

The Edough leptynites, Annaba, NE Algeria, are they good indicators to the origin of the biotite gneisses ?

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Abstract : The petrology and chemistry of eleven leptynites from the Edough metamorphic complex are described. Geochemical studies suggest that the rocks are metamorphosed crustally-contaminated granites while detailed trace element modelling indicates they are neither partial melts of the intimately associated biotite orthogneisses nor they represent their more differentiated end-member. It is concluded that the leptynites are acid dykes or sills crystallised from a later magma relative to that from which the biotite orthogneisses were generated and hence cannot be used as a guide to the origin of the biotite gneisses.

Key words : Edough, leptynites, petrogenesis, S-type, dyke, sill.

Les leptynites de l'Edough, Annaba, NE Algérie, sont-elles de bons indicateurs pour l'origine des gneiss à biotite ?

Résumé : La pétrologie et la chimie de onze leptynites du complexe métamorphique de l'Edough sont décrites. Des études géochimiques suggèrent que ces roches sont des granites métamorphisés influencés par une composante crustale. Des modèles détaillés basés sur les éléments en trace indiquent que les leptynites ne sont, ni des produits de fusion partielle des orthogneiss à biotite, ni leurs composants plus différenciés. Il est conclu que les leptynites sont des dykes ou sills cristallisés d'un magma différent de celui à partir duquel les gneiss à biotite sont dérivés et en conséquence ne peuvent pas être utilisés comme indicateurs de l'origine des gneiss à biotite.

Mots clés : Edough, leptynites, pétrogenèse, S-type, dyke, sill.

INTRODUCTION

The Edough massif is the easternmost metamorphic complex of northern Algeria and consists mainly of gneisses and pelites (e.g. Hilly, 1962 ; Vila, 1970 ; Marignac, 1985 ; Gleizes *et al.*, 1988 ; Ahmed-Saïd and Leake, 1992, 1993, 1993 a & b ; Ahmed-Saïd *et al.*, 1993). The biotite gneisses form the lowest unit and whether augen-bearing or not, are made of 15-60 % ^xMg 0.30-0.40 biotite, 25-35% quartz, 15-25% ^{An}10-40 plagioclase, 10-25% ^{Or}80-90 K-feldspar, 0,8% ^xMg 0.08-0.25 garnet ± amphibole

± tourmaline ± fibrolite ± andalusite ± secondary muscovite with accessory zircon and apatite. The biotite gneisses were calc-alkaline igneous rocks which underwent high temperature ($T=800\pm 50^{\circ}\text{C}$) and medium pressure ($P=4\pm 1\text{ kb}$) isochemical metamorphism (Ahmed-Saïd and Leake, 1993). The gneisses are immediately overlain by biotite - garnet - muscovite - plagioclase - quartz ± staurolite ± sillimanite ± andalusite termed the garnet pelites which are followed by muscovite - biotite - graphite ± kyanite ± andalusite ± staurolite ± garnet ± K-feldspar ± plagioclase schist termed the kyanite pelites ($T=600\pm 30^{\circ}\text{C}$,

P=7-9 kb). Above this unit are Palaeozoic (Ilavský and Snopková, 1987) andalusite-rich pelites regularly alternating with centimetre to metre-sized feldspathic metaquartzites ($T=500\pm 50^{\circ}\text{C}$, $P=2.5\pm 1\text{ kb}$) and sometimes containing some 0.5-100m thick muscovite-rich augen orthogneisses.

The biotite gneisses examined at Cap de Garde and along the Annaba-Seraïdi road and indeed in most parts of the easternmost parts of the massif (fig. 1) contain layers (usually 1.5 x 5 m but up to 6 x 40 m in size) of well foliated leucocratic rocks which, for the sake of simplicity, will be termed leptynites. Since the origin(s) of the biotite gneisses is still controversial, it is thought that the leptynites may give valuable information in this respect and hence could be used as tracers to the origin of the biotite gneisses during mapping especially as previous workers (e.g. Gleizes *et al.*, 1988) link the leptynites with the orthogneisses and there is no unequivocal field evidence to the origin of these rocks. To achieve this, 20 thin sections were examined and eleven rocks were analysed in the Department of Geology and Applied Geology, University of Glasgow for both trace and major elements using the methods of Leake *et al.* (1969) and Harvey *et al.* (1973) respectively.

PETROLOGY AND GEOCHEMISTRY

The leptynites are medium to fine grained well foliated rocks and are confined to and always concordant with the biotite gneisses. Both rock types consist of the same mineralogy but with different proportions; the leptynites being essentially poorer in biotite and garnet and richer in quartz and K-feldspar compared with the biotite gneisses. The two rocks are intimately associated and occasionally grade to one another thus leaving the question open to whether they are contemporaneous and thus are of the same

origin; the leptynites are the more differentiated end-member of the biotite orthogneisses, they are rocks resulted from the partial melting of these biotite gneisses and were subsequently segregated therein or indeed they are rocks of completely different origins. The leptynites are composed of 35-55% quartz, 25-45% partly sericitized K-feldspar, 20-35% generally fresh unzoned An_{5-25} plagioclase, 2-25% pale brown biotite plates (X_{Mg} (ions $\text{Mg}/\text{Fe}+\text{Mg}$) = 0.20-0.35), 0.5-6% essentially unzoned poikiloblastic almandine (X_{Mg} = 0.1-0.25), 0.5-3% grey bluish zoned tourmaline with accessory zircon, apatite and secondary muscovite. Like the Edough biotite and muscovite gneisses (Ahmed-Saïd and Leake, 1993, 1993a), the leptynites do also contain occasional augen (average 1.2 x 0.3cm in diameter) of essentially unzoned and partly sericitized K-feldspar which can form an angle of about 15-20° with the foliation planes.

The large mineralogical variations of the leptynites particularly in terms of their quartz, biotite, K-feldspar and plagioclase contents is clearly reflected in their chemistry (table 1). SiO_2 varies from 75.24 to 78.20 wt%, MgO from 0.0 to 0.51 wt%, K_2O and Na_2O from 1.74 to 5.18 and from 2.45 to 4.60 wt% respectively. The chemistry (table 1) indicates a granitic-rhyolitic origin for the leptynites or arkosic with detrital quartz, feldspar and mica. The generally medium and occasionally coarse texture of the rocks coupled with their high P_2O_5 exclude them from being metarhyolites (e.g. Leake and Singh, 1986) and figure 2A excludes them from being metamorphosed arkoses with detrital quartz, feldspar and mica. Inspection of figure 2B (and also *al-alk* vs *k*, *ti*, *c*, *mg*, *Fe*, *Rb*, *Ba* and *Ce*; not shown) indicates an unmistakably ortho origin for the leptynites probably as granites and this is supported by the K/Rb, K/Ba and Rb/Sr ratios (table 1). It is therefore of interest to study their petrogenesis and relations to the biotite gneisses.

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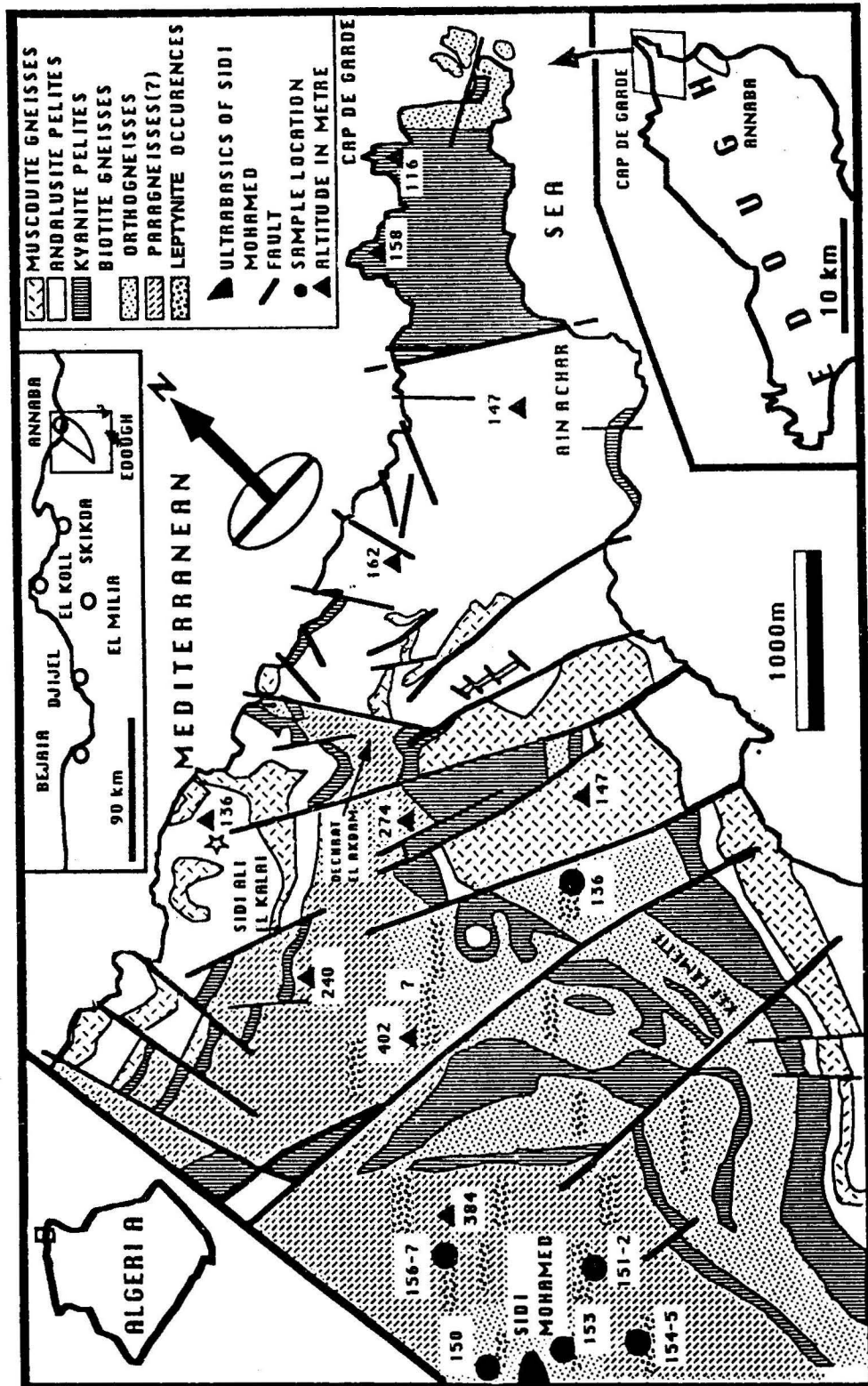


Fig. 1: - Geological sketch map of the easternmost parts of the Edough (after Gleizes *et al.*, 1988; Ahmed-Said and Leake, 1993) showing sample location and areas of leptynite occurrences.

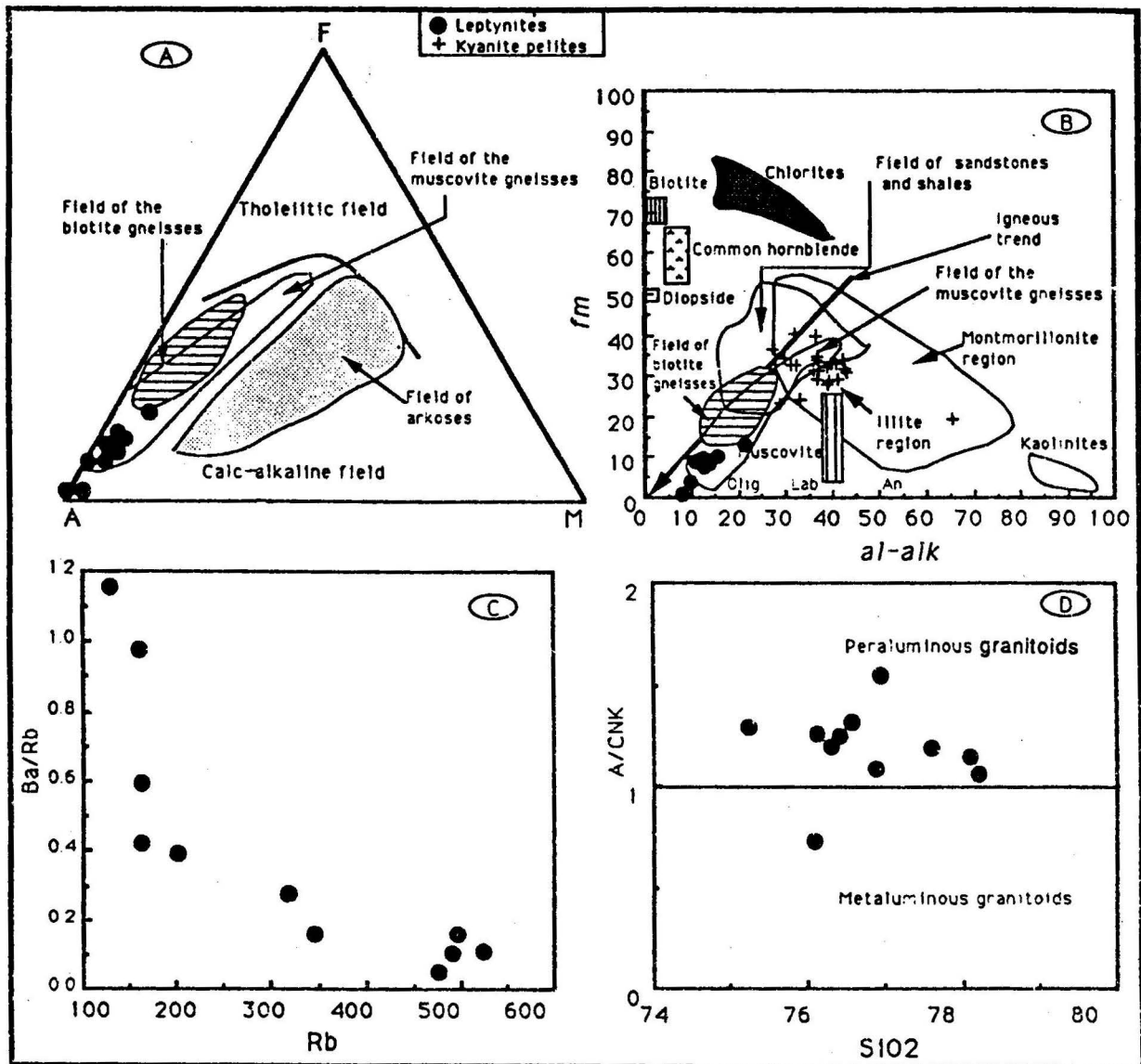


Fig. 2 - A: AFM ($A = K_2O + Na_2O$, $F = FeO + 0.9Fe_2O_3$, $M = MgO$) ternary plot showing the calc-alkaline affinities and non-arkosic nature of the leptynites. The curve separating the tholeiitic and calc-alkaline fields is after Irvine and Baragar (1971) and the fields of arkoses (Van de Kamp *et al.*, 1976), biotite gneisses (Ahmed-Said and Leake, 1993) and muscovite gneisses (Ahmed-Said and Leake, 1993a) are also illustrated.

B: Niggli *al-alk* versus *fm* revealing the igneous nature of the leptynites. The igneous trend arrow presents the Sierra Nevada plutonic suites. The fields of the Edough biotite orthogneisses and muscovite gneisses, the Edough kyanite pelites and some common clay and igneous minerals are also shown.

C: Ba/Rb against Rb of the leptynites showing the control of Ba by K-felspar.

D: A/CNK (mol Al₂O₃/mol (CaO + K₂O + Na₂O)) versus SiO₂; (White and Chappell, 1983) plot illustrating the I- and S-type character of the leptynites.

Table I - Chemical analysis of leptynites (the averages are recalculated to 100% on a volatile-free basis).

	AS136	AS150	AS151	AS152	AS153	AS154	AS155	AS156	1	σ	2	σ
Major elements wt%												
SiO ₂	76.95	78.08	77.61	75.24	76.14	76.30	76.43	76.58	77.56	0.86	71.3	2.41
TiO ₂	0.19	0.10	0.10	0.10	0.12	0.08	0.12	0.15	0.11	0.03	0.59	0.16
Al ₂ O ₃	13.29	12.12	12.44	13.19	13.22	13.01	12.98	13.42	12.91	0.50	15.04	0.9
Fe ₂ O ₃	0.56	0.36	0.62	0.63	0.03	0.33	0.59	0.45	0.39	0.19	0.85	0.30
FeO	0.94	0.52	0.62	0.45	0.73	0.60	0.62	0.84	0.52	0.29	3.04	0.93
MnO	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.00	0.05	0.02
MgO	0.51	0.38	0.26	0.30	0.35	0.43	0.33	0.35	0.29	0.15	0.87	0.30
CaO	0.35	0.58	0.45	0.32	0.23	0.35	0.33	0.44	0.58	0.44	1.66	0.59
Na ₂ O	3.68	3.51	2.66	2.59	3.14	2.81	2.74	2.45	3.29	0.66	2.22	0.40
K ₂ O	1.74	3.38	4.80	5.00	4.51	5.18	4.84	4.93	4.19	0.98	4.22	0.80
P ₂ O ₅	0.19	0.16	0.15	0.14	0.14	0.14	0.16	0.18	0.19	0.02	0.16	0.02
L.O.I.	1.47	1.00	0.57	1.77	1.25	0.90	0.82	0.36				
Total	99.89	100.2	100.3	99.75	99.87	100.15	99.97	100.17	100		100	
Trace elements ppm												
Rb	163	201	318	496	345	477	492	524	330	150	177	36
Ba	69	79	89	78	55	23	52	57	83	40	440	117
La	2	4	6	4	4	bdl	6	20	6	5	29	6
Ce	0	8	6	3	bdl	2	9	25	11	9	64	12
Y	14	24	21	10	7	5	0	7	11	7	23	8
Zr	89	72	76	55	68	66	68	70	71	9	202	34
Sr	53	84	42	29	34	36	32	25	59	34	126	36
Ga	19	15	18	15	17	20	10	19	15	3	18	1
Co	3	0	5	2	2	1	3	bdl	1	1	8	3
Ni	9	22	bdl	bdl	17	26	24	30	15	11	14	4
Cr	2	bdl	bdl	bdl	bdl	bdl	bdl	bdl	-	-	39	15
K/Rb	88.6	139.6	125.3	83.7	108.5	90.15	81.7	78.1				
K/Ba	209	355.2	447.7	532.1	680.7	827	772.7	718				
Rb/Sr	3.08	2.39	7.57	17.10	10.14	13.25	15.37	20.96				

1= average 11 leptynites (three samples are taken from Ahmed-Said and Leake, 1993)

2= average 27 biotite gneisses (Ahmed-Said and Leake, 1993a)

bdl= below detection limits (La=3.9ppm, Ce=3.2ppm, Co=3.2ppm, Ni=4.8ppm, Cr=1.9ppm)

PETROGENESIS

To evaluate the petrogenesis of the leptynites, equilibrium batch melting of the Edough biotite gneisses, a greywacke composition and the continental crust and equilibrium fractional crystallisation of a mantle derived basaltic magma models were tested. The models are based on Rb, Ba, Sr and Zr using partition coefficients from Ewart (1982), Henderson (1982), Mahood and Hildreth (1983) and Nash and Crecraft (1985).

Since minor phases such as zircon, apatite, allanite, titanite etc. can be residual after melting or involved during fractional crystallisation (e.g. Hanson, 1978; Michael, 1988), Zr is modelled assuming residual and non-residual zircon in both partial melting and fractional crystallisation models.

Melting of the biotite gneisses

The biotite gneisses form the lowest known lithologic unit and are probably also the oldest rocks of NE Algeria and since similar rocks outcrop further to the west of the Edough district such as those exposed at Skikda, El Koll, El Milia (fig. 1), the present study is also relevant to any similar rocks in these areas.

Figure 3 shows that any partial melting products of the biotite gneisses would be substantially higher in Ba and Zr than the measured values of the leptynites and although the modelled Sr values are clearly inconclusive, the measured Sr concentrations fall swifter with increasing Rb contents than is expected in partial melting (i.e. relative to the modelled values). Partial melting of a greywacke as a starting composition (e.g. the average Proterozoic greywackes of Hoggar, Algeria; Caby *et al.*, 1977) (Rb=41ppm, Ba=743ppm, Sr=383 ppm) or average greywackes; Wedepohl 1978 (Rb = 46ppm, Ba = 316ppm,

Sr=400ppm, Zr=387ppm) would clearly generate melts richer in Sr, Ba and Zr than the measured concentrations in the elements concerned of the studied leptynites as do the partial melting products of the continental crust; Krauskopf 1967 (Rb=140ppm, Ba=580ppm, Sr=450ppm, Zr=200ppm). It is therefore concluded that the leptynites cannot have formed by melting only; in agreement with their mixed I-S type character (fig. 2D; White and Chappell, 1983; Chappell and Stephens, 1988).

Fractional crystallisation of a granitoid magma

The decrease of both Sr and Ba with increasing Rb (fig. 3) reflecting the more compatible behaviour of Sr and Ba and more incompatible Rb, indicates the importance of feldspar-controlled fractionation processes. Further, the swift decrease of Ba and Sr with increasing degree of fractionation suggests that fractionation of plagioclases was preceded by fractionation of K-feldspar resulting in a change in the bulk D for both Ba and Sr with increasing fractionation; an observation supported by figure 2C. Zr is clearly less sensitive compared with Ba and Sr suggesting that its abundance and also that of Y (not shown) is controlled mostly by the distribution of accessory zircon, although the slight negative correlation of Zr with Rb may be due to a small proportion of Zr being incorporated in the common minerals during fractionation. Nevertheless, fractionation curves of a near "ternary minimum" assemblage of plagioclase, K-feldspar and quartz are calculated (fig. 3) taking a primitive starting composition of Rb = 150ppm, Ba = 400ppm, Sr = 300ppm and Zr = 130ppm).

Although the modelled and measured values of Ba, Sr and Zr show a general agreement, the fall of the measured concentrations is clearly but insignificantly less pronounced than is expected

in pure fractional crystallisation of a mantle-derived basic magma (if we take the same starting concentrations of the modelled elements then at $Rb \geq 450$ ppm, Sr should be approaching zero and $Ba = 50$ ppm which is not precisely the case in the present samples; the four samples with $Rb = 477$ -524 ppm have concentrations $Sr = 25$ -36 ppm and $Ba = 23$ -78 ppm respectively) and this is possibly

due to contamination from a crustal source which is in agreement with their mixed I- and S-type character (fig. 2D). the inaccuracies of the modelling computations could also be an additional but certainly not an alternative cause.

DISCUSSION AND CONCLUSIONS

The evidence presented above excludes the leptynites from being derived by partial melting of the biotite gneisses, a greywacke or indeed the continental crust but indicates formation by crystal fractionation of a slightly crustally contaminated magma. Thus, it is of particular interest to see whether these rocks could represent the more differentiated end-members of the magma from which the biotite orthogneisses were derived. To achieve this Sr, Ba and Zr of both the biotite gneisses and the leptynites are plotted against Rb

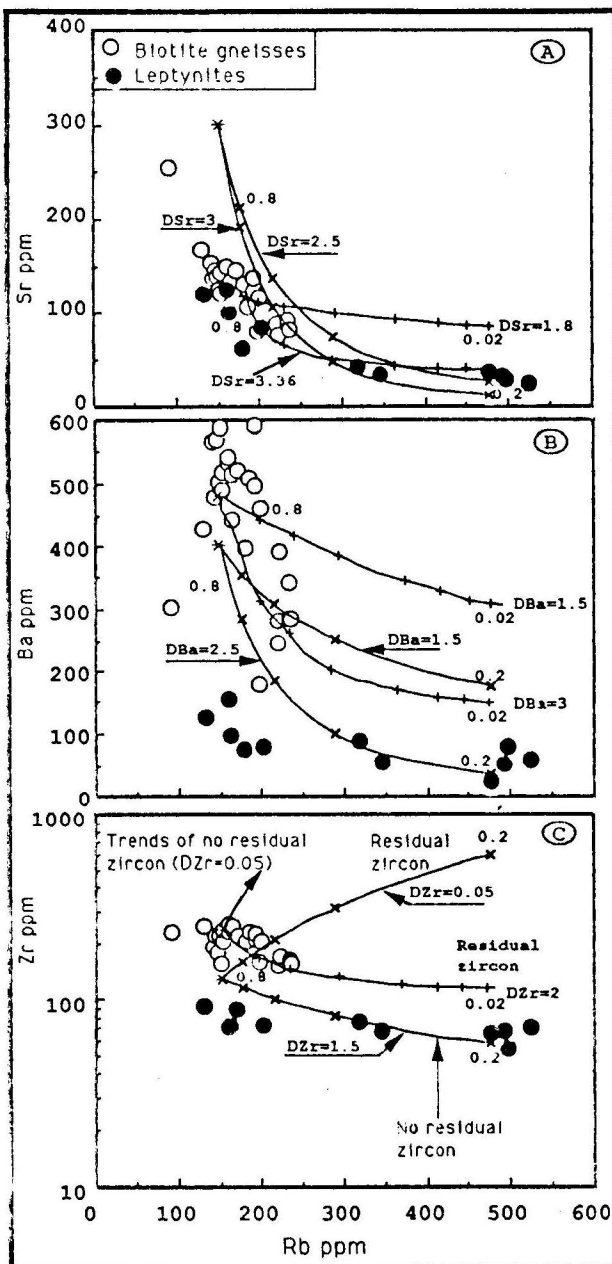


Fig. 3 - Rb versus Sr (A), Ba (B) and Zr (C) binary diagrams comparing computed fractional crystallization and melting models with the measured concentrations in the elements concerned for the studied leptynites (the biotite gneisses are also shown for comparison). Melting models (+) are constrained by plagioclase dominated residual assemblages using the equation of Consolmagno and Drake (1979; $C_l/C_o = 1/F + D(1-F)$) and taking the average biotite gneisses (asterisk) as the starting composition ($Rb = 177$ ppm, $Ba = 440$ ppm, $Sr = 126$ ppm, $Zr = 202$ ppm; $D^{Rb} = 0.36$, $D^{Ba} = 1.5$ and 3 , $D^{Sr} = 1.8$ and 3.36 , $D^{Zr} = 0.05$ and 2). In fractional crystallization models (x), the fractionation curves are computed using the Rayleigh distillation equation ($C_l/C_o = F^{D-1}$) for starting composition (asterisk) of $Rb = 150$ ppm, $Ba = 400$ ppm, $Sr = 300$ ppm, $Zr = 130$ ppm and taking $D^{Rb} = 0.28$, $D^{Ba} = 1.5$ and 2.5 , $D^{Sr} = 2.5$ and 3 , $D^{Zr} = 0.05$ and 1.5). C_l = concentration of an element in the forming or residual liquid; C_o = concentration of the element in the initial solid or magma; F = degree of partial melting (0.02, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8); f = degree of fractional crystallization (0.2, 0.4, 0.6, 0.8); D = bulk partition coefficients ($D = \sum X_\alpha \cdot D_\alpha$ with X_α = Initial solid/liquid phases proportions and D_α = crystal/liquid partition coefficients).

and the computed fractionation curves discussed above are also reported to see whether the two rocks types form fractionation continuum. Figure 3 strongly rules out the possibility that the leptynites could have any fractionation link to the biotite gneisses. The general agreement in trends between the modelled and measured Sr concentrations of the biotite gneisses and the leptynites (fig. 3A) is probably generated by plagioclase being major differentiating phase in both rock types rather than being due to a differentiating continuum which would otherwise be revealed by the Ba and Zr versus Rb plots. It can therefore be concluded that the leptynites are not derived neither by partial melting of the biotite gneisses nor they are their more differentiated end-members and thus cannot be used as indicators to the origin of the biotite gneisses. The leptynites, which post-date the biotite gneisses, were probably well differentiated dykes/sills crystallised from a predominantly I-type liquid and were subsequently crustally contaminated during ascent. The occasional field gradation noted between these leptynites and the biotite gneisses is believed to be of deformational origin.

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