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A strike-slip fault corridor within the Alpujarra Mountains (Betic Cordilleras, Spain)

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With 6 figures

Zusammenfassung

In einem langen Korridor in der Internzone der Betischen Kordilleren, der im Norden durch die Sierra Nevada und im Süden von den Sierren Lujar, Contraviesa und Gador begrenzt wird, sind zwei Streifen mit Blattverschiebungen zu beobachten. Sie streichen etwa E-W und sind gut entlang des 85-km-langen Gürtels aufgeschlossen.

Die charakteristischen Merkmale von Blattverschiebungen wie etwa kataklastische Gesteine mit verschiedenen texturierten Verwerfungsbrekzien, welche auch bis zu mehreren Metern große Gesteinsblöcke enthalten, beginnende Schieferung und Harnischbildung, zeigen die dextrale Natur der Bewegung. Daneben treten NW-SE und NNE-SSW streichende Störungen auf, die offensichtlich nach der Bildung der E-W verlaufenden Blattverschiebungen entstanden sind. Das Ausmaß des lateralen Versatzes ist schwer abzuschätzen.

Diese Bewegungen finden seit dem mittleren Miozän statt und sind möglicherweise immer noch aktiv.

Abstract

In a long »corridor« in the internal zone of the Betic Cordilleras, bounded to the north by the Sierra Nevada and to the south by the Sierras Lujar, Contraviesa and Gador, two discernible bands of strike-slip faults exist: These bands lie in an approximately E-W direction and are well exposed throughout and beyond the 85 km long belt.

The characteristic features of strike-slip faults, such as cataclastic rocks composed of variously textured fault breccia, which also include fragments of rocks up to several metres in size, incipient foliation, and striation demonstrate the right-lateral nature of the displacement. There are also fractures which run in a NW-SE and NNE-SSW direction, and apparently originated after formation of the E-W faults. The magnitude of lateral displacements is difficult to calculate. Evidence of considerable vertical movement can be found locally.

These strike-slip displacements have essentially occurred since the middle Miocene period and might still be taking place.

Résumé

Dans un long couloir situé dans la zone interne des Chaînes Bétiques et limité au Nord par la Sierra Névada et au Sud par les Sierras de Lujar, Contraviesa et Gador, s'observent deux trains de failles de décrochements. Ces trains ont une direction à peu près E-W et sont bien exposés tout au long des 85 Km de cette zone.

Les traits caractéristiques des décrochements, tels que cataclasites, brèche de faille avec fragments de roches jusqu'à plusieurs mètres de longueur, schistosité naissante et striation, démontrent la nature dextre du déplacement. Il existe aussi des fractures de direction NW-SE et NNW-SSW qui se sont vraisemblablement formées postérieurement aux failles E-W. La valeur du déplacement latéral est difficile à estimer. On rèléve localement des indices de mouvements verticaux importants.

Ces décrochements se sont produits essentiellement à partir du Miocène moyen et peuvent encore se poursuivre aujourd'hui.

Краткое содержание

Во внутренней зоне Бетских Кордильер в длинном коридоре, ограниченном на севере Сиеррой Невадой, а на юге Сиеррой Люхар, Сиеррой Контаверза и Сиеррой Гадор, устанивили два горизонтальных сдвига. Они простираются примерно в E-W направлении и хорошо обнажены вдоль пояса в 85 км. Характерными чертами горизонтальных сдвигов является то, что в них образуются катакластические седименты с брекчиями сбросов, имеющих различную текстуру и в которых включены блоки пород величиной в несколько метров. На поверхности этих блоков видна начинающаяся сланцеватость и штриховка, которые указывают на направление движения этих блоков вправо. Кроме того здесь установлено простирание структурных элементов в NW-SE и NNE-SSW направлении появившееся явно после

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образования горизонтального сдвига, простирающегося на E-W. Объем бокового смещения оценить трудно. Эти движения начались в среднем миоцене и, возможно, активны и по сей день.

I. Introduction

This article describes the long band of strike-slip faults wich are present in a corridor of the Alpujarra mountains, and the effects of these faults on both the older metamorphic rocks and the more modern Neogene and Quaternary deposits.

The Alpujarran corridor lies within the Betic Cordilleras to the south of the Sierra Nevada and north of the Sierras Lujar, Contraviesa and Gador, and forms a narrow depression flanked by mountains, approximately 85 km long and between 2 to 6 km wide (fig. 1).

Geologically almost the whole mass of the Sierra Nevada belongs to the Nevado-Filabride complex and is made up of schists, quartzites and, to a lesser extent, marbles, dating from the Triassic, the Paleozoic or even older.

On the lower slopes of the Sierra Nevada, thrust over the Nevado-Filabrides, are found rocks of the Alpujarride complex, extending southwards to the sea. This complex is made up of schists, phyllites and quartzites of Paleozoic and Triassic age and of marble and more or less metamorphosed dolomitic limestone of the Triassic period. The metamorphism shown by this complex, just as that of the Nevado-Filabrides, is of alpine origin.

The Neogene deposits appear normally at the lowest points of the depression overlying the Alpujarride complex, although locally they may be in direct contact with the Nevado-Filabrides. The oldest Neogene rocks are marls of Early Burdigalian age. They precede the formation of the corridor and occur in isolated localities at its western end. On top of these, or sometimes lying directly on Alpujarride rocks, there appear transgressive marly calcareous deposits which contain a pelagic fauna of Middle Miocene age (Serravallian). The next, Serravallian-basal Tortonian rock unit is, again, discordant and consists of reddish detritic materials in its lower, and restricted shallow-water facies in the upper part. This can be seen in various outcrops, near Cadiar for example. These rocks outcrop extensively and are frequently highly tectonised.

Above these deposits directly upon Alpujarride rocks, is found a discordant sequence of Early Tortonian age, beginning with bioclastic limestones, passing into silts and marls. These silts and marls include levels of turbidites and channel deposits of very coarse detritic material. On top of these and discordantly in the Western Sector there appears a continental sequence beginning with reddish and grey detritic rocks that pass upwards into pebbles and boulders derived from the Nevado-Filabrides. Towards the Eastern Sector these deposits change into silts and sands with interbedded conglomerates, containing a marine fauna of Late Tortonian-Messinian age.

In the Neogene deposits one finds numerous and considerable changes in facies, indicating considerable tectonic activity.

In many places there appear other discordant deposits. These are made up of very thick, red and grey conglomerate sequences containing thick beds of red clays. These are similar to the continental Guadix Formation of Pliocene and Quaternary age, from the north side of the Sierra Nevada.

There are also very well developed alluvial-fan deposits along the boundary between the Central-Eastern and the Eastern Sectors, which are affected by several fractures and show slight folds parallel to these fractures. Their age is probably Pliocene(?)-Quaternary.

Finally, there appear other continental deposits of Pliocene to Quaternary age, mostly in the form of piedmonts and ancient river beds, some of which are topographically much higher than the level of the present hydrographic network.

Both the Nevado-Filabride and the Alpujarride complexes have been studied by numerous geologists and it is not the intention of this report to give an exhaustive description of them. Suffice it to refer to the work of PUGA (1971) and the maps, to scale 1:50.000, drawn by ALDAYA et al. (1979 and in the press) and DIAZ DE FEDERICO et al. (1981), whick contain references to previous works.

The Neogene deposits have been investigated by several geologists. DURAND DELGA & FONTBOTE (1960) describe the area around Ugíjar and refer to Neogene beds which have been considerably affected by reverse faults in an area to the east of the Alpujarran corridor, in the Sierra de Alhamilla. It is also worth mentioning the works of RODRIGUEZ-FERNANDEZ (1982), GONZALEZ-DONOSO et al. (1983) and OTT D'ESTEVOU (1980).

SANZ DE GALDEANO (1983) and SANZ DE GALDEANO et al. (1984) describe the essential features of post-alpine fracturing at the western end of the corridor in question and those of the Betic Cordilleras in general. Finally ALDAYA et al. (1984) report the existence of the Mecina fault, which extends along the contact between the Alpujarride and Nevado-Filabride complexes and which they describe as being a transtensive feature.

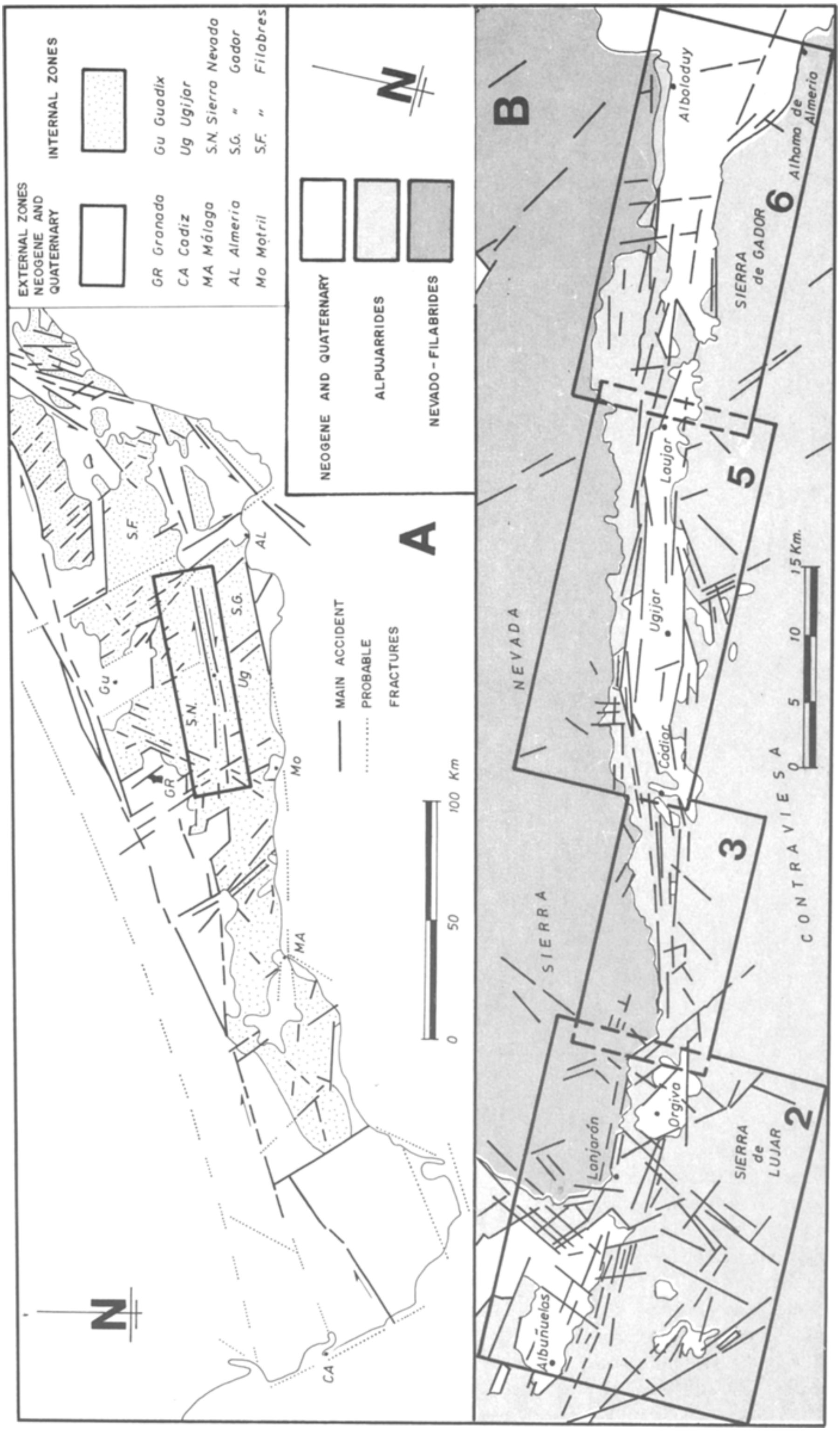


Fig. 1.a. Location within the Betic Cordilleras of the study area.

Fig. 1.b. Overall plan of the Alpujarran Corridor. The precise position can be seen in A. Numbers for the inset frames 2, 3, 4 and 5 refer to subsequent figures of the same number.

II. Fracturing

Alpine structuring of the Betic Zone began during the Eocene, or perhaps earlier (Upper Cretaceous?) and lasted until the Early Miocene. This does not mean that there were no later stages of important deformation, as will be seen. During this period occurred metamorphism of the internal zone and its movement westwards relative to the external Betic and Rifean zones. It was this movement that caused the internal zone to wedge itself between the external ones (ANDRIEUX et al. 1971). The contact between the internal and external zones was clearly formed in the Burdigalian, although there had been movements prior to this age. This contact trended approximately in a N70E sense and was essentially a right-lateral transcurrent event with a relative displacement of perhaps 300 km. Other parallel faults were formed both in the internal and external zones (SANZ DE GALDEANO 1983, and SMET 1984). Further fractures appeared, trending in a more E-W direction, but as part of the fault system as a whole which moved in a right lateral sense. It were these E-W strike-slip faults which created the Alpujarran corridor.

II-1. A description of the E-W to N70E faults

These faults are clearly visible throughout the length of the corridor (fig. 1–6). They form two large groups of fracture lines, though in places they merge sufficiently to make it difficult to distinguish clearly between the two groups.

In order to describe the characteristics of the fractures it is convenient to divide the corridor into four sectors: the western sector from around Beznar to Orgiva, the west-central sector from Orgiva to Cadiar, the east-central sector from Cadiar to Laujar de Andarax (with Ugijar in the middle) and the eastern sector to around Alhama de Almería.

II-1-a. The Western Sector.

In this sector fracture lines occur on the southern flank of the Sierra Nevada as well as on the northern flank of the Sierra de Lujar, but it is difficult to find sufficient evidence to determine the sense of movement. Where they can be observed there seem to be several types of faulting, such as normal and reverse faults, which obscure the strike-slip movements. In some places, however, horizontal striation is present. Aerial photographs reveal some possible lines of strike-slip fractures but in the field it is usually not possible to establish their existence with any certainty (fig. 2).

II-1-b. The West-Central Sector.

In this sector, in the Alpujarride complex on the slopes of the Sierra Nevada, fracture lines can be seen outcropping clearly and at times dramatically. Such is the case with the great dolomitic limestone scarp which runs from a little to the west of Castaras, passes through Nieles and Timar and ends in the proximity of Cadiar. This scarp is not only of great geological interest when studied in detail, but also very spectacular when seem as a whole from a distance. Here one can find an enormous number of very well preserved horizontal striations, which clearly and without doubt indicate the right-lateral nature of the strike-slip. But, as shown in figs. 3 and 4 (cross section A-A'), it is not the only fracture in this area. In fact it is part of a fault zone of over 500 m in width. In its southern part the superficial rocks affected by the fault are Alpujarride metapelites. Bands of crushed rocks, which are darker than the surrounding, uncrushed rocks, have been formed. These bands of cataclastic rocks are, in general fault breccias or fault gouges but they also show foliations subparallel to the slip, containing numerous fragments of lense-shaped rocks, whose trails serve to indicate the sense of the movement. Locally there are large, exotic, tectonic limestone lenses, the presence of which would be inexplicable unless it is assumed that they have been tectonically transported along the strike-slip fault. They can be up to 50 m in length with long, horizontal or nearly horizontal striations parallel to the fault, and the lenses themselves are aligned in the direction of the fault. Tortonian marine conglomerates are also found among the crushed and striated elements of the fault breccia. Still further to the south in the area of Lobras there appears another band of fractures in which, if less spectacular, the Neogene deposits are better preserved. The Serravallian-basal Tortonian rocks are clearly truncated and the fault zone in the adjacent Alpujarrides has a width of more than 30 m. In the Neogene deposits horizontal striations occur. Nearby possible late Tortonian-Messinian deposits are found which partly cover the fault traces, but elsewhere these deposits can be observed clearly affected by the wrench-slips. The wrench faults have also created some tectonic windows of lower Alpujarride units and the dolomitic limestones thus revealed are elongated in the direction N80E. Horizontal striations can also be seen. There is a good example of such a window on the road to Lobras.

II-1-c. The East-Central Sector.

This sector is indubitably the most geologically interesting of the four. The formation of cataclastic

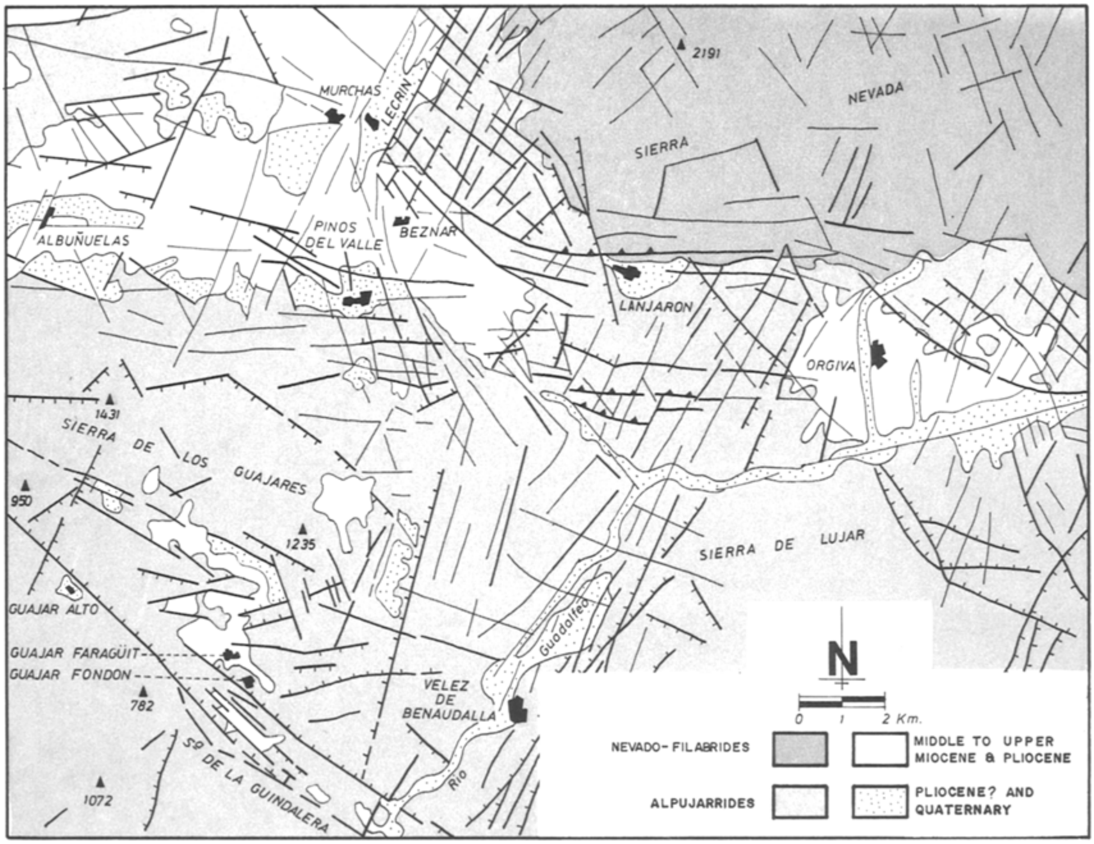


Fig. 2. Western Sector of the Alpujarran Corridor. Thin lines indicate probable fractures. (Taken from SANZ DE GALDEANO et al. 1984.)

rocks both in the Neogene and Alpujarride deposits and even in the Nevado-Filabrides is much more wide-spread than in the westerly sectors. Two groups of faults that correspond exactly to the fault lines in the previous sectors can be clearly distinguished.

The northern group of faults (fig. 3, cross-section B-B' to G-G' and fig. 5)

Here the Castaras-Cadiar fractures continue. From the location where the secondary road to Yator branches off the main road through the Alpujarran corridor just north of Cadiar, till 1 km to the west the rocks are very finely crushed (cross section B-B'). The resulting breccia (or gouge) is composed of Alpujarride phyllites and also contains highly striated rocks of the Serravallian-basal Tortonian sequence. This fault runs eastward towards Yator and here vertical Tortonian deposits can be seen. The vertical component of the displacement must be at least 200 m, but many horizontal striations are found along the fault traces. The road, which runs northward cuts across two more bands of crushed rock. In one of these there are boulders of several cubic metres with superficial striations, clearly demonstrating that they have been rolled around during displacement. These curved striations follow horizontal planes. In this fault zone there is evidence of incipient foliation.

To the north of Ugijar, between Yegen and Laroles, the Miocene deposits are notably affected by wrench-faults. 3 km to the north of Ugijar there appears a band of completely fractured Alpujarride phyllites and quartzites which also contains fractured Serravallian-basal Tortonian rocks. The fault zone is very steep in this area. This band splits into two branches in a westward direction. The southern branch, locally dipping to the south gradually loses the phyllites and finally the fault breccia consists

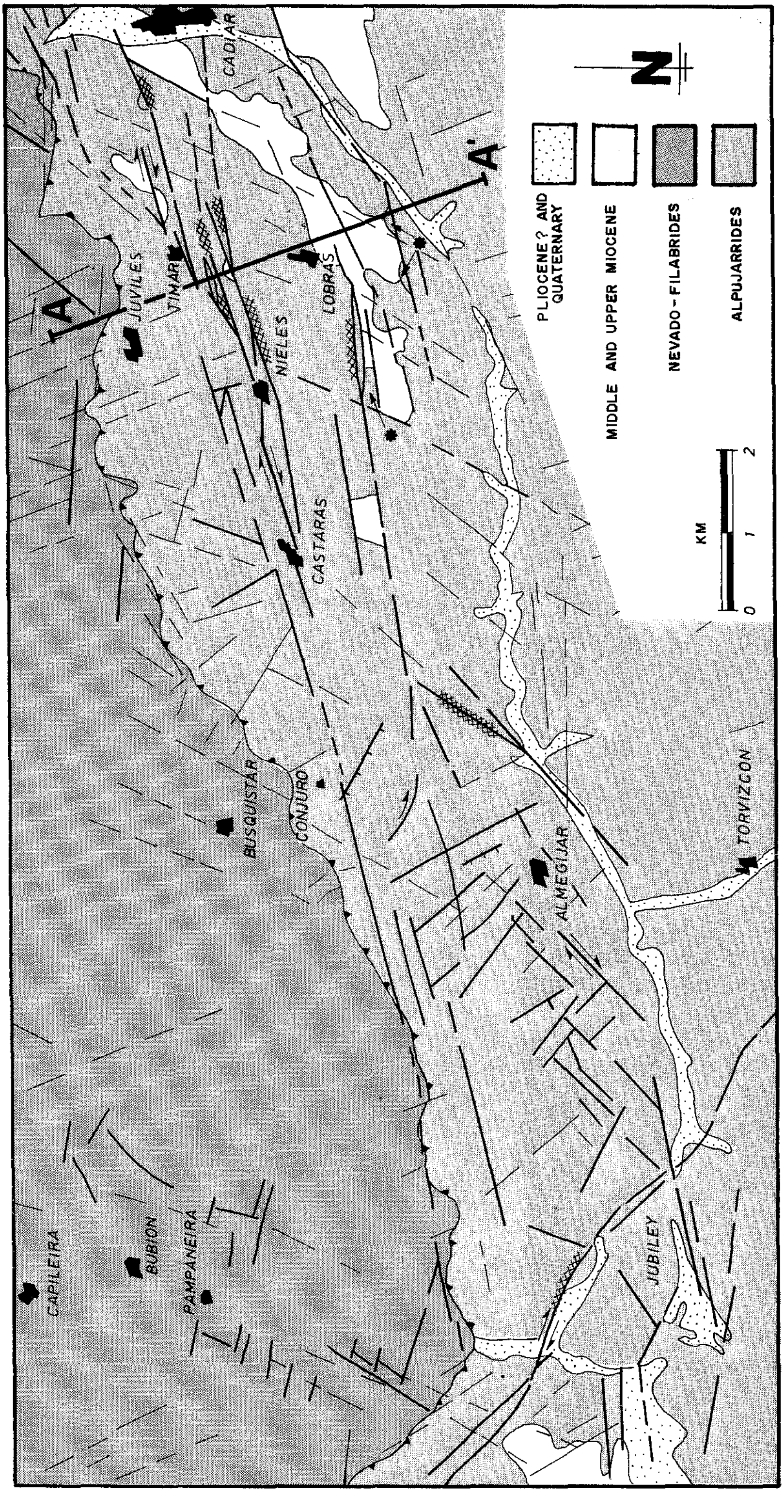


Fig. 3. West-Central Sector of the Alpujarran Corridor. Tectonic windows produced by strike-slip faults are indicated as asterisks. Zones of intense crushing are indicated by cross-hatching.

only of crushed Neogene deposits. The crushed Neogene rocks are clearly visible, even from a distance of some kilometres, owing to common efflorescences of gypsum, which impart a light color to the terrain. There are also severe deformations in the rocks adjacent to the fault.

The northern branch of the fault continues in a almost straight line and shows severely deformed Neogene rocks. At the point where the two branches separate several inclusions of Neogene deposits are found within the phyllites. There is one outstanding outcrop visible from the road (km. 57, UTM co-ordinates: VF 944936), where the Miocene appears discordantly above the Alpujarrides and is in turn overthrust by Alpujarride rocks which, at first sight, might even be interpreted as a gravitational slide towards the south. However, this is not the case. On climbing the Neogene hillock it can be clearly seen that these rocks are vertically embedded in the phyllites. Its flat top comprises an area of more than 200 sq.m., is distinctly striated and cut by channels in a direction N80E (fig. 4, sketch E). A similar structure is found in the vicinity of Yator and to the south of Yegen, where large dolomitic limestone boulders occur, completely covered by striations indicating the direction of displacement. These two sites are mentioned because of their clarity and ease of access, but further examples can be found both to the east and west of the Yegen area. The band of crushed rock reflecting the strike-slip character of the fault continues westward for several kilometres. The phyllites contain large quantities of Neogene rocks in the form of elongated lense-shaped boulders whose tails again extend in the direction of displacement. They are often completely contained within the phyllites and consequently are only visible in the sections of »barrancos« (steep-sided, eroded, stream beds). The opposite can also be seen, with bands of phyllites included within Neogene deposits.

Further to the north there is another band of crushed rocks at a point of contact between phyllites and Neogene deposits. Its characteristics are similar to those described above, though the fault splits into several branches within the phyllites and contains large »fishes« of dolomitic limestone whose sides are completely striated horizontally. A good example can be found at the locality VF 9 19937.

The southern group of faults

These faults, although somewhat less spectacular than the northern group, are nevertheless very clearly visible from the air and in the field and show very distinct contrasts in colour. They also show evidence of brecciation and incipient foliation in the fault zones, which include Neogene rock fragments within the crushed schists and phyllites as well as striated boulders following the flow-line of the displacement. Striations are abundant and clearly indicate right-lateral movement. The fault lines are almost completely rectilinear. Locally normal or reverse faulting appears. Neogene deposits are of lower Tortonian-Messinian age, similar to those found to the east of Cherin.

II-1-d. The Eastern Sector

On the northern side of the corridor the fault lines described in the above sector continue from Laujar de Andarax to Alboloduy. Between Laujar and Canjayar the bands of crushed rock occur in the Alpujarrides and in the Miocene deposits. The contact between the Alpujarride and the Nevado-Filabride rocks bends northward in this area and appears to be unaffected by the transcurrent movements.

The fault traces are clearly visible in two localities. One is 2 km WSW of Beires (km 35.8 on road 332, see fig. 6 and cross-section H-H' of fig. 4) and the other on the same road where it passes over Capitan hill (fig. 6). In both these localities bands of crushed rocks with foliation and long horizontal striation lines can be seen. Locally they might appear to be reverse faults but in fact are right-lateral strike-slip faults.

From Canjayar onwards, the fault line follows the contact between the Nevado-Filabrides on one hand and the Alpujarrides and the Miocene on the other. Through the effects of the slip the Alpujarride rocks are here restricted to a long, very narrow strip of outcrops that locally disappears completely, so that the Miocene deposits are in direct contact with the Nevado-Filabride rocks.

A little further to the west, along the old road to Ohanes two huge Alpujarride dolomitic limestone and phyllite blocks some 50 m in length occur within the Miocene of the fault zone (cross section I-I' of fig. 4). Incipient foliation and horizontal striations are clearly visible.

The strike-slip faults continue until they reach a point a little to the east of Alboloduy, where the Alpujarride rocks disappear and the corridor as such ends. To the north of Alboloduy some fault lines can still be seen, which, locally, have the appearance of reverse faults but in fact show evidence of both horizontal right-lateral movement and an element of vertical movement. The same can be seen in the Nevado-Filabride complex, with bands of generally steeply inclined (60 degrees or more) crushed rock, although locally these bands can show less inclination.

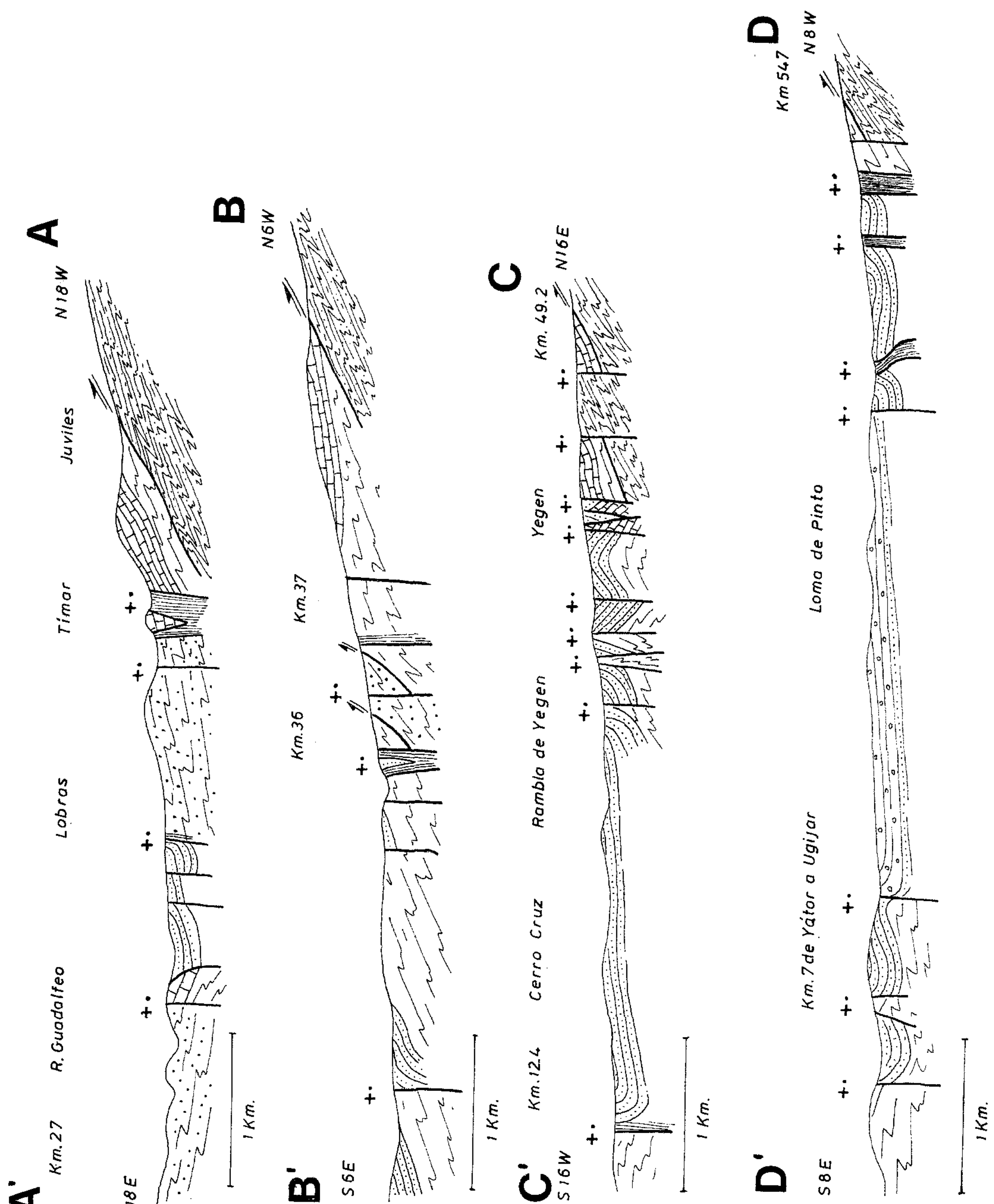
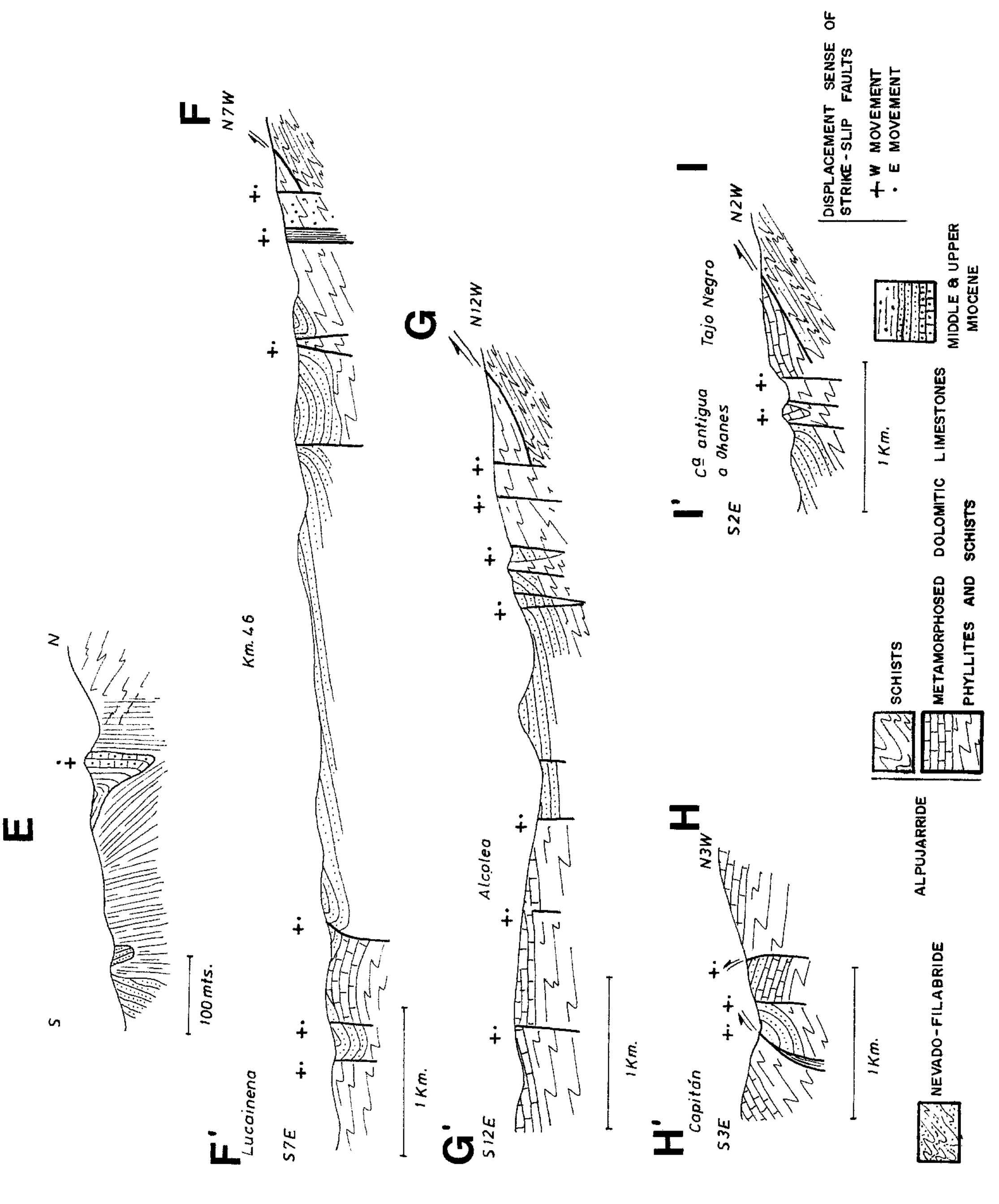


Fig. 4. Geological cross-sections of the Alpujarran Corridor. Locations may be found in figs. 3 (cross-section A-A'), 5



(cross-sections B-B' to G-G') and 6 (cross-sections H-H' and I-I'). Heavily shaded areas indicate zones of intense crushing.

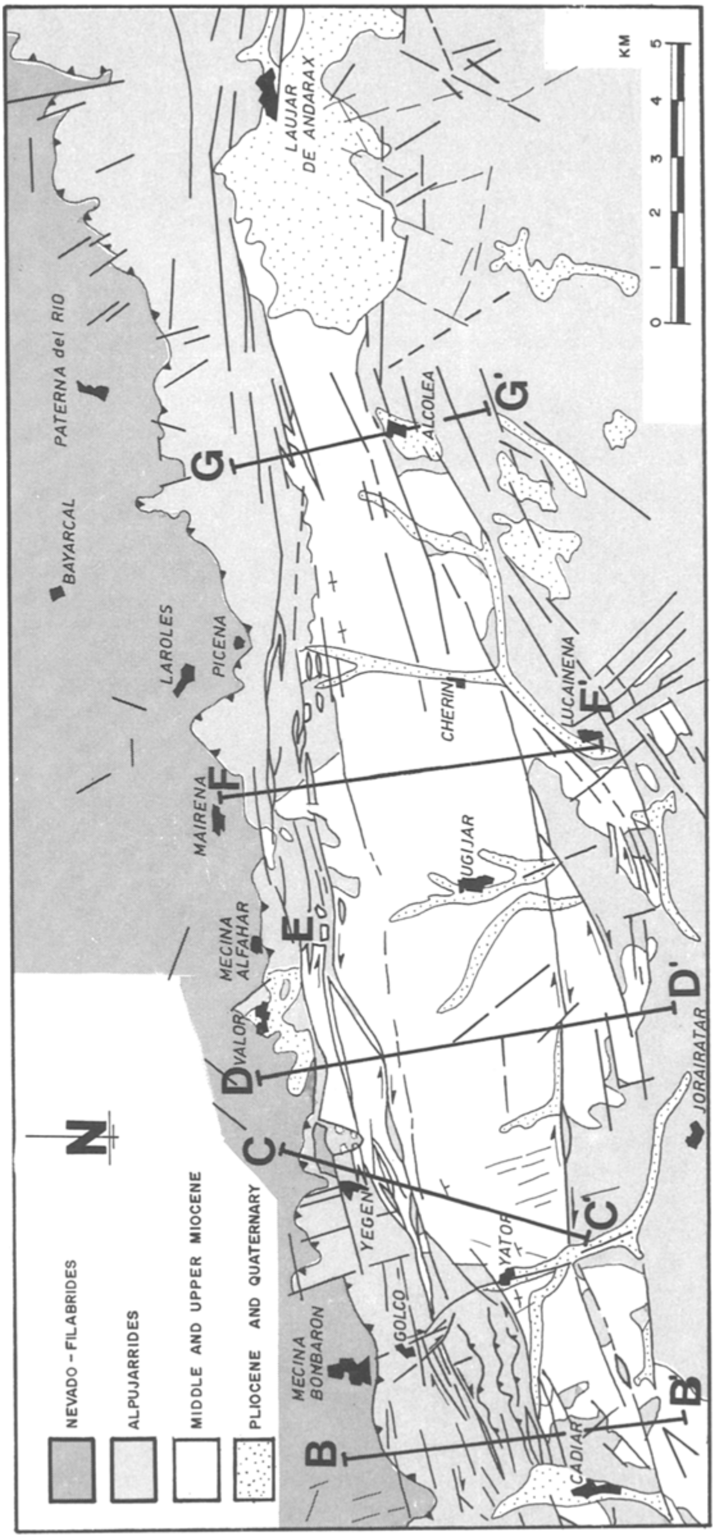


Fig. 5. East-Central Sector of the Alpujarran Corridor. The thick parallel solid lines indicate areas of intensive crushing.

To the south of this corridor sector there are fewer bands of fracturing. These occur in many points of contact between the dolomitic limestones of the northern flank of the Sierra de Gador and the Tortonian deposits of the corridor itself. In places there has been vertical movement to the extent of 700 m. and vertical strations can be seen, for example at Alhama de Almeria. There are also, however, oblique displacements and others with horizontal striations which indicate pure strike slip. An example of this latter, horizontal, movement can be seen in vicinity of Ragol (UTM WF 292945) in a small barranco, visible from the Ragol to Instincion road where the distinctly striated fault plane is visible.

In the basin interior there are also faults which may seem to affect Neogene deposits. To the east of Padules, for example, a vertical band of crushed rock extends in a E-W direction. In other places, between Bentarique and Terque, the river Andarax follows the trace of one of these faults. This appears clearly from the sharp change in lithology between the two banks of the river.

II-1-e. Subsidiary thrust sheets

In the East-Central Sector, both to the north of Cadiar and of Ugijar, several thrust sheets of Alpujarride material are intercalated within the bands of the strike-slip faults. Neogene deposits are similary affected. Thrusting varies between a direction parallel to the strike-slip and a angle of some 30°, but locally it may be even more, attaining directions which approximate NE-SW. In some cases, particularly in the western zone of this thrust-sheet area, the thrusts appear to have had a northern sense and in others a south-eastern or even southern sense.

These thrust-sheets are interpreted as being subsidiary to the strike-slip displacements, in the same manner as HARDING (1974) and several later geologists have recorded in other regions. Furthermore, a real transition exists between the strike-slip bands and the thrust-sheets, in such a way that as the faults change direction they decline from the vertical and gradually flatten out. Nevertheless, the predominant direction of displacement identified in these thrust-sheets by the striations and foliation is the same as that of the wrench fault. Thus in some places the sheets have the appearance of completely flat surfaces, but with clear evidence of an almost E-W displacement.

One further detail is the occasional existence, on the slopes of the Sierra Nevada, of Alpujarride and even Nevado-Filabride rocks emplaced above Neogene or Alpujarride deposits. This appears to be a recent phenomenon, it is the result of lateral gravitational sliding, and presents no problem in the geological analysis of the fault corridor.

II-1-f. Foliation

Materials principally encountered in the fault bands range from fault breccias through fault gouge to fault pug. At several points, however, marked foliation can be seen in rocks which are not completely coherent. This foliation is parallel or subparallel to the direction of displacement and, locally, may be notably oblique. Normally there are also lenses or even large blocks with »tails« stretching in the direction of the movement.

The foliation is generally in a vertical plane, although where thrust sheets have been produced it may progressively lose inclination until it lies almost flat (through the influence of older pre-existing surfaces). Thus, where the schistosity of the phyllites, schists or quartzites dips a few degrees and the foliation is less intense, the latter may have adopted the plane of the older surface. The same may occur in faults where the crushing has been less significant. These too may be controlled by older surfaces and develop with a preference towards levels of lower cohesion, such as phyllite layers within quartzites.

A clear loss of inclination can also be observed in the vicinity of large boulders which are at times incorporated in the faults. Close to the bottoms of these boulders vertical foliation will twist rapidly and align itself with the new surface; that is, adapt itself to the movement of the boulder. Large masses produce the same effect as boulders and the resultant foliation takes on the appearance of sheets. However, as mentioned above, analysis of the striations clearly indicates the direction and sometimes the sense of the displacement.

II-1-g. The limits of the Corridor

At its western limit in the Lecrin valley the three principal Betic Cordilleran systems of strike-slip fractures merge (SANZ DE GALDEANO et al. 1984, see fig. 2) and the overall picture becomes somewhat more complex. Nevertheless, the E-W faults continue in a westerly direction to the vicinity of Zafarraya-Colmenar, where they enter the point of contact between the internal and external zones of the Betic Cordilleras. The epicentre of the disastrous earthquake of Christmas 1884 was in the sector of Zafarraya-Arenas del Rey.

At the eastern extreme, in the Almería, Tabernas and Sorbas basins it is difficult to see a distinct conti-

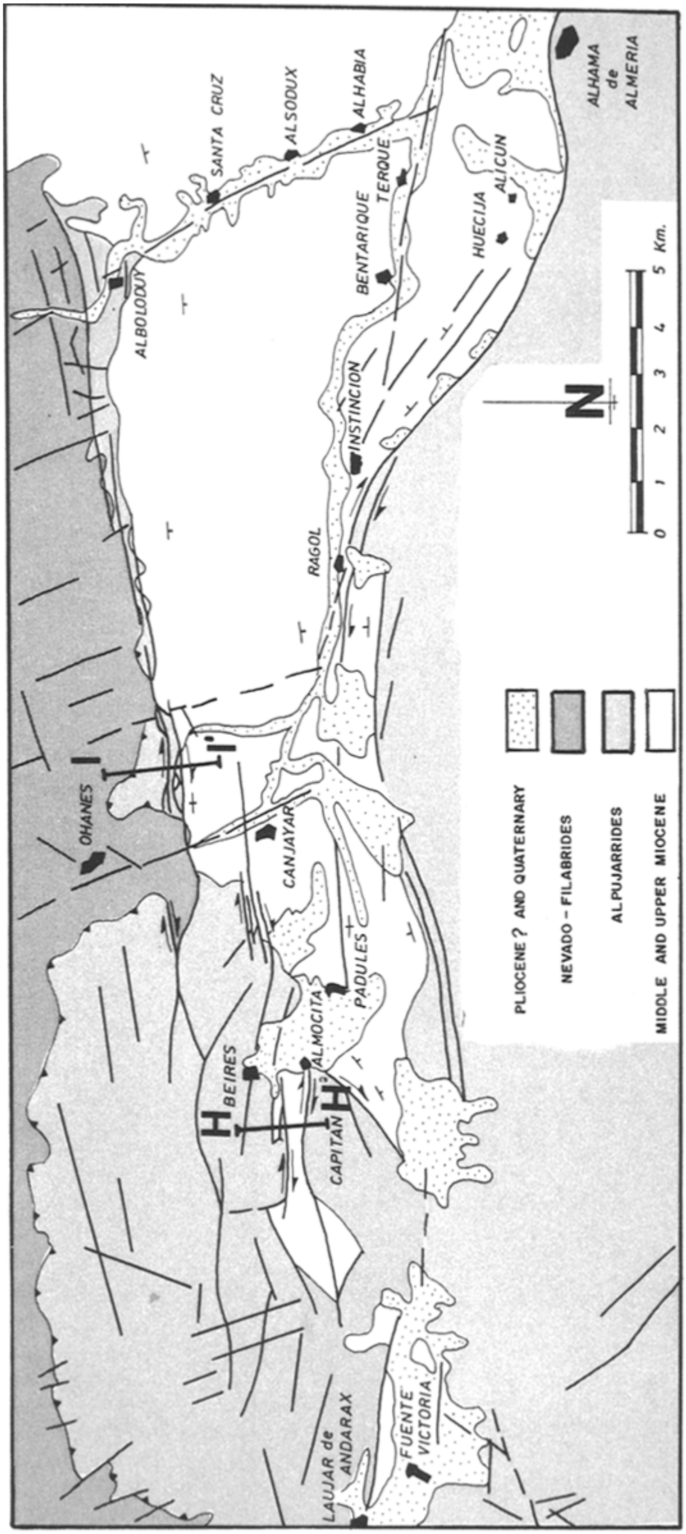


Fig. 6. Eastern Sector of the Alpujarran Corridor.

nuation of the fault. However, there are points, for example to the north of the Sierras Alhamilla and Cabrera, where clear fractures bear witness to the continuity of wrench-faults. The tectonic sedimentary relationship of this area has been well described by OTT D'ESTEVOU (1980).

II-2. The NW-SE and NNE-SSW fractures

The formation of these faults appears to have taken place slightly after that of the N70E to E-W faults. Although they appear abundantly as joints which affect the metamorphic and Neogene rocks, faults also exist (SANZ DE GALDEANO et al. 1984 and in the press).

As mentioned above, at the western limit of the corridor there exist NW-SE faults, continuations of which are clearly discernible in the vicinity of Granada. Others running NNE-SSW make up part of the western edge of the Sierra Nevada (SANZ DE GALDEANO et al. 1982). Further to the east several significant examples of these faults define part of the present hydrographic network, and at the eastern limit of the corridor the existence of the Tabernes-Almería basin itself is partly a result of these same faults.

In general the NW-SE faults are right-lateral, while the NNE-SSW faults are left-lateral. Nevertheless, indisputable evidence has also been found for left-lateral displacement in NW-SE faults: viz. relative displacements of N70E to E-W faults, the sense of striations, and the growth of minerals in the fault plane.

III. The Chronology and importance of the displacements

The N70E to E-W faults appeared at the end of the Early Miocene or perhaps a little later, and were apparently very active during the rest of the Neogene and even into the Quaternary. Deformation of the oldest deposits of the Serravallian-lower Tortonian formations are particularly important.

The other two fault systems appear to be slightly later in origin and reflect a separate set of stresses. Thus the N70E to E-W faults were essentially formed by a stress whose principal axis σ_1 would have been in the direction WNW-ESE, while the other two fault groups (NW-SE, right-lateral and NNE-SSW left-lateral) were the result of a stress axis σ_1 almost N-S, slightly tending towards the west. Left-lateral displacements of the NW-SE system correspond to a movement conjugated to the N70-100E slip.

Thus, there appear to have been two essential movements in the region: The first which wedged the internal zones of the Betic Cordilleras between the external zones (a product of an eastward movement, of the Iberic block due to the widening of the Atlantic, and the second a product of the approximation of Africa to the Iberian peninsula. Both these movements could have their origin in the displacement of Africa and Europe to the east and to the north.

Once the three original fracture systems had been created, movements along the fault traces occurred according to the orientation of a stress at any particular moment. That is, the movements may have been various and recurrent during the time since their formation. Furthermore, the existence of some fractures has affected the movement of those adjacent. It would seem from observations in the region that the predominant stress during the Quaternary has been approximately N-S and that vertical readjustments have also taken place during this period. One possible results of this N-S stress can be seen to the east of Orgiva where there exist a number of vertical fractures which affect Pliocene-Quaternary deposits and Alpujarride limestones. These take the form of joints running N30W and N20E and thus are apparently conjugate.

However, not all the faults are of a strike-slip nature. There are clearly discernible examples of normal and oblique faults and, in fact, the corridor under discussion owes its very existence to the vertical displacements which delimit the northern and southern boundaries and form the walls of this complex »graben«.

In the Corridor the lateral distance of displacement is very difficult to calculate solely from field evidence, as the present geological structure of the Betic Cordilleras runs in almost the same direction as the N70E to E-W fractures. Laterally displaced elements thus often betray no recognisable signs of »movement«.

From data obtained in neighbouring areas one might arrive at a tentative figure for lateral displacement in the E-W system of some tens of kilometres, but as yet there is no concrete evidence to support this conjecture. In the other two systems in this corridor displacements in the order of some 500 m or less can be seen. At times, despite the fact that the visible fracture is long, the movement involved would appear to be almost nil.

The vertical displacements are very significant, both at the northern and southern edges of the corridor. In the neighbourhood of Lanjaron, for example, the vertical movement has been at least 800 m. Prof. Fernandez Rubio (pers. comm.) has recorded the results of a test bore for water, carried out at the contact zone between the Alpujarride and Nevado-Filabride complexes in the village of Lanjaron. The bore reached a depth of 117 m where it encountered CO_2 at a pressure of 27 atms., resulting in a large quantity of material being expelled from the bore in a violent explosion. This material included Miocene rocks which appear to be volcanic, though there is a total absence of any volcancic rock at superficial levels in this area.

Some of the natural springs in the area are also thermal.

These findings appear to confirm the hypothesis that fracturing in this zone is very considerable and reaches great depths.

At the northern edge of the Sierra de Gador vertical displacements can be in the order of some 700 m and the overall displacement, comprising a combination of purely vertical and lateral slips with a vertical component, can cumulatively reach 1000 m or more, even though each individual displacement is less.

In this eastern extreme of the corridor the thermal springs of Alhama de Almería occur.

Moreover the Mecina fault described by ALDAYA et al. (1984) is worth mentioning. According to these geologists the contact zone between the Nevado-Filabrides and the Alpujarrides, the latter originally being an overthrust complex, today represents a transtensive fault with right-lateral and right-oblique movement. The vertical displacement could be some 2.000 m. The trend of striations is parallel or subparallel to one of the fault systems described in this paper (N50-70E) and plunges WSW in fault planes which dip 20°–30° in direction N160–180E.

One of the present authors (S. de G.) holds the view that the extent of vertical displacement (approximately 2000 m) which ALDAYA et al. (op. cit.) base on the apparent disappearance of one of the Alpujarride nappes (Lujar nappe), is open to doubt. SANZ DE GALDEANO's opinion is that the Lujar nappe does not disappear but continues in this area as the Castaras nappe, identified by ALDAYA et al. as being a separate feature. Furthermore, as described elsewhere in this paper, zones occur in which the contact with the Nevado-Filabride complex is vertical and affected by strike-slip faults which cut obliquely across the Alpujarrides and even across Neogene deposits. At other points of contact between the Alpujarride and Nevado-Filabride complexes and in the Nevado-Filabride complex itself there can indeed be seen evidence of oblique movement, such as described by ALDAYA et al. (op. cit.). This evidence is interpreted as proof of the existence of other faults, subsidiary to the system described here and a further indication of the diversity of the movement suggested. ALDAYA'S team also claims that the Mecina fault changes direction at the extreme western end of the corridor, at Nigüelas, to the northwest of Lanjaron. It appears that, after continuing for some 80 km in a direction N70E to E-W, it abruptly changes course and runs for some 20 km in a direction N-S to NNE-SSW. The present authors incline to the opinion (see also SANZ DE GALDEANO et al. 1982) that this apparent change in direction is merely the result of the N70E to E-W fractures intersection the NNE-SSW fault system. Abundant examples to support this view are visible in the study area.

In summary the succesion of movements in the Alpujarran Corridor may be roughly synthetized as follows: during lower Burdigalian the Corridor did not exist as such. Even fracture movements during middle Miocene (lower and middle Serravallian), seem not to have individualized the Corridor, although the basin starts to restrict its length.

Important horizontal movements and other vertical ones are produced at upper Serravallian – basal Tortonian, clearly individualizing the Corridor, that at the same time yields thick clastic wedges. As it was pointed out, the deformation stage of lower Tortonian is very important, being of this age many of the movements previously described. The Corridor divides itself in several sub-basins, with various sedimentations and subsidences. Thus in the sector analyzed in this work, marine series become substituted by a system of alluvial fans proceeding from Sierra Nevada. These fans will eventually be covered by a new marine series during upper Tortonian – Lower Messinian. During middle Messinian the sea retreats itself from the Corridor at its eastern end, where new horizontal movements are also more evident. In Pliocene and Quaternary, new vertical movements took place, even though there are traits of horizontal ones.

At regional level it is observed that fractures E-W to N70E also appears, both at the Internal and External zones (fig. 1 A). As a matter of fact, the contact between both zones is of N7OE general trend and is essentially a transpressive accident, with a clockwise movement. All moved practicaly during the same stages except the contact accident between Internal and External zones, that seems to be older. Thus as early as the begining of Miocene it allowed the first movements toward the West of the Internal Zones, very separated at that time of its present position, 300 km about. During the lower Burdigalian, the accident between both zones was almost totaly blokked, and new others fractures of the same general trend such that of the Alpujarran Corridor contributed to this movements.

As a result of all those movements, the following features were stamped in the Betic Cordilleras:

a) A wedge movement of the internal zones toward the W created the Gibraltar arc, thus appearing as a tectonic arc, and not a paleogeographic one. The External ones, not the Internal, are those that approximately design the arc.

b) Important displacement was caused toward the W and NW in the External zones and there some structures of approximately N – S direction occurred. Important rearrangement of its units took place in the Internal zones.

c) To a good extent they are responsible for the formation of pull-apart basins, such as the Granada basin can be considered, and other basins located above the strike – slip accidents, such as the Alpujarran Corridor. Therefore movements of these fractures have conditioned the thickness and type of sediments of Neogene and Quaternary materials.

d) Many of these fractures, moving again, produced important vertical movements and, are in great part responsible for the rugged present relief.

e) Roughly, present superficial and middle depth seismicity, is essentialy located within these fracture lines.

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