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New data from Orihuela and Callosa Mountains (Betic Internal Zone, Alicante, SE Spain). Implications for the "Almágride Complex" controversy

Nuevos datos de las Sierras de Orihuela y Callosa (Zona Interna Bética, Alicante, SE de España). Implicaciones en la controversia sobre el "Complejo Almágride"

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Abstract

In this paper, we present the results of the stratigraphic and structural study of the Orihuela and Callosa Mountains (Alicante province, SE Spain), belonging to the Internal Betic Zone. The terrains cropping out in this area had been assigned by previous authors to the Ballabona-Cucharón Complex, lately redefined as the Almágride Complex. New data afforded in this work lead us to propose a new stratigraphic succesions, structural division, and geodynamic evolution. We also assign both mountains ranges to the lower Alpujarride Complex, confirming that the Almágride Complex is not a singular element of the Betic Cordillera.

Keywords: Alpujarride Complex, Almágride Complex, Internal Betic Zone, Betic Cordillera, Alicante province.

Resumen

En este trabajo presentamos los resultados del estudio estratigráfico y estructural de las sierras de Orihuela y Callosa (provincia de Alicante, SE de España), pertenecientes ambas a la Zona Interna Bética. Estas sierras fueron asignadas por autores precedentes al Complejo Ballabona-Cucharón, más tarde redefinido como Almágride. Los datos presentados en este trabajo nos llevan a proponer una nueva serie estratigráfica, división tectónica y evolución geodinámica del sector estudiado. Así mismo, asignamos las unidades reconocidas a la parte inferior del Complejo Alpujárride, confirmando que el Complejo Almágride no debe ser considerado como elemento singular de la Zona Interna Bética.

Palabras clave: Complejo Alpujárride, Complejo Almágride, Zona Interna, Cordillera Bética, provincia de Alicante

1. Introduction

The Internal Betic Zone has been classically divided into three main complexes called, from bottom to top: Nevado-Filabride, Alpujarride and Malaguide; although several authors have proposed further elements (Simon, 1964; Egeler and Simon, 1969a and 1969b). Rocks constituting the Internal Betic Zone show variable metamorphic grade, ranging from very high in the case of Nevado-Filabride and some Alpujarride units to non-metamorphic, as in the case of the Malaguide cover.

The study area comprises Orihuela and Callosa Mountains, two promontories emerging from the Lower Segura basin in SE Spain, situated on the boundary between Alicante and Murcia provinces (Fig. 1). These mountains are composed of low-grade metamorphic rocks which have been attributed to different elements of the Betic Cordillera (Kampschuur, 1972; de Boer *et al.*, 1974; de Jong, 1991). From a structural standpoint, de Boer *et al.* (1974) defined three units in the Orihuela Mountains, from bottom to top: Bermejo, Túnel and Orihuela units. They also defined two units in the Callosa Mountains: Redovan and Callosa units. Inside these latter units several informal formations were described.

The assignation of Orihuela and Callosa Mountains to a palaeogeographical element of the Betic Cordillera have been a matter of discussion. They were assigned by Kampschuur (1972) to the Alpujarride Complex, later to the Ballabona-Cucharón Complex by de Boer *et al.* (1974) and finally to the Almágride Complex (de Jong, 1991).

Our studies put forward a more accurate stratigraphy and structure that enable us to propose a new tectonic organization and geodynamic evolution. On these bases, we discuss the tectonic attribution of the terrains outcropping in both Orihuela and Callosa Mountains.

2. Stratigraphic data

In the Orihuela and Callosa Mountains, we have differentiated two informal formations (Fig. 2): first, a lower *meta-detrital formation* made of phyllites and quartzites and, second, an upper *carbonate formation*, including three members (going to the top: *lower calcareous-dolomitic member*, *limestone and marl member*, and *upper calcareous member*; Fig. 2).

2.1. Meta-detrital formation

This formation is composed of bluish slates and phyllites with alternating quartzites of pinkish, reddish, whitish, and greenish colours. In this formation appear bodies of mafic sub-volcanic rocks sub-parallel to the stratigraphic markers. In the upper part of this formation a discontinuous gypsum level outcrops, reaching 20 m thick, although due to its poor lateral continuity it could not be mapped. This formation presents an upwardly coarsening trend, as in the upper part the quartzites are more abundant. The greatest thickness of this meta-detrital formation is 170.

2.2. Carbonate formation

We distinguish three different members within the carbonate formation: a *lower calcareous-dolomitic member*, a *limestone and marl member* and an *upper calcareous member*.

The *calcareous-dolomitic member* is constituted by dolostones, limestones, and marls. The lower part of this member is formed by massive or very thick-layered limestones and dark dolostones showing an intense recrystallization. At the base, there is a highly recrystallized discontinuous dark dolostone bed occasionally with zebra dolostones (up to 3 m thick). Also, several interbedded yellow dolomitic strata appear, transitioning laterally to synsedimentary breccias. A widespread characteristic of this lower part of the member is the presence of intense bioturbation, which may occasionally reach 95% of the total rock volume. Occasionally, limestone cores with original facies are preserved in the dolomitic mass, exhibiting mudstone, oolitic grainstone and (algal-laminated) bindstone textures. Towards the middle part of this member a marl intercalation occurs. The upper part of the member consists of limestones organised in metric cycles with upward terrigenous enrichment, representing the transition to the following member. The observed thickness of this member is about 300 m.

The *limestone and marl member* is composed of two different parts: a lower one formed by grey and yellow carbonates in well defined beds 45-60 cm thick, and an upper one made of thinner yellowish, highly bioturbated limestones and marls. Occasionally there appear levels rich in lamelibranchs, foraminifera, remnants of fishes, ostracoda and conodonta, but no biostratigraphic determination was possible. de Boer *et al.* (1974) cited the presence of *Pseudofurnishius murcianus*, indicating an upper Ladinian to lower Carnian age for this member. Grey limestones with very thin brownish layers of marls and scattered nodules of chert occur in the uppermost part of this member. This level laterally grades to well-bedded limestones and dolostones with evaporite casts. Finally, the top is comprised of dolostones with centimetric beds of intraformational breccias. This member is roughly 75 meters thick.

The *upper calcareous member* is formed by yellow limestones with some detrital micas, arranged in decimet-

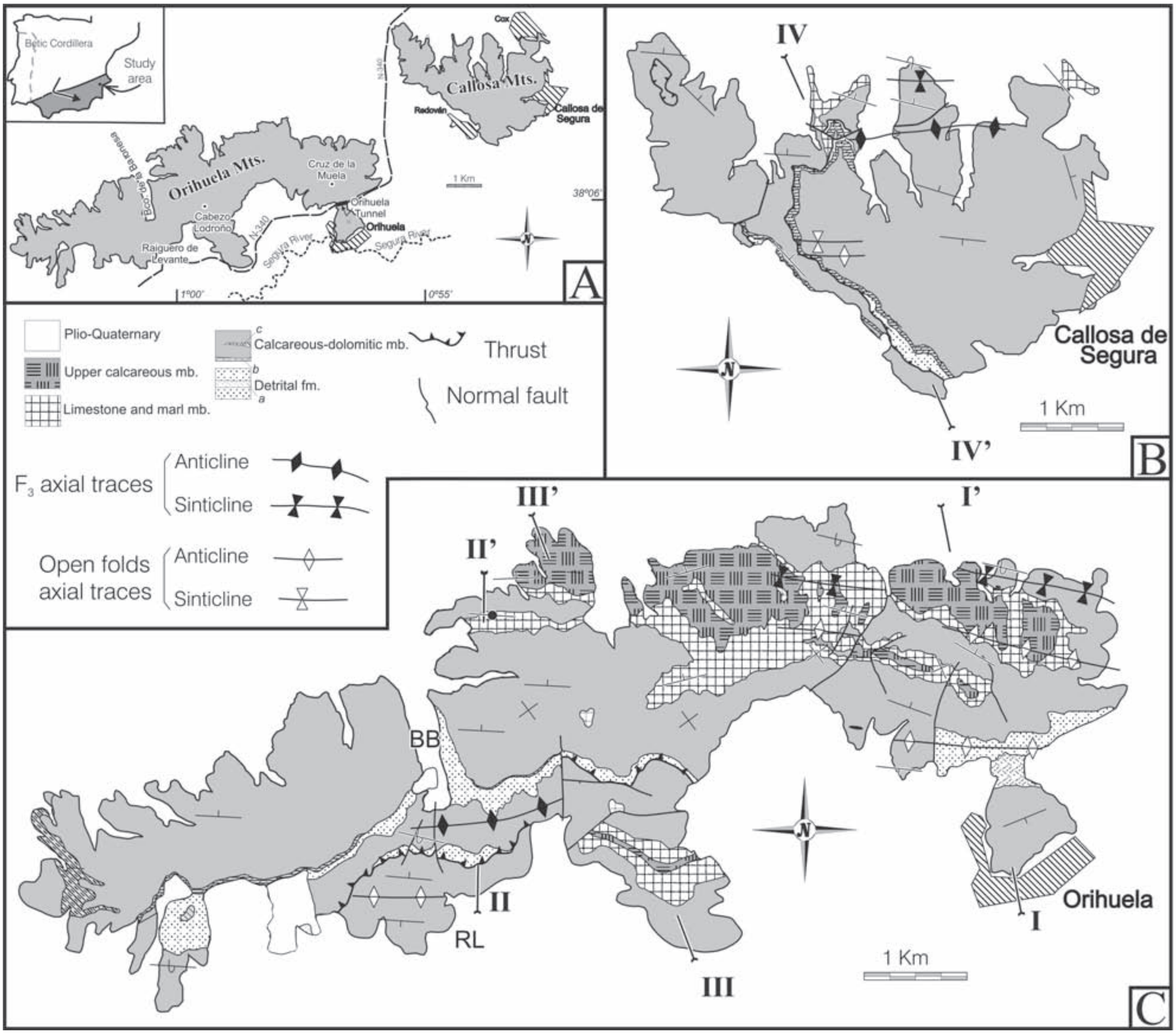

Fig. 1.- A: Situation of the study area. B: Geological map of the Callosa Mountains. C: Geological map of the and Orihuela Mountains. *a*) Basic sub-volcanic rocks; *b*) black dolostones; *c*) marl intercalation. BB: Barranco de la Baronesa; RL: Raiguero de Levante.

Fig. 1.- A: situación geográfica del área estudiada. B: Mapa Geológico de la Sierra de Callosa. B: Mapa Geológico de la Sierra de Orihuela. *a*) Rocas sub-volcánicas básicas. *b*) Dolomías negras. *c*) Intercalación margosa. BB: Barranco de la Baronesa; RL: Raiguero de Levante.

ric beds. Occasionally, light-yellow dolostone beds can occur. Laterally, these limestones change to a gypsum level with black dolostone clasts, up to 20 m thick. The total thickness of this member is at least 100 meters.

3. Structural features

The meso- and macro-structural features have been analysed along different sections traversing the Orihuela and Callosa Mountains. More than 60 thin sections of the meta-detrital formation have also been studied in order to elucidate the microtectonics. This study reveals a common sequence of deformational episodes recognised in both the Orihuela and the Callosa Mountains.

In the studied thin sections a relict first foliation (S_1) was locally recognized, accompanied by crystallization of light greenish-white mica and quartz. This first foliation is not related to meso-scale structures observed in the area.

A second foliation, S_2, constituting the main foliation observed in the study area, is developed by microfolding of S_1 and consists of a crenulation cleavage marked by the crystallization of white mica and quartz. S_2 is sub-parallel to the lithologic contacts and shows heterogeneous dipping due to successive deformation phases.

In some thin sections a later foliation, S_3, can be recognized, developed by microfolding or ductile to semi-brittle shear of S_2. At the outcrop scale centimetric to hectometric ENE-WSW folds are observed, affecting the main foliation (S_2) and also the lithologic contacts (Figs.

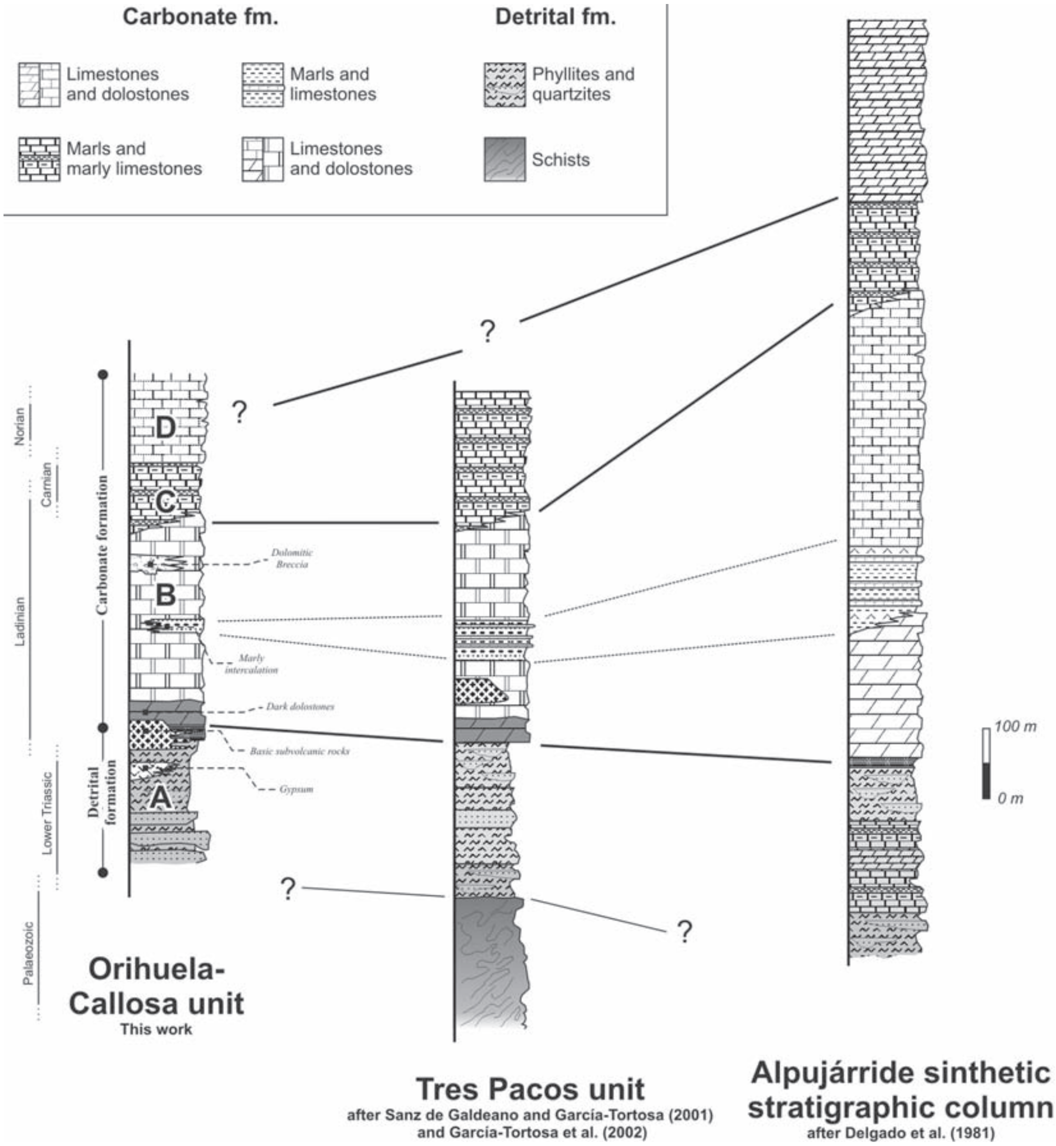

Fig. 2.- Integrated stratigraphic column of the Orihuela-Callosa unit (A. Meta-detrital formation; B. Calcareous-dolomitic member; C. Limestones and marls member; D. Upper calcareous member) and its correlation with the Tres Pacos Unit (after Sanz de Galdeano and García-Tortosa, 2001, and García-Tortosa *et al*., 2002) and with the Alpujárride synthetic stratigraphic column (after Delgado *et al*., 1981).

Fig. 2.- Columna estratigráfica sintética de la unidad de Orihuela-Callosa (A. Formación meta-detrítica; B. miembro calizo-dolomítico; C. miembro de calizas y margas; D. miembro calizo superior) y su correlación con la Unidad de los Tres Pacos (Sanz de Galdeano and García-Tortosa, 2001 y García-Tortosa *et al*., 2002) y con la columna sintética del Complejo Alpujárride propuesta por Delgado *et al*. (1981)

1 and 3). These folds are south vergent in the Orihuela Mountains, but north vergent in the Callosa Mountains. As the deformation evolves, some of those vergent anticlinal folds develop basal thrusts (Figs. 1 and 3), producing a general structure characterized by the presence of tectonic slices (see Discussion below). The thrust cropping out north of the locality Raiguero de Levante is also affected by a south-vergent fold (Fig. 3, section II-II').

The contact surfaces between the meta-detrital basal formation and the overlying carbonate formation are mostly low-angle faults, with subtractive characteristics, and a WNW transport direction. Metric folds related to this faults can be locally observed (as in the Barranco de la Baronesa area).

All these structures are affected by hectometric open folds with highly dipping axial planes (Figs. 1 and 3) and two sets of normal faults (NNW-SSE and NNE-SSW, respectively).

4. Discussion

4.1. Tectonic organization

In the Alpujarride Complex, different tectonic units with regional significance have been defined, denoted with diverse names according the sector considered (see

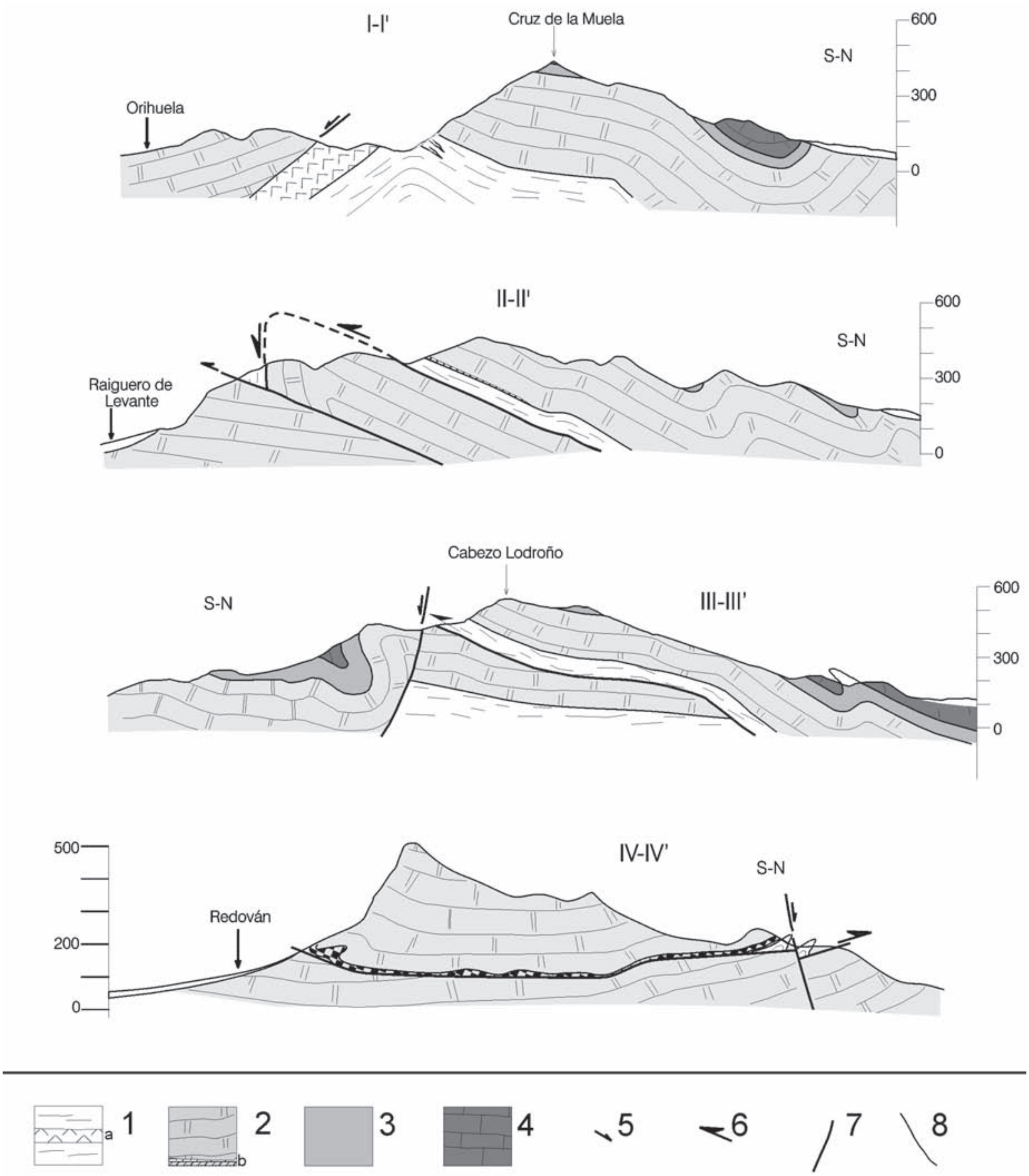

Fig. 3.- Geological cross sections (situation in Fig. 1). 1) Meta-detrital fm., a) Basic sub-volcanic rocks; 2) Calcareous-dolomitic mb., b) basal black dolostones; 3) Limestones and marls mb.; 4) Upper calcareous mb.; 5) Sense of displacement of normal fault; 6) Sense of displacement of thrust; 7) Tectonic contact; 8) Stratigraphic contact (locally tectonized).

Fig. 3.- Cortes geológicos (situación en la Fig. 1). 1) Formación meta-detrítica, a) rocas subvolcánicas básicas; 2) miembro calizo-dolomítico; b) dolomías negras; 3) miembro de calizas y margas; 4) miembro calizo superior. 5) Sentido de desplazamiento de fallas normales. 6) Sentido de desplazamiento de cabalgamientos. 7) Contacto tectónico. 8) Contacto estratigráfico (localmente tectonizado).

Sanz de Galdeano, 1997 for a detailed review). In the case of the Orihuela Mountains, three units were defined by de Boer *et al.* (1974), from bottom to top: the Bermejo, Túnel, and Orihuela Units. The Bermejo Unit was distinguished from the Orihuela Unit by the existence of a tectonic contact between them north of the locality Raiguero de Levante, responsible for the duplication of part of the stratigraphic succesions (Figs. 1 and 3). The stratigraphic sequences recognized below and above this contact are exactly the same, even to metric scale. Consequently, we propose to consider Bermejo and Orihuela Units as "*tectonic slices*", *i.e.* minor tectonic sheets with only local significance and developed within a single tectonic unit of regional significance. The Túnel unit was defined on the basis of no clear palaeontological criteria: de Boer *et al.* (1974) proposed the Ladinian-Carnian age for the Túnel Unit, while the basal part of the overlying Orihuela Unit was considered as Carnian or older according to lithological correlation with the neighbouring Sierra of Carrascoy. However, in the small ravines north of the tunnel on national road N-340, carbonatic level are interbeded in the meta-detrital formation of the Túnel Unit (*sensu* de Boer *et al.,* 1974), becoming thicker and more abundant towards the top. In our interpretation, these rocks constitute the stratigraphic gradational transition to the overlying carbonates, considered up to now as belonging to the Orihuela Unit; moreover, the recrystallization caused by the intrusion of mafic sills in the lower part of the succesion crosses the assumed tectonic contact separating the two units. Briefly, according to these observations, the Orihuela Mountains are viewed as a single tectonic unit with regional significance, even if divided into two tectonic slices.

In a similar way, in the Callosa Mountains, two units were differentiated (Redovan and Callosa Units; de Boer *et al.,* 1974). Nevertheless, once again the stratigraphic sequences below and above this contact are exactly the same. Therefore, the existence of two tectonic units with a regional significance is not justified.

Moreover, the succesions recognized in the Callosa Mountains is quite similar to that outcropping in the Orihuela sector. Consequently, we propose grouping both mountain ranges into a single regionally significant tectonic unit: the Orihuela-Callosa unit. For this unit, we show (Fig. 2) a stratigraphic column with a single integrated sequence.

4.2. Geodynamic evolution

We have grouped the different tectonic phases recognized in the Orihuela and Callosa Mountains in two deformational cycles. The first cycle comprises the synmetamorphic tectonic phases.

The *first tectonic cycle* includes three different deformative phases. i) The first syn-metamorphic phase, responsible for the S_1 foliation. This phase is not related to meso-scale structures. ii) The second phase, also synmetamorphic, is characterized by the development of a second foliation (S_2), which is more clearly present in the terrigenous members and less defined in the carbonate ones. S_2 is the main foliation observable in the area, both at micro- and meso-scales. iii) The third phase is syn-metamorphic, compressional and responsible for the development of micro-scale to hectometric overturned folds, affecting not only S_2 main foliation but also the stratigraphic contacts. Locally, an axial-plane foliation (S_3) is developed. During this third phase, later brittle additive contacts also appear. Vergent folds and thrusts are synchronous, as indicated by the presence of folded thrusts (Fig. 3, section II-II') and thrust-related folds (Fig. 3, section III-III'). Folds related to this third phase are contrary vergent in the Orihuela and Callosa Mountains (to the south and to the north, respectively). We have found no evidence explaining this situation; it could be produced by a differential rotation of both ranges, related to later deformational episodes, as have been recognized in other sectors near the study area (Allerton *et al.* 1992; Allerton *et al.*, 1993).

The *second tectonic cycle* comprised two later deformative phases: iv) The fourth phase is responsible for the low-angle extensional faults and, locally, overturned folds. v) The last phase produces open folds with a subvertical axial plane and an E-W axial direction, in addition to two sets of normal faults, forming 50º-70º with the axial direction (*i. e.*, NNW-SSE and NNE-SSW).

The geodynamic evolution discussed is in good agreement with that generally accepted in the eastern sector of the Alpujarride Complex (Azañón *et al.*, 1997; Booth-Rea *et al.*, 2002; Martín-Rojas, 2006).

4.3. Orihuela and Callosa Mountains tectonic attribution

The outcropping rocks in the Orihuela and Callosa Mountains were initially assigned to the Alpujarride Complex (Kampschuur, 1972), later to the Ballabona-Cucharón Complex (de Boer *et al.*, 1974) and finally to the Almágride Complex (de Jong, 1991).

In the Sierra de Almagro (Almería province), five tectonic units were defined in the 60' (Simon, 1963; Simon, 1964), ascribing the upper four units to the Alpujarride Complex. This author also affirmed that the lowermost unit (Almagro Unit) had no relation with this complex, as it was palaeogeographically situated north of the Nevado-Filabride Complex; defining a new element in the Internal Betic Zone: the Almágride Complex (Simon, 1987). The Ballabona-Cucharón Complex was defined by Egeler and Simon (1969a), which included not only the Almagro Unit, but also the overlying Ballabona and Cucharón Units. These authors affirmed that the Ballabona-Cucharón complex was characterized by the abundance of gypsum within the Triassic metapellitic interval of its stratigraphic succesions.

Afterwards, two new complexes were differentiated: the Almágride and the Ballabona-Cucharón Complexes (Simon *et al.*, 1976; Simon and Kozur, 1977). The Almágride Complex was described as having several similarities with the Subbetic (Besems and Simon, 1982; Simon y Visscher, 1983), a domain of the External Betic Zones. Following this idea, the Almágride was considered as a fragment of the Subbetic domain subducted under the Internal Betic Zone (Simon, 1987).

A recent revision of the Sierra de Almagro sector (Sanz de Galdeano and García-Tortosa, 2002; García-Tortosa, 2002), where both the Ballabona-Cucharón and the Almágride Complexes were defined, has demonstrated that the Ballabona, Cucharón, and Almagro Units are in fact a single tectonic unit, called by these authors the Tres Pacos Unit, as they reinterpret the previously considered thrust surfaces as normal stratigraphic contacts that have been tectonically disturbed. Moreover, Sanz de Galdeano and García-Tortosa (2002) affirm that according to its stratigraphic and structural characteristics the Tres Pacos Unit is the lowermost unit of the Alpujarride Complex in the Sierra de Almagro, and that it appears over, and not under, the Nevado-Filabride Complex. This tectonic situation demonstrates that the Tres Pacos Unit cannot be assigned to the Subbetic Domain. According to these authors, all the outcrops previously assigned to the Ballabona-Cucharón and Almágride Complexes should be included in the Alpujarride Complex.

The Orihuela and Callosa Mountains outcrops are isolated by Neogene to Quaternary deposits from other outcrops of the Betic Internal Zone, so that their position in the general structural stack of the Internal Betic Zone cannot be ascertained. However, their characteristics clearly indicate that they belong to the Alpujarride Complex. The stratigraphic organization we recognized can be correlated with those proposed in other sectors of the Internal Betic Zone (Fig. 2). In the upper part of the meta-detrital formation a gypsum intercalation up to 20 m thick crops out in the Orihuela and Callosa Mountains, equivalent intercalations have been described in the Sierra de Baza (Delgado, 1978; Delgado *et al.*, 1981), in the Murcia province (García-Tortosa, 2002), and in the Sierra de Gádor sector (Martín-Rojas, 2006). The *lower calcareous-dolomitic member* we here define can be correlated with the "lower carbonate formation" of Tres Pacos unit (García-Tortosa *et al.*, 2002) as well as with the Ladinian members proposed by Delgado *et al.* (1981) in their general stratigraphic column of the Alpujarride Complex for the central sector of the Betic Chain. Within this *lower calcareous-dolomitic member* a marl intercalation occurs in the study sector. This intercalation could be equivalent to the "marl-calcareous member" of the Tres Pacos Unit (García-Tortosa *et al.*, 2002) and to the "well bedded calcschists" member of Delgado *et al.* (1981). The *limestone and marl member* corresponds to the upper part of the carbonate formation of the Tres Pacos unit (García-Tortosa *et al.*, 2002) and to the Carnian marl member of Delgado *et al.* (1981). Finally, the *upper calcareous member* could represent the transition to the dolomitic Norian member of Delgado *et al.* (1981).

Other criteria proposed by de Boer *et al.* (1974) to affirm that the Orihuela and Callosa Mountains do not belong to the Alpujarride Complex but rather to the External Betic Zone include the presence of "*Muschelkalk-like*" facies and very thick gypsum levels. However, several authors have shown that evaporitic levels in the Alpujarride Complex are not scarce, and can sometimes be considered as a typical characteristic (Delgado *et al.*, 1981; García-Tortosa, 2002; Martín-Rojas *et al.*, 2002; Martín-Rojas, 2006). Similarly, the shelly beds remembering the Muschelkalk facies have also been described in several areas of the Alpujarride Complex (Jacquin, 1970; López-Garrido *et al.*, 1997; García-Tortosa *et al.*, 2002).

Thus, due to the very similar stratigraphy and tectonic evolution of the Orihuela and Callosa Mountains in comparison to the lower units of the Alpujarride Complex in the eastern sector of the Betic Chain, we interpret these outcrops as belonging to this complex. There is no evidence indicating the existence of rocks with a Subbetic affinity in the study area. This data also support the theory proposed by Sanz de Galdeano and García-Tortosa (2002) that the Almágride Complex does not exist as a singular element of the Internal Betic Zone.

5. Conclusions

After cartographic revision, structural analysis and lithostratigraphic studies in the Orihuela and Callosa Mountains, we propose a new tectonic organization for these terrains. They constitute a single unit of regional significance, called the Orihuela-Callosa unit, although it is structured in several minor tectonic slices. Inside this unit, we differentiate (from bottom to top): a basal meta-detrital formation and un upper carbonate formation. The carbonate formation is composed by a *calcareous-dolomitic member*, a *limestone and marl member* and an *upper calcareous member.*

The geodynamic evolution of the Orihuela and Callosa Mountains comprise a first syn-metamorphic tectonic cycle (including three deformative phases) and a second tectonic cycle (involving an extensional deformative phase and a latter compressional event), in good agreement with that proposed for other sectors of the Alpujarride Complex.

The similarity between the stratigraphic succesions recognized in this work and those of the lower Alpujarride units cropping out in other sectors of the Betic Internal Zone, as well as the coincidence in their respective geodynamic evolution allow us to assign the Orihuela and Callosa Mountains to the Alpujarride Complex. These facts together with other data contributed by several authors in the last few years lead us to propose the definitive elimination of the term "Almágride Complex", referring to a singular element of the Betic Cordillera.

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