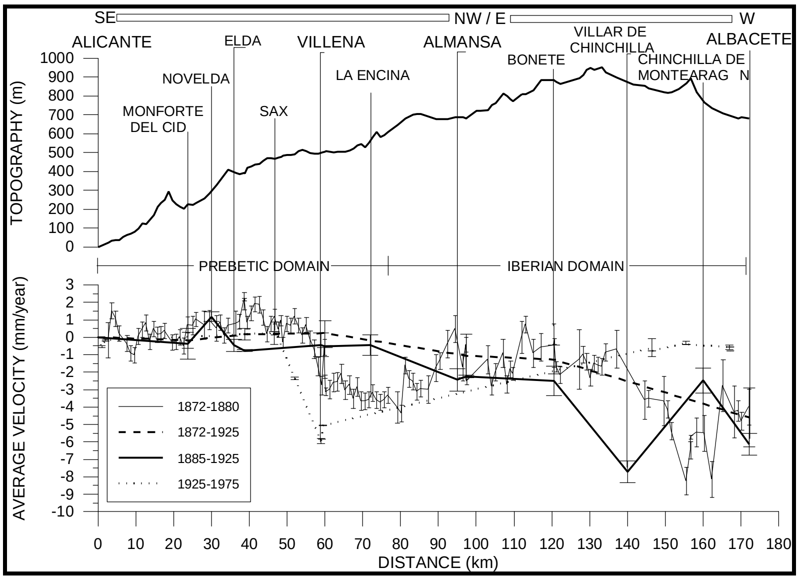

Figure 2: Average velocities between Alicante and Albacete (in mm/year), related to Alicante, obtained from the comparison of the IGN leveling lines (1872, 1880, 1885, 1925 and 1975). The error bars represent two standard deviation related to the previous bench mark. The above profile represents the topography of the profile in meters.

Alicante-Almería line

This line was leveled in 1934 and 1976. The 42 year time span Alicante-Almería profile constructed shows three main anomalies: a subsidence of the San Javier bench marks (4 mm/year); a step between Águilas and Terreros (1 mm/year); and a sinking (2 mm/year) of the Almería basin bench marks (figures 1 and 3).

The San Javier and Almería anomalies can be associated with compaction of young sediments. Nevertheless, it should be borne in mind that in the Almería basin there are NW-SE faults that affect the Quaternary sediments (Montenat, 1990; Sanz de Galdeano, 1983; 1990). These faults can be associated with the moderate seismicity that characterizes the Almería basin, where a destructive earthquake took place in 1487 (figure 1). Thus, the subsidence of the Almería bench marks can also be related to tectonic movements. On the other hand, the Águilas-Terreros anomaly can be attributed to the tectonic activity of the N-S oriented Cocón-Terreros fault zone together with other internal faults of the area (figures 1 and 3). The profile indicates that the vertical movements near the Palomares fault zone (figure 1) have been practically insignificant during this century.

Almería-Málaga line

The line was leveled three times (1903, 1934 and 1976/84), which allows us to construct two different profiles: Almería-El Palo (near Málaga) (1903-1934) and Almería-Calahonda (1934-1976) (figure 4).

The 31 year time span Almería-El Palo profile shows a sinking of a large part of the Alborán coast in relation to Almería and to Málaga. Thus, the Adra-Salobreña block sinks 1 mm/year in relation to Almería and Almuñécar, and the La Rábita-Calahonda block sinks 2 mm/year in relation to Adra and Salobreña (figures 1 and 4). This subsidence must be related to the recent activity of the NW-SE and NE-SW faults which affects this zone of the Alborán coast (Sanz de Galdeano, 1983; 1990; Buforn et al., 1995) (figure 1) and can be associated with the seismic activity of the area.

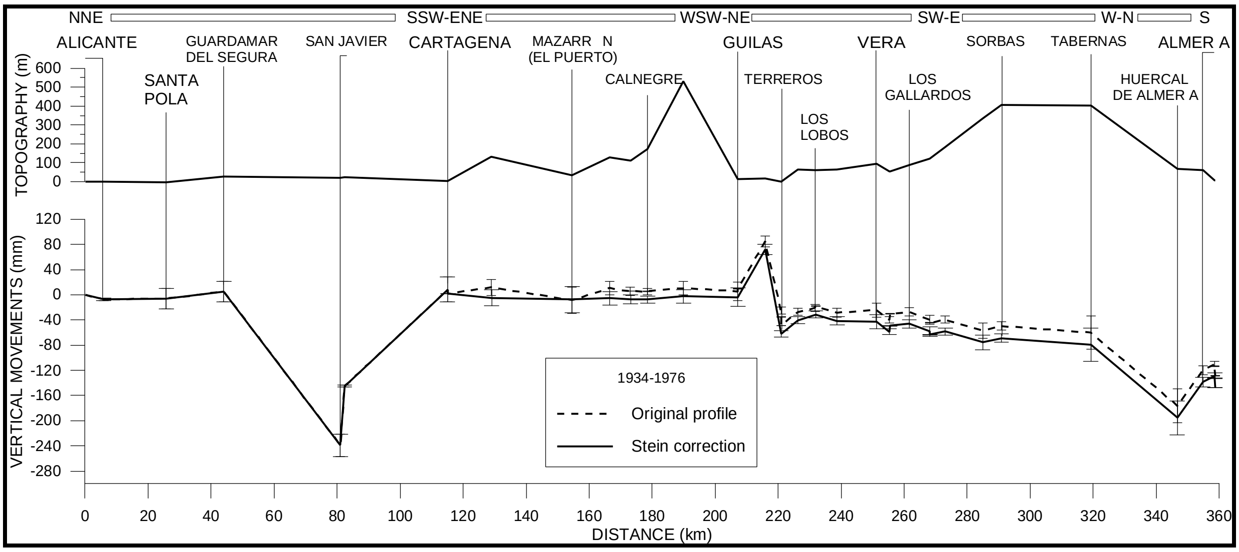

Figure 3: Recent vertical movements between Alicante and Almería (1934-1976), related to Alicante. The error bars represent two standard deviation related to the previous bench mark. The above profile represents the topography of the profile in meters.

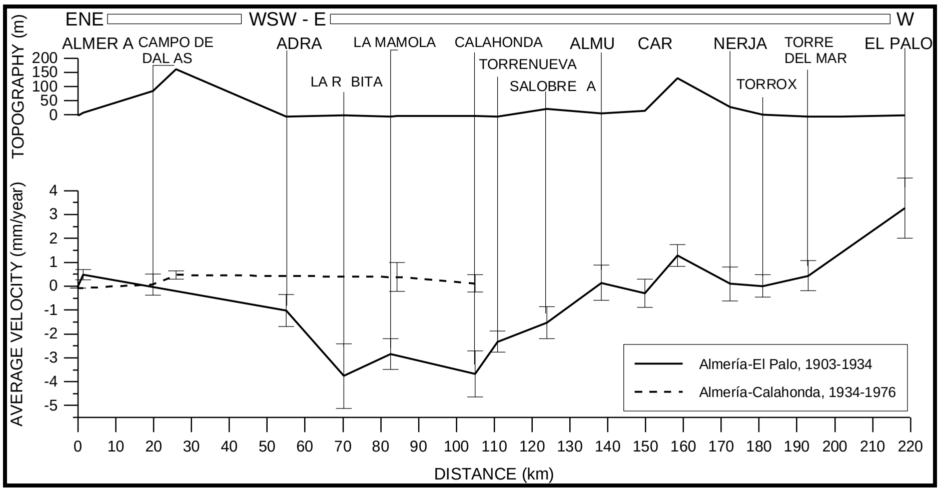

Figure 4: Average velocities between Almería and El Palo (near Málaga) (1905-1934) and between Almería and Calahonda (1934-1976), related to Almería. The error bars represent two standard deviation related to the previous bench mark. The above profile represents the topography of the profile in meters.

By contrast, the later 42 year time span Almería-Calahonda profile does not show any significant movement. This controversy can be explained if we consider that the observed movements between 1903-1934 have a coseismic origin. In fact, in 1910 a I=VIII earthquake affected the village of Adra, and some other I=VI took place between 1903 and 1934. On the other hand, between 1934 and 1976 no I>V earthquakes were felt in the area (I.G.N., 1983). Given the information of the two profiles, Calahonda has sunk 1 mm/year with respect to Almería, between 1903 and 1976.

Almería-Linares line

This line was leveled in 1903 and 1933. The original 31 year time span recent vertical movements profile between Larva and Almería shows a systematic correlation between movements and topography, which was corrected with the Stein method (1981) (figure 5).

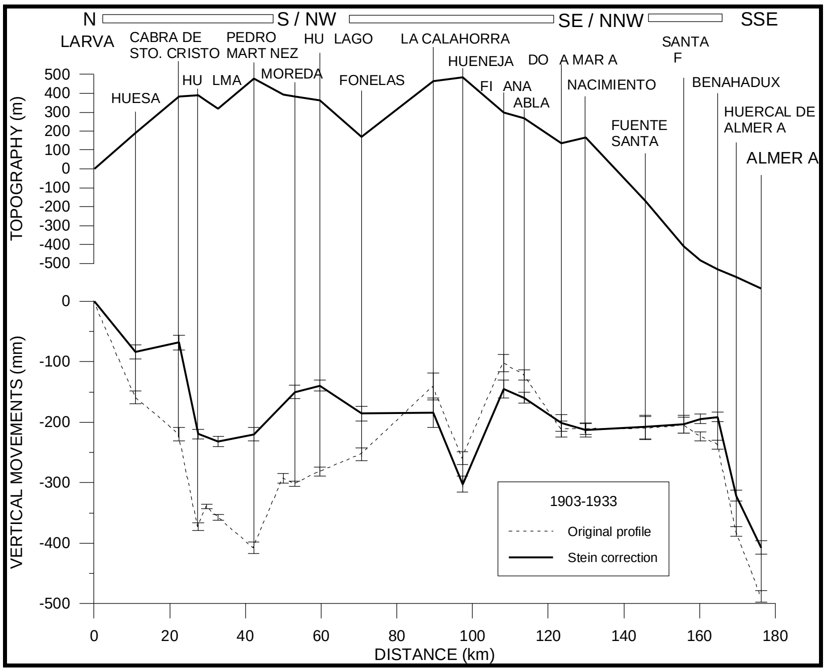

Figure 5: Recent vertical movements between Larva (Jaén) and Almería (1903-1933) related to Larva. The error bars represent two standard deviation related to the previous bench mark. The above profile represents the topography of the profile in meters.

The Larva-Almería profile shows four significant anomalies (figure 5): a sinking of the Huélma bench mark in relation to the Cabra de Santo Cristo of about 5 mm/year of average velocity; a rise of the Moreda bench mark in relation to Pedro Martínez of about 2 mm/year; a negative spike of the Hueneja bench mark, of about 4 mm/year, which reveals a sedimentary or antropic origin; and a subsidence of the Almería bench mark, related to Benahadux, of 7 mm/year.

The Pedro Martínez-Moreda step can be associated with the recent tectonic activity of the ENE-WSW oriented Cádiz-Alicante fault zone, and the Cabra de Santo Cristo-Huélma step can be related to the tectonic activity of the fault that runs some kilometers to the north of the Cádiz-Alicante fault in the same direction (figures 1 and 5) (Sanz de Galdeano, 1983; 1990; Buforn et al 1995). Nevertheless, as the high average velocities of these steps contrasts with the relatively low seismicity of the area (no destructive earthquakes have affected this zone (I.G.N., 1983)) a part of these anomalies has to be related to sedimentary processes, but a aseismic movement is also possible.

The subsidence of the Almería basin bench marks, also present in the Alicante-Almería profile (figure 3), can be associated with the recent activity of the NW-SE faults which characterizes this zone, although the moderate seismicity of the area (I.G.N., 1983) can not account for that high average velocity. For this reason, a large part of the anomaly has to be of sedimentary origin.

Conclusions

The results show the existence of important anomalies mainly located near major tectonic structures which show neotectonic features and seismicity (I.G.N., 1983; Sanz de Galdeano, 1983; 1990; López Casado et al., 1987; Buforn et al., 1995; Giménez, 1997), although some of the anomalies are due to sedimentary effects. It should be pointed out that most of the observed anomalies can be related to ENE-WSW faults, which can be associated with a reverse movement, or to NE-SW and NW-SE oriented faults which show a normal component of movement. These vertical movements are in accordance with the Betics stress tensor determined with different methodologies, which indicates the existence of an approximately N-S compression together with an E-W extension (Boccaletti et al., 1987; Sanz de Galdeano, 1990; Galindo-Zaldívar et al., 1993; Buforn et al., 1995).

If the observed rates of vertical deformation are considered constant in time and if we assume that the deformation results in big earthquakes, with no ductile deformation, an estimate of the recurrence periods of M=6.0 earthquakes can be made. Thus, considering 1 meter of displacement for an M=6.0 earthquake (Wells and Coppersmith, 1994), the return periods obtained range between 250 and 1000 years. These return periods agree with the ones deduced from the seismic catalogues in areas where there is sufficient information (I.G.N., 1983; Giménez, 1997).

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