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THE OLIGOCENE-MIOCENE GHOMARIDE COVER: A PETRO-SEDIMENTARY RECORD OF AN EARLY SUBSIDENT STAGE RELATED TO THE ALBORAN SEA RIFTING (NORTHERN INTERNAL RIF, MOROCCO)

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Abstract: New sedimentological, petrographic and structural data have been collected from the Oligocene-Miocene terrigenous deposits unconformably overlying the highest tectonic units of the Internal Rifian Chain (Ghomaride Units). These new data show (i) the abundance of coarse-grained facies (disorganized and organized conglomerates and pebbly sandstones), (ii) a sedimentary supply from very slightly metamorphic Paleozoic sources and from Mesozoic carbonate cover and (iii) the dominance of a mainly extensional syn-sedimentary tectonic activity. Stratigraphic and petrographic characters point out a paleogeographical scenario where the Ghomaride Units, believed to be the sources of the analysed successions, fed small "satellite basins" located above the fold-thrust belt by means of gravity and debris flow processes. Moreover, the low textural maturity of the analysed sandstones seems to suggest conditions of short transports linked to a rugged topography and to a very unstable tectonic setting. Structural data acquired, in good agreement with that of literature, confirm the existence of a mainly extensional tectonic activity which lasted from the Late Oligocene up to Middle Burdigalian times during the deposition of the analysed successions. So, within a mainly extensional geodynamic context, a continuous rapid erosion of the highly elevated parts (mainly Ghomaride Units) of the folded thrust belt, progressively uplifted, produced the sedimentary supply. During this Late Oligocene–Lower Miocene rifting stage, some of these "satellite basins" evolved, in the rear of the Rifian fold-thrust belt, to more subsiding areas as "continental trenchs" and triggered the opening of the Alboran Sea.

Key words: Morocco, Rif Mediterranean belts, Oligocene-Miocene rifting, sedimentary petrography, turbidite sandstone suites.

Introduction, geological setting and objectives

The internal zones of the Betic Cordillera (Spain) and of the Rif (Morocco) are geologically homologous (Didon et al. 1973; Durand-Delga & Olivier 1988) and characterized by the superimposition of several basement nappes, belonging to the Alboran terrane (Chalouan et al. 2001; Michard et al. 2002), locally with remnants of their original Mesozoic-Cenozoic sedimentary cover. In the Rifian Chain these are commonly regrouped into the Ghomaride, Sebtide and "Dorsale Calcaire" Units (structurally from top to bottom), the latter representing remnants of a Mesozoic carbonate platform evolving into terrigenous deposits during Eocene–Oligocene times (Wildi 1983).

The Ghomaride nappes (Fig. 1), the highest tectonic elements, mainly consist of slightly metamorphic Paleozoic successions (Durand-Delga & Kornprobst 1963; Kornprobst 1974; Chalouan 1986), organized into four tectonic units (from the base to the top: Aâkaïli, Koudiat-Tizian, Beni-Hozmar and Talembote Unit; Chalouan 1986; Azzouz 1992), the total thickness of which does not exceed 5000 m (Chalouan & Michard 1990). Each of these Ghomaride Units has its unconformable Mesozoic-Cenozoic sedimentary cover (Durand-Delga et al. 1964; Belhadad 1983; Maate 1984; Bouhdadi 1985; Chalouan 1986; Feinberg et al. 1990; Ouazani-Touhami 1994), which could be considered as a lateral equivalent of the so-called "Dorsale Calcaire" Units (Wildi 1983; Maate 1996, with references), detached from the uppermost Sebtide Units and piled up in front of the Ghomaride realm. The Mesozoic portion of this succession (Middle Triassic reddish quartzose sandstones and conglomerates, Upper Triassic dolomites, Liassic limestones and reddish silts; Maate 1984) can be related to the Tethyan rifting processes. In contrast, the younger deposits (Microcodium and Nummulitic limestones and mainly calcareous conglomerates; Maate 1984, 1996; Maate et al. 1991; Ouazani-Touhami 1994), aged to Late Eocene (Olivier 1979; Olivier et al. 1979), could represent a depositional sequence post-dating an early Alpine compressive event (Martin-Algarra et al. 2000).

Some of the Ghomaride Units, at the top, are transgressively and unconformably covered and sealed (Durand-Delga 1980; Feinberg et al. 1990; Maate et al. 1995; Martin-Algarra et al. 2000) by Oligocene-Miocene successions (Chattian to lower Burdigalian; Belhadad 1983; Feinberg & Olivier 1983; Maate

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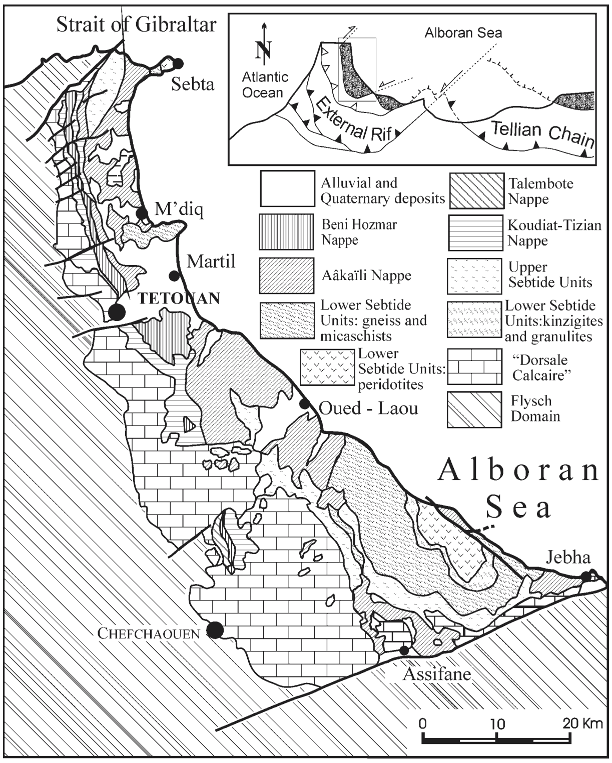

Fig. 1. Geological sketch map of the internal zones of the Rifian Chain (Morocco).

1984; Martin-Algarra 1987; Feinberg et al. 1990; Maate et al. 1995). These Ghomaride nappe covers, the object of this study, display sandstones, marls, and carbonatoclastic deposits organized in thick conglomeratic bodies with presence of metric olistoliths. These successions, well known also in the Betic Cordillera where they unconformably overlie the Malaguide Units (equivalent to the Ghomaride Units), have formally been subdivided into two successive sedimentary cycles (Chalouan 1987; Martin-Algarra 1987; Maate 1996): the earlier (Upper Oligocene up to the Oligocene-Miocene boundary) is related to the Ciudad Granada (Betics) and Fnideq (Rif) Formations, while the latest, referred to as the Viñuela (Betics) and Sidi Abdesslam (Rif) Formations, is dated as Early Miocene (mainly Lower Burdigalian). This second sedimentary cycle is well known all along the Maghrebian Chain (Guerrera et al. 1993), being in good agreement with the tectono-sedimentary evolution of the internal domains of the Kabylides (Algeria, Oligo-Miocene Kabyle; Tefiani 1970; Raymond 1976; Gelard 1979; Géry et al. 1981) and of the Calabria-Peloritani Arc (Sicily, Stilo-Capo d'Orlando Formation; Ogniben 1973; Puglisi 1987; Patterson et al. 1995; Bonardi et al. 1996; Cavazza et al. 1997).

In this paper, we point out new petrographic and sedimentologic data about some Oligocene-Miocene deposits of the Ghomaride nappe cover (Fnideq and Sidi Abdesslam Formations). In agreement with previous works (Chalouan 1986; Chalouan et al. 2001) we show that these deposits can be tentatively related to the Late Oligocene rifting phase which widely affected the western Mediterranean region, as a prelude to the Miocene opening of new oceanic areas (i.e. the Algero-Provençal Basin Auct.).

Sedimentology and lithostratigraphy

Four stratigraphic sections of the Oligocene-Miocene deposits of the Ghomaride nappe cover, unconformably sealing several Ghomaride Units in the Rif Chain, as above mentioned, were measured and sampled: the Kellaliyine and Beni Maâdane Sections, representative of the Ciudad Granada-Fnideq Formation Cycle, and the Sidi Abdesslam and Boujarrah Sections, representative of the Viñuela-Sidi Abdesslam Formation Cycle[1].

Ciudad Granada–Fnideq Formations

The Ciudad Granada–Fnideq Formations (Upper Oligocene up to the Oligocene-Miocene boundary, Zone NP25 of Martini 1971, in Feinberg et al. 1990; Maate 1996 and bibliography therein) regroup the syn-orogenic conglomeratic-arenaceous-pelitic successions, which unconformably overlay the Malaguide–Ghomaride nappes and their Mesozoic cover (Martin-Algarra 1987; Guerrera et al. 1997).

In the Rifian sector this cycle can be subdivided into two mainly conglomeratic intervals:

1. A lower siliciclastic conglomeratic interval (east and north-east of Tetouan), directly overlying the Paleozoic basement and/or its Mesozoic carbonate cover. In the Beni Maâdane area and also in the Kellaliyine quarry, this interval stratigraphically rests on an arenaceous-pelitic lithofacies, about 4 m thick (Fig. 2). The sedimentological character of this conglomeratic interval suggests processes such as debris

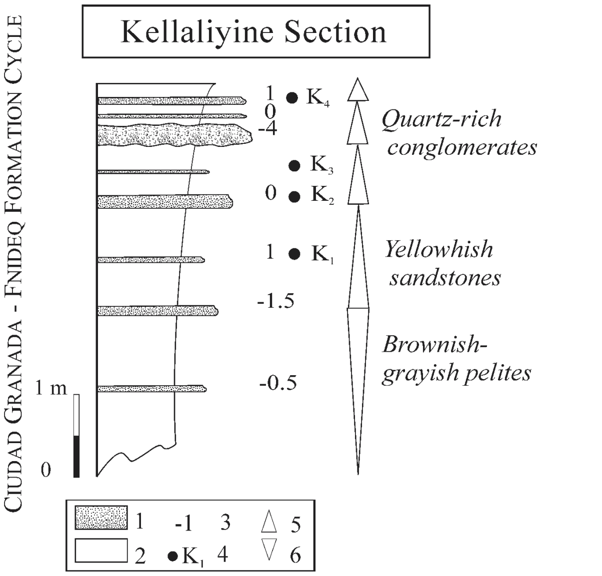

Fig. 2. Simplified stratigraphic section of the Kellaliyine outcrop (Upper Oligocene–Aquitanian?; Internal Rif, Morocco). 1 — arenaceous lithofacies; 2 — pelitic lithofacies; 3 — grain size in φ scale; 4 — location of the analysed samples; 5 and 6 — positive and negative cycles, respectively.

[1]Kellaliyine Section (lat 35°36'13 N and long 5°20'39 W), Beni Maâdane Section (lat 35°34'20 N and long 2°17'30 W), Sidi Abdesslam Section (lat 35°35'13 N and long 5°15'56 W), Boujarrah Section (lat 35°36'01 N and long 5°21'19 W).

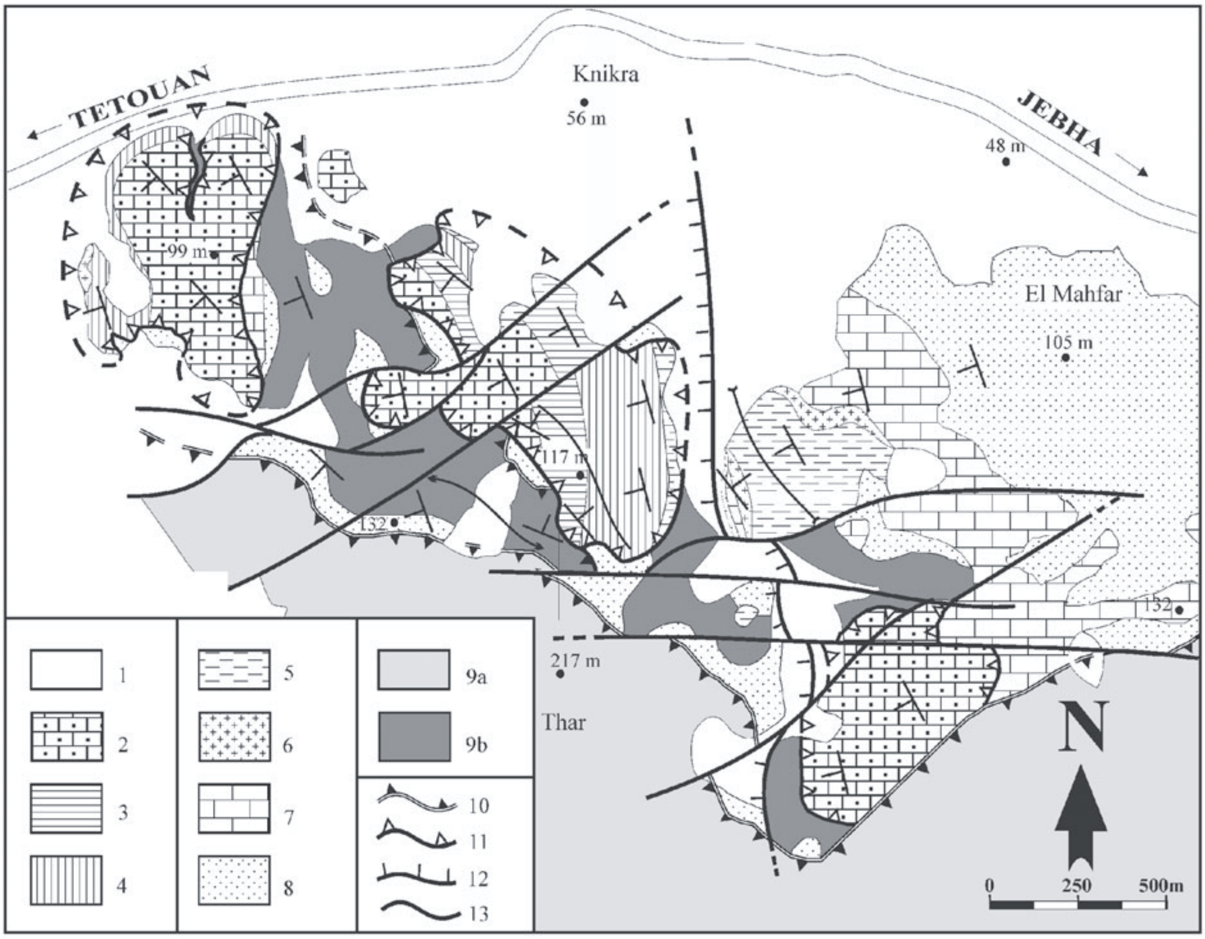

Fig. 3. Geological sketch map of the Beni Maâdane area (Internal Rif, Morocco) showing the mainly conglomeratic Oligocene-Miocene deposits of the Ghomaride nappe covers. 1 — Pliocene and Quaternary deposits; Oligocene-Miocene deposits of the Ghomaride nappe cover: Upper Conglomeratic Interval: 2 — calcareous conglomerates, 3 — mixed conglomeratic lithofacies (siliciclastic and calcareous), 4 — siliciclastic conglomerates; Lower Conglomeratic Interval: 5 — marls, 6 — siliciclastic conglomerates; 7 — limestones and dolostones (Upper Triassic to Lower Lias); 8 — Verrucano-like red clays, sandstones and conglomerates (Triassic); 9 — Paleozoic basement of the Ghomaride Units: (a) Beni Hozmar and (b) Aâkaïli nappes; 10 — nappe stacking contacts; 11 — low angle normal faults; 12 — high angle normal fault; 13 — strike-slip faults.

flows and/or as highly concentrated turbidity currents with traction transport as bed-load, which can be related to those of the *disorganized and organized conglomerates* (facies $A_{1.1}$ and $A_{2.1}$ of Pickering et al. 1989).

2. An upper mainly calcareous conglomeratic and arenaceous interval, about 150 m thick (Beni Maâdane Section, Figs. 3 and 4), made up of matrix and clast-supported *organized and disorganized conglomerates*, displaying a thinning- and fining-upward trend and also characterized by the occurrence of plurimetric calcareous and arenaceous olistoliths and of the following lithofacies:

- *organized and disorganized pebbly sandstones*, made up by sandstone bodies up to 6 m thick, with repetitive normal and/or inverse graded sequences and with clay chip horizons, interpreted as the sedimentary result of high concentration turbidity currents or as the mass deposition from hyperconcentrated flows of a pebbly-sandy mixture (facies A_2 and $A_{1.4}$ of Pickering et al. 1989).
- *stratified sandstones and gravelly sandstones*, represented by medium- to very coarse-grained sandstone beds, up to 1 m in thickness, with crude lamination and normal or reverse grading, resulting from multiple traction carpets under high density turbidity current conditions (facies F_4 and $B_{2.1}$, according to Mutti 1992 and to Pickering et al. 1989, respectively).
- *classical turbidites*, characterized by medium- to coarse-grained graded sandstones with complete or incomplete Bouma sequences, derived from unstable high density turbidity currents (facies F_7-F_8-F_{9a} of Mutti 1992 and facies C_2 of Pickering et al. 1989).

These two conglomeratic intervals are separated by yellowish-brownish massive clays (about 190 m thick, Fig. 4) with thin-bedded and fine-grained reddish turbidites, the thickness of which increases upward.

Viñuela–Sidi Abdesslam Formations

In the Internal Rif this second sedimentary cycle consists of an Early to Middle Burdigalian depositional sequence (N5–6 of Blow 1969, in Maate 1996), known as Sidi Abdesslam For-

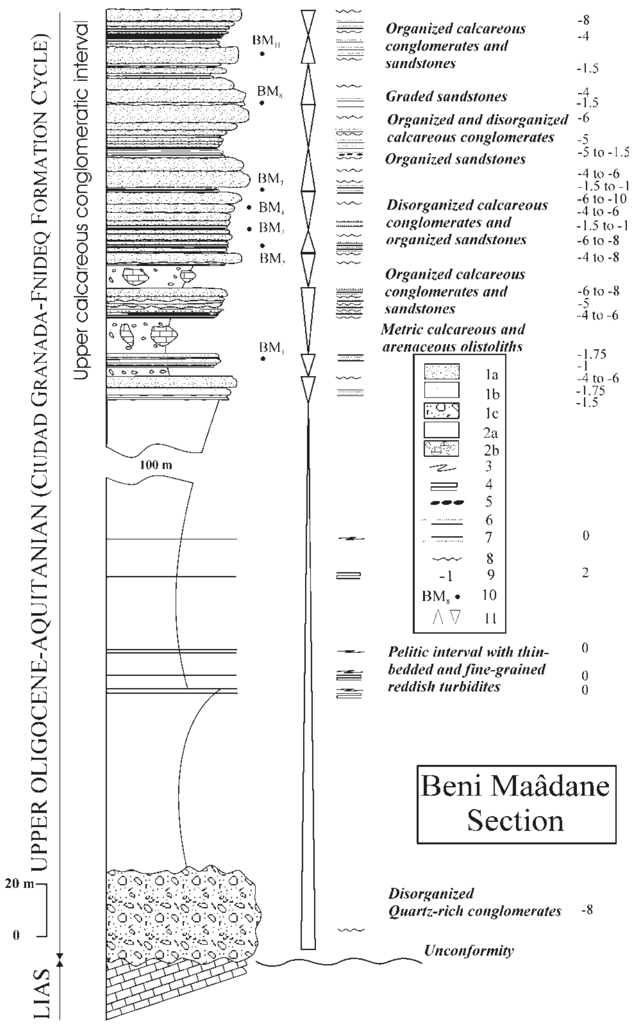

Fig. 4. Simplified stratigraphic section of the Beni Maâdane outcrop (Upper Oligocene–Late Aquitanian; Internal Rif, Morocco). 1a — calcareous conglomerates and chaotic facies, 1b — arenaceous lithofacies, 1c — lower siliciclastic conglomeratic interval; 2a — pelitic lithofacies, 2b — metric olistoliths; 3 — convolute laminations; 4 — parallel laminations; 5 — mud clasts; 6 and 7 — normal and inverse grading, respectively; 8 — scouring. For the other symbols see Fig. 2.

mation, unconformably overlying the Ghomaride and the Sebtide Units (Chalouan 1987; Maate 1996).

The Sidi Abdesslam Section (Fig. 5; Martin-Algarra 1987; Ouazani-Touhami & Chalouan 1995), begins with an arenaceous-pelitic lithofacies, marked by yellowish-reddish coarse-grained sandstones at the bottom (about 8.5 m thick) and grading upward to yellowish marls with fine-grained and thin-bedded turbidites. Successively, after about 200 m of unexposed section, the Sidi Abdesslam Formation shows a conglomerate interval made up by *disorganized and organized breccias and conglomerates* (24 m thick) with angular to subangular Paleozoic pebbles floating into an abundant fine-grained sandy matrix. These conglomerates are associated with chaotic facies (e.g. slumps) and, locally, with graded coarse-grained yellowish-brownish sandstones.

The base of this section has been related to the Fnideq Formation (Ouazani-Touhami & Chalouan 1995) and the geometrical relations with the overlying polygenic conglomerates of the Sidi Abdesslam Formation are marked by a gentle unconformity.

At the top of this conglomerate–arenaceous interval the Sidi Abdesslam Formation continues with yellowish thin-bedded and fine-grained calcareous turbidites (not more than 2 m thick) grading upward to mainly pelitic facies (about 20 m

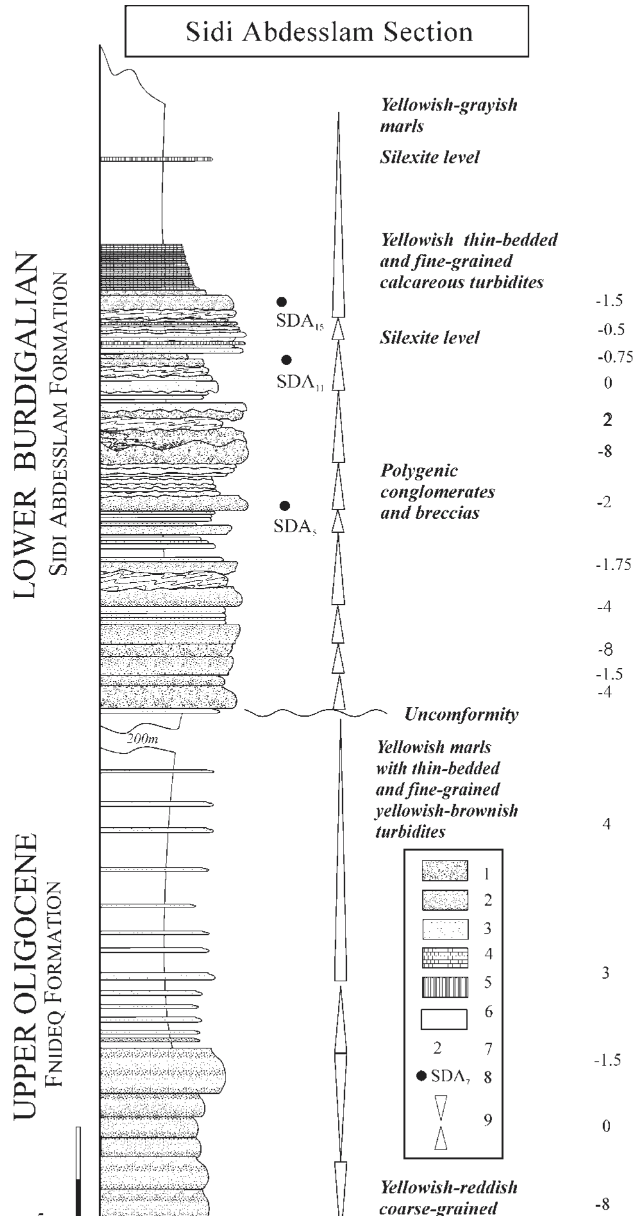

Fig. 5. Simplified stratigraphic section of the Sidi Abdesslam Formation (Lower Burdigalian) at the homonymous locality (Ghomaride nappe cover, Internal Rif, Morocco). 1 — conglomerate and breccia lithofacies; 2 — gravelly to medium-grained sandstones; 3 — fine-grained sandstones; 4 — thin-bedded calcilutites; 5 — silexite levels; 6 — marls and pelitic lithofacies. For the other symbols see Fig. 2.

thick), characterized by rare arenaceous beds and by the occurrence of some whitish "silexite" beds (Maate 1996). These clays increase in thickness in the Boujarrah Section (up to 100 m, Fig. 6), where "silexite" levels and amalgamated turbiditic sandstone beds, about 2 m thick, have been observed, respectively, at the base and in the middle portion of this section.

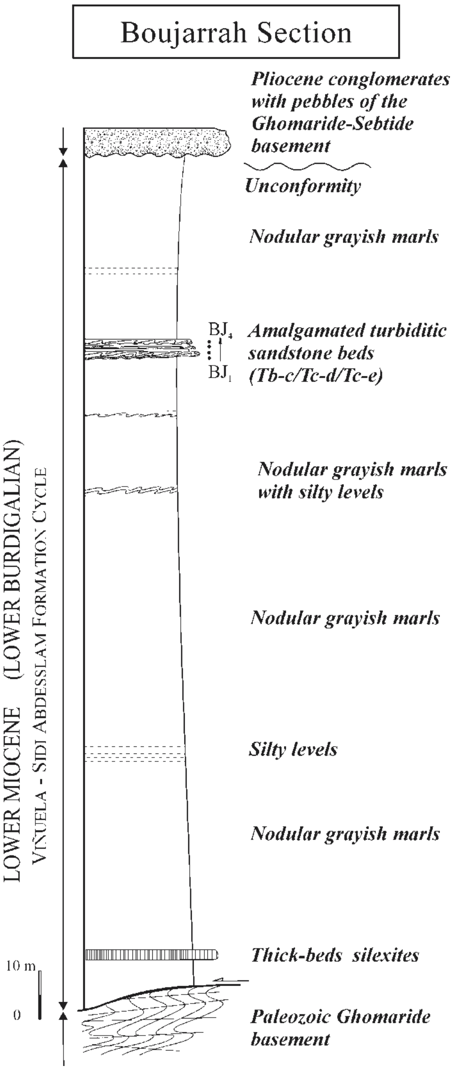

Fig. 6. Simplified stratigraphic section of the Sidi Abdesslam Formation (Lower Burdigalian) at the Boujarrah outcrop (Ghomaride nappe cover, Internal Rif, Morocco).

Petrographic characters of the sandstones

Table 1 lists the gross composition of the sandstone levels characterizing the Ciudad Granada-Fnideq Formation and Viñuela-Sidi Abdeslam Formation Cycles. The mean values of the detrital modes known in literature for these formations (Guerrera et al. 1977; Puglisi et al. 2001) are shown in Table 1 and compared with the new petrographic data here obtained. In Table 1 are also shown the compositional parameters adopted for the modal analysis; these have been performed according to the criteria suggested by Gazzi (1966), Dickinson (1970) and by Gazzi et al. (1973), in order to minimize the dependence of rock composition on grain size. The $\mathbf{Q_m}$, **F** and $\mathbf{L_t}$ parameters are also included in this Table, as suggested by Graham et al. (1976) and by Dickinson & Suczek (1979) as a means of recognizing the provenance of the clastic supply (**QFL** and $\mathbf{Q_mFL_t}$ parameters, in fact, emphasize the maturity and provenance of the sandstones, respectively).

In the first cycle eleven sandstone samples have been analysed: four collected from the *lower siliciclastic conglomeratic interval* (East and North-East of Tetouan, near the Kellaliyine village; samples $K_1 \rightarrow K_4$) and seven from the *upper calcareous conglomeratic interval* (Beni Maâdane Section; samples $BM_1 \rightarrow BM_{11}$).

On the basis of their composition all the analysed sandstones can be referred to the litharenite group. Small differences, in fact, observed among the two sets of sandstones are not significant and the framework modes of the studied rocks as well as their textural characters point to the same provenance and to very similar conditions of sedimentary transport, usually not prolonged and related to a very rugged topography.

Ciudad Granada-Fnideq Formation Cycle

The sandstones of the Fnideq Formation sampled within both the lower siliciclastic and upper calcareous conglomeratic intervals show a very similar composition. The first ones ($\mathbf{Q}_{62.1}\mathbf{F}_{3.2}\mathbf{L}_{34.7}$, $\mathbf{Qm}_{38.8}\mathbf{F}_{3.2}\mathbf{Lt}_{58.0}$) are characterized by the abundance of quartz grains and of lithic fragments, with a very low content of feldspars. The lithic fraction is mainly represented by quartzites, metasedimentary rocks (quartzose metarenites and metalimestones), rare phyllites and alterated volcanic rocks, these last with porphyritic structure, groundmass with fluidal texture, and with almost all mineralogical components poorly preserved.

The sandstones of the Beni Maâdane Section (upper calcareous conglomeratic interval) can also be ascribed to the litharenite family ($\mathbf{Q}_{54.3}\mathbf{F}_{1.7}\mathbf{L}_{44.0}$, $\mathbf{Qm}_{31.8}\mathbf{F}_{1.7}\mathbf{Lt}_{66.5}$) showing abundant fragments of quartzites, semischists, chlorite-schists, mixed with a few of micritic limestone. Moreover, in some clast we also observe the biotite as accessory component of phyllite fragments, testifying to a metamorphic grade of the source rocks slightly higher than that recognized for the provenance of the Kellaliyine outcrop sandstones. However, for both successions it is possible to exclude a conspicuous contribution from plutonic and/or high grade metamorphic sources. The content of feldspars, in fact, is very scarce in spite of the abundance of quartz and lithic fragments, the latter being represented by a small amount of volcanic clasts. Furthermore, the sandstones of both the lower siliciclastic and upper calcareous conglomeratic intervals usually show a low textural maturity (poor sorting, abundance of angular to subangular quartz grains, presence of a large amount of siliciclastic matrix, often pseudomatrix-like, *sensu* Dickinson 1970) which strongly points to very short transports.

A provenance from volcanic sources is supported within this upper calcareous conglomeratic interval, well exposed in the Beni Maâdane Section, by the presence of abundant volcanic pebbles. The petrographic characters of these volcanic

Table 1: Modal point counts of the analysed sandstones of the Fnideq–Ciudad Granada and Sidi Abdesslam–Viñuela Formations.

	Ciudad Granada - Fnideq Formation Cycle											Viñuela - Sidi Abdesslam Formation Cycle							Ciudad Granada Formation[1] (n = 6)		Fnideq Formation[2] (n = 3)		Viñuela Formation[1] (n = 5)		Sidi Abdesslam Formation[2] (n = 6)	
	Lower siliciclastic conglomeratic interval				Upper calcareous conglomeratic interval (Beni Maâdane Section)							Boujarrah Section				Sidi Abdesslam Section										
	K_1	**K_2**	**K_3**	**K_4**	**BM_1**	**BM_2**	**BM_3**	**BM_4**	**BM_7**	**BM_8**	**BM_{11}**	**BJ_1**	**BJ_2**	**BJ_3**	**BJ_4**	**SDA_5**	**SDA_{11}**	**SDA_{15}**	**x**	**σ**	**x**	**σ**	**x**	**σ**	**x**	**σ**
Q_m	22.6	25.1	24.9	26.8	18.7	17.5	19.1	20.3	18.5	21.2	19.9	23.6	25.0	21.9	22.8	31.1	27.2	26.7	12.5	3.03	66.0	4.88	24.5	5.0	27.2	3.20
Q_p	16.1	13.7	16.3	17.2	14.9	16.3	15.0	16.7	15.7	16.5	16.0	9.1	8.4	11.7	12.7	6.5	5.3	3.2	17.0	1.24	7.2	1.47	17.5	2.09	6.6	1.45
Qr	6.9	4.9	4.1	3.8	5.8	4.1	3.7	2.2	5.1	4.3	3.7	4.5	3.1	2.8	4.6	3.4	3.0	4.8	0.1	0.24	-		0.2	0.35	4.1	1.53
Ch	2.9	3.3	1.2	1.1	0.9	-	1.3	1.1	1.1	-	0.9	1.2	1.9	-	-	-	-	0.6	1.0	0.86	1.7	0.40	0.9	0.73	1.6	1.42
Ps	2.1	1.5	1.7	1.6	0.9	1.1	1.6	1.0	-	-	1.3	4.9	5.2	6.5	4.0	3.8	2.5	2.6	3.7	0.85	6.4	1.67	3.7	1.01	6.5	0.95
Pr	-	-	1.2	0.5	-	-	0.5	-	-	0.5	-	0.6	-	-	-	1.1	-	1.2	-		-		0.1	0.16	-	
Ks	1.3	-	-	-	-	-	-	0.6	-	-	-	-	0.8	-	1.2	2.6	2.5	1.7	-		-		0.2	0.24	0.8	0.77
Kr	-	0.6	-	-	-	0.5	-	-	-	0.6	-	1.2	-	1.7	1.2	-	0.5	-	-		-		-		-	
Lv	3.5	-	1.7	2.1	4.5	3.9	5.0	3.7	1.2	-	3.9	0.6	-	1.8	-	-	-	0.6	0.2	0.30	-		0.4	0.38	-	
Lc	3.3	4.6	5.8	2.0	13.7	13.6	11.9	13.3	14.6	13.5	13.5	9.6	8.9	8.5	7.9	9.8	6.5	5.4	20.4	9.63	5.8	5.35	16.9	1.37	6.8	2.35
Lm	20.7	21.2	19.9	22.3	13.6	15.1	16.7	15.2	17.7	16.7	15.9	25.7	27.2	24.9	23.8	27.9	26.0	25.8	29.3	6.56	7.2	2.30	18.9	7.45	28.8	3.77
Ms	2.8	4.9	5.8	4.7	4.8	6.5	6.2	8.7	9.4	8.8	9.4	6.9	7.5	8.9	7.5	4.4	9.3	8.9	3.0	1.92	0.7	0.57	3.3	1.72	5.3	1.10
Mr	4.3	3.8	4.1	4.2	5.2	5.0	5.6	4.3	3.9	3.1	2.3	4.9	3.8	2.3	4.4	2.1	4.7	3.2	0.4	3.24	-		0.4	0.18	3.0	1.05
Al	1.6	0.9	1.2	1.4	2.1	2.9	1.6	-	1.2	1.1	1.6	1.1	-	1.1	-	1.1	0.5	1.7	-		-		0.1	0.10	0.8	0.64
Mt	8.7	4.4	9.2	8.9	11.0	9.3	8.8	10.5	8.9	10.5	8.7	6.1	5.9	7.9	6.8	6.2	8.5	9.5	0.8	0.96	4.0	1.88	0.8	1.03	0.6	0.76
Cm	3.2	11.1	2.9	3.4	3.9	4.2	3.0	2.4	2.7	3.2	2.9	-	2.3	-	3.1	-	3.5	4.1	11.5	1.63	1.0	0.73	12.1	1.50	7.9	2.25
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	
Q	61.1	62.8	60.5	63.2	55.2	52.6	52.3	54.4	54.7	57.3	54.0	47.4	47.8	45.5	51.3	43.7	48.4	48.7	36.6	4.68	79.4	3.26	51.6	6.90	48.0	4.62
F	4.3	2.8	3.8	2.7	1.2	2.2	2.8	2.2	-	1.5	1.7	8.3	7.4	10.4	8.2	8.7	7.4	7.5	4.4	1.04	6.7	1.89	5.0	1.58	8.9	1.84
L	34.6	34.4	35.7	34.1	43.6	45.2	44.9	43.4	45.3	41.2	44.3	44.3	44.8	44.1	40.5	47.6	44.2	43.8	59.0	5.21	13.9	3.47	43.4	7.62	43.1	4.91
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	
Q_m	37.1	40.0	37.7	39.5	33.6	30.0	30.5	30.3	31.9	34.8	31.5	34.7	35.0	30.8	35.0	40.0	41.1	43.4	16.0	5.93	70.0	3.31	28.8	6.04	38.1	5.24
F	4.3	2.8	3.8	2.7	1.2	2.2	2.8	2.2	-	1.5	1.7	8.3	7.4	10.4	8.2	8.7	7.4	7.5	4.4	1.04	6.7	1.89	5.0	1.58	8.9	1.84
L_t	58.6	57.2	58.5	57.8	65.2	67.8	66.7	67.5	68.1	63.7	66.8	57.0	57.6	58.8	56.8	51.3	51.5	49.1	79.6	6.50	23.2	4.42	66.3	7.26	53.0	5.37
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	

x and **σ** = mean framework modes and standard deviation; n = number of analysed samples. **1** — Ciudad Granada and Viñuela Formations (Betic Cordillera), analyses from Guerrera et al. (1977); **2** — Fnideq and Sidi Abdesslam Formations (Rif, Morocco), analyses from Puglisi et al. (2001).

Symbols of the parameters adopted for the modal analysis

$Q = Q_m + Q_p$, where: **Q** = total quartzose grains, **Q_m** = monocrystalline quartzose grains (including **Q_r** = quartz in coarse-grained rock fragments, i.e. > 0.06 mm), **Q_p** = polycrystalline quartzose grains (including **Ch** = chert);

F = P + K, where: **F** = total feldspar grains, **P** and **K** = plagioclase and potassium feldspar single grains (**Ps** and **Ks**) or in coarse-grained rock fragments (**Pr** and **Kr**);

L = Lv + Lc + Lm, where: **L** = unstable fine-grained rock fragments (< 0.06 mm, i.e.: **Lv** = volcanic, **Lc** = carbonate and **Lm** = epimetamorphic lithic fragments);

$Lt = L + Q_p$, where: **Lt** = total lithic fragments (both unstable and quartzose);

M = micas and/or chlorites, in single grains (**Ms**) or in coarse-grained rock fragments (**Mr**);

Al = other mineral grains, **Mt** = siliciclastic matrix; **Cm** = carbonate cement.

rocks are hardly defined because of their alteration. Some of the pebbles show evidence of porphyritic structure (Fig. 7a), due to the presence of plagioclase phenocrysts in a holocrystalline to oligohyaline fine-grained groundmass, mainly formed by a felt of twinned plagioclases, opaque minerals and femic minerals, these last nearly always altered and replaced into a calcite-vermiculite aggregate and locally into chlorite.

Other volcanic pebbles show an ophitic-like texture, made up by a subhedral plagioclase felt with the interstices filled by opaque minerals and by mafic minerals almost completely altered, whereas in other volcanics it is also possible to observe an abundance of gas-bubble vesicles filled by secondary calcite (Fig. 7b).

Viñuela-Sidi Abdesslam Formation Cycle

Within the Sidi Abdesslam Formation the seven sandstone samples have been collected from the Boujarrah outcrop, already studied by Maate et al. (1995) and dated as lower Burdigalian, and from the Sidi Abdesslam Section (Mediterranean coast, 4 km S of Martil; Chalouan 1987; Martin-Algarra 1987; Maate et al. 1995; Maate 1996; Puglisi et al. 2001).

The sandstones of both these outcrops are characterized by abundant quartzose-lithic detritus coupled with a low content of feldspars and their compositions are very similar ($\mathbf{Q}_{48.0}\mathbf{F}_{8.6}\mathbf{L}_{43.4}$-$\mathbf{Qm}_{33.9}\mathbf{F}_{8.6}\mathbf{Lt}_{57.5}$ and $\mathbf{Q}_{46.9}\mathbf{F}_{7.7}\mathbf{L}_{45.4}$-$\mathbf{Qm}_{33.3}\mathbf{F}_{7.7}\mathbf{Lt}_{50.6}$, for the Boujarrah and the Sidi Abdesslam outcrops, respectively).

The slightly more lithic nature of the sandstones of the Viñuela-Sidi Abdesslam Formation Cycle could tentatively be considered as an element of discrimination even if the populations of lithic grains are essentially indistinguishable qualitatively in the two sets of analysed sandstones (Fig. 7c,d). These rocks show strong affinities with the sandstones of the Ciudad Granada-Fnideq Formation Cycle and their provenance also appears to be linked to metasedimentary and epimetamorphic rocks rather than to plutonic and/or high grade metamorphic sources (Fig. 8).

Furthermore, the very poor sorting, the low roundness of the clasts (usually angular to subangular shaped detrital grains) and the presence of siliciclastic matrix characterize a very low textural maturity for these sandstones, suggesting also in this case very short transports, probably related to a rugged topography and to a very unstable tectonic setting.

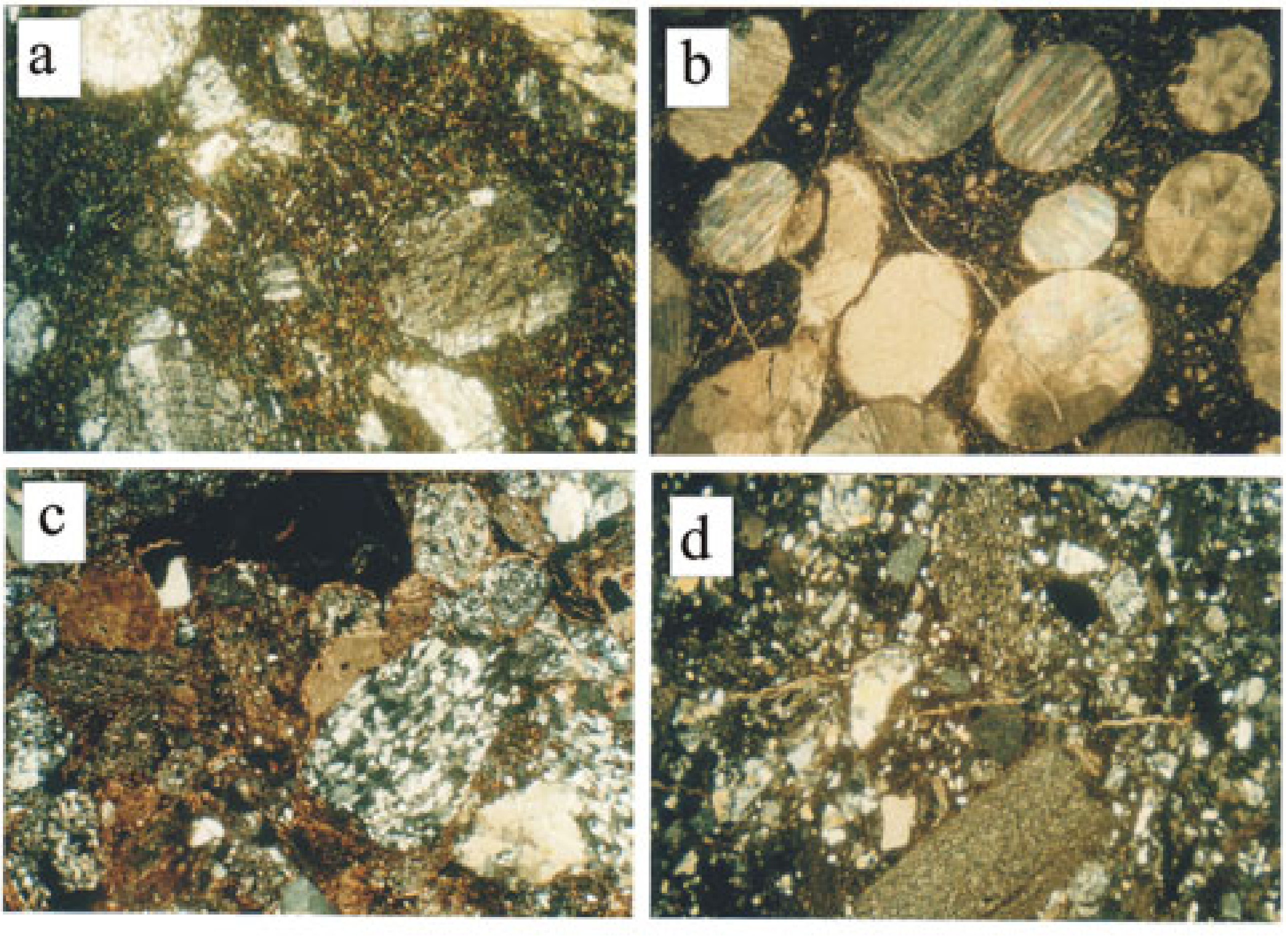

Fig. 7. Thin section photomicrographs of two different volcanic pebbles collected from the Beni Maâdane Section and of two sandstones representative of the two sedimentary cycles. Volcanic rocks show evidence of **(a)** slightly porphyric structure (plagioclase phenocrysts floating in a oligohyaline fine-grained groundmass with feldspars, femic and opaque minerals) and **(b)** abundance of gas-bubble vesicles filled by secondary calcite. Sandstones of both the Fnideq **(c)** and Sidi Abdesslam **(d)** Formations show a mainly quartzose-lithic composition.

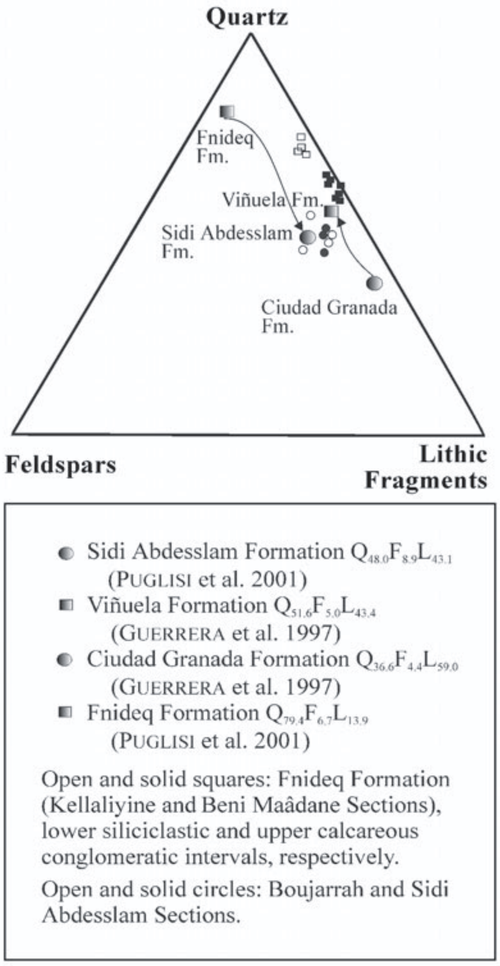

Fig. 8. Quartz–Feldspar–Lithic fragments diagram showing the framework modes for the analysed sandstones from the Oligocene-Miocene cover of the Ghomaride Units. The arrows show possible evolutive trends. Open and solid circles and squares = new data, grey squares and circles = data from literature, as shown on the panel under the QFL plot.

Tectonic setting

Modern orogenic models (Dewey 1988; Michard et al. 2002) suggest that lithosphere thickening and extensional tectonics controlled by internally generated forces are contemporaneous and subsequent to the regionally compressive regimes linked to the north-south convergence of the African and European plates (Platt & Vissers 1989). Thus, Oligocene compressive events responsible for the deformation and stacking of the Ghomaride nappes in the internal Rifian zones have been followed by exhumation and uplift processes of the fold-thrust belt which occurred in an extensional geodynamic context during Late Oligocene times (Doglioni et al. 1999; Chalouan et al. 2001).

This mainly extensional tectonic regime was dominant and lasted up to Middle Burdigalian times being accompanied by the input of detrital supply from the uplifted blocks toward small basins located above the fold-thrust belt itself. Traces of extensional tectonic events predating the onset of the Late Oligocene unconformable sedimentation above the Ghomaride nappes are testified by the presence of:

- decimetric to plurimetric high angle conjugated NNW-SSE normal faults, affecting the Paleozoic basement near the Fnideq village (Chalouan 1986) and sutured by the Late Oligocene-Aquitanian deposits of the Fnideq Formation (Feinberg et al. 1990),
- tardi-metamorphic flexures, evolving to ductile-brittle normal faults filled by quartzose-feldspatic veins and revealing a mainly NE-SW extensional trend, observed within the gneiss and micaschists of the lower Sebtide Units at the Cabo Negro and Bou Ahmed localities, north and south of Tetouan (Benmakhlouf 1990; Benmakhlouf & Chalouan 1991) and in the Beni Mzala area (Zaghloul 1994).

Further extensional episodes are well marked in both the above described sedimentary cycles. In fact, at the base of the Fnideq Formation the presence of syn-sedimentary normal faults with a NE-SW extensional axis (Feinberg et al. 1990) could imply the temporal continuum of the same extensional event. The coexistence of NW-SE regional compressive constraints, almost orthogonal to this extensional trend, is suggested by the occurrence of decimetric folds with the NE-SW axis (Ouazani-Touhami 1994; Chalouan et al. 1995). On the contrary, the overlying pelitic interval (more than 190 m thick) with thin-bedded and fine-grained reddish turbidites could record an early subsidence episode, contemporaneous to a period of tectonic quiescence.

Furthermore, at the top of the Fnideq Formation in the Beni Maâdane area, that is within the upper calcareous conglomerate interval, as well as at the base of the Sidi Abdesslam Formation (Fig. 9) several decimetric syn-sedimentary normal faults of Aquitanian and Burdigalian age and with a mainly NW-SE extensional trend have been found (Benmakhlouf 1990; Ouazani-Touhami 1994; Chaouni 1996). This last extensional episode probably reflects a tectonic reactivation of the tilted listric normal faults by increasing of subsidence and rejuvenation of relief giving a rugged topography as testified by the thick calcareous conglomerates in the upper interval of the Fnideq Formation (Fig. 10). This event would have been followed by a period of tectonic quiescence which marks the end of this cycle, materialized by the occurrence of more than 20 m of yellowish marls with thin-bedded turbidites above a thick (8.5 m) arenaceous body (Puglisi et al. 2001). Note that the highest levels of the Viñuela-Sidi Abdesslam Formation Cycle in the Sidi Abdesslam outcrops also show syn-sedimentary normal faults with an ENE-WSW (Ouazani-Touhami 1994; Ouazani-Touhami & Chalouan 1995) to E-W extension (Chaouni 1996).

Successively, during and after Lower Miocene sedimentation, a drastic contraction was responsible of the piling-up of the Ghomaride–Sebtide–Dorsale Units and of their overthrust onto the Flysch and the External Domains. The main deformations of the Ghomaride realm, which post-date the nappe stacking and their overthrust onto the Sebtide Units, are characterized by NW to NE trending open folds, coupled with brittle thrusts and back-thrusts (locally, low angle normal faults) and by sinistral and dextral strike-slip fault systems, as recognized at the Jebha-Chrafat and Jebel Fahies localities, to the south and north of the Rifian Chain, respectively (Olivier

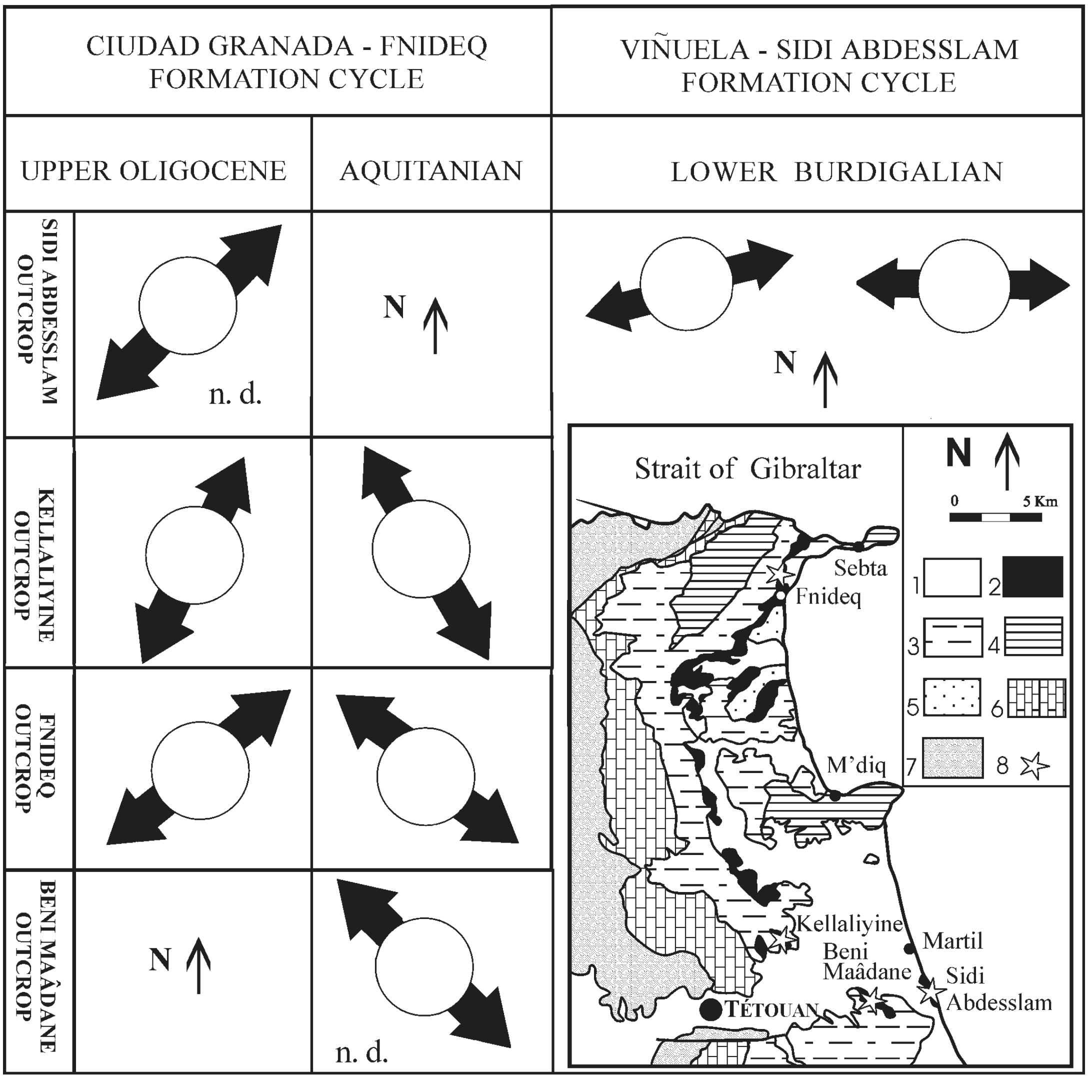

Fig. 9. Scheme of distribution of the syn-sedimentary normal faults located within the Oligocene-Miocene Ghomaride nappe cover (after Benmakhlouf 1990, Ouazani-Touhami 1994 and Chaouni 1966, with the integration of new data marked as n.d.). At the bottom, on the right, the geological sketch map with the location of the stations: 1 — Pliocene and Quaternary deposits; 2 — Oligocene-Miocene Ghomaride nappe cover; 3 — Ghomaride Units; 4 — Sebtide Units; 5 — Numidian Flysch; 6 — "Dorsale Calcaire"; 7 — Flysch Domain; 8 — location of the stations.

1982; Morley 1987; Frizon de Lamotte 1987; Zaghloul 1994; Zaghloul & Chalouan 1997). These deformations also affect the Oligocene-Miocene Ghomaride nappe covers as testified by the presence of a lot of decimetric to metric sinistral and dextral strike-slip faults (Benmakhlouf 1990; Chaouni 1996).

Discussion

The above reported facies analyses yield a better definition of the sedimentological features of the two sedimentary cycles characterizing the Oligocene-Miocene successions of the Ghomaride nappe cover. High density turbiditic flows (very coarse- and coarse-grained facies such as disorganized and organized conglomerates and pebbly sandstones) are dominant in the Ciudad Granada-Fnideq Formation Cycle, whereas a thinning- and fining-upward megasequence with massive polygenic conglomerates and breccias grading upward to thin-bedded calcareous turbidites with nodular yellowish-brownish marls and silexite levels characterize the Viñuela-Sidi Abdesslam Formation Cycle.

Thus, the whole successions of both the analysed cycles seem to have been controlled by highly concentrated turbidity currents with the exception of short vertical interruptions characterized by mainly pelitic lithofacies with thin-bedded turbidites, which mainly mark the highest stratigraphic levels. At the top of the Sidi Abdesslam Formation, in fact, the succession acquires sedimentological characters probably linked to low density turbidity currents.

Petrographic analyses indicate a very similar sedimentary supply for the sandstones of both the Ciudad Granada-Fnideq Formation and Viñuela-Sidi Abdesslam Formation Cycles,

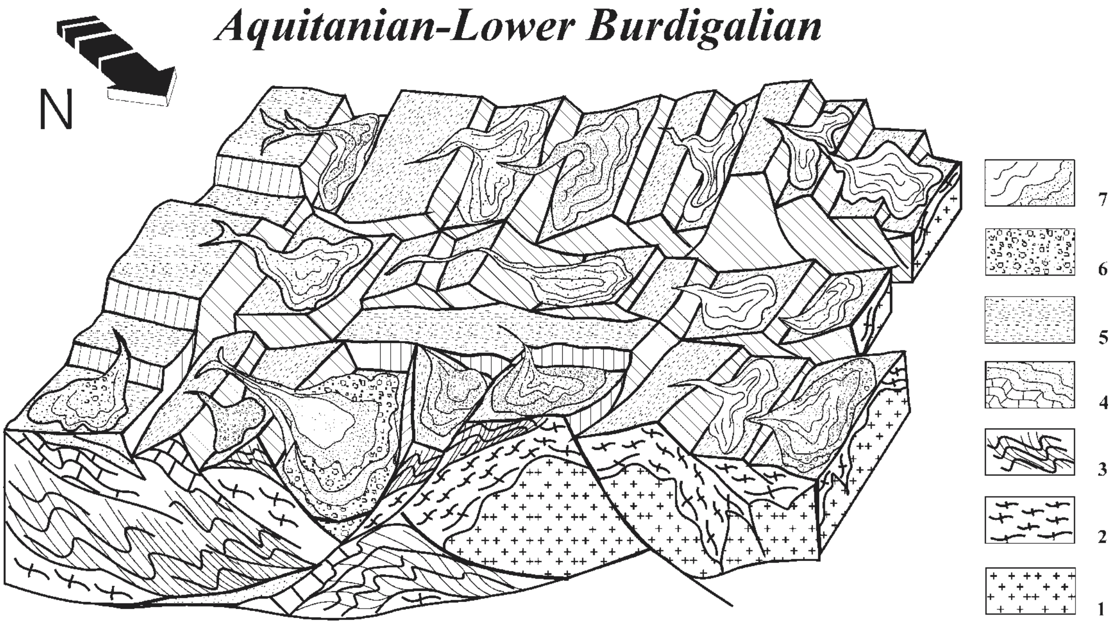

Fig. 10. Block diagram showing the paleogeographical setting of the internal part of the Ghomaride realm during the early rifting stage related to the opening of the Alboran Sea of the north-occidental margin of "Mesomediterranean terrane". **A:** Crystalline basement of the Ghomaride Domain: 1 — plutonic rocks (granites and granitoid rocks); 2 — high grade metamorphic rocks (augen gneiss and micaschists); 3 — low grade metamorphic rocks, such as metasedimentary (metapelites) and phyllites. **B:** Pre-nappes Triassic to Paleogene sedimentary cover of the Ghomaride Domain: 4 — carbonate and siliciclastic deposits (Triassic–Upper Eocene); **C:** syn- to late-orogenic siliciclastic flysch of the Ghomaride Domain: 5 — thin-bedded sandstones with marly-pelitic intervals, 6 — siliciclastic and carbonate-clastic conglomerates, 7 — fine- to medium-grained sandstones, microbreccias and microconglomerates.

mainly consisting of metasedimentary and epimetamorphic detritus with carbonate clasts, rather than of plutonites and high grade metamorphites as testified by the scarcity of feldspar grains. These data could justify the hypothesis of a drainage basin made up by the Ghomaride realm rocks, believed to be the sediment sources rather than the Sebtide Domain, and by their mainly carbonate Mesozoic sedimentary covers.

Such a paleogeographical hypothesis could help to interpret the analysed successions as elements of slope apron depositional systems pounded between fault tilted blocks, controlled by gravity and debris flow processes and related to backarc basins.

Thus, the sedimentary infilling of these basins, considered to be syn- to late-orogenic because of their contemporaneity with the main orogenic events of uplift and nappe exhumation (Puglisi et al. 2001), is mainly controlled by normal faults at the rear of the chain which provides spectacular sediment dispersal by means of gravity mass flows.

Therefore, the paleogeographical scenario is closely connected to a geodynamic context where the crust, very thickened by compression and subduction processes, before and during the stacking of the Ghomaride nappes onto the Sebtide Units, could have suffered an important extensional buoyancy of the folded overthrust belt responsible for its progressive uplift in the innermost areas. In this way the highly elevated parts of this tectonic edifice (Ghomaride Units p.p.) could have been progressively uplifted and suffered a continuous rapid erosion during Oligocene times, feeding small intramontane "satellites basins" produced by extensional effects and located behind the piled nappes, above the Ghomaride–Sebtide Units.

In the Gibraltar Arc, in fact, the exhumation of the Sebtide (Rif) and Alpujarride (Spain) Units, the consequent tectonic deformation and the stacking of the Ghomaride–Malaguide nappes in the internal Betic–Rifian zones were concomitant with the input of detrital supply within small "basins" (Martin-Algarra et al. 2000; Puglisi et al. 2001). Thus, the consequent syn- to late-orogenic sedimentation recorded in the two successive sedimentary cycles above described could have been contemporaneous with the younger thrusts achieving the deformation of the more external unites of the internal zones.

In conclusion, it is possible to admit that a dominant mainly extensional tectonic activity lasted from the Late Oligocene up to Middle Burdigalian times with permutation of the extension directions during the Chattian-Aquitanian boundary, related to the similar values of the intermediate and lower stresses ($\sigma_2 \approx \sigma_3$).

Owing to this extensive normal faulting, the Sebtide Units and the overlying metamorphic slices, during their uplift, underwent a considerable thinning up to 10 km (Chalouan et al. 1995). In fact, the extensional episodes affecting the Sebtide–Ghomaride nappes, here aged Late Oligocene up to Lower Miocene times, perfectly coincide with the radiometric ages measured in the Sebtide Units (about 22 Ma in average; Michard et al. 1983, 1991; Saddiqi 1988), representing the passage during their uplift at the depth of about 10 km (Chalouan et al. 1995). Successively, the distension reached the most external point of the Internal Rif (i.e. the boundary zone between the "Dorsale Calcaire" and the Flysch Domain) during Aquitanian times, when blocks and olistoliths of the "Dorsale Calcaire" nourished the more proximal area of the flysch basin (the Predorsalian Domain, Auct.)[2].

Some of these rifts and particularly the more subsident, located in the innermost part of this Domain (in relation to the present geography) and oriented in the same way to the coast line (e.g. deposit of the synclinal of Haddou–Fnideq, of Sidi Abdesslam, Beni Maâdane, and Jebha) seem to be precursors of "continental troughs" which evolved into the present Alboran Sea. As suggested for the Calabria-Peloritani Arc by Weltje (1992) a pattern similar to the "arc migration model" (Malinverno & Ryan 1986) could be proposed for the Oligocene-Miocene evolution of the Gibraltar Arc. It allows us to adequately explain the "roll back" which occurred during Oligocene–Miocene times (De Jonge & Wortel 1990; Royden 1993; Lonergan & White 1997; Frizon de Lamotte 2000), the southward Maghrebian thrusting and the opening of the Alboran Sea and the Algero-Provençal Basin (Burrus 1984; Bouillin 1984; Rehault et al. 1984).

Conclusions

Thus, in conclusion, the sedimentological and petrographic data obtained in this study suggest for the Oligocene-Miocene deposits of the Ghomaride nappe cover the following remarks:

— provenance of the clasts from the same Ghomaride realm rocks,

— gravity mass flows, mainly highly concentrated turbidity currents were responsible for the short transport of the sediments within,

— small backarc basins, strongly controlled by extensional tectonics, and

— penecontemporaneous with the orogenic events of uplift and exhumation of the folded overthrust belt.

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[2]Moreover, it seems that also the more internal flysch has been deposited in a subsident foredeep submitted to a divergent geodynamic context, at least during Upper Oligocene–Aquitanian times (Zaghloul et al. 2002).

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