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Comments on the Liassic age ascribed to the Bou Adel oceanic gabbro (Central Mesorif, Morocco) by Michard *et al*. (2018), and stratigraphic and palaeogeographic arguments for a latest Jurassic-earliest Cretaceous age

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ABSTRACT

In the median part of the Rif Belt (Mesorif Zone), Upper Jurassic-Lower Cretaceous deposits contain numerous relics of volcanic materials (basalt pebbles and interstratified lava flows), and several large gabbro massifs, especially in the Central Mesorif. The most important of these massifs, Bou Adel, was regarded as an intrusive gabbro of varying age (according to successive authors: Barremian, Late Jurassic to Senonian, and Bathonian respectively), and recently as an oceanic gabbro of latest Jurassic-earliest Cretaceous. Based on a radiometric (190 ±2 Ma) date from zircon grains, Michard *et al*. (2018) ascribed an Early Jurassic (Liassic) age to this gabbro. Consequently these authors proposed a new interpretation of the oceanic opening of the External Rif Domain related to the eastwards expansion of the Central Atlantic oceanic rift. They also hypothesized that the Upper Jurassic-Lower Cretaceous volcanic lavas and the ophiolite complexes of the Mesorif Zone are heterochronous and correspond to two, distinct and separated in time, magmatic events. This new age ascribed to the Bou Adel gabbro and the new interpretation of the oceanic opening of the External Rif disagree with the stratigraphic data and the geodynamic framework of the External Rif domain during the Mesozoic. On the base of numerous stratigraphic data and the palaeogeographic evolution, we evidence herein that the volcanic lavas and the oceanic gabbros of the Mesorif Zone all originated from the same geodynamic event related to the westwards expansion of the Tethys Ocean at the Jurassic-Cretaceous boundary, and that these oceanic gabbros are ophiolite complexes of the Senhadja and Bou Haddoud nappes, thrusted over the External Mesorif Zone during the Alpine Miocene orogeny.

Keywords: External Rif Belt, Jurassic-Cretaceous boundary, ophiolite complexes, radiometric age, stratigraphic and palaeogeographic data, volcanic lava flows.

Comentarios sobre la edad liásica atribuida al gabro oceánico de Bou Adel (Mesorif Central, Marruecos) por Michard et al. (2018), y argumentos estratigráficos y paleogeográficos para una edad Jurásico Superior-Cretácico Inferior

RESUMEN

En la parte media del Cinturón del Rif (Zona Mesorif), los depósitos del Jurásico Superior-Cretácico Inferior contienen numerosos relictos de materiales volcánicos (clastos de basalto y flujos de lava interestratificados), y varios macizos de gabro, especialmente en el Mesorif Central. El más importante de estos macizos, Bou Adel, ha sido considerado como un gabro intrusivo de edad variable (de acuerdo a autores sucesivos: Barremiense, Jurásico Superior a Senoniense, y Batoniense), y recientemente como un gabro oceánico del Jurásico Superior-Cretácico Inferior. En base a una datación radiométrica (190 ±2 Ma) a partir de granos de circón, Michard et al. (2018) proponen una edad Jurásico Inferior (Lías) a este gabro. Consecuentemente los autores proponen una nueva interpretación para la apertura oceánica del Domínio Externo del Rif relacionado a la expansión hacia el este del rift oceánico del Atlántico Central. Los mismos autores formulan la hipótesis de que las lavas volcánicas del Jurásico Superior-Cretácico Inferior y los complejos ofiolíticos de la Zona Mesorif son heterocrónicos y corresponden a dos eventos magmáticos distintos y separados en el tiempo. Esta nueva edad asignada al gabro de Bou Adel y la nueva interpretación de la apertura oceánica del Rif Externo no están de acuerdo con los datos estratigráficos ni con el marco *geodinámico del dominio del Rif Externo durante el Mesozoico. Sobre la base de numerosos datos estratigráficos y de la evolución paleogeográfica, se muestra aquí la evidencia de que las lavas volcánicas y los gabros oceánicos de la Zona Mesorif se originaron todos ellos del mismo evento geodinámicos relacionado a la expansión hacia el oeste del océano del Tethys en el límite Jurásico-Cretácico, y que estos gabros oceánicos son complejos ofiolíticos de los mantos Senhadja y Bou Haddoud, empujados sobre la Zona Mesorif Externa durante la orogenia miocena alpina.*

Palabras clave: Cinturón Externo del Rif, límite Jurásico-Cretácico, complejos ofiolíticos, edad radiométrica, datos estratigráficos y paleogeográficos, flujos volcánicos de lava.

Introduction

The Bou Adel massif, one of the large magmatic massifs of the External Rif (Fig. 1), has been known as a granite massif since the seminal works of Marçais (1938), Lacoste and Marçais (1938), and Lacoste (1941) and on the basis of the 1/50,000 geological maps of Taounante-Ain Aicha (Suter, 1964a) and Dhar Souk (Vidal, 1983a). Suter (*ibid.*) regarded it as a granitic ripped from the Paleozoic basement and Vidal (*ibid.*) considered it as an intrusive gabbro of Barremian age. Harmand *et al.* (1986) described the Bou Adel massif as an intrusive gabbro inducting a metamorphic contact in “hornblende hornfels facies” affecting Callovian-Oxfordian sandstone and Upper Jurassic limestone and they gave it a setting up age spanning from the Late Jurassic to Senonian. Based on K-Ar radiometric age (166 ±3 Ma), Asebriy (1994, p. 51) assigned a Callovian age to the Bou Adel gabbro. Benzaggagh *et al.* (2014) and Benzaggagh (2016) demonstrated that this massif, likewise similar massifs eastwards (Dar Bou Aza, Kef El Ghar, and Taineste), corresponds to a genuine ophiolite complexes, evidencing an oceanic opening of the External Rif Domain, at least in its median part (Mesorif Zone) during the latest Jurassic-earliest Cretaceous. Based on a radiometric age (190 ±2 Ma) of zircon grains from the sample BA07, Michard *et al.* (2018) assigned a Early Jurassic age (Liassic) to the Bou Adel gabbro, and subsequently, to the seafloor-spreading beginning through the External Rif Domain. Based on this unique dating, these authors postulated that the oceanic crust

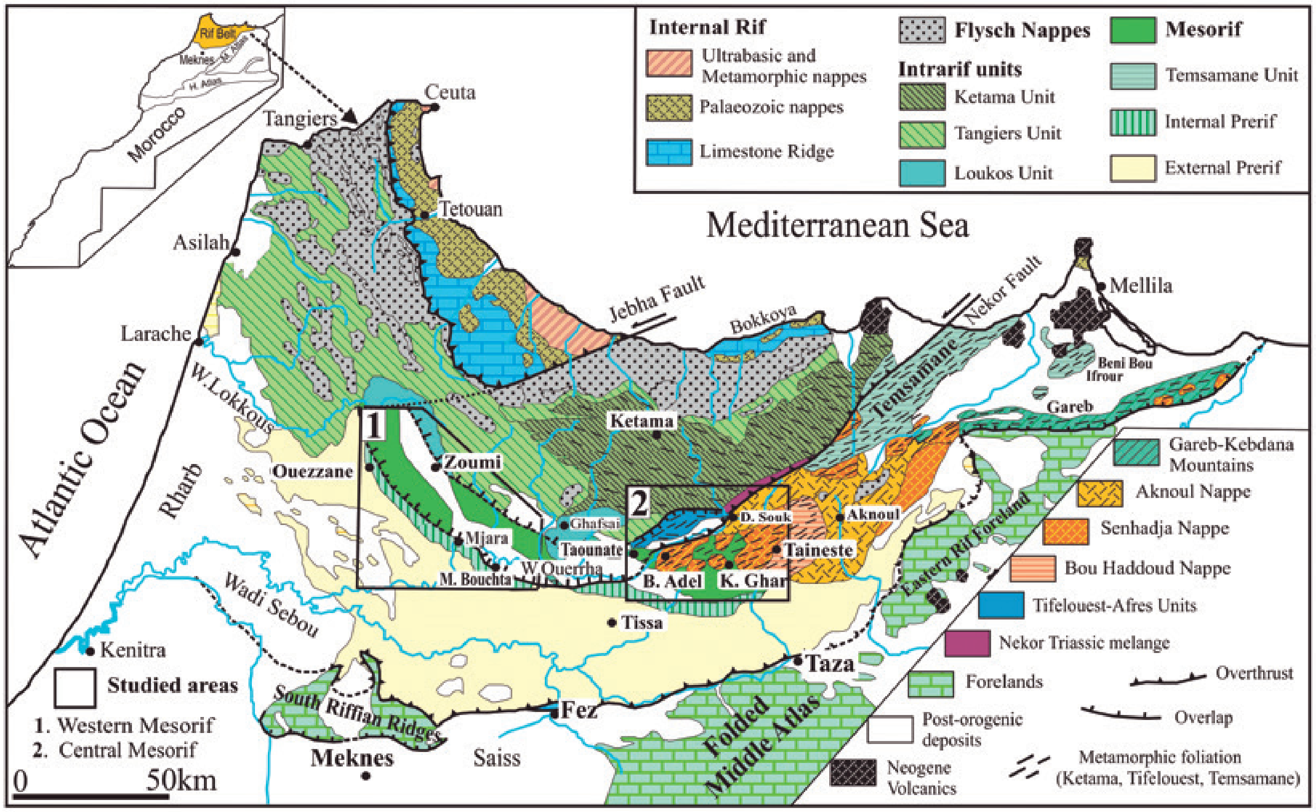


Figure 1. Structural map of the Rif Belt (from Suter, 1980a, *in*: Michard, 1976; amended with data from Suter, 1980a-b).
Figura 1. *Mapa estructural del Cinturón del Rif (de Suter, 1980a, en: Michard, 1976; modificado con datos de Suter, 1980a-b).*

of the External Rif originated from the eastwards expansion of the Central Atlantic, and not from the westwards expansion of the Tethys Ocean, as previously generally accepted. These authors also hypothesized that the Jurassic-Cretaceous volcanic lavas of the Mesorif Zone and the ophiolite complexes of the Senhadja and Bou Haddoud Mesorif nappes are diachronous and correspond to two, distinct and separated in time, magmatic events. According to the same authors, the first magmatic event corresponds to the eastwards expansion of the oceanic rift of the Central Atlantic during the Early Jurassic; the second event would have originated from the Late Jurassic to Berriasian activity of the North-African Transform Fault, or along some synthetic faults. On the basis of numerous stratigraphic data and the palaeogeographic evolution of the External Rif Basin, we intend to demonstrate in this paper that: (i) the Upper Jurassic-Lower Cretaceous volcanic lavas of the Mesorif Zone and the ophiolite complexes of the Central Mesorif all originated from the same geodynamic event; and (ii) both the Early Jurassic age ascribed to the ophiolite complexes and the new interpretation of the oceanic opening of the External Rif disagree with previously well-grounded stratigraphic data, and accepted geodynamic and palaeogeographic frameworks of the External Rif during the Mesozoic. In order to better understand the geological evolution of the External Rif Basin during the Mesozoic, and the setting up of the post Triassic-earliest Jurassic volcanic lavas and the ophiolite complexes, it is necessary to give a brief overview on the Triassic-Lower Cretaceous stratigraphic sequence of the External Rif Basin, since the stratigraphic sequences are the most important markers of the successive geodynamics and palaeogeographic evolution stages of the sedimentary basins.

Triassic-Lower Cretaceous stratigraphic sequence and palaeogeographic and geodynamic evolution of the External Rif Basin

The present overview relies on Suter's Figure 2 (1967, *in*: Michard, 1976) illustrating the Meso-Cenozoic stratigraphic sequence and the main evolutionary stages of the External Rif Basin in a clear and succinct way. This synthetic figure was originally developed from numerous data accumulated over several years of field observations through the External Rif Belt, within the scope of the establishment of several geological maps (Suter, 1961, 1964a-b, 1980a-b). This

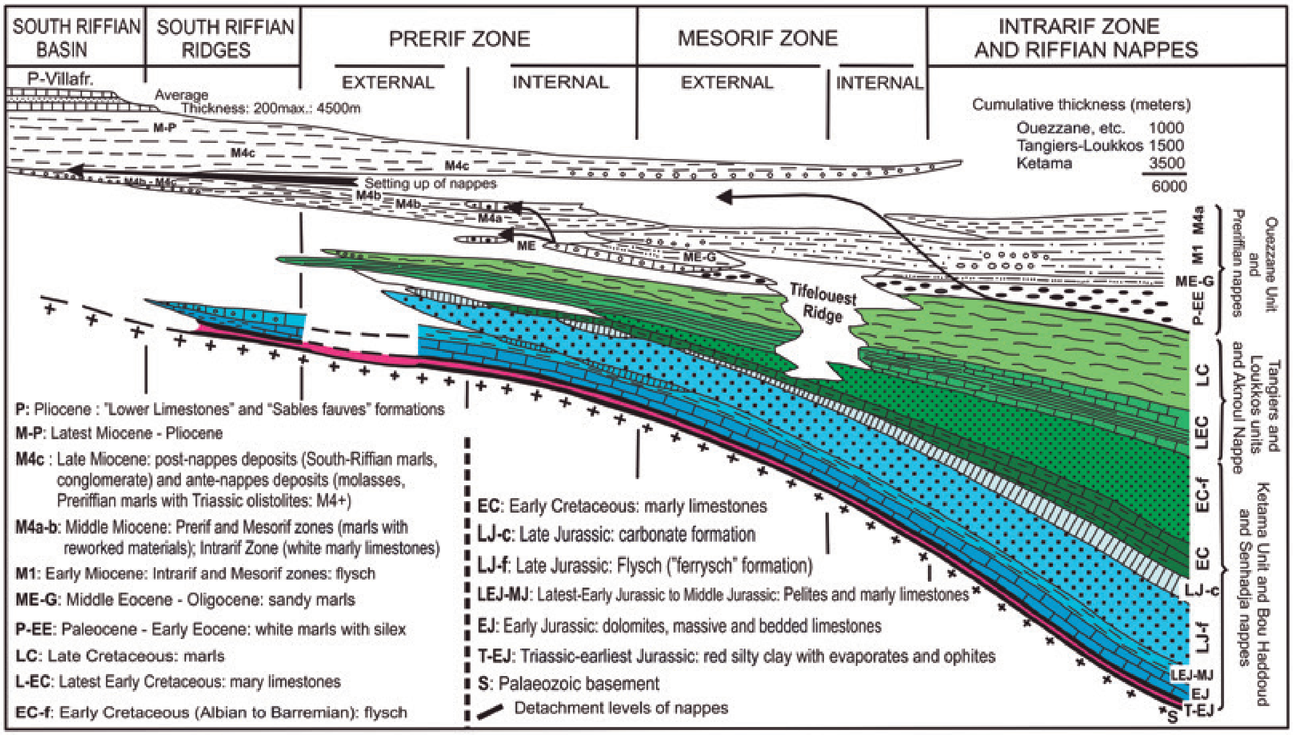


Figure 2. Synthetic scheme of the Meso-Cenozoic stratigraphic sequence of the External Rif Basin (from Suter, 1967; *in*: Michard, 1976; slightly amended). *N.B.* The original caption, in French, was translated into English by the authors of this paper.

Figura 2. *Esquema sintético de la secuencia estratigráfica Meso-Cenozoico del Cuenca Externa del Rif (de Suter, 1967; in: Michard, 1976; ligeramente modificado). N.B. El pie de figura originalmente en francés fue traducido por los autores de este trabajo.*

overview is additionally supported by a collection of geological data from other authors (e.g., Fig. 3), and our own field data. For more illustrations related to this issue, see: Benzaggagh (2011, 2016), Benzaggagh *et al*. (2014) and the reference list below.

Triassic-earliest Jurassic

Facies

In the whole External Rif Basin (Figs. 2, 3A), Triassic-lowermost Jurassic deposits consist of red silty-clays with evaporates, gathering igneous or metamorphic lithoclasts ripped from the Palaeozoic basement and containing often altered interstratified basalt lava flows (ophites). Such a Triassic plastic material is always found in abnormal positions and underlines major tectonic contacts (thrusts, overlaps,...) or redeposited as olistolites, especially into the Senonian marls of the Western External Rif or into the Miocene marls of the External Prerif (Fig. 5A).

Palaeogeography and geodynamics

Triassic-lowermost Jurassic facies of the External Rif Belt document a shallow lagoonal basin with intercalations of basalt lava flows, and corresponding to an intracontinental rift (Fig. 3B) initiated during the earliest stages of the Gondwana breakup.

Early Jurassic (Sinemurian to Domerian)

Facies

In the External Rif, Lower Jurassic deposits (Figs. 2, 3) consist of a thick carbonate formation (ca. 500 m) of Sinemurian-lower Carixian massive limestone (Bulundwe Kitongo, 1987; Papillon, 1989; Favre, 1992), with neritic fauna (calcareous algae, large benthic foraminifers,...), overlain by upper Carixian-Domerian bedded limestone, with pelagic and/or benthic fauna (ammonites, belemnites, foraminifers, sponges,...). Several large exposures of this formation outcrop along the south side of the Middle Ouerrha Valley (e.g., Jebels Sidi Messaoud, Amergou, Arechgou, Beni Ouassal, Sidi Redouane,...), overlapping the Lower Cretaceous marls of the Internal Prerif (Benzaggagh, 2016).

The alignment of these massifs over several dozens of kilometers along the south side of the Ouerrha valley, from Taounante to Mjara, underscores a major abnormal tectonic contact within the Mesorif Zone.

These limestones are also outcropping within several thrusted units of the Bou Haddoud and Senhadja Mesorif nappes (Leblanc, 1983; Vidal, 1983a; Papillon, 1989), namely: Jebels Asfellou, Taineste, Azrou-Akchar, Drinkel, Teirara, and they also constitute the "Middle Liassic" carbonate massifs of Jebels Tiflouest, Tafraout, and Afrès, backthrusting the south front of the Ketama Unit (Andrieux, 1971; Favre, 1992; Benzaggagh, 2016), and the limestone blocks of the Bou Adel village and those of Jebel Keil resting as mega-olistolites on the Bou Adel ophiolite complex (Benzaggagh, 2016).

Palaeogeography and geodynamics

In the External Rif, as in all the other basins of Moroccan Alpine Domain, between the Mediterranean Sea and the South Atlas Fault (Folded and Tabular Middle Atlas, High Atlas, South Riffian Ridges, Eastern Rif Foreland, and Eastern Meseta,...), Lower Jurassic deposits consist of dolomites, and massive limestones with neritic fauna during the Sinemurian-early Carixian, corresponding to shallow inner-platform environment, and upper Carixian-Domerian marly limestone and bedded limestone with pelagic fauna, corresponding to an outer-platform to shallow basinal environment.

According to Michard *et al*. (2018), this time interval corresponds to the early stage of the ocean floor spreading in the External Rif Domain from the Central Atlantic. But (i), as shown above, the Lower Jurassic facies document shallow environments in all Morocccan basins; (ii), none of the authors who had been studying these series has ever reported the occurrence of such magmatic materials, nor any stratigraphic disorder that could support the presence of such an oceanic rift at that time.

Latest Early Jurassic-Middle Jurassic (Toarcian to Bajocian)

Facies

In the External Rif, the Toarcian-Bajocian deposits (Figs. 2, 3) usually outcrop above the "Middle Liassic" carbonate massifs (e.g., Jebels Amergou, Arechgou, Beni Ouassal, Sidi Redouane, Azrou-Akchar, Tiflouest). This stratigraphic interval is represented by condensed series (100 to 300 m-thick) with pelagic fauna (ammonites, *Zoophycos*, micro-filaments and radiolarians), as follows: Toarcian-Aalenian, consisting of marls, marly limestone, and bedded limestone; and Bajocian, most often represented by red marly limestone displaying ammonitico-rosso facies (Suter, 1965; Bulundwe Kitongo, 1987; Papillon, 1989; Favre, 1992).

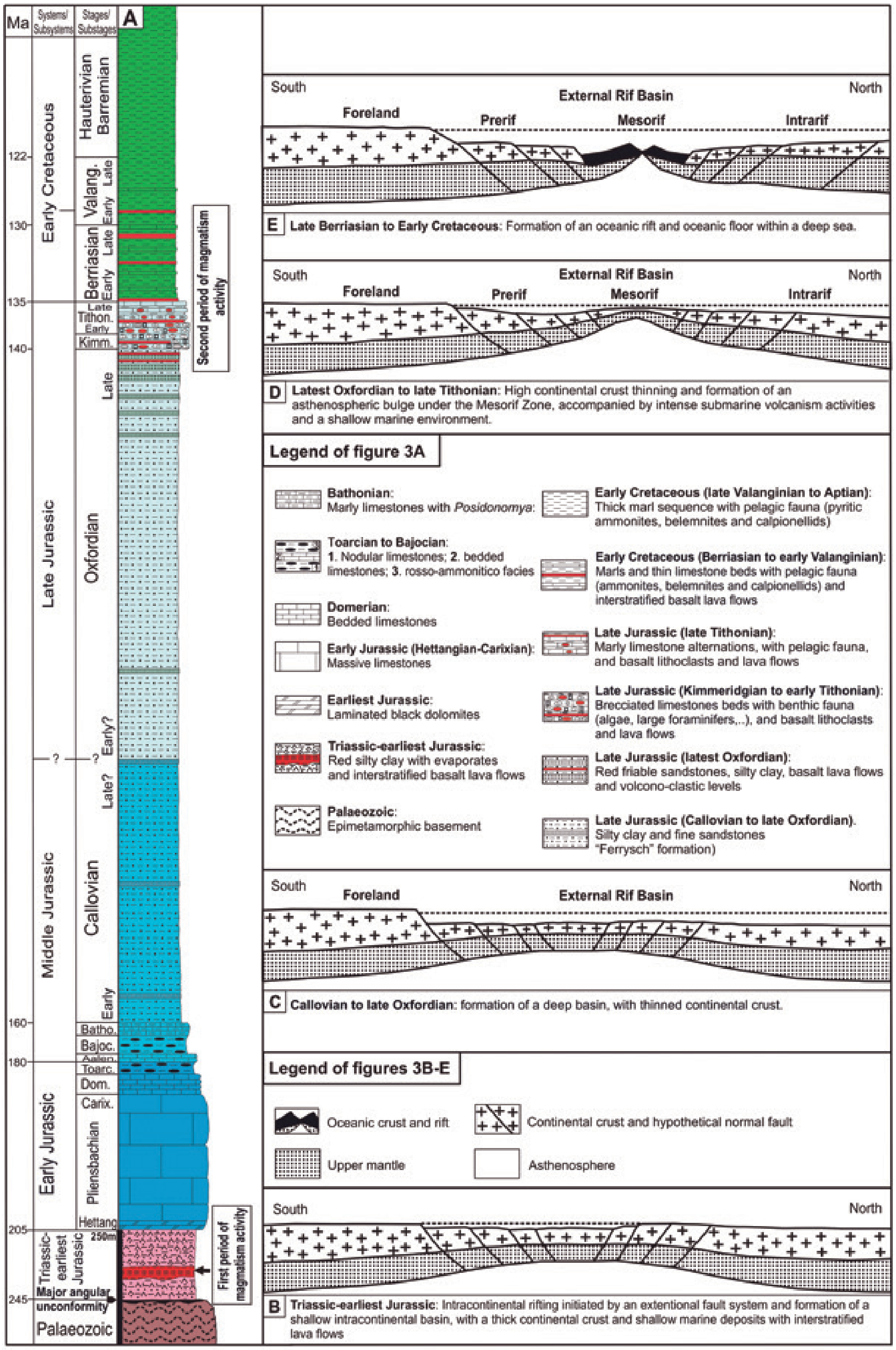


Figure 3. A) Synthetic Triassic to Lower Cretaceous stratigraphic column of the Mesorif Zone, compiled from data by Suter (1965), Andrieux (1971), Leblanc (1979), Wildi (1981), Favre (1992), and Benzaggagh (2000); radiometric ages were compiled from Dictionary of Earth Sciences (Michel *et al*., 1997). B-E) Hypothetical north-south cross sections showing the main stages of the palaeogeographic and geodynamics evolution of the External Rif Basin. B) During the Triassic-earliest Jurassic; C) from Callovian to late Oxfordian; D) from latest Oxfordian to latest Tithonian; E) from early Berriasian and during the Early Cretaceous. Sedimentary cover was not considered.

Figure 3*. A) Columna estratigráfica sintética del Triásico al Cretácico Inferior compilada a partir de datos de Suter (1965), Andrieux (1971), Leblanc (1979), Wildi (1981), Favre (1992), and Benzaggagh (2000); las edades radiométricas se compilaron de Dictionary of Earth Sciences (Michel et al., 1997). B-E) Cortes hipotéticos norte-sur mostrando las principales etapas de la evolución paleogeográfica y geodinámica de la Cuenca externa del Rif. B) Durante el Triásico-Jurásico Inferior; C) del Calliviense al Oxfordiense Superior; D) del final del Oxfordiense al final del Titoniense; E) del Berriasiense Inferior y durante el Cretácico Inferior.*

Palaeogeography and geodynamics

Toarcian-Bajocian facies and fauna of the External Rif evidence an outer-platform to relatively deep-basinal setting, with a continental crust probably much thinner than during the previous periods (Fig. 3C). Once again, we notice that none of the authors who had been studying these series has ever reported the occurrence of any magmatic material.

Middle Jurassic (Bathonian)

Facies

In the External Rif, Bathonian outcrops are scarce and consist of marls, marly limestone and platy microfolded limestone, often rich in microfilaments.

Palaeogeography and geodynamics

Around the Bajocian-Bathonian boundary, the Moroccan Alpine Domain had undergone a fundamental palaeogeographic change (Benzaggagh *et al.*, 2016). All the basins located east of the Western Moroccan Meseta emerged. Anticlinal ridges and synclinal depressions with continental deposits are formed in the Folded Middle Atlas, and the Central and Eastern High Atlas (Studer and du Dresnay, 1980; Haddoumi *et al.* 2008, 2010). In the External Rif Basin, the Bathonian facies document an outer platform to basinal environment similar to those of the previous period.

Late Jurassic (Callovian to Oxfordian)

Facies

In the External Rif, Callovian-Oxfordian deposits (Figs. 2, 3A) correspond to a thick monotonous detrital series (1,500 m-thick) called 'ferrysch' formation (Wildi, 1981), consisting of alternations of thin fine-grained sandstone beds and silty clays. This formation is exposed in very large outcrops in the Mesorif and Internal Prerif zones (Fig. 5B), the southern front of the Ketama Unit, the Senhadja and Bou Haddoud nappes. Wildi (1981) regarded it as a deep sea fan comparable to that of the Nile River. Nevertheless, in the Mesorif Zone, the top of the 'ferrysch' formation presents over a few dozens of metres thickness, friable red sandstone with relatively coarse quartz grains, indicating shallower environments than during the Callovian-Oxfordian *pro parte*. Synchronous to this lithological change are the first post Triassic-earliest Jurassic volcano-sedimentary events (Figs. 3A, 4F) spread through the whole Mesorif Zone.

Palaeogeography and geodynamics

Facies of the most part of the 'ferrysch' formation evidence a deep basinal environment with a strongly thinned continental crust (Fig. 3C). Furthermore, the facies of the top 'ferrysch' formation in the Mesorif Zone, illustrate a rapid transition to a shallowing environment (Figs. 3A, 4A-F), announcing the onset of a fundamental palaeogeographic change of the External Rif Basin.

Late Jurassic (Kimmeridgian to early Tithonian)

Facies

At the Kimmeridgian-Tithonian boundary two major geological events occurred: a sudden drop in terrigenous inputs and the onset of a carbonate platform over the whole External Rif Basin (Figs. 2-4). This platform which has been strongly dismantled by the Alpine Miocene orogeny, forms alignments of decametric to barely kilometric blocks called 'sofs', in the Internal Prerif and the Mesorif zones. These 'sofs' document three successive facial types (Benzaggagh and Atrops, 1997), from south to north: (i) 'sofs' with *neritic facies* (200 to 400 m); (ii) 'sofs' with *pelagic facies* (10 to 70 m), in the Internal Prerif Zone; and (iii) 'sofs' with *brecciated limestone facies* (10 to 150 m), in the Mesorif Zone, the Bou Haddoud and Senhadja nappes, and the south front of the Ketama Unit. These latter "sof" group are locally rich in autochthonous benthic fauna of the photic zone (calcareous algae, large foraminifers, crinoid ossicles,…) and also contain pelagic fauna. Within the stratigraphic series of this 'sof' group are intercalated several interstratified basalt lava flows and cemented or marly matrix breccias (1 to 20 m-thick), containing angular, centimetric to metric, limestone and sandstone lithoclasts, and basalt pebbles (Figs. A3, 4A-F).

Palaeogeography and geodynamics

The north-south arrangement and the east-west extension of the facial 'sof' group suggest a clear trend to a shallowing and a strong topographic unevenness of the External Rif Basin during the Kimmeridgian-early Tithonian. Three palaeogeographic zones can be distinguished: shallow inner-platform and outer-platform in the Internal Prerif Zone, and a broad median ridge in the Mesorif and partly in the Intrarif zones (Ketama Unit). Such a palaeogeographic framework is consistent with Suter's palaeogeographic scheme (Fig. 2) based upon lateral facies and thickness variations of the Upper Jurassic carbonate formation. This

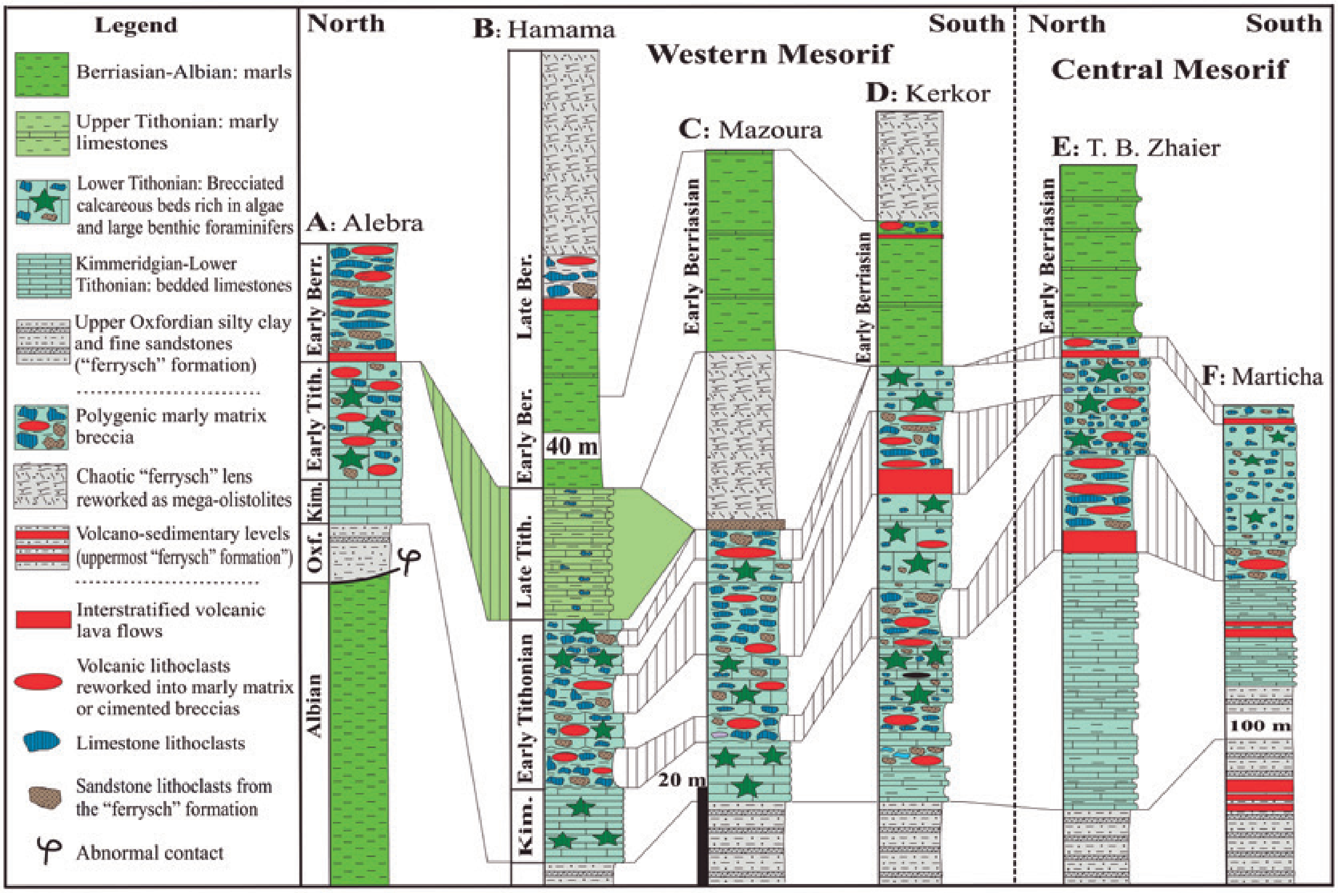


Figure 4. Main Mesoriffian outrops with volcanic materials and volcano-sedimentary events around the Upper Jurassic-Lower Cretaceous boundary. A-D) Western Mesorif. E) Bou Haddoud Nappe. F) Central Mesorif.

Figura 4. *Principales afloramientos del Mesorif con materiales de eventos volcánicos y volcano-sedimentarios en torno al límite Jurásico Superior-Cretácico Inferior. A-D) Mesorif Occidental. E) Manto Bou Haddoud. F) Mesorif Central.*

major palaeogeographic change of the External Rif Basin, synchronous to an intense volcanic activity, undoubtedly originated from a lithospheric bulge along the Mesorif Zone (Fig. 3D), preceding the continental breakup and the formation of an oceanic rift, then an oceanic floor during the Early Cretaceous.

Effects of volcanic activities and basement uplift on sedimentary environments

The uplift of the External Rif basement at the Oxfordian-Kimmeridgian boundary generated favourable conditions to the onset of the Upper Jurassic carbonate platform. Tectonic instabilities and volcanic activities accompanying this uplift are responsible for the strong brecciation of the Kimmeridgian-lower Tithonian carbonate formation in the whole median part of the External Rif, as well as the local, total or partial, dismantling of this formation. Additionally, in many outcrops of the Mesorif Zone and the Senhadja Nappe, a thermal metamorphism resulting from the volcanic lava flows had turned some limestone and sandstone lithoclasts into marble or quartzite (Benzaggagh, 2011, 2016).

Late Jurassic-Early Cretaceous (late Tithonian to Barremian)

Facies

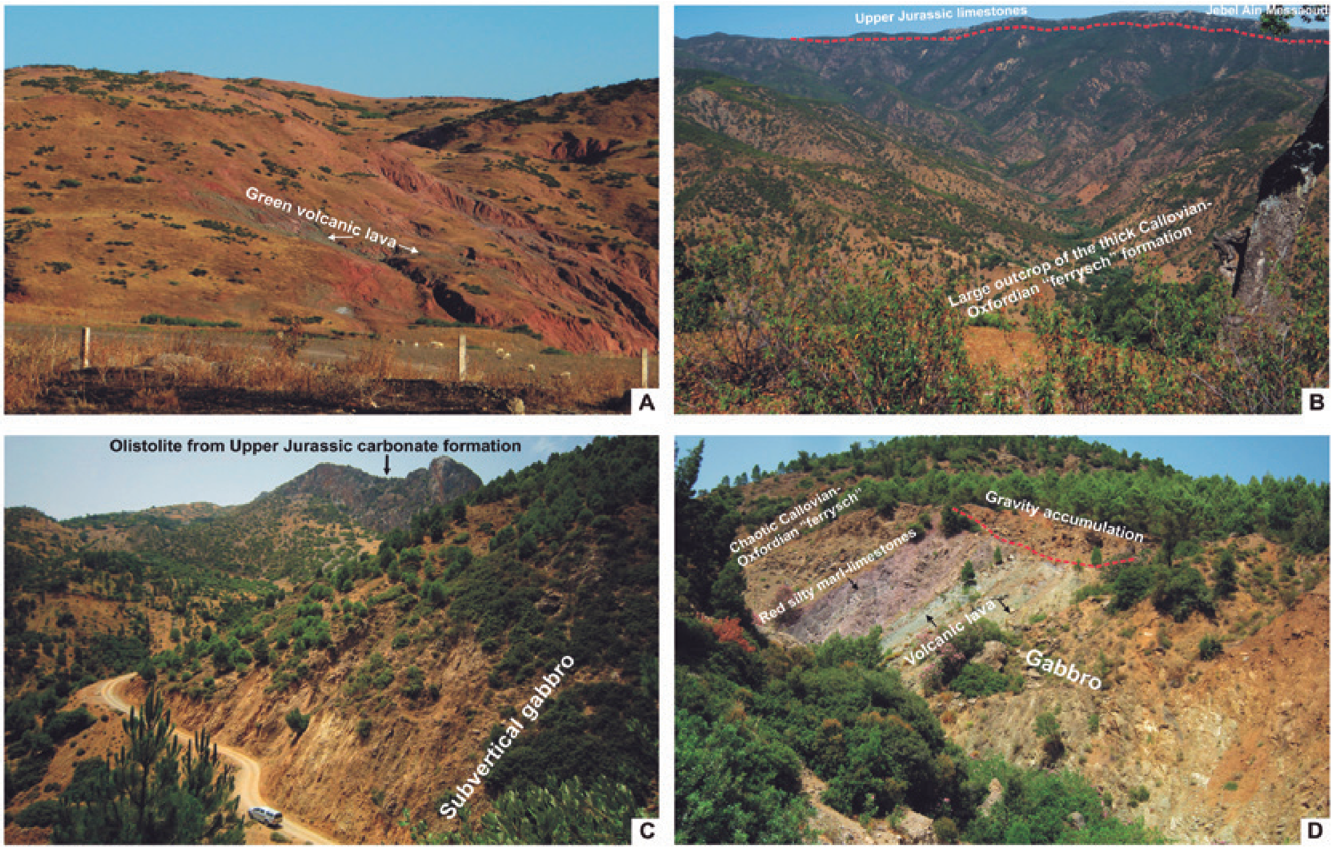
In the External Rif, late Tithonian-Early Cretaceous (Berriasian to Barremian) is represented by thick marls and marly limestone formations with pelagic fauna, thicker in the Ketama Unit than in the Mesorif and Internal Prerif zones (Fig. 2). In the Mesorif Zone, the Senhadja and Bou Haddoud nappes, and the south front of the Ketama Unit, the Lower Cretaceous marls display numerous evidence of volcanic activities, dated of early Berriasian to Valanginian by means of ammonites and calpionellids; amongst others: the lower Berriasian volcanic lava of Jebels Alebra (Fig. 4A), Mazoura (Fig. 4C) and Kerkor (Fig. 4D); the upper Berriasian interstratified lava flows of the eastern side of Jebel Hamama (Fig. 4B), and the volcanic lavas of the Valanginian marls of Mjara, and those of the Ketama Unit (Favre, 1992). Volcanic materials attributed to the Barremian were reported in several localities of the Senhadja Nappe (Vidal, 1979, 1983a-b).

Palaeogeography and geodynamics

From the late Tithonian to the Early Cretaceous, the stratigraphic series of the External Rif document a deep basinal environment, definitely with an oceanic rift and oceanic floor in the process of formation under a thick, and mostly plastic Jurassic sequence (Fig. 3E), prone to huge landslides as mega-olistolites.

Effects of volcanic events on sedimentary environments

At the Tithonian-Berriasian boundary, the External Rif Basin was subjected to a new palaeogeographic change. The sedimentary environments support deeper basinal settings. This palaeogeographic change is synchronous to numerous volcanic activities that concern the whole median part of the External Rif. In several localities among the Mesorif Zone, the Lower Cretaceous stratigraphic series are strongly disturbed by subsurface sliding of huge slabs ripped from the two Upper Jurassic formations and resting as mega-olistolites on the Lower Cretaceous marls (Benzaggagh and Habibi 2006; Benzaggagh, 2011, 2016). As is the case on the eastern side of Jebel Hamama (Fig. 4B), there a hectometric 'ferrysch' hill, very chaotic, lies on the upper Berriasian marls through the volcanic lava aforementioned and a volcano-clastic level yielding, besides volcanic lavas, metric blocks of Upper Jurassic limestone and sandstone. At Jebel Kerkor (Fig. 4D) a decametric lens of 'ferrysch' lies on the lower Berriasian marls, by a volcano-clastic level. At Jebel Mazoura (Fig. 4C), a 'ferrysch' lens is intercalated between the lower Tithonian limestones and the lower Berriasian marls. Lower Tithonian limestones are capped by a mega-breccia with volcanic lithoclasts. At Kortba, decametric slabs of Upper Jurassic limestone are lying disorderly on the Valanginian marls (Benzaggagh and Habibi, 2006).



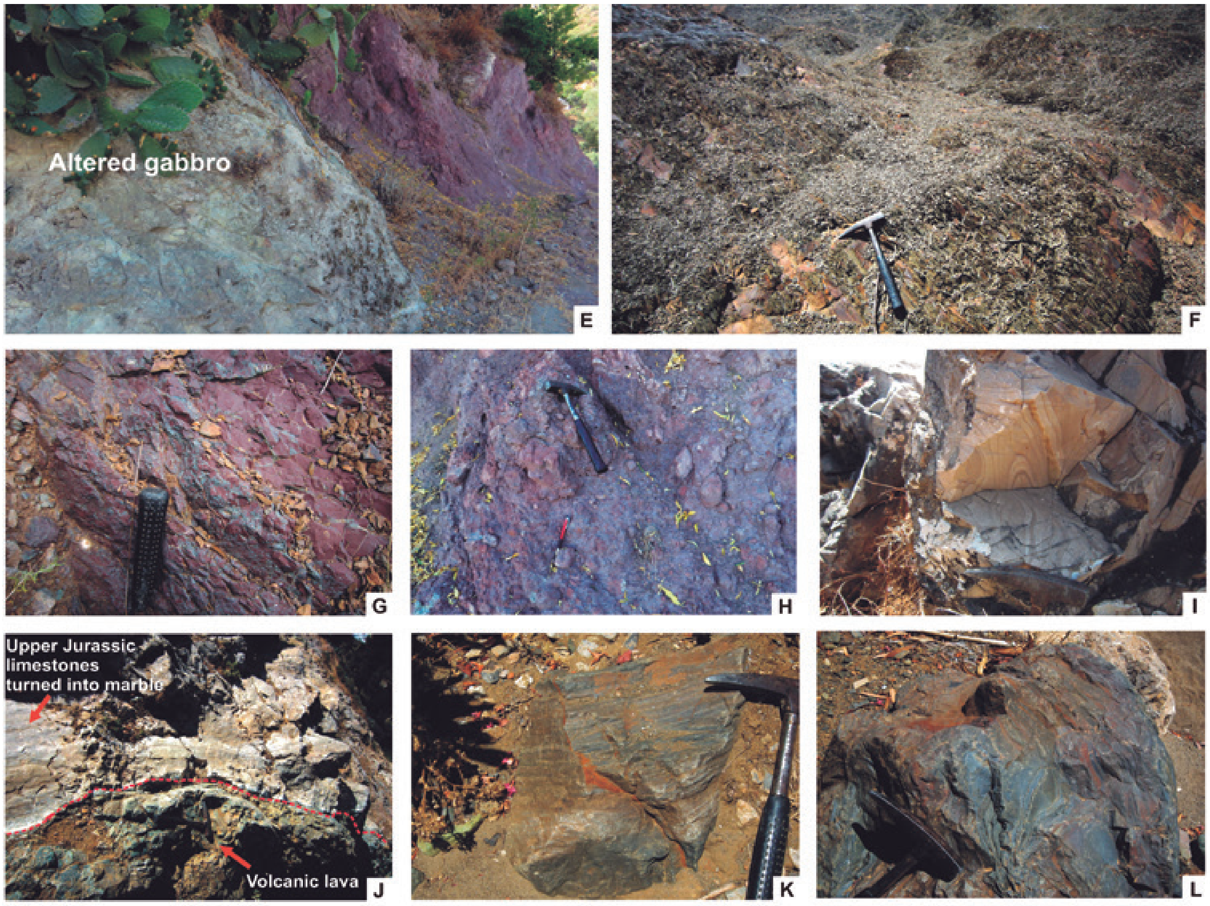


Figure 5. Some geological aspects of the External Rif Belt related with the subject of this paper. A. Triassic-earliest Jurassic outcrop of red silty clay, with evaporates and interstratified volcanic lava packaged in the Miocene marls of the External Prerif (3 Km west of Tissa). B. Large outcrop of are thick Callovian-Oxfordian "ferrysch" formation, consists of silty clay and fine sandstone alternation, overlain by Kimmeridgian-lower Tithonian carbonate formation (Bou Haddoud Nappe, 5 to 10 km south of Taineste). C. Thick stratified oceanic gabbro sequence, of sub-vertical dip; in background, gabbros of low dip are overlying by mega-olistolite, probably from the Upper Jurassic carbonate formation (Senhadja Nappe, 3 to 5 km north of Kef El Ghar). D. Ophiolite complex of Jebel Karia, showing the succession of: thick sequence of gabbros; light-green stratified volcanic lavas; red silty marls and silty marly limestones; and chaotic thick series of silty clay and fine sandstone from the "ferrysch" formation (Senhadja Nappe, 3 km north of Kef El Ghar). In this outcrop we note the absence of the volcano-clastic level and any thermal metamorphism affecting the Upper Jurassic lithoclasts. E. Altered sub-vertical stratified gabbro overlain in concordant dip by a red volcano-sedimentary level. In this outcrop we also note the absence of the volcano-clastic level and any thermal metamorphism affecting the Upper Jurassic lithoclasts (Senhadja Nappe, 100 m south of Taineste). F. Lower Cretaceous marls affected by a double fracture cleavage, chip chopping (Senhadja Nappe, 10 to 15 Km northwest of Kef El Ghar). G. Details of the red silty marls and silty marly limestone level of the Jebel Karia ophiolite complex. H. Details of the red volcano-sedimentary level of the Taineste ophiolite complex. I. Upper Jurassic limestone block in the volcano-clastic level of the Dar Bou Aza Ophiolite complex turned into marble by the volcanic lava flows (Senhadja Nappe, 15 km west of Kef El Ghar). J. Volcano-clastic level of the Dar Bou Aza Ophiolite complex showing Upper Jurassic limestone block turned into marble by volcanic lava flows (Senhadja Nappe, 15 km west of Kef El Ghar). I and J, from the same volcano-clastic outcrop. K-L. Callovian-Oxfordian fine sandstone blocks of the "ferrysch" formation turned into quartzite by the volcanic lava (scree blocks in Wadi Azrou from volcano-clastic level of the Bou Adel ophiolite complex, Senhadja Nappe, 500 m south of the Bou Adel spring).

Figure 5. *Algunos aspectos geológicos del Cinturón del Rif Externo relacionados con la temática de este trabajo. A. Afloramiento Triásico-Jurásico Inferior de arcilla limosa roja, con evaporitas y lava volcánica interestratificada embebidas en las margas de Mioceno del Prerif Externo (3 km al oeste de Tissa). B. Amplio afloramiento de la potente formación "ferrysch" del Calloviense-Oxfordiense, consistente en la alternancia de arcilla limosa y arenisca fina, y superpuesto por formación carbonática del Kimmeridgiense Titoniense Inferior (Bou Haddoud Nappe, 5 a 10 km al sur de Taineste). C. Potente secuencia de gabro oceánico estratificado, de buzamiento sub-vertical; al fondo, gabros de bajo buzamiento superpuestos por mega-olistolitos, probablemente de la formación carbonatada del Jurásico Superior (Senhadja Nappe, 3 a 5 km al norte de Kef El Ghar). D. Complejo ofiolítico de Jebel Karia, mostrando la sucesión de: una potente secuencia de gabros; lavas volcánicas estratificadas de tonos verdosos claros; margas limosas rojas y calizas margosas limosas; y potente serie caótica de arcilla limosa y arenisca fina de la formación "ferrysch" (Senhadja Nappe, 3 km al norte de Kef El Ghar). En este afloramiento es de notar la ausencia del nivel vocano-clástico y que no hay signos de metamorfismo termal que afecte a los litoclastos del Jurásico Superior. E. Gabro alterado con estratificación sub-vertical superpuesto por un nivel vocano-sedimentario de color rojo y del mismo buzamiento. In este afloramiento también es de destacar la ausencia del nivel volcano-clástico y cualquier signo de metamorfismo termal afectado a los litoclastos del Jurásico Superior (Senhadja Nappe, 100 m al sur de Taineste). F. Margas del cretácico Inferior afectadas por una fractura doble de exfoliación, con escisión en astillas (Senhadja Nappe, 10 a 15 Km al noroeste de Kef El Ghar). G. Detalles del nivel de margas limosas rojas y caliza margosa limosa del complejo ofiolítico de Jebel Karia. H. Detalles del nivel vocano-sedimentario rojo del complejo ofiolítico de Taineste. I y J. Bloque calizo del Jurásico Superior en el nivel vocano-clástico del complejo ofiolítico Dar Bou Aza convertido en mármol por los flujos de lavas volcánicas (Senhadja Nappe, 15 km al oeste de Kef El Ghar). J. Nivel vocano-clástico del complejo ofiolítico de Dar Bou Aza. I y J son del mismo afloramiento volcano-clástico. K-L. Bloques de arena fina del Calloviense-Oxfordiense de la formación "ferrysch" transformada en cuarcita por la lava volcánica (cantos en Wadi Azrou del nivel volcano-clástico del complejo ofiolítico de Bou Adel, Senhadja Nappe, 500 m al sur de la fuente Bou Adel).*

Arguments for a latest Jurassic-earliest Cretaceous age of the Central Mesorif ophiolite complexes

The Bou Adel ophiolite complex, like any other ophiolite complexes of the Central Mesorif, consists of stratified gabbros, capped by volcanic lava flows, volcano-clastic levels, and mega-olistolites of Middle to Upper Jurassic materials (Benzaggagh, 2016, Fig. 6). These four levels constitute a homogeneous and indissociable lithostratigraphic unit. Besides volcanic lavas, the volcano-clastic levels contains lithoclasts from dismantled pre-existing formations, amongst others: sandstone and limestone lithoclasts from the 'ferrysch' and the Kimmeridgian-lower Tithonian carbonate formations respectively, and marly limestone possibly from the upper Tithonian alternations, as well as ophicalcite lithoclasts. Some lithoclasts of the volcano-clastic levels are transformed into marble (Fig. 5I-J) or quartzite (Fig. 5K-L) by volcanic lavas, as is the case in several localities of the Western Mesorif and the Senhadja Nappe, without any gabbros occurring. It becomes obvious that these volcanic and volcano-clastic levels are slightly younger than the youngest lithoclasts they contain, which means, at least posterior to the Tithonian. Consequently, a latest Jurassic-earliest Cretaceous age appears logical and consistent, given the lithoclasts found in the volcano-clastic levels, but also compared to the Berriasian-Valanginian lava flows of the Mesorif Zone, Bou Haddoud and Senhadja nappes and Ketama Unit, which are all most definitely synchronous to the volcanic lavas of the ophiolite complexes. So, it is logical to conclude that the volcanic lavas of the middle part of the Rif Belt and those of the ophiolite complexes all originate from the same and single geodynamic event. Based on the stratigraphic contacts, Vidal (1979) gave a Barremian age to the gabbro of the studied area. Harmand *et al.* (1986) on the base on the metamorphism affecting sandstone and limestone lithoclasts from the two Upper Jurassic formations, gave a setting up age to the Bou Adel gabbro ranging from the Late Jurassic to Senonian. Though slightly younger these ages are consistent and agree with our field observations and results.

It is very interesting to note that the ophiolite complex of Jebel Karia (3 km northwest of Kef el Ghar), presents a particular lithostratigraphic succession consisting of: a thick sequence (at least 200 m, Fig. 5C) of gabbros often altered; a stratified layer (10 m) of light green volcanic lava; and a stratified red sedimentary layer (7 m), overlain bay a very chaotic thick series of silty clay and fine sandstone from the "ferrysch" formation (Fig. 5D), and mega-limestone blocks strongly dislocated and very likely from the Upper Jurassic carbonate formation (Fig. 5C).

This red stratigraphic level had been previously qualified as a radiolarian level (Benzaggagh *et al.*, 2014). Analysis of this level shows that it is rather a red silty marl and silty marly limestone level (Fig. 5D, G) resting directly on the volcanic lava without any thermal metamorphism.

Further east, at the village of Taineste, verticalized stratified gabbros are surmounted in concordant dip by a red volcano-sedimentary level (Fig. 5E) consisting of red marls and fine lithoclasts of limestone, sandstone and marly limestone (Fig. 5H) once again without any thermal metamorphism.

We also note the total absence of lithoclasts with thermal metamorphism in these two localities.

These facts testify that these red sedimentary levels were deposited under calm tectonic sedimentary conditions on a cooled oceanic floor, outside the active oceanic rift of that time.

Consequently, these autochthonous deposits are posterior to the formation of the first oceanic floor slices (in its stratigraphic acceptance) of the External Rif Basin, and they unambiguously demonstrate that the substratum of the Rif Trough in its eastern part had really reached the stage of an oceanic crust.

The dating of these levels, especially the first one, allows us to frame the age between the first stages of the oceanic opening (oceanic rift stage), which is certainly latest Jurassic-earliest Cretaceous in age, as given by the Upper Jurassic sandstone and limestone lithoclasts of the volcano-clastic levels of the ophiolite complexes and the age of the formation and the exhumation of a real oceanic crust, which is logically prior to the age of the overlying red marl and marly limestone levels.

Significance of the 190 ±2 Ma age ascribed to the Bou Adel gabbro

Analysis of zircon grains from the Bou Adel gabbro by Michard *et al.* (2018) provided two different radiometric ages: 2 Ga and 190 ±2 Ma. The first age was assigned by these authors to a xenocrystic zircon inherited from an ancient continental crust, most likely the West-African Craton. The second age (190 ±2 Ma) quite matches within the age group (196-200 Ma) compiled from dozens of Triassic-earliest Jurassic basalt samples of the Eastern Atlantic Margin, namely Morocco and Portugal (Knight *et al.*, 2004; Verati *et al.*, 2007). This age (190 ±2 Ma) is most likely related to the first, Triassic-earliest Jurassic, magmatic event of the External Rif. This first magmatic event had taken place in an intracontinental basin with a thick continental crust (Figs. 2, 3B) as evidenced by the coeval sedimentary facies. In fact, crustal thinning would have taken several million years (probably 30 to 40 Ma) before the final continental breakup around the Jurassic-Cretaceous boundary and then the formation of an oceanic rift and floor (Fig. 3D-E) during the Early Cretaceous.

Direction of the oceanic expansion in the External Rif Domain

The most extensive ophiolite complexes of the Rif Belt are all situated within the Central Mesorif, between Bou Adel and Taineste. There and in all the areas of the Eastern External Rif (Temsamane Mesorif, Gareb and Beni Bou Ifrour mountains), the Mesozoic series are the most highly tectonized and deformed of the whole Rif Belt, on both macro- and microscopic scales (Andrieux, 1971; Leblanc, 1979; Suter, 1980a-b; Favre, 1992; Negro *et al.*, 2007). The plastic Mesozoic materials of these series in all these geological domains are affected by a double schistosity (Fig. 5F), epizonal metamorphic, metric and millimetric folds highly crinkled, boudinages, compression joints, mineral dissolution and recrystallization. At a larger scale, the southern side of the Ouerrha Valley, between Bou Adel and Taineste (Fig. 1) shows the superimposition of several thrust sheet units of materials from the lower part of the of Jurassic Lower Cretaceous sequence, called the Lower Riffian nappes ("nappes rifaines inférieures": Senhadja and Bou Haddoud, Leblanc, 1979). These two nappes, particularly the Senhadja one, carried away the aforementioned ophiolite complexes. The northern side of the Ouerrha Valley documents the backthrusting of the large "Middle Liassic" carbonate massifs (Jebels Tiflouest, Tafraout and Afrès) on the southern front of the Ketama Unit that Andrieux (1971) formerly regarded as of northern-Ketama origin.

In the Western Rif, between Taounate and Ouezzane (Fig. 1), the tectonic deformations of the Mesozoic series were much less sizeable, given the absence of metamorphism, schistosity and microtectonic structures. The main tectonic events affecting this area are the over-thrusts of large "Middle Liassic" carbonate massifs on the Lower Cretaceous marls of the Internal Prerif, all along the southern side of the Ouerrha Valley, underscoring a major overlap within the Mesorif Zone, and the presence of a few klippe nappes of Upper Jurassic materials ('ferrysch' and Upper Jurassic limestone) on the same marls in the Moulay Bouchta area (Benzaggagh, 2016). Therefore, it becomes obvious that, during the Jurassic and the Cretaceous, the External Rif Basin had been broader east than west, and consequently widely opened towards the Tethys Ocean, forming its westwards extension.

Tectonic transport of ophiolite complexes

Benzaggagh *et al*. (2014) and then Michard *et al*. (2018) assumed that all the ophiolite complexes of the Central Mesorif had been transported laterally over several hundreds of kilometres either from east to west (Benzaggagh *et al*., 2014), or from west to east (Michard *et al*., 2018). In fact, all the structural units of the Central Rif (Ketama Unit, Mesorif, Internal Prerif, Bou Haddoud and Senhadja nappes) display similar stratigraphic sequences and, accordingly, also recorded the same Mesozoic geological evolution and events, with some lateral facies and thickness variations in the respective formations, related to the sedimentary environmental settings. So far, no exotic structural units carried from east to west or from west to east have ever been evidenced in these areas and fully documented with field observations. The longest tectonic displacement of the structural units (magmatic basement and sedimentary cover) in these areas occurred roughly from north to south (from NE to SW, or NW to SE), related to both early and middle Miocene paroxysmal alpine orogenic phases. The main tectonic effects of such shortenings have already been exposed above. This all means that the ophiolite complexes of the Senhadja and Bou Haddoud nappes are the obducted evidence of a subducted oceanic floor during the Miocene Alpine Orogeny (Benzaggagh, 2016), as is the case for the ophiolite complexes of the Alps and those of the other Tethyan Ranges.

Conclusions

The Mesozoic stratigraphic series of the External Rif Belt evidence that the first post Triassic-earliest Jurassic volcanic events took place from the latest Oxfordian and lasted at least up to the Valanginian. These magmatic events affected the whole median part of the External Rif, from Taineste to Ouezzane (Mesorif, Senhadja and Bou Haddoud nappes, and the southern front of the Ketama Unit). The sedimentary lithoclasts of the volcano-clastic levels of the ophiolite complexes of the Central Mesorif, as well as the overlying olistolites, all evidence that the volcanic and volcano-clastic levels of these ophiolite complexes are slightly younger than the Upper Jurassic carbonate lithoclasts they contain.

It is also clear that the volcanic lava and the underlying gabbros are synchronous to the Berriasian-Valanginian lava flows of the median part of the External Rif. Consequently, all the magmatic materials studied herein originated from a single geodynamic event, related to the activity of an oceanic rifting from the latest Jurassic, then to the oceanic floor spreading during the Early Cretaceous. This all means that: (i) the External Rif Belt was much wider east than west during the Jurassic and the Cretaceous interval times, and subsequently widely opened towards the Tethys Ocean as a western arm; (ii) the direction of movement of the structural units (magmatic basement and sedimentary cover) was roughly from north to south, inducing an impressive thrusting of the Mesorif nappes with deep sedimentary materials and ophiolite complexes (Senhadja and Bou Haddoud) over the External Mesorif; (iii) the position of the ophiolite complexes at the base of several thrusted units, particularly of the Senhadja Nappe, demonstrates that these ophiolite complexes represent obducted slabs of an oceanic crust that was once subducted. It should also be noted that the lateral displacements, from east to west or from west to east, inferred for these magmatic materials, are not supported by any field argument and are in disagreement with all the former geological studies on the External Rif Belt, and that the 190 ±2 Ma radiometric age attributed to the Bou Adel gabbro is very probable, in connection with the first magmatic event of the External Rif Belt, i.e., the Triassic-earliest Jurassic magmatic event.

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