Sanz de Galdeano, C. y López Garrido, A.C., 2016. The nevado-filábride complex in the western part of Sierra de los Filabres (Betic Internal Zone), structure and lithologic succession. *Boletín Geológico y Minero*, 127 (4): 823-836
ISSN: 0366-0176
DOI: 10.21701/bolgeomin.127.4.005

The nevado-filábride complex in the western part of Sierra de los Filabres (Betic Internal Zone), structure and lithologic succession

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ABSTRACT

In the western part of Sierra de los Filabres (in the Nevado-Filábride Complex, within the Betic Internal Zone) several tectonic units have been described, in varying numbers depending on the author describing them. However, new cartographical data show that the limits of these units pass through the lithological formations without displacing them. Moreover, the rocks belonging to some units that are supposedly situated in a lower tectonic position really belong to higher formations. From bottom to top, these lithological formations are the following: (1) dark schists and quartzites; (2) quartzites, sandstones, sands, lutites, schists, and mica schists; (3) schists; (4) marbles, schists, and mica schists. High-angle reverse faults are associated with the great E-W anticline of Sierra de los Filabres. The existence of sands and apparent lutites visibly interlayered between rocks, such as schists and mica schists with garnets, poses a metamorphic problem that has not as yet been addressed.

Keywords: Betic Internal Zone, metamorphism, Nevado-Filábride Complex, tectonic units

El complejo Nevado-Filábride en la parte occidental de la Sierra de los Filabres (Zona Interna Bética), estructura y sucesión litológica

RESUMEN

En la parte occidental de la Sierra de los Filabres (perteneciente al Complejo Nevado-Filábride, en la Zona Interna Bética) se han descrito diversas unidades tectónicas, en muchos casos diferentes de un autor a otro. Sin embargo, una nueva cartografía permite concluir que todos los límites de estas unidades pasan a través de las formaciones litológicas que allí existen sin desplazarlas. Además, rocas atribuidas a algunas unidades que se consideran en una posición tectónica inferior realmente pertenecen a formaciones altas. Estas formaciones son, de abajo arriba: 1) esquistos oscuros y cuarcitas, 2) cuarcitas, areniscas, arenas, lutitas, esquistos y micacitas, 3) esquistos y 4) mármoles, esquistos y micacitas. Fallas inversas de alto ángulo se asocian con el gran anticlinal E-O de la Sierra de los Filabres. La presencia de arenas y de las aparentes lutitas intercaladas entre rocas tales como esquistos y micacitas con granates plantea un problema metamórfico no abordado hasta el momento.

Palabras clave: Complejo Nevado-Filábride, metamorfismo, unidades tectónicas, Zona Interna Bética

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

La estructura y división en unidades del complejo Nevado-Filábride es un tema muy discutido. Algunos autores lo dividen en varias unidades o mantos, así en el manto del Veleta y el del Mulhacén (Puga, 1971) o en los mantos de Ragua, Calar Alto y Bédar-Macael (Martínez-Martínez et al., 2002), mientras que otros autores no las llegan a distinguir (Brouwer, 1926; Galindo-Zaldívar, 1993). En nuestra opinión, muchas de *las divisiones en unidades están fundamentalmente basadas en datos petrológicos que en muchos casos no han sido contrastados con los datos de campo. Estudios sucesivos se basan en los anteriores, pero sin hacer revisiones de los datos iniciales. En el presente artículo se presenta una nueva cartografía de la parte occidental de la Sierra de los Filabres, en lo referido al complejo Nevado-Filábride, y con ellos se aporta la descripción de las formaciones litológicas que allí lo componen. Todos estos datos permiten aclarar la existencia o no de las unidades previamente diferenciadas.*

El Nevado-Filábride es el complejo inferior de la Zona Interna Bética (Fig. 1). Está formado por un basamento atribuido al Paleozoico y una cobertera permo-triásica y fue metamorfizado en la orogenia Alpina. En cualquiera de las divisiones en unidades o mantos antes citada (o en otras que contemplan aún más unidades) el contacto entre ellas se suele considerar que corresponde a zonas de cizalla.

En el área estudiada, Fallot et al. (1960) señalaron la existencia de arenas, areniscas y lutitas intercaladas entre esquistos, micacitas y cuarcitas. Pero posteriores trabajos, con la excepción de Jabaloy y González Lodeiro (1988) y Jabaloy (1993) las han ignorado por completo. Estos últimos autores incluyen algunas de ellas en la que llamaron unidad de Bodurria que consideraron tiene un menor grado de metamorfismo y una posición tectónica inferior. Su división en unidades no coincide, ni en el nombre ni en el espacio, con otras anteriores ni con las indicadas por otros autores posteriores.

El objetivo del presente artículo es presentar una nueva cartografía, junto con la descripción de las formaciones litológicas que allí forman la secuencia del Nevado-Filábride, lo que permite aclarar la estructura del sector.

La sucesión litológica

En la descripción que sigue nos ceñimos a los aspectos de visu. Para una descripción petrológica más profunda remitimos a anteriores trabajos (Navarro Vázquez y Velendo Muñoz, 1979; Aldaya, 1990; Jabaloy, 1993 y Booth et al., 2015).

Son cuatro las formaciones litológicas diferenciadas (Fig. 2). La primera, que ocupa la posición inferior, corresponde a esquistos oscuros y cuarcitas. Es una monótona formación con un espesor de varios miles de metros, aunque en el área de estudio solo afloran los 500 m superiores. Corresponde al antiguamente llamado "Cristalino de Sierra Nevada" (Brouwer, 1926). Las tres restantes formaciones se sitúan en lo que este mismo autor denominó la Mischungzone. La segunda formación está formada por arenas, areniscas, cuarcitas (en transición de unas a otras) (Fig. 3), rocas de apariencia lutítica que pasan a esquistos y micacitas con gruesos granates. Todos estos materiales alternan entre sí. La tercera formación corresponde fundamentalmente a esquistos con granates y la cuarta a mármoles en los que se intercalan esquistos y micacitas (e incluso algún nivel de arenas). El espesor de las tres formaciones superiores rebasa el kilómetro, aunque hay muchos cambios laterales, tanto en espesor como en litología. En todos los casos el contacto entre las formaciones es de aspecto estratigráfico, en transición gradual, aunque se ha señalado que entre las dos primeras formaciones puede hacer una discordancia marcada por metaconglomerados (Gómez-Pugnaire et al., 1981). Existen además rocas ígneas básicas (y algunas ácidas) intercaladas sobre todo en las formaciones segunda y cuarta. Ahora forman metabasitas y ortogneises.

Estructura

La estructura general del área estudiada es un gran anticlinal E-O (Fig. 4) que se acompaña con pliegues de menor tamaño (aunque sean kilométricos), y por fallas inversas de gran ángulo, observables sobre todo hacia la parte oriental. Esta estructura se muestra también en parte de la Fig. 5 y sobre todo en los cortes geológicos de la Fig. 6. Las fallas pueden deducirse con facilidad cuando los esquistos de la formación inferior cabalgan a la segunda formación en la que afloran muy bien las arenas. En esos casos el contraste litológico es muy marcado. Estas fallas se han producido debido a la falta de espacio que se produjo cuando se formó el citado gran anticlinal. La vergencia de las fallas es generalmente hacia el sur en la parte sur, y hacia el norte en la parte norte, con algunas excepciones en esta parte.

Discusión y conclusiones

No es difícil establecer la sucesión litológica pues la calidad de los afloramientos es generalmente buena, lo que permite establecer fácilmente el orden de superposición de las rocas. De estas, las más llamativas son las arenas, areniscas y lutitas intercaladas con esquistos y micacitas. Algunos de los afloramientos de

estas rocas los situó Jabaloy (1993) en la unidad de Bodurria que aparecería en cuatro ventanas tectónicas bajo una unidad cabalgante, si bien estas rocas se pueden observan en muchos puntos más. Y, en nuestra opinión, no están formando ventanas tectónicas y ocupan posiciones estratigráficas y tectónicas altas. Además los contactos propuestos para esas ventanas tectónicas pasan a través de las formaciones litológicas sin que se observe ningún desplazamiento. Y lo mismo ocurre con todas las otras divisiones en unidades propuestas en este sector por otros autores, y con las unidades propuestas para este sector descritas en otros sectores del Nevado-Filábride y que, según el modelo que siguen, se atribuyen a alguna parte del área estudiada. En nuestra opinión, cualquier propuesta de división en unidades debe poder ser sustentada por desplazamientos observados en las formaciones litológicas, salvo en caso de despegues de carácter local, pues si fueran muy importantes producirían la desaparición o la duplicación de alguna formación. Esto también es aplicable a las zonas de cizalla previamente propuestas y estudiadas (por ejemplo la zona de cizalla de Dos Picos, en la parte E de la Fig. 6) cuyas trazas, como grandes cizallas, no soportan tampoco su examen sobre el terreno.

La existencia del gran anticlinal E-O es aceptada generalmente, si bien las fallas inversas de gran ángulo no se conocían. Por otra parte, si se sigue la estructura del sector hacia Sierra Nevada, en el sector de Ocaña, se deduce que entre ambas sierras tiene que existir una gran falla cuyo carácter desconocemos, pero cuyo salto vertical es al menos de 1800 m.

De acuerdo con la anterior discusión, pensamos que en el área estudiada el Complejo Nevado-Filábride solo corresponde a una simple unidad tectónica en la que se diferencian cuatro formaciones litológicas. Coincidimos con las interpretaciones previas que indican que este complejo fue subducido y que sufrió varias etapas de metamorfismo. Después se formaron el gran anticlinal, los otros pliegues de menor envergadura y las fallas inversas. Más tarde se produjo una progresiva exhumación del conjunto, dándose al tiempo un proceso de extensión.

Desde un punto de vista paleogeográfico, el comienzo de la sedimentación de la segunda formación inició un nuevo ciclo de sedimentación acompañado por una subsidencia. Esta fue facilitada por la formación de fracturas que permitieron además la salida de las rocas ígneas. De acuerdo con varios autores (por ejemplo Gómez-Pugnaire et al., 2012) este ciclo comenzó durante el Pérmico inferior y continuó a lo largo del Triásico.

Finalmente, en nuestra opinión, deben iniciarse estudios para aclarar por qué existen arenas, areniscas y lutitas intercaladas con rocas tales como esquistos y micacitas con granates. Estos trabajos darán información sobre el metamorfismo en sí, y de la distribución real del mismo en el complejo Nevado-Filábride.

Como corolario, pensamos que en estudios tectónicos y petrológicos, particularmente en áreas metamórficas, es necesario confeccionar previamente una cartografía detallada y tener un buen conocimiento de las sucesiones litológicas. Esto que es bien conocido, si se olvida conducirá a unos resultados que probablemente serán erróneos.

Introduction

The structure of the Nevado-Filábride Complex is a topic of considerable discussion and debate. This is particularly the case for all factors pertaining to the division of this area in tectonic units. Whereas some authors claim that there are various (or even a great many) units, others assert that there is only one unit, apart from the local thrust that can locally repeat the successions. This is important because an accurate understanding of the geological evolution of this complex, and even of the entire Betic Internal Zone, partially depends on its structure.

In our opinion, many of the interpretations of this structure are based on models mainly derived from petrological results that have never been sufficiently contrasted with field data (this is something that must be done before presenting interpretations). Nonetheless, these models have become widely accepted and are regarded as valid for the entire complex despite the fact that the results obtained are not compatible with field observations. Rather surprisingly, subsequent studies have based their research directly on these results without any revision of the data (particularly the cartographic information) that they are based on.

A new cartography of the western sector of Sierra de los Filabres now provides a more in-depth knowledge of the distribution of the lithological formations and thus of the structure of this area. These new data orientate the discussion concerning the differentiation, or not, of the units.

Geological setting

The Betic Cordillera is divided into External and Internal Zones, moreover the Flysch units and Neogene basins (Durand-Delga and Fontboté, 1980). The External Zone (Fig. 1A) corresponds to the sedimentary Mesozoic and Tertiary cover of the south and southeast border of the Iberian Paleozoic Massif. Based on the proximity to this massif, it is subdivided into Prebetic and Subbetic zones (Vera, 1988).

From bottom to top, the Internal Zone includes the following complexes: (i) Nevado-Filábride; (ii) Alpujárride; (iii) Maláguide; (iv) Betic Dorsal (Durand-Delga and Fontboté, 1980). The Nevado-Filábride and Alpujárride complexes (Fig. 1B) were metamorphosed during the Alpine orogeny, when their current structure was formed. Both complexes have Palaeozoic and Triassic successions. The existence of Jurassic and younger successions is debatable. The Maláguide Complex, characterized by wide Paleozoic, and locally Mesozoic and Tertiary outcrops, was only slightly affected by the Alpine metamorphism, whereas the Betic Dorsal is generally not metamorphosed.

The Nevado-Filábride Complex is currently divided into three units (or nappes), which from bottom to top are the Veleta (or ~Ragua), the Mulhacén (or ~Calar Alto), and the Bédar-Macael units (the authors of this and other divisions are indicated in the general background and in the antecedents of the study area). The cited division is based on differences in metamorphic features. More specifically, the units with a greater degree of metamorphism are located in

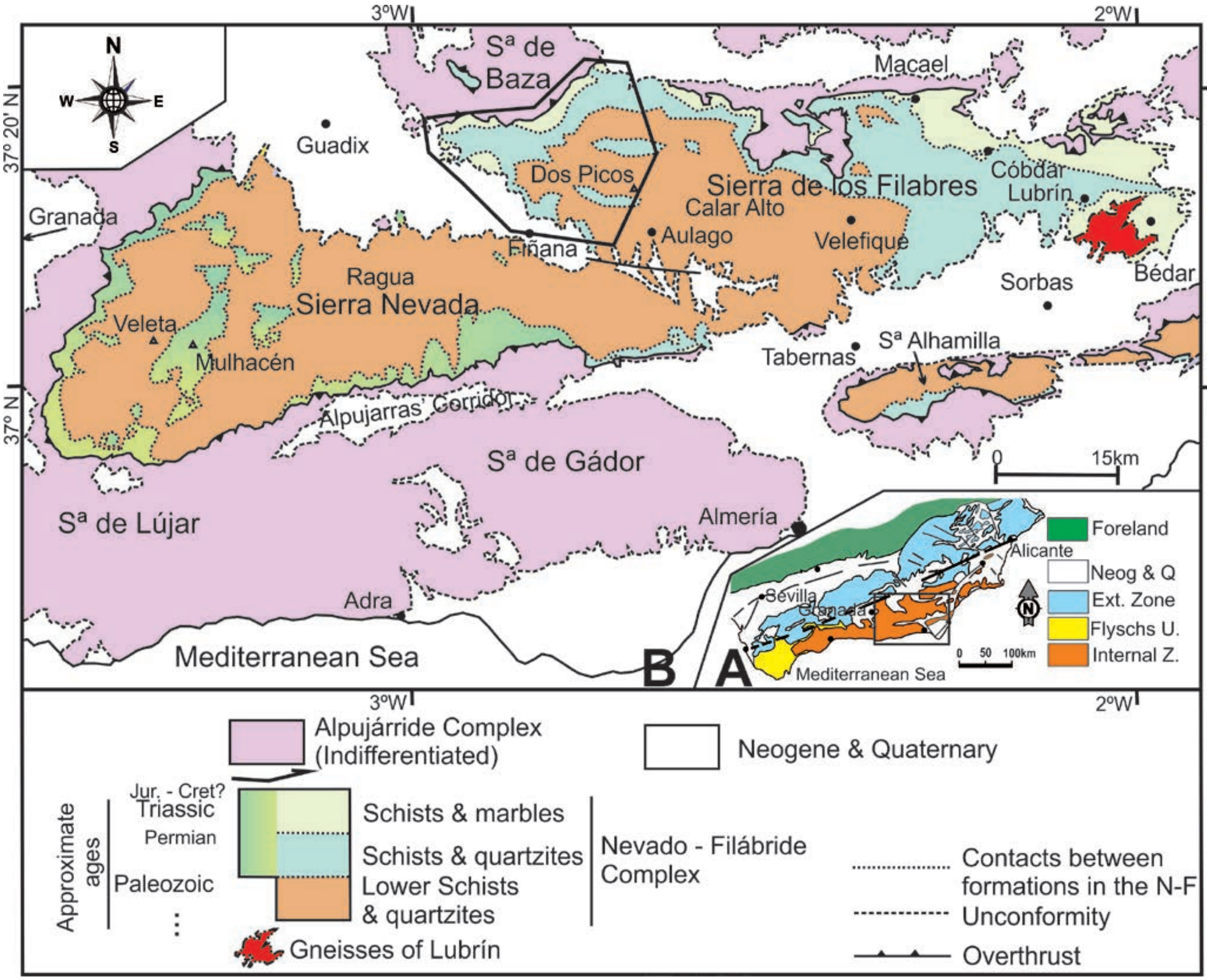

Figure 1. Regional setting. A: General situation of the Nevado-Filábride Complex in the Betic Cordillera. B: Scheme of the Nevado-Filábride Complex (without the eastern part). The irregular inset marks the position of Figure 4.

Figura 1. *Situación regional. A: Localización del complejo Nevado-Filábride en la Cordillera Bética. B. Esquema del complejo Nevado-Filábride (sin su parte oriental). El polígono irregular indica la posición de la Fig. 4.*

higher tectonic positions. Contact between the units is assumed to correspond to tectonic detachments, which are ductile shear zones, whose exact location is usually not specified. The following section describes the progressive division in units over time, and discusses whether this division corresponds to reality.

General background

Brouwer (1926) differentiated two large formations in the *Penninic Betics* (his term for the Nevado-Filábride Complex). The lower formation, the *Kristallijne Schisten* (Crystalline of Sierra Nevada), is formed by a monotonous succession of dark mica schists with graphite and quartzites, probably Paleozoic, and an upper ensemble, the *Mischungzone* (Mixed Zone), composed of schists, quartzites, marbles, gneisses, serpentinites, and amphibolites. Van Bemmelen (1927) and Westerveld (1929) called this upper ensemble the *Penninic Mesozoic Zone*.

Fallot *et al*. (1959, 1960) found a possible disconformity between the schists of Sierra Nevada (over 5000 m thick) and the *Mischungzone*. In their study, they expressed doubts as to the autochthony or allochthony of these rocks, and discussed both possibilities. Three years later, Egeler (1963), who was the first to use the term *Nevado-Filábride Complex,* stated that it included the two formations of Brouwer. (1926). The possible existence of various tectonic units was also considered.

The division of the Nevado-Filábride Complex in units or nappes first began with Nijhuis (1964), who studied the eastern area of Sierra de los Filabres and divided the *Mischungzone* into various units, whose lithological sequences span from the Pre-Permian to the Triassic and "younger ages". Subsequently, Helmers and Voet (1967), Egeler and Simon (1969), Vissers (1977), Linthout and Vissers (1979), and De Jong (1993), amongst others, described more units in the central and eastern part of Sierra de los Filabres within the Nevado-Filábride Complex.

In Sierra Nevada, Puga (1971) differentiated two main nappes. The bottom nappe was that of the Veleta (approximately equivalent to the Crystalline of Sierra Nevada) and the top nappe was that of the Mulhacén, subdivided into various tectonic units. Martínez-Martínez (1984-85) accepted this division and presented a map of the lithological formations of Sierra Nevada and Sierra de los Filabres. Gómez-Pugnaire (1988) also divided the area into the Veleta and Mulhacén nappes. However, this division was not accepted by everyone. A case in point is Galindo Zaldívar (1993), who failed to detect any tectonic contact between the Veleta and Mulhacén nappes. Nonetheless, Puga *et al*. (2002) proposed the differentiation of the Nevado-Filábride Complex into the Veleta and Mulhacén Complexes.

Gómez-Pugnaire *et al*. (2000, 2004 & 2012) and López Sánchez-Vizcaíno *et al*. (2001) describe lithostratigraphic successions of the Nevado-Filábride Complex formed by the superposition of the different nappes, in which the rocks become progressively younger from the lower to the upper levels. According to these authors, the contact between the corresponding positions of the Veleta and Mulhacén nappes is marked by an erosion surface in which there are conglomerates.

Martínez-Martínez *et al*. (2002) renamed the Veleta nappe and called it the Ragua unit. The new names for the upper units were Calar Alto (instead of Mulhacén) and Bedar-Macael. These name changes were justified because the Calar Alto unit should occupy part of the top level formerly attributed to the Veleta nappe. The new limits of these units are different from the previous ones established by the same authors (Martínez-Martínez *et al*., 1997). In a later work, Martínez Martínez *et al*. (2010) maintained the same names and limits that were used in 2002, and which were also used by Augier *et al*. (2005) and Booth *et al*. (2015).

Antecedents in the study area

Fallot *et al*. (1960) were possibly the first authors to study Sierra de los Filabres in some detail. Probably one of the most interesting aspects described is the existence of sands and sandstones with an apparently very low degree of metamorphism, as also occurs in the case of the lutites.

The study area occupies part of three geological maps on a scale of 1:50000 (Navarro Vázquez and Velendo Muñoz, 1979; Aldaya *et al*., 1980; Delgado *et al*., 1980). In all of the maps, the tectonic units follow the nomenclature of Puga (1971) and Puga *et al*. (1974), the Veleta and Mulhacen nappes. The cartography of Navarro Vázquez and Velendo Muñoz (1979) has been widely accepted without further discussion.

Gómez-Pugnaire (1979) studied the western part of Sierra de los Filabres and drew a schematic map, in which a pre-Permian basement was differentiated from a Permo-Triassic cover. Gómez-Pugnaire *et al*. (1981) documented the existence of metaconglomerates in this area, whose position, according to the description given, could correspond to the separation of the previously mentioned basement and cover. Gómez-Pugnaire *et al*. (1982) highlighted the presence of pre-Cambrian fossils in metapelite samples of the basement. Nevertheless, since the exact location of these fossils was never specified nor photographs of them ever provided, their existence has never been confirmed. Gómez-Pugnaire and Franz (1988) presented a schematic map of this area, which separated the basement of the Veleta nappe from that of the Mulhacen nappe.

In his study of the western part of Sierra de los Filabres, Jabaloy (1985) distinguished the Monterillo unit (bottom) and the Dehesa unit (top). However, a few years later, Jabaloy and González Lodeiro (1988) and Jabaloy (1993) explored the same area and found two different tectonic units, namely, the Bodurria and Sierra de los Filabres units. The limits of these units differed from those of the Monterillo and Dehesa units. The new studies states that the Bodurria unit outcrops in tectonic windows and has a lower degree of metamorphism than the thrusting unit. Despite dealing with the same area, the limits of these units do not coincide with those specified by Navarro Vázquez and Velendo Muñoz (1979).

García-Dueñas *et al*. (1988) defined the Dos Picos shear zone. This shear zone, initially contractional, was subsequently reactivated under extensional conditions. González Casado *et al*. (1995) arrived at a similar conclusion. These articles claim that the Bedar-Macael unit is located in the study area, and contains most of the marble, except for the lower layers that belong to the Calar Alto unit. This view is also shared by Augier *et al*. (2005) and Booth *et al*. (2015).

Research objective

The main research objective of our study is to present a geological map of the study area, which would permit us to deduce the structure of the western sector of Sierra de los Filabres. In order to create this map, it was necessary to establish the lithological succession, and progressively specify it with greater accuracy, according to how our cartography was advancing. According to the results of this cartography and the lithologic succession obtained, many aspects of the previous cartographies and of the previous division into units are discussed.

The lithological succession

The following description corresponds to characteristics that are clearly visible in the field. Accurate petrological descriptions of the area can be found in previous studies (i.e. Navarro Vázquez and Velendo Muñoz, 1979; Aldaya, 1990; Jabaloy, 1993; Booth *et al*., 2015).

In the western part of Sierra de los Filabres all of the lithological formations of the Nevado-Filábride Complex crop out, with the exception of certain ones to the east in the province of Murcia (Laborda *et al*., 2014), which do not coincide either in age or lithology. As previously mentioned, Brouwer (1926) divided the lithological succession into two main parts: a lower part named the Crystalline of Sierra Nevada and an upper part called the *Mischungzone*. We divided the *Mischungzone* into three clearly differentiated formations (Fig. 2).

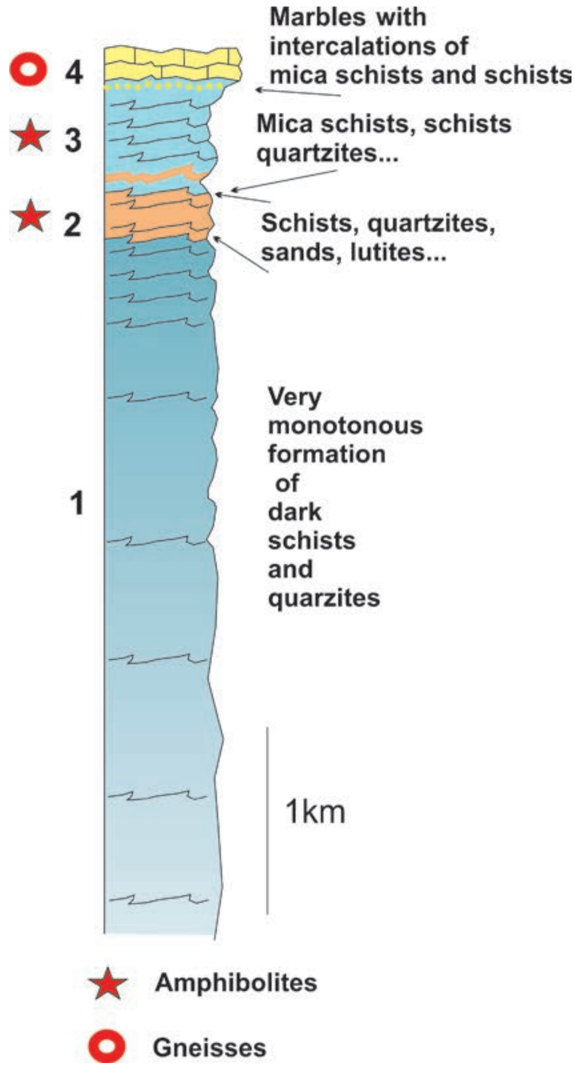

Figure 2. Schematic lithological succession of the Nevado-Filábride in western Sierra de los Filabres. The numbers correspond to the equivalent formations.

Figura 2. *Sucesión litológica esquemática del Nevado-Filábride en la parte occidental de la Sierra de los Filabres. Los números corresponden a las formaciones equivalentes.*

Lower formation: dark schists and quartzites.

The lower formation, which corresponds to the Crystalline of Sierra Nevada, consists of a very monotonous formation of dark schists and quartzites. The schists are generally more abundant than the quartzites, though the quartzites are locally well represented. The thickness of the layers is usually very slight and can be measured in decimetres or centimetres. The graphite is responsible for the black colour of the schists. These rocks have a thickness of over 4000 m (Fallot *et al.*, 1960) though only the upper 500 metres are visible in this area. The age generally attributed to these rocks is Paleozoic (Gómez-Pugnaire *et al.*, 2012).

Second formation: quartzites (and sands), apparent lutites, schists, and mica schists.

This formation is very interesting, not only because of the variety of rocks, but particularly because of the presence of soft white and yellow sands. These sands are visible throughout the study area (Fig. 3, 1-4) and are situated between other types of rock in the same formation. It is even common for

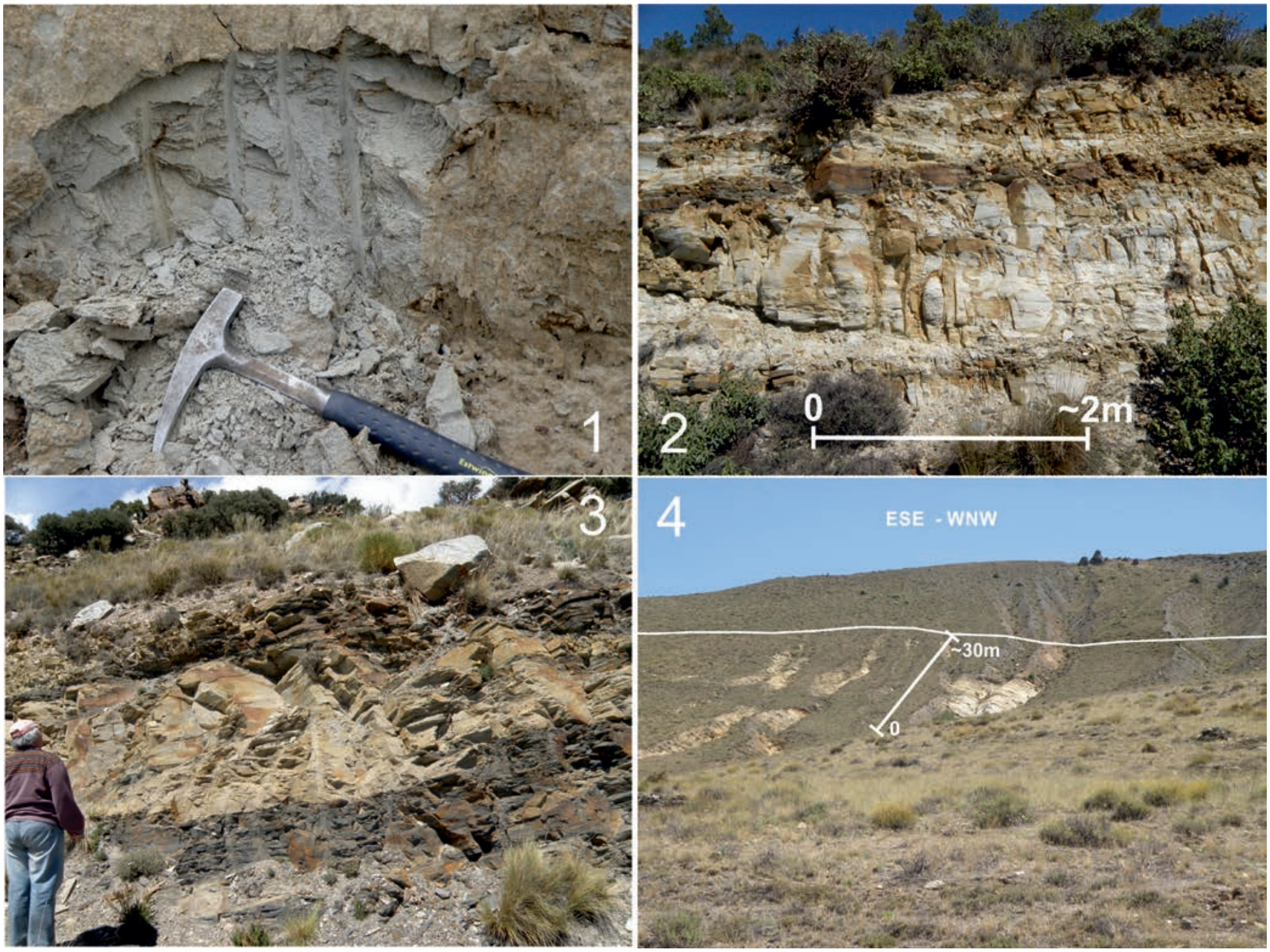

Figure 3. 1) Sands within the second formation, which can be removed with a hammer. 2) Sands of the second formation, situated between lutites. 3) Sandstones in the second formation, situated between lutites. 4) Sands and other rocks in the second formation thrust by dark schists of the first formation. The dip of this reverse fault, which can be seen laterally (area of Benacebada), is not shown in this photo.
Figura 3. *1) Arenas en la segunda formación, que pueden ser movidas con un martillo. 2) Arenas de la segunda formación, situadas entre lutitas. 3) Areniscas en la segunda formación, situadas entre lutitas. 4) Arenas y otras rocas de la segunda formación cabalgadas por esquistos oscuros de la primera. El buzamiento de esta falla inversa, que puede verse lateralmente (en el área de Benacebada) no se muestra en la foto.*

them to transitionally pass and become very hard quartzites. They are thus characterized by a wide range of intermediate degrees of hardness. In some places, a cross lamination is visible in the sands and quartzites. Although this formation is the richest in sand, layers of sand have also been observed in higher formations, even up to the marbles. Probably the most spectacular area where these sands are found is situated directly to the NW of Benacebada in the eastern section of Figure 4, although there are excellent outcrops in many other places as well.

Also visible in many places are apparent grey-blue lutites, which intercalate and alternate with the sands or quartzites, (Fig. 5 A). These rocks have very thin, flat schistose laminae, in many cases without any visible minerals, except for white and locally dark micas. However, these rocks show a gradual transition to schists with garnets (even with a diameter larger than 1cm) and to mica schists also rich in garnets. This transition occurs horizontally as well as vertically. In some cases, rocks of both types are vertically situated less than one metre from each other.

This formation also locally presents marbles, practically limestones, rich in joints filled by calcite. They are configured in thin layers of one decimetre or less and their apparent degree of crystallization is low. One of the largest outcrops of these rocks is situated near the top of Cerro del Lastonar (1783 m),

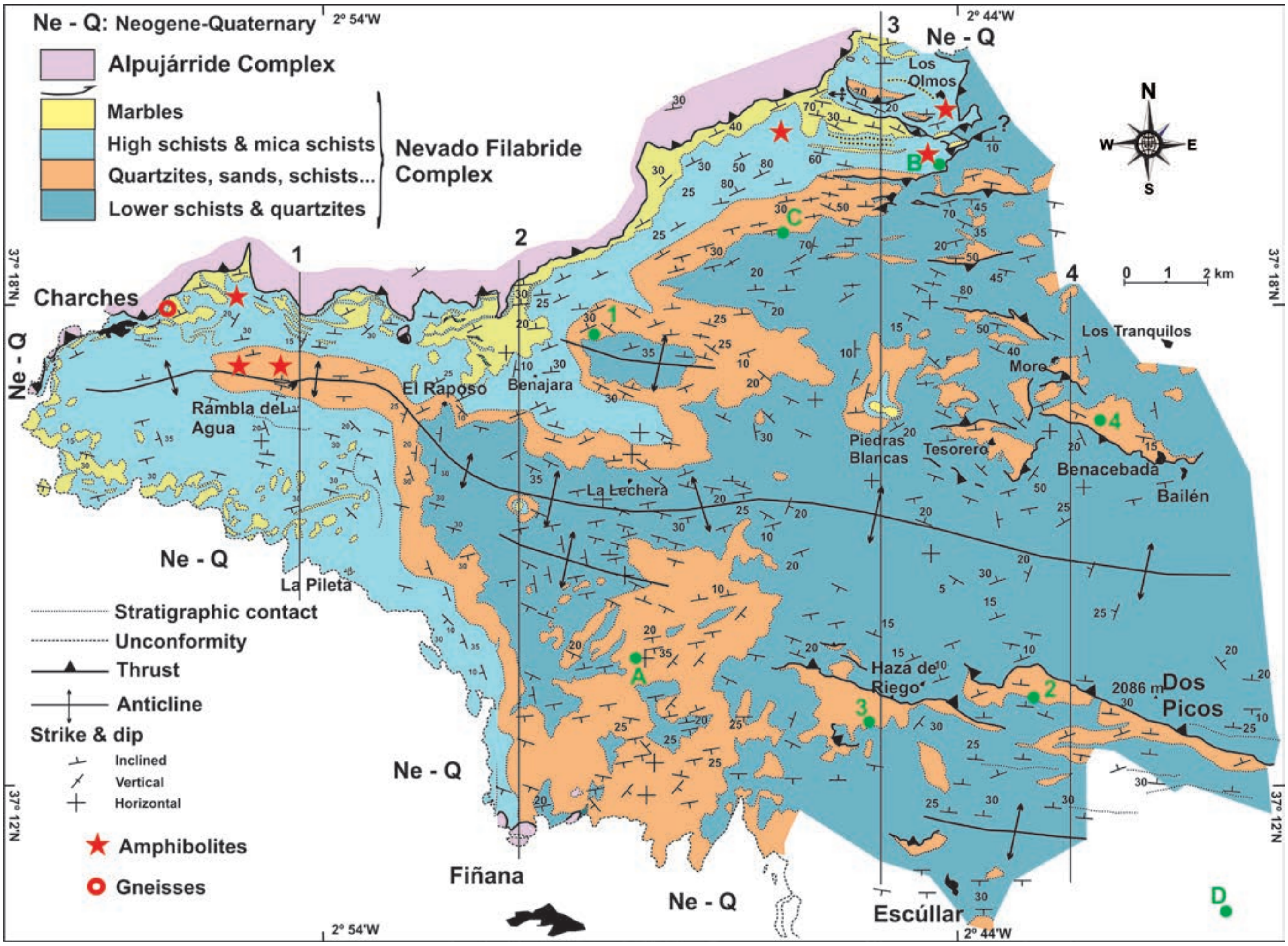

Figure 4. Geological map of the western part of Sierra de los Filabres. It was originally made on a scale of 1:25000 scale though here the scale is smaller. The position of cross-sections of Fig. 6 is marked. 6. The approximate position of the images in Figs. 3 and 5 is marked with small green circles.

Figura 4. *Mapa geológico de la parte occidental de la Sierra de los Filabres. Originalmente se hizo a escala 1.25000, aunque aquí la escala es menor. Se indica la posición de los cortes de la Fig. 6. La posición aproximada de las imágenes de las Figs. 3 y 5 se indica con pequeños círculos verdes.*

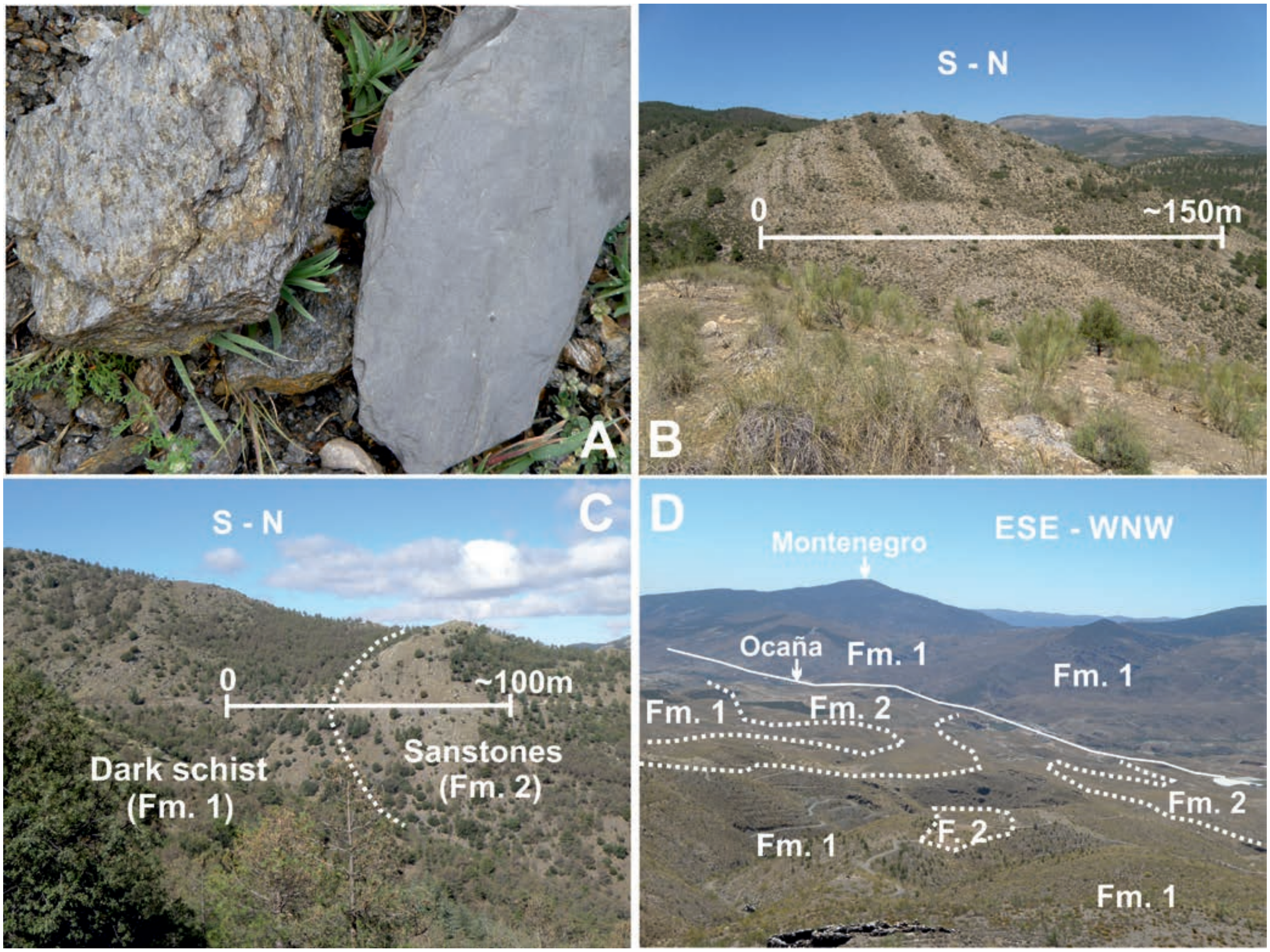

Figure 5. A) Comparison between schists and lutites repeatedly intercalated in the levels of second formation and intercalated between sands, sandstones, and quartzites. B) Partial view of the marbles in the fourth formation. As can be observed, in many cases, there are different bands corresponding to intercalated schists and mica schists. C) Contact between the dark schists of the first formation and sandstones of the second formation. In this case, the contact is reversed, although laterally they become normal. D) Panoramic view of the SE part of the study area, and surroundings. Southwards, the rocks in the second formation collide with the dark schist in the first formation.

***Figura 5**. A) Comparación entre esquistos y lutitas repetidamente intercalados en niveles de la segunda formación e intercalados entre arenas, areniscas y cuarcitas. B) Vista parcial de los mármoles de la formación cuarta. Como puede verse, en muchos casos hay diferentes bandas que corresponden a intercalaciones de esquistos y micacitas. C) Contacto entre esquistos oscuros de la primera formación y areniscas de la segunda. En este caso está invertido, aunque lateralmente pasa a ser normal. D) Vista panorámica de la parte SE del área estudiada y de sus alrededores. Hacia el sur, las rocas de la segunda formación chocan con los esquistos oscuros de la primera.*

approximately 1,750 m to the WNW of El Raposo (see Fig. 4).

Third formation: schists.

At many points above these rocks, there is a formation of schists, generally with garnets. The schistosity is undulated largely because of the garnets (as well as other minerals), whose size is of various millimetres and can even be larger than one centimetre. The colour of these schists ranges from grey to greyish blue. Locally, it is also possible to observe layers of mica schists and quartzites (though rarely sand).

The age generally attributed to the second and third formation is Permian (see for instance Nijhuis, 1964).

Fourth formation: marbles, mica schists and schists

The most abundant rocks in the fourth formation are marbles (Fig. 5 B). They are very crystalline and are either found in layers thicker than 1m or in thin beds. Interbedded with the marbles are schists and mostly mica schists. Depending on the location, the marbles are more or less massive, though in other places, their layers disappear laterally.

To the south, in the area of the mines of La Pileta, approximately 6 km to the SE of Charches (see Fig. 4), the marbles and even the schists are mineralized by iron oxides. These mineralizations were also exploited in the area of El Tesorero situated to the west of Benacebada, where the schists of the second formation are found.

In La Canaleja, approximately 1.5 km to the north of Benajara (see Fig. 4), several levels of sand are visible within the marbles; these sands have the same characteristics as those in the second formation.

This formation is generally attributed to the Permian-Triassic (Nijhuis, 1964).

Metabasites and gneisses

In the second formation, and even in the third and fourth formations, amphibolites are present at certain locations (see Figs. 2 and 4). Their configuration, when visible, consists of interlayered rocks with a local thickness of more than 10 m.

Although gneisses are regionally more abundant, in the study area they were only found to the east near Charches, where they are located between the marbles. The gneisses are generally characterized by phenocrysts of feldspar with little prismatic crystals of tourmaline.

Thickness of the second, third, and fourth formations

Figure 2 shows the approximate thickness of the second, third, and fourth formations, which comes to roughly 1km. However, in reality, this thickness varies since the distribution of lithologies changes from one location to another. This is particularly evident in the “compact” appearance of the marbles to the north of Benajara (Fig. 4) whereas in the area of Los Olmos, they are divided in many different layers. The third formation is very well developed to the south of Rambla del Agua, though in the area of Benajara, the second and third formations are thinner. On the whole, and with local variations, the thickness tends to progressively increase eastwards.

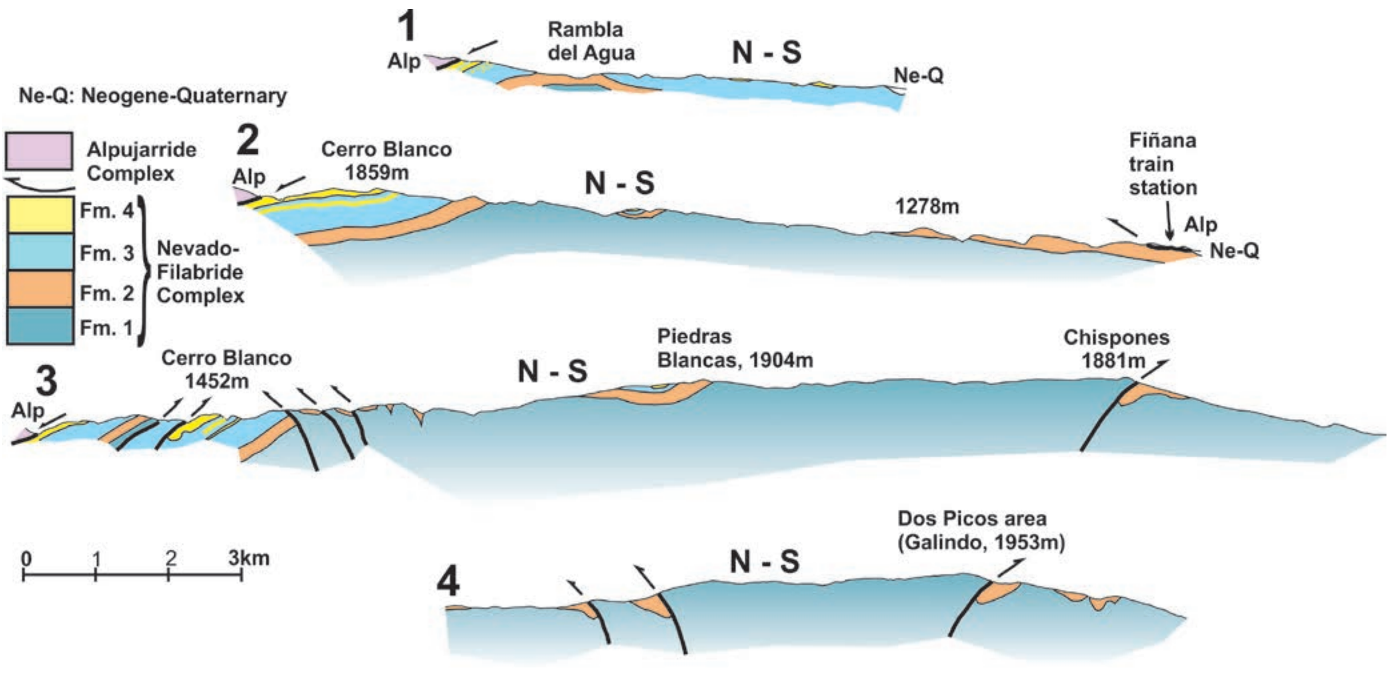

Figure 6. Cross-sections showing the general structure of the western part of the Nevado-Filábride. See Figure 4 for their position.
Figura 6. *Cortes geológicos que muestran la estructura general de la parte occidental del Nevado-Filábride. Véase la Fig. 4 para su situación.*

The limits of the formations

According to Gómez-Pugnaire *et al*. (1981), conglomerates are found at the point of contact between the first and second formations, which clearly indicates a disconformity. Although we have not directly observed this disconformity, we believe it exists. Most of the other points of contact between the formations are not sharp, but rather transitional. For instance, in many places, the marbles do not suddenly appear but instead gradually become visible in the fine interlayered levels between the schists.

Structure

The general structure of the western part of Sierra de los Filabres is an E-W anticline (Fig. 4), which is accompanied by folds of lesser importance (although of kilometric size) and by faults, particularly to the east. This structure, which is shown in the cross-sections of Figure 6, can also be deduced from Figure 4. The cartography in Figure 4 initially appears to have some complex local areas but this is because of the intersection of the structure with the topography.

Cross sections 1 and 2 show the structure of the western end of Sierra de Los Filabres. On the whole, it is an anticline, which is slightly vergent to the north. The Alpujárride Complex is located at its extremes, thrusting the Nevado-Filábride Complex. The thrust obliquely cuts the Nevado-Filábride. As can be seen in cross section 2, the general anticlinal structure is affected by a smooth syncline.

Cross sections 3 and 4 depict the structure of the eastern part of the study area (Fig. 6). Although the general anticline shape (accompanied by smaller folds) continues in this area, there are also numerous high-angle reverse faults, something rather uncommon in the Nevado-Filábride Complex. Figure 4 shows the distribution of these faults, though in all likelihood there are actually more faults than those represented. These faults are visible because of the clear lithological contrast. More specifically, the dark schists of the lower formation that thrust Formation 2 are superposed on the clear sands and quartzites (see Figs. 3 and 4). Generally, the surface of the faults can be clearly distinguished.

The vergence of the reverse faults is centrifugal in relation to the central part of the sierra. It is southwards in the south and northwards in the north (Fig. 4) except for the northern part of cross section 3, where southward vergence reappears.

Discussion

Establishing the lithological succession is not difficult because the quality of the outcrops is generally good and is combined with an irregular topography, which permits a clear view of the order of superposition of rocks.

Probably the most intriguing rocks of the Nevado-Filábride Complex are the sands, sandstones, and lutites, clearly interlayered with other rocks of the second lithological formation, and also in certain places, with rocks of the third and fourth formations. They highlight a very interesting problem, which has still not been addressed. Apart from Fallot *et al*. (1960), who cited the presence of these rocks, all subsequent articles have ignored them, despite the abundance of their outcrops, with the exception of Jabaloy (1993). This author mentioned their existence and situated them in his Río Bodurria unit. According to him, this unit is thrust by the Sierra de los Filabres unit, and its metamorphic degree is lower than that of the second unit. He placed the Bodurria unit in four tectonic windows, in which sands crop out together with other rocks. However, the proposed limits of these windows do not affect the layers of the formations. Furthermore, we do not know why many outcrops of this same type of rock have not been marked in other places where they are clearly exposed.

Generally speaking, the separation between the first and second formation in the study area is not mentioned in the previous literature with the partial exception of Gómez-Pugnaire (1979), whose schematic map includes part of this contact. This omission is striking since this contact can be followed without difficulty, even in places where it is locally inverted (see Fig. 5, D). Notwithstanding, Gómez-Pugnaire and Franz (1993) separated the dark schists of the basement of the Mulhacen nappe from those of the Veleta map, probably in an effort to conciliate their data with the model proposed in Puga (1971). However, this differentiation is not consistent with the cartography of the site.

In previous articles, the differentiation of the marbles is generally accurate though the supposed separation of the marbles in the Calar Alto and Bédar Macael units (e.g. Martínez Martínez *et al*., 2002) is somewhat forced because it follows a model of nappes established in other areas, which can also be discussed (see Sanz de Galdeano *et al*., 2016).

The existence of the large E-W anticline is generally accepted. The only novelty is the presence of high-angle reverse faults. These faults clearly reflect the lack of space generated by the formation of the big

E-W anticline, which permitted a larger clenching of the structure.

Directly to the south of the study area, a large fault can be deduced in the sector of the passage between Sierra Nevada and Sierra de los Filabres (Fig. 1B). In this position, rocks in the second formation are in contact with lower levels of the dark schists in the first formation (Fig. 5, D), which is very well developed in Sierra Nevada. Since there no space for a fold, the existence of a fault should be considered. Even though we do not know the nature of this fault, when the altitudes of the second formation around Ocaña are compared with those in the high areas of Sierra Nevada, the throw is at least on the order of 1800 m.

In our opinion, the limits of the various tectonic units proposed in the literature are artificial and do not correspond to reality because they cross through continuous lithological formations. In some cases, the relative tectonic position of these units even seems to be totally erroneous. This is the case of the position of the Rio Bodurria unit (Jabaloy, 1993) and the large tectonic window proposed by Navarro Vázquez and Velendo Muñoz (1979) several kilometres to the north of Escúllar, which was situated in a low tectonic position. Nevertheless, the rocks are really in a higher position and belong to the second and third formations. Although the existence of new tectonic units is always an open possibility, such divisions and their cartographic limits should be firmly based on knowledge of the lithological formations in the area. Only then is it possible to determine whether contacts are tectonic or not.

Several previously cited articles highlight the existence of the Dos Picos shear zone. Dos Picos is a mountain (see eastern border of Fig. 4) where a high-angle reverse fault is clearly visible and where the lower formation thrusts the second one. At this location and further west, without rejecting the existence of local shear zone bands, the structure can be followed as shown in Figure 4. To the east of the study area, the proposed Dos Picos shear zone crosses through not displaced striking E-W layers of schists and quartzites, where, in our opinion, it cannot be really traced.

Based on the previous discussion, it is our belief that the Nevado-Filábride Complex in the study area is only composed of a single tectonic unit with four formations, which, according to the generally accepted age attributions, span from the Paleozoic to the Triassic.

According to the general interpretation, which our proposal coincides with, this complex was subducted, and metamorphosed in various stages. Afterwards, the large anticline, other smaller folds and the reverse faults were formed. Later, the complex was progressively exhumed, and subsequently underwent a process of extension.

From a stratigraphical and paleogeographical perspective, the beginning of the sedimentation in the second formation seems to initiate a new cycle of sedimentation accompanied by a subsidence that progressively produced a marine transgression. This subsidence was caused by an extension facilitated by fractures whose existence led to the extrusion of the previously mentioned igneous rocks. According to many authors (e.g. Gómez-Pugnaire *et al.*, 2012), this cycle began during the lower Permian and continued throughout the Triassic.

Finally, it is our opinion that studies should be performed to discover the reason why sands, sandstones, and lutites are found at the site, when initially their presence there is not compatible either with the interlayered schists and mica schists or with the progressively higher metamorphic degree of the upper units. In all likelihood, further work on this topic will provide valuable information, not only about the metamorphism itself, but also about the different positions occupied by the rocks of the Nevado-Filábride Complex during the deformation, particularly during the subduction process. Similar types of rocks in the second formation (i.e. the Benitagla formation in Sanz de Galdeano *et al.*, 2016) not only appear in western Sierra de los Filabres, but also in certain places in the north and west areas of Sierra Nevada. They can also be found to the east at locations such as Monteagudo, north of Uleila del Campo, 12 km west of Lubrín (see Fig. 4) though only in the form of sandstones and quartzites with well-conserved cross-bedding stratification.

Conclusions

As reflected in the cartography, four lithological formations can be differentiated in the study area. The lowest formation consists of dark schists and quartzites. The second formation is composed of quartzites, sandstones, sands, lutites, schists, and mica schists. The third formation mainly consists of schists, and the fourth formation is composed of marbles, schists, and mica schists.

According to the cartography, the contacts between these formations seem to be mainly stratigraphical. Consequently, the division of the area in various tectonic units is not supported by the field data obtained at the site. In fact, practically all of the limits of the previous proposed units pass through the lithological formations, without displacing them. Moreover, rocks in certain units, which are regarded as being in a lower position, actually belong to higher formations.

High-angle reverse faults are well expressed in the field. In fact, these faults contributed to alleviate the lack of space caused by the formation of the great E-W anticline of Sierra de los Filabres.

The sedimentation of the second formation marks the beginning of a subsidence process culminated by the deposits of carbonates, which are now marbles. This subsidence was facilitated by fractures that permitted the extrusion of igneous rocks.

An important metamorphic problem, which has still not been addressed, is presence of sands and lutites interlayered between rocks, such as schists and mica schists with garnets. Their presence is not consistent with the progressively higher metamorphic degree of the upper part of the Nevado-Filábride Complex. This also indicates the need for an explanation of the coexistence of interlayered rocks of apparently different metamorphic degrees.

As a corollary, we think that in tectonic and petrologic studies, particularly in metamorphic areas, it is necessary to have previously a detailed cartography and a good knowledge of the lithological successions. This is something well known, but if it is forgotten, part of the results obtained will probably be erroneous.

Acknowledgements

This study is one contribution of the groups of research RNM- 370 and RNM 376 of the Junta de Andalucía. We are grateful to J.J. Durán (IGME), M. Martín-Martín (Univ. Alicante) and I. Argyriadis (La Cadière d'Azur) whose corrections and suggestions improved the article.

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Recibido: octubre 2016
Revisado: noviembre 2016
Aceptado: diciembre 2016
Publicado: diciembre 2016