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Neogene folds in Ronda Depression (Western Betic Cordillera)

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Abstract: The Ronda Depression is filled by Neogene sediments on the boundary between Subbetic reliefs, with NE-SW structural trends, and the frontal Subbetic Chaotic Complexes. The folding style in the Subbetic Units of Western Betics is strongly controlled by the rheology of the rocks: thick and massive beds of Jurassic limestones over Triassic marls and gypsum with plastic behaviour. Main deformation structures in the sedimentary infill of the Ronda depression are simultaneous box folds with NNE-SSW and WNW-ESE trends that only affect its southwestern part. This distribution of folds is a consequence of the inherited fold trend that affected the basement during Early Burdigalian age.

Keywords: Ronda Depression, Western Betic Cordillera, fold development, Subbetic Chaotic Complexes.

The Ronda Depression is located at the boundary between the Subbetic Units (External Zones) and sediments of the Flysch Units of the Betic Cordillera (Fig. 1). Subbetic Units are constituted by Triassic to Middle Miocene sedimentary rocks with local intercalations of igneous rocks. The Subbetic structure in this region (Internal Subbetic or Penibetic) is described by Crespo-Blanc and Campos (2001) as a NW-vergent fold-and-thrust belt, post-Early Burdigalian in age. These NE-SW folds, which affect the Internal Subbetic, are cut by thrust, probably rooted in the Triassic rocks.

Towards the mountain front of the cordillera, Subbetic Units are widely deformed and show a chaotic structure (Pérez-López and Sanz de Galdeano, 1994). These Subbetic Chaotic Complexes are mainly composed of a Keuper Triassic matrix including post-Triassic blocks, some of them of Middle Miocene age. This complex is deformed by the combined development of thrusts, slides, transcurrent faults and diapirism (Pérez-López and Pérez-Valera, 2003).

Flysch Units crop out in the Betic Cordillera lengthwise along the contact between the Internal and External Zones, mainly in the broad area of the Campo de Gibraltar, and over different Subbetic Units. The Mesozoic and Cenozoic sediments that constitute these units are turbiditic clays and marls.

The sedimentary infill of the Ronda Depression is entirely Late Miocene in age and was divided into different formations by Serrano (1979) and Rodríguez-Fernández (1982). From bottom to top are: I) the Gastor formation: sands, silts and heterogeneous conglomerates of Tortonian age; these rocks crop out unconformably over Triassic basement rocks at the northwestern border of the depression, II) the Tajo formation: heterogeneous

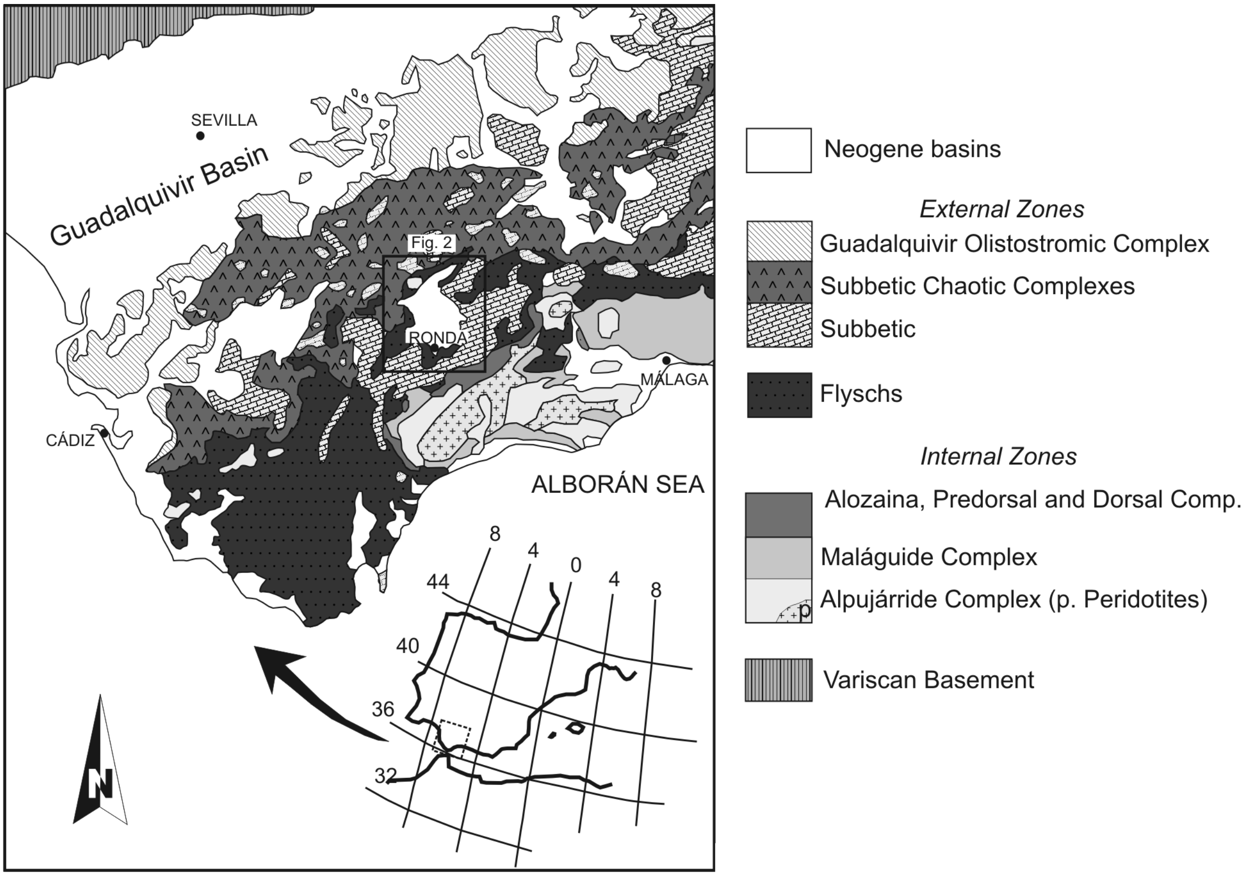

Figure 1. Geological setting of the Ronda Depression in the framework of the Betic and Rif Cordilleras.

conglomerates of pre-late Tortonian age with clasts proceeding from the Subbetic and Flysch southern units; this formation lies unconformably over the Flysch Units, III) the Mina formation is located conformably over the Gastor formation and is composed of marls and sandy silts of Early Tortonian-Late Messinian age; it is well represented in the western half of the depression, and IV) the Setenil formation is Late Tortonian-Late Messinian in age and crops out in most of the depression, except for the northwestern part; it lies over basement rocks or Mina formation sediments, although it could also be in facies transition with this formation. Rodríguez-Fernández (1982) divided this formation into two members: a limestone member and a calcarenite member.

The aim of this contribution is to describe the folds that developed heterogeously in the Neogene sedimentary infill of the Ronda Depression. The development of these structures is discussed, taking into account their geometrical features and the heterogeneous character of the pre-Miocene basement.

Folds

The main deformation structures that affect the Neogene sediments of the Ronda Depression are NNE-SSW and WNW-ESE kilometric folds (Fig. 2). These structures have a heterogeneous distribution, being mainly located in the southern and southwestern parts of the depression. In the eastern sector outcrops are scarce because the zone is extensively cultivated and there are no significant reliefs due to the low dip of the marls. In the northern part, however, fluvial incision allows us to observe tilted Tortonian calcarenites, forming a homoclinal structure. Therefore, folds probably do not propagate through these two regions (Fig. 3A).

The Salinas fold is a NNE-SSW box-shaped antiform with a 2 km wide crest. The dip of the flanks (Fig. 2) increases sharply from 20º to 70º. This fact produces straight boundaries in the topography intersection that are not related to large NE-SW normal faults as was pointed out by previous authors (Serrano, 1979). The antiform culmination is essentially flat, with dips lower than 20º.

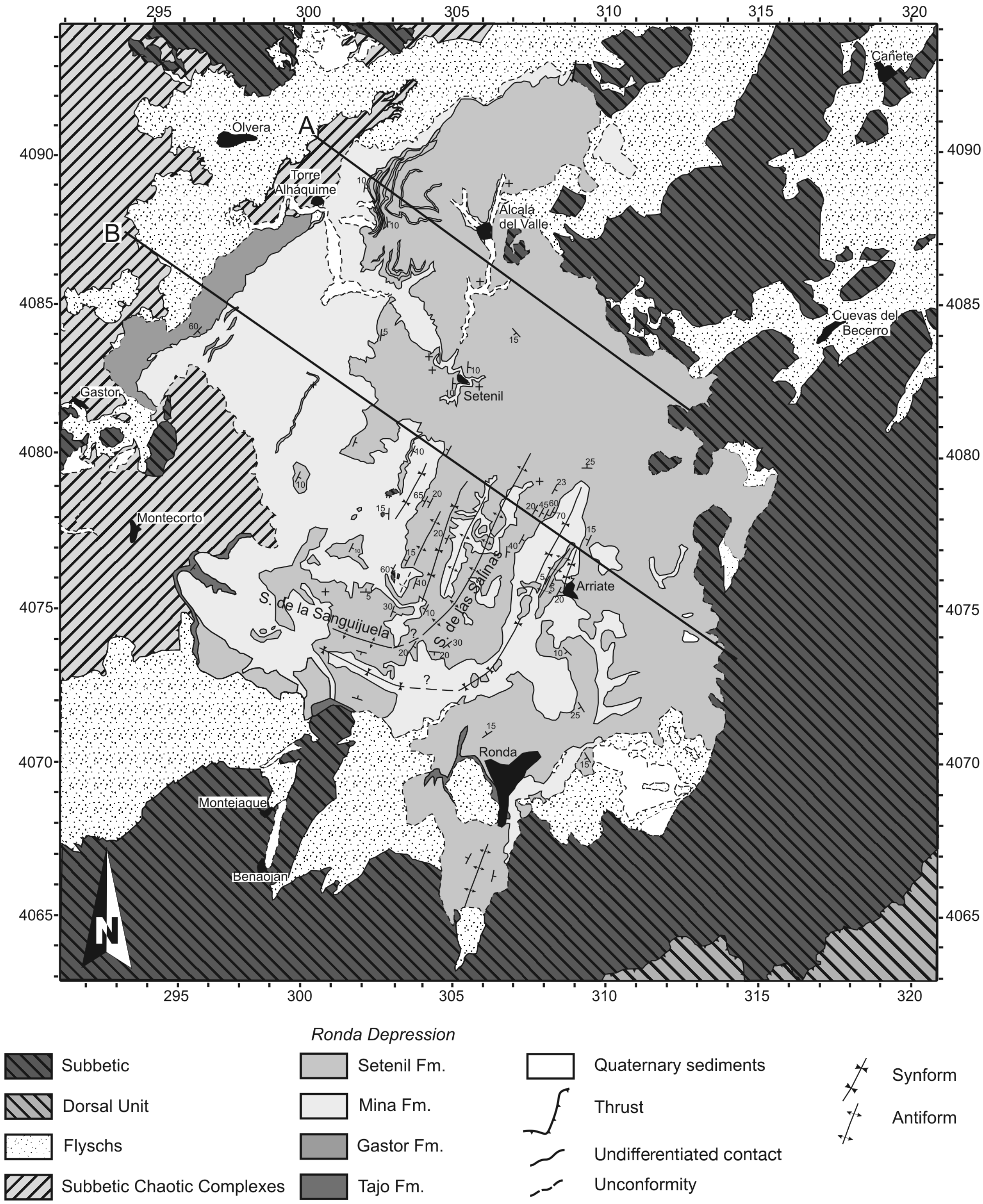

Figure 2. Geological and structural map of the Ronda Depression. Cross sections of figure 3 are located. Coordinates are in kilometers.

The geometry of the fold could thus be described as a box-fold without vergence (Fig. 3B). Previous authors (Rodríguez-Fernández, 1982) point to the local presence of some patches of Triassic rocks outcropping in the core of the antiform. However, in this area only Tortonian calcarenites from Setenil formation and some patches of Messinian marls have been distinguished in this study. Parallel to the Salinas fold it was possible to describe up to six cartographic folds, constituting a fold set that deforms a 6 km long and 8 km wide region.

The WNW-ESE Sierra de la Sanguijuela antiform, located to the SW of the Salinas fold, runs parallel to the southwestern boundary of the depression. Its geometry is similar to that of the Salinas antiform and could be considered as the prolongation of this fold because there are no interference structures between the two, although there is a sharp change in fold axis orientation. There are no minor folds parallel to the Sanguijuela antiform, as occurs in the Salinas one. On both sides of these folds there are two synforms with the same direction, NE-SW in the Salinas sector and WNW-ESE in the Sanguijuela one. Marls of Mina formation outcrops in the core of both synforms.

As we pointed out before, there is another set of folds with metric wavelength and the same orientation as the Salinas antiform, approximately N30ºE (Fig. 2). Its geometry is open, with flanks dipping around 15-20º. These minor folds are fundamentally located in the crest zone of the Salinas fold and deform the calcarenites of the Setenil formation. It is not possible to determine whether these minor folds also deform the Upper Messinian limestone member of the Setenil formation, because there are very few outcrops of these rocks, and in all of them a 10º souteastwards dipping is observed. Crespo-Blanc and Campos (2001) considered that these late open folds deform the thrust planes separating Flysch and the Subbetic Units. However, the continuity with the folds observed in the depression is not well constrained because field observation does not evidence that the basal unconformity has been affected by these structures.

The most recent rocks deformed by the kilometric box-folds are Tortonian calcarenites. In the whole depression there are no Pliocene deposits and the Quaternary sediments are reduced to the non-deformed river channels. Although it is not possible to determine the end of the activity of these folds, field observations enable us to ascertain that both types of folds were simultaneously active later on, in Late Tortonian to Late Messinian age.

Discussion and conclusions

Serrano (1979) proposed a strictly diapiric origin of the Salinas fold conditioned by the presence of ductile Triassic rocks in its core. Although the presence of Triassic rocks plays an important role in the development of the fold, the existence of previous structures conditioned its orientation

In a first event of post-Early Burdigalian deformation, the NE-SW to NNE-SSW fold and thrust belt that determine the internal structure of the Subbetic was developed. In this stage, with a NW-SE compression, the accumulation of low density Triassic rocks in elongated bodies in the core of folds was produced. The main part of brittle and ductile deformation of the outcropping tectonic units in Western Betics was formed before Tortonian, because rocks of this age lie unconformably over the External Zones and Flysch Units. In addition, their deformation is local and slight. In the Ronda Depression, the Late Tortonian to Late Messinian sediments were deposited unconformably and fossilized the basement folds formed in the Burdigalian stage.

During Late Tortonian-Late Messinian, zones with high accumulation of low density Triassic rocks and considerable load due to the overlying sequence

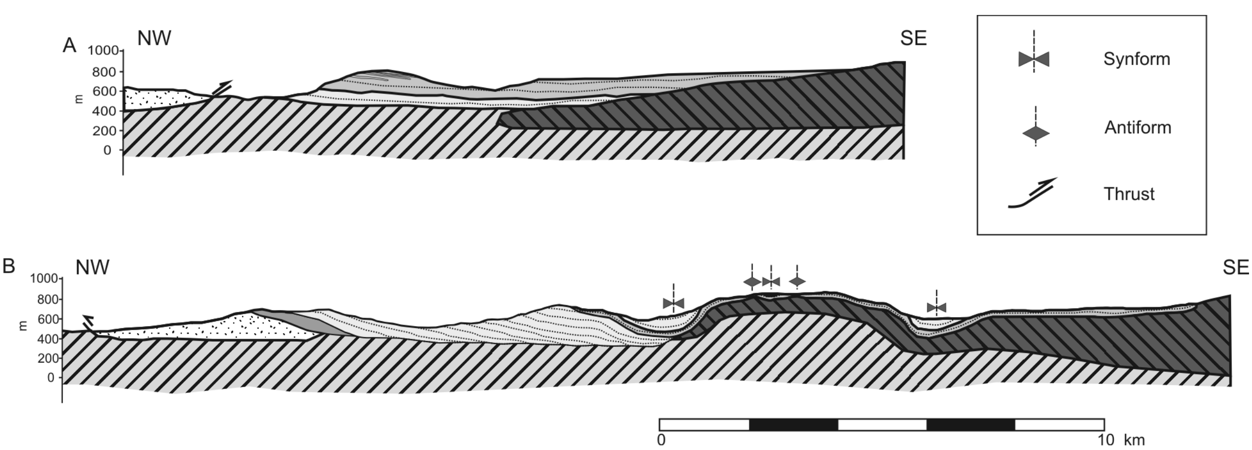

Figure 3. Geological NW-SE cross-sections of the Ronda Depression. The position of the cross-sections is located in figure 2.

underwent diapiric uplifting. This process occurred in the core of the Salinas antiform. The flow of Triassic rocks may be responsible for the local development of this non vergent box-fold located only in this sector of the depression. The elongated geometry of the fold is probably conditioned by the inherited disposition of the parallel folds that deformed the Subbetic basement in the Burdigalian.

The development of the Sanguijuela fold was produced due to the interaction of the Triassic rocks ascending with the WNW-ESE rigid and thick limestones of the sothwestern boundary of the depression. The non-existence of dome-and-basin interference type structures, generally developed in orthogonal trending folds, can be explained if this occurred simultaneously to the NNE-SSW ones. The orientation is determined by the rheological contrast between the infill sediments and the rigid border of the depression. Similar examples of diapir related folds covered by deformed Neogene sediments have been described by other authors in the Guadix-Baza Basin (López-Garrido and Vera, 1974; Estévez *et al.*, 1978). Although the existence of low density Triassic rocks is a necessary condition to the reactivation of the folds, other factors must already exist to start this process: load, presence of fluids and a sharp upwards increase of density in the sedimentary sequence.

The location of the folded area over the Triassic basement, besides the box shape of the folds and the simultaneous development of orthogonal folds, suggest that the diapiric mechanism related to the vertical motion of Triassic rocks was mainly responsible of its development. Thus, the fold features are directly conditioned by the inherited basement rheology, and also the geometry of structures related to a previous deformation stage that occurred in the zone at the Burdigalian.

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