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STRUCTURE OF THE BLANCA UNIT (ALPUJARRIDE COMPLEX, BETIC CORDILLERA, SPAIN). REGIONAL IMPLICATIONS

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ABSTRACT

The stratigraphic series of the Blanca Unit is formed by a lower sequence of metapelites (migmatites, gneisses and schists) and an upper sequence of Triassic marbles.

The structure of the unit is characterized by N-S and E-W folds, generally isoclinal, with reversed limbs, giving rise to a dome-basin pattern. There are also sheath folds.

To explain these structures a model is proposed involving westward displacement with frontal and lateral folds. This occurred under highly ductile conditions.

INTRODUCTION

The Blanca Unit is situated in Andalusia (Spain) between the cities of Malaga, in the NE, and Marbella, in the SW (Figs. 1 & 2). This unit, forming two abrupt sierras (Blanca and Mijas) reaches a maximum height of 1270 m a.s.l. at Lastonar summit, in the Sierra Blanca, whereas the lowest areas, in the Torremolinos sector, measure 100 m in altitude.

Geologically, these Sierras are composed fundamentally of marble attributed regionally to the Middle and Late Triassic, belonging to the Alpujarride Complex, within the Internal Zones of the Betic Cordillera. These Internal Zones are divided into three tectonically superimposed complexes, which, from bottom to top, are: Nevado-Filabride, Alpujarride and Malaguide. The first two complexes are affected by alpine metamorphism.

In the present study of the Blanca Unit, we describe the stratigraphic series, but a special emphasis is made on its intricate structure. A model explaining this structure and the regional setting are also considered.

Previous researchers

In 1949, Blumenthal drew a geological map of the coastal chain to the west of Malaga, marking the possible existence of peridotites under Sierra Blanca. Hoeppener *et al.* (1964), studied the Alpujarride units outcropping in the western part of the Cordillera. Mollat (1968) defined the Blanca Unit and considered that this unit constitute a tectonic window of the Alpujarride Complex. Biot (1971) studied the petrographic characteristics of the transition series from the gneisses and schists to the marble in the area of Mijas. Piles et al. (1978 a & b) mark a thrust contact between gneisses of the metapelite formation. Tubía (1985) considered the stratigraphic series to have two fundamental types of marbles: one blue, generally calcareous, towards the bottom; and another white, dolomitic, towards the top.

Martín-Algarra (1987) described a stratigraphic series with a polarity opposite to that presented by Tubía (1985) with regard to the sequence of marbles. Balanyá & García-Dueñas (1991) include the Blanca Unit within the Guaro Nappe.

There are many other works discussing the tectonic position of the peridotitic

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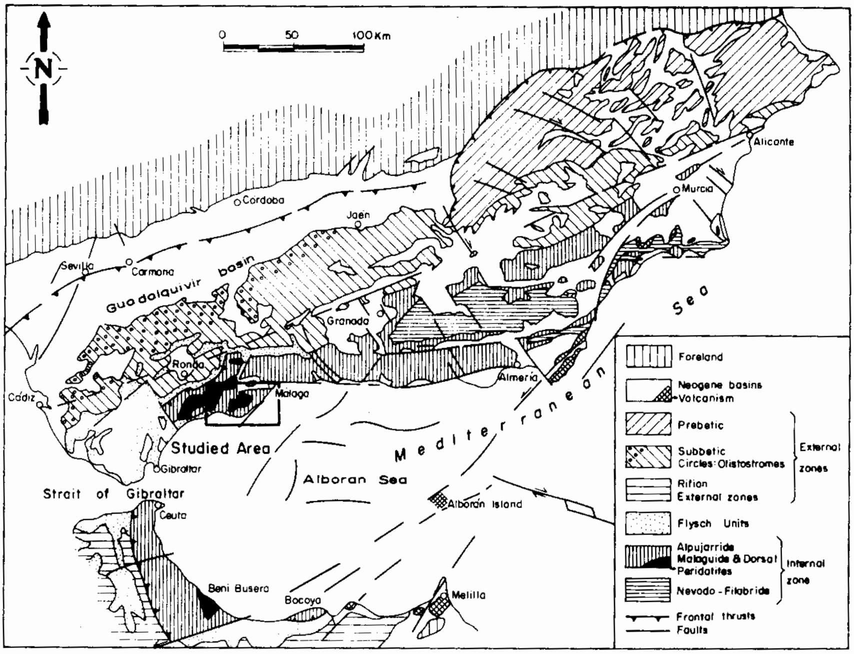

Fig. 1: Situation of the Blanca Unit in the Betic Cordillera (from Sanz de Galdeano, 1992).

masses in the study area. Several authors agree with the original hypothesis of Mollat (1968), according to which the peridotites masses lie over the Blanca Unit (Lundeen, 1978; Tubía *et al.*, 1993, etc.). Nevertheless, there are also some researchers who hold the opposite opinion (Loomis, 1975 and Torres Roldán, 1979). Finally, a third possibility, supported by Kornprobst (1976), suggests the existence of the peridotitic masses in the bottom and top of the Blanca Unit.

LITHOLOGIC SEQUENCE

The lithologic sequence which has been recognized in the Blanca Unit appears to be composed of a lower metapelitic formation and an upper formation of marbles, between which a gradual stratigraphic transition is identifiable.

Metapelitic formation

In the lower part of this formation, in inverted position and near or in contact with the overlying peridotites, coarse-grained migmatites, composed mainly of plagioclase, potassium feldspar, quartz and cordierite, have been found. Over the migmatites, dark gneisses with quartz, plagioclase, ortose, sillimanite, biotite and granate have been recognized (Piles *et al.*, 1978 a & b; Tubía, 1985). Upwards in the series appear light schists with sillimanite and a member of quartzites in the upper part. These rocks present intercalated amphibolites and are regionally attributed to the Permo-Werfenian or older (Delgado *et al.*, 1981). The minimum thickness of the metapelitic series in this sector is an estimated 400 m.

The stratigraphic transition between the metapelites and the marble is seen over a distance of up to 100 m in thickness, in which levels of gneisses and schists with amphibolites, alternate with levels of bluish, grey and even banded marbles.

Lower marbles

The lower marbles are massive, foetid, of light colours and generally white, with local grey, rose and yellowish tones. This rock, usually extremely recrystallized, has a coarse grain size and may present saccharoidal consistency. The marble is composed almost exclusively of dolomite (Biot, 1971). Metapelitic levels also appear, discontinuous and dispersed, with thicknesses varying from several centimetres to ten metres. This marble presents an estimated thickness of about 300 m. The age estimated from regional geological criteria (Delgado *et al.*, 1981) is Anisian-Ladinian.

Marbles with intercalated schists and calcschists

This formation of calcareous marble is usually separated from the lower by an intercalation of schists, quartzites, calcschists and more or less marmoraceous levels, with an overall thickness of 60 to 70 m. The marbles are in general well stratified in beds varying in thickness from a few centimetres to one metre. The colour of these marbles is primarily blue and grey by alteration. These marbles are composed fundamentally of calcite, with minor quantities of quartz, mica and talc (Tubía, 1985; Martín-Algarra, 1987).

In all of this second formation of marble, metapelitic intercalations are very abundant and discontinuous, with a thickness of between a few centimetres and a dozen metres. The thickness of the group of marbles with calcschists is an estimated 300 m, and the age may be considered Late Ladinian to Carnian, by correlation with other Alpujarride sectors (Delgado *et al.*, 1981; Sanz de Galdeano 1989).

STRUCTURE OF THE BLANCA UNIT

The most important features of the structure were produced under ductile conditions, with high temperature and intense pressure. In this unit the folds generally have inverted limbs, many of these being isoclinal.

This unit presents two well differentiated sectors, corresponding to the Sierra de Mijas and to the Sierra Blanca (Fig. 2).

The structure in Sierra de Mijas

In Sierra de Mijas the folds have a predominant ESE-WNW strike (Fig. 3, cross-sections 1, 2 & 3), although, in the extreme west the trend is variable, following the curved form of the Sierra. The ESE-WNW folds verge towards the N, except in the northern part of its central and northwestern areas, where the

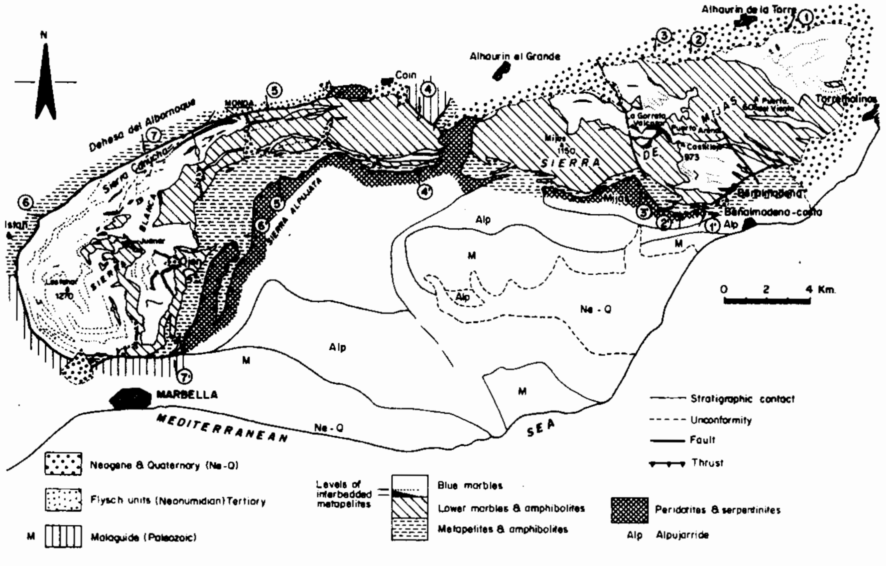

Fig. 2: Simplified lithologic map of the Blanca Unit. The contacts in the area without symbols, south of the Blanca Unit, are only marked to show the general distribution of rocks. There, the continuous lines correspond to tectonic and intrusive contacts.

structures verge to the S. In any case, the vergence is invariably towards the interior of the Sierra. The folds present a stretching lineation parallel to their axes.

In the central part of the Sierra de Mijas complex structures develop, such as sheath folds of variable sizes. One notable example is the sheath fold to the NNE of the Puerto del Arenal, up to a kilometre in length and very flattened, but many others abound with variable scale (generally from about one to ten metres in length).

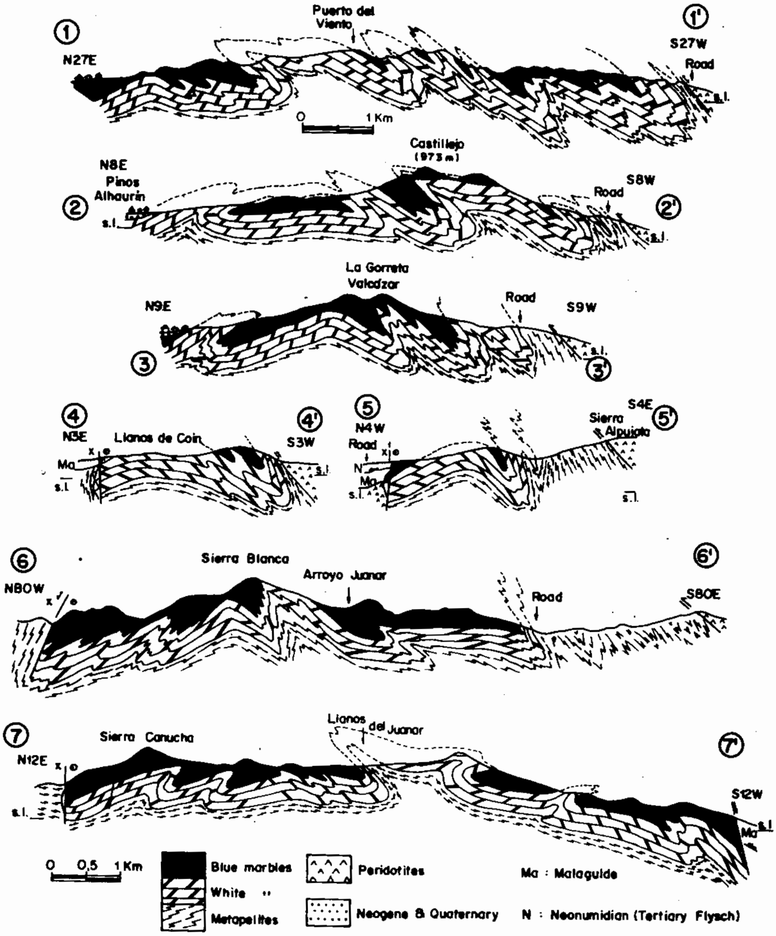

Fig. 3: Geological cross-sections of the Blanca Unit. Their position is marked in Figures 2 and 4. Fig. 4.- Tectonic scheme of the Blanca Unit and the Sierra Alpujata.

The structure of Sierra Blanca

Whereas the eastern part of Sierra Blanca presents E-W folds, verging toward the N (Fig. 3, cross-sections 4 & 5), the western part presents a complex interference of two systems of folds: Some, the more conspicuous, with an approximate N-S trend, and others, with E-W strike (Fig. 4). Both systems present different vergences according to their position, but usually towards the interior of the Sierra. Thus, the N-S system verges westerly in the eastern part and easterly in the western part. The E-W folds verge northerly and southerly, and repeat these opposing vergences locally in two successive sets (Fig. 3, cross-sections 6 & 7).

The interference of these two directions of folding gives rise, especially in the central part of Sierra Blanca, to a structure roughly resembling an egg carton, that is, a series of domes, in the nuclei of which the lower marbles outcrop, and even the metapelitic formation (Juanar area), and basins, occupied by the blue marble.

The limits of Sierra de Mijas and Blanca

The continuity between Sierra Blanca and Sierra de Mijas is cut off by the

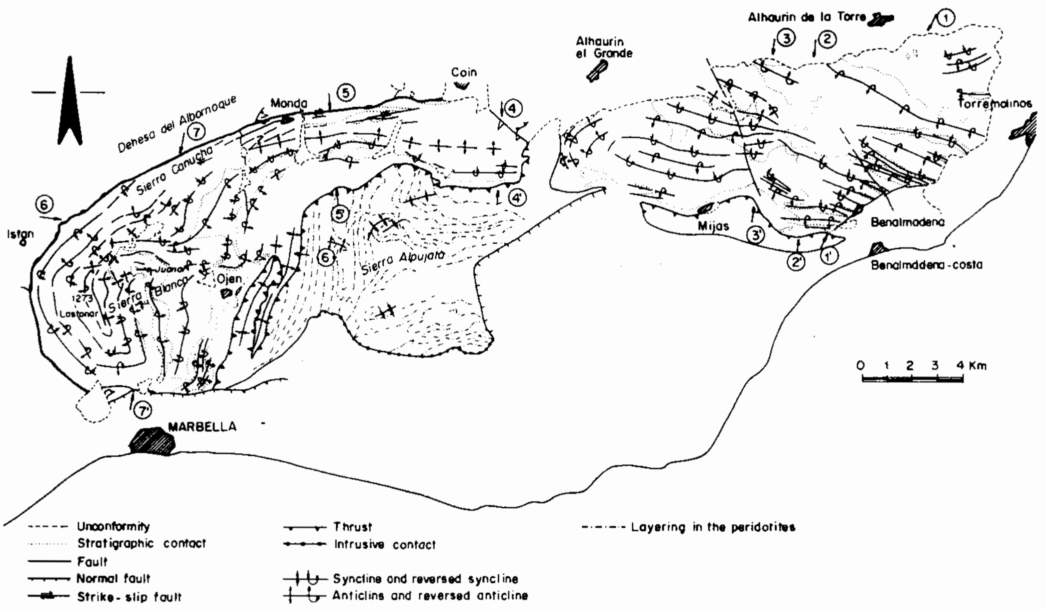

Fig. 4: Tectonic scheme of the Blanca Unit and the Sierra Alpujata

thrust of the peridotites of the Sierra Alpujata (Figs. 2 and 4). This fact caused the thinning and stretching of the metapelitic formation at the eastern end of the Sierra Blanca and at the same time different metapelite and marble fragments were dragged and imbedded in the bottom of the peridotites.

On the northern border this thrust is affected by a dextral strike-slip fault (the Albornoque fault, described by Tubía, 1985). This fault shows a spectacular stretching of the structures in the N of Sierra Blanca. There are many fishes of variable size, from ten metres up to a kilometre in length, composed of peridotites, metapelites, marble of different types, and even of Malaguide slate.

The western edge of the Sierra Blanca is also tectonic, as can be deduced by the fact, among others, that numerous remains of pinched serpentine appear among the metapelites and marbles of the Sierra Blanca. The structures visible in these serpentine fishes show, from the spring of Istán towards the northeast, horizontal movements associated with the Albornoque fault as well as vertical movements towards the south (Fig. 4). In general, in this latter part, the contact between metapelites and marble dips consistently to the W, at least 50°.

The extreme south of the Sierra Blanca is affected by an important fault in an E-W direction (Fig. 4), showing a normal, fundamentally vertical movement of over 1000 m, with a fault-plane slope of 70-80°S.

The east and southeast edge of the Sierra Blanca appears to be generally in gradual stratigraphic transition, although reversed, between the bottom metapelites and the lower marble. The metapelite sequence, extremely folded, contains, from bottom to top: schists, gneisses and migmatites and the peridotites of Sierra Alpujata overthrust these rocks (Tubía, 1985) (Fig. 2).

The eastern limit of Sierra de Mijas is affected by younger fractures, marking the contact between the marbles and the Neogene and Quaternary sediments in the area of Torremolinos.

GENESIS OF THE STRUCTURE OF THE BLANCA UNIT

The approximate E-W direction of the Blanca Unit folds immediately suggests a compression roughly N-S. The directions of the folds coincide in general with those found in other sectors of the Alpujarride complex. The double vergence towards the N in the southern part of the Sierra de Mijas, and towards the S in the northern part, has its equivalent in the Sierra Tejeda (Sanz de Galdeano, 1989), where there are also sheath folds, although these have been observed only in small and medium scale. In any case, both sets of folds, those which verge towards the N and those towards the S, may be related to the same compression phase. Furthermore, both sets of folds, on forming, accentuated the lack of space in the central sector of the Sierra de Mijas. This caused the sheath folds to form precisely there, extruded towards the E and the W. It should be noted that the stretching lineation of the ESE-WNW folds is deformed, adapting to the new limbs of the sheath folds. The main sheath fold (approximately 2 km in length) can be deduced cartographically and appears extremely flattened vertically and extruded mainly towards the E.

But the N-S compression does not explain the formation of the N-S fold present in Sierra Blanca or the curved folds in the western end of the Sierra de Mijas. Thus, we might consider two phases of deformation more or less close in time: a N-S compression with the formation of the E-W folds and afterwards a movement towards the W, giving rise both to the N-S folds and the curved folds.

Nevertheless, the structures of the Sierra Blanca support an interpretation in which the westerly movements would have a primordial role, similar to the westerly movement of the Internal Zones (Andrieux *et al.*, 1971; Durand-Delga & Fontboté, 1980, among others). Thus, the structure of the Sierra Blanca can be explained with a model similar to that proposed by Frizon de Lamotte et al. (1991), for various areas of the Betic Cordillera. According to this model, during the movement of a unit, lateral folds are formed, which might present opposite vergences, and frontal deformations appear.

To apply this model to the Blanca unit, we must start at the moment when, as the westerly movement began, the Sierra de Mijas was still joined to the Sierra Blanca. During the displacements, always under ductile deformation conditions, this movement began to be meet increasing resistance from the interior of the Internal Zones, when these pushed the External zones, and the Sierra Blanca rotated anti-clockwise on the western edge (which currently constitutes its principal nucleus); something similar occurred with the peridotites of the Sierra Alpujata. At the same time, part of the unit broke off and individualized, constituting the present-day Sierra de Mijas, in which western edge curved folds formed (Fig. 4).

The rotation of the nucleus of the Sierra Blanca caused earlier folds in approximately a E-W direction to veer in a N-S direction, and the continuation of the process of this westerly movement pressed the folds even more. In the last phases of the rotation, new E-W folds formed which caused the interference described above.

Folds are found which affect the peridotites in the Sierra Alpujata (Fig. 4) and which present the same directions (N-S and E-W) as in the Blanca Unit, showing that they formed simultaneously with the Sierra Blanca and therefore that the peridotites were already situated largely in their present position, above the Blanca Unit. Moreover, the presence of migmatites in the nucleus of Sierra Blanca suggest the existence of other peridotitic masses under the Blanca Unit, as thought Kornprobst (1976).

The deformation operated largely under ductile conditions, with high temperature and extreme pressure. In fact, Tubía and Gil- Ibarguchi (1991) show the presence of eclogites intercalated between the migmatites and the amphibolites that appear to the east and southeast of the Sierra Blanca.

CHRONOLOGY

The principal features of the structures described seem to have formed before the end of the Aquitanian, given that there are transgressive formations from this age and from the Early Burdigalian (formations of the type found at Las Millanas and La Viñuela) which fossilized the contacts between the Malaguide and Alpujarride Complexes (Bourgois, 1978; Martín-Algarra, 1987; Sanz de Galdeano *et al.*, 1993).

From the Aquitanian, or perhaps slightly before, until the Middle Miocene, the Internal Betic-Rif zones were pushed towards the west (Andrieux *et al.*, 1971; Durand-Delga & Fontboté, 1980; Wildi, 1983; Martín-Algarra, 1987; Sanz de Galdeano, 1990). Taking into account these ages and those concerning metamorphism proposed by Jabaloy *et al.* (1993) for other areas of the Cordillera, the structure of the Sierra Blanca must have formed from the end of the Oligocene to the Early Aquitanian.

The Albornoque fault must have begun its movement at the point when ductile deformations changed to fragile, which, in the first stages caused the important stretching of the northwest of the Sierra Blanca. This activity began possibly in the Middle Aquitanian and probably did not continue after the Burdigalian, or at most until the Middle Miocene.

CONCLUSION

The Blanca Unit, belonging to the Alpujarride Complex of the Betic Cordillera, presents a stratigraphic series formed by a lower sequence of metapelites (migmatites, gneisses, schists and quartzites) attributed to the Permo-Werfenian (or older) and another upper sequence of marbles, between which there is a gradual stratigraphic transition. Within the carbonate sequence, we can differentiate a lower formation, with some 300 m in thickness, of white dolomitic marble (lower marbles), attributed to the Anisian-Landinian and an upper formation of marble, mainly calcareous, presenting numerous metapelitic intercalations. The thickness of this upper marble is of some 300 m and the age is estimated as being Late Ladinian-Carnian.

The structure of the Blanca Unit is made up of folds in an E-W direction in the Sierra de Mijas and in the eastern part of Sierra Blanca, with formation of double vergence and sheath folds, whereas in the western part of Sierra Blanca there are N-S and E-W folds whose interference gives rise to an egg-carton effect, in the form of a dome-basin pattern. The vergence of the folds are consistently towards the interior of the Sierra, though some E-W folds show a double sequence of opposing vergences.

These structures could be explained by a N-S compression and subsequent westerly movement. Nevertheless, a model of movement towards the west with frontal folds and lateral folds, would explain the two phenomena jointly. During the westward advance, the most westerly part of the Sierra Blanca appears to have rotated anti-clockwise practically 90°. The peridotites of the Sierra Alpujata show the same direction of folding.

In any case, the principal features of the structure of the Sierra Blanca appear to have been formed under ductile conditions. The overthrusting peridotite masses of the Sierra Alpujata contributed to reaching the temperatures necessary to produce these conditions.

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