



PALEO GEOGRAPHIC RECONSTRUCTION OF THE BETIC-RIF INTERNAL ZONE: AN ATTEMPT

Reconstrucción paleogeográfica de la Zona Interna Bético-Rifeña: un intento

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Abstract: *The different lithological sequences and structures of the tectonic complexes of Betic-Rif Internal Zone are compared in order to essay a paleogeographic reconstruction. During the Paleozoic they were situated eastward of the Iberian Variscan domains, sharing part of its characteristics. From the Permian a new sedimentary basin began to be differentiated, first evolving in the area formerly occupied by the Nevado-Filábride Complex, followed by that of the Alpujárride Complex and finally by that of the Maláguide Complex. Their stratigraphic characteristics permit to reconstruct their paleogeographic features, showing a disposition in more or less parallel bands, together with the former passages existing between these complexes. The main difficulty is to explain how these bands ended up westward, in the area of contact with the Subbetic domain of the External Zone. In this aspect, the Dorsal Complex, which is located in the Internal Zone in contact with the External Zone and in other different positions, plays a fundamental role to reconstruct the original paleogeographic relations. It is mainly related to the Maláguide Complex but extending to adjacent areas, formerly occupied great part of this western end of the bands and adapted its shape to the contact area. Later, during Alpine orogeny, the Betic-Rif Cordillera was structured, and the Dorsal Complex in particular was forced to occupy different tectonic positions, a fact that complicates the paleogeographic reconstruction.*

Keywords: *Alpujárride Complex, Dorsal Complex, Maláguide Complex, Nevado-Filábride Complex, Betic-Rif Internal Zone.*

Resumen: *Se comparan las secuencias litológicas y las estructuras de los complejos tectónicos de la Zona Interna Bético-Rifeña para proponer una reconstrucción paleogeográfica. Durante el Paleozoico los materiales que constituyen esta Zona Interna se situaban en la prolongación oriental del Macizo Ibérico, y en consecuencia comparten con sus dominios parte de sus características, aunque hayan cambios laterales. Aproximadamente a partir del Pérmico en esa región oriental comenzó a formarse una nueva cuenca sedimentaria, primero en el área ocupada originalmente por el Complejo Nevado-Filábride, después, al ir expandiéndose, por la del Alpujárride y finalmente por la del Complejo Maláguide. Esta fue la cuenca sedimentaria original de la Zona Bético-Rifeña y en ella se depositaron sedimentos pérmicos (incluso del Carbonífero terminal) a triásicos en adelante (dependiendo del momento de la diferenciación en cada dominio). Este relleno sedimentario es parecido entre los complejos Nevado-Filábride y Alpujárride, aunque hay un cierto desfase en las edades, al menos las de inicio de sedimentación. También hay similitudes (y alguna notable diferencia) en las rocas ígneas que contienen (ácidas, básicas y ultrabásicas). El complejo Maláguide presenta mayores diferencias, pero existen unas unidades (las unidades Intermedias) que aseguran el tránsito sedimentario entre los complejos Alpujárride y Maláguide. La reconstrucción paleogeográfica de todos estos complejos muestra una disposición en bandas aproximadamente paralelas con el Complejo Nevado-Filábride más al norte y el Maláguide más al sur. La dificultad se encuentra en saber encajar la terminación de estas bandas hacia el oeste, en el área de contacto con el dominio Subbético (Zona Externa Bética). En este aspecto, el Complejo de la Dorsal juega un papel fundamental para reconstruir esas relaciones originales, debido a su posición en la Zona Interna en contacto con la Zona Externa y en otras diferentes posiciones. La Dorsal, directamente relacionada con el Maláguide, se extendió además a áreas adyacentes y ocupó gran parte de esta terminación occidental de las bandas. De esta manera, no solo se*



depositó sobre parte del Complejo Maláguide a la vez que hacia el sur continuaba hacia la Predorsal, sino que también formaba parte de la cobertura del Complejo Alpujárride, y además estaba en contacto con la Zona Externa Bética, en particular con el Subbético. Esta disposición paleogeográfica original se perdió durante la orogenia Alpina, cuando la Cordillera Bético-Rifeña fue estructurada. Entonces la Dorsal se vio forzada a ocupar diferentes posiciones tectónicas, dependiendo de sobre qué dominio se había depositado originalmente, lo que complicó su reconstrucción. Por eso, conocer la disposición original de la Dorsal, comparándola con la actual, resulta esencial para la reconstrucción paleogeográfica.

Palabras clave: Complejo Alpujárride, Complejo de la Dorsal, Complejo Maláguide, Complejo Nevado-Filábride, Zona Interna Bético-Rifeña.

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Introduction

The Betic-Rif Cordillera, situated in the western end of the Mediterranean Sea (Fig. 1A), is divided into Internal and External zones, each containing different domains. The present structure of the Betic-Rif Cordillera (Fig. 1B) was formed during the Alpine orogeny. Earlier, during the Mesozoic, the region underwent a dual process of extension and transcurrent; but, with the anticlockwise rotation of Iberia towards the end of the early Cretaceous (Gallastegui

Suárez, 2000) and the onset of compression between Africa and Europe, the geodynamic situation changed. The structuring of the Betic-Rif Cordillera took place throughout the Cenozoic.

The External Zone of the Betic Cordillera corresponds to the Mesozoic and Cenozoic sedimentary cover of the Paleozoic Iberian Massif along its SE and S borders (Vera, 2001, 2004). It is divided into Prebetic and Subbetic domains (Fig. 2). The Prebetic was a domain closer to the Iberian Massif than the Subbetic, and its lithologic sequences mainly have

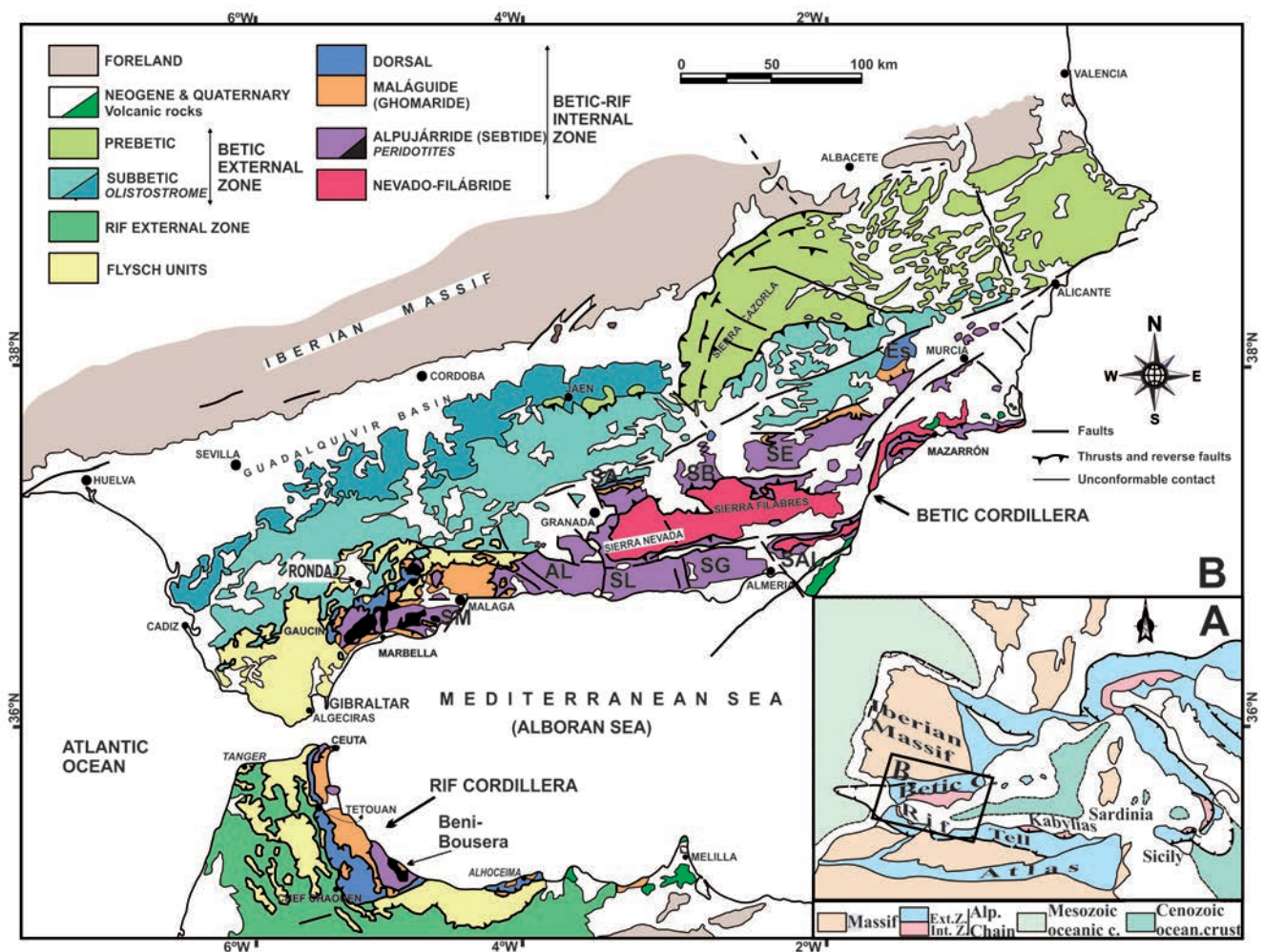


Fig. 1.- A. Regional geologic scheme of the western Mediterranean area, the Betics and the Rif being situated at its western end. B. General geologic map of the Betic Cordillera and part of the Rif. AL: Sierra Almiijara, Es: Sierra Espuña, SA: Sierra Arana, SAL: Sierra Alhamilla, SB: Sierra de Baza, SE: Sierra de las Estancias, SG: Sierra de Gádor, SL: Sierra de Lújar, SM: Sierra de Mijas.

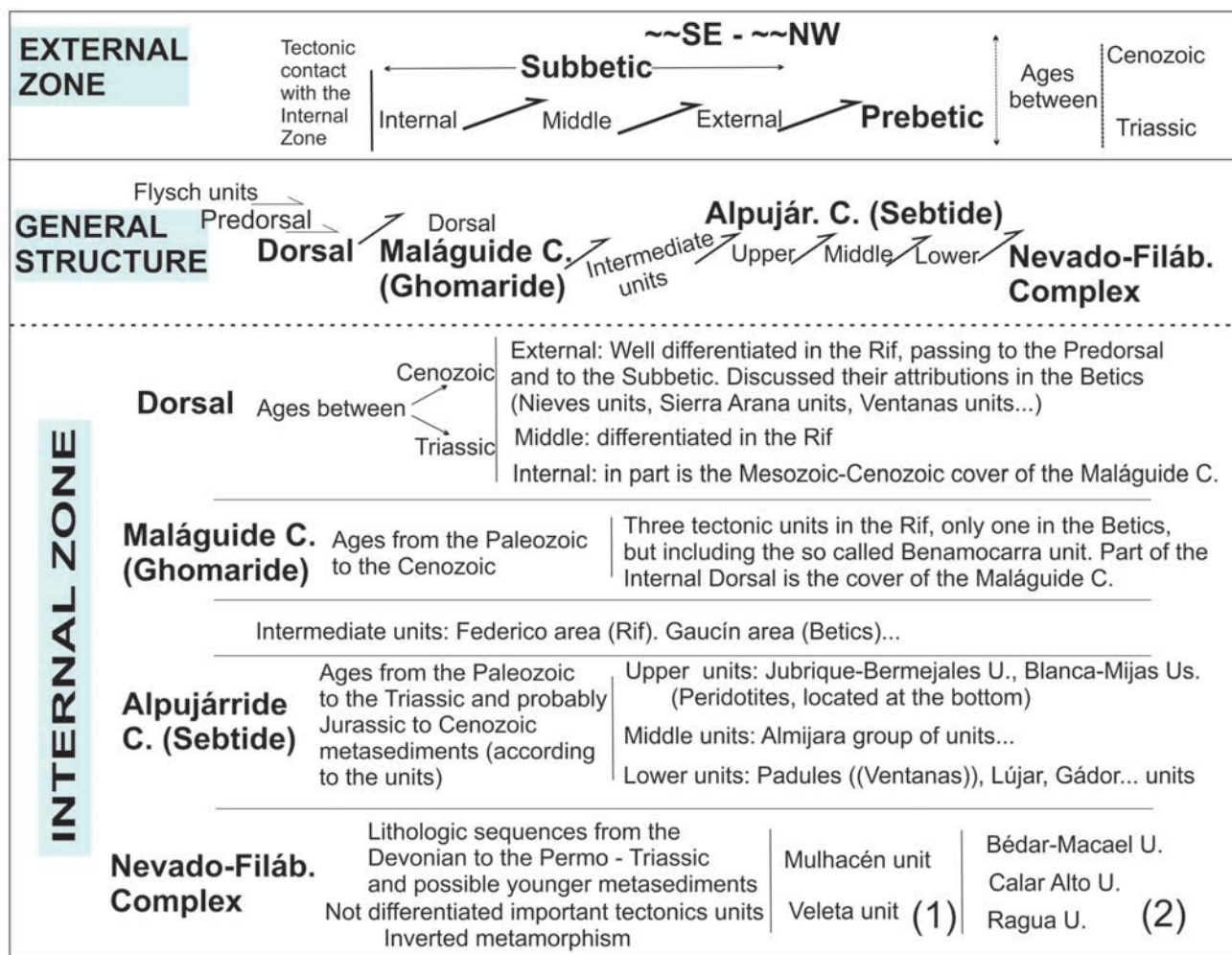


Fig. 2.- Very general scheme of the geologic features of the Betic Cordillera (and part of the Rif). 1 and 2 refer to two of the more used previous tectonic divisions of the Nevado-Filábride Complex: 1, Puga *et al.* (1974); 2, Martínez-Martínez *et al.* (2002).

shallow marine and even continental sedimentary characters. The Subbetic is largely made up of deeper marine sediments. Stratigraphic formations in several sectors attest to paleogeographical passages between the Prebetic and Subbetic. The former relations existing between these passages are not difficult to infer: the two domains were narrowly linked and transitioned from one to another.

The Rifian External Zone corresponds partially to the sedimentary cover of the northern border of the Paleozoic Moroccan Meseta, and especially to deeper sectors formerly situated northward and northeastward. In a simplified division, it is formed by the Prerif, Meserif and Intrarif, the Prerif being the domain closest to the Moroccan Meseta (Chalouan and Michard, 2004; Chalouan *et al.*, 2008). While on the whole their paleogeography can be envisaged, this does not mean that it is totally understood at present.

The Internal Zone is common to the Betics and the Rif. It contains four superposed tectonic complexes (from bottom to top; Fig. 2): the Nevado-Filábride (not present in the Rif), the Alpujarride (called Sebtide in the Rif), the Maláguide (Ghomaride in the Rif) and the Dorsal (*Dorsale calcaire* of Durand-Delga and Fontboté, 1980).

In addition, Flysch units are well represented in the Gibraltar area (Campo de Gibraltar units) and particu-

larly in the Rif. The original sedimentary basin of the Flysch units was situated between the Betic-Rif Internal Zone and the Rifian External Zone (or, considering a wider region, between the Betic-Rif Internal Zone, the Kabylas in Algeria, the Peloritani Mountains and the Calabrian internal units in Italy to the N, and the External Zone of the Rif, Tell and Sicilian and Calabrian external units to the S).

Aim of the article

The paleogeographic relationships between the different domains of the Internal Zone, and the relations formerly concerning the Internal and External zones, are still not totally clear. In this article research efforts have focused on comparing their lithological sequences, their structures and mutual relationships, as well as their geological evolution, in order to present a tentative essay of their paleogeographic reconstruction. Therefore, the objective of this paper is to assemble the current data to shed light on the former paleogeographic relations existing among the different domains of the Betic-Rif Internal Zone and with the Betic External Zone. After the discussion, a proposal for a paleogeographical reconstruction is presented.

Background

The name Nevado-Filábride comes from Egeler (1963). Earlier, Brouwer (1926) differentiated two great formations in the "Penninic Betics", as he called this complex. The lower formation, the "Crystalline of Sierra Nevada" (*Kristallijne Schisten*), is formed by a monotonous succession of dark schists with graphite and quartzites, probably Paleozoic in age. The upper formation, the "Mixed Zone" (*Mischungszone*), is made up of schists, quartzites, marbles, gneisses, serpentinites, and amphibolites (Figs. 2 and 3A).

Later, Nijhuis (1964) studied the eastern part of Sierra de los Filabres and distinguished several tectonic units. Later authors identified more units, synthesized by Egeler and Simon (1969). In Sierra Nevada, Puga (1971) and Puga *et al.* (1974) distinguished two great nappes, the Veleta and the Mulhacen. Puga *et al.* (2002) proposed the differentiation of this complex into the Veleta and Mulhacen complexes. The Veleta nappe/unit corresponds approximately to the "Crystalline of the Sierra Nevada", while the Mulhacen nappe corresponds to the *Mischungszone*. Many authors followed this division (Martínez-Martínez, 1984-85; Gómez Pugnaire, 1988; Bakker *et al.*, 1989; De Jong, 1993). Later, Martínez-Martínez *et al.* (2002) introduced several changes in the limits and names of the units of the Nevado-Filábride Complex, variations adopted by Augier *et al.* (2005) and Booth *et al.* (2015), among others. The latter authors consider the existence of shear zones separating the units. However, not all researchers agree that tectonic contacts separate the proposed units, including Galindo Zaldívar (1993), Sanz de Galdeano and López-Garrido (2016a), Sanz de Galdeano *et al.* (2016) and Sanz de Galdeano and Santamaría-López (2019).

Van Bemmelen (1927) coined the word Alpujárride to refer to previously distinguished tectonic nappes, *e.g.* those of Lújar, Lanjarón and Guájar, mostly found in the Alpujarras region (S of Sierra Nevada). Westerfeld (1929) called them Alpujárride Nappes. Much later, Durand-Delga and Kornprobst (1963) used the term Sebtime to designate the equivalent domain in the Rif. Egeler and Simon (1969) also distinguished a lower complex that they called Ballabona-Cucharón (later called Almagrídide), at present not considered (see Sanz de Galdeano, 1997). On the whole, the Alpujárride tectonic units can be divided into three tectonic groups (Fig. 2), according to their positions (Aldaya *et al.*, 1979).

Over the Alpujárride Complex lie several units whose characteristics reflect a transitional passage from the Alpujárride to the Maláguide units; they are the Intermediate units (Fig. 2). The better known groups of these units are situated near Ceuta (the Federico units), and in the proximities of Gaucín (the Casares units, ~80 km WSW of Malaga), on either side of the Strait of Gibraltar (Didon *et al.*, 1973). A general overview of these units can be found in Sanz de Galdeano *et al.* (2001).

Blumenthal (1927) designated as *Malagensisches Betikus* the area of Malaga presenting Paleozoic successions with fairly well conserved Mesozoic and Cenozoic cover. Nevertheless, part of this area is now considered to belong

to the Alpujárride Complex. But the name of Maláguide (Maláguide Complex) is used nowadays. Durand Delga and Kornprobst (1963) introduced the name Ghomarides for equivalent rocks in the Rifian Internal Zone.

The denominations *Dorsale* and *Dorsale calcaire* were used informally by Marín and Fallot (1932) and Fallot (1937). These names were applied in the Rif for units partially linked to the Ghomarides, and originally referred to the mountains from Chaouen northward. The name *Dorsale* was first used in reference to the Betics by Durand Delga and Foucault (1967) – *Dorsale bétique*. The term Rondaides was used in the Betics (Blumenthal, 1928; Dürr, 1967; among others). Felder (1980) held that the Rondaides were formerly situated near the Maláguide and Alpujárride complexes. Later, the name of Frontal Units (Serrano, 1998; Vera, 2004) has also been used. But probably the one imposed is that of *Dorsale* or Dorsal and for this reason is used here.

Zone Prédorsalienne was used by Durand Delga (1972), and *Unités prédorsaliennes* by Didon *et al.* (1973). Predorsal refers to units that evidence the former transition existing between the Dorsal and the Flysch basin situated S of the Internal Zone and N of the Rif and Tell External Zones.

Betic-Rif Internal Zone and Subbetic lithological sequences

The Nevado-Filábride Complex

The older rocks. In the area of Sierra Almenara-Lomo de Bas (Murcia province) (Fig. 1B) the probably oldest lithological sequences of the Nevado-Filábride Complex crop out (Fig. 3A). They begin with dark speckled schists several hundreds of meters thick, and lying above there are limestones or limestone marbles with fossils. They are overlaid by a lithologic formation of dark schists that are not completely exposed in the Lomo de Bas area, but they are present especially in the Sierras Nevada and Filabres.

In the cited limestones, Lafuste and Pavillon (1976) and Laborda *et al.* (2014) determined fossils from the Devonian, the latter authors giving an age that corresponds to the Emsian (407–393 Ma).

The dark schists. This formation corresponds to dark graphitic schists and quartzites, the rocks of the "Crystalline of Sierra Nevada" defined by Brouwer (1926) (Fig. 3A). This unit is very thick, roughly 3600 m (Fallot *et al.*, 1960, estimated some 5000 m) and its facies is similar to that of the Culm.

Santamaría-López and Sanz de Galdeano (2018) dated detritic zircons obtained from samples of the dark schists (taken from lower to upper parts of the formation in the Sierras Nevada and Filabres). Ages of 340–330 Ma and younger are common, indicating Variscan or tardy-Variscan plutonism. Naturally, the zircon-bearing meta-sediments are younger, their age ranging from late Carboniferous to early Permian, in line with the ages of the orthogneisses (see below).

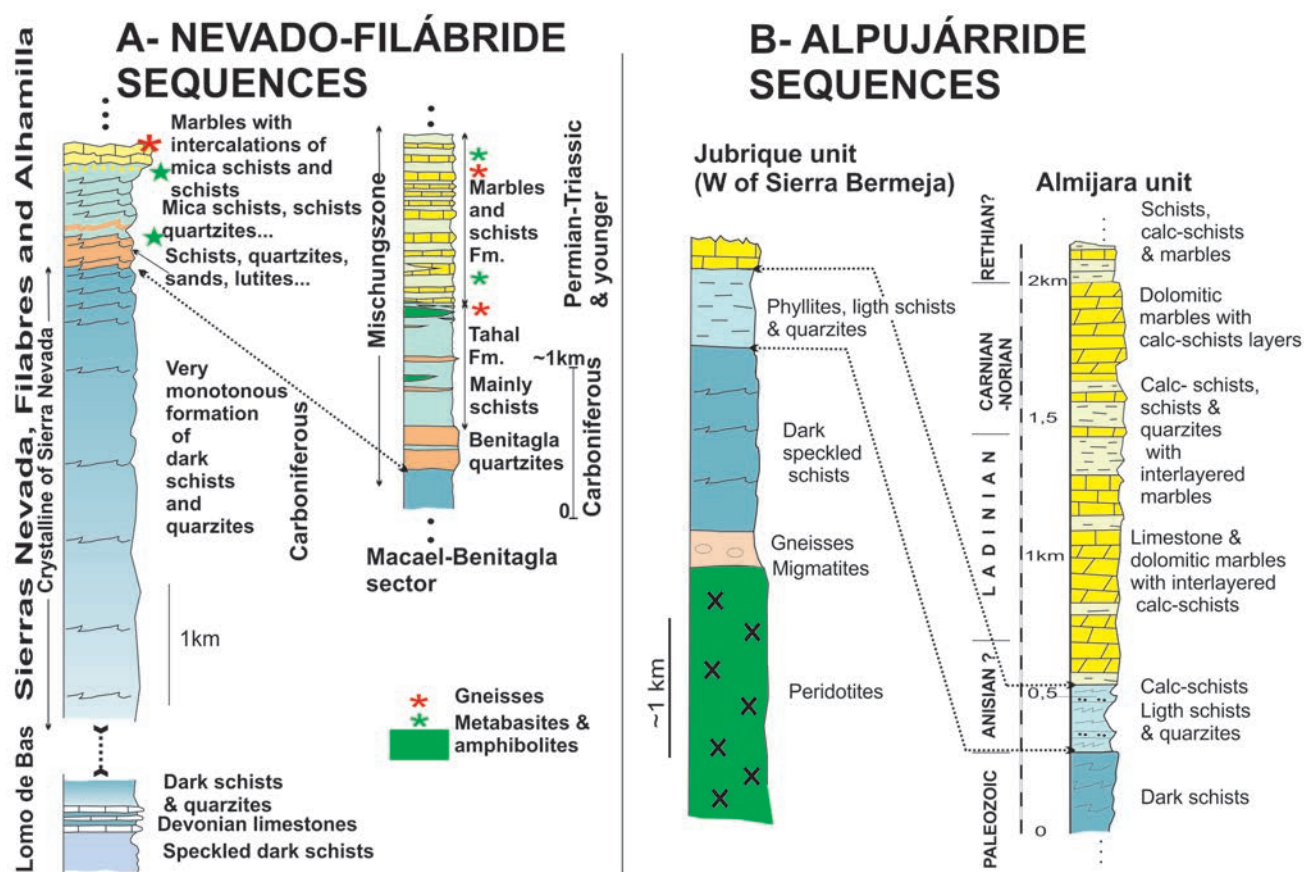


Fig. 3.- Synthesis of the lithologic sequences of the Nevado-Filábride Complex (A) and of the Alpujarride Complex (B). The Almjara unit corresponds to the middle Alpujarride group of units (taken from Sanz de Galdeano and López Garrido, 2003) and the Jubrique-Reales unit to the upper group. Note the different scales of these columns.

The upper formations. Above the dark schists lies the *Mischungszone* (Fig. 3A). As this name indicates, different types of rocks coexist here (schists, quartzites, marbles, gneisses, serpentinites, and amphibolites) and in some cases appear to be mixed, although they are not.

There is a gradual transition between the underlying dark schists and the upper formations. Towards the top of the dark schists, levels of quartzites in light tones appear progressively interlayered among the dark schists, marking the stratigraphic transition to the upper formations.

At the lower part of these upper formations, some places show a great abundance of quartzites (the Benitagla quartzites of Sanz de Galdeano *et al.*, 2016 and Sanz de Galdeano and Santamaría-López, 2019) (Fig. 3A), locally reaching a thickness over 400 m. They are overlaid by light schists (the Tahal schists), likewise of variable thickness, most likely about 500 m in the area of Tahal (Almería province). In other sectors, *e.g.* the western border of Sierra de los Filabres and in Sierra Nevada, thicknesses are clearly lower and even the differentiation of these two formations is not clear.

Layers of marbles begin to appear within the light schists, and are progressively dominant towards the top (Fig. 3A), included among schists, mica schists, micacites and quartzites. The schists and mica schists contain, among other minerals, garnets whose size is generally greater than those found in the dark schists of the "Crystalline of Sierra Nevada" formation. This difference in the size of garnets and other minerals, indicating a greater metamorphic de-

gree, is the basis for the differentiation of the tectonic units of the Nevado-Filábride Complex (Puga, 1971; Puga *et al.*, 1974, 2002; Gómez Pugnaire and Franz, 1988; Augier *et al.*, 2005; Martínez Martínez *et al.*, 2010; Both-Rea *et al.*, 2015, among many others).

The thickness of the formation in which the marbles are abundant surpasses 1000 m in the northern central part of Sierra de los Filabres, and laterally decreases. In some places the marbles are totally dominant.

The ages of the marbles are not well known. Compared with the Alpujarride marbles they apparently correspond to the middle-late Triassic, but Gómez-Pugnaire *et al.* (2012) dated as Carboniferous-Permian some orthogneisses situated in layers near the marbles. Moreover, in Sierra de los Filabres, Rodríguez Cañero *et al.* (2017) obtained conodonts in carbonate levels dated as Bashkirian (Carboniferous), pointing to an age between 315 and 323 Ma. Tendo *et al.* (1993) presented images of possible Cretaceous foraminifers obtained in marbles from upper layers within the lithologic sequence. This means that the marbles could even comprise Jurassic and Cretaceous times.

The igneous rocks. The Nevado-Filábride Complex also includes basic, ultrabasic and acid igneous rocks (Fig. 3A). Generally, the basic and ultrabasic rocks begin to appear in the transition between the dark schists and the upper formations, and become locally very abundant near the limit between the schists of Tahal and the formation of marbles, and even within the marbles formation.

The acid rocks correspond to orthogneisses interlayered among the metasediments, although there is an important granitic pluton now transformed into orthogneisses. It is the Lubrín-El Chive pluton, which intruded near the surface, reaching the lower layers of marbles. The ages of these rocks were obtained by studying the relations of U-Pb in zircons. For the Lubrín-El Chive metagranite, Priem *et al.* (1966) proposed an age of 275 ± 30 Ma, Andriessen *et al.* (1991) of 267 ± 29 Ma, and Nieto (1996) estimated an age of 307 ± 34 Ma.

In orthogneisses within the schists of the upper formations, Gómez-Pugnaire *et al.* (2012) calculated an age of 292 ± 3 Ma in Sierra de Filabres. Meanwhile, in the western part of Sierra Nevada, Gómez-Pugnaire *et al.* (2004) and Martínez-Martínez *et al.* (2010) obtained late Carboniferous ages, whereas Gómez-Pugnaire *et al.* (2012) reported early Permian ages, as did Ruiz-Cruz and Sanz de Galdeano (2017).

The Alpujárride Complex

Paleozoic formations. Many Alpujárride units have rocks attributed to the Paleozoic. The upper unit (Jubrique-Bermejales unit, also called Los Reales unit) includes at their lowermost part the huge mass of the Ronda Peridotites (Figs. 1B, 2 and 3B). Around the peridotites there is an aureole of migmatites and gneisses, in which Ruiz Cruz and Sanz de Galdeano (2014) obtained two age peaks at 330 ± 9 and 265 ± 4 Ma. These ages can be interpreted as characterizing, respectively, the time of the emplacement of the peridotites and a later thermal episode. These ages mean that the rocks in which the peridotites were emplaced are older. Comparable rocks, though without visible peridotites, are exposed in the area of Torrox (~42 km E of Malaga), where a huge mass of gneisses, originally a granitic pluton, can be found. For these orthogneisses Zeck and Whitehouse (1999) obtained an age of 285 ± 5 Ma (early Permian).

Over the migmatites and gneisses in the Jubrique area a transitional and gradual passage to dark schists, locally with quartzites, is seen (Fig. 3B). The thickness of the dark schists is variable, reaching in this area values up to 1500 m, while in the central area of the Alpujárride Complex, south of Sierra Nevada, they reach more than 1000 m.

Upon these schists, in the areas of San Pedro de Alcántara, Istán, Marbella and Sierra Blanca (situated between 64 and 43 km WSW of Malaga) (Fig. 1B), there are Carboniferous orthogneisses whose origin corresponds to acidic volcanic rocks. But part of these rocks has been associated with a Cenozoic thrust of the peridotites and interpreted as a dynamo-thermic formation (Tubía *et al.*, 2013, among others), although such a thrust does not exist according to another study (Sanz de Galdeano, 2017). For Acosta-Vigil *et al.* (2004) these rocks have Permian ages.

Triassic and younger rocks. The passage from the Paleozoic basement to the Triassic rocks probably is an unconformity. The Triassic succession corresponds generally to phyllites of bluish grey color, locally with greenish, red and violet tones. Interlayered with the phyllites are also quartzites, very abundant in some places, particularly to-

ward the top, along with gypsum, of dominant white and red colours. The light schists and the phyllites reach over 500 m in thickness. Many units contain intercalated metabasites, at present amphibolites, in some cases up to 30 m thick and more than 1 km long.

Usually the phyllites and quartzites are overlaid by several meters of yellow calc-schists (Fig. 3A), passing upwards to limestones and dolomitic marbles. A general view of these carbonates can be found in Delgado *et al.* (1981), Sanz de Galdeano (1997) and Alonso-Chaves *et al.* (2004). Within these marbles several formations can be distinguished, whose ages span from the Anisian-Ladinian to the Norian (Delgado *et al.*, 1981). Within the Carnian there are also metadetritic rocks interbedded with the carbonates. Locally the thickness of the marbles surpasses 1300 m.

In an upper position, some units show an alternation of metadetritic sediments and marbles, probably reaching the Hettangian, first age of the Jurassic. This possible passage to the Jurassic is addressed in the next paragraphs.

The Ventanas units

This strange name is used to denominate four tectonic windows (*ventana* = window) situated to the NE of Granada. Their names are Mora, Calabozo, Pulpito and Alfacar (Figs. 4 and 5). At present, they are thrust by Alpujárride units, and at depth, these four tectonic windows probably form a single unit. They present well-developed Mesozoic and Cenozoic formations that have close similarities with those of the Dorsal units, which are present precisely in the neighboring areas, as specified later. For this reason, and although they occupy a tectonic position under the Alpujárride Complex (the Dorsal units are situated over the Maláguide Complex and this over the Alpujárride Complex; Fig. 2), the Ventanas units have been compared with those of the Dorsal (Foucault, 1976), and attributed to it. At the same time, they have been considered as possibly pertaining to the Internal Subbetic (García Dueñas and González Donoso, 1970; García Dueñas and Navarro Vila, 1976; Navarro Vila and García Dueñas, 1980).

The Mora unit holds particular interest. It is thrust by an Alpujárride unit and, in the opinion of Sanz de Galdeano *et al.* (1995a, b, c), it has the same tectonic position as the Padules unit (pertaining to the lower group of Alpujárride units) (Fig. 2). From bottom to top, the Mora unit presents the following succession (Fig. 5B): 1) dark limestones with several intercalations of dolomites, with local flint nodules to the top. These rocks are slightly metamorphosed. The age attributed is late Ladinian-Carnian; 2) dolomites attributed to the Norian, white and grey limestones dated by López López *et al.* (1988) as Rhaetian (end of the Triassic) and lower Jurassic neptunic dykes. On the whole, these carbonatic sediments have a thickness of the order of 700–800 m; 3) Nodular, at many points red, limestones (upper Jurassic), white and yellow marls (lower Cretaceous), salmon marls and marlstones (upper Cretaceous-Paleocene), and an Oligocene-Aquitania lithology similar to that existing in the Dorsal, in the NE of Granada and in other places (the Horca Formation of Felder, 1980).

The Triassic limestones and dolostones of the Mora unit are similar to those existing in Alpujárride units, particularly in the Padul unit (Fig. 5B) or the Lújar unit, SW of Sierra Nevada.

The Intermediate units

These units have a metamorphic degree greater than that of the Maláguide Complex, situated above them, and

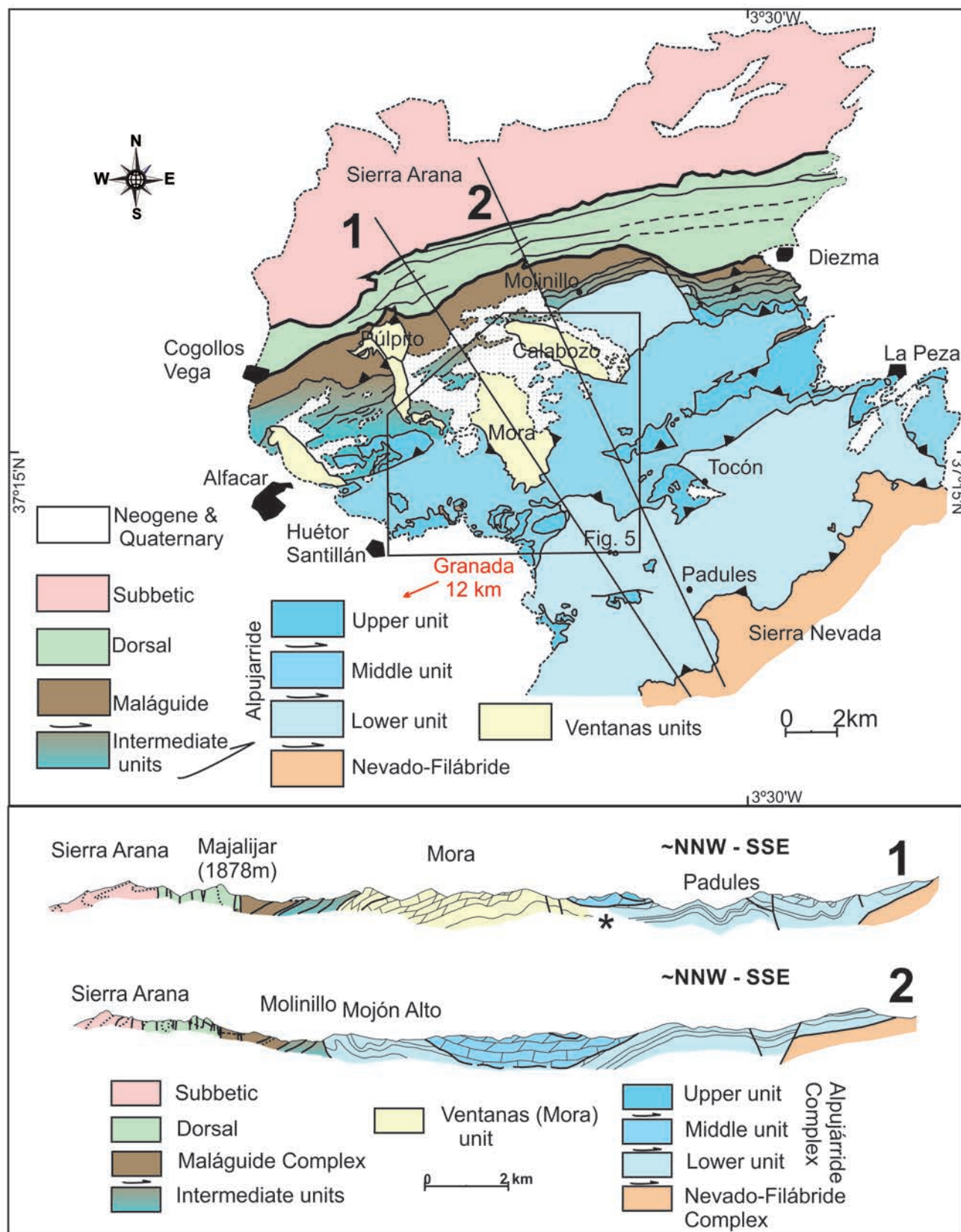


Fig. 4.- The area of Sierra Arana-Mora, including the Ventanas units (the square indicates the position of the map of Fig. 5). In the cross sections the star indicates the position of the possible passage from the Mora unit to that of Padules.

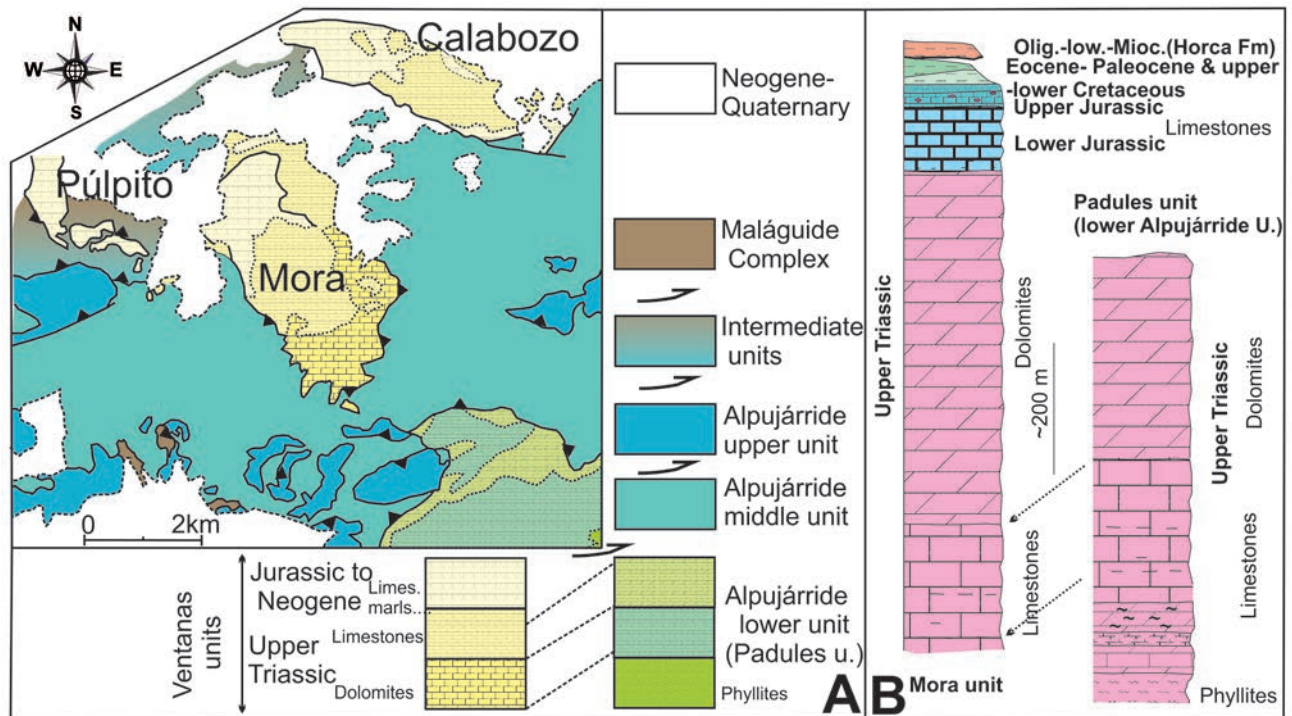


Fig. 5.- A. Map of the La Mora and Calabozo units (Ventanas units; its position is indicated in Fig. 4). B. Lithologic sequences of the Ventanas units, mainly taken from the Mora window, and comparison with the Padules Alpujarride sequence.

lower than that of the upper group of Alpujarride units lying beneath them (Fig. 2). This is particularly visible in the passage from the Carboniferous Maláguide rocks - not metamorphic - to equivalent rocks in the Alpujarride Complex, every lower unit showing a greater degree of metamorphism observable in the metapelites and in conglomeratic layers.

In these units the Triassic sequences also have intermediate characteristics, particularly visible in the detrital successions. The red clays, silts, sandstones and conglomerates of the Maláguide Complex change progressively in the Intermediate units, passing to phyllites, quartzites and stretched conglomerates.

The Maláguide Complex

The Paleozoic formations. A synthesis of the Paleozoic sequences of the Maláguide (Fig. 6) was presented by Mäkel (1985), and later completed by Martín-Algarra *et al.* (2004), who describe the older rocks of the Maláguide Complex as shales with intercalations of feldspathic quartzites having a slightly metamorphic aspect. The thickness of this formation is at least of several hundred meters. In these rocks Martín-Algarra *et al.* (2009) found upper Ordovician and Silurian conodont associations in the area of Ardales (~42 km to the WNW of Malaga).

Below this formation, the Benamocarra unit, situated to the E of Malaga, has been attributed by several authors (*e.g.*, Aldaya *et al.*, 1979) to the Alpujarride Complex. Nevertheless, according to Ruiz-Cruz (1997) there is a lithologic and metamorphic continuity between the Maláguide and Benamocarra sequences, which suggests the appurtenance of the latter unit to the Maláguide Complex (Fig. 6).

My own field observations match this opinion. The thickness observed in the Benamocarra unit surely surpasses 400 m.

Overlaying the previously cited Silurian shales, lower and middle Devonian limestones are found, in many cases with thin and warped stratification (*calizas alabeadas*). Chalouan (1986) described the Talembote unit (~34 km SSE of Tetouan) in the Ghomarides, where the Devonian limestones reach at least 300 m in thickness.

Above the Devonian limestones, dark radiolarites (lydites) of Tournaisian age can locally be found with a thickness of roughly 10 m. They are overlaid by Visean shales and limestones and a thick and monotonous succession of dark shales and graywackes of Culm facies aspect, including conglomerate layers at its lower and upper parts. However, Mayoral *et al.* (2018) data seems to indicate a very shallow marine environmental area of deposit. The upper conglomerates, locally more than 50 m thick, are generally called Marbella conglomerates (of Permian age, Esteban *et al.*, 2017). All these conglomerates contain pebbles and cobbles of granites, gneisses and limestones. Herbig (1985) mentioned comparable sediments in the Paleozoic lithologic series of Menorca Island.

The Triassic formations. There is an unconformity between the Marbella conglomerates (not always present) and the first sediments attributed to the middle Triassic. Part of the Triassic sediments corresponds to conglomerates of Verucano facies, but there are also abundant levels of sandstones and lutites with predominant white, red and green colors. Locally levels of carbonates, mainly dolomites, are present. There are also levels of gypsum, mainly toward the top of the sequence, and locally dolerites. The thickness of these deposits is highly variable, reaching 200 m in some

places, and their age is Anisian-Ladinian (middle Triassic).

The Jurassic to Cenozoic formations. The first Jurassic sediments (probably including part of the late Triassic) are dolomites, limestones. Their dominant colors are yellow or white, in contrast to the variegated tones of the underlying sediments and their thickness may locally be greater than 100 m (Mäkel, 1985). To the top they can include silex and marlstones, passing to nodular red limestones, locally with silex, and marls.

The lower Cretaceous succession presents several stratigraphic hiatuses, depending on the place (Martín-Martín *et al.*, 2004). Generally, it is formed by marls and marlstones with different colours: those of the Berriasian-Barremian are white, while those of the Albian, and perhaps the Aptian, usually have more greenish tones. The upper Cretaceous (and part of the Paleocene) is formed by marls and marlstones of predominant salmon tones, locally with some interbedded turbiditic levels. The thickness of these sediments varies: those belonging to the early Cretaceous may reach 150 m in the thicker areas, while those of the late Cretaceous reach 200 m. The Paleocene to lower Oligocene formations present many hiatuses, indicating an active tectonic period (Martín-Martín *et al.*, 1997).

Younger sediments, from the late Oligocene to the early Miocene, are clearly discordant over any other formations of the Maláguide Complex. These formations are contemporary with the tectonic structuring of the Maláguide Complex.

Finally deserving mention are the dykes of basic rocks in the Paleozoic formations. Torres-Roldán *et al.* (1986) attributed them an early Miocene age.

The Dorsal

The Dorsal presents Mesozoic and Cenozoic formations (Figs. 2 and 7A). According to its position with respect to the Maláguide-Ghomaride Complex, it can be divided - particularly in the Rif - into the Internal, Middle and External Dorsal. The Mesozoic successions of the Internal Dorsal is so narrowly linked to the Maláguide that in many cases it cannot be differentiated from the Mesozoic sediments of the latter complex.

The Dorsal in the Rif has important outcrops from the S border of the Strait of Gibraltar (W of the town of Ceuta) to the area SE of Chef Chaouen (~45 km SSE of Tetouan). It is divided in many tectonic units (Kornprobst, 1966;

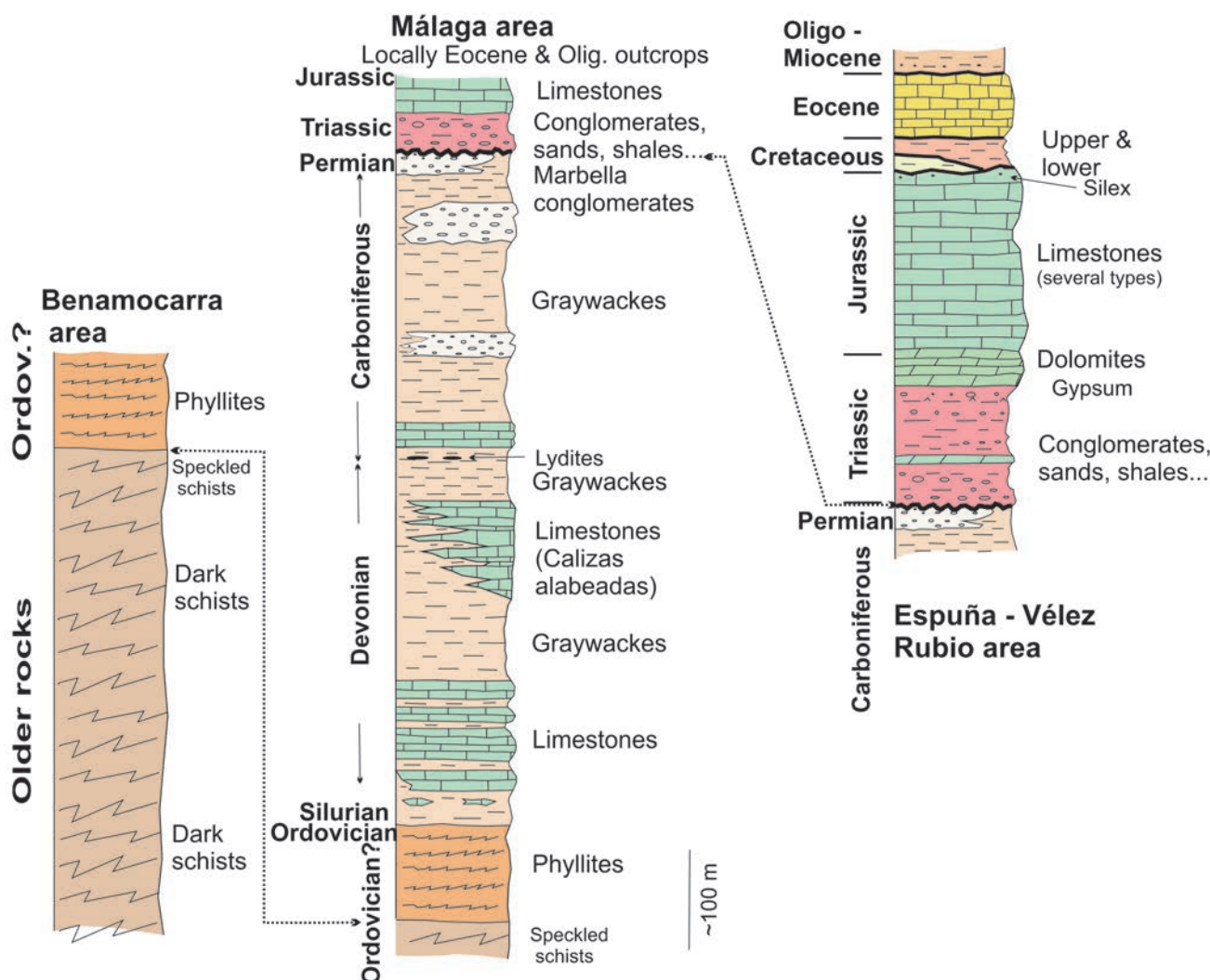


Fig. 6.- General synthetic lithologic sequences of the Maláguide Complex. Although the Jurassic to Cenozoic sequence is well conserved in the España area, in most sectors it has disappeared.

Wildi *et al.*, 1977; Nold *et al.*, 1981; Wildi, 1983; Hlila *et al.*, 1994; among others).

Lithological sequences in the Rif. The Internal Dorsal is formed by "Permo"-Triassic red sandstones, silts and clays (visible over the Paleozoic basement at scarce points, and similar to those of the Maláguide Complex; Fig. 7A). Above there are dolomites (late Triassic) and white limestones and limestones with silex (early Jurassic). To the top there are incomplete sequences of red nodular limestones (late Jurassic) and Cretaceous marls.

In the Middle Dorsal, the Paleozoic basement is not visible and the detritic Triassic sediments are usually not visible and the dolomites present marly intercalations (see Fig. 7A).

In the External Dorsal the first outcropping rocks are upper Triassic dolomites, followed by alternations of the marls, nodular limestones and limestones with silex of the early Jurassic. The overlaying successions correspond to middle and upper Jurassic radiolarites and nodular limestones, and locally lower Cretaceous white marls and salmon marls of the late Cretaceous-Paleocene. Likewise

found are Eocene limestones and breccias, and yellow-orange sands, clays and marls of the Oligocene, separated by many stratigraphic hiatuses.

Lithological sequences in the Betics. The Dorsal appears in two main areas, by the western end of the Internal Zone, and in Sierra Arana (to the NE of Granada) (Fig. 1).

In the western part, the Nieves unit (~8 km S of Ronda) is the most interesting. It is formed by upper Triassic dolomites (in their southern outcrops transformed in marbles), locally limestones, and marls (Dürr, 1967), with a thickness up to 1000 m (Fig. 7A). The sequence continues with limestones containing silex (early Jurassic) followed by nodular limestones, marls and radiolarites (middle and late Jurassic) of reduced thickness. The Oligocene, perhaps reaching the bottom of the Aquitanian (Miocene), is formed by clays, sands and marls mainly orange in colour (Horca Formation).

Unconformably overlying the Nieves unit is the "Brecha de La Nava" (rests inherited from the same unit), probably of late Aquitanian age (Martín-Algarra and Estévez, 1984). Generally this unit is attributed to the External

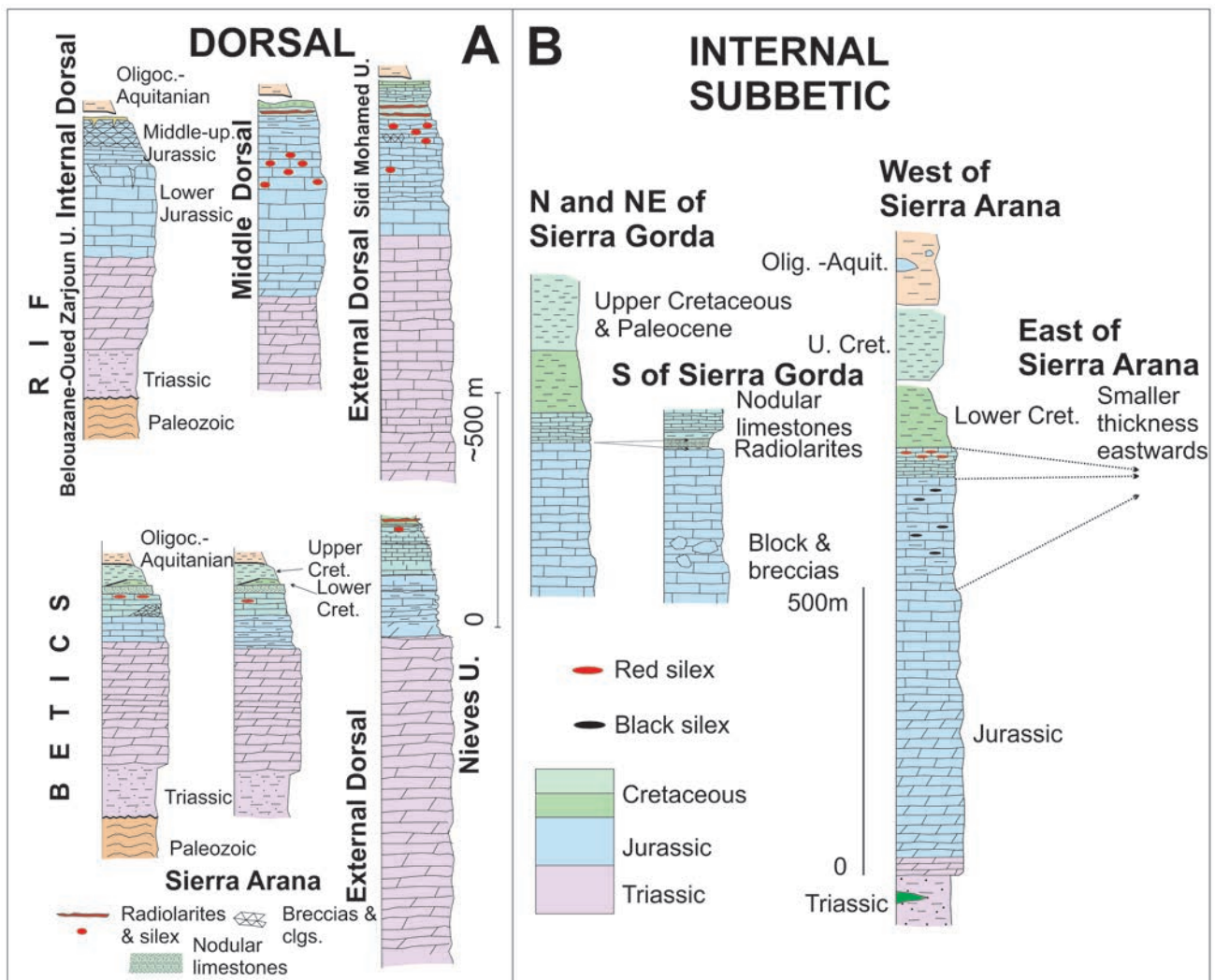


Fig. 7.- A. Some representative lithologic sequences of the Dorsal Complex in the Rif and the Betics. Note the presence of the Oligocene-Aquitanian unconformable formation (Horca Fm) at the top of the units. In some columns, although not indicated, there are also Eocene deposits. Part of the data are taken from Wildi (1983). B. Synthesis of two lithologic sequences of the Internal Subbetic. Note the presence of intraformational breccias and blocks in the Jurassic limestones.

Dorsal, but Delgado *et al.* (1981) include it in the Alpujárride Complex.

Nearby there are other units (Andreo *et al.*, 2004), not as well preserved, featuring breccias, mainly situated in the Jurassic sediments and probably resulting from synsedimentary faults (Bourgois, 1978). Many of these units present the Horca Formation. These units can be considered, depending on the case, as belonging to the External or the Internal Dorsal, or belonging to the Predorsal (Olivier, 1984) (see Sanz de Galdeano, 1997). These different attributions give an idea of how uncertain their exact paleogeographic situation is, and at the same time of the proximities and similarities existing in these domains.

To the NE of Granada, in Sierra Arana, Balanyá (1984) distinguished the Internal and External Dorsal. Sanz de Galdeano and López Garrido (2016b) revised this area and indicate:

1) The relations between the Internal Dorsal and the Maláguide Complex in this area are totally direct. The Internal Dorsal can be considered as the cover of this complex, sharing the detritic Permo-Triassic sediments.

2) The sequences previously attributed to the External Dorsal in this area have many similarities with those of the Internal Dorsal, and also with the Subbetic sequences lying directly to the N. The dolomites and lower limestones of Triassic?- early Jurassic age are comparable in all these units. In the middle and upper Jurassic succession, there are limestones and nodular limestones to the top, many having silex (comparable to the silex of the narrow Subbetic unit). Intraformational breccias and conglomerates, even more than 30 m thick, crop out in some places. White marls of the early Cretaceous are locally present, while salmon marls and marlstones of the late Cretaceous-Paleocene are better represented. The Oligocene-Aquitainian formation, equivalent to the Horca Formation, crops out widely, and locally present rests of lydites and other rocks indicating an origin from the Maláguide Paleozoic basement.

The Predorsal

In Morocco there are Predorsalian units in the proximity of Alhoceima and also between the Chef Chaouen area and the Strait of Gibraltar (Olivier, 1984). This domain presents different types of sediments, with a noteworthy existence of radiolarites near Bab Taza (~13 km SE of Chef Chaouen) (El Kadiri, 1984).

Approximately 6 km W of Ceuta is the Jebel Musa, attributed to the Dorsal, to the Predorsal, and also to a differentiated domain, the Tariquide ("domain Tariquide" of Durand-Delga *et al.*, 2005). These authors further include in the Tariquide the "Rock" of Gibraltar and a small outcrop (Los Pastores) situated near Algeciras. Along with thick Triassic-lower Jurassic carbonates there are middle-upper Jurassic radiolarites, and the Cretaceous is partially represented.

In the Betics, aside from the mentioned outcrops of the Tariquide-Predorsal, there are other elements attributable to the Predorsal. Some of them are situated in the proximities of Gaucín (~84 km WSW of Malaga) (Fig. 1B). However, they might be considered as belonging to the External Dorsal. In

general, they constitute dispersed units with more or less common characteristics. Some of their Cenozoic formations are comparable to those of the Flysch units.

The Subbetic (External Zone)

The former Subbetic basin was by no means a homogeneous domain, having within swells and troughs of different values of subsidence, particularly during the Jurassic. This feature permits its differentiation into the External, Medium and Internal Subbetic (Fig. 2) (for a general overview of the Subbetic see the corresponding chapter in Vera, 2004).

The External and Internal Subbetic were situated in two different swells, the External Subbetic being closer to the Iberian Paleozoic Massif margin. Both areas present a carbonatic Jurassic sequence of reduced thickness if compared with the Medium Subbetic situated in between. The Jurassic of the Medium Subbetic is moreover represented by dolomites and limestones at the bottom, marls, marlstones, and radiolarites, and the late Jurassic by limestones sometimes showing a red nodular character. Also in this domain there are basic volcanic rocks extruded from the Triassic to the early Cretaceous, and in some scarce cases till the beginning of the late Cretaceous.

The Internal Subbetic, also known as the Penibetic particularly in the western sector, is in tectonic contact with the Betic Internal Zone. The Triassic lithological sequences (Fig. 7B) begin with clays, silts, sands, sandstones, and also gypsum, particularly towards the top. Interbedded are dark limestones of Muschelkalk facies. In the top dolomites of Rhaetian-early Jurassic age appear. Locally there are volcanic rocks.

The Jurassic of the Internal Subbetic begins with dolomites (several hundred meters thick) and limestones (also several hundred meters thick) followed by limestones (of very different thickness and continuity) containing dark silex; condensed red nodular limestones reach the top of the Jurassic, even the Berriasian. The latter sediments may also present silex, usually red or green. Locally, intraformational breccias are present along all the Jurassic succession and they can be found even in lower Cretaceous sediments. These breccias have been reported, for instance, in the area of Zafarraya (SW border of the Granada basin) by Sanz de Galdeano (2011), and in the Sierra Arana (to the NE of Granada) by Sanz de Galdeano and López Garrido (2016b).

The lower Cretaceous succession is formed by marls and marlstones of white-light color, while the upper Cretaceous and Paleocene corresponds to salmon marls and marlstones. The thickness of these sediments is highly variable, from 0 m to hundreds of meters, because there are important stratigraphic hiatuses. The Eocene is only locally represented, while the Oligocene-Aquitainian formation, equivalent to the Horca Formation, crops out in some places, as in the N part of Sierra Arana area; yet in this case remains of lydites have not been identified (unlike in similar sediments existing directly to the S, but belonging to the Dorsal).

Main data of the structure of every complex, and relations existing among them

The present structure of the Betic-Rif Cordillera was formed during the Alpine orogeny, and its differentiation in complexes occurred thereafter.

Structure of the Nevado-Filábride Complex

As indicated previously, different tectonic divisions have been proposed for this complex. But some authors (Galindo-Zaldívar, 1993; Sanz de Galdeano and López-Garrido, 2016b; Sanz de Galdeano *et al.*, 2016) believe these divisions lack support in view of cartographic data. In short, this complex would instead constitute a single unit formed through a continuous lithological sequence (Figs. 2 and 3A), although having an inverted metamorphism (Santamaría *et al.*, 2019), progressively decreasing from top to bottom of the lithological series, something related to the subduction process.

The structure in the sierras Nevada and Filabres is simple: it consists of two large E-W anticlines, with smaller subordinate folds (Fig. 8). There are also faults of diverse character, such as the reverse faults in Filabres formed during the folding of its anticline (Sanz de Galdeano and López-Garrido, 2016a). This simple structure contrasts sharply with the minor structures existing within layers and among several layers. Indeed, within the layers there are very tight folds, with clear transpositions. But - at least according to cartographic data - they do not coincide with the structures at large scale. This might be explained by the simple shear deformations that occurred during the subduction of the Nevado-Filábride Complex.

Another discussed aspect concerns to the significance of ultrabasic rocks existing in the Nevado-Filábride Complex. Some authors think that they represent a new formed oceanic crust clearly breaking the future tectonic complex (Puga *et al.*, 2002, 2017) whereas others propose that they only represent an important extensional episode, producing a crustal thinning but not a real oceanic crust (Jabaloy *et al.*, 2015; Sanz de Galdeano and Santamaría, 2019). The present work supports the second interpretation, especially for the type of lithologic contacts observed in these rocks.

The superposition of the Alpujárride Complex over the Nevado-Filábride is generally clear, owing to the different metamorphic degree of the rocks of the two complexes. However, taking into account some ages obtained, for instance in Gómez-Pugnaire *et al.* (2012), a question can be proposed: are the lithologic sequences of the Nevado-Filábride Complex prolonged as far as those of the Alpujárride Complex? At places it appears to be so, a single and continuous lithologic sequence, *i.e.* the marbles and schists of the Nevado-Filábride Complex continuing in the phyllites and carbonates of the Alpujárride Complex. Yet such an interpretation does not work, for instance, in the lower Alpujárride Lújar unit, which directly thrusts the Nevado-Filábride. In the southern part of this unit, underlying (in non-tectonic contact) the Triassic carbonates and the lower phyllites, there are schists attributable to the Car-

boniferous-Permian (right end of cross section 4 in Fig. 9). Moreover, the formation of schists and marbles of the Nevado-Filábride is absent. This existence of two different formations of Carboniferous schists in the two complexes, with duplications of ages in the lithological sequences, is sufficient reason to discard the proposed prolongation.

Structure of the Alpujárride Complex

The superposition of different tectonic units of this complex is easy to see, since generally the lithologic contrast at the contacts of the units is clear, for instance dark schists thrusting white marbles. In some cases however, metadetrital rocks interlayered between marbles have been considered as belonging to another unit, hence a new unit has been described. Furthermore, a misinterpretation of the position of the peridotites in relation to Alpujárride lithologic sequences gave rise to a multiplication of the number of units.

Taking into account these possible sources of error, the structure of the Alpujárride is simple in terms of the differentiation of units, but within each unit the structure of folding and fracturing can be complicated in some cases. For instance, from E to W, the structure of Sierra de Gádor (Jacquin, 1970), of sierras Almijara and Tejada (on the S border of the Granada basin; Sanz de Galdeano, 1989), and that of sierras Blanca and Mijas (~45 and 25 km SW of Malaga; Sanz de Galdeano and Andreo, 1995) are characterized by very well developed great folds. These folds generally present northward vergence, coexisting in some cases with southward and even eastward vergences (Fig. 9).

Relations between the Alpujárride and the Maláguide complexes

The Maláguide overthrust the Alpujárride Complex, in some places taking in between the Intermediate units. Overall the relationship is not complicated, except in two specific areas. One concerns the Benamocarra unit, considered to belong to the Alpujárride Complex (Elorza, 1982, among others) and thrust by the Maláguide Complex. But this unit is made up of several types of schists, progressing upwards to Paleozoic lutites of the Maláguide Complex. That is, instead of a sharp tectonic contact indicating the presence of a thrust, there is a gradual lithologic transition from the "Benamocarra unit" to the lower Paleozoic levels recognized as forming part of the Maláguide.

Another possible source of misinterpretation is situated N of the village of Benadalid (near Gaucín). There Paleozoic formations of the Maláguide Complex are situated directly over Paleozoic Alpujárride formations, a position that could be considered as stratigraphic prolongation (Navarro-Vila and Tubía, 1983). In this case, this possible stratigraphic prolongation can be discarded because laterally the higher parts of the Alpujárride lithological sequence and the Intermediate units progressively appear in between the two basement formations. Many materials are tectonically cut, but this does not indicate a transitional passage.

The Intermediate units, when present, are significant. Tectonically situated between the two complexes, they attest to a sedimentary transitional passage in between, also showing a gradual increase in the metamorphic degree towards the Alpujarride Complex.

Relations among the Ventanas units, the Alpujarride Complex and the Dorsal

The tectonic position of the Ventanas units is similar to that of the lower Alpujarride Padules unit in the sector NE

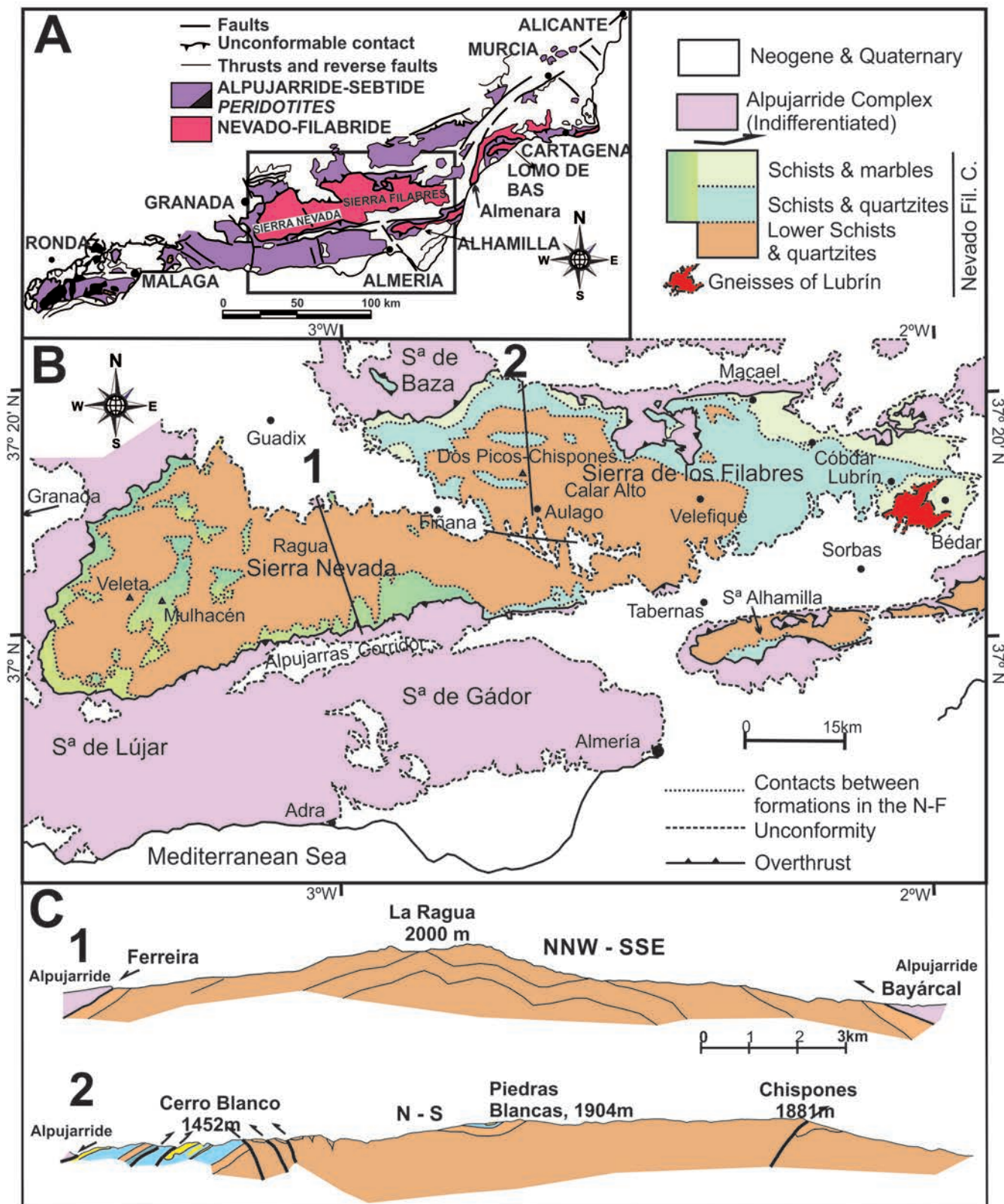


Fig. 8.- Schematic map of the Nevado-Filábride Complex. A. General distribution of the Nevado-Filábride Complex. B. The Nevado-Filábride Complex in sierras Nevada and Filabres (see rectangle in A for location). C. Cross sections showing the general structure (see location in B).

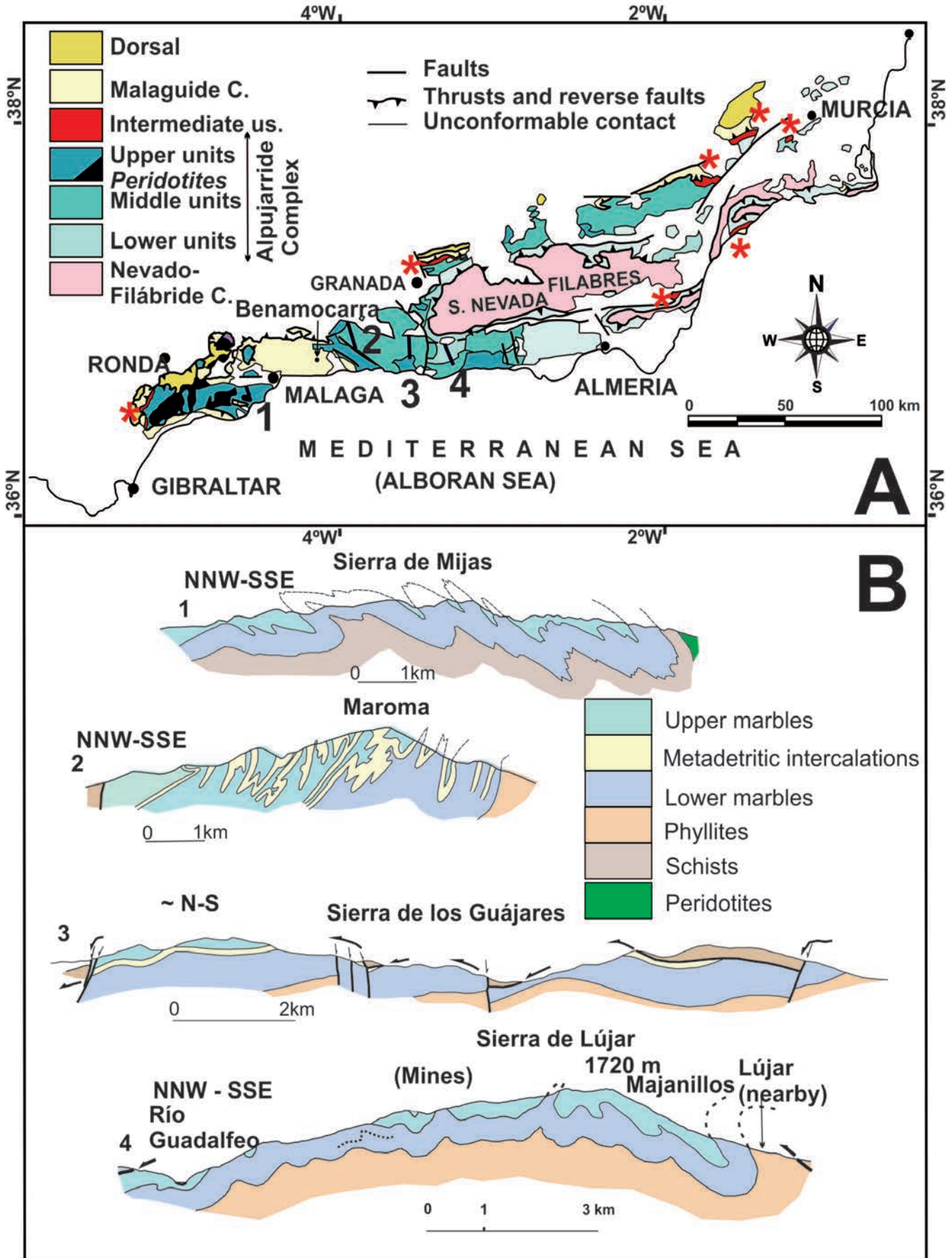


Fig. 9.- A. Schematic distribution of the complexes of the Betic-Rif Internal Zone indicating the position of the Intermediate units situated between the Maláguide and Alpujarride complexes (positions marked by red asterisks) and the main groups of the Alpujarride units. B. Cross sections showing part of the structure of the Alpujarride Complex (see location in A).

of Granada. For this reason, and because of their stratigraphic similitudes, they would form part of the Padules unit, hence of the Alpujárride Complex (Figs. 4 and 5). Moreover, their tectonic position is clearly different from that of the Dorsal, whose units are placed over the Maláguide Complex.

The Alpujárride Complex and the Dorsal are in contact in the sector of Las Nieves unit (south of Ronda), generally attributed to the External Dorsal. This unit is thrust by Los Reales unit, especially - but not only - by its peridotites. Owing to this thrust, the southern border of the Las Nieves unit is reversed and metamorphosed. But this tectonic contact would be a consequence of the westward displacement of the Internal Zone during the Burdigalian, not only of original paleogeographical proximity.

Structure of the Maláguide Complex

In the Betics the main tectonic feature of the Maláguide Complex is its thrusting over the Alpujárride Complex. No remarkable tectonic units have been described therein, though in places, such as W of Marbella, it is deformed by many different types of faults. In contrast, the Rif's equivalent complex, the Ghomaride, is structured in three main tectonic units (Chalouan, 1986).

Relations between the Maláguide Complex and the Dorsal and Predorsal

In the Betics the Maláguide Complex is thrust by the Dorsal. This is visible for instance at the western end of the Betic Internal Zone, in the area of Gaucín, as well as to the NE of Granada. In the Rif, the general situation is equivalent, but in some cases it is the Ghomaride Complex that thrusts the Dorsal. This can easily be explained as a result of posterior backthrusts.

Structure of the Internal Subbetic

The Internal Subbetic is characterized by the existence of folds (predominantly with E-W strikes, and N-S strikes at its western end). Moreover, there are numerous faults, the most important being those of E-W direction and having a dextral strike-slip character. According to Martín-Algarra (1987), Crespo (2008) and Sanz de Galdeano (2011), they were formed by the lateral push of the Internal Zone when it was displaced westwards.

Relations between the Internal Subbetic and the complexes of the Internal Zone

The contact of the Subbetic with the Internal Zone is always tectonic. In the western part of the Betic Internal Zone, the Dorsal thrusts over the Subbetic, but generally the contact, when visible, corresponds to dextral strike-slip faults. Only in the sector situated to the W of Sierra Espuña (~36 km WSW of Murcia) the Subbetic thrusts units of the Dorsal. Elsewhere the contact is with the Maláguide Complex, always of tectonic character.

Discussion

Relations among the Nevado-Filábride, Alpujárride and Maláguide complexes

In light of the comparison of the Nevado-Filábride and Alpujárride complexes, the following observations are noteworthy:

1) The general distribution of the lithological sequences in the two complexes share similarities: there is a Paleozoic metadetrritic sequence overlaid by carbonate deposits and other metasediments.

2) The Devonian limestones of the Nevado-Filábride Complex are not registered in the Alpujárride. Furthermore, the Carboniferous-Permian metamorphosed Culm facies has enormous thickness in the first complex, but smaller in the second.

3) At the bottom of the upper Alpujárride unit there are huge outcrops of peridotites, whose age of intrusion is Carboniferous, while they do not exist in the Nevado-Filábride Complex. But nevertheless, basic rocks (covering a broad span of time from the Carboniferous) are present in both complexes and the Nevado-Filábride Complex also contains ultrabasic rocks but in this case together with these basic rocks, unlike (as far as we know) the Alpujárride.

4) The upper units of the Alpujárride Complex feature an important episode of acid rocks extruding at the end of the Carboniferous-early Permian. In the Nevado-Filábride Complex gneisses began to appear practically at the same ages, but continued a longer time, probably reaching the Triassic if not more. The Lubrín-El Chive metapluton of the Nevado-Filábride is late Carboniferous-lower Permian in age, more or less of the same age as the Torrox metapluton of the Alpujárride.

5) The carbonate sedimentation apparently began somewhat earlier in the Nevado-Filábride Complex than in the Alpujárride. This type of deposit continued during the Triassic (or in the case of the Alpujárride Complex, began then) and, very probably, during the Jurassic and even the Cretaceous in both complexes (in the Alpujárride Complex bearing relation with the Ventanas units).

The sedimentation of carbonates was due to the transgression of the sea thanks to the beginning of the extension and subsidence, just after the Variscan orogeny, something that occurred within a context of tectonic instability and fracture formation that also allowed the exit of more igneous rocks.

The previous data permit us to establish a close relationship between the two complexes, involving a formal continuity from one to the other, although in the Nevado-Filábride the marine transgression began somewhat before.

Comparing the Alpujárride and Maláguide complexes, it can be seen that their Paleozoic lithological sequences share the presence of lutites (schists or phyllites in the Alpujárride) mainly corresponding to the Carboniferous. But the Devonian limestones of the Maláguide Complex have not been recorded, to date, in the Alpujárride (though much lesser thick, they are present in the Nevado-Filábride Complex).

Concerning Triassic and younger sediments (or metasediments in the Alpujárride complex) certain differences are significant: the Maláguide Triassic detritic sequences often

show larger grain sizes, with abundant conglomerates and sandstones; in the Alpujarride, these rocks are present but generally are not abundant, and the grain size of the metasediments is smaller. The carbonates are also different, those of Triassic age being thicker in the Alpujarride Complex. Jurassic and younger sediments are well developed in the Maláguide Complex, better than in the Alpujarride (practically limited to the Ventanas units). On the whole, the Alpujarride Triassic carbonates apparently began to be deposited before than those of the Maláguide. This means that from the Nevado-Filábride Complex, passing through the Alpujarride, to the Maláguide Complex, the formation of the first carbonates is diachronic, being older in the Nevado-Filábride.

The paleogeographic image deduced (as explained below) is that formerly the area now corresponding to the three main complexes of the Betic-Rif Internal Zone was situated in the prolongation of the Iberian Massif, an area where a new sedimentary basin began to be individualized at the end of the Carboniferous-Permian. This process started in the north and progressively extended southwards. First the Nevado-Filábride depositional area was formed, then that of the Alpujarride, and finally southwards, and with lesser subsidence, the Maláguide area, disposed in three more or less parallel bands. These three bands existing from the Permian-Triassic onwards could not extend indefinitely towards the W. They must come to an end, as the Betic External Zone and part of the Dorsal (see below) were situated in this direction. The more complicated paleogeographic problem to be resolved surrounds this aspect.

Some authors, e.g. Jabaloy *et al.* (2015) present the Alpujarride and Maláguide complexes as forming part of a so-called Alboran Domain, independent of the Nevado-Filábride Complex. Yet this domain was tectonically individualized from the early Miocene (Boillot *et al.*, 1984; Sanz de Galdeano, 1997) while, previously, during the Mesozoic the three main complexes were in continuity.

Relations among the Alpujarride Complex and the Ventanas and Dorsal units

As indicated above, the Ventanas units can be considered to form part of the Padules unit, and consequently of the Alpujarride Complex (Figs. 4 and 5), having a different tectonic position than that of the Dorsal, whose units are situated over the Maláguide Complex. But the similarities existing between the lithological sequences of the Dorsal and the Ventanas units are undeniable (see above).

Important similarities also exist between the lithological sequences of the Internal Subbetic and the Dorsal, something that seems to be more than a simple coincidence.

Essay of the paleogeographic reconstruction of the Betic-Rif Cordillera

The previous data must be combined with the different positions occupied by the present Iberian Peninsula and the former basin of the Betic-Rif Internal Zone over time (the reconstruction of these different positions is mainly adopted from Dercourt *et al.*, 1993).

The initial position corresponds to the Carboniferous-early Permian (Fig. 10). Then Iberia was situated eastwards of its present position, practically in front of the Algerian current coastline. This position of Iberia is obligatory to permit a good fit between the North American and European coasts before the onset of the opening of the Atlantic Ocean. In this time, the basement of the present complexes of the Internal Zone lay in the eastward continuation of the Variscan Iberian Massif, which probably formed an arc facilitating connection with the Moroccan Meseta (Simancas *et al.*, 2005). This connection was cut by an important nearby E-W fault, thus permitting subsequent differential movements between Africa and Iberia, whose character, dextral or sinistral, changed with time.

The different relative positions existing between Iberia and the NW of Africa throughout the Mesozoic and the Cenozoic are indicated in Fig. 10. Iberia continued moving eastward in relation to Africa till the middle Jurassic, owing to the more substantial opening of the central Atlantic to the W of Iberia. Later, the South Atlantic began to open more quickly and the relative motion changed (for more details of the Iberian movements in these times see Rosenbaum *et al.*, 2002, and also Sibuet *et al.*, 2012).

During this period the distance between Iberia and Africa increased, and the study area underwent noticeable extension, then forming deep fractures. This permitted extrusions of volcanic rocks from the late Carboniferous-Permian to the Triassic and Jurassic, not only in the Internal Zone, but also in adjacent areas as the Subbetic. In addition, the increased space permitted the formation of the Flysch basin, south of the Dorsal and Predorsal.

With the anticlockwise rotation of Iberia during the early Cretaceous, the scenario changed and from the late Cretaceous the Alpine orogeny began and continued during the Cenozoic, forming in these times the main features of the Betic-Rif Cordillera. Finally, in the early Miocene the westward drift of the Betic-Rif Internal Zone took place (Durand-Delga, 1980; Boillot *et al.* 1984; Sanz de Galdeano, 1990) (Fig. 10). In this drift process, part of the tectonic units previously formed were dragged in its northern border, in contact with the Betic External Zone, undergoing more tectonic complications. Then the Subbetic was deformed and rotated clockwise (Fig. 10).

According to this reconstruction, the Dorsal would formerly have a curved shape from the S to the W of the Maláguide basin, continuing from there to the NE, in the western end of the Alpujarride basin (Fig. 11). This shape partially coincides with the idea of Martín Algarra (1987), who proposed the existence of two "dorsals", one situated to the S of the Maláguide and another to the N.

This shape of the Dorsal can explain the stratigraphic similarities among the Ventanas units, the Dorsal and the Subbetic. That is, while the Ventanas units formed part of the Dorsal, at the same time they constituted the stratigraphic cover of part of the Alpujarride basin. This curved shape also fits with the distribution of the transgressive Oligo-Aquitania formation (Horca Formation) present in the Subbetic, in the Dorsal and even in the Ventanas units. The posterior structuring of the Inter-

nal Zone in the Sierra Arana-Mora area led that part of the Dorsal (the Ventanas units) to be currently thrust by several units, including the Maláguide Complex, while the rest lie above it.

Conclusions

During the Paleozoic, the present Betic-Rif Internal Zone basement was situated in the eastern prolongation of

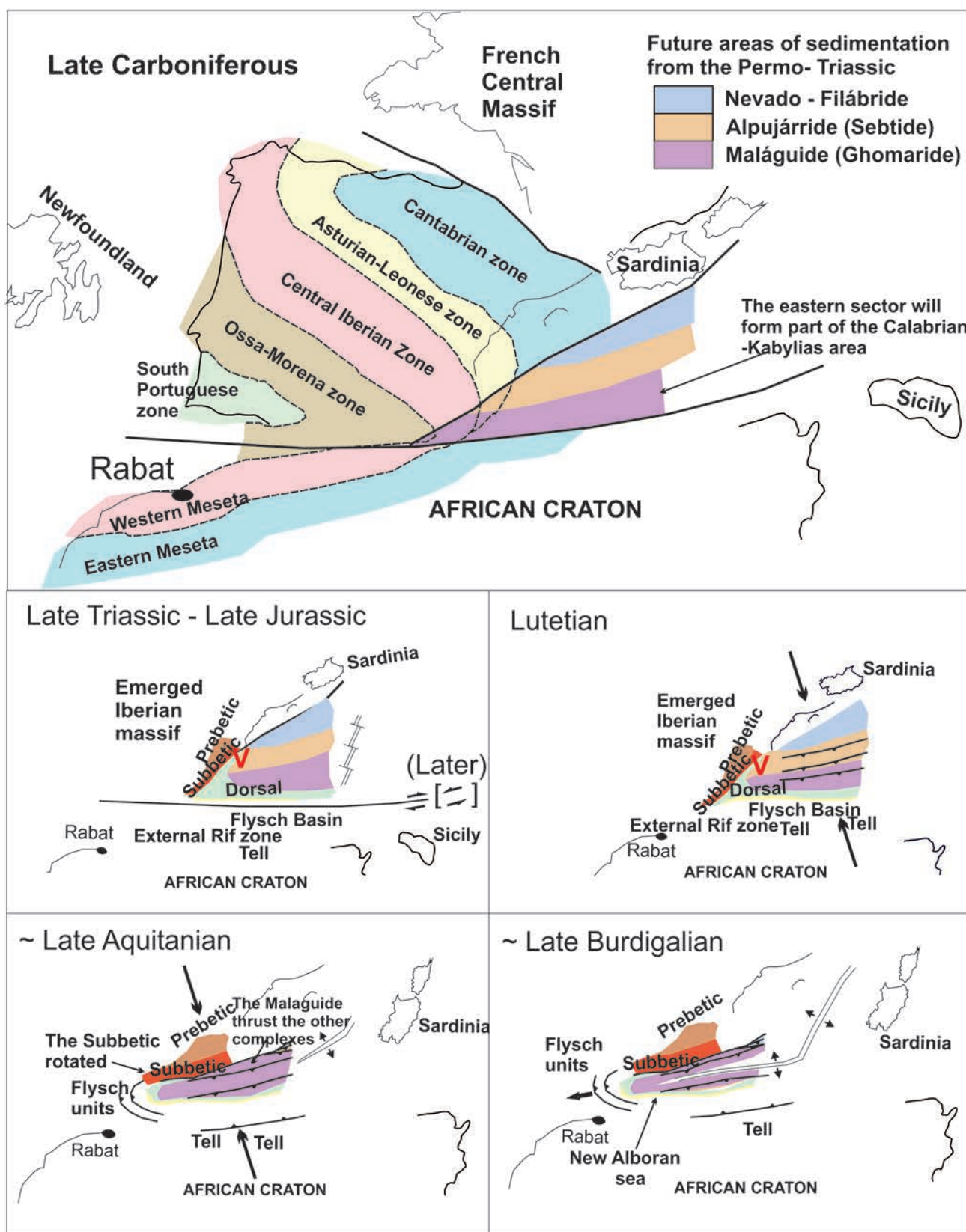


Fig. 10.- Essay of the different positions occupied by the Betic-Rif Internal Zone along the time. The relative positions between Iberia and NW Africa is taken from Dercourt *et al.* (1993). Note the general Subbetic clockwise rotation during the early Miocene. The red letter V indicates the former position of the Ventanas units.

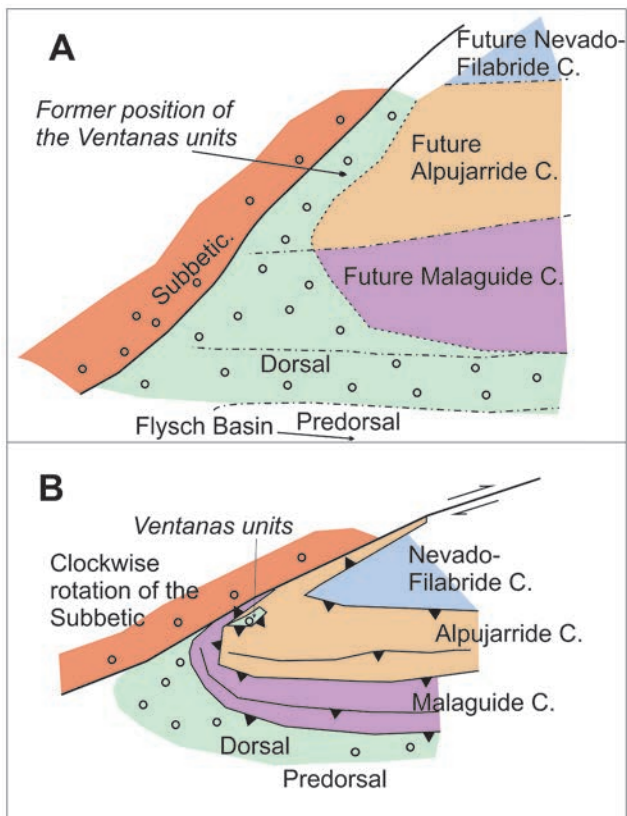


Fig. 11.- Very general geological sketch of the positions of the Dorsal, the Ventanas units and the Subbetic. A. Before main structuring of the Internal Zone. Small circles indicate part of the region later occupied by the Oligocene-Aquitainian formation (Horca Fm), though it extended to other sectors. B. Present general distribution of the diverse complexes in this area. The Ventanas units are signaled in their current position.

the Variscan Iberian Massif, although obviously presenting lateral changes, as usually happen in sedimentary basins. In this eastern position a new sedimentary basin was formed including the three future complexes. In it, faulted in many places, the Nevado-Filábride passed more or less transitionally to the Alpujarride Complex and it, in turn, to the Maláguide Complex, forming more or less parallel bands. The exact form of each of these bands can be debated, but not the passage from one to another, which seems to be clearly established.

The formation of this basin was diachronic: at the end of the Carboniferous-Permian the area of the future Nevado-Filábride Complex began its subsidence, somewhat before that of the Alpujarride Complex, which was before that of the Maláguide Complex. These bands end laterally westward, at the contact with the Betic External Zone (specifically with the Internal Subbetic).

The Dorsal is part of the cover of the Maláguide Complex, and also its prolongation to the S, passing to the Predorsal and then to the Flysch basin. To the W the Dorsal adapted its shape to the borders of the bands, even coming to form part of the Alpujarride cover. At the same time, the Dorsal was in contact with the Subbetic. Later, during the Alpine orogeny, the structuring of the complexes forced the Dorsal to occupy different tectonic positions particularly in the sector of Sierra Arana-Mora.

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