The transition from basement-involved thick-skinned to detachment thin-skinned tectonics in the Basque-Pyrenees: The Burgalesa Platform and vicinities.

Eloi Carola[1]*, Josep Anton Muñoz[1], Stefano Tavani[2], Eduard Roca[1]

[1]*GEOMODELS Research Institute, Departament de Geodinàmica i Geofísica, Universitat de Barcelona. C/ Martí Franquès s/n. 08028 Barcelona, Spain*

[2] Dipartimento di Scienze della Terra. Università Federico II, Napoli. Italy.

* Corresponding author: Eloi Carola.
e.carola@ub.edu; eloicarola@gmail.com
Universitat de Barcelona, Facultat de Geologia.
C/ Martí Franquès s/n
08028 Barcelona
Tel.: +34 934034028

Bullets:

- Determination of the transition from thick-skinned to thin-skinned in the Burgalesa Platform of the Basque-Pyrenees.

- New interpretation model for the Burgalesa Platform with thick-skinned tectonics at the western boundary and thin-skinned tectonics at the eastern one.

- Thickness distribution of the Upper Triassic salt allowed the detachment of the Mesozoic succession.

Keywords: Thick-skinned; Thin-skinned; Inversion Tectonics; Basque-Pyrenees; Cantabrian Mountains; Burgalesa Platform.

Abstract

Interpretation of seismic data at the margins of the Burgalesa Platform in the Basque-Cantabrian Pyrenees has allowed proposition of a new structural model that combines different modes of deformation during oblique tectonic inversion, conditioned by the distribution of Triassic salts. Deformation was decoupled by the presence of the salt horizon between basement-involved thrusts inverting formerly Triassic and Late Jurassic-Early Cretaceous extensional faults and a detached thrust system involving the Upper Triassic to Neogene sedimentary package. Such different styles of deformation were not only stacked vertically above and below the salt, but most importantly, they change from one to the other along strike across the transversal edges of the Triassic salts. The Burgalesa Platform detached thrust system was confined between the basement-involved structures of the Cantabrian Mountains westward and the NW tip of the Iberian basement-involved structures (San Pedro) southward. This together with the obliquity between the Pyrenean contractional shortening direction and the strike of the previous extensional faults, mostly at the late stages of deformation, determined the strike-slip reactivation of the basement-involved inverted faults and the lateral extrusion of the Burgalesa Platform detached Mesozoic successions above the salt toward the SE to form a prominent thrust salient oblique to the main Pyrenean trend. The proposed model combines thick-skinned with thin-skinned structural styles during oblique tectonic inversion and is consistent with the surface data, including the fracture system, the available subsurface data and the mechanical stratigraphy.

1 Introduction

Structural style of orogenic systems depends on many factors such as crustal rheology, inherited structure or distribution of weak horizons (Ellis *et al.*, 1998;

Beaumont *et al.*, 2000; Bug and Greya, 2005; Butler *et al.*, 2006; James and Huismans, 2012). Positive inversion tectonics, understood as the contractional reactivation of an extensional fault, has been documented since the 1980's in sedimentary basins using seismic data (e.g. Badley *et al.*, 1989; Chapman, 1989), field studies (e.g. Schröder, 1987; Butler, 1989) and analogical modelling (e.g. Koopman *et al.*, 1987; McClay, 1989). During the inversion and with the progressive incorporation of the basin into the fold and thrust belt, several geological features must be taken into account. Among others: i) the position of inherited extensional faults causing weak points within the crust and acting these as preferential deformational paths (e.g. Coward, 1994; Holdsworth, 2004; Sepher and Cosgrove, 2005; Carrera *et al.*, 2006; Mouthereau and Lacombre, 2006, Amilibia *et al.*, 2008, among others); ii) the rheology of materials and the presence of weak layers promoting the partition of deformation and controlling the evolution during inversion or the decoupling between the cover and the basement (e.g. Davis and Engelder, 1985, Bassi G. 1995; Steward *et al.*, 1997; Steward and Argent, 2000); iii) the variation in stratigraphic thickness or lateral changes in facies inside the basins, due to differential subsidence, fault activity, salt mobilization or erosion controlling the spacing and distribution of main faults as well as the position of lateral structures and its propagation in space (e.g. Davis and Engelder 1985; Jaumé and Lillie, 1988; Calassou *et al.*, 1993; Boyer, 1995; Mitra, 1997; Corrado *et al.*, 1998; Macedo and Marshak, 1999; Fischer and Jackson, 1999; Soto *et al.*, 2002; Spratt *et al.*, 2004; Marshak, 2004; Pfiffner, 2006). All these parameters result in two different styles of deformation during the evolution of the thrust belt. Thick-skinned tectonics, in which the basement is involved such as the inner parts of some orogens like the Alps, the Pyrenees or the Andes contrasting with the thin-skinned tectonics in which the cover is detached from the basement such as the external parts of the Pyrenees or the Zagros among others. Additionally, some orogens present along-strike or along-time variation in the style of deformation (Hill *et al.*, 2002; Mazzoli *et al.*, 2008).

These two styles of deformation are present in the Basque Pyrenees and the Cantabrian Mountains of the Pyrenees. The first, with thin-skinned tectonics with the Mesozoic cover detached from the basement at the Upper Triassic salt layer. The second, with thick-skinned tectonics with the basement involved within the structures (Muñoz, 1992, 2002; Alonso *et al.*, 1996, Pulgar *et al.*, 1999; Vergés *et al.*, 2002; Gallastegui, 2000; Roca *et al.*, 2011). The Burgalesa Platform is the area where the along-strike transition between the two styles occurs. Both thin-skinned and thick-skinned tectonic models have been proposed in order to explain the evolution of the area either with surface geology or subsurface data thus explaining the surface geology (Hernaiz, 1994; Hernaiz *et al.*, 1994; Malagón *et al.*, 1994; Rodríguez-Cañas *et al.*, 1994; Serrano *et al.*, 1994; Espina *et al.*, 1996; Espina, 1997; Pulgar *et al.*, 1999; Gallastegui, 2000; Tavani *et al.*, 2011; Quintana, 2012). The aim of this work is in one hand, to integrate the surface and subsurface data with the observations and constraints reported by other authors in order to propose a new evolution model for the Burgalesa Platform. This model contains the transition between the two styles of deformation present along-strike of the studied area. On the other hand, to better characterise the configuration of the extensional basin that controlled the contractional deformation during the Pyrenean Orogeny and the implication that it had.

2 Geological setting

The structural evolution of the doubly-vergent Pyrenean Orogen was controlled by the inversion of Lower Cretaceous extensional basins (Beaumont *et al*., 2000; Jammes *et al.*, 2014). The extensional event related to the opening of the North Atlantic and the Bay of Biscay during Late Jurassic-Early Cretaceous resulted in the development of intracontinental basins at the rift margins, the exhumation of continental mantle at the last stages of rifting, and the spreading of oceanic crust at the western Bay of Biscay ridge (Roca *et al*., 2011). This event allowed the local deposition of more than 10 km of syn-rift sediments overlying the Jurassic carbonates and the stretched and thinned continental crust (e.g. Le Pichon and Sibuet, 1971; Montadert *et al*., 1979; García de Cortázar and Pujalte, 1982; Pujalte, 1982; Mathieu, 1986; Ziegler, 1987; García-Mondéjar *et al.*, 1996; Bois *et al.*, 1997; Pedreira *et al.*, 2007; Ruiz, 2007; Ferrer *et al.*, 2008; Jammes *et al.*, 2009, Roca *et al.*, 2011). The convergence between the Eurasian and the Iberian plates during Late Cretaceous-Cenozoic produced the subduction of Iberia towards the north, with the subsequent inversion of the inherited Mesozoic basins (e.g. Le Pichon and Sibuet, 1971; Muñoz, 1992, 2002; Alonso *et al.*, 1996; Vergés and García-Senz, 2001). The along strike structural changes of the Pyrenean orogen resulted from the inversion of a segmented rift system at the northern Iberian margin (Roca *et al.*, 2011). Thus, the Cantabrian Mountains, the Basque-Pyrenees and the Pyrenees s.s. are distinct structural domains of the Pyrenean orogen bounded by transfer faults inherited from the previous Early Cretaceous extensional system (Fig. 1A).

The Cantabrian Mountains, at the western part of the Pyrenean orogen (Fig. 1A and B), are constituted by Paleozoic rocks deformed during both the Variscan Orogeny (Pérez-Estaún *et al.*, 1991) and the Pyrenean Orogeny, as well as by the Permian, Triassic and Late Jurassic-Early Cretaceous extensional events. Pyrenean contractional deformation caused the reactivation of the Variscan faults and the tightening and steepening of previously developed folds (Pérez-Estaún *et al.*, 1988; Alonso *et al.*, 1996; Pulgar *et al.*, 1999; Alonso *et al.*, 2009). Most of the contractional deformation has been accommodated into the northern retro-wedge along the Cantabrian margin. In the southern part (pro-wedge) the thrust system involves the Variscan basement and displaced the Cantabrian Mountains towards the south over the Duero foreland basin (Álvarez-Marrón *et al.*, 1996; Pulgar *et al.*, 1997; Gallastegui, 2000; Gallastegui *et al.*, 2002; Pedreira, *et al.*, 2003; Pedreira *et al.*, 2007; Roca *et al.*, 2011; Martín-González and Heredia, 2011, among others). The thrust front mostly corresponds to a fault propagation fold with its related frontal thrust only outcropping in some areas (Fig. 1A and B). As a result, the Duero basin shows a major syncline geometry.

Further east the Basque-Pyrenees (Fig. 1A and C) resulted from the inversion of the W-E striking Upper Jurassic-Lower Cretaceous Basque-Cantabrian Basin during the Pyrenean deformation. This is one of the basins that were developed at the southern passive margin of the Bay of Biscay. The Basque-Pyrenees are displaced southward more than 15 km over the Ebro Foreland Basin by means of a south-directed low-angle thrust detached into the Upper Triassic evaporites (Martínez-Torres, 1993; Carola *et al.*, 2013). The frontal structure (Sierra de Cantabria Frontal Thrust) and associated folds present a north-facing concave shape in map view where in the central parts they strike almost W-E whereas, at the edges they progressively rotate to a more WSW-ENE and NW-SE orientation in the east and west respectively (Fig. 1A).

In continuation with the Cantabrian Mountains and to the southwest of the Basque Pyrenees there is a distinct structural domain known as Burgalesa Platform (Fig. 1A). It consists of a moderately deformed succession of Triassic to Upper Cretaceous sediments with some preserved syn-tectonic Miocene continental rocks. The Burgalesa Platform shows a thrust salient with a prominent bend at its eastern edge where structures change the trend from WNW-ESE to NE-SW (Fig. 1A).

There is not a consensus as far as the tectonic style and the structural evolution of the Burgalesa Platform are concerned. Different structural models have been proposed during the last decades, among them the most distinct ones are: i) low-angle thin-skinned; ii) low-angle thick-skinned, and iii) transpressive high-angle thick-skinned (Fig. 1D). In the thin-skinned model, the Jurassic-Cretaceous succession is detached from the Variscan basement into the Triassic evaporites and transported at least 10 km southward (Hernaiz, 1994; Hernaiz *et al.*, 1994; Malagón *et al.*, 1994; Rodríguez-Cañas *et al.*, 1994; Serrano *et al.*, 1994). The low-angle thick-skinned model is based on the existence of a basement-involved low-angle thrust below the Mesozoic succession, in continuation with the floor thrust of the thrust system deforming the Cantabrian Mountains (Espina *et al.*, 1996; Alonso *et al.*, 1996; Espina, 1997; Pulgar *et al.*, 1999; Gallastegui, 2000; Alonso *et al.*, 2007; Quintana, 2012). Finally, in the third model the contractional structures are transpressive elements related with high-angle and deeply-rooted right-lateral strike-slip faults, such as the Ubierna fault (Tavani *et al.*, 2011). The implication of this third model is that the Burgalesa Platform Domain would represent an uplifted area of the deformed Duero foreland.

These contrasting models are based on different data sets, mostly from surface geology, that at least partially support the proposed structural evolution for each model. A question arises about which of these models is the most consistent with all the available data in the area (surface and subsurface) and compatible with other considerations such as the inherited structures, the mechanical stratigraphy of the rocks involved or the kinematics of the area. This work brings together subsurface and surface data in order to discuss a new model. Any proposed structural model would have to consider the Late Jurassic-Early Cretaceous extensional faults that deformed the area as well as the presence of a thick layer of Triassic salts as drilled by numerous wells.

3 Tectonostratigraphic units of the Burgalesa Platform

The stratigraphic succession of the study area can be divided into several units, which are associated to the different tectonics events that took place from Triassic to Cenozoic times (Fig. 2).

The Paleozoic succession is made up of Ordovician quartzites and phyllites , Devonian ferruginous sandstones, Carboniferous limestones and Permian clays. The Lower to Middle Triassic sediments are constituted by conglomerates and sandstones of the Buntsandstein facies and dolostones of the Muschelkalk facies, which are associated to the rifting stage that produced the breakup of Pangea (Van Veen, 1965; Wagner *et al.*, 1971; García-Mondéjar *et al.*, 1986; Alonso, 1987). All the pre-Upper Triassic succession is referred as basement throughout the paper.

Above, the Upper Triassic Keuper facies consists of salt, anhydrite, gypsum and shales with sub-volcanic basic intrusions. This unit is the most important detachment level. Its ability to flow under the right conditions is the responsible of its irregular distribution as evidenced by the amount of diapirs present in the study area (i.e. Aguilar (Serrano and Martínez del Olmo, 2004), Poza de la Sal (Hempel, 1967; Quintà *et al.*, 2012), Salinas del Rosío (Hernáiz and Solé, 2000), among others). This unit is widespread all along the Pyrenees, although it is absent in significant areas (i.e. eastern Pyrenees, aragonese western Pyrenees) as well as in the Cantabrian Mountains.

After the Triassic extensional event, a quiescence stage took place during the Jurassic. This period of time is characterised by the development of a carbonate ramp, mainly limestones and dolostones with interbedded evaporites at the lower parts of the unit. Whereas, deep marine hemipelagic sediments with limestones, marls and shales characterise the upper portions of this unit (Pujalte *et al.*, 1988; Robles *et al.*, 1989, 2004; Quesada *et al.*, 1991, 1993, 2005; Aurell *et al.*, 2003).

The second and main extensional event is related to the opening of the North Atlantic and the Bay of Biscay during the Late Jurassic to Early Cretaceous. The stratigraphic record of this period in the Burgalesa Platform is characterised by fluvio-deltaic siliciclastic sandstones that locally reach more than 4 km (Pujalte, 1981, 1982; Pujalte *et al.*, 1996, 2004; Hernández *et al.*, 1999). Forced folding of the Jurassic succession and salt mobilization took place during this extensional event (Tavani *et al.*, 2013).

The upper Albian-Upper Cretaceous succession is made up of conglomerates and sandstones at the base and limestones and marls at the top post-dating the Early Cretaceous extension. It is associated to a gradual deepening of the succession passing from continental to marine environment during several transgressive events (Aguilar, 1971; Ramirez del Pozo, 1971; Portero, 1979).

The Cenozoic syn-orogenic sediments are mainly constituted by conglomerates, sandstones and red clays. The pebbles and cobbles are mainly from the Upper Cretaceous limestones and dolostones (Portero *et al.*, 1979). This unit is restricted to the border of the study area (i.e. Ebro and Duero foreland basins) and also in the Bureba Sub-basin and Villarcayo syncline (Fig. 3).

4. Structure of The Burgalesa Platform

The internal structure of the Burgalesa Platform is dominated at surface by wide and gentle folds with very shallow dips affecting the Upper Cretaceous limestones. Most of the contractional structures are located between the thrust front and the Ubierna fault where they define a narrow belt of folds and related thrusts (Folded Band, Fig. 3). North of the Ubierna fault there is a structural continuity between the Cantabrian Mountains and the Burgalesa Platform at surface as evidenced by a continuous tilted panel towards the ESE of Triassic to Upper Cretaceous rocks overlying the Variscan basement (Fig. 3). To the north, there is also an apparent structural continuity with the Basque Pyrenees, although a series of anticlines and faults connect the structures in the Ebro reservoir area with the Sierra de Cantabria Frontal Thrust, thus representing the northern edge of the Burgalesa Platform (Fig. 3). The SE part of the Burgalesa Platform is characterised by NE-SW trending folds (Hontomín flexure, Rojas), along which salt structures occur (Poza de la Sal, Hontomín and Rojas domes). These folds developed during the sedimentation of the Miocene fluvial deposits that finally covered them, masking the relationships between the NE-SW structures, the Ebro Basin and the Sierra de Cantabria frontal thrust. The upper and younger Miocene conglomerates define a re-entrant in map view between the Sierra de Cantabria thrust front and the Burgalesa Platform (Fig. 3). At surface the significance of such re-entrant cannot be deciphered, mostly if it is only the result of the unconformable disposition of the Miocene conglomerates over the NE-SW structures that would connect with the Sierra de Cantabria thrust or if, alternatively, represents a structural re-entrant of the Ebro Basin between the Basque Pyrenees and the Burgalesa Platform. The solution given to this uncertainty has a strong impact on the structure and the deduced structural evolution of the Burgalesa Platform and can only be resolved by subsurface data as will be discussed later on. The Miocene syn- to post-tectonic sediments of the Duero Basin also mask the frontal structure of the Burgalesa Platform and also the available subsurface data is crucial for its proper understanding.

Here below the main structural features of the Burgalesa Platform and its relationships with the surrounding units will be discussed in detail taken advantage of the available seismic sections and well data acquired in the area for hydrocarbon exploration.

4.1. Interpretation of the seismic and well data

A seismic profile across the Cantabrian Mountains thrust front, west of the Burgalesa Platform, shows the thick-skinned structural style of this unit as well as its relationships with the Duero foreland basin (Fig. 4). The floor of the Paleogene-Neogene Duero Basin is characterised by a continuous and constant thickness succession of the upper Albian-Upper Cretaceous post-rift sediments (sandstones of the Utrillas Fm. and limestones) unconformably overlying the Paleozoic basement rocks (Gallastegui, 2000). These sediments crop out at surface in the hangingwall of the frontal thrust with subvertical to overturned northward steeply dipping beds structurally above the Devonian rocks. The bedding attitude of the Cretaceous sediments in the hangingwall together with the location of the south-dipping reflections of the equivalent succession in the seismic section define the frontal syncline of a fault propagation fold and demonstrate the reduced displacement of the frontal thrust in the subsurface. Moreover, this thrust does not reach the surface as the younger syn-orogenic Neogene conglomerates, adjacent to the thrust front, show a progressive unconformity above the Paleogene vertical conglomerates that overlie the Upper Cretaceous limestones (Fig. 4). Thrusts and related folds also affect the basement and the Upper Cretaceous sediments in the Duero foreland basin. Their displacement caused growth geometries in the younger Neogene clastic sediments (Fig. 4).

An E-W seismic profile across the eastward tilted panel of Triassic to Lower Cretaceous stratigraphic units illustrates the transition between the eastern edge of the Cantabrian Mountains and the Burgalesa Platform Domain (Fig. 5). In this section, the east-dipping panel of continuous and strong reflections attributed to the Jurassic and to the Lower Cretaceous terminates in a syncline. Below the Mesozoic tilted panel, a set of west-dipping reflections has been imaged into the chaotic seismic facies of the basement between 3,5 and 2 TWT seconds (Fig. 5). It has been considered as a continuous seismic event, which merges with the axial surface of the above described syncline at the bottom of the Mesozoic succession, and interpreted as a thrust involving the basement of the Cantabrian Mountains, climbing up section laterally into the Upper Triassic evaporites of the Burgalesa Platform. This structure has the same structural position as the frontal anticline of the Cantabrian Mountains in the hangingwall of the floor thrust of the basement-involved thrust system, but differently with respect to the Duero basin the thrust was not emergent as it detached into the Triassic salts. Thus, east of the syncline, the Mesozoic succession of the Burgalesa Platform has been detached above the basement.

Detachment of the Burgalesa Platform from the basement can also be deduced from the interpretation of the seismic lines located further east. Two seismic lines across the Huidobro anticline, at the northern edge of the Burgalesa Platform, reveal a significant structural relief of the Jurassic succession above a continuous set of gently northward-dipping reflectors interpreted as the top of the basement (Fig. 6). The identification of the different packages of reflectors relies not only on their seismic facies, but also on the data supplied by the Tejón Profundo-1 well in the S-84-110 seismic line (Fig. 6A). The Tejón Profundo-1 well, drilled in the Huidobro anticline, encountered a repetition of the Mesozoic succession at 1700 meters below the surface. In addition, the register shows a thick salt succession (1200 m) underneath the lower Jurassic without reaching the bottom of the Keuper at the end of the well (3800 m.b.s.). The most puzzling geometry revealed by these seismic lines and the well is the mismatch of the positive structural relief when comparing the top of the Jurassic succession and the bottom of the Upper Cretaceous sediments. The amplitude of the anticline related to the back-thrust that duplicated the Jurassic and Lower Cretaceous beds decreases significantly in the Upper

Cretaceous succession. Moreover, there are no evidence of growth sediments into this succession and, most importantly, these sediments where deposited before the onset of the Pyrenean convergence. The Lower Cretaceous succession presents a thickening towards the south being this succession almost twice thicker than the succession in the Huidobro anticline where, in its turn, the Upper Triassic is significantly thicker. These relationships reveal salt withdrawal and salt inflation (Fig. 6).

East of the Huidobro anticline, the northern edge of the Burgalesa Platform is characterised by the NW-SE trending Villalta anticline (Fig. 3). An oblique seismic section across it shows its structure at depth (Fig. 7). The Upper Triassic to Jurassic succession of the NE limb of the anticline is involved into a hangingwall ramp above a flat-lying thrust that would be the eastward continuation of the back-thrust imaged in the Huidobro anticline by N-S trending seismic profiles (Figs. 6 and 7). The flat-lying reflections in the footwall would be in continuation with the Lower Cretaceous to Triassic succession drilled by the Tejón Profundo-1 well underneath the Huidobro back-thrust. These sediments are involved in the Poza de la Sal antiform and the related salt structure (Figs. 3 and 7). In the central sector of the seismic profile the shallower Mesozoic-Cenozoic reflectors appear folded in contrast with the flat-lying reflectors underneath at 2 TWT seconds. In the easternmost part, the Cenozoic and Upper Cretaceous sediments of the foreland basin have been imaged by more than 2 TWT seconds of strong, continuous and parallel reflections. They present similar signature and seismic facies as shown by seismic profiles in the Duero Basin further to the west. The lower reflections are characterised by an upper continuous and high amplitude set of reflectors above a semitransparent unit and a lowermost unit of continuous reflections lying above the acoustic basement. These 3 seismic units correspond to the Upper Cretaceous succession of the Duero Basin, which has been drilled by numerous exploration wells (compare Figs. 9 and 4, Gallastegui, 2000). The Cenozoic sediments progressively cover the allochtonous Mesozoic units towards the west, although the sole thrust truncates the lower ones. West of the thrust front the reflectors corresponding to the autochthonous Upper Cretaceous are difficult to follow westward underneath the sole thrust. They are truncated at the western edge of the profile by a strong west-dipping reflection that has been interpreted as a footwall ramp of the sole thrust.

The SE edge of the Burgalesa Platform corresponds to the NE-SW trending Rojas anticline (Fig. 3). A seismic section across the northern continuation of the Rojas anticline below the Miocene sediments shows a frontal thrust and a related anticline similar to and in continuation with the frontal structure described in the previous seismic section (Figs. 7 and 8). As a result, the geometry of the thrust front at the SE edge of the Burgalesa Platform would show a significant thrust salient, concave to the WNW, if the younger Miocene sediments would be removed. The seismic section of Figure 8 shows the relationships between the Burgalesa Platform and the Ebro foreland basin at its westernmost reentrant between the Burgalesa Platform and the Basque Pyrenees (Fig. 3). In the eastern portion of the section, the foreland is imaged as a layer cake succession of strong and continuous reflectors of the Cenozoic and Upper Cretaceous sediments. The thrust truncates the lower part of the Cenozoic succession and its related anticline shows growing relationships with the middle to upper part of the Cenozoic foreland basin sediments corresponding to the Early to Middle Miocene. The western part of the seismic section is dominated by a wedge of Lower Cretaceous sediments sandwiched between lower subhorizontal reflectors, Jurassic in age, and an upper east-dipping panel of Upper Cretaceous sediments. The Lower Cretaceous wedge thins eastward and the reflectors onlap onto the Jurassic succession

A seismic section located northeastward of the Burgalesa Platform and crossing the Sierra de Cantabria Frontal Thrust shows the thin-skinned tectonic style of deformation in this part of the orogen (Fig. 9). The Jurassic to Cenozoic succession has been detached above the Upper Triassic salts and thrusted on top of the flat-lying Cretaceous to Cenozoic sediments of the Ebro foreland basin in continuation with the foreland described in previous seismic sections. The foreland is imaged as a layer cake parallel succession at all directions as shown by the W-E and S-N sections in which no deformation is visible. In this area, more than 1.5 seconds TWT thick succession of strong and continuous reflections alternate with weak reflections attributed to the Cenozoic foreland basin infill. Additionally in the Rioja 1 well, located towards the south-east in the Ebro foreland basin, more than 3 km of Cenozoic succession was testified (Lanaja, 1987). Below the Cenozoic, strong and continuous reflections characteristic of the Upper Cretaceous seismic facies and the upper Albian overlie the basement. In the hangingwall, the Lower Cretaceous succession experiences a thickening towards the north. The northern part of the section is characterised by the Villarcayo syncline filled with Cenozoic sediments and where the Trespaderne-1 well is located.

4.2. Interpretation of the structure: integration of surface and subsurface data

Three south-north and one northwest-southeast cross-sections integrating the surface geology and the subsurface data, allow to determine on one hand, the transition between the two styles of deformation and on the other hand, the structural significance of the Burgalesa Platform with respect to the Pyrenean Orogen (Fig. 10).

The westernmost S-N cross-section is characterised by basement involved structures, outcropping in the northern sector, whereas, detached structures occur in the southern part (I-I' in figure 10). The transition between the two domains occurs southwards of the Golobar fault where the depocenter of the syn-extensional sediments is located. South of this transition, the syn-rift succession progressively thins contrasting with the Triassic salts that thickens towards the Ubierna Fault. The wells drilled in the hangingwall of this structure (i.e. Basconcillos-1 and Abar-1) testify both, a strongly incomplete Jurassic succession and the duplication of the syn-rift sediments below the Jurassic. The interpretation for this structure is that of a small back-thrust, rooted into the Triassic salt layer cutting a previously developed extensional fault that produced the partial omission of the Jurassic and the thickening of the Triassic salt. Southwards, in the folded band, both the Jurassic and the syn-rift successions are reduced. The thrust system climbs up southwards being this part of the Burgalesa Platform riding over the Duero Foreland Basin and also over the north-directed and basement involved San Pedro structure.

Similar to the previous one, the middle S-N cross-section shows the involvement of the basement in the northern sector and the detachment of the Mesozoic in the southern one (II-II' in figure 10). The transition between the two styles takes place northwards of the Lower Cretaceous depocenter where the Cadialso-1 well drilled more than 3 km of syn-rift sediments. The northern area is characterised by the presence of a salt wall in the Ebro area in which the Cabañas-1 well testifies the omission of the Jurassic succession. To the north, the surface geology allows to constrain the thrust that uplifts the Jurassic succession outcropping westwards of the trace of the cross-section (Fig. 3). South of the depocenter the syn-rift succession thins until it reaches the Ayoluengo salt-cored structure, where the wells drilled a thickness of *ca.* 1000 meters of Lower Cretaceous rocks. The southern sector of the Burgalesa Platform is characterised by the thrusting over the Duero Foreland Basin and by a thinning of both, the Jurassic and syn-rift successions. The southernmost part of the cross-section is where the San Pedro wells are located, constraining the presence of this structure at depth.

The easternmost S-N cross-section here presented shows the prolongation of the Ebro reservoir salt wall at the northern sector (III-III' in figure 10). In this area, the Navajo-1 well testifies a thin syn-rift succession directly overlying the Triassic salts, with the omission of the Jurassic rocks. The well drilled more than 2000 meters of Triassic salts and reached the top of the basement at 3900 meters below the surface (m.b.s.). Contrasting with this, the adjacent Arco Iris-1 and Manzanedo-1 wells drilled all the Cretaceous and the Jurassic successions. These data suggest that the Navajo antiform resulted from the squeezing of a salt wall related with an Early Cretaceous extensional fault in the hangingwall of a basement involved thrust.

In the Huidobro area, as stated before, the back-thrust duplicates the succession as testified by both, the Tejón Profundo-1 well and the seismic line (Fig. 6). However, a problem arises when comparing the amount of shortening observed in the pre-rift Jurassic horizons and the one observed in the Upper Cretaceous beds (Fig. 10). Part of this mismatch in the amount of shortening can be the result of the obliquity between the cross-section and the thrust transport direction. Nevertheless, this would not explain the observed difference. In addition, this would not also explain the differences in structural relief between the deeper structural levels and the shallower ones (Fig. 6). Such difference in the structural relief results into the unconformity at the bottom of the post-rift upper Albian-Upper Cretaceous sediments and the erosional truncation geometry of the syn-rift horizons below the unconformity, mostly visible in the southern limb of the Huidobro anticline (see details in the seismic lines of Fig. 6). Differences in the structural relief can be partially explained by salt inflation during rifting. The southern limb of the salt body drilled by the Tejón Profundo-1 well will be the locus of the back-thrust during the subsequent contractional deformation at Paleogen-Neogene times (Hernaiz et al., 1994; Malagón et al., 1994). The other explanation for the observed structural relationships, and mostly the unconformity observed at the bottom of the post-rift succession, would be that part of the observed contractional deformation is pre upper Albian, and thus linked with the extensional system as part of a toe system. The Early Cretaceous extensional basins were transported to the N-NE and detached above the Triassic salts. The structural relief created by salt structures during the extensional deformation, such as salt walls and diapirs along the northern edge of the Burgalesa Platform would have controlled the geometry and location of contractional structures in the northern part of Burgalesa Platform. The possible existence of salt welds basinward the salt structures would have enhanced the contractional reactivation of the flanks of the salt structures facing the rift margin. The existence of Early Cretaceous contractional features were already cited by Serrano *et al.* (1994), although not documented, these contractional structures are commonly related with the distal parts of extensional systems (Peel *et al.*, 1995; Rowan *et al.*, 1999; Rowan *et al.*, 2004; Lacoste *et al.*, 2012; Cartwright *et al*., 2012, among others). Southwards, the thrust system climbs up section and overrides the Duero Foreland Basin. In this part, a narrow corridor between the Burgalesa Platform and the San Pedro Structure is present.

Finally, the NW-SE section illustrates the transition between thick-skinned and thin-skinned styles of deformation in the NW-SE direction (IV-IV' in figure 10). In the north-western part, the basement is involved in the thrust system and as a consequence the Mesozoic sequence is uplifted and tilted towards the SE as described in figure 5. In this portion, the Coto-1 well drilled a thin Triassic salt succession before the top of the basement at *ca*. 3000 m.b.s. Eastward, the Mesozoic succession is detached into the Triassic salts as stated before (Fig. 5). The hangingwall cutoff of the basement coincides with the depocentre of the syn-rift sediments, as does in sections I and II, where Triassic salts were thin, either depositionally or by welding during the salt withdrawal towards the margins of the basins. The syn-rift succession thins above the inflated salt, reaching less than 1000 meters in the Huidobro-2 well. From this sector to the Villalta-1 well, the oblique to the transport view of the back-thrust is the main structural feature as described in figure 7. In this section, the differences in the structural relief between the Upper Cretaceous beds and the Jurassic ones in relation with the thrust that duplicates the pre-rift succession, as well as the lack of evidence of a major back-thrust at surface, reinforces the Early Cretaceous age for part of this structure. The south-eastern edge of the Burgalesa Platform is characterised by the perpendicular view of the salt-cored Rojas structure and the frontal thrust system climbing over the Ebro Foreland Basin.

Determining the main succession boundaries by integrating all the subsurface data allows to characterise the distribution pattern of the main depocenters and thinned areas (Fig. 11). The distribution of the Triassic salt layer has two main trends in the Burgalesa Platform. On the one hand, the NE-SW orientation present in the Ayoluengo and Rojas area where in this latter case a total thickness of 1400 meters was drilled by the well Rojas NE-1. On the other hand, the WNW-ESE orientation present along the northern block of the Ubierna Fault System, where the wells Abar-1 with 1000 meters, the Pino-1 with 300 meters or the Montorio-1 with 450 meters of salt is present, and along the Villalta anticline in where the Tejón Profundo-1 well drilled more than 1200 meters of Upper Triassic salts. All these thicknesses are minimum values because the wells did not drilled the whole Upper Triassic reaching the succession located below. In contrast, the Coto-1 well only drilled 100 meters of Triassic salts and reached the basement at more than 4000 meters below the surface. In contraposition, the Lower Cretaceous distribution can be summarised in an opposite manner of the Upper Triassic salt distribution. The thinned areas corresponds to the thickened salt areas such as the northern block of the Ubierna fault in the Ayoluengo structure and in the Villalta areas. The thickened syn-rift area is located to the NW where the salt accumulation is minimum. Even though in this area the Lower Cretaceous is outcropping and the total thickness cannot be precisely determined, a total thickness of almost 3000 meters is registered by the Coto-1 well. The thinned south-eastern area is associated with the boundary of the extensional basin during the Cretaceous as demonstrated by the seismic line described in figure 8 where the syn-rift drastically reduces its thickness and also how onlap onto the Jurassic. The onlap stated before, extends in a broad band almost parallel to the Ubierna fault trace displaying a southwards direction of migration (Fig. 12A). The map view trace of the onlaps has a roughly WNW-ESE orientation with a bend in the middle where it attains a more NW-SE orientation thus similar as the Ubierna fault. A S-N seismic section crossing the southern limit of the Burgalesa Platform shows a southern sector, in which thrusts deform the whole Mesozoic successions and a northern sector where cover deformation is almost absent (Fig. 12B). The southern area corresponds to the Folded Band located southwards of the Burgalesa Platform and the seismic facies do not allow to interpret the Mesozoic successions. Whereas, the northern area is characterised by north-dipping pre-rift panel, a sedimentary wedge constituted by syn-rift successions and an almost horizontal post-rift succession eroding the one located immediately below (Fig. 12B). Within the sedimentary wedge, the sedimentary geometry observable onlaps both the pre-rift and the syn-rift successions with a southwards direction of migration extending from the northern limit of the seismic and ending close to the Ubierna fault.

5 Discussion

The data and structural interpretations herein included demonstrate the strong decoupling of the Mesozoic successions from the basement rocks located below the Upper Triassic salts in the Burgalesa Platform and, in general, in the Basque Pyrenees. Decoupling occurred during both the Late Jurassic-Early Cretaceous extensional deformation and the subsequent tectonic inversion and fold and thrust development at Paleogene-Neogene times.

The scarcity of extensional faults bounding the main depocenters of the syn-rift sequences, the onlap geometries of the syn-rift beds onto the Jurassic carbonates lying above the Triassic salts and all the observed salt structures that developed during the extensional deformation suggest that salt decoupled deformation above and below. Of particularly relevance are the contractional structures described in the northern part of the Burgalesa Platform (Fig. 6). They involve a few kilometres of shortening and demonstrate decoupling and a significant detachment of the cover of the Burgalesa Platform to the N-NE during thin-skinned extensional deformation.

Extensional faults affecting the cover mostly emerged at the rift margins, at present inverted along the thrust front southward the Ubierna fault system. These faults marked a sharp transition in the stratigraphic record. Thus, at the rift shoulders, at present the Duero and Ebro foreland basins, the Mesozoic pre-rift sequences are not preserved, the syn-rift sediments were not deposited and the upper Albian post-rift sequences unconformably overlie the basement rocks. This stratigraphy is constant in the foreland all along the thrust front including in the Bureba re-entrant at the NE edge of the Burgalesa Platform (Fig. 7 and 9). In the hangingwall of the marginal extensional detachment a gap in the pre-rift Jurassic should be expected to account for the onlap geometries in the Burgalesa Platform, as observed in the most frontal preserved thrust imbricates. Such Jurassic gaps related with the extensional detachment have also been observed and described further east in the Basque Pyrenees and in the Bay of Biscay (Jammes *et al.*, 2009; Rowan, 2014).

The extensional faults affecting the Upper Triassic salts as well as the cover in the Burgalesa Platform produced the migration of salt. The sedimentation of the syn-rift successions accentuated the salt mobilisation (Vendeville and Jackson, 1992; Hudec and Jackson, 2007, among others). At the end of the extensional deformation, the salt thickness distribution pattern was characterised by two areas of major accumulation surrounded by areas where the thickness of the salt layer was depleted and even welded (Fig. 11). The WNW-ESE orientation was associated to inherited Late Permian-Triassic extensional structures reactivated during the Late Jurassic-Early Cretaceous extensional event and the NE-SW orientation associated to newly develop extensional faults (Tavani and Muñoz, 2012 and Tavani *et al.*, 2013). The Ubierna, Huidobro and Navajo areas are characteristic of the first orientation whereas, the Rojas area at the easternmost boundary is characteristic of the second orientation. As a consequence, this salt distribution has a strong impact during the inversion of the basin. This characteristic is well known and the configuration of the former basin, the mechanical stratigraphy and the thickness and the spatial distribution of the ductile levels can determine differential advance of the thrust system towards the foreland basin with respect to areas where this level is absent or strongly reduced (Jaumé and Lille, Davis and Engelder, 1985; Bahroudi and Koyi, 2003; Luján *et al.*, 2003; Sepehr *et al.*, 06; Vidal *et al.*, 2009; among others).

Extensional faults thinning the basement below the Triassic salt should be expected to occur northward the emergent marginal extensional fault system. The Ubierna fault and related salt structure would be located above a basement-involved high-angle extensional fault offsetting the base of the salt. However, the salt was thick enough to allow decoupling during northward-directed detachment and developed drape folds above the basement step. A northward displacement of more than 10 km above the extensional detachment is necessary to explain the width of the observed onlap geometries north of the Ubierna structure as shown in figure 12. This would be also consistent with the described syn-extensional contractional features northwards and the distribution of the syn-rift depocenters.

The spatial and thickness distribution of the Triassic pre-rift salt was dependent on the geometry of the Triassic extensional faults, which controlled the topography at the time of evaporite deposition during the late to sag phase of the Triassic rifting. In the western part of the Basque Pyrenees Triassic extensional faults (Ubierna, Golobar and Rumaceo faults among others) were arranged in a left stepped way. Rely ramps connecting the extensional faults were characterised by eastward dipping panels, some of them probably breached as suggested by Espina (1997), and defined an approximately north trending western edge of the Triassic salts.

Decoupling did not occur at the western edge of the Burgalesa Platform because of the absence of the Upper Triassic salts, either by no deposition or by erosion during the Late Jurassic-Early Cretaceous rifting. The western edge of the Triassic salts coincides with the transition from the thin-skinned tectonic style of the frontal part of the Basque Pyrenees and the Burgalesa Platform eastward to the thick-skinned tectonic style of the Cantabrian Mountains westward. There, coupling of the basement and cover during the Pyrenean deformation resulted in an increase of the structural relief and the eastward plunge of the structures at the eastern termination of the Cantabrian Mountains (Alonso *et al.*, 1996; Espina, 1997; Tavani *et al.*, 2013). Recent AFT and ZHe thermochronological data by Fillon (2012) along a cross-section in the eastern part of the Cantabrian Mountains yield a Late Eocene age for the onset of the exhumation of the basement involved during the inversion of the Cabuérniga and Rumaceo faults. Exhumation continued southward into the hangingwall of the Golobar fault at Oligocene times. A youngest Early Miocene exhumation age was acquired in the basement rocks in the hangingwall at the western termination of the Ubierna fault once uplift ended further north. Southward migration of basement exhumation is consistent with a forward propagating thrust system involving both basement and cover rocks and inverting the previously developed Triassic and Late Jurassic-Early Cretaceous extensional faults (Alonso *et al.*, 1996; Fillon, 2012). Moreover, the old exhumation ages (Jurassic to Paleocene) recorded in Cretaceous and Stephanian rocks along the thrust front (Fillon, 2012) demonstrate the limited amount of uplift and related displacement of the frontal thrust in agreement with the fault-propagation fold model suggested by Alonso *et al.* (1996).

As stated before, this N-S western boundary of the Burgalesa Platform has an eastward plunge, for this reason, the map view allows to project the surface geology towards the east and to extrapolate the subsurface geology downwards as shown by Tavani *et al.* (2013). However, in the light of the surface and subsurface data provided in this work, we must clarify that this down-plunge projection cannot be extrapolated eastward the transition between the two styles of deformation. This is because more to the east the Upper Triassic salt layer detaches the Mesozoic succession from the basement (Fig. 5). This disharmony between the cover and the basement is denoted by the surface geology in the area east of Aguilar where the cover structures are not reflected into the basement and with the amount of contractional and salt structures aligned along this N-S boundary such as the Aguilar, the Reinosa or the Pas structures from south to north (Espina, 1997, Fig. 3). The only structure that partially truncates the décollement level at the western Burgalesa Platform is the Golobar fault (Fig. 3). This would be in agreement with the right-lateral strike slip reactivation of the formerly inverted Golobar extensional fault during the last stages of deformation (Tavani *et al.*, 2011), coeval with the progression of deformation into the basement below the Burgalesa Platform (Fig. 5 and 10). Uplift and exhumation of the hangingwall of the Golobar fault during tectonic inversion occurred at Oligocene times (Fillon, 2012) and the right-lateral reactivation with reduced uplift would be younger.

Integration of all the observations, constraints and data presented in this work together with the data reported by several authors in the last years, requires a new model to explain the structural evolution of the Burgalesa Platform. The proposed model is a combination of thin-skinned and thick-skinned modes of deformation. Decoupling and related thin-skinned structures have been controlled by the initial distribution of Triassic salts. On the contrary, basement-involved structures have mostly determined by the reactivation of extensional faults. Oblique inversion tectonics played also a significant role. The increase of the obliquity between the strike of the faults and the shortening direction as the Pyrenean deformation progressed would have favoured strike-slip reactivation, both in the cover and in the basement, and lateral extrusion of the Burgalesa Platform (Tavani *et al.*, 2011; Quintà and Tavani, 2012).

The thick-skinned domain is characterised by the WNW-ESE to W-E basement-involved thrust structures of the Cantabrian Mountains (Alonso *et al.*, 1996; Gallastegui, 2000; Tavani *et al.*, 2013) and the Duero foreland basin (Fig. 4, Gallastegui, 2000). In addition, in this area, Tavani *et al.* (2011) reported the transpressive reactivation of outcropping faults (i.e. Ubierna, Golobar, Rumaceo). The thin-skinned domain spans eastwards of the basement cutoff along most of the entire Burgalesa Platform and also in the Basque-Pyrenees. This domain is characterised by the detachment and south-eastwards extrusion of the Burgalesa Platform as previously pointed out by Rodríguez Cañas *et al.* (1994) and Tavani *et al.* (2011).

The moderate deformation of the Upper Cretaceous sediments, with predominant subhorizontal beds at a roughly similar height, and the strong deformation along the southern and eastern edges of the Burgalesa Platform (Folded Band and Rojas structure respectively) are consistent with a fold and thrust belt detached on salt, being its edges determined by the abrupt termination of the Triassic salts in the hangingwall of previous extensional faults. The interpretation of the seismic data in the Bureba re-entrant of the Ebro foreland basin at the northern edge of the Rojas structure is crucial for the thin-skinned interpretation of the Burgalesa Platform (Fig. 3). The continuity of the seismic stratigraphy of the Bureba re-entrant with the Ebro and Duero basins, the salient geometry of the Rojas structure and the attitude of the different tectonostratigraphic packages there demonstrate detachment and thrusting of the Mesozoic successions of the Burgalesa Platform above the Duero-Ebro basins (Figs. 8 and 9). Thrust transport direction would be to the SE as suggested by the geometry of the Rojas salient (Rodríguez Cañas *et al.*, 1994). The geometry of the Bureba re-entrant prevents any attempt to connect the NE-SW trending Rojas structure with the Sierra de Cantabria frontal thrust with a continuous NE trend (Fig. 3) as it is done in many published structural sketches of the area. Moreover, a NW-SE trending thrust connecting the Rojas and Poza de la Sal is required to account for the stratigraphic differences between the foreland and the Burgalesa Platform, as observed in seismic sections (Fig. 7 and Fig. 8). The resulting geometry of the SE edge of the Burgalesa Platform can be hardly explained by a thick-skinned structural style. It would require the tectonic inversion of three different extensional faults: the Ubierna fault southward, the Rojas one eastward and a northern SW dipping one. There are evidence for the first two, but not for the latter. In addition, inversion of such fault system involving the basement would require vertical tectonics and piston-like deformation mode. This is not compatible with surface data neither with the geometries observed in seismic lines.

The attitude of the autochthonous Upper Cretaceous top cutoff line, located in the footwall of the sole thrust, gives an idea of the allochthony of the Burgalesa Platform. To know the position of such line, the NW tip of the Bureba re-entrant (Figs. 3 and 9) can be connected with the northernmost outcropping Upper Cretaceous folded sediments of the Duero foreland basin that are located to the south of the eastern Cantabrian Mountains basement rocks tip (Figs. 3 and 13). Such a line has an almost W-E trend in continuation with the equivalent cutoff line in the footwall of the Sierra de Cantabria frontal thrust (Fig. 13). The quality of the available seismic data does not allow to fully constrain the position of this line at depth below the Burgalesa Platform.

As shown in many tectonic settings (i.e. contractional, extensional or strike-slip) when a ductile level like salt or even shales is present the deformation is decoupled between the basement and the cover (Jaumé and Lille, 1988; Peel *et al.*, 1995; Coward and Stewart, 1995; Rowan *et al.*, 1999; Withjack and Callaway, 2000; Durand-Riard *et al.*, 2013; among others). This fact would make difficult to explain that in the study area, where a thick salt succession is present, the deformation was not decoupled across this layer thus resulting in a thick-skinned deformation.

With the proposed model, the amount of overlap between the allochthonous Mesozoic succession of the Burgalesa Platform and the autochthonous Mesozoic of the Ebro and Duero Foreland increase towards the southeast. This is denoted in figure 13 where the actual thrust front limit of the Burgalesa Platform and the limit of the Upper Cretaceous Autochthonous Footwall Cutoff (UCAFC) are overlapped. As shown for the south-eastern part of the cross-section IV-IV' (Fig. 10) and at the seismic section (Fig. 7) the amount of south-east displacement of the Burgalesa Platform with respect to the autochthonous is almost 15 km being this value close to the right-lateral displacement for the Ubierna Fault System pointed by Tavani *et al.* (2011). This south-east displacement is also in agreement with the Upper Cretaceous fracture pattern of the Burgalesa Platform (Quintà and Tavani, 2012).

This proposed model reflects the actual configuration of the studied area but it resulted from the partitioning of deformation through time. For such reason, the evolution is subdivided into three main stages each one characterised by a different kinematic of the structures. During the early stages of deformation, the north-directed basement-involved thrusts deforming the San Pedro structure were developed. At this time, the Burgalesa Platform was southward displaced thus reactivating and inverting the former extensional faults detaching the whole Mesozoic succession above the Upper Triassic salts. At the end of this deformational period, the San Pedro structure resulted in a NW-SE orientation in map view (Fig. 13). As deformation continued, the Burgalesa Platform was displaced towards the south until it overrode the San Pedro structure (Fig. 3). At this point, and may be because this latter structure acted as a backstop for the southward displacement of the Burgalesa Platform, the WNW-ESE Ubierna fault was reactivated in a right-lateral sense thus forcing the Burgalesa Platform to extrude towards the south-east overriding the Ebro Foreland Basin. During the last stages of deformation, the reactivation of basement structures deformed the Duero foreland and also the western Burgalesa Platform. Regarding to the reactivation of the Golobar fault, it would be in agreement with the deformation of the inner parts of the fold and thrust belt in order to preserve the tapper (Davis *et al.*, 1983; Dahlen, 1990; Boyer, 1995, among others). In addition, the oblique inversion of basement structures located below the detached

Mesozoic succession could be expected during the late stages of deformation as it progressed south-eastwards.

Even though the similarities in structural style between the San Pedro structure and the structures deforming the Duero foreland basin south of the Cantabrian Mountain front they were disconnected and are related to different thrust belts during the Cenozoic contractional stage. This asseveration is supported by the foreland deformation map pattern and by the relative timing between the different structures of both sectors partially constrained by the relative age of growth sediments and the exhumation ages of the eastern Cantabrian Mountains. On the one hand, the NW-SE San Pedro structure would be related to the Iberian Range. The north-directed basement-involved thrust of the San Pedro structure and the decrease of deformation westwards of this structure would be in agreement with the attribution of this structure as the westward continuation of the northern wedge of the Iberian Range in which the same characteristics are described (Álvaro *et al.*, 1979; Guimerà, 1984; Guimerà *et al.*, 1995; Salas *et al.*, 2001; Guimerà *et al.*, 2004). In addition, the obliquity between the NW-SE San Pedro structure and the WNW-ESE Burgalesa Platform together with the relative timing, being the San Pedro structure overrode by the Burgalesa Platform, also supports the disconnection between the two structural units. On the other hand, the southern deformation of the Cantabrian Mountain would be related to the Pyrenees instead of the Iberian Range. The eastwards decrease of deformation of the W-E orientated south-directed basement-involved structures described in the foreland together with the relative timing between the structures and the thermochronological ages of the Cantabrian Mountains are in agreement with the southward propagation of deformation of the Pyrenees.

6 Conclusions

The data presented in this study allowed to propose a new evolution model for the Burgalesa Platform which fully match with all the surface, subsurface and mechanical stratigraphic constraints. It supports the interpretation of the Burgalesa Platform as a result of the interference between thick- and thin-skinned styles of deformation, both in time and space, during the Cenozoic contractional stage. The western part or the Burgalesa Platform, close to the Cantabrian Mountains, is characterised by south-directed basement-involved structures whereas, the eastern part is characterised by thrusts detached at the Upper Triassic salts overriding the foreland basin. These differences are related to the distribution of the Upper Triassic salt layer, resulted from the Triassic and Late Jurassic-Early Cretaceous extensional events, that controlled the deformation during the Pyrenean Orogeny. The boundary that divides the two styles of deformation connects the easternmost deformation of Cantabrian Mountains in the Duero foreland basin with the western area of the Basque Pyrenees. This boundary crosses the Burgalesa Platform between the Golobar and Ayoluengo areas with a SW-NE orientation.

The confined location of the Burgalesa Platform with respect to the Cantabrian Mountains and the San Pedro structure together with the obliquity between the strike of extensional faults and the shortening direction of the Pyrenean Orogeny conditioned the evolution of the Burgalesa Platform. During the early stages of deformation, the southward displacement of the whole Basque-Cantabrian Pyrenees was coeval with the northward-directed San Pedro structure. As deformation continued, the right-lateral reactivation of the Ubierna Fault System, due to the backstop produced by the San Pedro Structure, resulted in the more than 15 km of south-east lateral extrusion of the Burgalesa Platform over the Ebro Foreland Basin. At the last stage of contraction reactivation of basement thrusts at the western sector deformed the Duero Foreland Basin as well as the Burgalesa Platform.

7 Acknowledgments

This work was carried out under the financial support of INTECTOSAL (CGL2010-21968-C02- 01/BTE) and CIUDEN (FBG305657) projects and also the "Grup de Recerca de Geodinàmica i Anàlisi de Conques" (2009SGR-1198). The Instituto Geológico y Minero de España (I.G.M.E.) is thanked for providing seismic sections. We also thank Seismic Micro-Technology and Midland Valley which generously provided Kingdom Suite and Move software.

8 References

Aguilar, M.J. 1971. Correlaciones por ciclos de aporte en el Albense de la Cuenca Cantábrica. *Acta Geológica Hispánica* **6**, 92-96.

Alonso, J.L. 1987. Estructura y evolución tectonoestratigráfica de la región del Manto del Esla (Zona Cantábrica NW de España). Tesis Doctoral. Universidad de Oviedo. 276pp.

Alonso, J.L., Pulgar, J.A., García-Ramos, J.C., Barba, P., 1996. Tertiary Basins and Alpine Tectonics in the Cantabrian Mountains. In: Friend, P.F., Dabrio, C.J., (eds.). Tertiary basins of Spain: The stratigraphic record of crustal kinematics. Cambridge, Cambridge University Press, 214-227.

Alonso, J.L., Pulgar, J.A., Pedreira, D. 2007. Relieve de la Cordillera Cantábrica. *Enseñanza de las Ciencias de la Tierra*, **15.2**, 151-163.

Alonso, J.L., Marcos, A., Suárez, A. 2009. Paleogeographic inversion resulting from large out of sequence breaching thrusts: The León Fault (Cantabrian Zone, NW Iberia). A new picture of the external Variscan Thrust Belt in the Ibero-Armorican Arc. *Geologica acta*, **7**, 451-473.

Álvarez-Marrón, J., A. Pérez-Estaún, J.J. Danñobeitia, J.A. Pulgar, R. Martínez Catalán, A. Marcos, F. Bastida, P. Ayarza Arribas, J. Aller, A. Gallart, F. Gonzalez-Lodeiro, E. Banda, M.C. Comas and D. Córdoba. 1996. Seismic structure of the northern continental margin of Spain from ESCIN deep seismic profiles. *Tectonophysics*. vol. 264, pp. 153-174.

Álvaro, M., Capote, R., Vegas, R. 1979. Un modelo de evolución geotectónica para la cadena Celtibérica. *Acta Geologica Hispanica*, **14**, 172-181.

Amilibia, A., Sàbat, F., McClay, K.R., Muñoz, J.A., Roca, E., Chong, C. 2008. The role of inherited tectono-sedimentary architecture in the development of central Andean mountain belt: Insights from the Cordillera de Domeyko. *Journal of Structural Geology*. **30**, 1520-1539.

Aurell, M., Robles, S., Bádenas, B., Rosales, I., Quesada, S., Meléndez, G., García-Ramos, J.C. 2003. Transgressive-regressive cycles and Jurassic paleogeography of northeast Iberia. *Sedimentary Geology*, **162**, 239-271. doi:10.1016/S0037-0738(03)00154-4.

Badley, M.E., Price, J-D., Backshall, L.C. 1989. Inversion, reactivated faults and related structures: seismic examples from the southern North Sea. In: Inversion tectonics Cooper, M.A. and Williams, G.D. (eds). *Geological Society Spececial Publications*. **44**, 201-219.

Bahroudi, A. and Koyi, H.A., 2003. Effect of spatial distribution of Hormuz salt on deformation style in the Zagros fold and thrust belt: an analogue modelling approach. *Journal of the Geological Society of London* **160**, pp. 719-733. doi: 10.1144/0016-764902-135.

Barnolas, A., Pujalte, V., 2004. La Cordillera Pirenaica. In: Vera, J.A. (Ed.), Geología de España. Madrid, SGE-IGME, 233–343.

Bassi, G. 1995. Relative importance of strain rate and rheology for the mode of continental extension. *International Journal Geophysics*. **122**, 195-210.

Beaumont, C., Muñoz, J.A., Hamilton J., Fullsack, P., 2000. Factors controlling the Alpine evolution of the central Pyrenees inferred from a comparison of observations and geodynamical models. *Journal of Geophysical Research*, **105**, 8121-8145.

Bois, C.; Pinet, B., Gariel, O. 1997. The sedimentary cover along the ECORS Bay of Biscay deep seismic reflection profile. A comparison between the Parentis basin and other European rifts and basins. *Mémoires de la Societé Géologique de France*, **171**, 143-165.

Boyer, S. 1995. Sedimentary basin taper as a factor controlling the geometry and advance of thrust belts. *American Journal of Science*. **295**, 1220-1254.

Bug, J.P., Greya, T.V. 2005. The role of viscous heating in Barrovian metamorphism of collisional orogens: thermomechanical models and application to the Lepontine Dome in the Central Alps. *Journal Metamorphic Geology*, **23**, 75-95.

Butler, R.W.H., Tavarnelli, E., Grasso, M. 2006. Structural inheritance in mountain belts: an Alpine–Apennine perspective, *Journal of Structural Geology* **28**, pp. 1893-1908. doi:10.1016/j.jsg.2006.09.006.

Butler, R.W.H. 1989. The influence of pre-existing basin structure on thrust system evolution in the Western Alps. In: Inversion tectonics Cooper, M.A. and Williams, G.D. (eds). *Geological Society Spececial Publications*. **44**, 105-122.

Calassou, S., Larroque, C., Malavielle, J. 1993. Transfer zones of deformation in thrust wedges: An experimental study. *Tectonophysics*, **221**, 325-344.

Carola, E.; Tavani, S.; Ferrer, O.; Granado, P.; Quintà, A.; Butillé, M.; Muñoz, J.A. 2013. Along-strike extrusion at the transition between thin- and thick-skinned domains in the Pyrenean Orogen (northern Spain). In *Thick-skin-dominated Orogens: From initial inversion to full accretion*. Nemcok,M.; Mora, A.R.; Cosgrove, J.W. (eds). *Geological Society of London Special Publications* **377**, DOI:10.1144/SP377.3.

Carrera, N., Muñoz, J.A., Sàbat, F., Mon, R., Roca, E. 2006. The role of inverion tectonics in the structure of the Cordillera Oriental (NW Argentinean Andes). *Journal of Structural Geology*, **28**, 1921-1932.

Cartwright, J., Jackson, M., Dooley, T., Higgins, S. 2012. Strain partitioning in gracity-driven shortening of a thick, multilayered evaporite sequence. In: *Salt Tectonics, Sediments and Prospectivity*. Alsop, G.I., Archer, S.G., Hartley, A.J., Grant, N.T., Hodgkinson, R. (eds). *Geological Society of London Special Publications* **363**, 449-470.

Chapman, T.J. 1989. The Permian to Cretaceous structural evolution of the Western Approaches Basin (Melville sub-basin), UK. In: Inversion tectonics Cooper, M.A. and Williams, G.D. (eds). *Geological Society Spececial Publications*. **44**, 177-200.

Corrado, S., Bucci, D., Naso, G., Faccenna, C. 1998. Influence of paleogeography on thrust system geometries: an analogue modelling approach from the Abruzzi-Molise (Italy) case history. *Tectonophysics*, **296**, 437-453.

Coward, M.P., 1994. Inversion Tectonics. In: Hancock, P.L. (Ed.), Continental Deformation, Pergamon Oxford, 289-304.

Coward, M.P., Stewart, S. 1995. Salt-induced structures in the Mesozoic-Tertiary cover of the southern North Sea U.K. *In:* M.P.A. Jackson, D.G. Roberts, and S. Snelson (eds). Salt tectonics: a global perspective. *AAPG Memoir*, **65**, 229-250.

Dahlen, F.A. 1990. Critical taper model of dold-and-thrust belts and accretionary wedges. *Annual reviews earth and planetary science*. **18**, 55-99.

Davis, D., Suppe, J., Dahlen, F.A. 1983. Mechanics of Fold-and-Thrust belts and accretionary wedges. *Journal of Geophysical Research*, **88**, 1153-1172.

Davis, D.M., Engelder, T. 1985. The role of salt in fold-and-thrust belts. *Tectonophysics* 119, 67-88.

Durand-Riard, P., Shaw, J.H., Plesch, A., Lufadeju, G. Enabling 3D geomechanical restoration of strike- and oblique-slip faults using geological constraints, with applications to the deep-water Niger Delta. *Journal of Structural Geology*, **48,** 33-44. DOI: 10.1016/j.jsg.2012.12.2009.

Ellis, S., Beaumont, C., Jamieson, R.A., Quinlan, G. 1998. Continental collision including a weak zone: the vise model and its application to the Newfoundland Appalachians. *Canadian Journal of Earth Science*, **35**, 1323-1346.

Espina, R.G. 1997. La estructura y evolución tectonoestratigráfica del borde occidental de la Cuenca Vasco-Cantábrica (Cordillera Cantábrica, NO de España) Ph.D. Thesis, Univerity of Oviedo. 230pp.

Espina, R.G., De Vicente, G., Muñoz Martín, A. 1996. Análisi poblacional de fallas alpinas en el borde occidenteal de la Cuenca Vasco-Cantábrica (Cordillera Cantábrica, NO de España). *Geogaceta.* **20** 936-938.

Ferrer, O., E. Roca, B. Benjumea, J. A. Muñoz, N. Ellouz, and MARCONI Team. 2008. The deep seismic reflection MARCONI-3 profile: role of extensional Mesozoic structure during the Pyrenean contractional deformation at the eastern part of the Bay of Biscay. *Marine and Petroleum Geology,* **25(8)**, 714-730. doi:10.1016/j.marpetgeo.2008.06.002.

Fillon, C. 2012. Spatial and temporal variation in Cenozoic exhumation of the Pyrenean-Cantabrian mountain belt: coupling between tectonics and surface processes. PhD Thesis. Institut des Sciences de la Terre de Grenoble (ISTerre), Grenoble, France. 202p.

Fischer, M.P., Jackson, P.B., 1999. Stratigraphic controls on deformation patterns in fault-related folds: a detachment fold example from the Sierra Madre Oriental, northeast Mexico. *Journal of Structural Geology* **21**, 613-633.

Gallastegui, J. 2000. Estructura cortical de la Cordillera y Margen Continental Cantábricos: Perfiles ESCI-N. *Trabajos Geología,* **22**, 9-234.

Gallastegui, J., J. A. Pulgar, and J. Gallart. 2002. Initiation of an active margin at the North Iberian continent-ocean transition. *Tectonics,* **21(4)**, doi: 10.1029/2001TC901046.

García de Cortázar, A., Pujalte, V., 1982. Litoestratigrafía y facies del grupo Cabuérniga (Malm-Valanginiense Inferior?) al S deCantabria-NE de Palencia. *Cuadernos Geología Ibérica* **8**, 5-21.

García-Mondéjar, J., Pujalte, V., Robles, S. 1986. Características sedimentológicas secuenciales y tectoestratigráficas del Triásico de Cantabria y Norte de Palencia. *Cuadernos de Geología Ibérica,* **10**. 151-172.

García-Mondéjar, J., Agirrezabala, L.M., Aranburu, A., Fernández-Mendiola, P.A., Gómez-Pérez, I., López-Horgue, M., Rosales, I. 1996. Aptian-Albian tectonic pattern of the Basque-Cantabrian Basin (northern Spain). *Geological Journal* **31**, 13-45.

Guimerà, J. 1984. Palaeogene evolution of deformation in the north-east Iberian Peninsula. *Geological Magazine*, **121**, 413-420.

Guimerà, J., Alonso, A., Mas, R. 1995. Inversion of an extensional-ramp basin by a newly formed thrust: The Cameros Basin (N Spain). *In:* Buchanan, J.G. and Buchanan, P.G. (eds). *Basin Inversion.* Geological Society of London Special Publications, **88**, 433-453.

Guimerà, J., Mas, R., Alonso, Á. 2004. Intraplate deformation in the NW Iberian Chain: Mesozoic extension and Tertiary contractional inversion. *Journal of the Geological Society of London* **161**, 291-303.

Hempel, P.M. 1967. Der diapir von Poza de la Sal (Nordspanien). *Beiheft Geologisches Jahrbuch* **66**, 95-126.

Hernáiz, P.P., Solé, J. 2000. Las estructuras del diapiro de Salinas del Rosío y del alto de San Pedro-Iglesias y sus implicaciones en la evolución tectónica de la transversal burgalesa de la Cordillera Vascocantábrica-Cuenca del Duero. *Rev. Soc. Geol. España* **13** 471-486.

Hernáiz, P.P., Serrano, A., Malagón, J., Rodríguez Cañas, C. 1994. Evolución estructural del margen SO de la cuenca Vasco Cantábrica. *Geogaceta*. V15. pp. 143-146.

Hernáiz, P.P. 1994. La falla de Ubierna (margen SO de la cuenca Cantábrica). *Geogaceta*. **16**. 39-42.

Hernández, J.Mª., Pujalte, V., Robles, S., Martín-Closas, C. 1999. División estratigráfica genética del grupo Campóo (Malm-Cretácico Inferior, SW Cuenca Vascocantábrica). *Rev. Soc. Geol. España* **12** 377-396.

Hill, K.C., Kendrick, R.D., Crowhurst, P.V., Gow, P.A. 2002. Copper-gold mineralisation in New Guinea: tectonics, lineaments, thermochronology and structure. *Australian Journal of Earth Sciences.* **49**, 737-752.

Holdsworth, R.E., 2004. Weak faults, rotten cores. *Science* **303**, 181-182. doi: 10.1126/science.1092491.

Hudec, M.R., Jackson, M.P.A. 2007. Terra infima: Understanding salt tectonics. *Earth Science reviews* **82**, 1-28. DOI: 10.1016/j.earscirev.2007.01.001.

Jammes, S., G. Manatschal, L. Lavier, and E. Masini. 2009. Tectonosedimentary evolution related to extreme crustal thinning ahead of a propagating ocean: the example of the western Pyrenees, *Tectonics,* **28**, TC4012, doi:10.1029/2008TC002406.

James, S., Huismans, R.S. 2012. Structural styles of mountain building: controls of lithospheric rheologic stratification and extensional inheritance. *Journal of Geophysical Research*, **117**, 1978-2012.

Jammes, S., Huismans, R.S., Muñoz, J.A. 2014. Lateral variations in structural style of mountain guilding: controls of rheological and rift inheritance. *Terra Nova* DOI:10.1111/ter.12087.

Jaumé, S. C., R. J. Lillie. 1988. Mechanics of the Salt Range-Potwar Plateau, Pakistan: A fold-and-thrust belt underlain by evaporites, *Tectonics*, **7**, 57- 71.

Koopman, A., Speksnijder, A., Horsfield, W.T. 1987. Sandbox model studies of inversion tectonics. *Tectonophysics*, **137**, 379-388.

Lacoste, A., Vendeville, B.C., Mourgues, R., Loncke, L., Lebacq, M. 2012. Gravitational instabilities triggered by fluid overpressure and downslope incision - Insights from analytical and analogue modelling. *Journal of Structural Geology*, **42**, 151-162. DOI: 10.1016/j.jsg.2012.05.011.

Lanaja, J. M. 1987. *Contribución de la exploración petrolífera al conocimiento de la Geología de España.* IGME, Serv. Oubl. Min. Indust. Energ., Madrid. 465 pp.

Le Pichon, X., Sibuet, J.C., 1971. Western extension of boundary between European and Iberian plates during the Pyrenean orogeny. *Earth and Planetary Science Letters* **12**, 83-88. doi:10.1016/0012-821X(71)90058-6.

Luján, M., Storti, F., Balanyá, J.C., Crespo-Blanc, A. and Rossetti, F., 2003. Role of décollement material with different rheological properties in the structure of the Aljibe thrust imbricate (Flysch Trough, Gibraltar Arc): an analogue modelling approach. *Journal of Structural Geology* **25**, pp. 867–881. doi:10.1016/S0191-8141(02)00087-1.

Macedo, J., Marshak, S. 1999. Controls on the geometry of fold-thrust belt salients. *Geological Society of America Bulletin*, **111**, 1808-1822.

Malagón, J., Hernáiz, P.P., Rodríguez Cañas, C., Serrano. 1994. Notas sobre la inversión tectónica y aloctonia de la cuenca Vasco-Cantábrica. *Geogaceta*. **15**. 139-142.

Marshak, S., 2004. Salients, recesses, arcs, oroclines, and syntaxesda review of ideas concerning the formation of map-view curves in fold-thrust belts. In: McClay, K.R. (Ed.), Thrust tectonics and hydrocarbon systems. *Memoir of the American Association of Petroleum Geologists* **82**, pp. 131-156.

Martínez-Torres, L. M. 1993. Corte balanceado de la Sierra Cantabria (cabalgamiento de la Cuenca Vasco-Cantábrica sobre la Cuenca del Ebro), *Geogaceta*, **14**, 113-115.

Martín-González, F. & Heredia, N. 2011. Complex tectonic and tectonostratigraphic evolution of an Alpine foreland basin: The western Duero Basin and the related Tertiary depressions of the NW Iberian Peninsula. *Tectonophysics* 502, 75-89. doi:10.1016/j.tecto.2010.03.002.

Mathieu, C. 1986. Histoire géologique du sous-basin de Parentis. *Bulletin des Centres de Recherches Elf-Aquitaine (Production)*, **10**, 33-47.

Mazzoli, S., D'Errico, M., Allega, L., Corrado, S., Invernizzi, C., Shiner, P., Zattin, M., 2008. Tectonic burial and 'young' (b10 Ma) exhumation in the southern Apennines fold and thrust belt (Italy). *Geology* **36**, 243-246.

McClay, K.R. 1989. Analogue models of inversion tectonics. In: Inversion tectonics Cooper, M.A. and Williams, G.D. (eds). *Geological Society Spececial Publications*. **44**, 41-59.

Mitra, G. 1997. Evolution of salients in a fold-and-thrust belt: the effects of sedimentary basin geometry, strain distribution and critical taper. In: Sengupta, S. (Ed.) Evolution of Geological Structures in Micro- to Macro-scales, Chapman and Hall, London. 59-90.

Montadert, L., Charpal, O., Roberts, D. G., Guennoc, P., Sibuet, J. C. 1979. Northeast Atlantic passive margins: rifting and subsidence processes. *American Geophysics Union, Revue*, **3**, 154-186.

Mouthereau, F., Lacombre, O. 2006. Inversion of the Paleogene Chinese continental margin and thick-skinned deformation in the Western Foreland of Taiwan. *Journal of Structural Geology*. **28**, 1977-1993.

Muñoz, J. A. 1992. Evolution of a continental collision belt: ECORS-Pyrenees crustal balanced section, in *Thrust Tectonics*, edited by K. R. McClay, pp. 235-246, Chapman and Hall, London.

Muñoz, J. A. 2002. The Pyrenees, in *The Geology of Spain*, edited by W. Gibbons and T. Moreno, pp. 370-385. Geological Society of London, London.

Pedreira, D., J. A. Pulgar, J. Gallart, and J. Díaz. 2003. Seismic evidence of Alpine crustal thickening and wedging from the western Pyrenees to the Cantabrian Mountains (north Iberia). *Journal of Geophysical Research*, **108**(B4), doi: 10.1029/2001JB001667.

Pedreira, D., Pulgar, J. A., Gallart, J., Torné, M. 2007. Three-dimensional gravity and magnetic modeling of crustal indentation and wedging in the western Pyrenees-Cantabrian Mountains, *J. Geophys. Res.*, **112**(B12405), doi: 10.1029/2007JB005021.

Peel, F., Travis, C.J., Hossack, J.R. 1995. Genetic structural provinces and salt tectonics of the Cenozoic offshore US gulf of Mexico: a preliminary analysis. *In:* M.P.A.

Jackson, D.G. Roberts, and S. Snelson (eds). Salt tectonics: a global perspective. *AAPG Memoir*, **65**, 153-175.

Pérez-Estaún, A., Bastida, F., Alonso, J.L., Marquinez, J., Aller, J., Álvarez-Marrón, J., Marcos, A., Pulgar, J. 1988. A thin-skinned Tectonics Model for an arcuate fold and thrust belt: The Cantabrian Zone (Variscan Ibero-Armorican Arc). *Tectonics* **7**, 517-537.

Pérez-Estaún, A., Martínez-Catalán, J.R., Bastida, F. 1991. Crustal thickening and deformation sequence in the footwall to the suture of the Variscan belt of northwest Spain. *Tectonophysics.* **191**. 243-253. doi:10.1016/0040-1951(91)90060-6.

Pfiffner, O. A. 2006. Thick-skined and thin-skined styles of continental contraction. In:Mazzoli, S. and Butler, R. W. H. (eds) *Styles of Continental Contraction. Geological Society of America Special Paper*, **414**, 153-177. doi: 10.1130/2006.2414(09).

Portero, J.M., Ramírez del Pozo, J., Aguilar, M. 1973. Mapa geológico 1:50.000, Hoja 170 (Haro). IGME.

Pujalte, V., Robles, S., Valles, J.C. 1988. El Jurásico marino de las zonas de alto sedimentario relativo del borde SW de la Cuenca Vasco–Cantábrica (Rebolledo de la Torre, Palencia). *In: III Coloquio de Estratigrafía y Paleogeografía del Jurásico de España. Libro guía de las excursiones*. Ciencias de la Tierra (Instituto de Estudios Riojanos), **11**, 85–94.

Pujalte, V., Robles, S., Hernández, J.Mª. 1996. La sedimentación continental del Grupo Campóo (Malm-Cretácico basal de Cantabria, Burgos y Palencia): testimonio de un reajuste hidrográfico al inicio de una fase rift. *Cuad. Geol. Ibérica*, **21** 227-251.

Pujalte, V., Robles, S., García-Ramos, J.C., Hernández, J.M. 2004. El Malm-Barremiense no marinos de la Cordillera Cantábrica. *In:* Vera, J.A. (ed.) *Geología de España.* SGE-IGME, Madrid, 288-291.

Pujalte, V. 1981. Sedimentary succession and palaeonvironments within fault-controlled basin: the "Wealden" of the Santander area, Northern Spain. *Sedimentary Geology* **28**, 293-325.

Pujalte, V. 1982. La evolución paleogeográfica de la cuenca “Wealdense” de Cantabria. *Cuadernos de Geología Ibérica*, **8** 65-83.

Pulgar, J.A., Pérez-Estaún, A., Gallart, J., Álvarez-Marrón, J., Gallastegui, J., Alonso, J.L. and ESCIN Group. 1997. The ESCIN-2 deep seismic reflection profile: a traverse across the Cantabrian Mountains and adjacent Duero basin. *Revista Sociedad Geológica de España*. **8**, 383-394.

Pulgar, J. A., Alonso, J. L., Espina, R. G., Marín, J. A. 1999. La deformación alpina en el basamento varisco de la Zona Cantábrica, *Trabajos de Geolología.* **21**, 283-294.

Quesada, S., Robles, S., Pujalte, V. 1991. Correlación secuencial y sedimentológica entre registros de sondeos y series de superficie del Jurásico Marino de la Cuenca de Sanander (Cantabria, Palencia y Burgos). *Geogaceta* **10**, 3-10.

Quesada, S., Robles, S., Pujalte, V., 1993. El Jurásico Marino del margen suroccidental de la Cuenca Vasco-Cantábrica y su relación con la exploración de hidrocarburos. *Geogaceta* **13**, 92-96.

Quesada, S., Robles, S., Rosales, I., 2005. Depositional architecture and transgressive–regressive cycles within Liassic backstepping carbonate ramps in the Basque–Cantabrian basin, northern Spain. *Journal Geological Society of London*. **162**, 531-548.

Quintà, A., Tavani, S., Roca, E. 2012. Fracture pattern analysis as a tool for constraining the interaction between regional and diapir-related stress field: Poza de la Sal Diapir (Basque Pyrenees, Spain). In: *Salt Tectonics, Sediments and Prospectivity*. Alsop, G.I., Archer, S.G., Hartley, A.J., Grant, N.T., Hodgkinson, R. (eds). *Geological Society of London Special Publications* **363**, 521-532.

Quintà, A., Tavani, S. 2012. The foreland deformation in the south-western Basque-Cantabrian Belt (Spain). *Tectonophysics.* **576-577**. 4-19. DOI: 10.1016/j.tecto.2012.02.015.

Quintana, L. 2012. Extensión e inversión tectónica en el sector central de la región Vasco-Cantábrica (Cantabria, Vizcaya, norte de España). PhD Thesis. Universidad de Oviedo, Oviedo. Spain. 560pp.

Ramírez del Pozo, J. 191. Bioestratigrafía y Microfacies del Jurássico y Cretácico del Norte de España (Región Cantábrica). *Memorias Instituto Geológico y Minero de España* **78**, 1-357.

Riba, O. and Juardo, M. J. 1992. Reflexiones sobre la geología de la parte occidental de la Depresión del Ebro. *Acta Geologica Hispanica*, **27**, 177-193.

Robles, S., Pujalte, V., Valles, J.C. 1989. Sistemas sedimentarios del Jurásico de la parte occidental de la Cuenca Vasco-Cantatábrica. *Cuadernos Geología Ibérica*. **13**, 185-198.

Robles, S., Quesada, S., Rosales, I., Aurell, M., García-Ramos, J.C. 2004. El Jurásico marino de la Cordillera Cantábrica. In: Vera, J.A. (ed.) Geología de España. SGE IGME, Madrid, 279-285.

Roca, E., Muñoz, J.A., Ferrer, O., Ellouz, N. 2011. The role of the Bay of Biscay Mesozoic extensional structure in the configuration of the Pyrenean orogen: Constraints from the MARCONI deep seismic reflection survey. *Tectonics*. **30**. TC2001. doi: 10.1029/2010TC002735.

Rodríguez Cañas, C., Hernáiz, P.P., Malagón, J., Serrano, A. 1994. Notas sobre la estructura cabalgante de Rojas-Santa Casilda. *Geogaceta* **15**, 135-138.

Rowan, M.G., Jackson, M.P.A., Trudgill, B.D. 1999. Salt-Related fault families and fault welds in the Northern Gulf of Mexico. *AAPG Bulletin*, **83**, 1454-1484.

Rowan, M.G., Peel, F.J., Vendeville, B.C. 2004. Gravity-driven Fold Belts on passive Margins. *In:* McClay (eds). Thrust tectonics and hydrocarbon systems. *AAPG Memoir*, **82**, 157-182.

Rowan, M. 2014. Passive-margin salt basins: hyperextension, evaporite depositioon, and salt tectonics. *Basin Research*, **26**, 154-182. DOI: 10.1111/bre.12043.

Ruiz, M. 2007. Caracterització estructural i sismotectònica de la litosfera en el Domini Pirenaico-Cantàbric a partir de mètodes de sísmica activa i passiva, Ph.D. thesis, Univ. Barcelona, Barcelona, Spain.

Salas, R., Guimerà, J., Mas, R., Martín-Closas, C., Meléndez, A., Alonso, Á. 2001. Evolution of the Mesozoic Central Iberian Rift System and its Cainozoic inversion (Iberian Chain). *In:* Ziegler, P.A., Cavazza, W., Robertson, A.H.F., Crasquin-Soleau, S. (eds). *Peri-Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and PAssive Margins. Mémories du Muséum National de l'Historie Naturelle, **186**, 145-185.*

Schröder, B. 1987. Inversion tectonics along the western margin of the Bohemian Massif. *Tectonophysics*, **137**, 93-100.

Sepehr, M., Cosgrove, J., Moieni, M. 2006. The impact of cover rock rheology on the style of folding in the Zagros fold-thrust belt. *Tectonophysics*, **429**, 265-281. DOI: 10.1016/j.tecto.2006.05.021.

Sepher, M., Cosgrove, J.W. 2005. The role of the Kazerun fault zone in the formation and deformation of the Zagros fold-thrust belt, Iran. *Tectonics.* **28**. TC5005.

Serrano, A., Martínez del Olmo, W. 2004. Estructuras diapíricas de la zona meridional de la Cuenca Vasco-Cantábrica. In: Vera, J.A. (Ed.), Geología de España. SGE-IGME Madrid, pp. 334–338.

Serrano, A., Hernáiz, P.P., Magalón, J. Rodríguez-Cañas, C. 1994. Tectónica distensiva y halocinesis en el margen SO de la cuenca Vasco-Cantábrica. *Geogaceta*. **15**. 131-134.

Soto, R., Casas, A.M., Storti, F., Faccenna, C. 2002. Role of lateral thickness variations on the development of oblique structures at the Western end of the South Pyrenean Central Unit. *Tectonophysics*, **35**, 215-235.

Spratt, D.A., Dixon, J.M., Beattie, E.T. 2004. Changes in structural style controlled by lithofacies contrast across transverse carbonate bank margins - Canadian Rocky Mountains and scaled physical models. In: McClay, K.R. (Ed.), *Thrust tectonic and hydrocarbon systems: AAPG Memoir*, **82**, 259-275.

Steward, S.A., Argent, J.D. 2000. Relationship between polarity of extensional fault arrays and presence of detachments. *Journal of Structural Geology*. **22,** 693-711.

Steward, S.A., Ruffell, A.H., Harvey, M.J. 1997. Relationship between basement-linked and gravity-driven faults systems in the UKCS salt basins. *Marine and Petroleum Geology,* **14**, 581-604.

Tavani, S., Muñoz, J.A. 2012. Mesozoic rifting in the Basque-Cantabrian Basin (Spain): Inherited faults, transversal structures and stress perturbation. *Terranova*. **24**, 70-76. DOI: 10.1111/j.1365-3121.2011.01040.x.

Tavani, S., Quintà, A., Granado, P. 2011. Cenozoic right-lateral wrench tectonics in the Western Pyrenees (Spain): The Ubierna Fault System. *Tectonophysics*, **509**, 238-253. DOI: 10.1016/j.tecto.2011.06.013.

Tavani, S.; Carola, E.; Granado, P.; Quintà, A.; Muñoz, J.A. 2013. Transpressive inversion of a Mesozoic extensional forced fold system with an intermediate décollement level in the Basque-Cantabrian Basin (Spain). *Tectonics* v32. DOI:10.1002/tect.20019.

Veen, V. 1965. The tectonic and strarigraphic history of the Cardaño area, Cantabrian Mountains, northern Spain. *Leisde. Geol. Meded.* **35**, 45-104.

Vendeville, B.C., Jackson, M.P.A. 1992. The rise of diapirs during thin-skinned extension. *Marine and Petroleum Geology*. **9**, 331-353.

Vergés, J., García-Senz, J. 2001., Mesozoic evolution and Cainozoic inversión of the Pyrenean Rift, in *Peri-Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and Passive Margins*, edited by P. A. Ziegler et al., *Mém. Mus. National Hist. Nat.,* **186**, 187-212.

Vergés, J., Fernàndez, M., Martínez, A., 2002. The Pyrenean origen: pre-, syn-, and post-collisional evolution. In: Rosenbaum, G., Lister, G.S., (Eds.), Reconstruction of the Evolution of the Alpine-Himalayan Orogen. Journal of the Virtual Explorer 8, 57–76.

Vidal-Royo, O., Koyi, H.A., Muñoz, J.A. 2009. Formation of orogen-perpendicular thrusts due to mechanical contrasts in the basal décollement in the Central External Sierras (Southern Pyrenees, Spain). *Journal of Structural Geology* **31**, 523-539.

Wagner, R.H., Winkler Prins, C.F., Riding, R.E., Wagner-Gentis, C.H.T. 1971. Lithostratigraphic units of the lower part of the Carboniferous in northern León, Spain. *Trabajos de Geología* **4**, 603-663.

Whithjack, M.O., Callaway, S. 2000. Active normal faulting beneath a salt layer: An experimental study od deformation patterns in the Cove Sequence. *American Association of Petroleum Geologists Bulletin.* **84**, 627-651.

Ziegler, P.A. (Ed.), 1987. Compressional Intra-Plate Deformation in the Alpine Foreland. *Tectonophysics*, vol. 137, 420 pp.

9 Figure caption

Figure 1: A) Elevation map of the W-E Pyrenean Orogen and surroundings with the major domains labelled. STZ and PTZ corresponds to Santander and Pamplona Transfer Zones respectively. B and C) S-N cross-sections of the Cantabrian Mountains and the Basque-Pyrenees (Modified from Pulgar *et al.*, 1999; Riba and Jurado, 1992). D) Schematic S-N models purposed by different authors in order to explain the main features and the deformation style of the Burgalesa Platform Domain and adjacent areas.

Figure 2: Cronostratigraphic column of the study area with the main tectonic events that took place. (Partially modified from Barnolas and Pujalte, 2004).

Figure 3: Geological map of the Burgalesa Platform and surroundings with the location of the different seismic lines, wells and cross-sections shown in this work as well as the foreland deformation interpreted from the seismic sections.

Figure 4: S-N seismic section of the Duero Foreland Basin and the eastern part of the Cantabrian Mountains with thrusts affecting the Cenozoic succession as well as the Mesozoic and the basement. See figure 3 for location.

Figure 5: W-E seismic section showing the involvement of the basement in the western sector of the Burgalesa Platform producing the plunge observable in the Mesozoic succession at surface. See figure 3 for location.

Figure 6: S-N seismic sections located in the Huidobro area where the Tejón Profundo-1 well testifies a repetition of the Mesozoic succession and how this back-thrust is imaged in the lines. Note how the structural relief decreases westwards. See figure 3 for location.

Figure 7: W-E seismic section in the Villalta area showing the hangingwall cutoff of the back-thrust present in this sector of the Burgalesa Platform. The deeper reflectors show the transversal extensional fault delimiting the former Basque-Cantabrian Basin and how during the inversion of the basin, the Mesozoic succession was south-eastwards displaced favoured by the presence of the Upper Triassic salts acting as a detachment level. See figure 3 for location.

Figure 8: Composed W-E and SW-NE seismic section in the Bureba sub-basin reflecting the eastward thinning of the Lower Cretaceous succession related to the extensional event that produced forced folding of the Jurassic units. The contractional structure, displacing the Mesozoic succession towards the SE, is fossilised by the Cenozoic sediments of the Bureba and the Ebro Foreland Basin. See figure 3 for location.

Figure 9: W-E seismic section of the Bureba re-entrant displaying flat-lying Mesozoic and Cenozoic successions and S-N seismic section of the western part of the Basque-Pyrenees with the Mesozoic and Cenozoic succession southward displaced by a thrust detached at the Upper Triassic salt that overrides the Ebro Foreland Basin.

Figure 10: Cross-sections of the study area. Three in a S-N orientation and one in a NW-SE with both, the main areas and wells labelled. See figure 3 for location.

Figure 11: Schematic map with the distribution of the salt thickened areas and the location of the syn-rift depocenters and thinned parts and also the location of some of the wells of the study area.

Figure 12: A) Geological map with the distribution of the onlap geometries observed in the seismic sections. Red arrows indicate the direction of migration of the onlaps. B) S-N seismic section crossing the Folded Band and the Burgalesa Platform highlighting the onlaps.

Figure 13: Map of the study area and surrounding with the movement directions of each area and also the main domains (i.e. Thick-skinned, Thin-skinned and Autochtonous) described in the text and present in the area. UCAFC corresponds to Upper Cretaceous Autochtonous Footwall Cutoff.

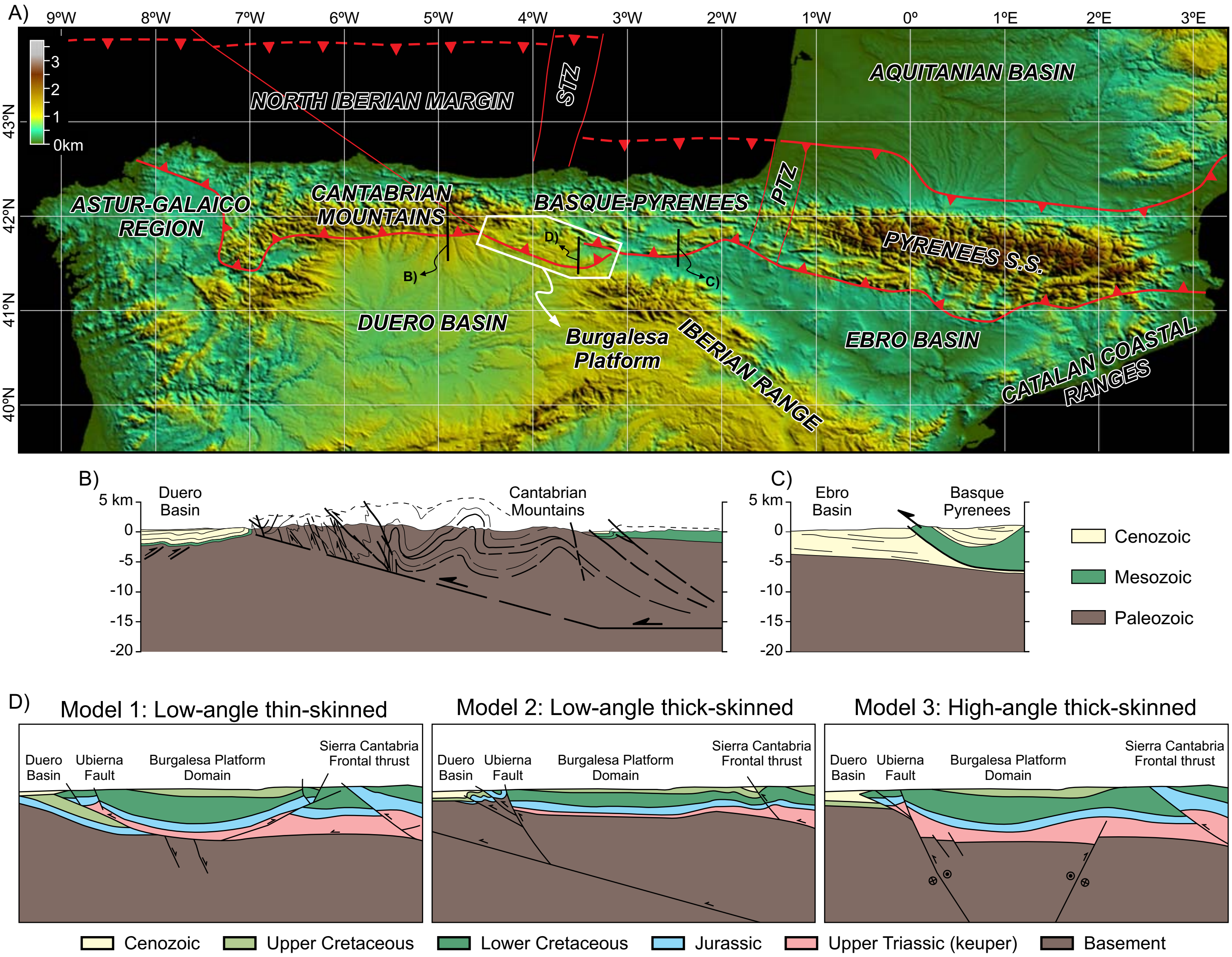


Fig. 1 (double column)

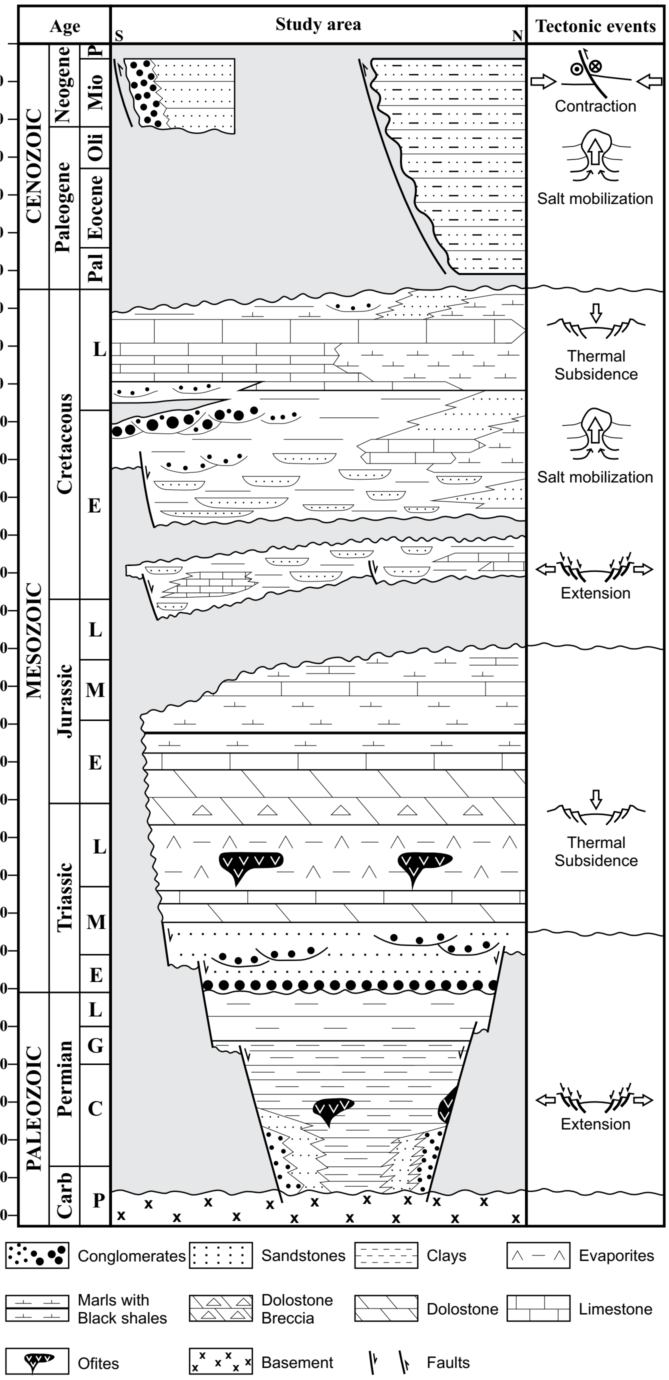


Fig. 2 (single column)

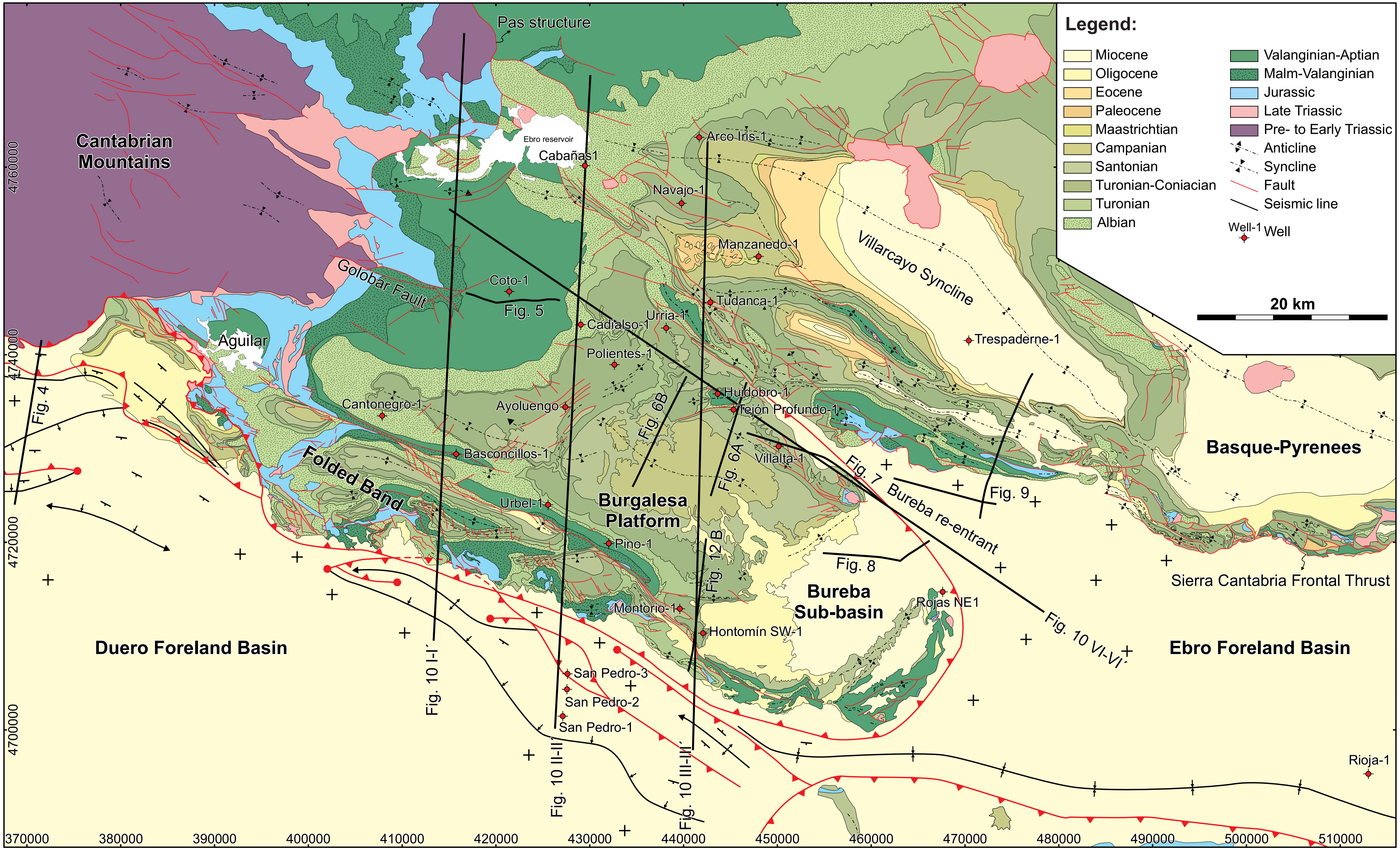


Fig. 3 (double column)

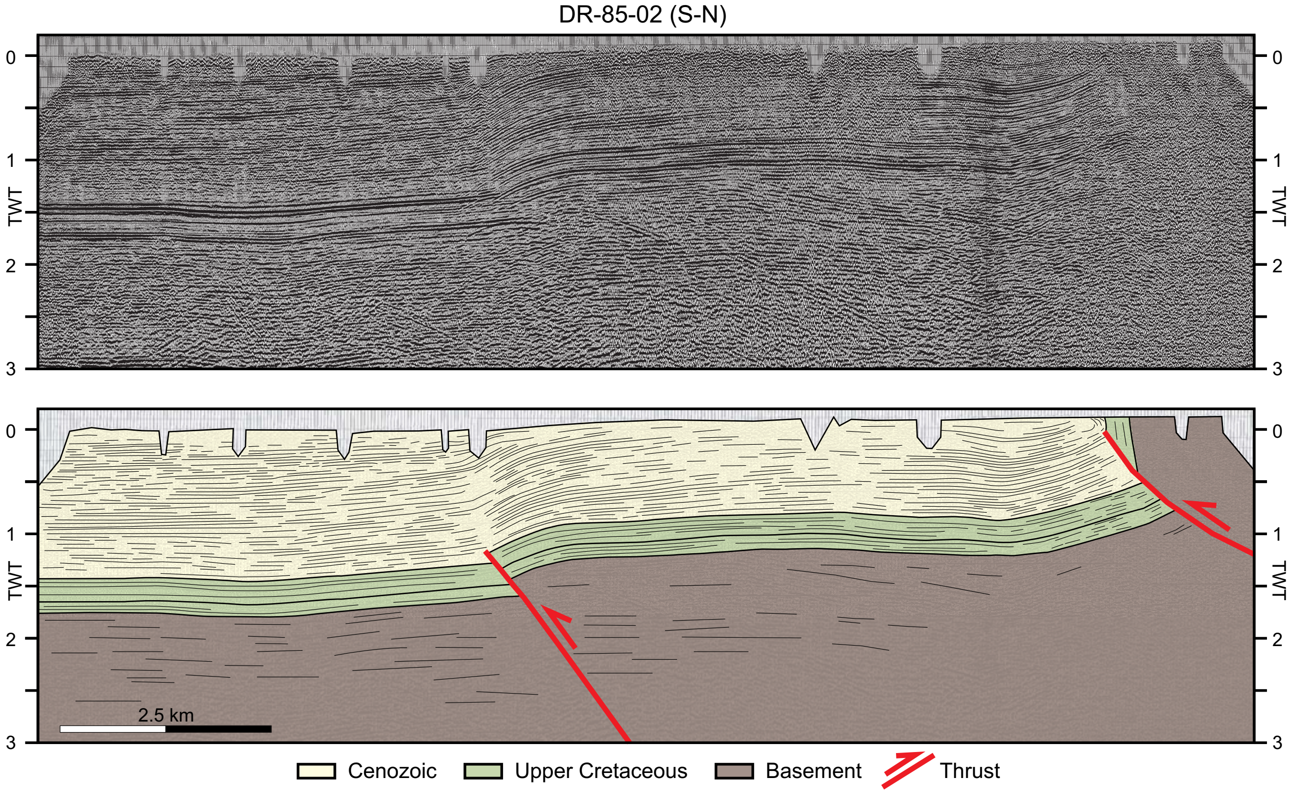


Fig. 4 (double column)

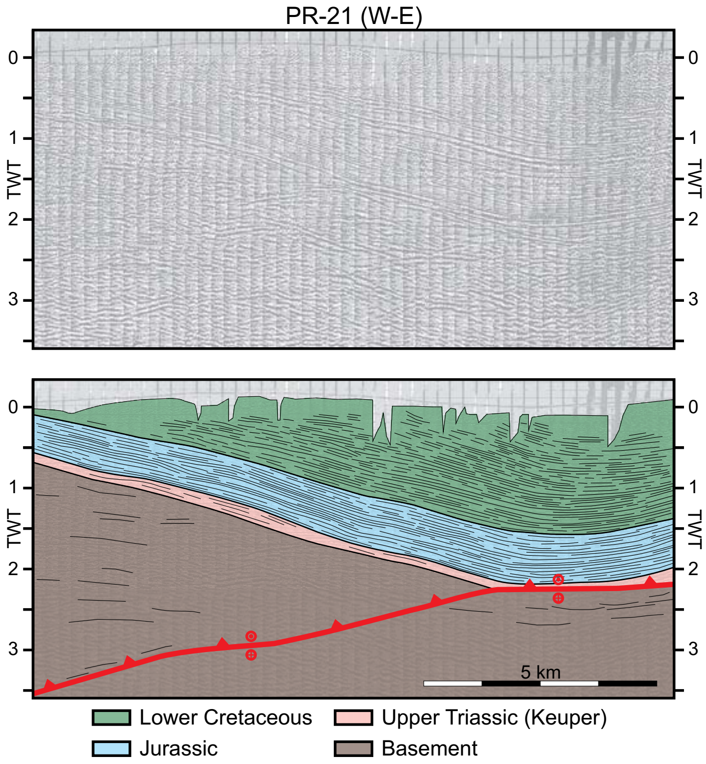


Fig. 5 (single column)

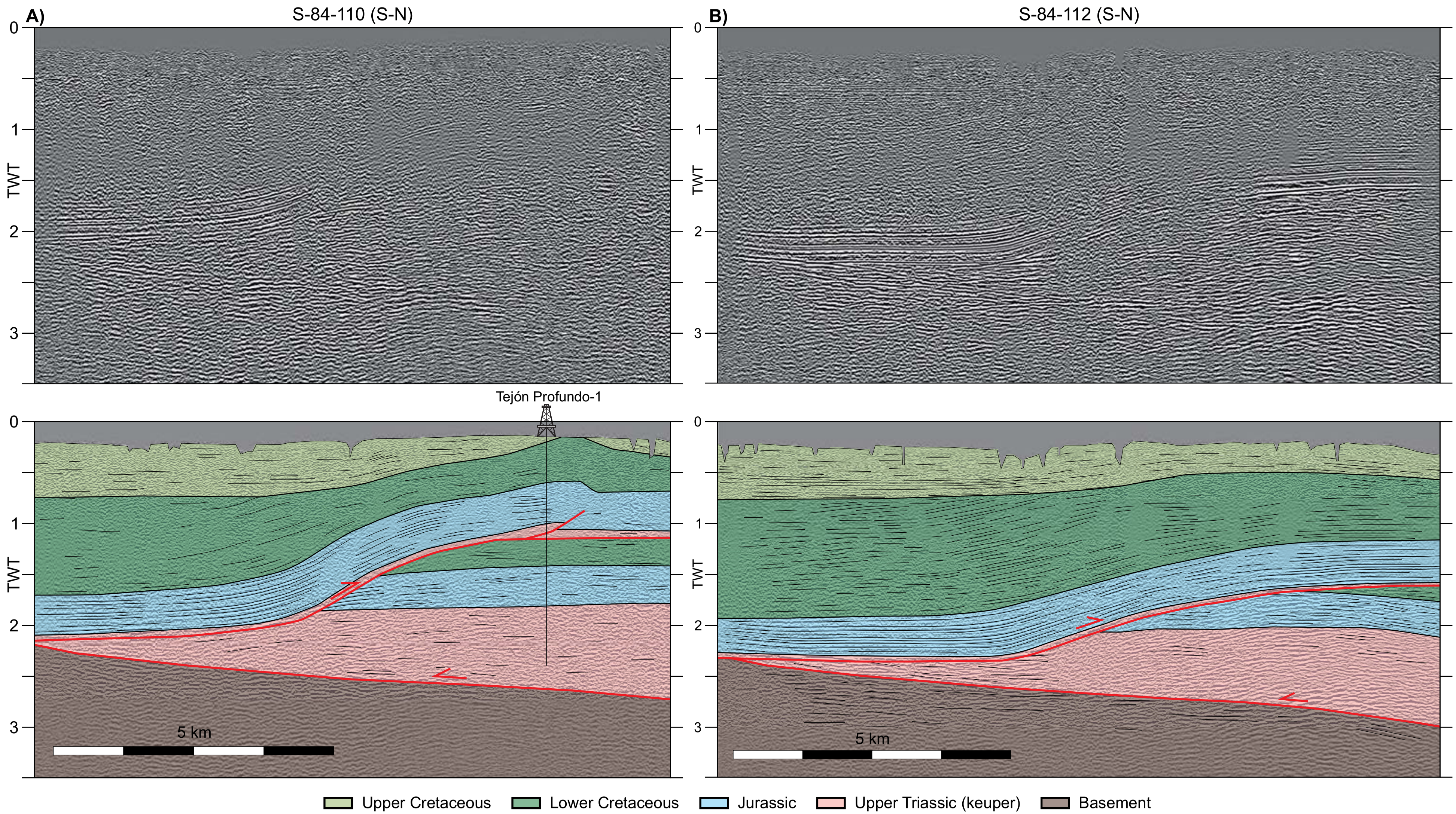


Fig. 6(double column)

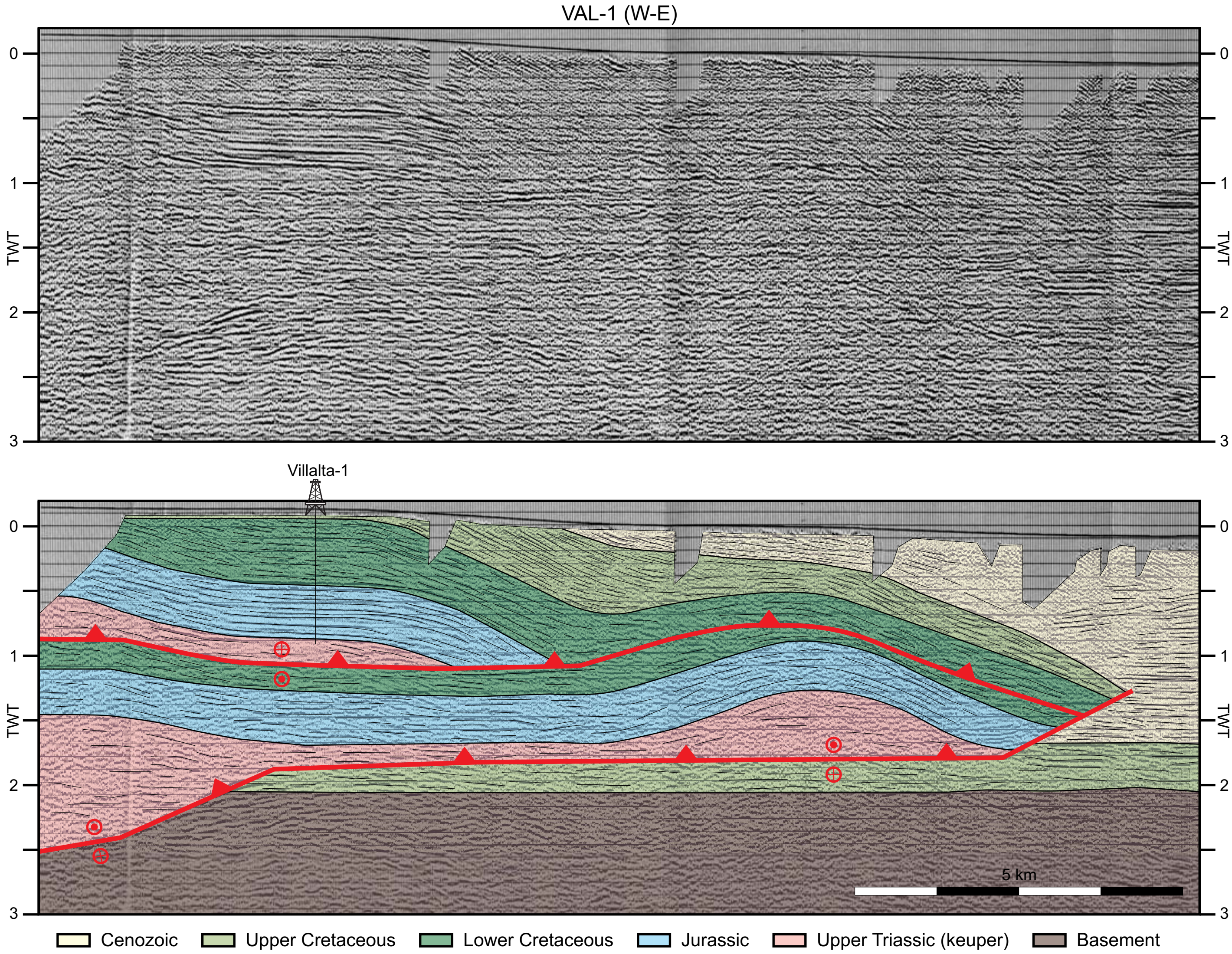


Fig. 7 (double column)

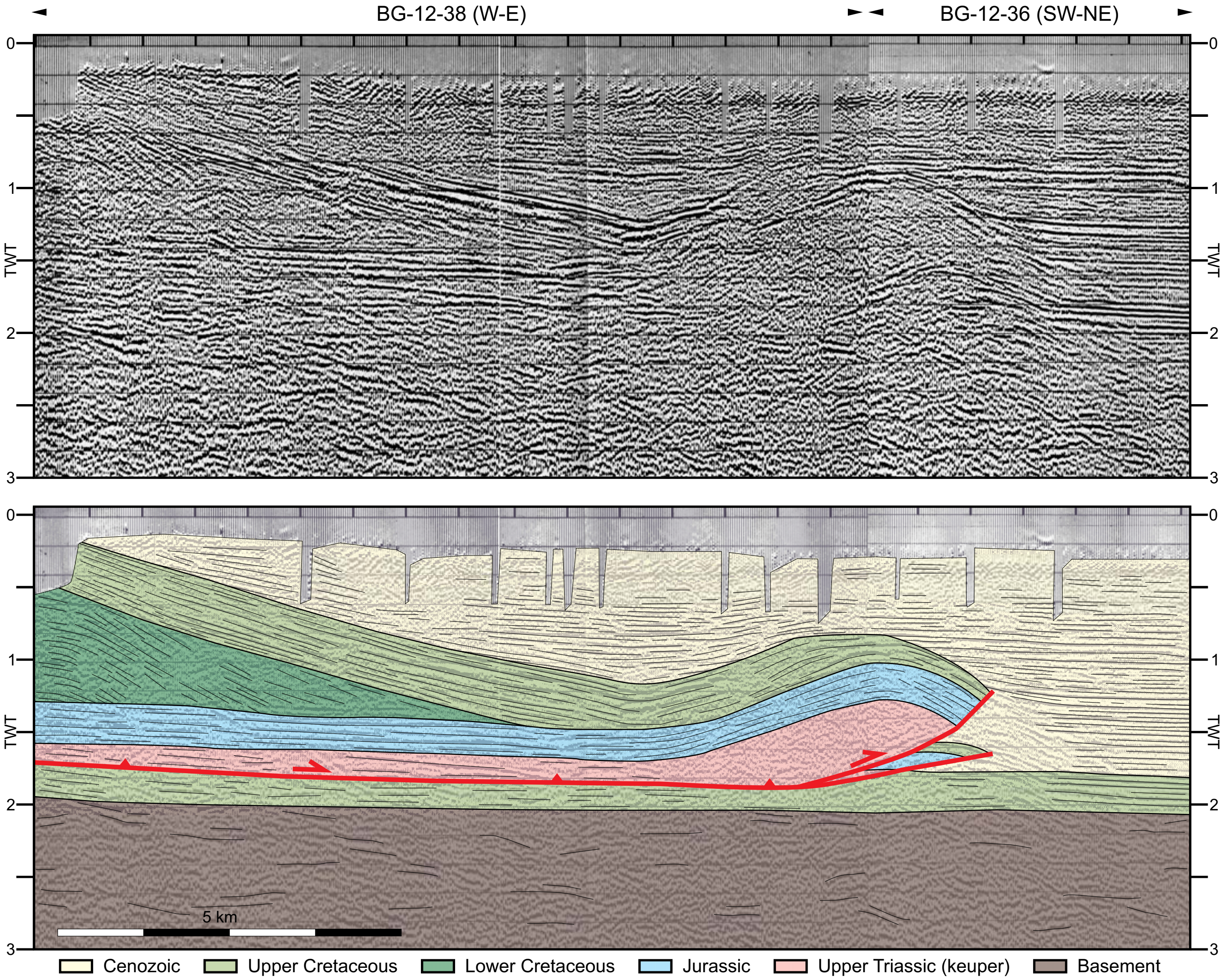


Fig. 8 (double column)

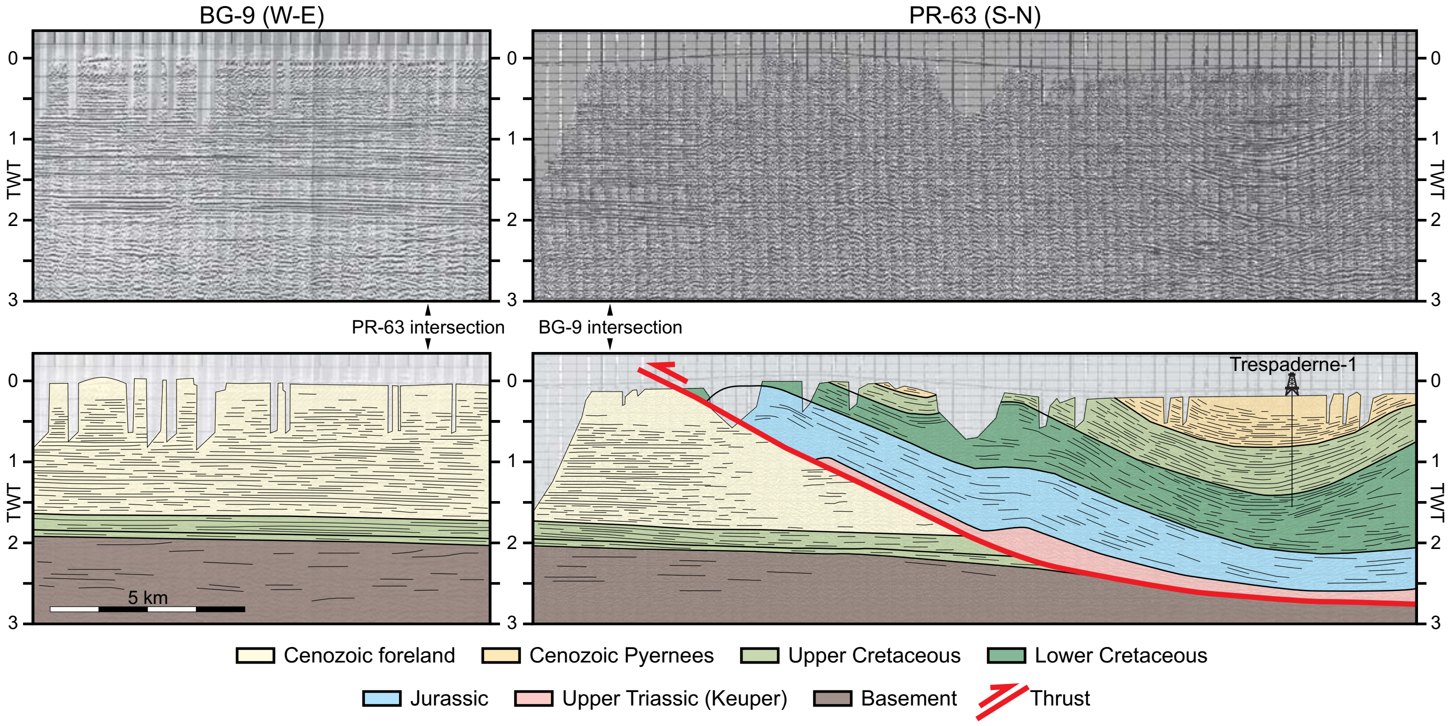


Fig. 9 (double column)

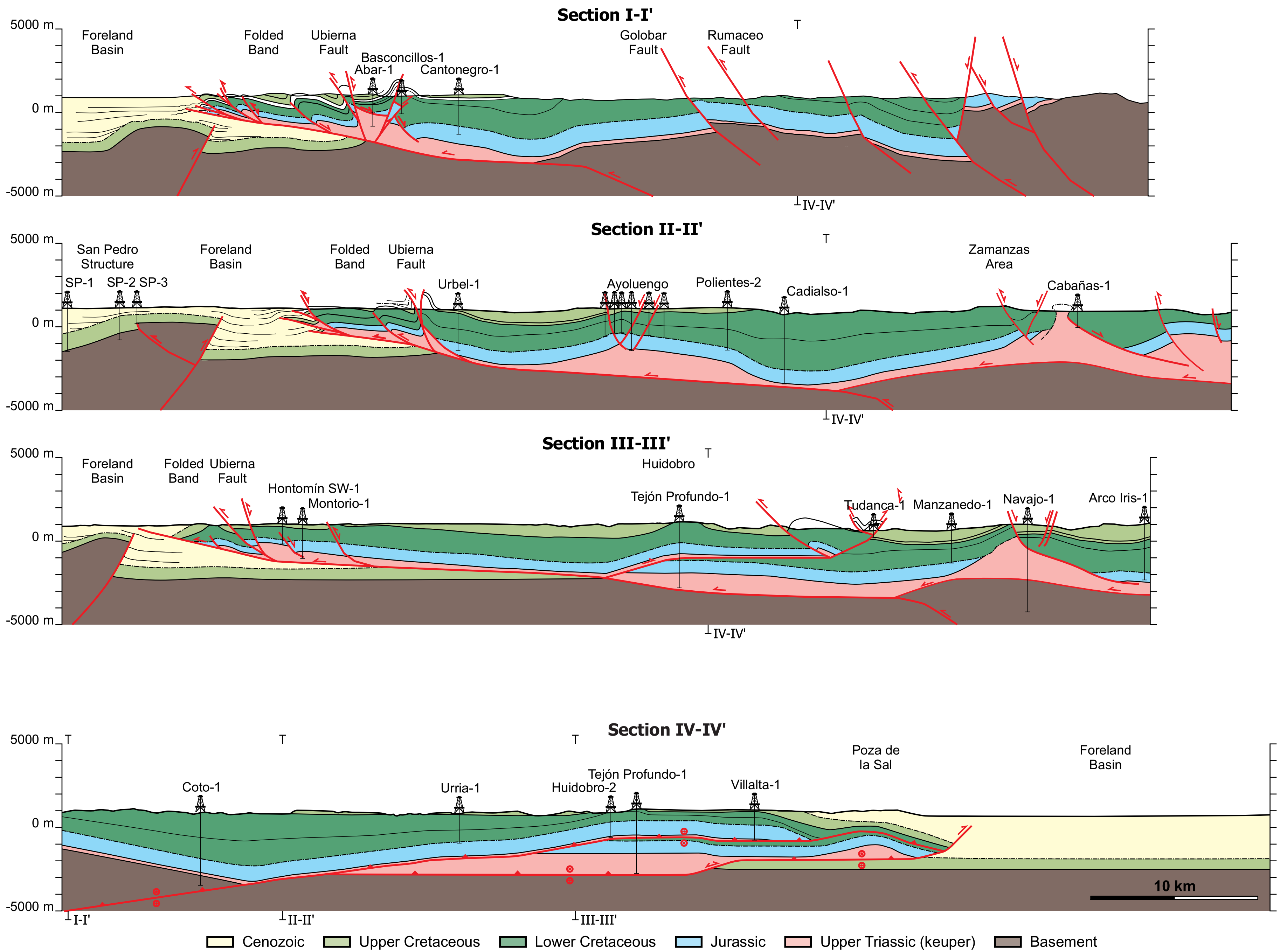


Fig. 10 (double column)

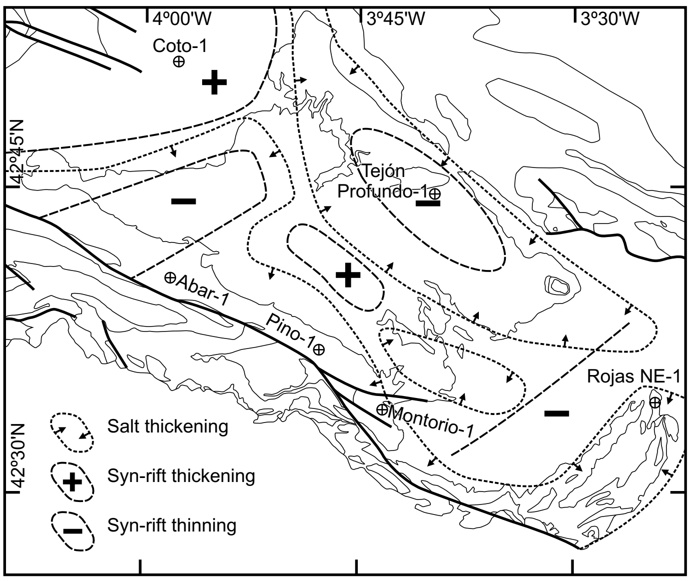
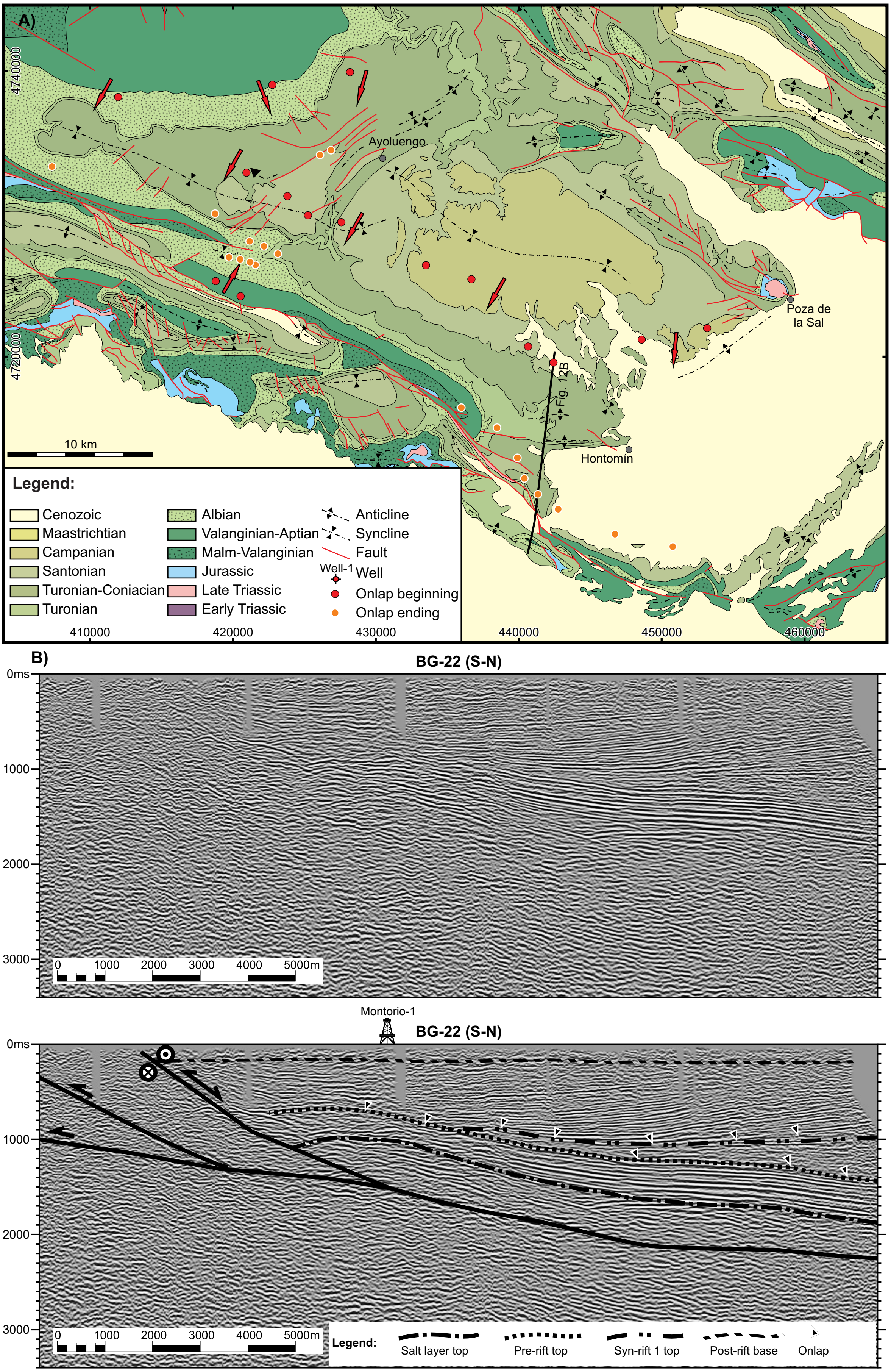


Fig. 11 (single column)

Fig. 12 (double column)



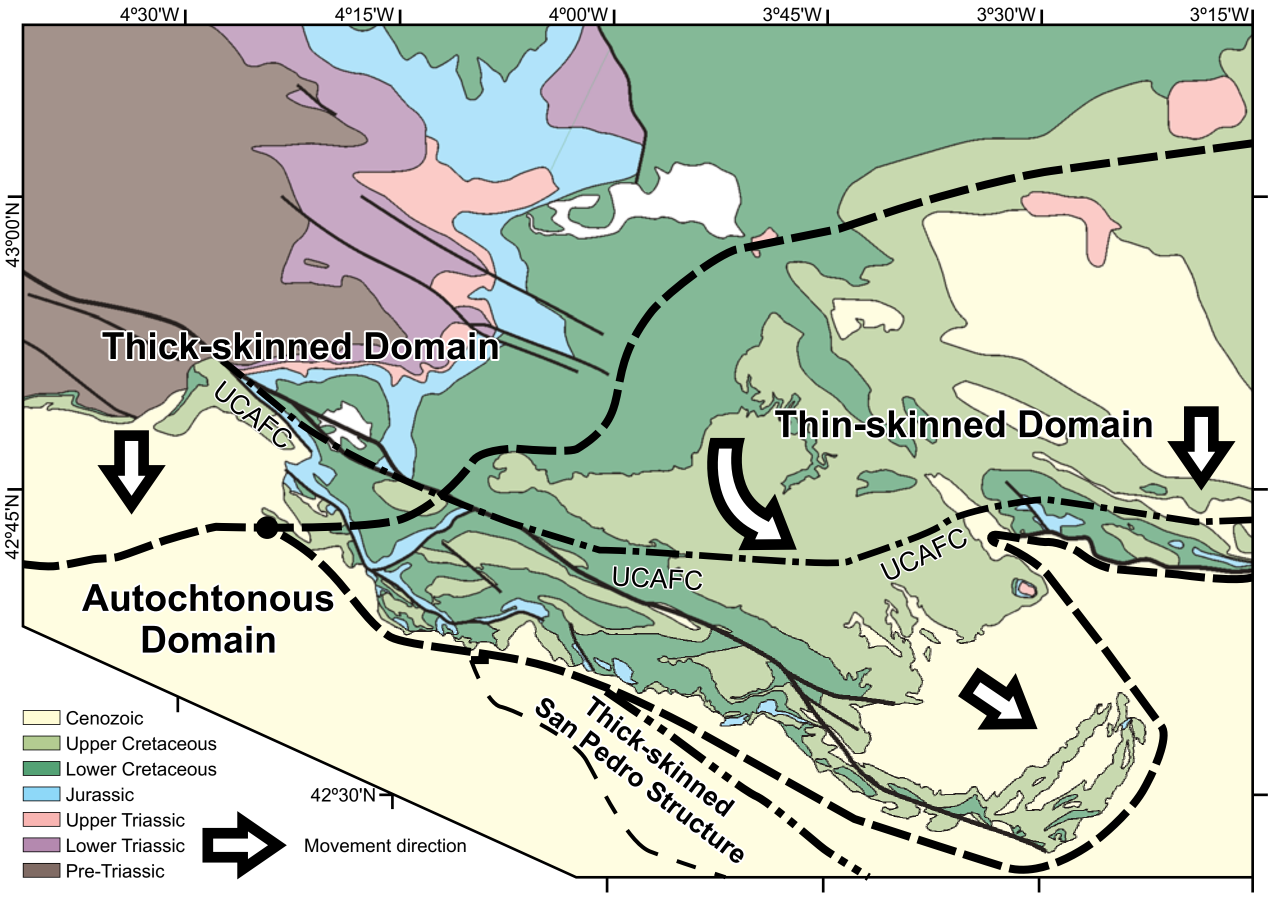


Fig. 13 (double column)