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Oligocene-Miocene sandstone suites from the Gibraltar and Calabria-Peloritani Arcs: provenance changes and paleogeographic implications

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Abstract: Oligocene-Miocene turbiditic flows which formed thick sedimentary successions cropping out in the internal sectors of the Betic-Maghrebian Chain, Tell and Calabria-Peloritani Arc, are commonly related to the dismantling of pre-Alpine crystalline basements. These are now included in different tectonic edifices along the central-western peri-Mediterranean Alpine Chain but originally they could have belonged to the same crustal block, known as the AlKaPeCa Block (Al = Alboran, southern Spain and northern Morocco, Ka = Kabylian, Algeria, and PeCa = Calabria-Peloritani Arc). Detrital modes from Oligocene-Miocene late-orogenic sandstone suites, unconformably overlying the uppermost structural units of the Betic-Rifian Chain and the Rifian "Dorsale Calcaire" Units, show a provenance closely related to source areas mainly formed by Mesozoic carbonate sedimentary covers and, partially, by very slightly metamorphic rocks. In contrast, sandstones of equivalent late-orogenic successions from the Calabria-Peloritani Arc appear to be mainly derived by the erosion of high rank metamorphic and plutonic sources, which can be identified with the Hercynian basement rocks, now forming the highest structural units of the Arc. This bimodality of provenance (carbonate covers with, partially, epimetamorphic sources against a mainly plutonic and/or gneissic supply in the Gibraltar and Calabria-Peloritani Arcs, respectively) occurring between coeval late-orogenic sandstone suites, equivalent for age, geological significance and structural position, can be justified by admitting that the Internal Domains, which played a role as sediment sources, did not belong to the same crustal block or they were already separated as the consequence of an incipient break-out and fragmentation of the AlKaPeCa Block before the Late Oligocene (age of the base of the studied late-orogenic deposits).

Key words: Oligocene–Miocene, Betic-Rifian Chain, Calabria-Peloritani Arc, paleogeography, provenance, sedimentary petrography, turbidite sandstone suites.

Introduction, geological setting and objectives

The internal zones of the Betic-Rifian Chain (Fig. 1) are characterized by the superimposition of several basement nappes, belonging to the Alboran terranes (Chalouan et al. 2001; Michard et al. 2002) and commonly re-grouped, from the bottom to the top, into the Nevado-Filabrides Units (not present in the Rif), Ghomaride/Malaguide, Sebtide/Alpujarride Units (Morocco/Spain, respectively) and "Dorsale Calcaire" Units (so-called in the Rifian Chain from the French geological literature after Fallot 1937), which were located in a distinct domain extending south of the Ghomaride/Malaguide Realm (Wildi 1983; Serrano et al. 2006).

The highest tectonic units (Ghomaride/Malaguide Nappes; Figs. 2 and 3) mainly consist of very slightly metamorphic Paleozoic successions subdivided, in the Rifian Chain, into minor thrust sheets unconformably covered by Mesozoic-Tertiary sedimentary deposits (Chalouan 1986; Chalouan & Michard 1990).

The Mesozoic sedimentary formations are composed of Triassic reddish quartzose sandstones and conglomerates and Upper Triassic dolomites and Liassic limestones, related to the Tethyan rifting. The younger deposits (Late Eocene Nummulitic limestones and carbonate conglomerates) are collected in a detrital marine sequence post-dating an early Alpine compressive event (Maate 1996; Martin-Algarra et al. 2000).

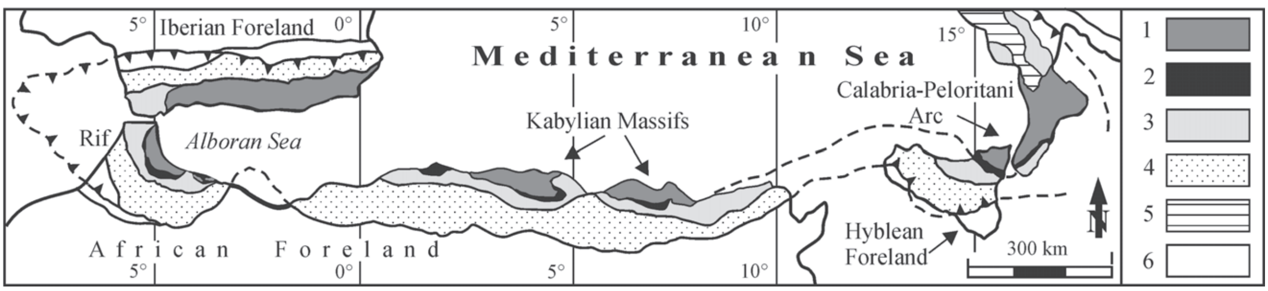


Fig. 1. Sketch map of the Alpine chains in the central-western Mediterranean region. **1** — Internal Domain Units; **2** — "Dorsale Calcaire" Units; **3** — Flysch Domain Units; **4** — Betic and Maghrebian External Units; **5** — Apenninic External Units; **6** — Foredeep and Foreland.

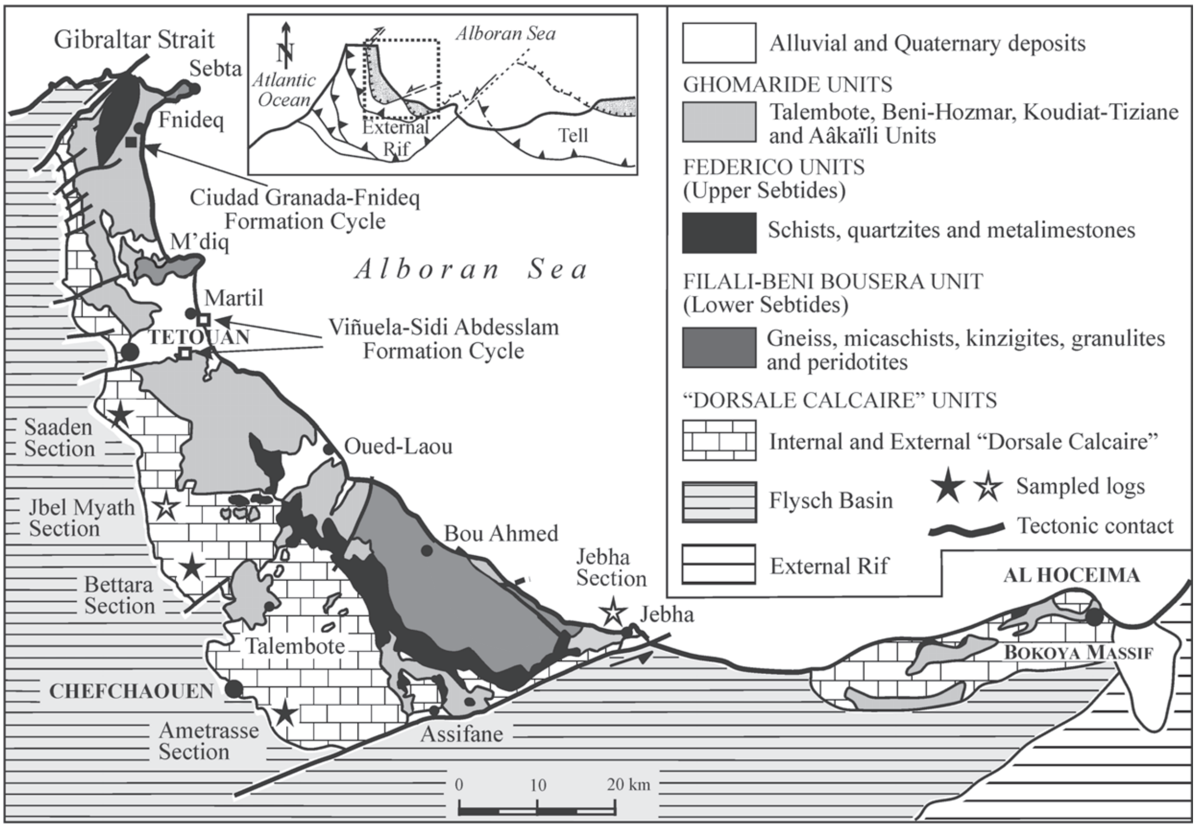
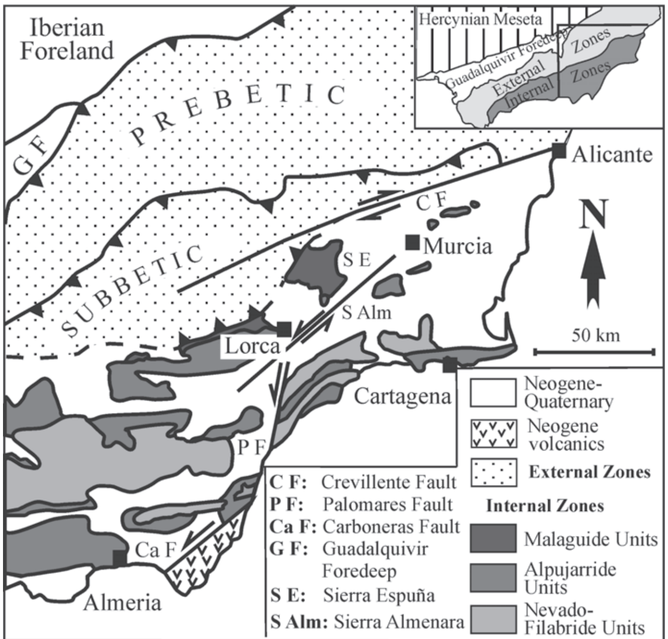


Fig. 2. Geological sketch map of the Internal Zones of the Rifian Chain (after Suter 1980; Chalouan 1986 and Chalouan & Michard 1990). Black and white asterisks = External and Internal "Dorsale Calcaire Units" (Saaden, Bettara, Ametrasse Sections and Jbel Myath, Jebha Sections, respectively); black and white squares = Ciudad Granada-Fnideq Formation Cycle and Viñuela-Sidi Abdesslam Formation Cycle (Fnideq and Sidi Abdesslam Formations, respectively).



The sampled outcrops of the Ciudad Granada-Fnideq Formation Cycle (Rio Pliego Fm) and Viñuela-Sidi Abdesslam Formation Cycle (El Niño Fm) are located in the Sierra Espuña area.

Fig. 3. Geological sketch map of the eastern Betic Cordillera (after Lonergan 1991, modified).

The "Dorsale Calcaire" Units also represent remnants of a Mesozoic carbonate cover, made up of a Jurassic-Cretaceous carbonate platform evolving into terrigenous deposits during Eocene–Oligocene times (Wildi 1983). These "Dorsale Calcaire" Units, in fact, have been regarded as a lateral equivalent of the Mesozoic-Cenozoic cover of the Ghomaride Units (Wildi 1983; Maate 1996, with references therein), detached from the uppermost Sebtide Units and piled up in front of the Ghomaride realm. These units have been subdivided into External and Internal "Dorsale Calcaire" Units by Nold et al. (1981) and Olivier (1984) on the basis of the different sedimentary facies related to deep-sea and platform successions of external and internal sectors, respectively.

In the Rif, some of the Ghomaride Units, as well as the "Dorsale Calcaire" Units, are unconformably overlain and sealed by Oligocene-Miocene successions (Durand-Delga & Fontboté 1980; Feinberg et al. 1990; Maate et al. 1995), organized in sandstone suites with arenaceous, pelitic and thick conglomeratic lithofacies (Zaghloul et al. 2003).

These terrigenous deposits are well known in the Rif, in the Betic Cordillera and in the internal domains of the easternmost Maghrebian Chain (Kabylides and Calabria-Peloritani Arc sectors). They have been formally subdivided into the following two sedimentary cycles (Chalouan 1987; Martin-Algarra 1987; Maate 1996; Martin-Algarra et

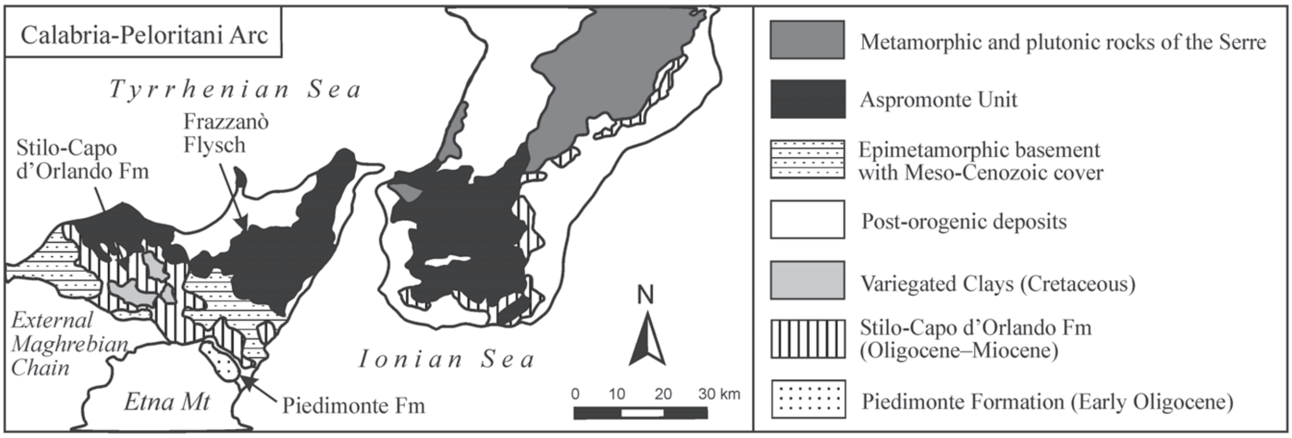


Fig. 4. Geological sketch map of the Calabria-Peloritani Arc showing the outcrops of the Oligocene-Miocene sandstone suites compared in this paper.

al. 2000; Serrano et al. 2006, 2007): the Ciudad Granada-Fnideq Formation Cycle (Upper Oligocene-Early Miocene boundary) and Viñuela-Sidi Abdesslam Formation Cycle (mainly Lower Burdigalian).

Puglisi et al. (2001) first recognized the possibility of the comparison with the syn- and late-orogenic flysch deposits marking the younger successions involved in the deformations of the basement nappes and the oldest ones unconformably overlying the Calabria-Peloritani tectonic edifice, respectively (Fig. 4).

The Viñuela-Sidi Abdesslam Formation Cycle, in particular, is well known all along the Maghrebian Chain where it can be compared with the tectonic-sedimentary evolution of the internal domains of the Kabylian massifs ("Oligo-Miocène Kabyle", Géry et al. 1981 and references therein). Similarly, the Stilo-Capo d'Orlando Formation (Puglisi 1998 and references therein) represents the tectonic-sedimentary evolution of the Calabria-Peloritani Arc.

Thus, the aim of this paper is to discuss the recently collected petrographic data from these Oligocene-Miocene turbiditic successions of the Betic-Rifian Chain and to compare them with those of equivalent sedimentary successions from the Calabria-Peloritani Arc. The petrographic characters of these sandstones and their provenance are discussed and interpreted here in order to debate the paleogeographic context of the Internal Domains, supposed to be the sediment sources of the analysed arenaceous successions.

Furthermore, the paleogeographic evolution of these areas is detected here and 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 (Cherchi & Montandert 1982; Rehault et al. 1984, 1985; Dercourt et al. 1986; Boccaletti et al. 1990).

Detrital modes of sandstones and related provenance changes

The sandstones of the Ciudad Granada-Fnideq Formation Cycle come from the Betic Cordillera (Rio Pliego Formation Auct.; Guerrera et al. 1997; Gigliuto 2005) and from the Rif (Fnideq Formation; Puglisi et al. 2001; Zaghloul et al. 2003).

The sandstones of the Viñuela-Sidi Abdesslam Formation Cycle were sampled in the Betic Cordillera (El Niño Formation Auct.; Gigliuto 2005) and in the Rif (Sidi Abdesslam Formation; Puglisi et al. 2001; Zaghloul et al. 2003).

Table 1 lists the means and standard deviations of the detrital modes of Oligocene-Miocene sandstones collected from several logs sampled in the internal sectors of the Betic-Rifian Chain (Figs. 2 and 3) and from coeval and equivalent turbidite successions of the Calabria-Peloritani Arc (Fig. 4).

Modal data from all the sandstones have been acquired using the same methodology, consisting of modal point counting in thin section, 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.

Table 1 also includes the **Qm**, **F** and **Lt** parameters (Monocrystalline Quartz, Feldspars and Total Lithic Fragments, respectively), suggested by Graham et al. (1976) and by Dickinson & Suczek (1979) as a means of recognizing the provenance of the clastic supply.

Quartz is nearly always present and, locally, it is the most abundant mineral. Thus, in order to appreciate the contribution of different lithologies of the sources areas, the detrital quartz has been distinguished in monocrystalline and polycrystalline quartz grains (Table 1), the first ones representative of coarse-grained plutonic and/or high rank metamorphic rocks, whereas the second ones are supposed to be derived mainly from fine-grained epimetamorphites.

High contents of feldspars are present only in the late-orogenic Oligocene-Miocene sandstone suites of the Calabria-Peloritani Arc. In fact, all the sandstones of equivalent successions of the Betic-Rifian Chain are almost completely devoid of feldspars (Figs. 5 and 6) or, if present, they never exceed 4.0–4.5 %. In particular, feldspars are practically absent in the sandstones of the Internal and External "Dorsale Calcaire".

Scarcity or lack of feldspars is balanced by a relative abundance of lithic fragments, mainly represented by (**a**) an al-

Table 1: Comparison between the detrital modes of the Oligocene-Miocene sandstones suites from the internal domains of the Betic, Rifian and Sicilian Maghrebian Chains.

	Lower Cycle								**Upper Cycle**									
	Ciudad Granada-Fnideq Formation Cycle				**Lower Oligocene turbidites of the Calabria-Peloritani Arc**				**Viñuela-Sidi Abdesslam Formation Cycle**				**Oligocene-Miocene covers of the Rifian "Dorsale Calcaire"**				**Calabria-Peloritani Arc: Stilo-Capo d'Orlando Formation[8]**	
	Upper Oligocene/Lower Miocene boundary				**Lower Oligocene**				**Lower Miocene (Aquitanian-Burdigalian)**				**Upper Oligocene to the Lower Miocene (Aquitanian)**				**Upper Oligocene-Lower Miocene**	
	Rif[1]		**Betic Cordillera[2]**		**Piedimonte Formation[3]**		**Frazzanò Flysch[4]**		**Rif[1]**		**Betic Cordillera[5]**		**Internal "Dorsale Calcaire"[6]**		**External "Dorsale Calcaire"[7]**			
	x	s	**x**	s	**x**	s	**x**	s	**x**	s	**x**	s	**x**	s	**x**	s	**x**	s
Q_m	21.3	3.10	12.7	1.70	28.3	4.51	36.4	7.33	25.4	3.15	24.5	2.71	22.7	3.14	29.1	3.34	32.2	5.40
Q_p	15.8	0.98	16.9	0.75	6.2	2.16	11.5	4.21	8.1	3.40	17.4	2.12	10.2	2.25	13.6	1.43	5.5	3.82
Qr	4.4	1.23	0.1	0.26	4.4	2.82	5.6	3.44	3.7	0.85	0.2	0.37	-		0.2	0.22	3.8	2.75
Ch	1.2	1.01	1.0	0.96	0.3	0.38	0.5	0.43	0.5	0.75	0.9	0.78	2.5	1.04	5.4	1.68	0.2	0.33
Ps	1.2	0.66	3.3	1.19	9.1	2.30	12.2	5.81	3.8	1.94	3.7	1.07	0.2	1.04	1.0	0.49	14.7	4.31
Pr	0.2	0.39	-		2.8	1.15	1.4	1.78	0.4	0.54	0.1	0.17	-		-		3.8	1.15
Ks	0.2	0.41	-		1.7	3.21	3.2	2.17	1.2	1.07	0.2	0.25	-		-		8.5	2.28
Kr	0.1	0.26	-		0.5	0.41	0.5	1.09	0.5	0.67	-		-		-		2.8	0.75
Lv	2.7	1.76	0.2	0.33	0.1	0.16	0.3	0.28	0.4	0.66	0.4	0.40	-		-		0.1	0.15
Lc	10.0	4.92	20.0	3.04	7.4	6.82	3.1	5.26	7.2	3.30	16.8	4.15	53.7	4.91	19.6	4.92	0.3	0.51
Ls	-		4.4	2.97	-		-		-		0.6	0.93	0.7	0.32	2.5	1.18	-	
Lm	17.7	2.86	25.0	4.63	4.9	2.83	6.1	4.55	23.0	7.09	18.3	7.69	3.4	1.12	20.4	5.07	2.1	1.83
Ms	6.5	2.23	2.9	2.1	5.3	3.15	9.3	4.03	7.6	1.68	3.3	1.83	0.5	0.25	1.0	0.53	14.2	5.43
Mr	4.1	0.93	0.5	0.81	1.0	0.73	1.9	2.46	3.0	1.46	0.4	0.79	-		-		1.4	1.35
Op			-		-		-				-		0.1	0.21	0.1	0.08	-	
Al	1.4	0.72	-		1.1	0.83	0.5	0.77	0.8	0.63	0.1	0.24	-		-		0.5	0.90
Mt	9.0	1.73	0.7	1.07	1.9	1.68	2.8	1.93	7.2	1.38	0.8	1.09	0.9	0.29	2.7	2.0	5.7	3.30
Cm	3.9	2.44	11.6	1.81	25.0	4.16	4.9	5.52	1.8	1.81	9.2	5.18	5.0	1.34	3.9	1.37	4.2	8.25
	100.0		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**	
Q	57.1	4.08	36.6	5.23	59.6	5.25	66.9	5.67	47.6	2.42	51.6	7.62	38.0	7.48	52.2	7.67	56.3	3.11
F	2.3	1.20	4.4	1.16	21.5	6.11	21.3	4.38	8.3	1.06	5.0	1.68	0.2	0.16	1.1	0.56	40.3	5.82
L	40.6	4.83	59.0	5.82	18.9	4.15	11.8	8.72	44.1	2.07	43.4	8.14	61.8	7.52	46.7	7.94	3.4	4.72
	100.0		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**	
Q_m	34.3	3.77	15.3	8.14	49.7	6.18	52.0	4.13	37.1	4.44	29.5	6.83	23.3	6.07	31.5	6.36	49.0	5.80
F	2.3	1.20	4.4	1.16	21.5	6.11	21.3	4.38	8.3	1.06	5.0	1.68	0.2	0.16	1.1	0.56	40.0	5.82
L_t	63.4	4.48	80.3	5.69	28.8	3.81	26.7	7.75	54.6	3.82	65.5	7.53	76.5	6.12	67.4	6.47	11.0	4.30
	100.0		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**		**100.0**	

x and **s** = average and standard deviation.

$Q = Q_m + Q_p$, where: **Q** = total quartzose grains, **Qm** and **Qp** = monocrystalline and polycrystalline quartzose grains (the last including the chert grains);

F = total feldspar grains, here exclusively represented by single grains of plagioclase (**Ps**);

L = Lm + Ls + Lv + Lc, where: **L** = unstable fine-grained rock fragments (< 0.06 mm, including: **Lm** = epimetamorphic, **Ls** = sedimentary, **Lv** = volcanic, **Lc** = carbonate rock fragments, the last including the fossils);

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

Ms = micas and/or chlorites in single grains; **Op** = opaque minerals, **Mt** = siliciclastic matrix; **Cm** = carbonate cement;

Analyses from: **1** – Zaghloul et al. (2003), **2** – Guerrera et al. (1997), Gigliuto (2005), **3** – Carmisciano et al. (1981), Cassola et al. (1991), **4** – Carmisciano & Puglisi (1978b), Nigro & Puglisi (1993), **5** – Gigliuto (2005), **6** – Zaghloul et al. (2005), **7** – Gigliuto (2005), Puglisi & Gigliuto (2006), **8** – Puglisi (1998).

most exclusive carbonate fraction in the Internal "Dorsale Calcaire" sandstones (Zaghloul et al. 2005; Fig. 5), (**b**) fine-grained very slightly metamorphic rocks, such as quartzites, semischists and metasedimentary rocks, mixed with carbonate rock fragments (micritic limestones, calcarenites, oolitic limestones and rarely fossils) in the External "Dorsale Calcaire" sandstones (Gigliuto et al. 2003; Gigliuto 2005) and by (**c**) metasedimentary up to epimetamorphic rock fragments in the sandstones of the Ciudad Granada-Fnideq and Viñuela-Sidi Abdesslam Formation Cycles (Fig. 6; Puglisi et al. 2001; Zaghloul et al. 2003).

So, the provenance of the Internal "Dorsale Calcaire" sandstones can be related to the erosion of carbonate successions, probably representing the Mesozoic-Cenozoic cover of the Paleozoic basement, partially formed by epimetamorphic rocks, as testified by the rare occurrence of similar clasts (not more than 5.0–6.0 %, Zaghloul et al. 2005). Provenance of the External Dorsale Calcaire sandstones, instead,

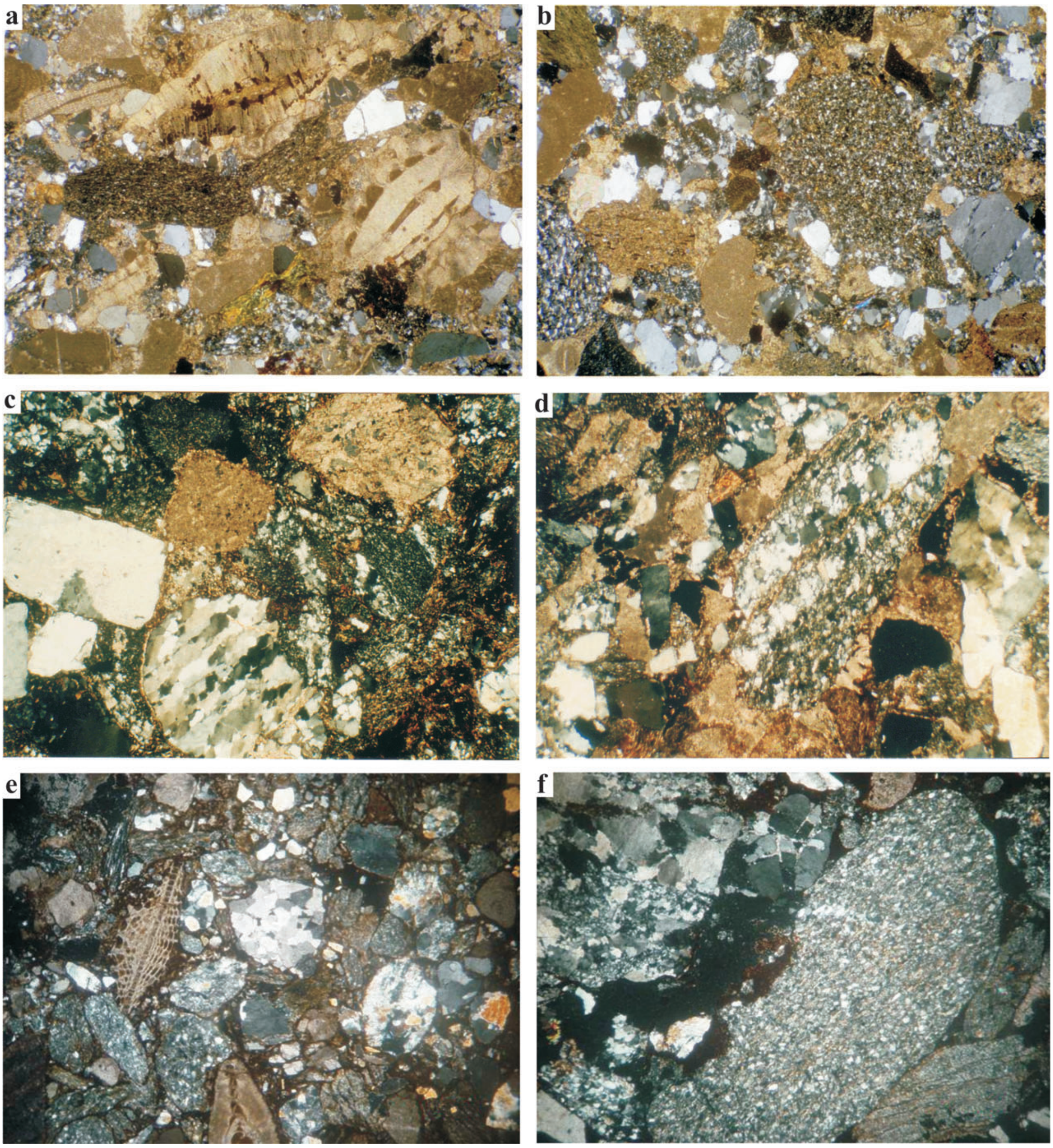


Fig. 5. Detrital frameworks of Oligocene-Miocene arenites from Internal and External "Dorsale Calcaire" (**a** and **b**, respectively) and from sandstone suites unconformably overlying the Ghomaride Units (**c** and **d**: Sidi Abdesslam Formation, Rif) and the Malaguide Units (**e** and **f**: El Niño Formation, Betic Chain). Feldspars are nearly always absent and polycrystalline quartz grains (c, d and e), carbonate rock fragments and fossils (mainly macroforaminiferal remnants, a and e) are the most common components of the lithic fraction.

seems to be linked to a deeper erosion level which more strongly affected the Paleozoic basement, as the result of unroofing processes and higher erosion rates (Zaghloul et al. 2005).

This type of provenance has already been suggested for the Ametrasse Unit by Wildi (1983), which also found at the top of the succession rare pebbles of Paleozoic schists and gneiss, and by Maate et al. (1993) in the Saaden Unit. Puglisi et al. (2001) and Gigliuto et al. (2003) recognized this similar provenance in both these units and interpreted the increase of the crystalline clast content as a consequence of uplift and/or overthrust tectonic deformations in the source areas.

Finally, the sandstones belonging to the Ciudad Granada-Fnideq Formation Cycle ($\mathbf{Q_{36.6}F_{4.4}L_{59.0}}$ and $\mathbf{Q_{57.1}F_{2.3}L_{40.6}}$, Rif and Betics, respectively) and to the Viñuela-Sidi Abdesslam Formation Cycle ($\mathbf{Q_{51.6}F_{5.0}L_{43.4}}$ and $\mathbf{Q_{48.6}F_{4.3}L_{47.1}}$, Rif and Betics, respectively; Table 1, Fig. 6 and references therein) show a

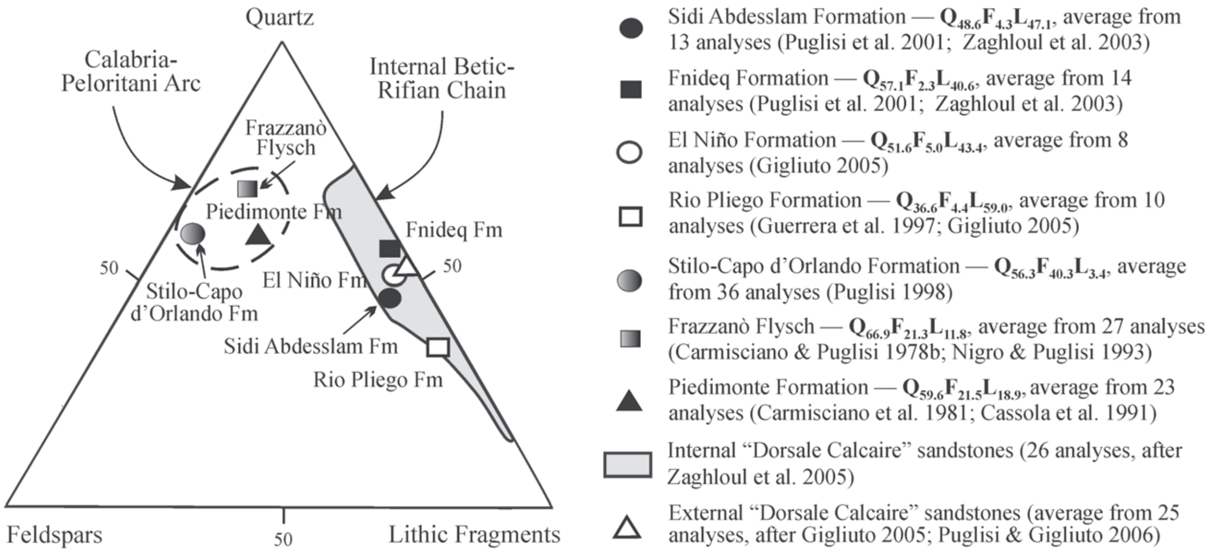


Fig. 6. Detrital modes of sandstones from Oligocene-Miocene late-orogenic successions of the Internal Domains of the Betic (El Niño, Rio Pliego Fms), Rifian (Sidi Abdesslam and Fnideq Formations, Internal and External "Dorsale Calcaire") and Sicilian Maghrebian Chains (Stilo-Capo d'Orlando Formation); these last also include modal data regarding syn-orogenic successions (i.e. Piedimonte Formation and Frazzanò Flysch). Two distinct areas characterize the compositional fields of the sandstone suites: left and right side of the diagram for the Sicilian Maghrebian and Betic-Rifian Chains (dashed line and grey area, respectively).

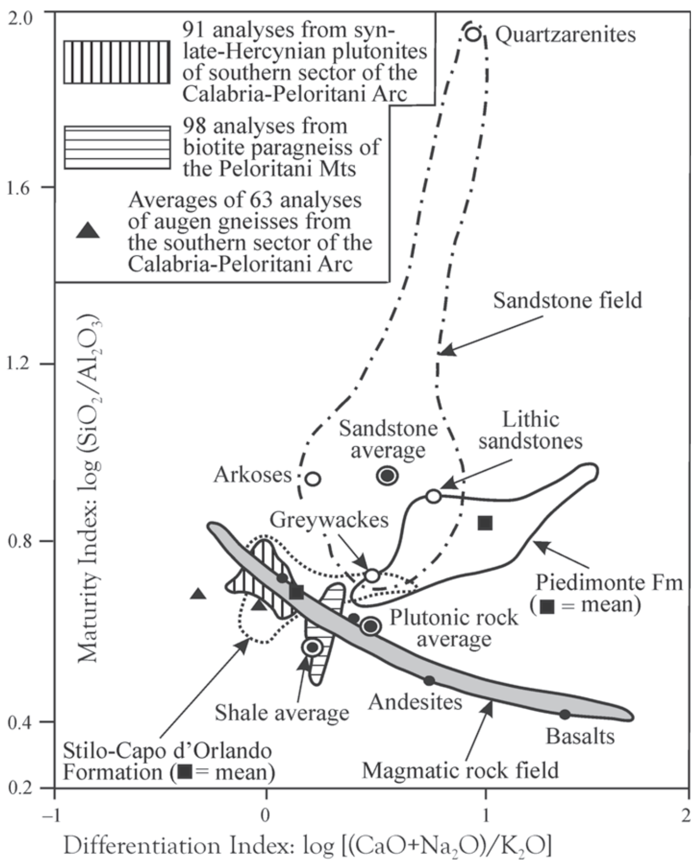


Fig. 7. Maturity and Differentiation Indexes of the late-orogenic Oligocene-Miocene sandstone suites of the Calabria-Peloritani Arc (references in Table 1), compared with terrigenous and magmatic rocks of the literature (data from Garrels & Mackenzie 1971) and with plutonic and high rank metamorphic rocks of the Calabria-Peloritani Arc (data from Atzori et al. 1976, 1985, 1988, 1989; Atzori & Lo Giudice 1982a,b; D'Amico et al. 1982).

composition considerably more siliciclastic, with minor amounts of carbonate rock fragments. Anyway, this type of detrital framework, characterized by abundant metasedimentary and epimetamorphic rock fragments, also seems to confirm the same provenance of the External "Dorsale Calcaire" sandstones and to exclude a contribution from plutonic and/or high grade metamorphic sources (Zaghloul et al. 2003).

In contrast, the late-orogenic Oligocene-Miocene sandstone suites of the Calabria-Peloritani Arc show an arkosic composition well marked by relatively high contents of feldspars, both K-feldspars and plagioclases (Carmisciano & Puglisi 1978a,b; 1982). This composition has been related to granitic and/or gneissic sources, tentatively identified with the rocks of the Aspromonte Unit (Puglisi 1991, 1992, 1994), the uppermost structural unit of the tectonic edifice forming the Calabria-Peloritani Arc.

In this paper the comparison has also been extended to the Lower Oligocene syn-orogenic successions of the Calabria-Peloritani Arc (i.e. Frazzanò Flysch and Piedimonte Formation) with the aim of verifying the occurrence of compositional changes over time.

On the whole, this type of provenance seems to characterize all these turbidite successions of the Calabria-Peloritani Arc with small differences linked to the tectonic evolution and to the differential uplift of the internal sectors of this paleodomain (Puglisi 1998). Thus, in any case a provenance from granitic and/or gneissic sources is also supported by geochemical data related to the major-oxide compositions of the sandstones and by further petrographic information regarding the structural character of the plagioclase twins (Puglisi 1994, 1998).

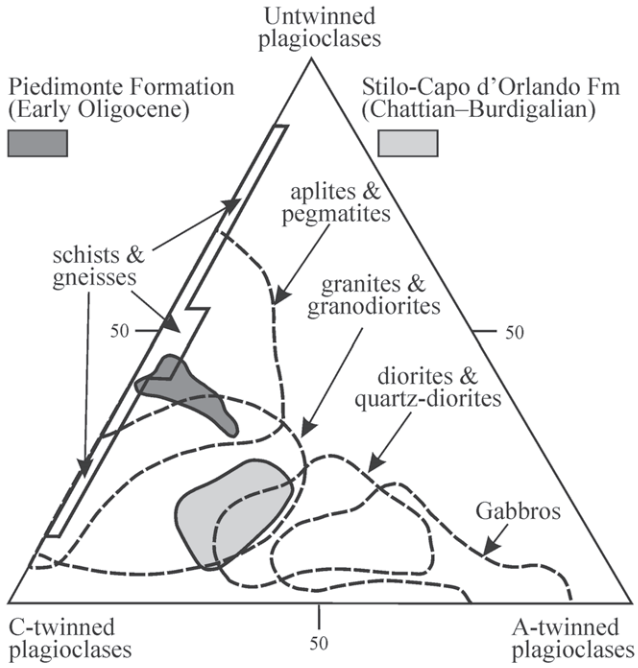


Fig. 8. Diagram showing the frequencies of untwinned and twinned plagioclases (these last subdivided in C- and A-twins, see text) recognized within the Oligocene-Miocene sandstone suites of the Calabria-Peloritani Arc (from Puglisi 1998) and compared with various plutonic and metamorphic rocks (from Gorai 1951).

In fact, by using traditional parameters such as the Maturity [log (SiO_2/Al_2O_3)] and Differentiation Indexes [log ($CaO+Na_2O)/K_2O$)] and according to Garrels & Mackenzie's (1971) diagram (Fig. 7), a perfect correspondence between the Stilo-Capo d'Orlando sandstones and the syn- to late-Hercynian plutonites of the Aspromonte Unit has been verified (Puglisi 1998).

Further information about the clastic provenance of these turbidite successions have also been obtained by Puglisi (1998) by analysing the different populations of the plagioclase twins, according to the Gorai's (1951) suggestions, successively re-worked by Tobi (1962), Pittman (1970) and Helmold (1985).

The ternary diagram of Fig. 8 (after Puglisi 1998) shows the relative frequencies between untwinned and twinned plagioclases, these last subdivided into A-twins (albite and pericline laws) and C-twins (all the other laws; Gorai 1951), for various plutonic, volcanic and metamorphic rocks. The plagioclase twins of the late-orogenic Oligocene-Miocene sandstone suites of the Calabria-Peloritani Arc (Stilo-Capo d'Orlando Formation) show strong affinity with the granitic-granodioritic field, thus suggesting a provenance mainly linked to plutonic sources, already hypothesized by the geochemical character of the sandstones.

The Quartz-Feldspars-Lithic Fragments ternary plot of Fig. 6 shows the above mentioned differences of composition between the coeval and equivalent sandstone suites of the internal sectors of the Gibraltar and Calabria-Peloritani Arcs. Very distinct quartzose-lithic and quartzose-feldspathic compositions (right and left side of the diagram), in fact, characterize the Oligocene-Miocene arenaceous products of the internal sectors of the Betic-Rifian Chain and of the Calabria-Peloritani Arc, respectively. In particular, the wide area comprising the compositions of the Internal "Dorsale Calcaire" sandstones is due to the dispersal of the carbonate rock contents which is not constant in all the analysed sections.

Paleogeographic and paleotectonic setting of the western Mediterranean

The provenance of the Oligocene-Miocene sandstone suites cropping out in the internal sectors of the Betic-Maghrebian Chains is commonly connected to the dismantling of the so-called AlKaPeCa Block (Al = Alboran, southern Spain and northern Morocco, Ka = Kabylian, Algeria, PeCa = Calabria-Peloritani Arc, sensu Bouillin et al. 1986).

The original location of this source area is still strongly debated. Many authors, in fact, consider this area as belonging to the southern paleomargin of the Iberian Plate (Biju-Duval et al. 1977; Bouillin et al. 1986, 2007; Stampfli et al. 1998; Sanz de Galdeano et al. 1993, 2001; Rosenbaum et al. 2002; Mauffret et al. 2004; Schettino & Turco 2006), whereas other authors hypothesize the existence of an independent microplate located between the European and African Plates according to Andrieux et al. (1971), Andrieux & Mattauer (1973) and Guerrera et al. (1993).

The first paleogeographic hypothesis, accepted here, seems to reach the higest consensus because it is strongly supported by much data.

Thus, on the base of the above-mentioned data, it is possible to emphasize a strong difference of composition between the Oligocene-Miocene sandstone suites of the internal domains of the Gibraltar and Calabria-Peloritani Arcs. Consequently, these different detrital modes characterize sedimentary provenances which cannot be linked to the same paleogeographic scenario.

Two different interpretations can be suggested to justify this evidence. The first one hypothesizes that the Betic-Rifian and Calabria-Peloritani internal sectors might not belong to the same paleodomain, already identified with the AlKaPeCa Block; they could have been distinctly separated, thus forming different source areas supplying different sedimentary basins not necessarily adjacent.

In contrast, if these sectors really belonged to the same AlKaPeCa Block, the different provenances described above can be justified by admitting that these sediment sources were already separated at the beginning of the deposition of the described Oligocene-Miocene sedimentary successions. This hypothesis is adopted here because strongly supported by recent studies regarding the opening and the geodynamic evolution of the western Mediterranean basins.

In fact, Rosenbaum et al. (2002) suggest that the extension in the western Mediterranean started 32–30 Ma and Cavazza & Wezel (2003) even recognize that the Mediterranean rifting occurred from the Early Oligocene by inducing the development of several grabens in southern France and Sardinia, both on-land and offshore. Schettino & Turco (2006), in their recent plate reconstruction, also admit that extensional activity was already occurring in the late Rupelian and that a short time span (31.1 to 28.0 Ma) brought completion of the formation of the Valencia trough, considered to be slightly younger than the Gulf of Lion and slightly older than the opening of other oceanic spaces, such as the Provençal Basin and the west Alboran Sea (Rosenbaum et al. 2002).

These extensional processes, mainly governed by subduction rollback coupled with a relatively slow convergence between Africa and Europe, occurred on the overriding plate in a back-arc position (Rosenbaum et al. 2002). Successively, extensional tectonics also occurred in the fore-arc region to form the Corsica, Sardinia and Algeria Basins together with the above-mentioned west Alboran Basin (Mauffret et al. 2004, 2007).

In conclusion, these extensional processes triggered the break-up of the AlKaPeCa Block and the drifting of all the microplates as long as subduction rollback took place (Rosenbaum et al. 2002) and until they accreted to the adjacent continents by largely undergoing tectonic deformations in the Alpine orogeny (Stampfli et al. 1998).

Concluding remarks

On the basis of the evidence of an incipient fragmentation of the AlKaPeCa Block it is possible to hypothesize a paleogeographic scenario where the different microplates were already widely separated in the middle Chattian (Fig. 9) in order to justify different supplies in different sedimentary basins.

This tectonic control both in the source areas and in the basins suggests further inquiries on tectonic and stratigraphic evolution (vertical and lateral) of the petrographic composition of the sedimentary successions.

Thus, progressive dismantling of these already separated different crustal sectors, not necessarily formed by the same type of rocks, fed several sedimentary basins with diversified detrital products. These sedimentary deposits can correspond to the Oligocene-Miocene sandstone suites of the internal areas of the Gibraltar and Calabria-Peloritani Arcs, whose sandstones show different compositions connected to a distinct provenance.

Furthermore, it is well known that (**a**) in the Rifian Chain the emplacement of the different Ghomarides Units and also the Ghomarides/Sebtides tectonic contact would be antecedent to the Oligocene/Miocene boundary (Feinberg et al. 1990; Maate et al. 1995; Serrano et al. 2006, 2007), because it is sealed by the Ciudad Granada-Fnideq Formation Cycle, as well as (**b**) in the Calabria-Peloritani Arc the Alpine nappes with remnants of Hercynian basement were already piled up before the unconformable deposition of the Upper Oligocene–Lower Miocene Stilo-Capo d'Orlando Formation (Puglisi 1998 and references therein).

Thus, it is possible to emphasize that all the AlKaPeCa-derived microplates were already separated, widely drifted and partially accreted onto the different African sectors before the Late Oligocene (age of the base of the analysed successions) and not during and/or after the Burdigalian (Martin-Algarra et al. 2000; Bonardi et al. 2003).

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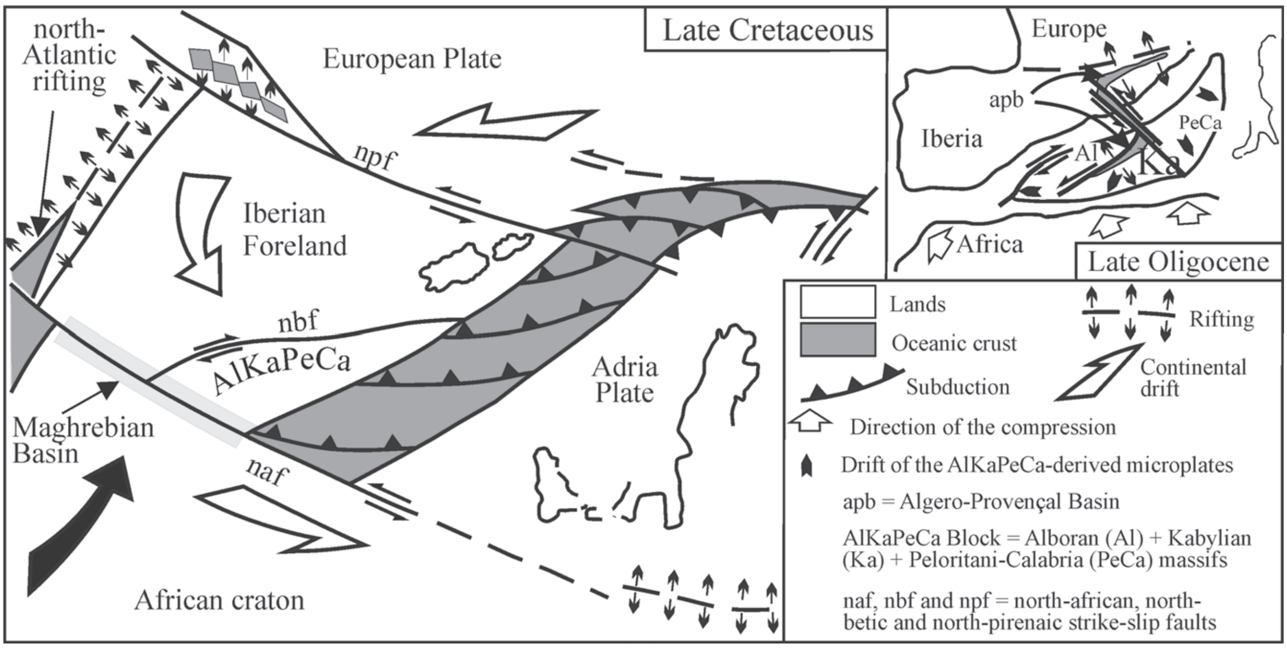

Fig. 9. Paleogeographic evolution of the western Mediterranean area during late Cretaceous–late Oligocene times up to the beginning of break-up of the AlKaPeCa Block, supposed to be originally located in the southern paleomargin of Iberia (modified after Cassola et al. 1990a,b).

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