Trachytes and phonolites from the Mont-Dore region, Auvergne, France

Henning SØRENSEN[1], Ulla BERNTH[2] and Robert BROUSSE[3]

[1] *Geological Institute, the University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K., Denmark*
[2] *Danish Technological Institute, Gregersensvej, Post Box 141, DK-2630 Taastrup, Denmark*
[3] *38, Rue Langlois, F-92160, Antony, France*

ABSTRACT. The volcanic rocks of the Col de Guéry region comprise basanite, hawaiite, trachyandesite, trachyte and phonolite, and consist of silica-saturated as well as silica-undersaturated rocks. The suite from basanite via hawaiite to trachyandesite and some trachytes is interpreted to have been formed from a basanitic magma by crystal fractionation processes. A group of trachytes and phonolites emplaced at about 2.0 Ma are mineralogically as well as geochemically related and enriched in Na, K, Cs, Th, Zr and Y, and depleted in Mg, Fe, Ca, Nb, Ta, Ba, Sr, Ti, P and REE, especially the MREE from Nd to Tb. From petrographic and geochemical data it is concluded that the melts forming these trachytic and phonolitic rocks have been formed from separate pulses of magma which were derived by fractional crystallisation of alkali basaltic or basanitic/tephritic magmas in deep magma reservoirs coupled with mixing of basic and trachytic melts in the reservoirs. The differences in Nb contents and Zr/Nb ratios between the geographically separated occurrences may be a result of heterogeneities in the source region of the parent magmas and different degrees of crustal contamination, but can most simply be explained by different fractionation patterns of independent melts, not least differences in oxygen fugacities during crystallisation of the melts.

KEY WORDS: trachyte, phonolite, le Mont-Dore, enclaves, Nb and Ba depletion, magma mixing.

Introduction

The Mont-Dore massif, Auvergne, Massif Central, France, is located between the Chaîne des Puys to the north and Cézalier and Cantal to the south (Fig. 1). It is made up of a great variety of volcanic rocks, which have been shown to belong to three volcanic cycles (Glangeaud et al. 1965). Each cycle comprises silica-saturated as well as silica-undersaturated rock series, which are considered to have been derived from different basic primary magmas (Brousse 1961a). More recently, Briot et al. (1991) have proposed that AFC processes within the upper crust have played an important role in the evolution of the silica-saturated series in Mont-Dore, whereas the silica-undersaturated series was not modified by crustal contamination, perhaps because the evolution of the most developed undersaturated rocks, the phonolites, took place in sealed magma chambers. Lacroix (1917), Decobecq (1987) and others have studied en-

	Rocks							Enclaves		
	Col de Guéry	Sanadoire	Tulliere	Puy Cordé	Trioulérou	Bozat	F[me] Puy May	Sanadoire	Trioulérou	Puy Cordé
Rock no.	88-924	88-901	88-955	97-108-2	88-953	97-110	88-951	L 5	97-107A	97-108C
Age (Ma)	-	1.83 ± 0.10	2.10 ± 0.10	2.03 ± 0.11	2.01 ± 0.06	0.73 ± 0.04	-	(Brousse, 1961b)	-	-
Rock type	Trachyte	Trachyte	Trachyte	Phonolite	Phonolite	Phonolite	Phonolite	Foidite	Tephrite	Phonotephrite
SiO_2	57.09	59.08	61.51	59.83	60.84	60.84	61.008	39.15	47.94	49.162
TiO_2	1.06	0.7	0.22	0.429	0.23	0.5	0.373	3.3	2.32	2.098
Al_2O_3	18.05	19.29	19.97	19.84	19.87	19.05	19.816	14.6	19.28	16.43
Fe_2O_3	2.25	2.14	1.48	1.44	1.09	1.6	1.783	9.15	5.16	3.778
FeO	2.28	1.21	0.58	0.98	0.85	1.11	0.42	6.45	2.74	4.14
MnO	0.14	0.13	0.13	0.14	0.13	0.19	0.13	0.7	0.16	0.167
MgO	1.88	0.87	0.18	0.49	0.17	0.43	0.239	5.3	3.73	4.644
CaO	3.46	3.17	0.87	1.55	0.93	1.39	1.083	14.4	6.06	6.57
Na_2O	5.18	5.48	6.92	8.21	8.18	7.76	7.04	2.4	3.17	6.8
K_2O	5.61	5.66	6.13	6.09	6.08	5.8	6.359	0.9	3.86	2.779
P_2O_5	0.22	0.13	0.01	0.06	0.01	0.08	0.047	1.75	0.48	0.531
LOI	2.05	1.47	1.18	0.63	0.41	0.27	1.117	2.55	4.56	2.461
Total	41.12	39.55	37.45	39.43	37.72	37.68	38.034	58.2	51.52	50.398
CIPW										
Qz	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Or	34.04	34.18	36.97	36.34	36.53	34.71	38.24	5.32	24.04	16.92
Ab	39.36	44.81	50.45	39.14	44.23	47.42	46.19	10.42	28.26	25.79
An	8.76	11.57	4.34	0.00	0.00	0.02	3.77	26.41	28.38	6.29
Ne	3.99	1.39	5.04	16.07	13.68	10.33	7.81	5.35	0.00	18.13
Ac	0.00	0.00	0.00	1.17	0.76	0.00	0.00	0.00	0.00	0.00
Di	5.85	2.83	0.00	3.59	2.33	2.8	1.05	26.18	0.00	18.68
Wo	0.00	0.00	0.00	1.22	0.77	1.21	0.00	0.00	0.00	0.00
Hy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1	0.00
Ol	2.07	0.63	0.32	0.00	0.00	0.00	0.08	0.83	6.09	3.18
Mt	3.35	2.34	1.69	1.52	1.23	2.35	0.72	13.26	2.77	5.64
Hm	0.00	0.57	0.34	0.00	0.00	0.00	1.32	0.00	3.53	0.00
Il	2.07	1.36	0.43	0.82	0.44	0.96	0.71	6.26	4.64	4.11
Ap	0.53	0.31	0.02	0.14	0.02	0.19	0.12	4.14	1.2	1.29
D.I.	77.39	80.38	92.46	91.55	94.44	92.46	92.24	21.09	52.3	60.84
A.I.	0.81	0.78	0.90	1.01	1.01	1.00	0.93	0.34	0.49	0.86

Tab. 1a. Chemical analyses of selected trachytes and phonolites and of the enclaves in these rocks.

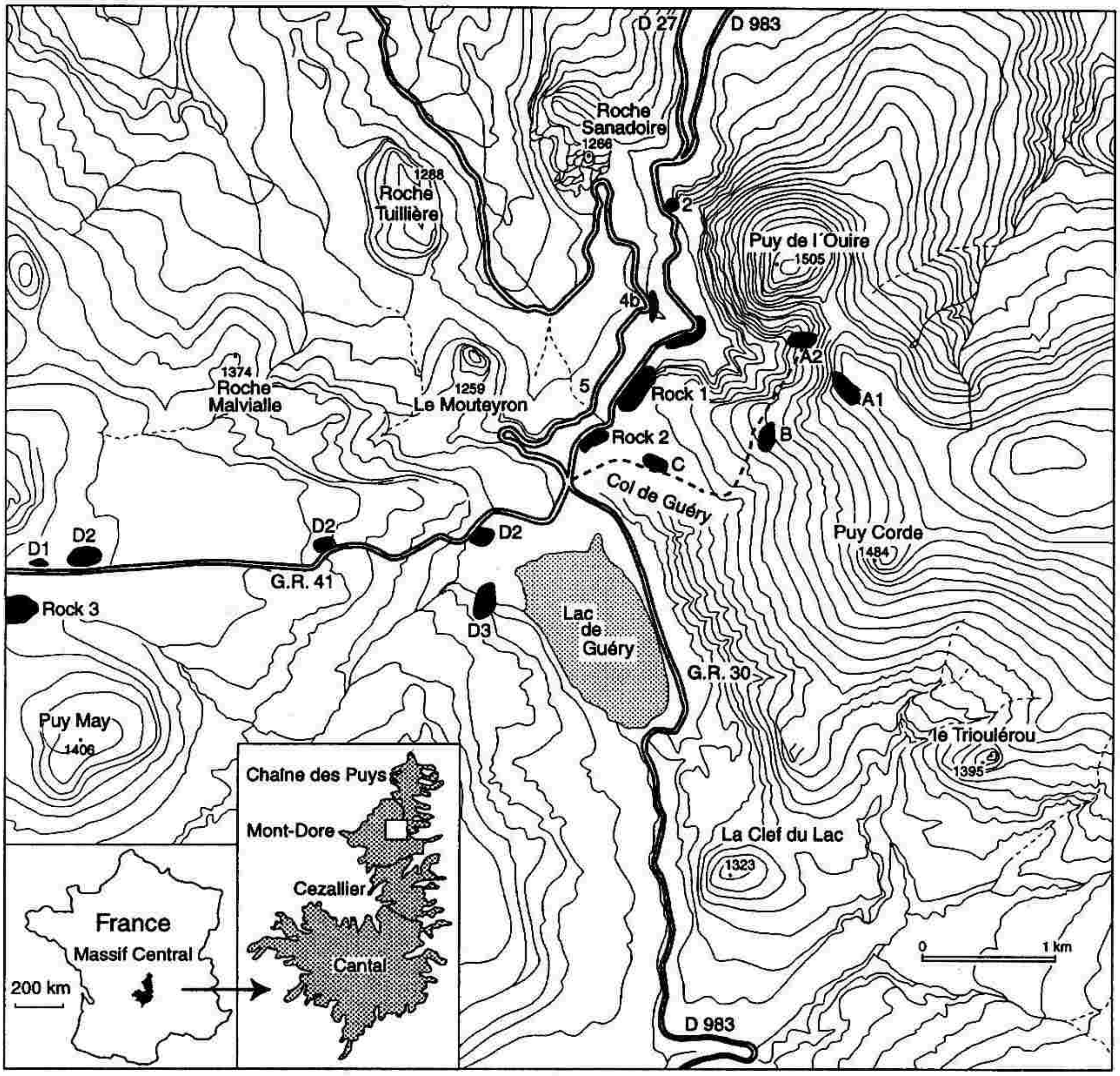

Fig. 1. Maps showing the location of the Mont-Dore massif in France and the localities sampled in the Col de Guéry area.

claves in the volcanic rocks of Mont-Dore and have demonstrated the importance of magma mixing in the formation of the enclaves and their host rocks.

General geology and petrography

The trachytes and phonolites in the Col de Guéry area (Fig. 1) studied in the present paper belong to the silica-undersaturated suite of rocks of the Middle Volcanic Cycle of the Mont-Dore massif, which comprises basanite/tephrite, hawaiite, trachyandesite, trachyte and phonolite (Brousse et al. 1989). The predominant trachyandesitic rocks were erupted during two periods: 2.5–2.1 Ma and 1.9–1.6 Ma, the trachytes and phonolites at about 2.0 Ma as separate events (Cantagrel and Baubron 1983). The trachytes and phonolites form separate necks and flows. They are vesicular and porphyritic and show a continuum in chemical and modal compositions. There are scarce phenocrysts (and xenocrysts) of alkali feldspars, plagioclase, forsteritic olivine, pargasitic and kaersutitic amphibole, diopside–hedenbergite, Fe-Ti oxides, and in cases aegirine augite, biotite, nepheline, sodalite, hauyne–nosean, zircon and titanite. The matrix is dominated by laths of alkali feldspar with interstitial plagioclase, feldspathoids, clinopyroxene, amphibole, titanite, apatite and Fe-Ti oxides.

We have examined two types of enclaves in trachytes and phonolites from the Col de Guéry area. The first one forms rounded or angular masses up to a few cm across and is composed of aggregates of mm-sized grains of amphibole, clinopyroxene, biotite, apatite, etc. The second type forms ball-like or lenticular bodies, up to 10 cm or more across, of porphyritic and vesicular rocks having mm-sized phenocrysts of kaersutitic to pargasitic amphibole, diopside–hedenbergite, aegirine – augite, plagioclase, alkali feldspars, sodalite and hauyne – nosean, Fe-Ti oxides and rare biotite. Amphibole may constitute up to 80 vol.% of the phenocrysts. There are xenocrysts of forsteritic olivine, An-rich plagioclase, Ti- and Al-rich diopside–hedenbergite and titanite. The matrix of the enclaves is made up of acicular amphibole and clinopyroxene, Fe-Ti oxides and apatite with interstitial feldspars and sodalite.

Geochemistry

The Trioulérou and Puy Cordé phonolites are weakly peralkaline with an agpaitic index of 1.01, the other rocks have indices lower than 1.0.

In the geochemical diagrams the Mouteyron and Tuilliére trachytes and the Trioulérou and Puy Cordé phonolites form a distinct group. In the text below, they will be referred to as the 2.0 Ma rocks, since they were formed at 2.0 ± 0.10 Ma according to the K/Ar dating.

In the variation diagrams in Fig. 2 at about 60 wt.% SiO_2, the

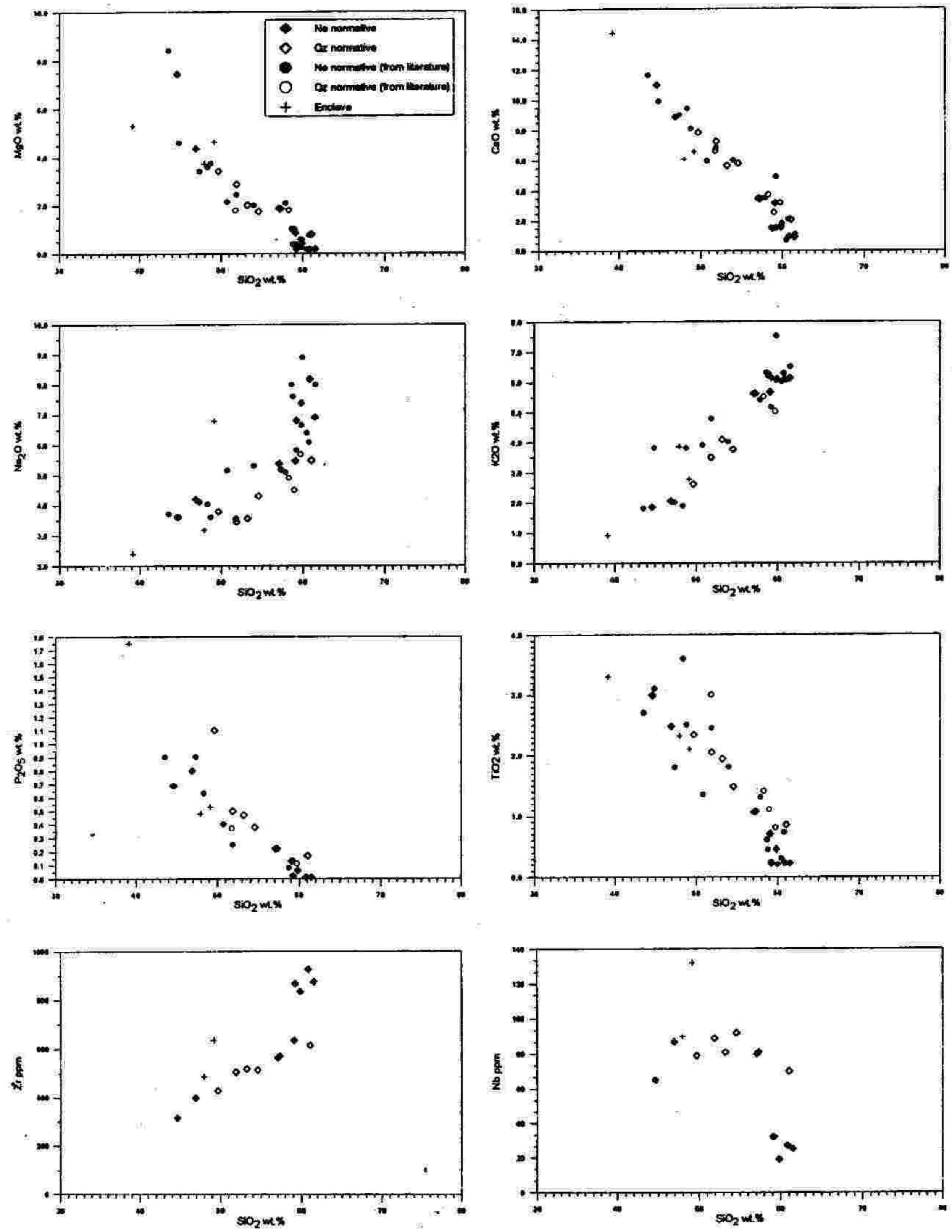

Fig. 2. Variation diagrams of selected elements and trace elements in the analysed rocks in the Col de Guéry area.

	Rocks							Enclaves	
	Col de Guéry	Sanadoire	Tuiliere	Puy Cordè	Trioulérou	Bozat	F$^{me.}$ Puy May	Trioulérou	Puy Cordé
Rock no.	88-924	88-901	88-955	97-108-2	88-953	97-110	88-951	97-107A	97-108C
Age (Ma)	-	1.83 ± 0.10	2.10 ± 0.10	2.03 ± 0.11	2.01 ± 0.06	0.73 ± 0.04	-	-	-
Rock type	Trachyte	Trachyte	Trachyte	Phonolite	Phonolite	Phonolite	Phonolite	Tephrite	Phonotephrite
Sc	5	3	1	3	<1	<1	1	18	16
V	101	60	27	39	24	24	45	232	189
Cr	53	13	n.d.	5	0	1	0,7	20	76
Ni	21	7	5	6	3	4	3	15	46
Cu	14	8	<2	10	5	8	6	28	27
Zn	82	76	76	69	76	72	61	255	96
Rb	145	184	275	253	266	209	228	193	123
Sr	451	575	13	129	21	82	157	495	508
Y	24	18	13	12	10	20	16	27	23
Zr	558	624	929	869	965	794	863	636	486
Nb	155	100	98	88	101	144	100	132	90
Cs	3	4	8	6	7	5	6	13	36
Ba	876	821	6	191	6	191	264	804	673
La	84	77	77	62	72	90	71	77	56
Ce	171	118	83	71	77	126	91	133	105
Nd	45	33	12	16	12	29	19	45	40
Sm	6.8	3.7	0.6	1.3	0.7	2.8	1.7	6.9	6.2
Eu	1.6	1.2	0.2	0.4	0.2	0.7	0.5	2.1	2,0
Tb	0.8	0.5	0.1	0.2	0.2	0.4	0.3	1.0	0.9
Yb	2.7	1.8	1.6	1.7	1.2	2.2	1.7	2.8	2.2
Lu	0.4	0.3	0.3	0.3	0.2	0.4	0.3	0.4	0.3
Hf	10.7	10.5	15.7	13.4	15,0	13.9	15,0	13.0	9.0
Ta	8.2	4.5	2.2	1.8	2.3	5.1	3.0	5.5	4.1
Th	18.3	20.3	37.9	26.1	36.2	28.5	23.0	19.0	14.0
U	n.d.	5.0	9.7	n.d.	12.1	7.8	n.d.	n.d.	n.d.
Y/Nb	0.155	0.180	0.133	0.136	0.099	0.139	0.160	0.205	0.256
Yb/Ta	0.332	0.400	0.727	0.944	0.522	0.431	0.567	0.509	0.537
Zr/Nb	3.600	6.240	9.480	9.875	9.554	5.514	8.630	4.818	5.400

Tab. 1b. REE and other trace elements in the rocks listed in Table 1a. Concentrations in ppm; n.d. – not determined.

phonolites and trachytes show a sharp increase in Na_2O, Zr (and also Rb, Cs, Th, U) and a depletion in P, Ti, Nb (and also Ta, Sr, Ba, the REE, especially the MREE and Y).

The trace elements indicate a mixed origin of the rocks of the enclaves (Tab. 1). The contents of Sc, V, Cr, Ni, Cu, Ba and Y are similar to those of the basanite–hawaiite stage; Rb, Sr, Zr, Sm and Th recall the trachyte stage; REE, Hf, and Ta the basanite as well as the trachyte stages. The enclaves have higher contents of Cs than the other rocks of the area.

Discussion

In the Col de Guéry area the sequence basanite to *q*-normative trachyandesite, which is found in a limited geographical area, may form a series derived from a basanitic magma by crystal fractionation processes. This view is supported by the Y/Nb, Yb/Ta, Zr/Nb ratios which are relatively constant. The shift from silica-undersaturated to silica-saturated rocks may be explained by early separation of amphibole as proposed by Maury (1976) and others. The transition from silica-undersaturated to saturated compositions may also be explained by contamination with crustal material as it has been proposed by Brousse (1961a). The generally linear trends from basanite to trachyandesite and some trachytes in Fig. 1. may furthermore be explained as a result of mixing of basanitic and trachytic melts (Gourgaud 1991).

The 2.0 Ma rocks have practically identical geochemical parameters. Their Y/Nb and Zr/Nb ratios differ from those of the basanite-trachyandesites and the other trachytes of the area (Table 1). This, and the fact that the 2.0 Ma rocks are *ne*-normative and the trachyandesitic rocks *qz*-normative, indicate that they cannot have been derived from the last-named rocks by simple fractionation processes. The geochemical signature of the 2.0 Ma rocks can be explained by fractionation processes in a basanitic to alkalibasaltic magma. Amphibole fractionation can explain the low contents of the MREE (cf. Briot et al. 1991; Wilson et al. 1995). The depletion in Nb and Ta may be a result of ilmenite and titanite fractionation (cf. Stimac and Hickmott 1994).

The 2.0 Ma rocks show very weak Eu anomalies, which may be explained by oxidation conditions of the magma infavourable for the formation of Eu^{+2}. Maury et al. (1980) estimated the oxygen fugacity of the Mont-Dore magmas to lie well above the NNO buffer based on Fe-Ti oxide geobarometry. This is in excellent agreement with our data for the Fe-Ti oxides of the trachytes and phonolites; they belong to the ilmenite–hematite series having 60–80 mol. hematite.

The discussion of the geochemistry of the 2.0 Ma trachytes and phonolites leads to the conclusion that these rocks were formed from melts that cannot have been derived directly from the basanite – trachyandesite series of the area. It is also clear that there is a break in the evolution from not only the basanite – trachyandesite series, but also from the other trachytes of the area. The most likely interpretation is that the trachytes and phonolites were formed from independent magma pulses from deep reservoirs of basanitic/tephritic magmas.

Mixing of magmas has been proposed to be an important process in the evolution of the volcanic rocks of Mont-Dore (e.g. Downes 1987; Gourgaud 1991). In the Col de Guéry area the mineralogical and chemical data for the 2.0 Ma trachytes and phonolites and their enclaves indicate complex processes of formation and disequilibrium features such as embayment of grains, overgrowths and reaction zones. Thus, the partly resorbed cores of An-rich plagioclase in zoned grains af feldspars, corroded and broken grains of Ti-Al-rich clinopyroxene and corroded grains of forsteritic olivines may represent remnants from a more basic magma, which coexisted with the phonolitic magma. This indicates that the rocks are mixtures of crystals brought up from depth and minerals formed by *in situ* crystallisation of the magma. The textures and chemical and modal compositions of the tephritic enclaves do not favour the view that these enclaves represent samples of the parent magma of the 2.0 Ma trachytes and phonolites. They may be samples of rocks from the roof and walls of the magma chamber, in which the trachytic–phonolitic melts were formed by fractionation processes, or be products of consolidation of contaminated basic melts coexisting with the trachytic–phonolitic melts. The chemical compositions of the enclaves from the Puy Cordé and Trioulérou phonolites (Tab. 1), when compared with those of the host phonolites, are enriched in Ti, P, Mg, Fe, Ca, V, Ni, Sc, Cs, Ba, Sr, (Nb), Ta and the REE, and impoverished in Si, Na, K, Rb, Zr, Hf and Th, features complementary to the chemical composition of the host rocks. It is of particular interest to note that the enclaves have higher contents of Nb, Ta, Ba, etc. than the host rocks, which supports the view that fractional crystallization can be responsible for the low contents of these elements in the 2.0 Ma rocks.

There is a marked variation in Nb contents and Zr/Nb ratios in the trachytes and phonolites of the region: The Sanadoire trachyte has the same Nb content as the 2.0 Ma rocks including the F^{mc} de Puy May, about 100 ppm Nb, but a different Zr/Nb ratio, 6.7, against 8.5–9.8. The Bozat phonolite located 10 km to the south has 144 ppm Nb and Zr/Nb = 5.5. The F^{mc} de Puy May trachyte is not dated, the Bozat phonolite is more than 1 m.y. younger than the 2.0 Ma rocks. In Cantal, 40 km further to the south, phonolites erupted between 6.5 and 7.0 Ma, and have 132–438 ppm Nb, Zr/Nb = 4.5–11 (Wilson et al. 1995). These variations in Nb contents and Zr/Nb ratios may reflect differences in the chemical composition of the geographically separated source regions of the melts, or different conditions of formation and contamination of the melts, but also, as the most simple process, they can be explained by differences in the fractionation patterns of the melts, hereunder not least differences in oxygen fugacities during consolidation of the melts.

References

BRIOT D., CANTAGREL J.M., DUPUY C. and HARMON R.S. 1991. Geochemical evolution in crustal magma reservoirs: trace-element and Sr-Nd-O isotopic variations in two continental intraplate series at Monts Dore, Massif Central, France. *Chem. Geol.*, 89, 281–303.

BROUSSE R. 1961a. Minéralogie et pétrographie des roches volcaniques du massif du Mont-Dore (Auvergne). III: Les deux associations magmatiques. *Bull. Soc. franc. Minér. Cristall.*, 84, 245–259.

BROUSSE R. 1961b. Analyses Chimiques des Roches Volcaniques Tertiaires et Quaternaires de la France. *Bull. Serv. Carte Géol. France*, 263, 1–140.

BROUSSE R., RANCON J-P., TEMPIER P. and VEYRET Y. 1989. Bourg-Lastic, *Carte Géologique de la France 1/50,000. Éditions du BRGM - BP 6009 - 45060,* Orléans Cedex 2 - France.

CANTAGREL J.M. and BAUBRON J.C. 1983. Chronologie des éruptions dans le massif volcanique des Monts Dore. Implications volcanologiques. *Bulletin du BRGM*, No. 1/2, 123–142.

DECOBECQ D. 1987. *Approche pétrologique du reservoir magmatique du Massif du Mont-Dore par les enclaves associes.* Ph.D. Thesis, Université de Paris-Sud, 204 pp.

DOWNES H. 1987. Tertiary and Quaternary volcanism in the Massif Central, France. In FITTON J.G. and UPTON B.G.J. (eds.): *Alkaline Igneous Rocks*, 517–530. *Geological Society Special Publication*, 30, *Blackwell Sci. Publ.*, Oxford.

GLANGEAUD L., BOBIER C., DUMESNIL P., LETOLLE R., LEPVRIER P. and VIGNERON. 1965. Géochronologie et évolution paléomagnétique, géochimique, pétrologique et tectonophysique du massif volcanique du Mont-Dore (France). *Bull. Soc. géol. France*, 7, 1010–1025.

GOURGAUD A. 1991. Comagmatic enclaves in lavas from the Mont-Dore composite volcano, Massif Central, France. In DIDIER J. and BARBARIN B. (eds.): *Enclaves and Granite Geology*, 221–233. *Elsevier*, Amsterdam.

LACROIX A. 1917. Les laves haüyne d'Auvergne et leurs enclaves homeogenes: importance théorique de ces dernieres. *C. R. Hebd. Acad. Sci. (Paris)*, 164, 581–588.

MAURY R.C. 1976. *Contamination (par l'encaissant et les enclaves) et cristallization fractionnée de séries volcaniques alcalines, continentales (Massif Central francais) et océaniques (Pacifique Central): l'origin des laves acides.* Ph.D. Thesis, Université de Paris-Sud, 455 pp.

MAURY R.C. D'ARCO P. and BROUSSE R. 1980. Températures et fugacités d'oxygéne des magmas intermédiaires et différenciés du Mont-Dore. *C. R. somm. Soc. géol. France*, 1980, fasc. 6, 242–245.

STIMAC J. and HICKMOTT D. 1994. Trace-element partition coefficients for ilmenite, orthopyroxene and pyrrhotite in rhyolite determined by micro-PIXE analysis. *Chem. Geol.*, 117, 313–330.

WILSON M., DOWNES H. and CEBRIA J.-M. 1995. Contrasting fractionation trends in coexisting continental alkaline magma series; Cantal, Massif Central, France. *J. Petrol.*, 36, 1729–1753.