SERPENTINITE SLIVERS AND METAMORPHISM IN THE EXTERNAL MAGHREBIDES: ARGUMENTS FOR AN INTRACONTINENTAL SUTURE IN THE AFRICAN PALEOMARGIN (MOROCCO, ALGERIA)

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Resumen: La principal sutura del orógeno Maghrebí (la Zona de los Flyschs) se extiende entre las unidades externas del paleomargen Maghrebí y los terrenos Alboran-Kabilias (Zonas Internas). En este trabajo describimos una zona de sutura subsidiaria dentro del propio paleomargen Maghrebí. Esta sutura intra-continental está documentada en el Rif oriental, entre los dominios del Intrarif y Mesorif, por la existencia en la Zona de Falla de Nekor de la lámina de peridotitas de Beni Malek, que aparecen asociadas a metabasitas y serpentinitas retrabajadas. En las unidades de Ras Afrou, Tres-Forcas y Khebaba el metamorfismo de presión intermedia y baja temperatura (MP-LT) con cloritoide y fengita se ha datado como del Oligoceno terminal (>23 Ma, ^{40}Ar-^{39}Ar) y se interpreta que está asociado a la subducción de las unidades del Mesorif bajo el dominio Intrarif de Ketama. Al igual que en el macizo de Orán, las láminas de peridotitas, asociadas con los esquistos con cloritoide, son cabalgadas por los mantos externos mas distales. Al Oeste de la Zona de Falla de Nekor, la sutura desaparece, aunque los basaltos con clastos retrabajados de gabro que se encuentran en la base de la unidad de Ketama, pueden corresponder con la inversión durante el Oligoceno-Mioceno de una cuenca estrecha, de edad Jurásica-Cretácica, cuyo substrato sería un manto serpentinizado. Esta cuenca se extendía por el margen Norte-Africano, al Sur del propio Tethys Liguro-Maghrebí.

Palabras clave: Colisión, metamorfismo, sutura intra-continental, Rif, Maghrebides.

Abstract: The main suture of the Maghrebide orogen (Flysch Zone) extends between the External units of the Maghreb paleomargin and the Alboran-Kabylides terranes (Internal Zones). We describe a subsidiary suture zone within the Maghreb paleomargin itself. This intracontinental suture is documented in the Eastern Rif between the Intrarif and Mesorif External domains by the occurrence, in the Nekor Fault Zone, of the Beni Malek serpentinite sliver associated with metabasites and reworked serpentinite layers. The medium pressure, low temperature (MP-LT) chloritoid-phengite metamorphism of the Ras Afraou, Tres-Forcas and Khebaba units, dated as late Oligocene (>23 Ma; ^{40}Ar-^{39}Ar), can be interpreted as linked to the subduction of the Mesorif units beneath the Intrarif Ketama domain. Likewise in the Oran massif, serpentinite slivers associated with chloritoid-bearing schists are overthrust by the most distal External nappes. West of the Nekor Fault Zone, the suture disappears, but basalts with reworked gabbro clasts at the bottom of the Ketama unit are likely related to its westward continuation under the Intrarif floor-thrust. The External Maghrebide suture would correspond to the Oligocene-Miocene inversion of a narrow, Jurassic-Cretaceous basin floored by serpentinized mantle, and extending within the North-African margin south of the Ligurian-Maghrebian Tethys itself.

Key words: Collision, metamorphism, intracontinental suture, Rif, Maghrebides.

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Twelve years ago, Victor García-Dueñas, together with two of his young colleagues and former students, drew the attention of the scientific community to the serpentinite sliver and chloritoid-bearing metapelites of the Cape Tres Forcas (Taryat) massif close to Melilla in the Eastern Rif (García-Dueñas *et al.*, 1995). As a tribute to his memory, we revisit the Eastern Rif in the present paper to integrate the Tres Forcas massif in the structure of the Maghrebide belt (Fig. 1). We interpret the Tres Forcas serpentinite sliver and underlying MP-LT metamorphism as the trace of an intracontinental suture within the Maghrebide External Zones.

An intracontinental suture may be defined as the result of a minor subduction zone involving a narrow, thinned crust/oceanic crust seaway between two continental domains. The Mediterranean Alpine belts offer at least two examples of such sutures: (1) the Briançonnais Front, which derives from the subduction of the proximal European margin beneath the Middle Penninic submarine plateau, formerly a distal block of this margin (*e.g.*, Stampfli *et al.*, 2002; Michard *et al.*, 2004), and (2) the North-Pyrenean Fault, which should result from the aborted subduction of the Iberian lithosphere beneath the European plate, following an earlier, short-lived opposite subduction (Choukroune *et al.*, 1989). Both these intracontinental sutures are associated with scarce peridotite slivers and low to medium P/T metamorphism, except where superimposed by typical oceanic subduction (Western Alps).

In the following, we present evidence for the occurrence of an oblique, intracontinental suture zone extending at least from the Central Rif to the Oran area, i.e. over 400 km longitudinally within the Maghrebide External Zones (Fig. 1). The eastward continuation of this suture zone up to the Cheliff massif south of Algiers will be advocated in another paper (Durand-Delga *et al.*, in prep.). The present study is mainly based on re-examination of varied natural sections of Eastern Rif and on the recent, mineralogical and geochronological analyses performed by one of us in this region (Negro, 2005; Negro *et al.*, 2007). Controversial hypotheses have been presented in the literature concerning the origin of the chloritoid-bearing units of Eastern Rif, either from the Internal Zones (Suter, 1980b; García-Dueñas *et al.*, 1995) or External Zones of the Rif belt (Frizon de Lamotte, 1985, 1987b), respectively. We contend that, in fact, these MP-LP metamorphic units have to be linked to the intracontinental suture defined above in the Maghrebide External Zones.

Geological setting

The Rif belt constitutes the western segment of the Alpine Maghrebide belt (Durand-Delga and Fontboté, 1980; Bouillin, 1986), which connects with the Betic Cordilleras through the Gibraltar Arc (Fig. 1). The Rif belt (Fig. 2) includes three major structural domains, from top to bottom, i) the Internal Zones, or Alboran Domain; ii) the Maghrebian Flysch nappes; and iii) the External Zones.

The Rif Internal Zones include two groups of nappes showing a metamorphic core complex-like geometry (García-Dueñas *et al.*, 1992; Michard *et al.*, 2006). The upper plate corresponds to the Ghomaride-Malaguide nappes, which mainly consist of Paleozoic rocks affected by low-grade Variscan metamorphism (Chalouan and Michard, 1990). The lower plate corresponds to the Sebtide-Alpujarride units, affected by Alpine low- to high-grade, medium to high-pressure metamorphism (Bouybaouene *et al.*, 1995). These metamorphic units consist of mantle peridotites and granulites (Beni Bousera, Ronda), gneiss and mica-schists, and metamorphic remnants of Permian-Triassic cover rocks (Federico metapelites and marbles). The Internal Zones include also the Dorsale Calcaire, which originates from the Mesozoic-Cenozoic sedimentary cover of the Alboran Domain paleomargin, north of the Ligurian-Maghrebian Ocean (El Hatimi *et al.*, 1991; El Kadiri *et al.*, 1992).

The Maghrebian Flysch nappes are formed by remnants of the sedimentary infill of the latter ocean, associated with scarce ophiolitic slivers (Durand-Delga *et al.*, 2000). These nappes root beneath the Internal Zones and overlie the External Zones, except for some back-thrust units in western Betics, northern Rif and Kabylias. Thus, the highly dilacerated contact at the bottom of the Alboran Domain represents the main suture zone of the Maghrebide orogen.

The Maghrebide External Zones derive from the North-African paleomargin inverted during the Cenozoic collision of the Internal Zones (Wildi, 1983; Favre *et al.*, 1991). In the Rif belt, they are divided, from NE to SW and top to bottom, into the Intrarif, Mesorif and Prerif Zones (Suter, 1980a, b). Within each of these zones, deep rooted, para-autochthonous units contrast with diverticulated, gravity-driven nappes thrust over the more external domains. The Intrarif zone

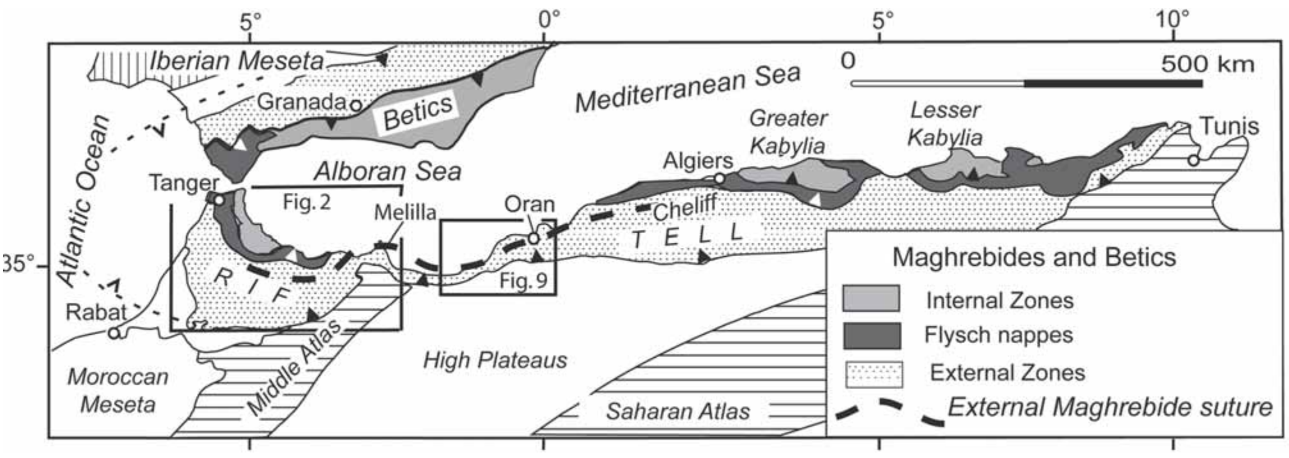

Figure 1.- Sketch map of the Maghrebide belt (except its easternmost, Sicilian segment) and Gibraltar Arc, with location of the intracontinental suture zone hypothesized in the present work. Framed: figure 2 and figure 9.

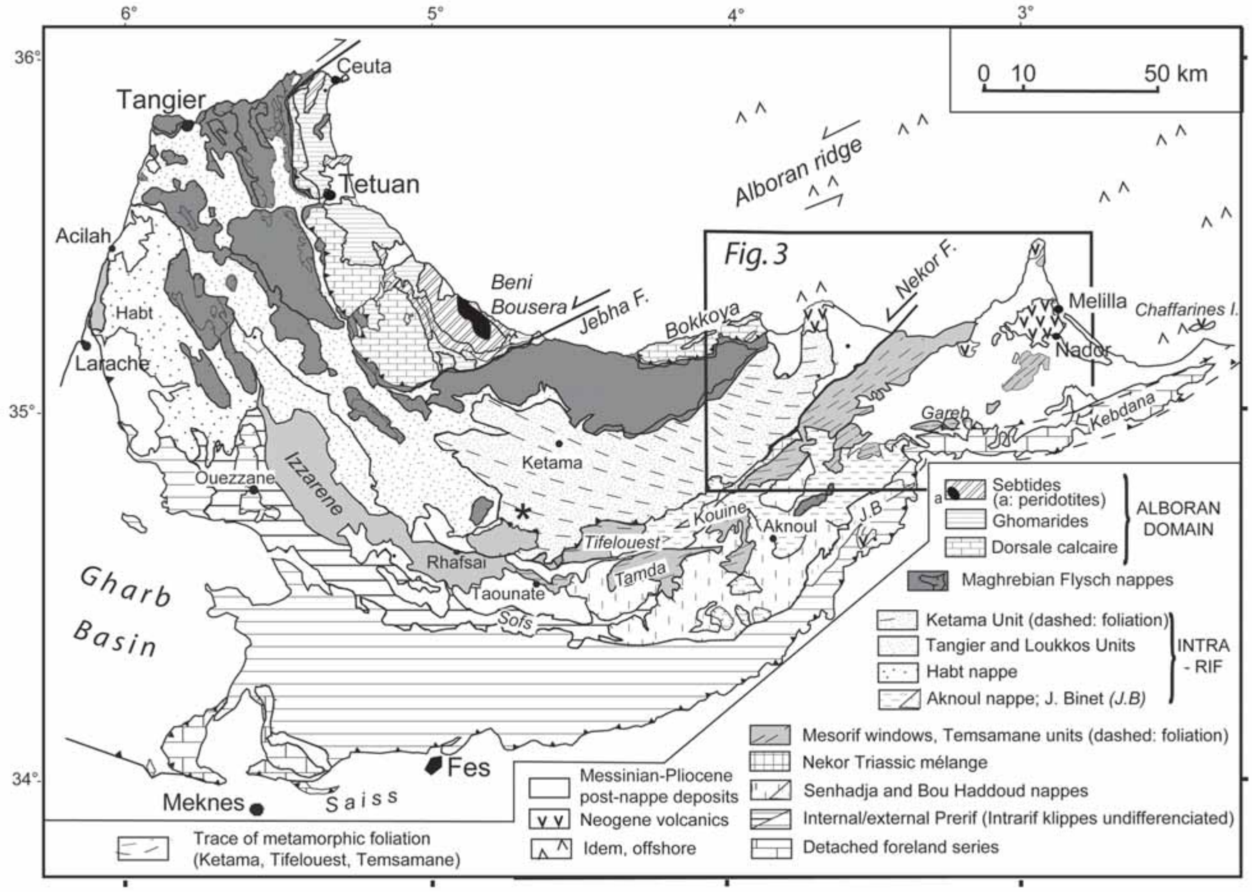

Figure 2.- Structural map of the Rif belt, with emphasis on the External Zones. Simplified from Suter (1980b) and Chalouan *et al.* (2001). Framed: figure 3. Asterisk: Taounat Lekchour volcanic level (Zaghloul *et al.*, 2003).

includes the deep Ketama unit (Triassic to Albo-Cenomanian), the Tanger unit, partly detached from Ketama, and the Habt and Aknoul nappes (Late Cretaceous-Cenozoic), completely detached from Ketama. The Mesorif Zone shows allochthonous units including Paleozoic-Paleogene formations thrust over tectonic windows whose series end with Middle Miocene turbidites. The Prerif Zone consists of Jurassic-Miocene units detached on the underlying Triassic evaporites and thrust over the Upper Miocene foredeep (Gharb Basin, Saiss). The thrusts are sealed by the transgression of Upper Tortonian-Messinian conglomerates and sandy marls, subsequently folded (*e.g.*, Taounate «post-nappe» syncline).

The tectonic structures observed in the Rif External units and overlying Flysch outliers show an overall southwest-ward displacement (Frizon de Lamotte *et al.*, 1991). Two major NE-trending left-lateral faults, namely the Jebha Fault, south of the northern Rif Internal Zones, and the Nekor Fault, between the Central and Eastern Rif, give additional evidence of the obliquity of the collision of the Alboran Domain against Africa (Leblanc and Olivier, 1984; Frizon de Lamotte, 1985).

Mesorif structure

The overall structure of the Mesorif Zone in Central and Eastern Rif deserves a specific description as a base for the inference of a suture zone in this area.

Central Rif

In the Central Rif (Fig. 2), the Mesorif Zone includes antiformal windows (Tamda, Jebel Kouine) cored by Lower-Middle Miocene turbidites and olistostromes, and overthrust by Mesozoic units of more internal origin. The latter units include the Tifelouest-Tafraout-Rhafsai folded duplexes, rooted at the front of the Ketama massif, and the Senhadja nappe which forms unrooted klippes on top of the Miocene turbidites (Frizon de Lamotte, 1985, 1987a; Favre, 1992). The Tifelouest units and Senhadja nappe show Jurassic sequences typical of a distal margin environment. Additionally, the Senhadja nappe contains Triassic rocks (reddish sandstones and pelites, spilitic dolerites and gabbros) and Paleozoic quartzites and phyllites. The Mesorif Jurassic-Lower Cretaceous series crop out also in the Izzarene Forest of Western Rif, and in the rocky ridges («sofs») which outline the Mesorif-Prerif boundary. Everywhere within the Mesorif domain, rapid facies and thickness changes in the Lower and Middle Jurassic carbonates and marls characterize the syn-rift evolution of the paleomargin (Favre, 1992, 1995). The post-rift sequence includes Middle-Upper Jurassic deep-sea fan facies («ferrysch»; Wildi, 1981; Favre *et al.*, 1991), Tithonian-Berriasian micrites and Neocomian pelites. In the Tifelouest units, the Cenozoic series include unconformable blocky marls poorly dated as

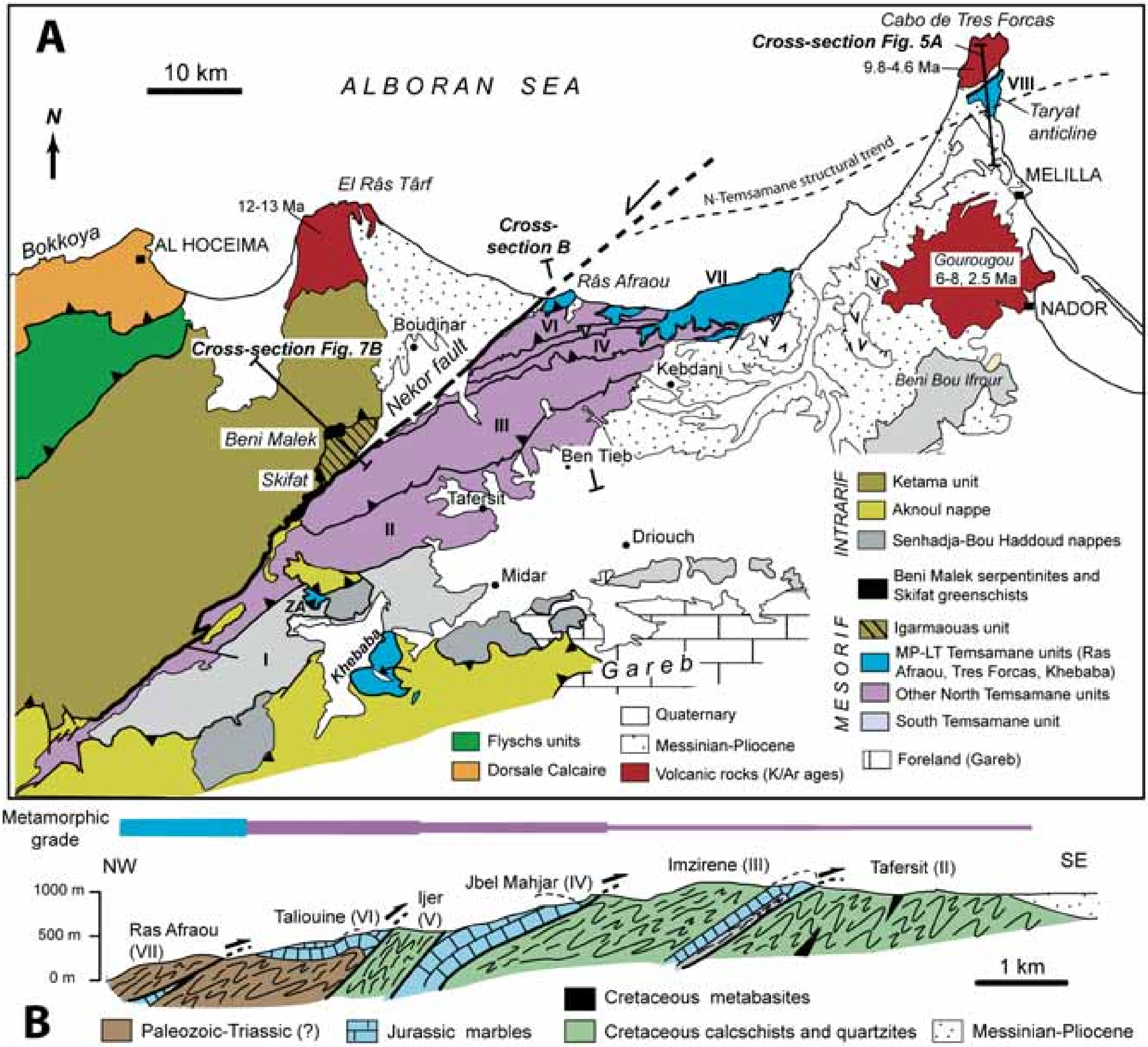

Figure 3.- Structural map of Eastern Rif (**A**) and cross-section of the North Temsamane massif (**B**), after Frizon de Lamotte (1985) and Negro *et al.* (2007). AT: Ain Tasseda; ZA: Zaouyet Sidi Hadj Ali (Khebaba group). K/Ar age of volcanoes after El Azzouzi *et al.* (1999) and Münch *et al.* (2001).

Late Oligocene (presence of both Nummulites and Lepidocyclines; M. Durand-Delga, *in litt.*, 2007), followed upward by deeply discordant olistostromes (Late Oligocene-Aquitanian?) and Aquitanian-Middle Serravallian turbidites (Frizon de Lamotte, 1985; Favre, 1992). The Mesozoic formations are strongly folded, duplicated and affected by synmetamorphic, shallow-dipping foliation, whereas the olistostromes and overlying turbidites are only affected by a steeply dipping spaced cleavage. The occurrence of foliated pebbles of Mesozoic and Eocene metasediments in the Late Oligocene-Aquitanian olistostromes yield evidence for a main tectonic-metamorphic phase during the Late Eocene-Oligocene.

Eastern Rif

In the Eastern Rif (Figs. 2 and 3), the South Temsamane unit (= unit I) corresponds to the north-eastern continuation of the Tamda-Kouine Mesorif windows. This unit I offers an almost complete and virtually unmetamorphosed stratigraphic succession (Fig. 4A). In contrast, the North Temsamane massif consists of stacked tectonic units (units II-VII) whose stratigraphic sequences are truncated by the intervening thrust faults, whereas the metamorphic grade increases gradually from bottom to top of the tectonic pile (Figs. 3B and 4B). The southernmost units II-V consist of strongly folded Jurassic-Cretaceous metasediments with rare mafic intercalations. A major recumbent fold is outlined by the Jurassic marbles in unit IV (Jbel Mahjar). The uppermost units VI (Taliouine) and VII (Ras Afraou) expose undated metapelites and quartzites with scarce marbles layers. The fact that these formations are overlain by Liassic dolomitic marbles in the Taliouine unit supports their attribution to the Paleozoic and/or Permian-Triassic. The latter age has been favoured for the Ras Afraou unit where dark red-coloured quartzose metapelites evoke locally

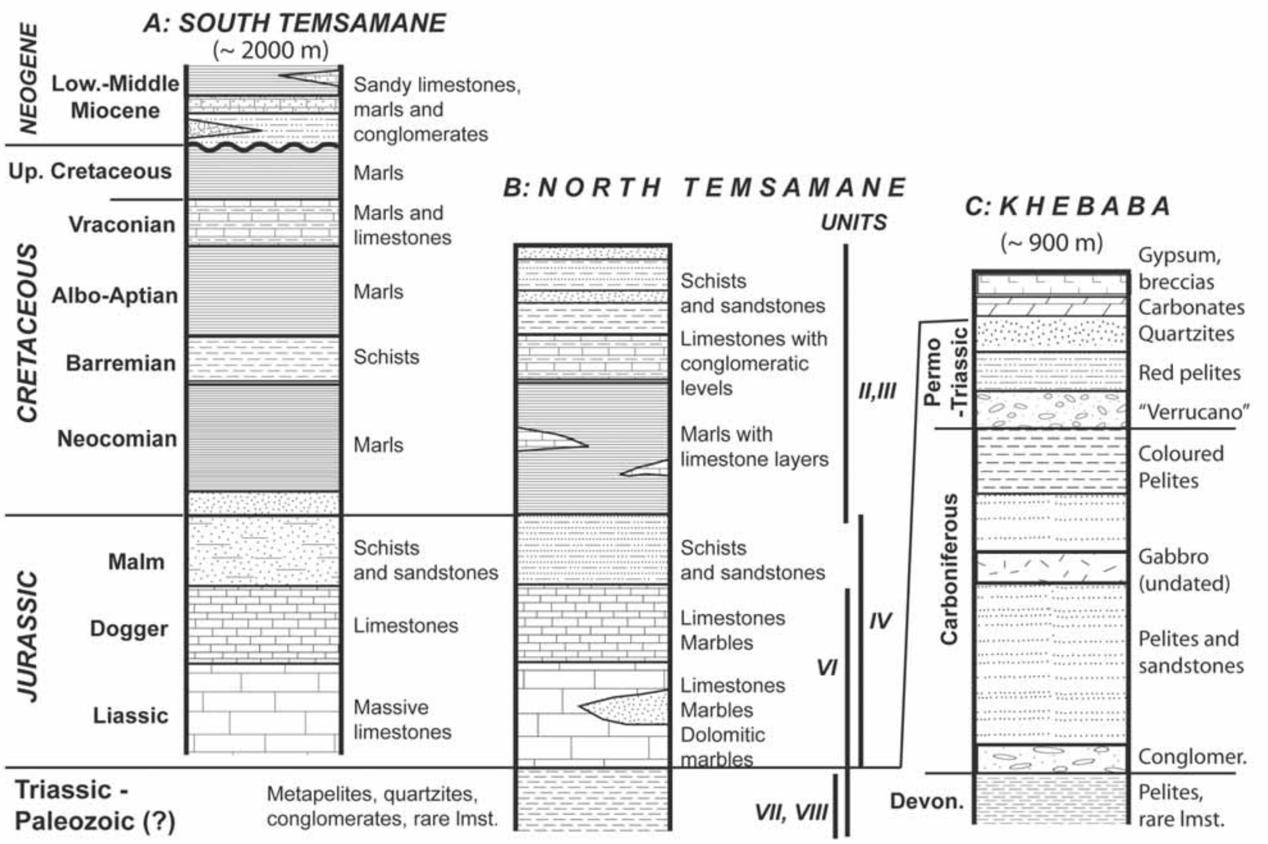

Figure 4.- Stratigraphy of the Temsamane and Khebaba units, after Frizon de Lamotte (1985), Negro *et al.* (2007) and Darraz and Leblanc (1989), respectively. Temsamane columns (A, B) not to scale.

(Cape Ras Afraou) the Permian-Triassic metasediments of the upper Sebtides units (Suter, 1980a; Frizon de Lamotte, 1985; see Discussion). However, in the eastern part of unit VII (Kebdani region; Choubert et al., 1984b) the lithological facies would rather evoke pre-Permian Paleozoic material.

Two isolated metamorphic units also occur in Eastern Rif (Fig. 3), i.e. the Taryat (Tarjat) anticline of the Tres-Forcas massif, where García-Dueñas *et al.* (1995) discovered the presence of chloritoid, and the Khebaba massif where the latter mineral was first observed by Darraz and Leblanc (1989). The Tres-Forcas massif (Fig. 5) corresponds to the uplifted border of an Upper Miocene tilted block (Guillemin *et al.*, 1983). It consists essentially (Taryat anticline) of metapelites, quartzites, black cherts and scarce marbles which compare to the lithofacies of the Temsamane units VI-VII. Thus, this massif can be referred to as the unit VIII of the Temsamane tectonic pile, consistent with its geographic location (Fig. 3) and metamorphic characteristics (see below). This unit is overlain by a sliver of greenschists and serpentinite, in turn overthrust by a thin succession of Carboniferous (?) sediments.

As for the Khebaba massif and associated elements (Zaouyet Sidi Hadj Ali, Ain Tesseda), they correspond to a group of tectonic klippes sandwiched between the

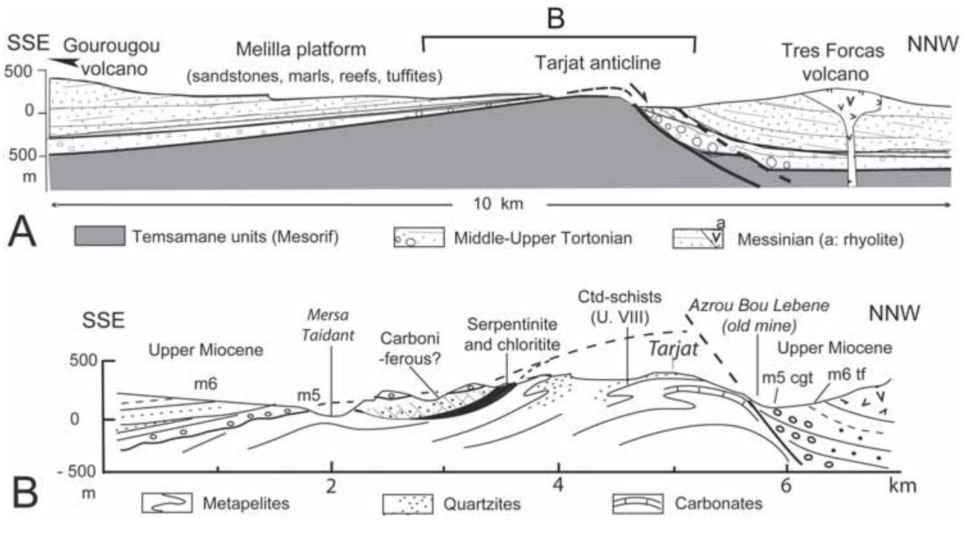

Figure 5.- The Tres-Forcas (Taryat) metamorphic massif and its tectonic setting (see figure 3 for location). **A**: General cross-section drawn after the geologic map 1:50,000, sheet Melilla (Guillemin *et al.*, 1983), and after Cornée *et al.* (1996) and Münch *et al.* (2001). **B**: Cross-section of the Taryat (Tarjat) anticline, after Guillemin *et al.* (1983) and personal observations. m5: Middle-Upper Tortonian; m6: Upper Tortonian-Messinian; cgt: conglomerates; tf: tuffites.

South Temsamane unit and the Aknoul nappe (Frizon de Lamotte, 1985; Darraz and Leblanc, 1989; Faure-Muret *et al.*, 1994). They mainly consist of Devonian and Early Carboniferous metasediments followed upward by Middle-Upper Triassic (?) series (Fig. 4C) Thus, the structural setting of the Khebaba group compares with that of the Senhadja klippes, whereas its stratigraphy and metamorphic grade resemble the ones of the northernmost Temsamane units.

Alpine metamorphism in the External Rif

West of the Nekor Fault

The Ketama Jurassic-Cretaceous series are recrystallized under low grade greenschist-facies conditions, with temperature lower in the upper part of the unit than in the lower part (200-250°C and 250-300°C, respectively; Frizon de Lamotte and Leikine, 1985; Leikine *et al.*, 1991), and pressure close to 3 kbar. Recrystallization is associated with south-verging recumbent or overturned folds (Fig. 6A), refolded by upright folds (Andrieux, 1971; Frizon de Lamotte, 1985). K-Ar datings did not yield reliable results due to the low-metamorphic grade and the abundance of clastic muscovite grains. In contrast, apatite fission track analysis indicates that the post-metamorphic cooling to *ca.* 100°C occurred at about 14-15 Ma (Azdimoussa *et al.*, 1998).

In the Mesorif Tifelouest unit (Favre, 1992), a closely similar tectonic-metamorphic evolution can be observed, being dated stratigraphically since syntectonic recrystallization affects the series up to the Late Oligocene (?) blocky marls inclusively and not the overlying Late Oligocene-Aquitanian olistostromes (see above section). Therefore, the metamorphism of the Tifelouest and (most probably) Ketama units occurred during the Late Oligocene interval (~28-23 Ma). Later during the orogenic evolution, upright folds with axial-planar spaced cleavage developed in the Mesorif units (crenulation cleavage in the foliated Tifelouest material; pressure solution cleavage in the Lower-Middle Miocene of the Mesorif windows). This anchimetamorphic event took place during the late Serravallian-early Tortonian interval, before the transgression of the late Tortonian-Messinian «post-nappe» sediments.

East of the Nekor Fault

The South Temsamane units only display an anchimetamorphic evolution as in the Central Rif windows. In contrast, the North Temsamane units exhibit greenschist-facies recrystallizations whose grade increases upward in the tectonic pile, indicating a post-metamorphic stacking event (Fig. 3B). Usual mineral assemblages are chlorite-phengite-quartz-albite in metapelites, and tremolite-epidote-albite-chlorite-sphene in metabasites (Unit VI). Chloritoid appears in the Ras Afraou unit (Unit VII) in association with high-Si phengite (Negro, 2005; Negro *et al.*, 2007). The peak P-T conditions are estimated at 7-8 kbar, 350 ± 30°C, corresponding to medium pressure, low temperature (MP-LT) metamorphism. The coeval, ductile structures include WSW-trending, S-verging overturned folds with gently dipping axial-planar foliation (Fig. 6B) associated with ENE-trending stretching lineation and top-to-the-WSW shear indicators (Frizon de Lamotte, 1985; Negro *et al.*, 2007).

The Taryat schists of the Tres-Forcas massif (Unit VIII) recrystallized under P-T conditions barely higher than those of the Ras Afraou unit (phengite-chloritoid assemblages equilibrated at ~8 kbar, 400 ± 30°C; Negro *et al.*, 2007). Ductile deformation is analogous in both units.

The occurrence of chloritoid was noticed by Darraz and Leblanc (1989) in the Khebaba massif, but assigned to Hercynian recrystallization. However, Negro (2005) observed this index mineral in association with phengite within Permian-Triassic metasediments, thus demonstrating its Alpine age. The estimated peak P-T conditions are similar to

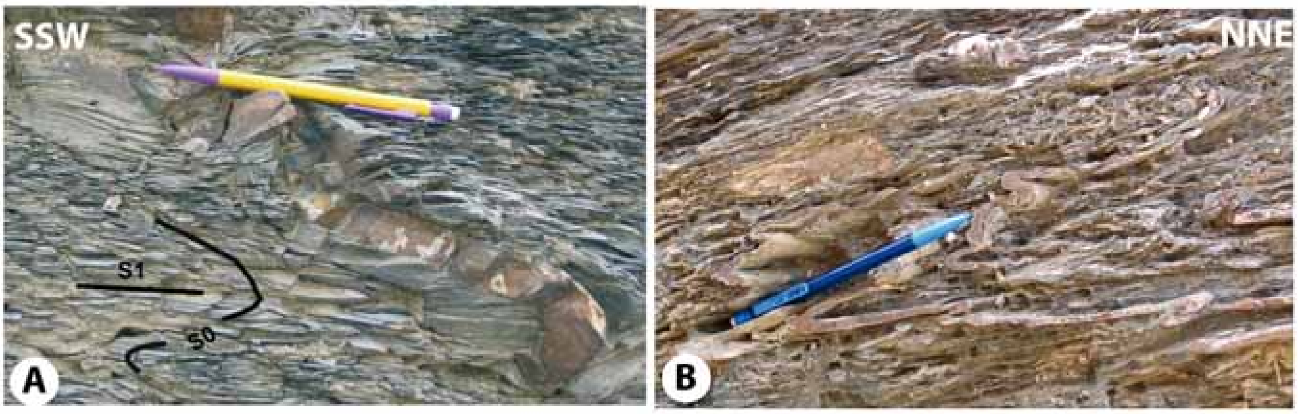

Figure 6.- Syn-metamorphic folds from the External Rif. **A**) Ketama unit, Aptian-Albian sandy shales; minor folds with axial plane slaty cleavage S1 in the inverted limb of a major fold, 20 km south of Ketama. **B**) Eastern Ras Afraou unit (Kebdani); recumbent minor folds and associated sub-horizontal foliation. These metasediments include banded sandy metapelites, thick quartzite beds and some carbonate layers. Uncertain age (Paleozoic to Triassic?).

those of the Tres-Forcas unit, i.e. 7-8 kbar, 420 ± 30°C (Negro *et al.*, 2007).

Therefore, the Ras Afraou, Tres-Forcas and Khebaba units suffered a MP-LT Alpine metamorphism at depths of about 20-25 km, with a burial metamorphic gradient of ~15°C/km, which is typical of subduction zones (Negro *et al.*, 2007). Early ^{40}Ar-^{39}Ar phengite datings (Monié *et al.*, 1984) yielded an age of 28.6 ± 1 Ma for the peak metamorphism of Unit V, whereas a low-grade crystallization stage was dated at 8 Ma. Negro (2005) obtained three groups of ^{40}Ar-^{39}Ar results, depending on the structural location of the mica grains, from samples collected in the Ras Afraou (western and eastern parts) and Tres-Forcas units (Negro *et al.*, in prep.). Results of *ca*. 23-20 Ma characterize the minimum age of high-Si phengite grains preserved in the intrafolial quartz segregates from both units, being referred to the peak pressure metamorphism. A second group of results at ~15-10 Ma, also obtained from both units, characterize the phengite lamellae from the foliation, and then are referred to the ductile deformation associated with the south-westward exhumation of the metamorphic units. The low-temperature dates at ~10-6 Ma are obtained from the illite-kaolinite-bearing retrogressed samples, thus reflecting the late brittle-ductile deformation of the tectonic pile.

Mesozoic crustal thinning between the Intrarif and Mesorif Zones

In the North Temsamane domain, dolerite sills intrude the Jurassic-Cretaceous formations, being affected by the regional syntectonic recrystallization (Frizon de Lamotte, 1985; Faure-Muret *et al.*, 1994). These metadolerites testify to the importance of the paleomargin thinning in the distal Mesorif area during the Early Cretaceous.

Such crustal thinning is still better documented by the occurrence of the Beni Malek serpentinite massif in the Nekor Fault corridor (Figs. 3 and 7). The presence of these remarkable rocks has been known for long (Russo and Russo, 1929; Choubert *et al.*, 1984a), but its geodynamic significance was recognized more recently (Michard *et al.*, 1992). The massif forms a kilometre scale lens at the bottom of the Ketama unit and overlies a metasedimentary unit (Igarmaouas unit), intermediate between the Ketama and North Temsamane complexes (Fig. 7A). The ultrabasites correspond to serpentinized spinel lherzolites. They are partly draped by a cover sequence consisting of limestones with ophiolitic clasts (Late Jurassique-Early Cretaceous?). Laterally (near Skifat village), the massive serpentinite is replaced by greenschists which correspond to metabasites and recrystallized ophiolitic sand (ophicalcites). The Beni Malek unit has been interpreted (Michard *et al.*, 1992) as a sliver of a Jurassic-Cretaceous oceanic crust formed dominantly by tectonic denudation of mantle rocks (non-volcanic rift-margin), as in the Western Alps or along the west Iberian margin (Manatschal and Bernoulli, 1999). Modelling of the regional magnetic anomaly (Elazzab *et al.*, 1997) suggests that the serpentinite-metabasite sliver is derived from a deeper and larger serpentinite body obducted onto the Mesorif units (Fig. 7B).

The serpentine and chloritoid-rich schist sliver of the Tres-Forcas massif (Guillemin *et al.*, 1983; García-Dueñas *et al.*, 1995) can be correlated with the Beni Malek-Skifat sliver, as they both occur on top of the Temsamane metamorphic pile. This confirms the occurrence of a thinned-crust area north of the eastern Mesorif Zone. Likewise in the Central Rif, west of Taounat Lekchour (Fig. 2), a volcanogenic level with ocean-derived elements is interbedded at the bottom of the Late Jurassic-Early Cretaceous Ketama series (Zaghloul *et al.*, 2003). The 3 m-thick level consists of a vacuolar, diopside-rich olivine-bearing matrix including sedimentary and magmatic clasts, up to 30 cm in size. The sedimentary clasts are pelagic limestones, whereas the magmatic clasts include diabases, dolerites and gabbros. Geochemical data show a broad spectrum of E-MORB-type trace element patterns. All these features suggest an explosive, intraoceanic emplacement (Zaghloul *et al.*, 2003).

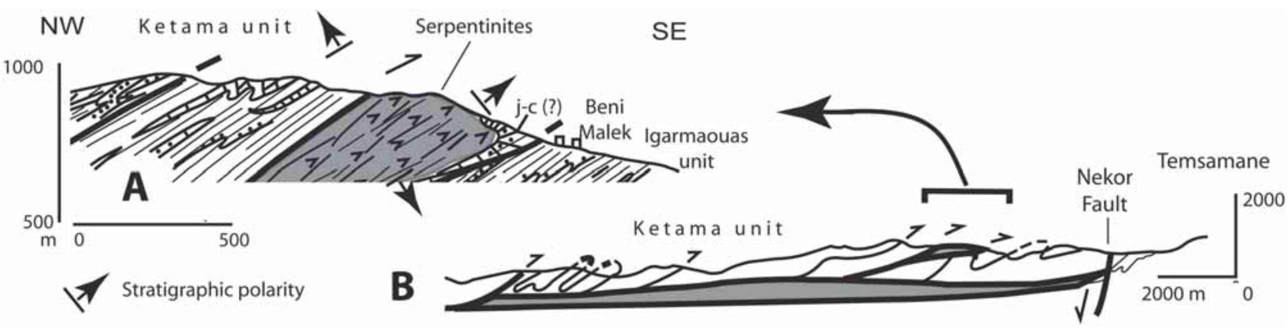

Figure 7.- The Beni Malek ultrabasite sliver (see figure 3 for location). **A**: Geological cross-section, after Michard *et al.* (1992). (j-c?): carbonates with serpentinite clasts (Upper Jurassic-Lower Cretaceous?). Igarmaouas and Ketama units: metapelites, quartzites, meta-calcarenites. **B**: 2D interpretation of the aeromagnetic anomaly, after Elazzab *et al.* (1997). The anomaly extends NW of the serpentinite outcrops, which therefore correspond to a sliver detached from a large cryptic body at shallow depth.

Interpretation and discussion

Origin of the Eastern Rif MP-LT units

The role of basement faults during the development of the Rif External Zones remains a matter of debate. The External Rif has been described either as a thin-skinned foreland belt, detached on the Upper Triassic evaporites (*e.g.*, Suter, 1965; Faure-Muret and Choubert, 1971a; Morley, 1987; Platt *et al.*, 2003), or as a thick-skinned belt with shortening of the basement through distributed reverse faults (Andrieux, 1971; Michard, 1976; Leblanc, 1979; Frizon de Lamotte *et al.*, 2004; Michard *et al.*, 2005; Crespo-Blanc and Frizon de Lamotte, 2006). Obviously, the significance of the Eastern Rif metamorphic units (particularly of the most recrystallized) is a key problem to resolve between such tectonic interpretations. Faure-Muret and Choubert (1971b) considered that the entire Temsamane stack of recumbent folds was derived from Mesozoic-Lower Miocene series rooted, together with the overlying Senhadja nappe, beneath the Ketama unit (see also Leblanc, 1979). These authors considered the Beni Malek «ophiolite» as rooted in an external «furrow» south of the Ketama domain. However, as the red sandy-pelitic metasediments of the Ras Afraou and Khebaba units resemble the Permian-Triassic series of the upper Sebtides, Suter (1980a, 1980b) suggested that these units as well as the Tres-Forcas massif could represent Sebtide outliers. García-Dueñas *et al.* (1995) compared the structure of the Taryat anticline to that of the Alboran Domain. These authors suggested that the Taryat serpentinite sliver could be equivalent to the Beni Bousera-Ronda peridotites, and the overlying Carboniferous section to the Ghomaride complex. Negro (2005) and Negro *et al.* (2007) present both the external and internal origin hypotheses without favouring one or the other.

However, Triassic redbeds and carbonates are common in both the Internal and External Rif Zones. Likewise similar metamorphic facies may have developed in distinct structural domains of the belt. Thus, the analogy between certain outcrops of the Temsamane and upper Sebtide units does not constitute any evidence for an internal origin hypothesis. In contrast, we consider the following arguments as strong enough to discard the hypothesis:

I) As a general rule, in the Northern Rif and Bokkoya regions, the Alboran Domain overlies the External Zones through a pile of internal nappes (Dorsale, Predorsalian and Flysch units). In contrast, none of these nappes are preserved under the Ras Afraou and equivalent units.

II) In the Alboran Domain, the Ronda and Beni Bousera peridotites are located at the bottom of high-grade Alpujarride-Sebtide units, thousands of metres deeper than the medium-grade Federico units and the overlying Malaguide-Ghomaride complex. Contrastingly, the Taryat serpentinites are located between the alleged equivalent of the Sebtide and Ghomaride complexes.

III) The Alpujarride-Sebtide metamorphic units were being exhumed at 25-23 Ma (*e.g.*, Michard *et al.*, 2006, and references therein), whereas the Temsamane units were still at their peak metamorphic conditions at ~28-23 Ma.

IV) If the Ras Afraou and Khebaba units were Sebtide outliers, they would have crossed the Intrarif domain before the detachment of the Aknoul nappe, as the latter nappe overlies the Khebaba massif. However, it is hardly conceivable that the Sebtides could have overthrust the Intrarif domain without triggering the detachment of the Aknoul nappe.

We infer that the Ras Afraou, Tres Forcas and Khebaba units originate from the External domain itself. Therefore, a subduction zone responsible for their MP-LT metamorphism must be hypothesized along the northern border of the Mesorif. The varied Temsamane units would have been located at varied depth in the subduction zone, consistent with the metamorphic gradient observed across the massif. In the following, we refer to this subduction zone (and to the corresponding suture) as the «Mesorif subduction (suture) zone» (MSZ) – or «External Maghrebide subduction (suture) zone», at larger scale (cf. Fig. 1).

Mesorif subduction zone

The inferred tectonic scenario can be summarized as follows (Fig. 8). During the Jurassic-Cretaceous, the North-African margin included a distal block (Intrarif) separated from the more proximal margin (Mesorif, Prerif) by a narrow, thinned crust/serpentinite floored basin (North Mesorif basin = future MSZ; Fig. 8A). During the Oligocene (Fig. 8B), the Africa-Iberia convergence triggered the main Maghrebide subduction zone along the northern border of the Ligurian-Maghrebian Ocean, i.e. the subduction probably responsible for the Alpujarride-Sebtide metamorphism (Faccenna *et al.*, 2004; Chalouan and Michard, 2004), although alternative scenarios can be proposed (Durand-Delga, 2006). However, plate convergence also caused a subsidiary subduction to develop along the northern boundary of the North Mesorif basin. This was the MSZ, responsible for the North Temsamane metamorphism.

By the early Middle Miocene (Fig. 8C), suturing of the Maghrebian Ocean was achieved south of the Alboran Domain, whereas oblique collision still developed along the MSZ. This would account for stacking of the Temsamane units onto thicker

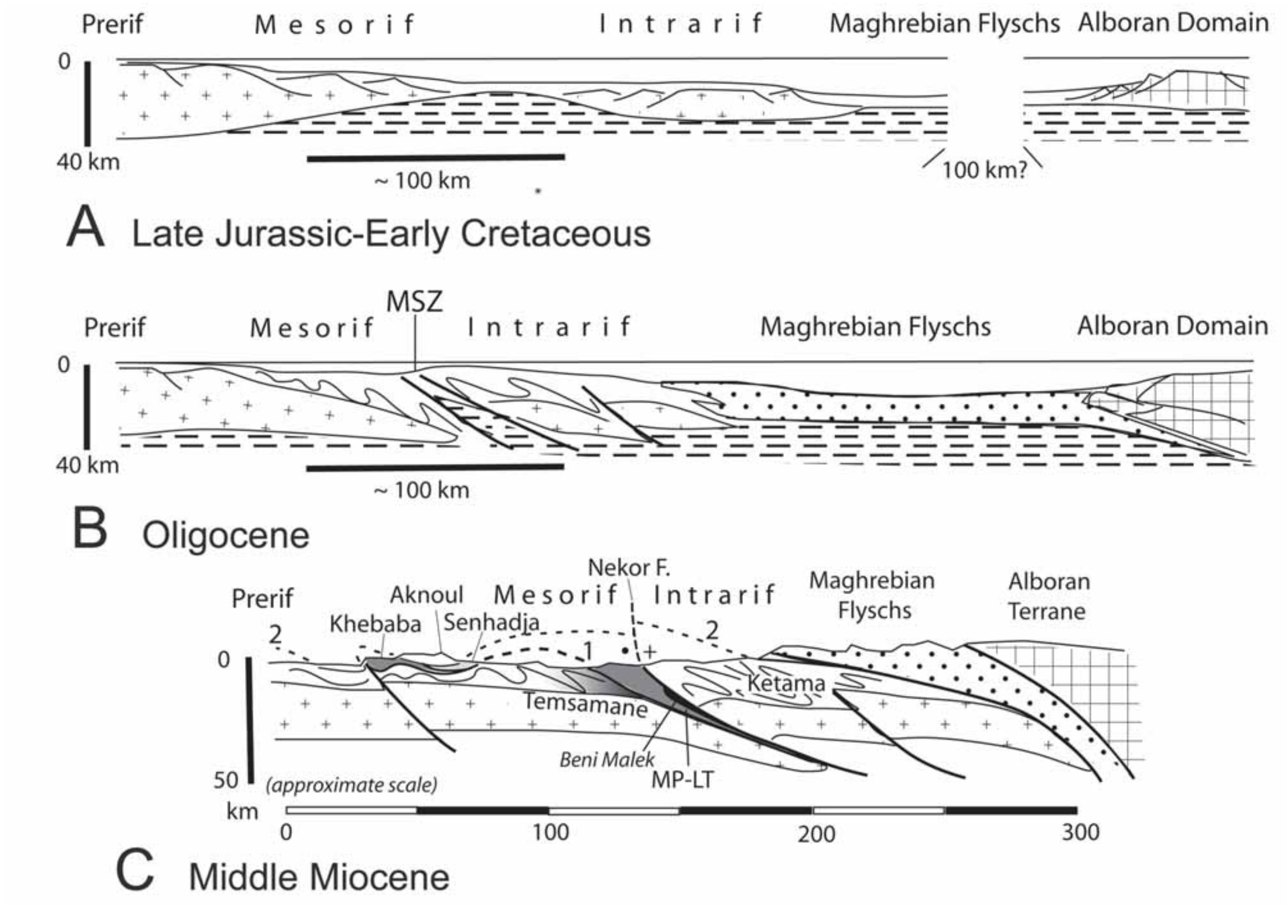

Figure 8.- 2D sketch of the tectonic evolution of the Mesorif Suture Zone (MSZ). **A**) Schematic restoration of the Jurassic-Cretaceous setting, after Michard *et al.* (1992), slightly modified. **B**) Oligocene setting, involving two competing subduction zones, i.e. the MSZ in the fragmented African paleomargin, and the Maghrebian subduction beneath the Alboran Domain. **C**) Diagrammatic cross-section of the Eastern Rif after Negro *et al.* (2007), modified. 1, 2: successive thrusting episodes, both included in the late Serravallian-middle Tortonian interval.

continental crust (thrust contact #1 in Fig. 8C), and for their subsequent exhumation due to isostatic rebound (cf. ^{40}Ar-^{39}Ar ages at ~15-10 Ma). It is worth noting that Mid-Serravallian is paleontologically dated in the uppermost beds of the southern Mesorif windows (Septfontaine *in* Frizon de Lamotte, 1985), which gives a proxy of 13-12 Ma for the age of the thrust contact #1. Middle Miocene is also dated in some western Intrarif units which are lateral equivalent of the Aknoul nappe: Serravallian in the External Tanger unit (Zaghloul *et al.*, 2005), Langhian in the Habt nappe (Zakir *et al.*, 2004), and Mid-Serravallian in the Intrarif-derived Ouezzane nappe (Ben Yaïch, 1991). Thus, the Aknoul nappe emplacement (thrust contact #2) would rapidly follow the Mesorif thrusting, being probably a late Serravallian-Messinian polyphase process. Consistently, the Jebel Binet formations, deposited upon the Aknoul and Bou Haddoud nappes before their final emplacement onto the Prerif, are dated from the upper Tortonian-lower Messinian (Septfontaine, 1983). The late orogenic evolution of the Intrarif-Mesorif includes a middle Tortonian shortening event (^{40}Ar-^{39}Ar ages at 10-6 Ma). This event was probably responsible for the subsequent gravity-driven collapse of the prism, documented in the post-nappe basins of the Central Rif (Samaka *et al.*, 1997).

Longitudinal extension of the Mesorif Suture Zone

The structure and geometry of the MSZ has been deeply marked by the obliquity of the Alboran Domain-Africa convergence (Frizon de Lamotte, 1987a; Spakman and Wortel, 2004). The Nekor Fault Zone, which represents a late left-lateral ramp of the Alboran-Ketama thrust, determines the westward truncation of the Temsamane units. Farther west, the external-ward thrust of the Intrarif may explain the disappearance of the metamorphic, internal part of the Mesorif, buried beneath the Intrarif. However, the volcanogenic level of Taounat Lekchour (Zaghloul *et al.*, 2003), described above, suggests that an oceanic crust was also present south of the central Intrarif during the Jurassic-Early Cretaceous. The former continuation of the external thinned crust/oceanic crust zone toward the Western Rif is debatable.

On the other hand, an eastern continuation of the MSZ can be traced in the External Tell up to the Oran and Arzew massifs, i.e. 250 km east of the Tres-Forcas transect (Fig. 9). In the south-western Coastal Massifs of the Oranais region, the chloritoid-bearing Haouariya unit (Guardia, 1975) is an equivalent to the Tres Forcas and Khebaba units. The Haouariya unit consists of chloritoid-bearing (MP-LT?) metapelites,

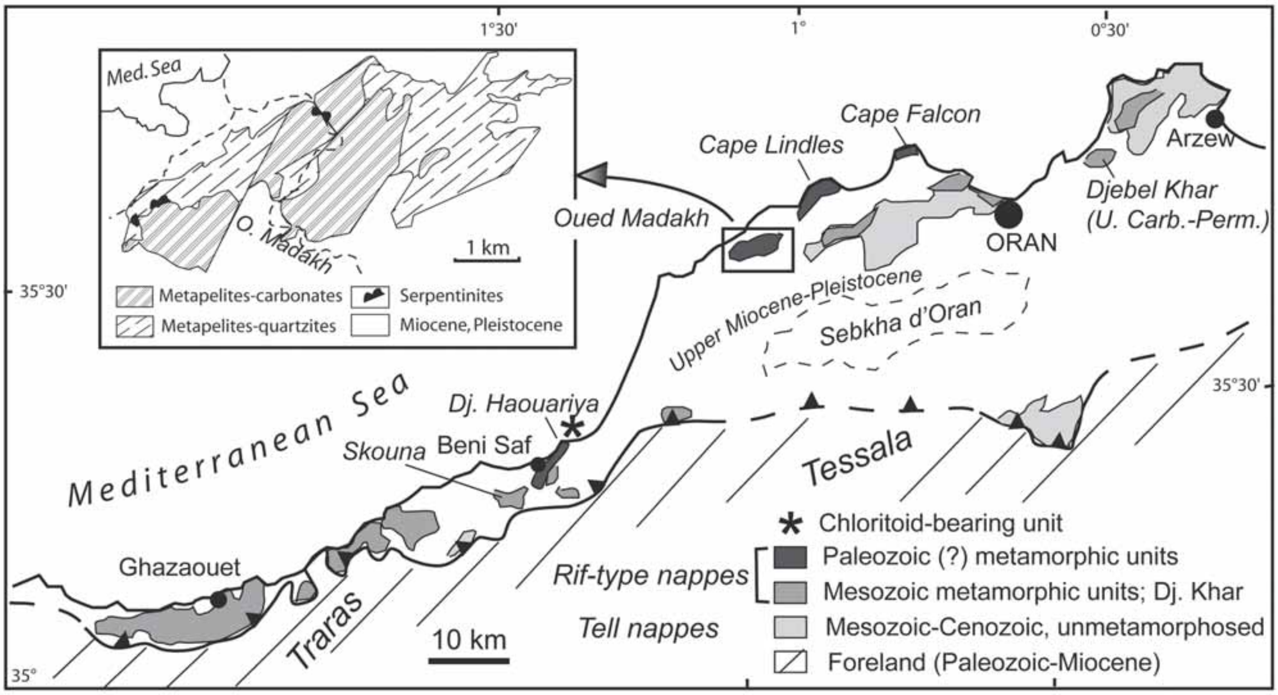

Figure 9.- Generalized map of the Oranais Coastal Massifs, after Wildi (1983). The details in the south-western massifs are after Guardia (1975) and in the north-eastern massifs (including the Oued Madakh insert), after Fenet (1975). Although the varied units are more scattered than in the Temsamane area, the extension of the MSZ metamorphism and serpentinite slivers is clearly evidenced there.

quartzites and conglomerates whose protolith is ascribed to the Carboniferous and Permian. It is overlain by the Skouna metamorphic unit, devoid of chloritoid and consisting of metapelites, quartzites and carbonates assigned to the Jurassic-Cretaceous. The Haouariya-Skouna metamorphic stack is overlain by low-grade or unmetamorphosed units, from bottom to top the Chaotic Complex (mainly Triassic), Chouala Nappe (mainly Lower Cretaceous) and Senonian Nappe of Upper Tellian origin, comparable to the Aknoul and Bou Haddoud Intrarif nappes and capped by several klippes of Numidian Flysch. In the north-eastern Coastal Massifs, the serpentinite outcrops mentioned by Sadran (1952, 1958) in the Oued Madakh massif form a group of tectonic lenses pinched in the shallow-dipping thrust contact between a lower unit, equivalent to the Haouariya one, and an upper unit comparable to the Skouna (Fenet, 1975). The internal structure of the metamorphic Paleozoic massifs (Haouariya, Madakh and Cape Lindles) resembles that of the North Temsamane, being characterized by recumbent folds, shallow-dipping axial-planar foliation and strong ENE-trending stretching lineation. A poorly metamorphic Upper Carboniferous-Permian unit is also observed east of Oran city (Djebel Khar), which evokes the uppermost sliver of the Tres-Forcas massif.

Therefore, the extension of the Temsamane-Khebaba typical association of serpentinite slivers and MP-LT (?) metamorphism (chloritoid-bearing metapelites in Carboniferous-Triassic protoliths) is clearly documented in the Oranais Coastal Massifs. The eastward continuation of the same structural zone up to the Cheliff massifs south of Algiers (Fig. 1) will be discussed in another paper (Durand-Delga *et al.*, in prep.).

Conclusion

In the present study, a point is made on two geodynamic markers, i.e. MP-LT metamorphism (mostly developed in Paleozoic-Triassic rocks) and ultrabasites slivers, observed in the External Maghrebides. The P-T significance of the mineralogical assemblages was previously determined by one of us in the Eastern Rif (Negro *et al.*, 2007), based on recent advances in handling phyllosilicate-rich, high-variant metamorphic assemblages (*e.g.*, Vidal and Parra, 2000). The interpretation of the ultrabasite and associated metabasite slivers was helped by the comparison with other continental margins, either inversed (Adria paleomargin in the Alps) or not (Galicia margin).

Our conclusion is that an internal-ward dipping suture zone occurs between the Intrarif and Mesorif domains of the western Maghrebides. The «Mesorif Subduction Zone» (MSZ) operated in the context of the Oligocene-Miocene oblique collision of the Alboran Domain against Africa. The MSZ appears as a subsidiary locus of lithosphere shearing with respect to the main Maghrebide subduction zone between the Alboran and Flysch Domains. As the MSZ developed within the African paleomargin, it can be referred to as an intracontinental subduction zone, although its development was favoured by the occurrence of strongly thinned lithosphere between the proximal and distal parts of the margin.

The MSZ can be followed longitudinally over 500 km in the Rif-Tell External Zones, based on peridotite remnants and metamorphism, and would continues eastward over 200 km at least (Durand-Delga *et al.*, in prep.). Thus, the MSZ could be also referred to as the «External Maghrebide Suture Zone». The MP-LT metamorphic massifs of the western External Maghrebides originate from this subsidiary subduction zone, and not from the main Maghrebian subduction zone.

Last but not least, this study confirms the major contrast, recently emphasized (Crespo and Frizon de Lamotte, 2006), between the thin-skinned External Zones of the Betic Cordilleras and the mostly thick-skinned External Zones of the Maghrebides.

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