GEOLOGICA CARPATHICA, DECEMBER 2005, 56, 6, 517–530

Stratigraphy and provenance of Lower and Middle Miocene strata within the External Tanger Unit (Intra-Rif sub-Domain, External Domain; Rif, Morocco): first evidence

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(Manuscript received July 15, 2004; accepted in revised form June 16, 2005)

Abstract: New biostratigraphic, petrographic and sedimentological investigations on Saf Lahmame marly-arenaceous succession of the External Tanger Unit (Intra-Rif sub-Domain, External Domain) indicate an age not older than Burdigalian–Serravallian. The medium- to fine-grained sandstones of the Saf Lahmame succession show mainly graded and massive amalgamated beds organized in thinning- and fining-upward sequences. Medium-grained deposits reflect a continual process of aggradation beneath a high-density turbidity current and by a very quick deposition for freezing of a dense cohesionless suspension under a highly concentrated flow. A fine-grained facies association reflects slow accumulation of mud and biogenic materials and diluted and low concentration turbidity currents. The sandstones of the sublitharenite/quartzarenite groups are characterized by common occurrence of glauconite grains. Their provenance seems to be exclusively related to the African Craton, which is in good agreement with the published data on the composition of the Numidian and Numidian-like sequences in the Rif, Betic and Apenninic-Maghrebian Chains. The SE and NW paleoflows within these sandstones could reflect a multisource alimentation from instable marginal areas of the Africa.

Key words: Lower–Middle Miocene, Morocco, Rif Chain, provenance, nannoplankton, planktonic foraminifers, sandstones, turbidite.

Introduction

The Rif is located at the western ending of the Maghrebian Chain and, together with the Betics, forms the main Alpine orocline of the western and central Mediterranean Sea. The Maghrebian Chain consists of Rif, Tell and Sicilian orogenic domains (Durand-Delga 1980; Durand-Delga & Fontboté 1980; Fig. 1a). Betic and Maghrebian Chains namely, Internal Domains of Rif (Morocco), Kabylies (Algeria), Peloritani and Calabria (Italy) are derived from the collision and break-up, since the Early Miocene, of a continental microplate initially located between Europe and Africa, this latter is known as “Mesomediterranean Terrane” or “AlKaPeCa” block (Al — Alboran, southern Spain and northern Morocco, Ka — Kabylia, Algeria, PeCa — Calabria-Peloritani Arc) (sensu Guerrera et al. 1993 and Michard et al. 2002, respectively).

The Mesozoic-Cenozoic terrains cropping out through the Maghrebian Chain are related to three main paleogeographical realms: Internal Domain, Flysch Domain (Mauretanian Flysch, Massylian Flysch, Numidian sequence and Mixed Successions, sensu Carmisciano et al. 1987 and Guerrera et al. 1987, 1992) and External Domain. The latter displays a Triassic-Tertiary sedimentary succession, originated from the African paleomargin. Since the Early Miocene this margin has been progressively involved in foreland basins (Guerrera et al. 1993), with several depositional systems through the whole Maghrebian Chain, consisting of turbiditic successions such as the well known Numidian Flysch and Numidian-like sequences, namely holoquartzose turbidites and marly-clayey successions (Durand-Delga et al. 1960–1962).

The Upper Oligocene-Middle Miocene successions of the External Domain of the Rif, all supplied by the erosion of the African Craton, have been considered as Numidian-like sequences. These are the Asilah Sandstones (Critelli 1985; Cazzola & Critelli 1986–87) and the Larache Sandstones (Didon & Hoyez 1978), belonging to the Habt Nappe (sensu Suter & Fiechter 1966) and to the Ouezzane Nappe (sensu Wildi 1983), respectively. All these units, regrouped within the Upper Intra-Rif nappes (sensu Leblanc 1979) and mainly formed by Middle Miocene successions, are considerably widespread in the External Rif Domain, probably representing the transition between the Intra- and Meso-Rif sub-Domains. They are completely detached from their Cretaceous substratum and transported far away to the SW (Hottinger & Sutter 1961; Durand-Delga 1972; Lespinasse 1975; Benyaich 1991; Frizon de Lamotte

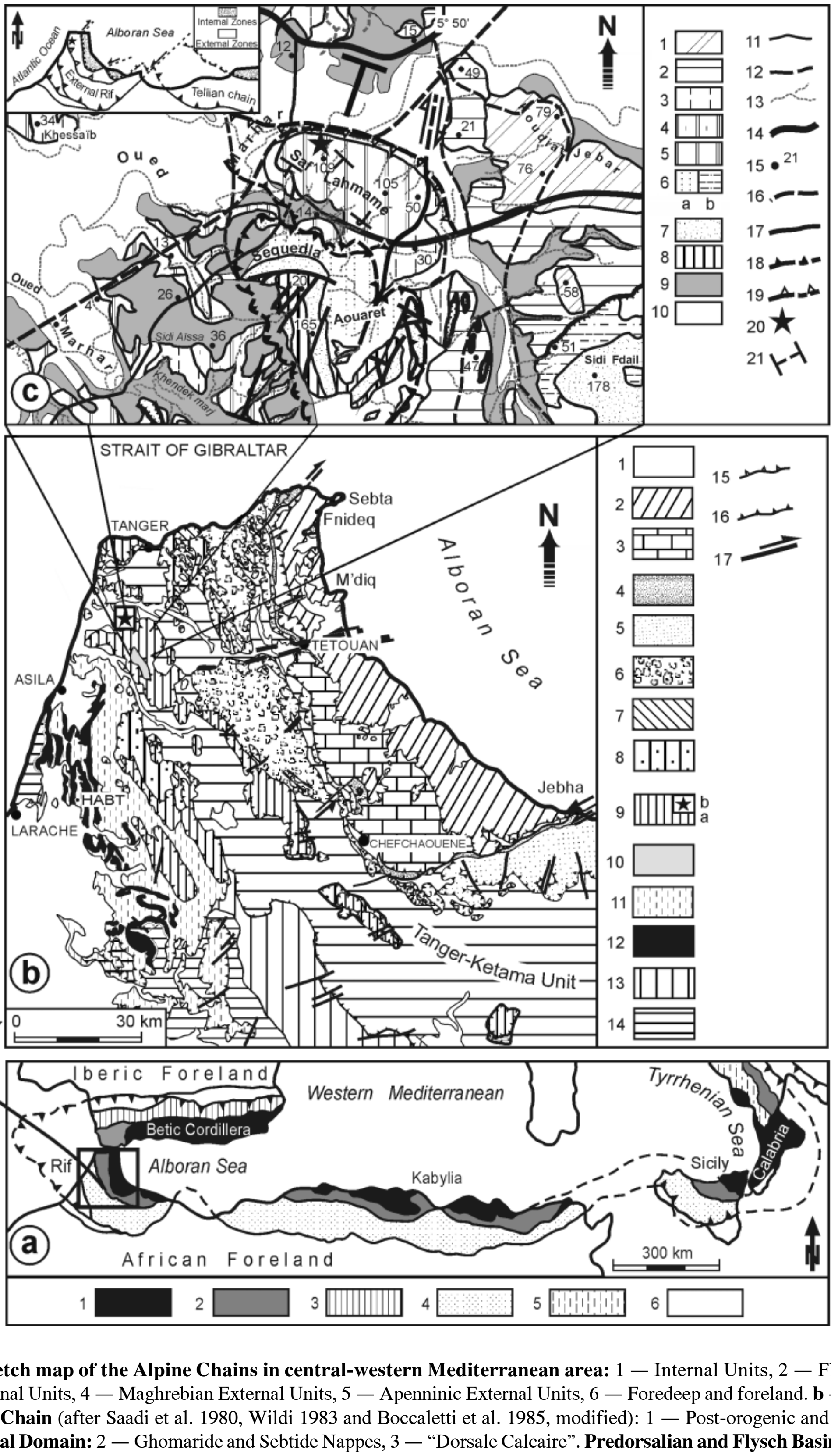

Fig. 1. a — Sketch map of the Alpine Chains in central-western Mediterranean area: 1 — Internal Units, 2 — Flysch Domain Units, 3 — Betic External Units, 4 — Maghrebian External Units, 5 — Apenninic External Units, 6 — Foredeep and foreland. **b — Structural sketch map of the Rif Chain** (after Saadi et al. 1980, Wildi 1983 and Boccaletti et al. 1985, modified): 1 — Post-orogenic and Pliocene-Quaternary deposits. **Internal Domain:** 2 — Ghomaride and Sebtide Nappes, 3 — "Dorsale Calcaire". **Predorsalian and Flysch Basin Domains:** 4 — Predorsalian Units, 5–6 — Mauretanian Domain ("Tisirène" and "Beni Ider" Nappes, respectively), 7 — Mixed Successions. **External Domain; Massylian sub-Domain:** 8 — "Melloussa-Chouamat" Nappe, 9a — Numidian Sequence, 9b — supra-Numidian Interval. **Intra-Rif sub-Domain:** 10 — Intra-Rifian Zones, 11 — Intra-Rifian Nappes, 12 — Asilah-Larache Sandstones (Habt Nappe), 13 — Meso-Rifian Zone, 14 — Pre-Rifian Zone, 15 — main back-thrust front, 16 — overthrust or nappe boundary, 17 — strike slip faults. **c — Geological map of Seqedla area** (simplified and modified from the Geological Map of Tanger Al Manzla, 1:50,000). *(Continued on next page.)*

et al. 1991; Tejera de Leon 1993; Chalouan et al. 2001; Zakir & Chalouan 2003; Zakir 2004).

The Intra-Rif nappes display a simple internal structure characterized by open folds and, locally, by a pre-nappe cleavage (Leblanc 1979). They overthrust the Meso-Rif and Pre-Rif sub-Domains, and they are tectonically overlain by the Numidian Nappe (Fig. 1b).

The Intra-Rif sub-Domain and, in particular, the Tanger Unit, are affected by complex tectonic structures, due to the superposition of longitudinal and transversal compressive deformations of Miocene age, characterized by disharmonic folds and double verging folds with rough cleavage (El Mrihi 1995). These compressive structures are then overprinted by a generalized release as recorded by the widespread radial extension occurring during Late Miocene–Early Pliocene times (Saji 1993; Chaouni 1996).

This paper aims to propose the first multidisciplinary investigation on Lower and Middle Miocene siliciclastic sediments occurring within the undetached Tertiary succession of the External Tanger Unit (Durand-Delga et al. 1985). We emphasize for the first time the provenance and provide the exhaustive biostratigraphy of this succession by means of foraminifers and nannoplankton assemblages and, also, a new sedimentological characterization of the Neogene siliciclastic deposits of the External Tanger Unit. This multidisciplinary approach will provide some answer keys that lead to a preliminary paleogeographical scenario of the external portion of the Rif Chain during the Neogene.

Stratigraphy of the Tanger Unit

The Tanger Unit represents the tectonic substratum of the flysch nappes, cropping out SE of Chefchaouen town in a disharmonic structure (Lespinasse 1975). The Tanger Unit tectonically overlies the Ketama Unit, which is mainly characterized by several kilometers thick Albian-Aptian black flysch sequence ("schisto-gréseux" flysch of the French Authors, Andrieux 1971).

The Tanger Unit has been subdivided into two lithostratigraphic successions (Durand-Delga et al. 1960–1962; Lespinasse 1975), deposited in different paleogeographical sectors of the basin: the Internal Tanger Unit (W of Tétouan), bordering the "Dorsale Calcaire", and the External one, which shows a wide distribution of Paleogene to Middle Miocene strata.

— The Internal Tanger Unit is characterized by a Cretaceous succession showing at the base Cenomanian greenish shales (locally purplish-blue), grading upward to a siliceous shale key-bed. The carbonate content increases upwards, where the succession is characterized by meter-sized beds of limestone and cherty limestone, interbedded with black siliceous shales. At the top, Upper Senonian grey marls and medium-bedded microbreccias occur (Didon et al. 1973).

— The External Tanger Unit is formed by an Upper Cretaceous-Neogene succession. The lower part of this succession is represented by thick Middle-Upper Senonian grey or blackish marls with abundant nodules of limestones. They are overlain by Campanian-Maastrichtian marls and graded limestones; this succession lies onto Lower Senonian shales and Cenomanian clayey limestones (Durand-Delga et al. 1985). Medium-bedded microbreccias occur at the top of the succession, locally together with pebbles, blocks, and sometimes sedimentary klippen of Orbitolina limestones of a middle Cretaceous age (Didon et al. 1973).

The Paleogene and Neogene deposits of the External Tanger Unit, cropping out to the SSW of Tangier, near Oued Marhar (Geological map of Tanger-Al Manzla 1:50,000; Figs. 1c, 2), lie directly above the Campanian-Maastrichtian marls with "yellowish nodules" formed by limestone and shale. They are represented by the following lithofacies:

— marls with black flint ("facies Suessonien") of Late Paleocene–Early Eocene age (Durand-Delga et al. 1985),

— Lower-Middle Eocene whitish pelagic marls and/or marly limestones with black flint nodules and Lutetian black marls with yellow limestone nodules (Lespinasse 1972; Didon et al. 1973; Lespinasse 1975; Durand-Delga et al. 1985). The Upper Eocene-Lower Oligocene sediments are not well characterized and need a review of biostratigraphic content,

— Middle Eocene-Oligocene marls with thin-bedded turbiditic sandstones (Durand-Delga et al. 1985),

— thick greenish marls and decimeter to meter-sized yellowish-brownish turbiditic sandstones interbedded with thin-layered marls. These strata have been referred to the Late Oligocene and the Early Miocene by Durand-Delga et al. (1985). Their biostratigraphic position is re-examined, and it indicates an age not older than Early Burdigalian to Late Serravallian.

Sedimentology

A stratigraphic section has been measured and sampled within the Lower-Middle Miocene succession of the Tanger Unit: the Saf Lahmame section, located to the south of Tangier, near the rail road (Geological Map of Tanger-Al Manzla; X1: 458.95, Y1: 560.30, X2: 459.15, Y2: 560.55 (Figs. 1c, 3)).

Bedding style and thickness, sedimentary structures, texture and composition have been used to define different turbiditic facies and their associations. Facies

Fig. 1. *(Caption contiued)* **Tanger Unit (Intra-Rif sub-Domain):** 1 — marls and marly limestones with "yellowish nodules" and clay facies (Campanian–Maastrichtian), 2 — clay facies (Campanian–Maastrichtian), 3 — marls with black flint (Suessonian facies) (Lower Paleocene–Upper Eocene), 4 — marls with thin-bedded turbiditic sandstones (Middle Eocene–Oligocene), 5 — marls with thick-bedded turbiditic sandstones (Burdigalian–Serravallian). **Numidian Sequence:** 6a — Brown mudrocks to rare *Tubotomaculum*, 6b — Variegated Clays with *Tubotomaculum* (Upper Oligocene), 7 — Numidian Flysch (Aquitanian), 8 — marls and sandstones with "countourites" facies (Burdigalian). **Quaternary to Recent deposits** (fluvial terraces and continental alluvial aprons): 9 — Lower Quaternary to Recent deposits (Salétien to Soltanien), 10 — Rharbian and present deposits. **Conventional symbols:** 11 — geological trace, 12 — track, 13 — hydrographic network, 14 — main road, 15 — height spot, 16 — railroad, 17 — strike-slip fault, 18 — thrust, 19 — back-thrust, 20 — location of the stratigraphic section, 21 — location of the cross-section.

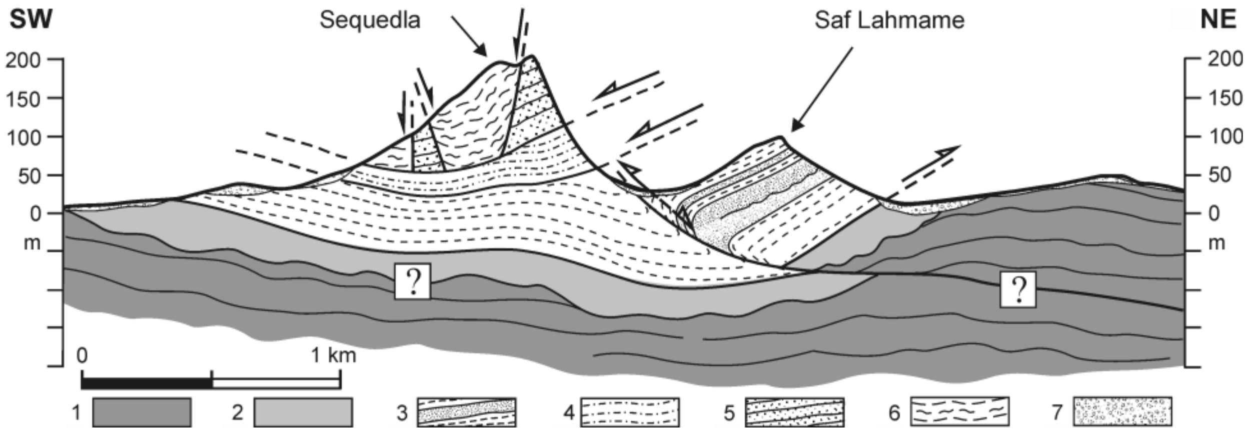

Fig. 2. Interpreted cross-section through Saf Lahmame–Sequedla area. **External Tanger Unit:** 1 — marls and marl-limestones with "yellowish limestone nodules" and mudrocks (Campanian–Maastrichtian), 2 — marls to black flint (Suessonian facies) (Upper Paleocene–Lower Eocene), 3 — marls and turbiditic sandstones (Middle Eocene–Middle Miocene). **Numidian Sequence:** 4 — brown mudrocks to rare *Tubotomaculum,* (Upper Oligocene), 5 — Numidian Flysch (Aquitanian), 6 — grey marls with sandstones to "countourites" facies (Burdigalian). **Quaternary to Recent deposits:** 7 — fluvial terraces and continental alluvial aprons.

classification has been performed according to the schemes suggested for deep water siliciclastic sediments by Lowe (1982), Pickering et al. (1989) and Mutti (1992).

Facies description

The section starts with whitish marls with flint, overlain by marls by a low-angle inverse fault slightly dipping NW (Figs. 1c, 2). The greyish-greenish marl deposits, about 150 m thick are ensued by a sandstone bed-key up to 13 m thick, formed by mainly meter- to decimeter-sized yellowish fine-grained sandstones first attributed to the Upper Oligocene-Lower Miocene boundary by Durand-Delga et al. (1985) (Figs. 1c, 2).

The vertical arrangement of the facies indicates a fining upward evolution (FTU; Fig. 3), where the main marly-arenaceous lithofacies recognized in this section, from the bottom to the top, are characterized by the three following stratigraphic intervals:

1 — The lower interval is represented by medium- to fine-grained and mainly normal graded sandstones ("classical turbidites" *sensu* Walker 1978), organized in amalgamated beds (5 m of total thickness) with partial Bouma sequences and with sole marks and fossil traces often occurring at their base. The internal structures of these sandstones show essentially base-missing Bouma sequences, defined by Allen (1984) as "base-cut-out sequences" (T_{b-e}, $T_{b-c/e}$). The sand/mud ratio decreases upward and the paleocurrent analysis indicates the northward (SE to NW and SW to NE) transport direction (mainly from SE to NW) which turns into south-eastwards flows (NW to SE) at the top of this section.

2 — The middle stratigraphic interval is represented by massive, structureless, flat-floored medium- to fine-grained sandstones and topped by some crude horizontal laminations (50 cm to 3 m thick) (locally with load structures) with a gritty and/or silty-clayey matrix. These latter display dish structures, centimeter- to decimeter-sized pipe and pillar structures in the middle and upper parts of their massive division. A slight normal grading and/or locally some successive erosive surges with reworked centimeter-sized mud clasts occur. Moreover, some decimeter-sized scour-and-fill structures (about 50 cm) are also present.

At the middle part of this interval, these sandstones (1) show locally clay chip and mud clast horizons, or (2) they are scoured by metric amalgamated turbiditic strata or by residual very fine-grained turbidites whose grain size abruptly decrease upwards.

3 — The upper stratigraphic interval is characterized by a fine-grained facies association (150 m thick), represented by 3 to 5 m thick bundles containing thin-bedded sandstones alternating with massive white-green marly-clayey strata. The thin-bedded sandstones are mainly fine- to very fine-grained, flat floored and sharp-topped, grading upward to silty-marly strata through fine-grained parallel laminations. These fine-grained sandstones are mostly base-missing with $T_{c/e}$ Bouma sequences with scarce small prod and flute casts.

Facies interpretation

The deposits of the lower stratigraphic interval, usually considered as products of unstable high density turbidity currents, are interpreted as equivalent to the C_2 and F_7–F_8–F_{9a} facies of Pickering et al. (1989) and Mutti (1992) respectively. Their paleoflow fluctuation could reflect multisource provenance within unsteady marginal areas of the tilted African paleomargin.

The deposits of the second stratigraphic interval are related to the evolution of a high density turbidity current (Mutti 1992), where massive structures are interpreted as the results of very quick deposition for freezing of a dense cohesionless suspension apparently lacking in post-depositional liquefaction/fluidization (Lowe 1982), under a highly concentrated flow (Middleton & Hampton 1976; Walker 1978; Lowe 1982; Mutti 1992). The occurrence of scouring and normal grading could be interpreted as turbulent imprint of turbidity current where quick packing of grains justifies the fluid escape (Lowe 1976; Pickering et al. 1989). The presence of clay chip and mud clast horizons within strata could indicate separate flow portions of different behaviour (Postma et al. 1988).

The massive sandstones, located within this interval, could be interpreted as products of sedimentation by continuous aggradations beneath high-density turbidity currents with sediment passing through an active basal layer of hindered settling involving grain-flow, fluidized-flow and liquefied-flow processes (Stow et al. 1994).

The restricted range of grain sizes requires input from a sand-dominated source and the apparent thickness of some beds results from amalgamation of several thinner beds. These deposits are interpreted as equivalent to the $B_{1.1}$ facies of Pickering et al. (1989) or to the $F_8/F_{8\text{-}9}/F_{7\text{-}8\text{-}9}$ facies of Mutti (1992).

The fine-grained lithofacies of the third stratigraphic interval are interpreted as due to slow accumulation of mud and biogenic materials (Stanley & Maldonado 1981; Thornthon 1984; Pickering et al. 1986). These facies represent the product of dilute and low concentration turbidity currents, thus corresponding to the D_2 group of facies of Pickering et al. (1989) and, also, to the T_0–T_8 divisions of Stow & Shanmugam (1980).

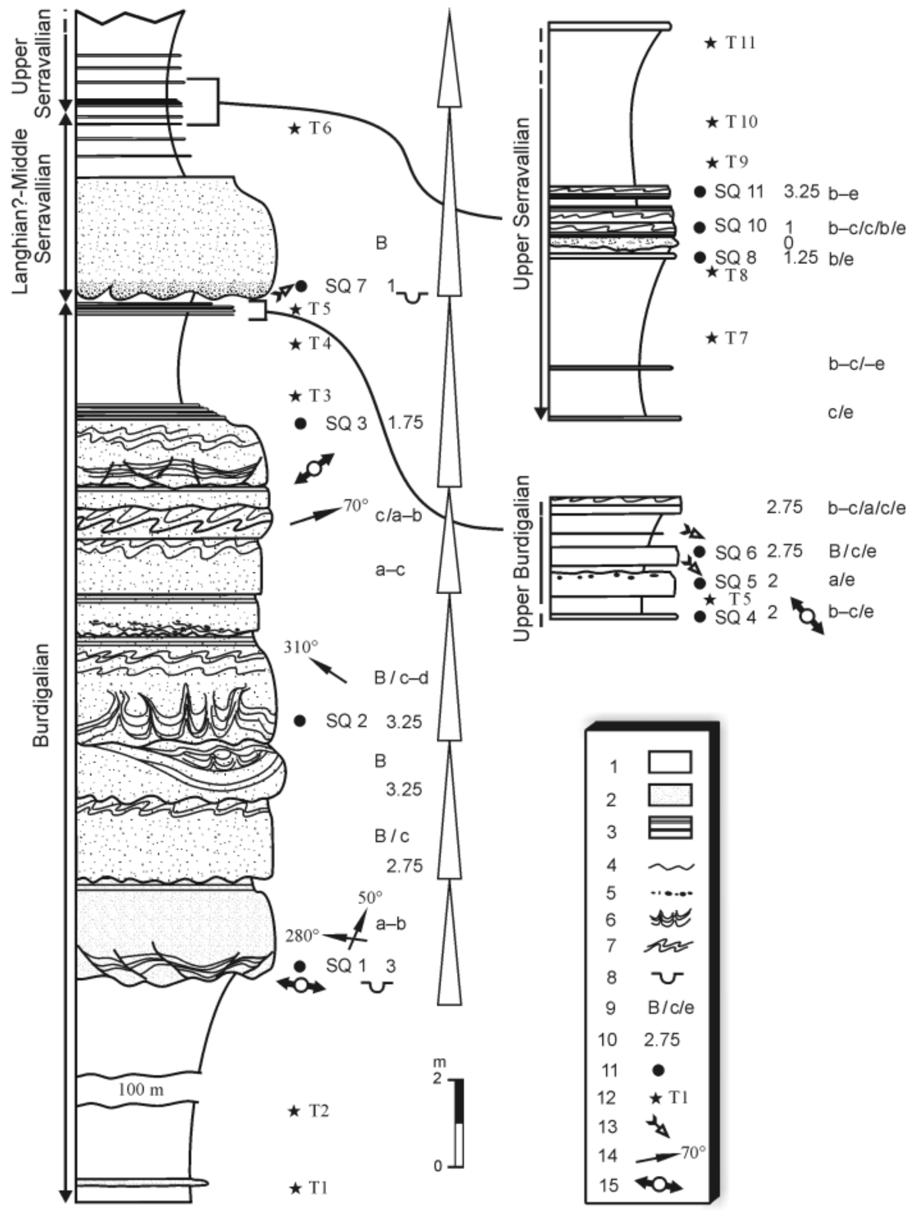

Fig. 3. Saf Lahmame stratigraphic section. **1** — grey pelites, **2** — thick-bedded turbidite sandstones, **3** — thin-bedded turbidites, **4** — erosional contact and scours, **5** — clay chips, **6** — dish and pillar structures, **7** — convolute laminations and slump, **8** — load casting, **9** — Bouma sequences, **10** — grain size in φ scale, **11** — location of sandstone samples, **12** — location of mudrock samples, **13** — paleocurrent directions, **14** — main paleoflow directions of slumps, **15** — direction of syn-sedimentary distension.

Petrography and provenance

Petrographic study of arenaceous samples from the studied succession has been carried out by means of modal point counting in thin section in order to recognize the gross composition and the textural characters of the grains and to detect the provenance. The modal analyses — first presented here — 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 the rock composition on grain size.

The detrital framework of the analysed rocks is characterized by the presence of an intrabasinal fraction represented by fossils (carbonate intrabasinal grains, **CI**) as well as by glauconite grains and opaque minerals (non-carbonate intrabasinal grains, **NCI**) together with a non-carbonate and carbonate extrabasinal fraction (**NCE** and **CE**, respectively; Table 1).

This classification (Zuffa 1980, 1985) is shown in the **NCE–NCI–CI** ternary plot (Fig. 4) representing one of the main triangles of the tetrahedral three-dimensional configuration suggested for the first-level classification of the arenites[1]. Thus, all analysed rocks fall in the "sandstone s.s." field showing more than 50 % of **NCE** grains. The **Q–F–L** ternary plot, instead, represents a second-level classification where the different types of sandstones are distinguished.

[1] The numbers within the brackets indicate the content of the **CE** fraction not represented in the diagram.

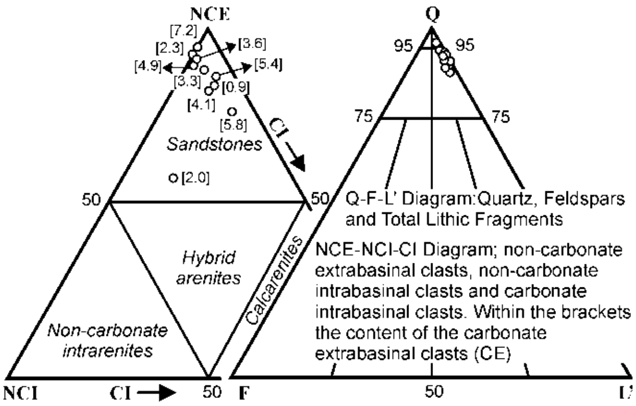

Fig. 4. Diagrams showing detrital modes of the analysed samples, according to Zuffa's.

The presence of carbonate and non-carbonate intrabasinal fractions is here supported by the following microscopic observations:

— the carbonate intrabasinal grains, locally abundant (max. 16.0 %) are mainly represented by fossils and, subordinately, by ooids and scarce peloids. The fossils, mainly planktonic foraminifers and rare bioclasts, are always present as well preserved single grains and do not occur within carbonate rock fragments. This can be surely related to a very short mechanical transport and testifies to their intrabasinal character;

— the non-carbonate intrabasinal population is mainly represented by glauconite grains (max. 25 %) and by very low contents of opaque minerals. Glauconite is usually supposed to be an authigenic mineral formed in a marine environment, under reducing to slightly oxidizing conditions on the continental shelf (Folk 1974; Pettijhon 1975; Odin 1985; Kelly & Webb 1999; Hesselbo & Huggett 2001). Glauconite particles are nearly always well rounded and very similar in grain size to other detrital clasts. Nevertheless, this roundness does not indicate a highly turbulent environment or prolonged transports, but it appears to be closely related to the stage of growth of the mineral (Odin 1985).

Table 1 lists the compositional parameters adopted for modal analysis of External Tanger Unit sandstones. According to Zuffa (1980, 1985) the non-carbonate and carbonate extrabasinal fractions have also been distinguished (**NCE** and **CE** in Table 1, respectively).

The first population is subdivided into three main compositional classes **Q**, **F** and **L** (Quartz, Feldspars and Lithic fragments) and it is the most abundant, whereas the second one (**CE**) is exclusively represented by rare carbonate rock fragments (max. 6.5 %).

Quartz is the most abundant mineral within the non-carbonate extrabasinal fraction (88.7 % to 97.1 %; **Q–F–L** ternary plot, Table 1 and Fig. 4); so, the analysed rocks can be referred to sublitharenite/quartzarenite groups (*sensu* Folk 1974). Accordingly to Basu et al. (1975) and Basu (1985), two different types of detrital quartz have been distinguished: 1 — the monocrystalline quartz grains, subdivided into varieties of low and high undulosity (i.e. ≤5° or >5° apparent angle of extinction) and 2 — the polycrystalline quartz grains, with few or many subgrains (≤ 4 or > 4).

The quartz of the analysed rocks is largely represented by monocrystalline grains. The polycrystallinity quartz varieties, being less stable, strongly point to selectively destruction by mechanical factors during prolonged transports as well as during successive sedimentary cycles (Blatt & Christie 1963; Connolly 1965; Basu 1985). Thus, the abundance of monocrystalline quartz grains, mainly characterized by low rather than high undulatory extinction, can also suggest its polycyclic origin.

Good sorting of the clasts together with moderate to high roundness of detrital quartz grains seem to confirm this hypothesis, as emphasized by Suttner et al. (1981) for the bulk of ancient quartzarenites.

Feldspars are very rare and exclusively represented by plagioclase in single grains. Few lithic clasts are present, mainly consisting of fine-grained sedimentary rock fragments (< 0 .06 mm) as non-carbonate quartzose siltites.

The non-carbonate extrabasinal fraction also includes low, but important, percentages of ultra-stable heavy minerals (zircon, tourmaline and rutile), thus confirming the high compositional maturity of the analysed rocks.

Interstitial components are mainly represented by carbonate cement and by very low amounts of siliciclastic matrix. Locally, silica cement is also present as concretionary quartz overgrowths bordering, in optical and crystallographic continuity, the ghost outline of the original detrital quartz grains.

Biostratigraphy

Techniques and methods

The biostratigraphical study was performed on calcareous nannofossils present in 11 samples collected from the Saf Lahmame section.

The samples were prepared following the "**C**" procedure of de Capoa et al. (2003) and Eshet (1996) and nannofossils have been observed by an optical microscope at 1250× magnification. The biostratigraphic analysis is based exclusively on the first occurrences (FO), allowing an evaluation of ages as *"not older than ..."* (de Capoa et al. 2000, 2003).

The studied thin sections of the arenites of the External Tanger Unit contained mainly well preserved planktonic foraminifers, filled with a brown matrix. Well preserved radiolaria are also present (SQ7 sample on Fig. 3).

Neogene biostratigraphic schemes for the Mediterranean region of Martini (1971), Okada & Burky (1980), Berggren et al. (1985, 1995), Perch-Nielsen (1985a,b), Varol (1989, 1999), Cande & Kent (1992), Fornaciari & Rio (1996) have been applied.

Planktonic foraminifers

The good preservation of foraminifers and radiolaria indicates that the faunal association is probably in situ and did not suffer significant transportation. The planktonic foraminiferal assemblage consists of globigerinids, *Globigerinoides*

Table 1: Modal point counts of the External Tanger Unit arenites.

			SQ 1	SQ 2	SQ 3	SQ 4	SQ 5	SQ 6	SQ 7	SQ 8	SQ 10	SQ 11	x	σ
NCE	Q	Q_m’	55.1	46.0	47.8	49.7	47.9	55.1	50.9	34.1	41.3	55.3		
		Q_m’’	17.4	23.4	17.9	18.2	18.3	17.5	13.0	11.4	11.8	13.2		
		Q_p’	0.2	1.7	0.8	1.5	0.5	1.6	2.1	2.5	2.2	0.9		
		Q_p’’	1.0	2.7	4.0	4.0	2.8	2.4	2.6	2.0	2.8	2.2		
		Ch	1.0	1.2	0.3	2.3	0.5	3.6	1.0	0.4	3.6	3.0		
	F	Ps	0.5	0.7	–	–	0.2	0.4	–	0.2	0.6	0.3		
	L	Ls	3.2	2.4	1.9	2.5	2.1	2.8	2.1	1.9	1.7	1.1		
		Ms	0.2	–	–	0.4	–	–	–	–	–	0.3		
		Al	1.7	1.9	0.8	1.5	3.2	5.6	2.1	0.6	1.1	2.2		
CE		Lc	4.5	6.5	4.8	3.2	3.9	2.2	2.9	1.8	5.2	0.8		
NCI		Gl	4.1	3.1	3.4	4.0	7.8	3.6	4.5	25.8	4.3	5.9		
		O. M.	1.5	1.0	0.6	1.1	0.5	0.7	0.8	1.0	0.7	0.3		
CI		Fo	0.5	–	7.0	0.4	6.5	–	4.8	10.1	14.3	7.0		
		Mt	0.5	–	–	–	0.3	–	0.8	–	0.9	–		
		Cm	8.6	9.4	10.7	11.2	5.5	4.5	12.4	8.2	9.5	7.5		
			100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	
		NCE	88.5	88.3	82.3	90.2	80.2	93.2	85.1	57.8	72.6	84.8		
		CE	4.9	7.2	5.4	3.6	4.1	2.3	3.3	2.0	5.8	0.9		
		NCI	6.1	4.5	4.5	5.7	8.8	4.5	6.1	29.2	5.6	6.7		
		CI	0.5	–	7.8	0.5	6.9	–	5.5	11.0	16.0	7.6		
			100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	
		Q	90.1	88.7	91.0	93.0	91.9	93.7	93.3	92.8	89.1	97.1		
		F	0.6	0.8	–	–	0.2	0.5	–	0.4	0.9	0.4		
		L’	9.3	10.5	8.6	7.0	7.9	5.8	6.7	6.8	10.0	2.5		
			100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	

Symbols of the parameters adopted for the modal analysis

(1) **NCE** = non-carbonate extrabasinal clasts including **Q**, **F** and **L**, where:
Q = total quartzose grains subdivided into:
Q_m = monocrystalline quartzose grains with low and high undulosity (<5° and >5°, Q_m’ and Q_m’’, respectively),
Q_p = polycrystalline quartzose grains with few or many subgrains (≤4 and >4 crystalline units per grain, Q_p’and Q_p’’, respectively), and
Ch = chert;
F = total feldspar grains, here exclusively represented by single grains of plagioclase (**Ps**);
L = unstable lithic clasts here exclusively represented by fine-grained sedimentary rock fragments (<0.06 mm, **Ls**);
M = micas and/or chlorites in single grains (**Ms**);
Al = other mineral grains, mainly represented by ultrastable heavy minerals as zircon, tourmaline and rutile.
(2) **CE** = carbonate extrabasinal clasts consisting of low contents of micritic limestones and of fine-grained detrital limestones (**Lc**).
(3) **NCI** = non-carbonate intrabasinal clasts including:
Gl = glauconite grains and
O.M. = opaque minerals.
(4) **CI** = carbonate intrabasinal clasts, represented by few amounts of oolithic clasts and by a locally abundant content of fossils (**Fo**).
Mt = siliciclastic matrix, **Cm** = carbonate cement and **L’** = total rock fragments, carbonate and non-carbonate extrabasinal lithic clasts (i.e. **Lc**+**Ls**).

sp. and *Orbulina* sp. The presence of the genus *Orbulina*, first occurrence of which is dated to the Late Langhian–Early Serravallian, attributes an age not older than Middle Miocene to the analysed samples. Among benthic foraminiferal specimens of the Rotaliina and Textulariina suborders are present. Rotaliina have shells made of low-magnesian calcite and dominate bathyal environments, while Textulariina have shells made of agglutinated sand and silt grains and are most abundant and diverse in neritic environments and at great abyssal depth below the calcite compensation depth. Consequently, the planktonic and benthic foraminiferal association is indicative of a basinal environment.

Nannoplankton assemblage

All samples of the Saf Lahmame section are productive. However, the marker species have been recognized only in 5 samples, in spite of the applied concentration methods. Most of the specimens are affected by dissolution and are poorly preserved.

The lower part of the Neogene succession of Saf Lahmame section starts with green marls with *Sphenolithus belemnos* as a marker taxon associated with a nannoplankton assemblage with *Coccolithus pelagicus, Cyclicargolithus floridanus, Discoaster deflandrei* (sample T1; Table 2 and Fig. 5). The first

Table 2: Biostratigraphic results of nannoplankton assemblages of the Neogene of the Saf Lahmame section (External Tanger Unit).

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Bianthalithus sparsus									□		
Calcidiscus macintyrei						★					
Coccolithus pelagicus	■	■	■	■	■	■	■	■	■	■	■
Coronocyclus nitescens								■			
Cyclicargolithus abisectus		■					□		□		□
Cyclicargolithus floridanus	■		■			■			□	□	
Discoaster barbadiensis									□		
Discoaster cf. *variabilis*		★									
Discoaster deflandrei	■	■		■	■	■	■	■	■	■	■
Discoaster kugleri							★		★		
Discoaster musicus					★				□	□	
Discoaster ornatus						□					
Discoaster sp.						■					
Discoaster tani					□	□			□		
Discoaster variabilis					★	■					■
Ericsonia cava										■	
Helicosphaera carteri		■					■		■		
Helicosphaera cf. *intermedia*											□
Helicosphaera cf. *stalis*									■		
Helicosphaera euphratis									□	□	
Helicosphaera mediterranea										□	
Micula concava							□				□
Nannotetrina quadrata									□	□	
Pontosphaera multipora							■		■		
Prediscosphaera cretacea				□							
Quadrum gartneri											□
Reticulofenestra bisecta								□			□
Reticulofenestra daviesi										■	
Reticulofenestra gartneri							■		■		
Reticulofenestra hillae				□	□						
Reticulofenestra minuta						■			■	■	
Reticulofenestra minutula									■		■
Reticulofenestra perplexa		■		■		■	■	■	■	■	■
Reticulofenestra pseudoumbilicus >7 µm						★	■		■	■	
Reticulofenestra reticulata		■									
Reticulofenestra umbilicus					□				□	□	
Sphenolithus abies							■	■	■	■	
Sphenolithus belemnos	★										
Sphenolithus ciperoensis							□				
Sphenolithus delphix									□		
Sphenolithus dissimilis									□		□
Sphenolithus moriformis		■			■						
Sphenolithus radians									□		
Tribrachiatus orthostylus									□		
Triquetrorhabdulus carinatus		■				□					
Umbilicosphaera rotula											■
Watznaueria barnesae		□					□			□	□
Zygrhablithus bijugatus										□	
★ Markers ■ Occurrence □ Reworked											

occurrence of *Sphenolithus belemnos* (Fig. 5) is in the Zone **NN2**$_{top}$ of Martini (1971), equivalent to the Zone **CN2**$_{base}$ of Okada & Bukry (1980) and **MNN3a** of Fornaciari & Rio (1996) thus indicating an age not older than Early Burdigalian. *Discoaster* cf. *variabilis* occurs within sample T2 and could probably indicate an age not older than Late Burdigalian.

Samples from middle part of the section (T3 and T4) are characterized by a common occurrence of a nannoplankton assemblage with *Coccolithus pelagicus, Discoaster deflandrei*, *Reticulofenestra perplexa* (Table 2). Within T5 sample *Coccolithus pelagicus, Discoaster deflandrei, Sphenolithus moriformis* associated with *D. musicus,* and *D. variabilis* occur as marker taxa (Fig. 5). The first occurrence of the last taxa is in the Zone **NN4** of Martini (1971), equivalent to the Zone **CN3** of Okada & Burky (1980), thus indicating an age not older than Late Burdigalian.

The base of the higher part of this section (T6, sample) is characterized by the occurrence of *Coccolithus pelagicus,*

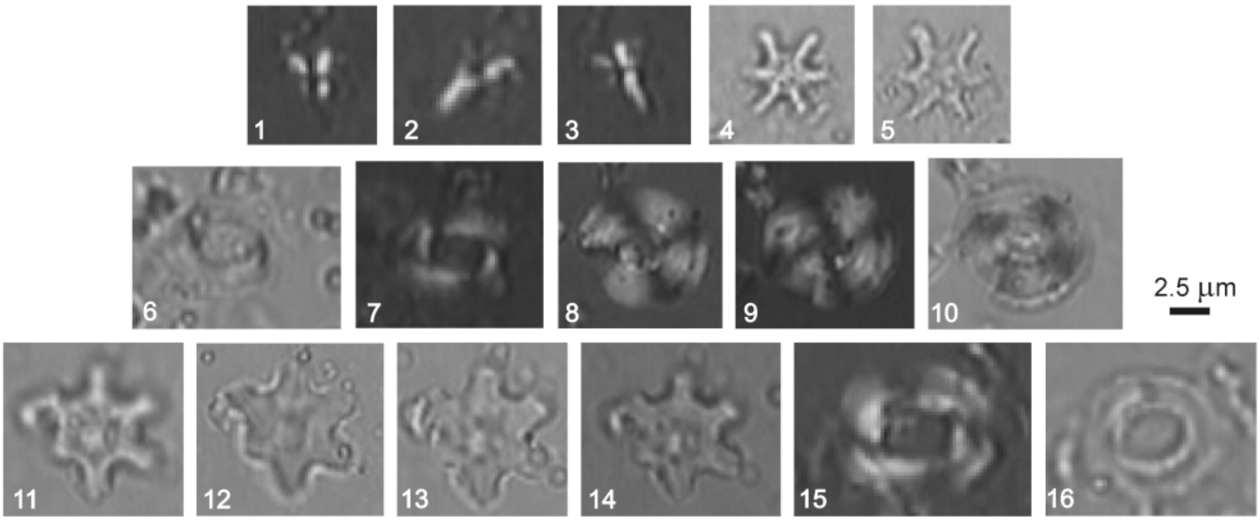

Fig. 5. Calcareous nannofossils microphotographs from the Saf Lahmame Section (External Tanger Unit). **1–3** — *Sphenolithus belemnos* (sample **T1**, nicols X); **4, 5** — *Discoaster musicus* (sample **T5**, phase contrast); **6, 7** — *Reticulofenestra pseudoumbilicus* (>7 μm) (sample **T6**, nicols X); **8–10** — *Calcidiscus macintyrei* (sample **T6**, nicols X); **11–14** — *Discoaster kugleri* (sample **T7**; phase contrast); **15, 16** — *Reticulofenestra pseudoumbilicus* (>7 μm) (sample **T9**, nicols X and phase contrast).

Cyclicargolithus floridanus, Discoaster deflandrei, D. variabilis, D. sp., *Reticulofenestra minuta, R. perplexa* (Table 2) and the first occurrence of *Calcidiscus macintyrei, R. pseudoumbilicus* (>7 μm) (Table 2 and Fig. 5), representative of the **NN6** Zone of Martini (1971), equivalent to the **CN5a** Zone of Okada & Bukry (1980) and to the **MNN6** Zone of Fornaciari & Rio (1996). Thus, an age not older than Middle Serravallian can be inferred for the base of the uppermost levels of the section.

The higher up levels (T7, T8, T9, T10, T11 samples) are characterized by a common occurrence of *Coccolithus pelagicus, Coronocyclus nitescens, Discoaster deflandrei, D. variabilis, Ericsonia cava, Helicosphaera carteri, H.* cf. *stalis, Pontosphaera multipora, Reticulofenestra daviesi, R. gartneri, R. minuta, R. minutula, R. perplexa, R. pseudoumbilicus* (>7 μm), *Sphenolithus abies, Umbilicosphaera rotula.* The first occurrence of *Discoaster kugleri* (samples T7, T9; Table 2 and Fig. 5), is representative of the **NN7** Zone of Martini (1971), equivalent to the **CN5b** Zone of Okada & Bukry (1980). It is indicative of an age not older than Late Serravallian for the uppermost levels of this section.

New biostratigraphic data inferred from both nannofossils and planktonic foraminiferal assemblages indicate that the lower part of the studied section is not older than Early Burdigalian. The topmost strata according to nannofossils and foraminiferal associations are not older than Serravallian. This age is considerably younger than the Late Oligocene–Aquitanian age first dated by Durand-Delga et al. (1985).

Discussion and geodynamic context

The Neogene geodynamic evolution of the External Tanger Unit succession could be reconstructed by means of new biostratigraphic and petrographic results described in this paper together with the recent data available in literature.

Firstly, it is important to underline that the Intra-Rif sub-Domain, regrouping both the Tanger and Ketama Units, mainly formed by Mesozoic-Tertiary successions, is locally well marked by a Paleogene sedimentation hiatus in the Internal Tanger Unit (Lespinasse 1975) and by the presence of Lower Miocene conglomerates unconformably overlying the Jurassic-Neocomian successions located in the more external areas of the Ketama Unit and belonging to the Meso-Rif Units (Tiflouest area, south of the Ketama Unit; Favre 1992).

The above mentioned unconformity could highlight the occurrence of a pre-Miocene tectonic event, which also seems to be recorded within the Internal Tanger Unit, by a Paleogene sedimentation hiatus, while the sedimentation is continuous synchronously up to the Serravallian within the External Tanger Unit.

This Paleogene hiatus and the unconformities occurring within the External Domain could be interpreted as the result of the onset of the Maghrebian subduction, where the African paleomargin and the related thinned and partially "oceanic" crust (Michard et al. 1992; Zaghloul et al. 2003) start to be subducted beneath the southern-occidental ending of the "Mesomediterranean Terrane" microplate mainly during the Late Oligocene (Chalouan & Michard 2004 and bibliography therein).

Later, during the Neogene, the paroxysmal deformation phase responsible for the closure of the Flysch Basin and for the thrusting of the flysch nappes onto the External Domain mainly occurred during the Late Burdigalian and Langhian p.p. (Zaghloul 2002; Zaghloul et al. 2004). This main compressive phase is post-dated by the Middle Miocene "post-nappes" Beni Issef Formation (quartzarenites and marls with resedimented cobbles and boulders deriving from flysch nappes), stratigraphically resting on the

Intra-Rif Units (Tanger and Loukkous Units) at the edge of the Basin Flysch accretionary prism (Durand-Delga & Lespinasse 1965; Didon & Feinberg 1979).

Successively, the Neogene deformation reaches the Intra-Rif and Meso-Rif sub-Domains, whose Lower-Middle Miocene syn-tectonic deposits have been progressively involved within the mainly westwards and southwestwards thrusting since the Late Serravallian (BenYaich et al. 1988; BenYaich 1991; Tejera de Leon 1993; Favre 1995; Chalouan et al. 2001; Tejera de Leon & Duée 2003).

The most external area of the External Domain plays the role of proto-Rif foredeep of the former accretionary proto-Rif prism structured from the Late Burdigalian up to the Early–Middle Tortonian. This compressive event is post-dated by the occurrence of the Upper Tortonian "post-nappes" deposits unconformably lying on the Intra-Rif, Meso-Rif and Pre-Rif Units (Mediouni & Wernli 1978; Feinberg 1986; Kerzazi 1994).

Concluding remarks

The Neogene siliciclastic succession of the External Tanger Unit, ranging in age from Early Burdigalian to Late Serravallian, displays a depositional trend suggesting a general upward increase of sedimentary influx into a subsiding area.

Sedimentological features of the arenites of the analysed section reflect a continual deposition by aggradational processes, from high-density turbidity currents. In contrast, the fine-grained lithofacies (massive white-green marly-clayey beds and thin-bedded arenites) reflect slow accumulation of mud and biogenic materials by diluted and low concentration turbidity currents.

The paleocurrents indicate transport directions mainly towards the NW and, subordinately, to the SE. This fluctuation could reflect a multisource provenance from unstable marginal areas of the tilted African margin.

The petrographic characters of the arenites permit to refer their composition to the sublitharenite/quartzarenite groups with the omnipresent occurrence of glauconite grains.

Even if glauconite is not a precise indicator of depth because its occurrence has also been recognized at more than 800 m of depth (Porrenga 1967; Odin & Matter 1981; Odin 1985), it is always associated, in the analysed arenites, with planktonic foraminifers. This testifies to the deep water origin of the glauconite.

These data allow us to suppose that the studied Neogene strata of the External Tanger Unit have been deposited on the African continental shelf probably in the middle and lower bathyal zones.

The provenance of this siliciclastic material seems to be exclusively related to the African Craton. This hypothesis, is supported by the dominant occurrence of well rounded monocrystalline quartz grains and by the presence of low, but important, percentages of ultra-stable heavy minerals (zircon, tourmaline and rutile), both testifying to long selective mechanical transports due to successive sedimentary cycles.

Furthermore, the petrographic characters and compositions of the analysed arenites are very similar to those observed within Numidian and Numidian-like sandstones of the Betic and Apenninic-Maghrebian Chains (Chiocchini et al. 1978; Pendon 1978; Loiacono et al. 1983; Ardito et al. 1985; Cazzola & Critelli 1986–87; Carbone et al. 1990; Moretti et al. 1991; Guerrera et al. 1992).

Finally, the Burdigalian and Langhian-Serravallian strata belonging to the Neogene succession of the External Tanger Unit have been involved in the westward thrusting carrying the Flysch Basin nappes and the internal part of the External Domain onto the more external part of the latter.

Acknowledgments: Financial support was provided by the Italian MURST and by the U.F.R. "Géologie Méditerranéenne" as grants to D. Puglisi (University of Catania, Italy) and to M.N. Zaghloul (Université AbdelMalek Essaadi of Tétouan, Morocco), respectively. We thank J.J. Cornée (University of Lyon I), D. Frizon de Lamotte (University of Cergy-Pontoise), the responsible editor of Geologica Carpathica T. Peryt (Geological Institute of Warszawa, Poland) and an anonymous Referee for their careful revision of the manuscript. Authors are also grateful to V. Perrone (University of Urbino, Italy) and to Stuart J. Jones (University of Durham, U.K.) for the careful discussions and comments and for the revision of the English text of this paper.

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