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The Iberian Plate: myth or reality?

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ABSTRACT

The plate tectonics theory generally leads us to consider that Iberia was an independent plate separated from Europe by the North Pyrenean Fault (NPF). The NPF has been commonly interpreted as a transform fault associated with a huge counterclockwise transverse and rotational movement that allowed the opening of the Bay of Biscay and the relative eastward motion of Iberia during the Mesozoic. According to some interpretations, this movement may have generated an interplate gap several hundreds of km wide, which led to the creation of an oceanic crust during the Late Jurassic and Early Cretaceous. However, field studies recently carried out in the Pyrenees do not support these interpretations. The North Pyrenean Fault (NPF) of Tertiary age is observed in the central and eastern Pyrenees, where pioneering researchers defined it as separating the North Pyrenean Zone from the Axial Zone.However, this fault cannot be identified in the western part of the range to the west of the Ossau valley. Consequently, the geodynamic evolution of Iberia has always been dependent on Europe, especially during the failed oceanic rifting in the Mid-Cretaceous. Indeed, during this period, a central zone of crustal thinning occupied by turbiditic basins separated the European from the Iberian continental crust, with a very localized mantle exhumation found only in the Mauleon basin. Therefore, far from being an interplate range, the Pyrenees can neither be considered as an intraplate unit. We can define this orogenic belt as resulting from the "Tertiary tectonic inversion of a Mid-Cretaceous rift system". According to this new interpretation, Iberia would not have been an isolated plate but represented an unstable, outlying part of Europe. Rather than displaying the features of a rigid lithospheric unit with well-defined boundaries, Iberia grouped together different crustal blocks undergoing specific movements at particular times. During the Mesozoic, normal, reverse or strike-slip displacements along their boundary faults generated several *en échelon* basins (Bilbao, Logroño, Soria and Maestrazgo in Spain; Parentis, Arzacq and the North Pyrenean Flysch Trough in France) whose diachronous development accounts very well for the opening of the Bay of Biscay and the relative W-E sinistral movement of the Iberian crust with respect to the European crust. In this way, we note a more marked paleogeographic shift in the western Basque region than in eastern Catalonia. Therefore, the Pyrenees were not generated by an "interplate collision", but merely reflect the confrontation of two distended but continuous continental domains during the Tertiary, leading to the incipient underthrusting of the Iberian crust under the European crust. This zone of confrontation/convergence does not correspond in any way to the NPF, but rather comprises a complex imbricated structure revealed by a jump in the Moho, both in the Pyrenees and in the Cantabrian belt, which has recently become known as the "North Iberian Fault ".

Key words: Iberia, Europe, plate tectonics, European continental crust, Iberian continental crust, North Pyrenean Fault, North Iberian Fault

La placa Ibérica: ¿Mito o realidad?

RESUMEN

La teoría de la tectónica de placas generalmente nos lleva a considerar que Iberia fue una placa independiente, separada de Europa por la falla Norpirenaica (FNP). De esta manera, la FNP ha sido interpretada normalmente como una falla transformante asociada con un gran movimiento antihorario transverso y rotacional que permitió la apertura del Golfo de Vizcaya y el movimiento relativo de Iberia hacia el este durante el Mesozoico. Según algunas interpretaciones, este movimiento podría haber generado una brecha entre placas de varios cientos de kilómetros de amplitud, que condujo a la creación de corteza oceánica durante el Jurásico Superior y Cretácico inferior. Sin embargo, estudios de campo llevados a cabo recientemente *en el Pirineo no apoyan estas interpretaciones. La FNP de edad terciaria se observa en el Pirineo central y oriental, donde los primeros investigadores la definieron como el límite entre la Zona Norpirenaica y la Zona Axial. Sin embargo, esta falla no puede ser identificada en la parte occidental de la cordillera, al oeste del valle de Ossau. En consecuencia, la evolución geodinámica de Iberia ha sido siempre dependiente de Europa, especialmente durante el fallido rifting oceánico del Cretácico medio. De hecho, durante este período, la corteza continental Europea y la Ibérica estaban separadas por una zona central de adelgazamiento cortical ocupada por cuencas turbidíticas. La exhumación mantélica se localizaba únicamente en la cuenca de Mauléon. Por lo tanto, lejos de ser una cordillera entre-placas, el Pirineo no puede tampoco ser considerado como una unidad intraplaca. Podemos definir este cinturón orogénico como el resultado de la «inversión tectónica durante el Terciario de un sistema de rift del Cretácico medio». De acuerdo con esta nueva interpretación, Iberia no sería una placa aislada sino que representa una parte inestable en la periferia de Europa. Más que mostrar las características de una unidad litosférica* rígida con límites bien definidos, Iberia agrupaba diferentes bloques corticales sometidos a movimientos específicos en momentos concretos. Durante el Mesozoico, desplazamientos normales, inversos o de desgarre a lo largo de las fallas que los limitan, generaron varias cuencas en échelon *(Bilbao, Logroño, Soria y Maestrazgo en España; Parentis, Arzacq y el surco Flysch Norpirenaico en Francia) cuyo desarrollo diacrónico da cuenta de la apertura del Golfo de Vizcaya y del movimiento relativo W-E sinistrorso de la corteza ibérica con respecto a la corteza Europea. De esta manera, observamos un decalaje paleogeográfico* más marcado en el País Vasco occidental que en Cataluña oriental. Por lo tanto, el Pirineo no fue generado por una «colisión entre-placas», sino que simplemente refleja la confrontación de dos dominios continentales distendidos pero continuos durante el Terciario, que conduce a la subducción incipiente de la corteza Ibérica bajo la corteza Europea. Esta zona de confrontación / convergencia no se corresponde en modo alguno con la FNP, sino que comprende una estructura imbricada compleja puesta de manifiesto por un salto en el Moho, tanto en el Pirineo como en la franja cantábrica, que recientemente ha sido denominada como la «Falla *Noribérica».*

Palabras clave: Iberia, Europa, placa tectónica, corteza continental Europea, corteza continental Ibérica, Falla Norpirenaica, Falla Noribérica

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

En los trabajos recientes (Le Pichon et al., 1970, Masson and Miles, 1984, Olivet, 1996, Olivet et al., 1983, Rowley and Lottes, 1988, Savostin et al., 1986; Sibuet and Colette, 1991; Stivastava et al., 1990) la Península Ibérica es generalmente considerada como una placa independiente, separada de Europa por una falla transformante denominada « Falla Norpirenaica » (Figura 1). A veces se considera que el dominio móvil que permitió el deslizamiento entre-placas, anterior a la fase de compresión pirenaica estaba compuesto de corteza jurásica y neocretácica muy adelgazada (Stämpfli, 2011) pudiendo alcanzar hasta 230 km de amplitud (Sibuet and Colette, 1991). Hay incluso quien considera que involucró a la corteza oceánica, englobando materiales mantélicos exhumados (Vissers and Meyer, 2011).

Los datos de campo aportados en el presente trabajo no permiten apoyar tales interpretaciones. Esto nos lleva a proponer un nuevo modelo para las relaciones estructurales y geodinámicas entre Europa e Iberia y sacar a la luz la verdadera naturaleza de uno de estos dos dominios, denominado normalmente con el nombre de placa Ibérica.

La Falla Norpirenaica (FNP): ¿falla mesozoica transformante o simple falla terciaria inversa, localizada únicamente en el Pirineo central y oriental?

Este accidente fue definido por De Sitter (1953) como una falla terciaria fruto del rejuego inverso de una antigua falla normal mesozoica presente únicamente en el Pirineo central y oriental. Más tarde fue incluida en una zona de fallas que separan la Zona Axial de la Zona Norpirenaica, esta vez en todo el orógeno (De Sitter, 1956). Sin embargo ciertos autores como Castéras (1954, 1974) subrayan la ausencia de tal accidente en el Pirineo occidental.

A partir de entonces, la FNP fue considerada como una falla transformante que separa las placas europea e ibérica y controla el movimiento relativo antihorario de más de 500 km de esta última placa a lo largo del Mesozoico (Olivet, 1996). Los diferentes modelos utilizados (Le Pichon et al., 1970; Choukroune et al., 1973a, 1973b) se enfrentan con incompatibilidades paleogeográficas, particularmente en la zona norpirenaica (Peybernes, 1976) donde existen fallas transversas tales como las fallas de Bigorre y de Cataluña (Souquet and Mediavilla, 1976; Souquet et al., 1977; Debroas et al., 1978). El desplazamiento fue entonces explicado considerando que la componente de desgarre se ejerce en una zona de deformación que abarca las cuencas flysch norpirenaicas recientemente consideradas como cuencas de tipo "pull appart" (Choukroune and Mattauer, 1978). Al mismo tiempo, los nuevos datos geofísicos llevaron a diferentes autores (Daignères et al., 1982; Soutiau and Sylvander, 2004) a considerar que la FNP estaba representada en el conjunto del Pirineo por un salto del Moho entre una corteza Ibérica gruesa (50 km) y ligera, y una corteza europea más delgada (30 km) y más pesada.

Nuestro trabajo confirma la presencia de la FNP de De Sitter en el Pirineo central y oriental y su ausencia en el Pirineo occidental (Canerot et al., 2001; Canerot, 2008a y 2008b), donde incluso se puede observar el paso lateral de las unidades norpirenaicas a unidades pertenecientes a la « Alta Cadena Primaria » (Figura 2). Por lo tanto, ¿puede ser explicado el desplazamiento sinistrorso relativo entre Europa e Iberia?

Una zona de deformación regional: relaciones geodinámicas entre Europa e Iberia

Ahora sabemos que los rellenos de las cuencas sedimentarias mesozoicas no revelan diferencias paleogeográficas significativas a lo largo del conjunto del dominio pirenaico aquí considerado (Faure, 2002; Faure et al., 2010). Así se puede explicar la apertura del Golfo de Vizcaya mediante la participación de una amplia zona de deformación establecida entre el Macizo Central al NE y la Meseta española a SW (Canerot, 2008; Canerot et al., 2012). Así, del Lias al Albiense, este dominio sufre una transtensión sinistrorsa NW – SE que conduce a la formación de cuencas diacrónicas de tipo « pull appart », tales como las cuencas del Maestrazgo, de Soria-Logroño, de Bilbao, de Parentis-Arzacq, o incluso las cuencas flysch norpirenaicas. La sedimentación es muy activa: 10.000 m en el Maestrazgo (Salas et al., 2001) (Figura 3); 6000 m en Soria-Logroño (Salomón, 1982) (Figura 4) y 5000 m para las cuencas norpirenaicas (Debroas, 1990 y 2003; Souquet et al., 1985) (figura 5). Se constata así que la tasa acumulada de desgarre sinsedimentario a lo largo del Jurásico y del Cretácico es suficiente para compensar la apertura del golfo de Vizcaya.

Por otra parte se puede explicar la rotación sinistrorsa de 35° para el conjunto de Iberia durante este período (Van der Voo, 1969; Galdeano et al., 1989; Moreau et al., 1992; Osete et al., 2011) teniendo en cuenta que esta zona de deformación se compone de un conjunto de bloques corticales (macizos de las Landas, de Asturias, del Ebro y de Cataluña) animados por movimientos rotacionales internos específicos. Pero el campo de deformación es más importante en el País Vasco occidental que en la Cataluña oriental (Faure et al., 2010; Canerot y Bilotte, 2012) lo que significa que la corteza Ibérica era probablemente mucho más extensa de norte a sur que en la actualidad.

La Falla Noribérica: zona de subducción continental de la corteza ibérica bajo la corteza europea

En general se acepta (Souquet et al., 1977; Boillot et al., 1984; Debroas, 2003; Canérot, 2008) que el Pirineo resulta de la inversión tectónica terciaria de las fosas flysch cretácicas, poniendo en contacto sus márgenes continentales ibérico y europeo. Contrariamente a ciertas hipótesis (Sibuet y Colette, 1991; Vissers y Meijer, 2011; Stämpfli, 2011), no hubo ninguna corteza oceánica entre Europa e Iberia durante el Jurásico y Cretácico inferior. Por lo tanto, la presencia de corteza adelgazada y, muy localmente, de lherzolitas del manto (Debroas et al., 2010), no puede probar la formación de la cadena a partir de un proceso de colisión entre placas.

La compresión regional relacionada con el desplazamiento de la placa africana hacia el norte, conduce a la delaminación de la corteza continental ibérica y al hundimiento gradual de sus unidades bajo la corteza continental europea. La geometría resultante en abanico disimétrico está claramente definida en el perfil ECORS del Pirineo central (Roure et al., 1989) y, en menor medida, en el perfil Pirineo occidental-Arzacq (Damotte and Daignères, 1998).

La confrontación intercortical da lugar a un engrosamiento de la corteza Ibérica (hasta 50 km) en comparación con su homóloga europea, que nunca supera los 30 km (Souriau y Sylvander, 2004). Esta geometría induce un salto en el Moho que resulta del apilamiento de las unidades de corteza ibérica (Figura 6). Esta estructuración está bien ilustrada en el Pirineo central por los mantos de Gavarnie y de Monte Perdido (Seguret, 1969) donde la erosión reciente ha exhumado a la vez los materiales superficiales transportados *hacia el sur y las migmatitas de Gèdre, más profundas y sub-transportadas esta vez hacia el norte. En el sector más septentrional de Pierrefitte-Nestalas y de Argelès-Gazost, las estructuras pirenaicas se verticalizan gradualmente. Estas se sitúan entonces precisamente a la derecha del salto del Moho. Este dominio, conocido en el conjunto del Pirineo (Souriau and Sylvander, 2004), ha sido recientemente designado con el nombre de « Falla Noribérica »* (FNI) (*Canérot, 2008; Canérot et al., 2012) (Figura 7).*

Así definida, la FNI engloba la FNP de De Sitter (1953). Esta desaparece bruscamente hacia el este en las proximidades del Golfo de León, recientemente abierto en el Oligoceno. Hacia el oeste, la FNI se prolonga hasta alcanzar la cadena Cantábrica, donde se observa el mismo sub-arrastre de unidades de corteza ibérica hacia el norte (Pedrera et al., 2003; Ferrer et al., 2008).

Conclusión: Ibéria es una parte móvil de Europa

La articulación entre Iberia y Europa no corresponde a una falla transformante Mesozoica. Esta se produce, por contra, dentro de una amplia zona de deformación que separa el Macizo Central francés de la Meseta española. La apertura del golfo de Vizcaya y el desplazamiento sinistrorso relativo de la zona Ibérica hacia el este se explica por la participación de una dinámica de bloques dotados de movimientos rotacionales específicos. La compresión regional terciaria conduce a la delaminación de la corteza Ibérica y a su hundimiento progresivo bajo su homóloga europea. Esta evolución tectónica lleva a la individualización de una zona de engrosamiento cortical con salto del Moho, denominada Falla Nor-Ibérica.

En estas circunstancias, Iberia permaneció unida a Europa, especialmente en el Cretácico inferior, durante la abortada apertura del rift pirenaico, y no puede ser considerada como una placa independiente. Nosotros la interpretamos aquí como una parte inestable de la placa europea.

Introduction

After the late 1960s, according to the plate kinematic models applied to south-western Europe (Le Pichon *et al.,* 1970; Masson and Miles, 1984; Olivet, 1996; Olivet *et al.,* 1983; Rowley and Lottes, 1988; Savostin *et al.,* 1986; Sibuet and Colette, 1991; Srivastava *et al.,* 1990), the Iberian Peninsula was generally considered as an independent plate separated from Europe by a major transform fault named the North Pyrenean Fault (NPF). The proposed geodynamic models involved a relative Mesozoic interplate shift of 300-500 km before the end-Cretaceous and Paleogene Pyrenean compressional phase (Fig. 1). Some of these models introduced the development of a mobile interplate Pyrenean domain made up of thinned Upper Jurassic and Lower Cretaceous crust (Stämpfli, 2011), reaching a width of up to 230 km in the eastern part of the belt (Sibuet and Colette, 1991). This domain could have even been occupied by oceanic floor involving exhumed mantle rocks during this period of the Mesozoic (Vissers and Meijer, 2012).

At present, geological field data collected in the Pyrenees do not fit with these hypotheses based on global plate tectonics. In this paper, we first discuss in detail the geodynamic and structural relationships between Europe and Iberia during the alpine orogeny,

Figure 1. The Mesozoic counterclockwise rotation of Iberia (after J.L. Olivet, 1996). Note the large shift (more than 500 km) taking place between Europe and Iberia during the Cretaceous. 1: Tithonian (>150 Ma); 2: Barremian-Aptian (120 Ma); 3: Coniacian (88-90 Ma). White: position of Iberia during the Campanian (80 Ma).

***Figura 1.** La rotación mesozoica antihoraria de Iberia (J.L. Olivet, 1996). Destaca el importante decalaje (más de 500 km) entre Europa e Iberia durante el Cretácico. 1. Titónico (>150 Ma); 2: Barremiense-Aptiense (120 Ma) ;* 3 : *Coniaciense (88-90 Ma). En blanco: posición de Iberia durante el Campaniense (80 Ma).*

mainly along the classical NPF. The presented results then lead us to propose a new regional evolution model highlighting the real nature of the southern domain, which has previously been referred to as the Iberian plate.

The North Pyrenean Fault (NPF): Mesozoic regional transform fault or Cenozoic, reverse fault only in the eastern and central Pyrenees?

The NPF was first formally defined by De Sitter (1953) as a major reverse fault of Tertiary age, which separates the North Pyrenean Zone from the Axial Zone in the Central Pyrenees of Ariège and Haute-Garonne. This reverse fault reworked a pre-existing normal fault of Mesozoic age (mainly Cretaceous). Subsequently, De Sitter (1956) included this fault within a North Pyrenean Fault Zone, which appeared to extend eastward to the Alps and westward to the Cantabrian and even the Asturian Mountains. However, Castéras (1954 and 1974) and others soon pointed out the absence of the NPF in the Western Pyrenees and considered that an en-echelon fault zone situated between the Pyrenees and the Cantabrian belt could represent it.

After the 1970s, with the emergence of Global Plate Tectonics and the proposed interpretations in terms of plate kinematics, several authors proposed that the NPF really corresponded to an E-W-trending transform fault separating the European plate to the north from the Iberian plate to the south. During the Mesozoic, counterclockwise wrench faulting along this fault could have generated a shift of more than 500 km of Iberia compared to Europe (see the presented models in Olivet, 1996).

Since then, studies carried out in the Pyrenees have focused on the identification, mapping and interpretation of this strike-slip fault, whose activity brought about major paleogeographic changes, especially during the Jurassic and Early Cretaceous. The proposed geodynamic models (Le Pichon *et al.,* 1970; Choukroune *et al.,* 1973a, 1973b) involved wrench faulting along a curved NPF, but they were soon found to be incompatible with regional paleogeographic constraints, especially in the North Pyrenean domain. To overcome these difficulties, a new model was proposed that invoked a wide mid-Cretaceous transform zone affecting part of the northern Pyrenees and southern Aquitaine (Choukroune and Mattauer, 1978). The Pyrenean Flysch Basins were interpreted as pull-apart basins generated by a regional W to E counterclockwise motion of several hundred km between the European and Iberian plates. This new interpretation preserved the huge displacement between both plates, but did not fit with the absence of a significant paleogeographic shift on the bordering European and Iberian margins of these basins (Peybernès, 1978). Therefore, the opening of the Bay of Biscay and the relative eastward displacement of Iberia with respect to Europe was interpreted through a regional shearing motion, with faults striking W-E and also transverse, SW-NE, as in the case of the Bigorre and Catalonia faults (Souquet et Médiavilla, 1976; Souquet *et al.,* 1977; Debroas *et al.,* 1978).

At the same time, the presence of a single fault between the European and Iberian plates has been corroborated by geophysical and especially seismological studies (Daignères et al., 1982; Souriau and Sylvander 2004). The NPF is newly characterized by a Moho jump between the thick (50 km) and light Iberian crust in the south and the thinner (30 km) but heavier European crust in the north. This major intracontinental scar (or suture) corresponds to a zone of high seismicity in the present day, especially in the western Pyrenees.

Recent studies allow us to confirm the presence of the NPF, as formerly described by De Sitter, in the central and eastern Pyrenees, and show that this fault is absent in the western part of the range where some North Pyrenean structures correspond to lateral units involved in the Axial Zone (or High Primary

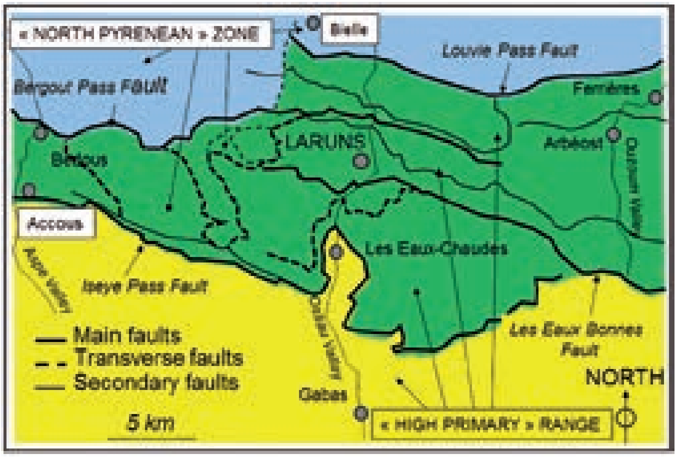

Figure 2. The Bielle – Accous Wrench Fault Zone (after J. Canérot, 2008). In this western part of the Pyrenees, the North Pyrenean Fault is absent. So, NW "North Pyrenean" units interfinger with SE units included within the Axial Zone or "High Primary Range", highlighting the NW-SE, transverse pattern of the belt.

Figura 2. *La zona de desgarre de Bielle – Accous (J. Canérot, 2008). En este sector del Pirineo occidental la falla Norpirenaica está ausente. Las unidades "norpirenaicas", noroccidentales, pasan lateralmente a las unidades surorientales pertenecientes a la Zona Axial, destacando así la estructuración transversa, NW-SE, del edificio pirenaico.*

Range, prefered to "Axial zone" which is much more frequently used in papers written in English, but which is controversial because we consider that the belt axis runs along the North Iberian Fault seen here after), in particular along the Bielle-Accous wrench fault zone (J. Canérot *et al.,* 2001; J. Canérot, 2008a and 2008b) (Fig. 2). But how can we explain the opening of the Bay of Biscay and the counterclockwise movement of Iberia with respect to Europe?

Regional deformation zone: geodynamic relationships between Europe and Iberia

The hypothesis of a North Pyrenean transform fault necessarily implies that Iberia was an independent plate with well-marked boundaries, especially along the northern junction zone with Europe. Thus, in the previously mentioned geodynamic models, Spanish Catalonia during the Jurassic was located westward of the French Pays Basque, at a distance of up to 500 km from its present position. It is now well established (Fauré, 2002; Fauré *et al.,* 2010) that the Mesozoic trans-pyrenean sedimentary basins do not, however, exhibit significant shifts in the distribution of paleoenvironments over the area of their present-day outcrop.

The opening of the Gulf of Biscay has been recently interpreted (Canérot, 2008a, 2008b; Canérot *et al.,* 2012) without any major transcurrent motion, along the NPF, but instead involving a wide (up to 1000 km) deformation zone located between the north-eastern French Massif Central and the south-western Spanish Meseta. From the Lower Jurassic up to the Albian, which includes this stage of opening, the area in question suffered a NW-SE counterclockwise transtension leading to the formation of diachronous pull-apart basins distributed across the Aquitanian, Pyrenean and Celtiberian domains (Bourrouilh *et al.,* 1995; Bourrouilh, 2008). In this context, we should mention the basins of Maestrazgo (Late Jurassic-Aptian), Soria-Logroño (Neocomian-Barremian) and Bilbao (Aptian-Albian) in Spain, as well as the Parentis-Arzacq (Barremian-Albian) and North Pyrenean Flysch (Albian) basins in France. Synsedimentary wrench faulting and related subsidence allowed the deposition of near 10,000 m of sediments in the south-Iberian Basin (Salas *et al.,* 2001) (Fig. 3), 6,000 m in the Soria and Logroño basins (Salomon, 1982) (Fig. 4) and 5,000 m in the North Pyrenean Flysch Basin (Souquet *et al.,* 1985) (Fig. 5). We also note that the strike-slip displacement is greater in the Soria-Logroño basin (50 km) than in the North Pyrenean Ballongue Trough (20 km, according to Debroas, 1990

Figure 3. The South Iberian or Maestrazgo Basin. Note the high thickness of the sedimentary infilling (more than 8000 m) during the Jurassic-Lower Cretaceous period. A: emerged areas; B: continental deposits; C: shallow marine platforms; D: deep marine areas.

Figura 3*. La cuenca suribérica o cuenca del Maestrazgo. Destaca el gran espesor del relleno sedimentario (más de 8000 metros) del intervalo Jurásico – Cretácico inferior. A: Áreas emergidas; B: facies continentales; C: plataformas marinas; D: dominio marino profundo.*

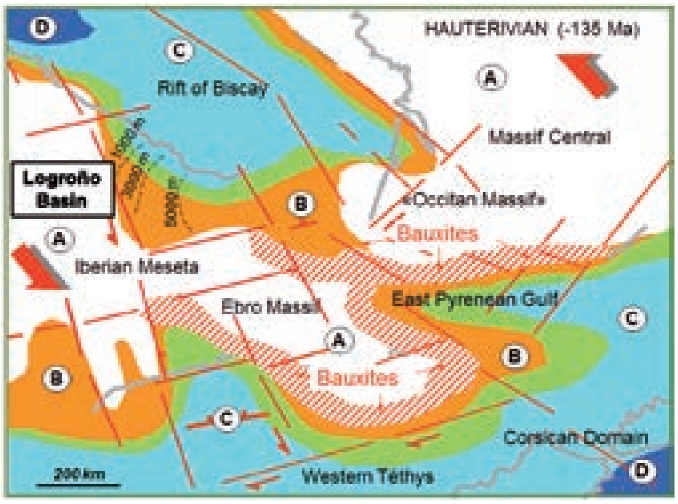

Figure 4. The Logroño Basin. Its Early Cretaceous sedimentary infilling is more than 6000 m thick. A: emerged areas; B: coastal plain environments; C: shallow marine platforms; D: deep marine basins.

Figura 4*. La cuenca de Logroño. Su relleno sedimentario cretácico inferior sobrepasa los 6000 metros de espesor. A: tierras emergidas; B: medio costero-littoral; C: plataformas marinas; D: medio marino profundo.*

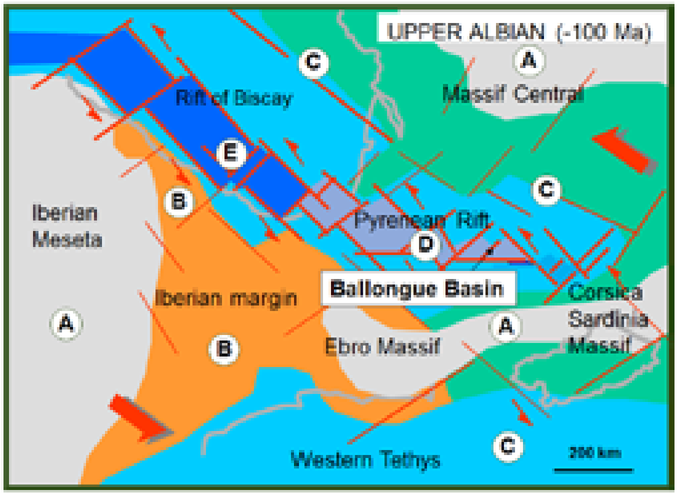

Figure 5. The Albian North Pyrenean trough. A: emerged areas; B: Utrillas-type sedimentation; C: shallow marine platforms; D: North Pyrenean flysch environments: E: Bilbao trough.

Figura 5*. La fosa norpirenaica albiense. A: dominio emergido; B: extensión de las Utrillas; C: plataformas marinas; D: dominio del flysch norpirenaico; E: fosa de Bilbao.*

and 2003).Therefore, we consider that the regional total diachronous shift of sedimentation during the Jurassic and Early Cretaceous provided enough space to accommodate the opening of the Bay of Biscay.

We need to check whether the considered deformation zone fits with the paleomagnetic data, which indicate a counterclockwise rotation of nearly 35° for the whole Iberian plate during the Early Cretaceous opening (Van der Voo, 1969, Galdeano *et al.,* 1989, Moreau *et al.,* 1992; Osete *et al.,* 2011). In the present interpretation, the considered area is made up of a mosaic of crustal blocks (e.g. Landes, Asturias, Ebro and Catalan Massifs) displaying internal rotation movements during this period of the Mesozoic. Concerning each of these blocks at different times, and with a specific intensity of deformation, the stress field induces a greater shift in the western Pays Basque than in eastern Catalonia. In view of the regional paleogeographic data (Fauré *et al., in* Gaillard and Hantzpergue eds., 2010; Canérot and Bilotte, *ibidem)*, the shift is weak between the Corbieres and the southern Pyrenean basins and stronger between the Aquitaine and the Cantabrian basins. Consequently, the Iberian crust was probably much more extended from north to south during this period than today. The Late Cretaceous and Early Tertiary compression indeed produced a strong shortening throughout the entire Iberian craton and especially in the Celtiberic and Pyrenean domains.

The North Iberian Fault: A Cenozoic continental subduction zone of the Iberian crust under the European crust.

It is commonly accepted (Souquet *et al.,* 1977; Boillot *et al.,* 1984; Debroas, 2003; Canérot, 2008a, 2008b) that the Pyrenees resulted from the Late Cretaceous and Paleogene juxtaposition of the Iberian margin with the European margin involving the imbricated north pyrenean Mid Cretaceous Flysch Basins. Contrary to certain hypotheses (Sibuet and Colette, 1991; Vissers and Meijer, 2012; Stampfli, 2011), there is no field evidence of the existence of an oceanic crust between the stable Europe and Iberia anywhere in the Pyrenean realm, even during the Jurassic and the Early Cretaceous. The former existence of this supposed oceanic crust cannot be inferred from available seismic imaging as it would have been subducted during the earlier stages of the Pyrenean orogeny. The sediments accumulated during this interval really indicate shallow-to-open marine conditions everywhere on a continental crust extending from the North Pyrenean Zone to the South Pyrenean Zone. The presence of a local thinned crust with reworked mantle rocks (lherzolites) exhumed in late Albian time, as observed only in the Mauleon Basin (Debroas *et al.,* 2010; Jammes *et al.,* 2010; Masini *et al.,* 2014; Tugend *et al.,* 2014), cannot, in our opinion, prove the genesis of the whole belt through an interplate collision process.

The regional Tertiary compression first led to a flaking of the Iberian continental crust and then, following the northward movement of the African plate, to the progressive underthrusting of the Iberia-derived crustal slice units below the European continental crust. The resulting geometry is clearly defined in the ECORS profile of the central Pyrenees (Roure *et al.,* 1989), but less well observed in the western Pyrenees-Arzacq profile (Damotte and Daignères, 1998). The section across the mountain range reveals an asymmetric fan-shaped pattern, with superficial structures in the European crust to the north, compared with deeper structures in the Iberian crust to the south (Fig. 6).

Geodynamic processes in the convergence zone lead to a thickening of the Iberian crust, which can reach 50 km compared to the European crust with thicknesses never in excess of 30 km (Souriau and Sylvander, 2004). This geometry involves a Moho jump that could result from the early stacking of the Iberian crustal units along the present Axial Zone. The resulting structure is well represented by the southern Pyrenean thrust sheets of the central Pyrenees, such as the Gavarnie and Mont Perdu

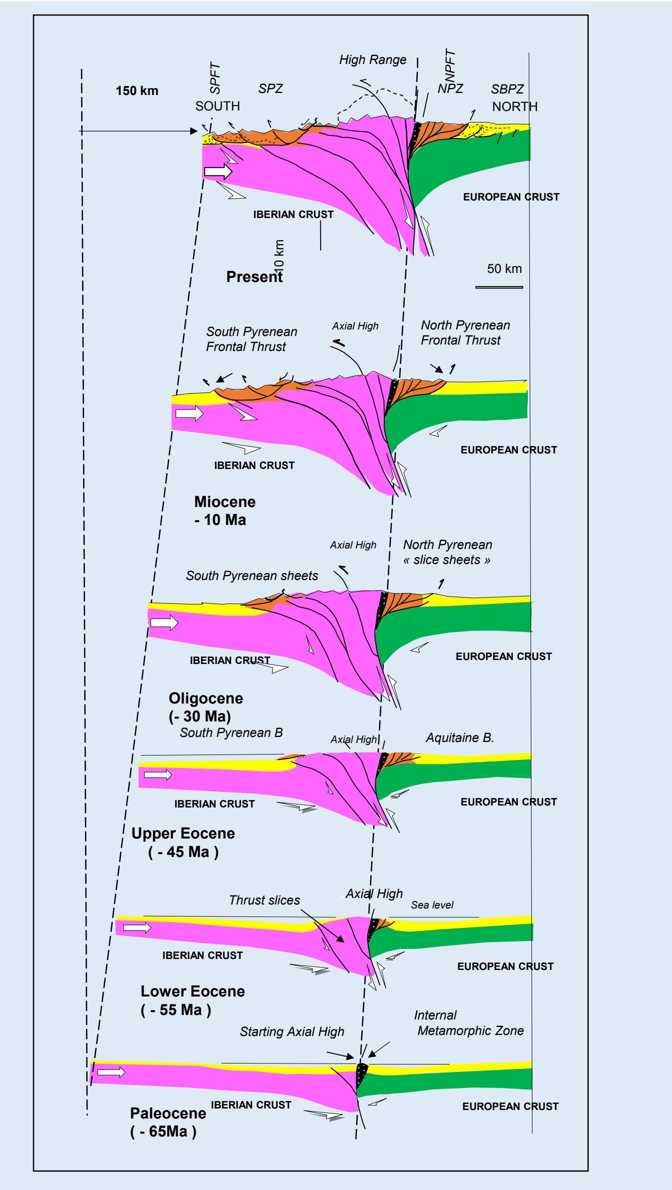

Figure 6. Diagrammatic sections showing the structural evolution of the Central Pyrenees during the Cenozoic Era. The northward (right) motion of Africa leads to the underthrust of the imbricated Iberian units under the European ones. Therefore, the resulting Axial Zone is mainly made up of Iberian crust elements. The southward verging sheets correspond to the reaction of the Iberian upper crust to this northward underthrusting. The general shortening (150 km) concerns mainly the Iberian crust which is much thicker than the corresponding European crust.

Figura 6. *Cortes esquemáticos mostrando la evolución estructural del dominio pirenaico central a lo largo del Cénozoico. El empuje africano hacia el norte (a la derecha), llevó a una delaminación de la corteza ibérica y a su hundimiento bajo la corteza europea. La zona axial resultante se compone de un apilamiento de láminas de corteza ibérica. Los mantos con vergencia sur resultan de la reacción de la corteza ibérica superficial a este infracabalgamiento hacia el norte. El acortamiento (estimado en 150 km), se produce esencialmente en el seno de esta corteza ibérica considerada aquí como fuertemente engrosada en comparación con su homóloga europea.*

units (Seguret, 1972). In this area, erosion has recently exhumed the southern Gedre migmatites, which were underthrust towards the north, thus determining the flat southward overthrusting of the Gavarnie and Mont Perdu sheets of Paleozoic and Mesozoic to Paleogene rocks. To the north of this thrust- sheet zone, the structures become progressively steeper to vertical near the convergence zone of Argelès-Gazost and Pierrefitte-Nestalas.

This latter structural zone, which lies precisely above the Moho jump, is very well represented along the eastern and central Pyrenees, between the Agly and the Ossau valleys, as well as in the western part of the range (Souriau and Sylvander, 2004). This structure has been recently called the "North Iberian Fault" (NIF) to highlight the existence of a zone of regional intercrustal convergence (Canerot, 2008a; Canerot *et al.,* 2012). Although this zone of deformation is up to 20 km wide at outcrop, it becomes narrower at depth, connecting gradually with the vertical offset of the Moho discontinuity (Fig. 7).

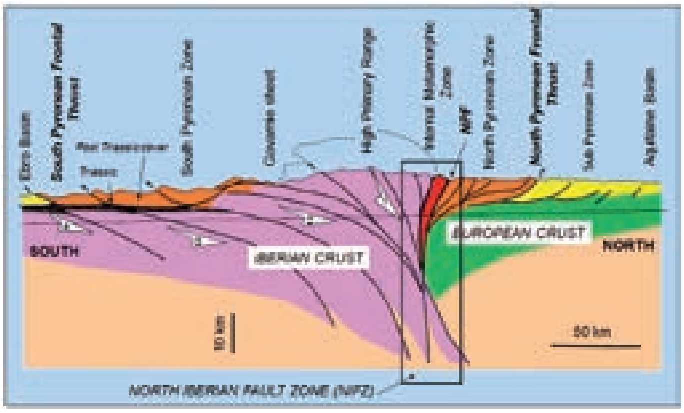

Figure 7. The North Iberian Fault Zone (NIFZ) in the Central Pyrenees. It corresponds to a deep deformation zone that developed gradually during the Tertiary facing period between the Iberian and European crusts of the Pyrenees. This more or less wide deformation zone is characterized by the thickening of the Iberian crust made up of imbricated sheets that gradually thrust under the European crust. The resulting structure involves the classical North Pyrenean Fault and leads to a Moho jump that stretches westward to the Cantabrian Mountains.

Figura 7. *La "Falla Noribérica" (NIFZ). Corresponde a una zona de deformación intensa que se desarrolla gradualmente a lo largo del Terciario, durante el periodo de colisión de las cortezas ibérica y europea del Pirineo. Esta zona, más o menos extensa, se caracteriza por un engrosamiento de la corteza ibérica debido a la progresiva imbricación de láminas (1 a 4) y su hundimiento relativo bajo su homóloga europea. La estructura resultante, remarcada por un salto en el Moho, engloba la falla Norpirenaica (NPF) de otros autores y se prolonga hacia el oeste del Pirineo, en dirección a la Cordillera Cantábrica.*

According to this new definition, the NIF locally involves the NPF as defined by De Sitter (1953). However, the former structure is radically different from the transform NPF leading hypothetically to a 500 km shift between the European and Iberian plates, and that, as indicated above, cannot be observed directly in the field nor indirectly inferred from seismic imaging. Although the newly defined NIF generated by the Late Cretaceous and Tertiary pyrenean compression disappears suddenly eastward in the recently (Oligocene) opened Gulf of Lions, it appears to continue westward of the Pyrenees, extending probably up to the Cantabrian Mountains. In this latter area, recent studies indeed suggest the presence of very similar structures of Iberian crust underthrusting Cantabrian structures towards the north (Pedreira *et al.,* 2003; Ferrer *et al.,* 2008; Tavani, 2014). Nevertheless, they by no means neglect the recent models of hyperextended crust and seafloor spreading in the western part of the Bay of Biscay (Tugend *et al.,* 2014).

Conclusion: Iberia is part of Europe

The boundary between Iberia and Europe cannot correspond to the NPF if we regard this structure as a transform fault associated with the W-E counterclockwise strike-slip movements that could have generated the opening of the Gulf of Biscay during the Late Jurassic and the Early Cretaceous. The junction between these two adjacent domains should rather be interpreted as a wide deformation zone separating the French Massif Central from the Spanish Meseta. This opening of the Gulf of Biscay can be explained by the rotational movements of the crustal blocks located in this area, associated with the diachronous normal, reverse or strike-slip displacements of the bordering faults which generated pull-apart basins. The proposed interpretation is also in agreement with regional paleogeographic variations during this period of the Mesozoic.

Hence, the Pyrenees cannot be defined in terms of a complete plate tectonics cycle of opening and later closing of two opposite (European and Iberian) continental margins bounded by oceanic crust. The formation of this range is rather the result of the structural inversion of a Cretaceous continental rift system, due to the Tertiary convergence between the European and Iberian sides of the rift system, lying to the north and to the south, respectively. The regional compressional regime led first to the deep imbrication/flaking of the previously thinned Iberian crust and later to its thickening caused by stacking of the new individualized thrust units along the present Axial Zone. In the final stages of this process, the Iberian side of the system underwent continental subduction under the European crust without involving pieces of oceanic crust anywhere, in spite of the local exhumation of the subcontinental mantle during the Late Albian. The resulting regional compression extends along a complex crustal fault zone associated with a Moho jump, well known in the Pyrenees and also westward in the Cantabrian Mountains. This deformation zone, which bounds the Iberian domain to the north, has been recently named the North Iberian Fault.

In view of this new structural interpretation, Iberia can no longer be considered as an independent plate with well-defined boundaries. The continuous connection of Iberia with Europe, especially during the Early Cretaceous, at the time of the failed opening of the Pyrenean rift, leads us to consider this massif as representing a southern unstable part of the European plate.

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