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SERIE DE ESTUDIOS GEOLÓGICOS

Número 7 1988

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THE EVOLUTION, IMPORTANCE AND SIGNIFICANCE OF THE NEOGENE FAULT SYSTEM WITHIN THE BETIC-RIFEAN DOMAIN

por
C. SANZ DE GALDEANO *

RESUMEN

En el ámbito Bético-Rifeño existen fallas importantes de dirección N60-70E (algunas de las cuales afectan a todo el grosor litosférico) que han sido heredadas en parte desde el Mesozoico. En el estadio Neoalpino, estas fallas adquirieron gran importancia cuando se produjeron los movimientos hacia el W de las zonas internas bético-rifeñas. Cuando cesaron estos movimientos, otros juegos de fallas, en especial las NE-SW, sinistrorsas, y en menor grado las NW-SE, dextrorsas, adquirieron gran importancia. La mayoría de estas últimas fallas se formaron durante el Neógeno, aunque ya existieran en el W de Europa antiguas fallas de dirección NE-SW. Sus movimientos contribuyeron en gran medida a la formación de las cuencas neógenas del ámbito Bético-Rifeño.
PALABRAS CLAVE: Sistema de fallas, ámbito Bético-Rifeño, neógeno.

ABSTRACT

In the Betic-Rifean Domain occur major faults of N60-70E direction (some of which transect the lithosphere), which have been inherited partially from the Mesozoic. In the Neoalpine stage, these faults acquired particular importance due to the movements towards the W of the Betic-Rifean Internal Zones. When such movement ceased, NE-SW sinistral faults and, to a lesser extent, NW-SE dextral faults acquired greater importance. Mostly of these last faults were formed during the Neogene, although ancient NE-SW faults existed already in W Europe. The different movements of these sets of faults have greatly contributed to the formation of the neogene basins within the Betic-Rifean Domain.
KEY WORDS: Fault system, Betic-Rifean Domain, Neogene.

INTRODUCTION

Several papers have already stressed the role of faults within the Betic-Rifean Domain, such as Leblanc and Olivier, (1984), Sanz de Galdeano (1983 and 1988), De Smet (1986), Larouzière *et al.*, (1988), Morel (in press), amongst

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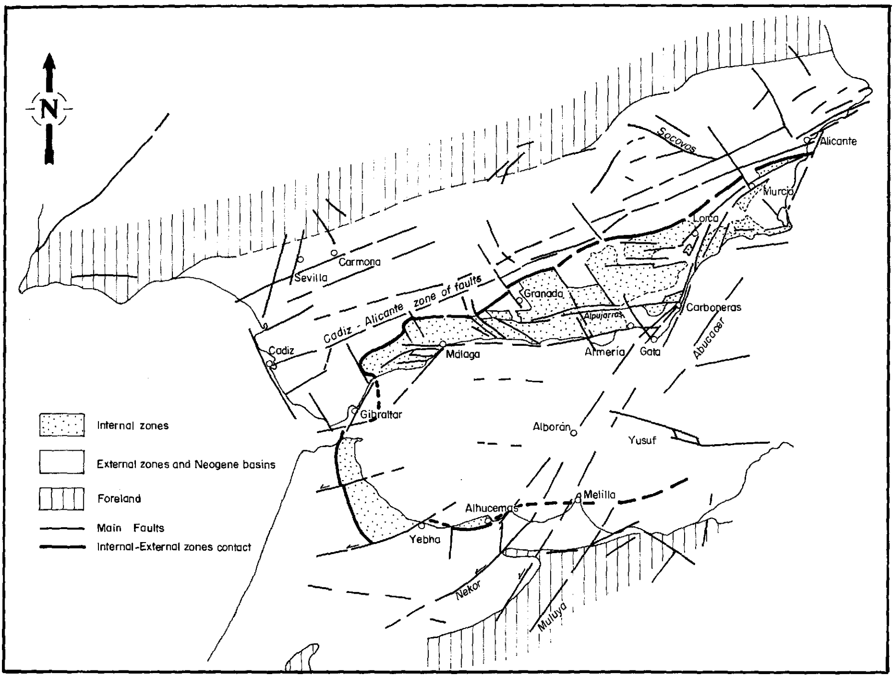

Figure 1.— Major Faults of the Betic-Rif Domain.

others. These papers have contributed to a better understanding of the meaning and evolution of the fault system in this region, emphasizing the importance of the strike-slip faults involving transpressive and, in some cases, transtensive movements as well as subordinate vertical movements.

The present paper aims to advance knowledge on this evolution and on the relative importance of each set of faults in the region (figure 1).

GEOLOGICAL SETTING

The Betic and Rifean Cordilleras are the westernmost Alpine Chains to arise from the ancient Tethys. Their Internal Zones are common, whereas the External Zones are not equivalent.

From the Triassic to the Eocene approximately, the relative positions between Africa and Iberia changed. Originally, Iberia was positioned almost directly opposite present-day Algeria position (figure 2), later shifted towards a more westerly position, with regard to Africa, and afterwards eventually moved towards the E in order to occupy its present position. These movements were facilitated by the existence of almost E-W megafaults, the Azores protofaults, which may have been divided into several lines, (Wildi, 1983).

The Internal Zones of the Betic and the Rifean Cordilleras were originally several hundred kilometres farther to the east. There they were subjected to

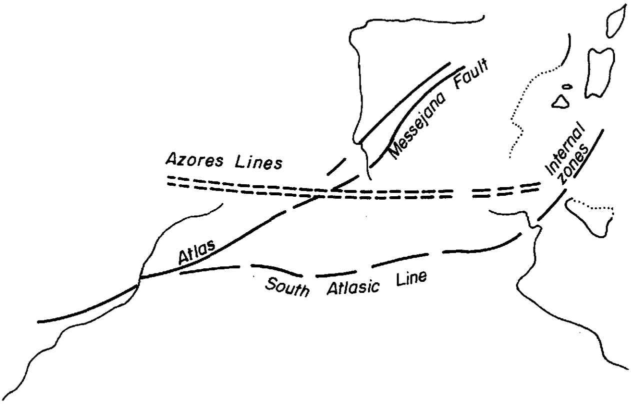

Figure 2.— Lower Liassic reconstruction of the relative position between Iberia and Northwest of Africa.

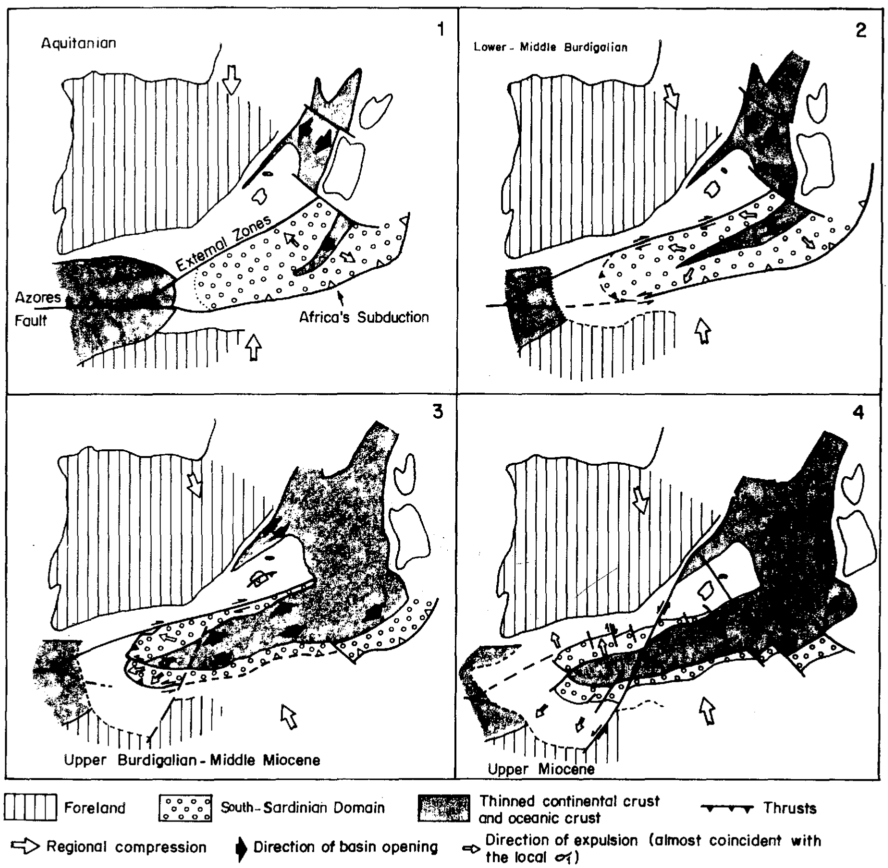

Figure 3. Kinematic reconstruction of the Expulsion of the Internal zones of the Betic and Rif Cordilleras towards the West, and regional and local direction of compressions.

Eo and Mesoalpine deformations (during the Upper Cretaceous-Paleocene and Eocene-Oligocene times respectively) and were metamorphized and repeatedly structured. In the Neoalpine stage, Africa was subducted under the Alboran Domain or «Alkapeca» (Alboran, Kabylia, Peloritano and Calabria) Domain (Bouillin *et al.*; *in* Weret, 1986) or South Sardinian Domain (Sanz de Galdeano, in press). This subduction decreased progressively towards the W, in coincidence with the prolongation of the Azores Fault. The lack of space caused in the Western Mediterranean by the mentioned subduction and the opening up of the Algero-Provençal Basin as a back-arc basin, in turn caused the expulsion of the Betic-Rif Internal Zones towards the west with movements occurring during the Lower and Middle Miocene up to the beginning of the Upper Miocene. In this time span, the general compression direction between Africa and Europe was almost N-S (NNW-SSE) (figure 3). The expulsion of the internal Zones, however, caused WNW-ESE compressions in the Betic Cordillera and WSW-ENE in the Rif; in other words, a «local» (large scale) stress field, clearly differentiated from regional stress. This has greatly influenced the meaning and the movements of the faults.

THE FAULTS PRIOR TO THE INTERNAL ZONES EXPULSION TOWARDS THE W. (EOCENE TO AQUITANIAN)

During the Eocene-Oligocene, the Azores fault (one or several lines of faults) ran between the External Zones of the Betics and Rif, with an approximate E-W direction. Apart form this fault, there were others in the External Zones of the Betic Cordilleras (such as the Antequera Fault, Martín Algarra, 1987) with an almost N70E direction, which acted as transtensional faults during the Mesozoic. Some of these faults must also have stretched out eastwards, towards sectors of the Western Mediterranean where, during the Eo and Mesoalpine stages, subduction and collision occurred respectively, although these barely had any repercussion farther to the W in the Betic or Rif External Zones.

In Central Europe, also during the Eocene?-Oligocene, the Rhine and Rhone grabens (almost N-S and approximately coincident with the regional compression direction) began to form. These grabens later extended towards the south, where, especially during the Burdigalian, the Algero-Provençal basin, and a little later, the Valencia trough (or North-Balearic Basin) were formed (figures 3 and 4).

In the south, in NW Africa, there are very old NNE-SSW faults in the Atlas (Tardi-Hercynian in origin) which contributed to the formation of grabens during the Mesozoic, where thick sediments were deposited in the Middle and, partially, in the High Atlas. After the relative movements between Iberia and Africa, these faults reached —in the Eocene-Oligocene— almost their present position, in coincidence with the geometric prolongation of the Rhone graben through the South Balearic Basin. This physical prolongation however, was not archieved even in the Lower Miocene.

Figure 4.— Grabens and strike-slip faults running from Northern Europe to NW Africa. Inspired in Ziegler (1987), Boillot et al. (1984) and Emery and Uchupi (1984).

THE FAULTS DURING THE EXPULSION OF THE INTERNAL ZONES TOWARDS THE WEST. (BURDIGALIAN AND MIDDLE MIOCENE PRO PARTE)

When these Internal zones advanced towards the W in the Burdigalian, one of the previous N60-70E direction faults came into action producing a major, dextral transpressive movement. This was the contact between the Internal and External Zones of the Betic Cordilleras (I.E.Z.C.), lithospheric in character, involving a displacement of several hundred kilometres. Subordinate thrusts are apparent at surface level. In the south, the subduction of Africa (Boillot *et al.*, 1984) under the Alboran Domain during the Neoalpine deformations may not have reached to the west the present-day position of the Rif as a result of its abatement on one of the possible eastern branches of the Azores Fault. This now coincides with the Jebha Fault (figure 1). According to the interpretation of Leblanc and Olivier (1984) this last fault moved during the Burdigalian. It's behaviour resembled the one of the I.E.Z.C., although its movement was sinistral in agreement with the σ_1 direction in this sector (ENE-WSW).

In so far as the Internal Zones movement towards the west was still of importance, the graben and strike-slip lineaments proceeding from the Rhine and Rhone grabens could not effectively be prolonged towards the south.

In the Betic Cordilleras, with σ_1 in an approximate WNW-ESE position, a dextral shear system, was established (Sanz de Galdeano, 1988), in which the I.E.Z.C., adquired significance as major fault (C) even though at the end of the Burdigalian became practically sutured (figure 5 and 6). Then the major movement continued along the Cádiz-Alicante fault zone (Crevillente fault) also of N60E direction and with the same characteristics and movements although situated within the External Zones. The new E-W faults were synthetic R-Type (Riedel) dextral faults, while the new formed NW-SE faults were antithetic R'-type, sinistral and therefore used different movements to those they later ac-

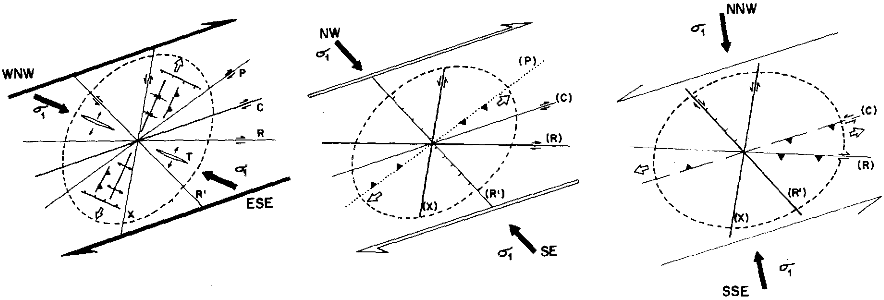

Figure 5.— Fractures and folds associated with a dextral simple shear system (as happened in the Betic Cordilleras, not in the Alboran Sea or in the Rif). C: Shear fault. R: Synthetic Riedel fault. P: Symmetric to R fault. R': Antithetic Riedel fault. X: Symmetric to R' fault. T': Tensional fractures. The different movements of the faults according to σ_1 directional changes (until the system becomes blocked) are shown. (From Sanz de Galdeano, 1988).

quired. The new NE-SW faults of the Betic Cordilleras either did not move or were sinistral, not very active X-type faults.

In the Rif, given that the Internal Zone outcrops are, by far, more limited and that the structuring of the External Zones held significant importance during the Tortonian, if is imposible for the movement to present a clear scheme of the shear system (in this case sinistral) like that for the Betic Cordilleras. However, there is little doubt that a similar scheme must indeed exist.

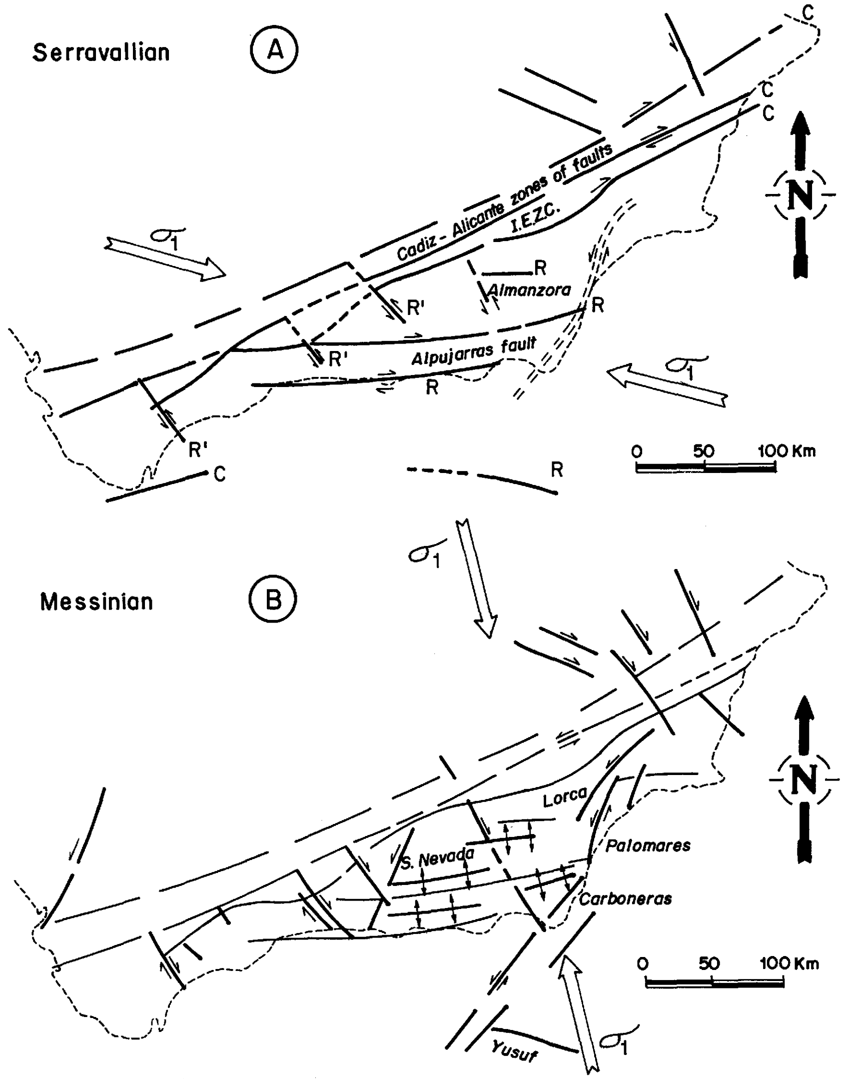

Figure 6.— Interpretation of the faults on the Betic Cordilleras. A) As a dextral simple shear system of faults with σ_1 in a WNW-ESE direction. B) NW-SE and NE-SW faults are more active with σ_1 in a NNW-SSE direction. See also the folds formed. Compare with Fig. 5 (from Sanz de Galdeano, 1988).

EVOLUTION OF FAULTS FROM THE MIDDLE (PRO PARTE) AND UPPER MIOCENE, AFTER THE RECOVERING OF THE ANCIENT GEODYNAMIC CONDITIONS (PRIOR TO THE EXPULSION OF THE INTERNAL ZONES)

When the movement of the Internal Zones towards the west progressively ceased and the corresponding expansion of the Alboran Sea decreased, the general compression direction existing in the region within the Betic-Rif Domain was re-established. In other words, in the Betic Cordilleras the position of σ_1 progressively changed, especially from the Tortonian onwards, from the WNW-ESE to the NNW-SSE direction (scheme 4 of figure 3).

In the Rif, the WSW-ENE direction became NNE-SSW. In both cases, they came close to a N-S orientation.

These directions should be considered in general terms, since each sector varies locally in detailed study. Although there are no direct data for the Alboran Sea, it is likely that the previously existing stretching disappeared during this period.

With this new position for σ_1, the importance and movements of the N60E to E-W fauts were largely reduced, while other faults ranging from NNE-SSW to NE-SW in direction appeared and/or emphasized their mobility. So came on scene the faults in the SE of Spain, which run from Alicante, through Lorca and Vera, up to Cabo de Gata, and cross the Alboran Sea to Morocco where they are known by the names of Nekor and Muluya faults. Leblanc and Olivier (1984) point out that the major movements of the Nekor fault occurred during the Tortonian. These faults acted with sinistral strike-slip. Their displacement in Spain has being reckoned up about 60 km, by taking into account their cross-cutting pattern with the E-W faults (Sanz de Galdeano, 1987).

In this way the lines of strike-slip faults and the grabens already originated in Northern Europe (figure 4) continued stretching southwards. They moved through the Rhine and Rhone grabens to reach the Western Mediterranean across the Algero-Provençal and the North-Balearic Basins. This extension towards the south would have previosly been impossible, as the opening up of the Alboran basin and the wedge like advance of the Internal Zones towards the west imposed a particular stress field in the Betic-Rif Domain at that moment.

Moreover, the continuation of the faults was facilitated farther to the south in the Atlas, due to the fact that the geometric prolongation of these faults was to be found along the old tardi-hercynian faults, produced as a consequence of the diverse movements between Africa and Iberia.

These NE-SW faults, therefore, were to acquire greater significance from the Tortonian onwards working as controls or vents for the expulsion of the abundant volcanic materials present in this sector. Moreover, in the Tortonian occurred aswell the major thrust in the External Zones of the Rif, from the NE to the SW, according to the σ_1 direction (NNE-SSW) predominating in this sector (Morel, in press).

The NW-SE faults, which are well represented in the Betic Cordilleras, moved as R' sinistral faults during the advance of the Internal Zones. Afterwards, as the σ_1 direction rotated, they changed the sense of their movements. Initially when the σ_1 direction coincided with their movements. Initially when the σ_1 direction coincided with their direction, they began to cause major vertical displacements. At this time, Tortonian and onwards, numerous intramontane depressions became progressively individualized in the Betic Cordilleras. Later with σ 1 in the NNW-SSE position these NW-SE faults began to move as dextral faults. Given that the obtuse bisectrix of the NW-SE and the NNE-SSW to NE-SW faults coincides *grosso modo* with the distension direction perpendicular to σ_1, both sets have, since then, presented vertical movements both in the Betics and in the Rif. The N60E to E-W faults, on the other hand, have remained practically blocked or moved slightly with sinistral slips (figures 5 and 6).

In spite of the predominance of the above-mentioned situation during the Pliocene and Quaternary, moments have been detected in which E-W to WNW-ESE compressions have prevailed in the Betic Cordilleras. This allowed the N60E to E-W faults to present new slight dextral movements (Estévez and Sanz de Galdeano, 1983).

Very little information is available from the Alboran Sea. It has already been mentioned that the NE-SW faults cross the Sea and determine the crest where the Alboran Island crops out. Mauffret *et al.* (1987) have also described the Yusuf fault as almost E-W with normal and dextral movements. Therefore it seems to be clear that in the Alboran Sea the same sets of faults which exist in the Betics and the Rif must have developed, although in an extensional geodynamic setting, during the Burdigalian and part of the Middle Miocene, and perhaps even part of the Tortonian.

DISCUSSION: SIGNIFICANCE AND CONSEQUENCES OF THE FAULTING

The important directions of faults in the Betic-Rif Domain coincide with those existing in W Europe and NW Africa formed during the tardi-Hercynian stage or dating from the beginning of the Mesozoic. The N60-70E to E-W faults have played a major role in the relative movements between Africa and Iberia and, therefore, in the paleogeography of the region. In the same way, the NNE-SSW to NE-SW faults must have existed in the birth of the Ligurian-Piemontese basin during the Jurassic. They were already in existence in the Atlas where they played a major role, as has already been mentioned, in the formation of grabens. Nevertheless the NNE-SSW, NW-SE and E-W sets of faults presently existing in the Betic Cordilleras were neoformed during the Neogene.

Following the destruction of the Ligurian-Piemontese basin in the Eo and Mesoalpine stages, the NNE-SSW faults of the North and Central Europe again began to propagate from the Rhine and Rhone grabens towards the south, with the opening of the Algero-Provençal Basin. Their propagation farther to the south was momentarily stopped during the Lower and Middle Miocene due to the expulsion of the Internal Zones from the Betic-Rif Domain towards the west. While this movement was taking place, the N60-70E faults and, to a lesser extent, the E-W faults, were to play the most important role in the Betic-Rif Domain.

The I.E.Z.C., therefore, is a dextral transpressive, lithospheric fault. Due to the Internal Zone movements, the External Zones, especially those in the

Betics, were cut, disorganized and also expelled. During this process the Gibraltar Arc was formed as a tectonic arc and olisthostromic formations occurred in the Cádiz Gulf, the Guadalquivir depression and the south of the Rif, which were placed in different movements dating from the Burdigalian to the Tortonian, or even later in the Gulf of Cádiz and the Rif. In association with this movements of the External Zones, within the Internal Zones, major extensional detachments occurred (García-Dueñas and Martínez Martínez, 1988) with a ENE-WSW movement sense, at the same time as the Alboran basin was being opened up and created.

As the I.E.Z.C. in the Betic Cordilleras and the Jebha fault in the Rif was becoming sutured, the movements of the faults continued along the Cádiz-Alicante fault area in the Betics and along the Temsamane fault (Frizon de Lamotte, 1982) in the Rif.

Once the W-component stress ceded with the subsequent paralysation of movement in the Internal Zones towards the W, and the NNW-SSE compressions progressively began to dominate, the NE-SW faults were able to extend. The latter crossed the Alboran Sea (Nekor and Muluya faults in the Rif) and they even managed to link up with the Atlas faults, judging from the alignment of both superficial and intermediate earthquakes (Buforn *et al.*, 1988, López Casado and Sanz de Galdeano, 1988). These faults then caused the major movements and controlled volcanism which was especially abundant in the Upper Miocene. The vertical movements of these and the NW-SE faults, which are now dextral, were responsible for the formation of many of the intramontane basins in the Betics and Rif. Simultaneously the significance of the N60-70 and E-W faults was then considerably reduced and their movements almost totally blocked.

CONCLUSIONS

a) The different sets of faults have substantially contributed to the structuring of the Betic-Rif Domain.

b) The N60-70E to E-W faults facilitated the expulsion of the Internal Zones towards the W, which, in turn, brought about the disorganization of the External Betic Zones and the formation of significant olisthostromic masses.

c) Once the N60-70E to E-W faults gradually became immobilized by the rotation of the compression direction, σ_1, towards the NNW-SSE position, the NE-SW faults acquired great significance. They controlled the neogenous volcanism in the SE of Spain and the NE of Morocco. They also linked the grabens and sinistral lithospheric faults of the North and Central Europe with the Atlas, thus constituting a weak crustal line which divides Europe in two part.

d) The NE-SW and NW-SE faults, moving jointly, present significant vertical displacements which have contributed to the formation of numerous intramontane basins in the Betic Cordilleras and the Rif.

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