Lithostratigraphy and geochemical composition of the Mt. Pourri volcanic basement, Middle Penninic W-Alpine zone, France

Autor(en): **Guillot, François / Desmons, Jacqueline / Ploquin, Alain**

Objekttyp: **Article**

Zeitschrift: **Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie**

Band (Jahr): **73 (1993)**

Heft 2

PDF erstellt am: **21.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-55577

SCHWEIZ. MINERAL. PETROGR. MITT. 73, 319–334, 1993

Lithostratigraphy and geochemical composition of the Mt. Pourri volcanic basement, Middle Penninic W-Alpine zone, France

by *François Guillot*[1], *Jacqueline Desmons*[2] and *Alain Ploquin*[2]

Abstract

The Mt. Pourri (or Northern Vanoise) massif belongs to the Briançon zone, an internal and metamorphic part of the Alpine belt. The pre-Permian, kilometer-thick sequence is composed of bimodal metavolcanites overlain by carbonaceous black schists containing mafic sills. The bimodal metavolcanites consist of green, layered mafic tuffs, white felsic granophyres and tuffs, some possibly derived from ignimbrites, and porphyritic metabasalts of tholeiitic composition. The abundance of quartz in the felsic rocks points to some degree of alteration, especially in the uppermost bimodal layers. The REE-profiles are flat, and the chemical compositions indicate an extensional tectonic setting of either within-plate or ocean floor character. In the black schists a felsic-sodic, volcanic-derived component prevails. Towards the top of the bimodal sequence a subvolcanic porphyroblastic granophyre body, dated by the U–Pb method on zircon as Late Cambrian, allows to propose ages for the whole series: Cambrian (bimodal volcanism), Ordovician-Silurian (-? Dinantian) (black schist deposition) and Ordovician to Devonian (-? Dinantian) (sill intrusion).

Similarities are discussed with coeval sequences in the Western and Eastern Alps, and in Variscan Europe (Provence, Vosges) where Variscan metamorphism was much stronger. No Variscan metamorphic imprint is identifiable in the Briançon zone, thus it could have been accreted to the European plate after the Variscan events.

Keywords: Paleovolcanism, granophyre, geochemistry, Variscan, Briançon zone, Western Alps.

Résumé

Le massif de Vanoise septentrionale, ou du Mont Pourri, appartient à la zone briançonnaise, un ensemble d'unités alpines où les métamorphismes alpins ont affecté tous les termes jusqu'au Cénozoïque. La série anté-permienne du Mont Pourri débute par des roches volcaniques bimodales (acides-basiques), d'épaisseur kilométrique, surmontées de schistes noirs, eux-mêmes contenant des sills basiques. Dans la série bimodale les métabasites du Mont Pourri ont des compositions de tholéiites anorogéniques. Les faciès hypovolcaniques acides, à reliques de textures rhyolitiques et granophyriques, ont conservé une composition de granite de zone anorogénique, alors que les roches acides d'épanchement sont fortement modifiées chimiquement, avec notamment une richesse anormale en silice des dernières assises méta-ignimbritiques. Ces modifications, comme la spilitisation des roches basiques, relèvent sans doute d'une altération hydrothermale précoce.

Le granophyre du Mont Pourri, situé lui aussi vers le sommet des assises bimodales, a fourni un âge isotopique de cristallisation magmatique proche de la limite Cambrien-Ordovicien. La moitié inférieure de la série, à magmatisme bimodal, pourrait dater du Cambrien au moins, la moitié supérieure, à schistes noirs et sills, pouvant représenter l'Ordovicien et/ou le Silurien, ou même le Dévono-Dinantien.

Des rapprochements lithologiques sont évoqués avec des séries de même âge des Alpes occidentales et orientales et quelques-unes de l'Europe varisque où le métamorphisme varisque a été fort. Il n'existe pas de trace identifiable de métamorphique varisque dans la zone briançonnaise, qui pourrait donc ne s'être accolée à la plaque européenne qu'après les événements varisques.

[1] Université des Sciences et Technologies de Lille, Laboratoire de Dynamique Sédimentaire et Structurale, Sciences de la Terre, F-59655 Villeneuve d'Ascq Cedex, France.

[2] Centre de Recherches Pétrographiques et Géochimiques – C.N.R.S., BP 20, F-54501 Vandœuvre-lès-Nancy Cedex, France.

Introduction

In the Northern Vanoise, an internal, metamorphic, area of the Alpine orogen (Fig. 1), we describe the lithostratigraphy of the pre-Alpine basement. The Mt. Pourri massif constitutes a part of the basement of the zone Vanoise-Mt. Pourri, alternatively called zone Vanoise-Ambin or zone Briançonnaise interne in France, or Zona Interna in Italy. Overlain by Permian grits and including carbonaceous black schists (thus resembling Upper Carboniferous coal measures), the Mt. Pourri series was thought to be Permo-Carboniferous in age (ELLENBERGER, 1958; FABRE, 1961; PERUCCIO-PARISON, 1984; GUILLOT and RAOULT, 1984) despite a few contrasting opinions based on the essential lithological differences with the zone Houillère series (GIGNOUX, 1929; BOCQUET [DESMONS], 1974 a, b; GUILLOT, 1987). The Permo-Carboniferous age attribution has been invalidated by a 507 ± 9 Ma U–Pb zircon dating of a granophyre body in the Mt. Pourri (GUILLOT et al., 1991). This Late Cambrian age (after HARLAND et al., 1990) confirms recent assumptions (DESMONS and FABRE, 1988; DESMONS and PLOQUIN, 1989; DESMONS, 1992) regarding the presence of lower Paleozoic and older basements in the Penninic zone.

The Mt Pourri sequence is presented below together with improved analytical data, especially REE data. The case of the only dated rock, i.e. the Mt. Pourri granophyre, at first supposed to be intrusive (GUILLOT et al., 1991) but which is probably hypovolcanic, is thoroughly discussed.

The geochemistry has been investigated by 156 major elements analyses (ELLENBERGER, 1958; PERUCCIO-PARISON, 1984; ABOUCHAMI, 1986; GUILLOT, 1987; this paper). In table 1 we give only representative analyses selected following the criteria of PEARCE (1983a). Detailed analytical results are available through C.R.P.G. (ARTEMISE data bank). According to geochemical studies

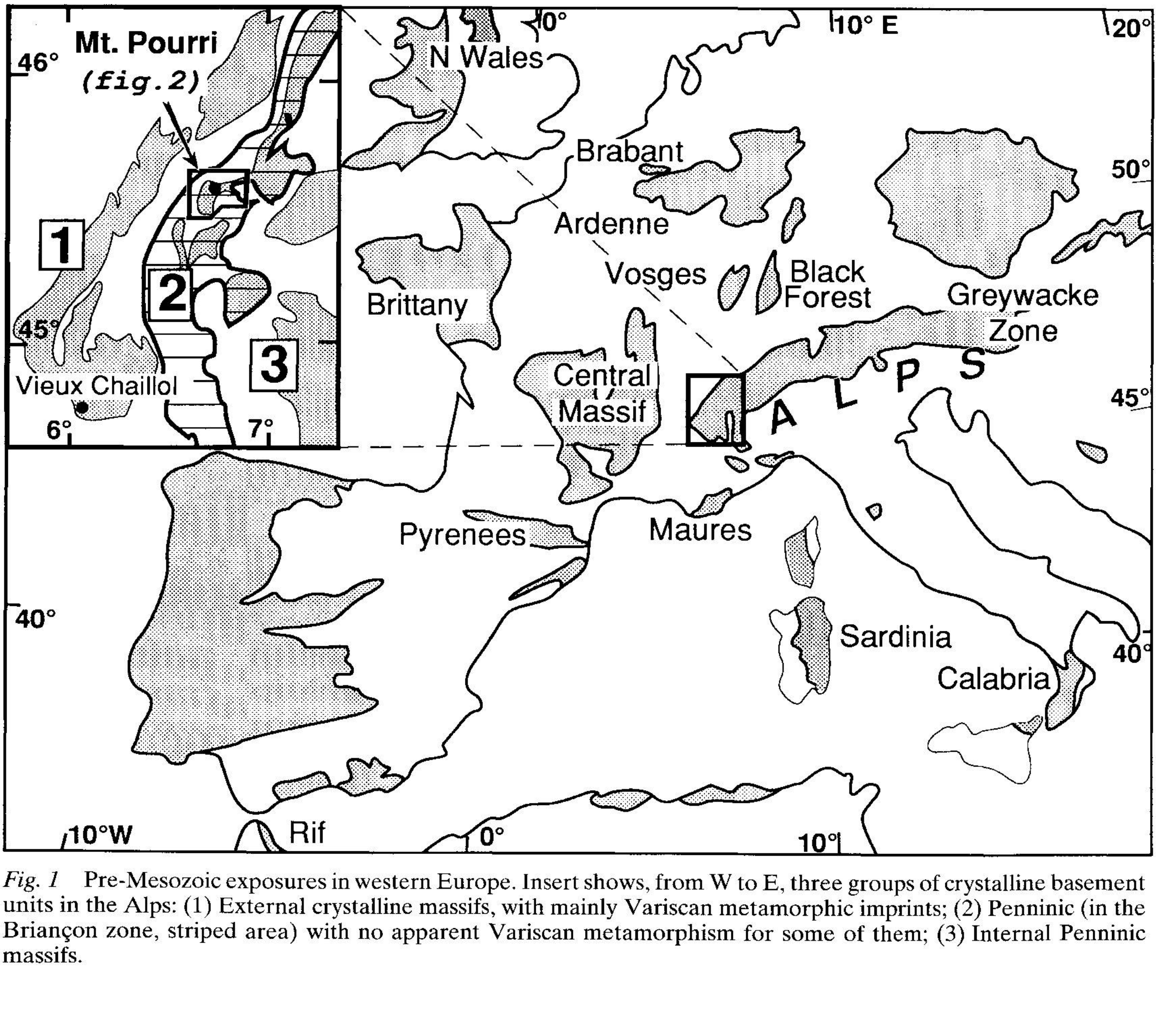

Fig. 1 Pre-Mesozoic exposures in western Europe. Insert shows, from W to E, three groups of crystalline basement units in the Alps: (1) External crystalline massifs, with mainly Variscan metamorphic imprints; (2) Penninic (in the Briançon zone, striped area) with no apparent Variscan metamorphism for some of them; (3) Internal Penninic massifs.

performed on the Permian (AINARDI, 1976) and Meso-Cainozoic (BROUDOUX et al., 1984) sequences from the same Vanoise-Mt. Pourri zone, a chemical characterization of the stratigraphic units is possible. Their whole-rock chemical features have been preserved, apparently not too altered by the Alpine metamorphism.

Situated in the upper Isère valley, the Mt. Pourri is the highest peak (Fig. 2) of Northern Vanoise. The massif is a stack of NW-verging tectonic sheets, many of them with inverted limbs. The rocks have been severely folded and schistified, thus, the reported thicknesses (Fig. 3) tend to be inaccurate. It is nowhere easy to separate Alpine mechanical contacts from the stratigraphic ones, or Alpine foliation(s) from any previous planar structure(s). For the purposes of this paper, only the major faults and thrusts are mapped (Fig. 2). More detailed structural accounts are available in DEBELMAS et al. (1989), and in DEBELMAS and CABY (1991).

Lithostratigraphy

The outcrops rarely give clear evidence concerning the mode of emplacement of the rocks, the igneous origin of which is often better supported

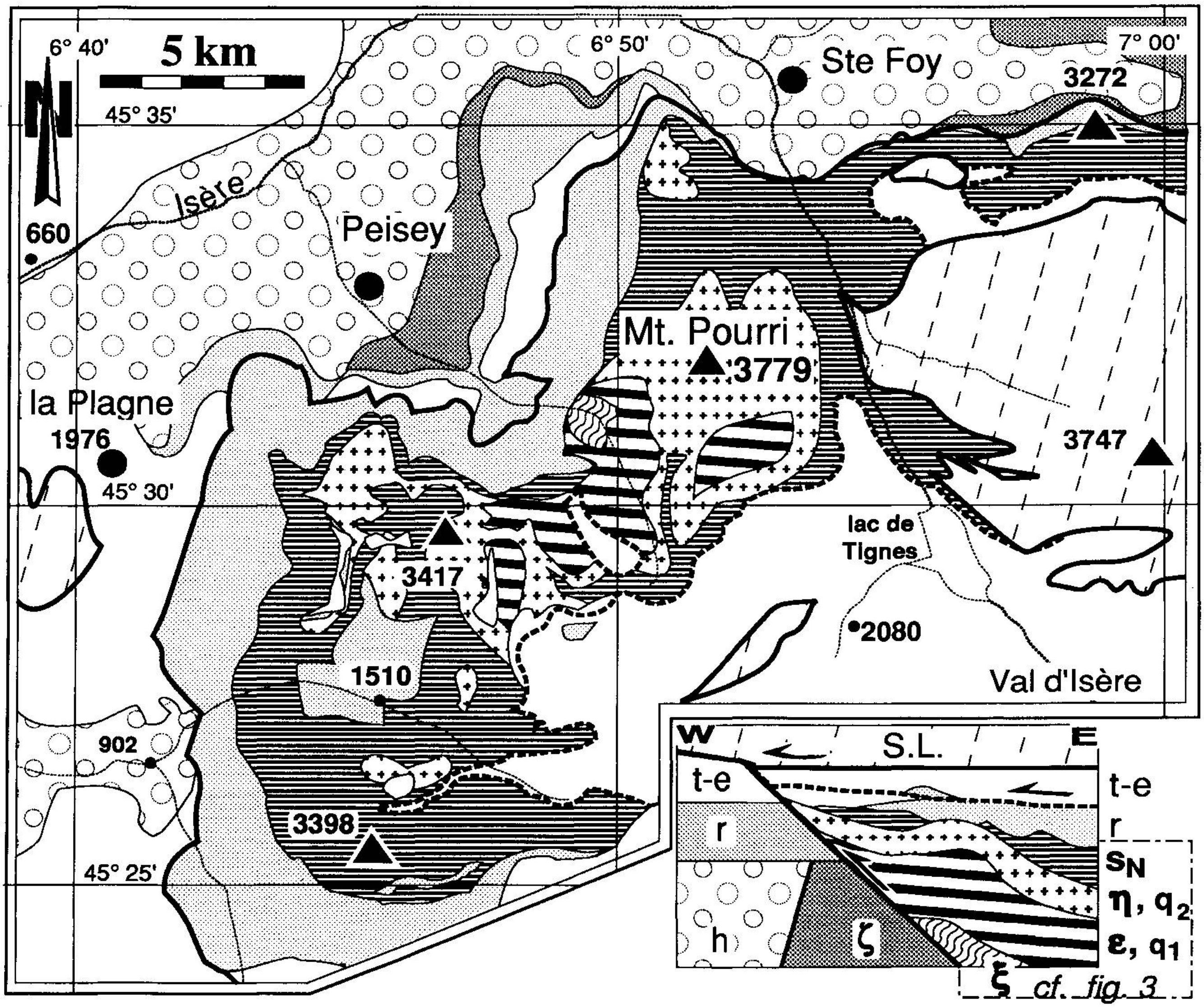

Fig. 2 Geological map of the Mt. Pourri (or Northern Vanoise) massif and its surroundings. Insert presents a tentative section at the onset of the main Alpine thrust events. Key to symbols of rock types: ζ: (Precambrian ?) Sapey-Peisey gneisses – h: Upper Carboniferous coal measures – r: (Permo-Triassic New Red Sandstones ?) variegated sericite grits, sandstones – t–e: Triassic to Cainozoic cover rocks – S.L.: allochthonous, Jurassic to (Upper) Cretaceous "Schistes lustrés". Abbreviations used in figures 2 to 8 and table 1: ξ, ε, q_1, η, q_2, s_N: see text and figure 3.

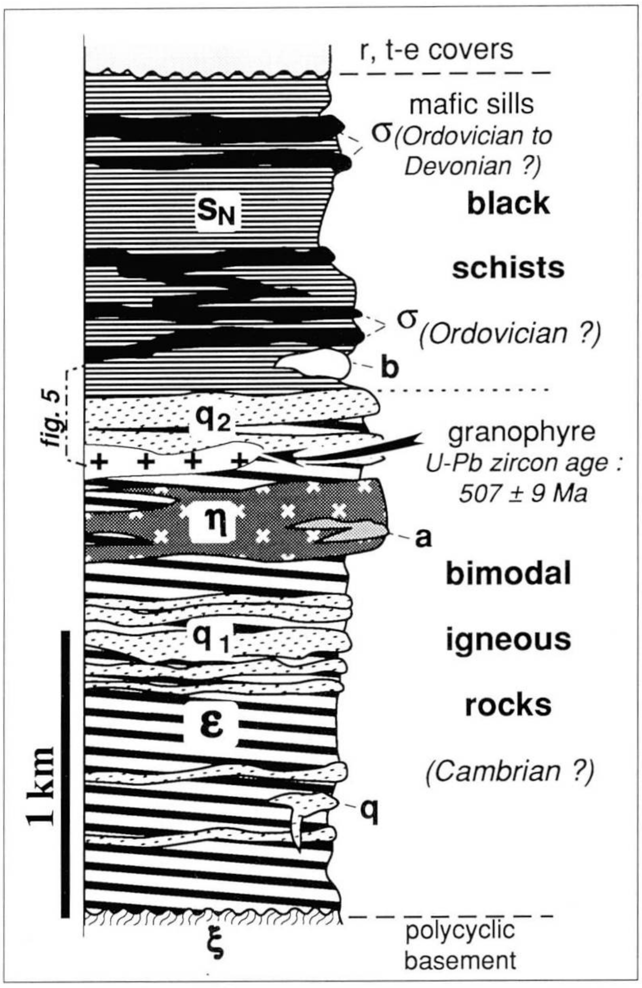

Fig. 3 Lithostratigraphic column of the Mt. Pourri sequence. After GUILLOT (1987). Facies symbols (details: see text): ξ, garnet micaschist; ε, layered mafic tuff; q_1, layered felsic tuff, lower cluster; q, felsic stock; η, laccolithic metabasalt; a, plagiogranite stock; q_2, layered felsic tuff, upper cluster; s_N, black schists; b, light-coloured mafic stock; σ, mafic sills.

by their whole rock chemistry than by what remains of their primitive structure. Evidence from field mapping show that the Mt. Pourri formations are layered, and that similar kilometer-thick sequences are found without major changes along several sections. A lithostratigraphic column has been reconstructed (Fig. 3), modified slightly after GUILLOT (1987).

Garnet-micaschists (ξ in Figs 2–3; E6°50'–N45°32', «cascade de la Gurraz») are regarded as a remnant of an older basement sequence on the basis of their higher-grade metamorphic associations. The overlying lower Paleozoic series is several kilometers thick, with a lower half of green-and-white banded metavolcanites and an upper half of black schists containing mafic sills (Figs 2–3). No sedimentological or paleontological evidence supporting this bulk polarity has been reported. However, the Permian sericite grits do overlay the lower Paleozoic sequence unconformably through a depositional contact (GUILLOT and RAOULT, 1984) and the most commonly overlain rocks are the black schists (Fig. 2). We thus think, from this field evidence, that the black schists are stratigraphically higher, and younger, than the green-and-white banded metavolcanics. In the following paragraphs we subdivide the rocks into three types in order to emphasize the variations within each: mafic rocks, leucocratic felsites, and black schists.

Mafic rocks

– *Layered tuffs*. The lower half of the Mt. Pourri sequence is composed of banded alternations of green rocks (ε in Fig. 3) and subordinate white felsic tuffs (q, q_1, q_2). A frequent millimetric layer-parallel foliation commonly resembles an ignimbritic welded structure. Along many mafic bands, distinctive pistacite nodules, up to 1 cm in diameter, have a roughly concentric-radial structure, and could represent the early post-magmatic infillings of vesicles in shallow eruptive basalts (FISHER, 1984).

– *Laccolithic metabasalt*. The 50 to 200 m-thick, light blue-green, massive η formation has a porphyritic texture owing to dark actinolite phenoclasts 1 to 5 mm in size, some of which represent previous clinopyroxene-replacing hornblende (samples from «la Saulire», E6°46'–N45°27'; ELLENBERGER, 1958). Because of its thickness and massiveness, η might have been emplaced partly as a laccolithic basalt. This rock type has been encountered in several sections, always approximately at the same level of the general log (Fig. 3), near to, and under, the uppermost quartzitic layers (q_2, in Fig. 3). One occurrence (E6°45'– N45°31' , «Pointe de Friolin»), although massive, contains pods of a leucocratic albite-quartz rock (a on Fig. 3 and Tab. 1). Since the η metabasalt has a well-defined lithostratigraphical position, it should represent one eruptive phase, during which thick basaltic lava bodies were interbedded with, or intruded into, coeval tuffs, ashes and sediments.

– *Sills*. In the upper black schists, the metabasites form up to 5 m-thick dark green massive beds (σ), representing either sheet-like intrusions, dykes or more probably sills, as suggested by their local parallelism, by their symmetrical contacts with the host schists and by the absence of eruptive structures such as breccias, vesicles, pillows or laminae. Although pale green metapelite-like lay-

Tab. 1 Representative analyses of Mt. Pourri basement rock types. Analyses by ICP (C.R.P.G., Nancy). Key to symbol of rock types: see figure 3 and text. altered σ consists of a mafic, carbonate-, muscovite-, pyrite-rich sill located in the lower part of the black schists. tr. or < 5 or < .5: content lower than the detection threshold.

		LOWER MAFIC ROCKS						FELSIC		ROCKS		BLACK SCHISTS		MAFIC SILLS		
	sample No.	3039B	2126B	3108B	3038B	3037B	9021	9019	3107B	2121B	3064B	3005B	3017B	3014B	2130B	3110
	rock type	ε	ε in q_2	η	η dark	a	lampro-phyre	grano-phyre	q	q_1	q_2	s_N	s_N	b	σ	σ altered
Major elements (%)	SiO_2	49.22	48.07	45.96	49.53	62.12	55.30	75.53	77.81	76.05	91.40	58.32	67.70	41.67	47.71	43.94
	Al_2O_3	16.17	13.48	16.73	15.48	13.96	12.71	12.44	11.96	12.46	2.54	17.28	14.58	23.76	12.83	14.45
	Fe_2O_3	11.38	13.28	11.08	11.25	9.39	12.36	1.67	1.29	2.29	1.12	7.58	4.69	5.87	16.00	9.40
	MnO	0.16	0.20	0.17	0.17	0.11	0.16	tr.	tr.	0.02	0.03	0.10	0.07	0.08	0.26	0.17
	MgO	6.26	5.30	7.16	6.12	1.95	3.87	0.32	0.20	0.85	0.22	3.40	1.79	8.35	4.91	7.73
	CaO	6.48	9.25	9.28	8.89	2.22	3.08	0.06	0.14	0.06	1.20	1.85	2.11	13.43	9.64	9.33
	Na_2O	4.75	2.91	3.08	4.01	5.66	1.21	3.62	1.88	4.94	0.04	3.15	4.33	1.77	1.27	1.06
	K_2O	tr.	tr.	0.08	0.02	0.10	5.87	4.77	5.15	1.77	0.55	2.62	1.37	0.04	0.03	1.24
	TiO_2	1.43	2.41	1.27	1.52	1.21	2.32	0.17	0.10	0.14	0.04	0.77	0.75	0.30	3.29	1.12
	P_2O_5	0.16	0.43	0.13	0.20	0.30	0.68	0.12	tr.	0.02	0.03	0.19	0.12	0.07	0.50	0.00
	L.O.I.	3.79	4.45	4.83	2.34	2.77	1.95	0.52	1.21	1.21	1.80	4.49	2.23	4.41	3.35	11.79
	total	99.80	99.78	99.77	99.53	99.79	99.51	99.22	99.74	99.81	98.97	99.75	99.74	99.75	99.79	100.23
Trace elements (ppm)	Ba	5	< 5	28	< 5	49	601	587	617	510	147	638	438	29	56	251
	Be	1.1	1.7	0.68	1.2	0.8	2.9	1.7	1.29	2.08	< .5	1.6	1.2	< .5	1.79	
	Co	64	24	62	61	47	13	< 5	57	< 5	129	49	53	78	32	86
	Cr	91	177	42	108	5	7	< 5	< 5	5	12	101	81	872	55	158
	Cu	12	29	58	18	22	25	5	8	5	< 5	57	11	10	57	21
	Ga	25	27	26	30	27	24	13	22	25	5	25	22	70	28	
	Nb	5	14	< 5	7	7	21	13	9	10	< 5	9	7	7	17	
	Ni	46	38	65	34	< 5	8	< 5	< 5	< 5	6	51	16	162	26	76
	Rb	5	5	6	5	6	276	127	162	49	15	85	38	6	6	11
	Sc	33.9	36.2	30.5	34.09	19.78	23.39	3.4	6.9	2.2	2.5	14.8	13.3	25	39.7	
	Sr	251	283	166	308	69	55	9	15	23	12	103	249	252	454	203
	Th	<5	< 5	< 5	5	< 5	5	15	13	10	< 5	6	6	15	< 5	
	V	259	284	225	245	100	143	< 5	< 5	< 5	10	121	95	107	394	215
	Y	31.24	39	23.49	39.1	36	89.48	83.03	66.17	90.8	5.48	16	17	14	63.6	
	Zn	98	105	74	96	67	138	24	48	80	13	80	69	36	123	
	Zr	102	199	67	139	262	327	282	144	271	29	131	177	21	259	
REE (ppm)	La	6.45		3.44	12.98		31.01	47.63	44.02	41.77	6.45				18.62	
	Ce	15.83		9.43	28.03		73.45	100.14	90.88	87.89	12.94				44.75	
	Nd	11.98		7.86	19.08		41.62	47.69	45.18	47.53	5.74				31.95	
	Sm	4.44		2.86	6.27		11.20	12.20	11.01	13.13	1.25				9.44	
	Eu	1.58		1.28	1.82		2.61	0.95	0.60	1.62	0.31				2.94	
	Gd	5.07		3.73	6.64		10.92	11.62	9.81	13.41	0.85				10.72	
	Dy	5.24		3.81	6.55		12.89	12.87	10.68	14.06	0.98				10.84	
	Er	3.84		3.01	4.30		8.22	7.70	6.03	8.05	0.54				5.86	
	Yb	3.01		2.30	3.64		8.52	8.03	6.32	8.11	0.49				5.65	
	Lu	0.55		0.42	0.64		1.42	1.34	1.06	1.37	0.07				0.97	
	La/Yb	2.1		1.5	3.6		3.6	5.9	7.0	5.2	13.2				3.3	

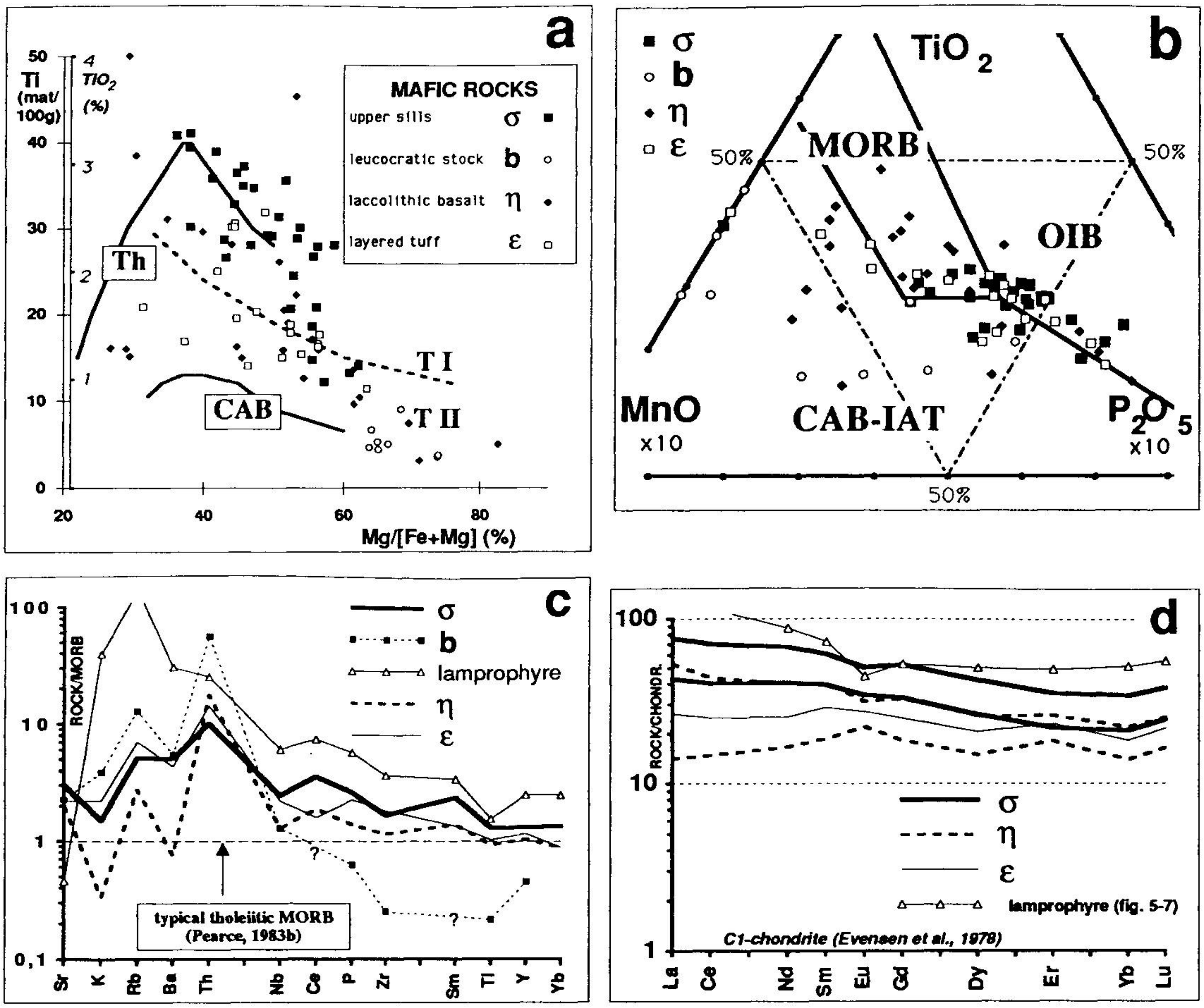

Fig. 4 Mafic rock geochemistry. Key to symbols of rock types: see text and figure 3. a: Ti vs Mg/[Fe + Mg] plot (GUILLOT et al., 1986) – mat/100g: 10^{-3} atom-grams per 100 g rock – CAB: trend of the Vourinos (Greece) calk-alkaline basalts – Th: trend of the Thingmülli tholeiites (Iceland) – T I / T II: statistical boundary between Ti-rich type I, and Ti-poor type II, tholeiitic basalts. b: after MULLEN (1983) – OIB, MORB, CAB-IAT: respectively ocean-islands basalts, mid-oceanic ridge basalts, and calk-alkaline basalts – island arc tholeiites. c: trace element contents normalized to MORB (PEARCE, 1983b). d: REE contents normalized to chondrite (EVENSEN et al., 1978).

ers might represent a sort of transition towards the black schists, they show no chemical difference from the black schists. Thus, there is a compositional gap between the sills and their host rocks (e.g., see their respective 47.5 ± 2.2% and 64.7 ± 4.8% average SiO_2 contents).

– *Light-coloured mafic rocks.* In the black schists, a large body of light-coloured basic rock (b in Figs) outcrops in only one place (E6°49'30"–N45°29'; "val de Genêt"). Its geochemical composition is quite distinctive (Tab. 1 and Fig. 4), with a probable plagioclase-cumulate trend.

MINERAL COMPOSITION

Thin sections of the mafic rocks show green actinolite, often rimmed by sodic blue amphibole, chlorite, epidote, albite, quartz, leucoxene-rimmed ilmenite, and subordinate carbonate, pyrite, iron oxide and apatite. Typically, rounded pistacite phenoclasts have been found in the well-layered mafic rocks (ε). Green to blue-green actinolite phenocrysts in a saussuritized plagioclase matrix are typical of the mesocratic laccolithic metabasalt (η). Skeletal leucoxene-ilmenite to-

Tab. 2 Mafic rocks: statistical relationships between Ti-content and atomic Mg/[Fe + Mg] ratio. The corresponding data points are plotted in figure 4a. Symbols of rock types: see figure 3 and text.

mafic rock type	number of analyses	average TiO_2-content ± st. dev.	computed intercept with Mg/[Fe + Mg] axis (Fig. 4a)	correlation coefficient of TiO_2 and Mg/[Fe + Mg]
σ	31	2.30 ± 0.66%	74% + 7 –5	–.80
b	9	0.52 ± 0.33%	75% + 3 –2	–.74
η	25	1.60 ± 0.94%	74% + 18 –10	–.58
ε	17	1.65 ± 0.52%	73% + 27 –14	–.44

gether with Fe-rich actinolite are especially abundant in the sills within the black schists (σ). The light-coloured mafic formation (b) is comprised of colourless actinolite within an albite matrix clouded by very fine-grained pale epidote.

GEOCHEMISTRY

Some of the analyses are of layered mafics of the lower section (ε), which we consider to be pyroclastites, perhaps redeposited. This mode of emplacement may have altered the magmatic geochemistry to an extent which remains difficult to estimate. Such alterations are thought to be partly responsible for the random scattering of the data points in the diagrams (Fig. 4). If we consider only rocks, such as η and σ, which were undisputedly undissociated massive lavas, the grouping of their representative points is much better: both give a tholeiite-like alignment in AFM, and in Mg/(Fe + Mg) versus Ti plots (Fig. 4a).

– *Major and trace element data.* The massive metabasaltic laccolith η is lighter coloured than the intra-blackschists sills σ, a fact reflected in its lower Ti and Fe and higher Al and Si contents (Tab. 1). On figure 4a where the differences in Ti-contents are emphasized, comparable maximal (initial ?) Mg/[Fe + Mg] ratios can be roughly estimated for each lineage, by statistically extrapolating each alignment to the intercept with the Mg/[Fe + Mg] axis. As indicated by the growing precision of these extrapolations (Tab. 2), the random dispersion of the representative points decreases from ε to σ.

The compositional differences, because of their stratigraphic character, suggest an evolution of the tectonic setting (even though this setting still has to be specified) and/or of the mode of emplacement of the magmas and/or of the amount of late-magmatic alteration. A back-arc basin setting could be envisaged for the first magmatic events, whereas the late sills plot nearer to anorogenic, within-plate or ocean floor basalts. On the Ti versus V diagram (Shervais, 1982; not shown), or on the $MnO/TiO_2/P_2O_5$ ternary plot (Fig. 4b), the diagnosis is similar, with the suggestion that σ could be ocean island basalts. The spider-diagram (Fig. 4c) drawn according to Pearce (1983b) indicates high values of Th and Ba, which this author considers as "the most distinctive features in patterns exhibited by contaminated basalts". But among the patterns given in figure 4c, the variations in K, Rb, Ba and Th contents could also be related to some kind of late- to post-magmatic mobility.

– *REE data.* The REE contents of representative mafic samples (Tab. 1) are 16 to 39 times the chondrite content in samples from the bimodal sequence (ε, η), and 36 to 60 times in the sills (σ). La/Yb ranges from 1.5 to 3.3. The light REE content grows together with the (Fe,Ti)-enrichment, which may reflect a growing differentiation. The REE-richest rock is a biotite lamprophyre, included into the Mt. Pourri granophyre (see that section). The REE patterns are flat, with no marked Eu-anomaly (Fig. 4d). These characters are again consistent with P-MORB or within-plate basalt affinities, and they at least preclude any orogenic tectonic setting.

Felsic rocks

The felsic rocks constitute either layers: q_1, q_2, or massive pods: a, q, granophyre (Fig. 3). Both types are located in the lower half of the series, interbedded with, or included into mafic units. Their SiO_2-content ranges from 62% (a) through 75% (granophyre, q, and some q_1 samples) to 90–92% (other q_1, and q_2). Because of such large variations, and under the hypothesis that all the felsic rocks derived from similar rhyolitic or granitic magmas, some kind of late- or post-magmatic alteration has to be advocated. Our main concerns are: (1) to describe and explain the wide compositional range; (2) to ensure that the tectonic setting indicated by the geochemical characters is in reasonable agreement with the ocean- or within-plate tectonic settings deduced from the coeval mafic rock geochemistry. Since the granophyre seems to be the least altered felsic rock, its composition has been used as a basis of comparison, with respect to the tracing of tectonic settings as well as the quantification of alteration processes.

The a leucocratic albite-quartz rock (Tab. 1, Fig. 3) has already been investigated by ELLENBERGER (1958) and GUILLOT (1987). This albite-rich, K_2O-poor rock, with albite-quartz intergrowths, resembles a plagiogranite as defined by COLEMAN and DONATO (1979), and could represent a local, sodic differentiation of the η laccolithic basalt. Such rocks have often been found in shallow levels of ophiolitic complexes, associated with extrusive keratophyre (COLEMAN and DONATO, 1979).

PETROLOGY

– *The Mt. Pourri granophyre.* Only one granophyre occurrence is known in the area (E6°51'–N45°34.5'), although similar rocks are present further NE in the zona interna (val de Rhêmes: ELTER and coll., 1983; DEBELMAS and CABY, 1991). It deserves to be described in more detail, owing to the significance of its 507 ± 9 Ma age (GUILLOT et al., 1991). With respect to the age of the series, the main question is to know whether the granophyre was emplaced as a late intrusion or crystallized at the same time as the host rocks. Previous authors (ELLENBERGER, 1958; CABY, 1974; MARION, 1984) suggested it was a plutonic, granite-type mass. Owing to its more massive and harder nature than many other rock types of the Mt. Pourri, its igneous texture has been better preserved from Alpine deformation. After BOCQUET [DESMONS] (1974a) we believe that the granophyre derived from a subvolcanic body rather than from a pluton sensu stricto, because it is crudely layered and it grades continuously upwards (Fig. 5) into layers of banded felsic and mafic rocks analogous to the bimodal volcanic levels (mafic ε, and felsic q_1 or q_2 tuffs). Some granophyric samples show centimetric layers made of contiguous nodular feldspathic warts. Such textures could indicate a pervasive late-magmatic, syn-welding recrystallization of the feldspars through alkali-rich fluids in a still highly porous rock. This process appears to be the major cause of the myrmekite growth.

The granophyre has been studied using cathodoluminescence microscopy coupled with

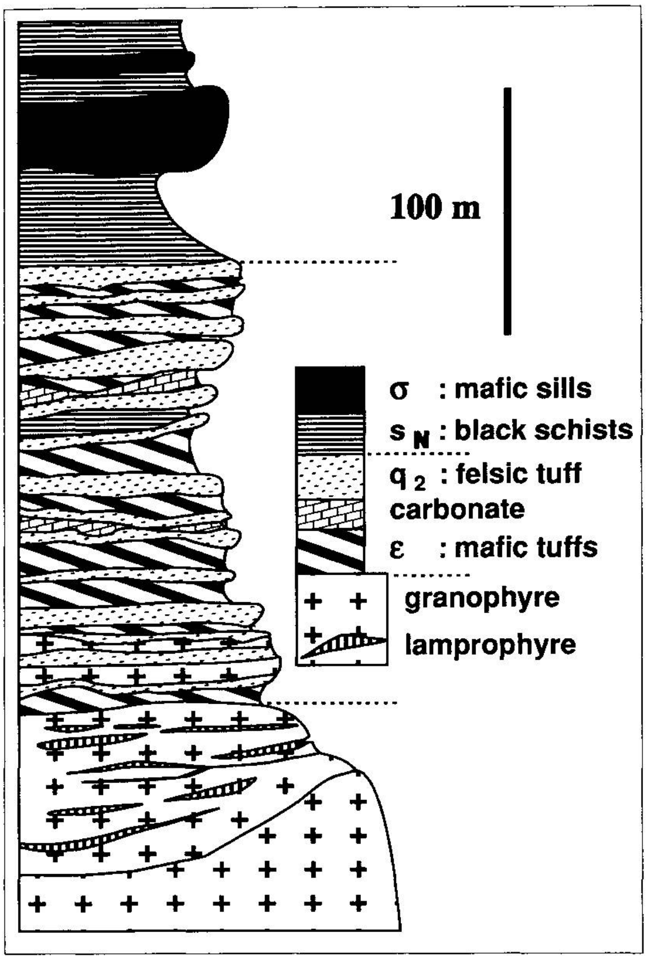

Fig. 5 Mt. Pourri granophyre: field section showing an upward transition to (s_N) black schists containing (σ) mafic sills. Key to symbols: see text and figure 3. The lamprophyre contains more than 60% of fine-grained green biotite, together with abundant apatite. The middle banded complex (q_2, ε) includes thin carbonate seams or layers, while some (ε) mafic bands are made of deep-blue amphibole needles in a coarse-grained pistacite matrix.

microprobe analyses. The K-feldspar and quartz myrmekite forms additional rims or warts, around composite albite + K-feldspar porphyroblasts, but also isolated flakes in the matrix. Such myrmekitic textures may indicate devitrification processes under pneumatolytic conditions (BAILEY et al., 1924), or late replacement of alkali feldspar by quartz (HOPSON and RAMSEYER, 1990; COLLINS, 1990). In any case, they result from late-magmatic processes rather than a metamorphic event. The crystallization order appears to be the following: (1) albitic core (dark, velvet-like red in CL; high-T albite ?) (2) K-feldspar rim (ochre yellow in cathodoluminescence microscopy) (3) myrmekitic rim and matrix (quartz + albite + K-feldspar resp. dark violine, dark red and greyish-white in cathodoluminescence microscopy). Besides the predominant quartz and feldspars, the rock is spotted by flakes of green biotite, white mica and chlorite.

Several zircons have been found in each thin section, which is exceptional in Mt. Pourri rocks. They yielded a U–Pb zircon age of 507 ± 9 Ma (GUILLOT et al., 1991). The autochthonous nature of the zircons is supported by their morphology (high-temperature and high-agpaicity morphological types after PUPIN, 1980). The proportion of extractable zircon is less than 1 mg per kg, i.e. less than 1 ppm. According to experimental studies by WATSON (1979), such a proportion is less than the present (Na + K)/Al molar ratio (90 ± 2%) and the zirconium content of the whole rock (277 ± 7 ppm) suggest. This could result either from the loss of a certain amount (10%?) of alkalis after the emplacement of the magma, or from the preferential distribution of molecular zircon in very small, unextractable crystals, or from a combination of both factors. Both are in favour of a granitic melt not far from peralkaline composition (where zircon crystals would be absent), and this could also explain the paucity and/or small size of the zircon crystals in the felsic rocks of the Mt. Pourri basement sequence.

– *Lamprophyre.* Within the granophyre, the only mafic occurrences are 10 to 50 cm-thick fine-grained dark green seams containing up to 50% of green titaniferous biotite (up to 1.5% of TiO_2), with albite, phengite, chlorite, and apatite. This rock deserves the name of metaminette, a kind of metalamprophyre (OBERHÄNSLI et al., 1991; ROCK, 1991). According to the flat REE spectrum (Fig. 6), this Mt. Pourri lamprophyre could be a rare example of a non calk-alkaline, maybe ocean island or within-plate tholeiitic, lamprophyre. In any case, its REE pattern is closely similar to the patterns of the granophyre and to the patterns of the Mt. Pourri mafic rocks (compare Fig. 6 with Fig. 4d), but dramatically differs from calc-alkaline lamprophyre REE patterns (Fig. 6).

– *Other felsic rocks.* White, thinly foliated, massive layers are interbedded with the mafic rocks of the lower half of the series (Fig. 3). Their frequence and thickness increase upward (first cluster q_1) before the abrupt disappearance of the bimodal eruptive rocks (second cluster q_2). These layered felsic rocks seem to have been derived from a primary rhyolite melt, because the small stock q (E6°48'30"-N45°29'40", Fond du Plan Richard; 100 m²) is composed of a similar rock, except that small embayed quartz grains have been found in thin sections. The white, layered felsic rocks only show a very fine-grained mixture of quartz and alkali-feldspar, with discontinuous laminae of pale green phengite. Zircons, much rarer than in the granophyre but with similar size and shape (high-temperature and high-agpaicity morphological types after PUPIN, 1980), have been found in some thin sections.

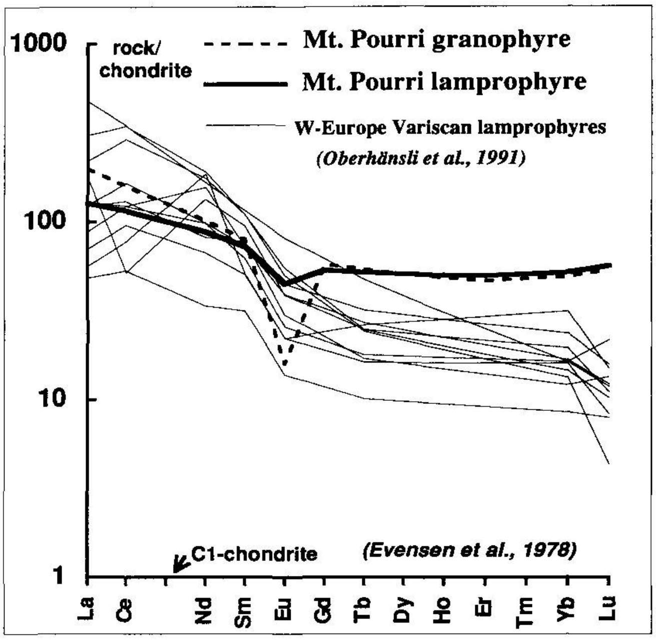

Fig. 6 Mt. Pourri lamprophyre: REE pattern compared with W-Europe Variscan lamprophyres. Data from OBERHÄNSLI et al. (1991): calk-alkaline suites from the Vosges and from the external crystalline massifs of the Alps. Chondrite values from EVENSEN et al. (1978).

From a comparison de visu with the Snowdon Caradocian volcanics of N-Wales (HOWELLS and LEVERIDGE, 1980; REEDMAN et al., 1987), we suppose that all the layered quartz-rich foliated rocks have been emplaced as welded ash-flow tuffs. It is not yet known whether they were deposited under subaqueous or subaerial conditions, and early sedimentary reworking cannot be excluded. COLEMAN and DONATO (1979) have named similar layered, fine-grained rocks from the upper, eruptive parts of ophiolite sequences "keratophyre". The local presence of decimetric nodules resembles some N-Wales tuffs (HOWELLS and LEVERIDGE, 1980), but still does not allow us to relate their genesis to definite conditions.

GEOCHEMISTRY OF THE FELSIC ROCKS

– *Granophyre.* The trace elements and REE contents of the granophyre indicate a within-plate granite or an ocean-ridge granite (Figs 6–7). There is no reason to believe, as it has been done previously (CABY, 1974; ELLENBERGER, 1958), that the granophyre was emplaced as a late Variscan pluton. Moreover, the absence of tourmaline, of well-developed muscovite and the paucity of zircon make it quite different from the S-type late Variscan granites (see also Fig. 6). When compared to the other Mt. Pourri felsic rocks, the trace elements and REE contents (Figs 6–7) appear similar to the less altered rocks (q, and some q_1 samples), with a much better compositional grouping of the granophyre (Figs 7 a, b). Hence the hypothesis that all the felsic rocks originated from similar magmas is supported by both the field evidence mentioned above (Fig. 5) and geochemical data (Figs 6–7).

– *Other felsic rocks.* Like the granophyre, all are very poor in Ca and P, and very rich in SiO_2 (Tab. 1, Fig. 8). In the lower felsic cluster (q_1), Na_2O is higher than K_2O. The upper felsic cluster (q_2) has a lower alkali-content, but with Na_2O always lower than K_2O. These values have been obtained for each of the sections where the q_1 and q_2 levels are found. Moreover, when intercalated in q $_2$, mafic levels (ε) have a distinctively high loss on ignition (anal. 2126B, Tab. 1), which has to be related to their chlorite (locally 50% in volume) and carbonate (up to 20% in volume) abundances. Such geochemical features of the q_2 felsic level and associated mafic rocks have proven to be invaluable regarding their position in the lithostratigraphic column. Note that some carbonates are also present in the layered bimodal complex overlying the granophyre (Fig. 5).

The SiO_2-content of the layered felsic rocks (Fig. 8b) is too high for their being an unaltered rhyolite. By contrast, the granophyre and the rhyolitic stock q show a moderate excess of silica, and a fair balance between their K_2O and Na_2O contents. This better preservation can be related to the fact that subvolcanic stocks did not undergo much alteration. On the contrary, layered felsic rocks may have suffered more transformations: eruptive fragmentation followed by redeposition, possibly with some kind of mechanical sorting; syn-cooling welding of the porous rock through fluid flow; weathering or subaqueous alteration.

Deep alterations are especially likely for the last felsic q_2 level where the changes are the most prominent, a fact which coincides with the peculiar stratigraphic location of this level. This felsic episode was indeed the last eruptive stage of the major bimodal volcanic cycle represented by the lower half of the series. We suppose that the rate of volcanic deposition slowed down drastically at that time, and that surficial alteration processes were extremely efficient, at the top of a still hot volcanic pile. These processes could have pro-

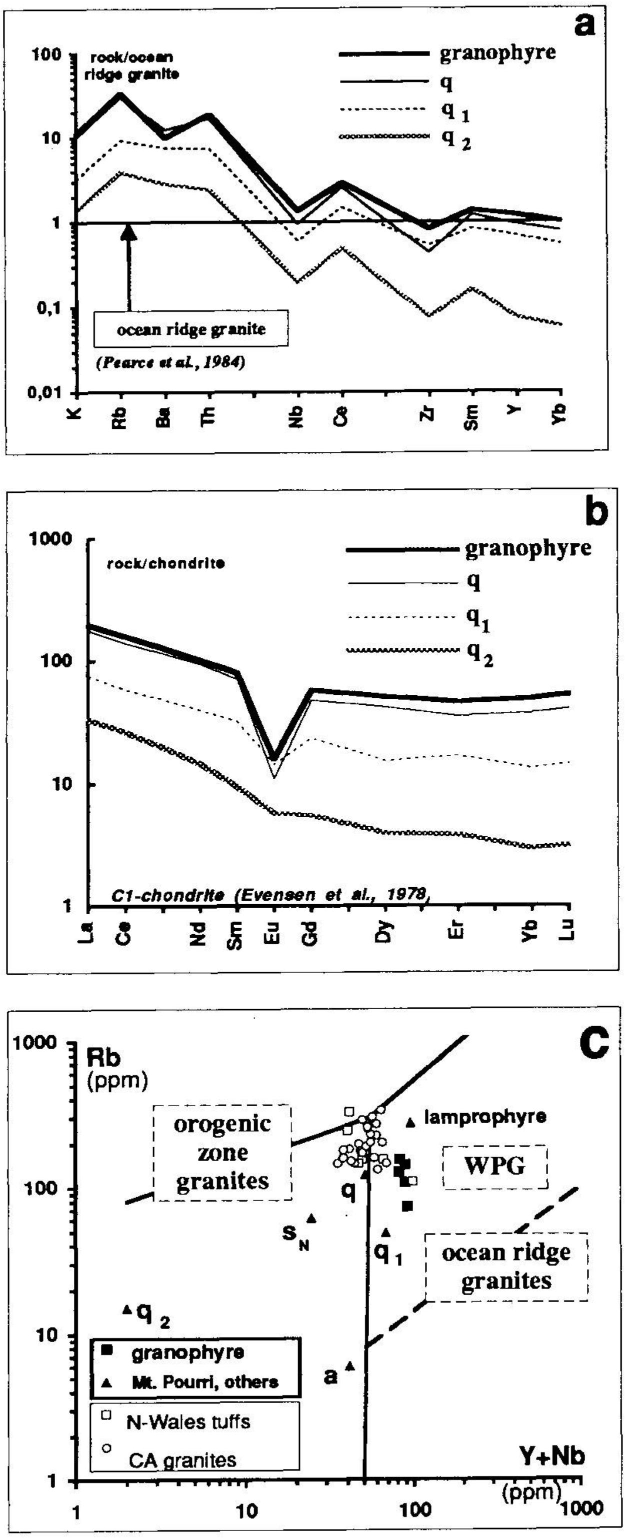

Fig. 7 Mt. Pourri felsic rocks: behaviour of REE and trace-elements. Key to facies symbols: see figure 3 and text. c: plot of Rb vs Y + Nb from PEARCE et al. (1984) – s_N, a, q, q_1, q_2, lamprophyre: representative points of average compositions, resp. of 1, 2, 2, 1, 1, 1 sample(s). W.-P.G.: within-plate granites – CA granites: Sapey-Peisey calk-alkaline gneisses, analyses by THÉLIN (1983; some exposures are shown on the map, see ζ in Fig. 2) – N-Wales tuffs: Caradocian rhyolite and tuff analyses from CAMPBELL et al. (1987).

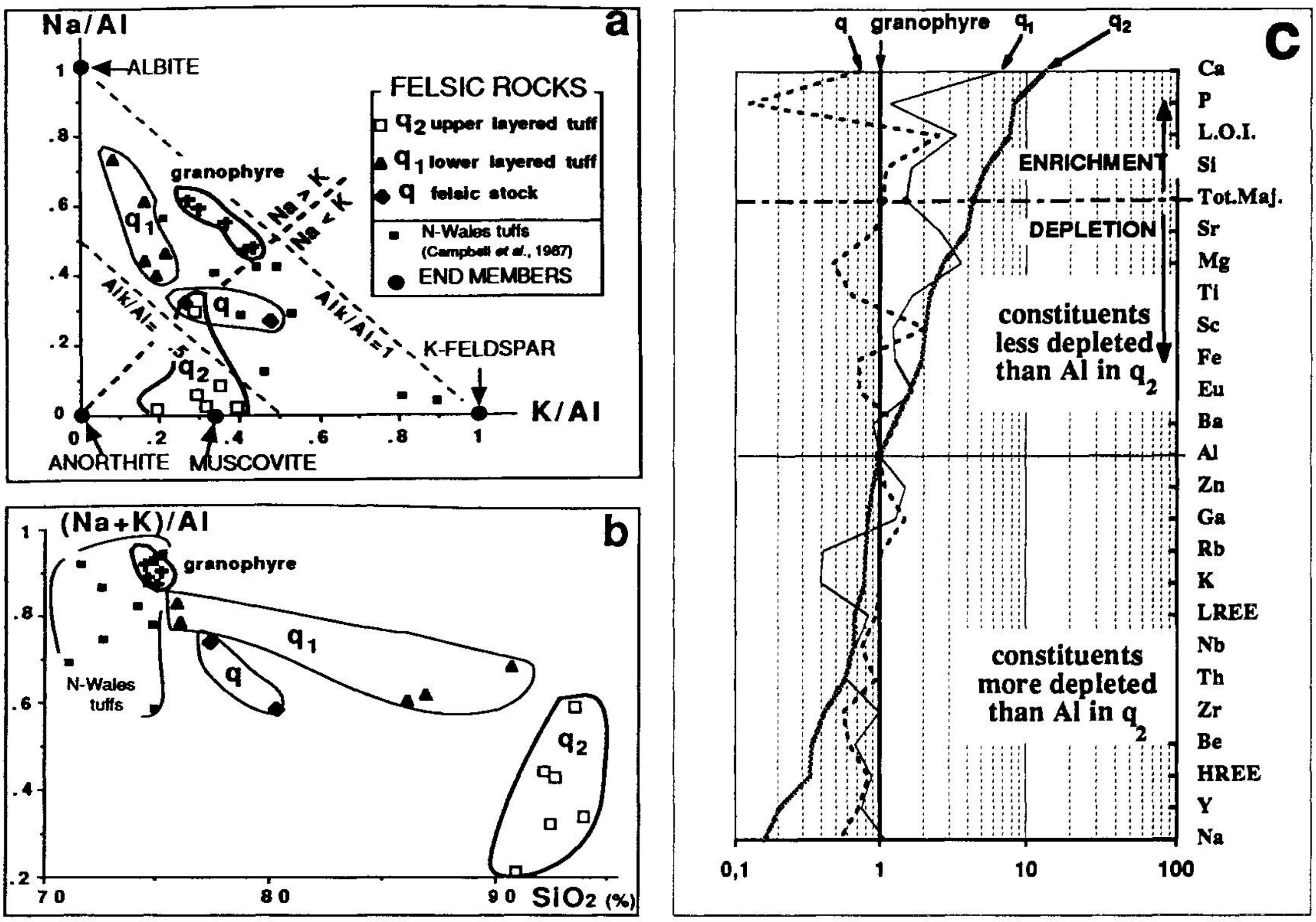

Fig. 8 Felsic rocks: alteration. Key to symbols of rock types: see figure 3 and text. a, b: Na, K, Al have been expressed in 10^{-3} atom-grams per 100 g of rock. N-Wales tuffs: after CAMPBELL et al. (1987). c: ratio of each constituent vs Al, in the mean analysis of a given facies, divided by the same ratio for the granophyre. The ratio is thus = 1 for the granophyre itself, and for Al. From bottom to top, the constituents have been classified following growing values of the latter ratio for q_2. Mean values based on 7 analyses of granophyre (mean Al_2O_3: 12.42%), 4 of q (mean Al_2O_3: 11.8%), 8 of q_1 (mean Al_2O_3: 8.2%) and 9 of q_2 (mean Al_2O_3: 2.8%). LREE: mean of La, Ce, Sm, Nd. HREE: mean of Gd, Dy, Er, Yb, Lu.

duced, in the upper felsic tuffs (q_2), a thorough leaching of the igneous feldspar, leaving only clay remnants. This is suggested by a K/Al vs Na/Al plot (Fig. 8a): the upper felsic tuff (q_2) has the same K/Al atomic ratio as pure muscovite or illite (K/Al = 1/3, Na ≈ 0), whereas the previous felsic rocks (q, q_1) plot closer to the albite-orthoclase tie-line (where [K + Na] / Al = 1/1). The strong decrease of the Al-silicates/quartz ratio could be related to some kind of silicification, after HOWELLS and LEVERIDGE (1980) and REEDMAN et al. (1987). The abundances of most constituents (Figs 7–8 and Tab. 1) strongly decrease from the granophyre and q through q_1 to q_2. In figure 8c, we have computed, for every constituent X, and for the average composition of every felsic rock type F, the ratio:

$$[\,X_F / X_{granophyre}\,] \,/\, [\,Al_F / Al_{granophyre}\,],$$

and ordered the constituents according to their ratios in q_2. The result suggests, rather than a massive SiO_2 inflow, a dissolution of igneous feldspars, followed by a preferential removal of Na, K and Al through fluids, together with REE (except Eu), Th, Y, Zr, and Nb (Fig. 7c). Fe–Ti contents seem to have better resisted. The gains in Ca and L.O.I. suggest a carbonatization, which is in fair accordance with the presence of carbonates in the mafic levels associated with q_2. The idea of a long-lasting, early but post-emplacement alteration, seems to be a better explanation than that of anomalous differentiation, while the hypothesis of Alpine major remobilization is precluded by the stratigraphical distribution of the chemical characteristics.

CONCLUSION TO THE STUDY OF THE FELSIC ROCKS

The granophyre was emplaced as a subvolcanic body, probably feldspar-porphyritic with a vitreous matrix. An early layering was reinforced or epigenized by intensive K-feldspar and complementary quartz crystallization and/or replacement. Supported by the geochemical characteristics, field evidence suggests that the granophyre was co-magmatic with the other, interbedded, felsic eruptive rocks. Moreover, the within-plate and/or ocean floor tholeiite lineage of the mafic rocks is also supported by the geochemical pattern of the coeval granophyre. Further important points are that no metamorphism was able to destroy the intimate late-magmatic textures of the granophyre, and that this 507 ± 9 Ma old (i.e. Cambrian/Ordovician boundary) rock is approximately at its stratigraphic position. The granophyre is probably contemporaneous with the end of the bimodal volcanism, hence its dating allows to propose ages for the main Mt. Pourri basement formations as indicated in figure 3.

Black schists

Most common is a sub-millimetric alternation of leucocratic (quartz + albite) and melanocratic (organic matter + phengite + chlorite) laminae, together giving a grey rock, in all cases intensely schistose. Locally the rock is crowded with black, 1-5 cm long needle-shaped spots. We assume that they represent the remains of fiamme. Moreover some pale green layers show a cinerite-like texture, with isolated actinolite and angulous quartz grains in a finer-grained matrix (GUILLOT, 1987). The fine-grained sedimentation, the lack of coarse volcaniclastic fragments and the rarity of zircon and tourmaline suggest that it was a distal subaqueous depositional site, far from any clastic source.

From the geochemical data (detailed interpretation of the geochemistry in GUILLOT et al., 1986; GUILLOT, 1987), the main question concerns the volcanic content of these deposits. If the possibility of a massive metasomatic soda-enrichment is rejected, the 47 available black schists analyses (examples in Tab. 1) unambiguously prove that the volcanic part is predominant, and that it must have been a dacitic, soda-rich volcanism. The non-volcanic part in this sedimentation could be restricted to organic matter, and to a minor illitic component (less than 20%?) of terrigenous origin.

The environment where the black schists formed was possibly a distal subaqueous site, far from continental, terrigenous sources (see discussion in GUILLOT, 1987). The high organic content could point to an anoxic, euxinic environment. Regarding the depth, the absence of vesicles in the metabasaltic sills indicates basaltic emplacement under the pressure compensation level (FISHER, 1984), and the absence of carbonates also suggests that the sedimentation took place below the carbonate compensation depth. On the whole, SCHLAEGEL-BLAUT's model (1990) of an intra-oceanic island volcanic source could be adapted to the Mt. Pourri black schists. There is no evidence against the idea of deep, distal re-deposits (through turbiditic flows?) of aerially erupted products piled up on the slopes surrounding an intra-basinal volcanic island.

Tectonic evolution

1. In pre-Ordovician times the tholeiitic volcanism was bimodal. The amount of felsic products increased upwards, and the last eruptions were increasingly intermittent, as indicated by deeper chemical alterations. The exact extensional setting (either oceanic or continental), which produced the very differentiated magmas, is unclear. Perhaps it was the edge of a passive continental margin (similar to the Tertiary volcanism of Scotland) or a hot spot. Ultramafic and gabbroic rocks are absent, felsic tuffs indicate a high degree of differentiation and some structures remind of ignimbrites. All these features stand in contrast with the idea of an ophiolitic origin which would be only supported by the MORB-like chemistry of the mafic rocks. The only ophiolite of this age in the Western Alps occurs in the Belledonne external crystalline massif (MÉNOT et al., 1988)

2. Around the Cambrian/Ordovician boundary, the bimodal volcanism had ended. The top of the volcanic pile was submitted to an intense, long-lasting alteration. As no conglomerates or coarse sediments are to be found, a distal position is assumed. The alteration may have been mostly hydrothermal (LEMIÈRE, 1983) and submarine. Possible mechanisms are post-volcanic subsidence, and/or thermal detumescence of the lithosphere. The duration of that alteration episode is not known.

3. An euxinic depositional environment persisted, possibly as late as the Middle Ordovician (an intense Middle Ordovician volcanic activity is known in the Pyrenees and in Austria) to Upper Silurian times (Silurian black shales in Ardennes,

Pyrenees, Spain). Dacitic, soda-rich cinerites were redeposited together with euxinic sediments. There are indications for some shallow-water to subaerial stages (fiamme, cinerites, etc.), but no coarse deposits and no breccias are found. The age could also be Lower Ordovician, or taking into account the ages of comparable rocks in the Pyrenees, Austria and the Ardennes, Middle Ordovician to Silurian, or even, conceivably, Devonian-Dinantian.

4. Sheeted sill-intrusions of tholeiitic basalt were emplaced in the Mt. Pourri sequence, perhaps related to a phase of within-plate rifting. The possible ages range from Ordovician to Middle Devonian (-? Dinantian). They are older than the overlying Permian deposits, and older than Silesian, owing to the chemical dissimilarities with the calc-alkaline volcanic rocks of the zone Houillère (see discussion in GUILLOT et al., 1986).

The ages are given with very wide brackets in order to take all extant possibilities into account. Owing to lithological comparisons (see below) and assuming that during Variscan times all future Briançon basements did belong to one domain, we favour lower Paleozoic ages for all protoliths. However a Caledonian-Variscan sedimentary, magmatic and metamorphic evolution has been proposed by other authors (e.g., THÉLIN, 1989) and the matter is still debated.

Comparisons

– *The Vieux Chaillol sequence.* LE FORT (1973) has given the first lithostratigraphic description of a pre-Upper Carboniferous basement in the Western Alps. In the Vieux Chaillol, a part of the Haut Dauphiné-Pelvoux external crystalline massif (Fig. 1), the sequence has been strongly folded and metamorphosed (presence of kyanite) during pre-Alpine orogenies. The Vieux Chaillol series has been attributed to Devono-Dinantian times (LE FORT, 1973; GIBERGY et al., 1970). Supported by the recent study of a similar situation (P.-L. GUILLOT, 1991), we believe that this age attribution is no longer tenable, on the basis of four independent reasons. (1) The Visean to Late Carboniferous granites of the neighbouring region have intruded and hence post-date, the Vieux Chaillol series. (2) Conversely, the amphibolite facies metamorphism and intense pluriphase folding that the series has suffered did not affect the adjacent granites. (3) The bimodal geochemistry of the series is not readily compatible with the S-type Carboniferous granites. (4) Finally, the Vieux Chaillol sequence is similar to the Mt. Pourri, with an alternation of mafic and felsic levels in the lower half, followed by a second half of albite-rich black schists. Not far from the top of the bimodal mafic/felsic set of the Vieux Chaillol sequence, a thin discontinuous marble level might represent the same event as the carbonate-enrichment in q_2. The Vieux Chaillol black schists, like the Mt. Pourri black schists, can be assumed to be Ordovician in age. Hence, the top, matrix-supported conglomerates of the Vieux Chaillol sequence, containing boulders, some 10 m^3 in size, could have been derived from the Ordovician inlandsis on the Saharian shield.

– *The Maures sequence.* In Provence (southern France), the crystalline Maures massif includes a series of greywackes. Some black shales have yielded Llandovery to Tarannon graptolites in the western, weakly metamorphosed part of the massif (GUEIRARD et al., 1970). Underlying the metamorphosed equivalent of the black shales in the central part of the Maures massif, meta-igneous felsic rocks have yielded several Late Cambrian–Early Ordovician ages by U–Pb zircon dating (SEYLER, 1983, 1986). The associated mafic rocks are at the boundary between alkaline and tholeiitic. By comparable methods, although independent of ours, SEYLER (1986) produced roughly similar results to those presented here about the felsic rocks. This author also found orthogneisses to be primarily peralkaline and partly secondarily depleted in alkalis.

– *Vosges massif.* The Sainte-Marie-aux-Mines sequence (FLUCK, 1980) again displays a lithostratigraphical and geochemical succession similar to Mt. Pourri. It has been considered as equivalent to the Black Forest "leptyno-amphibolite" series by WIMMENAUER and LIM (1988). These northernmost occurrences (Fig. 1) of similar series suffered a 470 Ma granulitic metamorphism, suggesting that, in the axial part of the Variscan chain, some parts of a Mt. Pourri type domain could have been very early reworked and deeply buried. A Late Cambrian–Early Ordovician general extensional regime could be invoked.

– *French Central Massif.* In the French Central Massif, mafic-felsic associations form the so-called "leptyno-amphibolites" complexes, metamorphosed under middle- to high-grade conditions. These complexes are variously interpreted (see discussion in SANTALLIER et al., 1988). In the western part of the Central Massif, such a bimodal association is included in the "middle allochthonous" (LEDRU et al., 1989). According to radiometric data obtained from volcanic rocks included in the complex and from intrusive plutonic bodies, the minimum ages are Ordovician and Cambrian. The tectonic setting of these complexes is disputed. PIQUÉ et al. (1992) have proposed that these complexes are connected with an attenuation of the sialic crust, itself coeval with the deposition of lower Paleozoic platform sequences and the formation of subsiding troughs, the sequence being subsequently affected by Ordovician distension and early Variscan, Silurian convergence. Sequences including dark metasedimentary rocks are found, but here Variscan metamorphic and deformational overprints reach amphibolite to granulite facies in the central part of the Variscan orogen. Therefore the distinction between Variscan sequences and pre-Variscan basements is difficult and in many cases not yet attained.

– *Eastern Alps: Austroalpine basements.* Some similarity is found between the Mt. Pourri series and the Greywacke Zone (Fig. 1) in Austria as described by HEINISCH (1988), SCHLAEGEL-BLAUT (1990) and NEUBAUER (1990). Here, subaerial ignimbrites and within-plate basaltic flows and sills, associated with both proximal and distal turbidites of Ordovician to Devonian stratigraphic age, are interpreted as representing a passive continental margin subjected to extensional tectonics (marginal basin). The geochemical characteristics of the mafic rocks are not unlike those of the Mt. Pourri.

– *Other areas in the Alpine belt.* Similarly, mafic and felsic volcanic rocks of various ages and chemical compositions are included in schists or shales from many other parts of the Alpine belt s.l. (see data in SASSI and ZANFERRARI, 1990): for instance, in Sardinia, where Upper Ordovician alkaline mafic rocks and Lower Ordovician felsic to intermediate rocks are described; in the Apuan and the Tuscan basement (e.g., MORETTI et al., 1990; CONTI et al., 1991); in Calabria (e.g., the Bottigliero unit: ACQUAFREDDA et al., 1988), where pre-Devonian-? Ordovician, black shales are associated with volcanic tholeiites; in the Carpathians (e.g., the Western Carpathians: GRECULA and HOVORKA, 1987) but with dissimilar REE patterns; in the Ghomaride nappes of the Moroccan Rif (CHALOUAN and MICHARD, 1990), where spilites included in predominant carbonate rocks are stratigraphically dated as Upper Silurian.

Toward early Paleozoic reconstructions

At the present time it is not clear if all the above-mentioned occurrences are of the same age and if they include magmatic rocks of the same geochemical trends. Similar extensional processes may have been repeated and identical ages must not be inferred on the sole basis of lithological or geochemical characters. Radiometric or other age constraints are still severely lacking in these basement areas. Nevertheless, several Mt. Pourri type sequences can be found in the Alpine belt and its surroundings. It was already recognized by STAUB (1948) that in the Alps they are older than Variscan but younger than the high- to medium-grade crystalline basement.

According to DESMONS (1992 a, b), these similarities in the pre-Variscan basements are explained by a common origin in the Gondwanan plate to which the future Penninic basements belonged until Alpine times. Following an identical Proterozoic and early Paleozoic evolution, pieces of the crystalline Panafrican (?) basement and its unmetamorphosed cover could have been accreted in Variscan times to Baltica (Maures, Vosges, external crystalline massifs of the Alps), and in the Alpine times to Eurasia (Alpine internal zones). In this way the differences in Variscan overprint are explained.

The Mt. Pourri sequence constitutes an invaluable piece of evidence for the pre-Variscan and Variscan paleogeography in the Alps. The lack of discernible pre-Alpine metamorphism in this lower Paleozoic sequence testifies to the lack or weakness of any Variscan imprint. At the onset of the Alpine orogenic cycle, the sedimentary and magmatic characteristics of the Mt. Pourri sequence were still almost unaltered.

References

Unpublished diplomas and theses are available through the central library of each French university.

ABOUCHAMI, W. (1986): Etude pétrographique et géochimique de quelques roches basiques provenant de la zone briançonnaise interne (Alpes occidentales). Mém. D.E.A., Univ. Nancy, 38 p. (unpubl.).

ACQUAFREDDA, P., LORENZONI, S. and ZANETTIN LORENZONI, E. (1988): La sequenza paleozoica dell'Unita di Bocchigliero (Sila, Calabria). Rendic. Soc. Geol. It., 11, 5–22.

AINARDI, J.L. (1976): Le Permo-Trias épimétamorphique de la région de La Plagne-Champagny--en-Vanoise (Alpes occidentales françaises). Caractères pétrographiques et géochimiques des minéralisations uranifères et de leur environnement. Thèse Doct. Spéc., Univ. Nancy, 118 p. (unpubl.).

BAILEY, E.B., CLOUGH, C.T., WRIGHT, W.B., RICHEY, J.E. and WILSON, G.V. (1924): Tertiary and post-Tertiary geology of Mull, Loch Aline and Oban. Brit. Geol. Surv. Mem., HMSO eds, 2nd print. 1987, 445 p.

BOCQUET [DESMONS], J. (1974a): Etudes minéralogiques et pétrologiques sur les métamorphismes d'âge alpin dans les Alpes françaises. Thèse Etat, Univ. Grenoble, 490 p. (unpubl.).

BOCQUET [DESMONS], J. (1974b): Le socle briançonnais de Vanoise (Savoie): arguments en faveur de son âge anté-alpin et de son polymétamorphisme. C.R. Acad. Sci. Paris, 278, D, 2601–2604.

BROUDOUX, B. (1985): Géologie des unités de Vanoise septentrionale et méridionale de Pralognan à Tignes (Alpes de Savoie). Thèse 3e cycle, Univ. Lille, 229 p. (unpubl.).

BROUDOUX, B., DEBRABANT, P. and RAOULT, J.-F. (1984): Géochimie des calcaires et encroûtements du Malm à l'Eocène en Vanoise: données préliminaires (Zone briançonnaise interne, Alpes). Ann. Soc. géol. Nord, Lille, 104, 193–207.

CABY, R. (1974): Gneiss permocarbonifères d'origine granitique dans la Zone houillère et la Zone du Grand-Saint-Bernard en Val d'Aoste (Italie). Géol. Alpine, Grenoble, 50, 39–44.

CAMPBELL, S.D.G., REEDMAN, A.J., HOWELLS, M.F. and MANN, A.C. (1987): The emplacement of geochemically distinct groups of rhyolites during the evolution of the Lower Rhyolitic Tuff Formation caldera (Ordovician), North Wales, U.K. Geol. Mag., 124 (6), 501–511.

CHALOUAN, A. and MICHARD, A. (1990): The Ghomarides nappes, Rif coastal range, Morocco: a Variscan chip in the Alpine belt. Tectonics, 9, 1565–1583.

COLEMAN, R.G. and DONATO, M.M. (1979): Oceanic plagiogranite revisited. In: F. BARKER (Ed.), Trondhjemites, dacites and related rocks. Elsevier, Amsterdam, 149–168.

COLLINS, L.G. (1990): Comment on "Cathodoluminescence microscopy of myrmekite". Geology, 18, 1163–1164.

CONTI, P., GATTIGLIO, M. and MECCHERI, M. (1991): The overprint of the Alpine tectono-metamorphic evolution on the Hercynian orogen: an example from the Apuan Alps (Northern Apennines, Italy). Tectonophysics, 191, 335–346.

DEBELMAS, J. and CABY, R. (with the coll. of ANTOINE, P., ELTER, G., ELTER, P., GOVI, M., FABRE, J., BAUDIN, T., MARION, R., JAILLARD, E., MERCIER, D. and GUILLOT, F.) (1991): Feuille Sainte-Foy-Tarentaise. Carte géol. France (1/50,000), B.R.G.M., Orléans, 728.

DEBELMAS, J., ANTOINE, P., BARBIER, R., BARFÉTY, J.-C., BROUDOUX, B., DONDEY, H., FABRE, J., FUDRAL, S., GUILLOT, F., JAILLARD, E., LU, C.Y., MÉRIAUX, O., PERUCCIO-PARISON, M.-D., RAOULT, J.-F. and SCHADE, J. (1989): Feuille Moûtiers. Carte géol. France (1/50,000), B.R.G.M., Orléans, 751.

DESMONS, J. (1992a): The Briançon basement (Pennine Western Alps): Mineral composition and polymetamorphic evolution. Schweiz. Mineral. Petrogr. Mitt., 72, 37–55.

DESMONS, J. (with a contribution by D. MERCIER) (1992b): Passing through the Briançon zone (Briançonnais, France). In: J. VON RAUMER and F. NEUBAUER (Eds), The pre-Mesozoic geology of the Alps. Springer-Verlag, Heidelberg-Berlin, 277–293 (in press).

DESMONS, J. and FABRE, J. (1988): Contribution à la connaissance pétrographique du Mont Pourri (Savoie, France); conséquences structurales. Géol. Alpine, Grenoble, 64, 13–26.

DESMONS, J. and PLOQUIN, A. (1989): Chimisme du Briançonnais – Grand Saint-Bernard anté-mésozoïque (Alpes occidentales): une vue synoptique. Géol. Alpine, Grenoble, 65, 1–31.

ELLENBERGER, F. (1958): Etude géologique du pays de Vanoise. Mém. Carte géol. France, Impr. Nationale, Paris, 561 p.

ELTER, G. with the coll. of CASTELLO, P., CIGOLINI, C., COMPAGNONI, R., DAL PIAZ, G.V., LOMBARDO, B., RONCO, C.P. and SODERO, D. (1987): Carte géologique de la Vallée d'Aoste. C.N.R., Centr. stud. probl. orog. Alpi occid., Torino.

EVENSEN, N.M., HAMILTON, P.J. and O'NIONS, R.K. (1978): Rare-earth abundances in chondritic meteorites. Geochim. Cosmochim. Acta, 42, 1199–1212.

FABRE, J. (1961): Contribution à l'étude de la zone houillère en Maurienne et en Tarentaise (Alpes de Savoie). Mém. B.R.G.M., Orléans, 2, 315 p.

FISHER, R.V. (1984): Submarine volcaniclastic rocks. In: B.P. KOKELAAR and M.F. HOWELLS (Eds), Marginal basin geology. Geol. Soc. Spec. Publ., 16, 5–27.

FLUCK, P. (1980): Métamorphisme et magmatisme dans les Vosges moyennes d'Alsace, contribution à l'histoire de la chaîne varisque. Sci. Géol., Strasbourg, 62, 1–247.

GIBERGY, P., LACOMBE, P. and VIALON, P. (1970): Caractères des faciès attribuables au Dévono-Dinantien et de leur métamorphisme, dans le massif des Ecrins-Pelvoux (Alpes du Dauphiné, France). C.R. Acad. Sci. Paris, 270, D, 756–759.

GIGNOUX, M. (1929): Les problèmes géologiques de la région Vanoise-Mont Pourri. Trav. Lab. Géol. Grenoble, 15, 98–142.

GRECULA, P. and HOVORKA, D. (1987): Early Paleozoic volcanism of the Western Carpathians. In: P. FLÜGEL, F.P. SASSI and D. HOVORKA (Eds), Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts. Mineralia slovaca – Monography, Alfa Bratislava, 251–270.

GUEIRARD, S., WATERLOT, G., GHERZI, A. and SAMAT, M. (1970): Sur l'âge llandoverien supérieur à tarannonien inférieur des schistes à Graptolites du Fenouillet, massif des Maures (Var). Bull. Soc. géol. France (7), 12, 195–199.

GUILLOT, F. (1987): Géologie de l'Antépermien de Vanoise septentrionale (zone briançonnaise interne, Alpes occidentales, Savoie, France). Thèse Doct. Univ. Lille, 280 p. (unpubl.).

GUILLOT, F., LIÉGEOIS, J.P. and FABRE, J. (1991): Des granophyres du Cambrien terminal dans le Mont Pourri (Vanoise, zone briançonnaise): première datation U–Pb sur zircon d'un socle des zones internes des Alpes françaises. C.R. Acad. Sci. Paris, 313, 2, 239–244.

GUILLOT, F., PLOQUIN, A., RAOULT, J.-F. and PERUCCIO-PARISON, M.-D. (1986): Les séries antépermiennes de Vanoise septentrionale (zone briançonnaise, Alpes de Savoie): lithologie et géochimie dans le massif de Bellecôte; arguments pour un âge antéhouiller. C.R. Acad. Sci. Paris, 303, 2, 1141–1146.

GUILLOT, F. and RAOULT, J.-F. (1984): Permien et base du Trias en Vanoise septentrionale: données nouvelles et hypothèses (zone briançonnaise interne, Alpes françaises). Ann. Soc. géol. Nord, Lille, 104, 183–192.

GUILLOT, P.-L. (1991): Place et signification de la "série satinée" de Belledonne dans l'édifice de nappes du bâti varisque français. C.R. Acad. Sci. Paris, 312, 2, 1581–1585.

HARLAND, W.B., ARMSTRONG, R.L., COX, A.V., CRAIG, L.E., SMITH, A.G. and SMITH, D.G. (1990): A geologic time scale 1989. Cambridge Univ. Press, 263 p.

HEINISCH, H. (1988): Hinweise auf die Existenz eines passiven Kontinentalrandes im Altpaläozoikum der nördlichen Grauwackenzone – Ostalpen. Schweiz. Mineral. Petrogr. Mitt., 68, 407–418.

HOPSON, R.F. and RAMSEYER, K. (1990): Cathodoluminescence study of myrmekite. Geology, 18, 336–339.

HOWELLS, M.F. and LEVERIDGE, B.E. (1980): The Capel

Curig volcanic Formation. Reports Inst. Geol. Sci., London HMSO, 80/6, 1–23.
LEDRU, P., LARDEAUX, J.-M., SANTALLIER, D., AUTRAN, A., QUÉNARDEL, J.-M., FLOC'H, J.-P., LEROUGE, G., MAILLET, N., MARCHAND, J. and PLOQUIN, A. (1989): Où sont les nappes dans le Massif central français? Bull. Soc. géol. France (8), 5, 605–618.
LEMIÈRE, B. (1983): L'amas sulfuré de Chizeuil (Saône et Loire). Doc. B.R.G.M., Orléans, 54, 1–144.
LE FORT, P. (1973): Géologie du Haut-Dauphiné cristallin (Alpes françaises), étude pétrologique et structurale de sa partie occidentale. Sci.Terre, Nancy, 25, 1–373.
MARION, R. (1984.): Contribution à l'étude géologique de la Vanoise, Alpes occidentales. Le massif de la Grande Sassière et la région de Tignes-Val d'Isère. Thèse 3e cycle, Univ. Chambéry, 172 p. (unpubl.).
MÉNOT, R.-P., PEUCAT, J.-J., SCARENZI, D. and PIBOULE, M. (1988): 496 My age of plagiogranites in the Chamrousse ophiolite complex (external crystalline massifs in the French Alps): evidence of a lower Palaeozoic oceanization. Earth Planet. Sci. Lett., 88, 82–92.
MORETTI, A., MELETTI, C. and OTTRIA, G. (1990): Studio stratigraphico e strutturale dei Monti Romani (GR-VT). 1: Dal Paleozoico all'orogenesi alpidica. Boll. Soc. Geol. It., 109, 557–581.
MULLEN, E.D. (1983): $MnO/TiO_2/P_2O_5$: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis. Earth Planet. Sci. Lett., 62, 53–62.
NEUBAUER, F. (1990): Das südliche Wechselkristallin (Ostalpen): Relikt eines aktiven Kontinentalrandes. TSK III Symposium, Graz (19–21 April, 1990), 143–146.
OBERHÄNSLI, R., KRÄHENBÜHL, U. and STILLE, P. (1991): Contrasting REE characteristics in meta-lamprophyres from Variscan massifs of the central Swiss Alps and REE pattterns in lamprophyres from Variscan terranes of Western Europe. Schweiz. Mineral. Petrogr. Mitt., 71, 53–62.
PEARCE, J.A. (1983a): A "user's guide" to basalt discrimination diagrams. Unpubl. Rept., The Open University, Milton Keynes-GB, 37 p.
PEARCE, J.A. (1983b): Role of the subcontinental lithosphere in magma genesis at active continental margins. In: C.J. HAWKESWORTH and M.J. NORRY (Eds), Continental basalts and mantle xenoliths. Shiva, Orpington, 230–249.
PEARCE, J.A., HARRIS, N.B.W. and TINDLE, A.G. (1984): Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol., 25, 956–983.
PERUCCIO-PARISON, M.-D. (1984): Problèmes pétrochimiques et structuraux en Vanoise septentrionale. Thèse 3e cycle Paris-Orsay, 358 p. (unpubl).
PIQUÉ, A., PLOQUIN, A., QUÉNARDEL, J.M. and SANTALLIER, D. (1992): The French Paleozoic terranes. In: D. KEPPIE (Ed.), Pre-Mesozoic geology in France and related areas. Springer-Verlag, Heidelberg-Berlin (in press).
PUPIN, J.P. (1980): Zircon and granite petrology. Contrib. Mineral. Petrol., 73, 207–220.
REEDMAN, A.J., HOWELLS, M.F., ORTON, G. and CAMPBELL, S.D.G. (1987): The Pitts Head Tuff Formation: a subaerial to submarine welded ash-flow tuff of Ordovician age, North Wales. Geol. Mag., 124, 427–439.
ROCK, N.M.S. (1991): Lamprophyres. Blackie, Glasgow, 285 p.
SANTALLIER, D., BRIAND, B., MÉNOT, R.-P. and PIBOULE, M. (1988): Les complexes leptyno-amphiboliques (C.L.A.): revue critique et suggestions pour un meilleur emploi de ce terme. Bull. Soc. géol. France (8), 4, 3–12.
SASSI, F.P. and ZANFERRARI, A. (Eds) (1990): Pre-Variscan and Variscan events in the Alpine-Mediterranean belts. Stratigraphic correlation forms. Rendic. Soc. Geol. Ital., 12, 95–347.
SCHLAEGEL-BLAUT, P. (1990): Der basische Magmatismus des nördlichen Grauwackenzone, Oberostalpines Paläozoikum. Abh. Geol. B.-A., Vienna, 43, 1–149.
SEYLER, M. (1983): Géologie de la partie centrale des Maures. Conséquences sur l'évolution géodynamique du massif. Géol. France (2), 1, 1–2, 81–96.
SEYLER, M. (1986): Petrology and genesis of Hercynian alkaline orthogneisses from Provence, France. J. Petrol., 27, 1129–1251.
SHERVAIS, J.W. (1980): Ti-V plots and the petrogenesis of modern and ophiolitic lavas. Earth Planet. Sci. Lett., 59, 101–118.
STAUB, R. (1948): Aktuelle Fragen im alpinen Grundgebirge. Schweiz. Mineral. Petrogr. Mitt., 28, 422–442.
THÉLIN, P. (1983): Les gneiss œillés de la Nappe du Grand Saint-Bernard, essai d'évaluation des critères susceptibles d'en préciser l'hérédité pré-métamorphique (Alpes valaisannes, Suisse). Thèse Doct. Univ. Lausanne, 485 p.
THÉLIN, P. (1989): Essai de chronologie magmatico-métamorphique dans le socle de la nappe du Grand Saint-Bernard: quelques points de repère. Schweiz. Mineral. Petrogr. Mitt., 69, 193–204.
WATSON, E.B. (1979): Zircon saturation in felsic liquids: Experimental results and applications to trace element geochemistry. Contrib. Mineral. Petrol., 70, 407–419.
WIMMENAUER, W. and LIM, S.K. (1988): L'association leptyno-amphibolique de la Forêt-Noire (R.F.A.). Bull. Soc. géol. France (8), 4, 35–41.

Manuscript received January 4, 1993; revised manuscript accepted April 21, 1993.