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Geochemistry (geochronology)

Geochemistry and geochronology of mafic rocks from Bamenda Mountains (Cameroon): Source composition and crustal contamination along the Cameroon Volcanic Line

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Abstract

Mafic rocks from the Bamenda volcanic province along the Cameroon Volcanic Line have been dated from 17 to 0 Ma. Associated with some trachytes and rhyolites, this volcanism covers a period of more than 25 Ma. The studied rocks are basalts to mugearites. Most of them have been contaminated by continental crust during their transit to the surface. The oldest rocks are the most contaminated. One group of samples shows high Eu, Sr and Ba contents. This characteristic is not due to crustal contamination process, but has a mantle source origin. We argue that these characteristics have been acquired by mixing of melts formed by partial melting of mantle pyroxenites with melts formed in mantle peridotites. Such pyroxenites have been observed as mantle xenoliths in the Adamaoua province, and their chemical and isotopic compositions are consistent with such a model. ***To cite this article: P. Kamgang et al., C. R. Geoscience 340 (2008).***

Résumé

Géochimie et géochronologie des roches basiques des monts Bamenda (Cameroun) : composition de la source et contamination crustale le long de la ligne volcanique du Cameroun. Les roches basiques de la province volcanique de Bamenda, appartenant à la Ligne Volcanique du Cameroun, ont été datées entre 0 et 17 Ma. Associées aux roches acides (trachytes et rhyolites), le volcanisme de cette province s'étale sur plus de 25 Ma. Les roches étudiées vont des basaltes à des mugéarites. La plupart ont été contaminées par la croûte continentale pendant leur remontée vers la surface, les roches les plus vieilles étant les plus contaminées. Certaines roches présentent de fortes teneurs en Eu, Sr et Ba, qui ne sont pas en relation avec les phénomènes de contamination crustale, mais trouvent leur origine dans la source des magmas. Les données géochimiques présentées sont en accord

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avec une origine des magmas dans cette région, par mélange entre des magmas issus de la fusion partielle de pyroxénites et des magmas issus de la fusion de péridotites. ***Pour citer cet article : P. Kamgang et al., C. R. Geoscience 340 (2008).***

Keywords: Bamenda Mountains; Cameroon Volcanic Line; Basaltic lavas; K/Ar ages; Geochemistry

Mots clés : Monts Bamenda ; Ligne volcanique du Cameroun ; Laves basaltiques ; Âges K/Ar ; Géochimie

1. Introduction and geological setting

The Bamenda mountains, located between the Santa and Sabga localities, represent one of the most important volcanic province of the continental part of the Cameroon Volcanic Line (CVL). They lie between the Bambouto mountains to the south-west and the Oku massif to the north-east (Fig. 1) and have been poorly studied [4,5,12]. This volcanic province is made of mafic and felsic rocks emplaced on a Panafrican or older basement. An earlier study of the felsic rocks [8] has shown that the volcanism covers a large period of time, at least from 10 to 22 Ma, and that the felsic magmas have been largely contaminated during their evolution in crustal magma chambers.

We present new geochronological and geochemical data on the mafic rocks from the Bamenda volcanic province in order to discuss the relationship between

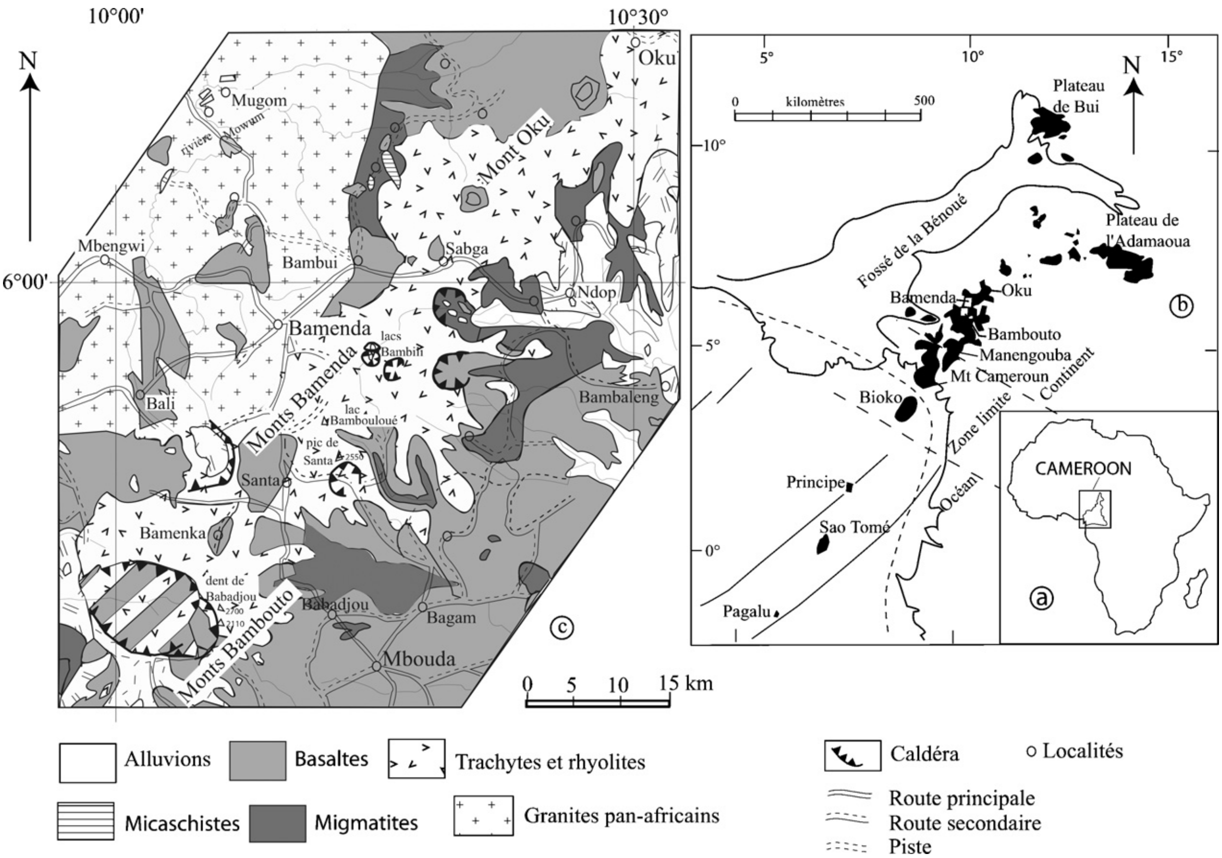

Fig. 1. Map of the studied area showing: ⓐ the location of Cameroon in Africa; ⓑ the location of the Bamenda mountains along the CVL; and ⓒ a simplified geological map of the studied area. Modified from [8].

Fig. 1. Carte montrant : ⓐ la position du Cameroun en Afrique ; ⓑ la position des monts Bamenda le long de la Ligne Volcanique du Cameroun; ⓒ une carte géologique simplifiée de la zone étudiée. Modifié d'après [8].

mafic and felsic magmas and to deal with the nature and composition of the mantle source of the magmas.

2. Petrography

Mafic rocks from the Bamenda mountains have various major element compositions, and in the $Na_2O + K_2O$ vs. SiO_2 diagram [9], range from basalts to mugearites (Fig. 2). Some samples have low silica contents and plot in the basanite field. All of the samples have alkaline affinity, but the series (including felsic rocks) is clearly discontinuous between mugearites and trachytes (Fig. 2). Basanites contain large olivine and clinopyroxene phenocrysts (up to 2 mm). Nepheline is sometimes present in the mesostase, associated with plagioclase, clinopyroxene and Fe-Ti oxides. The most mafic rocks contain mainly olivine and clinopyroxene phenocrysts, while in the mugearites plagioclase phenocrysts are more abundant.

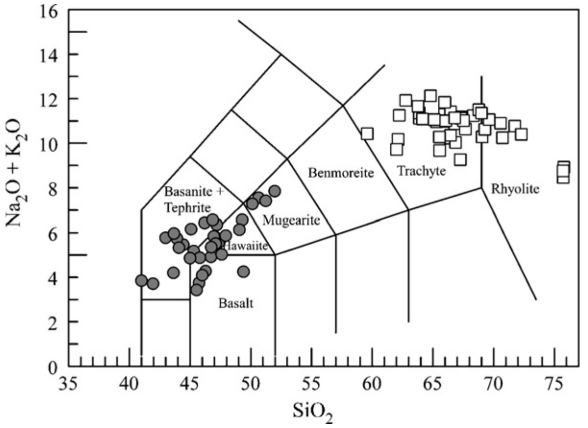

Fig. 2. Alkali vs. silica content [9] showing the diversity of the Bamenda mafic rocks (grey circles) as well as the composition of the related felsic rocks (white squares) from the same volcanic province [8].

Fig. 2. Diagramme alcalins/silice [9] pour les basaltes (cercles gris) des monts Bamenda. Les roches acides (carrés blancs) de la même zone sont aussi reportées pour comparaison [8].

3. Geochronology

Ten samples have been dated by the K-Ar method at CRPG in Nancy [19] or at the University of Queensland in Australia. The data are presented in the Table 1. The ages range from 17.6 Ma to Present. Even if these ages are not representative of the whole volcanic province, they show that mafic volcanism exists over a long period of time and is partly coeval to the felsic volcanism (from 12 to 27 Ma, [8]). However, very recent ages obtained on some mafic rocks have not been found among the felsic ones. The age of the mafic volcanism of the Bamenda area is consistent with ages measured for the volcanism of the other volcanic provinces from the Oku massif to the north to the still active Mount Cameroon to the south [3]. Consequently, volcanism in the Bamenda volcanic province exists over a more than 25 Myr period, without any spatial evolution.

Table 1
K-Ar ages obtained on some mafic rocks from the Bamenda area.
Tableau 1
Âges K-Ar obtenus sur quelques roches basiques de la région de Bamenda.

Sample	Rock	K_2O (%)	$^{40}Ar^*$ (10^{15}at/g)	$^{40}Ar^*$ (10^{-6} cm^3/g)	Age (Ma)	Error (1σ)	Laboratory
BA61	Basalt	1.19	0	0	0	0	CRPG (Nancy)
BA31	Basanite	1.65	0.0006	0.021	0.4	0.1	CRPG (Nancy)
BA10	Basanite	1.52	0.00189	n.a.	1.2	0.2	CRPG (Nancy)
BA24	Basanite	1.91	0.0021	0.079	1.3	0.1	CRPG (Nancy)
BA73	Basanite	2.016	0.0076	0.282	5.5	0.4	CRPG (Nancy)
BA37	Basanite	1.31	0.0086	0.322	7.6	0.2	CRPG (Nancy)
BA68	Basanite	1.72	0.0124	0.462	8.3	0.3	CRPG (Nancy)
BA42	Hawaiite	1.6	0.0236	0.877	16.9	0.3	CRPG (Nancy)
BA60	Hawaiite	1.91	0.03525	n.a.	17.6	0.3	CRPG (Nancy)
BA60	Duplicate		0.0351	n.a.	17.4	0.8	CRPG (Nancy)

Sample	Rock	K_2O (%)	$^{40}Ar^*$ (%)	$^{40}Ar^*$ (10^{-12} mol/g)	Age (Ma)	Error (1σ)	Laboratory
BA87	Basalt	0.63	8.48	4.011	4.4	1.4	Univ. Queensland (Australia)

The following decay constants were used: $^{40}\lambda_e = 0.581 \times 10^{-10}$ a^{-1} and $^{40}\lambda_\beta = 4.962 \times 10^{-10}$ a^{-1}.
n.a.: not available.
Les constantes de désintégration utilisées sont les suivantes : $^{40}\lambda_e = 0{,}581 \times 10^{-10}$ a^{-1} *et* $^{40}\lambda_\beta = 4{,}962 \times 10^{-10}$ a^{-1}.
n.a. : donnée non disponible.

4. Geochemistry

Major and trace element whole rock analyses have been obtained by ICP-AES and ICP-MS, respectively, at the CRPG in Nancy. Sr and Nd isotopes were analyzed by TIMS at the University of Clermont-Ferrand in France, while Pb isotopic ratios have been acquired by TIMS at the University of Queensland in Australia. The studied mafic rocks have silica contents ranging from 41 to 52%, with MgO ranging from 2.5 to 11.3%. When compiled together with the previously studied felsic rocks of the same volcanic province [8], the range in major element composition is consistent with a fractional crystallization process accounting for the evolution from the most mafic rocks to the more differentiated rhyolites. This implies fractionation of olivine, clinopyroxene and Fe-Ti oxides, with late crystallization of plagioclase. However, the size of the Bamenda volcanic province as well as the extension of the volcanic activity over more than 25 Myr and the diversity of the most mafic magmas imply that the samples are nor belonging to a single magmatic series. Their genesis probably involves different partial melting episodes in the mantle, with different melt fractions and possibly different source compositions. Consequently, a detailed study of the fractionation processes between the different samples would have no geological signification.

The mafic rocks from Bamenda have parallel and rather homogeneous REE patterns showing light-REE enrichment, with La_n/Yb_n ratios ranging from 10 to 19, and La concentrations from 100 to 300 times the chondritic value (Fig. 3). Nine samples have a slight positive Eu anomaly but do not show any plagioclase accumulation.

Extended trace element patterns also show some interesting peculiarities. They are rather parallel for all the samples, which all possess a small negative Zr and Hf anomaly (Fig. 4). The mafic rocks have very low Rb concentrations (23 to 51 ppm) and variable but high Ba concentrations (310 to 1350 ppm). Most of the samples showing a positive Eu anomaly also have a positive Sr anomaly and the highest Ba concentrations. As these samples have high Eu, Sr and Ba contents but do not have large amounts of plagioclase phenocrysts, we can consider that these geochemical features are characteristics of the magma itself and not due to mineral accumulation.

Sr, Nd and Pb isotopic ratios obtained on selected samples are presented in Fig. 5. Present-day $^{87}Sr/^{86}Sr$ ratios vary from 0.70307 to 0.70424 while the $^{143}Nd/^{144}Nd$ ratios range from 0.512616 to 0.512911.

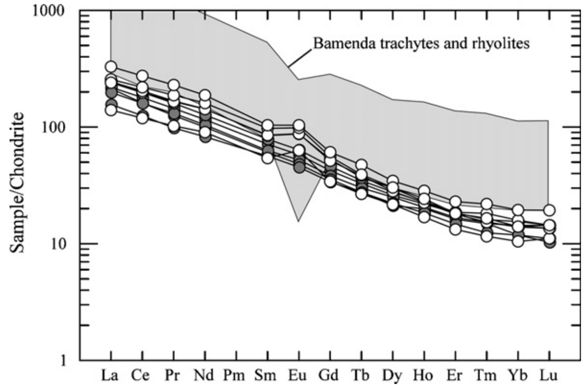

Fig. 3. Chondrite normalized rare earth element patterns for some representative mafic rocks from the Bamenda province. The white circles are samples with a positive Eu anomaly while the grey circles represent samples without this anomaly. The grey field represents the composition of the felsic rocks from the same area [8]. Chondrite values from [1].

Fig. 3. Spectres de terres rares normalisés à la chondrite pour quelques roches représentatives des laves basiques des monts Bamenda. Les cercles blancs représentent des échantillons possédant une anomalie positive en Eu, alors que les cercles gris représentent des échantillons ne possédant pas cette anomalie. Le champ grisé correspond à la composition des roches acides de la même région [8]. Valeurs de la chondrite selon [1].

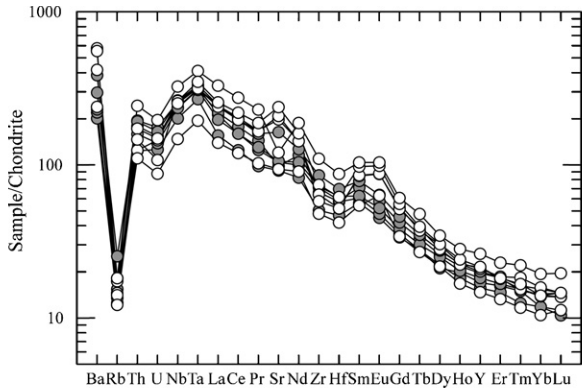

Fig. 4. Chondrite normalized trace element patterns for some representative mafic rocks from the Bamenda province. The white circles are samples with a positive Eu anomaly and for some of them a positive Sr anomaly, while the grey circles represent samples without this anomaly. Chondrite values from [1].

Fig. 4. Spectres d'éléments traces normalisés à la chondrite pour quelques roches représentatives des laves basiques des monts Bamenda. Les cercles blancs représentent des échantillons possédant une anomalie positive en Eu et pour certains d'entre eux en Sr, alors que les cercles gris représentent des échantillons ne possédant pas ces anomalies. Valeurs de la chondrite selon [1].

The Pb isotopic composition covers a large spread of values, with $^{206}Pb/^{204}Pb$ ranging from 17.32 to 20.25. No age correction has been applied for these isotopic compositions, because the age of the samples is not

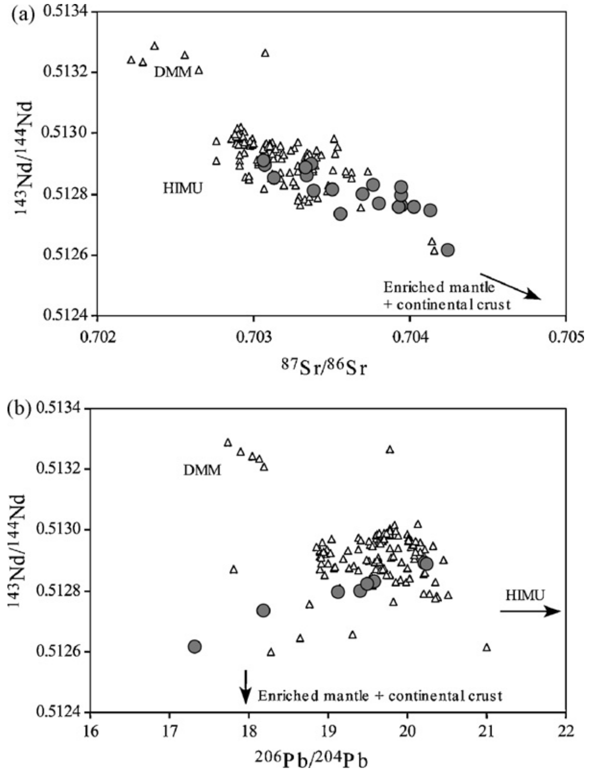

Fig. 5. Present-day a: Nd–Sr and b: Nd–Pb isotopic compositions of the mafic rocks (grey circles) from the Bamenda volcanic province. The small triangles are lavas and xenoliths from different localities of the CVL [2,6,10,11,17]. The location of DMM and HIMU mantle components [7] is indicative.

Fig. 5. Diagrammes isotopiques a : Nd–Sr et b : Nd–Pb (rapports isotopiques actuels) pour les roches basiques (cercles gris) des monts Bamenda. Les triangles représentent la composition isotopique des laves et des enclaves provenant d'autres provinces volcaniques de la ligne du Cameroun [2,6,10,11,17]. La position des composants DMM et HIMU est indicative et tirée de [7].

always known and can vary from 0 to more than 20 Ma. The most sensitive ratio to the age correction is for Sr. The maximum value obtained for Rb/Sr in a Bamenda mafic rock is 0.06, which would correspond to a correction of 5×10^{-5} on the $^{87}Sr/^{86}Sr$ ratio for an age of 20 Ma. This correction is not significant and does not change anything about the interpretation which can be addressed from the presented data.

Sr and Nd isotopic values obtained for the Bamenda samples are similar to the previously published values acquired on the mafic rocks from the CVL [2,6,10,11,17] with a few samples having the most radiogenic Sr and the less radiogenic Nd isotopic composition measured along the CVL. Measured Pb isotopic compositions are positively correlated with Nd isotopic ratios and negatively correlated with Sr isotopic values. On one side, these correlations point towards a component with low Pb isotopic values. High Sr isotopic ratios in mafic rocks have been interpreted either as the contamination of mafic magmas by various amounts of continental crust [15–17] or by the involvement of an enriched lithospheric mantle component [14,17].

5. Discussion

5.1. Crustal contamination of mafic magmas

Some chemical and isotopic characteristics of volcanic rocks can be acquired by interactions with crustal rocks during magma transfer from the mantle to the surface and also during the storage of these magmas in crustal magma chambers at different crustal levels and their differentiation through crystal fractionation. This contamination has already been observed and characterized for the felsic rocks from the Bamenda volcanic province [8]. The negative correlation between MgO and Sr isotopic ratio (Fig. 6a) and the positive one with Nd isotopic ratio clearly indicates that the isotopic variations observed in the mafic rocks were mainly acquired by interaction with crustal rocks in the course of the differentiation of the magmas. The Sr and Nd isotopic ratios are also well correlated with the La/Nb ratio, consistent with a contamination by a high La/Nb component, typical of rocks from the continental crust (Fig. 6b). This crustal contaminant also has very low Pb isotopic composition ($^{206}Pb/^{204}Pb < 17.5$; $^{207}Pb/^{204}Pb < 15.4$ and $^{208}Pb/^{204}Pb < 37$). This contamination process by a contaminant with low Pb isotopic composition has already been observed in the other volcanic provinces from the CVL [6,17] but not with isotopic values as low as some observed in the Bamenda volcanic rocks. These observations imply that geochemical data from the CVL volcanic rocks must be studied with great care, even for mafic rocks, before being interpreted in terms of mantle source heterogeneities.

One key point of this crustal contamination problem is the strong positive correlation observed between the $^{87}Sr/^{86}Sr$ isotopic ratio and the age of the studied samples (Fig. 7). This correlation also exists for Nd isotopic composition as well as for the La/Nb ratio. The oldest rocks have the highest Sr isotopic compositions, the lowest Nd isotopic ratios and the highest values for the La/Nb ratio. These correlations indicate that the crustal contamination process became less and less important through time in the Bamenda province. Different mechanisms can account for this time evolution. The country rocks can become more and more refractory with time and can be isolated from the circulating magmas due to the crystallization of the

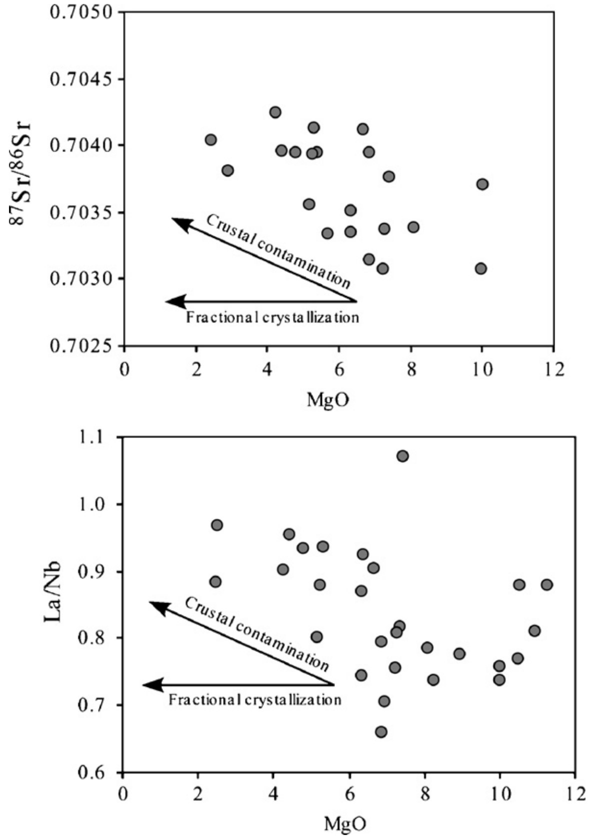

Fig. 6. $^{87}Sr/^{86}Sr$ and La/Nb variations vs. MgO contents of the mafic rocks. Indicative trends for fractional crystallization and crustal contamination confirm that the Bamenda mafic rocks have interacted with the continental crust during their evolution.

Fig. 6. $^{87}Sr/^{86}Sr$ et La/Nb en fonction de la teneur en MgO des roches basiques de Bamenda. Les tendances indicatives de cristallisation fractionnée et de contamination crustale confirment que les magmas basiques de Bamenda ont interagi avec les roches de la croûte continentale.

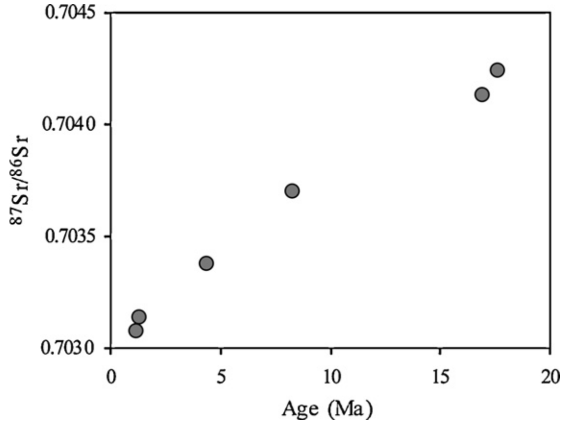

Fig. 7. Present-day $^{87}Sr/^{86}Sr$ vs. age of the mafic samples from Bamenda.

Fig. 7. Rapport $^{87}Sr/^{86}Sr$ (rapport isotopique actuel) mesuré en fonction de l'âge des roches basiques de Bamenda.

previous magmas in the conduit, or a change in the extensional regime of the whole area can facilitate the circulation of the magmas through the crust, thus preventing interactions of these magmas with the country rocks. Whatever the reason for this time evolution, this implies that the most recent volcanic rocks of the Bamenda province are the most interesting to study the nature and the composition of their mantle source because they are the less contaminated by the overlying crustal rocks.

5.2. Nature and composition of the mafic magma source

Despite evidences for crustal contamination of the mafic magmas before their emplacement at the surface, several observations can be emphasized in order to discuss the nature and composition of the mantle source of the magmas in the general framework of the CVL. Only the most recent rocks, younger than 5 Ma, are not significantly affected by contamination and so their chemical and isotopic composition bring some information about their source. These rocks have low Sr isotopic composition but high Pb isotopic ratios ($^{206}Pb/^{204}Pb = 20.25$ in BA47), among the highest values measured so far in the CVL. This component with radiogenic Pb isotopic composition has been attributed to the continental lithospheric mantle structured during the opening of the South-Atlantic ocean and the emplacement of the mantle plume presently located beneath the island of St Helena [6]. The crustal contamination which has affected the older mafic magmas does not allow one to assess the time evolution of the participation of this lithospheric mantle component in the genesis of the Bamenda magmas.

High concentrations in Eu, Sr and Ba in some of the studied samples give insights about the nature and the chemical composition of the mantle source of the volcanism in that area. These high trace element concentrations are correlated neither to the Sr and Nd isotopic compositions of the rocks, nor to the MgO contents or the La/Nb ratio. This means that these high concentrations are not acquired during the crustal contamination process but instead have something to deal with the composition of the source of the magmas. Two series of rocks, one with high Sr contents and another one with low Sr concentrations have already been observed in the mafic rocks from the nearby Bambouto volcanic province [13]. In both volcanic

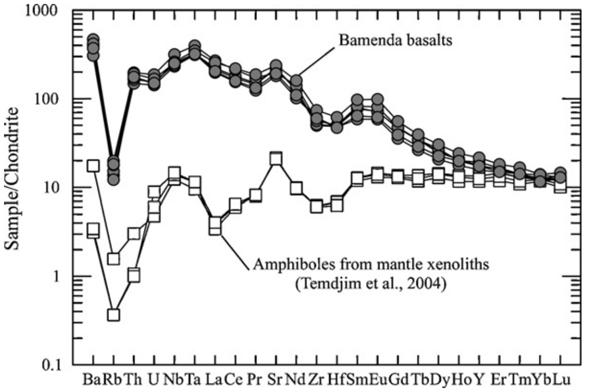

Fig. 8. Trace element composition of some Bamenda basalts with Sr and Eu positive anomalies compared to the composition of pargasites from amphibole-bearing spinel lherzolites from the Nyos locality [18].

Fig. 8. Teneurs en éléments traces normalisées à la chondrite de quelques basaltes de Bamenda comparées à celles de pargasites provenant de lherzolites à spinelle du volcan de Nyos [18].

provinces, the existence of these two rocks series with different trace element composition but with similar isotopic ratios imply that two mantle sources with different trace element compositions but similar isotopic compositions have contributed to their genesis. This trace element difference can be attributed to different mineralogies of the source. For the Bambouto volcanic province, the high Sr rock series has been explained by the partial melting of an amphibole-bearing metasomatized mantle source [13]. Such a mantle has already been observed in Cameroon and especially in mantle xenoliths from the Nyos volcano where amphibole-bearing spinel lherzolites have been described [18]. The high Sr and Ba contents of amphiboles in these mantle samples, as well as their low Zr and Hf contents make them potential candidates for the source of the high-Sr mafic magmas (Fig. 8). However, these amphiboles do not show the high Eu content observed in the Bamenda mafic rocks and their participation to the genesis of these magmas do not explain these positive Eu anomalies.

The pyroclastic deposits from the Youkou volcano, in the Adamaoua volcanic field, contain mantle xenoliths and especially garnet-bearing pyroxenites. Whole rock chemical composition of these samples (Chazot et al., in preparation) shows that they are enriched in Sr and Ba and also possess a Eu positive anomaly in their REE patterns, as well as low Zr and Hf contents. These pyroxenites also contain apatite, which is in good agreement with the observation that the Bamenda basalts with the highest Eu and Sr anomalies also have the highest P_2O_5 contents. Furthermore, the Sr and Nd isotopic composition of the pyroxenite xenoliths is not very different from that measured in the Bamenda mafic volcanic rocks. Partial melting of these pyroxenites and mixing of these magmas with magmas generated in associated spinel or garnet lherzolites can explain the chemical and isotopic characteristics of the Bamenda volcanic rocks. The similarity of the isotopic compositions of the two different kinds of mafic rocks in the Bamenda province implies a recent origin for the mantle source enriched in Eu, Sr and Ba or a time evolution of the source with low Rb/Sr and moderate Sm/Nd ratios, which is the case for the Youkou pyroxenites.

6. Conclusion

Mafic volcanic rocks ranging from basalts to mugearites were emplaced in the Bamenda volcanic province between 17 and 0 Ma. These rocks are associated with trachytes and rhyolites in the same area and this volcanism covers a period of more than 25 Ma. Differences between the chemical composition of the studied samples are mainly due to crystal fractionation process in magma chambers. However, correlation between differentiation indexes and isotopic and some trace element ratios are consistent with assimilation of crustal material during the differentiation, the oldest rocks being the most contaminated. Some samples show high concentrations in Eu, Sr and Ba, independent from the mineralogy of the rocks and from the contamination processes. This selective trace element enrichment without different Sr, Nd, Pb isotopic compositions indicates a metasomatized amphibole-bearing mantle source or, most probably, the participation of pyroxenites in the genesis of the magmas in the mantle. High Eu, Sr, Ba pyroxenites have been sampled in mantle xenoliths from the Adamaoua province and their trace element and isotopic compositions are consistent with the data obtained on the high-Sr rocks from Bamenda. Mixing of partial melts from these pyroxenites with melts formed from associated spinel or garnet lherzolites can account for the chemistry of the Bamenda mafic rocks. When the melts originate only from mantle peridotites, they do not show this selective enrichment. This peridotite–pyroxenite association in the mantle probably formed during the opening of the South-Atlantic ocean and the emplacement of the St Helena mantle plume. More geochemical information is needed on the most recent volcanic rocks from the Bamenda province to get a better understanding of the mantle processes occurring beneath the CVL.

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