Terra Nova
August 2016, Volume 28 Issue 4 Pages 245-256
http://dx.doi.org/10.1111/ter.12215
http://archimer.ifremer.fr/doc/00333/44417/

The Minorca Basin: a buffer zone between the Valencia and Liguro-Provençal Basins (NW Mediterranean Sea)

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Abstract :

Detailed analyses of seismic profiles and boreholes in the Valencia Basin (VB) reveal a differentiated basin, the Minorca Basin (MB), lying between the old Mesozoic Valencia Basin sensu strico (VBss) and the young Oligocene Liguro-Provençal Basin (LPB). The relationship between these basins is shown through the correlation of four Miocene-to-present-day megasequences. The Central and North Balearic Fracture Zones (CFZ and NBFZ) that border the MB represent two morphological and geodynamical thresholds that created an accommodation in steps between the three domains. Little to no horizontal Neogene movements are found for the Ibiza and Majorca Islands. In contrast, the counterclockwise movement of the Corso-Sardinian blocks induced a counterclockwise movement of the Minorca block towards the SE along the CFZ and NBFZ, during the exhumation of lower continental crust in the LPB. This new understanding implies pure Neogene vertical subsidence in the VBss and places the AlKaPeCa northeastward of the present-day Alboran Area.

General Setting

Although the Valencia Basin (VB) is recognized as a former Mesozoic basin (Maillard, 1992; Roca, 1992, 2001; Ayala *et al.,* 2015), it is generally considered to be an aborted Miocene back-arc basin in the southwestward continuation of the Liguro-Provençal Basin (LPB). Two main types of models are normally proposed for its evolution during the Neogene: 1) a continuity from the LPB to the Alboran domain going through the VB (e.g. Doglioni *et al.,* 1997, 1999; Lonergan & White, 1997; Gueguen *et al.,* 1998; Faccenna *et al.,* 2004; Jolivet *et al.,* 2006) or 2) a segmented and multi-phased response between the LPB and VB (e.g. Rehault *et al.,* 1984; Sanz de Galdeano 1990; Maillard & Mauffret, 1999; Maerten & Seranne 1995; Roca, 2001). In both cases, the North Balearic Fracture Zone (NBFZ) played a key role in this opening "swinging door" movement (as described by Martin, 2006), leading to the counterclockwise rotation of the Corsica-Sardinia microplate and a clockwise rotation of the Balearic promontory during the Oligocene-Early Miocene (e.g. Auzende *et al.,* 1973; Dewey *et al.,* 1973; Mauffret *et al.,* 1995; Olivet, 1996; Maillard & Mauffret, 1999; Gueguen *et al.,* 1998; Gattacceca *et al.,* 2007; Carminati *et al.,* 2012). Southwest of the NBFZ, two secondary transfer zones are also suggested, the Central Fracture Zone (CFZ) between Minorca-Mallorca islands, and the Ibiza Fracture Zone (IFZ) between Mallorca-Ibiza islands.

The initial rifting phase during the Neogene (Chattian / Early Burdigalian) is recorded in the sedimentary strata of the Gulf of Lion (GOL) (Edel, 1980; Gorini *et al.,* 1993; Ferrandini *et al.,* 2003; Gattacceca *et al.,* 2007) and similar deltaic to shallow marine environments are recorded on the Catalan margin in the northwestern part of the VB (Roca *et al.,* 1999; Roca, 2001). On the Ebro margin (Tarragona trough) and on land (Valles-Penedes graben), the synrift deposits are described as Burdigalian to Langhian/Early Serravallian (Clavell &

Berastegui, 1991; Bartrina *et al.* 1992; Alvarez de Buergo & Melendez-Hevia 1994; Cabrera and Calvet, 1996; Martinez Del Olmo, 1996; Rodriguez-Murillas *et al.,* 2013).

In this study, based on a large set of seismic data and boreholes, we detail the sedimentary architecture, the nature of the base of the Tertiary series, the segmentation of the VB, and also highlight the role of tectonic heritage in the subsidence history of each segment.

Correlation along the study area

Our study is based on a large set of seismic and borehole data gathered during the extensive French academia-industry programs (Actions-Marges, GRI Téthys Sud), in close collaboration with the Total and Schlumberger groups (Figure 1). Due to this dense set of profiles, seismic reflectors were identified and successfully correlated to previous detailed studies in the LPB (Rabineau, 2001; Bache, 2008; Leroux, 2012). Ages of paleomarkers were defined using biostratigraphic data from thirty-eight boreholes in the VB and seven boreholes in the GOL.

The evolution and appearance of these seismic markers highlights the subdivision of the area into three domains: (1) the Valencia Basin *sensu strico* (VBss), limited to the NE by the CFZ, (2) the Minorca Basin (MB) bounded by the CFZ and the NBFZ, and (3) the LPB. Four megasequences are described along the VB and LPB (Figure 2):

(1) The Late Oligocene to Early Miocene megasequence, not visible on Figure 2, is essentially limited to the Catalan and GOL graben (e.g. Roca, 2001).

(2) The Miocene megasequence defined in the basin lies between the Tertiary basement and M30 (Figure 2). Several reflectors were correlated through the VB and LPB. M03 is a high-amplitude, continuous reflector dated to the top of the Burdigalian from correlation to Catalan margin boreholes (e.g. Barcelona Marino

B1 and C1). Its extent is limited to the MB and LPB. M06 and M08 are respectively estimated to be Langhian and Latest Serravallian to Early Tortonian (Benicarlo C1 and Tarragona trough boreholes). In the VBss, sediments below M06 include distal and pelagic Late Burdigalian to Langhian deposits. The continuity of M08 toward the MB and LPB is clearly conceivable, but a direct correlation was impossible due to unfavorable morphologies. The M11, dated as Late Tortonian to Early Messinian (borehole Benicarlo C1), is mainly an erosive surface in the VBss, which evolves into a conformable surface in the MB (M20b).

(3) The Messinian megasequence comprises the Lower Unit, Mobile Unit, Upper Unit (e.g. Lofi et al., 2011; Gorini et al., 2015), comprised between M30 and M30 surfaces. In the VBss, the base of the Upper Unit corresponds to the M30 surface, which is erosive or conformable and can be correlated in the upper margin with the Messinian Margin erosional surface (MES).

(4) The Pliocene to Quaternary megasequence covers most of the major structural highs. Large prograding and pro-aggrading clinoforms characterize the shelf due to high sediment supply and glacio-eustatic variations (e.g. Lofi et al., 2003; Kertznus and Kneller, 2009). Two prominent surfaces, P60 and P50, were correlated to Q10 and P11, dated at 0.9 Ma and 2.6 Ma, respectively (e.g. Rabineau et al., 2014; Leroux et al., 2014).

Segmentation and Individualization of the Minorca basin

Figures 3A, 3B, 4A, and 4B emphasize the evolution of these seismic markers along 6 NE-SW and 3 NW-SE profiles crossing the three basins. The Oligocene-Aquitanian megasequence is restricted to the GOL and Catalan margins. The Miocene and Messinian megasequences show a gradual thickening from the VBss towards the LPB. The thickness of the Miocene megasequence increases from 0-0.9 second two-way time (stwt) (VBss) to 1.1+/– 0.3 stwt (MB), and is fully developed in the LPB (1.4+/– 0.4 stwt) (Figure 3B). A new seismic-stratigraphic unit is also identified in the MB (green unit in Figure 3B), which increases in thickness towards the LPB. Continuous reflectors with medium-amplitude clinoforms that prograde toward the NE characterize this unit (Figures 2, 3B). The base of this Upper Miocene prograding sequence changes rapidly, from a truncation surface (VBss) to a correlative conformity (MB), and shows an increase in depth, from 3.3 s (VBss) to 4.5 s (MB), and ultimately to 5.2 s (LPB). The thickness of the Messinian megasequence varies: 0.05 to 0.3 s in the VBss, 0.6 to 0.7 s in the MB, and > 1.26 s in the LPB. Furthermore, the MB is characterized by the development of the Lower Unit and Mobile Unit (in the NE), whereas the full development of the Lower and Mobile units is limited to the LPB. The base of the Mobile Unit also evolves, from 4.5 s in the MB to ~5 s in the LPB. For Pliocene and Quaternary deposits, the variation in thickness is mainly controlled by sedimentary transport from the Ebro river (Nelson, 1990) and the Rhône river for the deep LPB (e.g. Leroux, 2012).

The segmentation into three domains appears in the Bouguer anomaly map and the residual geoid anomaly map, which show a strong SW-NE segmentation between the LPB, MB, and VBss (Ayala *et al.,* 2015), and also on the base of Tertiary map of the entire VBss-MB-LPB area (Figure 5). The base of the Tertiary in the MB presents a mean depth of 4.6 +/– 0.5 (stwt), intermediate between the VBss (3.5 +/– 0.3 stwt) and the deeper LPB (6.5 +/– 0.2 stwt) (Figure 3B). This segmentation is clearly depicted by the CFZ to the southwest of the MB and by the NBFZ to the northeast of the MB (Maillard & Mauffret, 1999). These differences in depth imply a difference in Neogene subsidence in the three segments, decreasing towards the SW. This is also observed in the first occurrences of marine sediments, which started at the Oligocene in the LPB and the Catalan margin (MB), and only at the Late Burdigalian-Langhian in the VBss (Figure 6). The Neogene subsidence in the VBss started later than it did in the LPB and MB.

Alternatively, some authors suggest another segment in the VBss with the Ibiza Fracture Zone (IFZ) (Maillard & Mauffret, 1999) explaining the suggested clockwise 93 km southeastward movement of Mallorca block. However, the authors state that IFZ is "*not documented as there is no or very little information in that region*", its presence was only presumed due to differences in crustal thicknesses (suggested to reach 13 km in the southwestern part). However, modern high-quality data presented by Alaya *et al.* (2015) falsifies this view and shows instead a thickness of 5 to 6 km in the SW part. Previous studies identified a Mesozoic basin in the whole VBss (e.g. Roca, 1992; Maillard, 1993), with a maximum thickness reaching more than 3 km. Toward the Balearic promontory the Estudio Sismico de la Corteza Ibérica (ESCI) profiles show a continuation of this Mesozoic basin (Roca *et al.*, in Cavazza *et al.,* 2004) and we infer that the VBss extends between the Ibiza and Mallorca Islands and the Ebro-Tarragona margin. In contrast, in the MB and LPB, the substratum is characterized by chaotic, hyperbolic, and medium-amplitude reflectors (Figures 2b and 2c). In the MB, mean velocities from the ESP60 profile (Figure 3B, cross section 3) were 4.2 to 6.1 km/s in the upper part of the Tertiary basement and were interpreted as Neogene volcanic layers (Mauffret *et al.,* 1995) (Figures 2, 3B, 4B). In the LPB, the domain limited between hinge line 3 and the proto-oceanic crust limit (Figure 5) has recently been identified as a thin layer of lower continental crust (C.C.) (Moulin et al., 2015), exhumed along a landward deep detachment (Séranne, 1999) and overlying an heterogeneous, intruded layer (gabbros or granulites), with velocities of 6.0 and 6.4 km/s for the upper layer and 6.6 to 7.5 km/s for the lower layer (Moulin *et al.,* 2015).

The Minorca Basin, a buffer segment

As previously shown by Roca (1992) and Ayala *et al.* (2015), there is little to no evidence of Neogene horizontal movement (no extension, very few faults observable on seismic data) in the offshore Mesozoic sedimentary sequences of the VBss. The neogene syn-rift deposits are localized either on land or on the MB borders (Figure 4, zoom A). Paleomagnetic data on the Balearic Islands describes two phases of Miocene rotation and is usually used for geodynamic reconstruction. However, these two phases of rotation are linked to the Betics compressive phase and should not be connected with the kinematic rotation of the islands (Parès *et al.,* 1992). If a rift had propagated into the VBss, the Mesozoic sedimentary sequences should also have been affected by the extension. On the contrary, the Neogene sedimentary layers in the central part of the VBss are horizontal and parallel (Figure 4, zooms B and C), which implies a vertical subsidence during this period, as has been described in sag basins where no extensive movements are depicted (Moulin *et al.,* 2005; Aslanian *et al.,* 2009). The significant thickness of Mesozoic deposits associated with thinning of the crust have led Roca and Guimera (1992) to propose a Mesozoic thinning that would account for at least half of the entire thinning, implying a huge tectonic heritage in the VBss. It is beyond the scope of this paper to discuss the genesis of the Mesozoic basin, but for the Neogene phase, movement of the Ibiza-Mallorca blocks toward the southeast in the VBss would imply major extensive deformations in the Mesozoic deposits, which are not observed on seismic data (Roca, 1992; Ayala *et al.,* 2015).

Following what was suggested by previous authors (e.g. Tassone *et al.,* 1996; Roca *et al.,* 1999), our results show that the MB and LPB exhibit the same Oligo-Miocene synchronous syn-rift sedimentary sequence, which does not support the hypothesis of rift propagation that should have produced diachronous sequences. The continuity between the two basins is further substantiated by the first occurrences of marine sediment at Oligocene times in the LPB and the Catalan margin (MB) (Figure 6).

The position of the almost rigid Corso-Sardinian block (Arthaud and Matte, 1977) before the Miocene rift phase implies that the Minorca block was about 100 km closer to the Catalan margin (Figures 6 and 8) at that time (e.g. Le Cann, 1987; Olivet, 1996). The NBFZ, which was, during the Pyrenean compressive phase, a dextral N-S transfer zone between the Iberian and Corso-Sardinian microplates (e.g. Olivet, 1996), was reactivated during the Oligo-Miocene extension phase, leading to the counterclockwise movement of the Corso-Sardinian block, which is accompanied by the counterclockwise movement of the Minorca block to the SE along the CFZ (Le Cann, 1987; Gueguen, 1995; Olivet, 1996), contrary to what was proposed based on scarce paleomagnetic data on the Balearic Island (Parès *et al.*, 1992). This movement coincides with the exhumation of the 4 km-thick lower C.C. in the LPB (a metamorphic core complex for Jolivet *et al.,* 2015). This movement stopped when the proto-oceanic crust started (Moulin *et al.,* 2015). During the Early Miocene-Messinian times, the two transfer zones, CFZ and NBFZ, accommodate the subsidence between the VBss (high position) and the LPB (deep domain) (Figures 3A, 3B).

While both VBss and LPB segments, (Leroux *et al.,* 2015), exhibit pure vertical subsidence (Figures 4B), the thinning process may not be the same, as VBss is a polyphased basin, and the LPB thinning was only during the Neogene and due to the exhumation of the lower C.C.. In between the VBss and LPB, the Minorca Neogene movement may have involved an exhumation, such as in the GOL, but the substratum may also comprise stretched and intruded upper C.C.. This issue is still open and will need the acquisition of additional wide-angle seismic data in the MB to be able to address the uncertainties.

The idea that the MB should be considered as a Neogene buffer zone between the young Oligocene-to-Miocene LPB and the old Mesozoic VBss, modifies the general view of the northern part of the Occidental Mediterranean Sea before opening (Figure 7). First, the divergent movements of the Kabylian blocks on one side and Peloritain-Calabria blocks on the other side appear at the southwards end of the buffer zone. Second, little to no Neogene movements for the Ibiza and Majorca Islands place the AlKaPeCa group (Alboran, Kabyle, Peloritain, and Calabrian blocks; e.g. Mauffret *et al.,* 1995) further to the southeast, northeastward of what is at present-day the Alboran Area.

ACKNOWLEDGEMENTS

This work was supported by the "Laboratoire d'Excellence" LabexMER (ANR-10-LABX-19) and co-funded by a grant from the French government under the program "Investissements d'Avenir", and by a grant from the Regional Council of Brittany.

It was further supported by CNRS and IFREMER, with additional support from the French Actions-Marges program (J.L. Rubino & P. Unternehr) and the GRI Méditerranée (Groupement Recherche et Industrie TOTAL-UPMC). The database was built thanks to the SIGEOF spanish site and cruises from French and Spanish teams. Additional industrial seismic lines were provided by Schlumberger. The authors acknowledge the fruitful and constructive reviews by Alexander Keith Martin and Francesca Sabat, as well as those from the editor Carlo Doglioni and his associate editor that greatly improved the manuscript.

Competing financial interests

The authors declare no competing financial interests.

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FIGURES

Figure 1: Location of the study area and dataset on the bathymetric and geological map of the Valencia basin s.l. Red boxes indicate location of seismic profiles presented in Figure 2, showing (from SW to NE) details of the Valencia basin s.s. (VBss), the Minorca basin (MB), and the Liguro-Provençal basin (LPB). Green box indicate location of seismic profiles zooms presented in Figure 4.

Figure 2: Correlation of stratigraphic markers from the SW (VBss) to the NE (MB and LPB). Names of Liguro-Provençal markers are derived from previous study (Bache, 2008; Leroux, 2012). Locations of seismic profiles are shown on Figure 1.

Figure 3A: Non-interpreted seismic profiles oriented SW-NE (location Figure 1) crossing the three defined Valencia s.s., Menorca and Ligurian-Provençal basins. MEDS76 profiles were provided courtesy of Schlumberger multiclient.

Figure 3B: Interpreted seismic profiles oriented SW-NE (location on Figures 1), highlighting the evolution of the Burdigalian-Messinian, Messinian trilogy and Pliocene-Quaternary megasequences and showing the general characteristics of each basin (explanation in the text).

Figure 4A: Non-interpreted seismic profiles oriented NW-SE (location on Figure 1) illustrating the Valencia s.s., Menorca and Ligurian-Provençal basins. Three zooms illustrate the various structural and subsidence style between the Catalan margin (MB) (zoom 1), the Tarragona trough (VBss) (zoom 2) and VBss's central depression (zoom 3). MEDS76 and MSP74 profiles were provided courtesy of Schlumberger multiclient.

Figure 4B: Interpreted seismic profiles oriented NW-SE (location on Figure 1) highlighting the evolution of the Oligocene-Aquitanian, Burdigalian-Messinian, and Pliocene-Quaternary megasequences and showing the general characteristics of each basin. On the Catalan margin the major half-graben is formed by major normal faults which led to the deposition of a sedimentary wedge during Oligocene to Aquitanian (zoom 1). On the contrary VBss basin records sub-parallel, horizontal and isopach strata in the deepest area during Langhian to Serravallian times (zoom 2 and 3). Sediments deformation are only due to triasic salt diapir activity (zoom 2).

Figure 5: Tertiary basement map in two-way time (s) of the NW Mediterranean sea highlighting the depth increase in steps from the VBss to the LPB. Two NW-SE oriented thresholds individualize the Minorca basin (CFZ: Central Fracture Zone; NBFZ: North Balearic Fracture Zone). Hinge Lines highlighted in the Liguro-Provençal basin show the main boundaries in the crustal evolution and subsidence response (from Leroux et al., 2015; Moulin et al., 2015). Cartography of the atypical oceanic crust result from a compilation of gravimetric, magnetic and velocity response (e.g. from Bache, 2008; Moulin *et al.,* 2015; Afilhado *et al.,* 2015).

Figure 6: Paleogeographic maps of the Valencia s.l. and Liguro-Provençal domains showing a repartition of marine water during Oligocene, Burdigalian and Langhian time. Circles represent facies observations from boreholes. Paleocoast positions are from Meulenkamp & Sissingh, 2003; Jolivet *et al.,* 2006; Roca *et al.,* 1999 combined to our seismic correlations.

Figure 7: Northwestern Mediterranean cinematic reconstruction before opening of Liguro-Provençal, Minorca and Algerian domains. Two options concerning the initial position of Ibiza and Majorca are shown. In red, Early Neogene situation of Corso-Sardinian, Minorca and Ibiza-Mallorca blocks proposed in this study (also suggested in Le Cann, 1987, Olivet, 1996, Bache, 2008, Bache *et al.*, 2010) (option a-no movement for Ibiza and Mallorca islands). In purple Early Neogene situation proposed by previous studies e.g. Maillard and Mauffret (1999) (option b-large movement for the Ibiza-Mallorca islands). The position of AlKaPeCa blocks are from Mauffret *et al.* (1995). Two options

concerning the initial situation of Alboran domain are also proposed following e.g. Mauffret et al. (1995) (option 1) and e.g. Doglioni et al. (1997) (option 2). The hachured area corresponds to the present day exhumed lower continental crust position as interpreted by Moulin *et al.* (2015).

Figure 1

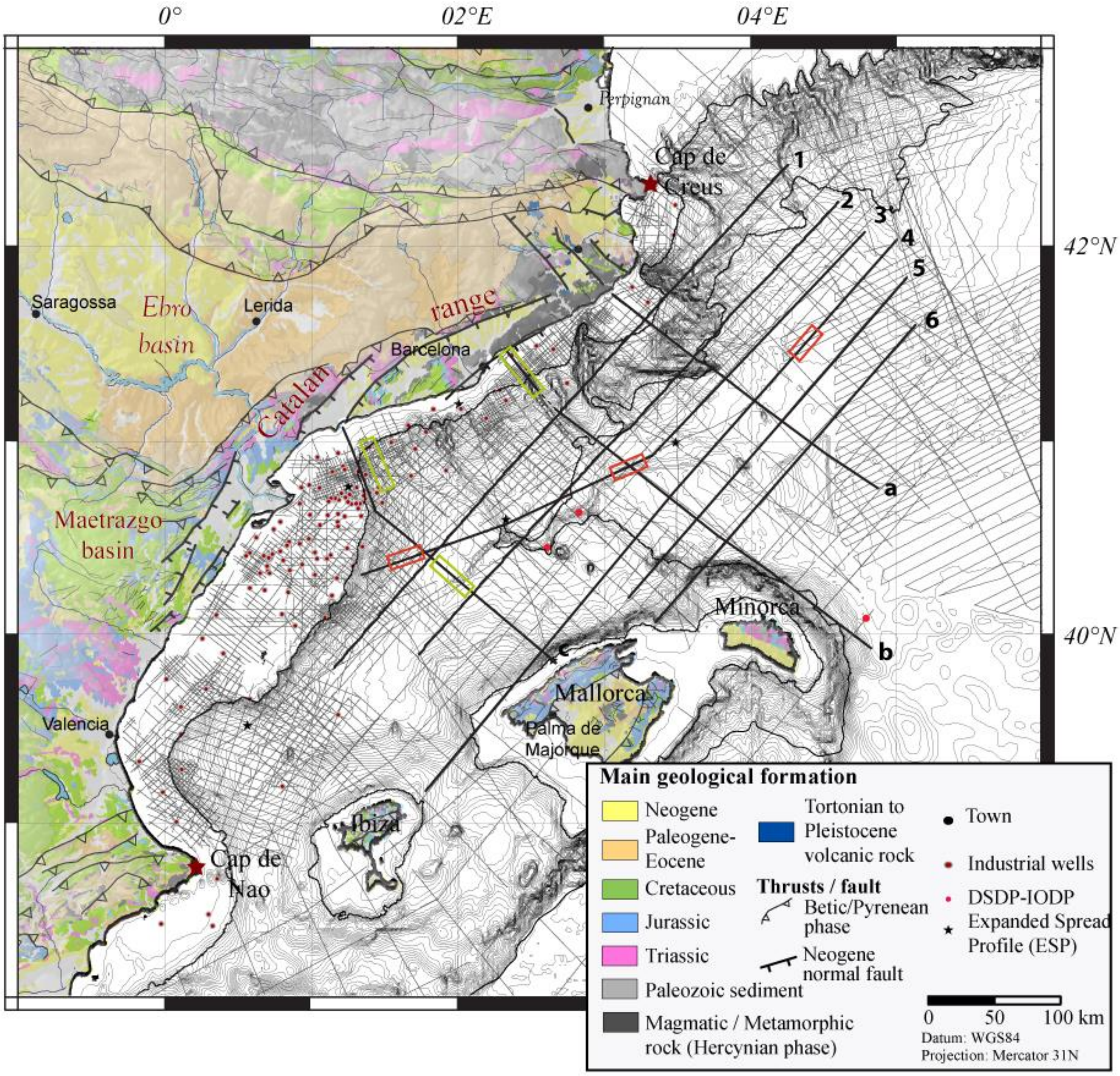
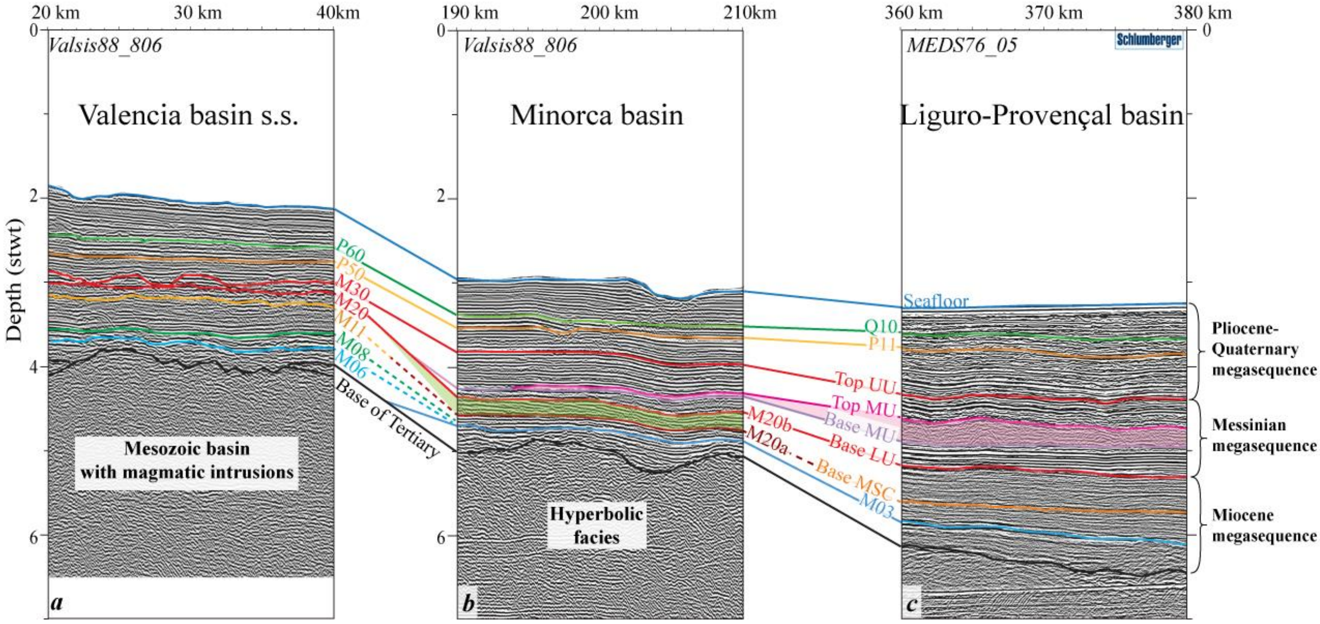
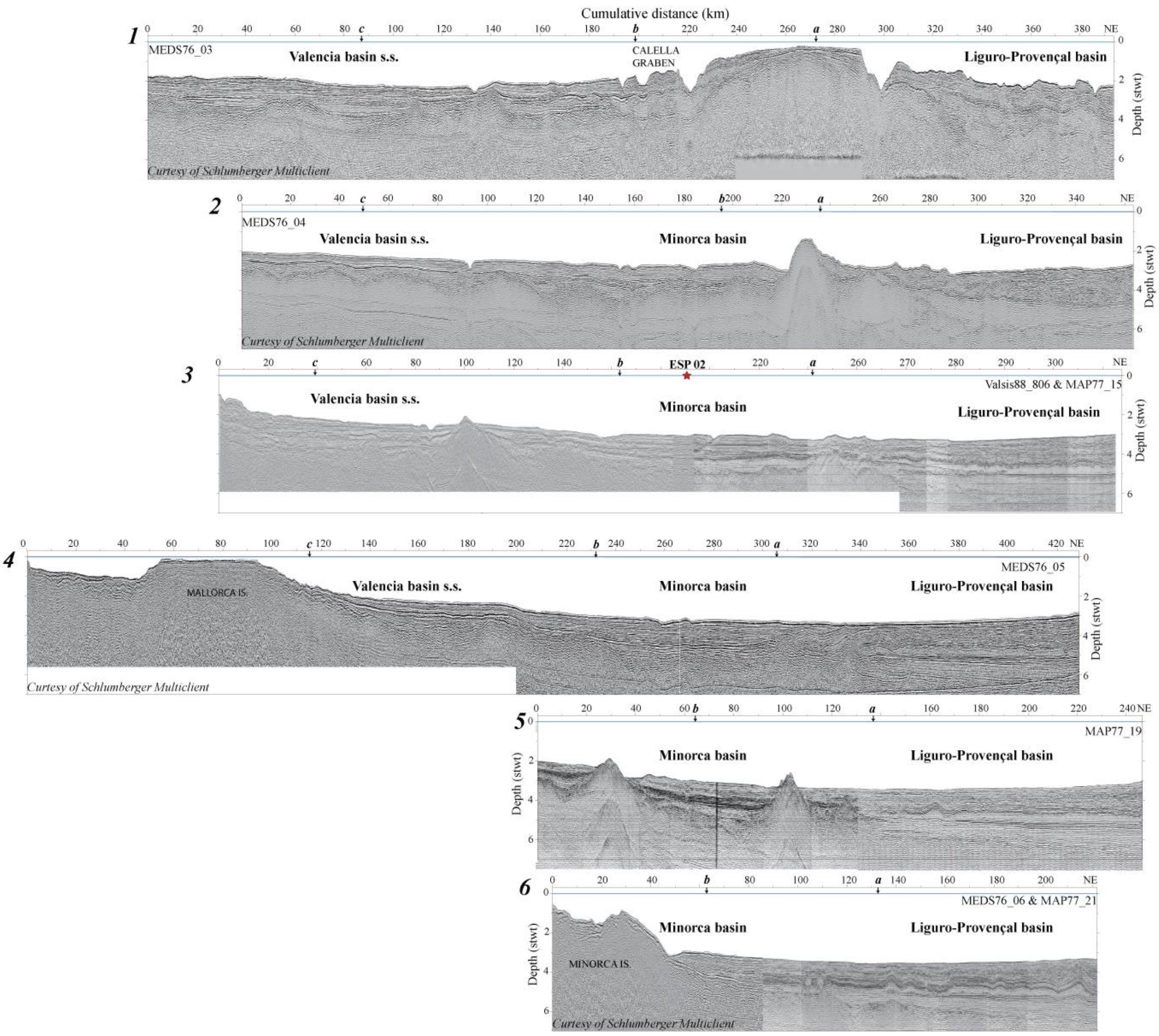

0°
02°E
04°E
42°N
40°N
Perpignan
Cap de Creus
Saragossa
Ebro basin
Lerida
Catalan range
Barcelona
Maetrazgo basin
Valencia
Cap de Nao
Ibiza
Mallorca
Palma de Majorque
Minorca
1
2
3
4
5
6
a
b
c
Main geological formation
Neogene
Paleogene-Eocene
Cretaceous
Jurassic
Triassic
Paleozoic sediment
Magmatic / Metamorphic rock (Hercynian phase)
Tortonian to Pleistocene volcanic rock
Thrusts / fault
Betic/Pyrenean phase
Neogene normal fault
Town
Industrial wells
DSDP-IODP
Expanded Spread Profile (ESP)
0 50 100 km
Datum: WGS84
Projection: Mercator 31N

Figure 2



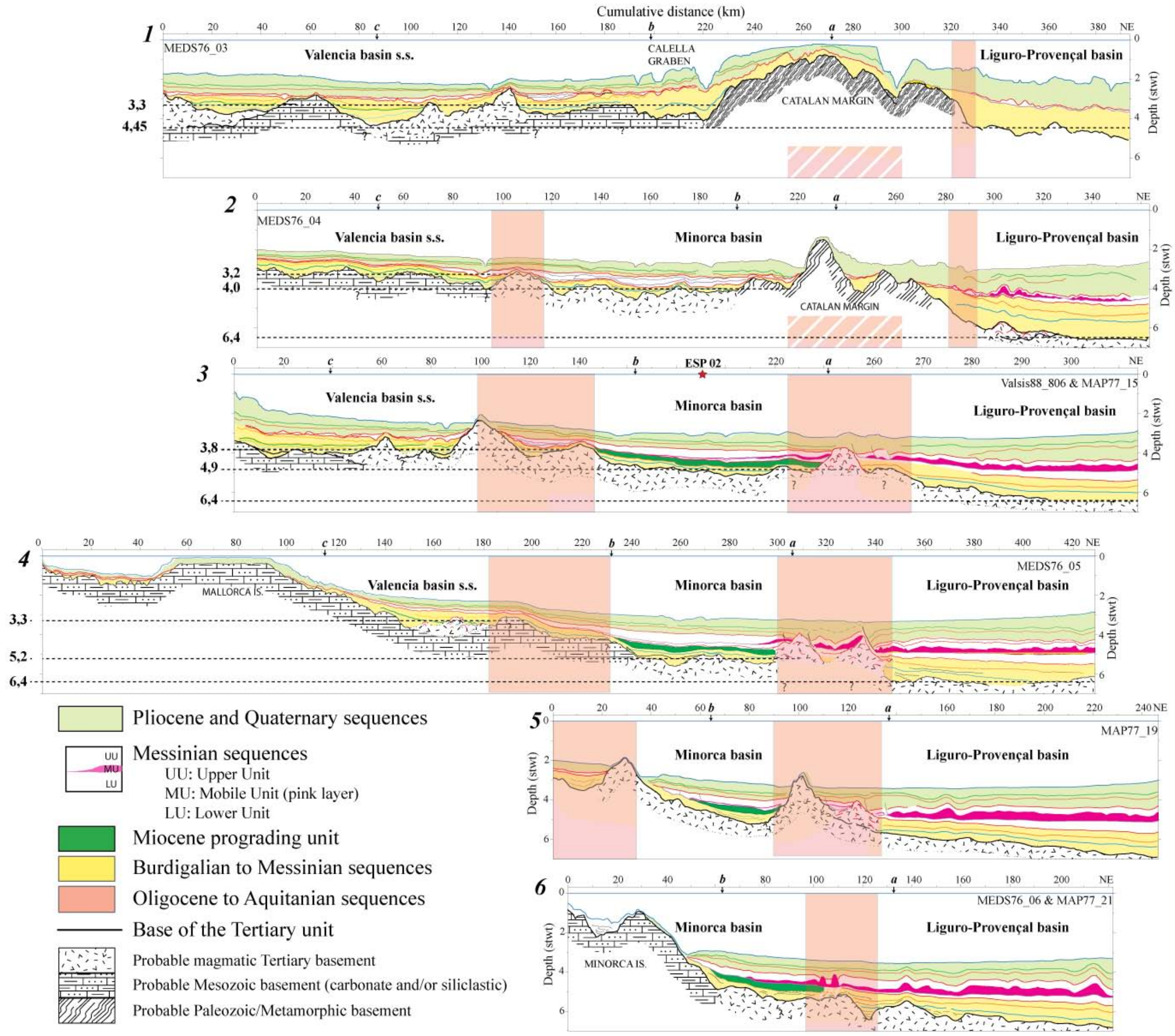
20 km
30 km
40km
190 km
200 km
210km
360 km
370 km
380 km
Depth (stwt)
Valsis88_806
Valsis88_806
MEDS76_05
Schlumberger
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
P60
P50
M30
M20
M11
M08
M06
Base of Tertiary
Mesozoic basin
with magmatic intrusions
Hyperbolic
facies
M20b
M20a
Seafloor
Q10
P11
Top UU
Top MU
Base MU
Base LU
Base MSC
M03
Pliocene-
Quaternary
megasequence
Messinian
megasequence
Miocene
megasequence
a
b
c

Figure 3A



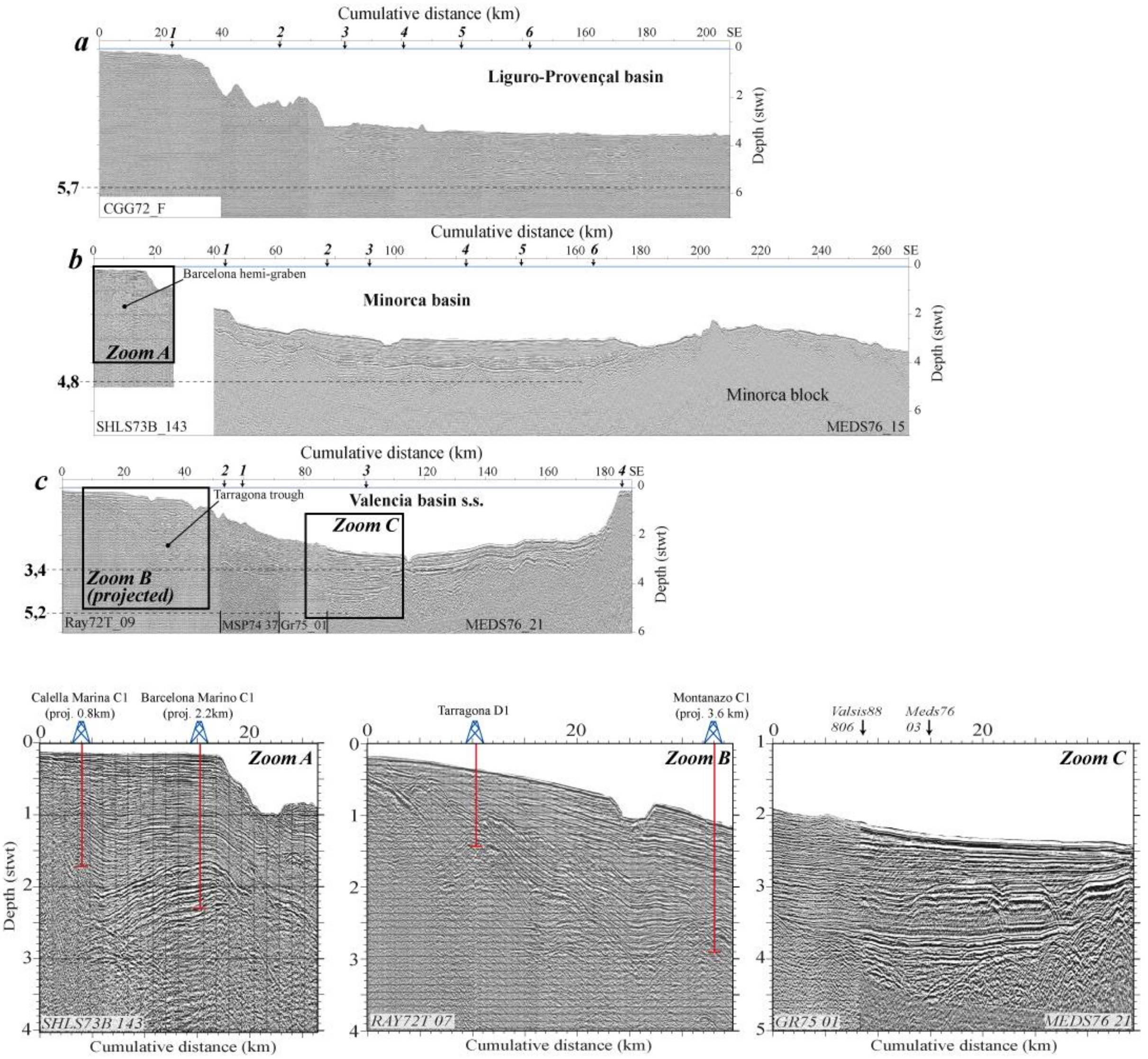
Cumulative distance (km)
1
MEDS76_03
Valencia basin s.s.
CALELLA
GRABEN
Liguro-Provençal basin
Depth (stwt)
Curtesy of Schlumberger Multiclient
2
MEDS76_04
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
Depth (stwt)
Curtesy of Schlumberger Multiclient
3
ESP 02
Valsis88_806 & MAP77_15
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
Depth (stwt)
4
MEDS76_05
MALLORCA IS.
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
Depth (stwt)
Curtesy of Schlumberger Multiclient
5
MAP77_19
Minorca basin
Liguro-Provençal basin
Depth (stwt)
6
MEDS76_06 & MAP77_21
Minorca basin
Liguro-Provençal basin
MINORCA IS.
Depth (stwt)
Curtesy of Schlumberger Multiclient

Figure 3B



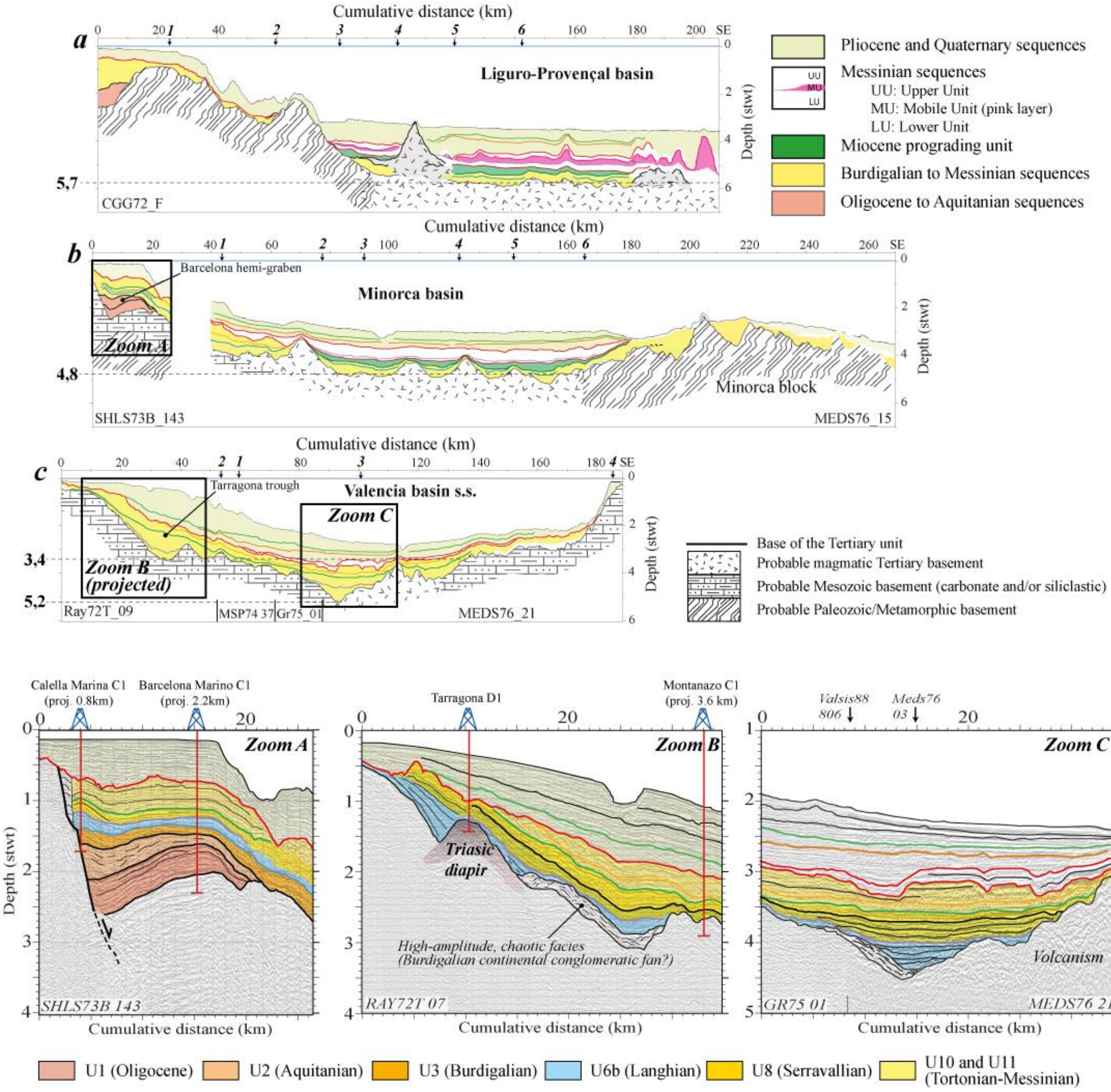
Cumulative distance (km)
1
MEDS76_03
Valencia basin s.s.
CALELLA GRABEN
CATALAN MARGIN
Liguro-Provençal basin
Depth (stwt)
2
MEDS76_04
Valencia basin s.s.
Minorca basin
CATALAN MARGIN
Liguro-Provençal basin
3
ESP 02
Valsis88_806 & MAP77_15
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
4
MEDS76_05
MALLORCA IS.
Valencia basin s.s.
Minorca basin
Liguro-Provençal basin
5
MAP77_19
Minorca basin
Liguro-Provençal basin
6
MEDS76_06 & MAP77_21
Minorca basin
Liguro-Provençal basin
MINORCA IS.
Pliocene and Quaternary sequences
Messinian sequences
UU: Upper Unit
MU: Mobile Unit (pink layer)
LU: Lower Unit
Miocene prograding unit
Burdigalian to Messinian sequences
Oligocene to Aquitanian sequences
Base of the Tertiary unit
Probable magmatic Tertiary basement
Probable Mesozoic basement (carbonate and/or siliclastic)
Probable Paleozoic/Metamorphic basement

Figure 4A



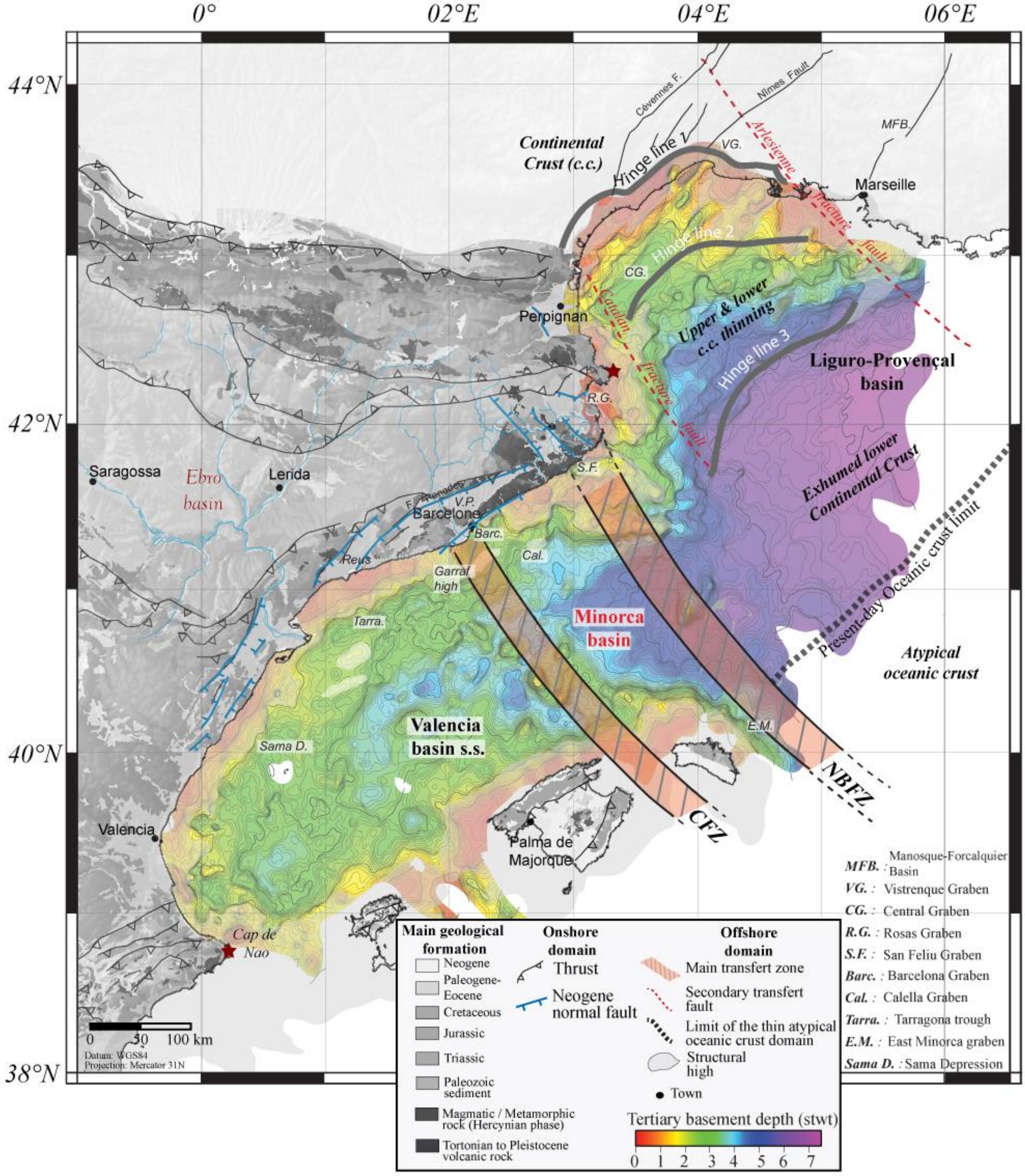
Cumulative distance (km)
a
Liguro-Provençal basin
Depth (stwt)
5,7
CGG72_F
b
Barcelona hemi-graben
Minorca basin
Zoom A
4,8
Minorca block
SHLS73B_143
MEDS76_15
c
Tarragona trough
Valencia basin s.s.
Zoom C
3,4
Zoom B (projected)
5,2
Ray72T_09
MSP74 37
Gr75_01
MEDS76_21
Calella Marina C1 (proj. 0.8km)
Barcelona Marino C1 (proj. 2.2km)
Zoom A
SHLS73B 143
Tarragona D1
Montanazo C1 (proj. 3.6 km)
Zoom B
RAY72T 07
Valsis88 806
Meds76 03
Zoom C
GR75 01
MEDS76 21

Figure 4B



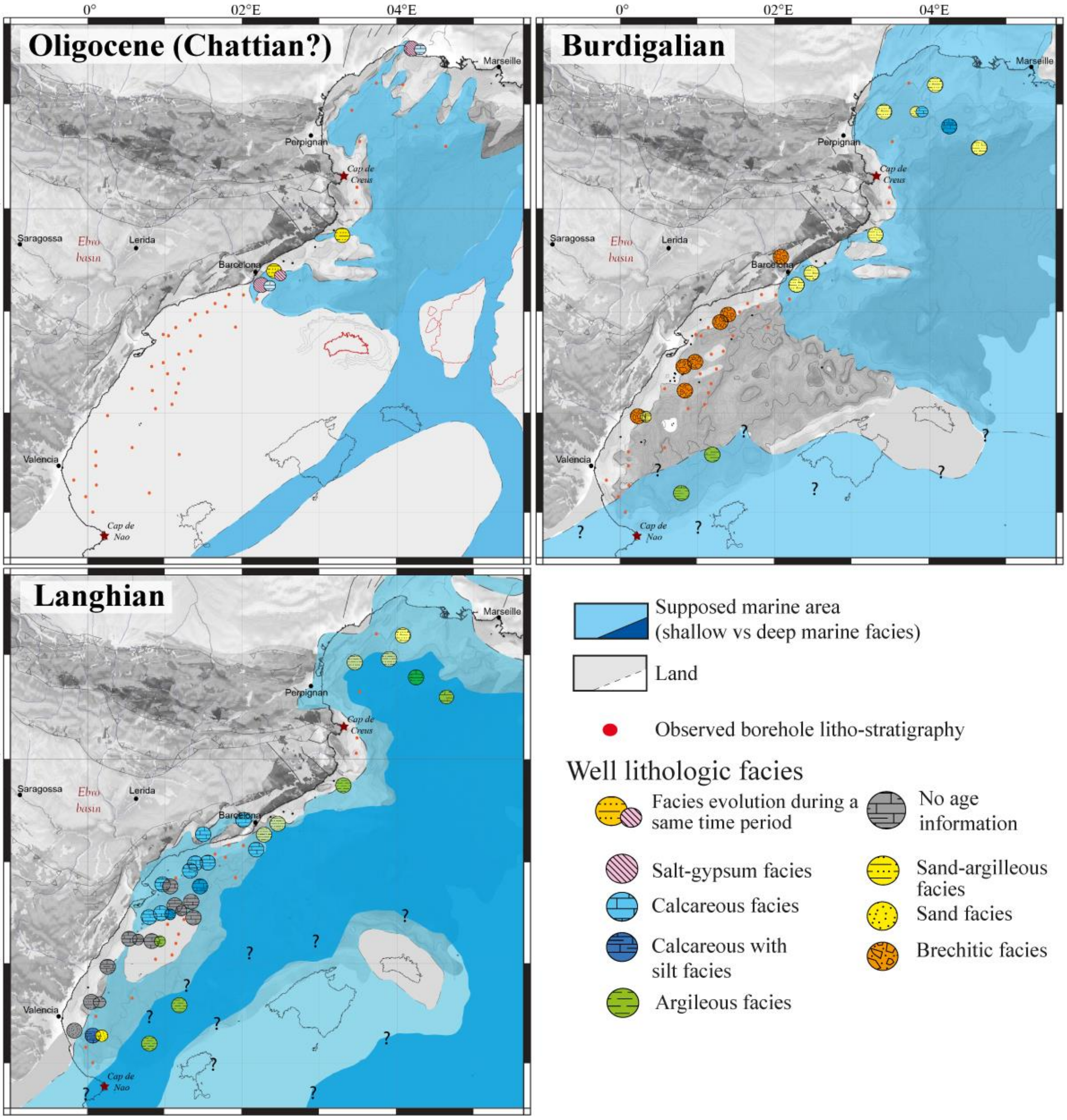
Cumulative distance (km)
a
Liguro-Provençal basin
Pliocene and Quaternary sequences
Messinian sequences
UU: Upper Unit
MU: Mobile Unit (pink layer)
LU: Lower Unit
Miocene prograding unit
Burdigalian to Messinian sequences
Oligocene to Aquitanian sequences
CGG72_F
5,7
Depth (stwt)
b
Minorca basin
Barcelona hemi-graben
Zoom A
Minorca block
SHLS73B_143
MEDS76_15
4,8
c
Valencia basin s.s.
Tarragona trough
Zoom B (projected)
Zoom C
3,4
5,2
Ray72T_09
MSP74 37
Gr75_01
MEDS76_21
Base of the Tertiary unit
Probable magmatic Tertiary basement
Probable Mesozoic basement (carbonate and/or siliclastic)
Probable Paleozoic/Metamorphic basement
Calella Marina C1 (proj. 0.8km)
Barcelona Marino C1 (proj. 2.2km)
Zoom A
SHLS73B 143
Tarragona D1
Montanazo C1 (proj. 3.6 km)
Zoom B
Triasic diapir
High-amplitude, chaotic facies (Burdigalian continental conglomeratic fan?)
RAY72T 07
Valsis88 806
Meds76 03
Zoom C
Volcanism
GR75 01
MEDS76 21
Cumulative distance (km)
U1 (Oligocene)
U2 (Aquitanian)
U3 (Burdigalian)
U6b (Langhian)
U8 (Serravallian)
U10 and U11 (Tortonian-Messinian)

Figure 5



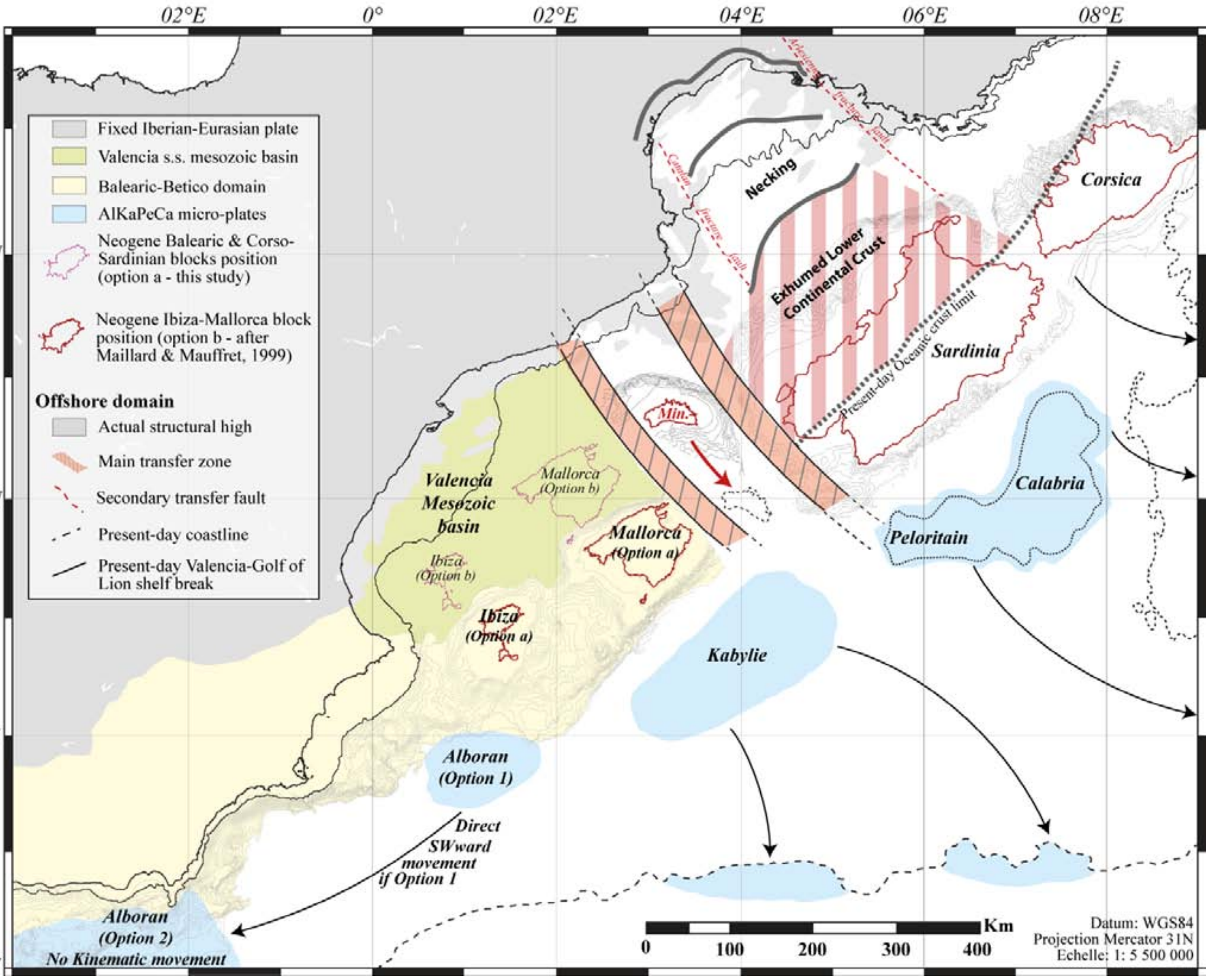
0°
02°E
04°E
06°E
44°N
42°N
40°N
38°N
Continental Crust (c.c.)
Hinge line 1
Hinge line 2
Hinge line 3
Cévennes F.
Nîmes Fault
VG.
MFB.
Arlesienne fracture fault
Marseille
CG.
Catalan fracture fault
Perpignan
Upper & lower c.c. thinning
Liguro-Provençal basin
R.G.
Exhumed lower Continental Crust
Present-day Oceanic crust limit
Saragossa
Ebro basin
Lerida
S.F.
F. Pyrenees
V.P.
Barcelone
Barc.
Reus
Cal.
Garraf high
Tarra.
Minorca basin
Atypical oceanic crust
Valencia basin s.s.
E.M.
Sama D.
NBFZ
CFZ
Valencia
Palma de Majorque
Cap de Nao
0 50 100 km
Datum: WGS84
Projection: Mercator 31N
Main geological formation
Neogene
Paleogene-Eocene
Cretaceous
Jurassic
Triassic
Paleozoic sediment
Magmatic / Metamorphic rock (Hercynian phase)
Tortonian to Pleistocene volcanic rock
Onshore domain
Thrust
Neogene normal fault
Offshore domain
Main transfert zone
Secondary transfert fault
Limit of the thin atypical oceanic crust domain
Structural high
Town
Tertiary basement depth (stwt)
0 1 2 3 4 5 6 7
MFB. : Manosque-Forcalquier Basin
VG. : Vistrenque Graben
CG. : Central Graben
R.G. : Rosas Graben
S.F. : San Feliu Graben
Barc. : Barcelona Graben
Cal. : Calella Graben
Tarra. : Tarragona trough
E.M. : East Minorca graben
Sama D. : Sama Depression

450 **Figure 6**



451
452

Figure 7


02°E
0°
02°E
04°E
06°E
08°E
42°N
40°N
38°N
36°N
Fixed Iberian-Eurasian plate
Valencia s.s. mesozoic basin
Balearic-Betico domain
AlKaPeCa micro-plates
Neogene Balearic & Corso-Sardinian blocks position (option a - this study)
Neogene Ibiza-Mallorca block position (option b - after Maillard & Mauffret, 1999)
Offshore domain
Actual structural high
Main transfer zone
Secondary transfer fault
Present-day coastline
Present-day Valencia-Golf of Lion shelf break
Necking
Exhumed Lower Continental Crust
Present-day Oceanic crust limit
Corsica
Sardinia
Calabria
Peloritain
Kabylie
Min.
Valencia Mesozoic basin
Mallorca (Option b)
Ibiza (Option b)
Mallorca (Option a)
Ibiza (Option a)
Alboran (Option 1)
Direct SWward movement if Option 1
Alboran (Option 2)
No Kinematic movement
Km
0
100
200
300
400
Datum: WGS84
Projection Mercator 31N
Echelle: 1: 5 500 000