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# The structural configuration of the eastern Sierra de los Filabres, SE Spain

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## Abstract

The eastern Sierra de los Filabres is constituted of several generations of thrust sheets which were formed during entirely different tectonic events. The oldest thrust sheets are present in the Mulhacen Complex. They were formed during the first phase of penetrative Alpine deformation, $D_{x-1}$, which is related to Cretaceous continent-continent collision. The second phase of penetrative deformation $D_x$ is also related to this collisional event.

During the second phase of thrust sheet formation, $D_{x+1}$, rocks from the Alpujarride Complex were placed directly on top of the Mulhacen Complex. These thrust sheets are related to a regional phase of heterogeneous extension and crustal thinning, active during the Late Oligocene to Early Miocene.

At least two subsequent phases of folding and overthrusting, $D_{x+2}$ and $D_{x+3}$, strongly modified the original superposition of tectonic units. $D_{x+2}$ deformation, characterized by strain partitioning, resulted in a detachment zone. In the northeastern part of the Sierra de los Filabres an imbricate stack was formed. During $D_{x+3}$ the detachment zone was reactivated. These movements were followed by development of low-angle extensional faults, dextral tear faults and finally a foreland dipping duplex. For the $D_{x+3}$ structures a Miocene age is suggested. $D_{x+1}$, $D_{x+2}$ and $D_{x+3}$ deformations have largely determined the present structure of the eastern Sierra de los Filabres.

## Introduction

The Sierra de los Filabres forms part of the Internal Zone of the Betic Cordilleras, which constitutes the Alpine fold and thrust belt of southern Spain. The structure of the Internal Zone is dominated by large scale overthrust units, which are mainly composed of dark-coloured Paleozoic and light-coloured Triassic metasediments. The units are commonly grouped into four thrust-sheet complexes, based on differences in tectono-metamorphic evolution. In order of tectonic superposition: 1) the Veleta Complex, characterized by LP/LT type metamorphism (Puga & Diaz de Federico 1978); 2) the Mulhacen Complex, affected by HP/LT metamorphism and subsequently overprinted by medium grade metamorphism of intermediate and low P/T type (Nijhuis 1964, Puga & Diaz de Federico 1978, Gomez Pugnaire & Fernandez-Soler 1987, Bakker et al. 1989); 3) the Alpujarride Complex, subjected to various metamorphic conditions, ranging from HP/LT to LP/HT (Westerhof 1975, Bakker et al. 1989, Goffé et al. 1988). In general the metamorphic grade of these rocks is considerably lower than that of the Mulhacen Complex; 4) the Malaguide Complex comprising very-low-grade to unmetamorphosed rocks (Egeler & Simon 1969).

In the northeastern part of the Internal Zone, Alpujarride thrust units overlie rocks of the Almagride Complex, which show strong stratigraphic affinities with Triassic rocks of the Subbetic (Simon 1987).

The difference in tectono-metamorphic evolution reflects different crustal positions during continent-continent collision, which characterizes the earliest stage of orogenesis. During this collision rocks of the Mulhacen Complex were underthrusted to a depth of approximately 37 km, as recorded by HP/LT mineral assemblages (Bakker et al. 1989). At this depth large-scale thrust sheets were formed, indicated by repetitions of lithostratigraphic units within the Mulhacen Complex (De Jong & Bakker 1991, this volume*).

Mineral parageneses also demonstrate HP/LT conditions for the earliest metamorphic phase in the Almanzora Unit of the Alpujarride Complex. However, maximum P and T conditions are lower than those for the Mulhacen Complex, indicative of a higher crustal level during collision.

The intervening crustal segment, which separated the Mulhacen Complex from the Almanzora Unit, was excised during a subsequent phase of heterogeneous extension and crustal thinning. The detachment contact between both sequences is a ductile shear zone. A marked difference in metamorphic crystallization is manifest across this contact. It has been argued that this extensional phase might have been related to the earliest stage of continental rifting and oceanic spreading, which affected the western Mediterranean from the Oligocene onwards (Bakker et al. 1989).

At least two subsequent phases of folding and overthrusting strongly modified the original superposition of tectonic units. Locally this has resulted in superposition of Mulhacen on top of Alpujarride units. These late thrust sheet contacts are unconformably covered by Late Miocene and younger deposits at the northern margin of the mountain range (Fig. 1).

Well-defined lithostratigraphic units from the Mulhacen and Alpujarride Complexes can be traced for several tens of kilometres in the eastern Sierra de los Filabres (De Jong & Bakker 1991, this volume), despite the complicated tectonic evolution. In this paper the regional distribution of these units, which has been subject of considerable debate (Nijhuis 1964, Bicker 1966, Helmers & Voet 1967, Langenberg 1972, Kampschuur 1975, Linthout & Vissers 1979), is explained in relation to their deformation history. Emphasis is put on the youngest three phases of penetrative deformation, $D_{x+1}$, $D_{x+2}$ and $D_{x+3}$, that largely shaped the present structure of the mountain range.

* Enclosures I and II, a coloured map and cross sections, are inserted in the back of the previous issue, Geologie en Mijnbouw Vol 70, nr 2.

## Units formed during continent-continent collision

The Mulhacen Complex in the Sierra de los Filabres comprises three major thrust-sheet units (cf. Encl. I in De Jong & Bakker 1991, this volume), formed during the earliest phase of penetrative ductile deformation. In order of tectonic superposition: 1) the Nevado-Lubrin Unit 2) the Macael-Chive Unit and 3) the Huertecicas Altas-Almocaizar Unit (Helmers & Voet 1967, Bakker et al. 1989). The units are composed of a basal sequence, of inferred Paleozoic age, of dark-coloured, graphite-rich micaschists. The upper two units contain Alpine gneissified Permian granites (Priem et al. 1966, Andriessen et al. in press). The basal sequences are covered by light-coloured meta-siliclastic rocks with numerous marble intercalations, for which a Middle to Late Triassic age has been suggested (Simon 1987, De Jong & Bakker 1991, this volume). The stacking of these three units thus has resulted in superposition of Paleozoic rocks on top of Triassic rocks.

On outcrop scale the tectonic contacts between the three units are parallel to the lithological layering. However, on a regional scale the contacts truncate the lithological layering as observable in the central part of the map area (De Jong & Bakker 1991, this volume), where the La Yedra 4 unit of the Nevado-Lubrin Unit is truncated by the basal contact of the Macael-Chive Unit.

$D_{x-1}$ structures are the oldest recognized deformation structures. They are observed in glauco-

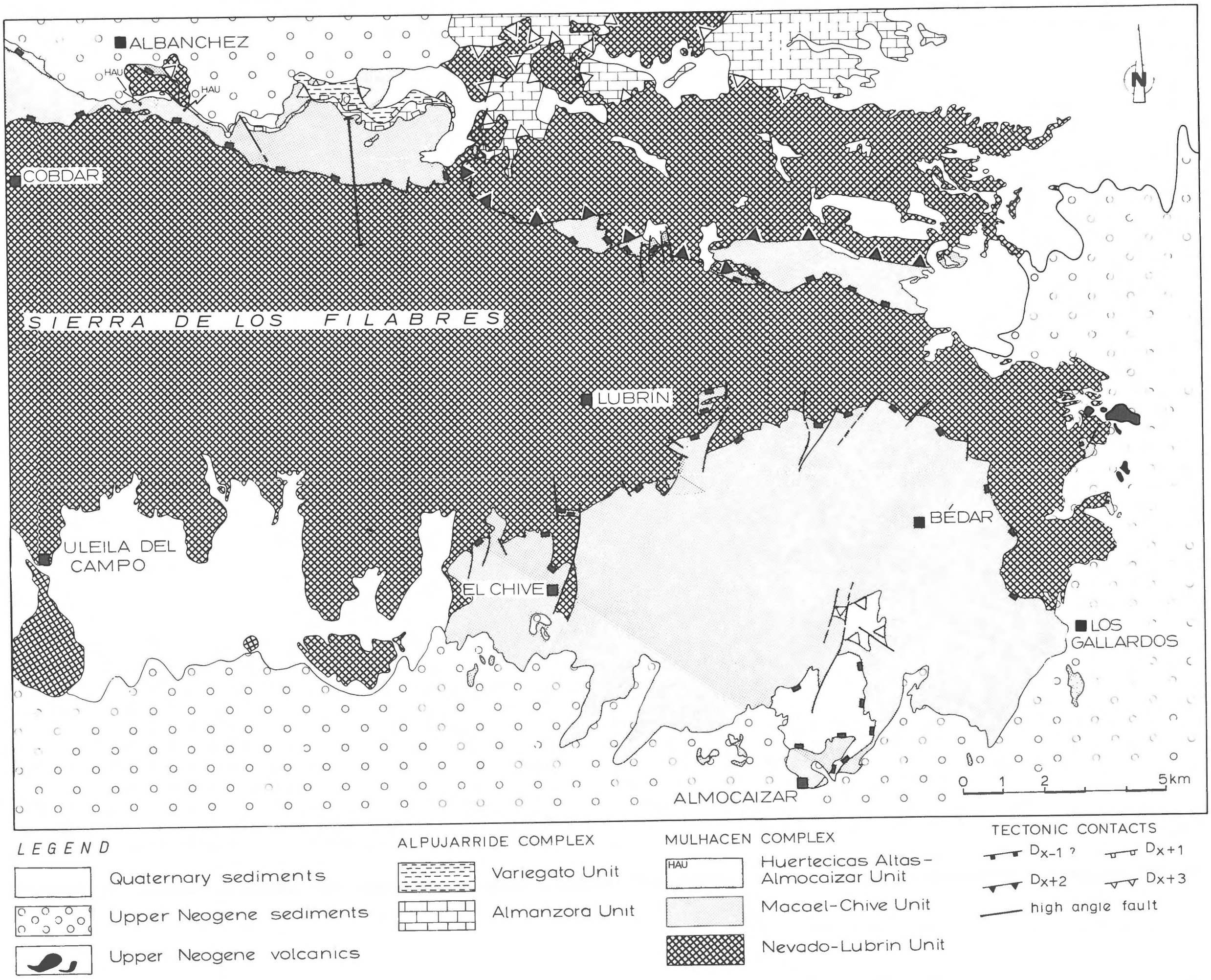


*Fig. 1.* Tectonic map of the eastern Sierra de los Filabres, slightly modified after Bakker et al. (1989). Straight line indicates section east of the hamlets Las Calesas and La Carrasca.

phane schists and in the core of the gneiss body of the Macael-Chive Unit. The structures include platy glaucophane-epidote-mica foliations and gneiss foliations with ESE-WNW trending mineral and stretching lineations. Asymmetric tails around feldspar porphyroclasts indicate WNW-directed shear. Synkinematic mineral assemblages point to pressure-temperature conditions of 0.9–1.1 GPa and 475–525° C (Bakker et al. 1989). $D_{x-1}$ structures are present as relics at different levels in all three thrust-sheet units of the Mulhacen Complex. This indicates the penetrative character of $D_{x-1}$ deformation.

The main foliation ($S_x$) was formed during $D_x$, which coincided with peak metamorphic conditions of 560–580° C at 0.7–0.9 GPa (Bakker et al. 1989). $S_x$ is generally developed as a transposition foliation parallel to the lithological layering, which encloses intrafolial folds, boudins and augen-structures. Locally $S_x$ forms the axial-plane cleavage of recumbent tight to isoclinal folds on centimetre to metre scale. In the hinge zones of these folds and in boudins and augen-structures $D_{x-1}$ structures are found. The ESE-WNW to SE-NW trending $D_x$ fold axes are parallel to a stretching lineation. The folds are locally sheath-like. During $D_x$ also numerous tension gashes were formed, filled with quartz and calcite, which were subsequently folded and

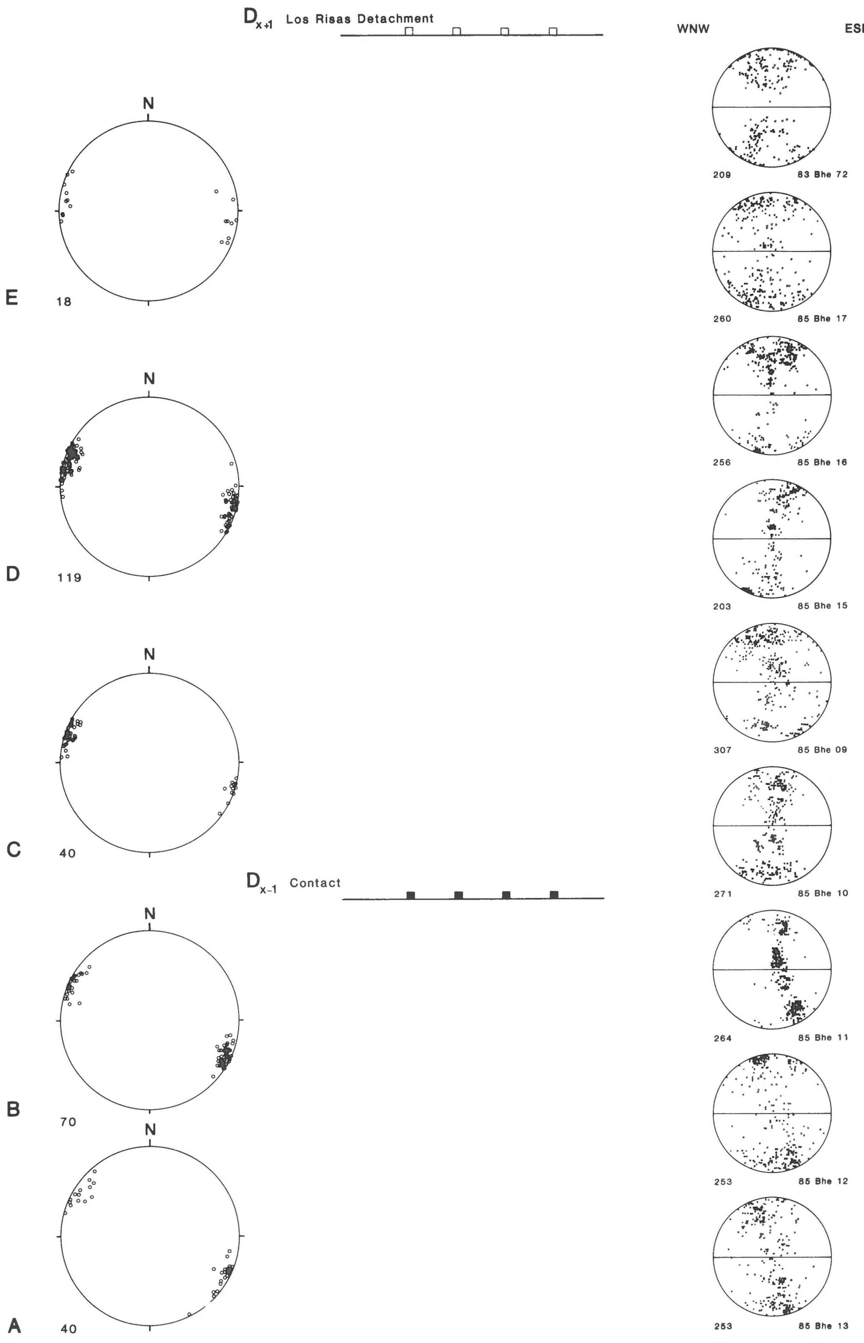


*Fig. 2.* Stereograms (lower hemisphere projection) showing on the left hand side the orientation of $D_x$ and $D_{x+1}$ mineral and stretching lineations, on the right hand side the relative position of $D_{x-1}$ and $D_{x+1}$ contacts and quartz c-acis fabrics (viewed towards the NNE) for a section east of the hamlets Las Calesas and La Carrasca. Stereogram A) from Muñoz Amphibole Micaschists, B) La Yedra Marbles and Schists, C) Aceituno Schists, D) Calesas Schists and Marbles, E) Macael Marbles. See text for discussion.

sheared parallel to $S_x$. They suggest a high vorticity during $D_x$. Strain analyses on deformed metabasites have revealed shear strains larger than 6. Since in the surrounding metasediments the shear strain has been considerably higher, discrete $D_x$ shear zones are almost absent and since size and aspect ratios of grains in monomineralic rocks seem to vary periodically, it is suggested that the $S_x$ foliation approximates a steady-state foliation (Means 1981). Quartz c-axis fabrics indicate dominant non-coaxial deformation and WNW to NW directed shearing during $D_x$.

Metamorphic and $D_x$ strain gradients are not observed across the thrust-sheet contacts, which implies that the contacts were formed before $D_x$. Unfortunately the relationships between $D_{x-1}$ structures and the thrust sheet contacts have been obliterated during $D_x$. If the thrust sheet contacts were formed before $D_{x-1}$, during the underthrusting process, this would probably have resulted in a mélange-type terrane. The regional continuity of well-defined lithostratigraphic units from the La Yedra sequence (De Jong & Bakker 1991, this volume), which can be traced over a distance of more than 30 km from east of the village of Lubrin to Purchena, rules out this possibility. The contact between the Tahal Schists and Carrasca Marbles can even be followed from Cartagena to the Sierra de Baza, over a distance of more than 100 km (Simon, pers. comm.). It is therefore suggested that stacking of the three major thrust sheets of the Mulhacen Complex took place during the first phase of penetrative alpine deformation, $D_{x-1}$.

## Units formed during extensional tectonics

The contact between the Mulhacen Complex and Almanzora Unit, the lowermost unit of the Alpujarride Complex in the area, was formed during $D_{x+1}$, at pressure – temperature conditions of at least 0.4 GPa and 450° C (Bakker et al. 1989). Small-scale $D_{x+1}$ structures include isoclinal similar folds, mylonites with associated E-W trending stretching lineations, and extensional crenulation cleavages (ECCs). The ECCs are most prominent just below the contact with the Almanzora Unit, which is a low-angle ductile shear zone. This detachment contact cuts eastward down section, into the underlying Mulhacen Complex. This is demonstrated by the eastward disappearance of the Huertecicas Altas-Almocaizar Unit in the northern part of the area (Cf. Encl. I in De Jong & Bakker 1991, this volume). Since this latter unit is also present in the southeastern part of the map area, it is concluded that the original detachment contact was spoon-shaped in three dimensions. Such geometry is comparable with the geometry of an extensional detachment zone in the eastern Alps, described by Selverstone (1987).

Structural and metamorphic data (Bakker et al. 1989) indicate that prior to $D_{x+1}$ the Almanzora Unit experienced a similar tectonic evolution as the Mulhacen Complex. However, it was underthrusted to a crustal depth of about 27 km, much lower than the 37 km of the Mulhacen Complex.

Due to poor exposure, the relative age of the tectonic contact between the Almanzora Unit and the overlying Variegato Unit is not known. On the basis of lateral extension and because the contact is folded and included in minor subsequent thrust sheets, a $D_{x+1}$ age is also assumed for this contact.

The increasing prominence of ECCs towards the detachment contact coincides with a moderate but consistent rotation of the mineral and stretching lineations. This is depicted in Fig. 2, which shows the orientation of the lineations for a section east of the hamlets Las Calesas and La Carrasca (Fig. 1; see also Encl. I in De Jong & Bakker 1991, this volume), where post $D_{x+1}$ deformation is generally weak and has not resulted in reorientation of older lineations. In this section the orientation of mineral and stretching lineations has been measured every 5 to 10 metres. It appears that the lineations rotate in a anti-clockwise fashion towards the detachment contact (Fig. 2). The anti-clockwise rotation is not expressed by the ECCs (Fig. 3). This is probably due to the limited zone in which the structures are present. However, the orientation of these ECCs show that the average dip of the eastern plunging set increases towards the detachment contact, whereas the dip of the western plunging set becomes slightly smaller. This pattern might suggest an E-vergent shearing.

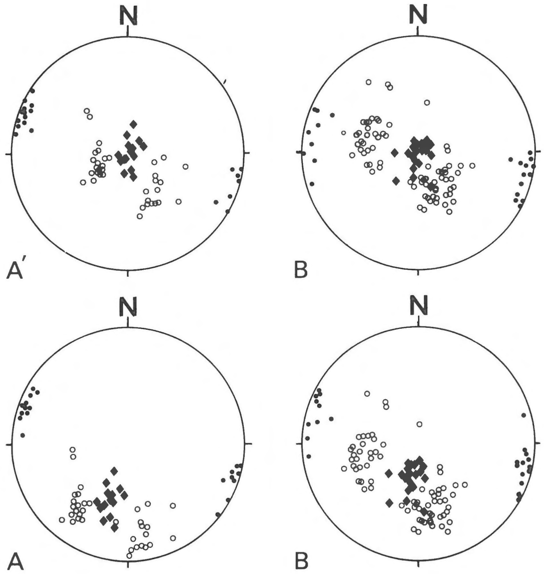


*Fig. 3.* Stereograms (lower hemisphere projection) showing the orientation of main foliation (black lozenges), ECC (open circles) and mineral and stretching lineations (dots) for two exposures along the section east of the hamlets Las Calesas and La Carrasca. A) from base of Macael Unit, B) 50 metres below $D_{x+1}$ contact, A[1]) and B[1]) rotated versions of A) and B) to extract $D_{x+2}$ rotation.

The gradual rotation of the lineations indicate that, during $D_{x+1}$ overprinting, the pre-existing linear anisotropy has been gradually adjusted to the new flow direction. The ECCs might reflect flow partitioning, suggesting that flow, in the micaschists, departed from progressive simple shear (Platt 1984).

From the same section samples of quartzites have been collected to study the development of quartz c-axis fabrics towards the detachment contact. The results are shown in Fig. 2. From this figure it appears that samples, which have been taken about 800 and 600 m below the detachment (85 Bhe 13/12) exhibit c-axis fabrics that point to non-coaxial deformation with a westward sense of shear. The axes are mainly oriented at a large angle to the foliation, suggesting that the rocks were deformed predominantly by basal slip. Samples taken at 500 and 400 m below the detachment (85 Bhe 11/10) show respectively a small circle distribution at a large angle to the foliation and a type II crossed girdle pattern (Lister 1977). Both patterns may indicate coaxial deformation in the constrictive domain. Sample 85 Bhe 15 exhibits a single c-axis girdle, which clearly indicates non coaxial deformation, with an eastward sense of shear. 85 Bhe 16 largely resembles an asymmetric type I crossed girdle, with predominantly basal slip. The pattern also suggests E-ward sense of shear. Samples 85 Bhe 17 and 83 Bhe 72, which are taken directly below the detachment, show small circle c-axis patterns centred around the foliation normal. This indicates coaxial deformation in the flattening field, which is consistent with the prominence of conjugate ECCs in this zone. In thin section it can be observed that grain-size reduction and optical reorientation is extended from the ECCs into the main foliation, indicating that the ECCs were formed during the latest increment of $D_{x+1}$ and reflect strain hardening.

In summary, the c-axis patterns indicate a shift from a WNW directed sense of shear in the deepest studied section, towards E-directed shear 50–100 m below the detachment. Directly below the detachment c-axis fabrics indicate coaxial flattening perpendicular to the foliation.

It is suggested that the shift in shear sense is related to the systematic rotation of the stretching lineations and reflects overprinting of the $S_x$ foliation during $D_{x+1}$.

The difference in temperature conditions between $D_x$ and $D_{x+1}$ is not reflected in the c-axis patterns. The quartz microstructures from samples showing a west or eastward sense of shear are similar.

## $D_{x+2}$ and $D_{x+3}$ structures

During $D_{x+2}$, which took place at about 0.3–0.4 GPa and 425° C (Bakker et al. 1989), the first generation of steeply dipping cleavages was formed. During this phase a marked contrast in rheological behaviour developed between the siliclastic Tahal Schists and the overlying alternating clastic and carbonate sequences.

This contrast is expressed by strongly differing amounts of flattening, reflected by the geometry of folds and prominence of cleavages. Taking the spacing of zones with prominent $S_{x+2}$ cleavage as a

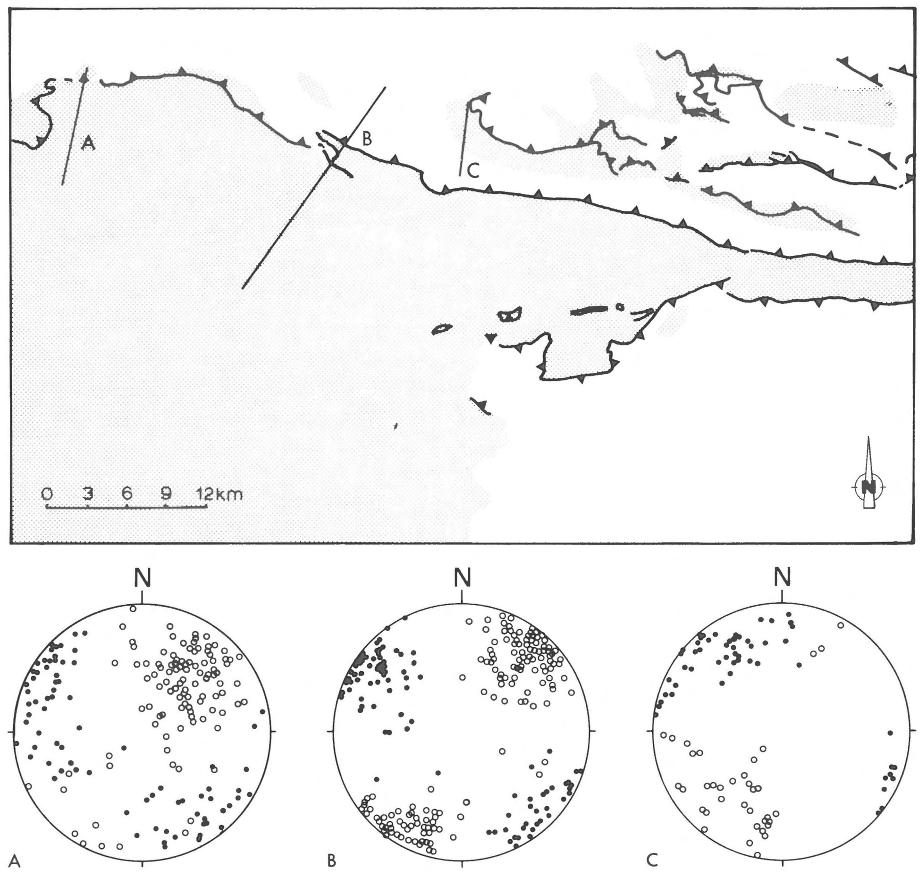


*Fig. 4.* Areal distribution of penetrative $D_{x+2}$ deformation (shading) and stereograms (lower hemisphere projection) showing the orientation of $D_{x+2}$ cleavages (open circles), fold axes and intersection lineations (dots). The eastern part of the map is based on data of Nijhuis (1964), Langenberg (1972) and De Jong (1985). The sections where the orientation data have been collected are indicated by a straight line.

rough measure, the finite ductile flattening of the Tahal Schists appears to be at least 3–5 times larger than that of its cover. The flattening in the overlying rock sequences was mainly compensated by up- and overthrusting. A detachment zone was formed at the contact of Tahal Schists and Carrasca Marbles. In the northeastern part of the area this detachment zone represents the sole thrust of an imbricate stack (Fig. 4 and Encl. I in De Jong & Bakker 1991, this volume), characterized by S-SW directed thrusts with associated S-SW vergent folds. The stack is bounded to the west by a lateral ramp. Thrusts of the imbricate stack crosscut the Nevado-Lubrin – Macael-Chive contact and place Nevado-Lubrin units directly on top of the Macael-Chive Unit. The Tahal Schists have not been included in the imbricates (cf. Encl. I in De Jong & Bakker 1991, this volume). Individual thrust sheets may attain thicknesses of more than 1000 metres (Encls I and II in De Jong & Bakker 1991, this volume). Thrust slices on outcrop scale have not been observed.

The intensity of folding and amount of flattening increases sharply towards the thrusts concurrent with increasing prominence of the axial-planar $S_{x+2}$ cleavage. Near the thrust planes $S_{x+2}$ is developed as a differentiated crenulation cleavage or tectonic banding. Here it is the most prominent planar structure. Away from the thrusts folds are absent or open and kink-like with a poorly developed axial-plane cleavage.

Directly below the detachment zone very tight,

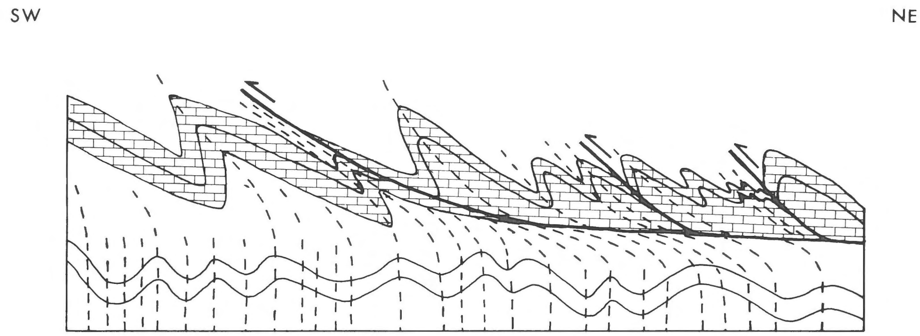


*Fig. 5.* Cartoon-like section demonstrating the structural configuration of the eastern Sierra de los Filabres just after $D_{x+2}$ deformation. Note the detachment zone at the contact Tahal Schists – Carrasca Marbles (brick notation) and south vergent $D_{x+2}$ folds near the thrust planes. The $S_{x+2}$ cleavage is indicated by a dashed line.

S-SW vergent flexural slip folds with a closely spaced differentiated axial-planar crenulation cleavage were formed. At lower levels in the Tahal Schists $D_{x+2}$ strain gradually decreases and upright open folds with broadly spaced crenulation cleavages are present. In the Tahal Schists $S_{x+2}$ is generally the most prominent tectonic plane. Figure 5 shows schematically the structural configuration just after $D_{x+2}$.

In general $D_{x+2}$ fold axes and intersection lineations are developed parallel to the previously formed prominent stretching lineations. This might indicate that the orientation of these $D_{x+2}$ structures was largely determined by the existing strong linear anisotropy. It would imply that these structures are not precisely indicative of the orientation of the stress system (Cobbold & Watkinson 1981), but only roughly indicate a NE-SW compression.

Deformation during $D_{x+3}$ was more heterogeneous than before. It was largely concentrated along the previously formed detachment zone (Fig. 6), which has been reactivated. Locally also the $D_{x+1}$ detachment between the Mulhacen Complex and Almanzora Unit has been affected and reactivated. Along the $D_{x+2}$ detachment zone $D_{x+3}$ resulted in open to tight folds with associated axial-planar crenulation cleavages. Two groups of folds can be distinguished, symmetrical disharmonic folds and asymmetrical disharmonic folds with a marked S-ward structural vergence. Both types of folds indicate flexural slip. The $S_{x+3}$ cleavage in the top of the Tahal Schists is locally developed as a differentiated crenulation cleavage forming the most prominent tectonic plane in the metapelites. Overprinting of broadly spaced $S_{x+3}$ cleavages on $S_{x+2}$ crenulation cleavages has locally resulted in conspicuous herringbone geometries.

Unlike $D_{x+2}$ linear structures, $D_{x+3}$ fold axes and intersection lineations have not formed parallel to older stretching lineations. In domains with prominent $D_{x+3}$ deformation, older structures have therefore been rotated around differently orientated $D_{x+3}$ fold axes, giving rise to poorly defined orientation distributions (Fig. 6). The $S_{x+2}$ cleavages in the Tahal Schists have rotated during $D_{x+3}$ from vertical towards south dipping in the western part of the area (Fig. 4).

Concentration of $D_{x+3}$ structures along the $D_{x+2}$ detachment zone indicates reactivation of this zone, which resulted in extensive brecciation and disruption of $D_{x+3}$ folds. The breccia are mainly found in lens-shaped zones, which may attain lateral magnitudes of several kilometres (cf. Encl. I in De Jong & Bakker, this volume). They are restricted to carbonate horizons. Brittle-ductile shear zones transverse the micaschists and carbonate rocks. Ductile and brittle deformation occurred intermittently in the carbonate rocks.

A north to northeast tectonic transport during $D_{x+3}$ is suggested by stretching lineations with associated asymmetric strain shadows in carbonate ultramylonites, slickensides, the orientation of $S_{x+3}$ cleavages, ECCs (Fig. 6) and rotated older structures.

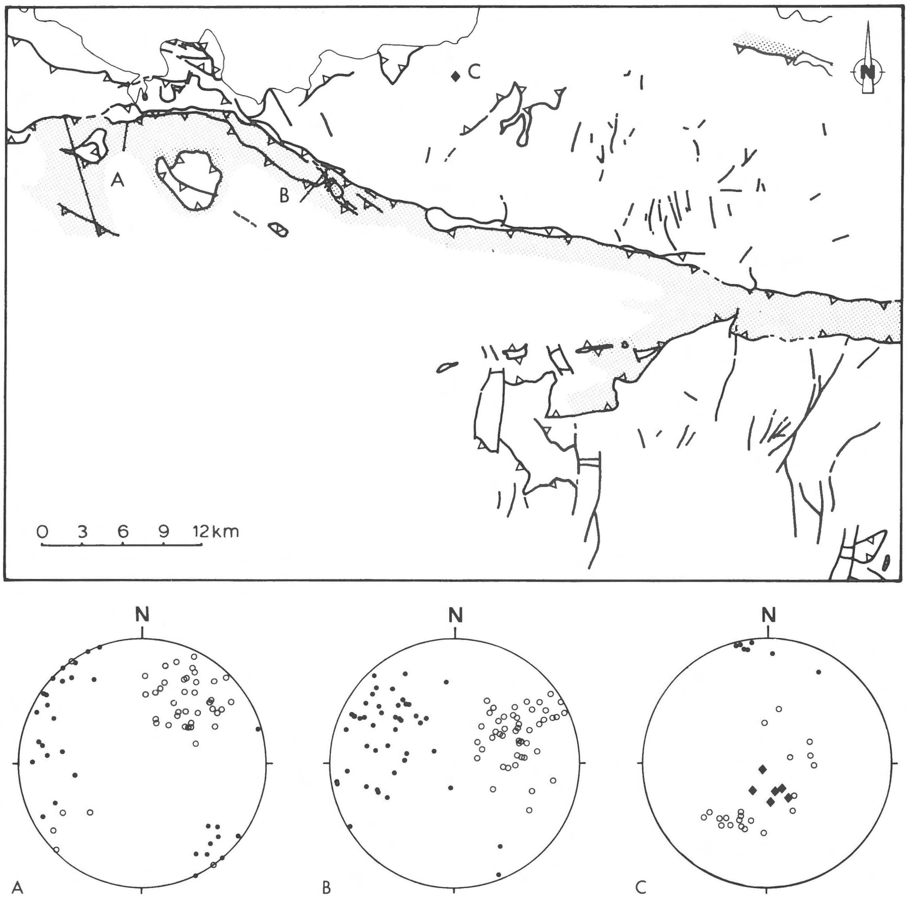


*Fig. 6.* Areal distribution of penetrative $D_{x+3}$ deformation (shading) and stereograms (lower hemisphere projection) showing the orientation of $D_{x+3}$ cleavages (A, B; open circles), fold axes and intersection lineations (dots) and $D_{x+3}$ ECCs (C; open circles), main foliation (black lozenges) and stretching lineations (dots). The steeply dipping, NNE trending faults visible on the map are partly formed during $D_{x+3}$. However, they have also been active after this phase. Note that these faults hardly displace the detachment zone at the contact of the Tahal Schists – Carrasca Marbles.

The eastern part of the map is based on data of Nijhuis (1964), Langenberg (1972) and De Jong (1985). The sections where the orientation data have been collected are indicated by straight lines (A, B) and a lozenge (C).

In a zone north of Cerro del Madroñal (Encl. I in De Jong & Bakker, this volume). $D_x$ and $D_{x+1}$ stretching lineations and $D_{x+2}$ foldaxes and cleavages have been rotated into a great circle distribution (Fig. 4). This rotation indicates differential movements as described by Fisher & Coward (1982). The continuity of the lithologic units indicate that the differential movements have not been large enough to cause large-scale fracturing. Moreover, no new cleavage was formed.

This zone marks the western limit of the $D_{x+2}$ imbricate stack. The area to the West is characterized by N to NE vergent thrusting and N-wards low-angle normal faulting (Encls I and II in De Jong & Bakker, this volume). Such extensional faulting has caused the local datum gap at the level of the Calesas Marbles and Schists north of La Carrasca (Encl. I in De Jong & Bakker, this volume). In this area also two prominent dextral tear faults have been developed, that also point to differential movements. The concurrent occurrence of tear faults and extensional faults suggests a causal relationship.

The low-angle extentional faults in the Macael-

Chive Unit were formed before the N to NE-ward up- and overthrusts and the Albanchez Duplex (Encl. II in De Jong & Bakker, this volume), a foreland dipping duplex in the sense of Boyer & Elliot (1982). Individual horses (Elliot & Johnson 1980) are composed of parts of all rock sequences of the Mulhacen Complex and Alpujarride Units. Tahal Schists are also included in the thrust slices, indicating that $D_{x+3}$ was no longer concentrated along the detachment zone between Tahal Schists and Carrasca Marbles. From this stage onwards thrust planes truncate this deepest lithostratigraphic unit. This order of development suggests piggy-back thrust propagation (Dahlstrom 1970).

The penetrative ductile structures of $D_{x+3}$ were formed at high temperatures of 510–550° C and pressure conditions above 0.2–0.3 GPa (Bakker et al. 1989). These high temperature conditions have been correlated with 20–23 Ma basaltic magmatism and solid state intrusions of ultramafic rocks in the western Betics (Bakker et al. 1989). For the brittle structures included in $D_{x+3}$ no P-T conditions have been established.

From the development of the Albanchez Duplex it appears that several generations of structures can be distinguished, i.e. $D_{x+3}$ cleavages and low-angle extensional faults, which are older than N to NE-ward up- and overthrusts. All of these structures might have been formed during progressive $D_{x+3}$ deformation, which lasted from 20–23 Ma until deposition of Late Miocene sediments.

In this scenario the tear faults and low-angle extensional faults may result from gravitational spreading and represent secondary faults related to an overlying major thrust plane (Mandle & Shippam 1981), that formed part of a larger scale overthrust zone. The subsequent imbrications and duplex were formed after the stress system had changed. Maybe due to sticking or drag along the sole thrust of this overthrust zone the Albanchez Duplex became foreland dipping. This hypothesis would imply the presence of a large-scale thrust plane at a lower crustal level.

The differential movements in the area north of la Carrasca can also be explained by sticking or drag along a sole thrust. Alternatively these movements might point to a variation of the gravitational potential along the overthrust zone.

Within this scenario of progressive deformation, various generations of structures have been formed at quite different crustal levels.

## Conclusions

From this study it appears that the eastern Sierra de los Filabres is constituted of several generations of thrust sheets which were formed during entirely different tectonic events. The oldest thrust sheets are present in the Mulhacen Complex and reflected by superposition of dark-coloured, graphite-rich micaschists of inferred Paleozoic, on top of light-coloured meta-sediments of Triassic age. Across the thrust sheet contacts no strain or metamorphic gradient is present. It is suggested that the thrust sheet contacts were formed during the first phase of penetrative Alpine deformation, $D_{x+1}$. This phase is related to continent-continent collision.

During the second phase of thrust sheet formation rocks from the Alpujarride Complex were placed directly on top of the Mulhacen Complex. This occurred during $D_{x+1}$, after peak metamorphic conditions in both complexes. Therefore, in addition to a strain gradient, a marked difference in metamorphic crystallization is noted across the thrust sheet contact between Almanzora Unit and Mulhacen Complex. Quartz c-axis fabrics demonstrate E-directed shear during $D_{x+1}$. It is suggested that these thrust sheets are related to a regional phase of heterogeneous extension and crustal thinning, which took place during the Late Oligocene to Early Miocene (Bakker et al. 1989).

Subsequent $D_{x+2}$ deformation is characterized by the first generation of steeply dipping cleavages and strain partitioning. In the Tahal Schists deformation was penetrative and ductile, whereas in its cover crustal shortening was mainly accomplished by brittle overthrusting. A detachment zone was formed between the Tahal Schists and its cover and in the northeastern part of the area an imbricate stack was formed.

During $D_{x+3}$ the detachment zone between the

Tahal Schists and its cover was reactivated. These movements were followed by development of low-angle extensional faults and dextral tear faults in the northwestern part of the area. All these structures were finally included in minor thrust sheets, that in the area near Albanchez constitute the foreland dipping Albanchez duplex. For the $D_{x+3}$ structures a Miocene age is suggested.

Due to $D_{x+2}$ and $D_{x+3}$ overthrusting the original superposition of tectonic units was strongly modified. Locally this has resulted in superposition of Mulhacen on top of Alpujarride Units. $D_{x+2}$ and $D_{x+3}$ deformations have largely determined the present structure of the eastern Sierra de los Filabres.

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