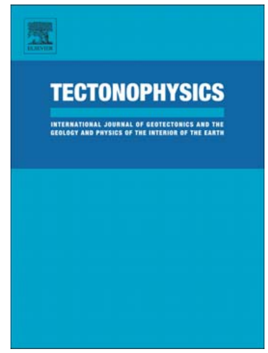
Accepted Manuscript



Extensional *vs* Contractional Cenozoic Deformation in Ibiza (Balearic Promontory, Spain): Integration in the West Mediterranean back-arc setting

Nathalie Etheve, Dominique Frizon de Lamotte, Geoffroy Mohn, Raquel Martos, Eduard Roca, Christian Blanpied

PII: S0040-1951(16)30173-1
DOI: doi: 10.1016/j.tecto.2016.05.037
Reference: TECTO 127124

To appear in: *Tectonophysics*

Received date: 8 December 2015
Revised date: 17 April 2016
Accepted date: 22 May 2016

Please cite this article as: Etheve, Nathalie, de Lamotte, Dominique Frizon, Mohn, Geoffroy, Martos, Raquel, Roca, Eduard, Blanpied, Christian, Extensional *vs* Contractional Cenozoic Deformation in Ibiza (Balearic Promontory, Spain): Integration in the West Mediterranean back-arc setting, *Tectonophysics* (2016), doi: 10.1016/j.tecto.2016.05.037

Extensional *vs* Contractional Cenozoic Deformation in Ibiza (Balearic Promontory, Spain): Integration in the West Mediterranean back-arc setting.

by

Nathalie Etheve[1], Dominique Frizon de Lamotte[1], Geoffroy Mohn[1], Raquel Martos[2, 4], Eduard Roca[2] and Christian Blanpied[3]

[1] *Université de Cergy-Pontoise, Département Géosciences et Environnement. 95300 Pontoise, France.*

[2] *Institut GEOMODELS, Universitat de Barcelona, Martí i Franquès s/n, 08028 Barcelona, Spain*

[3] Total EP, *2 place Jean Millier, 92078 Paris La Défense, France.*

[4] Present address: Royal Holloway University of London, COMPASS Research Group, Department of Earth Sciences, Egham, Surrey TW20 0EX, United Kingdom.

Abstract :

Based on field work and seismic reflection data, we investigate the Cenozoic tectono-sedimentary evolution offshore and onshore Ibiza allowing the proposal of a new tectonic agenda for the region and its integration in the geodynamic history of the West Mediterranean. The upper Oligocene-early Miocene rifting event, which characterizes the Valencia Trough and the Algerian Basin, located north and south of the study area respectively, is also present in Ibiza and particularly well-expressed in the northern part of the island. Among these two rifted basins initiated in the frame of the European Cenozoic Rift System, the Valencia Trough failed rapidly while the Algerian Basin evolved after as back-arc basin related to the subduction of the Alpine-Maghrebian Tethys. The subsequent middle Miocene compressional deformation was localized by the previous extensional faults, which were either inverted or passively translated depending on their initial orientation. Despite the lateral continuity between the External Betics and the Balearic Promontory, it appears from restored maps that this tectonic event cannot be directly related to the Betic orogen, but results from compressive stresses transmitted through the Algerian Basin. A still active back-arc asthenospheric rise likely explains the stiff behaviour of this basin, which has remained poorly deformed up to recent time. During the late Miocene a new extensional episode reworked the southern part of the Balearic Promontory. It is suggested that this extensional deformation developed in a trans-

tensional context related to the westward translation of the Alboran Domain and the coeval right-lateral strike-slip movement along the Emile Baudot Escarpment bounding the Algerian Basin to the north.

Key-words: *Ibiza Island, Balearic Promontory, West Mediterranean, Back-Arc setting, tectonic inversion.*

1. Introduction

The Cenozoic evolution of the Western Mediterranean is classically related to the slab roll-back of the Alpine-Maghrebian Tethys (e.g. Rehault et al., 1984, Bouillin, 1986; Frizon de Lamotte et al., 1991; Lonergan and White, 1997; Doglioni et al. 1997; 1999; Vergés and Sàbat, 1999; Jolivet and Faccenna, 2000; Rosenbaum et al., 2002; Roca et al., 2004) associated with the development of extensional basins in a back-arc setting (Carminati et al., 1998; Faccenna et al., 2001, 2004; Rosenbaum and Lister, 2004; Rosenbaum et al., 2008; Vergés and Fernandez, 2012). Some of these basins reached the breakup stage associated with the development of oceanic crust (e.g. Liguro-Provençal Basin, Algerian Basin, Tyrrhenian Basin) while others ended up as intra-plate rifted basins (Valencia Trough, Alboran Basin) (Fig. 1). The Valencia Trough/Liguro-Provençal basins are separated from the Algerian/Tyrrhenian basins by thicker continental domains representing narrow N to NE trending strips such as Corsica-Sardinia block or the Balearic Promontory (Fig. 1).

The Balearic Promontory lies at the junction between the Valencia Trough to the north, the Betics to the south-west and the Algerian Basin to the south-east (Fig. 1). During the Cenozoic, it recorded a succession of extensional and contractional events in relation with complex interactions between the European Cenozoic Rift System, the Pyrenean orogenic system, the Betics and the subduction of the Alpine-Maghrebian Tethys (Fontboté et al., 1990; Gelabert et al., 1992, Maillard et al., 1992, Mauffret et al., 1992, Roca and Desegaulx, 1992, Sabat et al., 1997; Acosta et al., 2002). It is classically considered that Ibiza, as the other Balearic Islands (Majorca and Minorca), belongs from a paleogeographic point of view to the external part of the Betics namely the Prebetic and Subbetic Zones (Fallot, 1922; García-Hernández et al., 1976; Azéma et al., 1979; Díaz de Neira and Gil-Gil, 2013). These zones consist of Triassic to Paleogene deposits belonging to the South-Iberian paleo-margin of the Alpine-Maghrebian Tethys. In Ibiza as in the External Betics, this sedimentary cover was detached from the Variscan basement along Upper Triassic evaporites and was involved in a fold-and-thrust system developed during Miocene times (Fallot, 1922; Rangheard, 1971; Fourcade et al., 1982; Durand-Delga and Rangheard, 2013). This contractional north-west verging deformation post-dates the formation of both Valencia and Algerian basins (Mauffret, 1979; Maillard et al., 1992; Maillard and Mauffret, 1993; Roca, 2001; Roca et al., 2004). It is worth noting that the Algerian Basin remained only weakly deformed at that time (Vergés and Sabat, 1999, Frizon de Lamotte et al., 2000; Roca et al., 2004).

Previous studies on Ibiza were either focused on the Mesozoic and Cenozoic stratigraphic and lithostratigraphic successions with the problem of its paleogeographic ascription (Azéma et al., 1979; Díaz de Neira and Gil, 2013) or on the architecture and geometry of the Miocene contractional deformations (Rangheard, 1971; Fourcade et al., 1982; Durand-Delga and Rangheard, 2013). However, less attention has been paid on the Cenozoic pre- and post-contractional evolution of the island and the inferences for the formation and evolution of the West Mediterranean.

The aim of this contribution is: 1) to fill this gap by investigating the whole Cenozoic tecto-sedimentary evolution of Ibiza, and comparing it with the neighboring offshore domains, 2) to integrate the tectonic agenda of the studied Balearic Promontory area in the course of the West Mediterranean geodynamic evolution. Based on new field evidences, balanced cross-sections and seismic reflection data, our results are incorporated at the scale of the Balearic Promontory and along a NW-

SE transect running from the Iberian mainland to Africa. Finally, the consequences for the West Mediterranean geodynamics are discussed.

2. Geological Setting: Ibiza in the frame of the Balearic Promontory

2.1 Geological setting of the Balearic Promontory

The Balearic Promontory forms a major NE-SW trending high encompassed between two main escarpments. The northern escarpment has been interpreted as the eastern continuation of the External Betic Front cross-cutting the south-east extensional margin of the Valencia Trough (Fontboté et al., 1990; Roca, 1992; Maillard, 1993; Maillard and Mauffret, 2013), whereas the southern one (the so-called Emile Baudot Escarpment) is considered as a major extensional/transform fault delineating the Algerian Basin (Maillard et al., 1992; Acosta et al., 2001, 2004; Mauffret et al., 1992, 2004). The position of the External Betic Front, either close to (Maillard and Mauffret, 1993; 1999) or several tens of km offshore (Fontboté et al., 1990; Sabat et al., 1997; Roca, 2001; Roca et al., 2004) of the Balearic Promontory, has been a matter of debate. Recent study (Driussi, 2014) favors the first hypothesis imposing an important right-lateral bending of the External Betic Front between the continental Iberia and the Balearic Promontory (Figs.1 and 2a).

The Balearic Promontory consists of an ~20 km thick (Banda et al., 1980; Pascal et al., 1992; Torné et al., 1992; Torné et al., 1996; Sàbat et al., 1997) crustal “horst” formed of Paleozoic rocks deformed during the Variscan orogeny and unconformably covered by about 1-3 km thick Mesozoic-Cenozoic cover (Fourcade et al., 1982). This sedimentary cover, usually detached at Upper Triassic evaporites, records a complex tectono-sedimentary evolution in which two major stages can be differentiated: (1) a Triassic to Early Cretaceous extensional stage with discontinuous rift events during the Late Triassic to Early Jurassic (associated with the opening of the Alpine-Maghrebian Tethys) and the Late Jurassic to Early Cretaceous (coeval with the opening of the Southern North Atlantic and Bay of Biscay), followed by (2) a Late Cretaceous to Cenozoic stage characterized by a range of extensional and contractional events (Fig. 3a).

Two major contractional events are recorded in the islands of the Balearic Promontory during the Cenozoic. The first, pre-late Oligocene in age is characterized by the development of thrusts and folds (Fallot, 1922; Darder, 1925; Roca, 1992). This deformation is classically correlated to the “Pyrenean” (middle to late Eocene) contractional event, which shaped the Pyrenees (Vergés et al., 2002), the Catalan Coastal Range (Lopez-Blanco et al., 2000) and the Iberian Range (Guimera et al., 2004) as well as the Atlas System on the other side of the Mediterranean (Frizon de Lamotte et al., 2000; Roca et al., 2004). This is supported by evidence for “Pyrenean” structures below the Miocene deposits in the Valencia Trough as well as folds in Majorca dated by the presence of Paleocene sedimentary rocks (Gelabert et al., 1992; Sàbat et al. 1997, Sàbat et al., 2011). Indeed, this first pre-Late Oligocene contractional event is unconformably overlain by uppermost Oligocene-lower Miocene successions. The base of these successions is characterized by a major regional unconformity resulting from complex vertical movements, likely associated with significant uplift and erosion, (Colom, 1975; Ramos-Guerrero, 1988). This major erosional unconformity [referred to as pre-Valencia-rift unconformity in this study (plate 1a)] is a common element for the Balearic Promontory, the Iberian and Catalan Coastal Ranges and the Valencia Trough. The second contractional event, early to middle Miocene in age, was intense and produced the main structural features of the present-day Majorca and Ibiza islands. It is characterized by the development of a NW-directed thrust-and-fold belt interpreted as the eastern termination of the External Betics.

Between these two contractional events, the dominant tectonic regime in the Balearic Promontory remains a matter of debate. In Minorca, Bourrouilh (1973) recognizes an extensional deformation event during the deposition of “Oligocene-lower Miocene” conglomerates. In Majorca, even if extensional faulting is locally recorded, most authors (Ramos-Guerrero et al., 1989; Gelabert et al., 1992; Gelabert, 1998; Sàbat et al., 2011) outline the prevalence of a contractional deformation event with folds and thrusts propagating from south-east to north-west. Finally in Ibiza, older studies done in the area also indicate a contractional deformation event during this time (Fallot, 1917; Fallot, 1948; Rangheard, 1971; Fourcade et al., 1982). Whereas some more recent studies (Durand-Delga and Rangheard, 2013) consider, thanks to new dating, that the compressional deformation occurred exclusively during the middle Miocene. In any case, with the exception of the work of Bourrouilh (1973) in Minorca, the late Oligocene-early Miocene extensional deformation usually associated with the formation of the Valencia Trough and Algerian Basin was up to now poorly recognized in the Balearic Islands.

Finally, by the Serravallian, the tectonic deformation observed in Ibiza decreased and seems to be restricted to the reactivation of some previous thrusts as extensional faults associated with the local formation of small sedimentary basins (Durand-Delga and Rangheard, 2013). Thus, the upper Serravallian to Quaternary deposits appears as sub-horizontal layers that unconformably overlay the previous deformed rocks. The base of this sequence is characterized by an unconformity referred to as the post-Betic unconformity in the present paper. In Majorca and in the entire offshore domain situated south of the islands, wide rift basins, like the Majorca Central Depression and the Formentera Basin (Fig. 2a), developed at that time (Fontboté et al., 1990; Sabat et al., 1997).

2.2 Stratigraphy and structural evolution of Ibiza

Ibiza is classically divided in three main structural units separated by major thrusts involving a rather complete Mesozoic sedimentary pile (Figs. 2, 3a and b). The definition of each unit can vary from one author to another depending on the chosen criteria. Following Durand-Delga and Rangheard (2013), we retain a classification, which is close to the initial one proposed by Fallot (1922). It is mainly based on differences in the Lower Cretaceous sedimentary successions (Díaz de Neira and Gil, 2013) and on the structural style which characterizes each unit.

Rocks older than Middle Triassic are not exposed in Ibiza. According to Rangheard (1971), the Middle Triassic to Tithonian stratigraphic record presents few lithological differences between the three main structural units (Figs. 3a and b). The Middle-Upper Triassic sediments display the typical Germanic facies with from bottom to top: 1) limestones and dolomites (Muschelkalk) and 2) marls, red clays and evaporites with interbedded volcanic rocks (Keuper) (Fourcade et al., 1982). This last formation constitutes an efficient décollement level, which has been reactivated throughout the tectonic history. Lower (and possibly Middle) Jurassic rocks display 100 to 200 m of shallow water marine limestones and dolostones brecciated at their top, followed by Upper Jurassic well-bedded limestones indicating a deeper environment (Rangheard, 1971; Azéma et al., 1979; Fourcade et al., 1982). From the Tithonian onward, facies and thickness variations allow the distinction of three individual stratigraphic domains, which correspond to the three tectonic units defined by previous studies (Figs. 3a and b) [see a review in Durand-Delga and Rangheard (2013) and Díaz de Neira and Gil (2013)]:

- In Unit I (northern part of the Island), the Cretaceous deposits are mainly neritic (Díaz de Neira and Gil, 2013) including: up to 300 m of Neocomian marls and clay limestones; almost 300 m typical Aptian "Urgonian" facies (thick massive limestones with rudists and orbitolinids); and less than 100 m of Albian marls and sandstones (Fourcade et al., 1982; Rangheard, 1971).
- In Unit II (middle part of the Island), the facies remains neritic and characterized by limestones up to the Valanginian then becoming pelagic with a thick marly unit (Rangheard, 1971).
- In Unit III (southern part of the Island), the Lower Cretaceous sediments are pelagic and mainly constituted by the marly facies of the Es Cubbels Formation, which are intensely folded and acted as minor décollement levels during the compressional deformation (Díaz de Neira and Gil, 2013; Rangheard, 1971).

These Lower Cretaceous facies and thickness changes (Fig. 3) are likely controlled by different rift episodes well documented in Iberia (García-Hernández et al., 1980; Roca et al., 1994; Salas et al., 1993, 2001; Vergés and Garcia-Senz, 2001).

The Upper Cretaceous deposits are mainly present in Unit III, more precisely in Sant Josep Sub-Unit located in the southwestern corner of the Island (Fig. 2). They have also been recognized in several outcrops in Unit II and as pebbles in the Miocene of Unit I (Durand-Delga and Rangheard, 2013). The Cenomanian is characterized by marls and limestones while the Turonian and Senonian are characterized by chalky limestones.

A major hiatus, likely associated with significant uplift and a weak angular unconformity, separates the Mesozoic sedimentary rocks from the overlying upper Oligocene to Burdigalian 100 m thick conglomerates (Fig. 3). Over these continental to shallow-water deposits or directly above the Mesozoic, the occurrence of lower to middle Miocene thick marine deposits in Ibiza has been known for a long time (Fallot, 1922). However they have only recently been dated (by nannofossils), allowing the characterization of upper Oligocene to Burdigalian conglomerates and subsequent Langhian calcareous turbidites (Rangheard et al., 2011). The reasons explaining the subsidence renewal during the Miocene remains a matter of debate. Chauve et al. (1982) and Fourcade et al. (1982) explained the thickness of the lower Miocene (Burdigalian-Langhian) sedimentation as a consequence of the development of a fore-deep and associated olistostromes along the thrust front of Unit II. This tectonic setting is close to the one proposed at a wider scale by Fontboté et al. (1990) and Sabat et al. (1997) who defend the idea of a lower-middle Miocene flexural basin along the southeastern margin of the Valencia Trough. Durand-Delga and Rangheard (2013) claim that they do not share the point of view of Chauve et al. (1982) and Fourcade et al. (1982) about the so-called “Langhian Foredeep”. Nevertheless, these authors failed to propose an alternative explanation.

3. Evidence for late Oligocene to early Miocene extensional deformation onshore and offshore Ibiza

3.1 Late Oligocene to early Miocene extensional deformation in Ibiza Island

The structure of Ibiza is characterized by the superimposition of successive tectonic events and, chiefly, by complex interaction between extensional and compressional events during the Oligo-Miocene. The pre-late Oligocene erosional surface (pre-Valencia rift unconformity) is offset by numerous high-angle extensional faults sealed locally by Langhian turbidites. These extensional faults can be identified everywhere in Ibiza and are particularly well exposed in Unit I, for example in the Na Xamena, Sant Miquel, Sant Joan and Cala d'Hort areas (see locations on figure 2b). From a general point of view, these extensional faults consistently predate the thrusts as inferred from cross-cutting relationships observed at map and outcrop scales (plate 1 b, Figs. 4, 5, 7 and 8).

In Na Xamena (Fig 4 a, b), along the north-western coast of the island, Aptian limestones and locally Albian marls present a 30° tilt toward the SSE. This Mesozoic succession is unconformably overlaid by flat upper Oligocene to lower Miocene massive polymictic conglomerates that appear clast-supported at the base of the sequence and become matrix-supported below the overlying Langhian turbidites. The clasts, ranging from several cm to dm, consist essentially of limestones derived from the reworking of the Mesozoic carbonates. The deposition of these clastic deposits was controlled by a major normal fault, responsible for the tilting of the Cretaceous sequence and the observed half-graben. To the south, the footwall block of the extensional fault was subsequently cut out by a thrust bringing the Upper Triassic Keuper formation directly over the Langhian turbidites (Fig. 4 c).

Similar extensional faults at smaller scale can be described further to the east, at Port Sant Miquel (Figs. 5 and 6). In this area, Aptian rudist-bearing limestones together with the pre-Valencia rift unconformity are tilted to the SW along several extensional faults delimiting small half-grabens (several tens of meters wide). These half-grabens, are also filled by syn-rift upper Oligocene to lower Miocene conglomerates whose thickness increase towards the faults defining wedge geometries. Up-section, the extensional faults are sealed by the Langhian turbidites which postdate its motion. Most of the observed normal faults display a planar geometry rooting probably at depth within the Upper Triassic evaporites (i.e. Keuper). At the top of the Langhian turbidites, a flat thrust separates Unit I from Upper Jurassic rocks pertaining to Unit II (Fig. 5).

Extensional faults are also well exposed north east of Sant Joan in the northeastern part of the island (Fig. 2b), where, again, they exert a control on the deposition of thick upper Oligocene to lower Miocene deposits (mainly conglomerates) lying uncomfortably on Aptian limestones (Fig. 7 b). As in Sant Miquel, only a secondary extensional fault system is displayed in the field. However, the observed geometry suggests the existence of a major NW-dipping fault below the over-thrusting Unit II (Fig. 7).

Along the western coast, a wide half-graben filled by upper Oligocene-lower Miocene conglomerates and Langhian turbidites locally associated with conglomerates (the so-called “Cala d’Hort Formation” dated by Rangheard et al., 2011) is displayed from Cala d’Hort to the foot of the Torre d’El Pirata Hill (Figs. 2b and 8). As in Na Xamena (Fig. 4), the initial major extensional fault delineating the half-graben is cut out by the floor-thrust of Unit II (Fig. 8 a, b). The hanging wall ramp anticline of this thrust is locally cross-cut by steep normal faults accommodating the deposition of upper Miocene sandstones (Marès Formation) (Fig. 8 a).

At the scale of the island, the late Oligocene to early Miocene extensional faults have essentially NE-SW and locally NW-SE trends and are only well preserved in the northern part of Ibiza (Unit I). The reason for such preservation may be: (1) the height of the downstream steps resulting from extensional faulting was here so large that it prevented a significant reactivation of the Upper Triassic basal décollement during the north-west propagating middle Miocene contractional deformation and/or (2) the presence of an inherited central horst located in Unit II that acted as a buffer zone during this contractional deformation.

In Units II and III, where the middle Miocene contractional deformation is more intense, the evidence for a late Oligocene to early Miocene extensional event is less clear. In relation to this last event, Unit II, located in the middle of the island (Fig. 2b), is characterized by the facts that: (1) Miocene deposits are mostly Serravallian to Tortonian [i.e. to the post-compressional deformation of Durand-Delga and Rangheard (2013)], and 2) these deposits unconformably overlay a deeply eroded Mesozoic cover resulting in the presence of large outcrops of Middle Triassic rocks (the older Mesozoic rocks cropping out in the island). These two attributes are well explained considering that, before the post Langhian inversion, Unit II formed a horst bounded by NW-dipping and SE-dipping extensional faults to the north and south respectively. Finally, Unit III (Fig. 2b) displays only few upper Oligocene to lower Miocene deposits. This is probably explained by the more intense middle Miocene contractional deformation, which characterized this unit. Most likely, the former late Oligocene to early Miocene basins have been completely eroded during and after the contractional deformation. The same configuration and the importance of subsequent contractional deformation probably explain why late Oligocene-early Miocene extensional faults have not been recognized in Majorca (Sàbat et al. 2011). On this island, the two main units forming the Tramuntana Range can probably be correlated to the Ibiza Units II and III (Fig. 2a). Moreover, the upper Miocene Main Majorca half-graben, which cut the Tramuntana Range to the south, can be followed south of Ibiza up to the Emile Baudot Escarpment (Fig. 2a).

3.2 Late Oligocene to early Miocene extensional deformation offshore Ibiza

The southern border of the Valencia Trough, offshore Ibiza, displays similar geometries to those observed onshore Ibiza. Occurrence of pre-middle Miocene high-normal faulting can be observed in seismic lines crossing this domain (Figs. 2c, 9a’ and 9b’).

Figure 9a’ displays a line drawing of an industrial NW-SE seismic section across the southern margin of the Valencia Trough. This seismic section intersects the Ibiza Marino An-1 well in which the Quaternary to Upper Jurassic sedimentary succession is displayed (Lanaja et al., 1987). Onshore Ibiza, a major erosional surface (i.e. the pre-Valencia rift unconformity), bounding the Mesozoic and Cenozoic sediments, can be tracked along the seismic section. This pre-Valencia rift unconformity is cross-cut and locally offset by several NW-trending extensional faults. Some of them have a listric shape, rooting into the Upper Triassic evaporites while the main one offsets the pre-salt substratum. The activity of these faults is likely associated with the collapse and lateral escape of pre-existing salt walls as suggested by the “turtle back” shape of the Ibiza Marino High (Fig. 9a’). The sediments filling the two half-grabens flanking this high are sealed by late Langhian sediments based on stratigraphic calibration in the well (Lanaja et al., 1987). These observations confirm a late Oligocene to early Langhian age for the normal faulting in this area as observed in Ibiza (this paper) and more generally in the Valencia Trough (Bartrina et al., 1992; Maillard et al., 1992; Roca and Guimera, 1992; Roca and Desegaulx, 1992; Driussi, 2014). Above the syn-rift deposits (Fig. 9a'), the late Langhian to Serravallian belongs to a well-marked transgressive sequence consisting mainly of shales interbedded with calcareous shales. However, it should be noted that the SE extensional fault shows evidence for more recent activity. In addition, on both sides of the fault, the Mesozoic succession is characterized by strong thickness variation that may represent evidence for former Mesozoic extension.

No post-middle Miocene compressional deformation is observed in the vicinity of Ibiza Marino An-1 (Fig. 9a'). Nevertheless, a parallel industrial seismic profile located further to the SE, approaching the Ibiza margin, provides evidences for the superimposition of a compressional episode. Figure 9b' proposes an interpretation of this seismic profile in which two salt-cored detachment-folds involving the whole Mesozoic cover are exposed. The north-western limb of the anticline located in the center of the profile is flanked by two generations of growth strata, separated by an unconformity (i.e. the post-Valencia rift unconformity). The deeper growth strata made by Oligocene to lower Miocene sedimentary sequence thickens generally towards the SE and the anticlinal limb. Such geometrical relation may document the activity of late Oligocene-early Miocene extensional faults. In contrast, the shallower growth strata document a general thinning of the sedimentary succession towards the anticline limb, giving evidence for a syn-folding growth strata formed during the late Langhian to Serravallian. It is worth noting the existence of a well-expressed collapse of the anticline crest and a small uplift of the seafloor showing that the halokinesis remains active.

At the first order, the observed configuration appears comparable to the one observed onshore in Cala d'Hort (Fig. 8). In both cases, the Neogene deposits rest directly over the Mesozoic rocks through an unconformity. The growth strata associated with normal faulting are sealed by the Post Valencia-rift unconformity (Fig. 9b'). The main difference is the break-through faulting, which in Cala d'Hort put the Mesozoic rocks over Langhian turbidites. As a consequence, the syn-folding deposits are not visible.

Finally, evidence for middle Miocene compressional deformation seems to be localized relatively close to Ibiza and disappeared rapidly towards the Valencia Trough toward the NW. Late Oligocene to early Miocene extensional deformation, although clear, remains moderate in the Valencia Through confirming that it cannot be responsible for the important crustal thinning observed in the SW part of the Valencia Trough (Roca and Guimera, 2015; Alaya et al. 2015; Pellen et al., 2016). Indeed, this crustal thinning must be mostly attributed to the Mesozoic evolution and notably the Late Jurassic-Early Cretaceous rifting episode, which characterizes the Iberian Plate.

4. Middle Miocene compressional deformation event in Ibiza

The geometric and chronologic relationships between the late Oligocene to early Miocene extensional and middle Miocene compressional phases are easily depicted at the rear of Unit I, in the southwestern part of Ibiza (Fig. 8). In this region, a normal fault associated with the deposition of a thick upper Oligocene to Langhian sedimentary sequence is overprinted and cut out by a thrust. Notably the thrust propagated along the footwall of the former extensional fault. The same pattern has been observed offshore, in the southern margin of the Valencia Trough, along the

Betic Front. This geometrical relationship between extensional and compressional structures is illustrated by three NW-SE generalized geological sections crossing the western, central and eastern parts of the Island (Figs. 2b, 10). The three sections present common features: Unit I remains weakly deformed with few folds detached above the Triassic evaporites (Keuper) and few thrusts; Unit II, which corresponds partly to a former horst, is generally not well exposed due to lush vegetation. However existing quarries suggest a higher strain state than in Unit I. Unit III is substantially deformed with recumbent folds and pervasive syn-folding cleavage (plate 1 c, e). The deformation is particularly well expressed in the layered Upper Jurassic to Cretaceous sediments characterized by an alternation of marls and limestones (Figs. 3 a and b).

-Western cross section (Fig. 10 a)

The section crosses the westernmost part of the island from Cala Vedella to Puig d'En Paleu (Fig. 2). The northern part of the section (Unit I) exposes a set of weakly inverted half-grabens bounded by NW-dipping normal faults and filled by upper Oligocene to middle Miocene sediments. Subordinate thrusts are also observed in Unit I rooting likely in the Upper Triassic décollement level. A more important extensional fault constitutes the inherited structure localizing the thrust-front of Unit II. This thrust can be followed continuously westward up to the south of the Cala d'Hort Half-graben (Fig. 8) and to Es Vedra Island (Fig. 2b). In Unit II, Miocene sediments rest directly over Upper Jurassic-Lower Cretaceous rocks, giving evidence for important pre-Miocene erosion. Given the low dip of the roof of Unit II (i.e. the absence of flat-ramp-flat geometry), it is necessary to involve the basement in the deformation. Therefore, we suggest that the transition from Unit I to Unit II and III is characterized by a change from thin-skinned to thick-skinned tectonic style. The front of Unit III is underlined by the over-thrusting of the Upper Cretaceous Lentrisca Formation over the Langhian turbidites. Such geometry imposes the activation of an intermediate décollement level. The best candidate is the Lower Cretaceous marls from the Es Cubbels Formation, which represents a weak level from a rheological point of view and is everywhere strongly deformed in Ibiza. We surmise that the minor folds involving both Es Cubells and Lentrisca Fms (plate 1, e) are developed over the upper flat at the top of Unit II. More significantly, we propose that at depth, the front of Unit III is localized by inherited Mesozoic extensional faults. Such inherited faults, also inferred offshore (Fig. 9b'), may explain the drastic facies change of Upper Jurassic to Lower Cretaceous sediments between Unit III and the others (Fig. 3). Toward the southern end of the cross section, older rocks (Jurassic) are involved in an asymmetric overturned fold with a steep forelimb and a more flat backlimb. Further south, overturned forelimbs with associated cleavage are observed in the Upper Jurassic sediments cropping out along the southern coast.

- *Central cross-section (Fig. 10 b)*

The central part of the island (Unit II) has little exposure due to dense vegetation. Therefore, this cross-section is split into two parts (Fig 2 b) in order to illustrate the structure of Units I and III respectively. To the north, the section (Port Sant Miquel) shows the thrusting of the Upper Jurassic limestone over Aptian-Albian limestone cropping out along the coast (Fig. 5). Further south, the upper Oligocene to lower Miocene conglomerates rest directly over the Jurassic. The southward tilting is likely controlled by an extensional fault cut out by the Sant Miquel thrust interpreted as Unit II front. Another thrust raised the Middle Triassic dolomites up to the surface; imposing a thick-skinned style. Such geometry also explains the general flat attitude of the bedding in Unit II. The second segment of the cross-section illustrates the tectonic style of Unit III characterized by large scale recumbent folds verging north-westward. The front of Unit III is marked by a major thrust putting the overturned forelimb of the Puig de Sa Vinya anticline over Langhian turbidites. At Cala Llonga another overturned forelimb (plate 1 c) is exposed and rests over the Es Cubbels décollement level. As in the western section, this tight folding is associated with cleavage development.

- *Eastern cross section (Fig. 10 c)*

This section crosses the easternmost side of the island, from the south-west of Cala d'en Serra to the north of Punta de Sa Torre (Fig. 2c). In the northern part, the observed geometries are similar to the ones observed in the western cross section. In particular, Unit I is characterized by preserved extensional structures, leading to the formation of the late Oligocene to early Miocene basin north-east of Sant Joan (Fig. 7). To the north-west, Unit II exposes two thrust-sheets forming a thin-skinned imbricate thrust system. The tectonic style changes to become thick-skinned at Talaia de Sant Vincent. As in the western and central cross-sections (Figs. 10 a and b), the front of Unit II (Port de Ses Caletes Thrust) is developed above a northwestward dipping pre-existing extensional fault. At the rear of Unit II, a horst inherited from the previous extensional events is translated over a basement fault joining the Keuper décollement right below the Talaia de Sant Viçent Thrust. This geometry, involving Cenozoic and Mesozoic extensional faults is very similar to the one described in the western cross-section at the transition between Units I and II. The Talaia de Sant Viçent sub-Unit (between Port de Ses Caletes and Cala de Sant Viçent) exposes a short overturned forelimb, ornamented by spectacular secondary folds and cut out by a break-thrust fault, and a long and flat back-limb. Such geometry again suggests involvement of the basement explaining the high level and the flat attitude of the back-limb. Further south, the Talaia de Sant Viçent sub-Unit is limited by a south-dipping normal fault likely inherited from a former Mesozoic extensional episode. The southern prolongation of the cross-section is oriented NNW-SSE (Fig. 2 b). At Cala de Sant Viçent, highly deformed Upper Jurassic alternation of limestones and marly limestones are thrusted over the Es Cubells Formation. The thrust (front of Unit III) may represent a reactivated former early Miocene normal fault likely associated with movement of thick Triassic evaporites (Platja Es Figueral). It has been reactivated by thrusts leading to the development of a set of south-vergent shear structures (plate 1, f). Two back-thrusts rooting in the basement are responsible for the southward back-thrusting of Muschelkalk dolomite. The cross-section presents at its southernmost end an over-thrusting of Muschelkalk deposits onto Miocene siltstones and marls.

The whole western cross-section and the northern part of the eastern cross-section have been restored to a point before the middle Miocene contractional shortening but after the late Oligocene-early Miocene extensional deformation. This restoration highlights the initial pre-middle Miocene configuration with a central horst in the middle of the Ibiza Island (Fig. 11). For the western cross-section, where Unit II is very narrow, the total shortening ratio is 16% and 4% if we consider only Units I and II situated below Roca Grossa (Fig. 10). For the eastern cross-section (Fig. 10), the shortening ratio is 30% for Units I and II (i.e. the part of the section restored on figure 11) but only 7% if we exclude the Talaïa de Sant Vincent sub-Unit. The shortening increases towards the SE but remains relatively low (<30%) compared to the shortening (> 100%) inferred from the cross-sections of Durand-Delga and Rangheard (2013).

5. Discussion

5.1 The structure of Ibiza

The classical description of Ibiza structures was strongly influenced by the tectonic style of the Western Alps and included the presence of large thrust-sheets ("nappes") and tectonic windows suggesting huge displacements of Units II and III (e.g. Durand-Delga and Rangheard (2013)). New observations combined with new cross sections enable us to drastically modify the structural model for Ibiza. We have recognized the occurrence of late Oligocene to early Miocene extensional faults onshore and offshore Ibiza. In particular, early Miocene extensional structures are well preserved in the northern part of the island (Unit I). Comparable geometries can be observed at the front of the Jura (Caër et al., 2015).

By contrast, extensional structures are not well preserved in Units II and III. This is probably due to their initial SE dip allowing a complete inversion and the coeval erosion of the related half-grabens. The same configuration and the importance of subsequent contractional deformation probably explain why late Oligocene to early Miocene extensional faults are poorly exposed in Majorca (Sàbat et al. 2011).

The deformation in Unit I is controlled by the Upper Triassic décollement level defining a typical thin-skinned tectonic style. In contrast, for Units II and III, the proposed model is fundamentally a thick-skinned model including activation of décollement levels along the Upper Triassic evaporites (Keuper) and Lower

Cretaceous marls (Es Cubbels). In the northern part of the island (as in the southern part of the Valencia Though) the late Oligocene to early Miocene NW-dipping normal faults allow the localization of the subsequent thrusts. By contrast, in the southern part of the island the SE-dipping normal faults acted as buttresses explaining the increased deformation (recumbent folding, cleavage etc.).

From a chronological point of view, Ibiza highlights syn- to post-Langhian contractional deformation related to the Betics. This tectonic agenda is consistent with the one proposed for the Eastern External Betics south of Valencia (De Ruig, 1992; Rubinat et al. 2012) but clearly different from the one proposed in Majorca (Sàbat et al. (2011) where a progressive compressional deformation starting during the late Oligocene and ending in Serravallian is suggested. Therefore, our new observations in Ibiza and in the Valencia Trough question the timing of deformation but also the significance of the upper Oligocene-lower Miocene conglomerates (syn-orogenic or syn-rift in origin) in Majorca. Furthermore, there is no equivalent of the Ibiza Unit I in Majorca, making it very difficult to recognize the tectonic inheritance in highly contracted rocks as exposed in the Ibiza Unit III.

5.2 New regional cross section through the Balearic Promontory

General cross-sections of the Balearic Promontory have already been proposed by Sabat et al. (1997) and by Roca et al. (2004). Both used the ESCI-Valencia Trough deep seismic reflection profile, which crosses the Promontory between Ibiza and Majorca. In these sections, the Mesozoic remains poorly delineated and no stratigraphic calibration is given for the Cenozoic. The tectonic scenario supported by these authors is close to the one defended by Fontboté et al. (1991). It supposes an early to middle Miocene extensional deformation event in the West-Valencian domain coeval with contractional deformation in the East-Valencian domain and in the Balearic Promontory. No extensional structures are present in the Promontory apart from the late Miocene normal faults observed in its southern part.

Thanks to industrial seismic sections and bore-hole data in the Valencia Trough, we are now able to propose a calibration for the Cenozoic and to follow the main discontinuities in the Promontory. On this basis, we have built a new generalized NW-SE cross-section from the Valencia Trough to the Algerian Basin passing west of Ibiza (Fig. 12). In the section, a thick Mesozoic sequence (locally reaching 5 km) can be identified up to the Emile Baudot Escarpment as suggested by Maillard (1992). The top of this Mesozoic sequence is capped in the NW by the Pre-Valencia rift unconformity and to the SE by a composite stack of the pre-Valencia, post-Valencia and post-Betic unconformities. At the rear of the Ibiza Unit III, the geometry of Mesozoic deposits cannot be understood without advocating the existence of Mesozoic normal faults not completely inverted during the subsequent episodes. Such a configuration has been proposed for the sections crossing the island (Figs. 10 a and c).

We postulate that the late Oligocene-early Miocene rifting event at the origin of the Valencia Trough is not limited to the Valencia Trough but likely encompassed the whole Balearic Promontory, as already suggested in Minorca (Bourrouilh, 1973), and expanded southward up to the Algerian Basin, which formed synchronously (Roca and Desegaulx, 1992; Arab et al., 2016). The Balearic Promontory can be consequently interpreted at that time as a complex horst system in between the Valencia Trough and the Algerian basin. However, the initial geometry of the Promontory's southern margin and its transition to the Algerian Basin (the so-called Emile Baudot Escarpment) is impossible to depict due to subsequent deformation

(Fig. 12). This comprises not only the middle Miocene compressional deformation but also the late Miocene rifting event, which is poorly exposed in Ibiza but well known in Majorca (Majorca Central Depression) and along the Promontory's southern margin (Sàbat et al., 2011; Driussi et al., 2015).

The late Miocene rifting is related to the formation of basins including the Formentera Basin (Fig. 2a; Fig. 12). The kinematics of these basins formation is not directly known. However, the map pattern (Fig. 2a) is compatible with pull-apart basins developed in the frame of a major right-lateral strike-slip movement along the Emile Baudot Escarpment (Mauffret et al., 2004). Moreover, micro-fault measurement performed by De Ruig (1992) in the Eastern Betics revealed the existence of ENE-WSW extensional deformation at that time.

5.3 The evolution of the Balearic Promontory in the frame of the West Mediterranean

The new tectonic regime proposed for the Balearic Promontory has to be integrated at the scale of the West Mediterranean and compared with the adjacent Iberian Range, Valencia Trough and Algerian Basin. A middle-late Eocene compressional event, the so-called "Pyrenean event", is recognized everywhere in the continental domains surrounding the West Mediterranean (Fig. 1). This period corresponds to the main tectonic event in two orogenic systems bordering the studied domain, namely the Iberian Range (Roca, 1994; 2001; Guimerà et al., 2004) to the north and the Atlas Domain to the south (Frizon de Lamotte et al., 2000; 2009; 2011). However, this event remains poorly observed in Ibiza, even though the limit between upper Oligocene-lower Miocene and Mesozoic sediments is exemplified by an important hiatus with an angular unconformity (plate1, a), that may be interpreted as the signature of this event (Fig. 3).

The late Oligocene-early Miocene rifting is likely present everywhere in the Balearic Promontory and now well documented in Ibiza. According to Pellen et al. (2016), we assume that the Cenozoic translation of Ibiza and Majorca relative to the Iberian mainland remained weak and without vertical axis rotation (Fig. 13) and that, consequently, the crustal thinning observed in the SW part of Valencia Trough (Fig. 1) is mainly related to an earlier (i.e. Mesozoic) rifting event (Alaya et al., 2015). The late Oligocene-early Miocene rifting has also been identified for a long time in the Kabylies (Algeria), where the so-called “Oligo-Miocene Kabyle” (OMK) is interpreted as syn-rift deposits developed along the southern margin of the Algerian Basin (Bouillin, 1977; Bouillin, 1984; Aïte and Gelard, 1997; Arab et al., 2016). More generally, both the Valencia Trough and the Algerian Basin extended to the southern tip of the European Cenozoic Rift System (ECRIS). The Valencia Trough developed over the Iberian Ranges. The Algerian Basin likely grows over the western Alpine Tethys suture (WATS in Fig. 13) (Doglioni et al., 1997; Carminati et al; 2012; Puga et al., 2011; Handy et al., 2010), which was just formed at that time and is presently exposed in part of the Alboran Domain cropping out in the Internal Betics. The subduction of the Eastern Branch of the Alpine Tethys (i.e. Maghrebian Tethys) below the eastern flank of Iberia was synchronously active (Fig. 13), so the region was in a singular position where an intracontinental rift system (i.e. ECRIS) is superimposed to a very recent suture and reaches a back-arc setting (Fig. 13).

The rifting failed in ECRIS and Valencia Trough but was successful in both the Liguro-Provençal and the Algerian basins separated by the North Balearic Transform Zone (NBTZ) also called “Accident Paul Fallot” (Durand-Delga and Fontboté, 1980) (Figs. 13 and 14). Drifting is interpreted to be triggered by slab roll-back, which started at c.a. 30 Ma in the Mediterranean (Jolivet and Faccenna, 2000). In the

Liguro-Provençal Basin, drifting started in the late Aquitanian (23-19 Ma) and ended in the Langhian (about 15 Ma) (Aslanian et al., 2012) (Fig. 14). In the Algerian Basin, the age of drifting as well as the orientation of spreading centers remains a matter of debate.

Notably the middle Miocene compressional deformation observed in Ibiza postdates the late Oligocene to early Miocene extensional deformation. At the end of the Eocene, the Kabylies were adjacent to the Balearic Promontory and subsequently thrusted over the African Margin during the Langhian (Vergés and Sàbat, 1999; Frizon de Lamotte et al., 2000; Rosenbaum et al., 2002; Medaouri et al., 2014) (Fig. 14). Therefore it appears that the Ibiza contractional event is contemporaneous with the docking of the Kabylies along the margin of Africa.

The timing asks questions about the rheological strength of the Balearic Promontory compared to the adjacent Algerian Basin, which is in contrast poorly affected by the contractional deformation. The puzzling question is to understand why the deformation is not expressed in this young and presumably weak Algerian Basin. The reason is likely that this basin remained active until to the late Miocene with seafloor spreading and asthenospheric mantle upwelling. We propose that this mantle activity prevented the inversion of the basin.

By the end of the middle Miocene, the Balearic Promontory was the site of a new rifting episode in a right-lateral transtensional context. On the other side of the Algerian Basin, this period marks the onset of slab tearing, which led to slab detachment migrating westward and eastward and ultimately to the formation of the Gibraltar and Tyrrhenian Arcs respectively (Spakman and Wortel, 2004; Mauffret et al., 2004; Medaouri et al., 2014; Van Hinsbergen et al., 2014; Bouyahiaoui et al., 2015; Do Couto et al., 2016) (Fig. 15). According to these authors, the northern and southern margins of the Algerian Basin became transform margins.

Tearing of the lithosphere subsequent to the slab detachment triggered a drastic change from N-S to E-W opening and also likely from hyper-extension to drifting (Mauffret et al., 2004; Van Hinsbergen et al., 2014), eventually leading to the lateral extrusion of the Alboran Domain to the West (Fig. 15). Moreover, the elongated spreading centers recognized in the Algerian Basin (Mauffret et al., 2004; Medaouri et al., 2014) are N-S to NNW-SSE, parallel to the direction of shortening observed in both the Balearic Promontory and Tell Mountains. The westward translation of the Alboran Domain, demonstrated by numerous kinematic indicators in the Betic-Rif system (e.g. Frizon de Lamotte et al., 1991; Platt et al.,2003; 2013; Frasca et al., 2015), is marked along the African margins by the development of pull-apart basins (Roure et al., 2012). Therefore, the right-lateral Formentera Basin could be a European equivalent of the left-lateral Cheliff Basin in eastern Algeria (Fig. 15).

The inversion of the Algerian Basin began recently during the Pliocene. It is expressed by a set of north-verging reverse faults present all along the Algerian margin (Déverchère et al., 2005) marking a possible onset of south-dipping subduction (Déverchère et al., 2005). It is worth noting that this tectonic activity is localized along the African margin (onshore and offshore) and does not affect the Balearic margin, which remained under an extensional regime.

6. Conclusion

In this work, we discuss the tectono-sedimentary evolution of Ibiza during the Cenozoic and propose a new tectonic regime for this island. We suggest that these new results can be extended to the whole Balearic Promontory and integrated in the frame of the West Mediterranean. Based on field work, balanced cross sections, seismic interpretations and integration of the regional evolution of the West Mediterranean, the following conclusions are drawn:

(1) Evidence for late Oligocene to early Miocene extensional deformation in Ibiza and along its northern margin is observed. This extensional event is characterized by the occurrence of fault-bounded basins filled by upper Oligocene-lower Miocene conglomerates and sealed by Langhian marls. At larger scale, we suggest that this rifting event initiated firstly at the tip of European Cenozoic Rift System (ECRIS) and then developed in a back-arc setting related to the subduction of the Maghrebian Tethys (or east Alpine Tethys) (Fig. 13). It is possible but not demonstrated that the ECRIS southward propagation triggered the change of subduction regime and the back-arc development, which characterizes the Mediterranean area since the early Miocene.

(2) The subsequent middle Miocene compressional deformation is characterized in Ibiza Units II and III by a typical thick-skinned style combined with the activation of different décollement levels in the cover (Fig. 10). The localization and the style of this deformation are controlled by the strong structural inheritance resulting from Mesozoic and Cenozoic extensional deformation. In spite of the lateral continuity between the external Betics and the Balearic Promontory (Figs. 1 and 2a), we show that this compressional deformation did not developed as a progressive deformation event related to the Betics as is usually the case for “external zones” of orogenic systems. Indeed, at that time, the Betics was absent south of Ibiza, where the Algerian Basin was already

developed (Fig. 14). It is necessary to consider that the compressive stresses were transmitted through the very young Algerian Basin, which, surprisingly, has not been inverted at that time (Fig. 14). We suggest that the fact that the Algerian Basin was still active and affected by back-arc asthenospheric rise could explain its strong rheological behavior. However, further work including modelling and a comparison with other back-arc evolution is required to better understand this puzzling configuration.

(3) Finally, the middle Miocene contractional deformation was followed by late Miocene to recent extensional deformation widespread in the Balearic Promontory. This event was associated with the formation of sedimentary basins, such as the Formentera Basin, interpreted as developing in a general right-lateral trans-tensional movement coeval with the westward movement of the Alboran Domain (Fig. 15). Given that a symmetrical evolution, i.e. left-lateral, can be observed in the Cheliff Basin located in Algeria on the other side of the Algerian Basin (Fig. 15), it is suggested that this major lateral displacement is not restricted to the Betic-Rif internal zone (Fig. 1), as frequently assumed, but was also relevant for domains pertaining to Europe and Africa respectively. Therefore, we suggest that the westward movement of Alboran cannot be linked only to the slab retreat of the Tethys oceanic lithosphere. The delamination of the sub-continental European and African lithospheric mantle could be proposed. Again, further work (including modelling) is necessary to further understand how such processes are related to slab retreat.

Acknowledgments: This paper benefited from discussions with many colleagues in particular:

Daniel Aslanian (IFREMER, Brest), Christian Gorini (UPMC), Marina Rabineau (CNRS, Univ. Bretagne Occidentale, Brest), Estelle Leroux (IFREMER, Brest), Romain Pellen (Univ. Bretagne Occidentale, Brest) and Julie Tugend (Univ. Strasbourg). Nathalie Etheve acknowledges TOTAL for PhD scholarship. Raquel Martos acknowledges TOTAL for Master scholarship. This paper is a contribution of the "Groupe Recherche Industrie" (GRI) "South Tethys margin" supported by TOTAL and also benefited from the financial support of SALCRETES (CGL2014-54118-C2-1-R) project. We thank Jeffrey Poort (UPMC) and Romain Pellen (IFREMER) for their involvement in the creation of the seismic database we used and M. Farran and ICM Barcelona for letting our team using their software. We also thank Denis Schnapper (TOTAL), Remi Eschard (TOTAL) and Christian Gorini (UPMC) for the effective management of the project. We thank Max Webb (Royal Holloway University) for his helpful contribution. Finally we thank Jaume Vergés and an anonymous reviewer for their very constructive review.

Figures Caption:

Fig. 1: Structural sketch map of the Western Mediterranean and North African regions showing the major Cenozoic structural trends (modified from Vergés and Sàbat, 1999 and Roca et al., 2004). An elevation map is displayed in the background. The studied areas are indicated by the red squares with location of figures 2a and b.

Fig. 2: Geological maps of the study area (see Fig. 1 for location). (a) Bathymetric map showing major tectonic features of the southwestern part of the Balearic Promontory and surrounding areas [modified from Sàbat et al, 2011; Driussi, 2014; Maillard and Mauffret, 1993; the geological boundaries are based on the ITGE geological map of the Iberian Peninsula, the Balearic islands and the Canary islands at the scale 1:1000000 (Caride de Liñan, 1994)). Two generations of extensional faults, corresponding to the late Oligocene-early Miocene and late Miocene respectively, are distinguished in the Balearic Promontory. Note the bending of the External Betics Front between Ibiza Island and the External Betics (Driussi, 2014). The thick red lines indicate the location of the seismic lines of the figures 9 and 12. (b) Structural map of Ibiza Island highlighting the three tectonic units. The boundary between Units I, II and III is deduced from structural and paleogeographic features. The red lines indicate the location of the three cross-sections presented in this study (a, b, c in Fig. 10). The localization of the field views described in Plate 1 are indicated by boxed letters (structural features modified from Díaz de Neira and Gil, 2009, 2014; Durand-Delga and Rangheard, 2013; Rangheard et al., 2011; Geological map modified from IGME, 1994; Bathymetric map after Sandwell and Smith, 1997).

Fig. 3: (a) Stratigraphic chart showing the lateral evolution of the Mesozoic and Cenozoic successions outcropping in the three tectonic units (Units I, II and III) of Ibiza and drilled in the offshore Cabriel B-2A well (see location on Fig. 2a). The Neogene volcanic rocks evolves from calc-alkaline to alkaline in the Valencia Trough (Martí et al., 1992), however the nature of those observed in Ibiza (Azéma et al., 1979) is unknown. The Middle-Late Jurassic hiatus in the Cabriel B-2A well denotes the presence of a Mesozoic high northwest of the Ibiza Island. A Middle Jurassic hiatus is also recognized in Ibiza and in the whole region (Azéma et al, 1979). The

main Cretaceous to Paleogene hiatus observed in Cabriel B-2A well and in Ibiza is commonly related to the Pyrenean contractional stage. (b) Correlated stratigraphic sequences of Units I, II and III respectively (modified after Azéma et al, 1979). The sedimentary successions are thinner in Unit II than in the other ones, indicating the presence of a horst during the Mesozoic but also during the Miocene in this Unit. CH= Cala d'Hort Formation, CJ= Cap Jueu Formation, EB= Es Botafoch Formation, EC= Es Cubells Formation, L= Llentrisca Formation, PJ= Punta Jondal Formation, PSC= Port de Ses Caletes Formation, PSM= Port Sant Miquel Formation, SM= San Miguel Formation. 1= Late Triassic to Early Jurassic rifting event ("Tethys rifting"); 2= Late Jurassic to Early Cretaceous rifting event; 3= "Pyrenean" contractional event, 4= Late Oligocene to early Miocene rifting event, 5= Langhian contractional event, 6= Serravallian extensional event. A= volcanic rocks (mainly ophites), B= Calc-alkaline volcanic rocks, C= Alkaline volcanic rocks (modified from Fourcade et al., 1982; Roca, 1992, 2001; Díaz de Neira and Gil, 2009, 2014; Rangheard et al., 2011; Durand Delga and Rangheard, 2013; Geologic time scale from Gradstein et al., 2012).

Fig. 4: Photo (a) and line drawing (b) illustrating of the Na Xamena Miocene basin (see Fig. 2b for location). The upper Oligocene-lower Miocene conglomerates rest unconformably on the Cretaceous deposits. Inset (c) is a simplified cross-section illustrating the tectonic configuration of the area. Seaward dipping listric extensional faults are responsible for the tilting of rudists-bearing limestones and coeval sedimentation of the conglomerates. The major extensional fault (not visible on the photo) is cut by a thrust that places the Mesozoic pile directly over the Langhian turbidites (c).

Fig. 5: Photo (a) and line drawing (b) illustrating Miocene extensional faults tilting the Cretaceous at the eastern side of the bay of Port Sant Miquel (see Fig. 2b for location). Note the unconformity between the Cretaceous and upper Oligocene-lower Miocene deposits, as well as how the extensional faults are usually sealed by the Langhian turbidites and marls. These last deposits are over-thrusted by Jurassic rocks of Unit II. Insert (c) is a stereoplot encompassing the dip of extensional faults and their main NW-SE orientation.

Fig. 6: Details of one of the half-grabens of figure 5 showing a wedge of upper Oligocene to lower Miocene conglomerates filling the accommodation space generated by a set of northeastward dipping extensional faults.

Fig. 7: Photo (a) and line drawing (b) located north-east of St Joan de Labritja (see location on Fig. 2; coordinates 39°5'23,80''N, 1°32'15.15''E) illustrating the extensional faults controlling the early-middle Miocene basins deposited over Unit I. The trend of these faults is NE-SW and they are related to the opening of the Valencia Trough. The thrust front (Sierra de Ses Roques Altes on Fig. 10a) delineating Unit II is an evidence for the subsequent middle Miocene contractional phase.

Fig. 8: Structure of Units I and II between Cala d'Hort and Torre Del Pirata (see Fig. 2b for location): (a) Simplified cross-section illustrating the tectonic style at the front of Unit II, where the structure of Unit I is interpreted as a late Oligocene to early Miocene half-graben and delimited to the south by a northwestward dipping extensional fault. The frontal thrust of Unit II is localized by this extensional fault. Note that toward the SE, the hanging wall is cut out by a steep post-contractional extensional fault that forms a half-graben filled by upper Miocene ("Marès")

sandstones (Rangheard et al., 2011). (b) Photo of the thrust between the Upper Jurassic-Lower Cretaceous limestones and the middle Miocene conglomerates of Unit I.

Fig. 9: Line drawing and stratigraphic interpretation of two seismic reflection industrial profiles, one at the Ibiza Marino AN-1 well location (a'), and the other one more to the Southeast (b') (see Fig. 2b for location). The salt in (a') is limited to the footwall of the main northwestward dipping extensional fault; the "turtle back" structure below Ibiza Marino An-1 well led to the formation of a salt weld at its base. The extensional faults mainly root in the Upper Triassic level. There is no evidence for contractional deformation in this area (a'). The salt-cored detachment-folds observed in (b') are likely localized by previous salt walls which were subsequently squeezed in response to the Langhian contractional phase. Lower Miocene wedges related to the late Oligocene to early Miocene extensional deformation are sealed by the Post-Valencia rift unconformity.

Fig. 10: Geological sections crossing western (a), middle (b) and eastern (c) parts of Ibiza Island (see Fig. 2b for location), emphasizing the structural style during extensional then compressional deformations. In many places, the thrusts are localized by former extensional faults. Note the different expression of the deformation in each structural unit; Unit III is highly deformed during the contractional phase while Unit I preserved the previous extensional faults. In Unit I the style of the deformation is thin-skinned with a major detachment level located in the Upper Triassic salt while it becomes thick-skinned in Units II and III. Extensional faults in black and white dashed lines are Mesozoic faults slightly inverted during the middle Miocene contractional phase.

Fig. 11: Restored cross-sections of the western cross-section (a') and the northern part of the eastern cross-section (b') (see the corresponding cross-sections (a) and (b) in Fig. 10). The restoration depicts the structures after the late Oligocene to early Miocene extensional phase and before the Langhian contractional deformation. The southern part of section b presented in figure 10 has not been restored due to a lack of constraints in the Triassic sequences which are not represented in this figure. The incipient Langhian thrusts are localized in black dashed lines. Note that some of them inverted previous extensional faults.

Fig. 12: Line drawing proposing a new interpretation of a general seismic section crossing the Balearic Promontory from the Valencia Trough to the Algerian Basin (location in Fig. 2a) (partly modified from Vergés and Sàbat, 1999; Sàbat et al., 1997; Frizon de Lamotte et al., 2000; Roca et al., 2004). The Valencia Trough is characterized by a preserved late Oligocene-early Miocene extensional deformation. The Balearic Promontory is bounded by the External Betic Front to the North and by the Emile Baudot Escarpment to the South. As seen in Fig.10, the deformation becomes thick-skinned at the front of Unit II. Mesozoic extensional faults (in black and white dashed lines) are responsible for the deposition of the thick Mesozoic sequence observed at the rear of Unit III (see also Figs. 10 a and c). They have been inverted during the post-Langhian contractional phase. The black and yellow dashed lines are the late Miocene extensional faults reactivating previous middle Miocene thrusts in the Formentera Basin (see Fig. 2a for location).

Fig. 13: Palinspastic structural reconstruction (a) and related cross section (b) of the Western Mediterranean at 30 Ma showing the configuration of the area during the late Oligocene-early Miocene extensional deformation observed in Ibiza Island. Note the continuity of the European Cenozoic Rift System (ECRIS) down to the Balearic

Promontory. We assume (according to Pellen et al., 2016) that Ibiza and Majorca remain in their present position relatively to stable Iberia. By contrast, Minorca is located closer to the Iberian margin. It is separated from Ibiza and Majorca by a transform zone, called Central Transform Zone (CTZ) by Pellen et al. 2016. More to the south, we propose that the CTZ joins the so-called Hannibal Ridge (HR) (Mauffret et al., 2004). The trace of the section (b) is shown in (a) between A and A'. Alb = Alboran Domain, Bal = Balearic Promontory, Cal = Calabria, CTZ= Central Transform Zone, GK= Great Kabylie, HR= Hannibal Ridge, IR = Iberian Ranges, LK = Lesser Kabylie, NBTZ = North Balearic Transfer Zone, Pe = Peloritan, Pyr = Pyrenees, WATS = Western Alpine Tethys Suture (modified from Vergés and Sàbat, 1999; Frizon de Lamotte et al., 2000; Roca et al., 2004; Hinsbergen et al., 2014; Medaouri et. al., 2014, Pellen et al., 2016).

Fig. 14: Palinspastic structural reconstruction (a) and related cross section (b) of the Western Mediterranean at 15 Ma showing the configuration of the area during the contractional deformation on Ibiza Island. Note the NW-SE shortening in and around Ibiza and south of the Kabylies. The Hannibal Ridge is bounding to the west a “true” oceanic domain located in between the Lesser Kabylie (LK) and Minorca. West of the Hannibal Ridge (HR), the presence of oceanic crust is not demonstrated in the Algerian Basin at that time. The trace of the section (b) is shown in (a). Alb = Alboran Domain, Bal = Balearic Promontory, Cal = Calabria, CTZ= Central Transform Zone, EBE = Emile Baudot Escarpment, GK= Great Kabylie, HR= Hannibal Ridge, IR = Iberian Ranges, LK = Lesser Kabylie, NBTZ = North Balearic Transfer Zone, Pe = Peloritan, Pyr = Pyrenees (modified from Vergés and Sàbat, 1999; Frizon de Lamotte et al., 2000; Roca et al., 2004; Hinsbergen et al., 2014; Medaouri et. al., 2014).

Fig. 15: Palinspastic structural reconstruction (a) and related cross section (b) of the Western Mediterranean at 10 Ma showing the configuration of the area during the development of the Formentera Basin. Note the transtensional movement along both margins in the Formentera and Cheliff Basins. We assume that at this stage, oceanic crust developed in the Algerian Basin as a consequence of the westward translation of the Alboran Domain. The trace of the section (b) is shown in (a).). Alb = Alboran Domain, Bal = Balearic Promontory, Bet = Betics, Cal = Calabria, CB= Cheliff Basin, CTZ= Central Transform Zone, EBE = Emile Baudot Escarpment, FEB= Formentera Basin, GK= Great Kabylie, HR= Hannibal ridge, IR = Iberian Ranges, LK = Lesser Kabylie, NBTZ = North Balearic Transfer Zone, Pe = Peloritan, Pyr = Pyrenees (modified from Vergés and Sàbat, 1999; Frizon de Lamotte et al., 2000; Roca et al., 2004; Hinsbergen et al., 2014; Medaouri et. al., 2014).

Plate 1: Field photos showing: (a) the unconformity separating the flat Burdigalian marls and conglomerates and the tilted Aptian limestones in Punta des Llosar; (b) the late Oligocene-early Miocene extensional faults cut by a middle Miocene thrust in Punta des Llosar; (c) the normal limb of a fold in the Malm limestones cut by a thrust in Cala Llonga; (d) Disharmonic folds affecting the Malm limestones in Sant Viçent; (e) the hinge of a recumbent fold in the Llentrisca limestones in Roca Grossa; (f) the ductile contractional deformation observed in the Triassic deposits of the Platja des Figuerals. See Fig. 2 for locations.

References:

Acosta, J., Munoz, A., Herranz, P., Palomo, C., Ballesteros, M., Vaquero, M., Uchupi, E., 2001. Geodynamics of the Emile Baudot Escarpment and the Balearic Promontory, western Mediterranean. Marine and petroleum geology 18(3), 349-369.

Acosta, J., Canals, M., Lopez-Martinez, J., Munoz, A., Herranz., P., Urgeles, R., Palomo, C., Casamor, J.L., 2002. The Balearic Promontory geomorphology (western Mediterranean): morphostructure and active processes. Geomorphology 49, 177-204.

Acosta J., Ancochea, E., Canals, M., Huertas, M.J., Uchupi, E., 2004. Early Pleistocene volcanism in the Emile Baudot Seamount, Balearic Promontory (Western Mediterranean Sea). Marine Geology 207, 247-257.

Aite, M.O., Gélard, J.P., 1997. Post-Collisional Palaeostresses in the Central Magrhebides (Great Kabylia, Algeria). Bulletin de la Société Géologique de France 168, 423-436.

Ayala, C., Torné, M., Roca, E., 2015. A review of the current knowledge of the crustal structure of the Valencia Trough Basin. Boletin Geologico y Minero 126 (2-3), 533-552.

Aslanian, D., Moulin, M., Schnurle, P., Klingelhoefer, F., Leroux, E., Rabineau, M., Gailler, A., Bache, F., Gorini, C., Kuroda, J., Eguchi, N., Droxler, A., Alain, K., Roure, F., Haq, B., 2012. Structure and evolution of the Gulf of Lions: The Sardinia seismic experiment and the GOLD (Gulf of Lions Drilling) project. The Leading Edge 31(7), 786-792.

Azéma, J., Chabrier, G., Chauve, P., Fourcade E., 1979. Nouvelles données stratigraphiques sur le Jurassique et le Crétacé du Nord-Ouest d'Ibiza (Baléares, Espagne). Geologica Romana 18 , 1–21.

Banda, E., Ansorge, J., Boloix, M., Cordoba, D., 1980. Structure of the crust and upper mantle beneath the Balearic Islands (Western Mediterranean). Earth and Planetary Science Letters 49 (2), 219-230.

Bartrina, M.T., Cabrera, L., Jurado, M.J., Guimerà J., Roca, E., 1992. Evolution of the Central Catalan Margin of the Valencia Trough (Western Mediterranean). Tectonophysics 203, 219-242.

Bouillin, J.P., 1977. Géologie alpine de la petite Kabylie dans les régions de Collo et d'El Melia (Algérie). Ph.D. thesis, Univ. Pierre et Marie Curie, Paris, France.

Bouillin, J.P., 1984. Nouvelle interprétation de la liaison Apennin-Maghrebides en Calabre ; conséquences sur la paléogéographie Téthysienne entre Gibraltar et les Alpes. Revue de Géographie Physique et de Géologie Dynamique 25, 321-338.

Bouillin, J.P., Le « bassin maghrebin », une ancienne limite entre l'Europe et l'Afrique à l'Ouest des Alpes, 1986. Bulletin de la Société Géologique de France 2, 547-558.

Bourrouilh, R., 1973. Stratigraphie, sédimentologie et tectonique de l'île de Minorque et du Nord-Est de Majorque (Baléares). La terminaison nord-occidentale des Cordillères bétiques en Méditerranée occidentale. Ph.D. thesis, Univ. Pierre et Marie Curie, Paris, France.

Bouyahiaoui, B., Sage, F., Abtout, A., Klingelhoefer ; F., Yelles-Chaouche, K., Schnürle, P., Marok, A., Déverchère, J., Arab, M., Galve, A., Collot, J., Y., 2015. Crustal structure of the eastern Algerian continental margin and adjacent deep basin:

implications for late Cenozoic geodynamic evolution of the western Mediterranean. Geophysical Journal International 201(3), 1912-1938.

Caër, T., Maillot, B., Souloumiac, P., Leturmy, P., Frizon de Lamotte, D., Nussbaum, C, 2015. Mechanical validation of balanced cross-sections: the case of the Mont Terri anticline at the Jura front (NW Switzerland). Journal of Structural Geology 75, 32-48.

Caride de Liñán, C. (bajo la dirección de), 1994. Mapa Geológico de la Península Ibérica, Baleares y Canarias. Escala 1:1000000. Instituto Tecnológico Geominero de España.

Carminati, E., Wortel, M.J.R., Spakman, W., Sabadini, R., 1998. The role of slab detachment processes in the opening of the western-central Mediterranean basins: some geological and geophysical evidence. Earth and Planetary Science Letters 160 (3-4), 651-665.

Carminati, E., Lustrino, M., Doglioni, C., 2012. Geodynamic evolution of the central and western Mediterranean: Tectonics vs igneous petrology constraints. Tectonophysics 579, 172-173.

Chauve, P., Chabrier, G., Fourcade, E., 1982. Données nouvelles sur la structure et l'évolution géodynamique de l'île d'Ibiza (Baléares), Comptes Rendus de l'Académie des Sciences, Série II, 295, 733–736.

Clerc, C., Lagabrielle, Y., 2014. Thermal control on the modes of crustal thinning leading to mantle exhumation: Insights from the Cretaceous Pyrenean hot paleomargins. Tectonics 33, doi:10.1002/2013TC003471.

Colom, G., 1975. Geologia de Mallorca. Diputacion Provincial de Baleares, Instituto de Estudios Balearicos, Patronato Jose Maria Quadrado, Consejo Superior de Investigaciones Cientificas, 2 Vols., 522 pp.

Darder, B., 1925. La tectonique de la région orientale de l'île de Majorque. Bulletin de la Société Géologique de France 4, XXV (1), 245-278.

De Ruig, M.J., 1992. Tectono-sedimentary evolution of the Prebetic fold belt of Alicante (SE Spain). Ph.D. thesis, Vrije Universiteit Amsterdam, 207 pp.

Déverchère, J., Yelles, K., Domzig, A., Mercier de Lépinay, B., Bouillin, J.-P., Gaullier, V., Bracène, R., Calais, E., Savoye, B., Kherroubi, A., Le Roy, P., Pauc, H., Dan, G., 2005. Active thrust faulting offshore Boumerdes, Algeria, and its relations to the 2003 Mw 6.9 earthquake. Geophysical Research Letters 32, L04311, doi:10.1029/2004GL021646.

Díaz de Neira, J.A., Gil, J., 2009. Unidades litoestratigráficas del Cretácico de Ibiza (Islas Baleares, España). Boletín de la Real Sociedad Española de Historia Natural (Sección Geológica) 103, 5–21.

Díaz de Neira, J. A., Gil, J., 2013. Ascription of the island of Ibiza to the Prebetic of Alicante (Betic Range, Spain) after correlation of Lower Cretaceous sedimentary succession., Cretaceous Res. 41, 194–209

Díaz de Neira, J. A., Gil, J. ,2014. Correlación litoestratigráfica entre las sucesiones mesozoicas de la isla de Ibiza y el Prebético de Alicante. Revista de la Sociedad Geológica de España 27(1), 91-110.

Do Couto, D., Gorini, C., Jolivet, L., Lebret, N., Augier, R., Gumiaux, C., D'Acremont, E., Ammar, A., Jabour, H., Auxiètre, J., L., 2016. Tectonic and stratigraphic evolution of the Western Alboran Sea Basin in the last 25Myrs. Tectonophysics (in Press).

Doglioni, C., Gueguen, E., Sàbat, F., Fernandez, M., 1997. The western Mediterranean extensional basins and the Alpine orogen. Terra Nova 9(3), 109-112.

Doglioni, C., Fernandez, M., Gueguen, E., Sàbat, F., 1999. On the interferente between the early Apennines. Maghrebides backarc extension and the Alps–Betics orogens in the Neogene geodynamics of the Western Mediterranean. Boll. Soc. Geol. Ital. 118, 75–89.

Driussi, O., 2014. Evolution de la region Baléares (Méditerranée occidentale) du Néogène à l'Actuel: aspects géodynamiques et paléoenvironnementaux. Ph.D. thesis, Université Toulouse, France.

Driussi, O., Briais, A., Maillard, A., 2015. Evidence for transform motion along the South Balearic margin and implications for the kinematics of opening of the Algerian basin. Bulletin de la Société Géologique de France 186, 353-370, doi:10.2113/gssgfbull.186.4-5.353

Durand-Delga, M., Fontboté, J.M., 1980. Le cadre structural de la Méditerranée occidentale. 26th Intern. Geol. Congr., Paris, Colloq. C5, 67-85.

Durand-Delga, M., Rangheard, Y. 2013. Structure de l'île d'Eivissa (Ibiza) et sa place dans le cadre baléare. Boll. Soc. Hist. Nat. Balears 56, 25-50. ISSN 0212- 260X. Palma de Mallorca.

Faccenna, C., Becker, T.W., Lucente, F.P., Rossetti, F., 2001. History of subduction and back-arc extension in the central Mediterranean. Geophys. J. Intern. 145, 1-21.

Faccenna C., Piromallo, C., Crespo-Blanc, A., Jolivet, L., Rossetti, F., 2004. Lateral slab deformation and the origin of the western Mediterranean arcs. Tectonics 23, TC1012.doi:10.1029/2002TC001488.

Fallot, P., 1917. Sur la tectonique d'Ibiza (Baléares). C. R. Acad. Sci. Paris 164, 186-187.

Fallot, P., 1922. Etude géologique de la Sierra de Majorque. Ph.D. thesis, Université de Paris, France. Lib. Polytech. Ch. Béranger. Paris et Liege, 480 pp

Fallot, P., 1948. Les cordilleras Bétiques. Estud. Géol., 8, 83-172.

Fontboté, J. M., Guimerà, J., Roca, E., Sàbat, F., Santanach, P.n Fernandez-Ortigosa, F., 1990. The Cenozoic geodynamic evolution of the Valencia Trough (western Mediterranean). Rev. Soc. Geol. Espana 3, 249-259.

Fourcade E., Chauve P., Chabrier G. 1982. Stratigraphie et tectonique de l'île d'Ibiza, témoin du prolongement de la nappe subbétique aux Baléares (Espagne). Eclogae geol. Helv. 75 (2), 415–436.

Frasca, G., Gueydan, F., Brun, J.P., 2015. Structural record of lower Miocene westward motion of the Alboran Domain in the Western Betics, Spain. Tectonophysics, 657, 1-20.

Frizon de Lamotte, D., Andrieux, J., Guézou, J. C., 1991. Cinématique des chevauchements néogènes dans l'Arc bético-rifain, discussions sur les modèles géodynamiques. Bull. Soc. Géol. Fr. 162, 611-626.

Frizon de Lamotte, D., Saint Bezar, B., Bracène, R., Mercier, E., 2000. The two main steps of the Atlas building and geodynamics of the western Mediterranean. Tectonics 19, 740–761.

Frizon de Lamotte, D., Leturmy, P., Missenard, Y., Khomsi, S., Ruiz, G., Saddiqi, O., Guillocheau, F., Michard, A., 2009. Mesozoic and Cenozoic vertical movements in the Atlas system (Algeria,Morocco, Tunisia): an overview. Tectonophysics 475, 9–28.

Frizon de Lamotte, D., Raulin, C., Mouchot, N., Wrobel-Daveau, J.-C., Blanpied, C., Ringenbach, J.-C., 2011. The southernmost margin of the Tethys realm during the Mesozoic and Cenozoic: initial geometry and timing of the inversion processes. Tectonics 30, TC3002.

García-Hernández, M., González Donoso, J.M., Linares, A., Rivas, P., Vera, J.A., 1976. Características ambientales del Lías Inferior y medio en la Zona Subbética y su significado en la interpretación general de la cordillera. Reunión sobre la Geodinámica de la Cordillera Bética y Mar de Alborán. Sec. Pub. Univ. Granada, pp. 125–157.

García-Hernández, M., López-Garrido, A. C., Rivas, P., Sanz de Galdeano, C., & Vera, J. A., 1980. Mesozoic palaeogeographic evolution of the External Zones of the Betic Cordillera. Geology En Mijnbouw, 59(2), 155-168.

Gelabert, B., Sabat, F., Rodriguez-Perea, A., 1992. A structural outline of the Sierra de Tramuntana of Mallorca (Balearics Islands). Tectonophysics 203 (1-4), 167-183.

Gradstein, F.M., Ogg, J.G., Smith, A.G. (Eds.), 2004. A Geologic Time Scale 2004, Cambridge University Press, Cambridge, 589 pp.

Guimerà, J., Más, R., Alonso, A., 2004. Intraplate deformation in the NW Iberian Chain: Mesozoic extension and contractional inversion. Journal of the Geological Society (London) 16, 291–303.

Handy, M.R., Schmid, S.M., Bousquet, R., Kissling, E., Bernoulli, D., 2010. Reconciling plate-tectonic reconstructions of Alpine Tethys with the geological-geophysical record of spreading and subduction in the Alps. Earth-Science Reviews, 102(3), 121-158.

Jolivet, L., Faccenna, C., 2000. Mediterranean extension and the Africa-Eurasia collision. Tectonics 19, 10951106.

Lanaja, J.M., 1987. Contribucion de la exploracion petrolifera al conocimiento de la geologia de Espana. IGME. Serv. Publishers Minnis. Industri. Energ., Madrid.

Lonergan, L., White, N., 1997. Origin of the Betic–Rif mountain belt. Tectonics 16, 504–522.

Lopez-Blanco, M., Marzo, M., Burbank, D.W., Vergés, J., Roca, E., Anadón, P., Piña, J., 2000. Tectonic and climatic controls on the development of foreland fan deltas: Montserrat and Sant Llorenç del Munt systems (Middle Eocene, Ebro Basin, NE Spain). Sedimentary Geology 138(1), 17-39.

Maillard, A., 1993. Structure et riftogenese du Golfe de Valence (Méditerranée Nord-Occidentale). Ph.D. thesis, Univ. Pierre et Marie Curie, Paris, France.

Maillard A., Mauffret A., 1993. Structure et volcanisme dans la fosse de Valence (Méditerranéen Nord-Occidentale). Bulletin de la Société Géologique de France 164, 365-383.

Maillard, A., Mauffret, A., 1999. Crustal structure and riftogenesis of the Valencia Trough (north-western Mediterranean Sea). Basin Res. 11, 357–379.

Maillard A., Mauffret A., 2013. Structure and present-day compression in the offshore area between Alicante and Ibiza Island (Eastern Iberian Margin). Tectonophysics 591, 116- 130.

Maillard A., Mauffret A., Watts A.B., Torne M., Pascal G., Buhl P., Pinet B., 1992. Tertiary sedimentary History and structure of the Valencia Trough (Western Mediterranean). Tectonophysics 203, 57–76.

Marti, J., Mitjavila, J., Roca, E., Aparicio, A., 1992. Cenozoic magmatism of the Valencia Trough (western Mediterranean): Relationship between structural evolution and volcanism. Tectonophysics 203(1), 145-165.

Masini, E.G., Manatschal, J., Tugend, J., Mohn, G., 2014. The tectono-sedimentary evolution of a hyper-extended rift basin. The example of the Arzacq-Mauléon rift system (Western Pyrenees, SW France). Int. J. Earth Sci., 1-28, doi:10.1007/s00531-014-1023-8.

Mauffret, A., 1979. Étude géodynamique de la marge des îles Baléares. Mémoires de la Société géologique de France LVI, 132, 94.

Mauffret, A., Maldonado, A., Campillo, A.C., 1992. Tectonic framework of the eastern Alboran and western Algerian basins, Western Mediterranean. Geo Mar. Lett. 12, 104–110.

Mauffret, A., Frizon de Lamotte, D., Lallemant, S., Gorini, C., Maillard, A., 2004. E–W opening of the Algerian Basin (Western Mediterranean). Terra Nova 16, 257–264.

Medaouri M., Deverchère, J., Graindorge, D., Bracene, R., Badji., R., Ouabadi, A., Yelles-Chaouche, K., Bendiab F., 2014. The transition from Alboran to Algerian basins (Western Mediterranean Sea): Chronostratigraphy, deep crustal structure and tectonic evolution at the rear of a narrow slab rollback system. Journal of Geodynamics 77, 186-205.

Pellen, R., Aslanian, D., Rabineau, M., Leroux, E., Gorini, C., Silenzario, C., Blanpied, C., Rubino, J.L., (2016) The Minorca Basin: a buffer zone between the Valencia and Liguro-Provençal basins (NW Mediterranean Sea) Terra Nova, *in press.*

Pascal, G., Torné, M., Buhl, P., Watts, A.B., Mauffret, A., 1992. Crustal and velocity structure of the Valencia Trough (Western Mediterranean). Part II, Detailed interpretation of five Expanded Spread Profiles. Tectonophysics 203, 21-55.

Platt, J. P., Allerton, S., Kirker, A., Mandeville, C., Mayfield, A., Platzman, E. S., & Rimi, A., 2003. The ultimate arc: Differential displacement, oroclinal bending, and vertical axis rotation in the External Betic-Rif arc. Tectonics *22* (3).

Plat, J.P., Behr, W.M., Johanesen, K., Williams, J.R., 2013. The Betic-Rif arc and its orogenic hinterland: a review. Annual Review of Earth and Planetary Sciences 41, 313-357.

Pomar, L., Marzo, M., Baron, A., 1983a. El Terciario de Mallorca. In: Pomar, L., Obrador, A., Fornos, J.J., Rodriguez-Perea, A. El Terciario de las Baleares (Mallorca-Menorca). Inst. d'Estudis Balearics, Univinersitat de Palma de Mallorca, 21-45.

Puga, E., Fanning, M., de Federico, A. D., Nieto, J. M., Beccaluva, L., Bianchini, G., & Puga, M. A. D., 2011. Petrology, geochemistry and U–Pb geochronology of the

Betic Ophiolites: inferences for Pangaea break-up and birth of the westernmost Tethys Ocean. Lithos 124(3), 255-272.

Ramos-Guerrero, E., 1988. El Paleógeno de las Baleares: Estratigrafía y sedimentología. Ph. D. thesis. Universitat de Barcelona, Spain, 212 pp.

Ramos-Guerrero, E., Rodríguez-Perea, A., Sàbat, F., Serra-Kiel, J., 1989. Cenozoic tectonosedimentary evolution of Majorca Island. Geodinamica Acta 3 (1), 53–72.

Rangheard, Y., 1971. Etude géologique des îles d'Ibiza et de Formentera (Baléares). Mem. Inst. geol. y min. Espana 82, 340.

Rangheard, Y., Müller, C., Durand-Delga, M., 2011. Apport de la micropaléontologie, spécialement du nannoplancton, à la connaissance de l'évolution géologique au Miocène de l'île d'Eivissa (Ibiza, Baléares, Espagne). Comptes Rendu Paleovol 10, 537-549.

Rehault, J.P., Boillot, G., Mauffret, A., 1984. The Western Mediterranean Basin geological evolution. Mar. Geol. 55, 447–477.

Roca, E., 1992. L'estructura de la Conca Catalano-Balear: paper de la compression I de la distension en la seva gènesi. Ph.D. thesis, Universitat de Barcelona, 330 pp.

Roca, E., 1994. La evolucion geodinamica de la Cuenca Catalano–Balear y areas adyacentes desde el Mesozoico hasta la actualidad. Acta Geol. Hisp. 29, 3–25.

Roca, E., Desegaulx, P., 1992. Analysis of the geological evolution and vertical movements in the Valencia Trough area, western Mediterranean. Marine and Petroleum Geology 9, 167–185.

Roca, E., Guimerà, J., 1992. The Neogene structure of the eastern Iberian margin: structural constraints on the crustal evolution of the Valencia Trough (western Mediterranean). Tectonophysics 203, 203–218.

Roca, E., Guimerà, J., Salas, R., 1994. Mesozoic extensional tectonics in the Southeastern Iberian Chain. Geol. Mag. 131: 155-168.

Roca, E., 2001. The Northwest Mediterranean Basin (Valencia Trough, Gulf of Lions and Liguro-Provençal basins); structure and geodynamics evolution. In: Ziegler, P.A., Cavazza, W., Robertson, A.H.F., Crasquin, S.S. (Eds.), Peri-Tethys memoir 6; Peri-Tethyan rift/wrench basins and passive basins. Mémoires du Muséum National d'Histoire Naturelle, 671–706.

Roca, E., Frizon de Lamotte, D., Mauffret, A., Bracène, R., Vergés, J., Benaouali, N., Fernàndez, M., Muñoz, J.A., Zeyen, H., 2004. TRANSMED Transect II: Aquitaine Basin–Pyrénées–Ebro basin–Catalan range–Valencia through–Balearic block–Algerian basin–Kabylies–Atlas–Saharan platform. In: Cavazza, R.W., Roure, F., Spakman, W., Stampfli, G.M., Ziegler, P.A. (Eds.), The TRANSMED Atlas — The Mediterranean Region from Crust to Mantle. Springer-Verlag, Berlin.

Roure, F., Casero, P., Addoum, B., 2012. Alpine inversion of the North African margin and delamination of its continental lithosphere. Tectonics 31, TC3006. http://dx.doi.org/10.1029/2011TC00298.

Rosenbaum, G., Lister, G.S., Duboz, C., 2002. Reconstruction of the tectonic evolution of the western Mediterranean since the Oligocene. In: Rosenbaum, G., Lister, G.S. (Eds.), Reconstruction of the evolution of the Alpine–Himalayan orogen: Journal of the Virtual Explorer, 7, pp. 107–130.

Rosenbaum, G., Gasparon, M., Lucente, F.P., Peccerillo, A., Miller, M.S., 2008. Kinematics of slab tear faults during subduction segmentation and implications for Italian magmatism. Tectonics 27. doi:10.1029/2007TC002143.

Rosenbaum, G., Lister, G.S., 2004. Formation of arcuate orogenic belts in the Western Mediterranean region. In: Susman, A.J., Weil, A.B. (Eds.), Orogenic curvature: integrating paleomagnetic and structural analyses. Geol. Soc of America Special Paper 383, pp. 41–51. Boulder, Colorado.

Rubinat M., Roca E., Escalas M., Queralt P., Ferrer O., Ledo, J.J., 2012. The influence of basement structure on the evolution of the Bicorb–Quesa Diapir (eastern Betics, Iberian Peninsula): contractive thin-skinned deformation above a pre-existing extensional basement fault. Int J Earth Sci (Geol Rundsch). doi:10.1007/s00531-012-0789-9.

Sàbat, F., Roca, E., Muñoz, J.A., Vergés, J., Sans, M., Masana, E., Santanach, P., Estevez, A., Santisteban, C., 1997. Role of extension and compression in the evolution of the eastern margin of Iberia: the ESCI–València Trough seismic profile. Rev. Soc. Geol. Esp. 8 (4), 431–448.

Sàbat, F., Gelabert, B., Rodriguez-Perea, A., Giménez, J. 2011. Geological structure and evolution of Majorca: Implications for the origin of the Western Mediterranean. Tectonophysics 510, 217-238

Vergés, J., Sàbat, F., 1999. Constraints on the Neogene Mediterranean kinematic evolution along a 1000 km transect from Iberia to Africa. Geological Society, London, Special Publications 156(1), 63-80.

Vergés, J., Fernàndez, M., 2012. Tethys-Atlantic interaction along the Iberia-Africa plate boundary: The Betic-Rif orogenic system. Tectonophysics 579, 144-172.

Salas, R., Casas, A., 1 993. Mesozoic extensional tectonics, stratigraphy and crustal evolution during the Alpine Cycle of the Eastern Iberian Basin. Tectonophysics 228, 33-55.

Salas, R., Guimerà, J., Mas, R., Martín-Closas, C., Meléndez, A., Alonso, A., 2001. Evolution of the Mesozoic central Iberian Rift System and its Cainozoic inversion (Iberian chain). Peri-Tethys Memoir 6, 145-185.

Smith, W. H., Sandwell, D. T., 1997. Global sea floor topography from satellite altimetry and ship depth soundings. Science 277(5334), 1956-1962.

Simó, A., Giner, J., 1983. El Neógeno de Ibiza y Formentera (Islas Baleares). Rev. Inv. Geol 36, 67-81.

Spakman, W., Wortel, M.J.R., 2004. A tomographic view on Western Mediterranean geodynamics. In: Cavazza, W., Roure, F., Spakman, W., Stampfli, G.M., Ziegler, P. (Eds.), The TRANSMED Atlas. The Mediterranean Region from Crust to Mantle. Springer, pp. 31–52.

Tugend, J., Manatschal, G., Kusznir, N. J., Masini, E., Mohn, G., Thinon, I., 2014. Formation and deformation of hyperextended rift systems: Insights from rift domain mapping in the Bay of Biscay-Pyrenees. Tectonics 33.

Torné, M., Pascal, G., Buhl, P., Watts, A.B., Mauffret, A., 1992. Crustal and velocity structure of the Valencia Trough (western Mediterranean), Part I. A combined refraction/wide-angle reflection and near-vertical reflection study. In: E. Banda and P.

Santanach (Editors), Geology and Geophysics of the Valencia Trough, Western Mediterranean. Tectonophysics 203, l-20.

Torné, M., Banda, E., Fernandez, M., 1996. The Valencia Trough: geological and geophysical constraints on basin formation models. Mémoires du Muséum national d'histoire naturelle 170, 103-128.

Tugend, J., Manatschal, G., Kusznir, N. J., Masini, E., Mohn, G., Thinon, I., 2014. Formation and deformation of hyperextended rift systems: Insights from rift domain mapping in the Bay of Biscay-Pyrenees. Tectonics 33(7), 1239-1276.

Vergés, J., Sàbat, F., 1999. Constraints on the Neogene Mediterranean kinematic evolution along a 1000 km transect from Iberia to Africa. In: Durand B., Jolivet L., Horcath F., Séranne M. (eds) The Mediterranean basins: tertiary Extension within the Alpine Orogen. Geological Society, London, Special Publications 156, 63-80.

Vergés, J., García-Senz, J., 2001. Mesozoic evolution and Cainozoic inversion of the Pyrenean rift. Mémoires du Muséum national d'histoire naturelle 186, 187-212.

Van Hinsbergen, D. J. J., Mensink, M., Langereis, C. G., Maffione, M., Spalluto, L., Tropeano, M., Sàbato, L., 2014. Did Adria rotate relative to Africa? Solid Earth 5, 611-629.

Van Hinsbergen, D. J., Vissers, R. L., Spakman, W., 2014. Origin and consequences of western Mediterranean subduction, rollback, and slab segmentation. Tectonics 33(4), 393-419.

Watts, A. B., Torné, M., 1992. Subsidence history, crustal structure, and thermal evolution of the Valencia Trough: A young extensional basin in the western

Mediterranean. Journal of Geophysical Research: Solid Earth (1978–2012), 97(B13), 20021-20041.

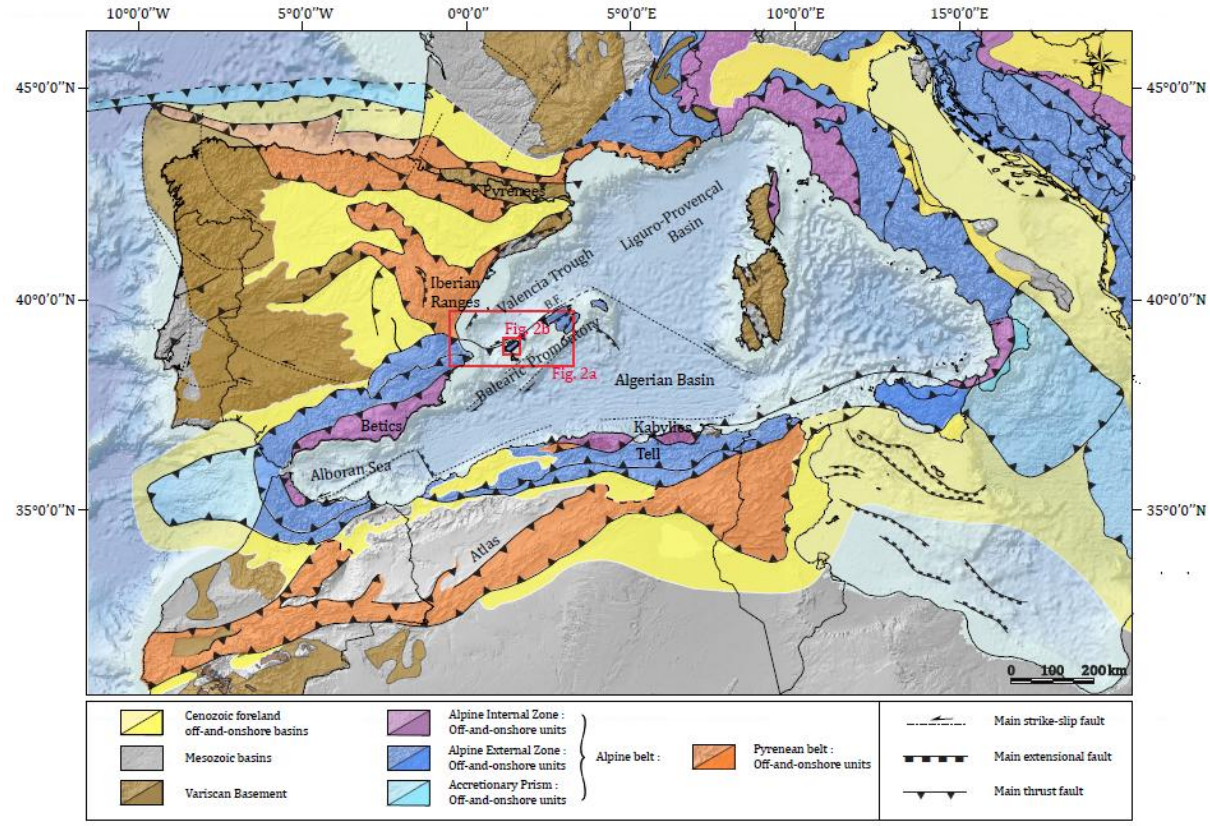
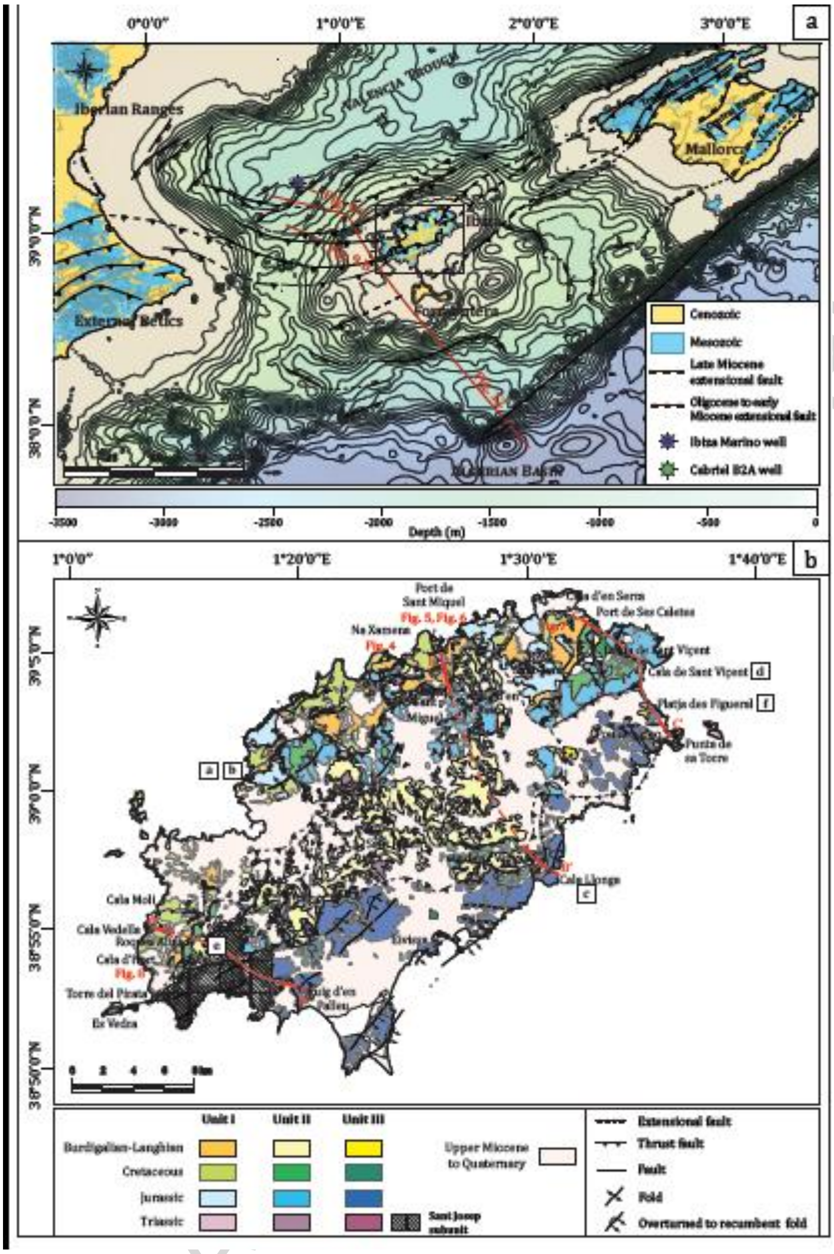

10°0'0"W
5°0'0"W
0°0'0"
5°0'0"E
10°0'0"E
15°0'0"E
45°0'0"N
40°0'0"N
35°0'0"N
Pyrenees
Liguro-Provençal Basin
Iberian Ranges
Valencia Trough
Fig. 2b
Balearic Promontory
Fig. 2a
Algerian Basin
Betics
Kabylies
Tell
Alboran Sea
Atlas
0 100 200 km
Cenozoic foreland off-and-onshore basins
Mesozoic basins
Variscan Basement
Alpine Internal Zone : Off-and-onshore units
Alpine External Zone : Off-and-onshore units
Accretionary Prism : Off-and-onshore units
Alpine belt :
Pyrenean belt : Off-and-onshore units
Main strike-slip fault
Main extensional fault
Main thrust fault

Figure 1



a
0°0'0"
1°0'0"E
2°0'0"E
3°0'0"E
39°0'0"N
38°0'0"N
Iberian Ranges
VALENCIA TROUGH
Mallorca
Ibiza
Formentera
External Betics
BALEARIAN BASIN
Cenozoic
Mesozoic
Late Miocene extensional fault
Oligocene to early Miocene extensional fault
Ibiza Marino well
Cabriel B2A well
Depth (m)
b
1°0'0"
1°20'0"E
1°30'0"E
1°40'0"E
39°5'0"N
39°0'0"N
38°55'0"N
38°50'0"N
Port de Sant Miquel
Fig. 5, Fig. 6
Na Xamena
Fig. 4
Port de Ses Caletes
Cala de Sant Vicent
Platja des Figueral
Punta de sa Torre
Cala Llonga
Cala Molí
Cala Vedella
Torre del Pirata
Es Vedra
Puig d'en Pallau
Unit I
Unit II
Unit III
Burdigalian-Langhian
Cretaceous
Jurassic
Triassic
Sant Josep subunit
Upper Miocene to Quaternary
Extensional fault
Thrust fault
Fault
Fold
Overturned to recumbent fold

Figure 2

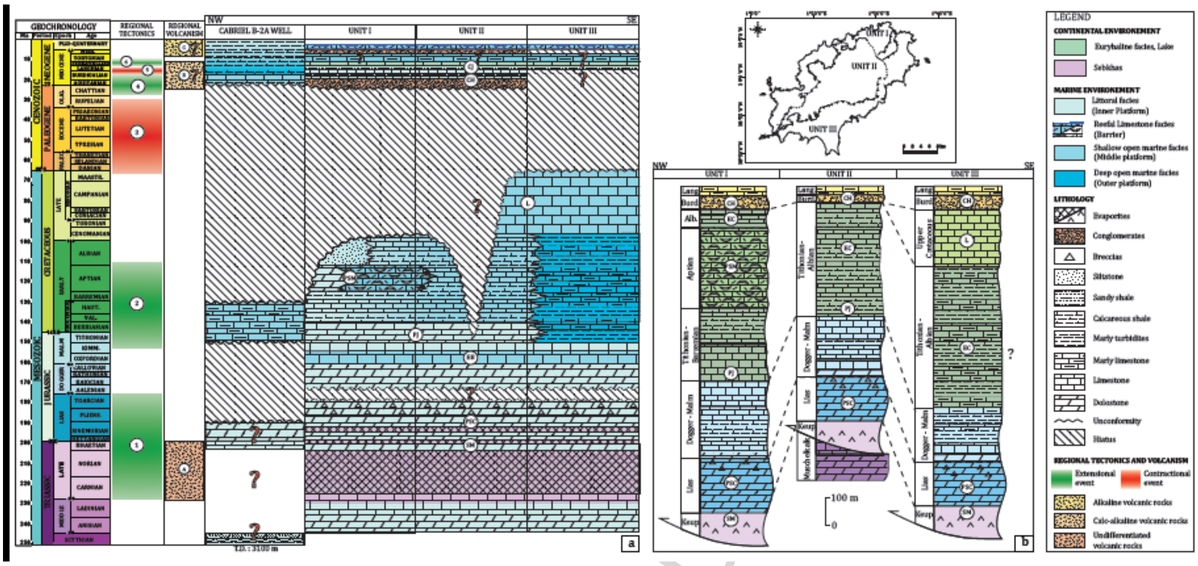


Figure 3

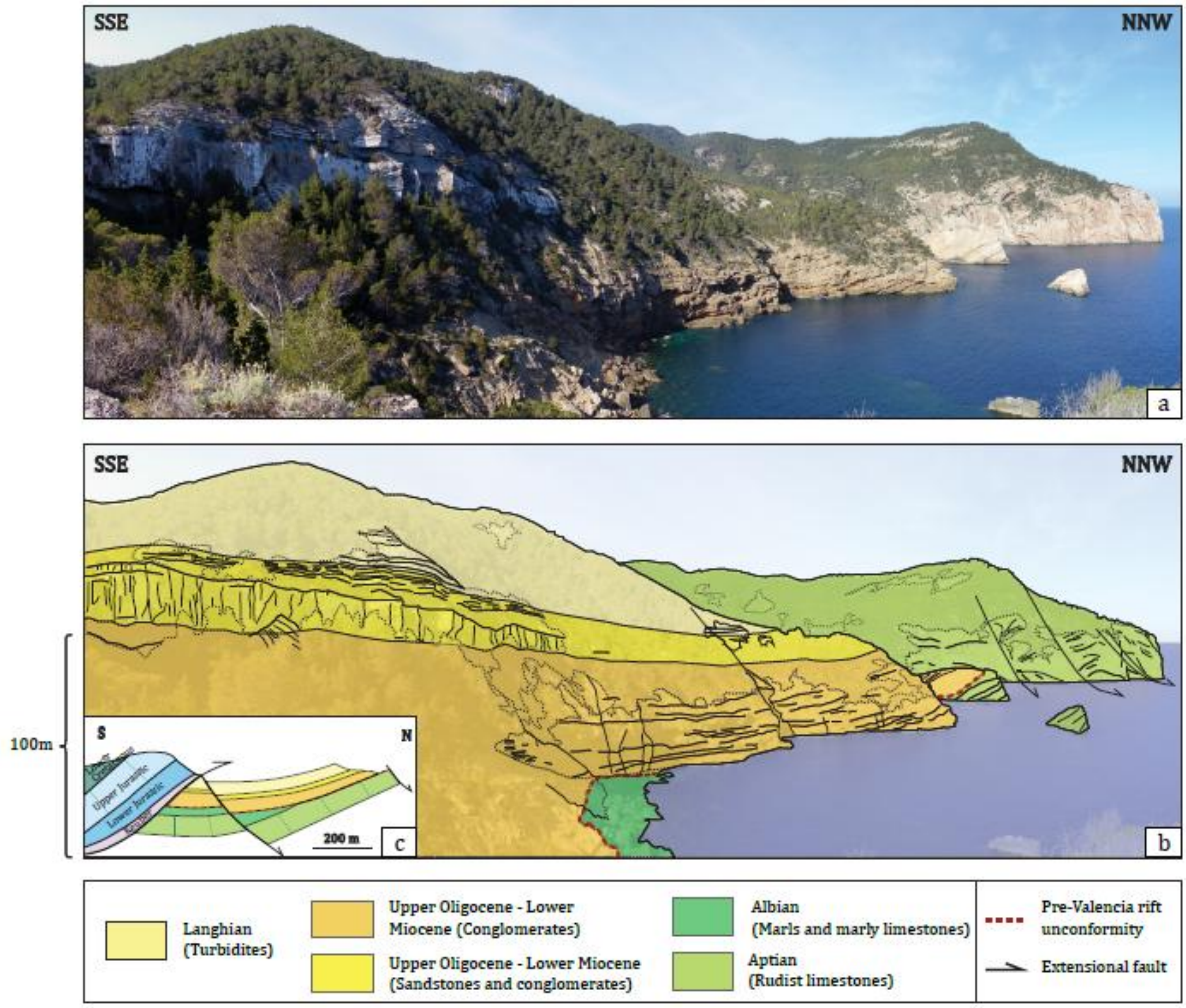

SSE
NNW
a
SSE
NNW
100m
S
N
Upper Jurassic
Lower Jurassic
200 m
c
b
Langhian
(Turbidites)
Upper Oligocene - Lower
Miocene (Conglomerates)
Upper Oligocene - Lower Miocene
(Sandstones and conglomerates)
Albian
(Marls and marly limestones)
Aptian
(Rudist limestones)
Pre-Valencia rift
unconformity
Extensional fault

Figure4

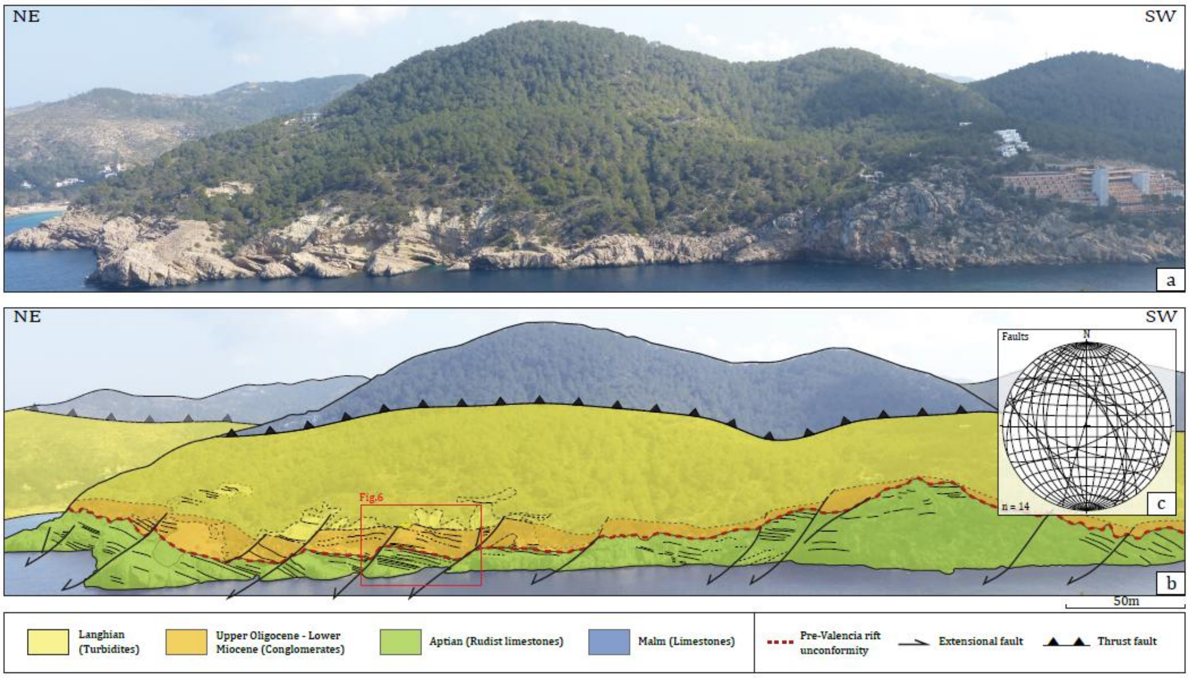

NE
SW
a
NE
SW
Fig.6
Faults
N
n = 14
c
b
50m
Langhian (Turbidites)
Upper Oligocene - Lower Miocene (Conglomerates)
Aptian (Rudist limestones)
Malm (Limestones)
Pre-Valencia rift unconformity
Extensional fault
Thrust fault

Figure 5

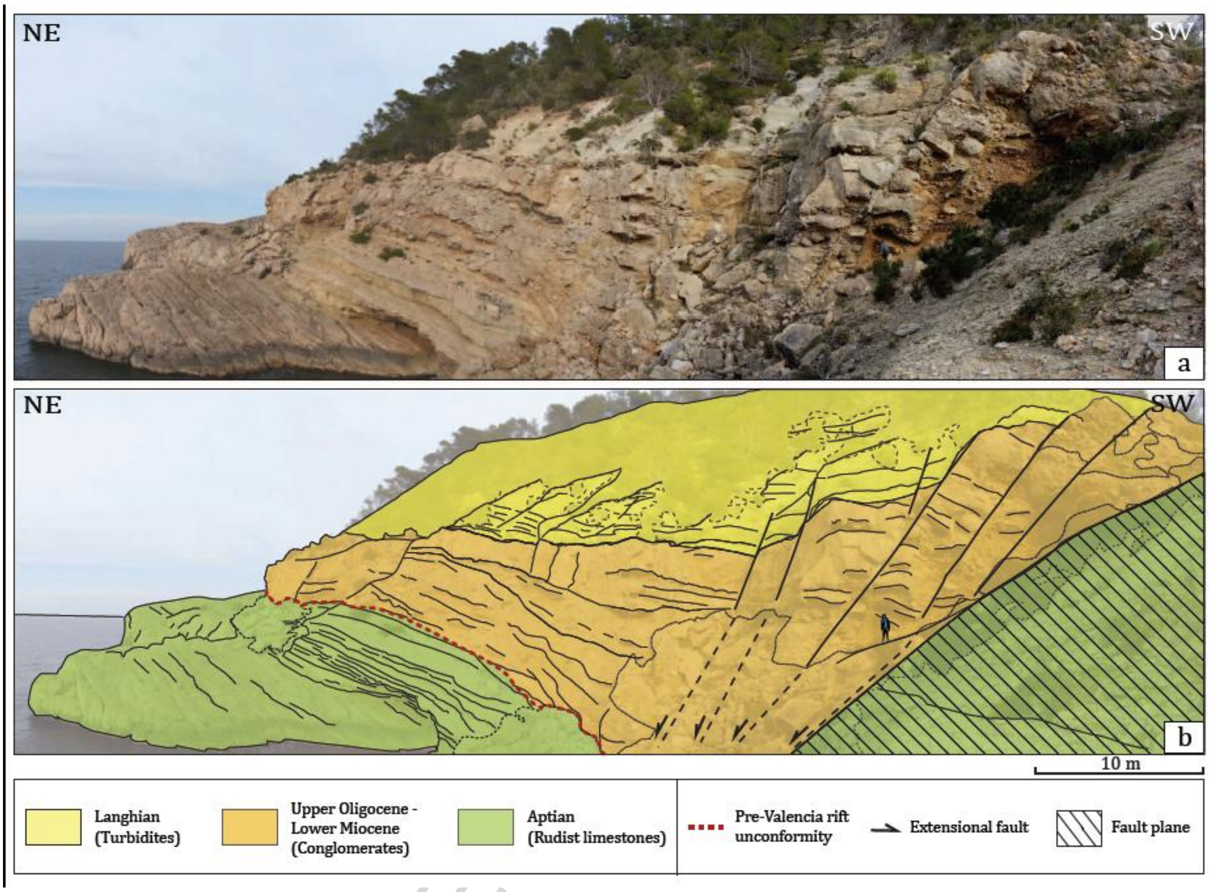

NE
SW
a
NE
SW
b
10 m
Langhian
(Turbidites)
Upper Oligocene -
Lower Miocene
(Conglomerates)
Aptian
(Rudist limestones)
Pre-Valencia rift
unconformity
Extensional fault
Fault plane

Figure 6

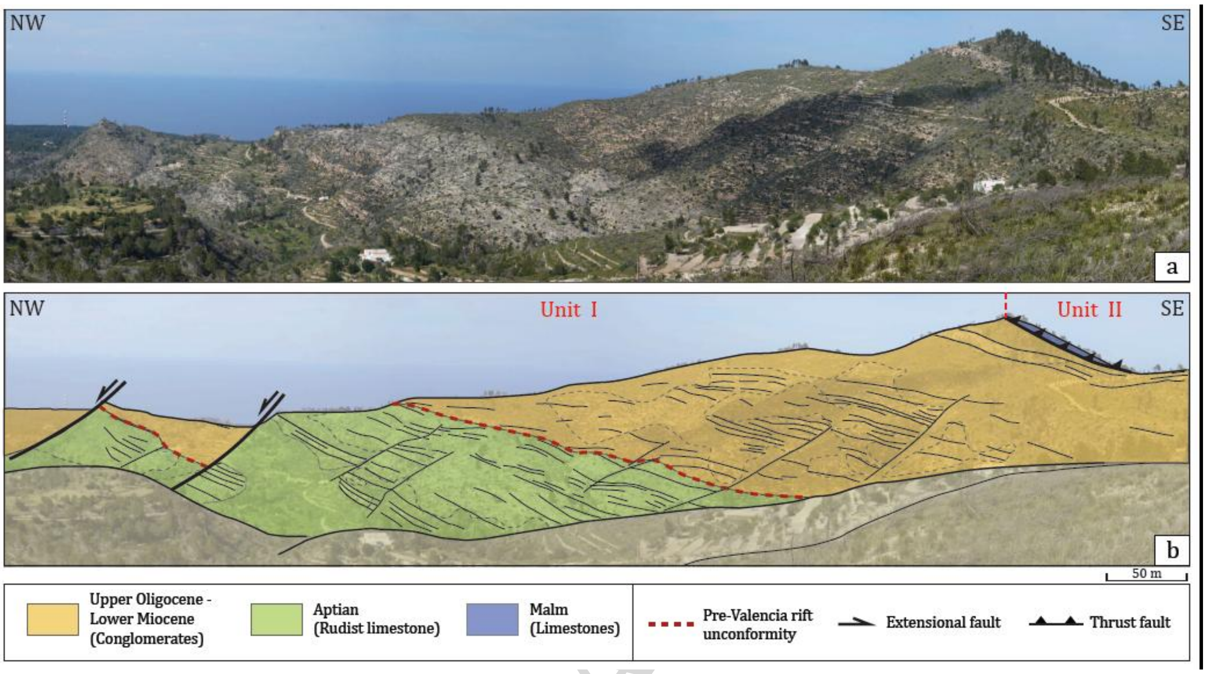
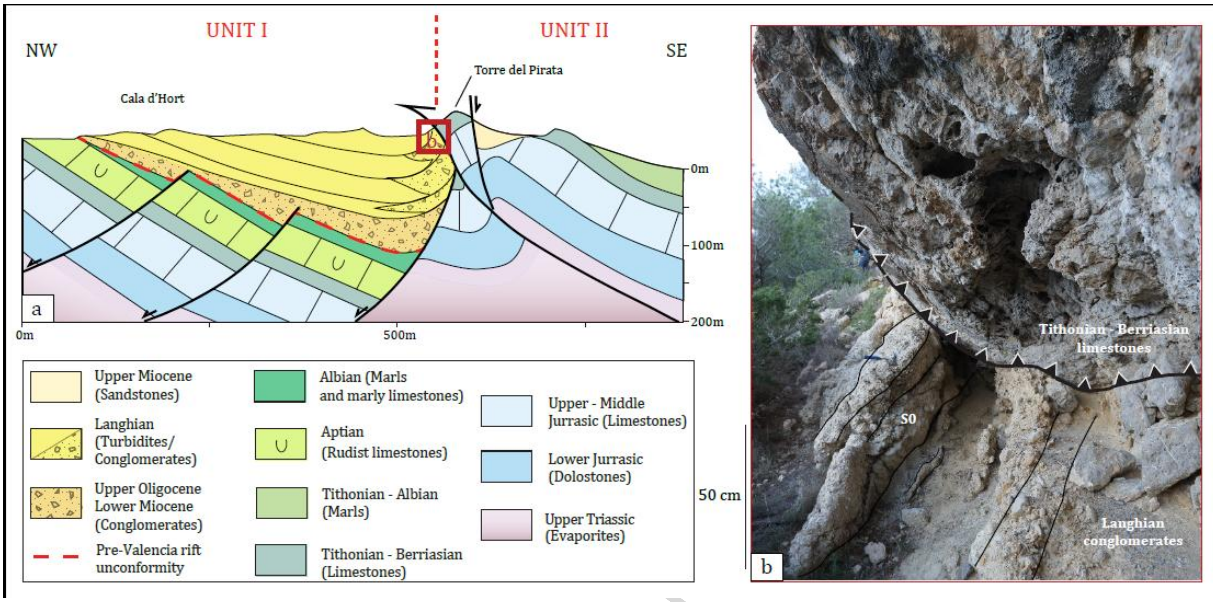

NW
SE
a
NW
Unit I
Unit II
SE
b
50 m
Upper Oligocene - Lower Miocene (Conglomerates)
Aptian (Rudist limestone)
Malm (Limestones)
Pre-Valencia rift unconformity
Extensional fault
Thrust fault

Figure 7



UNIT I
UNIT II
NW
SE
Torre del Pirata
Cala d'Hort
b
0m
100m
200m
a
0m
500m
Upper Miocene (Sandstones)
Langhian (Turbidites/ Conglomerates)
Upper Oligocene Lower Miocene (Conglomerates)
Pre-Valencia rift unconformity
Albian (Marls and marly limestones)
Aptian (Rudist limestones)
Tithonian - Albian (Marls)
Tithonian - Berriasian (Limestones)
Upper - Middle Jurrasic (Limestones)
Lower Jurrasic (Dolostones)
Upper Triassic (Evaporites)
50 cm
Tithonian - Berriasian limestones
S0
Langhian conglomerates
b

Figure 8

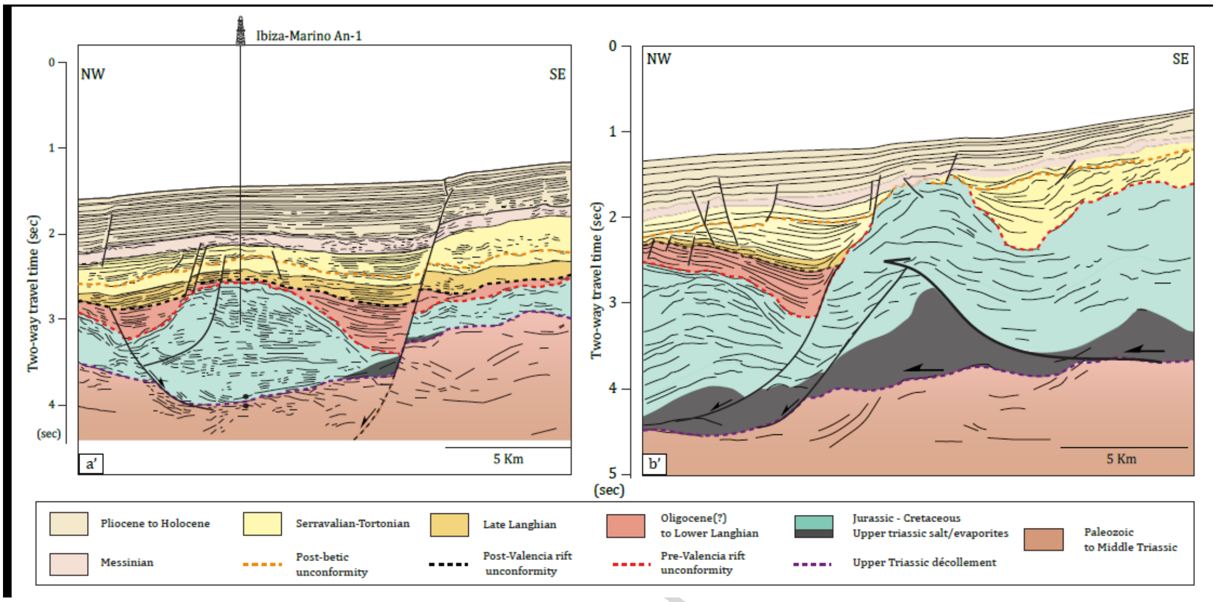

Ibiza-Marino An-1
NW
SE
Two-way travel time (sec)
0
1
2
3
4
(sec)
a'
5 Km
NW
SE
Two-way travel time (sec)
0
1
2
3
4
5
(sec)
b'
5 Km
Pliocene to Holocene
Serravalian-Tortonian
Late Langhian
Oligocene(?) to Lower Langhian
Jurassic - Cretaceous
Upper triassic salt/evaporites
Paleozoic to Middle Triassic
Messinian
Post-betic unconformity
Post-Valencia rift unconformity
Pre-Valencia rift unconformity
Upper Triassic décollement

Figure 9

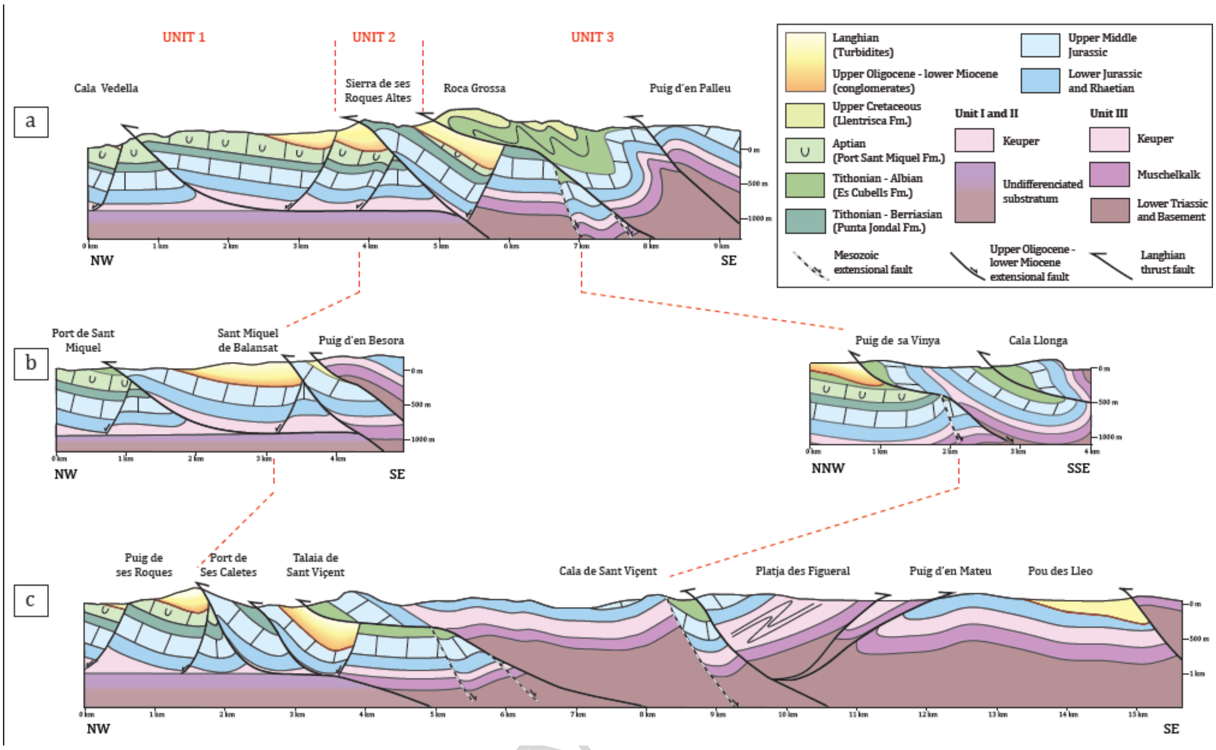
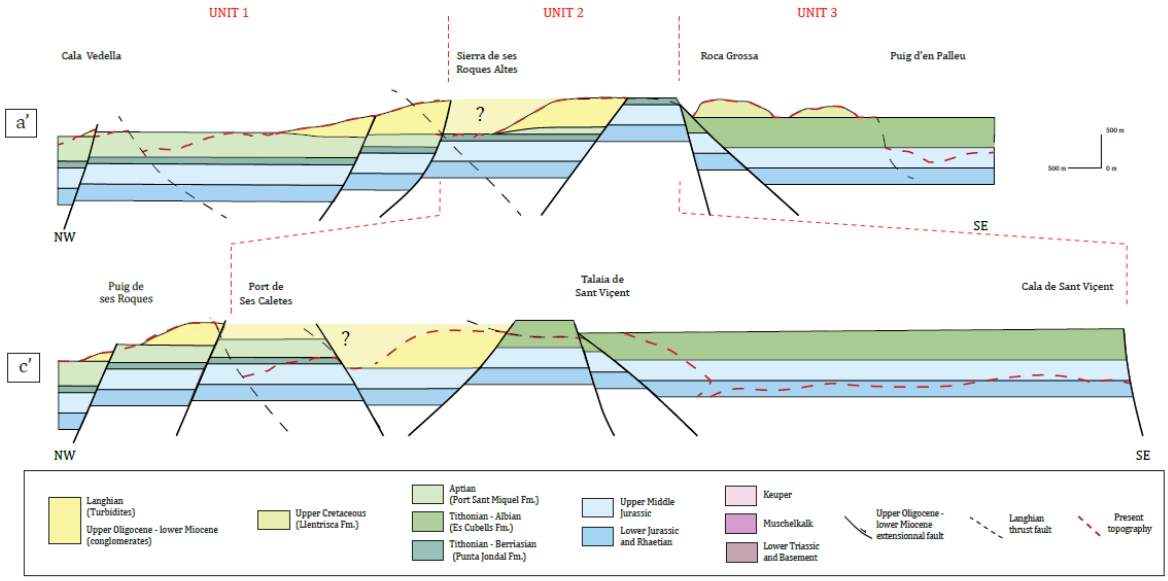
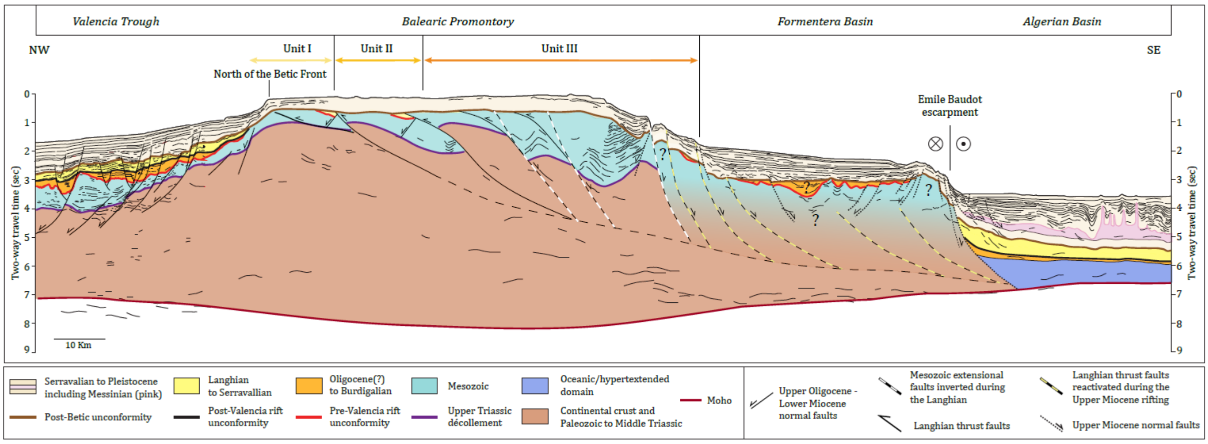

UNIT 1
UNIT 2
UNIT 3
Cala Vedella
Sierra de ses Roques Altes
Roca Grossa
Puig d'en Palleu
a
NW
SE
Port de Sant Miquel
Sant Miquel de Balansat
Puig d'en Besora
b
NW
SE
Puig de sa Vinya
Cala Llonga
NNW
SSE
Puig de ses Roques
Port de Ses Caletes
Talaia de Sant Viçent
Cala de Sant Viçent
Platja des Figueral
Puig d'en Mateu
Pou des Lleo
c
NW
SE
Langhian (Turbidites)
Upper Oligocene - lower Miocene (conglomerates)
Upper Cretaceous (Llentrisca Fm.)
Aptian (Port Sant Miquel Fm.)
Tithonian - Albian (Es Cubells Fm.)
Tithonian - Berriasian (Punta Jondal Fm.)
Upper Middle Jurassic
Lower Jurassic and Rhaetian
Unit I and II
Keuper
Undifferenciated substratum
Unit III
Keuper
Muschelkalk
Lower Triassic and Basement
Mesozoic extensional fault
Upper Oligocene - lower Miocene extensional fault
Langhian thrust fault

Figure 10



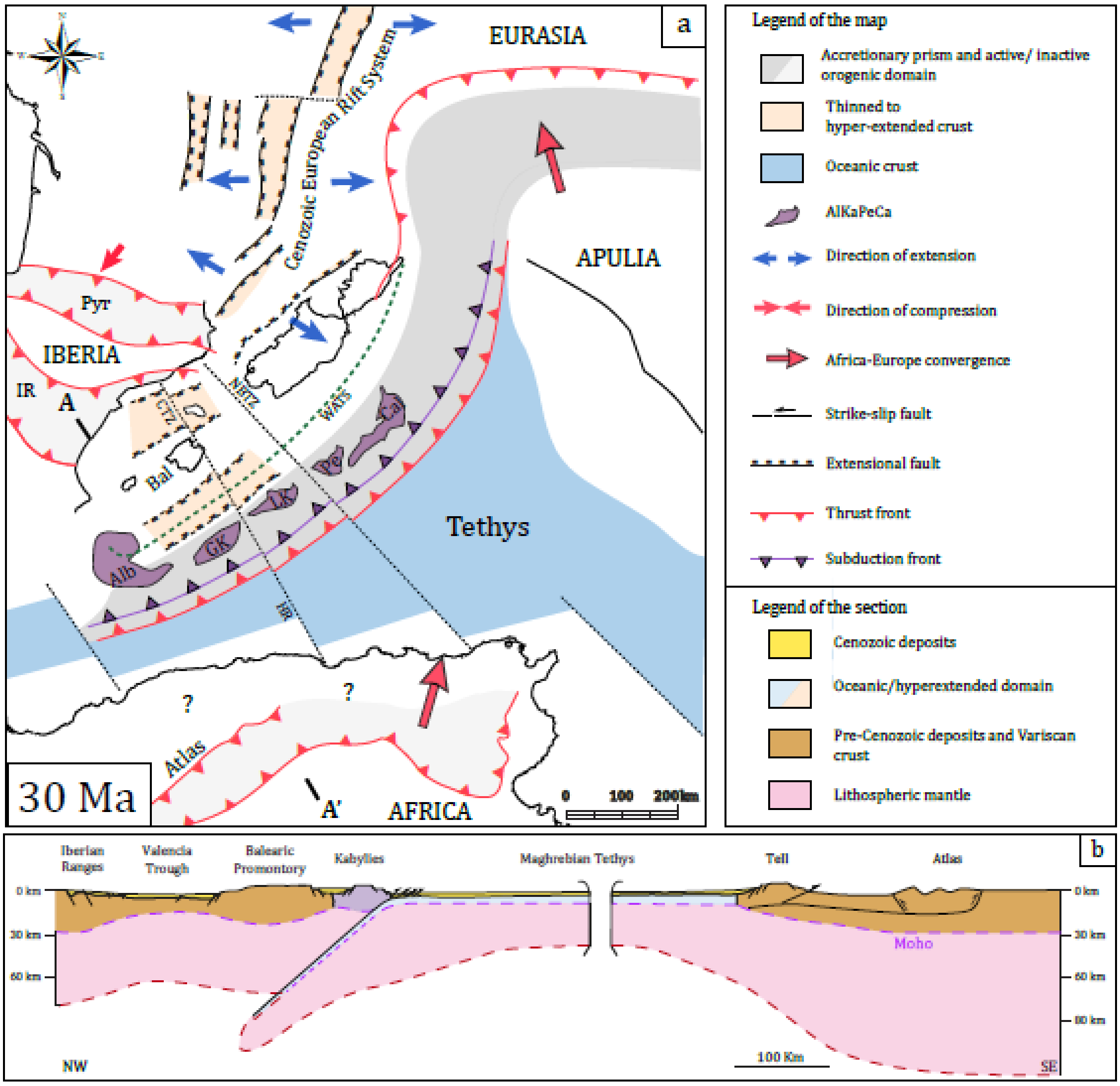
UNIT 1
UNIT 2
UNIT 3
Cala Vedella
Sierra de ses Roques Altes
Roca Grossa
Puig d'en Palleu
a'
?
NW
SE
500 m
500 m
0 m
Puig de ses Roques
Port de Ses Caletes
Talaia de Sant Viçent
Cala de Sant Viçent
c'
?
NW
SE
Langhian (Turbidites)
Upper Oligocene - lower Miocene (conglomerates)
Upper Cretaceous (Llentrisca Fm.)
Aptian (Port Sant Miquel Fm.)
Tithonian - Albian (Es Cubells Fm.)
Tithonian - Berriasian (Punta Jondal Fm.)
Upper Middle Jurassic
Lower Jurassic and Rhaetian
Keuper
Muschelkalk
Lower Triassic and Basement
Upper Oligocene - lower Miocene extensionnal fault
Langhian thrust fault
Present topography

Figure 11



Valencia Trough
Balearic Promontory
Formentera Basin
Algerian Basin
NW
SE
Unit I
Unit II
Unit III
North of the Betic Front
Emile Baudot escarpment
Two-way travel time (sec)
10 Km
Serravalian to Pleistocene including Messinian (pink)
Langhian to Serravallian
Oligocene(?) to Burdigalian
Mesozoic
Oceanic/hypertextended domain
Moho
Post-Betic unconformity
Post-Valencia rift unconformity
Pre-Valencia rift unconformity
Upper Triassic décollement
Continental crust and Paleozoic to Middle Triassic
Upper Oligocene - Lower Miocene normal faults
Mesozoic extensional faults inverted during the Langhian
Langhian thrust faults
Langhian thrust faults reactivated during the Upper Miocene rifting
Upper Miocene normal faults

Figure 12



a
EURASIA
Cenozoic European Rift System
APULIA
Pyr
IBERIA
IR
A
Bal
Tethys
Alb
GK
LK
Pe
Ca
Atlas
A'
AFRICA
30 Ma
0 100 200km
Legend of the map
Accretionary prism and active/ inactive orogenic domain
Thinned to hyper-extended crust
Oceanic crust
AlKaPeCa
Direction of extension
Direction of compression
Africa-Europe convergence
Strike-slip fault
Extensional fault
Thrust front
Subduction front
Legend of the section
Cenozoic deposits
Oceanic/hyperextended domain
Pre-Cenozoic deposits and Variscan crust
Lithospheric mantle
b
Iberian Ranges
Valencia Trough
Balearic Promontory
Kabylies
Maghrebian Tethys
Tell
Atlas
0 km
30 km
60 km
80 km
Moho
100 Km
NW
SE

Figure13

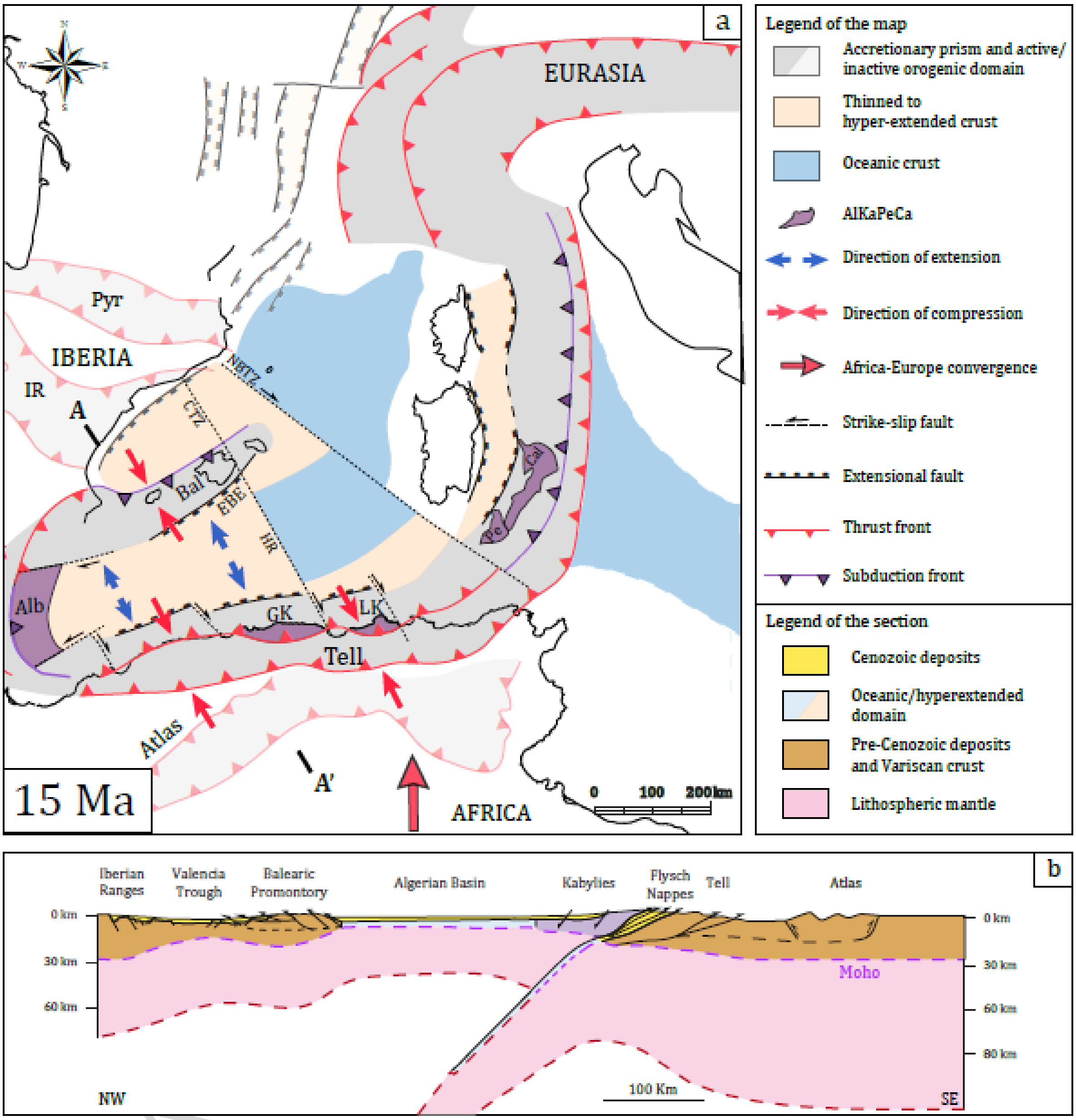

a
EURASIA
Pyr
IBERIA
IR
A
NBTZ
CTZ
Bal
EBE
HR
Alb
GK
LK
Tell
Atlas
A'
AFRICA
Cal
Pe
15 Ma
0 100 200km
Legend of the map
Accretionary prism and active/ inactive orogenic domain
Thinned to hyper-extended crust
Oceanic crust
AlKaPeCa
Direction of extension
Direction of compression
Africa-Europe convergence
Strike-slip fault
Extensional fault
Thrust front
Subduction front
Legend of the section
Cenozoic deposits
Oceanic/hyperextended domain
Pre-Cenozoic deposits and Variscan crust
Lithospheric mantle
b
Iberian Ranges
Valencia Trough
Balearic Promontory
Algerian Basin
Kabylies
Flysch Nappes
Tell
Atlas
0 km
30 km
60 km
80 km
Moho
100 Km
NW
SE

Figure 14

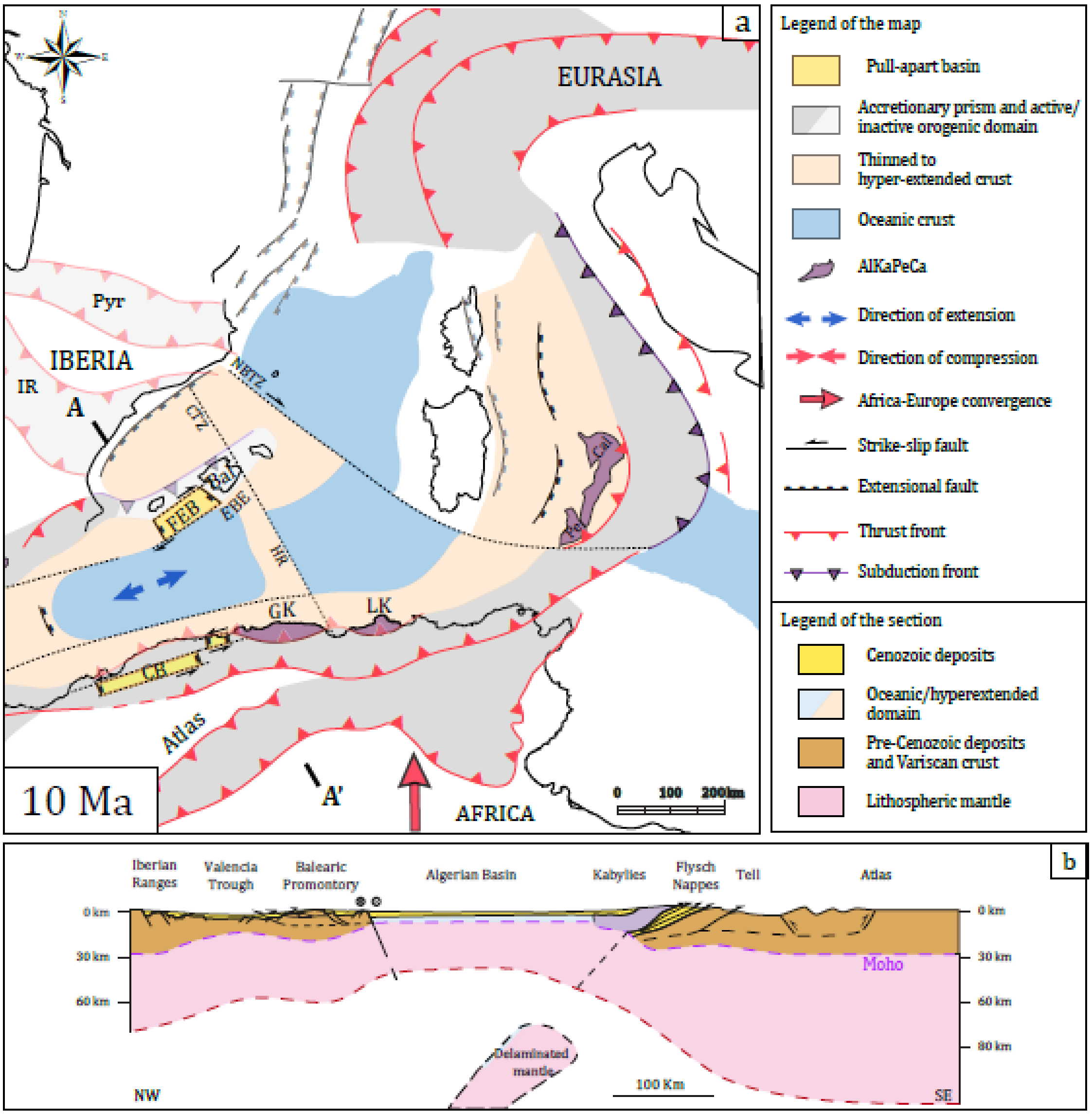

a
EURASIA
Pyr
IBERIA
IR
A
NBTZ
CTZ
Bal
FEB
EBE
HR
GK
LK
CB
Cal
Pel
Atlas
A'
AFRICA
10 Ma
0 100 200km
Legend of the map
Pull-apart basin
Accretionary prism and active/inactive orogenic domain
Thinned to hyper-extended crust
Oceanic crust
AlKaPeCa
Direction of extension
Direction of compression
Africa-Europe convergence
Strike-slip fault
Extensional fault
Thrust front
Subduction front
Legend of the section
Cenozoic deposits
Oceanic/hyperextended domain
Pre-Cenozoic deposits and Variscan crust
Lithospheric mantle
b
Iberian Ranges
Valencia Trough
Balearic Promontory
Algerian Basin
Kabylies
Flysch Nappes
Tell
Atlas
0 km
30 km
60 km
80 km
Moho
Delaminated mantle
100 Km
NW
SE

Figure 15

Highlights

- A late Oligocene to early Miocene extensional deformation is recognized in Ibiza Island.
- The middle Miocene contractional deformation observed in Ibiza is coeval to the docking of the Kabylies against the African margin.
- The middle Miocene contractional deformation does not affect the Algerian Basin, which remains active at this moment.