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PETROGRAPHY AND GEOCHEMISTRY OF GRANITOID PEBBLES FROM THE OLIGOCENE-MIOCENE DEPOSITS OF THE INTERNAL RIFIAN CHAIN (MOROCCO): A POSSIBLE NEW HYPOTHESIS OF PROVENANCE AND PALEOGEOGRAPHICAL IMPLICATIONS

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Abstract: The Oligocene-Miocene deposits of the Internal Domains and of the innermost sectors of the flysch basin, recognized along the Betic-Rifian Chain (Spain and Morocco; i.e. Malaguide/Ghomaride Units and *maurétanien* flysch, respectively), are characterized by the occurrence of crystalline pebbles within several conglomerate horizons. Their provenance is difficult to explain because of the absence of similar rocks in the pre-Alpine Paleozoic basement nappes of this chain. Geochemical characters of seven granitoid pebbles (two-mica, cordierite-bearing monzogranite up to leucomonzogranite), sampled from conglomerate lithofacies occurring within the above mentioned sandstone suites (Internal Rif and *maurétanien* sector of the flysch basin), have been determined and compared with other plutonic rocks of the Western Mediterranean and Iberian areas in order to detect their provenance. This comparison has been realized with the syn- to late-Hercynian plutonic bodies widespread in the Iberian, Moroccan (109 analyses from north-eastern Morocco, western High Atlas and from western-central Anti-Atlas), Kabylian and Calabria-Peloritani massifs (14 and 282 analyses, respectively) and with the pre-Hercynian Pan-African plutonites of Algeria (55 analyses). The obtained results show very strong geochemical affinities only with the Hercynian granitoids of the Iberian Massif (115 analyses from central Spain and from northern and central Portugal), thus emphasizing a new hypothesis for the provenance of the analysed pebbles with important paleogeographical consequences. Such a hypothesis of provenance, in fact, shows evidence that the AlKaPeCa block (i.e. Alboran–Spain + Kabylides–Algeria + Calabria + Peloritani massifs — southern Italy), at least during Oligocene times, must have been still in crustal continuity with the Iberian Massif, supposed to be the source area of the studied plutonic pebbles.

Key words: Morocco, Rif Chain, Oligocene-Miocene deposits, granitoid pebbles, petrography, geochemistry.

Introduction, geological setting and objectives

The provenance of the detrital elements of the Tertiary turbiditic successions of the Betic-Maghrebian Chain is commonly related to the crystalline rocks of pre-Alpine basements, now included in different tectonic edifices cropping out in the Alpine chains along the western Mediterranean (Fig. 1).

Oligocene-Miocene turbiditic flows, in fact, appear to be linked to the tectonic history of the southern paleomargin of the European plate, because their provenance is mainly derived from the dismantling of the so-called AlKaPeCa block (Al = Alboran, southern Spain and northern Morocco, Ka = Kabylia, Algeria, PeCa = Calabria-Peloritani Arc, *sensu* Bouillin et al. 1986) before and during its incipient break-up, fragmentation and deformation occurred since Oligocene times (Olivier 1978, 1979; Durand-Delga & Olivier 1988; Puglisi 1996).

Thus, the detrital modes of sandstone suites characterizing the Oligocene-Miocene *maurétanien* flysch[1] of the Betic-Rifian Chain (i.e. Algeciras and Beni Ider Flysch, Spain and Morocco, respectively), are mainly represented by quartz-feldspatic compositions and they suggest a provenance from plutonic and/or high rank metamorphic sources (Pendon & Polo 1975; Chiocchini et al. 1978; Guerrera et al. 1989; Rodriguez 1987; Puglisi & Carmisciano 1992; Puglisi et al. 2001; Zaghloul et al. 2002). In contrast, the coeval terrigenous deposits unconformably overlying the Malaguide–Ghomaride Units are well characterized by the abundance of quartz grains and of lithic fragments, with a very low content of feldspars. So, they appear to be mainly derived from epimetamorphic sources and from their mainly carbonate Mesozoic-Tertiary covers (Puglisi et al. 2001; Zaghloul et al. 2003).

Furthermore, in both these types of deposits, in the Betic Cordillera as well as in the Rifian Chain, it is possible locally

[1] This term is here used to represent the internal flysch deposits of the North Africa Flysch Basin (sensu Gelard 1969; Bouillin et al. 1970; Bouillin 1978) fed by the Internal Domains.

to observe several conglomeratic lithofacies containing well rounded plutonic and high rank metamorphic pebbles. Granitoid pebbles, in fact, have firstly been recognized by Olivier et al. (1979) within the Tertiary cover of the Ghomaride Units and recently found also within equivalent successions of the Betic Internal Domain (Martin-Algarra et al. 1995, 2000; Zaghloul et al. 2003). Successively, similar pebbles have also been found within conglomerate horizons marking the lower portion of the *maurétanien* Beni Ider Flysch (Puglisi et al. 2001; Zaghloul et al. 2002). The presence of similar pebbles strongly emphasizes a paleogeographical scenario where the provenance is unequivocally linked to a sedimentary supply from crystalline sources.

Nevertheless, in the Betic-Rifian Chain, it is difficult to explain this type of provenance because, up to now, plutonic rocks have never been recognized within the highest tectonic units of these tectonic edifices (i.e. the Malaguide and Ghomaride Units), whereas outcrops of syn- to late-Hercynian granitic rocks are very common in the Kabylides and in the Calabria-Peloritani Arc. So, only in the Betic Cordillera and in the Rif it is problematic to link this type of provenance with plutonic bodies which are not exposed.

The aim of this paper is to characterize and to detect the provenance of these plutonic pebbles and the possibility of their comparison with other similar rocks cropping out in different sectors of the Maghrebian Chain. Thus, the petrographic and geochemical results obtained for these granitoid pebbles, sampled from conglomerate lithofacies of the lower portion of the Beni Ider Flysch and of the Oligocene-Miocene successions (Fnideq Formation) unconformably overlying the innermost tectonic units of the Rifian Chain, are compared with the data available in literature for the syn- to late-Hercynian plutonic bodies of the Iberian, Moroccan and Kabylian massifs and also of the Calabria-Peloritani Arc.

Location, sedimentology and petrographic characters of the conglomerate intervals occurring within the Beni Ider Flysch and the Fnideq Formation

The studied plutonic pebbles have been collected from some conglomerate lithofacies characterizing the lower portion of the Beni Ider Flysch (*maurétanien* sector of the flysch basin) and the Ghomaride Complex covers (Fnideq Formation), both Oligocene–Miocene in age.

The following two sample areas have been selected to represent the conglomerate lithologies of both the above-mentioned sandstone suites: the Aïn-ech-Choûkâ area (south of the Ksar es Sghir village, Fig. 2) and the Beni Maâdane area (east of Tétouan, Fig. 2), where the lower portion of the Beni Ider Flysch and the upper part of the Ghomaride Complex cover are

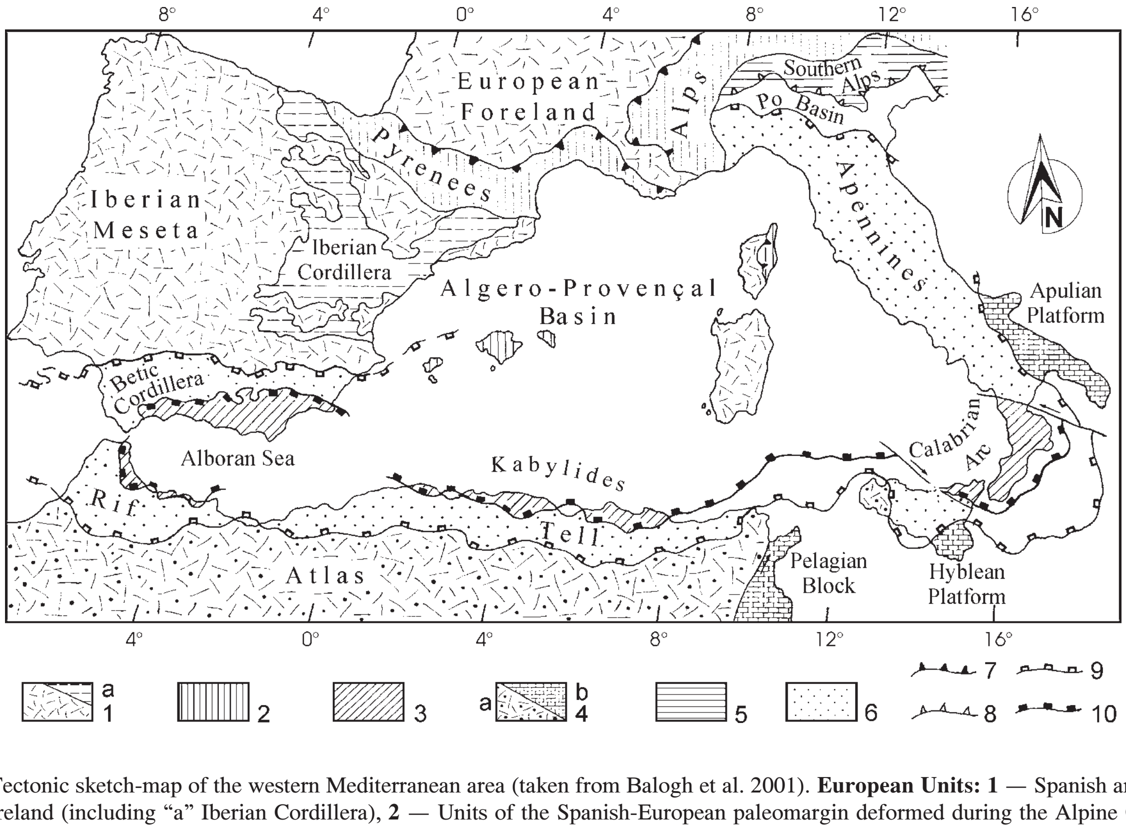

Fig. 1. Tectonic sketch-map of the western Mediterranean area (taken from Balogh et al. 2001). **European Units: 1** — Spanish and European Foreland (including "a" Iberian Cordillera), **2** — Units of the Spanish-European paleomargin deformed during the Alpine Orogeny (Pyrenees, Provençal Chain and Alps), **3** — Kabylo-Calabride Chain (including the internal units of the Betic Cordillera). **African Units: 4** — African Foreland (**a** = gently deformed: Atlas and Trapanese area; **b** = undeformed: Pelagian Block, Hyblean Plateau and Apulian Platform), **5** — Units of the African paleomargin deformed during the Alpine Orogeny (South-Alpine), **6** — African Units deformed during Apenninic-Maghrebian Orogeny (Apennines, Sicilian Maghrebian Chain, Rif, Tell and Betic Cordillera). **7–10** — Pennidic, South-Alpine, Kabylo-Calabride Chain and Apenninic-Maghrebian Chain fronts.

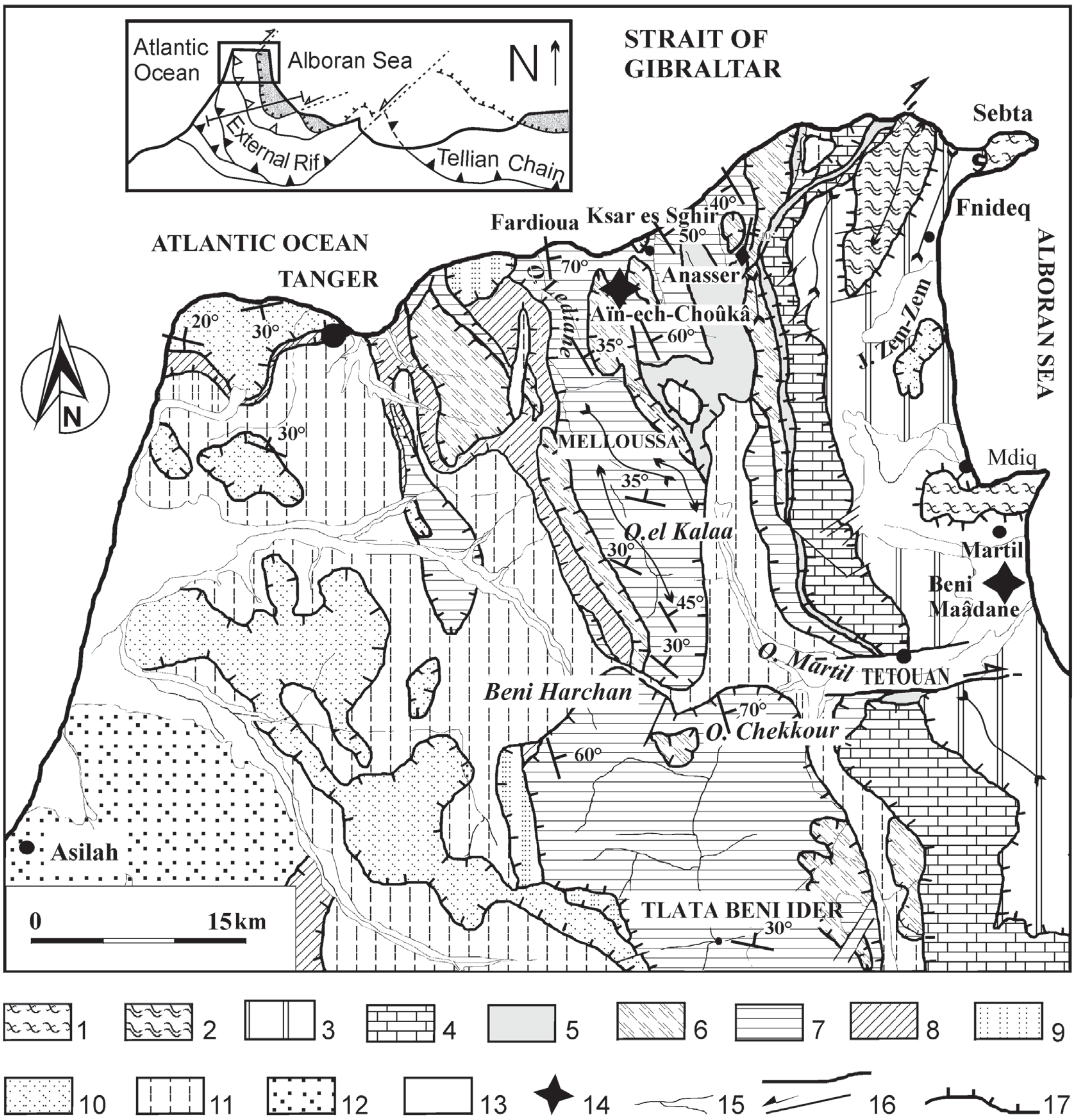

Fig. 2. Geological sketch-map of the northern Rifian Chain (after Zaghloul et al. 2002, modified). **Internal Units: 1** — Lower Sebtide Units (Filali and Hacho Units of Ceuta), **2** — Upper Sebtide Units (Federico Units), **3** — Ghomaride Units with Mesozoic-Cenozoic cover, **4** — "Dorsale Calcaire". **Flysch Domain Units: 5** — Predorsalian Units, **6** — Massylian Unit (Chouamat-Melloussa Unit) and **7–8** — Maurétanien Units (i.e. Tisirène and Beni Ider Nappes, respectively), **9** — Talâa Lakraa Unit, **10** — Numidian Flysch. **External Rifian Units: 11** — Tangier Unit, **12** — Habt and Loukkous Units, **13** — alluvial and Pliocene-Quaternary deposits. **Symbols: 14** — location of the study sections, **15** — hydrographic trace, **16** — main strike-slip faults, **17** — main overthrust contacts.

mainly represented by conglomerate intervals (Figs. 3 and 4, respectively).

Sedimentological characters of the conglomerate horizons with granitoid pebbles

The Aïn-ech-Choûkâ section (about 650 m thick, Fig. 3), aged Upper Oligocene–Lower Miocene (Zaghloul et al. 2002), shows abundant conglomerate lithofacies *("disorganized and organized conglomerates",* A_1 and A_2 facies sensu Pickering et al. 1989, respectively), interbedded with muddy gravels characterized by scattered pebbles (Zaghloul et al. 2002). This section has been subdivided (Zaghloul 2002 and by Zaghloul et al. 2003) into:

- A first petrofacies, about 150 m thick, formed by clast-supported and unsorted polygenic conglomerates (plutonic, volcanic, and metamorphic clasts, with sedimentary pebbles);
- A second petrofacies, about 190 m thick, represented by very poorly sorted and well-rounded matrix-supported sedimentary pebbles, cobbles and blocks, with very thick chert-bearing conglomerate bodies with abundant nummulite-bearing limestone clasts;
- A third petrofacies, about 300 m thick, made up by calcareous conglomerates (cobbles, boulders and blocks of dolorudites and nodular limestones), locally with white-grey calcareous olistoliths (5 to 10 m in size) and with boulders of Verrucano-like red quartzose sandstones. This lithofacies is almost devoid of crystalline pebbles. At the top of the section, a pelitic interval (80 m thick) with few arenaceous turbiditic

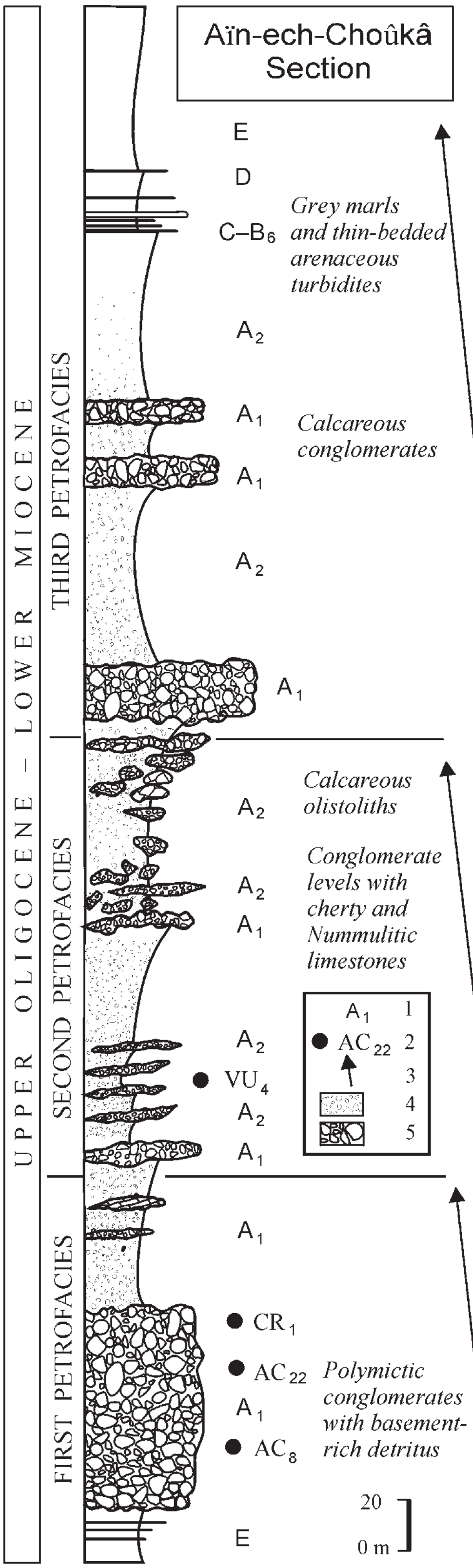

Fig. 3. Simplified stratigraphic column of the Oligocene-Miocene Beni Ider Flysch in the Aïn-ech-Choûkâ section (after Zaghloul et al. 2002, modified). **1** — Turbiditic facies, **2** — location of the analysed pebbles, **3** — positive cycles, **4** — very poorly sorted and well-rounded matrix-supported pebbles, **5** — unsorted clast-supported conglomerates.

bodies (up to 1 m thick; facies D, E and B_6 of Pickering et al. 1989, respectively), is present.

In the Beni Maâdane area (Fig. 4) two mainly conglomeratic horizons have been recognized:

1. A lower siliciclastic conglomeratic interval, with crystalline pebbles, directly overlying the Paleozoic basement and/or its Mesozoic carbonate cover and with sedimentological characters related to *"disorganized and organized conglomerates"* facies of Pickering et al. (1989), indicative of debris flows and/or highly concentrated turbidity current processes;

2. An upper mainly calcareous conglomeratic and arenaceous interval, about 150 m thick, made up of matrix and clast-supported *"organized and disorganized conglomerates"*, with thinning- and fining-upward trends and with the occurrence of plurimetric olistoliths. In this interval medium- to very coarse-grained sandstone beds (up to 1 m in thickness, *"stratified sandstones and gravelly sandstone"* facies of Pickering et al. 1989) as well as medium- to coarse-grained graded sandstones with complete or incomplete Bouma sequences (*"classical turbidites"*, sensu Pickering et al. 1989), are present testifying to transport processes mainly linked to unstable high density turbidity currents.

Yellowish-brownish massive clays with thin-bedded and fine-grained reddish turbidites (about 190 m thick, Fig. 4) separate the two conglomerate intervals.

Petrographic characters of the plutonic pebbles

The petrographic characters of 7 selected samples of less-weathered plutonic pebbles were performed by means of modal analyses (about 1200 points per sample) in order to detect the paragenesis and to classify the rock types (Table 1).

The analysed plutonic pebbles (4 collected from the Beni Ider Flysch and 3 from the Ghomaride Complex cover, i.e. Fnideq Formation), ranging in size from 3 to 10 cm, can be ascribed to the two-mica, cordierite-bearing monzogranite up to leuco-monzogranite clans. Their occurrence is high in the lower portions of the Beni Ider Flysch (about 10–15 % of the total clast population at the base of the Aïn-ech-Choûkâ section) and of the Ghomaride Complex covers (up to 25 % of frequency within the lower siliciclastic conglomeratic interval of the Beni Maâdane area).

These granitoid pebbles show a massive fabric, an inequigranular structure, mainly medium- (0.25–0.5 mm) to fine-grained and a hypidiomorphic to subhypidiomorphic texture.

The quartz (~ 33 %), usually as aggregates of anhedral crystals, slightly zoned and commonly subhypidiomorphic plagioclases (~ 27 % with An_{20-25}), K-feldspar (~ 27 %, mainly perthitic orthoclase and microcline) and small amounts of muscovite and biotite are the most important mineral phases. These values, in agreement with the mean of 14 samples of granitoid pebbles studied by Puglisi et al. 2001 (quartz ~ 41%, plagioclase ~ 38% and K-feldspar ~ 21%), characterize a paragenesis not much different between all the studied granitoid pebbles. In fact the BM_{12}, sample, which is clearly distinquished from the bulk of the other six samples by differ-

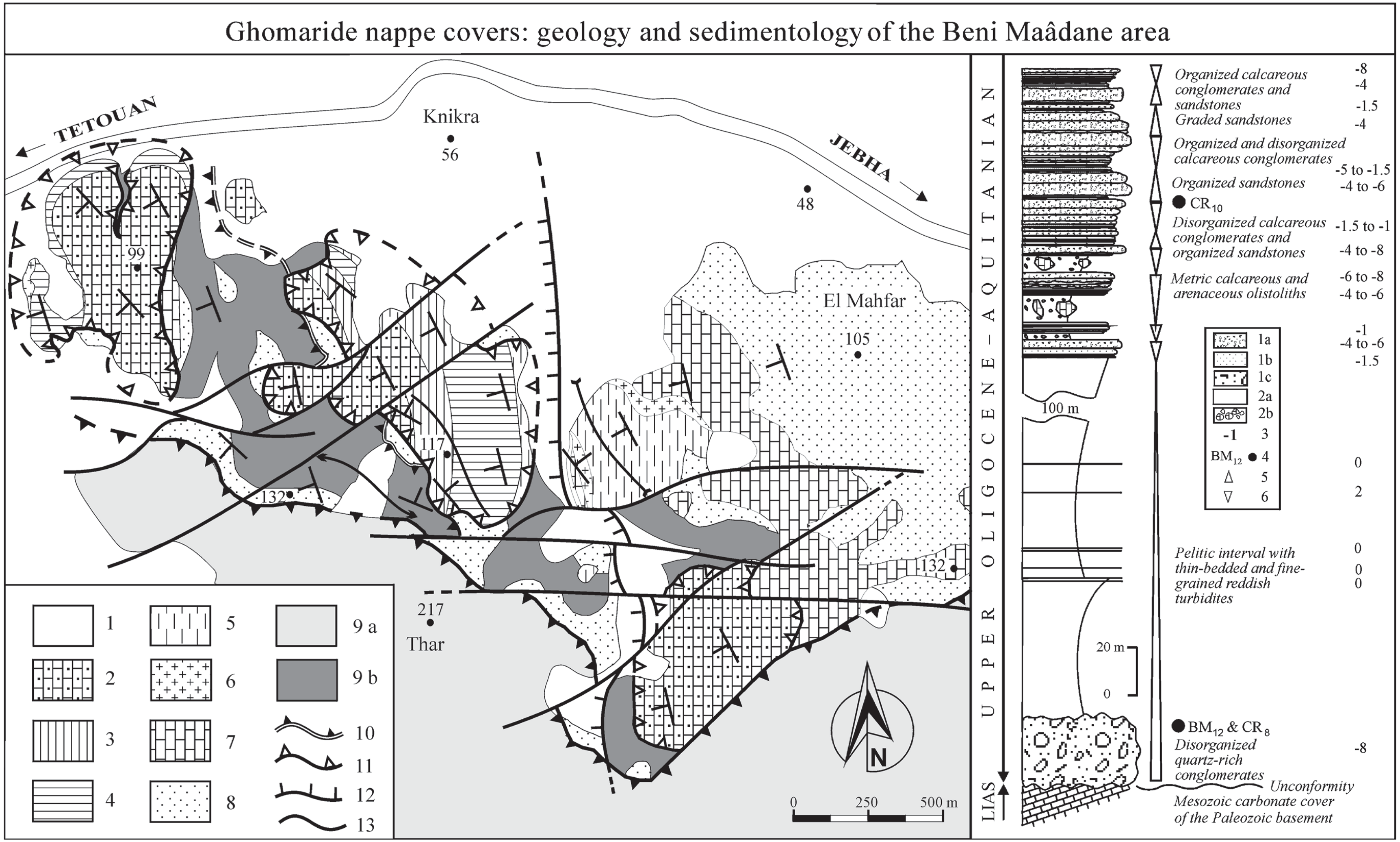

Fig. 4. Geological sketch map of the Beni Maâdane area (Internal Rif, Morocco; after Zaghloul et al. 2003) showing the mainly conglomeratic Oligocene-Miocene deposits of the Ghomaride Complex covers. **1** — Pliocene and Quaternary deposits. Oligocene-Miocene deposits of the Ghomaride Complex cover: *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 faults, **13** — strike-slip faults.

Right side: simplified stratigraphic section of the Beni Maâdane outcrop (Oligocene–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** — grain size in φ scale, **4** — location of the analysed samples, **5–6** — positive and negative cycles, respectively.

Table 1: Modal point counts of the analysed granitoid pebbles compared with other plutonic rocks of the Calabria-Peloritani Arc.

	Plutonic pebbles of the Oligocene-Miocene deposits of the Rifian Chain											Plutonic bodies of the Calabria-Peloritani Arc		
	New data							Ghomaride Complex covers				Sila Batholith (n = 65)[2]	Serre Batholith (n = 41)[3]	Aspromonte Batholith (n = 485)[4]
	Beni Ider Flysch				Ghomaride Complex covers			Beni Maâdane (n = 12)[1]		Gharrabo (n = 19)[1]				
	VU_4	CR_1	AC_8	AC_{22}	BM_{12}	CR_8	CR_{10}	x	σ	x	σ	x	x	**x**
Quartz	35.4	32.3	29.7	28.5	41.1	31.9	34.3	31.9	3.0	32.8	2.4	31.2	29.6	33.7
Plagioclase	23.7	31.1	33.6	29.8	17.4	24.1	28.1	22.8	3.2	316	2.2	34.3	40.5	37.2
K-feldspar	28.3	26.2	23.2	27.0	29.9	27.3	24.9	21.0	4.4	214	4.2	21.3	14.6	16.5
Biotite	3.5	4.9	7.5	9.7	1.9	10.4	3.8	7.3	1.7	6.5	1.7	8.1	12.8	6.3
Muscovite	6.6	3.7	4.1	3.1	8.1	4.3	7.7	7.8	3.5	6.6	1.0	4.3	1.6	5.7
Cordierite	-	0.5	0.8	0.7	-	0.5	-	0.8	0.5	0.4	0.3	0.1	-	tr
Opaque minerals	1.7	1.1	0.7	1.2	0.9	1.2	1.2	0.3	0.1	0.3	0.1	0.2	-	-
Accessory minerals	0.8	0.2	0.4	-	0.7	0.3	-	0.2	0.1	0.2	0.1	0.6	0.3	0.7
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**							

x and **σ** — average and standard deviation, respectively; **n** — number of analysed samples; **tr** — traces. **1** — analyses from Martin-Algarra et al. (2000); **2** — mean of two means from 65 analyses (Lorenzoni et al. 1979; Martin-Algarra et al. 2000); **3** — mean of four means from 41 modal analyses (Moresi & Paglionico 1975; Martin-Algarra et al. 2000); **4** — mean of four means from 485 modal analyses (Puglisi & Rottura 1973; Messina et al. 1974; Crisci et al. 1979; Ioppolo & Puglisi 1980. Authors emphasize the presence of sillimanite and of traces of andalusite and cordierite within the 20→92 % and the 1→15 % of the samples, respectively).

ent geochemical properties, is also microscopically very similar to the other granitoid pebbles. It shows, in fact, abundant quartz (~ 41 %), subordinate amounts of K-feldspar (~ 30 %) and of plagioclase (~ 17 %) and its state of preservation is good, with very scarce traces of alteration only testified by few plagioclase crystals very slightly involved in sericitization processes. These same very rare traces of alteration are also locally present within the other samples and, for this reason, we do not believe that they could be responsible for the geochemical difference of the BM_{12} sample, whose distinctive character will be successively discussed and tentatively explained.

Furthermore, in all the analysed samples very few heavy minerals (i.e. zircon, tourmaline, magnetite and rare apatite, usually never more than 0.8–1 %) and very small amounts of other products, probably derived by deuteric alteration mainly from plagioclases, have been observed to constitute the complementary characteristic mineral assemblage of these rocks.

Myrmekitic textures also occur and, locally, very sporadic traces of a probably green-schist metamorphic overprint have been recognized. An association of albite + white mica + epidote + chlorite, that is not pervasive and does not obliterate the original magmatic texture, is evidence of this.

Geochemical characters of the granitoid pebbles and their comparison with similar rocks of the Betic-Maghrebian Chain and of the Iberian Massif

Table 2 lists the analytical data of major-oxides, trace and rare earth elements (REE), determined in 7 granitoid pebbles and performed at the Activation Laboratories (Canada)[2] .

[2] Major-oxides (all with 0.01 % detection limits) and the Sc content have been determined by ICP, whereas trace elements together with rare earth elements have been performed by ICP/MS.

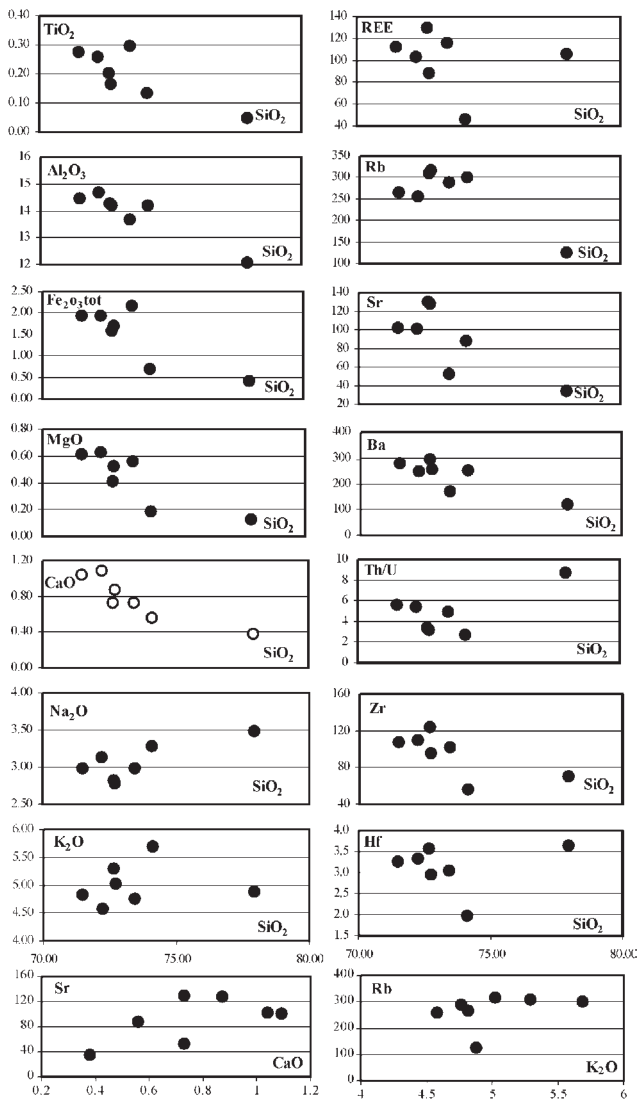

Fig. 5. SiO_2 vs. major-oxides and trace elements variation diagrams for the analysed plutonic pebbles.

The analysed granitoid pebbles show uniform major-oxide composition and trace element contents, characterized by a narrow range of SiO_2 (71.49–77.93 wt. %), by high Al_2O_3 (> 14 %) and A/CNK > 1 (comprised in the range 1.0–1.3), by low contents of femic elements [(TiO_2 + FeO_{tot} + MgO) < 3 %] and of CaO, Sr, Ba, and by relatively high contents of K_2O, Rb, Cs, Ta (Table 2). In addition, they are also characterized by a Th/U ratio ranging from 2 to 9 and by a relatively low content of ΣREE with an Eu anomaly and scattered HREE.

In the SiO_2 vs. alkali diagram all the samples exhibit a sub-alkaline character (K_2O/Na_2O ranges from 1.40 to 1.87), displaying a calc-alkaline affinity (high Al_2O_3, K_2O and low TiO_2).

Compared to the major elements, the ranges of variation observed for the trace elements are much greater. In the SiO_2 vs. major-oxides and trace elements variation diagrams (Fig. 5) it is possible to observe the distribution of the data points rather scattered in every case, but characterized by a continuous variation of composition within the population for six of analysed samples. Then, except the BM_{12} sample, a single population of samples well marked by a negative correlation for TiO_2, Al_2O_3, Fe_2O_{3tot}, MgO, CaO, REE, Sr, Ba, Th/U, Zr, Hf and by a positive correlation for Na_2O, K_2O and Rb may be recognized.

Moreover, before listing the geochemical data obtained and discussing their geological significance, we must underline that it could be very difficult to use the chemical data of the analysed pebbles to detect their tectonic setting, because possible mechanisms of alteration could have affected the rocks during the sedimentary processes and, probably, also modified their primary composition.

Nevertheless, we think that the primary composition of the analysed granitoid pebbles is substantially unchanged because the observed correlations (Fig. 5) seem to follow the common granitic trends. Alterations, in fact, are expected to produce a strong scattering within these trends.

The REE patterns are shown in Fig. 6. They are fractionated with a moderate Eu anomaly displaying congruent LREE pattern but HREE very scattered. Five samples show a common pattern typical of S-type granites. The AC_8 sample shows lowest REE, probably owing to still less occurrence of accessory minerals such as zircon: in fact, it also shows strong depletion of Zr, Y and Th. The BM_{12} sample shows strong Eu anomaly and higher HREE contents.

However, the observed chemical characters are consistent with the hypothesis of a common origin and provenance for six of the analysed samples. One of them (BM_{12} sample), instead, has clearly distinct composition. In the diagram of Fig. 7

Table 2: Major-oxide composition and trace element contents of the analysed granitoid pebbles.

	VU_4	CR_1	AC_8	AC_{22}	BM_{12}	CR_8	CR_{10}
SiO_2	72.72	72.66	74.11	73.44	77.93	72.23	71.49
TiO_2	0.16	0.20	0.13	0.30	0.05	0.26	0.28
Al_2O_3	14.21	14.29	14.22	13.67	12.06	14.68	14.48
Fe_2O_3	1.70	1.58	0.69	2.17	0.42	1.93	1.93
MnO	0.02	0.02	0.01	0.03	0.01	0.02	0.02
MgO	0.52	0.41	0.19	0.56	0.13	0.63	0.61
CaO	0.87	0.73	0.56	0.73	0.38	1.09	1.04
Na_2O	2.79	2.83	3.29	2.98	3.49	3.13	2.99
K_2O	5.02	5.29	5.69	4.76	4.88	4.58	4.82
P_2O_5	0.20	0.15	0.23	0.18	0.02	0.17	0.17
LOI	1.77	1.26	0.82	1.15	0.65	1.36	1.26
tot	**99.98**	**99.42**	**99.94**	**99.97**	**100.02**	**100.08**	**99.09**

Trace elements in p. p. m.

	detection limits	VU_4	CR_1	AC_8	AC_{22}	BM_{12}	CR_8	CR_{10}
Zr	0.1	103	126	57	106	74	118	115
Hf	0.1	2.9	3.6	2.0	3.0	3.7	3.3	3.3
Ta	0.01	2.7	3.0	3.9	1.9	3.8	1.9	1.9
Nb	0.5	12	15	15	14	14	12	12
La	0.01	19.1	27.9	9.4	22.8	14.0	21.2	22.4
Ce	0.01	37.7	54.9	19.5	47.8	44.9	44.3	49.3
Nd	0.01	15.9	23.3	8.1	21.4	14.4	19.8	21.5
Eu	0.005	0.50	0.58	0.49	0.46	0.13	0.54	0.57
Sn	0.5	17	18	12	9	3	9	8
Tb	0.01	0.4	0.6	0.3	0.7	1.1	0.4	0.5
Yb	0.01	1.0	1.7	0.5	2.0	4.7	1.0	1.0
Lu	0.002	0.14	0.23	0.07	0.27	0.68	0.15	0.15
Y	0.1	12	16	5	20	48	11	11
Th	0.05	9.8	12.8	4.9	11.4	19.0	12.0	12.5
U	0.05	3.1	3.8	1.8	2.3	2.2	2.2	2.2
Ba	0.1	256	296	253	170	122	249	279
Rb	0.1	318	310	300	289	125	257	267
Sr	0.01	128	130	88	52	34	101	102
Ga	1	20	21	16	20	19	19	19
Cs	0.1	36.9	32.3	11.9	30.7	0.9	22.3	21.4
Sc	2 p.p.m.	2	3	2	5	3	4	4

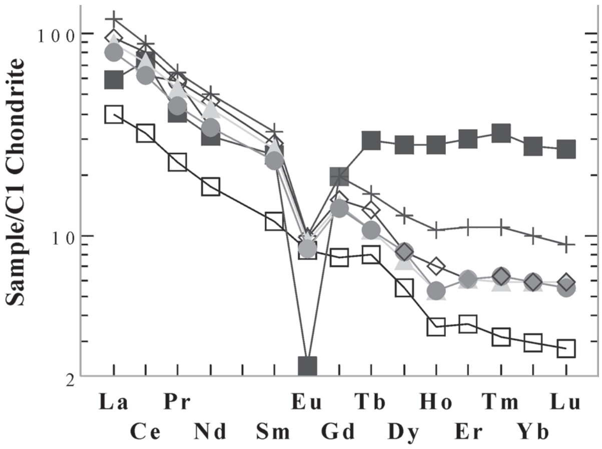

Fig. 6. Chondrite-normalized variation diagram showing the REE patterns of the analysed pebbles.

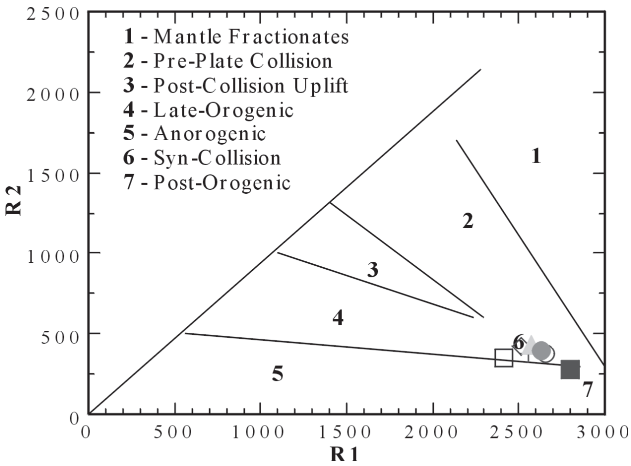

Fig. 7. $R_1 = [4Si - 11(Na+K) - 2(Fe+Ti)]$ vs. $R_2 = (6Ca+2Mg+Al)$ diagram showing the geological setting discrimination of different granitoid rock series. For symbols see Fig. 6.

(Batchelor & Bowden 1985), in fact, the BM_{12} sample falls in the post-orogenic granite field, while the other samples plot in the syn-collision granite field.

Furthermore, some chemical characters of this sample (high SiO_2, Y, HREE, low Al, Ca, Ba, Sr and largest negative Eu anomaly) are similar to those of A-type granites, which are well characterized by high Ga/Al ratio and high $\Sigma Zr + Nb + Ce + Y$ values (usually > 2.6 and > 350, respectively; Whalen et al. 1987). The BM_{12} sample, in particular, shows a high Ga/Al ratio (about 3.0) but coupled with a $\Sigma Zr + Nb + Ce + Y = 181$ and also with a lower Sn content. Nevertheless, its Ga content is not higher than that of the other samples, characterized by a Ga/Al ratio in the range 2.1–2.8 and by a $\Sigma Zr + Nb + Ce + Y$ in the range 97–212. Therefore the classification of the BM_{12} sample is dubious.

In order to identify the provenance of the studied pebbles, their analytical data have been compared with those of syn- to late-Hercynian granitoids coming from the Calabria-Peloritani Arc (282 analyses: Ayuso et al. 1994; Barone 2000; Caggianelli et al. 1994; Crisci et al. 1979; Fornelli et al. 1994; Ioppolo & Puglisi 1980; Messina et al. 1991a,b; Rottura et al. 1989b, 1991) and from the Kabylian massifs (14 analyses: Peucat et al. 1996).

The composition of the studied rocks overlaps the compositional field of the compared samples, with regard to major and some trace elements, but the Rb, Sr and Ba contents are rather different. The analysed pebbles (except the outsider one) show a higher Rb and lower Sr and Ba contents than the granitoids of the Calabria-Peloritani Arc and of the Kabylian massifs (Fig. 8). It is highly unlikely to link the contents of these elements to possible mechanisms of alteration responsible for a loss of Sr and Ba accompanied by an increase of Rb, as a kind of K-Rb metasomatism, which can occur only with great difficulty in hypergene conditions. Moreover, the analysed granitoid pebbles could contain carbonate products of alteration, which would produce an increasing of the Sr content rather than its decrease. That seems to be testified by the good correlation of CaO vs. Loss on Ignition (this last also including

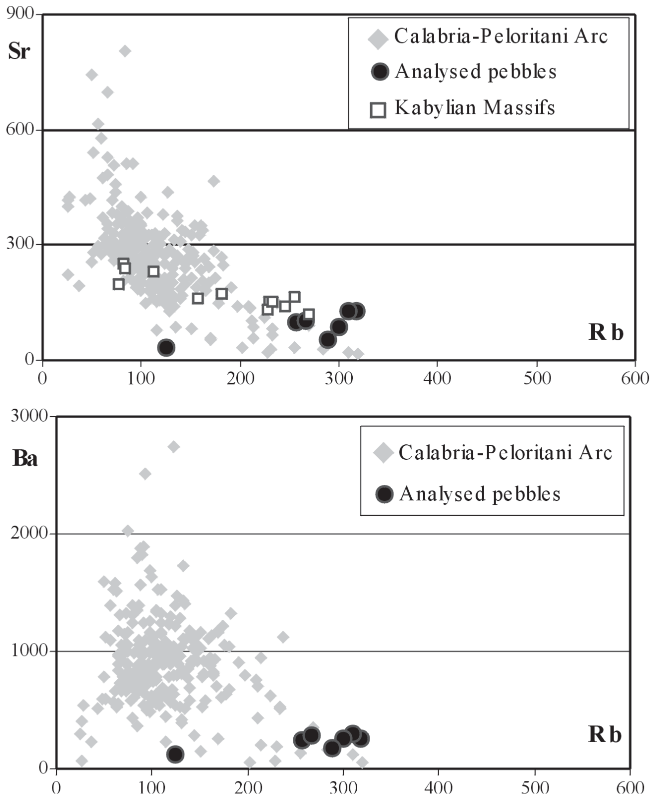

Fig. 8. Variation diagrams showing the Sr, Rb and Ba contents of the analysed pebbles compared with the syn- to late-Hercynian plutonic rocks of the Calabria-Peloritani Arc and of the Kabylian massifs.

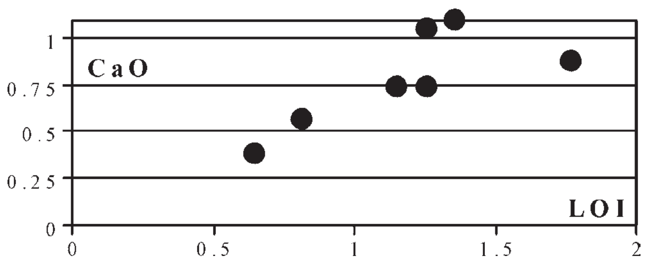

Fig. 9. CaO vs. LOI diagram showing a positive correlation.

some CO_2, Fig. 9). For this reason it is improbable that the granitoids of the Calabria-Peloritani Arc and of the Kabylian massifs represent the source lithotypes of the studied pebbles.

Then, we compared the pebble data with those of Hercynian and/or pre-Hercynian granitoids coming from the Iberian Massif (central Spain and northern and central Portugal, 115 analyses: Bea et al. 1994; Holtz & Barbey 1991; Mendes & Dias 1996; Neiva et al. 1987; Ramirez & Menendez 1999; Rottura et al. 1989a; Wickham 1987) and from the Morocco (north-eastern Morocco, western High Atlas and western-central Anti-Atlas; 109 analyses: Ajaji et al. 1998; Barbey et al. 2001; Eddif et al. 2000; El-Khanchaoui et al. 2001; Gasquet et al. 1992; Mortaji et al. 2000) as well as with the Pan-African plutonites of the Algeria (55 analyses: Cheilletz et al. 1992; Hadj-Kaddour et al. 1998; Kesraoui & Nedjari 2002).

The granitoids from Morocco show high Sr and Ba contents, higher than the studied pebbles, whereas the granitoids from Algeria show very scattered Rb contents of > 600 ppm (until 1698 ppm). The Rb, Sr and Ba contents of the studied pebbles are only quite equivalent to those of the Iberian Massif granitoids (Fig. 10) as well as the other geochemical characters (i.e. major-oxide composition and trace elements).

The Hercynian granitoids of Iberia (Spain and Portugal) have been subdivided, on the basis of their relationships with the main deformation events, into older syn-tectonic and younger post-tectonic granitoids (Oen 1958, 1970; Schermerhorn 1959). The studied pebbles exhibit chemical characters similar to those of syn- and post-collision granitoids.

So, in conclusion, the geochemical data obtained and the results of this comparison with many Hercynian and pre-Hercynian plutonic products characterizing the western peri-Mediterranean chains and their foreland areas allow us to admit that the analysed pebbles could well be mainly compared with the Hercynian granitoids of the Iberian Massif.

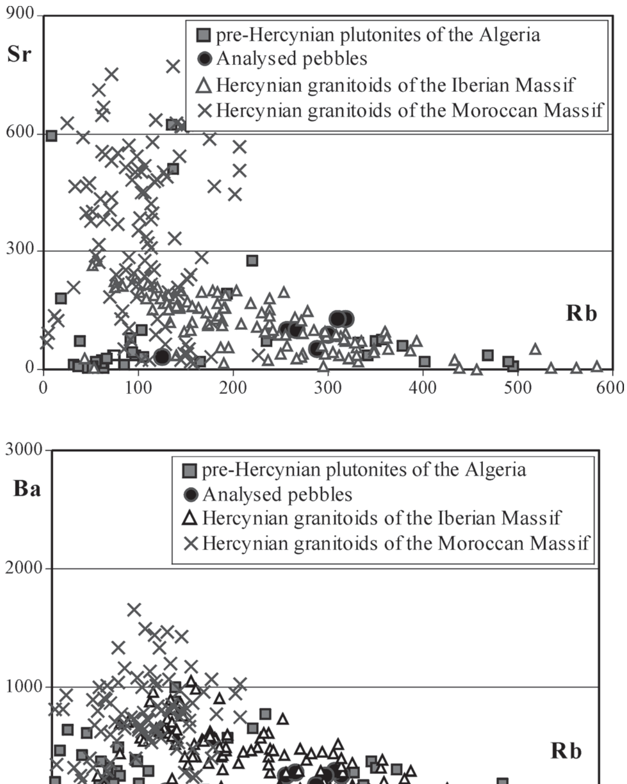

Fig. 10. Variation diagrams showing the Sr, Rb and Ba contents of the analysed pebbles compared with the Hercynian plutonic rocks of the Iberian and Moroccan massifs and with the pre-Hercynian plutonites of Algeria.

Conclusions

Petrographic affinities between granitoid pebbles very similar to those described here and the syn- to late-Hercynian plutonites of the Calabria-Peloritani Arc have been many times emphasized by studying the conglomeratic horizons of the Oligocene-Miocene covers of the Ghomaride/Malaguide complexes (Betic-Rifian Chain, Martin-Algarra et al. 1995, 2000; Zaghloul et al. 2003) and of the coeval more external deposits (Beni Ider Flysch), first recognized by Puglisi et al. 2001.

Also in this study the results of the modal analyses show a very close similarity between the composition of these plutonic pebbles (two-mica, cordierite-bearing monzogranite up to leuco-monzogranite) and that of the above mentioned plutonic bodies of the Calabria-Peloritani Arc, thus confirming the previous data collected by Puglisi et al. 2001.

Nevertheless, the comparison of some geochemical characters (mainly the Rb, Sr and Ba contents) seems to exclude the possibility of correlating the analysed granitoids with the plutonic rocks of the Calabria-Peloritani Arc and of the Kabylian massifs and, of course, to consider these areas as possible sediment sources. In the same way, the Hercynian plutonism characterizing the Moroccan (north-eastern Morocco, western High Atlas and western-central Anti-Atlas), as well as the Pan-African plutonites of Algeria, appear to be very different in geochemical composition from the analysed granitoid pebbles and so these rocks cannot be identified as source areas.

In contrast, the comparison with the Hercynian granitoids of the Iberian Massif (central Spain and northern and central Portugal) shows a very strong geochemical affinity with the plutonic pebbles described in this study.

Thus, owing to the small number of analysed granitoid pebbles, it is very difficult to support new hypotheses of provenance even if the above mentioned geochemical affinities could suggest a new paleogeographical scenario, where these granitoid pebbles could be closely linked to the Iberian Massif. These results seem to re-open the debate concerning the source areas of the granitoid pebbles found in sedimentary successions belonging to two adjacent paleogeographical domains (Internal Domain and Flysch Basin Domain of the Rif Chain) and they show two possible provenances.

The first one (Martin-Algarra et al. 1995, 2000) is related to a sediment source formed by a “presently lost continental crust realm”, originally located very near to the Malaguide/Ghomaride Domain. In this case, the plutonic sources are completely lacking in outcrop and, up to now, they have not been found because they are now (1) buried and/or obliterated under thick Miocene successions or (2) collapsed and submerged in the Alboran Sea. In this way, we suggest that the few but significant geochemical results of this study which provide evidence of igneous rocks forming this "lost continental crust realm" more similar to the Hercynian plutonites of the Iberian Massif rather than those of the Calabria-Peloritani Arc and/or of the Kabylides, as hypothesized by Martin-Algarra et al. (1995, 2000) should not be neglected.

The second possible alternative of provenance is to suppose the Iberian Massif as the source area of the analysed granitoid pebbles. In this case, we must hypothesize that, during Late Oligocene–Aquitanian times, it could have been an intermittent source area, which sporadically fed small satellite basins located in the more elevated portions of the folded overthrust belt (i.e. the Ghomaride Units, Zaghloul et al. 2003). That seems to be testified by the presence of episodic conglomerate horizons with granitoid pebbles, interbedded within the mainly arenaceous-pelitic succession of the Ghomaride Complex covers. According to the scarcity of feldspar grains within the sandstones (Zaghloul et al. 2003), in fact, the provenance of the whole succession has mainly been linked to the same Ghomaride realm rocks (metasedimentary and epimetamorphic rocks with carbonate covers), rather than to plutonic sources.

Furthermore, it is possible to admit that also the provenance of the Beni Ider Flysch is closely related to the Iberian Massif, and probably to its pre-Betic cover, at least for the lower portion of the succession where the composition of the sandstones is enriched in feldspars and where the coarse- to very coarse-grained (up to conglomerate) lithofacies shows an abundance of plutonic pebbles (Puglisi et al. 2001; Zaghloul et al. 2002).

In conclusions, if this second hypothesis of provenance is supported and confirmed by further data, than we could imagine a paleogeographical scenario consisting of a drainage basin made up also by the Iberian Massif terranes.

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