

# Differentiation of the Alpujarride tectonic units between Motril and Almuñécar (Granada province, Betic Internal Zone)

*Diferenciación de las unidades tectónicas alpujarrides entre Motril y Almuñécar (provincia de Granada, Zona Interna Bética)*

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## ABSTRACT

A new analysis distinctly differentiates the Alpujarride Salobreña and Almiijara tectonic units, to which were attributed a common marble formation, now separated in each unit; both units are entirely independent. These units underwent great shearing during the thrusting stage. Particularly the Almiijara unit disappeared in the eastern part of the study area, where the Salobreña unit was situated directly over the Escalate lower tectonic unit, a feature previously unknown. Moreover, in this sector, later faults contributed to a transversal cut of the Betic Internal Zone.

**Key-words:** Alpujarride Complex, tectonic units, thrust nappes.

## RESUMEN

Un nuevo estudio ha permitido la completa diferenciación de las unidades tectónicas alpujarrides de Almiijara y Salobreña, a las que se les había atribuido una formación común de mármoles a pesar del cabalgamiento que las separa. Ambas unidades son totalmente independientes. Durante la etapa de cabalgamientos se produjeron enormes cizallamientos, particularmente en la unidad de Almiijara, de manera que al E de la zona estudiada llega a desaparecer y la unidad de Salobreña se sitúa directamente encima de la unidad inferior de Escalate, algo no conocido anteriormente. Fallas posteriores han cortado transversalmente en este sector a la Zona Interna Bética.

**Palabras clave:** Complejo Alpujarride, unidades tectónicas, cabalgamientos.

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## Introduction

The differentiation of the Alpujarride tectonic units has been controversial in several areas of this complex. The present study deals with this topic in a sector situated south of the city of Granada (Spain), between two localities on the Mediterranean coast (Fig. 1): Almuñécar, practically at the limit between the Malaga and Granada provinces, and Motril, situated 25 km eastwards, lying south of the sierras Almiijara and Guájares.

This area is noteworthy not only for the presence of the thrusting of units, but also because the two upper ones have been interpreted as sharing the same marble formation on the top.

### Geological setting

In the Betic Cordillera the main domains are the External and Internal zones (Vera, 2004). The Internal Zone comprises three complexes that from bottom to top are: the Nevado-Filabride, Alpujarride and Malaguide. This study examines the relations existing between three super-

posed tectonic units of the Alpujarride Complex.

The lithological sequences of these three units are similar in many aspects, although the lower unit presents a lesser degree of metamorphism, while the upper one has a greater degree. Their lower formation is composed of metapelites, which currently, depending on the units, consist of dark Palaeozoic schists, light schists or phyllites and, above these, Triassic marbles (Figs. 2 and 3).

### Antecedents

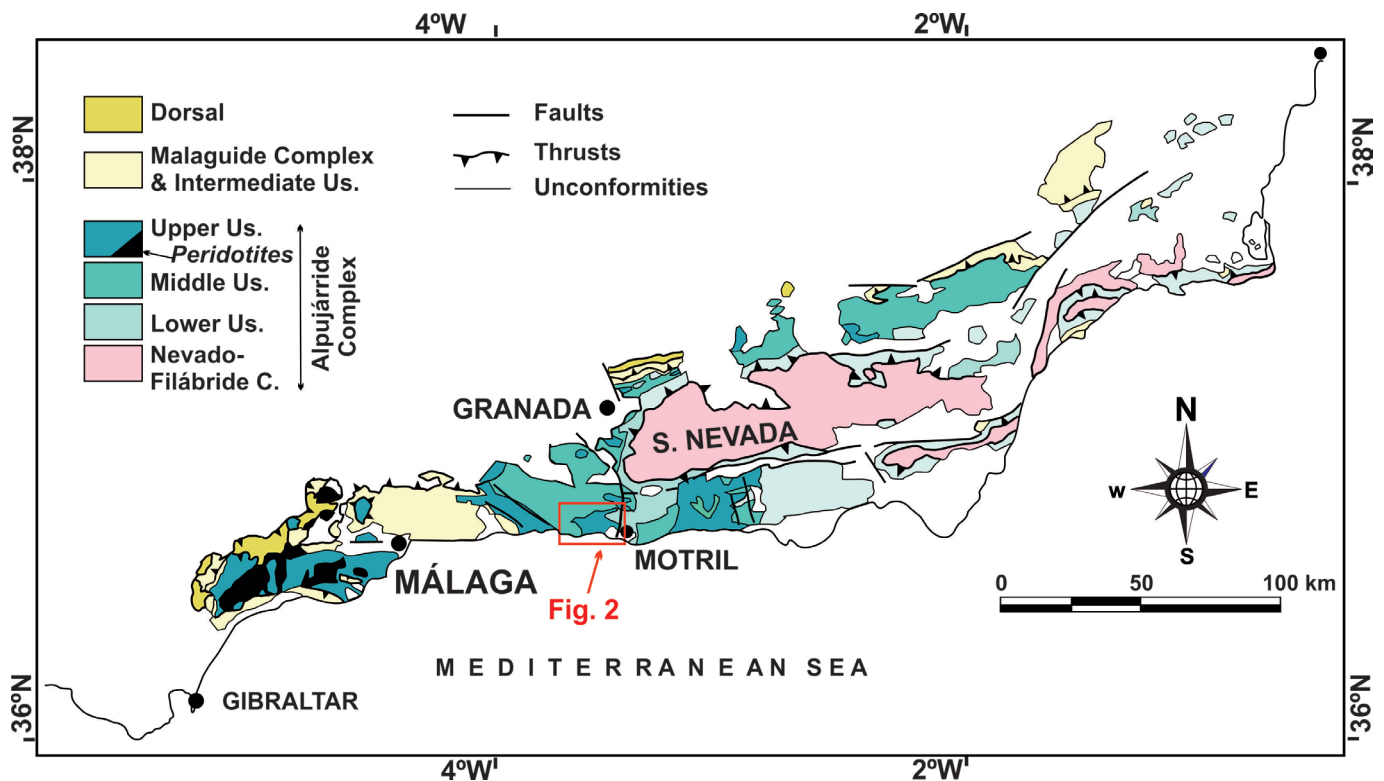
In reference to the tectonic units of this area, Avidad (1976), Avidad and García-Dueñas (1981), and Avidad *et al.* (1981) proposed a differentiation, in many aspects accurate, but at the same time introduced the problem of the existence of a common formation situated on top of two superimposed units. According to their differentiation, these authors distinguished four units in the area: at the bottom the unit of Alcázar, above the unit of La Herradura, thrust by the unit of Salobreña, and at the top the unit of Guájar. The two units concerned

with the possible common formation of marbles are those of Herradura and Salobreña.

Several later articles used the names proposed by the above authors, although Estévez *et al.* (1985), Sanz de Galdeano (1990) and Sanz de Galdeano and López-Garrido (2003) changed them: the lower unit, Alcázar, was renamed Escalate because in the locality of Alcázar the presence of this unit is doubtful. The middle unit, Herradura, was renamed Almiijara because, in the city of Herradura, outcrops of the Salobreña unit also exist and, moreover, form part of a greater unit, that of Almiijara. The upper unit, Salobreña, retains its name and encompasses the unit of Guájar.

### Aim of the article

As part of the discussion of the criteria for differentiating the Almiijara and Salobreña units, their geometries are presented, and special emphasis is given to the major shearing of the units present in the eastern part of the study area. This feature continues northwards to the area of Sierra Nevada.



**Figure 1. General distribution of the Alpujarride units in the Betic Cordillera. The position of the Fig. 2 is indicated. See figure in colour on the web.**  
 Figura 1. Distribución general de las unidades alpujarrides en la Cordillera Bética. Se indica la posición de la Fig. 2. Ver figura en color en la web.

### Differentiation of the Almiijara and Salobreña units and the geometry of their contact

Cross-section 1 (Fig. 3) presents the thrusting of the Salobreña unit above that of Almiijara. In its northern part, the Salobreña unit completely sheared the marbles of the Almiijara unit, while in the south they are partially conserved. In the south part of cross-section 2, the marbles of Almiijara are greatly sheared, undergoing major reductions in thickness, while in the middle part they are completely sheared. On the northern end, the Almiijara marbles present a reversed syncline and there, the schists of Almiijara have been partially sheared. Cross-section 3 shows that under the thrusting of the Salobreña unit the Almiijara marbles are completely sheared in its eastern part.

In their southern parts, cross-sections 4 to 6 present the Salobreña unit, while the Almiijara unit is situated on the northern sides. There, Avidad (1976) and Avidad and García-Dueñas (1981) place a stratigraphic contact in such a way that the marbles of Almiijara are also marbles of the Salobreña unit. However, an analysis of the contact there shows the presence of a normal fault with striae dipping to vertical, being in some cases somewhat oblique.

In the proximities of cross-sections 4 and 6, marble outcrops of the Salobreña unit are situated near those of the Almiijara unit, making it difficult to separate them directly. Nevertheless, both types of marbles, although located very close together, can be distinguished by three features: 1. The different position of these two formations of marbles located near each other (in the Salobreña unit they correspond to the basal marbles, while in the Almiijara unit, in the nearby sector, they occupy higher positions); 2. The presence of a normal fault similar to that cited more to the west, although generally less visible owing to the greater abundance of colluvial deposits; 3. The presence of a formation of quartzites situated near the bottom of the marbles of the Salobreña unit, while in the equivalent position, nearby, the Almiijara unit shows a formation of phyllites.

#### *The geometry of the Salobreña and Almiijara units in the study sector*

As indicated above, the Salobreña unit is not always tectonically situated over the same stratigraphic position of the Almiijara unit. In the Guájares mountains, its general position is over the marbles of the Almiijara unit, although

these marbles are cut locally at several heights. But southwards, for instance, in the Rescate sector, the marbles conserve remarkably little thickness, and in other places these have been completely sheared. Indeed a large part of the light schists of this Almiijara unit has been sheared.

The Almiijara unit is completely cut between the localities of Molvízar and Motril. This feature is visible in cross-sections 7 and 8, where the Salobreña unit is directly over the Escalate unit, and consequently the Almiijara unit, the middle unit, has disappeared.

Within the Salobreña unit, a zone with reversed structures is located to the north of Salobreña and Motril. In Fig. 2, these structures have been indicated by only a reversed anticline, although their precise form is difficult to express because within the dark schists they cannot not easily viewed. These reversed structures disappear southwards. Thus in the area next to the town of Salobreña the marbles of this unit are situated over the dark schists, while the light schists originally situated in between have been almost completely sheared. Where this contact is visible, it is a shear zone, bearing the remains of the light schists.

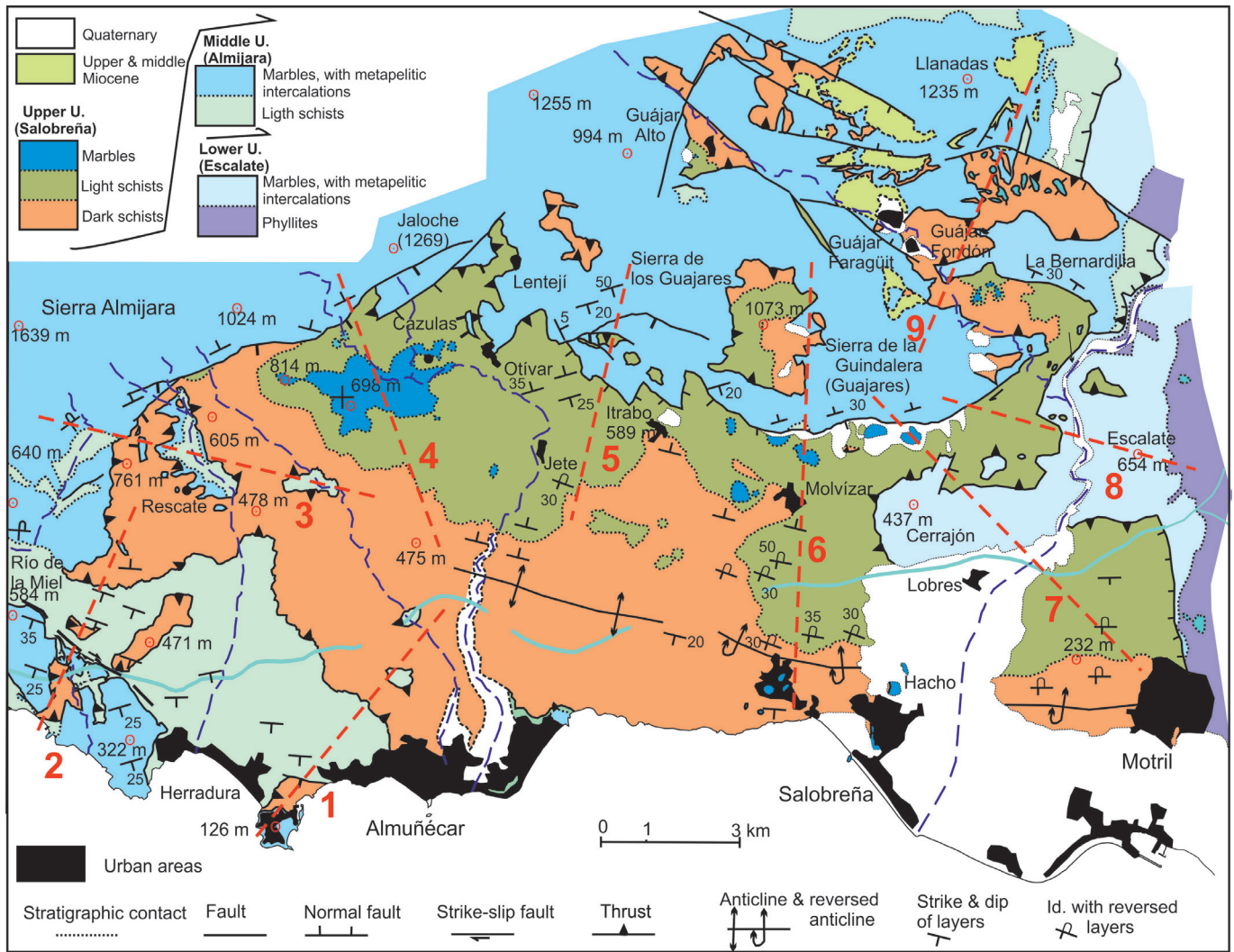


Figure 2. Geologic map of the study area. Its position is marked in Fig. 1. The cross sections of Fig. 3 are indicated. See figure in colour on the web. *Figura 2. Mapa geológico del área estudiada. Su posición se señala en la Fig. 1. Se indican los cortes de la Fig. 3. Ver figura en color en la web.*

### Interpretation of the structures observed and age of their formation

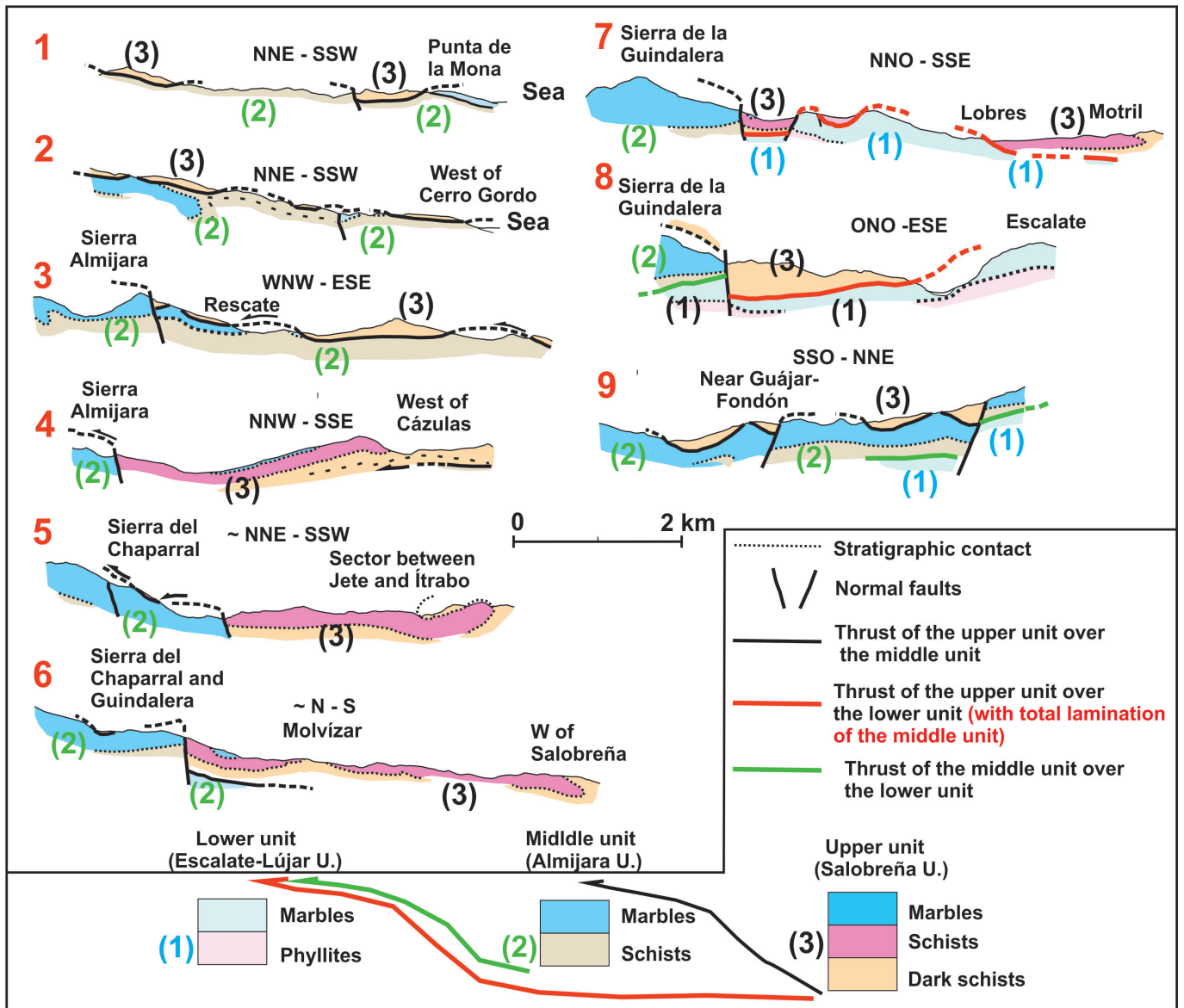
The structures described cannot be explained in a single stage of deformation. An initial stage involves the thrusting of the units. According to the interpretation of the evolution of the Internal Zone, this stage occurred at the end of the Oligocene-Aquitania (Vera, 2004), probably with N or NW vergences. Also, the total disappearance of the Almijara unit between the Salobreña and Escalate units may be related to this stage and should be the consequence of the volume of this last unit. That is, the Escalate unit is a local tectonic duplication of the Lújar unit (both units correspond to the lower Alpujarride units). This duplication at this stage reached a volume great enough to constitute a barrier that partially stopped the middle unit, the Almijara

unit, at the same time as it was sheared by the advance of upper unit, the Salobreña unit. Northwards of Escalate hill (Fig. 2), the Almijara unit gradually reappears between the lower and upper units (cross-section 9 in Fig. 3).

Westwards from Molvizar (Fig. 2), the Salobreña unit covers the subjacent units and it is not possible to determine from what point the Almijara unit is not totally sheared. At present, it is visible near Almuñécar, first showing schists, and then progressively marbles, already well conserved in the sector of the Río de la Miel. In this sector, some kinematic indicators imply displacements towards the WNW. This suggests a new stage of displacements in this direction, perhaps related with the western drift that the Betic Internal Zone underwent during the early Miocene but not later, because middle Miocene sediments fossilized the thrust structures in the area of the villages of Guájar (Fig. 2).

Major normal faults affected the thrust structures (Fig. 2), in some cases with a strike-slip component. As previously described, the sierras Almijara and Guájar present normal faults on their southern borders with throws of several hundred meters at some points. Also, near the Guájar villages, NW-SE normal faults appear while, near Motril and to the NE of Fig. 2, normal faults of approximate N-S direction occur, sinking the western block. All these faults also affect the upper Miocene sediments in the area of the Guájar, with throws of hundreds of meters. These help define the present western limit of the lower Alpujarride units, and, more to the north, that of the Nevado-Filabride Complex (Fig. 1).

The above-mentioned reversed structures of the Salobreña unit and the strong local shearing of its light schists are presumably related with the first stage of the thrusting of the units.



**Figure 3. Geologic cross sections of the study area.** Their positions are indicated in Fig. 2. The numbers in parentheses indicate the units signaled in the bottom of the figure. See figure in colour on the web.

*Figura 3. Cortes geológicos del área estudiada. Sus posiciones se señalan en la Fig. 2. Los números entre paréntesis indican la unidad señalada en la base de la figura. Ver figura en color en la web.*

**Conclusions**

The Salobreña and Almijara units appear to be completely separable, and the formation of marbles is independent in every unit. This indicates that there is no common formation of marbles.

During the thrusting of the units, major shears occurred, in such a way that the units were partially and even completely cut in some places, particularly the Almijara unit. This is the case in the area north of Motril where the Salobreña unit lies directly over the Escalate unit.

From the upper Miocene, the later stage of fracturing occurred together with regional uplift, which almost completely cut through the Betic Internal

Zone in an N-S direction. This cut contributed to form the western limit of the lower Alpujarride tectonic units and of the Nevado-Filabride Complex.

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