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Implication of the geology of the Guadaiza and Verde valleys (Malaga Province, Betic Cordillera) on the position of the Ronda peridotites and the structure of the Alpujárride Complex

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ABSTRACT

In the valleys of Guadiaza and Verde (the latter in its area of Hoyo del Bote), the tectonic window of the Guadaiza unit has been previously defined based on the interpretation that a formation existing there was a dynamothermal aureole formed under thrusting Ronda peridotites, this being interpreted as having occurred during the early Miocene. Nevertheless, the analysis of the geometrical relationship between this formation and the peridotites indicates that the cited formation is not situated under the peridotites, but above them and, moreover, the rocks of this supposed aureole present a lithological transition to others of Permian age, which are also situated over the peridotites. As a result, the supposed tectonic window does not exist and the number of tectonic units existing in the western part of the Alpujarride Complex diminishes. It is also clear that the peridotites of this region reached the surface during the Paleozoic.

Keywords: Alpujarride Complex, Betic Internal Zone, Ronda peridotites.

Implicación de la geología de los valles Guadaiza y Verde (provincia de Málaga, Cordillera Bética) en la posición de las peridotitas y en la estructura complejo Alpujárride

RESUMEN

En los valles del Guadiaza y Verde (este último en su área of Hoyo del Bote) se ha definido previamente la ventana tectónica de la unidad del Guadaiza, basada en la interpretación de que una formación allí existente corresponde a una aureola dinamotérmica formada bajo peridotitas de Ronda cabalgantes, hecho que consideran ocurrió durante el Mioceno inferior. Sin embargo, el análisis de la relación geométrica existente entre esta formación y las peridotitas indica que no está situada bajo ellas, sino encima. Además, las rocas de esta supuesta aureola presentan una transición litológica a otra formación de edad pérmica, también situada sobre las peridotitas. En consecuencia, la supuesta ventana tectónica no existe y el número de unidades tectónicas que existen en la parte occidental del Complejo Alpujárride disminuye. A la vez se muestra que las peridotitas de la región alcanzaron la superficie durante el Paleozoico.

Palabras clave: Complejo Alpujárride, Peridotitas de Ronda, Zona Interna Bética.

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

La existencia o no de la ventana tectónica del Guadaiza determina en gran medida la interpretación de las relaciones existentes entre la peridotitas de Ronda y el complejo Alpujárride. Un punto clave es si dichas peridotitas cabalgan o no a unas rocas que han sido denominadas gneises granitoides o bien migmatitas/diate-

xitas). Dicha posible ventana abarca buena parte del valle del río Guadaiza y el sector del Hoyo del Bote que hidrogeológicamente corresponde al valle del río Verde, si bien está desde el punto de vista geológico en total continuidad con las estructuras presentes en el valle del Guadaiza.

Antecedentes

Muchos autores (Lundeen, 1978, Lundeen et al., 1979; Dickey et al., 1979; Balanyá y García-Dueñas, 1991; Tubía, 1988; Sánchez Gómez et al., 1995 a y b, 2002; Esteban et al., 2008, 2010; Garrido et al., 2011; Tubía et al.,2013; Précigout et al., 2013; Platt et al., 2013) piensan que las peridotitas en los valles del Guadaiza y Verde, y en general en la parte occidental de la Zona Interna Bética (Figs. 1 y 2) cabalgaron durante la orogenia Alpina sobre diversas unidades alpujárrides, tales como la de Guadaiza, Ojén y Blanca. Otros autores (Loomis, 1972 a y b; Chamón Cobos et al., 1978; Piles Mateos et al., 1978 a, Torres-Roldán, 1983; y b; Sanz de Galdeano y Ruiz Cruz, 2016a; Sanz de Galdeano y López-Garrido, 2016b) indican que las peridotitas están situadas bajo las secuencias alpujárrides. Para los tres últimos autores el emplazamiento de las peridotitas se produjo antes del Mesozoico.

El presente artículo tiene como objetivo el análisis geométrico de la posición de las peridotitas de Ronda en relación a las secuencias alpujárrides, que es clave para dilucidar su significado y la evolución tectónica regional. Es decir, si las peridotitas se encuentran cabalgando a los materiales alpujárrides en la llamada "ventana tectónica del Guadaiza", la unidad de este nombre existe y ocupa una posición inferior y la interpretación de que en su cabalgamiento las peridotitas formaron una aureola dinamotérmica sería correcta. Pero si por el contrario las peridotitas se encuentran bajo dichos materiales alpujárrides, dicha ventana no existe, la "aureola dinamotérmica" hay que reinterpretarla, la estructura del Complejo Alpujárride en la parte occidental de la cadena es mucho más simple, y, no menos importante, las peridotitas de Ronda se encontraban ya bajo el Alpujárride durante el Paleozoico superior.

Situación geológica

La Cordillera Bética está formada por las zonas Interna y Externa (Fig. 1). La Interna está formada por cuatro complejos tectónicos, entre ellos el Alpujárride, en el que se sitúa el área estudiada. Este complejo presenta metamorfismo alpino y sobre él se encuentra el complejo Maláguide, apenas afectado por dicho metamorfismo. Deformaciones variscas afectaron a ambos complejos.

La principal estructuración de la Zona Interna ocurrió durante el Terciario, siendo expulsada hacia el oeste durante el Mioceno inferior (Durand-Delga y Fontboté; 1980; Wildi, 1983; Sanz de Galdeano, 1990).

Unidades tectónicas previamente diferenciadas en la parte occidental del complejo Alpujárride.

Las peridotitas de Ronda se sitúan bajo la unidad alpujárride de Jubrique/Los Reales (Fig. 1); así, al O de Sierra Bermeja las peridotitas están cubiertas por rocas paleozoicas y triásicas. Eso no es discutido. El problema se refiere a los sectores situados al E de Sierra Bermeja. Allí se han distinguido las unidades de Guadaiza, Guaro, Blanco y Ojén (Tubía et al., 2013; Esteban et al., 2008 y 2010, etc., etc.), siendo la más importante la de Guadaiza por las consecuencias tectónicas y paleogeográficas que se derivan de ella.

Según los citados autores, la unidad de Guadaiza es una ventana tectónica que aflora bajo peridotitas cabalgantes, en cuya base se formó una aureola dinamotérmica, las migmatíticas/diatexitas, un proceso que datan de unos ~22 Ma. Esas mismas rocas fueron llamadas gneises granitoides por Chamón Cobos et al. (1978) y Piles Mateos et al. (1978 a y b) quienes las consideran situadas sobre las peridotitas. Para Sanz de Galdeano y Ruiz Cruz (2016a) esas rocas tienen una edad aproximada de ~270 Ma.

Tipos de rocas presentes en los valles de los ríos Guadaiza y Verde

En el área de Jubrique (Fig. 2 y Fig. 3, columna A), al oeste del sector ahora estudiado, sobre las peridotitas hay una aureola (término 2 de la Fig. 3) de granulitas, kizingitas, que pasan a gneises con granates y a esquistos. Estas rocas no se han observado directamente sobre las peridotitas en los valles de Guadaiza y Verde, salvo en una zona de falla (dentro de la falla del Albornoque, Fig. 4) y en sectores más orientales, pero restos de las mismas también se encuentran englobados en los gneises granitoides que más abajo se citan.

Esquistos, generalmente oscuros, y cuarcitas son abundantes en ambos valles. Su espesor es superior a

250-300 m, aunque localmente pueden haber desaparecido o conservarse muy poco. Regionalmente se atribuyen al Paleozoico.

Los gneises granitoides/diatexitas, que contienen restos de los esquistos y de los gneises con granates (Fig. 3, columnas B y C, término 4, y Fig. 4) tienen espesores muy variables, hasta posiblemente superiores a 150 m. Hacia el oeste estos materiales desaparecen y ya no están presentes en el área de Jubrique (Fig. 3, columna A).

En el río Verde (sin incluir el sector del Hoyo del Bote) existen gneises blancos (Fig. 4, término 5 y columna C) considerados como migmatitas (migmatitas de Istán) datadas del Carbonífero terminal o del Pérmico inferior (Acosta-Vigil et al., 2014). Estas rocas pueden alcanzar un espesor superior a 200 m.

Las relaciones existentes entre los gneises granitoides y los gneises blancos se observan al N de Istán, donde niveles de las primeras rocas se intercalan entre las segundas y otras tienen un aspecto intermedio (Fig. 3, columnas B y C y Fig. 5).

Existen también esquistos y cuarcitas claros y mármoles, todos ellos atribuidos al Triásico (Fig. 3, columnas A, B y C).

Estructura de los valles del Guadaiza y Verde

En el sector del Guadaiza y del Hoyo del Bote

La estructura de su parte N se observa en el corte A (Fig. 6) cuya posición se indica en las Figs. 4 y 8. Se observa en dicho corte que los gneises granitoides se encuentran sobre las peridotitas, incluso en el área deprimida del Hoyo de Bote, rodeada de peridotitas. Ahí, la estructura corresponde a un sinclinal ~N-S situado entre dos anticlinales. En el núcleo de ese sinclinal hay un asomo de peridotitas claramente situado bajo los gneises (Fig. 7A).

En el resto de los cortes de la Fig. 6 la relación con las peridotitas es aún más clara, mostrando siempre que las peridotitas están bajo los gneises granitoides o bien bajo los esquistos oscuros. La Fig. 8 muestra la posición de los cortes en relación con la cartografía del sector.

El sector del río Verde

La estructura de este sector (Fig. 4), sin considerar en el mismo la zona del Hoyo del Bote, está dominada por la falla del Albornoque (Tubía, 1988), y por el cabalgamiento por el sur del complejo Maláguide. La falla del Albornoque forma diversas bandas fácilmente reconocibles sobre el terreno. Una de ellas separa los materiales del valle de los mármoles de Sierra Blanca.

Discusión

La estructura descrita indica que tanto los esquistos oscuros como los gneises granitoides y los blancos se sitúan sobre las peridotitas. Y esos dos tipos de gneises están directamente relacionados, los primeros situados preferente en la base de los segundos. Estos hechos tienen importantes consecuencias:

- *Los gneises granitoides no se formaron por el cabalgamiento de las peridotitas, pues dicho cabalgamiento, con una edad alpina atribuida, no existe. Una consecuencia importante de esto es que la ventana tectónica del Guadaiza no existe, no existe esta unidad.*
- *Las dataciones de los gneises granitoides (Sanz de Galdeano y Ruiz Cruz, 2016a), junto con las de los gneises blancos (Acosta-Vigil et al., 2014), y las relaciones observadas entre ambos tipos de rocas, indican que todos ellos se formaron en el Pérmico inferior. Probablemente la edad de ~22 Ma corresponda a un posterior evento alpino, si bien las rocas ya existían previamente.*
- *Estos gneises de edad pérmica (que engloban restos de rocas tales como gneises con granate similares a los de la aureola del término 2 de la Fig. 3) y su posición sobre las peridotitas, llevan a deducir que estas últimas alcanzaron la superficie ya durante el Paleozoico superior.*
- *La falla del Albornoque produce un importante corte en la continuidad de la región. Por ello, las sierras Blanca y Alpujata se encuentran separadas de la zona que tienen al oeste. Sin tener en cuenta esta discontinuidad, en todo este sector hay solo una unidad en el Alpujárride, la de Jubrique/Los Reales, tal como se señala en la Fig. 9.*

Sin embargo, sobre la unidad de Jubrique sí hay otras unidades (las unidades intermedias de Didon et al. 1973 y Sanz de Galdeano et al., 2001, o imbricaciones de Benadalid de Balanyá, 1991), además del complejo Maláguide.

La mayoría de los pliegues del sector occidental de la Zona interna tienen una dirección aproximada N-S, un hecho posiblemente relacionado con la deriva hacia el oeste que experimentó durante el Oligoceno-Mioceno inferior y medio (Sanz de Galdeano, 1990).

Conclusiones

Los gneises granitoides y los gneises blancos de los valles del Guadaiza/Hoyo del Bote y Verde se sitúan sobre las peridotitas. Ambos tipos de gneises están relacionados, de manera que, en su conjunto, los blancos se sitúan sobre los granitoides. Su edad es Pérmico inferior.

Los gneises granitoides no son la aureola dinamotérmica situada bajo las peridotitas, pues estas no los cabalgan. Por tanto, la ventana tectónica de la unidad de Guadaiza no existe, ni la propia unidad. Todo forma parte de la unidad de Jubrique/Los Reales, aunque la falla del Albornoque corta su continuidad.

De acuerdo con la posición que tienen las peridotitas de Ronda, bajo los esquistos oscuros y bajo los gneises (considerando también los restos que engloban) estas alcanzaron la superficie durante el Paleozoico superior.

Introduction

The structure and differentiation in tectonic units of the Alpujarride Complex in the western part of the Betic Internal Zone depend mainly on the interpretation of the relationship that exists between the Ronda peridotites and the Alpujarride lithologic successions in the Guadaiza and Verde valleys. The crucial point of the discussion is the geometric position that the peridotites hold with respect to the Alpujarride lithological sequences, specifically with two types of rocks, i.e. white gneisses (orthogneisses) and a formation called granitoid gneisses or migmatites and diatexites. To ascertain the real geometry of these contact areas is essential to assess the previous attributions and differentiations amongst the tectonic units.

The age of the crustal emplacement and exhumation of the Ronda peridotites is also involved, depending mainly on their geometric position. If the peridotites really thrust the gneisses and granitoids, the latter forming as a dynamothermal aureole, then their emplacement is younger than the gneisses and contemporaneous with the granitoids. On the contrary the peridotites would be older. Currently, the time of this emplacement is under debate, present opinions varying from Paleozoic to Alpine ages.

Background

Probably the most commonly accepted tectonic position for the Ronda peridotites in the area of the Guadaiza and Verde valleys, N of San Pedro de Alcántara and Marbella, and in general in the western zone of the Betics (Figs. 1 and 2) is that they thrust during the Alpine orogeny over different Alpujarride tectonic units (Lundeen, 1978; Dickey *et al.,* 1979; Balanyá and García-Dueñas, 1991; Tubía, 1988; Sánchez Gómez *et al.,* 1995 a and b, 2002; Esteban *et al.,* 2008 and 2010; Garrido *et al.,* 2011; Tubía *et al.,* 2013; Précigout *et al.,* 2013...).

But previously Loomis (1972a and b, 1975) describing the diapiric emplacement of the Ronda peridotites indicated that "the massif is covered with hornfels series roof rocks (unit 7) in the east up to the Sierra Blanca area". This author clearly differentiated between the rocks in contact with the peridotites in the Jubrique area (western border of Sierra Bermeja), the gneiss series, and the hornfels series from Blanca. Chamón Cobos *et al.* (1978) and Piles Mateos *et al.* (1978a and b) also interpreted that the peridotites were situated under the Alpujarride rocks of this area. Later, Torres-Roldán (1983) who used the name Blanca unit for many sectors situated between the N of Estepona and the Sierra Blanca itself, comprising the Guadaiza sector, also indicated that the peridotites were under this unit (see for instance the cross-section of his Fig. 2). Likewise, Sanz de Galdeano and Ruiz-Cruz (2016a), studying the area between Estepona and Benahavis (directly to the W of the Guadaiza Valley), contend that the Ronda peridotites are situated under the Alpujarride lithological sequence. These latter authors affirm the same for the Guadaiza valley, although they did not provide a detailed map of this area, and therefore some of the statements in this study could be questioned. Sanz de Galdeano and López-Garrido (2016), working in the sector situated immediately to the E (in the area of Sierra Blanca and Sierra Alpujata), concluded that, although there are many reversed structures (and also there is an important thrust of the peridotites of Sierra Alpujata over the Sierra Blanca), on the whole the Sierra Blanca is situated over the peridotites, this being an interpretation contrary to that of Tubía *et al.* (1997).

On the other hand, regarding the peridotites of Beni Bousera (in the Rif Cordillera) (Fig. 1), most of the interpretations favour a Variscan scenario (Kornprobst, 1976; Michard *et al.,* 1997; Bouybaouène *et al.,* 1998; Montel *et al.,* 2000; Rossetti *et al.,* 2010) independently of the posterior Alpine deformations. Finally, in the Ceuta area (on the southern side of the Strait of Gibraltar) and in the Jubrique area (in the

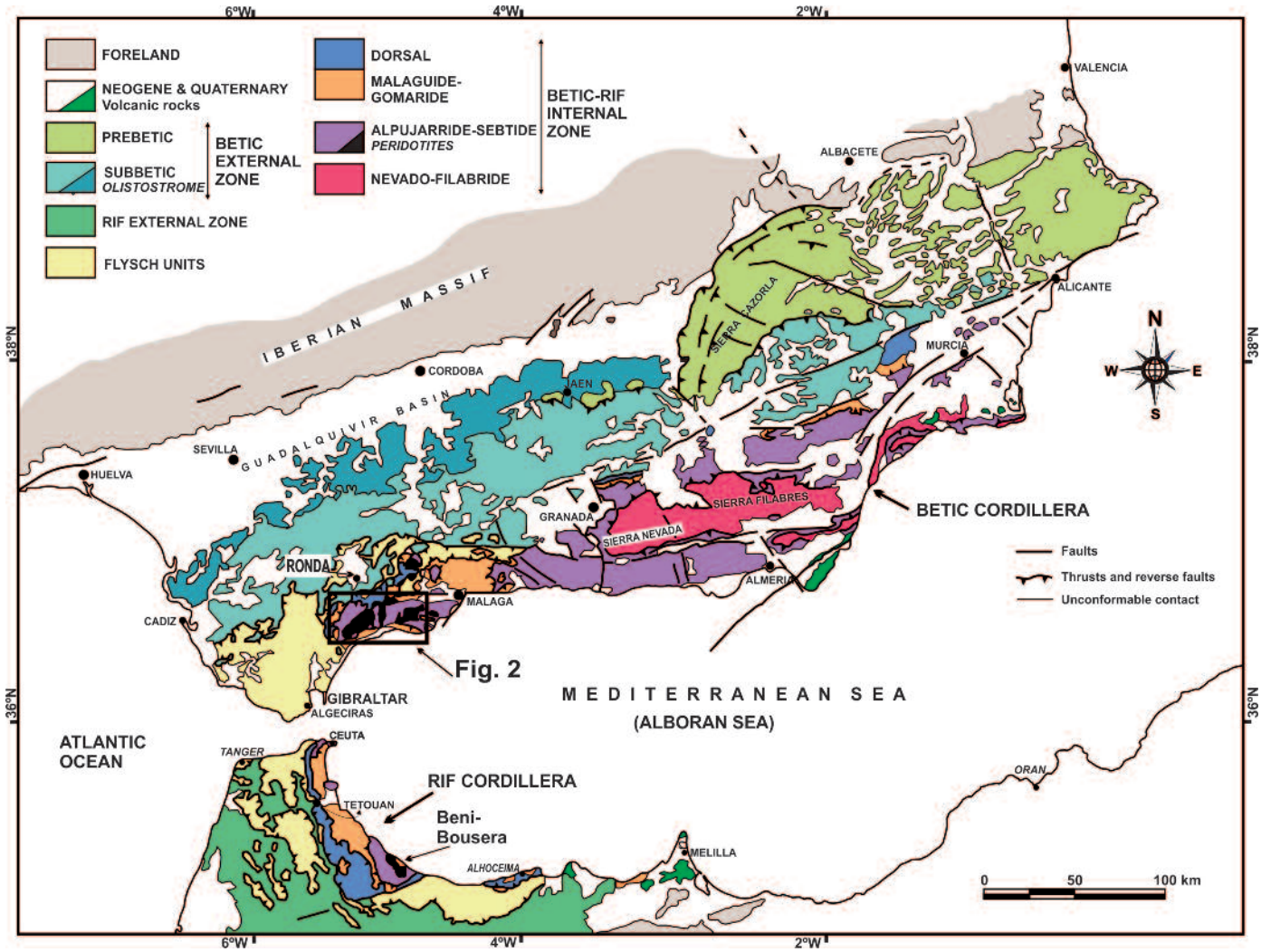

Figure 1. General geologic map of the Betic and Rif (in part) cordilleras. The area corresponding to Figure 2 is indicated by the rectangle.
Figura 1. *Mapa geológico general de la Cordillera Bética y de parte del Rif. El área que corresponde a la Fig. 2 se indica en el rectángulo.*

western part of the Alpujarride, Fig. 2), Sanz de Galdeano and Ruiz Cruz (2016b) and Ruiz Cruz and Sanz de Galdeano (2014) argued in favour of a pre-Mesozoic emplacement of the Ronda peridotites according to their respective petrological and zircon data as well as the structure of the areas concerned.

The geometric analysis of the position of the Ronda peridotites in relation to the Alpujarride lithological sequences is the key to resolving these questions: the existence or not of the Guadaiza tectonic window, the very existence of this unit, and, together with data concerning the age of the rocks, that of the emplacement of the peridotites. For this reason in this study, these geometric relationships are described at the very core of the discussion.

Geological setting

The Betic Cordillera is formed by the External and Internal Zones (Fig. 1). The External Zone occupies the northern part of the cordillera, constituting the S and SE sedimentary cover of the Paleozoic Iberian Massif.

The Internal Zone, common in the Betics and the Rif, is formed by four superposed tectonic complexes that from bottom to top are the Nevado-Filabride (outcropping only in the Betics), the Alpujarride, which is called Sebtide in the Rif; the Malaguide (Ghomaride in the Rif); and the Dorsal. The two lower complexes, Nevado-Filabride and Alpujarride, are affected by Alpine metamorphism, whilst the Malaguide and the Dorsal are generally not affected,

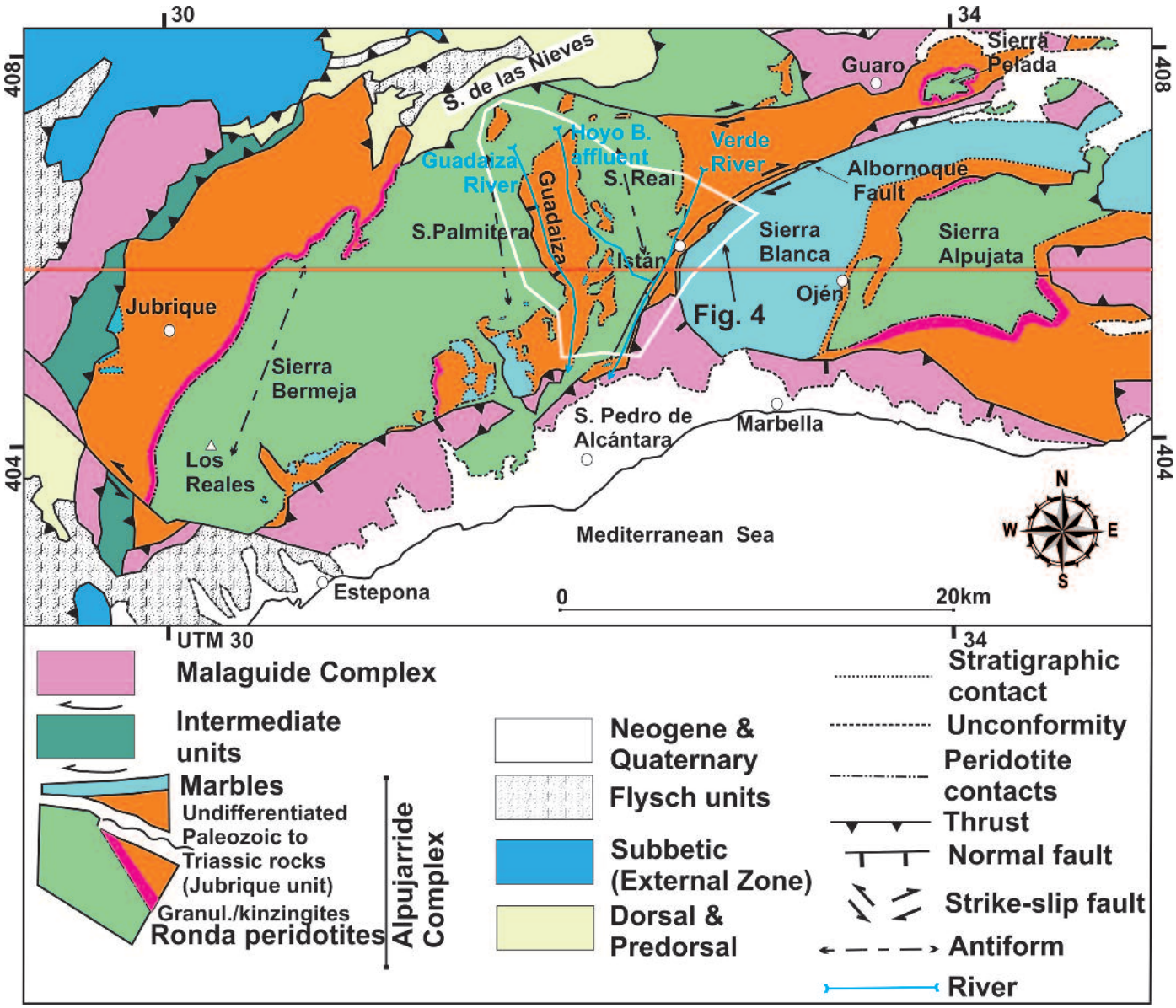

Figure 2. Schematic geologic map of the western part of the Betic Internal Zone. The polygon marked by white lines indicates the position of Figure 4 and the E-W red line crossing the figure corresponds to the cross-section of Figure 9. Modified from Sanz de Galdeano and Ruiz Cruz (2016a).

Figura 2. *Mapa geológico esquemático de la parte occidental de la Zona Bética Interna. El polígono marcado con líneas blancas indica la posición de la Fig. 4 y la línea roja E-O que cruza la figura corresponde al corte geológico de la Fig. 9. Modificado de Sanz de Galdeano y Ruiz Cruz (2016a).*

with local exceptions. Variscan deformations affected the Nevado-Filabride, the Alpujarride, and the Malaguide complexes.

The main structuring of the Internal Zone occurred during the Alpine orogeny, in a process that was accompanied - from the early Miocene - by its westwards drift (Durand-Delga and Fontboté; 1980; Wildi, 1983; Sanz de Galdeano, 1990).

Tectonic units previously differentiated in the Alpujarride Complex in the western part of the Betic Internal Zone

It is generally accepted that the Ronda peridotites are situated at the bottom of the Alpujarride unit called Jubrique or Los Reales (this later name includes the peridotites) (Fig. 1). The nucleus of Sierra Bermeja

(whose highest peak is Los Reales) is formed by peridotites covered by Paleozoic and Triassic rocks immediately to the W. The problems begin with the interpretations of the positions of the peridotites in relation with the Alpujarride lithological sequences in the sectors situated immediately to the E.

There, eastwards of Sierra Bermeja, four tectonic units have been distinguished (depending on the authors) within the Alpujarride Complex: Guadaiza, Guaro, Blanca, and Ojén. The most important of them, due to the tectonic and palaeogeographic implications, is the Guadaiza unit (Tubía *et al.,* 2013; Esteban *et al.,* 2008 and 2010, etc.).

This Guadaiza unit (whose outcrops are situated in the Guadaiza valley and in the Hoyo del Bote river, an affluent of the Verde river, in its western part) is considered to be a tectonic window cropping out under the peridotites thrusting it. In this thrust, under the peridotites, a dynamothermal aureole formed (composed of migmatitic rocks, diatexites), corresponding to the partial fusion of the Alpujarride lithological sequences. The above-mentioned authors consider these migmatitic rocks as having formed approximately ~22 Ma ago, i.e. during the early Miocene, the point in time of the peridotite thrust, according to their interpretation. In this sense, Platt et al. (2013) wrote that "the peridotites rest on a sequence of high-grade schist, marble, and granitic gneiss, with a layer several tens to 100 m thick of migmatitic breccia along the contact", their "Subperidotite complex". But, as previously indicated, Chamón Cobos *et al.* (1978) and Piles Mateos *et al.* (1978a and b) consider these rocks to be situated over the peridotites and called them granitoid gneisses. That is, if this latter interpretation is correct, then the existence of the thrust would be invalidated.

Concerning the above-cited granitoid gneisses/diatexites, Sanz de Galdeano and Ruiz Cruz (2016a) proposed an age of ~270 Ma in a dyke situated in equivalent rocks situated to the N of Estepona. For these latter authors, part of these rocks correspond to a meta-magmatic formation and a metadetrital formation, which includes many remains of previous rocks, such as kinzigites, granulites and gneisses corresponding to the aureole formed over the peridotites during their emplacement, and the dark schists. This aureole is visible for instance in the area of Jubrique (Fig. 2 and Fig. 3, column A) as indicated below.

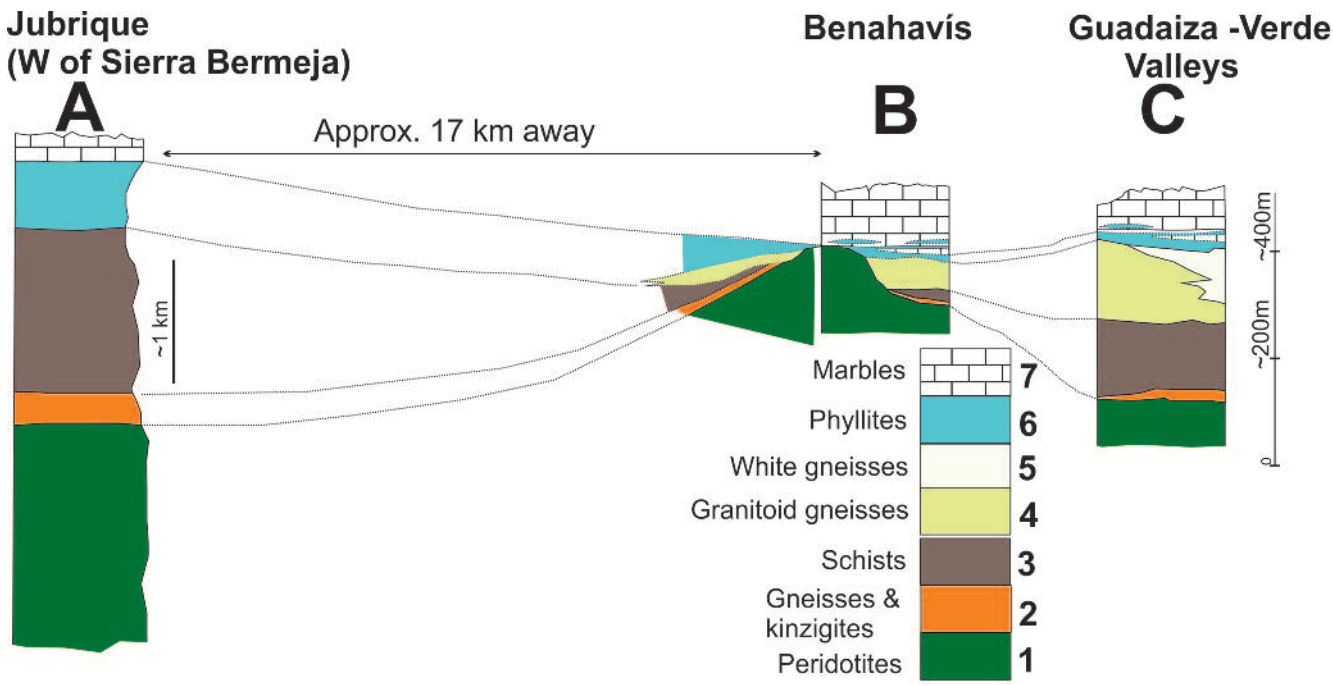

Figure 3. Synthetic and simplified lithologic columns of the Guadaiza-Verde Valleys, Benahavís and Jubrique indicating the lateral relations of the different formations. Note the very different geologic significance of the rocks of number 2 in relation to those of numbers 4 and 5. Also note that the scale of column A is different to that of columns B and C.

Figura 3. *Columnas litológicas sintéticas y simplificadas de Jubrique, Benahavís y de los valles de Guadaiza y Verde que indican las relaciones laterales de las diferentes formaciones. Obsérvese la muy diferente significación geológica de las rocas del número 2 en relación con las de los números 4 y 5. Obsérvese también que la escala de la columna A es diferente a la de las columnas B y C.*

Related to the Guadaiza unit, is that of Sierra Blanca unit, also interpreted as appearing in a tectonic window (Tubía *et al.,* 2013), an interpretation contradicted by Sanz de Galdeano and López Garrido (2016). The existence of the units previously cited depends on their tectonic relation with the Ronda peridotites, and, also, with the relationship between the marbles of Sierra Blanca and the schists of the area of Ojén (this village is situated in the SE part of Sierra Blanca; Fig. 2). This latter aspect, in our opinion, has been clarified in Sanz de Galdeano and López Garrido (2016), who indicated that the schists originally corresponded to the lower sequence situated under the marbles. For these reasons, we centre our attention on the Guadaiza and Verde valleys.

Types of rocks existing in the Guadaiza and Verde valleys

In these valleys the peridotites are the most abundant rocks. Generally they are serpentinized, at least partially (Pedrera *et al.,* 2016). More to the west, in the area of Jubrique, an aureole appears over the peridotites (Fig. 3, column A, number 2), made up of garnet-rich migmatitic granulites (kinzingites) extending to the top to gneisses with garnets and schists. This aureole also exists in Sierra Alpujata and in Sierra Pelada, this latter in the proximity of Guaro (NE of Fig. 2). Nevertheless, in the two valleys studied, these gneisses have not been seen *in situ*, with the exception of a fault zone (within the Albornoque Fault, "Tectonized rocks" in Fig. 4). The possibility of their presence cannot be totally ruled out in other points because the region is practically covered by woods that in many cases block any detailed view of the outcrops. They are visible as pebbles included in the granitoid gneisses to which we refer below.

Dark schists and quartzites crop out abundantly in the Guadaiza and Verde rivers. The thickness visible probably surpasses 300 m. The thickness visible probably surpasses 300m, although in many cases de conserved thickness is much smaller. Regionally they are attributed to the Palaeozoic (Olmo Sanz *et al.,* 1987).

Granitoid gneisses, containing many remains of schists and garnet gneisses abundantly crop out in the Guadaiza valley (Fig. 3, columns B and C, number 4, and Fig. 4). They were interpreted as diatexites by Esteban *et al.* (2008 and 2010) and Tubía *et al.* (2013), amongst others, corresponding to the aforementioned dynamothermal aureole situated under the peridotites, as indicated above. The thickness of these rocks is highly variable, and in many places does not in fact exist, whilst in other areas they can exceed 150 m.

In the Verde valley, some white gneisses (Fig. 3, column C, number 5) have been considered migmatites (the Istán migmatites) with an estimated age of ~280-290 Ma (Acosta-Vigil *et al.,* 2014). The thickness can be greater than 200 m.

It is important to indicate that the relationship between the granitoid gneisses and the white gneisses is especially visible along the road passing S of the Sierra Real (this name does not correspond to the peak Los Reales), some 300 m from the contact between the peridotites and the gneisses (point 36º, 35′, 56″ N - 4º, 56′, 44″W) (Fig. 4, approximately 2 km N of Istán.). In this sector it is possible to see layers of the granitoid gneisses interbedded in the white gneisses and vice versa. There are also layers with mixed appearances. A partial description of these aspects can be seen in the photos of Figure 5.

The contact between the dark schists and the granitoids is not visible at many points, although in general these latter rocks overlie the dark schists. However, this contact is not marked in Figure 4 with a distinct line. The reason is that the two types of rocks have almost the same colour and respond similarly to erosion, which, together with the woodlands, make it difficult to specify the exact position of the contact. In any case this was not the aim of this study, but rather to determine the position of these rocks in relation to the peridotites. In the Verde valley the white gneisses of Istán have an equivalent position to the granitoid gneisses, or with more precision, the white gneisses are over the granitoid gneisses, whose higher layers are present in this valley.

The Guadaiza-Hoyo del Bote area contains two more types of rocks: phyllites and quartzites with light tones and marbles. These are only small remains, not well conserved, and according their characteristics can be compared with Alpujarride Triassic rocks. These phyllites and quartzites have not been indicated in Figure 4, but they can be found near the remains of marbles visible in this figure, and they appear in the columns of Figure 3. The marbles of Sierra Blanca, and more to the W, of Benahavis, are equivalent.

The Malaguide Complex crops out to the SE, situated over the previously cited rocks. This complex is formed mainly by dark phyllites, shales, and grauwackes, although other types of rocks exist.

Structure of the Guadaiza and Verde Valleys

The description is divided into two parts. One corresponds to the Guadaiza and Hoyo del Bote sector (this latter area corresponding hydrologically to the Verde valley, although from position and geologic

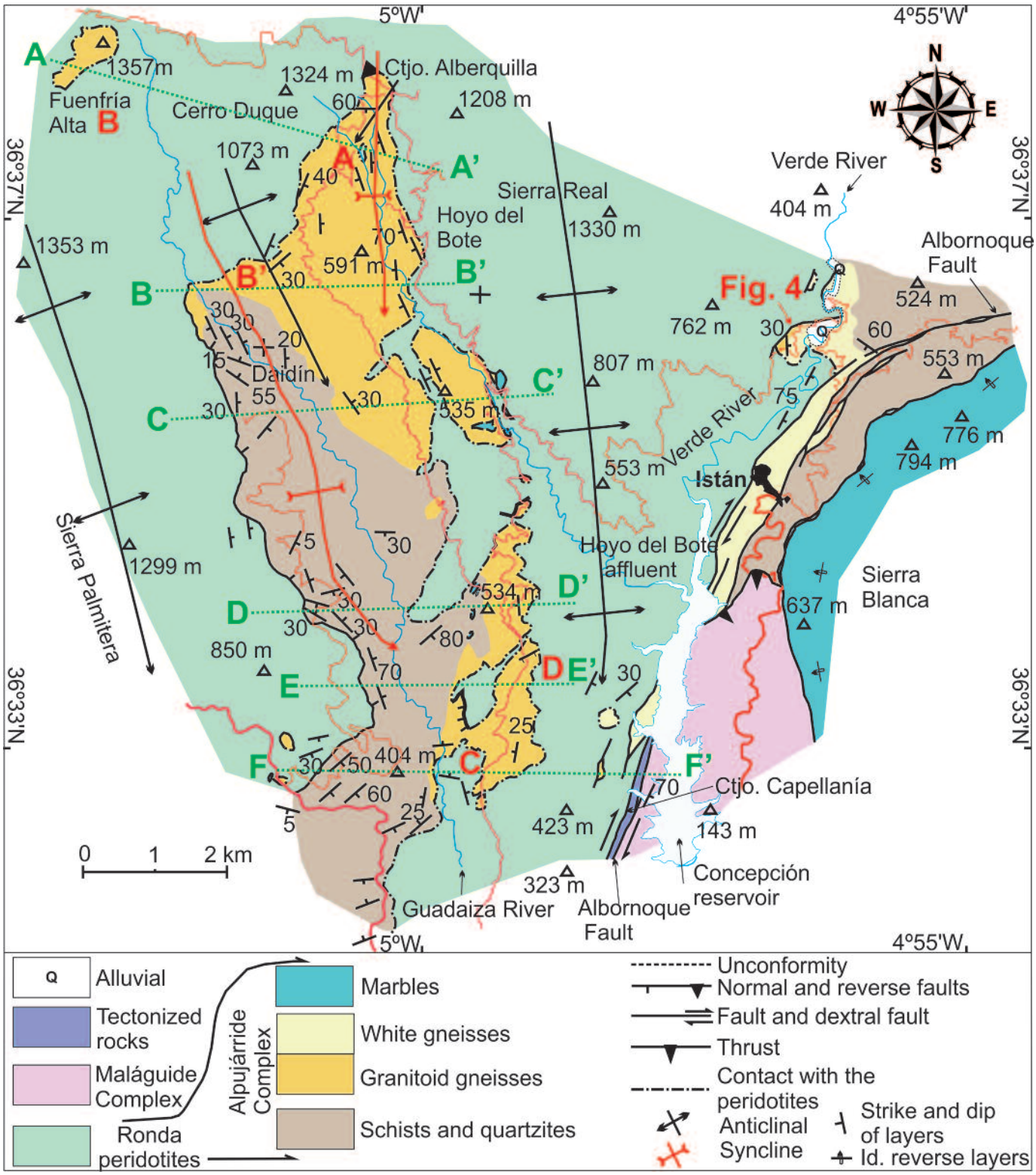

Figure 4. Geological map of the Guadaiza and Verde valleys (originally performed at 1:25000 scale). The position of the cross-sections of Figure 6 is indicated with green lines and letters. The area of the photos of Figure 5 is represented to the N of Istán in red colour. This same colour indicates the approximate position of the photos of Figure 7. Point B' in this figure indicates the position where photo B was taken.
Figura 4. *Mapa geológico de los valle del Guadaiza y Verde (realizado originalmente a escala 1:25.000). La posición de los cortes de la Fig. 6 se indica en líneas y letras verdes. El área de las fotos de la Fig. 5 se señala al N de Istán en color rojo y con el mismo color la posición aproximada de las fotos de la Fig. 7. El punto B' en esta figura indica la posición desde donde se tomó la foto B.*

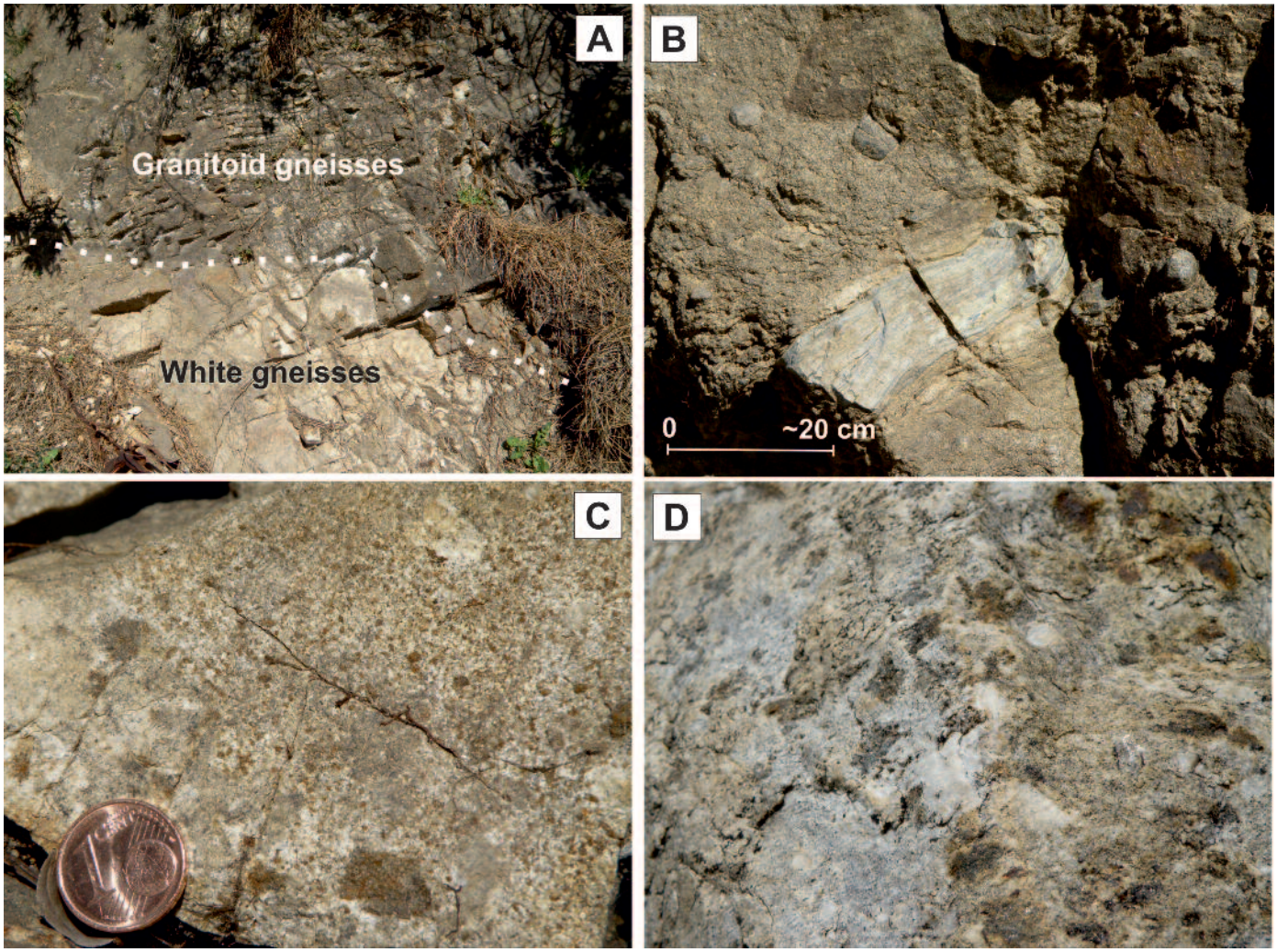

Figure 5. Several samples of the granitoid gneisses and the white gneisses. A: granitoid gneisses and white gneisses located in an area where the two types of rocks alternate. B: granitoid gneisses with rest of previous rocks (mainly schists but also garnet gneisses) situated near A. C: white gneisses containing many remains of previous rocks, with an intermediate aspect in relation to the granitoid gneisses. D: this image is similar to C, but the remains of previous rocks begin to be assimilated and their borders are partially blurred. The position of this figure is indicated in Figure 4, to the N of Istán.

Figura 5. *Varios aspectos de los gneises granitoides y los gneises blancos. A: gneises granitoides y gneises blancos situados en un área donde ambos tipos de rocas alternan. B. gneises granitoides con restos de rocas previas (sobre todo esquistos, aunque también hay gneises con granates) situados cerca de A. C: gneises blancos que contienen muchos restos de rocas previas, con un aspecto intermedio en relación a los gneises granitoides. D: esta imagen es similar a C, pero los restos de las rocas previas comienzan a ser asimilados y sus bordes están parcialmente borrados. La posición de esta figura se indica en la Fig. 4, al N de Istán.*

characteristics it has to be put together with the Guadaiza area). The other part is the Verde valley, from the Concepción reservoir to the N of Istán.

The Guadaiza - Hoyo del Bote sector

The structure of the northern area of this sector is indicated in the cross-section A of Figure 6 (see its position in Fig. 4). In the eastern part of this cross-section, the granitoid gneisses are situated in the bottom of a deep valley, dominated on the borders of the valley by the high relief of the Cerro del Duque and Sierra Real, where the peridotites crop out. This is probably the reason why the peridotites have been deemed to thrust over these gneisses. Moreover, at the northern end of the granitoid gneisses, on the road, the peridotites thrust these gneisses, although this structure disappears laterally, and the peridotites —particularly along the western border of Sierra

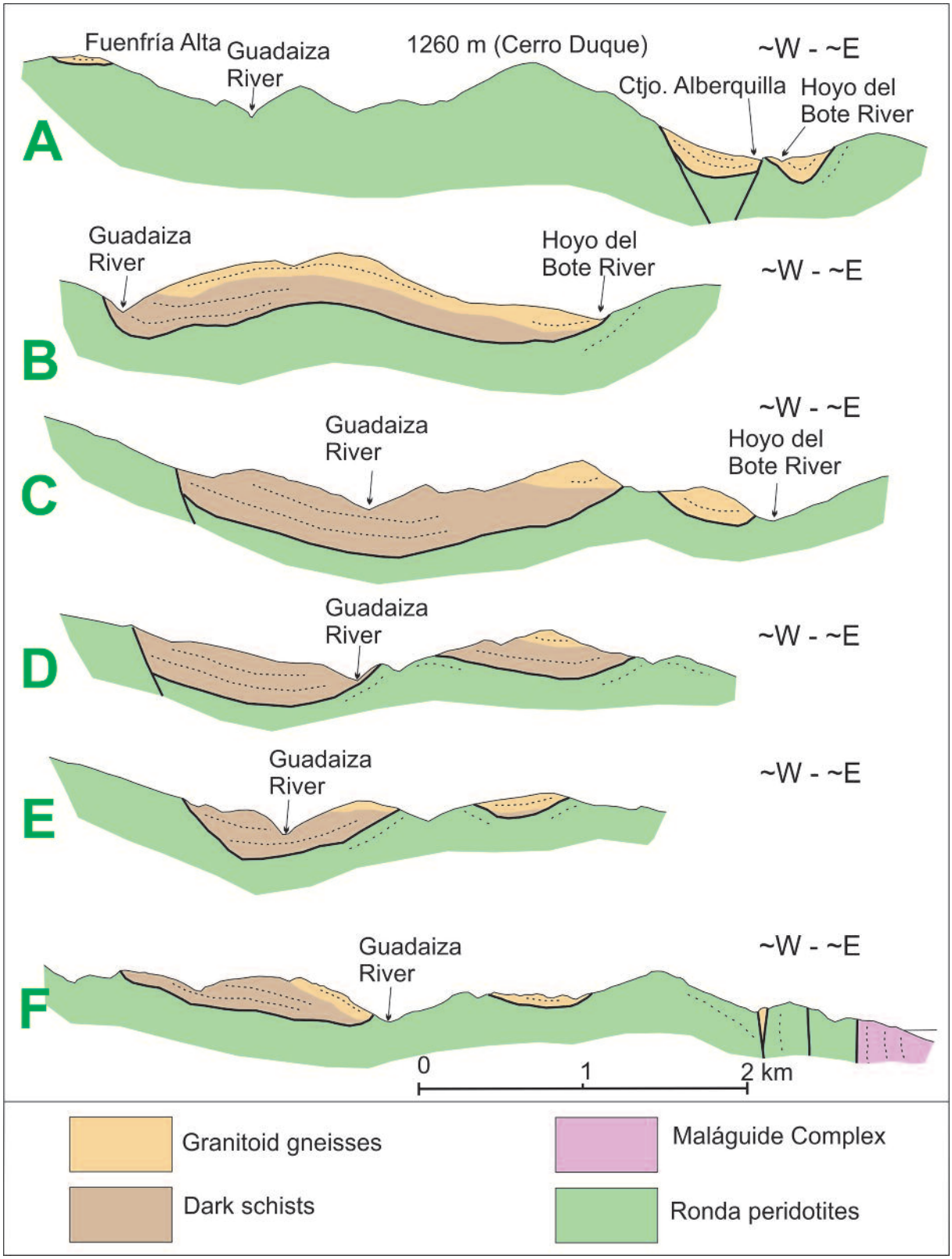

Figure 6. Geological cross-sections in the Guadaiza and Verde valleys. Their positions are indicated in Figure 4. The contact between the dark schists and the granitoid gneisses is only approximate.

Figura 6. *Cortes geológicos en los valles Guadaiza y Verde. Sus posiciones se indican en la Fig. 4. El contacto entre los esquistos oscuros y los gneises granitoides es solo aproximado.*

Real— lie under the granitoid gneisses on a surface that dips 65-75° westwards. On the whole, the structure corresponds to a ~N-S syncline, situated in middle of two anticlines (those of Cerro del Duque and Sierra Real) of similar direction.

This interpretation is reinforced by the presence of an outcrop of peridotites in the very bottom of the valley, near the Cortijo de Alberquilla (Figs. 4, 6A, 7A and 8), clearly covered by the granitoid gneisses (this outcrop is cited here probably for the first time, but it is critical as a clear reference of the tectonic position of the peridotites).

Moreover, at the west end of cross-section A (Fig. 6), in Fuenfría Alta Mountain, granitoid gneisses are very clearly situated over the peridotites (Figs. 4, 6A and 7 B). The same occurs with other outcrops not included in Figure 4, but that can be located on the map of Piles Mateo *et al.* (1978a).

Cross-section B (Fig. 6) shows an anticline in the granitoid gneisses and the dark schist. The existence of this anticline (the Cerro Duque anticline) is supported by the fact that the contact between the peridotites with granitoid gneisses and also with the dark schists in Cerro Duque Mountain clearly delineates it, with these gneisses overlying the peridotites. The hinge of this anticline is situated at point B' (Fig. 4).

Cross-sections C to F present the structure in the southern part of the Guadaiza River, an area where the relief is much more open and where the granitoid gneisses and the dark schists are clearly situated over the peridotites, as is visible at many points, e.g.in C and D of Figure 7 (the positions are indicated in Fig. 4).

The Verde valley (not including the Hoyo del Bote affluent)

This valley lies between the Sierra Real to the W and Sierra Blanca to the E. In it, particularly near Istán, the white gneisses and also the dark schists crop out. As indicated above, more or less 2 km north of Istán, granitoid gneisses appear at several points, marking the top of a transition to the white gneisses. These rocks overlie the peridotites.

From this area to the S, the structure corresponds to several lines of the dextral strike-slip fault of Albornoque (Tubía, 1988), as can be deduced from Figures 4 and 6 F. This is a major fault and within the bands in which it is divided, at many points the layers occupy a vertical position, as in the SW of the Concepción Reservoir. There the shales of the Malaguide Complex run vertically with many folds along a vertical axis, consistent with the dextral displacement. In the vicinity, within a tectonic band passing by the Ctjo. Capellanía (Fig. 4 and Fig. 6F), there are gneisses with garnets similar to those lying more to the W, on the western border of Sierra Bermeja or in Sierra Pelada, near Guaro. This is the only place where these elements have been identified *in situ* in the current study area. Together with these gneisses dark schists appear, all these rocks being strongly deformed.

These bands of the Albornoque Fault continue from Istán towards the NE. Some of the bands are clearly recognizable because of white gneisses contained within them, in contrast with the dark schists. The contact between the white gneisses and the dark schists with the marbles of Sierra Blanca is also one band of this fault. In between this contact line, there are elongated remains of peridotites/serpentinites. Moreover the marbles are reversed, like the greater part of the structure of this sierra.

Finally, it is necessary to indicate that in the study area the contact between the peridotites and the dark schists is generally covered by soil and woodland, but in the very scarce out crops visible (in two points) it is tectonized, indicating a certain detachment.

Discussion

According to the structure under study, the dark schists and the granitoid gneisses and the white gneisses are situated over the Ronda peridotites. Moreover, the granitoid gneisses and the white gneisses are not two independent types of rocks, in the sense that the former are situated in the bottom of the white gneisses, as is visible north of Istán. Both aspects have major consequences.

Firstly, granitoid gneisses were not formed by the thrust of the peridotites, because this thrust does not exist. Therefore, they do not correspond to the proposed dynamothermal aureole, forming migmatites-diatexites, situated in the bottom of the peridotites and dated to ~22 Ma ago (Esteban *et al.,* 2008 and 2010). Equivalent rocks were dated as ~270 Ma by Sanz de Galdeano and Ruiz Cruz (2016a) whereas the white gneisses were dated as 280-290 Ma by Acosta-Vigil *et al.* (2014). Probably the age of ~22 Ma corresponds to an Alpine tectonic rejuvenation of rocks where protoliths were previously formed during the Permian. Both types of rocks, granitoids and white gneisses, were formed over any kind of pre-existing rock, including the peridotites. Therefore, there is no doubt that the genesis of the granitoid/diatexite rocks should be reconsidered. They are comparable to the rocks of the Hacho de Ceuta, according to Sanz de

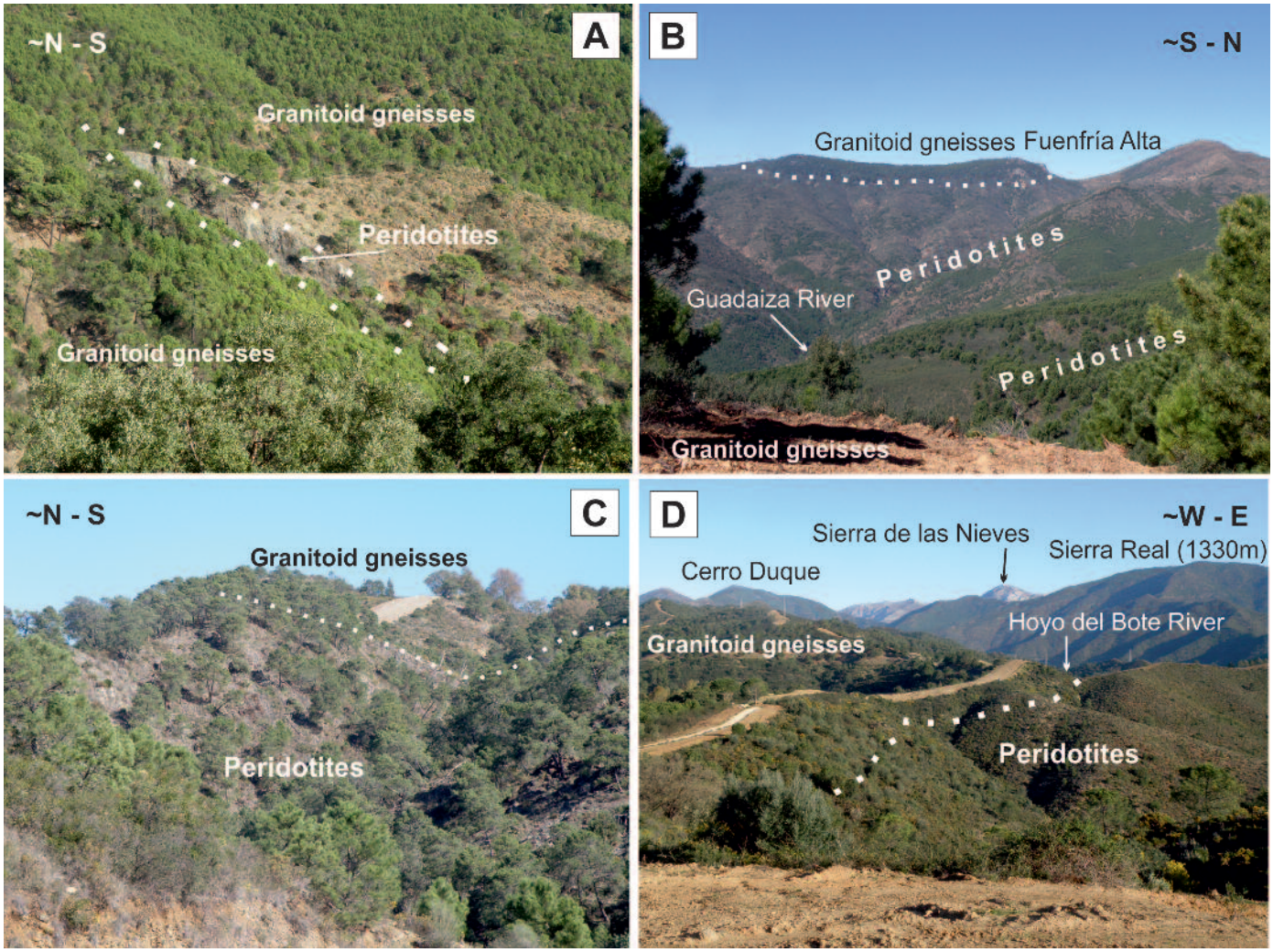

Figure 7. Some examples of the geometry of the contacts between the granitoid gneisses and the peridotites A: small outcrop of peridotites covered by granitoid gneisses, situated in the bottom of the Hoyo del Bote valley/affluent. This outcrop can be seen in cross-section A of Figure 6. B: granitoid gneisses in the top of the Fuenfría Alta, crowning the peridotites situated in a lower position. C and D: granitoid gneisses situated over peridotites, visible in more southerly sectors. The area corresponding to each photo is indicated in Figure 4 with red letters.

Figura 7. *Algunos ejemplos de la geometría de los contactos entre los gneises granitoides y las peridotitas. A: pequeño afloramiento de peridotitas, cubierto por los gneises granitoides, situados en la base del valle/río afluente Hoyo del Bote. Este afloramiento puede verse en el corte geológico A de la Fig. 6. B: gneises granitoides situados en lo alto de Fuenfría Alta, coronando las peridotitas situadas en una posición inferior. C y D: gneises granitoides situados sobre las peridotitas, visibles en sectores más meridionales. El área correspondiente a cada foto se indica en la Fig. 4 en letras verdes.*

Galdeano and Ruiz Cruz (2016b), and considered by these authors to be former volcanic/subvolcanic rocks, now forming two main types of orthogneisses.

One important consequence is that before the formation of these metavolcanic rocks the Ronda peridotites reached the surface, as claimed by Sanz de Galdeano and Ruiz Cruz (2016a) and Sanz de Galdeano and López Garrido (2016).

Considered in a wide area, the structure of the Guadaiza sector is really the eastern prolongation of that existing from Estepona, passing by Benahavís and reaching the Guadaiza River (Sanz de Galdeano and Ruiz Cruz, 2016a). These sectors are in complete continuity.

A consequence is that the Guadaiza tectonic window does not exist at all. All the lithological formations attributed to it are over the peridotites. For this reason the Guadaiza unit does not exist. The same applies to the Guaro unit, situated in part in the area of the Verde River, whose SW end is the Istán area.

Both supposed units occupy the same tectonic position, over the peridotites.

In the study area the contact between the schists and the peridotites is tectonized, as observed in some scarce points because it is generally covered by soil and woodland. In any case the peridotites are situated under the schists. This tectonic contact explains why the garnet gneisses are not usually visible, but does not explain the existence of the detachment itself. It indicates that some movement occurred among the peridotites and the dark schists. Perhaps it is related to the structuring in narrow N-S anticlines and synclines existing in this area, which - taking into account the very different rheology of the peridotites (forming huge masses) and the migmatites, gneisses and schists- produced the cited detachments. In fact, this same type of detachment has been observed in several places in the contact between the peridotites and the migmatites near Jubrique. In any case, the general geometric relationships existing amongst the different types of rocks are clear: the schists are situated over the peridotites. These N-S folds are connected, in our opinion, with the westward drift undergone by the Internal Zone during the early the Miocene (Durand-Delga and Fontboté, 1980, Sanz de Galdeano, 1990, etc.). These structures are superposed over the previous ones that have a more E-W orientation.

The Albornoque Fault is an important cut in the structure of this region. Its movements displaced the Sierra Blanca towards the south-west together with all the related sectors such as the Sierra Alpujata, where there is one major outcrop of the Ronda peridotites. In this sense, the sierras Blanca and Alpujata constitute a different tectonic unit separated from the more westward areas. However, ruling out the discontinuity introduced by the Albornoque Fault, we conclude that both of the cited sierras were the eastern prolongation of the unit of Jubrique-Los Reales, extending to the N of Estepona, Benahavís, Guadaiza, and Verde sectors.

The relationship between the peridotites of Sierra Alpujata and the marbles of Sierra Blanca has been discussed by Sanz de Galdeano and López Garrido (2016), who indicated that although the peridotites thrust during the Alpine Orogeny the SE border of Sierra Blanca (both the schists and the marbles) this structure disappears laterally and on the whole the peridotites are under the orthogneisses, rocks that at the top have a metadetrital formation (light schists, phyllites, and quartzites, Tubía *et al.,* 2013) finally passing to the marble. That is to say, in the area of sierras Blanca and Alpujata the following succession of events happened: during the Variscan the emplacement of the peridotites at the base of the Paleozoic Alpujarride sequences took place. Then, after a stage of uplifting and erosion, the extrusion of volcanic rocks occurred, now orthogneisses -equivalent to the granitoid gneisses of the Guadaiza area-, and began an important extension and subsidence. Then the metadetrital formation and the carbonates (of Triassic age), now marble, were deposited. Later, during the Alpine orogeny, the above-mentioned thrust and the reversed folds of Sierra Blanca were formed, although in the SE part of Sierra Blanca the original arrangement can still be observed, with the peridotites under the rest of the rocks of this zone.

This geologic evolution must be applied to the whole western part of the Alpujarride Complex, that is

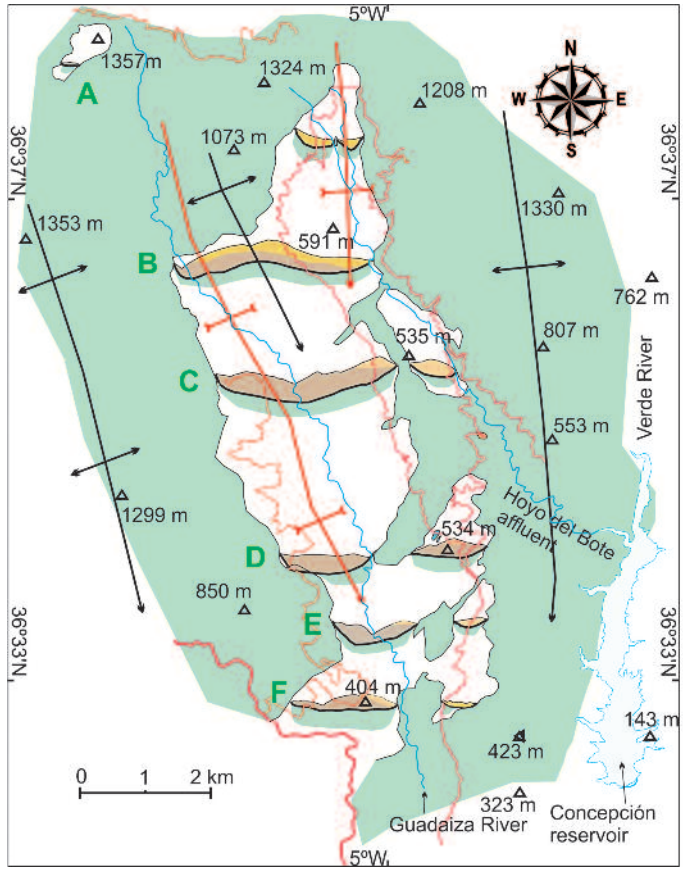

Figure 8. Cartographic scheme situating the cross-sections of Figure 6, and showing their positions in relation to the anticlines (in black) and synclines (in red) of the area. The rest of the legend coincides with that of Figure 6.

Figura 8. *Esquema cartográfico en el que se sitúan los cortes geológicos de la Fig. 6, mostrando sus posiciones en relación con los anticlinales (en negro) y los sinclinales (en rojo) existentes en esta área. El resto de la leyenda coincide con la de la Fig. 6.*

to say, from the Jubrique area to Sierra Blanca and even to Sierra de Mijas located further to the E. If we compare the P-T diagrams obtained by many authors (Torres-Roldán 1981, 1983; Balanyá *et al.,* 1997; Platt *et al.,* 2003; Esteban *et al.,* 2008; Acosta-Vigil et al. 2014; Barich *et al.,* 2014, among others) in the Jubrique and Guadaiza areas their contrasting metamorphic evolution is clear. This contrast could lead to the conclusion that they belong to two different units. But this is not necessary because the Jubrique and Guadaiza rocks correspond to two very different geologic stages. The first stage, in the Jubrique area (and other sectors), corresponds to the emplacement of the peridotites and the second stage occurred after a period of regional uplift, erosion and extension, in this case forming the rocks of the Guadaiza area (the granitoids gneisses and the gneisses). Obviously, the P-T conditions in both stages are necessarily very different and clearly contrasting, although now they are observed within the same unit. These contrasting conditions can already be deduced in part from Figure 3, in which the very different positions of the rocks forming the aureole above the peridotites and the granitoid gneisses and gneisses are visible, corresponding to two different stages separated in time.

These foregoing considerations lead to a reduction of the tectonic units distinguished in the western part of the Alpujarride Complex. In a general overview, the structure can be summarized in the tectonic cross-section drawn in Figure 9, which shows in a simplified view the general structure, in a W-E direction, of the western part of the Betic Internal Zone. This figure is meant only to facilitate the following description.

In the western part of this cross-section the Internal Zone thrusts the Subbetic (External Zone), both domains covered by the Flysch units. Within the Internal Zone, the Malaguide Complex thrusts the Intermediate units (Didon *et al.,* 1973; Sanz de Galdeano *et al.,* 2001) or the "imbrications of Benadalid" (Balanya, 1991), which made the tectonic and paleogeographical transition to the Alpujarride Complex.

The Alpujarride Complex is under the Intermediate units, forming the Jubrique-Reales unit which at the bottom bears the peridotites of Sierra Bermeja. This unit continues to the E and reaches the area of the Guadaiza Valley and, more eastwards, the Verde Valley, where the Albornoque Fault cuts off its continuity with the area of the sierras Blanca and Alpujata. In this latter area, although schematically, part of the inversions indicated by Sanz de Galdeano and López-Garrido (2016) are drawn. Finally, in the same eastward direction, the Malaguide Complex is again visible overthrusting the Alpujarride Complex, in this area without the presence of the Intermediate units.

Connected with the previously cited early Miocene westward drift process, the advance of the Internal Zone caused the Ronda peridotites, and other linked

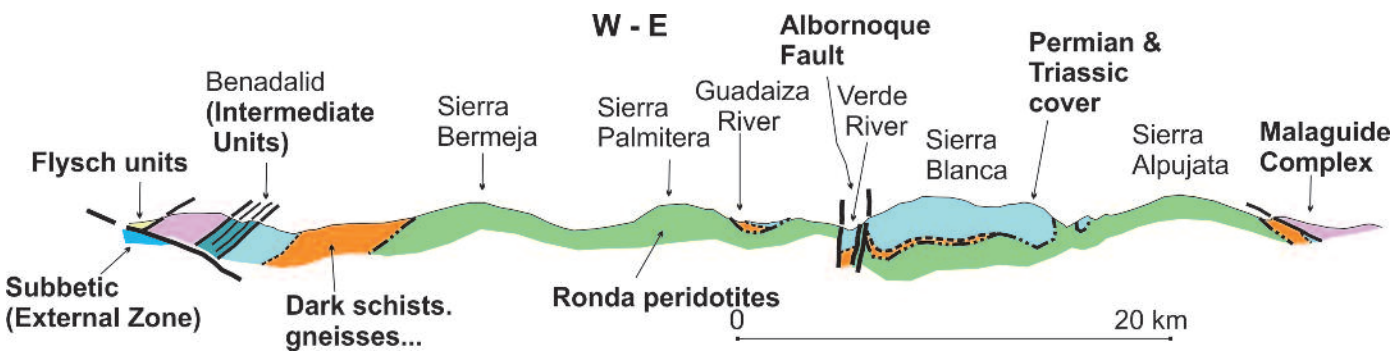

Figure 9. General cross-section showing the structure of the western part of the Betic Internal Zone. The horizontal scale is indicated, but the vertical one is exaggerated, not always with a same value, because in the case of the Intermediate Units it is exaggerated a little more, otherwise its design would be unclear. The sense of displacement of units/nappes is not indicated because in some cases they changed during the different stages of evolution of the structures. The bottom of the Internal Zone over the External Zone is not prolonged because its position is not sufficiently well known. The location of this cross-section is indicated in Figure 2. Symbols of the contact are similar to those of Figure 2. Note the meaning of the colours, indicated in the cross section itself.

Figura 9. *Corte general que muestra la estructura de la parte occidental de la Zona Interna Bética. La escala horizontal está indicada, pero la vertical está exagerada, no siempre con un mismo valor, pues en el caso de las Unidades Intermedias se exagera un poco más, pues de otra forma su dibujo quedaría empastado. Los sentidos de desplazamiento de las unidades/mantos no se indican porque en algunos casos han cambiado durante las diferentes etapas de evolución de las estructura. La base de la Zona Interna situada sobre la Externa no se prolonga porque no conocemos suficientemente bien su posición. La localización del corte geológico se indica en la Fig. 2. Los símbolos de los contactos son similares a los de la Fig. 2. Nótese el significado de los colores indicados en el propio corte.*

rocks, to partially thrust the Sierra de las Nieves unit (Fig. 2), whose southern part was reversed and metamorphosed (Dürr, 1963; Mazzoli and Martín Algarra, 2011; and Mazzoli *et al.,* 2013). However, this history is Alpine and clearly subsequent to the first emplacement of the peridotites and the formation of the granitoid and white gneisses, and should not be confused with the previous one.

Conclusions

The analysis of the geometrical relations existing between the Ronda peridotites and the dark schists and, particularly, with the granitoid gneisses and the white gneisses of the Guadaiza/Hoyo del Bote and Verde valleys indicates that all these latter formations are situated over the peridotites. Considering the age of the gneisses and the granitoid gneisses, the remains of rocks included in them, and their position, the Ronda peridotites were emplaced before the end of the Paleozoic.

Moreover, relationship between the granitoid gneisses and the white gneisses is clear and easily seen to the N of Istán, where the two types of rocks alternate, the white gneisses being on the whole situated over the granitoid ones. These rocks, metavolcanic, were formed during the Permian over the peridotites and other rocks.

Consequently, the granitoid gneisses do not correspond to the dynamothermal aureole situated under the peridotites during their overthrust, because this thrust does not exist. Furthermore, the Guadaiza unit, considered to be cropping out as a tectonic window, also disappeared because this structure does not exist, and must be considered as forming part of a wider Alpujarride unit, that of the Jubrique/Reales.

The same happened with other differentiated units of this sector, such as the Guaro, Ojén, and Blanca units, although the Albornoque Fault really cuts off the continuity of the Jubrique/Reales unit, and this eastern area of the sierras Blanca and Alpujata could be considered a separate unit, but with the same general tectonic position as the Jubrique/Reales unit.

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