COMPARISON OF LATE HERCYNIAN GRANODIORITE GEOCHEMICAL TYPOLOGY IN BÉNI-SNASSÈNE (NORTH-EASTERN MOROCCO), WITH IBERIAN HERCYNIAN MASSIFS

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Abstract: The late Hercynian Béni-Snassène massif is formed of calc-alkaline granite rocks of peraluminous character. The bulk of the massif is composed of biotite granodiorite, while the intrusive leucogranite is very minor in the exposed surface. Rare Earth Element patterns of the granodioritic rocks are slightly fractioned in light REE and are almost flat in heavy REE patterns. The high proportion of mafic microgranular enclaves, along with the previous data of intermediate strontium isotopic value (0.7084), suggest that the granodiorite represents hybrid magma (crust+mantle), produced in the lower crust by the melt which resulted from the interaction and mixing of mantle and crust. The orogenic calc-alkaline signature probably originated from a metasomatized mantle source. Due to their age (post main Hercynian phases), their chemical features (K_2O, LILE, LREE enriched) and the lack of subduction evidence, the Béni-Snassène granitoids are similar to those which originate in post-collisional settings.

Keywords: Béni-Snassène, Calc-alkaline, Granodiorite, Hercynian, Morocco, Peraluminous.

Resumen: Del estudio qeoquímico del macizo granodiorítico tardi-Hercinico de Béni-Snassène se deduce que pertenece al grupo de los granitoides calco-alcalinos peralumínicos. Desde un punto de vista geoquímico se caracteriza por el marcado fraccionamiento en tierras raras ligeras. Mientras que los contenidos en tierras raras pesadas muestran un espectro plano. La presencia de numerosos enclaves básicos, además del valor intermedio de las relaciones isotópicas iniciales de estroncio (0,7084), sugieren que la granodiorita representa un magma de origen híbrido, producido por interacción y mezcla de un magma de derivación mantélica y de líquidos que resultan de la fusión de la corteza inferior. Por su edad (post fase principal hercínica), sus características geoquímicas (enriquecimiento en K_2O, LILLE, LREE) y por su contexto geotectónico (ausencia de evidencias de subducción), los granitos de Béni Snassène son similares a los magmas de contextos post-colisionales. La impronta calco-alcalina estaría probablemente en relación con una fuente mantélica anteriormente metasomatizada.

Palabras clave: Béni-Snassène, Calcoalcalino, Granodiorita, Hercínico, Marruecos, Peralumínico.

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The Moroccan Hercynian belt is composed of the a pericratonic margin weakly mobilized in the Upper Paleozoic (Anti-Atlas Mountains) and Paleozoic terrains in northern Morocco, both were affected by Variscan movements during Late Devonian to Upper Carboniferous-Permian (*e.g.*, Michard *et al.*, 1983; Hoepffner, 1987; Tahiri, 1991; Piqué *et al.*, 1993). The Hercynian domain of northern Morocco, which has not been deformed by Atlasic and Rifain movements, constitutes the so-called Meseta, within which many works of classic stratigraphy (e.g., Destombes *et al.*, 1985) and of structural synthesis (*e.g.*, Piqué *et al.*, 1993 and references therein) have distinguished several structural zones, from West to East: Coastal Mole, the tectonic zones of the Central Meseta, the eastern napes zones, the eastern Meseta, and the zone of Rabat-Tiflet.

Hercynian granites are all located in the Moroccan mesetian domain. Most of these massifs are formed by circular plutons that cross Hercynian structures. They intruded at different levels into Paleozoic series and are generally limited by NE-SW shear zones.

Regional structural and geochronological constraints show that most of the granite rock seems to have intruded in the latest stages of the Hercynian deformation (*i.e.* Upper Carboniferous - Permian). According to Mrini *et al.* (1992), ages of these granite bodies ranging from 330 Ma to 250 Ma, enable the definition of two Hercynian magmatic episodes; (i) intrusion of granodiorite (330-275 Ma) and of leucogranite (300-275 Ma) plutons, (ii) intrusion of late and monzonitic alkali granites (275-250 Ma). Gasquet *et al.* (1996) propose three magmatic series: calc-alkaline, sub-alkaline, and peraluminous.

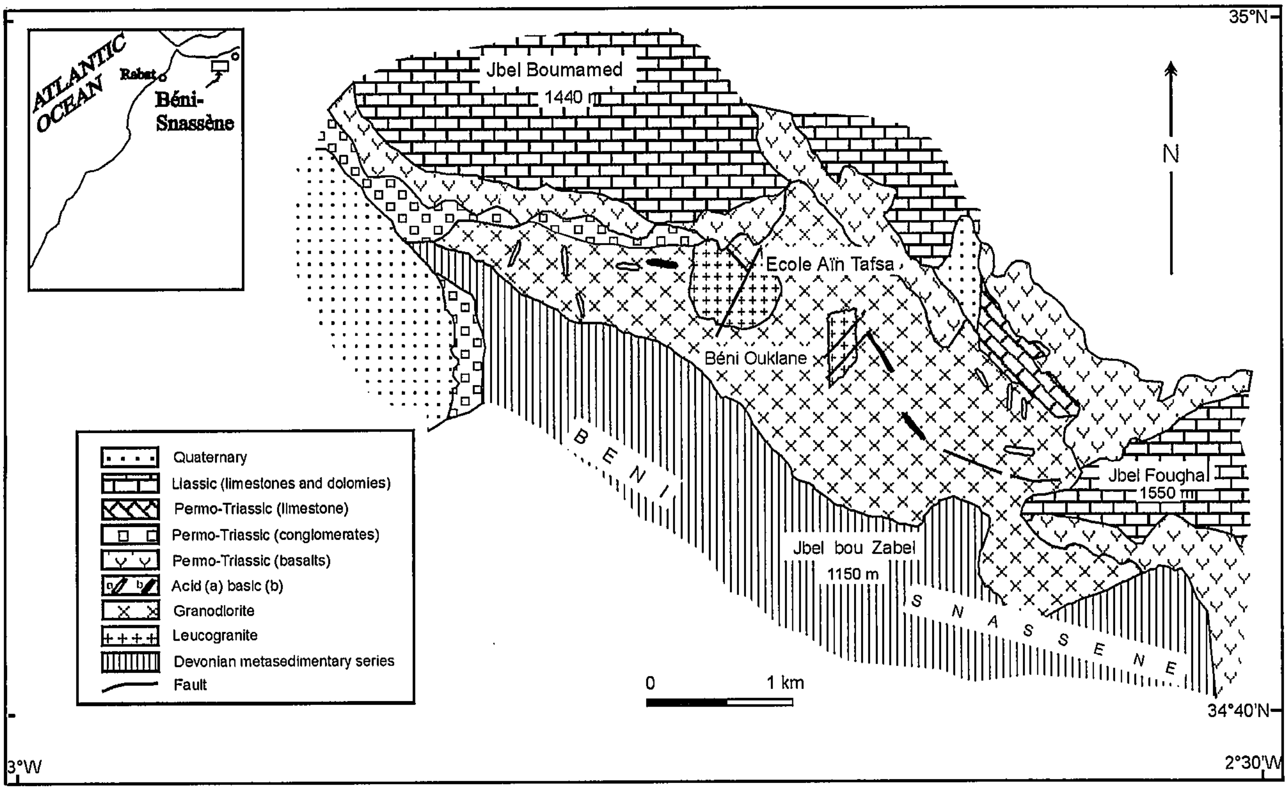

Figura 1.- Geological sketch of the Béni-Snassène granitic massif (modified from Tougant, 1989).

In spite of controversial interpretations, an intracontinental and post-collisional geodynamic setting is accepted by many authors (Diot, 1989; Lagarde *et al.*, 1992; Berrada, 1993; Boushaba, 1996; Gasquet *et al.*, 1996; El Hadi, 1998).

The purpose of this paper is to describe the geochemical classification of the granodioritic facies (eastern Moroccan Meseta) and to discuss its evolution within the regional geodynamic environment.

Geological setting

The late Hercynian Béni-Snassène granite massif (247±7Ma; Mrini *et al.*, 1992) is located in the eastern Moroccan Meseta, about 30 kilometres north-west of the city of Oujda (Fig. 1). The massif has an approximate elliptical-shape, and spreads from north-west to the south-east and is six to seven kilometres in length and two to three kilometres in width, covering a total surface of 17 km^2. It has outcrops within the Lower Devonian metasedimentary series (Marhoumi, 1984) that essentially contains graywackes rich in plant debris and interlayered with schist, slate and sandstone beds. This series is affected by regional greenschist metamorphism (370 Ma; Clauer *et al.*, 1980) which are accompanied by N 70° folding (Hoepffner, 1987). They are unconformably overlain by mesozoic rocks (Fig. 1).

Cartographical, petrographical and geochemical studies of the massif distinguish two main facies (Fig. 1): an important greyish granodioritic mass with or without feldspar phenocrysts, coarse-grained and which is volumetrically the largest lithological type within the massif. Granodiorites are intruded in its core by a finer grained leucogranite of a pinkish colour. The contact between the two facies, often badly defined, sometimes faulted, is marked by an important concentration of mafic microgranular enclaves (MME) in a transition zone of some ten meters.

Petrography

Granodiorite

The rock consists mainly of a greyish coarse-grained granite. The primary mineral paragenesis consists of plagioclase, quartz, orthoclase, biotite. Accessory minerals are apatite, zircon and allanite. There is a total absence of pyroxene and amphibole.

Plagioclase (40-50 % by volume) occurs usually as subhedral zoned crystals, averaging 1 to 1.5 mm in length. Plagioclase crystals are frequently polysynthetic and carlsbad twinned. Synneusis textures are common and sericitization is scarce. Its composition ranges from An_{35} (core) to An_{28} (rim) in an oscillatory zoning.

Quartz (17-30 %) occurs as euhedral crystals, more or less recrystallized, sometimes interstitial including biotite and plagioclase. It is cross-cut by some fissures filled by colourless muscovite.

Perthitic alkali feldspar (13-20 %) occurs in interstitial positions that are suggestive of late crystallization, which involves the inclusion of several mineral phases like euhedral plagioclase, biotite, quartz and apatite.

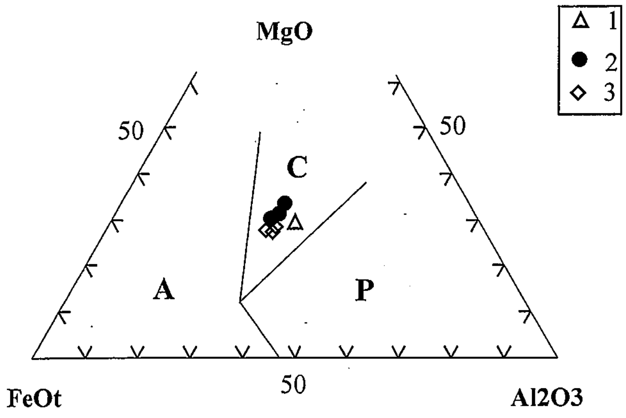

Figura 2.- Abdel-Rahmane's (1994) Al_2O_3-FeOt-MgO plot. A: Biotites in anorogenic alkaline suites, C: Biotites in calc-alkaline orogenic suites, P: Biotites in peraluminous suites. 1: Granodiorite, 2: Mafic enclaves, 3: Leucogranite.

Biotite (10-15 %) is the only ferromagnesian silicate found in the granodiorite. It occurs as subeuhedral flakes (0.5 mm), sometimes interstitial, including opaque, apatite and plagioclase grains. Biotite may be pseudomorphosed by chlorite and epidote. Using the Abdel-Rahman's discriminating diagram (1994), biotite from the granodiorite, leucogranite and mafic enclaves samples plot within the orogenic calc-alkaline field (Fig. 2).

Leucogranite

This crops out within granodiorite and differs from the latter by its pinkish colour due to its higher content in K-feldspar, by its finer grain size, and also by its high resistance to climate. The contact between the two types of rocks, often difficult to establish, is emphasised by the abundance of mafic microgranular enclaves. Microscopically, leucogranites show a finer-grained texture with mineral association including perthitic K-feldspar, plagioclase, quartz and biotite.

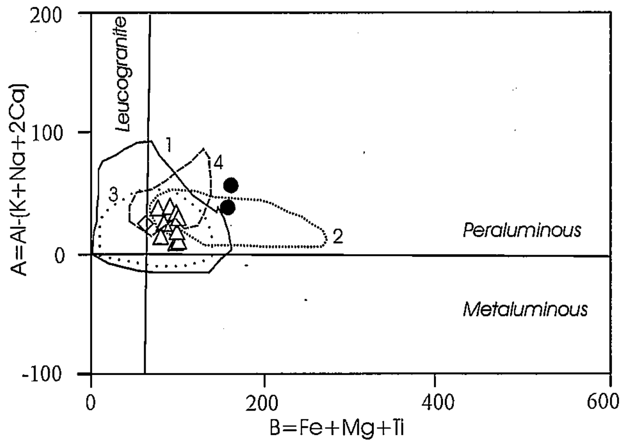

Figura 3.- The Béni-Snassène granites in the A-B diagram of Debon and Le Fort (1983). Symbols as for Fig. 2. 1.- Biotite granitoids (NW of Spain, Ortega and Ibarguchi, 1991). 2.- Santa Olalla (Salman, 2002). 3.- Gredos granites (Villaseca *et al.*, 1998). 4.- Boudoufoud granites (El Hadi, 1998).

Plagioclase (28-35 %) is the most abundant mineral. It occurs mainly as small subhedral crystals (1 mm) with a constant composition of oligoclase (An_{12}). It is albite, carlsbad, and sometimes pericline twinned. The core of the crystals concentrates an important quantity of secondary sericite.

Biotite (4-10 %) forms small euhedral flakes of a medium size (0.5 mm). It is relatively less chloritised than in the granodiorite facies. It includes apatite, zircon, and iron oxides.

K-feldspar (25-35 %) is abundant in this rock. It occurs in interstitial position (5 mm) including all the others mineral phases (euhedral and altered plagioclase, biotite, quartz, and acicular apatite).

Quartz (25-30 %) is either euhedral, sometimes interstitial, containing altered plagioclase and acicular apatite.

Accessory minerals are apatite, zircon and iron oxides.

Chemical Characteristics

Major, trace and rare earth element abundances of the selected samples are given in Table I. A whole-rock chemical analysis was determined by X-ray fluorescence and instrumental neutron activity at the Applied Geology Laboratory at the Catholic University of Leuven (Belgium). Some samples (BS21,14; BS20,12; BS20,14; BS21,11) have been determined by X-ray fluorescence and Instrumental Coupled plasma spectrometry at the Ecole des Mines at Saint Etienne (France). The precision and accuracy of the methods have been given by Chayla *et al.* (1973) and Leoni and Saitta (1976), respectively.

Major Elèments

Compositions of representative samples of granodiorite (Table 1) show that:

- Na_2O contents ranging from 2.6 to 3.7 (in weight %) are important and express the abundance of plagioclase (An_{28} and An_{35}). All the samples have K_2O / $Na_2O > 0.5$ (0.9-1.5) and they are thus classified as high potassic rocks. The values of the MgO, varying between 1.4 to 2.1 (in weight %), relate especially to the presence of biotites.

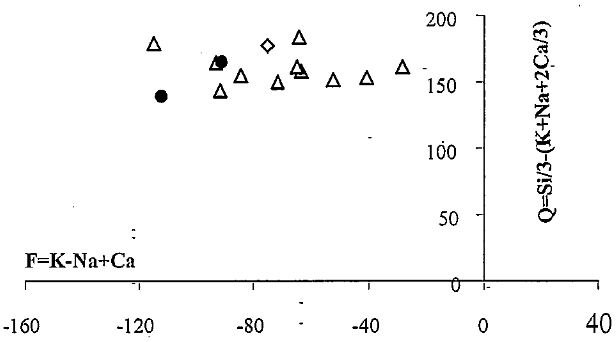

Figura 4.- The Béni-Snassène granites in the PQ diagram of De la Roche (1964). Symbols as for Fig. 2.

	Granodiorite											*Leucogranite*	*Xenoliths*	
Samples	BS21,14	BS3*	BS20,12	BS7*	BS21*	BS20,14	BS1*	B11	B15	B10	B16	X2	BS4,3	BS21,11
SiO2	66,34	66,95	67,10	67,04	67,27	67,44	67,57	69,01	67,62	68,28	67,41	72,00	61.93	62.90
TiO2	0,64	0,55	0.40	0,39	0,55	0,53	0,55	0.52	0.59	0,51	0,60	0,75	1.00	0,84
Al2O3	14,70	15,45	15,46	14,99	15,87	15,64	15,42	14,51	14,22	14,90	14,86	14,11	15,53	16,01
Fe2O3	0,66	0,59	0,41	0,48	0,56	0,55	0,61	0.18	0,18	0,10	0,56	0,30	1,17	1,18
FeO	3,30	2,97	2.07	2,38	2,81	2,76	3,06	2,89	3,40	2,88	2,79	1,49	3,90	3.93
MnO	0,12	0,08	0.10	0,07	0,08	0,08	0,10	0,07	0,11	0.08	0,08	0,05	0.10	0,14
MgO	2,21	1,82	1,42	1,55	1,77	2.07	1,71	1.36	1,89	1,52	1.78	0,49	3.36	3,21
CaO	1,63	2.05	2,76	1,72	2,44	2.45	2,77	2.70	2.37	1,98	2.32	1.34	2,51	3,18
Na2O	2,91	3,07	2,65	3,45	3,58	3,69	3,75	3.60	3,24	3,49	3,52	3,98	3,03	3,54
K2O	4,44	4,47	3,33	4,20	3,50	2,26	3.69	3,35	3,86	3,98	3,92	3,64	2,44	2,78
P2O5	0,22	0,00	0,14	1,40	0,13	0,19	0.00	0,12	0,12	0,10	0,13	0,00	0,39	0,26
LOI	1,39	0,61	3,90	1,07	1,29	2,05	0.61	0,74	1,55	1,22	1,19	1,17	3,78	1,03
Total	98.56	98,61	99,74	98,74	99,86	99.71	99,84	99,05	99,15	99,04	99,16	99,31	99,14	98,99
A/CNK	1,17	1.14	1,19	1,12	1,12	1,21	1,01	1.00	1,03	1,09	1,04	1,09	1,27	1,10
Sc	9,26		5,29			7,99		8.00	8,90	7,50	8,40	0,00	14,50	12,00
Cr	59.40		31,4			52,60		50,00	50,00	43.00	48,00	1,43	63,90	90,00
Co	12,20		3,44			7,14		8,50	9,80	7,31	9,80	0,43	17,90	13,60
Zn	76,50		35			42,30		48,00	64,00	74,00	68,00	21,50	121,00	76,60
Rb	143,40		138,6			86,90		148,00	141,00	152,00	151,00	33,66	140,40	146,00
Sr	297,00		137			361,00		407,00	416,00	434,00	470,00	6.65	298,00	396,00
Y	18,20		19,4			17,40		17,00	17,00	15,00	17,00	0,00	29,60	23,10
Zr	142,50		151,3			122,80		145,00	150,00	129,00	142,00	2,56	80.00	178,10
Nb	10,14		5,71			9,50		10,10	11,20	9,50	13,50	1,19	15,90	13,60
Ba	825,00		428			333,00		641,00	759,00	882,00	682,00	30,73	919,00	703,00
Hf	9,00		7,7			8,60		4,30	0,80	4,00	4,40		7,00	7,10
Ta	nd		nd			nd		1,11	1,33	1,13	1,69		nd	nd
Pb	32,80		8,3			14,10		18,00	20,00	37,00	25,00		18,40	20,30
Th	14,40		2,59			9,90		14,10	13,10	8,80	13,80		6,78	9,49
U	3,30		5,6			3,10		6,40	4,60	4,80	5,00		3,50	4,10
La	41,10		35,70			31,90		34,30	36,70	25,20	33,30		25,30	38,90
Ce	73,20		66,10			59,30		69,10	73,30	48,60	69,50		50,80	68,00
Nd	12,80		17,00			9,96		27,00	28,20	19,10	27,20		0,00	8,13
Sm	5,70		5,66			4,29		4,78	5,30	3,67	4,87		6,53	5,66
Eu	1,13		1,36			1,13		1,11	1,21	1,11	1,21		1,12	1,25
Tb	nd		nd			nd		0,58	0,58	0,47	0,57		nd	nd
Yb	1,72		1,49			1,58		1,59	1,63	1,40	1,73		2,70	2,25
Lu	nd		nd			nd		0,25	0,22	0,21	0,24		nd	nd
(La / Yb)	N15,98		16,02			13,50		14,43	15,06	12,04	12,87		6,27	11,56
(La / Sm)	N4,45		3,89			4,59		4,43	4,27	4,24	4,22		2,39	4,24

Table I-. Major, trace and rare earth element analyses of the Beni-Snassène granites. * Analyses from Rosè (1987).

- In the A-B diagram (Debon and Le Fort, 1983) (Fig. 3), where factor A is the Al saturation index and factor B is the sum of Fe+Mg+Ti, which reflects the content of ferromagnesian phases (Biotite, Amphibole, Pyroxene, etc.), there is a distribution of all representative samples of the granodiorite, within the peraluminous domain (zone I with biotite only).

- At first sight, their peraluminous character (Clarke, 1981) with A/CNK ($Al_2O_3/CaO+Na_2O+K_2O$, molar ratio) values varying between 1.00 and 1.21, points to an S-type provenance. However, the presence of mafic microgranular enclaves and the low $^{87}Sr/^{86}Sr$ initial ratio (0.7084±0.0001; Mrini *et al.*, 1992) point out that these granites are closer to I-type granitoids defined by Chappel and White (1974) or H-type after the classification of Castro *et al.* (1991). It is now accepted that some I-type magmas become moderately peraluminous for high degrees of fractionation and/or assimilation of large volumes of crustal material by basaltic liquids (*e.g.*, Atherton and Sanderson, 1987; Castro *et al.*, 1999). The Béni-Snassène granodiorite possibly corresponds to a modified I-type granitoid. Similar peraluminous biotite-granodiorites have been described in the Moroccan Meseta (El Hadi, 1998), as well as in the Iberian Massif, particularly in the Central Iberian zone (*e.g.*, Azevedo and Nolan, 1998; Villaseca *et al.*, 1998; Castro *et al.*, 1999; Salman, 2002 and references therein) (Fig. 3).

- In the PQ diagram of De la Roche (1964), the representative points of the granodiorite plot in adamellite field and define a general calc-alkaline evolution, in the range of series established by Albert *et al.* (1988) (Fig. 4). Such a trend is also consistent with the Peacock's classification (Fig. 5).

Trace elements

Figure 6 shows chondrite-normalized REE patterns. All the analysed granodiorite samples display

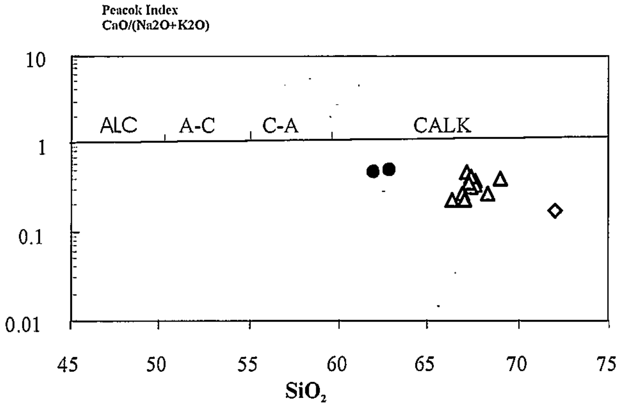

Figura 5.- Peacock index (1931) (CaO/Na$_2$O+K$_2$O) versus SiO$_2$. Symbols as for Fig. 2.

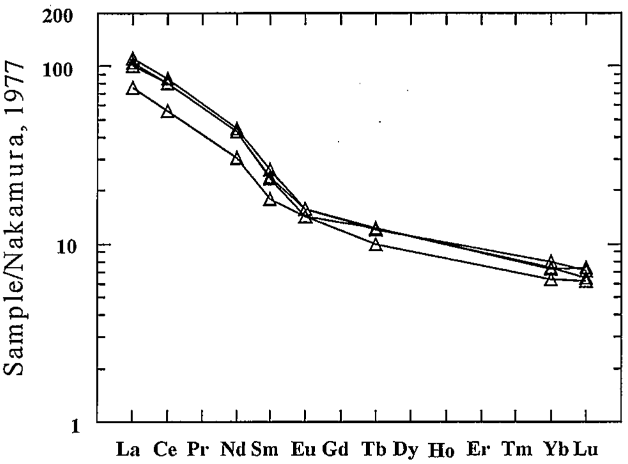

Figura 6.- Normalized chondrite (after Nakamura, 1974) REE patterns for Béni-Snassène granodiorite.

fractionated light REE (LREE) and flat heavy (HREE) patterns similar to calc-alkaline series (Cocherie, 1978). They show a high (La/Yb)$_N$ ratios ranging from 12 to 16. The negative Eu anomaly is practically negligible.

In a normalized trace element plot (Fig. 7), all the granodioritic samples exhibit similar patterns. They are characterized by high abundances of K, Rb, Ba, Ta and La (LILE/HFSE > 10 ratio), and relative depletion of Nb, typical of continental crustal material (Taylor and McLennan, 1985).

Discussion

Both major elements and REE abundances demonstrate that the Béni-Snassène granodiorite, constitutes a suite of peraluminous granite rocks of a calc-alkaline affinity.

As expected from the A/CNK ratios value (1.0-1.19), granodioritic samples seem to belong to S-type granites. Nevertheless, as inferred above (presence of micrograņular mafic enclaves-MME, relatively low ^{87}Sr/^{86}Sr ratios), suggest that rocks may not been exclusively derived from supracrustal sources. The composition of the region source and parental magma of the granodiorite could be approached from the MME. Their Mg number varying between 0.55 and 0.57 is not consistent with their derivation from mafic lower continental crust (Taylor and McLennant, 1985).

The origin of the granodiorite would be better approached with a detailed isotopic study (Sr, Nd, O). However, the occurrence of MME and the presence of oscillatory zoning in plagioclase, zircon typology data (El Hadi *et al.*, 1996; type-4 after Pupin, 1980) and the value of the initial strontium ratio (0.7084 ± 0,0001) seem to support a mixed crust-mantle origin (interaction between the continental crust and upper mantle in this region during Variscan orogeny). This explanation has also been applied to the Hercynian granites of the Moroccan Meseta (*e.g.*, Mrini *et al.*, 1992) and the Iberian Massif (*e.g.*, Moreno Ventas *et al.*, 1995; Castro *et al.*, 1999).

All the samples display negative Nb anomaly, which is interpreted as an indicator of crustal contamination of magma (Dupuy and Dostal, 1984), or as inherited from a metasomatized lithospheric mantle (Coish and Sinton, 1992). These features, combined with high Ba/Nb ratios (>30, after Gill, 1981) are similar to subduction-related magmas. However, the absence of a subduction zone and traces of blueschist metamorphism during the Hercynian orogenesis, shows that the Nb anomaly and the calc-alkaline signature derived from partial melting from a previously metasomatized lithospheric mantle during an earlier subduction event - probably Panafrican. As in the Alpine and Pyrenees regions, no evidence exists for Palaeozoic calc-alkaline magmatism to be associated with an active margin system. Permo-Carboniferous andesites and dacites from the Spanish Central System and Iberian Range were also considered as late-orogenic instead of subduction-related magmas (Thiéblemont and Teggey, 1993; Doblas *et al.*, 1994).

According to petrographical and geochemical features (presence of biotite, TiO$_2$ < 0.87 % wt, enrichment in K, Ba, Th and LREE, Rb/Zr < 2), the Béni-Snassène granodiorite is similar to granitoids from post-collisional context (Harris *et al.*, 1986).

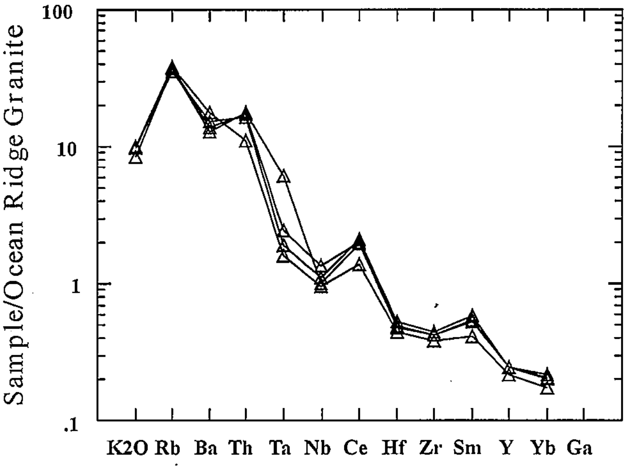

Figura 7.- Normalization diagram with respect to Primitive Ocean ridge granite (Pearce *et al.*, 1984) for the Béni-Snassène granodiorite.

Conclusions

Based on petrographical and geochemical evidence; the biotite granodiorite which constitutes the main volume of the Béni Snassène massif displays characteristics of high-K calc-alkaline I-type peraluminous magmatism. It shows many similarities with post collisional granitoids (as the Variscan Iberian granites) originated by partial melting from a related-subduction metasomatized mantle.

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