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Tholeitic basalts and ophiolitic complexes of the Mesorif Zone (External Rif, Morocco) at the Jurassic-Cretaceous boundary and the importance of the Ouerrha Accident in the palaeogeographic and geodynamic evolution of the Rif Mountains

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ABSTRACT

The stratigraphical series around the Jurassic-Cretaceous boundary of the External Rif Mountains, in particular those in the Mesorif Zone, exhibits many outcrops with volcanic materials spread westwards over 200 km. These materials show diverse aspects: basalt lithoclasts reworked into calcareous breccia beds or in marly matrix breccia, interstratified lava flows and volcanoclastic complexes incorporated within the Berriasian marls. In the Central Rif, several magmatic blocks outcrop, usually regarded as granite scales from the Paleozoic basement or as intrusive gabbros of Barremian age. Actually these magmatic massifs display typical ophiolitic sequences and they are overlaid by mega-olistoliths of Jurassic materials and locally by radiolarite layers. Geochemical analysis of several basalt and gabbro samples belonging to the Mesorif Zone evidenced that both display a typical E-MORB magma indicating at least partial oceanization of the Mesorif basement. Concerning geodynamics, the Mesorif Zone had undergone, at the Jurassic-Cretaceous boundary interval, two successive palaeogeographic phases: an uplift, close to emersion during the Kimmeridgian-Early Tithonian interval, stressed by important submarine volcanic activities and intense brecciation of the carbonate formations, followed by a general collapse at the Late Tithonian, underlined by lava flows, slumping as mega-olistoliths and the formation of an oceanic crust, at least in the Central Rif.

These magmatic materials, distributed on both sides of the Ouerrha Valley, evidence that this westwards extending valley (the Nekor Accident), may correspond in the Central Rif, to two palaeo-subduction planes which become two major overlapping thrusts in the western part of the Rif Mountains.

Key words: tholeitic basalts, ophiolitic complexes, possible palaeo-subduction, Jurassic-Cretaceous boundary, External Rif, Morocco

Basaltos toleíticos y complejos ofiolíticos de la zona mesorifeña (Rif externo, Marruecos) en el límite Jurásico-Cretácico y la importancia del Sistema del Ouerrha en la evolución paleogeográfica y geodinámica de cadena montaña del Rif

RESUMEN

Las series estratigráficas del límite Jurásico-Cretácico del Rif externo, en particular éstas del Mesorif, contienen numerosos rastros de actividad volcánica distribuidos de este a oeste a lo largo de 200 km. Estos materiales presentan aspectos variados: litoclastos de basaltos resedimentados dentro de bancos calco-brechificados o de brechas con matriz margosa; coladas de lavas interestratificadas y complejos vulcano-sedimentarios contenidos en las margas del Berriasiense. En el Rif central afloran importantes macizos magmáticos, considerados durante mucho tiempo, como fragmentos del zócalo granítico, acarreados tectónicamente o como los gabros *intrusivos. Estos macizos muestran, efectivamente, las típicas secuencias ofiolíticas y son coronadas por megaolistolitos de materiales jurásicos o localmente por capas de radiolaritas. Los análisis geoquímicos de varias muestras de basalto y gabros de la zona mesorifeña muestran que se tratan de dos casos, de un magma de tipo E-MORB, lo que indica una oceanización al menos parcial del zócalo del Mesorif. Respecto a la geodinámica, la zona mesorifeña ha experimentado en la transición del Jurásico-Cretácico dos situaciones paleogeográficas sucesivas: un levantamiento hasta la sub-emersión en el Kimmeridgiense-Titónico inferior, acompañado de una importante actividad volcánica y de intensas brechificaciones de las series carbonatadas; seguido de un colapso general a partir del Titónico superior, acompañado de efusiones volcánicas, deslizamientos sobre formas de megaolistolitos y la formación de corteza oceánica, al menos en la zona del Rif central. Estos materiales magmáticos que se repiten a un lado y otro del sistema del Ouerrha, indican que este sistema que se extiende al oeste de Nekor, corresponde probablemente, dentro del Rif central, a dos paleoplanos de subducción que convierten a dos importantes planos de superposiciones en la zona oeste de la cadena montañosa.*

Palabras clave: basaltos toleíticos, complejos ofiolíticos, posible paleo-subducción, limite Jurásico-Cretácico, Rif externo, Marruecos

VERSIÓN ABREVIADA EN CASTELLANO

Introducción y objetivo de estudio

Los autores que trabajaron en la cadena montañosa del Rif han considerado siempre el zócalo del surco del Rif externo formado por una corteza continental adelgazada. La abundancia de materiales magmáticos post-Triásicos incorporados en las series estratigráficas de la parte superior del jurásico y la base del Cretácico, muestra que el surco del Rif externo, especialmente en su parte media (Mesorif) , era en la transición Jurásico-Cretácico, la base de una importante actividad volcánica submarina . Los resultados de los análisis geoquímicos confirmaron el carácter oceánico E-MORB de estos materiales. Las secuencias litoestratigráficas de los macizos magmáticos del Rif central (Bou Adel, Kef El Ghar, Taïneste) y los análisis geoquímicos confirman que se trata de complejos ofioliticos. En la unidad de Temsamane (al noreste), las formaciones cretácicas se disponen directamente sobre las serpentinas de Beni Malek. Estas formaciones están afectadas, en esta unidad y en las unidades de Ketama y Tánger, por metamorfismo térmico, pre-orogénico (Cretácico) relacionado con la exhumación del manto superior bajo estas diferentes unidades. Por lo tanto, los complejos ofioliticos del Rif central y las serpentinitas de Beni Malek parecen ser evidencias de una zona de subducción denominada «Sutura mesorifeña».

El objetivo de este trabajo es poner de relieve la importancia de los materiales magmáticos del límite Jurásico-Cretácico del Rif externo y aclarar la evolución geodinámica del surco del Rif externo en relación con estos acontecimientos magmáticos.

Zona de estudio: Mesorif

El área mésorifeña ocupa la parte media de la cadena del Rif (Fig. 1-3). El sustrato Jurásico-Cretácico está ampliamente cubierto en gran parte por materiales aloctonos del intrarif y los depósitos neógenos post-orogénicos de las cuencas de Media Ouerrha y de Zoumi. Al norte, el área mesorifeña está cabalgada por las unidades parautóctonas de Kétama y de Tanger–Loukkos. Al sur, a lo largo del sistema del Ouerrha media, los terrenos de la zona mesorifeña cubren en un amplio cabalgamiento los terrenos del Prerif interno.

Series estratigráficas del límite Jurásico-Cretácico del Rif externo

Se componen de tres formaciones (Fig. 4A-F): Areniscas y arcillas limosas formación «Ferrysch» (1000 a 1500 m) Calloviense - Oxfordiense ; calizas del Kimmeridgiense – Titónico inferoir (10 a 200 m); margo-calizas y margas del Titónico superior - Aptiense (> 500 m).

Principales afloramientos de los materiales magmáticos del Rif externo

Materiales volcánicos

Las series estratigráficas de la parte superior del Oxfordiense al Berriasiense superior del Rif externo (Fig. 2-3) engloban los materiales magmáticos mostrando varios aspectos: litoclastos de basalto resedimentados, en *bancos calco-brechoides (Fig 4A-F; Fig. 5A-BB) o dentro de brechas con matriz margosa del Kimmeridgiense-Titónico; coladas de lava interestratificadas (Fig. 4A-B, D-E; Fig. 5C, E-F) y complejos vulcano sedimentarios envueltos en las margas del Berriasiense. Estos materiales se localizan en varias localidades (Fig. 2-3).* Mesorif: *Beni Routène, Alebra, Hamama, Zendoula, Harrara, Mazoura, Sidi Kassem, Kerkor, Mguedrouz, Koudiat Bouchta, Sahil, Azib El Bakori, Astar, Marticha y Tarhchenna;* Unidad de Kétama*: Bab El Filloul, Taounante Lakchour, Beni Berber, Tifelouest, Afres;* Manto de Bou Haddoud y Senhadja: *Taïneste, Tahar Bou Zhaïer, Zrarka, Es Smamda y Gada Ben Ayad. Estos materiales testimonio de una importante actividad volcánica en el límite Jurásico-Cretácico responsable de varios fenómenos geológicos particulares: brechificaciones intensas de los materiales de la formación carbonatada del Jurásico (Fig. 4A-F; Fig. 5A-B, G); desmantelamiento total o parcial de esta formación; deslizamientos sobre megaolistolitos (Fig. 4C-D) y metamorfismo térmico en cuarcitas, esquistos y mármoles que afecta areniscas y calizas del Jurásico (Fig. 5E, H).*

Complejos ofiolíticos

Entre Bou Adel y Taïneste, afloran importantes macizos (Fig. 3, 6-7; Fig. 8A-B) que muestran las secuencias típicas ofiolíticas (Fig. 9A-E). Estas últimas están constituidas por gabros masivos o estratificados (Fig. 8C-E; Fig. 10-E-G), microgabros, lavas volcánicas (Fig. 8F; Fig. 10H), niveles vulcanoclásticos (Fig. 8G-H; Fig. 10D) y megaolistolitos de caliza (Fig. 8A-B; Fig. 10G) o de areniscas de «Ferrysch» (Fig. 8H; Fig. 10E-F). Los niveles vulcanoclásticos están formados por basaltos, calizas, areniscas, oficalcitas (Fig. 10A), mármol (Fig. 10C-D), cuarcitas y esquistos (Fig. 10B). Se observa en estas zonas que la mayoría de los macizos carbonatados o areniscas del Jurásico corresponden a megaolistolitos que se desarrollaron a principios del Cretácico; y que el metamorfismo que afecta a algunos clastos, se relaciona con los efectos térmicos de las lavas volcánicas y no con un metamorfismo de contacto. Este metamorfismo térmico también afecta a los bloques calcáreos del Jurásico, situados por debajo de las serpentinitas de Beni Malek e islas tectónicas d'Aït Amrâne, al oeste del pueblo de Midar.

Evolución paleogeográfica y geodinámica del Rif externo en el límite Jurásico-Cretácico

A techo del Oxfordiense, el surco del Rif externo había experimentado un importante cambio paleogeográfico (Fig. 11A-B). Su parte media formaba un pliege poco profundo y localmente emergente. Este levantamiento, acompañado de una importante actividad volcánica e intensas brechificaciones de las series carbonatadas del Mesorif parecen estar asociadas a la individualización, en la parte superior del Jurásico, de una cámara magmática bajo la zona del Mesorif (Fig. 11B). A partir del Titónico superior (Fig. 11C), el surco del Rif externo sufrirá un rápido colapso, con importantes coladas de lava, deslizamientos bajo las formas de megaolistolitos y la formación, al menos en la zona del Rif central (Fig. 12), de una corteza oceánica bajo la espesa cubierta jurásica de materiales principalmente plásticos. Los indicios de ampliación hacia el este del Rif se encuentran en la unidad de Temsamane (serpertinitas de Beni Malek). Este periodo se caracterizó también por el inicio de la individualización de la corteza oceánica en el surco de los flyschs (Fig. 12).

Interpretación de la estructura geológica de la zona mesorifeña

Mesorif central: entre Taounante y Taïneste

En esta zona (Fig. 3), la vertiente sur del valle del Ouerrha (manto de Sanhadja), se formó a partir de materiales caóticos jurásicos, amontonados y desordenados, siendo arrastrados ampliamente a lo largo del Mesorif, y a menudo asociados con los complejos ofiolíticos. Esta área había sido interpretada como un enorme olitostroma de edad tortoniense conteniendo clastos de diferentes tamaños. En la vertiente sur de este valle, los materiales del Mesorif (Jebel Tifelouest-Jebel Afrès) descansan en forma de retrocabalgamiento sobre la unidad de Ketama. Este doble derrame, asociado a una intensa deformación tectónica y a los complejos ofiolíticos, permiten interpretar la estructura geológica de esta parte de la cadena montañosa del Rif, como una ancha dorsal con corteza oceánica rellena en el Cretácico superior, por megaolistolitos de materiales jurásicos (Fig. 11C). El zócalo de esta dorsal habría sufrido, durante el paroxismo orogénico del Mioceno, una doble subducción, al norte, pero sobre todo, hacia el sur (Fig. 13A-B), dando como resultado una fragmentación de la cubierta sedimentaria en varias capas vertientes hacia el sur, el sureste (Bou Haddoud, Senhadja y Aknoul) y parcialmente hacia el norte (Jebel Tifelouest-Jebel Afrès).

Mesorif central y occidental: entre Taounante et Ouezzane

La vertiente sur del valle del Ouerrha, entre Taounante y Mjara (Fig. 1), está caracterizado por numerosas islas tectónicas en el manto/capas de los materiales del Mesorif y la superposición, incluso deslizamientos, de varios macizos carbonatados del Lias medio: Jbels Amergou, Arechgou, Beni Ouassal y Sidi Messaoud, sobre las margas del cretáceo del Prerif interno (Fig. 14; Fig. 15A-B). La importancia del sistema del Ouerrha está marcado por un sistema de fallas normales, con una componente vertical en el Tortonienes (Fig. 13B), generando la formación de las cuencas postorogénicas del Ouerrha y de Zoumi y un movimiento invers, en el Plio-Cuaternario, responsable del plegamiento en sinclinales estrechos de las cuencas postorogénicas. Creemos que este importante sistema, que testigo de una gran fragilidad del zócalo del surco del Rif externo en su parte media, corresponde probablemente, en el Rif central, a dos paleo-planos de subducción que se convierten en la parte oeste de la cadena en dos mayores planos de cabalgamiento.

Conclusión

Este trabajo ha permitido descubrir numerosos afloramientos de materiales volcánicos intercalados en los niveles superiores del Oxfordiense al Berriasiense superior, repartidos a lo largo de toda la zona del Mesorif, la unidad de Kétama, los mantos intrarifeños de Bou Haddoud y de Sanhadja; para demostrar que los materiales magmáticos del Rif central, muestran secuencias ofiolíticas típicas; que estos materiales han sido generados por la actividad de una dorsal oceánica que se ha individualizado a partir del Jurásico superior bajo de una densa cobertura triásica-jurásica de materiales principalmente plásticos. Esto ha dado lugar a deslizamientos de megaolistolitos y a la formación de un enorme olitostroma. Se demuestra que los límites sur y norte del valle de l'Ouerrha, en el Mesorif central, corresponden a dos paleo-planos de subducción; que, durante la inversión tectónica del Mioceno, esta zona constituía el origen de los mantos inferiores del Rif (Bou Haddoud y Senhadja); que el sistema del Ouerrha corresponde en la parte oeste de la cadena a dos posibles principales planos *de cabalgamiento. El plano sur es responsable del desarrollo de numerosas islas tectónicas de los mantos del Mesorif y el establecimiento de importantes macizos carbonatados del Lías medio sobre las margas cretácicas del Prerif interno.*

Introduction

Previous authors tackling the geology of the Rif Mountains, among others: Andrieux (1971), Leblanc (1979), Suter (1965), Vidal (1977), Favre (1992), Wildi (1983), Asebriy (1994),... , considered that the crust of the External Rif trough had been suffering a high crustal thinning process during the Mesozoic, but without reaching the stage of an oceanic crust. However, several studies pointed out the importance, in geodynamic terms, of some post-Triassic magmatic materials incorporated within the Upper Jurassic-Lower Cretaceous deposits of the Rif Mountains, such as the Middle-Upper Jurassic (Dogger-Malm) boundary volcano-clastic complexes of the Bokkoya Predorsalian Zone and those of the preflysch series of the Tisirene nappe (Andrieux, 1964; Mattauer and Andrieux, 1963); the Middle Tithonian-Early Valanginian volcanic lavas of Jebel Tifelouest (Vidal 1983a, b; Favre, 1992); the volcano-sedimentary complexes of the western Mesorif, assigned to the Bathonian-Callovian (Ben Yaïch *et al.,* 1989); the Late Jurassic volcano-clastic breccias of the Ketama Unit (Zaghloul *et al*., 2003); the volcanic lavas, volcano-clastic breccias and the important gabbro massifs of the Central Rif, considered as intrusive, and assigned to Barremian in age (Vidal, 1979, 1983a, b). The stratigraphical studies carried out on the series around the Jurassic-Cretaceous boundary (Benzaggagh 2000; Benzaggagh and Habibi, 2006) allowed the identification of many outcrops with volcanic materials in the Mesorif Zone, the Ketama Unit, the Bou Haddoud and Senhadja Intrarifain Nappes. These magmatic materials evidence that the External Rif trough, especially its central part, was around the Jurassic-Cretaceous boundary, a site of intense submarine volcanic activities (Benzaggagh, 2011). The geochemical data (Durand Delga *et al*., 2000) obtained from basalt samples from the Predorsalian Zone and of the Tisirene Preflysch series, demonstrated E-MORB oceanic lavas. Similar results were obtained from the analysis of several volcanic samples of the Mesorif Zone. The study of the magmatic massifs of the Central Rif (Bou Adel and Kef El Ghar) and related geochemical data show that the lithostratigraphic sequence of these massifs corresponds to true ophiolitic complexes (Benzaggagh *et al.,* 2013). These preliminary data support the conclusion that these peculiar materials were generated by an active oceanic rift in process along the Mesorif Zone beginning from Latest Jurassic. In the eastern Rif Mountains, Michard *et al.* (1992) and Vázquez *et al.* (2013) showed that the Lower Cretaceous deposits of the Temsamane Unit overlap in a normal stratigraphic contact on the Beni Malek serpentines. This involves an exhumation of the upper mantle peridotites, in an oceanic environment, during the Cretaceous. Michard *et al.* (2007) showed that the Nekor Accident does not only correspond to a mere sinisterly strike-slip fault, as previously suggested by Andrieux (1971) and Asebriy *et al.* (1993), but rather to an oblique subduction surface of the Temsamane Unit under the Intrarifain Ketama Unit. This subduction, called the "Mesorif Suture Zone" (Michard *et al*., 2007), is marked by the obduction of the Beni Malek ultrabasic materials and by the development of a LT/MP metamorphism within the Temsamane Meso-Cenozoic deposits (Negro *et al*., 2007), characteristic of a subduction zone. Leblanc (1979) considered this accident as a major overthrust of the Ketama Unit on the Mesorif Zone. Leikine *et al*. (1991); Azdimousa *et al.* (2003) and Vázquez *et al.* (2013) showed that the Jurassic-Cretaceous deposits of the Temsamene, Ketama and Tangier Units are affected by an ant-orogenic metamorphism caused by a thermal flow, in relation with the exhumation of the upper mantle during the Cretaceous, beneath these different units.

This paper aims to underline the importance of the magmatic materials (volcanic lavas and ophiolitic complexes) around the Jurassic-Cretaceous boundary in the External Rif, and to describe the major outcrops, and specify the palaeogeographic and geodynamic evolution of the External Rif trough in relation with these magmatic events. Geochemical data from tholeitic basalts of Mesorifain sequences and gabbros of Bou Adel can be found in Benzaggagh *et al.* (2013).

Study area: the Mesorif Zone

Located between the Internal Prerif and the Intrarif Zones, the Mesorif Zone (Figs. 1-3.) delineates a 5 to 20 km-wide narrow band, spreading westwards over 200 km. The Mesorif Zone is also known as the Windows Zone (in: Michard, 1976) because its

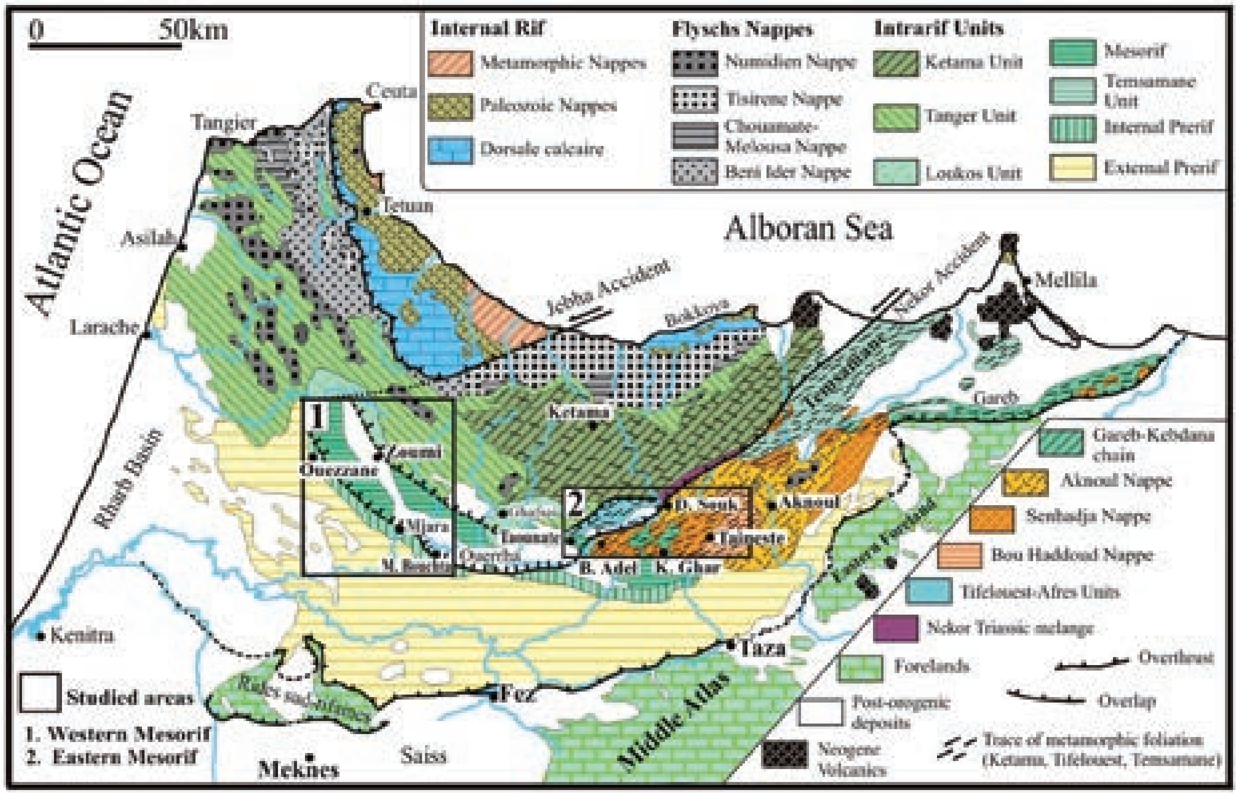

Figure 1. Structural map of the Rif Mountains (from Michard, 1976, modified).
Figura 1. *Mapa estructural de la cadena montañosa del Rif (modificado de Michard, 1976).*

Figure 2. Simplified map of the western External Rif from the 1/50000 geological maps of Zoumi (Bouhdadi, 1999), Terwal-Oulad Aïssa (Suter, 1990), Tafrannt de l'Ouerrha-Moulay Bou Chta (Suter, 1964a) and location of the main volcanic material outcrops of the Jurassic-Cretaceous boundary.

Figura 2. *Mapa simplificado de la zona oeste del Rif externo tomado de los mapas geológicos 1/50.000 de Zoumi (Bouhdadi 1999) Terwal-Oulad Aïssa (Suter, 1990) Tafrannt de l'Ourrha-Moulay Bou Chta (Suter, 1964a) y localización de los principales afloramientos de materiales volcánicos del límite Jurásico-Cretácico .*

Meso-Cenozoic substratum is often covered by Infrarifain nappes or by Neogene "post-orogenic deposits" of the Ouerrha and Zoumi basins. This substratum is considered as parautochthonous, but it is largely southward displaced by the Triassic clayey and saliniferous layers. It is affected by numerous reverse faults underlined by Triassic evaporatic injections and by the juxtaposition of terranes of various ages and the overlapping of stratigraphic series. Northwards, the Mesorif Zone is overlapped by the Intrarifain Parautochthonous Ketama Unit, with Jurassic-Middle Cretaceous materials, and the Tangier-Loukkos Units, with Late Cretaceous-Tertiary materials. Southwards, the contact with the Internal Prerif Zone corresponds to a major tectonic accident marked by the overlapping and the thrusting of Jurassic materials from the Mesorif Zone over the Early Cretaceous marls of the Internal Prerif.

Upper Jurassic-Lower Cretaceous stratigraphical series of the External Rif

They consist of three major formations (Fig. 4A-F): sandstone and silty clays (1,000 to 1,500 m thick) of Callovian-Oxfordian age, named the "Ferrysch" Formation (Wildi, 1981); the limestone (10 to 200 m thick) of Kimmeridgian-Early Tithonian age (Bulundwe 1987; Benzaggagh, 2000); the marly calcareous and marls of Late Tithonian-Aptian age (thicker than 500 m).

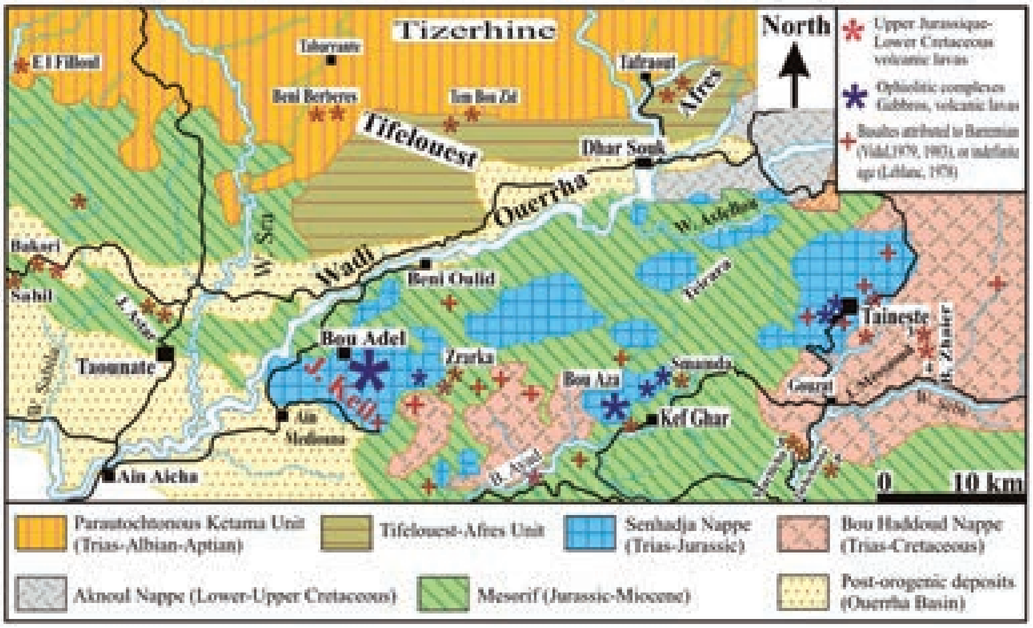

Figure 3. Simplified map of the Central External Rif from the 1/50000 geological maps of Beni Frassene, Dhar Souk (Vidal, 1979, 1983a), Rhafsaï-Kelaa Sless, Taounante-Aïn Aïcha (Suter, 1961, 1964b), Bab El-Mrouj-Taza Nord and Taïneste (Leblanc, 1978, 1983) and location of the main magmatic-rich outcrops: gabbros and volcanic lava of the Jurassic-Cretaceous boundary.

Figura 3. *Mapa simplificado de la zona externa del Rif central tomado de los mapas geológicos 1/50.000 de Beni Frassenè , Dhar Souk (Vidal, 1979, 1983a), Rhafsai-Kelaa Sless , Taounante-Ain Aicha (Suter, 1961, 1964b), Bab El- Mrouj-Taza Nord y Taïneste (Leblanc , 1978, 1983) y localización de los principales afloramientos magmáticos: gabros y lavas volcánicas del límite Jurásico-Cretácico.*

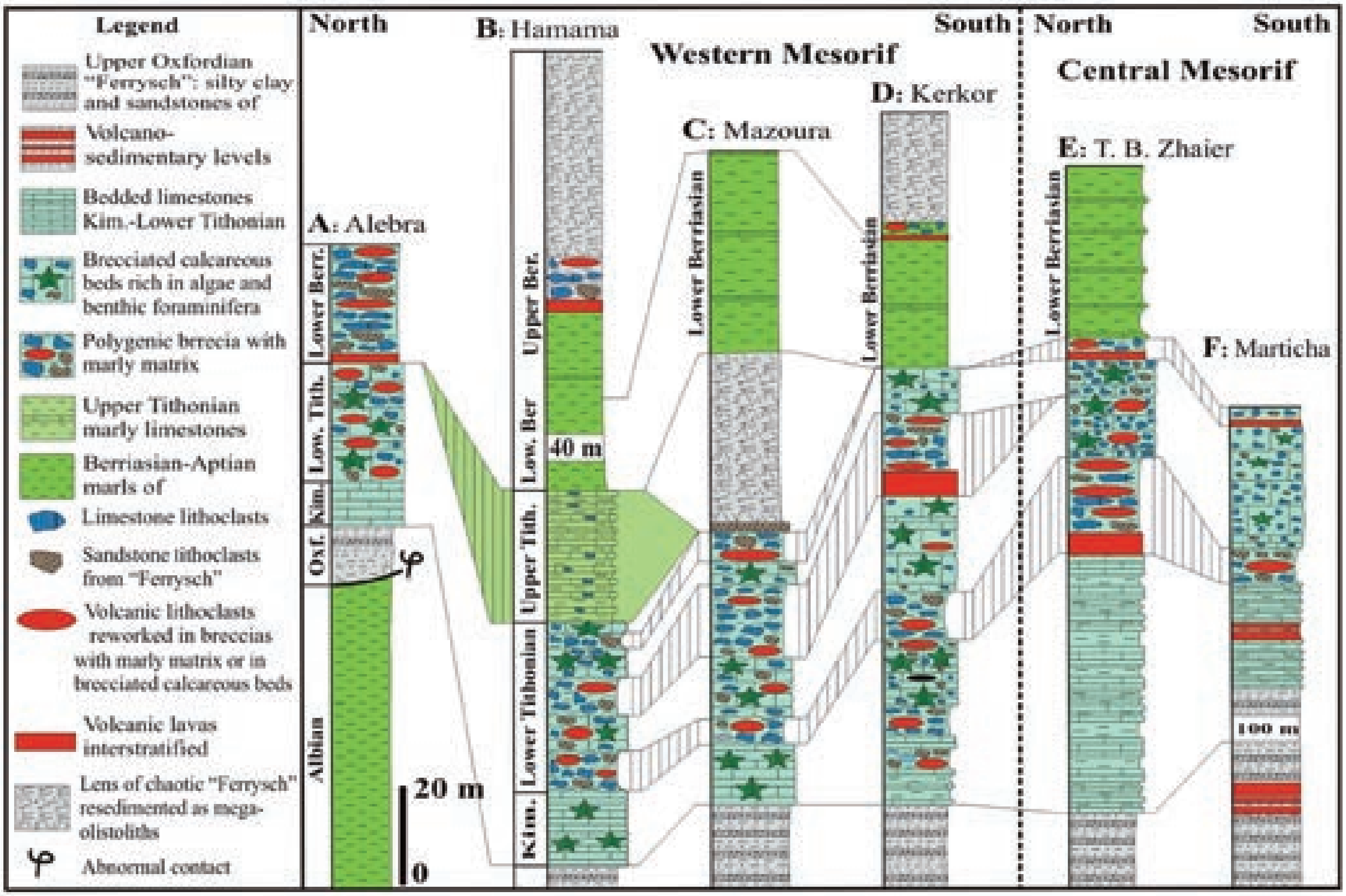

Figure 4. Stratigraphical sequences of the main outcrops of the Jurassic-Cretaceous boundary of the Mesorif Zone showing volcanic materials. A-D) Western Mesorif. E) Bou Haddoud nappe. F) Central Mesorif.

Figura 4. *Secuencias estratigráficas de los principales afloramientos del límite Jurásico-Cretácico de la zona del Mesorif mostrando materiales volcánicos. A- D) Mesorif occidental. E) Manto Bou Haddoud mantel. F) Mesorif central.*

Main magmatic-rich outcrops of the External Rif

The Uppermost Oxfordian to Late Berriasian stratigraphic sequence of the External Rif range displays numerous volcanic materials with various aspects: basalt lithoclasts reworked into calcareous breccia beds or into marly matrix breccia, interstratified lava flows; volcanoclastic complexes and important ophiolitic massifs.

Outcrops with volcanic materials

Basalt lithoclasts - Basalt lithoclasts reworked into calcareous breccia beds or into marly matrix breccias (over 20 m thick) are found in most calcareous blocks of Kimmeridgian-Early Tithonian age of the Mesorif Zone, Bou Haddoud and Senhadja nappes (Figs. 2-4), especially at Jebel Alebra, Hamama, Kerkor, Mazoura, Tahar Bou Zhaïer (Fig. 5A-B) and north of Douar Harrara. These lithoclasts are related to submarine volcanic activities in neighbouring areas.

Interstratified volcanic lavas and volcano-clastic breccias - They are found in several localities:

Mesorif Zone - On the eastern side of Jebel Hamama, above the Upper Berriasian marls rests an interstratified lava flow (Fig. 4B; Fig. 5C), covered by a volcano-clastic level (2-10 m thick) containing mega-clasts of basalt, sandstone and Upper Jurassic limestone (Fig. 5C-D). In Jebel Kerkor (Fig. 4D), the Lower Tithonian levels of calcareous formation exhibits an important lava flow and breccia with basalt lithoclasts. In Wadi Zendoula, east of Jebel Bou Rzine, the Kimmeridgian-Early Tithonian calcareous succession is overlain by a lava flow (Fig. 5E) and a volcanoclastic breccia. North of Douar Harrara (Fig. 2), less altered micro-gabbro veins and basalt lithoclasts are exposed in a large chaotic zone. In Jebel Mazoura,

Figure 5. A-B) Brecciated limestone beds of Early Tithonian age (1) containing basalt lithoclasts (2), Jebel Tahar Bou Zhaïer, Bou Haddoud Nappe, southeast of Taïneste village. C) Volcanic lava (1) resting above the Upper Berriasian marls (2), overlain by a volcano-clastic level (3), eastern side of Jebel Hamama. D) Volcano-clastic level (1) resting above the Upper Berriasian marls (2) and containing metric clasts of basalt, Upper Jurassic limestone and sandstone, overlain by chaotic "Ferrysch" (3) east side of Jebel Hamama. E) Lower Tithonian bedded limestone with vertical dip (1), overlain by a lava flow (2). The limestone beds underwent a thermal metamorphism into marble, Wadi Zendoula, West of Jebel Bou Rzine, North of Ouezzane. F) Volcanic lavas (1) interbedded within the carbonate formation (2) in the levels of the Kimmeridgian-Tithonian boundary, Jebel Tahar Bou Zhaïer. G) Calcareous formation of Kimmeridgian-Early Tithonian age (1), topped by a channelized syn-sedimentary mega-breccia (2) and containing numerous volcanic lithoclasts, Jebel Tahar Bou Zhaïer. H) Limestones of Upper Jurassic transformed into marble, Wadi Zendoula.

***Figura 5.** A-B) Capas de calizas brechoides del Titónico inferior (1) con litoclastos de basalto (2), Manto/ capas de Jebel Bou Tahar Zhaïer, Bou Haddoud, al sureste de la localidad de Taïneste. C) Lava volcánica (1) que se sitúan sobre de las margas del Berriasiense superior (2), cubierta por un nivel vulcanoclástico (3) sector oriental de Jebel Hamama. D) nivel vulcanoclástico (1) que se sitúa sobre las margas del Berriasiense superior (2) y que contiene clastos métricos de basalto, calizas y areniscas del Jurásico Superior, cubierta por el caótico «Ferrysch» (3) lado este de Jebel Hamama. E) Capas de calizas del Titónico inferior con buzamiento vertical (1), cubierta por un flujo de lava (2). Las capas de caliza estuvieron sometidas a un metamorfismo térmico en el mármol, Wadi Zendoula, al oeste de Jebel Bou Rzine, Norte de Ouezzane. F) lavas volcánicas (1) intercaladas dentro de la formación calcárea (2) en los niveles del límite Kimmeridgiense-Titónico, Jebel Bou Tahar Zhaïer. G) Formación calcárea del Kimmeridgiense-Titoniano inferior (1), coronado por una megabrecha sinsedimentaria canalizada (2) y que contiene numerosas litoclastos volcánicos, Jebel Bou Tahar Zhaïer. H) Calizas del Jurásico superior transformadas en mármol, Wadi Zendoula.*

the Lower Tithonian carbonate formation is overlain by a thick breccia (over 20 m thick) containing volcanic clasts (Fig. 4C). West of Douar Marticha (Fig. 3; Fig. 4F), the top of the "Ferrysch" Formation shows a volcano-sedimentary level (2-3 m) of several tens of metres long. Eastwards to Aazib El Bakori (Fig. 3), the basalt rocks outcrop over several tens of metres in contact with an Upper Jurassic carbonate formation completely transformed into marble. Near of Douar Sahil (Fig. 3), an important outcrop (over 250 m thick) showing a peculiar sequence, formed by chaotic silty clays from the "Ferrysch" Formation, containing in its lower part (over 150 m thick) metric blocks of basalt, microgabbro, sandstone, quartzite, marble and Upper Jurassic limestone. Its upper part (over 100 m thick) contains angular sandstone lithoclasts from the "Ferrysch" Formation within a silty clay matrix and marked by sedimentary bedding evoking slope deposits at the base of a fault escarpment in a marine environment. Other volcanic materials occur in several localities (Figs. 2, 3): Jebel Mguedrouz, Koudiat Bouchta, Sidi Kassem, Jebel Astar, Douar Marticha and Jebel Tarhchenna. Volcanic materials are reported (Fig. 3) from Kimmeridgian-Lower Valanginian levels of Jebel Tifelouest (Vidal, 1983a; Favre, 1992); West of Taounante Lakchour (Zaghloul, 2003) and near Bab El Filloul (Suter, 1964b) in Upper Jurassic levels; and at Jebel Afres and Beni Berber in deposits assigned to Middle Jurassic (Dogger) by Asebriy (1994).

Bou Haddoud Nappe - In Jebel Tahar Bou Zhaïer, levels of Kimmeridgian-Tithonian boundary are marked by an important breccia with basalt clasts and a thick interstratified lava flow (Fig. 3; Fig. 4d; Fig. 5F). Other magmatic materials occur in several localities around the Taïneste village (Leblanc, 1983).

Senhadja Nappe - Southeast of Douar Zrarka, the Upper Jurassic limestone, in reverse sequence exhibits an interstratified lava flow and volcano-clastic levels (Fig. 3). Northeast of Douar Es Smamda, this limestone is overlain by basalt rocks (over 20 m thick). Several other outcrops with magmatic materials assigned to Barremian are shown on the 1/50 000 geological map of Dhar Souk (Vidal, 1983a).

Volcano-clastic complexes packed in Lower Cretaceous marls

They are more frequent in the western part of the Mesorif Zone (Fig. 2), especially the Harrara complex, formed by altered lavas, contained in a marly matrix, and containing limestones clasts from Upper Jurassic formations. The Beni Routene complex is less chaotic, formed in its lower part by well stratified volcano-sedimentary levels, containing altered lavas and lithoclasts of limestone and sandstone from Upper Jurassic formations; its upper part is dominated by volcanic lava (over 10 m thick).

Peculiar phenomena in relation with volcanic activities - These volcanic activities are responsible for many peculiar geological phenomena, including:

Brecciation of the Upper Jurassic carbonate formation - The Upper Jurassic limestone formations of the Mesorif Zone mostly consist of cemented calcareous-brecciated beds with angular lithoclasts of limestones, sandstone and volcanic rocks (Fig. 4A-F; Fig. 5A-B). Within these formations, two to four levels of breccias with marly matrix (1 to 20 m thick) are intercalated, consisting of angular lithoclasts of volcanic, sandstone and limestone rocks, without any preferential graded bedding (Fig. 4A-F; Fi. 5G), reflecting an autochthonous dismantlement of the Upper Jurassic formations, and slidings over short distances in faulted environments.

Post-depositional erosion - In Jebel Mazoura, Alebra and Tahar Bou Zhaïer (Fig. 4A, C, D), the Upper Tithonian marly limestone alternations are missing, they were dismantled immediately after their deposition. These dismantlements affected the whole carbonate formation in the northern end of Jebel Tahar Bou Zhaïer. Therefore, the Berriasian marls overlay in contact with the "Ferrysch" Formation. Likewise North of Douar Harrara, polygenic breccias with volcanic lithoclasts, overlay directly on the formation. Lithoclasts rich in *Saccocoma* or calpionellids of Kimmeridgian-Late Tithonian age are frequent in these breccias.

Gliding as mega-olistoliths - North of Douar Harrara, Upper Jurassic mega-calcareous blocks outcrop in disorder. They are reversed or folded uncomformably to the post-sedimentary tectonics of this area. These blocks had undergone a synsedimentary sliding, immediately after their deposition. This is also the case at Qortba (Fig. 2), where Upper Jurassic decametric calcareous slabs, lay at random on the Valanginian marls. Some of these slabs appear in reverse series (Benzaggagh and Habibi, 2006). On the eastern side of Jebel Hamama, the Late Berriasian volcanoclastic level (Fig. 5D) is overlain by a hectometric hill of the "Ferrysch" Formation which is very chaotic, showing, through its whole thickness, the dismantled or folded sandstone beds in disorder, reflecting a synsedimentary slumping (Fig. 4B). In Jebel Kerkor

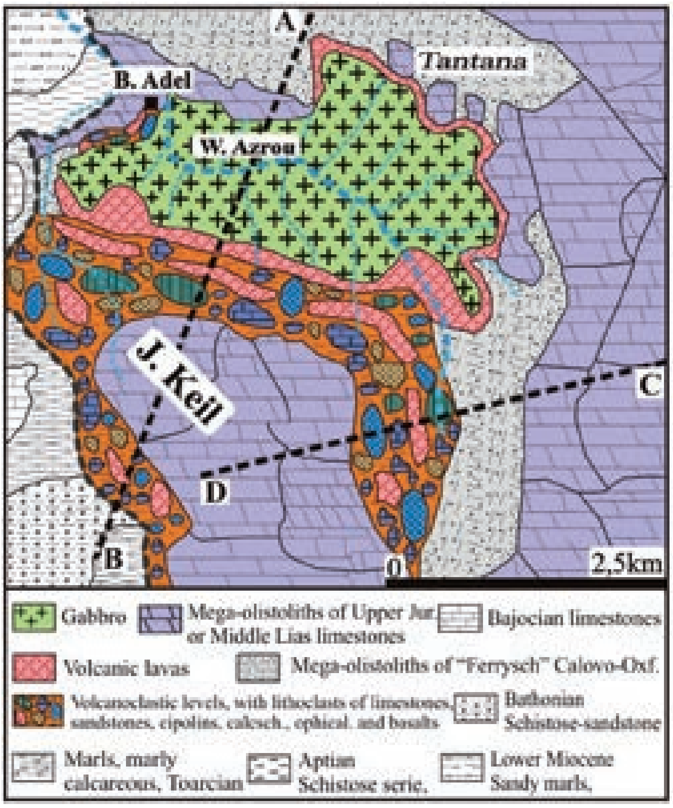

Figure 6. Simplified map of the magmatic massif of Bou Adel-Jebel Keil, from the 1/50 000 geological maps of Dhar Souk (Vidal, 1983a), Taounante-Aïn Aïcha (1964b) and personal observations.

Figura 6. *Mapa simplificado de los macizos magmáticos de Bou Adel-Jebel Keil, obtenido del mapa 1/50 000 de Dhar Souk (Vidal, 1983a), Taounante-Aïn Aïcha (1964b) y observaciones personales.*

(Fig. 4D), above the Berriasian marls, a breccia containing basalt lithoclasts, is overlain by a decametric sandstone lens from the "Ferrysch" Formation. In Jebel Mazoura (Fig. 4C), a "Ferrysch" lens is inserted between the Early Tithonian breccia and the Lower Berriasian marls.

Thermal metamorphism - In several Mesorifain outcrops, limestone or sandstone blocks from Upper Jurassic formations had been in contact with volcanic lavas and underwent a thermal metamorphism into marble or quartzite. This is the case in Wadi Zendoula (Fig. 5E, H), Aazib El Bakori, Gada Ben Ayad, Douar Zrarka, Douar Es Smamda, Dar Bou Aza, Kef El Ghar and in the chaotic outcrop of Douar Sahil. Jurassic carbonate blocks turned into marble, evidence of a thermal flux of Lower Cretaceous age, are reported at the base of the Beni Malek peridotites and in the Aït Amrâne klippes, to the west of the Midar village (Vázquez *et al.,* 2013).

Ophiolitic complexes

Central Rif magmatic mountains - a brief summary

The existence of magmatic materials in the Central Rif has been known since the works of Marçais (1938), Lacoste and Marçais (1938) and Lacoste (1941), reported granite outcrops near Taïneste, Kef El Ghar, Bou Adel and Jebel Teïrara. These authors also noticed in these areas the abundance of cipolin (marble) blocks thought to result from the erosion of the Paleozoic formations. Suter (1964b) and Vidal (1983a) published the 1/50 000

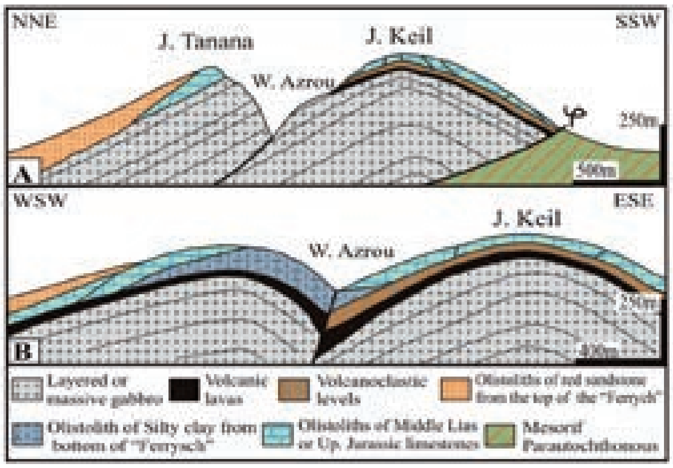

Figure 7. Cross sections (A and B) of Bou Adel-Jebel Keil (see locations in Fig. 5).

Figura 7. *Cortes geológicos (A y B) de Bou Adel-Jebel Keil (ver situación en Fig. 5).*

Figure 8. A) Jebel Keil, view from the south, forming a large anticlinal bulging, essentially consisting of magmatic materials (gabbros), topped by mega-olistoliths of Middle Liassic limestone. The village of Bou Adel in the foothills of the massif, Sanhadja Nappe, Central Mesorif. B) Same as A, seen from Jebel Tanana. C-D) Layered gabbros of the ophiolitic complex of Bou Adel. E) Alteration of gabbro in "fairy" chimney due to the presence of more resistant gabbro lenses with a dark colour, ophiolitic complex of Bou Adel. F) Volcanic levels of ophiolitic complex of Bou Adel, northern side of Jebel Keil. G-H) Volcanoclastic level of the ophiolitic complex of Bou Adel, south of Wadi Azrou.

Figura 8. *A) Jebel Keil, vista desde el sur, formando un gran anticlinal, que consiste esencialmente en materiales magmáticos (gabros), coronados por megaolistolitos de calizas del Lias medio. El pueblo de Bou Adel en las estribaciones del macizo, Sanhadja Nappe, Mesorif central. B) Lo mismo que A, visto desde Jebel Tanana. C-D) Capas de gabros del complejo ofiolítico de Bou Adel. E) La alteración de los gabros en "chimenea de hada" debido a la presencia de lentes de gabro más resistentes de color oscuro, complejo ofiolítico de Bou Adel. F) los niveles de complejos volcánicos ofiolítico de Bou Adel, al norte de Jebel Keil. G-H) Nivel de volcanoclásticos del complejo ofiolítico de Bou Adel al sur de Wadi Azrou.*

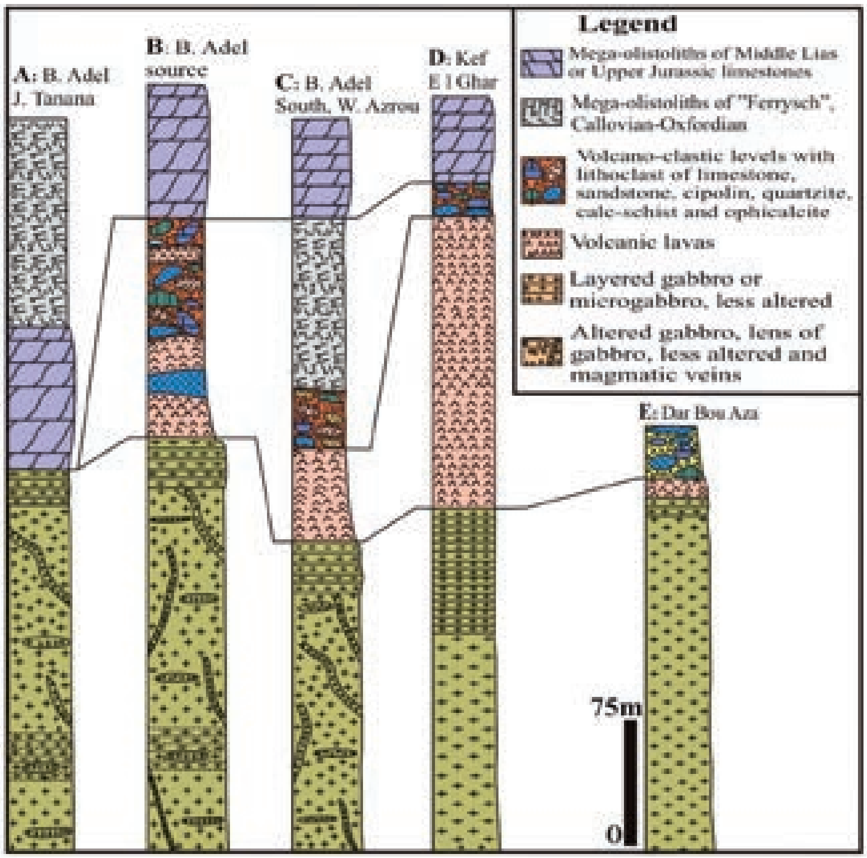

Figure 9. Stratigraphical sequences of ophiolitic sequences of the Central Rif: A-C) Bou Adel. D) Kef El Ghar. E) Dar Bou Aza.
Figura 9. *Columnas estratigráficas sintéticas de secuencias ofiolíticas del Rift Central: A-C) Bou Adel. D) Kef El Ghar. E) Dar Bou Aza.*

geological maps of Taounante-Aïn Aïcha and Dhar Souk. The Bou Adel magmatic mountain, straddling the two maps, is represented on the first map as ant-Triassic substratum scales and, on the second one, as intrusive gabbro of Barremian age. Harmand *et al.* (1986) described it as intrusive gabbro, inducing a contact metamorphic in "hornblende hornfels facies", and affecting the Upper Jurassic limestones and the Callovian-Oxfordian pelitic sandstone.

Geological structure of Jebel Keil and magmatic massif of Bou Adel

The Bou Adel village is located on the northern side of Jebel Keil (Fig. 5). This is one of the most important massifs of the Senhadja region, rising to 1,628 m and forming an enormous bulging anticline (Fig. 7A-B; Fig. 8A-B), widely moved southwards (Lacoste, 1934). The magmatic series that crops out to the north extends westwards for about 3 km long by 0.5 to 1,5 km wide. This most important magmatic massif of the External Rif Mountains is divided into two compartments by a deep watercourse, Wadi Azrou (Fig. 6; Fig 7A-B), leaving some 400 m-thick gabbro outcropping. Strongly altered, it forms the reservoir for the important water source of the Bou Adel village.

Ophiolitic sequences of Bou Adel and Jebel Keil

It is composed of gabbros with grainy, laminated or massive texture of light or dark colour, often altered, locally crossed by veins (Fig. 9A-C; Fig. 8A-E).). At the top, with a 4 to 10 m thickness, the gabbros are layered, display a microgranular texture with paler colour and are less altered. These levels are overlain by volcanic lavas, locally over 50 m thick (Fig. 8F; Fig. 9B-C) and volcano-clastic levels (Fig. 8G-H) containing, in addition of the basalt, the lithoclasts of limestone, sandstone, silty clays and ophicalcites (Fig. 10A). Many of these clasts had undergone thermal metamorphism into quartzite, schist (Fig. 10B) or marble (Fig. 10C-D). This level with metamorphic clasts is represented on

Figure 10. A) Ophicalcite blocks from volcanoclastic level of the northern side of Jebel Keil. B) Fine-grained sandstone from the base of the "Ferrysch" Formation, turned into shales by thermal metamorphism, volcanoclastic level on the northern side of Jebel Keil. C) Upper Jurassic brecciated limestone blocks transformed in marble inside the volcanoclastic level on the northern side of Jebel Keil. D) Marble bed, in a volcano-clastic level of the northern side of Jebel Keil. E) Altered gabbros, overlain by "Ferrysch" silty clays, in the ophiolitic complex of Kef El Ghar. F) Red sandstone from the top of the "Ferrysch" formation resting directly on the gabbro, immediately to the west of the spring of the Bou Adel village. G) Middle Liassic or Upper Jurassic limestone?, resting as mega-olistolith directly above the gabbro, without showing any contact metamorphism, southern side of Jebel Tanana, Bou Adel. H) Volcanic levels of ophiolitic complex of Kef El Ghar.
Figura 10. *A) Bloques de oficalcitas de nivel volcanoclásticos de la región norte de Jebel Keil. B) Arenisca de grano fino desde la base de la Formación "Ferrysch", convierto a en esquistos por metamorfismo térmico, nivel volcanoclástico en la región norte de Jebel Keil. C) Bloques de caliza bechoida del Jurásico transformada en mármol, dentro del nivel volcanoclásticos en la región norte de Jebel Keil. D) Banco de mármol, en un nivel volcanoclástico de la región norte de Jebel Keil. E) Gabros alterados cubiertos por arcillas limosas "Ferrysch", en el complejo ofiolítico de Kef El Ghar. F) Arenisca roja de la parte superior de la formación "Ferrysch" yaciendo directamente sobre los gabros, inmediatamente al oeste del pueblo de Bou Adel. G) Calizas del Lias medio o Jurásico superior sobre el megaolistolito directamente encima de los gabros, sin mostrar ningún metamorfismo de contacto, lado sur de Jebel Tanana, Bou Adel . H) Niveles de complejos volcánicos ofiolítico de Kef El Ghar.*

the 1/50000 maps of Taounante (Suter, 1964b) and Dhar Souk (Vidal, 1983a) as a cipolin and calcschist level. It crops out around the Jebel Keil (Fig. 6; Fig. 7A-B), suggesting its continuity and that of the underlying gabbros, in the sub-surface (see Lacoste, 1941; p. 249). Above, resting in disorder, chaotic decametric to hectometric olistoliths of silty clay from the bottom of the "Ferrysch" Formation (Fig. 8H), in the south of Wadi Azrou, followed by limestone blocks attributed to the Middle Liassic, forming the Jebel Keil peaks (Fig. 8A-B). On the northern side, the gabbros are always overlain by volcanic and volcanoclastic levels, of lesser thickness, then by mega-olistoliths of limestone or red sandstone from the top of the "Ferrysch" Formation (Fig. 10F). In the Bou Adel village, calcareous blocks, assigned to Middle Liassic, are deposited above the volcano-clastic level or directly above the gabbros (Fig. 10G). This very dislocated limestone shows no trace of metamorphism contact. We can conclude, for this area, that all calcareous and "Ferrysch" blocks of Jurassic are mega-olistoliths, reworked at the beginning of the Cretaceous, that the metamorphism affecting some clasts is related to the thermal effects of volcanic lavas and hydrothermal sources, not by a contact metamorphism induced by the intrusion of the gabbros. Phenomena, such as thermal metamorphism and slipped mega-olistoliths, are found in several outcrops of the Mesorif Zone independently of any gabbro outcrop.

Ophiolitic sequences of Kef El Ghar

North of the Kef El Ghar village, two major juxtaposed magmatic massifs outcrop (Fig. 3). They are formed by highly altered gabbros (Fig. 9D; Fig. 10E) with a grainy texture (over 200 m visibly), layered and less altered microgabbros (over 100 m), and important basalt flows, more than 150 m thick. They are overlain by volcano-clastic breccias (10 to 50 m) with clasts of limestone, marble, ophicalcites and by mega-olistoliths of "Ferrysch" or limestone of Middle Liassic or Late Jurassic age. Locally at Jebel El Karia, the gabbros are topped directly by a mega-olistolith from the bottom of the "Ferrysch" Formation (Fig. 10E) or by red radiolarite layers.

Ophiolitic sequence of Dar Bou Aza

This outcrop of several kilometres in size (Fig. 3; Fig. 9E), is formed by highly altered gabbros (over 500 m), surmounted by volcanic and volcanoclastic levels (50 m), containing metric marble clasts.

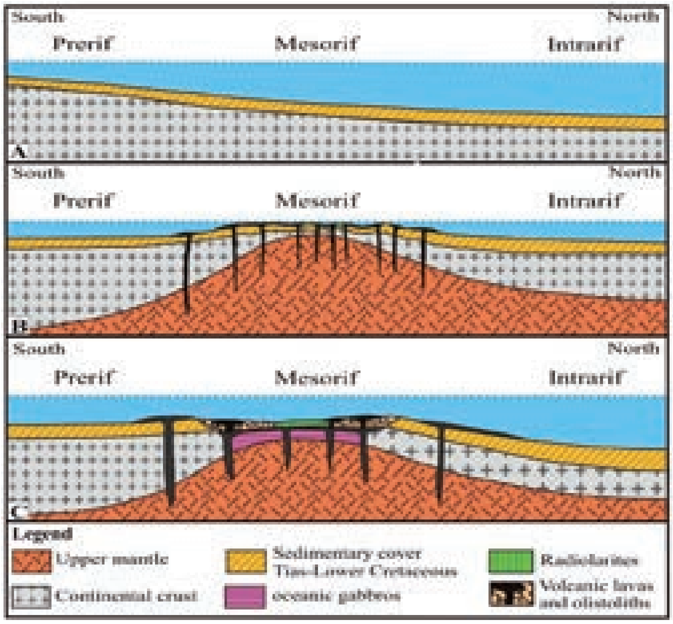

Figure 11. Palaeogeographic sections of the External Rif trough. A) Early-Middle Oxfordian. B) Kimmeridgian-Early Tithonian. C) Early Cretaceous.
Figura 11. *Secciones paleogeográficas en el Rif externo. A) Oxfordiense inferior-medio. B) Kimmeridgiense-Titónico inferior. C) Cretácico inferior.*

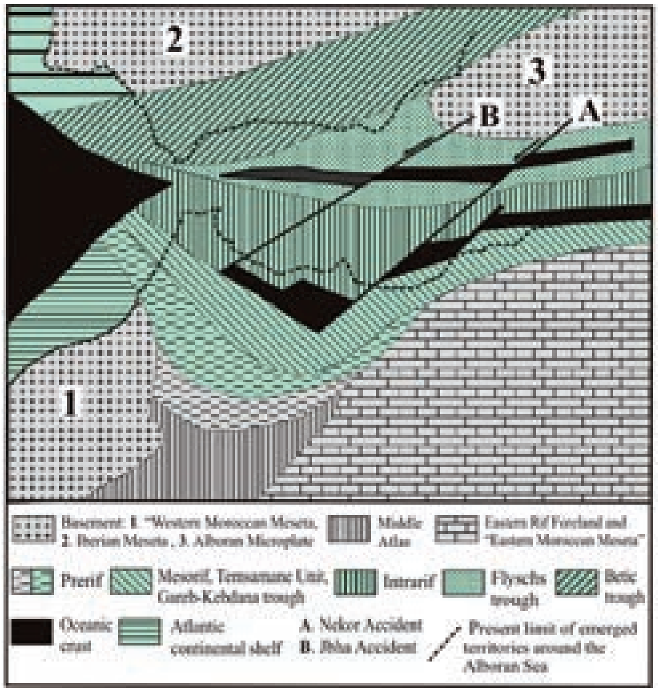

Figure 12. Hypothetical palaeogeographic map showing the main Cretaceous geological domains at the western end of the Tethys Realm; in grey, emerged areas; in light blue, marine areas.
Figura 12. *Hipotético mapa paleogeográfico que muestra las principales dominios geológicos del Cretácico en el extremo occidental del Reino de Tetis; en gris, áreas emergentes; en azul claro, áreas marinas.*

Palaeogeographic and geodynamic evolution of the External Rif trough at the Jurassic-Cretaceous boundary

During the Jurassic, *pro parte*, the stratigraphic series of the External Rif trough were similar in the three palaeogeographic zones of the External Rif: the Prerif, Mesorif and Intrarif (Suter, 1965), showing, at the Callovian-Oxfordian *pro parte* (Fig. 11A), increasingly deep environment facies from the south to the north (Wildi, 1981).

Around the Oxfordian-Kimmeridgian boundary (Fig. 11B), the Rif trough had suffered an important palaeogeographic change, as shown by a general uplift, towards the near emersion, especially in its central part, the Mesorif (Benzaggagh and Atrops, 1997). There extends a carbonate platform, showing in the Mesorif, calcareo-brecciated sequences, rich in algae, large benthic foraminifera and oolitic limestone of the photic zone (Fig. 4A-F). This uplift, which was accompanied by major volcanic activities and intense brecciation of the Upper Jurassic carbonate formation, seems to have been caused by the individualization of a magmatic chamber under the Mesorif Zone (Fig. 11B). This uplifting palaeogeographic change had also affected the eastern foreland of the Rif Mountains causing its definitive emersion at the end of the Upper Jurassic (Portlandian) (Catanéo, 1987).

During the Late Tithonian to Late Berriasian, the External Rif trough had undergone a rapid and general collapse, accompanied by lava flows, slumps as breccias or mega-olistoliths and formation of an oceanic crust, at least in the Central Rif (Fig. 11C; Fig. 12). This is the time of the individualization of an oceanic rift, under a thick Jurassic sequence, formed essentially by plastic materials.

Evidence of the eastwards extension of this rift occurs in the Mesorif Temsamane unit, represented by the Beni Malek serpentinite, topped in normal stratigraphic continuity by Lower Cretaceous shales (Michard *et al.*, 1992; Vázquez *et al.*, 2013).

This oceanic rift had created a deep rift graben that was filled by Jurassic mega-olistoliths, resting directly on a magmatic or volcanoclastic substratum, giving rise to a vast olistostrome, between at least Bou Adel, Kef El Ghar and Taïneste.

This was also the time of the beginning of the individualization of an oceanic crust in the Flysch Trough (Fig. 12), located farther to the north (Delga Durand *et al.*, 2000).

Geological structure of the Mesorif Zone

Central Mesorif - between Tounante and Taïneste

This area, located on either side of the Ouerrha Valley, between Bou Adel, Kef El Ghar, Taïneste and Dhar Souk (Fig. 1; Fig. 3), shows a complex geological structure.

South side of Ouerrha Valley - On this side, between Bou Adel and Taïneste (Sanhadja Nappe), the Jurassic deposits, largely thrusted over the Mesorif, are chaotic, dislocated and piled up in disorder and often associated with ophiolitic complexes. Vidal (1977, 1983a-b) interpreted the geological structure of this part of the Rif Mountains, as an enormous olistostrome formed by an autochthonous pelitic matrix of Tortonian age, containing clasts of variable size, metric to pluri-kilometres. He defined and extended the External Melange Zone, "Zone de mélange externe," to the Prerif and the Mesorif Zones. Without any doubt, most of the Jurassic outcrops of this area are composed of mega-olistoliths, but the setting up of which was closely related to the magmatic events of the Jurassic-Cretaceous boundary interval. Consequently, the olistostrome of Bou Adel-Taïneste (Fig. 11C) would have an Early Cretaceous age. However, the Tortonian age assigned by Vidal (1977, 1983a) is unlikely; on the one hand, the Tortonian deposits are missing within this geological structure; on the other hand, the post-orogenic Tortonian times, marked by the collapse of the Ouerrha Basin, were tectonically too calm to generate mega-olistolith sliding of such dimensions.

Northern side of Ouerrha Valley - On this part of the Ouerrha Valley, between Jebel Tifelouest and Jebel Afres, Andrieux (1971) correctly noted the peculiar pattern of the Jurassic series, forming several superimposed tectonic units, resting on backthrusting on the terranes of the south front of the Parautochthonous Ketama Unit. These terranes are affected by a ductile deformation: south-vergent folds and microfolds, show two well-marked foliation planes (S1 parallel to S0 and S2 with variable dip) and are affected by an epizonal metamorphism "green schist facies" affecting some volcanic lenses from the base of the Cretaceous sequences (Jebel Tifelouest).

Andrieux (1971; p.121) insisted on the fan shape structure of the Ouerrha-Nekor Valley and assigned an Ultra-Ketama origin to the backthrusted units of the northern side of the Ouerrha Valley (p. 111). This author also noticed that the schistosity and metamorphism affecting the Ketama Unit terranes and the northern side of the Ouerrha Valley, resulted from a strong tectonic clamping with an horizontal component, synchronous of an abnormally high thermal flux, comparable with that of the peripacific subduction belts (p. 143). Recent works (Leikine *et al.*, 1991; Azdimousa *et al.*, 1998, 2003; Vázquez *et al.*, 2013) showed that the phyllitic and non-phyllitic minerals of the Upper Jurassic silty clay and Cretaceous marl sequences of the Ketama and Tangier Units are marked by an ant-orogenic metamorphism of Barremian age in the South of the Ketama Unit, or of Campanian age in the center and the North of this unit. Vázquez *et al.* (2013) explain the origin of this metamorphism by a high heat flow induced by the exhumation of the upper mantle under the Ketama Unit during the Cretaceous. These authors concluded that the Cretaceous materials of the Ketama Unit rest directly above a serpentinized mantle in a scenario similar to that of the Beni Malek peridotites and their Cretaceous cover. These data are in accordance with ours, especially concerning the earlier exhumation of the upper mantle in the southern of the Ketama Unit, which is juxtaposed to the Mesorif zone.

We interpret the geological structure of this part of the Rif Mountains as a vast graben with an oceanic crust (Fig. 11; Fig. 12), filled up during the Early Cretaceous by mega-olistoliths of Jurassic materials. This oceanic crust had undergone during the Miocene orogenic paroxysm a double subduction (Fig. 13A-B), northwards, under the Ketama Unit, but above all southwards, under the Mesorif Zone, causing the flaking of the Meso-Cenozoic formations, overlaps and overthrustings of tectonic units, to the south and partially the north. These overlaps and overthrusts are responsible for the individualization of the Lower

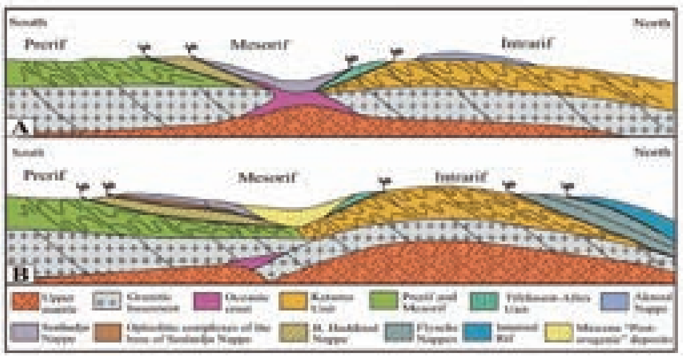

Figure 13. Schematic north-south cross sections illustrating the geological structure of the Central Rif through the Ouerrha Valley. A) At the beginning of the Miocene alpine orogeny. B) At the Tortonian, marked by the collapse of the Ouerrha Basin.

Figura 13*. Secciones esquemáticas norte-sur que ilustran la estructura geológica del Rif Central a través del valle del Ouerrha. A) Al comienzo del Mioceno durante la orogenia alpina. B) En el Tortoniense, marcado por el colapso de la cuenca del Ouerrha.*

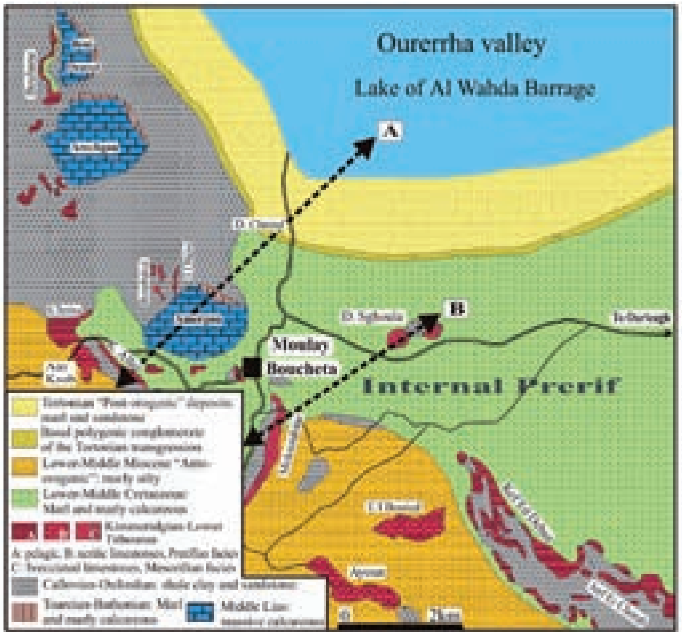

Figure 14. Simplified map of the Moulay Bouchta area, Middle Ouerrha, from the 1/50 000 geological map of "Tafrannt de l'Ouerrha-Moulay Bou Chta", (Suter, 1964a) and personal observations.

Figura 14. *Mapa simplificado del área de Moulay Bouchta, parte media Ouerrha, obtenido del mapa geológico 1/50 000 de "Tafrannt de l'Ouerrha-Moulay Bou Chta" (Suter, 1964a) y observaciones personales.*

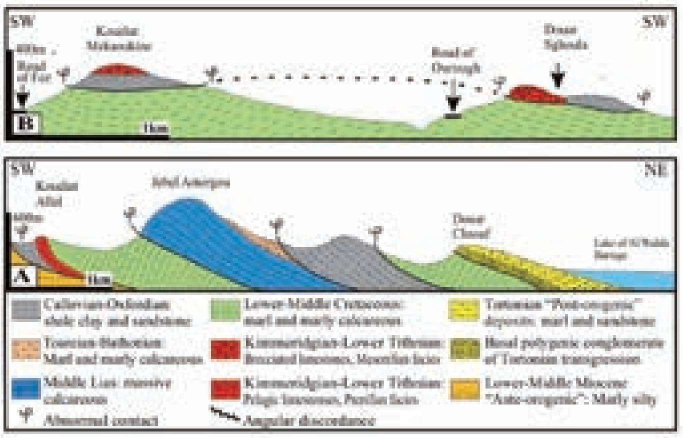

Figure 15. Cross sections of the Moulay Bouchta area, showing the overthrust and overlapping of the mesorifain nappes above the Internal Prerif marls, south of the Ouerrha Valley. A) Cross section through Jebel Amergou. B) Cross section through Jebel Mekaoukine.

Figura 15. *Cortes geológicos de la zona de Moulay Bouchta, mostrando el cabalgamiento y la superposición de las capas/mantos del Mesorif sobre las margas del Prerif interno, al sur del Valle Ouerrha. A) Sección transversal de Jebel Amergou. B) Sección del transversal de Jebel Mekaoukine.*

Rifain Nappes, Senhadja and Bou Hadoud, largely spread out on the Mesorif and also the backthrusting of Jebel Tifelouest-Jebel Afres Unit over the southern front of the Parautochthonous Ketama Unit. This genuinely explains the fan geological structure of the Ouerrha-Nekor Valley: the Infra-Ketama origin of the Lower Rifain Nappes (Leblanc, 1979, p. 141) and the stratigraphic disorder within some levels of Jurassic formations of Senhadja and partly the Bou Haddoud Nappes, reported by Leblanc (1979, p. 68) and that we also observed in several localities along the transverse Asfellou-Taïneste cross-sections.

Central and western Mesorif - between Taounante and Ouezzane

Between Taounante and Mjara (Fig. 1), the southern side of the Ouerrha Valley, is marked by numerous sheet klippes with Jurassic materials from the Mesorif Zone, resting in a horizontal position over the Lower Cretaceous marls of the Internal Prerif, especially in the Moulay Bouchta area (Fig. 14, 15A-B). Along of this tectonic Accident, several important calcareous Middle Liassic mountains rise to the surface, with or without any Jurassic-Cretaceous cover, resting with overthrust or overlapping on the Lower Cretaceous marls of the Internal Prerif, among others: Jebel Amergou, Arechgou, Beni Ouassal and Sidi Messaoud.

Between Mjara and Wadi Loukkos (Fig. 2), the Internal Prerif-Mesorif boundary, although less pronounced, is marked by a succession of several massifs with often reverse Jurassic-Cretaceous sequences: Koudiat Bouchta, Jebel Mguedrouz, Jebel Kerkor, Qortba,..., and by sheet klippes of Jurassic materials resting over the Cretaceous marls of the Internal Prerif (Jebel Sidi Redouane).

The boundary between the Mesorif and the Intrarif Zones, also overlapping, is often covered by Neogene "post-orogenic deposits" of the Zoumi Basin. The importance of the Ouerrha Accident is also marked by vertical movements with normal components during the Tortonian, responsible for the creation of the "post-orogenic basins" of Ouerrha and Zoumi; then by reverse movements during the Plio-Quaternary responsible for the folding in a narrow synclinal of the "post-orogenic basins".

We believe that this major accident, witnessing a high crustal fragility of the External Rif trough, in its middle part, corresponds to two possible palaeo-subduction surfaces in the Central Rif which turned into two major overlapping accidents elsewhere in the rest of the Rif Mountains. The southern overthrust plan delimits two, separate geological domains: the "Marly-schistose Zone" of the early authors, to the north, marked by high and steep reliefs and by the predominance of Jurassic-Lower Cretaceous formations; and the Prerif Zone "Zone de collines", in the south, dominated by Tertiary marls, forming moderately high hills.

Conclusions

Fieldwork investigation over several years has led us to reveal numerous volcanic-rich levels intercalated within Latest Oxfordian-Late Berriasian sequences, and distributed throughout the Mesorif Zone, Ketama Unit, Bou Haddoud and Senhadja Intrarifain Nappes. This study has also allowed us to demonstrate that the magmatic massifs of the Central Rif Mountains, between Bou Adel, Kef El Ghar and Taïneste, correspond to true ophiolitic complexes and that these magmatic materials were generated by the activity of an oceanic rift in the training process starting from the Latest Jurassic under a thick Jurassic sequence formed essentially by plastic materials of the Mesorif Zone. During the Early Cretaceous, this oceanic rift had generated, gliding mega-olistoliths and the formation of a vast olistostrome, in most parts of the Mesorif Zone. We suggest that the southern and northern boundaries of the Ouerrha Valley in the Central Rif, correspond to two palaeo-subduction surfaces and that this area was the origin of the Bou Haddoud and Senhadja Lower Rifain Nappes and the backthrusting of Jebel Tifelouest-Afres Unit, during the Miocene tectonic inversion and that the Ouerrha Accident corresponds to two major thrust planes in the western part of the Rif Mountains. The southern thrust is responsible for the establishment of several mesorifain sheet klippes resting in a horizontal position over the Lower Cretaceous marls of the Internal Prerif and the overlap of the important carbonate massifs of the Middle Liassic along the southern side of the Ouerrha Valley.

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