NEW STRATIGRAPHIC DATA OF THE OLIGO-MIOCENE TRANSGRESSIVE COVER OF THE GHOMARIDE UNITS (NORTHERN INTERNAL RIF, MOROCCO): IMPLICATIONS ON TECTONO-SEDIMENTARY EVOLUTION

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Resumen: Se aportan nuevos datos bioestratigráficos y de campo de la cobertera oligo-miocena de las unidades gomárides (Zona Interna Rifeña) concernientes**:** i) al ciclo Oligoceno terminal-Aquitaniense de las formaciones Fnidek-Ciudad Granada, cuya parte superior se ha datado en este trabajo con foraminíferos planctónicos como Aquitaniense terminal, y ii) al ciclo Burdigaliense de las formaciones Sidi Abdeslam-Viñuela, del cual se han descubierto cinco nuevos afloramientos situados al norte de Tetuán. Estos afloramientos presentan secuencias pelíticas que contienen horizontes silíceos intercalados en sus niveles superiores. Estos niveles contienen asociaciones de nannofósiles que datan la zona de *Sphenolithus belemnos* del Burdigaliense medio. Regionalmente, ambos ciclos pueden observarse en los mismos depocentros principales, aunque se observan importantes cambios laterales y verticales, especialmente en el paso de un ciclo a otro. De hecho, mientras en las partes centrales de los depocentros los dos ciclos pueden superponerse en continuidad estratigráfica, en los márgenes existen discordancias erosivas, a veces también angulares de bajo ángulo separándolos. Lejos de los depocentros principales, los conglomerados basales de uno u otro ciclo descansan independientemente sobre el basamento paleozoico, sugiriendo un desplazamiento de las áreas de sedimentación en el cambio de ciclo. Estos cambios paleogeográficos producidos por causas tectónicas quedaron sellados por los importantes retrocabalgamientos gravitacionales que dieron lugar al emplazamiento del Numídico del Jbel Zem Zem que cubren a los niveles marinos del Burdigaliense medio del techo del ciclo Sidi Abdeslam-Viñuela. Este emplazamiento se inició por el bloqueo del avance de las unidades internas del Rif que indujo los retrocabalgamientos, en parte también provocado por los procesos extensionales que ocurrían al Este, hacia el mar de Alborán. Se propone al respecto un posible escenario tectónico de la evolución terciaria del sector occidental del dominio de Alborán.

Palabras claves: cobertera Gomáride, Oligo-Mioceno, nanoplancton calcáreo, foraminíferos planctónicos, Jbel Zem Zem, retrocabalgamiento gravitatorio, Rif interno septentrional, Marruecos.

Abstract: New biostratigraphic and field data are gathered from the two Oligo-Miocene marine transgressive cover of the Rifian Ghomaride units: i) the latest Oligocene-Aquitanian Fnidek-Ciudad Granada cycle, the top of which is here dated with planktonic foraminifera as latest Aquitanian and ii) the Burdigalian Sidi Abdeslam-Viñuela cycle, for which five outcrops are newly discovered north of the city of Tetuan. These outcrops display pelitic sequences containing siliceous horizons in their upper levels. These levels yielded nannofossil assemblages indicating the middle Burdigalian *Sphenolithus belemnos* zone. Regionally, both cycles may occur in the same principal depocentres, but undergo significant lateral and vertical change in their stacking pattern. Indeed, while in the central parts of the depocentres the two successive cycles may conformably stack in a near stratigraphic continuity, in the marginal parts an erosional and/or a low-angle angular unconformity may separate them. Far from the main depocentres, the Fnidek and Sidi Abdeslam cycles independently rest on the Paleozoic basement through basal conglomerates, suggesting displacement of the areas of sedimentation in the change of cycle. These tectonically mediated paleogeographic changes culminated with gravitational back-slide processes that resulted in the emplacement of Jbel Zem Zem Numidian massif over the middle Burdigalian marine levels topping the Sidi Abdeslam-Viñuela cycle. This emplacement was initiated by a docking-induced back-thrusting, and subsequently triggered by a post-collision extensional event. A possible Tertiary tectonic scenario for the western front of the Alboran domain is proposed herein.

Key words: Ghomaride cover, Oligo-Miocene, calcareous nannofossils, planktonic foraminifera, Jbel Zem Zem, gravitational back-thrusting, Northern internal Rif, Morocco.

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The Gibraltar arc was structured mainly during the Miocene times around the Betic-Rif Internal Zone, variously referred to as the «South Sardinian Domain» (Sanz de Galdeano, 1990), «Alboran Domain» (García-Dueñas *et al.*, 1992), or «Exotic Alboran Terrane» (Chalouan *et al*., 2001) (Fig. 1A). Bordering this zone, especially from the south, was a huge, elongated basinal area, the so-called Maghrebian Flysch Trough that received during the Cretaceous-early Miocene times successive sandstone-flysch deposits. A narrow transitional area, i.e. the «Predorsalian zone», lies between these two large-scale paleogeographic areas. To the north and the NW, the westernmost part of the Flysch Trough and the Internal Betic-Rif Internal Zone were bounded by the south Iberian margin. To the south, the Mesorifian and the Prerifian units represent the North African margin (Fig. 1A).

The subsequent complex structuring of this initial paleogeographic setting is thought to be a consequence of the westward drifting during Miocene times of the Internal Betic-Rif Internal Zone and their subsequent docking against the flysch nappes. This scenario culminated in raising a frontal accretionary prism and the related back-thrust and gravitational back slide processes.

The Betic-Rif Internal Zone consists of a nappe pile deriving from Paleozoic-Mesozoic (and even older) terranes, affected either by high-grade (Sebtide-Alpujarride units) or low-grade (the overriding Ghomaride-Malaguide units) Alpine metamorphism. Externally, a 2-15 km wide frontal band, made up of an Alpine calcareous chain, i.e., the so-called *Dorsale Calcaire*, bounds the Rifian Ghomarides-Sebtides to the west and the south, and the Betic Malaguides-Alpujarrides units to the north. The Ghomarides consist of four nappes, which from the bottom to top are: Akaïli, Koudiat Tiziane, Beni Hozmar and the Talembote unit (Chalouan, 1986). These nappes consist of epi-metamorphic Paleozoic series, bearing, especially in the Akaïli unit, an unconformable patched Mesozoic-Cenozoic marine cover (e.g., Durand-Delga *et al.*, 1964; Maaté, 1984; Chalouan, 1986; Feinberg *et al.*, 1990; Hlila, 2005). The late Oligocene-early Miocene transgressive deposits of the Akaïli cover, develop in kilometre-scale outcrops of up 100 m in thickness, and show fining upward sequences with conglomerates, sandstones, shales and pelagic marls (i.e., Durand-Delga *et al*., 1964; Belhaddad, 1983; El Kadiri *et al*., 2000, 2001; Zaghloul *et al.*, 2003; Hlila, 2005).

This late Oligocene-early Miocene syn- to late orogenic unconformable cover has long attracted particular interest because it offers the opportunity to decipher the paroxysmal events that resulted in the nappe emplacement and Alpine metamorphism. Facies and erosional discontinuities led authors (Feinberg *et al.*, 1990; Maaté *et al.*, 1995) to distinguish two sedimentary formations: i) the latest Oligocene-Aquitanian pro-parte (p.p.) Fnidek Formation (FN.F.), and ii) the early Burdigalian Sidi Abdeslam Formation (SA.F.).

Extensive outcrops of both formations were previously described in the Malaguide domain (Bourgois *et al*., 1972a and b; Boulin *et al*., 1973; Didon *et al.*, 1973; González-Donoso *et al.*, 1981, 1982, 1988; Aguado *et al*., 1990; Sanz de Galdeano *et al.*, 1993; Serrano *et al*., 1995, 2006, 2007). According to these authors the aforementioned formations develop in two sedimentary groups: the «Ciudad Granada» Group (latest Oligocene-Aquitanian p.p.) and the Viñuela Group (early Burdigalian, e.g., Martín-Algarra, 1987; Guerrera *et al.*, 1993).

Despite the precise dating of many levels within these two groups, the stacking pattern of their depositional sequences and the temporary relation between the deposit of both groups and the phases of nappe structuring, still remain the subject of conflicting interpretations. Mainly two different opinions are observed:

i) The angular unconformity separating both groups is related to a possible latest Aquitanian, regional-scale contractional tectonic phase, which was accompanied by stacking nappe in the Betic-Rif Internal Zone (Mac Gillavry *et al.*, 1963; Geel, 1973; Bourgois *et al.*, 1973; Hermes, 1978; Mäkel, 1985; Martín-Algarra, 1987; Guerrera *et al.*, 1993, 1997, 2005; Martín-Martín, 1996; Martín-Martín and Martín-Algarra, 1997; Martín-Algarra *et al*., 2000; Bonardi *et al*., 2003). These authors claimed that true Sebtide-Alpujarride clastic pebbles occur only in the overlying early Burdigalian Sidi Abdeslam-Viñuela Group. This fact suggested to him that the Sebtides-Alpujarrides structured during the time span between Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela sedimentary formations. In addition, the Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela formations were unconformably deposited on the Malaguide-Ghomaride Complex, whereas on the Alpujarride-Sebtide Complex only Sidi Abdeslam-Viñuela formations are found, as far as is known.

ii) Both groups are separated by a near-conformable surface without any significant gap in

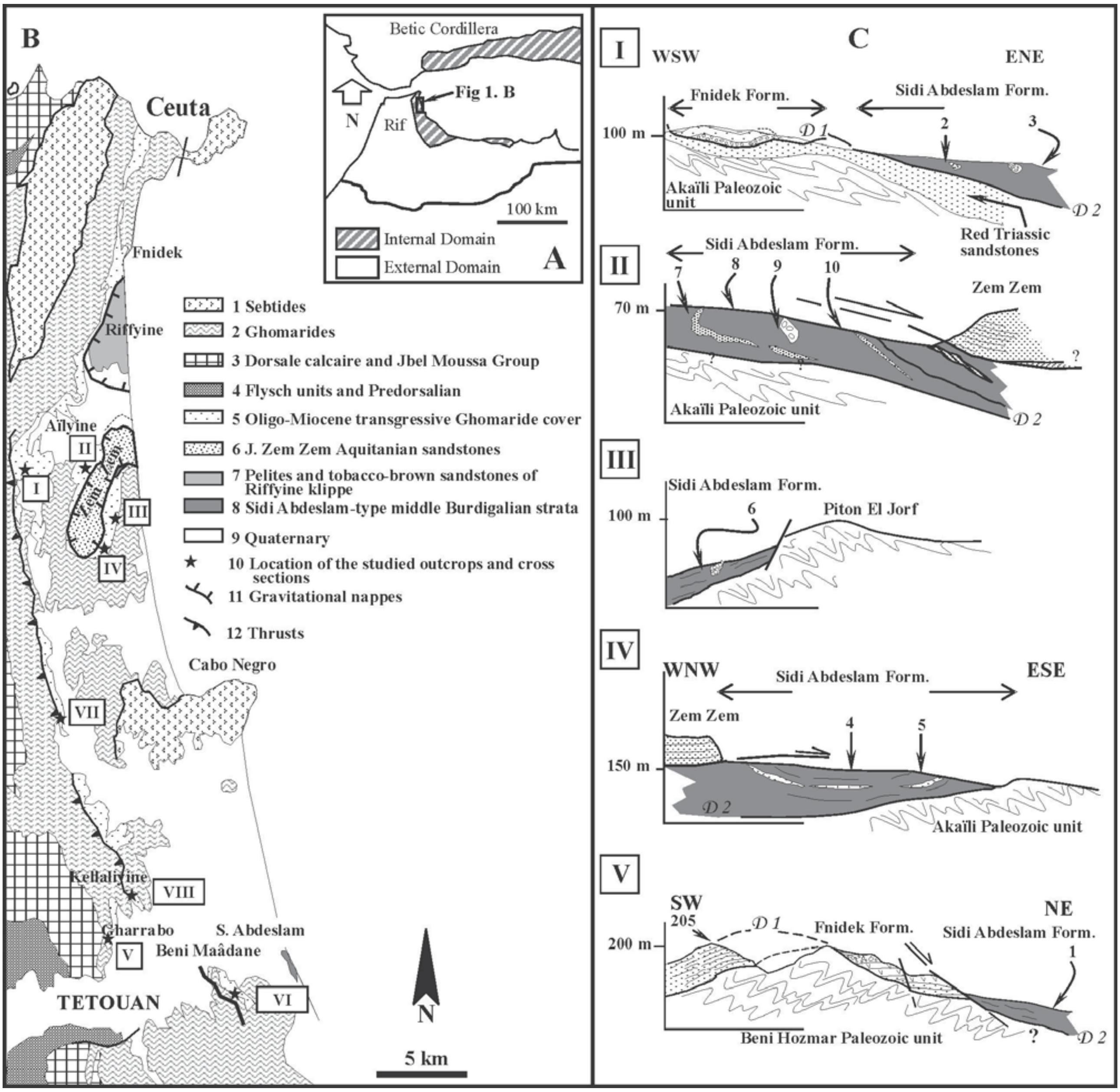

Figure 1.- A) General geologic setting of the studied area**. B)** Location map of the principal outcrops of the Oligo-Miocene Ghomaride cover north of Tetuan. **C)** Cross sections showing the relationships between the Oligo-Miocene formations themselves and between their Paleozoic basements. 1 to 10: sites of the samples.

between and they correspond to an entirely post-nappe cover, post-dating the main metamorphic and the nappe structuring events which occurred during the Oligocene times (Paquet, 1969; Rivière *et al*., 1980; Olivier, 1984; Platt and Vissers, 1989; Lonergan, 1991, 1993; Durand-Delga *et al.*, 1993; Lonergan and Mange-Rajetzky, 1994; Feinberg *et al*., 1990; Serrano *et al.*, 2006 and 2007). These authors stated that the Ghomaride-Malaguide nappe structuring and their subsequent thrusting on the Sebtides-Alpujarrides would have occurred before late Oligocene times, i.e. before the deposition age of the Fnidek-Ciudad Granada Group. The basal levels of this group would thus mark the first post-nappe marine strata, with clastic material delivered by the Ghomarides and also probably the Sebtides.

Concerning the stratigraphic stacking pattern of the Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela Groups, a disagreement still exists about the nature, the significance and the regional versus local occurrence of the unconformity separating these two sedimentary groups (e.g., discussion in Serrano *et al*., 2006, 2007).

In this debate, we would like to highlight here the fact that back-thrust processes resulted in emplacing the Flysch and Predorsalian nappes on the cover of the Oligo-Miocene Ghomaride, occurring precisely over the strata dated by middle Burdigalian *Sphenolithus belemnos*. This means that the paroxysmal structural event(s) would have continued at least until the middle Burdigalian, as also it were shown by Tent-Manclús *et* *al.* (2001) for the eastern Betic Internal-External zone boundary. As a result the Betic-Rif Internal Zone was actively pushed westwards due to the progressive opening of the Algerian Basin and the related thinning of the Alboran Sea region. Thus, the frontal part of the Internal Zone underwent an intense compression, whereas the interior, i.e., the Alboran region was submitted to extension.

Lithologic and biostratigraphic data

Figure 1B shows the structural context of the study sections, among which five sections were newly discovered (sections I-V), all belonging to the Sidi Abdeslam-Viñuela-type cycle (Fig. 1C). Figure 2 reconstructs the stratigraphic column of eight selected sections, from which new biostratigraphic data were obtained.

Fnidek-Ciudad Granada Formation

Originally, the Fnidek Formation was defined by Feinberg *et al*. (1990) close to the village of Fnidek located 35 km north of the city of Tetuan, where it was dated as late Oligocene-Aquitanian (p.p.), i.e., NP 25-NN1. Later, Maaté (1996) and El Kadiri *et al.* (2001) showed that this formation outcrops in many other sectors located north and south of Tetuan, namely the Kellalyine, Beni Maaden, Belouazen and Aïlyine areas. In all these outcrops controversies persist about: i) the exact age of the stratigraphic top of this formation, and ii) its stratigraphic relation with the overlying Sidi Abdeslam-Viñuela-type Formation (with a possible gap and/or discontinuity in between). Age data gathered herein give new insights into these two issues.

Kellalyine area.

Quartz-rich, polymictic, 5-8 m thick conglomerates mainly derived from Ghomarides-Malaguides form the base of the Fnidek Formation (column VIII in figure 2) in the Kellalyine area (lat 35°36’37N, long 5°21’14E in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a). Granite and high-grade migmatite pebbles of unknown origin are also present (Maaté, 1984, 1996; Martín-Algarra *et al.*, 2000; Hlila, 2005). We found that this basal interval progressively passes up to a yellow, fine-grained, 5 m thick sandstone/shale alternation with scarce thin-bedded conglomerates, which in turn pass to yellow and green pure pelagic marls (15 m thick). The latter facies yielded Aquitanian planktonic foraminifera-rich assemblages (Table I, samples 1-4) containing *Globgerinoides primordius*, *Globoquadrina dehiscens*, *Globogerina woodi* and *Globorotalia kugleri*.

Beni Maaden area.

In the Beni Maaden area (lat 35°34’26N, long 5°18’66E, in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a) located 10 km east of Tetuan, the Fnidek Formation unconformably covers

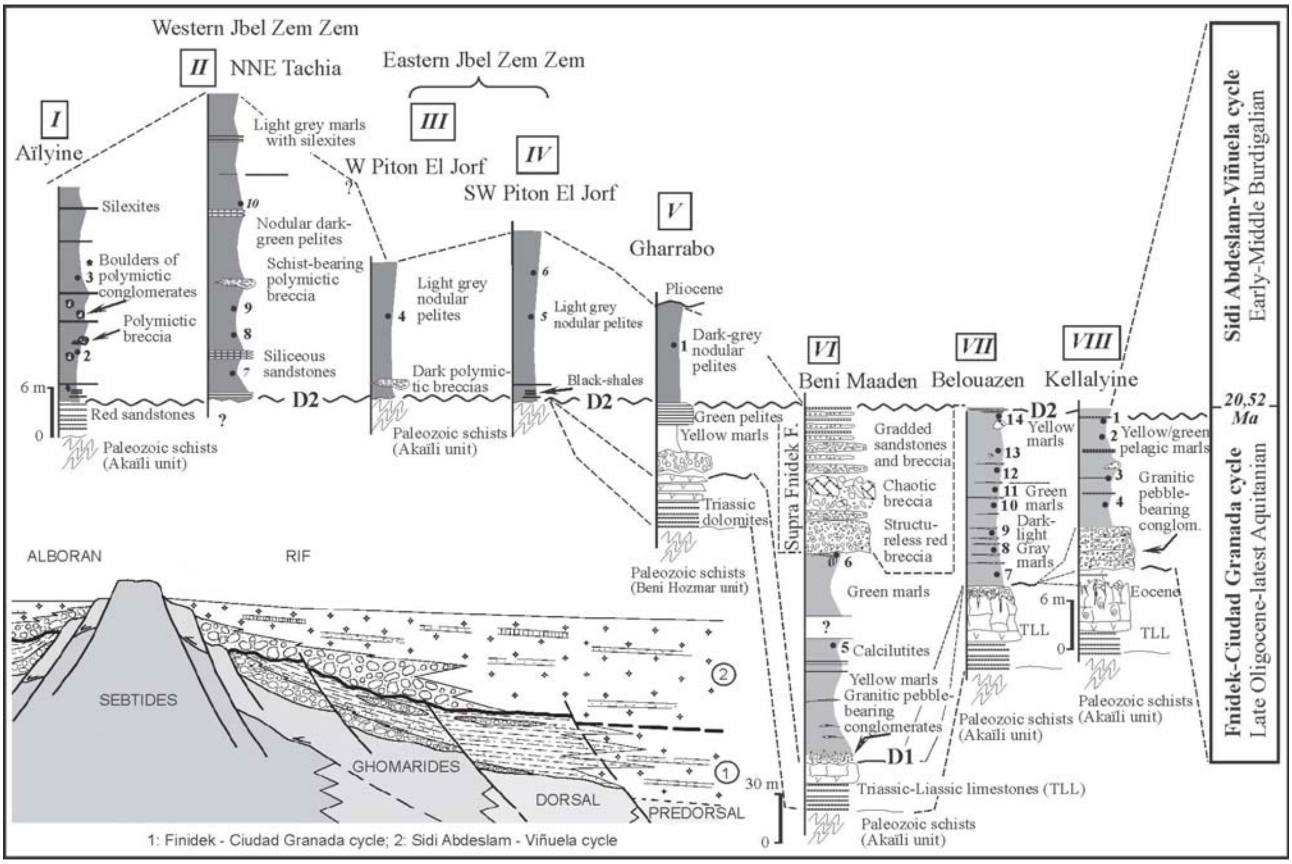

Figure 2.- Synthetic columns of the Ghomaride Oligo-Miocene formations from the northern Rif and sedimentary scheme of the rifian basin where Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela formations deposited.

the Ghomaride Akaïli unit. It is represented by a well-developed, 300-400 m thick, silici-clastic succession (column VI in figure 2), and similarly starts with 7-8 m thick quartz-rich polymictic conglomerates that transgressively rest on Liassic white limestones. These basal conglomerates directly pass up to yellow pelagic marls, which vertically become enriched in centimetric fine-grained sandstone intercalations and change to green marls upwards. Top surfaces of the last sandstone beds are capped with conspicuous Fe-crusts and fossilize well-developed slump structures as well as synsedimentary normal faults. Both structures mark extensional tectonic pulses. From the biostratigraphic point of view marls intercalated between the Fe-encrusted beds and those lying at the stratigraphic top of the whole marly succession yielded planktonic foraminifera assemblages (Table I, samples 5 and 6) containing *Globigerina woodi, Globorotalia kugleri, Globorotalia peripheroronda, Catapsydrax dissimilis, Globigerinoides primordius* and specimens showing primitive, poorly evolved, morphologies of *Globigerinoides trilobus* (*i.e. Globigerinoides inmaturus* Le Roy). These assemblages characterize sedimentation during the late Aquitanian. A huge gravity-flow event (250 m thick) suddenly interrupts the preceding marly regime and may laterally onlap the Paleozoic basement (Fig. 3A). This gravity event resulted in olistostromes and coarse-grained conglomerates. In some places, a sedimentary transitional interval lies between these marls and the first conglomeratic lenses, and consists of thin-bedded red sandstones (20-30 m thick) that progressively grade into thinning-upward brown sandstones (60-80 m thick). The discontinuous preservation of this intermediate interval shows that the sharp contact marls/conglomerates resulted from an important ravinement surface. These summital Fnidek conglomerates exhibit a mixture of granitic, schist and various basement-derived pebbles. We also note the presence of clasts and boulders derived from a Jurassic carbonate cover, as well as alkaline basalts, tuffite and limestone reefs of unknown origin.

Regionally, chaotic gravity flows commonly occur at the base levels of both studied sedimentary formations (Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela). They belong to a fining upward evolution, and are generally interpreted to be linked to transgressive pulses. Notably, in the Beni Maaden area, additional coarse-grained conglomerates lie at the summit levels of the Fnidek Formation, which raise the question about their triggering mechanisms and their paleotectonic significance (see below).

<u>Belouazen area.</u>

In the Belouazen area (lat 35°40’ 13N, long 5°25’78E in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a), 30 m-thick marls discordantly cover a Triassic-Liassic carbonate series of the Akaïli unit (column VII in figure 2). The lower third of these marls is dark to light gray in color,

AREAS	Kellalyine				Beni Maaden		Southeast Belouazen							
Species / Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Globigerina venezuelana Hedberg	●	●	●	●	●	●	●	●	●	●	●	●		●
Globigerina tripartita Koch	●		●	●					●	●		●		●
Globigerina euapertura Jenkins				●									●	●
Globigerina selli (Borsetti)	●	●					●	●		●		●		●
Globigerina ciperoensis Bolli	●	●	●	●	●	●			●	●			●	●
Globigerina angulisuturalis Bolli	●			●										
Globigerina praebulloides Blow	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Globigerina falconensis Blow												●		
Globigerina woodi Jenkins	●	●	●		●	●	●	●				●		●
Globigerinoides primordius Blow & Banner	●			●		●								●
Globigerinoides gr. *trilobus* (Reuss)						●								?
Neogloboquadrina nana (Bolli)	●	●	●	●	●	●	●	●	●		●		●	●
Neogloboquadrina siakensis (LeRoy)	●	●	●	●	●	●	●		●		●	●	●	●
Globorotalia kugleri (Bolli)		●			●			●	●	●		●		●
Globorotalia peripheroronda Blow & Banner					●									●
Globigerinita naparimaensis Brönnimann							●		●					●
Turborotalita quinqueloba (Natland)									●					
Globoquadrina globosa Bolli	●													
Globoquadrina baroemoenensis (LeRoy)					●		●		●	●				
Globoquadrina dehiscens (Chap., Parr & Coll.)		●	●				●			●	●		●	
Globorotaloides suteri Bolli	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Catapsydrax unicavus Bolli, Loebl. & Tappan	●	●		●	●	●	●		●	●	●			●
Catapsydrax dissimilis (Cushman & Bermúdez)	●			●	●									●

Table I.- Planktonic foraminifera assemblages extracted from the upper marly levels of the Fnidek-Ciudad Granada cycle formations.

whereas the two upper thirds have a gray-and-green ribbon aspect. The uppermost marly levels become yellow and contain spaced brown sandstone intercalations. From the top of these marly levels, we extracted late Aquitanian planktonic foraminifera-rich assemblages (Table I, samples 7-14), somewhat similar to those found in equivalent levels from the Beni Maaden area. However, in this case, the preservation state of the microfauna did not allow us to affirm the presence of dorsal apertures in the *G. trilobus* specimen's morphology. As in the Beni Maaden area the marly sedimentation regime here is interrupted by a small-scale gravitational chaotic discharge, which is dominated by several meter-scale limestone olistolites.

Sidi Abdeslam-Viñuela Formation

Figure 2 shows the main lithologic and stratigraphic features of the five sections newly discovered, belonging to this formation.

J. Zem Zem area.

a) Western side of the J. Zem Zem massif: NNE Tachia (lat 35°46'41N, long 5°23'33E in the geologic map of Sebta, Kornprobst and Durand-Delga, 1985b)

The first section discovered (column II in figure 2) outcrops immediately beneath the northeastern front of the J. Zem Zem Numidian massif. It consists of a 35 m-thick, marlstone-dominated succession arranged from the base onwards into three lithologic intervals: **i**) siliceous, light-green, fine-grained sandstones (1 m thick); **ii**) nodular dark-green, pelites (20-25 m thick) with spaced intercalations made up of micaceous, normally graded, lutites. Slump structures are abundant and indicate a slope depositional setting. The lutites seem to correspond to the distal part of coarsest turbidite flows, which form decimetre to metre-scale intercalations in adjacent outcrops (see below); **iii**) light-green micaceous pelites (8-10 m thick) with centimetre to decimetre-scale tufaceous silexite intercalations.

Biostratigraphically, the pelagic levels of the second interval yielded very scarce planktonic foraminifera, scarce radiolarians and nannoplanktonic assemblages (Table II, samples 7-10) indicative of the early Burdigalian *Discoaster druggi* zone by Martini (1971). The uppermost levels of this pelagic interval yielded reworked Eocene-Oligocene nannoflora together with autochthonous nannoplankton pointing to the *Sphenolithus belemnos* zone, precisely the *Helicosphaera ampliaperta* subzone differentiated by Martín-Pérez (1997), which indicates the middle Burdigalian.

	AREAS	Ghar rabo	Aïllyine		Eastern Zem Zem			Western Zem Zem			
	Species \ Samples	1	2	3	4	5	6	7	8	9	10
Calcareous nanoplankton	*Discoaster deflandrei* Bramlette & Riedel	•		•	•	•	•	•	•	•	•
	Discoaster druggii Bramlette & Wilcoxon	•		•	•	•	•	•	•		•
	Discoaster adamanteus Bramlette & Wilcoxon							•			
	Discoaster formosus Martini & Worsley							•			
	Braarudosphaera bigelowi (Gra & Braarud)	•									
	Geminilithella jafari (Müller)						•				•
	Pyrocyclus orangensis Backman									•	
	Pyrocyclus inversus Hay & Towe			•							
	Coccolithus pelagicus (Wallich)	•		•	•	•	•	•	•	•	•
	Coccolithus miopelagicus Bukry	•			•	•	•	•	•	•	•
	Cyclicargolithus abisectus (Müller)	•		•	•	•	•	•	•	•	•
	Cyclicargolithus floridanus (Roth & Hay)	•		•	•	•	•	•	•	•	•
	Helicosphaera carteri (Wallich)	•		•	•	•	•	•	•	•	•
	Helicosphaera euphratis Haq			•				•	•		
	Helicosphaera ampliaperta Bramlette & Wilcoxon									•	
	Helicosphaera perch-nielseniae (Haq)	•					•				•
	Sphenolithus dissimilis Bukry & Percival			•		•			•	•	•
	Sphenolithus moriformis (Brönnimann & Stradner)	•		•	•	•	•	•	•	•	•
	Sphenolithus belemnos Bramlette & Wilcoxon									•	•
	Sphenolithus calyculus Bukry			•						•	
	Sphenolithus conicus Bukry	•		•	•		•	•		•	
	Pontosphaera multipora (Kamptner)	•		•	•	•	•	•	•	•	
	Reticulofenestra bisecta (Hay, Mohler & Wade)	•		•	•	•	•	•	•	•	•
	Reticulofenestra gartneri Roth & Hay	•		•	•	•	•	•	•	•	•
	Reticulofenestra daviesii (Haq)	•		•			•			•	•
	Ilselithina fusa Roth	•		•		•	•				•
Planktonic foraminifera	*Globigerina praebulloides* Blow		•								
	Globigerina woodi Jenkis		•								
	Globigerina connecta Jenkins		•								
	Globigerinoides altiaperturus Bolli		•								
	Globigerinoides subquadratus Brönnim		•								
	Globigerinoides gr. *trilobus* (Reuss)		•								
	Neogloboquadrina siakensis (LeRoy)		•								
	Globorotalia peripheroronda Blow & Banner		•								
	Globigerinita naparimaensis Brönnimann		•								
	Catapsydrax dissimilis (Cushman & Bermúdez)		•								

Table II.- Nannoplankton and planktonic foraminifera assemblages extracted from the Burdigalian pelites of the Sidi Abdeslam-Viñuela cycle formations.

b) Eastern side of the J. Zem Zem massif: west of the Piton El Jorf (lat 35°45'35N, long 5°22'53E in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a)

Light-green nodular pelites (15-20 m thick) dominate the eastern side of the J. Zem Zem massif. They start at the west of the «Piton El Jorf», with basal breccias (1,5 m thick) that transgressively onset the Paleozoic Akaïli unit. These breccias consist almost exclusively of Ghomaride-derived schist pebbles and grade up into micaceous lutites identical to those described in the above-mentioned Tachia outcrop. True Sebtide ones aren't yet discovered in the Burdigalian Ghomaride cover. The remainder of the series become dominated by pure pelagic nodular marlstones that yielded a nannoplankton flora belonging to the *Discoaster druggii* zone (Martín-Pérez, 1997), this indicating the early Burdigalian (Table II, sample 4).

c) Eastern side of the J. Zem Zem massif: south-west of the Piton El Jorf (lat 35°44'33N, long 5°23'87E in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a)

The second «south-west Piton El Jorf» outcrop (column IV in figures 2 and 3B) develops in an open synform structure, which exhibits a light gray nodular pelites succession (20 m thick) that may directly cover the Paleozoic rocks. Black shales and fine-grained, dark sandstones discontinuously occur at the very base of this pelagic succession, a feature that possibly indicates oxygen-depleted depositional environments. With respect to the preceding outcrops, this succession seems to correspond to more distal parts of a same depositional setting. A nannoplankton flora indicates the *Discoaster druggi* zone of the early Burdigalian (Table II, samples 5 and 6). It is worth noting that Belhaddad (1983) previously extracted from adjacent outcrops nan-

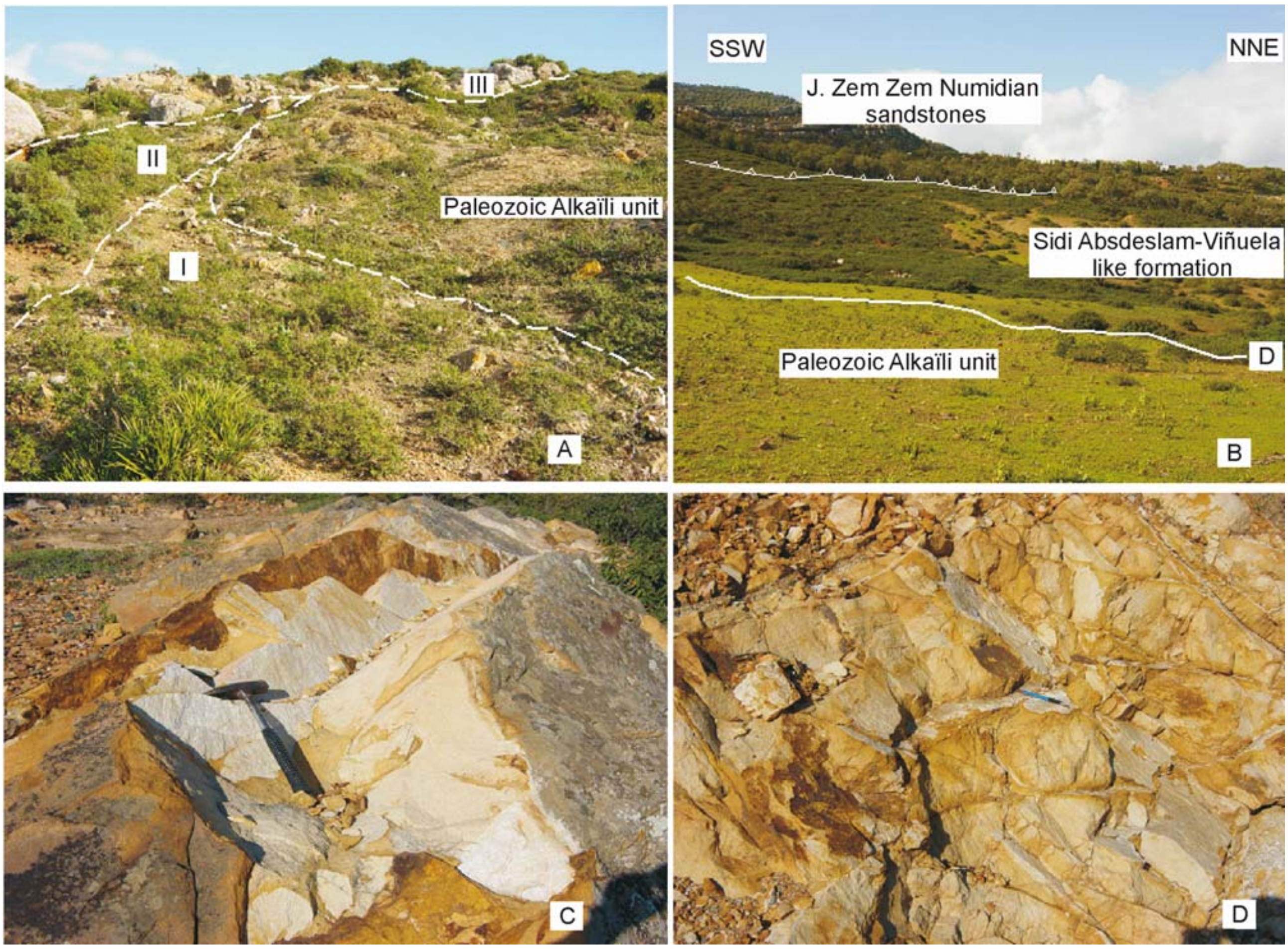

Figure 3.- A) Onset of the latest Aquitanian carbonate conglomerate (supra-Fnidek Formation) over the Akaïli Silurian-Devonian schists through a clear-cut «onlap» surface in Beni Maaden area. This surface can best be exemplified in the case of the interval III - Paleozoic contact. **B)** Panorama showing «Sidi Abdeslam-Viñuela like» formation discordantly lying on the Akaïli Palaeozoic basement east of Jbel Zem Zem. Both are overthrust by the Aquitanian holoquartzous sandstones of the Numidian Jbel Zem Zem Massif. **C)** Meter-scale high to moderate (45-60° E) N-S directed normal fault in the Aquitanian holoquartzous sandstones of J. Zem Zem massif, found in the left side of the coastal road 0,5 Km north of Restinga. The associated striae are N90-N100 directed and indicate slickenside towards the east. **D)** Meter-scale low angle (15-20° E) N160-180-directed fault in the same Aquitanian Numidian sandstones of the J. Zem Zem massif, found in the left side of the coastal road 0,5 Km north of Restinga. The associated striae are N70-90-directed and indicate a movement towards the East linked to the backslide process towards the interior of the belt. We can see also that the normal faults, crosscutting the low-angle faults are moderate- to high-angle. The two sets of fault were observed in the frontal part of the J. Zem Zem massif.

noflora no younger than the NN1 and NN1-2 zones, which belong to the Aquitanian-Burdigalian transition. Thus, our biostratigraphic result shows that the pelagic marine regime in the Ghomaride domain studied persisted here at least until the early Burdigalian times.

Aïlyine area.

The Aïlyine area (lat 35°46'66N, long 5°26'86E in the geologic map of Sebta, Kornprobst and Durand-Delga, 1985b) is of special importance in this work, since it displays one of the rare outcrops where the Fnidek-Ciudad Granada and Sidi Abdeslam-Viñuela formations studied stack in a single stratigraphic succession. Before we decipher their stratigraphic relationships, it is worth remembering that two cases may regionally occur: **i**) each of these formations may independently cover Triassic red strata and/or Paleozoic rocks, **ii**) the Viñuela-type marlstones may locally overlie the Fnidek ones through both a ravinement surface and a low-angle unconformity (e.g., Talembote area, El Kadiri *et al*., 2001). Stratigraphically, the Fnidek Formation (30 m thick) starts with Ghomaride-Malaguide in origin holoquartzous, channelized puddingstones, which change upwards to yellow pelagic marls with thin horizons of green pelites. The latter pelites become almost exclusive in the overlying levels before being discordantly tapped by nodular lime-poor marlstones (20-25 m thick) of the Sidi Abdeslam Formation. Here, this formation contains reworked blocks derived from the Fnidek basal conglomerates, and ends with ribbon tufaceous silexites. Age data from both planktonic foraminifera and nannoplankton demonstrate that these Sidi Abdeslam facies belong to the early Burdigalian (Table II, samples 2 and 3).

Gharrabo area.

The Gharrabo area (lat 35°35'22N, long 5°22'5E in the geologic map of Tetuan, Kornprobst and Durand-Delga, 1985a) consists of the Paleozoic Beni Hozmar unit and of its Triassic-Liassic carbonate cover (column V in figure 2). The two studied Fnidek and Sidi Abdeslam formations outcrop in two distinct sections. Both formations overlie this old carbonate cover through a conspicuous paleokarst surface. In some places, Viñuela-type pelites may directly overlie the Paleozoic rocks. Lithologically, basal conglomerates (2-3 m) and green pelites (8 m) with yellow marls in between made up the Fnidek Formation; whereas the Sidi Abdeslam Formation developed in carbonate-poor, nodular gray pelites (10-15 m), but here without showing its widespread basal conglomerates. Owing to these two features, the latter formation strongly recalls the Boujarrah Formation, recently described by Maaté *et al.* (1995) and dated as early Burdigalian. The rich nannoplankton flora (Martín-Pérez, 1997), we have extracted from thin carbonates horizons interlayered in the Gharrabo pelites, also indicate the early Burdigalian *Discoaster druggi* zone (Table II, sample 1).

Structural data

The structural data presented here concern only the Jbel Zem Zem area. Indeed, the Jbel Zem Zem massif displays three NNE/SSW-aligned blocks consisting of Aquitanian Numidian sandstones. These blocks range from 0.5 to 3 km^2 in surface with the southwestern blocks being larger than the northeastern ones, and lying at a higher altitude, up to 435 m (against 0-150 m for the NE blocks).

Generally, the J. Zem Zem blocks rest upon Tertiary marls and pelites that transgressively cover Devonian-Carboniferous rocks belonging to the Ghomaride Akaïli unit. Locally, they may rest directly upon this Paleozoic basement. The basal contacts have a vaguely NW to N strike and dips to the ENE to NE (5° and 15°). These contacts cut previous fold and thrust structures affecting the Numidian sandstone bars. The southern basal contacts may be perched at 250-300 m in altitude, whereas the northern ones may occur along the Restinga beach before disappearing below the Mediterranean coast.

All the J. Zem Zem blocks show evidence of this twofold structuring history. An early deformational phase resulting in decametre to hectometer-scale folds, which may be symmetric or asymmetric, inclined to overturned either towards the east or the west. The strike of these folds range from N150 to N-S. Reverse fold-faults and sub-meridian, decametre-to kilometre thrusting planes may be associated to the whole folding structure. The observed slickensides are N130-N00-directed and are dipping 20°-50° towards either the east or the west, which indicates a double tectonic vergency. The associated striae are N40-N90 directed. The subsequent structuring phase is characterized by two kinds of normal faults: **i**) low-angle extensional faults (5-15°) dipping towards the east or the NE, and showing N50-N100-directed striations. The latter give evidence that the J. Zem Zem massif emplaced through a gravitational sliding towards the east and the NE; **ii**) moderate- to high-angle faults (30-60°) dipping towards the east showing N90-N100-directed striations (Fig. 3C and D).

The low-angle extensional sets of faults are probably linked with the formation of the basal contact of the J. Zem Zem massif. The moderate- to high-angle normal faults subsequently crosscut the preceding low-angle faults.

On the whole, the folds and thrusting structures should be ascribed to the paroxysmal collisional phase responsible for the major thrust front along the Internal-External contact. The progressive blockage of this front caused the building of an accretionary prism from which the J. Zem Zem massif detached and gravitationally displaced over the *Dorsale Calcaire* and the Ghomaride domains. The principal mechanism that triggered this «backsliding» process was certainly the collapse of the Internal Domain and the Alboran Basin during the Miocene times, concurrently with the westward migration of the orogenic front over the external domain.

Indeed, similar examples of gravitational backsliding were also documented in many places throughout the Internal Domain by Chalouan *et al*. (1995). They were mediated by low-angle extensional faults dipping towards the Mediterranean. One of the conspicuous backsliding occurs in the central part of the Internal Domain (Cap Zaouia, Beni Bousera area) where kilometre-scale Paleozoic terranes detached from the Ghomaride nappes and gravitationally displaced through NE to E-directed low-angle normal faults over the Beni Bousera Sebtide massif. The resulting gravitational bodies are similar in size to the J. Zem Zem blocks.

It is noteworthy that J. Zem Zem-type backslide Numidian massifs also exist in the Tertiary Malaga Basin, i.e. north of Cártama (Sanz de Galdeano *et al*., 1993), where they partly occur as olistolits within the early Burdigalian levels (the so-called «Neonumidian», Bourgois, 1978). These observations in the Malaga basin indicate that the back-slide process seems to begin little before that in the Rif Cordillera.

Discussion

Fnidek-Ciudad Granada/Sidi Abdeslam-Viñuela boundary: expressions and tectono-sedimentary significance

Biostratigraphic data given above show that the pelagic depositional regime of the Fnidek-Ciudad Granada Formation lasted until the end of Aquitanian times. Locally, this formation can comformably pass up to the Sidi Abdeslam-Viñuela Formation as occurs especially in Betic Sierra Espuña (Rivière *et al*., 1980; Serrano *et al.*, 2007). However, other field evidence, mainly abrupt facies changes, sudden chaotic discharges, the onset of the Viñuela pelites directly onto new exposed Paleozoic substratum, may indicate that a possible tectonic event occurred in the time span in between:

- at the scale of the Betic-Rif Internal Zone, the two formations may separately cover the Paleozoic basement although they belong regionally to the same depositional areas (Bourgois *et al*., 1972a and b; Sanz de Galdeano and Lüpez-Garrido, 1991; Durand-Delga *et al*., 1993; El Kadiri *et al*., 2001; Serrano *et al.*, 2006, 2007). This twofold criterion can tentatively be explained by the fact that the Sidi Abdeslam-Viñuela depocentres originated through a partial shifting of the preceding Fnidek-Ciudad Granada depocentres;
- the Fnidek-Ciudad Granada basal conglomerates regionally develop in holoquartzous puddingstones bearing rare granite and migmatite pebbles. By contrast, Sidi Abdeslam-Viñuela basal conglomerates may rework a mixture of granitic, basaltic, limestone and schist pebbles coming from the Ghomaride and even typical Sebtide-Alpujarride remains. This polygenic mixture indicates that new source metamorphic terranes were tectonically exhumed and/or brought close to the early Burdigalian Sidi Abdeslam-Viñuela depocentres.

In the Spanish Malaga basin, a discontinuity was evidenced in the paleogeographic borders between the two formations studied, whereas towards the interior of the basin, these two formations are separated of a erosional surface lying between practically parallel layers (Serrano *et al.*, 2007).

In Italy, Guerrera *et al.* (1993) described age-equivalent formations in the Apenninic-Sicilian Domain, where these authors stressed that the Early Burdigalian Stilo-Capo d'Orlando Formation unconformably overlies the Oligo-Aquitanian Palizzi and Frazzanò-Piedimonte Formations.

Concerning the temporal relationships between the Fnidek and Sidi Abdeslam depocentres shifting and the tectono-metamorphic events in the Gibraltar arc, it is relevant to note that: i) the youngest HT/LP Sebtide metamorphism, unanimously dated at 22 ± 2 Ma BP (Michard *et al.*, 1983; Zeck *et al*., 1989, 1992; Monié *et al*., 1991; Negro, 2005), logically corresponds to that of the metamorphic mineral closure; ii) this absolute age obviously postdates both the metamorphism peak and the related nappe stacking. As such, the depocentre shifting and the facies change between the studied formations across the Aquitanian-Burdigalian transition (at 20,52 Ma according to the chronostratigraphic scale by Berggreen *et al*., 1995 and Hardenbol *et al*., 1998) cannot be directly ascribed either to the metamorphic events occurred within the Sebtides-Alpujarrides units, or to the Sebtides-Ghomarides nappe staking.

However, the necessary exhumation of the Alpujarride-Sebtide rocks may be explained by a rapid uplifting along faulted blocks in a transtensive tectonic regime during the Aquitanian-Burdigalian transition. In this way, the Alpujarride-Sebtide could have played the double-role of basement of some Sidi Abdeslam-Viñuela deposits and also acted as the source of their detritics. Indeed, the basal conglomerates of the Viñuela Formation (Las Millanas conglomerates, earliest Burdigalian) in Spain reworked the first true Alpujarride-Sebtide metamorphic rocks, namely lherzolite, gneiss and grenat-bearing micaschist pebbles (Bourgois, 1978; Durand-Delga *et al.*, 1993).

To complement these metamorphic and stratigraphic data, we suggest that it is possible that the Alpujarride-Sebtide ascension triggered the emplacement of the Malaguide-Ghomarides over the calcareous chain which induced its structuring, especially its internal part (internal Dorsal) and the related large-scale resedimentation in some Sidi Abdeslam-Viñuela depocentres (e.g. Talembote olistostromes, El Kadiri *et* *al.*, 2001). The driving forces behind this tectono-sedimentary scenario were likely responsible for both the locally observed Fnidek/Sidi Abdeslam unconformity along the borders of the basin and the above-mentioned depocentre-shifting process at the Aquitanian-Burdigalian transition.

Age and emplacement of the J. Zem Zem Numidian massif

Although the J. Zem Zem Numidian Klippe undoubtedly appears to be of external origin, both the age and process of its emplacement remain a subject of debate. Two independent hypotheses have been proposed: i) a back-thrust displacement causally linked to the general westward nappe emplacement during the early Miocene; ii) a post-orogenic gravitational sliding linked to the late-tectonic Alboran basin collapses. Based both on compiled data from equivalent Klippes in the Betic and Algerian Internal Zones (Bourgois, 1978; Raoult, 1974), as well as on the age data presented here from the underlying autochthonous pelagic strata, we attempt to present in the figure 4 a conciliatory scenario. Indeed, the Zem Zem Klippe would be related to both the west-verged nappe emplacement and to a subsequent east-verged gravitational collapse. Kinematically, these two processes could be logically interrelated in an accretionary prism setting, from the internal flank of which gravitational back-collapses may occur. Precisely, in the case studied here, the «encapuchonnement» process (Raoult, 1966; Hlila and Sanz de Galdeano, 1994) of the Haouz «Dorsale Calcaire» beneath the Flysch nappe pile would considerably enhance the back gravitational slides. Other klippes derived from the Predorsalian (Predorsalian Riffyine klippe) and the Flysch domain (Beni Ider slices) accompanied the J. Zem Zem Numidian massif and lend additional support to the scenario presented above.

This result is expected to shed light on the largest-scale back-slides processes developed over the Spanish

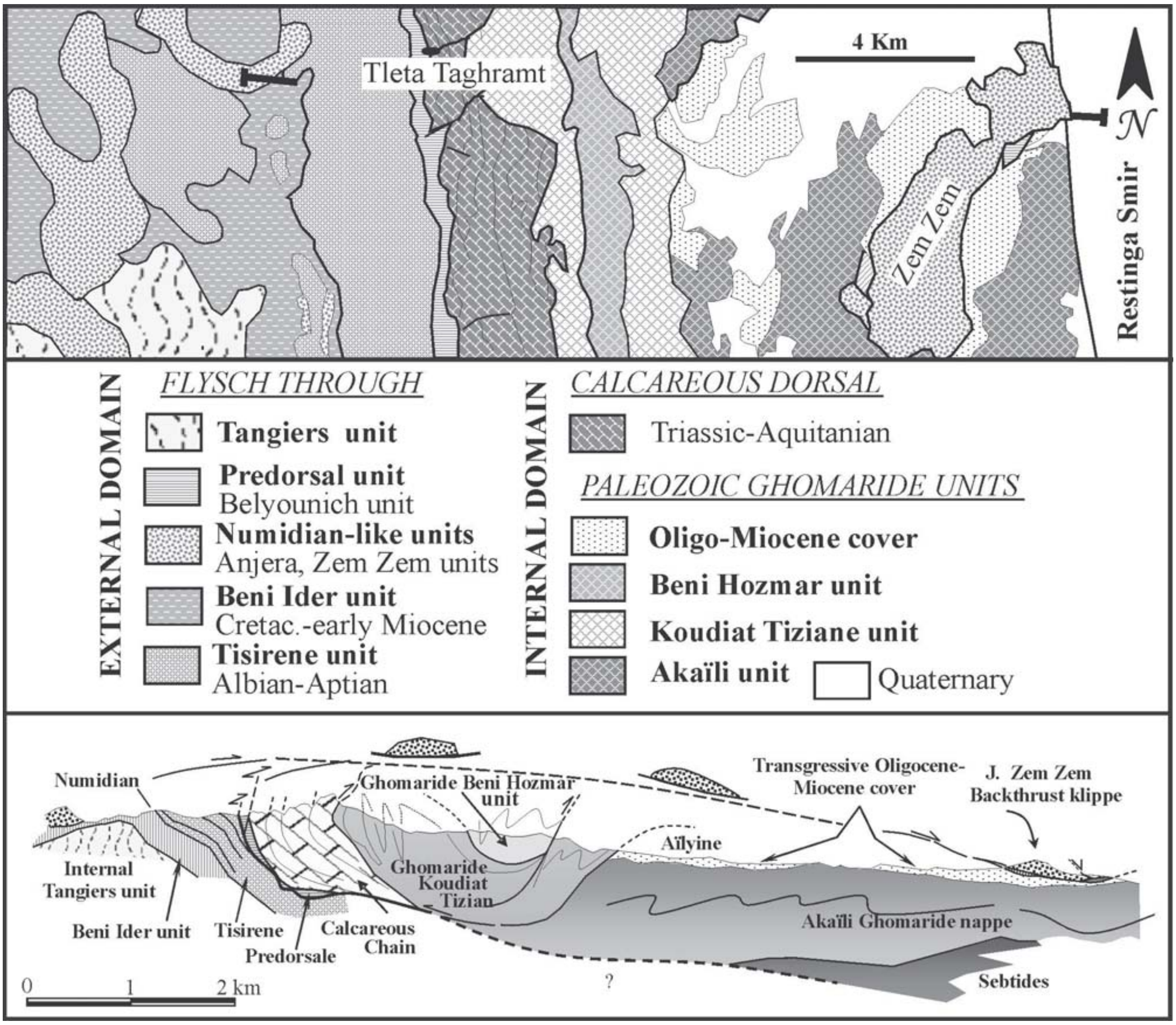

Figure 4.- Simplified geologic map (modified from Kornprobst and Durand Delga, 1985a) across a transect between J. Zem Zem and Bine El Ouidane and interpretative cross section highlighting the stacking pattern of the main internal and external units in the northern Rif belt.

Malaguides (e.g., Bourgois 1978's Olistostromes) and their Algerian equivalent in Little Kabylie (Raoult 1974's «supra-Kabyle nappes»).

Chronologically, the early to middle Burdigalian age inferred from the latest marine strata of the Ghomaride Tertiary cover (this work) as well as from the external Flysch series (Hoyez, 1989) indicates that the J. Zem Zem emplacement clearly postdates the middle Burdigalian Viñuela levels.

Conclusions

Integrated biostratigraphic data given here from the Ghomaride Tertiary cover, allows us to precisely define the time interval of the Fnidek and Sidi Abdeslam Formations, and to clearly correlate these two formations with their age-equivalent sedimentary cycles in the Spanish Malaguide domain (Ciudad Granada and Viñuela Formations, respectively).

Field evidence, particularly from the newly discovered outcrops, show that the Findek-Ciudad Granada and the Sidi Abdeslam-Viñuela Formations stack through an erosional and/or low-angle unconformity surface. It occurs especially in the marginal areas of depocentres where Sidi Abdeslam-Viñuela Formation may directly rest on the Paleozoic basement through chaotic basal conglomerates. This result fits well with the field data described in the Spanish Malaguides (Malaga and Sierra Espuña areas) by Serrano *et al*. (2006) and notably shows that a tectonically-mediated shifting in the depocentre axes occurred by the Aquitanian-Burdigalian transition. On the whole, the onset of the Sidi Abdeslam-Viñuela Formation onto both the Fnidek-Ciudad Granada Formation and the Malaguide-Ghomaride/ Alpujarride-Sebtide basement would have a causal link with transtensional events that resulted in the Sidi Abdeslam-Viñuela depocentres through a partial shifting of the preceding Fnidek-Ciudad Granada ones. It should be noted that these transtensional events immediately followed the metamorphic ones. As such, both transtensional and HT/LP metamorphic events may be regarded as causally linked in a same regional scenario, which was probably monitored by the opening of the Alboran Sea.

Concurrently, the westward drifting of the Betic-Rif Internal Zone trained the kinematics of the external migrating orogenic front, i.e. towards the «Dorsale Calcaire» and the Flysch domain. As a result, the left-behind Ghomaride terranes underwent more extension, which deepened the Viñuela depocentres. This tectonic setting culminated during the late Burdigalian times through uplifting an accretionary prism. This tectonic relief overhangs the Internal Zone coupled with internally juxtaposed Sidi Abdeslam-Viñuela troughs that triggered the back-sliding of the Numidian J. Zem Zem massif and the Riffiyine Predorsalian klippes.

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