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The Balearic Islands in the Alpine Orogeny

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ABSTRACT

The place of the Balearic Islands in the Alpine orogeny is examined using detailed sedimentology studies, stratigraphical studies from the Lower Devonian (Lochkovian) to modern times and a careful tectonic review of sedimentary formations from the Western Mediterranean. Despite being considered as the ultimate end of the north-eastern termination of the Betic Cordillera, the history of the Balearic archipelago seems to be closer to the tectonic opening of the Gulf of Valencia and to the Corsica-Sardinia rotation, and thus to the tectonic history of the Western Mediterranean Sea, than to the tectonics of the Betic Cordillera which appear as its symmetrical image with respect to this opening.

Key words: Balearic Islands, Mediterranean, Paleozoic, Maghreb, Gulf of Valencia

Las Islas Baleares en la Orogenia Alpina

RESUMEN

Se examina la posición de las Islas Baleares en la orogenia alpina usando exhaustivas revisiones sedimentológicas, estudios estratigráficos desde el Devónico Inferior (Lochkoviense) hasta la actualidad y una cuidada revisión tectónica de las series sedimentarias del Mediterráneo occidental. Aunque se considera como la terminación nororiental de las Cordilleras Béticas, el archipiélago balear se vincula más a la historia tectónica de la apertura del Golfo de Valencia y la rotación del bloque Corso - Sardo, y así a la historia tectónica del Mediterráneo occidental, que a la tectónica de las Cordilleras Béticas, la cual aparece más bien como su imagen simétrica en relación a esta apertura.

Palabras clave: Baleares, Mediterráneo, Paleozoico, Magreb, Golfo de Valencia

VERSIÓN ABREVIADA EN CASTELLANO

Introducción y metodología

La posición del archipiélago de las islas Baleares, equidistante de las costas de España, Francia, Norte de África así como de otras islas como Córcega (Francia) y Cerdeña (Italia) (Figura 1), ha sido durante muchos años un enigma geológico sin resolver para los precursores H. Hermitte and W. von Seidlitz (Figura 2), y sobre todo para P. Fallot. Además, el archipiélago se encuentra en la extensión NE de las cordilleras Béticas, pero ni su serie sedimentaria ni su tectónica parecen acordes con esta posición.

A partir de cartografías basadas en fotografías aéreas, el desarrollo de dos mapas geológicos a E. 1/50 000 permitió una mejor comprensión no sólo de la serie estratigráfica de Menorca y nordeste de Mallorca, sino también de las relaciones tectónicas entre sus formaciones sedimentarias y entre las propias islas. Las campañas oceanográficas han permitido también un conocimiento preciso de la batimetría y la naturaleza de ciertos fondos (Figura 3). De este modo se puso en evidencia la existencia de una serie sedimentaria que comienza en el Devónico inferior, incluye también las series Mesozoicas ya conocidas, pasa por el descubrimiento de un Oligoceno conglomerático y llega hasta el Messiniense marino y el Cuaternario. Los niveles de turbiditas (Figura 4) fueron estudiados en lámina delgada, se aplicaron tratamientos específicos para el estudio de conodontos, levigados de margas, etc...

La situación pre–alpina: un Océano Menorquín del Devónico al Carbonífero

En Menorca, la secuencia sedimentaria paleozoica incluye desde el límite Silúrico-Devónico hasta el Pérmico Superior. Tras un Lochkoviense con Monograptus praehercynicus *(Jaeger), se diferencia una primera cuenca detrítica de tipo flysch que funcionará hasta el Devónico superior. Es una cuenca oceánica profunda, similar a las actuales, donde la inestabilidad de sus márgenes así como la sobrecarga sedimentaria a nivel de la plataforma continental provoca una sedimentación por gravedad que se superpone a corrientes de fondo permanentes que retrabajan las capas ya depositadas. Graptolites, conodontos y tentaculites permiten una cronología fina de estos depósitos.*

En el Mediterráneo Occidental se llevó a cabo un estudio de depósitos de edad y de facies idénticos: en la parte continental de España, Argelia, Marruecos y Cerdeña.

Estas series sedimentarias, poco o nada metamorfizadas, van del Silúrico al Pérmico. Se superponen en láminas tectónicas alpinas en el Rif (Gomárides) y Sur de España (Maláguide), pero están in situ en la Cabilia (Figura 5) donde constituyen la cobertera reciente, más o menos despegada, del zócalo de Cabilia. Esta serie está in situ en Menorca y por lo tanto constituye el autóctono de los mantos Paleozoicos internos Alpinos.

Se distingue así un Devónico distal (Figura 6): flysch de Menorca , de la Khudiat Tizan (Marruecos), seguido de un flysch carbonífero, junto a un flysch carbonatado, de facies de talud continental a facies intermareales, según el momento, y de margen continental (Beni Hozmar, Alkaïli) a facies intermareales (Talembote) con un Carbonífero cada vez más proximal que contiene olitostromas y desde coladas de fango a olistolitos y guijarros, con gradiente del Rif (Marruecos) a Menorca (facies distales).

De acuerdo con los diferentes elementos retrabajados en el flysch Devónico, hay que reconstruir una zona emergida formada por rocas ricas en cuarzo, mica y feldespato. En el Devónico superior, una sedimentación carbonática con tentaculites y conodontos indica una cuenca menos profunda que la llanura abisal (ausencia de disolución de los carbonatos).

En Cerdeña, el Devónico datado de Iglesiente se presenta bajo una facies calcárea desconocida en las zonas perimediterráneas de las Baleares, del Maláguide (España), Gomárides (Marruecos) y de Chénoua (Cabilia). La única comparación posible es con la zona SE de Cerdeña, Gerrei.

En conclusión, en el Devónico, la cuenca oceánica representada en Menorca, el macizo de la Khudiat Tizan (Marruecos) y Chenoua (Argelia), estaría constituida por una gran llanura abisal, lo suficientemente profunda para eliminar todos los carbonatos (Figura 6), donde se desarrollaron potentes series turbidíticas.

Estas potentes series sedimentarias fueron posteriormente reactivadas y dispersadas por los orógenos hercínico y alpino. Este océano Devónico u « Océano Menorquin» incluiría Menorca (Islas Baleares, España), el macizo de la Khudiat Tizian (Marruecos) y Chenoua (Argelia). Divertículo posible del Paleo-Tethys, este océano no está incluido en las reconstrucciones paleogeográficas clásicas.

Los hallazgos tectónicos recientes en el Pirineo, Córcega y Cerdeña: el paleomagnetismo.

Diferentes autores, tras estudiar el paleomagnetismo de lavas de Córcega, concluyen, al final de los años sesenta, en una rotación de 44°+ 4° hacia el SE de Córcega y de Cerdeña, comenzando hacia – 21 ó – 23 Ma y finalizando hacia – 15 Ma. Para comprender la situación de las Baleares en el orógeno alpino, hay que remitirse a Córcega y Cerdeña y su posición en el Mediterráneo y ensayar primero la reconstrucción del conjunto en el Eoceno inferior, antes de la gran fase orogénica del Eoceno superior, que termina en el Mioceno basal antes de las aproximaciones que se van a producir. Córcega y Cerdeña pertenecen así al sistema alpino y el SW de Cerdeña, Iglesiente, se sitúa directamente al NW de la isla de Menorca justo al inicio del Mioceno (Figura 7).

En esta reconstrucción, se debe también tener en cuenta el acortamiento sufrido a lo largo de la zona pirenaica, así como de las cadenas catalanas, debido en conjunto al juego de desgarre de las fallas transformantes norpirenaicas y de las fallas de desgarre del promontorio balear (Figura 5). Este acortamiento puede ser evaluado en una distancia igual o superior a 200 km.

Basándonos en la carta batimétrica de la figura 3, se puede entonces ensayar el cierre del Golfo de Valencia (Figura 8), la apertura de este golfo puede ser así atribuida al rifting debido a un adelgazamiento cortical, hipótesis también apuntada para el Golfo de León. Esta apertura sería así responsable de la espectacular tectónica de la Sierra Norte de Mallorca, donde las tres mayores láminas tectónicas se han desplazado hacia el SE. Durante la apertura de un rift o de un adelgazamiento cortical, los bloques continentales de un lado y del otro sufren un ligero basculamiento hacia el exterior, con relación al centro de apertura, pudiendo entrañar la formación de láminas tectónicas (post-burdigalienses en Mallorca).

Una vez que el Golfo de Valencia se cierra (Figura 8), el archipiélago Balear representa las zonas de sedimentación (plataforma continental, talud continental) del continente ibérico, es decir, lo que se ha convenido llamar, en las Cordilleras Béticas, como el Prebético y el Subbético.

Las deformaciones tectónicas no se producen como se pensaba por un aplastamiento hacia el NW, sino al contrario, del NW hacia el SE, en el transcurso de la apertura del Golfo de Valencia, provocando el apilamiento de las láminas de la Sierra Norte tras el Burdigaliense (-15 Ma). Es una "retro-compresión". El acortamiento total en Mallorca sería así de más de 200 km. Esto sería igual para Ibiza, donde el sistema de escamas SW-NE está igualmente presente.

La disposición actual se muestra en la figura 9, poniendo en evidencia las fallas de desgarre entre las diferentes islas. Las estructuras cabalgantes de Mallorca van a chocar contra una de estas al norte, interrumpiendo el edificio de las Cordilleras Béticas.

Registro estratigráfico y sedimentológico de los movimientos tectónicos en el Oligoceno y el Mioceno inferior entre - 23 y - 15 Ma.

El descubrimiento de potentes depósitos conglomeráticos poco consolidados, de edad Oligoceno - Mioceno inferior, en la costa E-NE de la península de Fornells, entre las playas de Son Saura y de en Castell, a Es Macar de Su Llosa, da testimonio de una erosión muy sustancial de los relieves de la isla en esta época, posiblemente debido a un bajo nivel del mar. Estos conglomerados se forman por el apilamiento de secuencias donde 4 términos se repiten más o menos cada 60 m de espesor. Contienen cantos de las series del Mesozoico de Menorca, pero también cantos de Orbitolinas de un Cretácico inferior desconocido en Menorca. Han sido datados por los gyrogonites de Carofitas. Estos conglomerados están intensamente fallados y, a veces despegados sobre las formaciones previas.

Sedimentología y microfósiles indican que estos depósitos fueron depositados rápidamente según un pulso que provoca una alternancia grosera de pudingas y de los términos más finos, variados, en un ambiente deltaico, dentro de unas zonas lacustres a lagunares-lacustres, vecinas de zonas elevadas en vía de erosión.

Estos depósitos oligocenos están a su vez cortados por el trazado de la línea de costa actual, es decir, la falla de desgarre del NE de Menorca de orientación NW-SE. Representarían así el registro no sólo de los movimientos de apertura del Golfo de Valencia, sino también de la rotación del bloque Corso-Sardo (Figura 10).

Conclusiones

1) Importancia de las fallas de desgarre en el Mediterráneo Occidental y aislamiento y separación del bloque Balear de otros bloques continentales paleozoicos.

La diseminación de los diferentes elementos continentales del Paleozoico, o elementos internos paleozoicos: los macizos de Chenoua, de la Khudiat Tizan, d'Alkaïli, de Talembote, se debe al juego constante de fallas de desgarre (Figura 11) que han modelado la paleogeografía del Mediterráneo occidental antes de que los últimos movimientos alpinos los incorporaran bien a las Cordilleras Béticas en España, bien a las diferentes cadenas alpinas de África del Norte, pero preservan a las Baleares y en particular a Menorca donde el Helvetiense, Tortoniense y Mesiniense son marinos y no deformados.

2) Orogenia alpina

En Menorca, las fases de plegamiento registradas se han datado entre el Albiense basal y el Oligoceno superior, con una tectónica de cobertera pre-Oligoceno superior.

3) La aparición lenta pero repentina del Golfo de Valencia, sin duda ligada a la del Golfo de León, ha permitido a la isla de Menorca, únicamente, escapar a las fases ulteriores de deformación del Mioceno superior ya que en Menorca el Helvetiense, Tortoniense y Mesiniense son marinos y no deformados.

4) En consecuencia, las Islas Baleares pertenecen a las zonas Prebéticas y Subbeticas de Iberia, en la terminología de M. Durand Delga.

Introduction: Geology of the Balearic Islands and previous studies

The Balearic Archipelago (Spain, Fig. 1) is a continuation towards the NE of the mountainous mass of southern Spain, called the Betic Cordillera. It is composed, from SW to NE, of the main islands of Ibiza and Formentera, of Mallorca (with Cabrera) and of Menorca. As Ibiza, Formentera and Mallorca are mainly formed of Mesozoic and more recent formations, Menorca is constituted for the most part by Paleozoic formations which largely outcrop in its northern half. The question about its correlation in the Western Mediterranean has mystified a great number of researchers.

After a succession of precursors, Henri Hermite was the first to offer geological maps of Mallorca and Menorca (1878, 1879, 1888). In Mallorca, he supposed,

Figure 1. Position of the Balearic Islands Archipelago in the in Western Mediterranean Sea: with equal distances from the coasts of Spain, France, Corsica (France), Sardinia (Italy) and North Africa. From Bourrouilh, R., 2012, by courtesy of Elsevier.

Figura 1. *Posición del archipiélago Balear en el Mediterráneo occidental: equidistante desde las costas de España, Francia, Córcega (Francia), Cerdeña (Italia) y Norte de África. Segun Bourrouilh, R., 2012, cortesía de Elsevier.*

with reasons, that the Paleozoic is present at two km north of Estellench, in the open sea, close to the Sierra Norte (or Sierra Tramuntana). The Paleozoic is found on land, on the coast between Es Port d'en Canonge and Es Port de Valldemossa according to E. Ramos and A. Rodriguez-Perea (1985). The Paleozoic is pinched between two faults and, in the opinion of these authors, it could be Upper Devonian or Carboniferous.

After Henri Hermitte, Paul Fallot developed his thesis for the Sierra Norte (1922), in which he discovered and studied three large and long slabs, constituting the chain of the Sierra of Tramuntana and extending over an area 90 km long and 10 to 15 km wide. He traversed rapidly the Sierra de Levante, which occupies the NE part of Mallorca around the town of Arta, he then went to Menorca and Ibiza. In 1923, he discussed Menorca in a paper entitled "The problem of Menorca". Paul Fallot's conclusion was that the problem of Menorca is not solvable and remains unknown.

In 1931, von Seidlitz in his paper "Gebirge am Mittelmeer" discussed all the mountain chains of the Mediterranean Sea and, especially of the extensions of the Betic Cordillera towards the Balearic Islands. He pointed out the presence of Paleozoic pebbles (Culm) in the centre of Mallorca, in the central area of Sineu-San Juan (p. 499), and published, among others, this map of the Balearic islands (Fig. 2) in which the Balearic promontory is fractured by faults without, apparently, any throw of strike-slip movements.

J. S. Hollister (1934, 1942) looked again at the geology of Menorca. For this author, the formations extend from Upper Devonian to Carboniferous. The Upper Carboniferous (Stephanian) and the Permian are represented by *Agathiceras* and *Paragastrioceras,* under sandstone and red clay, in discordance, a point on which I do not agree.

In Mallorca, Hollister confirms the existence of very numerous greywake pebbles (probably identified

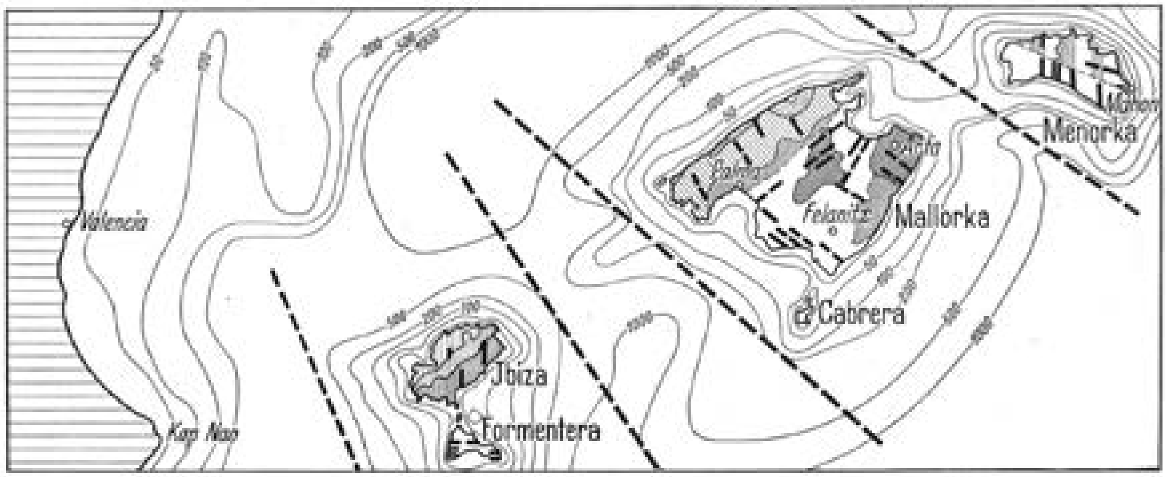

Figure 2. Geology of the Balearic promontory, (from H. Nolan 1887, 1893, 1894, 1895a and b, 1897, 1914, 1927; P. Fallot 1922 and B. Darder 1929) and fracturation from von Seidlitz, *in* von Seidlitz, 1931, Figure 116.

Figura 2. *Geología del promontorio Balear (según Nolan, 1887, 1893, 1894, 1895a and b, 1897, 1914, 1927; Fallot 1922 y Darder 1929) y fracturación según von Seidlitz, 1931 (figura 116).*

as Culm, up to 70 cm in diameter) in the Sineu-San Onofre area, pebble transport directions of which are from SE towards the NW and pebbles of which origin is the open sea of Mallorca, coming from a domain where the Budigalian is erosional and transgressive on the Paleozoic formations, but which has disappeared under the Mediterranean Sea. Hollister, following H. Stille (1927) considers that Menorca is the hinterland of the foldings of Mallorca.

Underwater corings, collected around the Balearic Archipelago, have shown the existence of Paleozoic rocks at the foot of the Sierra Norte (Bourrouilh & Mauffret, 1975, cores K.S. 09 and F 67) in the form of fragments of Culm and Devonian. In the SE of Menorca, core D.R. 20 has exhibited the existence of Carboniferous Culm, constituting the continental slope of the island. In the north of Menorca, core FOM P.73 has cut through some Culm and Devonian, infra-Lochkovian black shales, metamorphic sericitous microfolded schists.

The published marine map (*in* Bourrouilh and Mauffret, 1975, Fig. 1), reproduced here (Fig. 3), clearly shows the interruption of the Sierra Norte and Sierra de Levante tectonic units against a SE-NW fault which cuts the Balearic promontory as seen by von Seidlitz (1931). From comparisons with the geological maps of Menorca and the Sierras of Levante of Bourrouilh (1973, 1983), the shift of Menorca extends to a distance of more than 40 km towards the SE.

A search for a vanished ocean: Paleozoic paleogeography in the Western Mediterranean sea, "The Devonican Menorcan Ocean"

As for sedimentology and micropaleontology, comparisons between different Paleozoic formations have already been made in Bourrouilh and Lys, 1976, and Bourrouilh *et al.*, 1980, from different Mediterranean areas: comparisons with the Sardinian Paleozoic, with the Barcelona province and from the south of Spain around Malaga (Malaguide nappes) and from the Algeria (Chenoua mountain).

It is really in the Chenoua (Algeria) that the Menorcan (Spain) Paleozoic presents the most similarities and

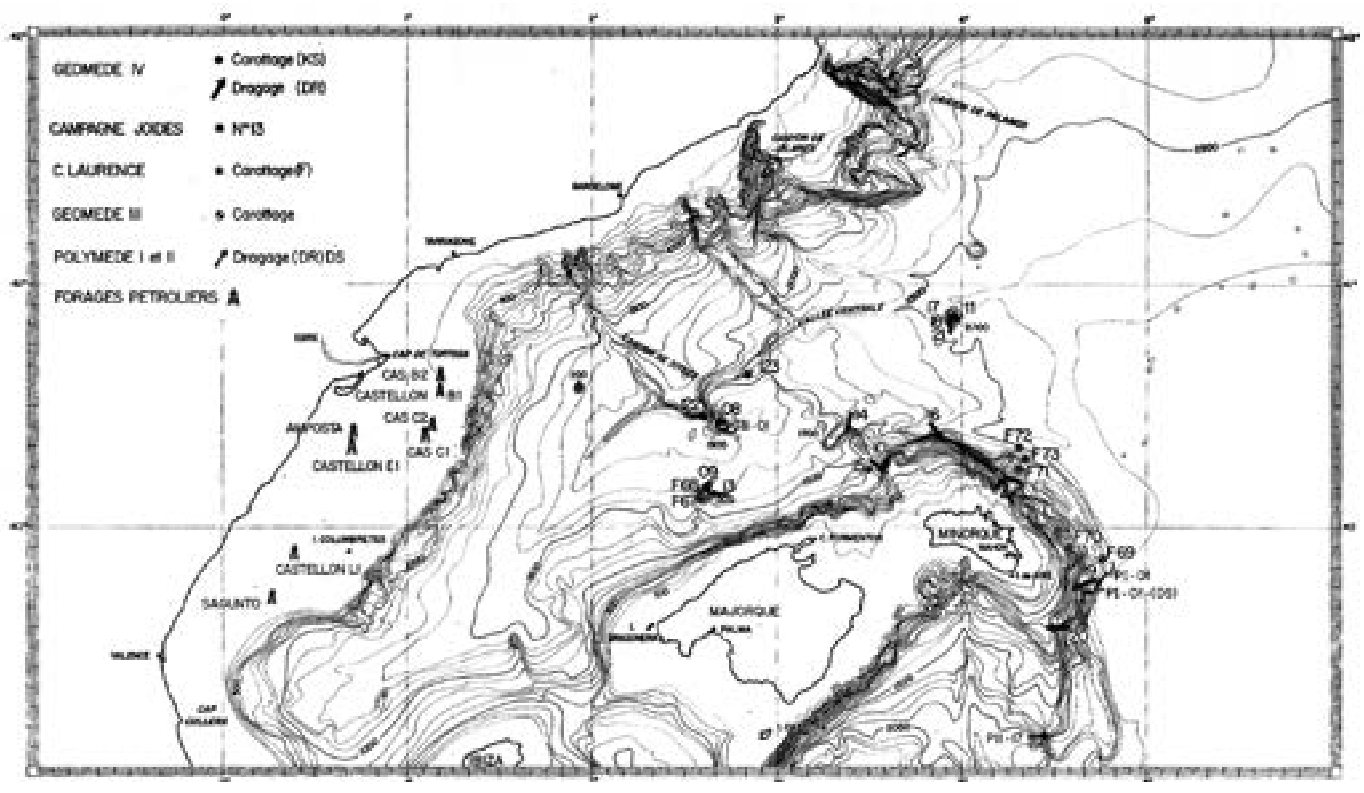

Figure 3. Detailed bathymetry of the Balearic Promontory in the Western Mediterranean Sea. Location of main 1975 known cores and marine campaigns. From Bourrouilh and Mauffret, 1975.
Figura 3. *Batimetría detallada del Promontorio Balear en el Mediterráneo Occidental. Localización de los principales 1975 sondeos y campañas marinas conocidas. Según Bourrouilh and Mauffret, 1975.*

affinities, and also with the internal Rif (Morocco) nappes, particularly the Kuhdiat Tizian nappes.

Menorca (Balearic Islands, Spain)

It is the only island of the Balearic archipelago to expose Paleozoic formations. It has a non-metamorphic aspect, composed of Devonian flysch (field and laboratory sedimentological sketches in Fig. 4), covered by a low or non-detritic carboniferous capped by a concordant Culm facies. The detrital basin began during Lochkovian times. Above Siluro-Devonian black shales, the flysch facies was forming little by little during *Monograptus praehercynicus* and *M. hercynicus* times, and reaches up to the Lower Praguian. Several sedimentation modes interlock: muddy and half-muddy flows, turbidite currents, bottom current, and grain by grain

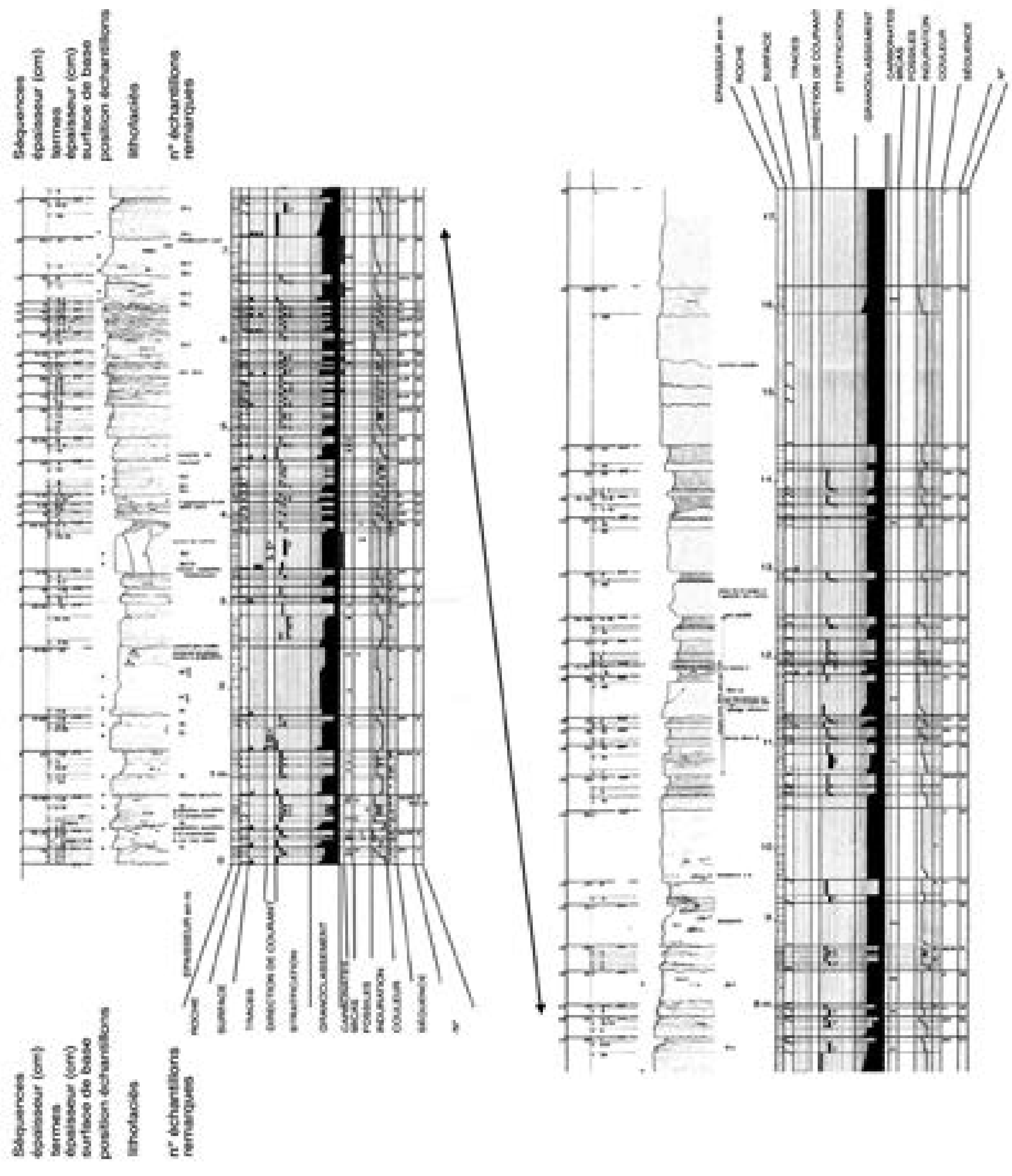

Figure 4. Detailed sedimentology studies (field and laboratory) of the Menorcan Devonian flysch, *in* Bourrouilh, 1970b: cross section of Cala Tirant (Tirant beach) from Bourrouilh 1967. Original dimensions 0.90 m on 0.27 m.
Figura 4. *Estudios sedimentológicos detallados (campo y laboratorio) del flysch devónico de Menorca, según Bourrouilh, 1970b: Corte de Cala Tirant (playa Tirant) según Bourrouilh, 1967. Dimensiones originales 0.90 m sobre 0.27 m.*

sedimentation. They are responsible for grain-sorted, rhythmic deposits of sandstone and shale, at the foot of an underwater slope.

From Upper Praguian to Zlichovian p. p., turbiditic sedimentation slows down and reworking is predominant. From Zlichovian to Upper Devonian, a second detritic phase is developing and ends with turbidites induced by early Variscan tectonics. The evolution of continental margins around the Devonian basin is discernible. During Lower Devonian, it is an oxygen-rich marine environment where Tentaculites, Bryozoa, corals and Conodonts are living. On this margin, the sedimentary overburden and winnowing are low. Thus, the erosion-sedimentation couple is also low.

During Upper Devonian, the turbidite studies show that, on a coastal margin, sedimentary series of shallow carbonates were forming with wackestones rich in Conodonts and scarce reefs. Erosion and earthquakes were shaking this margin generating turbidites, and a few basic lava flows were erupted.

The formation of the detrital basin and the deposition of its sediments seem to be linked to an abyssal plain of 3000 to 4000 m depth at the foot of a continental margin.

The Carboniferous of Menorca includes shale and radiolarites covered by Crinoid limestone and red shales from a Lower Carboniferous age. The limestones are identified by an Upper Visean microfauna, more precisely, the Serpukhovian (Lys *in* Bourrouilh 1973, 1983). Above, the Culm starts with the reappearance of red shales (with *Goniatites* cf *striatus*). The Culm facies goes from Upper Visean to Lower Bashkirian (Namurian N2), identified by an Ammonoïd fauna, and probably further up, because the upper limit of the Culm is an erosional one. In few outcrops, the Culm facies exhibits polygenic pebbles of an ancient substrate.

The Menorcan Culm contains polygenic mud flows with ancient magmatic, metamorphic and sedimentary substrate pebbles (Bourrouilh 1973, 1983). The base of the Carboniferous seems to proceed with an abyssal plain as in Devonian, but localized far away from continental margins because only red thin laminated shales and radiolarites are deposited. Continental masses are getting closer during the Culm facies because of its coarse deposits, mixed with some few limestones with radiolaria.

The continental margins around the Culm facies deposits seem different from the Devonian ones: richer in quartz and feldspathics, the Culm is derived from erosion of very muscovite-rich magmatic and metamorphic rocks. These muscovite clasts present all sizes, coming directly from an emerged metamorphic or magmatic substrate associated with an acid volcanism, perhaps during the Upper Visean. After taking into account different sedimentological criteria, this substrate should be placed to the east of the Menorca's modern position, the extension of the basin being north-south (Bourrouilh, 1975).

The Chenoua massif (Kabylies, Algeria)

The Chenoua is a small coastal massif, located around 70 km from Algiers, belonging to the internal Kabylian zones of the Alpine orogeny of North Africa (Fig. 5). The Paleozoic formations appear again 700 km westward in the Rif (Morocco). In 1942, A. Lambert and J. Flandrin described the Paleozoic formations of the Chenoua. It is composed of a Devonian flysch, extending from middle Devonian with Tentaculites, and Upper Devonian with corals and having older Siluro-Lower Devonian banks, but undated, probably Carboniferous.

M. Durand-Delga, in a paper by P. Séménoff-Tian-Chansky *et al.* (1961), completed the stratigraphy noting the existence of sandstone and schist (Culm facies) from Lower to Middle Carboniferous age. C. Lepvrier (1967) described the Chenoua structure and briefly recalled its stratigraphy.

Description of the Paleozoic succession was completed in 1976 (R. Bourrouilh, J. Helms, H. Jaeger and C. Lepvrier). It is composed, above the epizonal metamorphic ante-Lochkovian of the Berinshel islet, by a thick quartzo-shaly black flysch, first ante-Lochkovian, then Lower to Middle Lochkovian age with *Linograptus, posthumus*, or *Abiesgraptue sp.* indt., *Monograptus* cf. *microdon*, *Monograptus praehercynicus*.

Petrographically, this Lochkovian formation is formed by sandstones of centimetric to decimetric thick beds with turbidite structures, and of thicker black shales. A second outcrop, of a more recent Lochkovian age, contains *Monograptus* cf. *aequabilis*. Above, the sandstone turbidites become thicker (40 to 60 cm) and are enriched in carbonates, containing clasts of corals, brachiopods, bryozoas, crinoids, rare and broken conodonts and Nowakiids, probably with *Nowakia acuaria* from Lochkovian-Praguian (identified by J. Helms). Above, a thick series (200-300 m) is observed, composed of sandstone turbidites and bioturbated shales. Then carbonate sequences arrive with thin oblique laminations (1 cm or more). These levels evoked the Menorcan Praguian. The Middle and Upper Devonian, always under the flysch facies, follow above. Then, a mud flow exposure a few metres thick occurs which is about ten metres long, with numerous reworked corals, spiriferids, crinoids, clam fragments, etc. It is this muddy casting which has been studied by P. Séménoff-Tian-Chansky, J. Lafuste and M. Durand-Delga (1961) and has yielded a fauna from the Givetian-Frasnian. Following these, is the Lower Carboniferous with a Culm facies, intercalated by *Poteriocrinus* limestones, lying on these previous deposits.

The Limestone Axial Unit, despite the presence of a tectonic shearing contact, represents the Mesozoic cover of this Paleozoic sequence. In 1942, J. Flandrin and A. Lambert described the Trias of the Chenoua Massif, lying on the Paleozoic and composed, from bottom to top, of detrital and red Lower Permo-Trias, of Muschelkalk, formed by dolostones and limestones, and carniolas from Keuper. This triassic formation, incompletely dated, reminds strongly the one in Menorca (Bourrouilh, 1973, 1983).

In 1957, M. Durand-Delga gave the main characteristics of Chenoua Jurassic and Lower Cretaceous: after the carnolas, the Lias is formed by compact limestones, followed by ten metres, or more, of limestones in thin beds, from Dogger to Callovian, with *Posidonia ornati*, covered by limestones dated, for their upper part from Berriasian with Calpionelles, with *Nannoconus*, then marly Neocomian, going probably up to the Barremian. Above, M. Durand-Delga and J. Magné (1957) described outcrops of

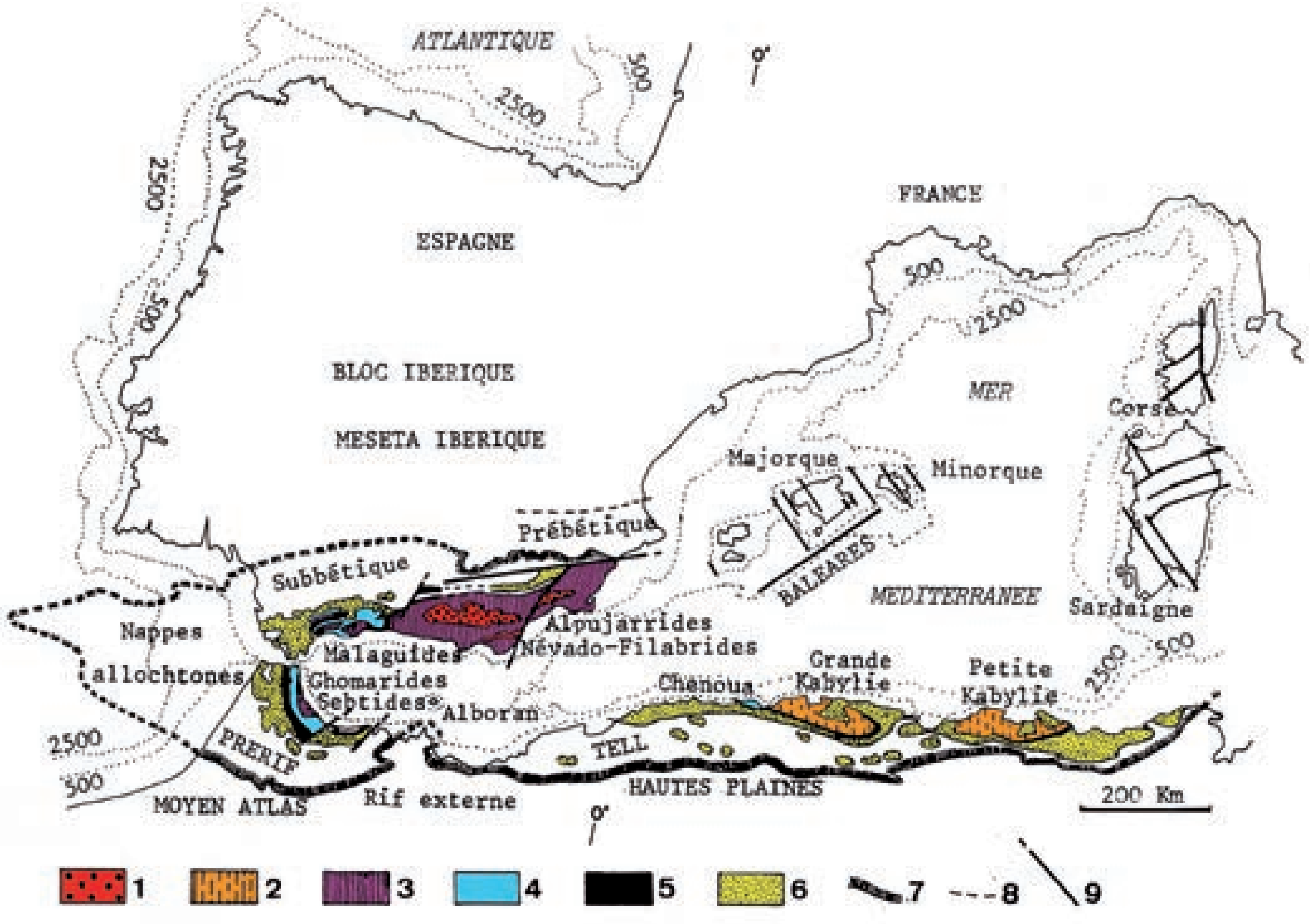

Figure 5. The Alpine orogeny in Western Mediterranean area (adapted from different authors, modified, in Bourrouilh *et al.*, 1976)
Internal zones : 1, Nevado-Filabrides. – 2, Kabylian massifs. 3, Alpujarrides (Spain), Septides (Morocco). – 4, Malaguides (Spain), Ghomarides (Morocco). – 5, main axes. External zones: 6, Flyschs.- 7, allochtonous units fronts. 8 – limits between Prebetic and Iberic Meseta. – 9, Main fracturation directions.

Figura 5. *La orogenia alpina en el Mediterráneo occidental (adaptado de diferentes autores, modificado, de Bourrouilh et al., 1976)*
Zonas Internas: 1, Nevado-Filábrides. – 2, Macizo de Cabilia. 3, Alpujárrides (España), Septides (Marruecos). – 4, Maláguides (España), Gomárides (Marruecos). – 5, ejes principales. Zonas Externas: 6, Flyschs.- 7, frente de unidades alóctonas. 8 – límites entre el Prebético y la Meseta Ibérica. – 9, Principales direcciones de fracturación.

schistose marls and limestones from Senonian, which are transgressive up to the Jurassic, then Campanian, composed of white shaly limestones, with Jurassic pebbles and a Maastrichian microfauna, and lastly whitish-grey marls of Danian, which is in contact with the Oligocene.

Ghomarides (Morocco)

In 1960-1962, M. Durand Delga, writing about the Ghomarids and the Malaguids, was stating: "The schistous and sandstone series of the Northern side of the Chenoua seemed to me astonishly identical to the ones of the internal Rif (Morocco) or of the Malaga nappe (Andalusia, Spain)". He was totally correct: it is the same Paleozoic series.

One knows that the internal part of the Betic Cordillera in Spain and their prolongation in the Moroccan Rif is composed of tectonic stacked nappes, the highest of which are formed of Paleozoic non- or weakly metamorphosed rocks, called Malaguids in Spain and Ghomarids in the Rif.

The internal part of the Rif is formed, for the most part, by weakly or non-metamorphic Paleozoic rocks, generally pinched tectonically between, in the west, by the massive carbonate nappes of the Rif Units and, to the east, by the metamorphic series of the Sebtids. Milliard (1959) and Kornprobst (1974) have considered that this Paleozoic was forming three tectonic superposed nappes or Ghomarid nappes: the nappe of Akaïli, of the Beni-Hozmar and of the Khudiat Tizian. In each of these nappes, the sedimentary Paleozoic series present differences, marked, above all, during the Devonian. The older basements of these series are unknown.

In the Beni-Hozmar series, the Devonian is composed of porcelained, tentaculitid limestones, in which, because of the presence of Conodonts, M. Lys has described, in 1975, the Givetian, Frasnian and perhaps Famenian. They lay directly on Orthoceratid limestones, themselves lying on silky schists with Upper Llandovery Graptolites (Agard *et al.*, 1958).

A little later (Bourrouilh and Jaeger, 1976), *Monograptus cf. praehercynicus*, i. e. the Lower to Middle Lochkovian, is identified in two layers of the Devonian flysch of the Kuhdiat Tizian Unit, thrusted upon the Carboniferous formations. Above, are found decalcified coarse turbidites with Tentaculites. In another layer, we have found, in an upper stratigraphic position, *Monograptus acquabilis acquabilis*, from Upper Lochkovian, then carbonate sequences, with oblique laminations, identical to the Menorcan Praguian.

This Devonian flysch is composed of graded turbidites and black mudstones. It is very thick (200-300 m) and is analogous to the Menorcan one (Bourrouilh, 1973, 1983).

In the Alkaïli Unit (Morocco), the classical « calizas alabeadas » (multifolded limestones) could be attributed *pro parte* to the Upper Devonian, by comparison with the work of Kockel and Stoppel (1962 a and b) and Geel (1973), in the Eastern Malaguids and they could probably be extended towards the Carboniferous, despite the fact that they are still formally identified (personal communication by Agustin Martin-Algarra). In both the Alkaïli and Beni-Hozmar nappes, Milliard (1959) has identified Carboniferous rocks, limestones with *Lonsdaleia*, foraminifera, algae, from the Upper Visean-Lower Namurian. The Carboniferous has been well identified in the Kuhdiat Tizian nappe (Bourrouilh, 1977) and it is formed of radiolarites and shales overtopped by a several hundred metres thick Culm facies, showing also mud flows with magmatic and metamorphic pebbles, but without any carbonate elements. This Culm facies is very enriched in tracks and bioturbations, and especially *Dictyodora liebeana*.

The Malaguids (Spain)

Blumenthal described in 1949 the "Marbella conglomerates". They are polygenic, with ancient substrate pebbles, carbonate pebbles and are locally associated with limestones. He found fossils in them, corals which were estimated to be from Middle to Upper Devonian in age by Gortani (*in* Blumenthal, 1949) and who noted foraminifera.

Micheleau (1942) refines Blumenthal's observations by attributing a Visean age to the coral fauna after having submitted them to Schindewolf for study.

Azema (1960) describes the Peluca conglomerates and mentions, in his paper, the first foraminifera found in the limestone elements. Revised by Lys, these foraminifera are limited to Upper Visean (*in* Lys and Boulin, 1968).

Geel (1973) worked only on the eastern Malaguids and mentioned, in one part, polygenic coarse conglomerates containing carbonate pebbles with a microfauna ranging from the final Famenian-Dasberg, laid in part during the base of Carboniferous and, in the other part, conglomerates equivalent to the Marbella ones. They contain, in addition, elements the size of which range from a few microns to more than 20 cm, in which he found Visean microfauna, in addition crinoïds clasts, bryozoa, etc.. Navas-Parejo *et al.*, 2012 identified hemipelagic conodont fauna in a carbonate horizon, cropping out in the Velez Rubio-Lorca Corridor, of Bashkirian-middle Moscovian age confirming a deeper paleogeography than was previously thought.

Our reconnaissance observations, made in 1970 in the Malaga mountains, have shown that the Peluca conglomerates should be interpreted as submarine mud flows (Bourrouilh & Lys, 1976, Bourrouilh 1977). The Marbella conglomerates are very probably the Spanish equivalent of the mud flows of the Alkaïli (*in* Bourrouilh *et al.,* 1976, p. 92). However, for all these domains, there are several levels of mud flows, but one of these is characterized by the presence of carbonate elements, giving the same fauna and microfauna, and which are locally associated with the mud and carbonate sand flows (Herbig 1984, 1989).

New observations have been reported by O'Dogherty *et al.* (2000) about stratigraphy and the presence of Lower Carboniferous in a chert-limestone interval (Falcona formation) and in limestone with conodonts. The reworked and rythmic mud and sand flow aspect of the Upper Carboniferous was confirmed later with the discovery of well dated Upper Devonian pebbles by Rodriguez-Canero and Martin-Algarra (2013) in mud flow underlying Tournaisian radiolarites. As for sedimentology, O'Dogherty *et al.*, 2000 confirm the presence of open marine and deep ocean environments. In 2010, Rodriguez-Canero *et al.* completed the stratigraphy by the discovery of late Ordovician conodont fauna, suggesting an eastward localization of the Malaguid terranes at that time compared with other Ordovician Iberian fauna.

Sardinia

An upper Silurian graptolite-rich black-shale sequence with calcareous intercalations, followed by Devonian well-layered tentaculitid limestones with shale intercalations in the lower part of the sequence, crops out in southwestern Sardinia (Alberti 1963; Vai & Coccoza 1986 ; Barca *et al.,* 1992; Vai 2001). Upper Devonian limestone yields *Clymenia*, crinoïds and conodonts.

The whole Devonian, only some 20 m thick in the Fluminese area, exceeds 400 m in the Monte Loro,

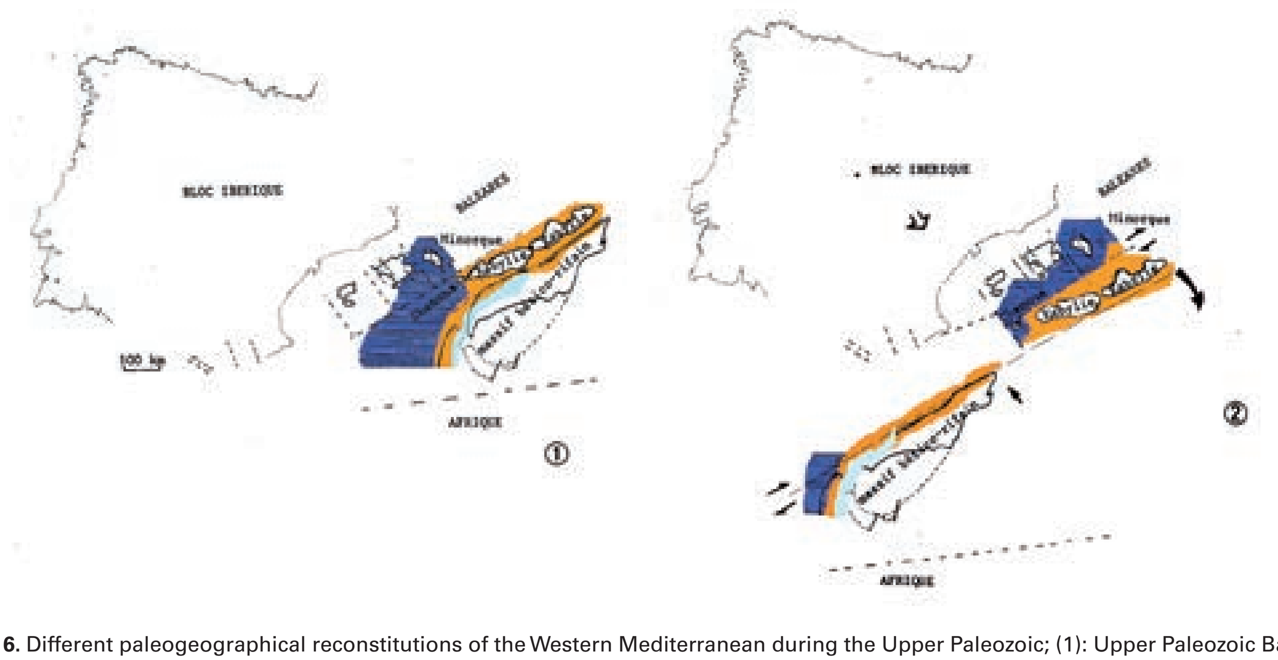

Figure 6. Different paleogeographical reconstitutions of the Western Mediterranean during the Upper Paleozoic; (1): Upper Paleozoic Basin *in* Bourrouilh and Lys 1976 ; (2): Distribution of the different sedimentary environments before the Alpine compressions, *in* Bourrouilh and Lys 1976, Bourrouilh and Gorsline, 1978, 1979. From Bourrouilh *et al.*, 1980 coloured. In deep blue: deep abyssal plain or distal turbidites facies: Menorca, Khudiat Tizian and Chenoua; in orange proximal coarse turbidite facies, at the foot of a continental slope: Alkaïli, Beni Hozmar; in light blue: continental plateau and intertidal facies: Beni Hozmar and Talembote. Half arrow: slip-strike faults.

Figura 6*. Diferentes reconstrucciones paleogeográficas del Mediterráneo occidental durante el Paleozoico superior; (1): Cuenca del Paleozoico superior (según Bourrouilh and Lys, 1976); (2): Distribución de los diferentes ambientes sedimentarios antes de la compresión alpina (según Bourrouilh and Lys, 1976, Bourrouilh and Gorsline, 1978, 1979). Modificado de Bourrouilh et al., 1980. En azul oscuro: llanura abisal profunda o facies turbidíticas distales: Menorca, Khudiat Tizian y Chenoua; en naranja facies turbidíticas proximales de grano grueso, al pie del talud continental: Alkaïli, Beni Hozmar; en azul claro: plataforma continental y facies intermareal: Beni Hozmar and Talembote. Semi-flechas: fallas de desgarre.*

Gerrei area, where it passes in continuing with marine calcareous facies to the Lower Tournaisian (Barca *et al.*, 1992). From Visean to Namurian, a thick package of sandstone and shale, called "Postgothlandinano" has been interpreted as a proximal turbidite Culm-like system (Vai and Cocozza, 1986 ; Barca *et al.,* 1992 ; Vai, 2001). Unconformable tabular continental deposits of isolated fluvial to lacustrine follow upwards during the late Carboniferous to early Permian time (Vai & Cocozza, 1986 ; Barca *et al.,* 1992 ; Vai, 2001).

In southeastern Sardinia, in the Gerrei area near Baccu Scottis, one can see a similarity between the Sardinian and Menorcan Devonian facies which can be assessed. Above Wenlockian to lower Ludlovian black shale, Ludlovian to lower Devonian limestone has been described (Helmcke, 1973); it is overlain by Lochovian black shale with *Monograptus uniformis* Pribyl and *Monograptus* cf. *praehercynicus* Jaeger exactly as in Menorca. This underlines the pertinence of the Mediterranean area to the Thuringian-Bohemian faunal province (Vai 1991, 2001) and a kind of relationship in the lower Devonian (Lochkovian) facies between Menorca and the Sardinian Gerrei area (Bourrouilh, 1975).

Conclusions: Paleogeographical reconstructions: the Devonian Menorcan Ocean

As for Sardinia (Italy), the dated Devonian of the Iglesiente shows a limestone facies unknown in the Balearic Islands, Malaguids (Spain), Ghomarids (Morocco) and the Chenoua (Algeria). The only possible link is with the SE area of Sardinia in the Gerrei area.

Based on the different elements reworked in the Devonian flysch, an emerged continental margin would have existed, exhibiting outcrops of rocks rich in quartz, micas and feldspathics where mud mounds were developing (Bourrouilh, 1981). During the Upper Devonian, there was carbonate sedimentation with Tentaculites and conodonts, indicating a shallower basin because of the non-dissolution of carbonates.

The base of the Menorcan Carboniferous of has no equivalent in the Iglesiente (Sardinia). The Culm facies of Menorca (from Upper Visean to Namunrian B) is very rich in vegetal clasts, running-tracks of organisms and Goniatites, indicating a proximal facies, in relation with the proximity of the mouth of a river. It is an analogue to the Khudiat Tizian Nappe Culm facies in Morocco (Bourrouilh & Jaeger, 1976) and identical to the one of the Great Kabylie in the Chenoua in Algeria (Bourrouilh *et al.*, 1976). As in these two domains, it contains very numerous trails and traces, especially *Dictyodora liebeana.*

The Carboniferous of the Akaïlii and Beni-Hozmar is the same. The mud and carbonate sand turbidites seem to precede, in the cross-section in field, the arrival of polygenic elements mud turbidites. The material they contain comes from a carbonate platform where there were growing reefs. The carbonate turbidites have a lesser extension than the polygenic turbidites. They are localized to the lone nappes of Akaïlii and Beni-Hozmar, as the sediments of the Khudiat Tizian, more distal, would occupy a more distant and, above all, deeper location in the Devono-Carboniferous abyssal plain. The polygenic turbidites have been observed from Gibraltar straight up the "Aarabene ras", so more than 80 km with constant sedimentological characteristics (Fig. 6). The scale of the phenomena varies between what we can call a mud flow, from a few centimetres to several metres thick, up to olistostromes of several tens of metres or hundred metres containing enormous olistolithes (Talembote).

During the Devonian, a basin, grouping Menorca (Baleares, Spain), Khudiat Tizan (Morocco) and the Chenoua and Kabylies mountains (Algeria), would be represented by a wide abyssal plain, deep enough to be depleted in carbonates by dissolution (Fig. 6) and where thick turbiditic sequences were spreading out. In reference to the paleo-map, this paleo-ocean seems to have existed between the closing Rheic Ocean in the south and the Paleo-Tethys Ocean to the north. It was surrounded by living sponge mud-mound-covered margins; these margins were built of muscovite-rich magmatic and/or metamorphic substrates. During Carboniferous, this "Menorcan Paleo-Ocean" was becoming shallower with an increase in clastic sediments and the appearance of vegetal clasts or phytoclasts. At this time, it may have been a gulf of the Paleo-Thetys, but it does not appear in classical paleogeography reconstructions (Dewey *et al.,* 1989; Scotese, 1997; Golonka, 2004). These rocks have been later reworked, folded and separated by the Variscan and Alpine orogenies.

Recent knowledge of the Pyrenees, Corsica and Sardinia: the extension of the Pyrenees towards the east in the Mediterranean region

A question that has not been answered concerns the prolongation of the Pyrenees in the Western Mediterranean. The North Pyrenean Thrust Front (NPTF) and the outer zones are obviously extended by the nappes of the Corbières Mountains and the Pyrenean stratigraphic succession towards the French

Provence. The North Pyrenean Fault, which forms the fault contact between the Iberian and the European plates, disappears beneath the Mediterranean Sea (Bourrouilh 1989, 2008, 2012).

We know that the Provence area and the southern Alps are associated with the Pyrenees and were folded in an east-west direction during Cretaceous and the Eocene, as far as Digne in Provence (France), the latest reference on the subject is the paper by Lacombe and Jolivet, 2005. The question remains, where is the prolongation of the Pyrenean High Chain and of the southern Pyrenees?

Paleomagnetism and geochronology

The Gulf of Lion shelf increases in width east of the Pyrenees. Recent interpretations (Synthèse des Pyrénées, 1996) suggest that the NPF continues under the Gulf of Lion shelf, south of the Catalan trough and then south of Nice (France), between Provence and Corsica (Fig. 7). The Moho is about 20 km deep in the Catalan trough and could be equivalent to what is observed on the ECORS profile for the European basement (R. Bourrouilh, 2012). A drill hole (CLP2) encountered Paleozoic phyllites, which were metamorphosed at 90 Ma (Turonian) (Fig. 7) could be interpreted as the North Pyrenean metamorphism event. However Figure 7 illustrates the Pre-Miocene setting before the opening of the Western Mediterranean and the rotation of the Corsica-Sardinia block.

Westphal (1967) was the first to report on the paleomagnetism of some Corsican rocks and, later, De Jong *et al.* (1969), Bobier and Coulon (1970) examined the Corsica-Sardinia paleomagnetism. Westphal (1967) and Westphal *et al.* 1976, claimed that the paleomagnetism of Corsican rocks evidenced a counterclockwise rotation of 30° for Corsica and of 60° for Sardinia. Later, Edel (1980), Edel *et al.* (2001) demonstrated that the counterclockwise rotation of the Corsica-Sardinia block was 44° ± 4°. The rotation began between 23 and 21 Ma (Base of Aquitanian) and finished about 15 Ma (Base of Langhian). According to these authors, the rotation is a back-arc opening, responding to the Calabrian subduction. Later Ferrandini *et al.* (2003) confirmed that the rotation was of 44° ± 4° and took place between the middle Aquitanian to Langhian. In 2007, Gattacceca *et al.* established that "the microplate, Sardinia, rotated 45° counter-clockwise after 20.5 Ma (Aquitanian). Rotation was essentially complete by 15 Ma. They estimate that 30° of rotation occurred between 20.5 and 18 Ma (Burdigalian) corresponding to the period of maximum volcanic activity in Sardinia." These authors postulate that this rotation is contemporaneous with the opening of the Liguro-Provençal back-arc oceanic basin.

Tectonics: movements of Mediterranean islands and foldings

Returning the Corsica-Sardinia block to its initial pre-Miocene position, along the Gulf of Lion-Provence deep isobath of the continental crust, we observe that we are not able to correlate the north-eastern Balearic Island, Menorca, with the SW part of Sardinia. The paleozoic series of Menorca, together with its Variscan tectonics (Bourrouilh 1973, 1983) are different from those of the SW part of Sardinia, apart from the Gerrei area. These are different Variscan domains.

We are obliged 1°) to put Corsica and Sardinia to their previous place in Mediterranean and 2°) to try to rebuild an assemblage, first during Lower Eocene, before the Upper Eocene great orogenic phase, then at the base of Miocene, before the huge compression which then occured. The position of the Balearic islands-Sardinia block has been already sketched in paleomap recontructions by others (Dewey *et al.*, 1989; Lacombe and Jolivet, 2005), but without field and shortening references.

During the Eocene time, the previous sketch does not fit and it is obviously false: unbalanced sections of tangential movements occurring during Upper Cretaceous (Provence, Pyrenees) are mentioned; the same for the strike-slip movements of the transform north-Pyrenean faults, as the Balearic Promontory have been mentioned. As for the different units replacing these effects, Muñoz (1992) evaluates the shortening of the Pyrenean central units (ECORS profil) to a little less than 150 km. This should give a hundred km for the Empurdan (eastern Pyrenees). These lengths (100 km) can also be applied for the areas located south of the North Pyrenean Fault (FNP) trace (Fig. 7).

The Catalan range shortening (Barcelona area) is probably negligible, but the strike-slip fracturation tectonic style between Mallorca and Menorca is certainly one of the players of the imposing tectonic seen in Mallorca, of the low energy tectonics in Ibiza and of the likely non-existent features in Menorca (Fig. 7).

Menorca with its continental plateau, is located more than 250 km from Barcelona; Mallorca, at 220 km about from Tarragona. If the Gulf of Valencia corresponds with an oceanic opening, resulting from the Corsica-Sardinia rotation (Maillard, 1993), these islands should also be located again along the

Barcelona coasts for Mallorca and to the north for Menorca.

From the previous published map (Fig. 3, from Bourrouilh and Mauffret, 1975), we can see first that the Sierra Norte tectonic slices come and strike against the Valencia trough, 1500 to 2000 m deep and having a very narrow continental plateau. Mechanically, how could we imagine that the Mallorcan slices, gliding over plastic Keuper gypsum, could stop without racing down the Valencian trough? Certainly not.

On the other hand, the 3 tectonic slices of the Sierra Norte are all inclined towards the SE, i.e. towards the outside of the Valencia trough, as if the extension was from the NW toward the SE, as if the Gulf of Valencia was opening following this direction. If we try to close again the Gulf of Valencia to place the Balearic Islands close to their initial location, this assemblage can fit around the - 500 m and - 1000 m isobaths, extreme limits of the continental plateau, the – 1500 m isobath being too deep and far below the limit of the continental plateau, given usually around – 200 m (Fig. 8).

With these conditions, the Balearic Islands represent the sedimentation zones (continental plateau,

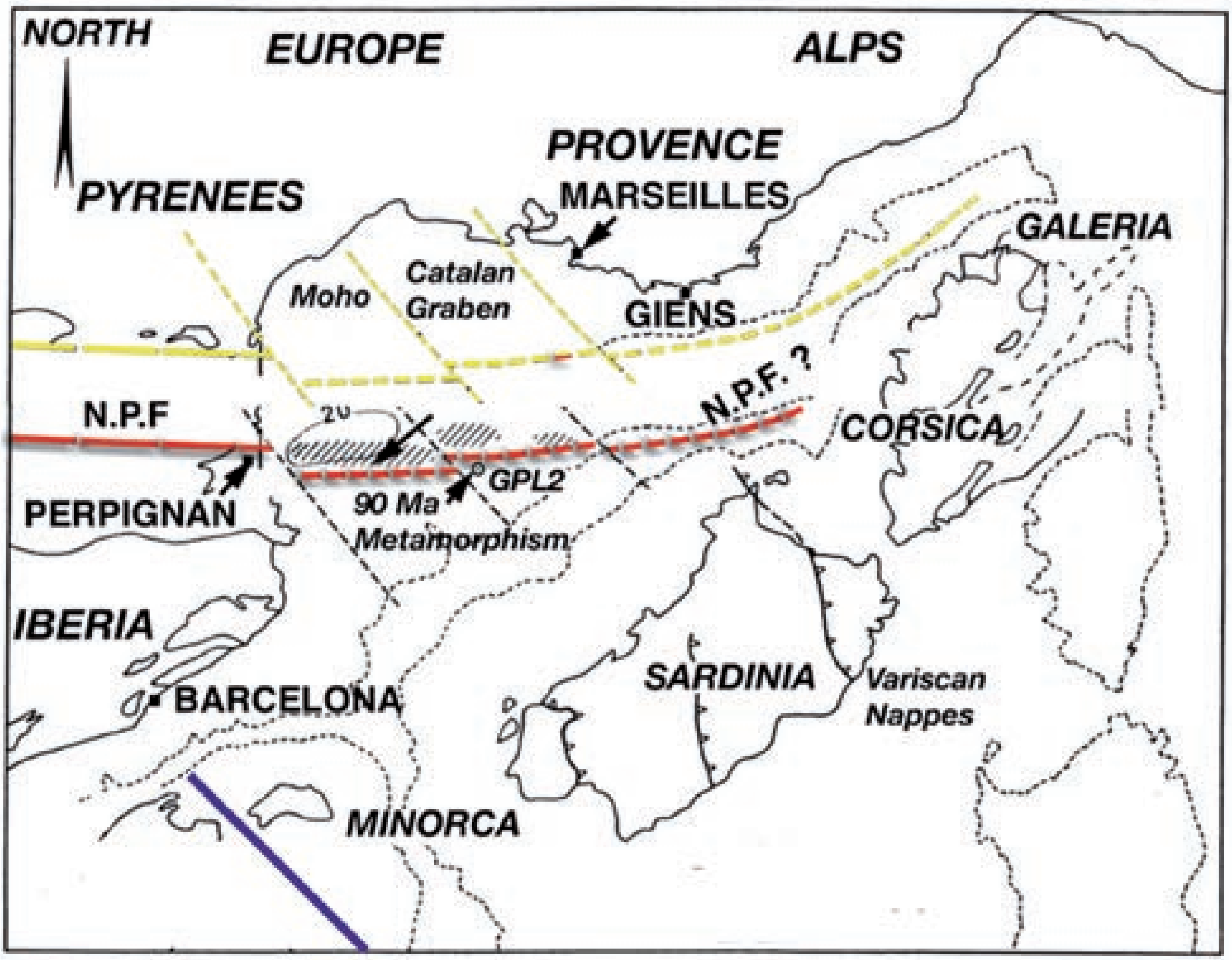

Figure 7. Possible prolongation of the North Pyreanean Fault (NPF on the figure), according to the Synthèse des Pyrenées, 1996 modified, and an attempt at reconstruction, before deformation, of the position of the different elements, taking into account the shortening of 200 to 300 km, on each side of the Pyrenees as evaluated by Munoz, 1992: in yellow the modern position as published in 1996, in red the reconstructed position (this paper) before compression, in violet the southern Menorcan fault.

***Figura 7.** Posible prolongación de la Falla Norpirenaica (NPF en la figura), (modificada de Synthèse des Pyrenées, 1996), e intento de reconstrucción, antes de la deformación, de la posición de los diferentes elementos, teniendo en cuenta un acortamiento de 200 a 300 km en cada lado del Pirineo (Muñoz, 1992): en amarillo la posición actual como fue publicada en 1996, en rojo la posición reconstruida (este trabajo) antes de la compresión, en morado la falla sur menorquina.*

continental slope) of the Iberian continent, i.e. what is usually called, in the Betic Cordillera, the "Prebetic" zone, then the "Subbetic" zone. These areas are only prolonging these zones towards the NE of Valencia (Fig. 8), which sink down in the Mediterranean Sea. Their tectonic relationship with the Iberian mountain ranges and the coastal Catalan ranges are older than the Eocene, and are formed essentially by the fault networks, as demonstrated by J. Canerot (1975).

In consequence, we are obliged to think that the tectonic deformations of the Balearic Islands were not produced, as previously thought, by a crashing toward the NW, but were produced in the reverse direction, from the NW toward the SE, during the Gulf of Valencia opening, provoking the piling up of the Sierra Norte tectonic slices, accompanied by a rocking motion of the Mallorcan continental mini-block of few degrees with respect to the horizontal direction and in a SE direction, as it was occurring during an oceanic opening (Gawthorpe & Leedert 2000). It is a retro-compression. The total shortening would be more than 200 km (the distance from Tarragona to Mallorca), representing a part of the shortening of the Sierra Norte tectonic slices. It should be the same, in a lesser proportion, for Ibiza where the SW-NE tectonic slice system is still present.

But if so, why is Menorca so little folded, apart from the Paleozoic formations which have been folded by Variscan phases? It is difficult to say. The only observation we can ascertain is the presence of a strike–slip fault between Menorca and Mallorca (Fig. 7, in violet). The overthrusted structures of Mallorca arrive, striking against this fault, interrupting the Sierra Norte piles (R. Bourrouilh, 1973, 1983).

On the NE side of this fault, the Island of Menorca is completely different; the tectonics there is modest and different from the Mallorcan one. One may conclude that the importance of the fault

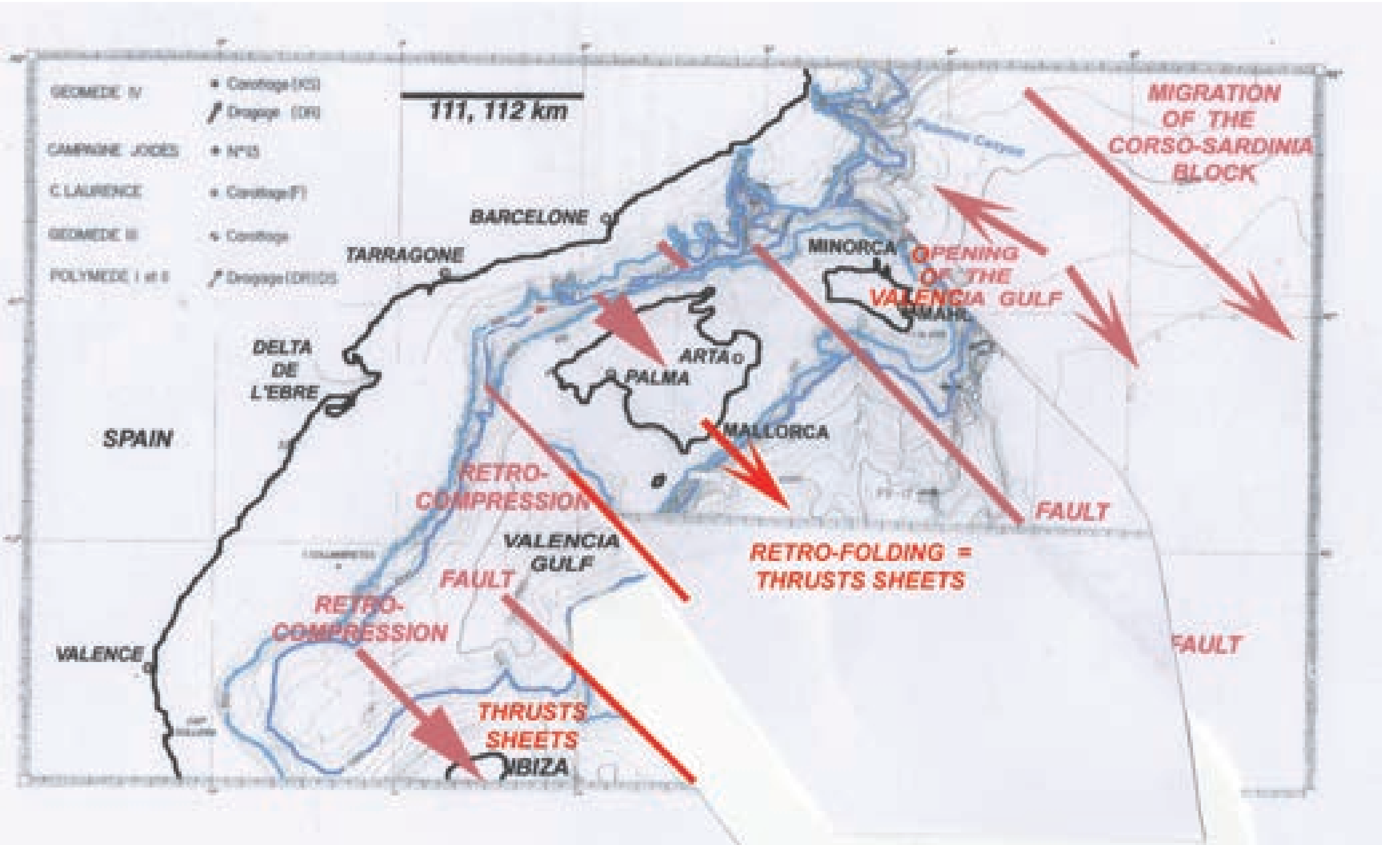

Figure 8. Retro-compression of the Balearic Islands and the Gulf of Valencia opening : Assemblage of the Balearic Islands along the Barcelona coast for Mallorca and along a more septentrional zone for Menorca, between the – 500 m to – 1 000 m isobaths. One may observe that Menorca still presents a shift towards the SW with respect to Mallorca, and in consequence cannot be its "avant-pays" foreland area.

Figura 8. *Retro-compresión de la apertura del Golfo de Valencia e Islas Baleares: Conjunto de las Islas Baleares a lo largo de la costa de Barcelona hacia Mallorca y a lo largo de una zona más septentrional hacia Menorca, entre las isobatas de -500 m y -1000 m. Se observa que Menorca todavía presenta un giro hacia el SW con respecto a Mallorca, y en consecuencia no puede ser su zona de « ante-país ».*

separating Mallorca and Menorca would be much more important than we might have thought initially; the Menorcan continental mini-block would not have been submitted to the few degrees of rocking movement that Mallorca has undergone and that was responsible for the slicing effects of the Sierra Norte Mesozoic formations on its Triasic slippery sole.

The hinterland of Mallorca is represented by the continental plateau on the east side of the island. We can observe that a great part of it is missing: the Kabylies (Algeria), which are also linked up to the SE of Menorca (Fig. 6).

The comparison between these Paleozoic formations (see above) has allowed the reconstruction of the internal zones of the Betic Cordillera (Bourrouilh & Gorsline 1978, 1979)

A sedimentological and stratigraphic witness of the Corso-Sardinian block: the Es Macar de Sa Llosa Oligocene conglomerate in Menorca

A sedimentological and stratigraphic aspect seems to corroborate the chronostratigraphical and paleomagnetic ages of the opening of the Liguro-Sardinian Ocean. As a matter of fact, in Menorca, few outcrops of Oligocene conglomerates have been discovered alterning with redish marls (Bourrouilh, 1970a). They are preserved only on the Northern coast of Menorca. They are easily seen, 50 to 60 m thick, in cliffs on the East side of Fornells peninsula and at Es Macar de Sa Llosa (Bourrouilh, 1973, p. 407-418), between the beaches of Son Saura and d'en Castell. They are deeply cut by numerous faults. The formation is composed by detrital sequences composed of four components: huge blocks, pebbles, marls with few pebbles and the last component finer and lime- enriched marls. The clasts come only from carbonates formations. Charophytes with ostracods have provided a basis for the dating : Oligocene to Lower Miocene. These sediments represent torrential deposits gathered inside shallow fresh water areas, lakes to lagoons, and closed to reliefs being deeply eroded. The blocks and pebbles come from the Menorcan Jurassic and Cretaceous formations but also from a Neocomian to Upper Aptian limestones unknown in Menorca.

The conglomerate formations of es Macar de Sa Llosa rework different Jurassic and Cretaceous levels for one part, and on the other part lie on different Cretaceous levels. Although it is a continental formation, these observations show

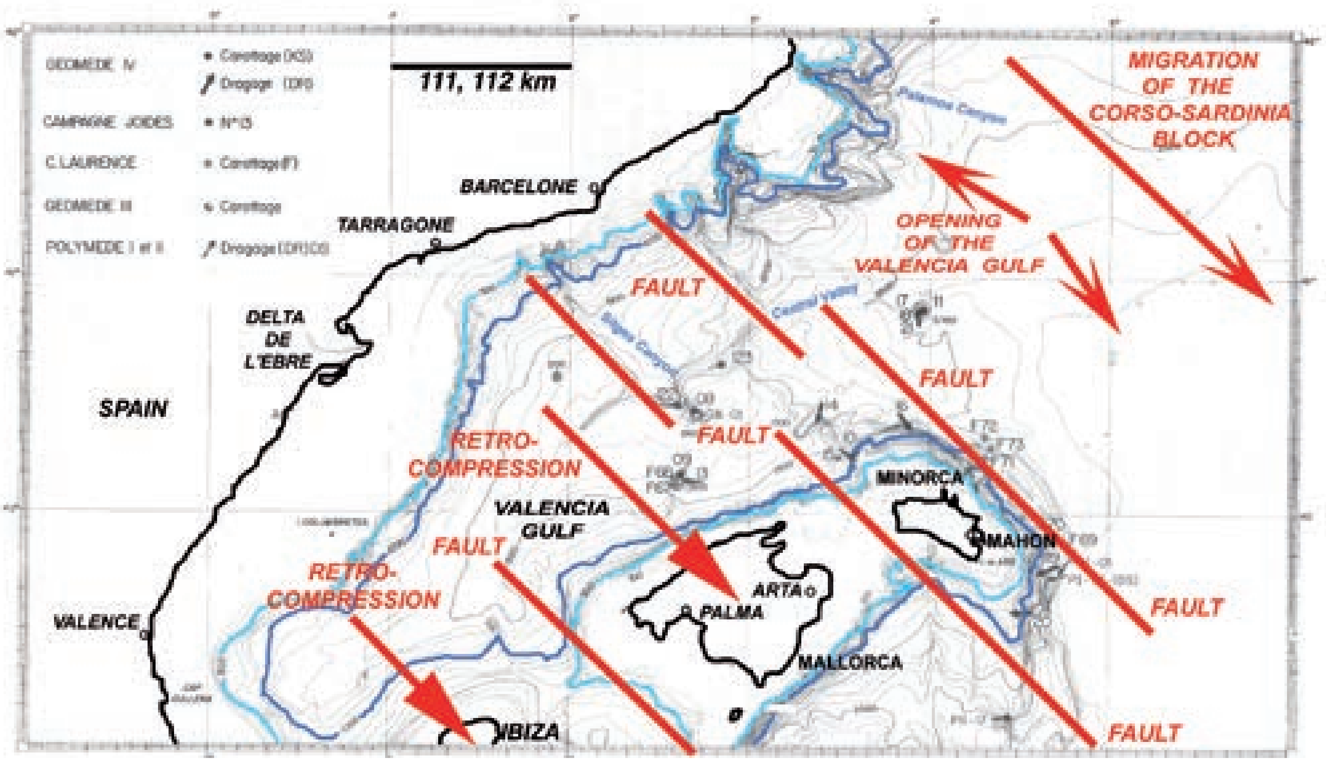

Figure 9. Retro-compression and the modern state of the Balearic Islands.
Figura 9. *Retro-compresión y estado moderno de las Islas Baleares.*

that there is a tectonic phase before the Oligocene-Lower Miocene that have folded the Cenozoic carbonate cover above a plastic Keuper, used as a decollement level (Bourrouilh, 1970). In addition, during their deposition, a distensional phase affects the conglomerates of Es Macar de Sa Llosa (Fig. 171, 2, *in* Bourrouilh 1973, vol. 2, p. 680-682), may be of Burdigalian age. The conglomerates do not go too far inside the island (1 km). They could be related to the filling of a basin located to the N and NE of Menorca and which has been cut by the fault separating Menorca from Sardinia near the Gerei area (Fig. 10). This fault seems to have been active after their deposition, so during and at the end of Lower Miocene (Burdigalian), because all the Southern part of Menorca is covered by Vindobonian and Messinian shallow marine limestones, considered as posterior to the major tectonic phases of the Balearic islands. The importance of the Oligo-Miocene deposits in Western Mediterranean have been also seen by other authors as Guerrera *et al.,* 1993, Bache, 2008, Bache *et al.,* 2010 with Nury et al. and Villeneuve *et al.,* in this book. These field results (Bourrouilh, 1973) confirm also the results of Gattacceca *et al.*, 2007, indicating that the rotation of the Corso-Sardenian block was finished at -15 Ma (Burdigalian).

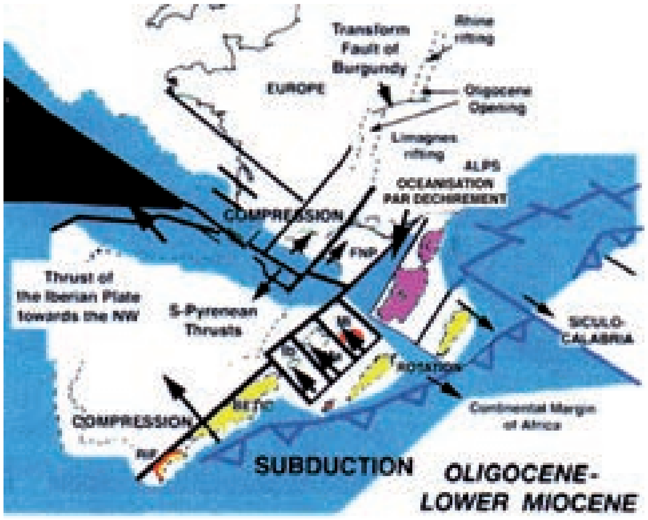

Figure 10. Tectonic Oligocene-Lower Miocene positions of the different elements in Western Mediterranean : Balearic Archipelago, Betic Cordilleras, Rif (Morocco), Chenoua and Kabylies (Algeria) and the Corso-Sardenia block (*in* Bourrouilh 2012, modified). In red : the Variscan inheritage: Menorca, Chenoua and Rif. From Bourrouilh 2012, modified, by courtesy of Elsevier.

Figura 10. *Posición tectónica en el Oligoceno-Mioceno inferior de los diferentes elementos en el Mediterráneo Occidental: Archipiélago Balear, Cordilleras Béticas, Rif (Marruecos), Chenoua y Cabilia (Algeria) y bloque Corso-Sardo (modificada de Bourrouilh, 2012). En rojo, la herencia varisca: Menorca, Chenoua y Rif.*

Conclusions

Links occur between one part the Pyrenees orogenies and the Liguro-Provençal Basin opening, and in the other part the Balearic position in the Western Mediterranean.

The Menorcan problem is nearly resolved (Fallot 1923, Bourrouilh 1963). It is connected not only to the opening of the Gulf of Valencia, but also to the formation of the Pyrenees and the Liguro-Provençal opening, making a complex moving puzzle of the remains of the small Variscan-origin continental block (Fig. 10), moving in different directions, at different speeds and at different times.

In conclusion, if the abyssal parts of the Lion Gulf and of the Gulf of Valencia are closed up, the Balearic tectonics may be explained as a consequence of an oceanic opening or a crustal thinning, by retro-compression, forming the Sierra Norte tectonic slices. The other consequences, for the Western Mediterranean, are the continuous strike-slip movements and the detaching of the Chenoua and Kabylies, for Algeria, of the Malaguids (and Alpujarides) for Spain and of the Ghomarids and Sebtides for Morocco, moving southwest-, south- or northward, from a long time ago, or only from the Lower Eocene (Fig. 11), until accretion and addition with Africa, on one part, and with Iberian block, on the other part, creating the wide area of the Western Mediterranean, *mare nostrum*, "our sea", the Latin denomination.

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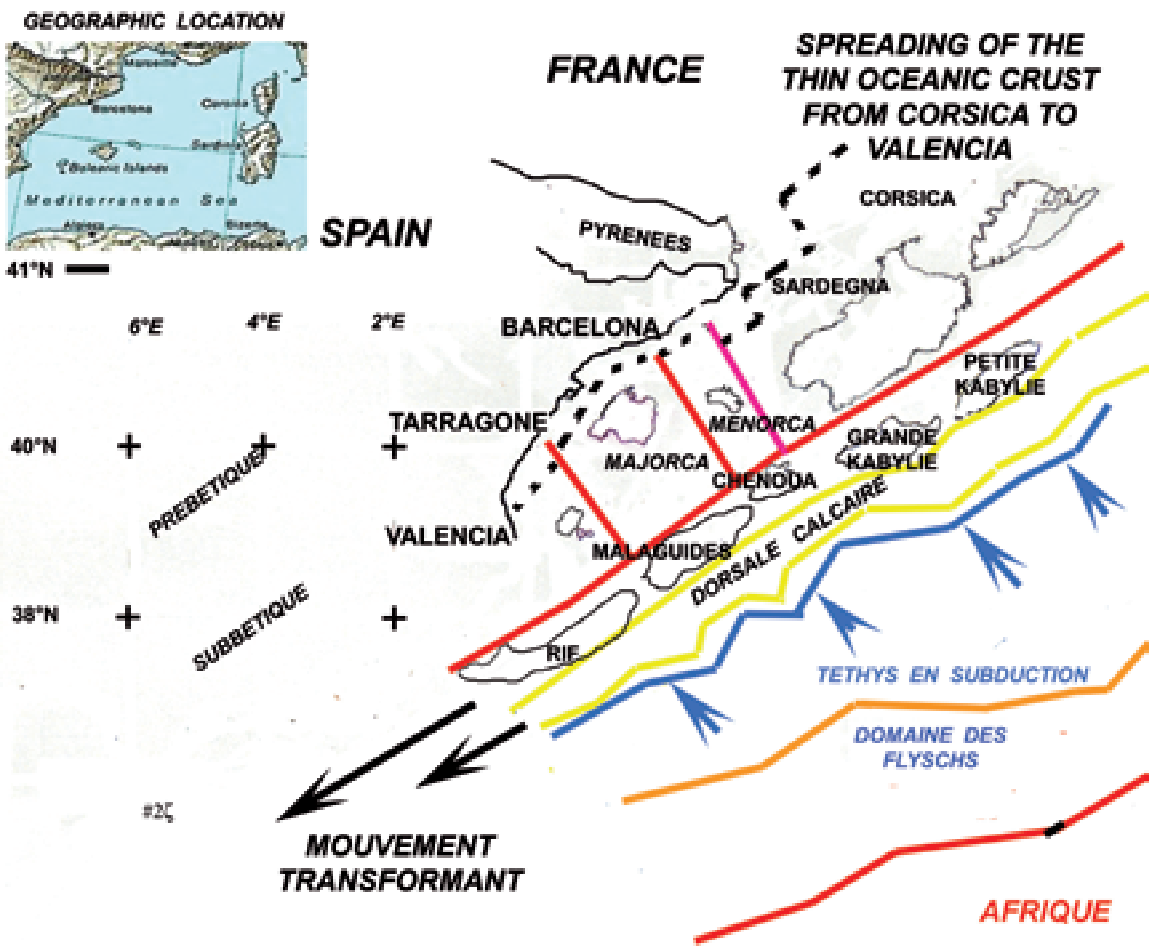

Figure 11. An attempt at Lower Eocene Mediterranean synthesis.
Figura 11*. Modelo de síntesis del Eoceno inferior mediterráneo.*

References

Agard, J., Destombes, J., Milliard, Y. et Morin, Ph. 1958. Sur l'existence du Llandovery supérieur dans le massif paléozoïque du Rif au Nord de Tétouan (Maroc septentrional). *Comptes Rendus Académie des Sciences de Paris*, 246, 2778-2780.

Alberti G., 1963. Sul Devonico inferiore e medio nella Sardegna meridionale. *Atti. Acad. naz. Lincei, Rendic-Rend. 8a Classe Sc. fis. e nat.*, ser. VIII, vol. XXXIV, fasc. 5, 553-559.

Azema, J. 1960. Étude géologique des abords de Malaga. *Estudios Geologicos,* XVII, 131-160, 29 fig., 1 carte, Madrid.

Bache, F. 2008. *Évolution Oligo-Miocène des marges du micro océan Liguro-Provençal.* Thèse, Université de Bretagne Occidentale, Géologie appliquée, 328 p., France.

Bache, F., Olivet, J.-L., Gorini, C., Aslanian, D., Labails, C. and Rabineau, M. 2010. Evolution of rifted continental margins : The case of the Gulf of Lions (Western Mediterranenean Basin). *Earth and Planetary Science Letters*, 292 (3-4), 345-356.

Barca, S., Carmignani, L., Eltrudis, A. 1992. Relationship between foredeep deposits and Hercynian nappe building in southeastern (Italy). In: Carmignani L. & Sassi F. P. (eds). *Contributions to the Geology of Italy,* Cocozza, T., IGCP n° 276, Newsletter 5, 33-44.

Blumenthal, M. 1949. Estudio geologico de las cadenas costeras al Oeste de Malaga, entre el Rio Ghadalhorce y el Rio Verde. *Boletin Instituto Geologico y Minero de Espana,* LXII, 13, 1-193.

Bobier, C. and Coulon, C. 1970. Résultats préliminaires d'une étude paléomagnétique des formations volcaniques tertiaires et quaternaires du Logudoro (Sardaigne septentrionale). *Comptes Rendus Académie des Sciences Paris*, 270, 1434–1437.

Bourrouilh, R., 1963 - Nota preliminar la tectonica de la isla de Menorca (Baleares, Espana). *Notas y Com. Inst. Geol. Y Min. de Espana*, 71, 261-264.

Bourrouilh, R. 1967. Le Dévonien de Minorque (Baléares, Espagne). Ses limites et sa place en Méditerranée occidentale. *International Symposium on the Devonian System (Calgary, Canada)*, II, 47-60, 1 tbl., 10 fig.

Bourrouilh, R. 1970a. Découverte d'Oligo-Miocène inférieur continental à Minorque. Conséquences paléogéographiques et tectoniques. *Comptes Rendus sommaires de la Société géologique de France,* 7, séance du 9 nov., 247-248, 2 fig.

Bourrouilh, R. 1970b. Le problème de Minorque et des Sierras de Levante de Majorque. *Annales de la Société géologique du Nord,* XC, 4, 13 fig. Rapport des Travaux du Centenaire des 27 et 28 Novembre 1970, 363-380.

Bourrouilh R., 1973. *Stratigraphie, sédimentologie et tectonique de l'île de Minorque et de l'extrémité NE de l'île de Majorque, Espagne. La terminaison nord-orientale de Cordillères Bétiques en Méditerranée occidentale*. Thèse d'État, Univ. P.-M.-Curie-Paris VI, 2 tomes, 822p., 196 fig., et 95 pl. dans le texte, 6 hors-texte : 2 cartes géologiques au 1/50 000 et fonds topographiques, 2 planches de coupes géologiques.

Bourrouilh, R., 1975. Le Paléozoïque supérieur des Baléares et du SW de la Sardaigne : une première comparaison. 3ème Réunion *Annuelle des Sciences de la Terre,* Montpellier, 23 au 25 avril 1975, p. 25.

Bourrouilh, R., 1977. Mise en évidence d'une série carbonifère dans l'unité de la Kuhdiat Tizian (zone interne paléozoïque du Rif, Maroc). Conséquences. *Comptes Rendus Sommaire de la Société géologique de France,* 4, 220-222.

Bourrouilh, R. 1978. Coulissages de plus de 700 km en Méditerranée occidentale : une tectonique de type californien, précédant les serrages miocènes. *Comptes Rendus Académie Sciences de Paris,* 286, D, 1339-1342, 2 figs.

Bourrouilh R., 1981. « Orthoceratitico-Rosso » et « Goniatitico-Rosso » : facies marqueurs de la naissance et de l'évolution de paléomarges au Paléozoïque. In: Farinacci A,. and Elmi, S. (eds), *Rosso Ammonitico Symposium Proceedings,* 49-59, 7 figs., 2 pl., Edit. Tecnoscienza, Roma.

Bourrouilh R., 1983. Estratigrafia, Sedimentologia y Tectonica de la Isla de Menorca y del Noreste de Mallorca (Baleares). La Terminacion Nororiental de las Cordilleras beticas en el Mediterraneo occidental. *Memoria Instituto Geologica Mineralogica de Espana*, t. 99, 1 vol. 692 p., 1 vol. 95 pl. et hors textes, 2 cartes geol. 1/50 000e.

Bourrouilh, R., 1989. Bay of Biscay-Pyrenees, Gibraltar Arc-Rif Betic and Scotia Arc : three responses of divergent-convergent and Transform Tectonics during the Atlantic evolution. *28th IGC, Washington, USA*, July 9-19, Abst. Vol. 3, 460-461.

Bourrouilh, R. 2008. L'Aquitaine et les Pyrénées : formation et évolution. In: Canérot, J., Colin, J.-P., Platel, J.-P. and Billote, M. (eds), *Les Pyrénées d'hier et d'aujourd'hui,* 55-80, Atlantica éditeur, Biarritz, France.

Bourrouilh, R. 2012. The Aquitaine Basin and the Pyrenees : geodynamical évolution and hydrocarbons. In: Roberts, D.G. and Bally A.W. (eds), *Phanerozoic Passive Margins, Cratonic Basins and Global Tectonic Maps,* 1 C, 22, 795-859, Elsevier.

Bourrouilh, R. and Gorsline, D. S. 1979. Pre-Triassic fit and alpine tectonics of continental blocks in the Western Mediterranean. *Geological Society America Bulletin*, 90, 1074-1083, 5 figs.

Bourrouilh, R., Cocozza, T., Demange, M., Durand-Delga, M., Gueirard, S., Guitard, G., Julivert, M., Martinez, F.J., Massa, D., Mirouse, R. et Orsini, J.B. 1980. Essai sur l'évolution paléogéographique, structurale et métamorphique du Paléozoïque du Sud de la France et de l'Ouest de la Méditerranée. *26ème Congrès géologique International, Colloque C6,* 159-188, 11 fig., Paris.

Bourrouilh, R. et Jaeger, H. 1976. Découverte de Lochkovien à graptolites dans l'unité de la Kuhdiat Tizian (zone interne du Rif, Maroc). *Comptes Rendus Académie des Sciences Paris,* 282, 409-412, 3 figs.

Bourrouilh, R., Helms, J., Jaeger, H. et Lepvrier, C. 1976. Présence de Lochkovien à graptolites dans le massif kabyle du Chenoua (Algérie). *Comptes Rendus Académie des Sciences Paris,* 282, 1769-1771.

Bourrouilh, R. & Lys, M. 1976. Sédimentologie et micropaléontologie d'olistostromes et coulées boueuses du Carbonifère des zones internes bético-kabylo-rifaines. *Annales de la Société géologique du Nord,* XCVII, 87- 94.

Bourrouilh, R. & A. Mauffret, 1975. Le socle immergé des Baléares (Espagne) : données nouvelles apportées par des prélèvements sous-marins. *Bulletin de la Société géologique de France,* 7, XVII, 6, 1126-1130.

Canérot, J. 1975. Recherches géologiques aux confins des Chaînes Ibérique et Catalane (Espagne). Thèse Sc. Toulouse, Université Paul-Sabatier, 1974, *Enadimsa Ediciones,* 4, 1-514, 121 figs, 38 pl., 10 tb., 1 carte géologique en couleurs au 1/200 000, 1 pl. coupes sériées, Madrid.

Darder, B. 1929. Le relief et la tectonique de l'île de Majorque. *Géol. Méd. Occ.*, vol. I, part II, 2, 79-100, pl. X à XXIII, 24 fig., 2 cartes.

De Jong, K.A., Manzoni, M. and Zijderveld, J.D.A. 1969. Paleomagnetism of the Alghero trachyandesites. *Nature*, 244 (5214), 67–69.

Dewey, J. F., Helman, M. L., Turco, E., Hutton, D. H. W. and Knott, S. D. 1989. Kinetics of the western Mediterranean. In: Coward, M. P., Dietrich, D. and Park, R. G. (eds), Alpine Tectonics, *Geological Society, London Special Publication*, 45, 265-283.

Durand-Delga, M. 1957. Nouvelles données sur le Jurassique supérieur et le Crétacé inférieur du Chénoua (Nord-Algérois). *Bulletin de la Société géologique de France,* 6è série, VII, 1129-1134.

Durand-Delga, M. et Magne, J. 1957. Observations sur le Crétacé supérieur du Chénoua (Nord-Algérois). *Compte Rendu sommaire Société géologique de France,* 259-261.

Durand-Delga, M., Hottinger, L., Marçais, J., Mattauer, M., Milliard, Y. et Sutter, G. 1960-1962. Données nouvelles sur la structure du Rif. In: Durand-Delga, M. (ed.), Livre à la *Mémoire du Professeur Fallot, Mémoire Hors série, Société géologique de France*, I, 399-422.

Edel, J.B. 1980. *Étude paléomagnétique en Sardaigne. Conséquences pour la géodynamique de la Méditerranée occidentale.* Thèse, Université de Strasbourg, 310 pp.

Edel, J.B., Dubois, D., Marchant, R., Hernandez, J. et Cosca, M. 2001. La rotation miocène inférieur du bloc corso-sarde. Nouvelles contraintes paléomagnétiques. *Bulletin de la Société géologique France,* 172, 275–284.

Fallot P. 1922. *Etude géologique de la Sierra de Majorque*. Thèse, 465 pages, 18 pl. hors texte, Librairie Polytechnique, Ch. Béranger, Paris et Liège.

Fallot, P. 1923. Le problème de l'île de Minorque. *Bulletin de la Société géologique de France*, 4, XXIII, 3-44.

Ferrandini, J., Gattacceca, J., Ferrandini, M., Deino, A., Janin, M.C. 2003. Chronostratigraphy and paleomagnetism of Oligo-Miocene deposits of Corsica (France): geodynamic implications for the Liguro-Provençal basin spreading. *Bulletin de la Société géologique de France,* 174, 357-371.

Flandrin, J. et Lambert, A. 1942. Sur le Trias du Massif du Chénoua (département d'Alger), *Comptes Rendus Académie des Sciences Paris,* 214, 626-627.

Gattacea, J., Deino, A., Rizzo, R., Jones, D.S., Henry, B., Beaudoin, B. and Vadeboin, F. 2007. Miocene rotation of Sardinia : New paleomagnetic and greochronolical constraints and geodynamic implications. *Earth and Planetary Science Letters,* 258, 359-377.

Gawthorpe, R. L. and Leeder, M. R. 2000. Tectono-sedimentary evolution of active extensional basins. *Basin Research,* 12, 195-218.

Geel, T. 1973. The Geology of the Betic of Malaga, the Subbetic and the zone between these two units in the Velez Rubio area (Southern Spain). *GUA Papers in Geology*, Ser. 1, 5, 1-181.

Golonka, J., 2004. Tectonic Evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics*, 381, 235-273.

Guerrera, F., Martin-Algarra, A. and Perrone, V. 1993. Late Oligocene-Miocene syn-/-late-orogenic successions in Western and Central Mediterranean Chains from the Betic Cordillera to the Southern Apennines. *Terra Nova,* 5, 525-544.

Hermite, H. 1878. Observations géologiques sur les îles Majorque et Minorque. *Comptes Rendus Académie des Sciences Paris,* 88, 1097-1099.

Hermite, H. 1879. *Études géologiques surles îles Baléares (Majorque et Minorque).* Thèse, Université de Paris, 357 p., 60 fig., 4 pl.

Hermite, H. 1888. Estudios geologicos de las islas de Mallorca. *Boletin Com. Mapa Geologica de Espana,* XV, 1-233, 60 fig.

Herbig, H.G. 1984. Reconstruktion eines nicht mehr existenten Sedimentationraumes. Die Kalkgerölle in Karbon-Flysch der Malagiden (Betische Kordillere, Südspanien), *Facies*, 11, 1-108.

Herbig, H.G. 1989. Carboniferous Palaeogeography of the West-Mediterranean Palaeotethys. In: Yugan, J., Chun (eds.), L. (eds.), XI e *Congrès International Strat. Géol. Carbonifère,* 4, 186-196, Beijing 1987.

Hollister, J. S. 1934. Die Stellung der Balearen im variscischen und alpinen Orogen. *Abhandlungen der Geselschaft für Wissenschaft, Göttingen, Mathematische - Physikalische Klasse* III, 10, 122-154, 17 fig., 5 pl.

Hollister, J. S., 1942. La posición de las Baleares en las orogenias varisca y alpina. *Publ. Alem. Geol. Esp.* 1, 71-102.

Kockel, F. & Stoppel, D. 1962a. Neue Conodenfunde ende Profile im Paläozoikum von Malaga (Südspanien). *Geologisches Jahrbuch,* 81, 413-480.

Kockel F. et Stoppel D., 1962b. Nuevos hallazgos de Conodonteos y algunos cortes em el Paleozoicos de Malaga (Sur de Espana). *Not. Com.Inst. Geol. y Min. Espana*, 68, 133-169.

Kornprobst, J. 1974. Contribution à l'étude pétrographique et structurale de la zone interne du Rif (Maroc septentrional). *Notes et Mémoires du Service Géologique du Royaume du Maroc*, 251, 256 p.

Lacombe, O. and Jolivet, L. 2005. Structural and kinetics relationships between Corsica and the Pyrenees-Provence domain at the time of the Pyrenean orogeny. *Tectonics*, 24, 1-20.

Lambert, A. et Flandrin, J. 1942, Les terrains primaires du Massif du Chénoua (département d'Alger). *Comptes Rendus Académie des Sciences Paris,* 215, 17, 28.

Lepvrier, C. 1967. Sur la structure du Massif du Chénoua (Algérie). *Bulletin Société géologique de France,* 7, IX, 859-864.

Lys, M. 1975. Micropaléontologie (Foraminifères) des formations marines du Carbonifère saharien. *VIIIème Congrès International de la Stratigraphie du Carbonifère,* I, Moscou.

Lys, M. et Boulin, J. 1968. Nouveaux repères paléontologiques dans le Carbonifère des Monts de Malaga (Espagne méridionale). *Comptes Rendus Académie des Sciences Paris,* D, 266, 1561-1563.

Maillard, A., 1993. *Structure et riftogenèse du Golfe de Valence (Méditerranée Nord-occidentale).* Thèse Doctorat, Univ. P.-et-M.-Curie-Paris VI, 284 p.

Micheleau, P., 1942. Das Paleozoikum des Betischen Ketten nordwestlich von Malaga. *Diss. Univ. Berlin*. Inédit.

Milliard, Y. 1959. Sur la présence d'assises carbonifères dans le massif paléozoïque interne du Rif (Maroc). *Comptes Rendus Académie des Sciences Paris,* D, 249, 1051-1052.

Munoz, J.A. 1992. Evolution of a continental collision belt: ECORS-Pyrenees crustal balanced cross-section. In: McClay, (ed.), *Thrust Tectonics,* 235-246, Chapman and Hall.

Navas-Parejo, P., Rodrigues-Canero, R. y Martin-Algarra, A. 2012. Primer registro de un horizonte estratigrafico hemipelagico con conodonts del Carbonifero Superior en el Complejo Malaguide (Cordillera Betica oriental). *Geogaceta,* 52, 81-84.

Nolan, H. 1887. Note sur le Trias de Minorque. *Bulletin Société géologique de France,* 3, XV, 593-599.

Nolan, H. 1893. Sur les terrains triasiques et jurassiques des îles Baléares. *Comptes Rendus Académie des Sciences Paris,* CXVII, 821-827.

Nolan, H. 1894 – Sur les Crioceras du groupe Crioceras duvali. *Bulletin Société géologique de France,* 3, XXI, 183-196, 10 pl.

Nolan, H. 1895a – Structure géologique de l'ensemble de l'archipel Baléares. *Bulletin Société géologique de France,* 3, XXIII, 76-91.

Nolan, H. 1895b. Sur le Jurassique et le Crétacé des îles Baléares. *Comptes Rendus Académie des Sciences Paris,* 117, 1360-1363.

Nolan, H. 1897. Note préliminaire sur l'île de Cabrera. *Bulletin Société géologique de France, 3, XXIV, p.* 303-305.

Nolan, H. 1914. *Notes sur certains points de la géologie des Baléares.* Manuscrit à l'Aténéo de Mahon (Minorque).

Nolan, H. 1927. *Le Muschelkalk de Minorque.* Manuscrit à l'Aténéo de Mahon (Minorque).

O'Dogherty, L., Rodrigues-Canero, R., Gursky, H.-J., Martin-Algarra, A., Caridroit, M. 2000. Nouvelles données sur la stratigraphie et la paléogéographie du Carbonifère inférieur des Malaguides (Cordillères bétiques, Espagne méridionales). *Comptes Rendus Académie des Sciences Paris,* IIA Earth and Planetary Science, 331, 533-541.

Ramos, E. and Rodriguez-Pereia, A. 1985. Découverte d'un affleurement de terrains paléozoiques dans l'île de Majorque (Baléares, Espagne). *Comptes Rendus Académie des Sciences Paris,* 301, II, 16, 1205-1207.

Rodriguez-Canero, R. and Martin-Algarra, A. 2013. Frasnian-Famenian crisis in the Malaguide Complex (Betic Cordillera, Spain). *Terra Nova,* 26, 38-54.

Rodriguez-Canero, R., Martin-Algarra, A., Sarmiento, G.N. and Navas-Parejo, P. 2010. First Late Ordovician conodont fauna in the Betic Cordillera (South Spain): a palaeobiogeographical contribution. *Terra Nova,* 22, 5, 330-340.

Scotese, C.R. 1997. *Continental drift.* 7th ed. PALEOMAP, Arlington, TX.

Semenoff-Tian-Chansky, P., Lafuste, J., et Durand-Delga, M. 1961. Madréporaires du Dévonien du Chenoua (Algérie), *Bulletin de la Société géologique de France,* 1961 (1962), 7è série, III, 290-319, 1 pl. 3 texte-pl., 4 fig. Résumé: Compte Rendu sommaire de la SGF, 1061, p. 191.

von Seidlitz, W. 1931. *Diskordanz und Orogenese der Gebirge am Mittelmeer,* 651 p. Berlin, Gebrüder Borntraeger.

Stille, H. 1927 – *Über westmediterrane Gebirgszusammenhänge.* Abhanglung en der Gesells. Wissens. Göttingen. Beitr. Geol. westlichen Mediterr., n°1, Berlin.

Synthèse géologique et géophysique des Pyrénées (1996), vol. 1 : introduction, géophysique, cycle hercynien. *BRGM - Instituto Tecnologico Geominero de España (ed.),* 729 p.

Vai, G.B. 1991. Paleozoic strike-slip rift pulses ans paleogeography in the circum Mediterranean Tethyan Realm. *Paleogeography, Paleoclimatology, Paleoecology,* 87, 253-282.

Vai, G.B. 2001. Basement and early (pre-alpine) history. In: Vai, G.B. & Martini, I.P. (eds.), *Anatomy of an orogen: the Apennines and Adjacent Mediterranean Basins,* 121-150, Kluwer Ac. Publ.

Vai, G.B. & Cocozza, T. 1986. Tentative schematic zonation of the Hercynian chain in Italy. *Bulletin Société géologique de France*, 8, 2, 95-114.

Westphal, M., 1967. *Contribution du Paléomagnétisme à l'étude des déplacements continentaux autour de la Méditerranée occidentale.* Thèse Université de Strasbourg.

Westphal, M., Orsini, J., Vellutini, P. 1976. Le micro-continent corso-sarde, position initiale : données paléomagnétiques et raccords géologiques. *Tectonophysics* 30, 141-157.

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