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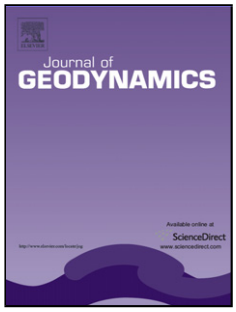

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Gravity anomalies and orthogonal box fold development on heterogeneous basement in the Neogene Ronda Depression (Western Betic Cordillera)

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Abstract:

The Ronda Depression constitutes a Neogene intramontane basin located in the External Zones of the Western Betic Cordillera. Major deformation structures affect only the southwestern part of its sedimentary infill and consist of NNE-SSW and WNW-ESE box folds that developed simultaneously. New gravity data reveal two negative NNE-SSW elongated Bouguer anomalies, unrelated to basin depocenters, but corresponding to the accumulation of low-density ductile Triassic basement rocks in the core of antiforms or directly under the northwestern undeformed sedimentary infill. The Subbetic basement is also deformed by Early Burdigalian to Serravallian NNE-SSW folds and thrusts, although there is no clear continuity with those affecting the Late Miocene sedimentary infill. The aim of this contribution is to describe in detail the Late Miocene folds that deform the Ronda Depression, as well as to discuss the role of the basement nature on their reactivation. The reactivation of the pre-Tortonian folds, due to the heterogeneous distribution of evaporitic Triassic rocks in the basement as well as the

presence of rigid limestones on the southwestern basin boundary, determined the simultaneous orthogonal fold development that only evidence local deformation.

Key words: Neogene basin, gravity models, low density basement, fold reactivation.

INTRODUCTION

The behaviour of ductile rocks facilitates the presence of detachment levels determining the style of deformation. Analogue modelling studies have focused on the effects of different rheological rock properties in detachment features (Nilforoushan and Koyi, 2007). Anomalous evaporitic rock accumulations located in these detachments greatly condition antiform nucleation (Bonini et al., 2003; Marques, 2006) and may favour the simultaneous development of oblique compressive structures, sometimes even orthogonal to the main structural trend (Callot et al., 2007; Crespo-Blanc, 2008). Such oblique folds and thrusts have usually been interpreted as a consequence of overprinted deformation stages (Caritg et al., 2003; Mon et al., 2005). Moreover, the accumulation of low-density evaporitic rocks at depth determines the development of vertical movements related to salt tectonics producing diapiric structures. These may be isometric or elongated, depending on the origin, evolution and initial distribution of low density rocks. Establishing the position of these low density evaporitic rock accumulations is essential for understanding the superficial folded structures. Gravity is a key for elucidating the position and geometry of such structures because they commonly give rise to a negative Bouguer gravity anomaly (Jallouli et al., 2005; Pinto et al., 2005).

Gravity studies in sedimentary basins also allow determining the thickness of the sedimentary infill, related to irregularities of the basal unconformity and the presence of recent deformation structures. In sedimentary basins, Bouguer anomaly minima are

generally interpreted as depocenters, considering that basement rocks are denser than the sedimentary infill. However, in basins with heterogeneous basements, the superposed effect of basement and infill rocks may give rise to a complex Bouguer anomaly pattern that needs to be more fully analysed in order to isolate each contribution.

The External Zones of the Betic Cordillera (Fig. 1) are composed of Mesozoic sediments with Triassic evaporitic rocks in the lower part of the sequence. In the westernmost sectors, these Mesozoic rocks are deformed mainly by NE-SW to NNE-SSW folds and thrusts rooted in the evaporitic rocks. However, fold and thrust trends change frequently along the Cordillera; and interference structures have been recognized, as in the eastern Betics (Sanz de Galdeano et al., 2006; García-Tortosa et al., 2007) and the central Betics (Crespo-Blanc, 2008). In any case, their simultaneous development is still under debate because in areas like the External Zones of the Central Betics, paleomagnetic studies (Platzman, 1992; Platt et al., 1995) have demonstrated a late rotation, suggesting a constant initial fold orientation. In many cases, establishing the age of deformation is complicated by the absence of a young sedimentary cover that could be used as a marker.

The study of folds in Neogene-Quaternary basins allows us to characterize the recent tectonic evolution simultaneous to relief uplift. Therefore, many research efforts have been undertaken in the eastern (Groupe de Recherche Neotectonique de l'Arc de Gibraltar, 1977; Marín-Lechado et al., 2007; Pedrera et al., 2007) and central (Ruano et al. 2004) part of the Cordillera. In addition, gravimetry has been widely used in the Eastern Betic Cordillera (Granada Depression, Morales et al., 1990; Campo de Dalías, Marín-Lechado et al., 2007) and in the Guadix-Baza Depression (Sanz de Galdeano et al., 2007) in order to determine sediment thickness distribution in Neogene-Quaternary

basins. However, no detailed tectonic or gravimetric research has been reported to date on the intramontane sedimentary basins of Western Betics.

The Tortonian–Messinian Ronda Depression, located in the External Zone of the Betic Cordillera, constitutes a good example of an intramontane depression that can provide new insights into the development of recent deformation consisting mainly of medium to large scale folds, and very scarce meso and microfaults. The aim of this contribution is to describe in detail the Late Miocene folds that deform its sedimentary infill, as well as their relationship with the heterogeneous pre-Miocene basement structure. New gravity data acquired for this study determine the distribution of evaporitic rocks below the sedimentary infill, and allow us to discuss the role of their distribution on the reactivation of basement antiforms that affect the Neogene infill.

GEOLOGICAL SETTING

The Betic-Rif Cordillera (Fig. 1) is an arc-shaped orogen that constitutes the western end of the Mediterranean Alpine chain. The outer arc of this orogen consists of a fold-and-thrust belt (External Zones), while the inner arc is composed of an allochthonous pile of tectonic complexes including metamorphic rocks (Internal Zones). The External Zones comprise the Subbetic and Prebetic zones, the latter outcropping only in the eastern Betic Cordillera. The Internal Zones are formed by three main complexes that are, from bottom to top: the Nevado-Filábride (outcropping only in the Eastern and Central Betics), the Alpujárride and the Maláguide complexes. In addition, the Dorsal and Predorsal complexes may be located in an intermediate position, in-between the Flysch Units and other units of the Internal Zones.

The Betic-Rif arc geometry developed during the latest Oligocene and Early to Middle Miocene as a result of the Eurasian-African plate convergence and the westward

drift of the Internal Zones. In the Western Betic Cordillera, this setting caused the northwestward thrusting and folding of the Mesozoic–Cenozoic rocks of the Subbetic Units in front of the migrating Internal Zones.

Since the Miocene, sedimentary basins were individualised and record the transition from marine to continental sedimentation as a consequence of relief uplift. Deposition in the External Zones mainly took place in the Guadalquivir foreland basin (Sanz de Galdeano and Vera, 1992; Viseras et al., 2004), and was conditioned by huge olistostromic masses from the frontal part of the External Zones. At the beginning of the Late Miocene, several piggy-back basins were individualized from the Guadalquivir foreland basin (Sanz de Galdeano and Vera, 1992), during the development of the Subbetic fold and thrust belt (Roldán-García, 1995; Ruano et al., 2004; Crespo-Blanc, 2007), with different sedimentary and tectonic signatures, due to the northwestward progression of their mobile basement.

The Ronda Depression (Fig. 1) constitutes one of the largest piggy-back basins in the Western Betics. It is located over the northwesternmost Subbetic Units with continuous structure, the Subbetic Chaotic Complexes and the Flysch Units. Subbetic Units are formed by Triassic to Middle Miocene sedimentary rocks with local intercalations of igneous rocks. The Subbetic structure in this region is described by Crespo-Blanc and Campos (2001) as a NW-vergent fold-and-thrust belt, post-Early Burdigalian in age. Within the Betic External Zones, Keuper Triassic levels have been traditionally considered as detachment levels where the main thrust structures are generally rooted.

Towards the northwestern 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, deformed by the combined development of thrusts, slides, transcurrent faults and diapirism (López-Garrido and Vera, 1974; Calaforra and Pulido-Bosch, 1999; 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 between the different Subbetic Units. The Mesozoic and Cenozoic sediments that constitute these units are turbiditic clays and marls.

The sedimentary infill of the Ronda Depression (Fig.2), Late Miocene in age, is divided into four formations (Serrano, 1979; Rodríguez-Fernández, 1982). From bottom to top these are: I) Gastor Formation, made up of sands, silts and heterogeneous conglomerates of Tortonian age that lie unconformably over the Triassic basement rocks in the northwestern border of the depression. II) Tajo Formation, formed by heterogeneous conglomerates of pre-Late Tortonian age with clasts sourced from the Subbetic and Flysch southern units. This formation lies unconformably over the Flysch Units. III) Mina Formation, located conformably over the Gastor Formation and composed of marls and sandy silts of Early Tortonian-Late Messinian age. It crops out in the western half of the depression. IV) Setenil Formation, Late Tortonian-Late Messinian in age, cropping out throughout the depression, except in 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) differentiated two members in this formation: a Limestone Member and a Calcarenite Member.

The Neogene sedimentary infill of the Ronda Depression lies unconformably upon the External Zones and Flysch basement. The boundaries of the depression are not conditioned by high angle faults such as those for many other basins of the Betic

Cordillera, like the Granada Basin (Rodriguez-Fernández and Sanz de Galdeano, 2006). Only locally inside the Ronda Depression can we find NE-SW and NNW-SSE minor normal faults, which do not reach cartographic scale. These brittle structures mainly deform the Tortonian calcarenites of the Setenil formation and are concentrated in the southern part of the basin.

ORTHOGONAL FOLDS IN THE RONDA DEPRESSION

The Neogene sediments of the Ronda Depression are deformed mainly by two sets of NNE-SSW and WNW-ESE kilometre scale folds (Fig. 2). These structures have a heterogeneous pattern of distribution and are 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 is no significant relief due to the low dip of the layers and the outcropping marls. In the northern part, however, fluvial incision allows us to observe tilted Tortonian-Messinian calcarenites (Fig. 3A). Thus, folds probably do not propagate through these regions and affect only the southwestern part of the Depression.

The Salinas Fold is the major structure observed in the whole Depression. It is a NNE-SSW box shaped antiform with a two-kilometre-wide crest. The dip of the flanks (Figs. 2, 3 and 4) increases sharply, from 20º to 70º. This feature produces straight boundaries in the topographic intersection that are not related to large NE-SW normal faults, as suggested by previous authors (Serrano, 1979). The antiform culmination is essentially flat, with dips lower than 20º. Therefore, the geometry of the fold could be described as a box-fold without vergence (Fig. 3B). Although previous authors (Rodríguez-Fernández 1982) point to the local presence of some patches of Triassic rocks cropping out in the core of the antiform, only Tortonian-Messinian calcarenites

176 from Setenil Formation and some patches of Messinian marls have been distinguished
177 in this study. Six cartographic folds could be described running parallel to the Salinas
178 Fold, constituting a fold set that deforms an area 6 km long and 8 km wide (Figs. 2 and
179 3B). In addition, it is possible to identify minor folds with metre wavelengths and the
180 same orientation as the Salinas antiform, approximately N30ºE. Their geometry is open,
181 with flanks dipping around 15-20º. These minor folds are fundamentally located in the
182 crest zone of the Salinas Fold and deform the calcarenites of Setenil Formation. It is not
183 possible to determine if they also deform the Late Messinian Limestone Member of the
184 Setenil Formation, because there are scarce outcrops of these rocks, and in all of them a
185 10º southeastward dip is observed.

186 The WNW-ESE Sierra de la Sanguijuela antiform (Fig. 2), situated SW of the
187 Salinas Fold, is parallel to the southwestern border of the Depression. Its shape
188 resembles that of the Salinas antiform and could be considered as the prolongation of
189 this fold, given that there are no interference structures between the two, although there
190 is a sharp change in fold axis orientation. There are no minor antiforms parallel to the
191 Sanguijuela antiform, in contrast to the Salinas one. On both sides of these folds there
192 are two synforms with the same orientation, NE-SW in the Salinas sector and WNW-
193 ESE in the Sanguijuela sector (Fig. 2 and 3B). Marls belonging to the Mina Formation
194 crop out in the core of these synforms.

195 The most recent rocks deformed by the kilometre scale box-folds are Tortonian-
196 Messinian calcarenites. The Depression contains no Pliocene deposits and the
197 Quaternary sediments are limited to non-deformed river channels. Although it is not
198 possible to determine the cessation of activity of these folds, field observations indicate
199 that both types of folding were simultaneously active in Late Tortonian to Late
200 Messinian times.

GRAVITY ANOMALY AND DEEP STRUCTURE

A new gravity survey was performed in the Ronda Depression in order to determine the sedimentary thickness and the deep geometry and nature of its basement. Data were acquired along several profiles covering all the sedimentary infill and the Depression boundaries. Measurement stations along profiles were spaced at an average of 250 m. Gravity data were acquired using a Master Worden gravimeter, with a maximum accuracy of 0.01 mGal. The measurement sites were located with an e-trex Garmin GPS and a barometric altimeter with 0.5 m altitude precision. The measurements were referenced to a base station of the I.G.N. national gravimetric network, located in Málaga, in order to calculate the absolute gravity value. Data acquisition was carried out in cycles of less than three hours in order to correct accurately the instrumental drift, tide variations and barometric changes. Topographic corrections were done using a digital terrain model with a grid of 10 m of cell size for the first 1600 m, and 200 m thereafter, to a total distance of 22 km. The Bouguer anomaly was calculated taking into account a standard density (d= 2670 kg/m^3) similar to the density of the Subbetic rocks that form the basement.

The heterogeneous basement lithology (and therefore density) of the region made it impossible to isolate the residual anomaly associated with the Neogene sedimentary infill of the Ronda Depression, and therefore constrain its thickness. At the southern boundary the basement is formed by Subbetic limestones with a high density contrast, whereas the northern basement comprises Triassic rocks and Flysch units with density values that are similar to or lower than the sedimentary infill.

In the Bouguer anomaly map 1:1.000.000 (I.G.N., 1976) (Fig. 5.A.), values in the southern part of the Ronda Depression increase progressively to the SE. However, in

the western and northern parts, the isolines have a N-S direction, and anomaly values increase gradually to the W. Changes in the direction of the regional anomaly signalled by this Bouguer anomaly map are probably related to the deep crustal structure and make it impossible to distinguish the anomaly related to the basement heterogeneities and the variations in thickness of sedimentary infill. Therefore, a 2D model that considers both sedimentary infill and shallow basement structures was made using the Bouguer anomaly, with the GRAVMAG V.1.7. program of the British Geological Survey (Pedley et al., 1993). A constant regional anomaly value due to the deep crustal structures was taken into account.

The main features of the detailed Bouguer anomaly map of the Ronda Depression (Fig. 5B) are two marked gravity minima observed in the middle and northwestern parts of the depression. The southernmost one is elongated in NE-SW orientation and reaches values of -88 mGal, while the minimum placed to the north reaches -78 mGal. These minima are not detected in the regional gravity map of Spain 1:1.000.000 (I.G.N., 1976; Fig.5.A.) due to its scale and to the large distance between measurements. There is a good correlation between the southernmost minimum and the main structures of the Ronda Depression.

In sedimentary basins, minima are generally related to depocentres located on synformal structures. Yet the correlation of the Bouguer gravity minima with the Depression's major structures evidences that the southernmost minimum is over the Salinas antiform, which is the main antiform of the Depression (Fig.5.B.). In some cases gravity minima could also be related to ancient depocentres that are inverted. However, this is not the situation in the Ronda Depression, where the lower parts of the sedimentary sequence are located in the core of the antiform. In other words, the gravity

anomaly in this region allows us to determine the basement structure of the depression, but does not enable us to estimate accurately the sedimentary infill geometry.

In order to integrate the surface geological data, a NW-SE gravity model orthogonal to the main NE-SW folds was developed (Fig. 5C). The average density assigned to each geological unit is related to the main lithology observed in the field according to Telford et al. (1990): 2300 kg/m^3 for the sedimentary infill, 2670 kg/m^3 for the Subbetic limestones, 2350 kg/m^3 for the Flysch sandstones, and 2000 kg/m^3 for the Triassic marls with gypsum. The anomaly values change gradually, with no sharp variations at the boundaries of the sedimentary infilling. This fact, together with the surface geological data, suggests that the borders of the depression are unconformities and are not related with high angle faults. In the southern part of the Depression, the Neogene sediments lie over Subbetic units with a continuous NE-SW structure. However, northwest of the Salinas fold, the basement has a chaotic structure and there are kilometre scale limestone blocks included in a Triassic matrix.

The thickness of the Neogene sedimentary infill is irregular and may attain 300 m according to the geological data and the gravity modelling, although this cannot be proved because there are no clearly related residual anomalies. Moreover, the thickness of Triassic rocks located at the base of the model cannot be established accurately due to the lack of other geophysical data such as well logs or seismic profiles. However, it is possible to determine the areas where these rocks are close to the surface and their geometry. The gravity method can provide evidence of lateral contrasts in density, but not the vertical contrast, as horizontal layers whose effect is a constant regional level may be overprinted upon regional anomalies.

DISCUSSION

In neotectonic studies, the precise dating of structures is essential for elucidating the tectonic evolution of a region. The study of deformed intramontane sedimentary basins is especially interesting, because it allows for precise estimations of the age of recent tectonic structures. However, it is necessary to establish the mechanisms of deformation in order to distinguish regional tectonic structures from local reactivations that may lead to erroneous interpretations. In this way, the development of orthogonal oriented structures, such as folds, should be analysed in detail in order to determine their simultaneous development in a deformation stage, or the overprinting that would provide evidence of two regional deformation stages. The presence of low density rocks at depth is the main mechanism responsible for reactivation of earlier structures through salt tectonics involving only local deformations. The Ronda Depression, affected by irregularly distributed orthogonal folds, provides a good opportunity to investigate the late development of folds and to discuss the implications thereof.

In the Western Betics, a main part of the brittle and ductile deformation of the outcropping tectonic units took place before Tortonian, as rocks of Late Miocene age lie unconformably over the deformed External Zones and Flysch Units. In addition, deformation in these Late Miocene rocks is local and generally of low intensity, consisting of tilting, gentle folds and very scarce faults with small displacements. The NE-SW fold-and-thrust belt that determines the structure of the Subbetic basement (Fig. 6A) was developed in a post-Early Burdigalian deformation event (Crespo-Blanc and Campos, 2001; Pérez-López and Pérez Valera, 2007; Crespo-Blanc, 2008). In this stage, accompanied by regional NW-SE compression due to the Eurasian-African plate convergence, low density rocks were differentially accumulated at the core of the antiformal structures.

Gravity data acquired in the Depression allow us to discern the different nature of the basement beneath the current Neogene sedimentary succession. This fact conditions the heterogeneous distribution of the folds deforming the Late Miocene infill. Subbetic limestones are identified continuously from the southern border of the Depression up to its central part. In addition, northwards of the Salinas antiform, large kilometre scale blocks of high density (Fig. 5C) are attributed to Jurassic limestones of the Subbetic units, which may represent the Subbetic Chaotic Complexes. Bouguer gravity minima point to areas of accumulation and the shallow position of the low density Triassic rocks. These minima have NE-SW elongated shapes (Fig. 5B), similar to the trend of the folds that deform the surrounding basement and the southern part of the Depression. In the northwestern minimum, the gravity model suggests that Triassic rocks are located directly under the undeformed sedimentary infill. However, the southeastern minimum coincides with the core of the Las Salinas antiform (Fig. 5B and C), suggesting that low density rocks were related to the fold development.

During Late Tortonian-Late Messinian, marine sediments of the Ronda Depression were deposited in a progressive unconformity (Rodríguez-Fernández, 1982) over the Salinas antiform due to the interference of sedimentation, erosion, and tectonic processes (Fig. 6B). The development of box-fold geometries could be the consequence of remobilization and uplift of previous thick Triassic rock accumulations (Fig. 6C) simultaneous with the uplift of the Betic Cordillera and the transition from marine to continental sedimentation. Other factors are needed to develop this type of fold in compressional settings, as has been established using analogue models (Bonini, 2003): the load due to the overlying sedimentary sequence, the presence of fluids and, indeed, a sharp inversion of density in the sedimentary sequence. The combination of these factors may condition the fold type: from type 1 (Bonini, 2003) localized above a thrust

up to type 2, formed in front of the most external thrust. The development of box fold geometries, as the Salinas-Sanguijuela antiform, is a transitional situation between these cases.

Previous studies (Serrano 1979) have proposed a strictly diapiric origin of the Salinas fold controlled by the presence of ductile Triassic rocks in its core. In any case, the previous tectonic setting would have conditioned an early NE-SW elongated accumulation of low-density rocks that determined the late reactivation of the fold. This setting, where the fold orientation is inherited, may then be analysed to understand the local deformations, but cannot be used to determine recent regional deformation stages.

The salt tectonics that occurred during the reactivation of the Salinas antiform may be responsible for its geometry and location, featuring sharp boundaries, box-fold shape without predominant vergence, and restricted deformation in the southeastern part of the depression. The orthogonal development of the Sanguijuela fold was produced roughly simultaneously to the formation of the Salinas fold. Both folds are connected along an area of highly curved crest line showing none of the typical dome-and-basin interference structures that are generally seen in orthogonal trending folds. The sharp change in orientation in the southern part of the Depression may be due to the WNW-ESE thick, rigid limestones of the southwestern boundary of the depression. The late folds do not propagate outside the depression. The competent folded upper layer, made up of the Jurassic limestones and Neogene sedimentary infill, accommodates the southward pushing of the Las Salinas antiform by the development of the La Sanguijuela antiform. Similar examples of fold development related to a high accumulation of ductile Triassic rocks have been described by other authors in the Betic Cordillera (López-Garrido and Vera, 1974).

348 The slightly deformed and unconformable Neogene sedimentary infill in the
349 Western Betic Cordillera suggests that the deformation is concentrated largely in
350 correspondence of deep rooted structures that only affect the frontal part. Piggy-back
351 basins like the Ronda Depression mainly underwent northwestward transport and uplift.
352 Crespo-Blanc and Campos (2001) considered the late folds to be open, deforming the
353 thrust planes that affect the basement of the depression. However, the continuity of the
354 folds affecting the surrounding basement with the folds observed in the Late Miocene
355 infill is not well constrained, and probably does not occur because field observations
356 give no evidence that the basal unconformity has been affected by these structures in the
357 basin boundaries. Thus, folds of the Late Miocene sedimentary infill are local, restricted
358 to the Ronda Depression and may not be used to date the regional deformation stages.
359
360 CONCLUSIONS
361 A detailed study of the Ronda Depression, including field geological and gravity
362 observations, has provided some insights for analysis of fold reactivation in a
363 framework of heterogeneity of the basement and sedimentary infill. An early
364 deformation stage during NW-SE African and Eurasian plate convergence affected the
365 basement during Early and Middle Miocene times and produced a NE-SW oriented
366 fold-and-thrust belt. During this stage, the accumulation of ductile low density Triassic
367 rocks, belonging to the Subbetic sequence, took place in the core of NW vergent folds.
368 Since the Late Miocene, the Ronda Depression may be considered a northward-moving
369 piggy-back basin, having experienced uplift, evidenced by the elevation of the
370 unconformable Tortonian-Messinian marine sediments, but scarce tectonic deformation.
371 The remobilization of this inherited and heterogeneous distribution of Triassic rocks is
372 evidenced by Bouguer gravity minima. The accumulation of low density basement

373 rocks controlled the development of the Salinas box-shaped antiform, while the
374 simultaneously developed orthogonal Sanguijuela fold is determined by the competent
375 southern border of the basin.

376 Reactivation of basement folds by diapirism is one of the main mechanisms of
377 deformation of the sedimentary infill placed above low density basement rocks.
378 Although reactivated folds are generally elongated and may be interpreted as a
379 consequence of a new regional tectonic compressive deformation stage, several features
380 may be considered as evidence of the different mechanisms at work during their origin:
381 heterogeneous fold distribution; no dominant vergence and mostly box geometries.
382 Furthermore, this setting can give rise to the simultaneous development of folds with
383 orthogonal axes. These recent folds are formed by salt tectonics and should be analysed
384 with caution, as has been done in the Ronda Depression, because they document local
385 deformation stages only.

386

387

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486
487 FIGURES

488

489 Figure 1. Geological setting of the Ronda Depression in the framework of the Betic and
490 Rif Cordillera.
491 Figure 2. Tectonic sketch of the Ronda Depression. Cross sections of Fig. 3 and gravity
492 profile of Fig. 5c are indicated. UTM coordinates are in kilometres.
493 Figure 3. Geological NW-SE cross-sections of the Ronda Depression. The position of
494 the cross-sections is marked in Fig. 2. Gravity data have been qualitatively taken into
495 account to constraint the deep structure. The legend is the same as in Fig. 2.
496 Figure 4. Panoramic view and orthophoto image of the Salinas Antiform. Photographs
497 show the high dip of the flanks in this box fold.

Figure 5. Bouguer anomalies and gravity model: a. Bouguer anomaly map of Betic Cordillera 1:1.000.000 (I.G.N. 1976); b. Bouguer anomaly map of Ronda Depression. The modelled profile and the axial traces of the folds are drawn (in grey: minor open folds; in white: Salinas and Sanguijuela folds); c. 2D NW-SE gravity model.

Figure 6. Tectonic evolution sketch of fold reactivation in the Ronda Depression. a) Post-Early Burdigalian deformation event that determines the structure of the Subbetic due to the NW-SE Eurasian-African plate convergence; b) During Late Tortonian-Late Messinian, marine sediments of the Ronda Depression were deposited in a progressive unconformity; c) Since Late Tortonian, remobilization and uplift of previous thick Triassic rock accumulations simultaneous to the uplift of the Betic Cordillera.

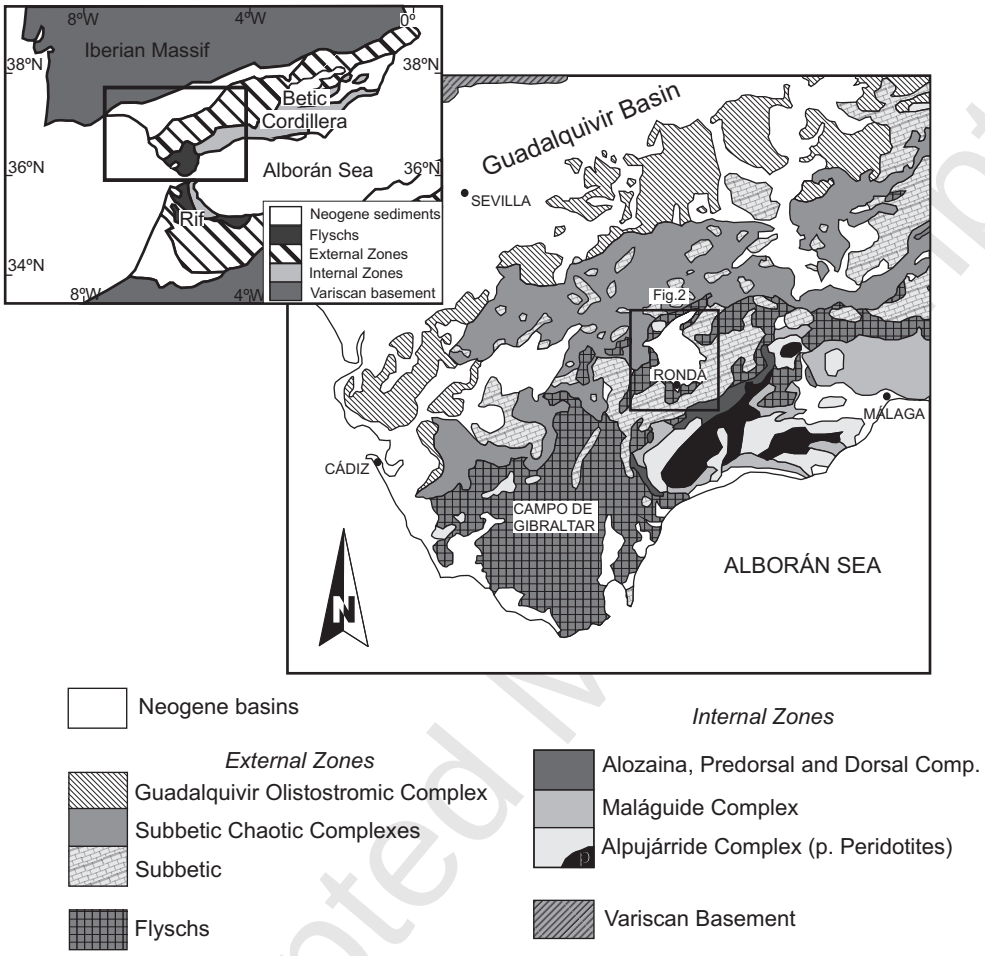
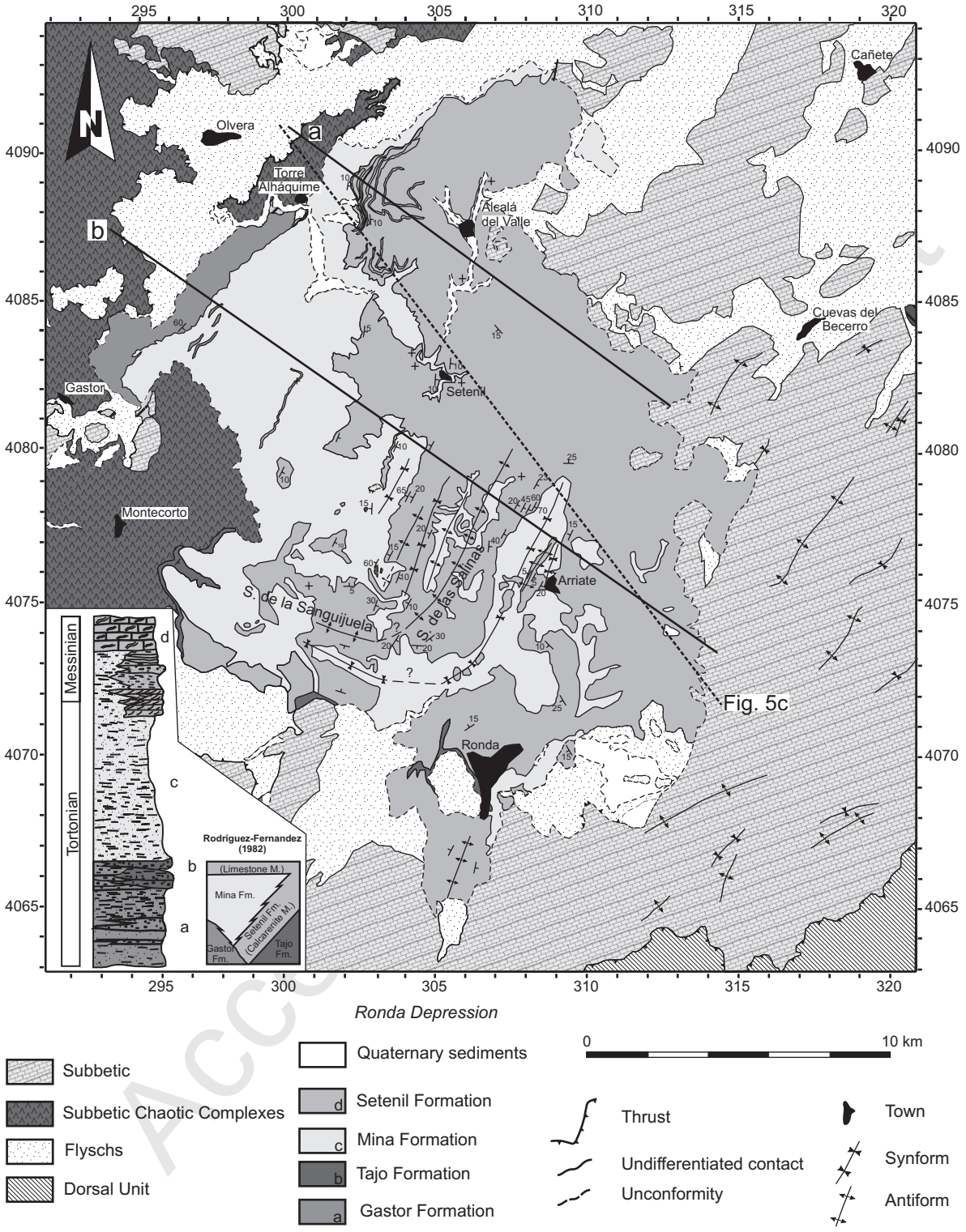


Fig.1 Ruiz-Constán et al.



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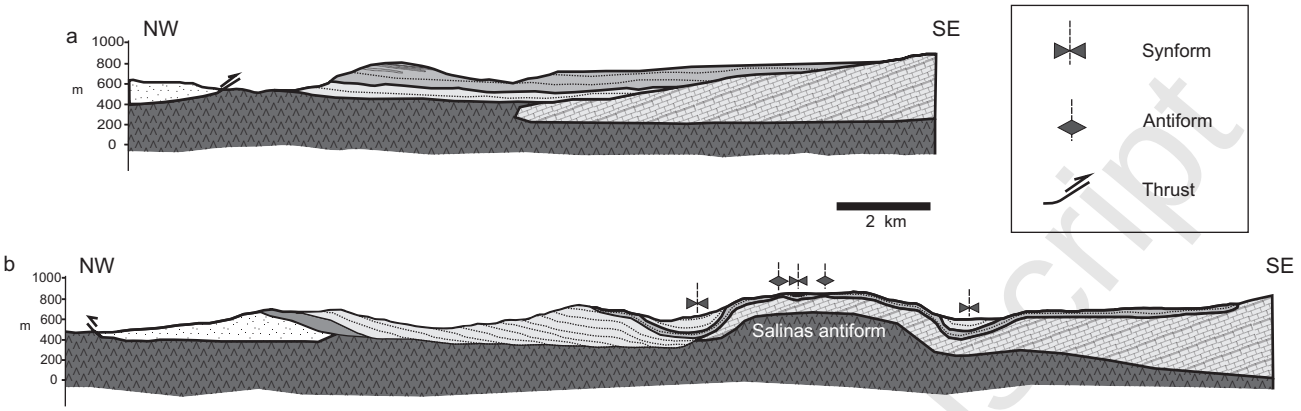

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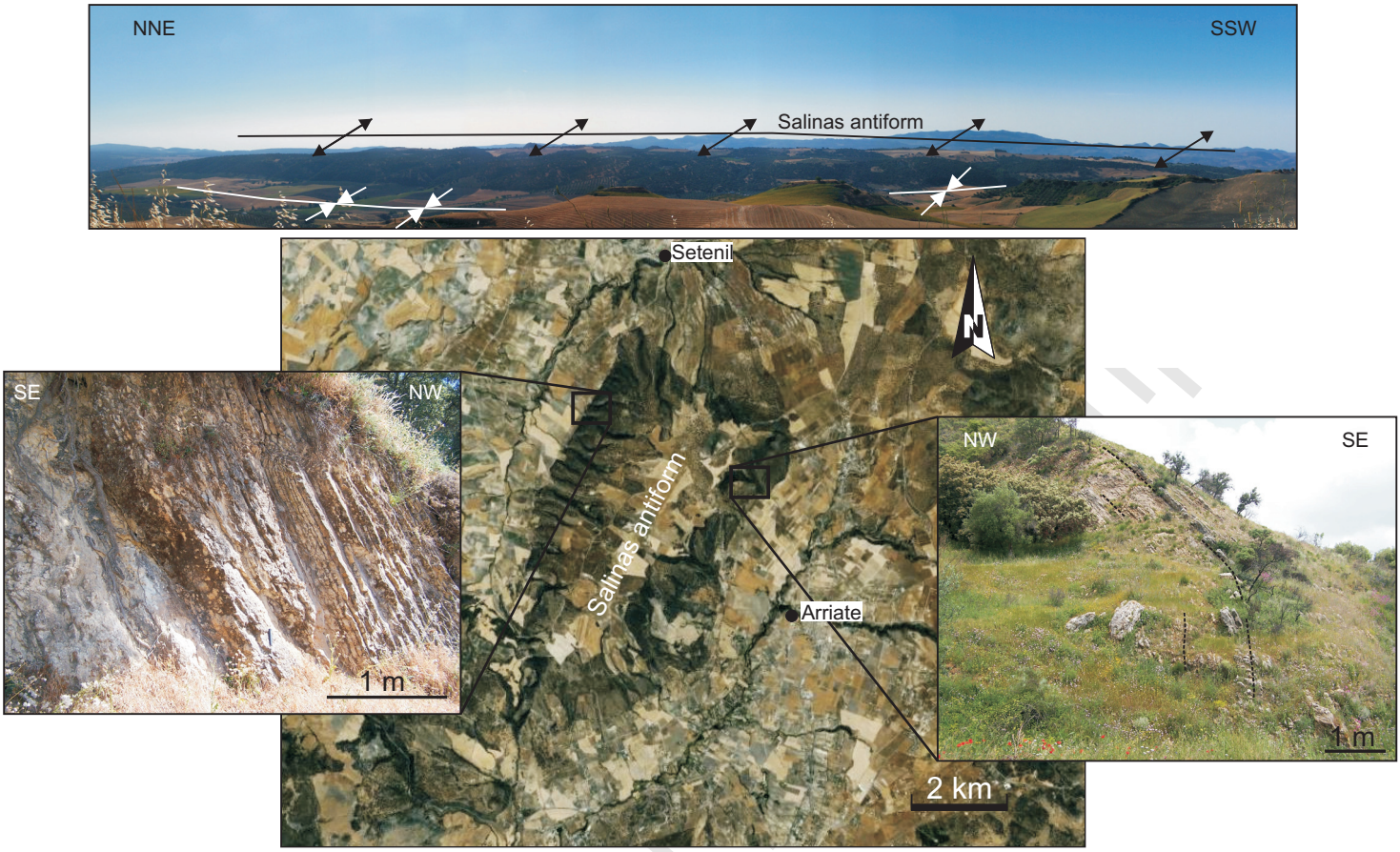

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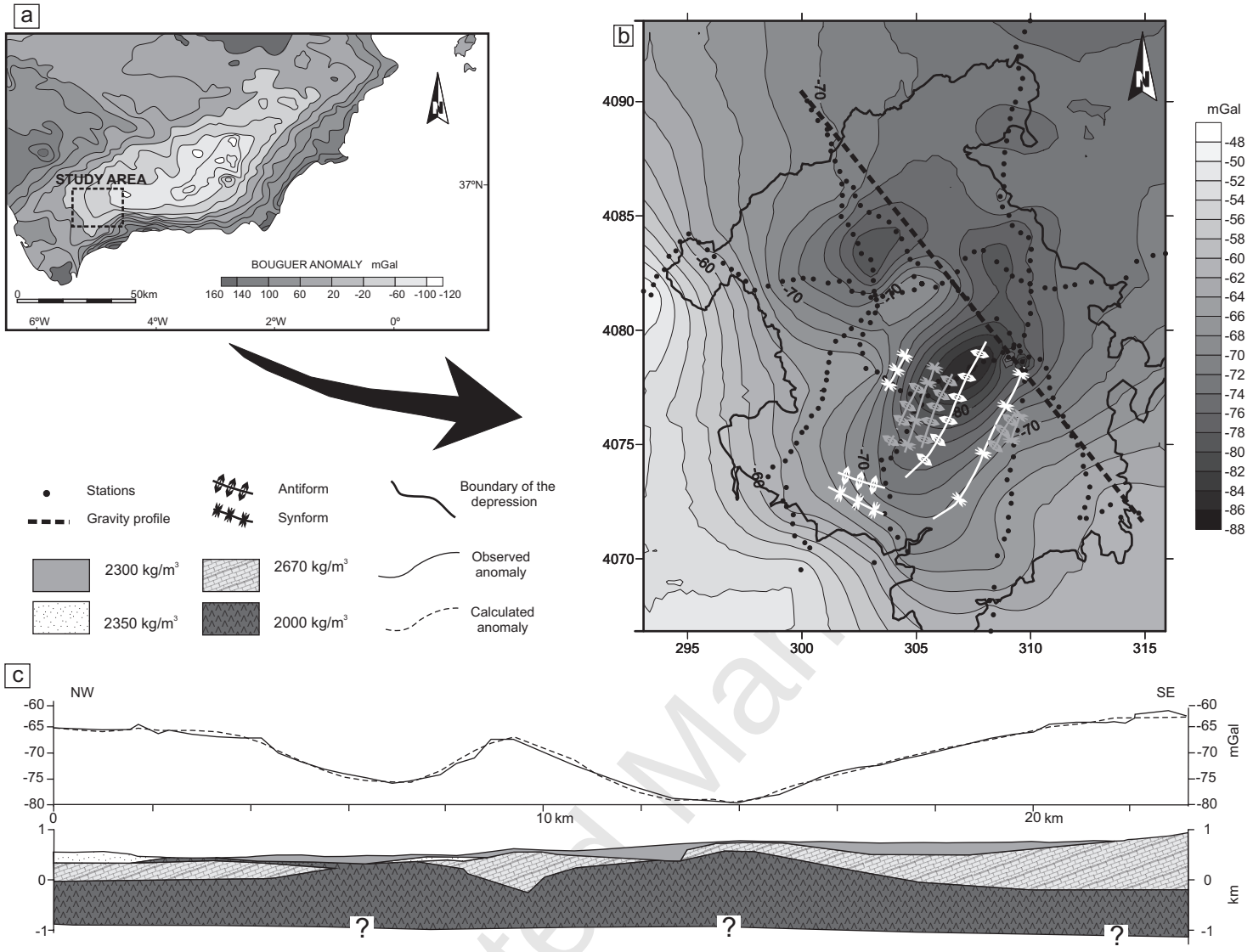

Fig.5 Ruiz-Constán et al.

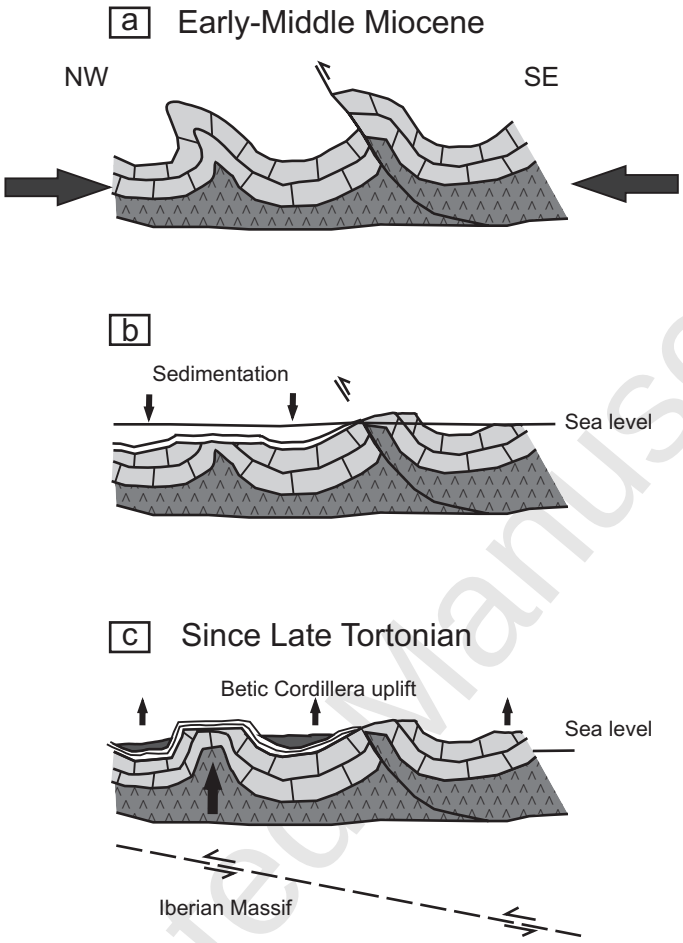

Fig6. Ruiz-Constán et al.