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Late Variscan granites of the Belledonne massif (French Western Alps): an Early Visean magnesian plutonism

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Abstract

Belledonne, one of the External Crystalline Massifs of the Alps, has widespread Late Variscan granitoids in its northeastern domain that constitute three strongly elongate plutons (Sept Laux, Saint Colomban, La Lauzière) intruding gneisses and migmatites. These plutons mainly consist of variably foliated biotite granites and granodiorites, associated with different proportions of enclaves and stocks of amphibole-biotite mafic rocks (e.g. vaugnerite, durbachite, monzonite, quartz syenite). They define similar highly magnesian suites of the subalkaline type (i.e. intermediate between alkaline and calc-alkaline or, in other words, alkali-calcic), usually rich in Ba, Sr, Th, U and light REE, that evolved independently of each other. Their respective emplacements have been dated by the single-zircon lead-evaporation technique at 343 ± 16 Ma (Saint Colomban), 341 ± 13 Ma (La Lauzière), and 335 ± 13 Ma (Sept Laux). Geochemical and chronological data show that the three plutons belong to a single Early Visean magmatic episode, possibly short-lived, comparable to the Mg–K plutonism reported from other Variscan massifs (e.g. Aar, Corsica, Southern Vosges, Bohemia). Their emplacement is related to the beginning of a first major period of extension and wrench tectonics that affected the entire Late Variscan belt of Western Europe. These plutons, probably composed of hybrid granitoids, may have been derived from both crustal and mantle source rocks.

Keywords: plutonic rocks, geochemistry, geochronology, Variscan orogeny, Belledonne massif, Western Alps.

Introduction

The External Crystalline Massifs (ECM) belong to the Pre-Triassic basement of the Western and Central Alps (VON RAUMER, 1984a,b; VON RAUMER et al., 1993; MÉNOT et al., 1994), comprising from south to north the Argentera, Pelvoux, Grandes Rousses, Belledonne, Mont-Blanc, Aiguilles-Rouges, Aar and Gotthard massifs (Fig. 1). Variscan plutonic rocks are widely represented within the different ECM (BONIN et al., 1993), although the level of knowledge varies greatly from one massif to another. In particular, reliable intrusion ages were almost completely lacking for granitoids of these ECM south of the Mont-Blanc massif (HUNZIKER et al., 1992). This paper focuses on the Variscan granites of the Belledonne massif, and is chiefly based on chemical (major and trace elements) and chronological (lead evaporation on single-zircon method) data. The aim of our study is to characterize these granites and constrain their positions within the Late Variscan plutonic and tectonic evolution.

Geological setting and petrography

The Belledonne massif is an elongate N 30°E-trending composite body. It consists of three main

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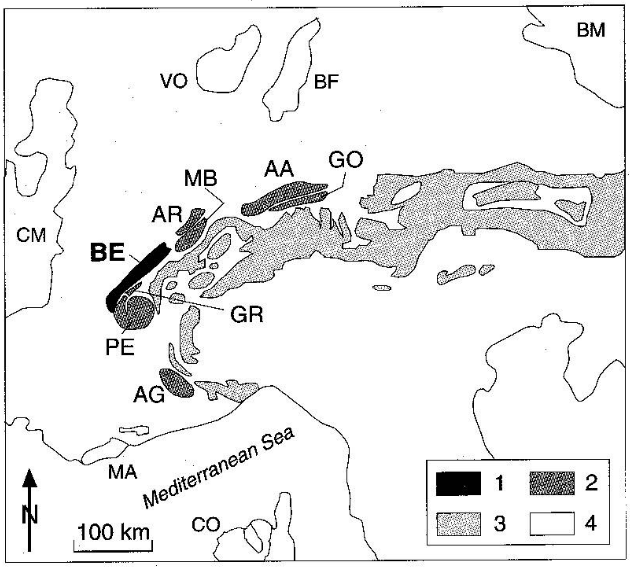


Fig. 1 Variscan basement in Central Europe (modified from VON RAUMER et al., 1993). 1 and 2 = External Crystalline Massifs of the Alps (1: Belledonne [BE] [study area]; 2: Aar [AA], Aiguilles-Rouges [AR], Argentera [AG], Gotthard [GO], Grandes Rousses [GR], Mont-Blanc [MB], Pelvoux [PE]); 3 = Variscan basement of Alpine nappes; 4 = European Variscan framework (Black Forest [BF], Bohemian massif [BM], Corsica [CO], French Massif Central [CM], Maures-Tanneron [MA], Vosges [VO]).

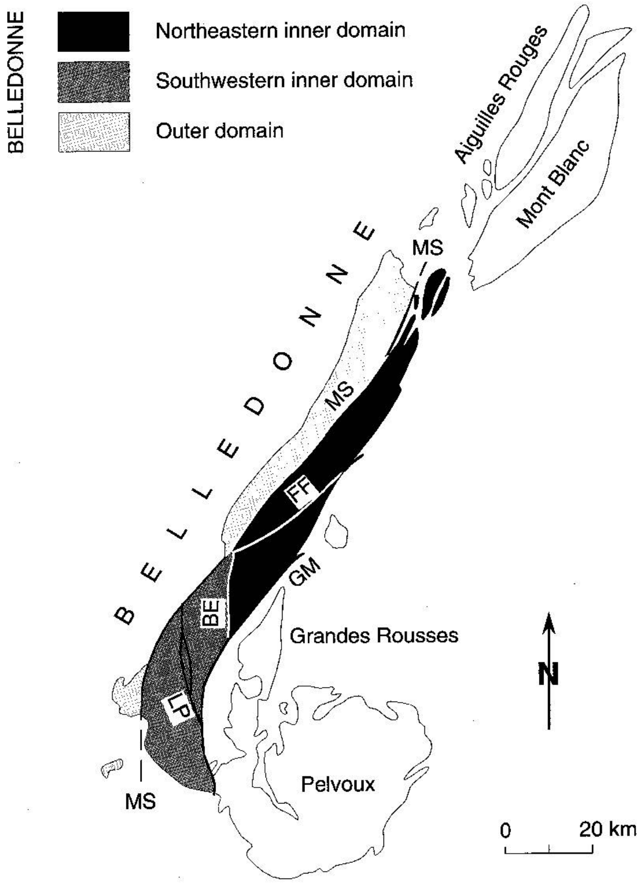


Fig. 2 Sketch map of the Belledonne massif (after VIVIER et al., 1987). Late Variscan strike-slip faults: BE, Belle Etoile; FF, Fond de France; GM, Grand-Maison; LP, La Pra; MS, "Median Syncline".

domains (terranes) characterized by distinct lithological, metamorphic, tectonic and magmatic features, namely an outer, a southwestern inner, and a northeastern inner domain (Fig. 2). These domains are representative of distinct internal zones of the Variscan belt, tectonically juxtaposed during the Early Carboniferous as a result of late orogenic strike-slip faulting (MÉNOT, 1987a, 1988).

The outer domain is composed of a sub-vertical metapelitic series ("Série satinée") of uncertain age (Brioverian, Early Palaeozoic or Early Carboniferous).

The southwestern inner domain results from the tectonic superposition, during the Early Carboniferous, of four contrasting formations: the Allemont-Rochetaillée Proterozoic to Early Palaeozoic (?) gneisses and amphibolites, the Chamrousse Cambrian-Ordovician meta-ophiolites, the Rioupéroux-Livet Devonian plutonic and volcanic complex (leptynitic and micaceous gneisses, amphibolites, felsic and mafic meta-volcanites, trondhjemites), and the Taillefer Visean (?) detrital and volcanic rocks (MÉNOT, 1987 b).

The northeastern inner domain comprises three main formations (VIVIER et al., 1987 and references therein; MÉNOT, 1988).

(1) A gneissic and amphibolitic basement displaying a polyphased metamorphic evolution with three successive stages: an eo-Variscan high-pressure event, Late Silurian-Early Devonian in age, a Barrovian stage of Devonian age leading to garnet-staurolite assemblages and subsequent anatexites, and an Early Carboniferous mylonitic retrograde metamorphic stage responsible for a penetrative and generalized sub-vertical foliation. The protolith of this basement could be of Early Palaeozoic age. It locally includes lenses of Early Ordovician porphyritic orthogneisses (BARFÉTY et al., in press).

(2) Green and black schists associated with felsic and mafic meta-volcanic rocks ("Schistes verts" formation). These epizonal rocks form a longitudinal belt, tectonically inserted within the gneissic basement. Ascribed to the Dinantian or Westphalian by BORDET and BORDET (1953), their age remains uncertain. Contrary to certain reports (BORDET, 1961; GROS, 1974), no granitoids intrude them (BOGDANOFF et al., 1991; ANTOINE et al., 1993).

(3) Three almost linear plutons – the topic of

this paper – emplaced into the basement during Variscan tectonics, elongated along a direction parallel to the main regional structures (ca. N 30°E), and showing a crude "en-échelon" pattern; from west to east, they are the Sept Laux, Saint Colomban and La Lauzière plutons (Fig. 3).

The nomenclature of plutonic rocks used in this paper is mainly based on the chemical-mineralogical classification of DEBON and LE FORT (1983, 1988) (Fig. 4a), which shows a good agreement with that of STRECKEISEN (1976). However, in order to make the paper clearer, the names "adamellite" and "granite" recommended by DEBON and LE FORT (1983) have been replaced by their approximate equivalents, i.e. "monzogranite" and "syenogranite" respectively.

SEPT LAUX PLUTON

The Sept Laux pluton, around 48 km long and covering approximately 95 km², intrudes gneisses and migmatites (CARME, 1970; GASQUET, 1979; VIVIER et al., 1987; DEBON et al., 1994; BARFÉTY et al., in press). Because of boudinage, its width varies between 2 and 5 km (Fig. 3). It displays conformable, locally cross-cutting, relationships with the surrounding rocks, along sharp and intrusive contacts. Its strongly deformed western margin is marked by the extensive development of mylonites. No clear contact metamorphism has been observed. The granitoids show a variably pronounced foliation, mainly related to the magmatic stage, generally steeply dipping and parallel to the margins of the pluton. The foliation is marked by biotite and, in some cases, by quartz aggregates, K-feldspar megacrysts and microgranular enclaves. The pluton is a syntectonic body of Visean age, the emplacement of which has been related to a polyphase opening event associated with thrust and strike-slip tectonics, probably under a transpressional regime (GUILLOT and PÊCHER in BARFÉTY et al., in press; PÊCHER, pers. comm.). At least to the south, the pluton exhibits a concentrically-zoned structure made up of an outer and an inner unit.

The *outer unit*, which is composite and highly heterogeneous, comprises a variety of foliated granites that can be divided into a porphyritic group (ca. 30%) and a fine-grained group (ca. 70%). The first group consists of light-coloured medium-grained porphyritic granodiorites and monzogranites (Fig. 4a) with quartz (ca. 25%; Tab. 1), microcline (megacrysts 1–4 cm in size), oligoclase, biotite (ca. 9%), apatite and zircon. The second group (fine-grained; 2–3 mm), which comprises monzogranites and accessory granodiorites and syenogranites (Fig. 4a), mainly leucocratic (Fig. 4b; Tab. 1), is younger than the porphyritic group because it contains angular porphyritic enclaves in places. The mineralogical composition is similar to that of the porphyritic granitoids. However, a small amount of muscovite is commonly present and aluminous minerals (cordierite, or garnet, or andalusite) exist locally in the most leucocratic members. Igneous mafic enclaves are widespread, particularly in the porphyritic granites, but their abundance is highly variable (< 1% to > 50%). In the Belle Etoile area, these enclaves form a large complex about 900 m long and 200 m wide, associated in the field and contemporaneous with fine-grained granites (LACHENY, 1995). The complex consists of vaugnerites, commonly rich in xenomorphic K-feldspar megacrysts (durbachitic character; SABATIER, 1980), with quartz (ca. 1–10%), oligoclase-andesine, amphibole, biotite, apatite (ca. 1–3%), ± titanite, ± allanite and zircon. No pyroxene is present. The vaugnerites plot in the syenite, quartz syenite, monzonite and quartz monzonite fields of the QP nomenclature diagram (Fig. 4a), whereas the isolated mafic enclaves are scattered between the vaugnerite and granite fields. The enclaves, of variable size (< 1 dm to

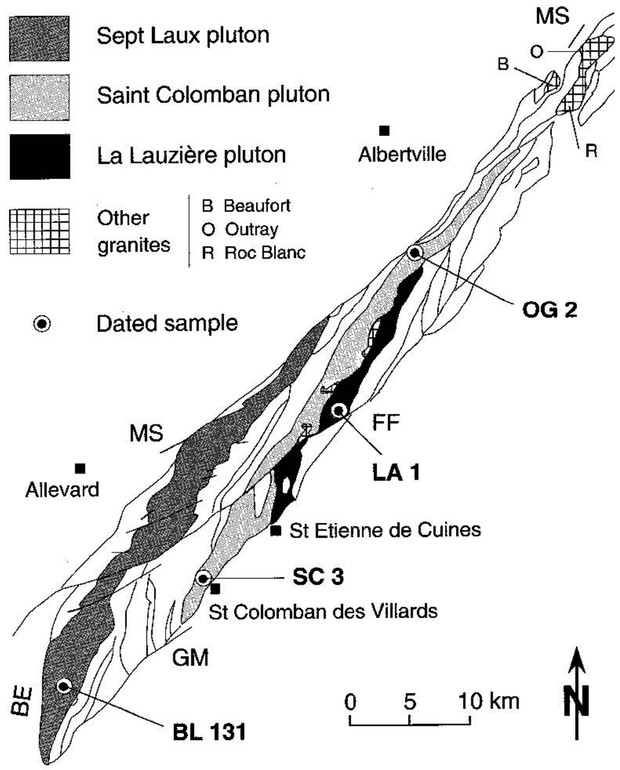


Fig. 3 Geological sketch map of the northeastern inner domain of the Belledonne massif (simplified from VIVIER et al., 1987). Metamorphic country rocks of the three plutons (Sept Laux, Saint Colomban, La Lauzière) are left blank. Other explanations as in figure 2.

Tab. 1 Mean chemical and mineralogical compositions of the main groups of rocks from the Sept Laux, Saint Colomban and La Lauzière plutons.

Pluton	**Sept Laux**					**Saint Colomban**		**La Lauzière**	
Group	1	2	3	4	5	6	7	8	9
n	4	19	12	9	9	37	10	21	21
SiO_2	69.62 ± 1.14	71.19 ± 1.11	54.78 ± 2.49	59.12 ± 2.83	70.07 ± 0.65	67.09 ± 2.47	55.28 ± 3.92	72.41 ± 2.98	59.40 ± 2.97
TiO_2	0.27 ± 0.03	0.22 ± 0.08	0.85 ± 0.17	0.73 ± 0.19	0.26 ± 0.01	0.42 ± 0.12	1.04 ± 0.28	0.28 ± 0.15	1.09 ± 0.25
Al_2O_3	15.78 ± 0.52	15.04 ± 0.36	11.68 ± 1.25	13.57 ± 1.11	14.96 ± 0.16	16.12 ± 0.87	15.78 ± 1.81	14.34 ± 1.13	15.80 ± 1.24
Fe_2O_3*	1.94 ± 0.10	1.56 ± 0.32	6.26 ± 0.44	5.66 ± 1.08	1.77 ± 0.07	2.89 ± 0.64	6.77 ± 1.48	1.60 ± 0.72	4.77 ± 1.03
MnO	0.03 ± 0.01	0.02 ± 0.01	0.10 ± 0.01	0.11 ± 0.03	0.02 ± 0.01	0.04 ± 0.01	0.11 ± 0.03	0.03 ± 0.02	0.09 ± 0.06
MgO	0.91 ± 0.09	0.54 ± 0.22	9.78 ± 3.27	6.19 ± 2.28	0.80 ± 0.06	1.50 ± 0.39	5.17 ± 1.84	0.74 ± 0.41	3.56 ± 1.30
CaO	2.11 ± 0.34	1.43 ± 0.33	6.08 ± 0.85	4.22 ± 0.76	1.48 ± 0.15	2.32 ± 0.77	5.30 ± 1.05	0.55 ± 0.35	3.26 ± 0.96
Na_2O	4.50 ± 0.22	4.17 ± 0.27	2.24 ± 0.37	2.86 ± 0.65	4.21 ± 0.08	3.98 ± 0.32	4.01 ± 0.76	3.86 ± 0.26	3.54 ± 0.59
K_2O	3.68 ± 0.71	4.34 ± 0.63	5.14 ± 1.15	4.23 ± 0.98	4.39 ± 0.24	4.02 ± 0.46	3.80 ± 0.69	5.25 ± 0.49	6.11 ± 0.92
P_2O_5	0.17 ± 0.13	0.11 ± 0.06	1.00 ± 0.26	0.65 ± 0.15	0.14 ± 0.03	0.17 ± 0.06	0.91 ± 0.27	0.10 ± 0.07	0.50 ± 0.16
L.O.I.	0.70 ± 0.17	0.69 ± 0.13	1.57 ± 0.35	1.58 ± 0.41	0.78 ± 0.17	1.19 ± 0.41	1.60 ± 0.35	0.69 ± 0.29	1.23 ± 0.36
Total	99.69	99.32	99.49	98.92	98.88	99.74	99.76	99.85	99.35
K/(Na+K)	0.35 ± 0.05	0.41 ± 0.05	0.60 ± 0.08	0.49 ± 0.11	0.41 ± 0.01	0.40 ± 0.04	0.39 ± 0.08	0.47 ± 0.03	0.53 ± 0.07
B = Fe+Mg+Ti	50 ± 2	36 ± 10	332 ± 84	234 ± 66	45 ± 2	79 ± 18	226 ± 61	42 ± 20	162 ± 48
Mg/(Fe+Mg)	0.48 ± 0.03	0.40 ± 0.05	0.74 ± 0.05	0.67 ± 0.06	0.47 ± 0.02	0.50 ± 0.04	0.59 ± 0.06	0.46 ± 0.09	0.59 ± 0.04
Quartz %	24.9 ± 4.1	27.3 ± 2.1	9.1 ± 3.0	17.3 ± 3.8	25.6 ± 1.1	23.6 ± 4.0	6.1 ± 5.2	28.7 ± 5.3	8.5 ± 4.0
Mafic minerals %	9.0 ± 4.0	6.4 ± 1.8	59.7 ± 15.2	42.1 ± 12.0	8.1 ± 0.4	14.2 ± 3.3	40.7 ± 11.0	7.5 ± 3.6	29.1 ± 8.6
Feldspars %	66.1 ± 4.1	66.3 ± 1.7	31.2 ± 15.3	40.6 ± 9.8	66.3 ± 1.2	62.2 ± 2.8	53.2 ± 10.7	63.8 ± 3.0	62.4 ± 8.3
Mean rock type	gd III	ad II	qsy IV	qmz IV	ad III	ad III	mz IV	gr II	qsy IV
Ba	1395 ± 275	1179 ± 283	2058 ± 646	1753 ± 417	1092 ± 87	848 ± 301	2169 ± 841	497 ± 250	2425 ± 639
Rb	140 ± 27	179 ± 54	249 ± 59	250 ± 75	174 ± 18	190 ± 37	178 ± 29	238 ± 52	238 ± 42
Sr	609 ± 77	517 ± 114	520 ± 121	552 ± 203	578 ± 47	400 ± 187	1063 ± 418	293 ± 157	1066 ± 423
$^{87}Rb/^{86}Sr$	0.7 ± 0.1	1.1 ± 0.5	1.5 ± 0.5	1.6 ± 0.9	0.8 ± 0.3	1.8 ± 1.2	0.6 ± 0.2	3.7 ± 3.3	0.8 ± 0.4
n	1	3	7	2	2	1	1	3	2
La	28.79	28.50 ± 9.16	56.40 ± 15.34	57.60 ± 15.08	32.45 ± 3.77	43.88	60.94	39.94 ± 7.70	64.78 ± 3.16
Ce	55.06	55.75 ± 19.89	120.66 ± 29.06	128.36 ± 42.77	62.96 ± 8.72	85.84	116.30	70.80 ± 16.34	151.05 ± 9.69
Nd	21.5	22.80 ± 11.43	65.99 ± 16.71	69.05 ± 23.73	24.44 ± 2.54	34.60	51.29	22.70 ± 6.59	76.13 ± 4.45
Sm	4.20	4.01 ± 1.99	12.67 ± 2.91	13.46 ± 3.83	3.97 ± 0.32	5.82	9.15	3.47 ± 1.15	13.38 ± 0.57
Eu	1.12	0.93 ± 0.37	2.51 ± 0.43	1.87 ± 0.02	0.90 ± 0.01	1.36	1.94	0.63 ± 0.21	2.68 ± 0.51
Gd	2.92	2.70 ± 1.51	7.32 ± 1.44	8.01 ± 2.43	2.46 ± 0.28	4.57	5.84	2.06 ± 0.47	7.04 ± 0.48
Dy	2.01	1.72 ± 0.80	3.82 ± 0.46	4.45 ± 1.32	1.76 ± 0.03	2.92	3.82	1.44 ± 0.41	4.77 ± 0.04
Er	0.92	0.87 ± 0.32	1.67 ± 0.22	1.88 ± 0.59	0.78 ± 0.02	1.25	1.64	0.76 ± 0.18	1.99 ± 0.06
Yb	0.85	0.86 ± 0.26	1.33 ± 0.20	1.65 ± 0.33	0.80 ± 0.02	1.11	1.60	0.83 ± 0.10	1.72 ± 0.23
Lu	0.13	0.13 ± 0.02	0.20 ± 0.04	0.24 ± 0.06	0.12 ± 0.00	0.20	0.23	0.14 ± 0.02	0.26 ± 0.04
Th	19.1	22.4 ± 6.0	32.5 ± 9.7	40.5 ± 18.3	18.8 ± 2.5	26.7	48.7	49.3 ± 5.2	47.0 ± 18.7
U	2.8	8.5 ± 6.3	9.9 ± 2.5	12.1 ± 4.2	4.0 ± 1.1	8.2	9.2	9.3 ± 1.1	7.9 ± 1.1
Y	9.9	9.3 ± 3.2	16.8 ± 2.0	20.3 ± 4.8	8.8 ± 0.2	13.1	18.3	8.2 ± 1.9	21.2 ± 0.7

> 10 m) and variably flattened, contain biotite and generally abundant amphibole, although relics of clinopyroxene are exceptional. Angular enclaves of the surrounding gneisses (and migmatites), ranging in size from a few millimetres to tens of metres, are also widespread, in particular along the eastern margin. They show a foliation parallel to that of the host-granites and consist of quartz, plagioclase, ± K-feldspar, biotite, ± muscovite, apatite and zircon.

The *inner unit* is a discontinuous elongate body, parallel to the long axis of the pluton and with a maximum width of 2 km. It mainly consists of a relatively homogeneous and poorly foliated medium-grained (ca. 4 mm) biotite monzogranite (Fig. 4a; Tab. 1), including very scarce (<< 1%) small mafic enclaves. The contacts of this monzogranite with the granites of the outer unit, either gradational or sharp, show that the inner unit was emplaced a short time after the intrusion of the outer fine-grained granites. In addition, elongate stocks of fine-grained leucocratic granodiorites and monzogranites with biotite ± muscovite locally occur along the median axis of the inner unit.

SAINT COLOMBAN PLUTON

The Saint Colomban pluton, 1–4 km wide, extends for about 50 km and covers some 60 km^2 (Fig. 3) (GASQUET, 1979; SIMÉON, 1979; VIVIER et al., 1987). The Roc Blanc and Outray granites to the north and the Alpetta orthogneisses of the Grandes Rousses massif to the south (Fig. 2), are probably part of the same plutonic body (AUMAÎTRE et al., 1985; BOGDANOFF et al., 1991; ANTOINE et al., 1993). To the west, the pluton is tectonically juxtaposed against the "Schistes verts" complex. Elsewhere, it locally intrudes gneisses and migmatites and in places includes them as enclaves up to several hectometres in size. Because of the locally gradational field relationship with migmatites, its emplacement is interpreted as being coeval with anatectic processes of inferred Devonian age (VIVIER et al., 1987). The Saint Colomban granitoids are commonly strongly foliated and partly recrystallized (blastomylonites), particularly in the northern part of the pluton and along its margins. They are therefore commonly described as orthogneisses in the literature, and a questionable Cambrian/Ordovician age of emplacement was even suggested on the basis of poorly constrained chronological data (DEMEULEMEESTER, 1982; AUMAÎTRE et al., 1985).

Porphyritic (or porphyroclastic) granites constitute the main rock type of the Saint Colomban pluton (VIVIER et al., 1987). They consist of medium-grained and variably foliated monzogranites and granodiorites (Fig. 4a) with quartz (ca. 24%; Tab. 1), microcline (abundant megacrysts, up to 8 cm long), oligoclase, biotite (ca. 14%), ± rare amphibole or muscovite, zircon, apatite, ± titanite, ± allanite. The blastomylonites display a recristallization of variable intensity marked by a development of sericite, chlorite, quartz, calcite, epidote, iron oxides, ± albite, ± biotite, ± (?) microcline (GASQUET, 1979). Locally, non porphyritic biotite granites also occur.

Mafic enclaves are highly abundant within the porphyritic granites of the southern part of the pluton, such as in the St Colomban des Villards region (Fig. 3) (VIVIER et al., 1987). They form variably flattened blobs with sinuous contacts, ranging in size from a decimetre to several metres. These foliated, fine- to medium-grained rocks, porphyritic in places, range in composition from monzogabbro, through monzonite, to quartz monzonite (Fig. 4a). They contain amphibole and bi-

Groups: *Sept Laux (outer unit):* 1 = porphyritic granites, 2 = fine-grained granites (hololeucocratic rocks excluded), 3 = Belle Etoile vaugnerites, 4 = isolated mafic enclaves; *Sept Laux (inner unit):* 5 = medium-grained granites; *Saint Colomban:* 6 = porphyritic granites, 7 = mafic enclaves; *La Lauzière:* 8 = granites (SiO_2 > 65%), 9 = quartz syenites (SiO_2 < 65%). n = number of analysed samples.
Major elements in oxide percentages; trace elements in ppm. Fe_2O_3* = total iron as ferric oxide; L.O.I. = loss on ignition; n.d. = not determined. B = Fe+Mg+Ti expressed in gram-atoms × 10^3. Quartz, mafic mineral and feldspar contents, in weight per cent, calculated from chemical analyses (LA ROCHE, 1964).
Rock type refers to the classification of DEBON and LE FORT (1983, 1988): ad adamellite (ca. monzogranite), gd granodiorite, gr granite (ca. syenogranite), mz monzonite, qmz quartz monzonite, qsy quartz syenite; to a first approximation, roman numerals respectively correspond to rocks with biotite > muscovite (II), biotite (III), biotite + amphibole (IV). $^{87}Rb/^{86}Sr$ ratio obtained by multiplying the Rb/Sr ratio by 2.8956 (SONET, pers. comm.). Errors on mean values are 1 sigma standard deviations.
Analyses selected from published and unpublished data (Sept Laux: DEBON [unpubl.], DEBON et al. [1994], LACHENY [1995], BARFÉTY et al. [in press]; Saint Colomban: GASQUET [1979], VIVIER [unpubl.]; La Lauzière: SIMÉON [1979], PONCERRY [1981], VIVIER [unpubl.]). Analyses performed using ICP-emission spectrometry (CRPG-CNRS, Nancy), except for the samples of SIMÉON and PONCERRY (X-ray fluorescence; Institut Dolomieu, Grenoble). A complete data set of the analyses may be obtained up on request from the first author.

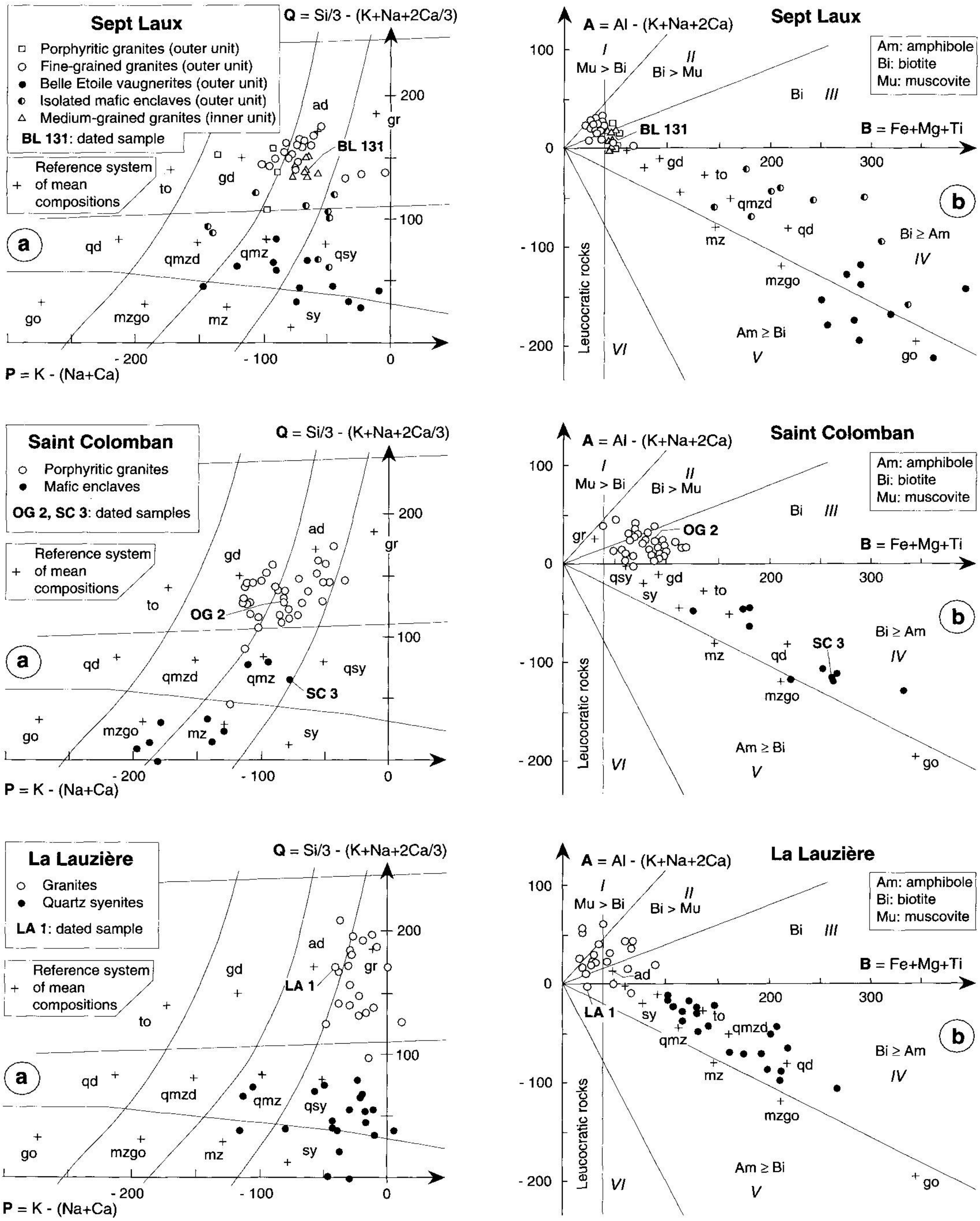
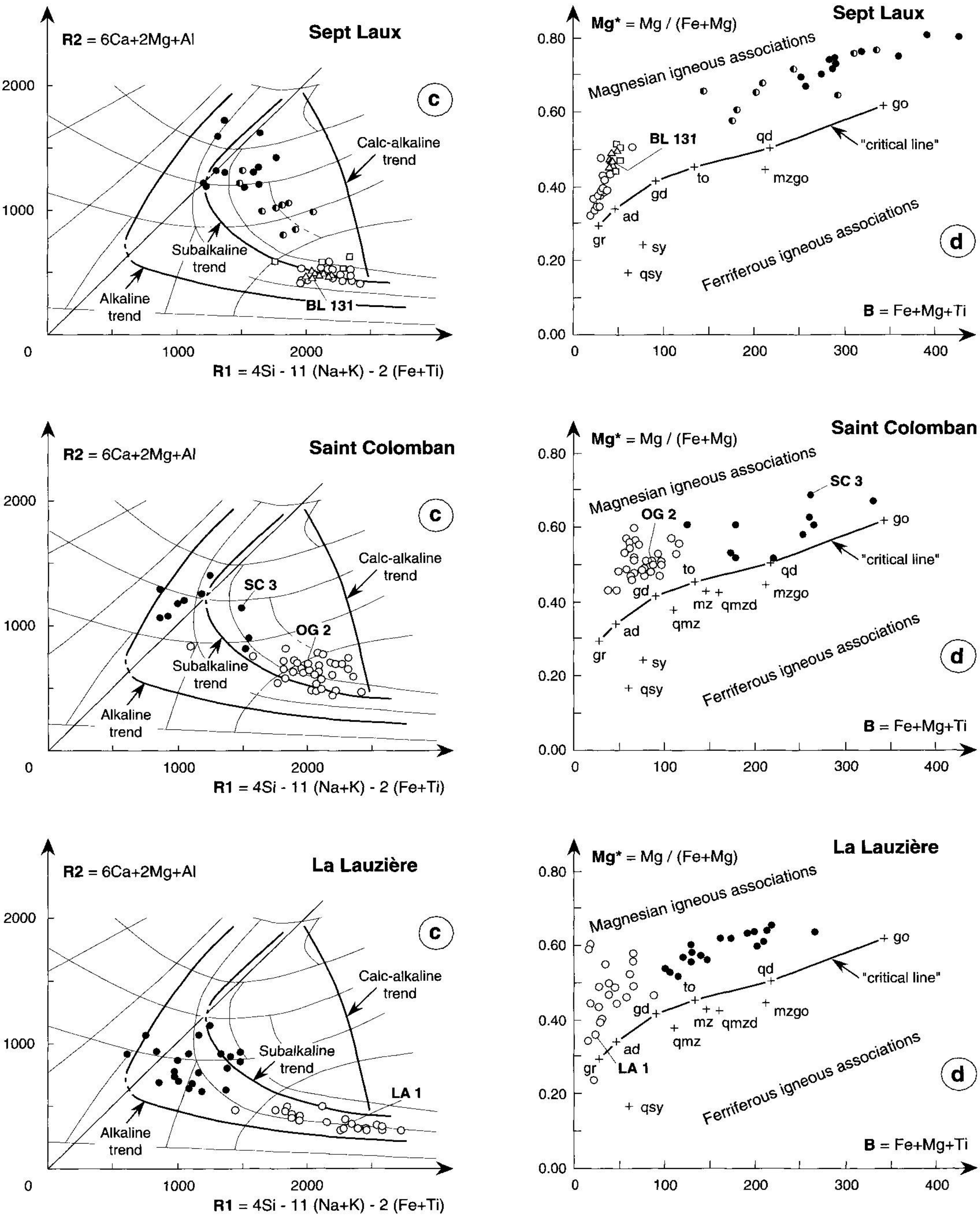


Fig. 4 Plot of the main groups of rocks from the Sept Laux, Saint Colomban and La Lauzière plutons on the QP, AB, Mg*B (DEBON and LE FORT, 1988), and R1R2 diagrams (LA ROCHE et al., 1980). Parameters expressed in gram-atoms × 10^3. QP = "nomenclature diagram". Each of its twelve sectors corresponds to a petrographic type: ad adamellite (ca. monzogranite), gd granodiorite, go gabbro, gr granite (ca. syenogranite), mz monzonite, mzgo monzogabbro, qd quartz diorite, qmz quartz monzonite, qmzd quartz monzodiorite, qsy quartz syenite, sy syenite, to



tonalite. AB = "characteristic minerals diagram". The six sectors (I to VI) correspond to specific mineralogical assemblages. Mg*B diagram: the "critical line" separates the magnesian and ferriferous igneous domains. R1R2 diagram: clearly distinguishes the calc-alkaline, subalkaline (alkali-calcic) and alkaline associations. Data from table 1.

otite. Allanite and titanite are common accessory minerals. Swarms of mafic enclaves are generally associated with heterogeneous, amphibole-rich porphyritic granodiorites. Field data suggest a contemporaneous emplacement for the enclaves and their host-granites.

LA LAUZIÈRE PLUTON

The La Lauzière pluton, 26 km long and 1–2 km wide, covers approximately 25 km^2 (Fig. 3) (SIMÉON, 1979; PONCERRY, 1981; AUMAÎTRE et al., 1985; VIVIER et al., 1987). The SW–NE-trending Fond de France strike-slip fault separates it into two parts, namely a northern and a southern part. To the east, its contact with the surrounding gneisses is faulted and to the west, it cross-cuts the foliation of the Saint Colomban granites in places (VIVIER et al., 1987). It is made up of medium- to coarse-grained rocks with little or no foliation, except in the vicinity of shear zones where a strong mylonitic foliation is present. Such shear zones are particularly common in the southern part of the pluton. According to field data, this pluton would be the youngest intrusion of the Belledonne massif.

The La Lauzière granitoids exhibit a wide variety of lithologies (SIMÉON, 1979; PONCERRY, 1981; AUMAÎTRE et al., 1985; VIVIER et al., 1987), which can be divided into two clearly distinct groups, namely a granite and a quartz syenite group (Fig. 4a; Tab. 1).

The granite group crops out in the northern part where it constitutes the dominant lithology, and chiefly comprises syenogranites, locally porphyritic, with quartz (ca. 29% on average), perthitic microcline, oligoclase, biotite in variable proportions (ca. 8%), apatite, zircon and titanite. Sericite, chlorite and epidote occur as secondary minerals.

The quartz syenite group makes up the southern part, together with intercalations and enclaves of the surrounding gneisses. It also occurs within the granites in the northern part as an elongate body, 0.6 km wide and extending N–S for 6 km, and as enclaves ranging in size from a few centimetres to a hundred metres. In addition to the dominant quartz syenites, this group also comprises quartz monzonites, monzonites and syenites (Fig. 4a). These quartz-poor rocks, locally porphyritic, consist of perthitic microcline, oligoclase-andesine, biotite, amphibole, apatite, zircon, and abundant titanite. Secondary (?) epidote is common.

Chemical-mineralogical data

Chemical data concerning the studied plutons are given in table 1. Major element data are presented in different diagrams according to the classifications of LA ROCHE et al. (1980) (Fig. 4c) and DEBON and LE FORT (1983, 1988) (Figs 4 a, b, d). Compositional characteristics of the different groups of granitoids are defined with reference to the mean compositions proposed by DEBON and LE FORT (id.) for the main plutonic rock types. The "subalkaline" associations, intermediate between alkaline and calc-alkaline (Fig. 4c), are

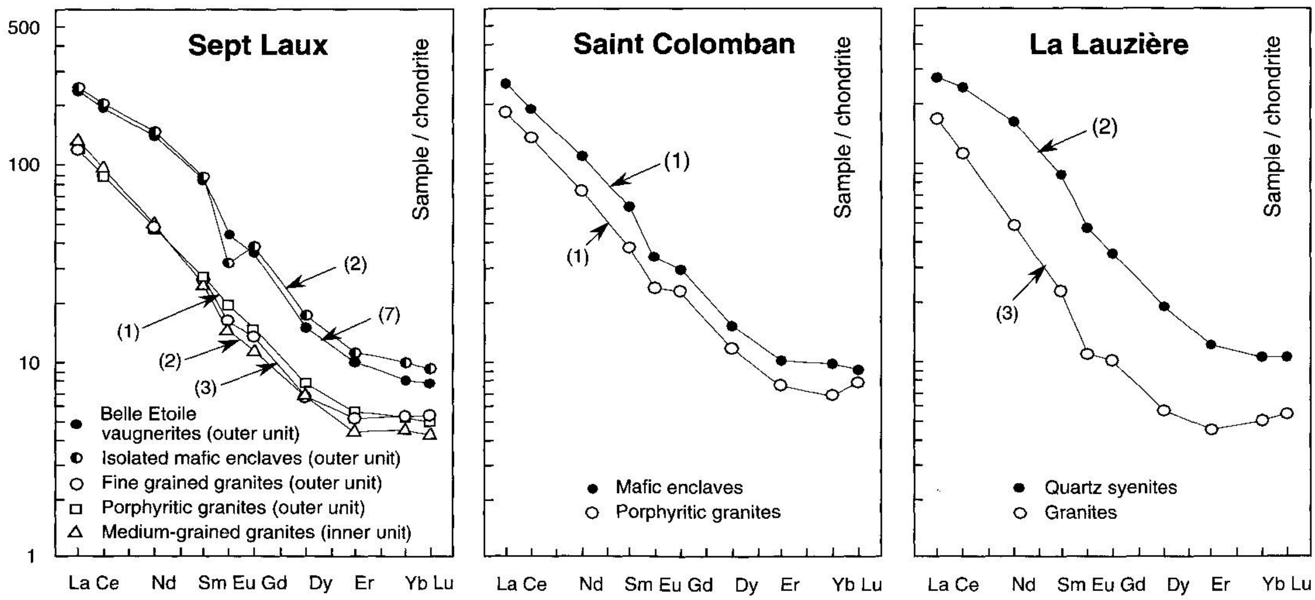


Fig. 5 Rare-earth element patterns of granitoids from the Sept Laux, Saint Colomban and La Lauzière plutons. Data (Tab. 1) normalized to chondritic values of EVENSEN et al. (1978). In parentheses, number of analysed samples.

equivalent to the "alkali-calcic" series of PEACOCK (1931).

SEPT LAUX PLUTON

Despite major textural variations, the three main granitic groups (porphyritic, fine-grained and medium-grained, respectively) of the Sept Laux pluton are compositionally similar and share common characteristics (Tab. 1; Figs 4, 5). They range from granodiorite, through predominant monzogranite, to rare syenogranite (Fig. 4a), generally light-coloured and variably peraluminous (Fig. 4b), quartz-poor but rich in feldspars, Na, Ba and Sr (Tab. 1). As a whole, these granitoids define an alumino-cafemic association (Fig. 4b) of the subalkaline type (Fig. 4c), more sodic than potassic [mean K/(Na+K) ratios vary between 0.35 and 0.41], with a pronounced magnesian character (Fig. 4d). It is a composite association, formed by the juxtaposition of distinct granitic groups that cannot derive from each other because they do not plot coherently on the same trend on the chemical diagrams (e.g. Fig. 4a). In other words, although the three granitic groups are most probably affiliated as indicated by their compositional similarities, they are not members of a single differentiation series, and most likely evolved independently of each other. The REE contents and patterns of the different groups also show close similarities (Tab. 1; Fig. 5); LREE concentrations are relatively high (La_N = 90–159) and the REE patterns are characterized by strongly fractionated LREE, weak or even absent Eu anomalies, and almost unfractionated HREE. Such patterns are quite comparable to those of subalkaline granitoids of other regions (e.g. western Pelvoux massif; BANZET, 1987).

The Belle Etoile vaugnerites constitute a highly magnesian (Fig. 4d) and dark-coloured subalkaline association (Fig. 4c). These rocks are rich in K and Mg (Tab. 1), and also in both compatible and incompatible trace elements (Ba: 1188–3095 ppm; Cr: 354–1297 ppm; Ni: 62–710 ppm; Rb: 135–324 ppm; Sr: 331–718 ppm; Th: 19–43 ppm; U: 6–14 ppm; Zr: 48–372 ppm; LACHENY, 1995; BARFÉTY et al., in press). Their REE concentrations are high and exhibit a rather regular fractionation (Fig. 5). Such chemical characteristics are well-established for vaugnerites of other regions (BANZET, 1987; SABATIER, 1991). The isolated mafic enclaves are approximately intermediate between vaugnerites and granites compositionally (Tab. 1), and display a wide scattering on the chemical diagrams (Fig. 4). Numerous studies on mafic enclave-granite host pairs (DEBON, 1991, and references therein) suggest that these enclaves could represent fragments of a vaugneritic magma modified to varying degrees by differential chemical exchanges with the enclosing granitic magma.

A geochemical gap separates the Sept Laux granites from their vaugneritic and mafic enclaves (Fig. 4). The two groups of rocks, however, share common compositional characteristics (e.g. subalkaline typology, high Mg/Fe ratios and contents in Ba or Sr, low Rb/Sr ratios, similar REE patterns) (Tab. 1; Figs 4, 5), thus indicating their close relationship.

SAINT COLOMBAN PLUTON

Porphyritic granites from the Saint Colomban pluton mainly consist of peraluminous (Fig. 4b), quartz-poor monzogranites and granodiorites (Fig. 4a), rich in Mg, Na, Ba, Sr and U (Tab. 1). They define an alumino-cafemic association (Fig. 4b) of the subalkaline type (Fig. 4c), more sodic than potassic [mean K/(Na+K) ratio of 0.40], with a marked magnesian character (Fig. 4d). The Saint Colomban granites chiefly differ from the Sept Laux ones by their higher contents in dark minerals (14.2% compared to 6.4–9.0% on average; Tab. 1; Fig. 4b, d), REE, Th, U and Y, lower concentrations in Ba and Sr, and by a significant shift towards the calc-alkaline domain on the R1R2 diagram (Fig. 4 c). The REE patterns are similar for the granites of both plutons (Fig. 5).

The mafic enclaves included within the porphyritic granites are metaluminous (Fig. 4b) monzogabbros, monzonites and quartz monzonites (Fig. 4a), generally depleted in feldspars but rich in dark minerals, Mg, Ba, Sr, Th and U (Fig. 4 b, d; Tab. 1). They define a cafemic (Fig. 4b) and magnesian (Fig. 4d) association of the subalkaline type (Fig. 4c), more sodic than potassic [mean K/(Na + K) ratio of 0.39]. Once again, the existence of common characteristics indicates a relationship between these enclaves and their host granites (e.g. REE contents and patterns; Fig. 5). The mafic enclaves mainly differ from the Sept Laux vaugnerites by being poorer in dark minerals (Fig. 4 b, d), Mg and K, richer in feldspars (Tab. 1), Al, Na, and Sr, and through their lower K/(Na + K) and Mg/(Fe + Mg) ratios (Tab. 1). The REE contents and patterns are similar for the two groups of rocks (Fig. 5).

LA LAUZIÈRE PLUTON

The two main groups of granitoids making up the La Lauzière pluton (i.e. granite and quartz monzonite) are compositionally distinct from each other (Fig. 4). The felsic group mainly comprises peraluminous syenogranites (Fig. 4 a, b), generally relatively depleted in quartz and Ca, but rich in Mg, Na, Sr, Th and U (Tab. 1). The mafic group is chiefly made up of metaluminous quartz monzonites (Fig. 4 a, b), depleted in quartz, feldspar, Si and Na, but rich in mafic minerals (Fig. 4d), Ti, Fe, Mg, Ca, Ba and Sr (Tab. 1). Each group defines a magnesian association (Fig. 4d), intermediate between the subalkaline and alkaline trends (Fig. 4c), with high K/(Na + K) ratios (0.47 and 0.53, respectively; Tab. 1). Although separated by a clear compositional gap, the two groups may belong to a single suite (Fig. 4). They display quite distinct but similar strongly fractionated REE patterns, comparable to those of felsic and mafic granitoids from the other two Belledonne plutons (Fig. 5). In particular, the REE contents and patterns of the quartz syenite group appear very similar to those of the Sept Laux vaugnerites.

In comparison to the Sept Laux and Saint Colomban granitoids, those of the La Lauzière pluton mainly differ by their more potassic character (Tab. 1; Fig. 4a) and a significant shift towards alkaline compositions (Fig. 4c).

Chronological data

Apart from a poorly constrained Rb–Sr whole-rock age of 322 ± 43 Ma obtained by DEMEULEMEESTER (1982) for the Sept Laux pluton and an age of 332 ± 13 Ma determined by the single-zircon lead-evaporation technique for the same pluton (DEBON et al., 1994), radiometric ages of emplacement were, until now, lacking for the Belledonne plutons.

Three samples from the Saint Colomban and La Lauzière plutons were dated by using the single-zircon step-wise Pb evaporation method developed by KOBER (1986, 1987) and discussed in COCHERIE et al. (1992). Complementary data concerning the Sept Laux sample formerly dated by DEBON et al. (1994) were also acquired.

Analysis is performed directly on a zircon crystal carefully selected according to morphological and optical criteria. The size of the crystals used in our study varies between 150 and 530 μm. Isotopic measurements were carried out on a Finnigan MAT 262 mass spectrometer in dynamic ion counting mode (BRGM, Orléans). Analytical data are presented in table 3. Errors are given at ± 1σ (COCHERIE et al., 1992), and are calculated using all the measured ratios of all the different steps considered for mean age determination. In our opinion, for the lead-evaporation method, such errors are more realistic than the ± 2 σ_m ones (m = mean, 2 σ_m = 2 $\sigma/\sqrt{n}$ with n = number of ratios), which can lead to values of about 1 Ma (e.g. 341 ± 1.2 Ma instead of 341 ± 13 Ma for the La Lauzière pluton; see later). The ages thus obtained are interpreted as emplacement ages.

SEPT LAUX PLUTON

The Sept Laux pluton has been dated at 332 ± 13 Ma (DEBON et al., 1994) based on results obtained on three zircons (A, B, D) from a medium-grained biotite monzogranite (sample BL 131; Fig. 3; Tab. 2). Zircon C was discarded because only one step was obtained.

This poorly foliated monzogranite sample is a typical representative of the inner unit of the pluton, which was emplaced not long after the fine-grained granites of the outer unit. Its zircon population, widely scattered in the centre of the classification diagram of PUPIN (1980), has I.A, I.T mean values of 381 and 395 respectively (Fig. 6). The age given by zircon D from two temperature steps (326 ± 10 Ma) departs from those obtained for crystals A and B (341 and 332 Ma respectively) (Tab. 3). Another zircon (Zr F) was therefore analysed in order to better constrain the previous data. Three temperature steps yielded similar ages of about 340 Ma, leading to a mean value of 340 ± 11 Ma, which is in good agreement with the ages of zircons A and B (Tab. 3). The mean age calculated with crystals A, B and F is 337 ± 13 Ma (417 isotopic ratios). If crystal D is added, the resulting age is 335 ± 13 Ma (532 ratios) (Fig. 7). Because this age concerns the inner unit, it represents a minimum age of emplacement for the Sept Laux pluton.

SAINT COLOMBAN PLUTON

Two granitoid samples were investigated from the Saint Colomban pluton, located in its northern (OG 2) and southern parts (SC 3) respectively (Fig. 3).

The *first sample* (OG 2), which represents the dominant plutonic unit (porphyritic biotite monzogranite; Tab. 2), is a strongly foliated and highly recrystallized porphyroclastic rock (orthogneiss). Its zircons are mainly squat, pink in colour and transparent; apatite inclusions are common. Certain crystals are highly coloured and opaque (metamict), or show an internal zoning or a dark core. Most are euhedral, but only 54% were suitable to be indexed according to the classification of PUPIN (1980). The zircon population, widely

Tab. 2 Chemical and mineralogical compositions of the four dated granitoid samples.

Pluton	Sept Laux	Saint Colomban		La Lauzière
Sample number	BL 131	OG 2	SC 3	LA 1
Location	N. side of the Eau d'Olle river	SE of Rognaix	N of St Colomban des Villards	NW of the Madeleine pass
x	6°04'11"E	6°27'16"E	6°13'12"E	6°21'24"E
y	45°12'40"N	45°34'40"N	45°18'22"N	45°26'41"N
z	1 460 m	550 m	1 815 m	2 620 m
Group	5	6	7	8
SiO_2	69.95	65.78	57.30	74.85
TiO_2	0.27	0.48	0.68	0.15
Al_2O_3	15.03	16.49	13.09	13.18
Fe_2O_3*	1.82	3.30	6.42	1.21
MnO	0.03	0.05	0.12	0.02
MgO	0.79	1.66	7.02	0.34
CaO	1.25	2.65	4.97	0.69
Na_2O	4.30	3.75	2.85	4.11
K_2O	4.41	4.04	4.84	4.93
P_2O_5	0.12	0.17	0.66	0.02
L.O.I.	0.77	1.30	1.33	0.30
TOTAL	98.74	99.67	99.28	99.80
K/(Na+K)	0.40	0.41	0.53	0.44
B = Fe+Mg+Ti	46	89	263	25
Mg/(Fe+Mg)	0.46	0.50	0.68	0.36
Quartz %	25.4	22.9	11.6	30.6
Mafic minerals %	8.2	15.9	47.4	4.6
Feldspars %	66.4	61.2	41.0	64.8
Rock type	ad III	ad III	qmz IV	ad IV
Ba	1187	944	3684	256
Be	5.19	6.32	4.15	9.01
Co	10	7.25	24.10	1.46
Cr	29	38.6	544	15.8
Nb	5	14.0	18.8	15.3
Ni	21	12.9	51.3	8.2
Rb	176	173	185	292
Sc	4.3	6.8	12.5	1.7
Sr	568	456	579	118
Th	17.1	26.7	48.7	43.3
U	4.78	8.18	9.15	8.82
V	25	48.4	111	9.5
Y	8.96	13.10	18.30	6.08
Zn	34	57.8	69.5	16.0
Zr	137	213	239	128
La	29.78	43.88	60.94	31.38
Ce	56.79	85.84	116.30	52.34
Pr	n.d.	9.57	12.73	4.89
Nd	22.64	34.60	51.29	15.11
Sm	3.74	5.82	9.15	2.15
Eu	0.89	1.36	1.94	0.38
Gd	2.65	4.57	5.84	1.51
Tb	n.d.	0.55	0.78	0.18
Dy	1.78	2.92	3.82	0.97
Ho	n.d.	0.56	0.68	0.19
Er	0.79	1.25	1.64	0.55
Tm	n.d.	0.17	0.22	0.09
Yb	0.79	1.11	1.60	0.73
Lu	0.12	0.20	0.23	0.12

Analysis by ICP-emission and ICP-MS (CRPG-CNRS, Nancy). Explanations as in table 1.

scattered in the centre of PUPIN's diagram, has I.A, I.T mean values of 439 and 435 respectively (Fig. 6). Radiometric dating was carried out on seven euhedral and transparent crystals, varying in size between 250 and 530 μm. Only six zircons gave an ion beam sufficient for analysis (Tab. 3). Except for zircon E, several temperature steps were recorded. The $^{206}Pb/^{204}Pb$ ratios of the different steps of zircons A, E and G are very low, as are those for the first two steps of zircon F; this indicates a large contribution of common lead and thus an important correction on measured ratios. Accordingly, errors on the ratios are relatively high and these analyses were discarded from the age calculation, with only the best temperature steps being retained. The age obtained on four evaporation steps (220 isotopic ratios) is thus 343 ± 16 Ma (Fig. 7).

The *second sample* (SC 3) represents a mafic enclave of the porphyritic granite, several metres in size. It is a foliated, medium-grained and dark-coloured quartz monzonite with amphibole, biotite and rare K-feldspar megacrysts (Tab. 2). Its zircons are very similar to those of the OG 2 orthogneiss, except that they are all euhedral, transparent and pink, enabling the whole population to be indexed. They are scattered in the central part of PUPIN's diagram (1980) with I.A, I.T mean values of 463 and 482 respectively (Fig. 6). Five crystals, 310 to 450 μm in size, were analysed (Tab. 3). Zircons D and E were discarded owing to their low $^{206}Pb/^{204}Pb$ ratios, as were the first two steps of zircon C. The young age of the first step of zircon B (330 ± 9 Ma) was not taken into account as it was considered as being related to radiogenic lead loss, commonly observed for low temperature evaporation steps. A mean age of 343 ± 14 Ma was calculated using six temperature steps (321 isotopic ratios) (Tab. 3; Fig. 7).

LA LAUZIÈRE PLUTON

The analysed sample (LA 1), collected from the northern part of the La Lauzière pluton, belongs to the granite group (Fig. 3). It is an unfoliated, medium-grained and leucocratic monzogranite with biotite and titanite (Tab. 2). Zircons are very large, abundant, pink in colour, euhedral and sometimes asymmetric. Opaque crystals with a milky aspect (metamict) also occur in places. Sixty-one per cent of the crystals were indexed. They are widely scattered in the centre of PUPIN's diagram (1980), and have I.A, I.T mean values of 495 and 457 respectively (Fig. 6). Five crystals (210 to 450 μm) were selected, but no record was obtained on zircon E (Tab. 3). Ages given by the first temperature step of zircons A and B are poorly defined because of high common lead correction. The low intensity of the Pb signal is responsible for the inaccurate age obtained for the second step of zircon B (330 ± 30 Ma). Only the three steps for zircons C and D and the second step for zircon A were retained for the age calculation (Tab. 3, Fig. 7). Accordingly, the mean age calculated from seven temperature steps (459 isotopic ratios) is 341 ± 13 Ma.

Discussion

The three Belledonne plutons (Sept Laux, Saint Colomban, La Lauzière) share a number of common features, including comparable geological settings, shapes, compositional characteristics, magmatic typologies, and ages of emplacement. In particular, they define similar highly magnesian (Fig. 4d) and subalkaline (alkali-calcic) associations, either typical (Sept Laux) or with a calc-alkaline (Saint Colomban) or alkaline (La Lauzière) affinity (Fig. 4c). Such distinct evolutionary trends demonstrate that they evolved independently of each other as discrete bodies. Although commonly more sodic than potassic, these plutons are good representatives of the so-called Mg–K plutonism (Sabatier, 1980, 1991; Rossi, 1986; Banzet, 1987).

REGIONAL IMPLICATIONS

The ages of emplacement obtained for the three Belledonne plutons are not significantly different, ranging from 343 ± 16 Ma (Saint Colomban), through 341 ± 13 Ma (La Lauzière), to 335 ± 13 Ma (Sept Laux). Errors on age determinations are too large to confidently distinguish between the plutons. These data contradict previous interpretations that considered, on the basis of field ob-

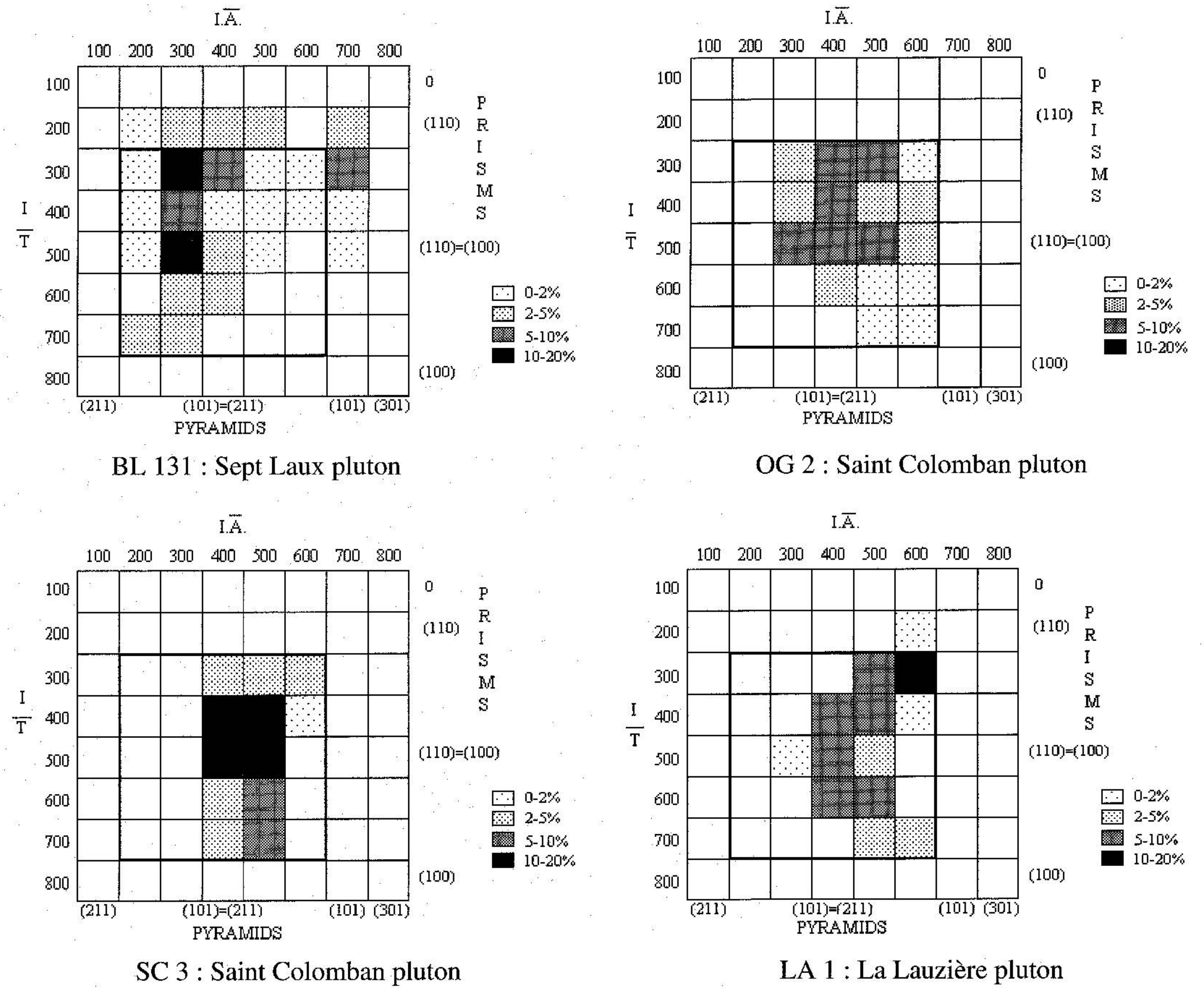


Fig. 6 Distribution of zircons from the four dated granitoid samples on the typological diagram of Pupin (1980).

Tab. 3 Analytical data and ages obtained by lead evaporation on single zircons from the Sept Laux, Saint Colomban and La Lauzière plutons.

Zircon number	Step number	T (° C)	Number of ratios	^{206}Pb / ^{204}Pb	^{208}Pb / ^{206}Pb	$^{207}Pb^{*}$ / $^{206}Pb^{*} \pm 1\sigma$	Step age ± 1σ (Ma)	Zircon age ± 1σ (Ma)	Mean age ± 1σ (Ma)
Sept Laux pluton (monzogranite BL 131)									
Zr A	1	1440	6	2444	0.049	0.05254 ± 63	309 ± 27		
	2	**1460**	**28**	**7739**	**0.033**	**0.05326 ± 28**	**340 ± 12**		
	3	**1480**	**21**	**13470**	**0.025**	**0.05325 ± 31**	**340 ± 13**	**341 ± 11**	
	4	**1540**	**32**	**16535**	**0.026**	**0.05335 ± 12**	**344 ± 5**		
Zr B	1	1440	48	369	0.173	0.05302 ± 42	330 ± 18		
	2	**1460**	**53**	**6770**	**0.058**	**0.05315 ± 21**	**335 ± 9**		
	3	**1480**	**27**	**7674**	**0.047**	**0.05347 ± 36**	**349 ± 15**	**332 ± 14**	
	4	**1540**	**63**	**12160**	**0.031**	**0.05283 ± 15**	**322 ± 6**		
Zr C	1	1460	36	16292	0.081	0.05366 ± 14	357 ± 6		**335 ± 13** (532 ratios)
Zr D	1	1440	31	14673	0.049	0.05235 ± 23	301 ± 10		
	2	**1460**	**57**	**32264**	**0.088**	**0.05294 ± 25**	**326 ± 11**		
	3	**1480**	**58**	**29630**	**0.085**	**0.05294 ± 20**	**326 ± 9**	**326 ± 10**	
Zr F	**1**	**1420**	**64**	**9008**	**0.050**	**0.05322 ± 18**	**338 ± 8**		
	2	**1440**	**63**	**17709**	**0.051**	**0.05324 ± 33**	**339 ± 14**	**340 ± 11**	
	3	**1460**	**66**	**25954**	**0.053**	**0.05333 ± 24**	**343 ± 10**		
Saint Colomban pluton (monzogranite [orthogneiss] OG 2)									
Zr A	1	1460	60	140	0.342	0.05195 ± 129	283 ± 56		
	2	1480	62	150	0.373	0.05268 ± 89	315 ± 38		
Zr B	1	1440	15	2800	0.040	0.05326 ± 69	340 ± 29		
	2	**1460**	**29**	**6160**	**0.041**	**0.05336 ± 45**	**344 ± 19**	**344 ± 19**	
Zr C	1	1440	31	3610	0.036	0.05340 ± 106	346 ± 44		
	2	**1500**	**66**	**3360**	**0.071**	**0.05324 ± 52**	**339 ± 22**		
	3	**1540**	**64**	**10400**	**0.067**	**0.05338 ± 33**	**345 ± 14**	**342 ± 19**	
Zr E	1	1440	67	240	0.221	0.05369 ± 207	358 ± 85		**343 ± 16** (220 ratios)
Zr F	1	1440	32	140	0.307	0.05390 ± 117	367 ± 48		
	2	1460	37	500	0.161	0.05364 ± 17	356 ± 7		
	3	**1480**	**61**	**2790**	**0.135**	**0.05337 ± 15**	**345 ± 6**	**345 ± 6**	
Zr G	1	1440	29	104	0.412	0.05286 ± 92	323 ± 39		
	2	1460	45	560	0.218	0.05317 ± 73	336 ± 31		
Saint Colomban pluton (quartz monzonite SC 3)									
Zr A	**1**	**1440**	**48**	**2770**	**0.091**	**0.05345 ± 48**	**348 ± 20**		
	2	**1460**	**57**	**3360**	**0.108**	**0.05340 ± 15**	**346 ± 6**	**347 ± 14**	
Zr B	1	1440	64	2390	0.101	0.05303 ± 21	330 ± 9		
	2	**1460**	**63**	**1130**	**0.130**	**0.05346 ± 25**	**348 ± 11**	**348 ± 11**	
Zr C	1	1440	48	510	0.178	0.05329 ± 42	341 ± 18		**343 ± 14** (321 ratios)
	2	1460	58	220	0.285	0.05429 ± 135	383 ± 55		
	3	**1480**	**62**	**1470**	**0.124**	**0.05324 ± 19**	**339 ± 8**		
	4	**1500**	**55**	**1100**	**0.269**	**0.05314 ± 22**	**335 ± 9**	**339 ± 12**	
	5	**1620**	**36**	**1880**	**0.129**	**0.05333 ± 48**	**343 ± 20**		
Zr D	1	1440	64	600	0.256	0.05296 ± 73	327 ± 31		
	2	1460	65	590	0.301	0.05340 ± 55	346 ± 23		
	3	1480	27	240	0.418	0.05350 ± 140	350 ± 58		
Zr E	1	1440	59	1000	0.156	0.05343 ± 86	347 ± 36		
La Lauzière pluton (monzogranite LA 1)									
Zr A	1	1440	63	156	0.346	0.05407 ± 205	374 ± 83		
	2	**1460**	**37**	**2540**	**0.257**	**0.05319 ± 33**	**337 ± 14**	**337 ± 14**	
Zr B	1	1440	50	475	0.471	0.05364 ± 150	356 ± 62		
	2	1460	65	1620	0.377	0.05303 ± 71	330 ± 30		
Zr C	**1**	**1440**	**66**	**1300**	**0.172**	**0.05319 ± 38**	**337 ± 16**		
	2	**1460**	**63**	**1710**	**0.144**	**0.05333 ± 33**	**343 ± 14**	**341 ± 15**	**341 ± 13** (459 ratios)
	3	**1480**	**41**	**1840**	**0.142**	**0.05341 ± 33**	**346 ± 14**		
Zr D	**1**	**1460**	**128**	**2870**	**0.346**	**0.05331 ± 26**	**342 ± 11**		
	2	**1480**	**61**	**5930**	**0.380**	**0.05340 ± 15**	**346 ± 6**	**342 ± 10**	
	3	**1500**	**63**	**1490**	**0.468**	**0.05326 ± 26**	**340 ± 11**		

New data, except for zircons A, B, C, D, from the Sept Laux granite (DEBON et al., 1994). Values used for age calculations in bold. Errors given at ± 1 σ. For explanations see text.

servations, the strongly deformed Saint Colomban granitoids (orthogneisses) as being representative of a probable Late Devonian (or even Cambrian/Ordovician) intrusive event, later followed by a two-fold Carboniferous event corresponding to the Sept Laux and La Lauzière plutons (AUMAÎTRE et al., 1985; VIVIER et al., 1987; MÉNOT, 1988). The present geochemical and chronological data show that the three plutons represent a single episode of highly magnesian subalkaline plutonism, possibly short-lived, at around 340 Ma (Early Visean; ODIN, 1994). However, age determinations are not sufficiently accurate to question the chronological order of emplacement inferred

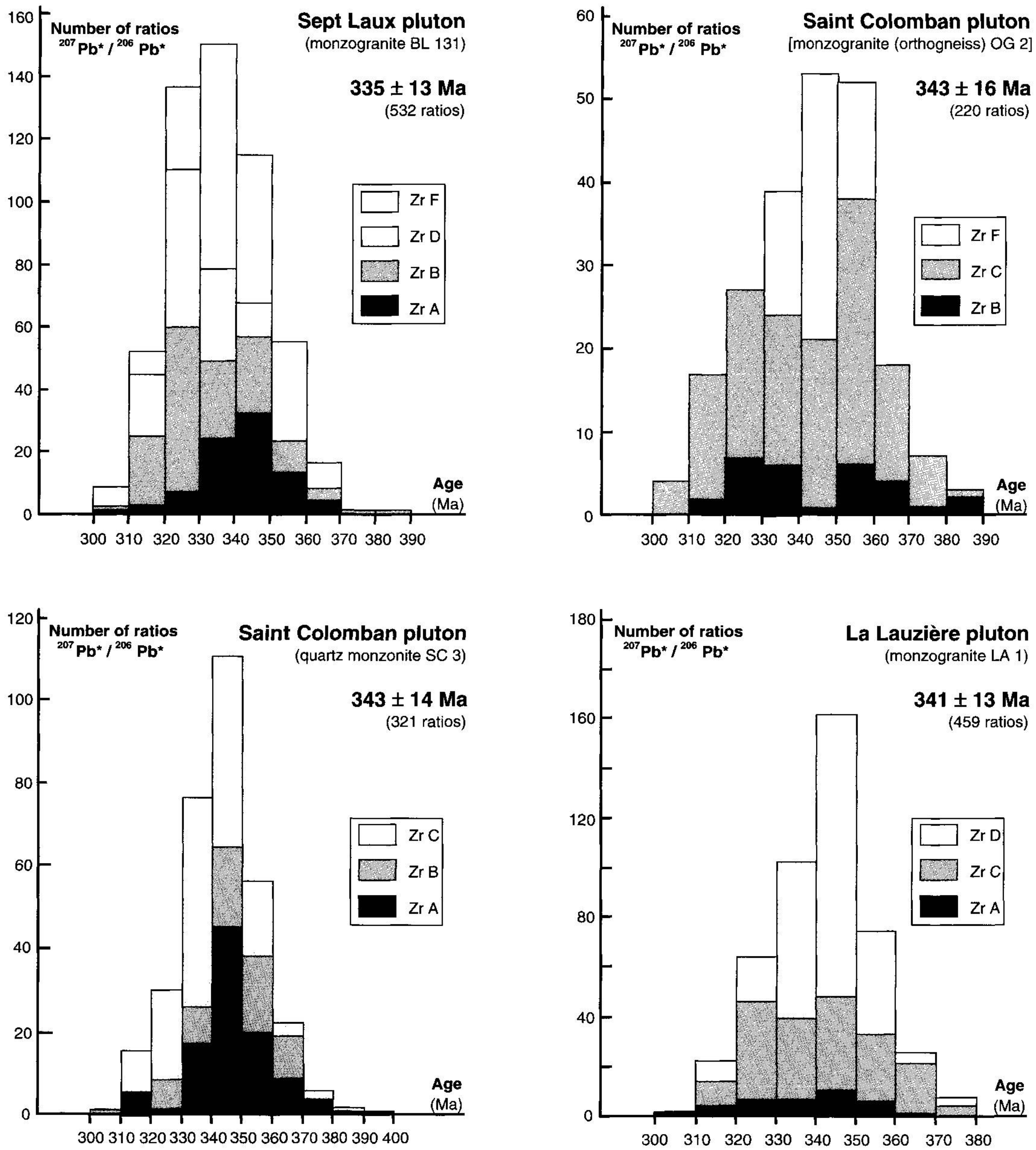


Fig. 7 Histograms showing the distribution of ages vs number of $^{207}Pb^*/^{206}Pb^*$ ratios for zircons from the four dated granitoid samples (BL 131, OG 2, SC 3, LA 1).

from field data, namely Saint Colomban, Sept Laux, La Lauzière. This order would correspond to the intrusion of increasingly alkaline granitoids (Fig. 4c).

The Roc Blanc and Outray granites and the Alpetta "orthogneisses" are probable extensions of the Saint Colomban pluton (see before). Accordingly, their ages of emplacement would be similar, close to ca. 340 Ma.

In the northeastern domain of the Belledonne massif, a polymetamorphic Variscan evolution comprising three successive events is recorded by the gneissic and amphibolitic basement (see before). It comprises a Barrovian event of inferred Devonian age, subsequent to crustal thickening and ending with anatectic processes responsible for the formation of migmatites. Field data indicate that the Saint Colomban granitoids may be coeval with migmatites. Consequently, the anatectic processes should also, at least in part, be Early Visean in age and not exclusively Late Devonian (ca. 360–370 Ma) as formerly proposed (VIVIER et al., 1987).

Recent structural studies (GUILLOT and PÊCHER in BARFÉTY et al., in press) corroborate the syntectonic emplacement, in a transpressional regime, of the Sept Laux pluton. This conclusion may also apply to the Saint Colomban and La Lauzière bodies owing to the similarities in shape, composition and age of the three plutons.

COMPARISONS WITH OTHER VARISCAN MASSIFS

The Late Variscan plutonism of the External Crystalline Massifs (ECM) of the Alps represents post-collisional intracontinental magmatism. It comprises two major suites of granitoids, one early (ca. 330–340 Ma; Visean) and highly magnesian, the other later (ca. 295–305 Ma; Stephanian) and more ferriferous (DEBON et al., 1994; DEBON and LEMMET, in prep.) (Fig. 8). Each suite was intruded at the beginning of one of the syn- to post-thickening extension periods recognized by BURG et al. (1994) in the western European Variscides, either the Late Visean-Westphalian event or the Late Stephanian to Early Permian event.

The three Belledonne plutons are typical representatives of the former suite (Fig. 8). Elsewhere among the ECM, this magnesian suite is also extensively developed in the Grandes Rousses and Pelvoux massifs (BANZET, 1987) where its age remains poorly constrained (e.g. age of ca. 340 Ma inferred for the Alpetta "orthogneisses" [see above]; whole-rock Rb–Sr dating of the Rochail granite [Pelvoux] at 331 ± 32 Ma [DE-

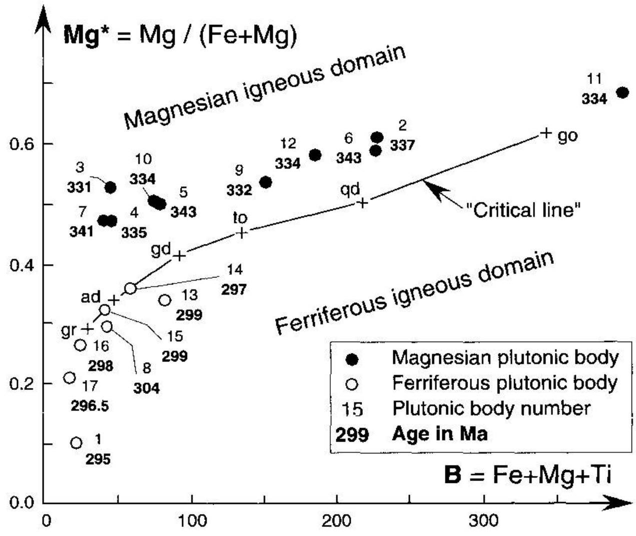


Fig. 8 Plot of dated plutonic bodies (mean compositions) from the External Crystalline Massifs of the Alps on the Mg*B diagram. Two main suites of granitoids can be distinguished, one early (ca. 330–340 Ma) and highly magnesian, the other later (ca. 295–305 Ma) and more ferriferous (simplified from DEBON and LEMMET, in prep.). Argentera massif: 1 = Argentera granite (FAURE-MURET, 1955; FERRARA and MALARODA, 1969), 2 = metamonzonites (LOMBARDO, pers. comm.; COLOMBO, 1996; LOMBARDO et al., 1997); Pelvoux massif: 3 = Rochail granite (BANZET and VIVIER, unpubl.; DEMEULEMEESTER, 1982); Belledonne massif (this study): 4 = Sept Laux granite (inner unit), 5 = Saint Colomban porphyritic granite, 6 = mafic enclaves of the Saint Colomban granite, 7 = La Lauzière granite; Mont-Blanc massif: 8 = Mont-Blanc porphyritic granite (MARRO, 1986; BUSSY, 1990; BUSSY and VON RAUMER, 1993); Aiguilles-Rouges massif: 9 = Pormenaz monzonite (BUSSY et al., 1998); Aar massif (SCHALTEGGER, 1990, 1994, and pers. comm.; SCHALTEGGER and VON QUADT, 1990; SCHALTEGGER et al., 1991; SCHALTEGGER and CORFU, 1992): 10 to 12 = shoshonitic-ultrapotassic suite, with 10 = Punteglias granite, 11 = Punteglias diorite, 12 = Giuv syenite, 13 to 17 = Central Aar Granite, with 13 = Grimsel granodiorite, 14 = Central granite s.l., 15 = Central granite s.s., 16 = Northern border facies, 17 = Mittagflue granite. Ages determined by whole rock Rb-Sr isochron with $\lambda^{87}Rb = 1.42 \cdot 10^{-11} \cdot a^{-1}$ (Argentera and Rochail granites), SHRIMP microprobe on zircon (Argentera metamonzonites), U-Pb on zircon ± monazite or titanite (Mont-Blanc, Aiguilles-Rouges and Aar granitoids), single-zircon Pb evaporation (Belledonne granitoids). Gotthard granites not plotted on the diagram [numerous datings at about 300 Ma (for a review, see SCHALTEGGER, 1994), but chemical analyses unavailable]. Other explanations as in figure 4.

MEULEMEESTER, 1982]). In addition, the magnesian suite occurs as small bodies in the Argentera massif (metamonzonites dated at 337 ± 8 Ma; LOMBARDO, pers. comm.; LOMBARDO et al., 1997), the Aiguilles-Rouges massif (332 ± 2 Ma-old Pormenaz monzonite; BUSSY et al., 1998), and the Aar massif (shoshonitic-ultrapotassic suite of SCHALTEGGER et al. [1991], dated by SCHALTEGGER and CORFU [1992] at 334 ± 2.5 Ma) (Fig. 8).

The magnesian suite forms part of the "Lower to Middle Carboniferous high-K calc-alkaline suites" recognized by BONIN et al. (1993) throughout the Variscan Alps. It has also been reported in other massifs of the Moldanubian zone of the Variscides (e.g. Corsica: 337–339 Ma [ROSSI and COCHERIE, 1995; MÉNOT et al., 1996]; Southern Vosges: 339–342 Ma [SCHALTEGGER et al., 1996]; Central Bohemia: 340–343 Ma [HOLUB et al., 1997]).

In the Aar massif, these magnesian plutonic rocks mark the beginning of the Late Variscan strike-slip tectonics and coincide with a first period of extension or transtension associated with the formation of volcano-sedimentary basins (SCHALTEGGER et al., 1991, 1993; SCHALTEGGER and CORFU, 1995). In the Alpine realm, they indicate a stage of uplift and erosion in a short-lived transpressional and/or transtensional regime (BONIN et al., 1993). In the Southern Vosges area, the rocks are linked to an extremely short-lived episode of extension, between ca. 345 and 340 Ma (Visean), marked by the development of a large volcano-sedimentary basin and the exhumation of adjacent high-grade gneiss rocks (SCHALTEGGER et al., 1996). As in these different regions, the Late Variscan Belledonne plutonism supports a (short-lived?) period of opening as soon as the Early Visean, in a bulk tectonic regime that in the Belledonne area, however, was more probably transpressional than transtensional. The "Schistes verts" formation of the northeastern Belledonne domain might be an equivalent of the Visean volcano-sedimentary rocks from the Southern Vosges (VIVIER et al., 1987) and Aar massif.

The first period of extension documented by BURG et al. (1994) in the European western Variscides, predominantly Late Visean-Westphalian in age, was a diachronous event, beginning in the inner, thickest parts of the Variscan belt. It was related to wrench tectonics reactivating thrust zones and took place during escape tectonics controlled by still active compressional forces. These processes induced an extension almost parallel to the Variscan belt, at a time when thermal relaxation was already occurring as suggested by voluminous crustal-derived plutonic rocks.

This geotectonic model is consistent with different characteristics of the ECM, in particular of the Belledonne massif. The ECM were part of the inner zone of the Variscides (VON RAUMER et al., 1993), i.e. of a domain propitious for an early development of the extensional processes, as soon as ca. 340 Ma according to the Belledonne granitoids. The intrusion of these granitoids was related to opening linked with thrust and strike-slip tectonics, as shown by the Sept Laux pluton, and was coeval with the tectonic juxtaposition ("collage"), by strike-slip faulting, of the three main Belledonne domains (terranes) during the Early Carboniferous times until the Visean at ca. 323 Ma (DEMEULEMEESTER, 1982; MÉNOT, 1987a, 1988; MÉNOT et al., 1987). The direction of opening linked with the emplacement of the Belledonne plutons was possibly perpendicular to their present elongation. Accordingly, it could have been WNW–ESE, the same as the extension direction recorded in many other Variscan regions for Middle Carboniferous times, especially in the neighbouring French Massif Central (see Fig. 1 in BURG et al., 1994).

The second period of extension recognized by BURG et al. (1994), namely the Late Stephanian to Early Permian event, is characterized by major stretching with an extensional direction mainly transverse to the Variscan belt. In the eastern French Massif Central, this direction was almost SSW–NNE, parallel to the present elongation of the Belledonne massif (see Fig. 2 in BURG et al., 1994). Most tectonic and metamorphic evolution of the Belledonne massif was apparently completed by the end of the Visean (MÉNOT, 1988). Subsequent extension, however, may have occurred, at least in the southwestern inner domain (GUILLOT and MÉNOT, work in progress), although restricted to upper crustal levels and only accompanied by the slight development of scarce anatectic melts. Unlike other Variscan regions, the Belledonne massif does not seem to be severely affected by the Stephanian-Permian period of extension, which could account for the fact that it is devoid of significant representatives of the latter plutonic suite distinguished in the ECM by DEBON et al. (1994), i.e. the ca. 300 Ma-old ferriferous suite.

SOURCE MATERIALS

The presence of Mg–K rich mafic rocks associated with the Belledonne granitoids (e.g. vaugnerite, durbachite, monzonite, quartz syenite) implies a contribution from a subcontinental mantle source, most probably enriched in incompatible elements (BANZET, 1987; WILSON, 1989, and references therein; SABATIER, 1991; SCHALTEGGER et al., 1991; SCHALTEGGER and CORFU, 1992). This indicates that, as emphasized by BURG et al. (1994), the Late Variscan strike-slip faults may have been lithospheric-scale, allowing mantle melts to rise into the upper crust (BANZET et al., 1985; SCHALTEGGER et al., 1991).

A geochemical gap separates the Belledonne granites from their mafic enclaves (Fig. 4), but the similar compositional characteristics (e.g. subalkaline typology, high Mg/Fe ratios, high contents in Ba and/or in Sr, Th, U, low Rb/Sr ratios, similar REE patterns) (Tab. 1; Figs 4, 5) demonstrate that they are related. Many studies on mafic/felsic igneous pairs of other regions (SABATIER, 1980, 1991; BANZET, 1987; DEBON, 1991; DIDIER and BARBARIN, 1991, and references therein) have shown, however, that the two groups of rocks are not cogenetic. Their relationship was most probably secondarily acquired through pervasive interaction between two originally independent magmas, one mafic and mantle-derived, the other felsic and probably crustal-derived. In this case, both the granites and their mafic enclaves would represent hybrid rocks, a conclusion that is supported by the rather low value (0.7066) obtained by DEMEULEMEESTER (1982) for the initial $^{87}Sr/^{86}Sr$ ratio of the Sept Laux granites and by the zircon typology. When plotted on the typologic diagram of PUPIN (1980) (Fig. 6) and according to their I.A, I.T mean values, the zircons from the four dated samples fall within (OG 2, SC 1, LA 1) or close to (BL 131) the domain ascribed to plutonic rocks of hybrid origin. The negative ε_{Nd} value (–5 at 335 Ma; LAPIERRE, pers. comm.) obtained from a monzogranite sample from the Sept Laux pluton corroborates the involvement of sialic crust.

Conclusion

The three plutons of the Belledonne massif (Sept Laux, Saint Colomban, La Lauzière) constitute a single episode of highly magnesian subalkaline (alkali-calcic) plutonism that occurred during the Early Visean about 340 Ma ago. They evolved independently of each other as discrete bodies, according to distinct evolutionary trends.

These granitoids, associated with mafic rocks of vaugneritic and durbachitic affinity, are related to Mg–K plutonism. They are typical representatives of the first Late Variscan plutonic suite recognized in the External Crystalline Massifs of the Alps. In many respects, their characteristics (age, composition) can be compared to those of Mg–K granitoids of other Variscan massifs (e.g. Corsica, Vosges, Bohemia).

Their emplacement, probably related to local opening linked with thrust and strike-slip tectonics, took place during a thermal relaxation event subsequent to maximum crustal thickening. This late collisional context was marked by the coeval intrusion of anatactic melts related to a medium-pressure metamorphic stage (VIVIER et al., 1987; VON RAUMER et al., 1993). Such a geodynamic environment, with Mg–K plutonism and medium-pressure metamorphism, is closely comparable with that described in northwestern Corsica during Visean times (MÉNOT et al., 1996).

This emplacement coincided with the onset of a first major period of extension throughout the Late Variscan belt (BURG et al., 1994). However, unlike other Variscan regions (e.g. Vosges), it probably occurred in a transpressional regime.

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