GEOCHEMISTRY, MINERALOGY AND PETROLOGY • SOFIA
ГЕОХИМИЯ, МИНЕРАЛОГИЯ И ПЕТРОЛОГИЯ • СОФИЯ
2010, **48**, 67-94.

Late Tertiary and Quaternary alkaline volcanism in the western Noun Plain (Cameroon Volcanic Line): New K-Ar ages, petrology and isotope data

Pierre Wandji, Pierre Wotchoko, Jacques-Marie Bardintzeff, Hervé Bellon

Abstract. The Neogene and recent volcanism located on the western side of the Noun River was emitted during several events i.e. effusive activity at 10.43 Ma, 4.60 to 4.15 Ma, explosive activity at 2.04 to 1.70 Ma and in recent times (0.40 Ma) as indicated by whole-rock K-Ar ages. The mineralogical composition of basalts is relatively homogeneous: olivine, clinopyroxene, plagioclase, Fe-Ti oxides and chromite. These alkaline sodic lavas contain variable proportions of normative nepheline (0 to 15 wt.%) or hypersthene (0.5 to 0.8 wt.%). The volcanic series, slightly differentiated (D.I. ranging between 18.6 and 39.2), evolve from picrites to alkali basalts and hawaiites. According to their geochemical behaviour, major elements show an enrichment in SiO_2 (41.2–46.4 wt.%), Al_2O_3 (11.4–17.1 wt.%), Na_2O (2.4–3.9 wt.%), K_2O (1.0–1.9 wt.%) and an impoverishment in MgO (13.8–4.6 wt.%) and CaO (11.9–7.6 wt.%). Some diagrams indicate a good correlation of the contents of some minor elements (U, Nb, Ta, La, Zr, Hf) with that of Th. *REE* patterns of the rocks are characterized by a positive anomaly in Eu ($2.75 < Eu/Eu^* < 3.09$), and present parallel profiles. Magmatic differentiation is controlled by the fractional crystallization of a primitive basaltic magma. The Sr and Nd isotopic data of two alkali basalts and one picrite evidence for the recent lavas of the Noun Plain their nearly similar $^{87}Sr/^{86}Sr$ (0.703157–0.703494) and $^{143}Nd/^{144}Nd$ (0.512875–0.512926) ratios. These results confirm that the studied lavas derive from a mantle source very close to the prevalent mantle type (PREMA) in which the HIMU pole plays a major role, as for others volcanic series of the Cameroon Volcanic Line (CVL).

Key words: Cameroon Volcanic Line (CVL), alkaline magmatism, K-Ar ages, Sr-Nd isotopes

Addresses: P. Wandji, P. Wotchoko – Laboratoire de Géologie, Ecole Normale Supérieure, Université de Yaoundé I, BP 47, Yaoundé, Cameroun; J.-M. Bardintzeff – Laboratoire de Pétrographie–Volcanologie et équipe Planétologie, UMR CNRS IDES 8148, bât. 504, Université Paris-Sud, 91405 Orsay, France and IUFM, Université de Cergy-Pontoise, 95000 Cergy-Pontoise, France; E-mail: jacques-marie.bardintzeff@u-psud.fr; H. Bellon – Université Européenne de Bretagne, UMR CNRS 6538, IUEM, Université de Bretagne Occidentale, 6 av. Le Gorgeu, CS 93837, 29238 Brest Cédex 3, France

Пиер Уанджи, Пиер Уочоко, Жак-Мари Бардинцеф, Ерве Белон. Къснотерциерният и кватернерен алкален вулканизъм в западната част на равнината Нун (Камерунската вулканска линия): петрология, изотопи и нови K-Ar данни за възрастта

Резюме. Вулканизмът на западния бряг на р. Нун се проявява неколкократно през Неогена до настоящето време: ефузивните прояви са датирани с K/Ar метод на 10,43 Ma, 4,60 и 4,15 Ma. Експлозивните прояви са датирани от 2,04 до 1,70 Ma, както и почти съвременни (0,40 Ma). Минераложкият състав на базалтите е относително хомогенен – изградени са от оливин, клинопироксен, плагиоклаз, Fe-Ti оксиди и хромит. Лавите са алкални, предимно натриеви, съдържат вариращи количества нормативен нефелин (0–15 тегл.%) или хиперстен (0,5–0,8 тегл.%). Слабодиференцираната серия (D.I. между 18,6 и 39,2) еволюира от пикрити и алкални базалти до хаваити. Според геохимичното си поведение главните елементи сочат обогатяване със SiO_2 (41,2–46,4 тегл.%), Al_2O_3 (11,4–17,1 тегл.%), Na_2O (2,4–3,9 тегл.%), K_2O (1,0–1,9 тегл.%) и обедняване с MgO (13,8–4,6 тегл.%) и CaO (11,9–7,6 тегл.%). На приложените диаграми се откроява добре изразена корелация между съдържанията на някои елементи-следи (U, Nb, Ta, La, Zr, Hf) с Th. Кривите на разпределение на *REE* сочат положителна европиева аномалия (2,75< Eu/Eu*<3,09) и паралелни профили. Магматичната диференциация е доминирана от фракционната кристализация на една примитивна базична магма. Sr и Nd изотопи на 2 алкални базалта и на един пикрит от съвременните лави на равнината на Нун сочат близки отношения $^{87}Sr/^{86}Sr$ (0,703157–0,703494) и $^{143}Nd/^{144}Nd$ (0,512875–0,512926). Тези резултати потвърждават, че изследваните лави произлизат от мантиен източник от тип PREMA, в които HIMU играе главна роля в съгласие с другите вулкански серии на Камерунската линия.

Introduction

The Cameroon volcanic line stretches both in the oceanic domain and continental lithospheres (Fitton 1987; Déruelle et al. 1991; Déruelle et al. 2007) in the extensional tectonic setting of the Central Africa (Fig. 1). The Noun Plain, drained by the Noun River, constitutes a natural boundary between the Bamileke Plateau on the southwest and the Bamoun Plateau on the northeast. The volcanism of this study area is characterized by two great eruptive types: fissural effusive volcanism and then explosive volcanism. The last explosive phase (strombolian volcanism) has built cones of pyroclastic projections and contributed to the enlargement of explosion craters. In this paper, we propose a petrological and geochemical study and dating of the lavas on the western side of the Noun River.

Volcano-tectonic evolution and K-Ar dating

The studied area covers a surface of 520 km^2 on the western side of the Noun River, at altitudes ranging between 1088 m and 1591 m. Our measurement of several hundred faults (Fig. 2) evidences two major directions: N130–140 and N30–40. Note that, in the great systems of fracturing of the Cameroon Volcanic Line determined by Moreau et al. (1987) and of West-Cameroon (Morin 1989), the directions of the faults are expressed along:

- the N40–50 direction;
- the N100–120 direction;
- the N150–160 direction.

These values are little bit different from 3 alignments determined by the 14 volcanic cones (Fig. 2) along the average major directions N35, N135 and N160. These cone alignments are the consequences of intense tectonics along the Cameroon Volcanic Line. But it is not excluded that other faults were reactivated by tectonics related to the recent volcanism in the Noun Plain.

The volcanic activity has produced deposits laying in discordance on the pan-african granitoids. These are flood basalts, pyroclastic projections, pyroclastic flows and based surge (Fig. 3). Various volcanic products witness for different eruptive styles (review in Bardintzeff & McBirney 2000). Thus, on the western side of Noun, different types of

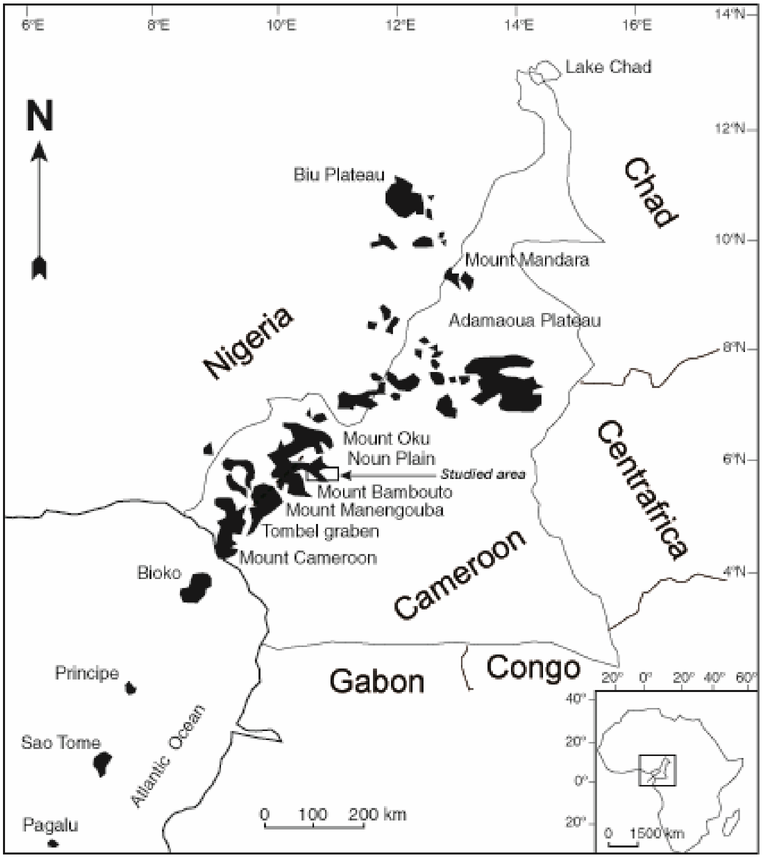

Fig. 1. The Noun Plain (rectangle) in the Cameroon Volcanic Line. Volcanoes are drawn in black

eruptive style constitute two successive volcanic episodes. These are: 1) an ancient effusive volcanism at the origin of pahoehoe and aa flows, which covers about 30 % of the surface of the plain; 2) an explosive volcanism essentially subrecent to recent. This has emitted pyroclastic projections that built 9 holomagmatic cones, 3 holohydromagmatic volcanoes, one hydroholomagmatic volcano and one hydromagmatic volcano (Wandji et al. 1994; Wandji 1998).

Three new K-Ar datings (Table 1) have been performed on whole-rocks at the Laboratoire de Géochronologie, Université de Bretagne Occidentale, Brest, France, following a similar basic analytical procedure as detailed in Bellon & Rangin (1991). Constants values of Steiger & Jäger (1977) have been used for age calculations. Uncertainties have been calculated using equations of Mahood & Drake (1982) and are given at 1 σ. These results complete the previous ages published by Wotchoko et al. (2005), all data being presented in Table 1 and samples addressed as follows: (Y11) Bamendjing, Yupé volcano; (D120) Galim, Mbéhuè volcano; (BO1) Boya, Boya volcano; (T10) Baleng, Tchanda Bororo volcano; (BK3) Kamkop; (BK5) Mifi river. All together, these results show at least that several events may be accounted for the Neogene to Quaternary i.e. effusive activity at 10.43 Ma, 4.60 to 4.15 Ma, and explosive activity at 2.04

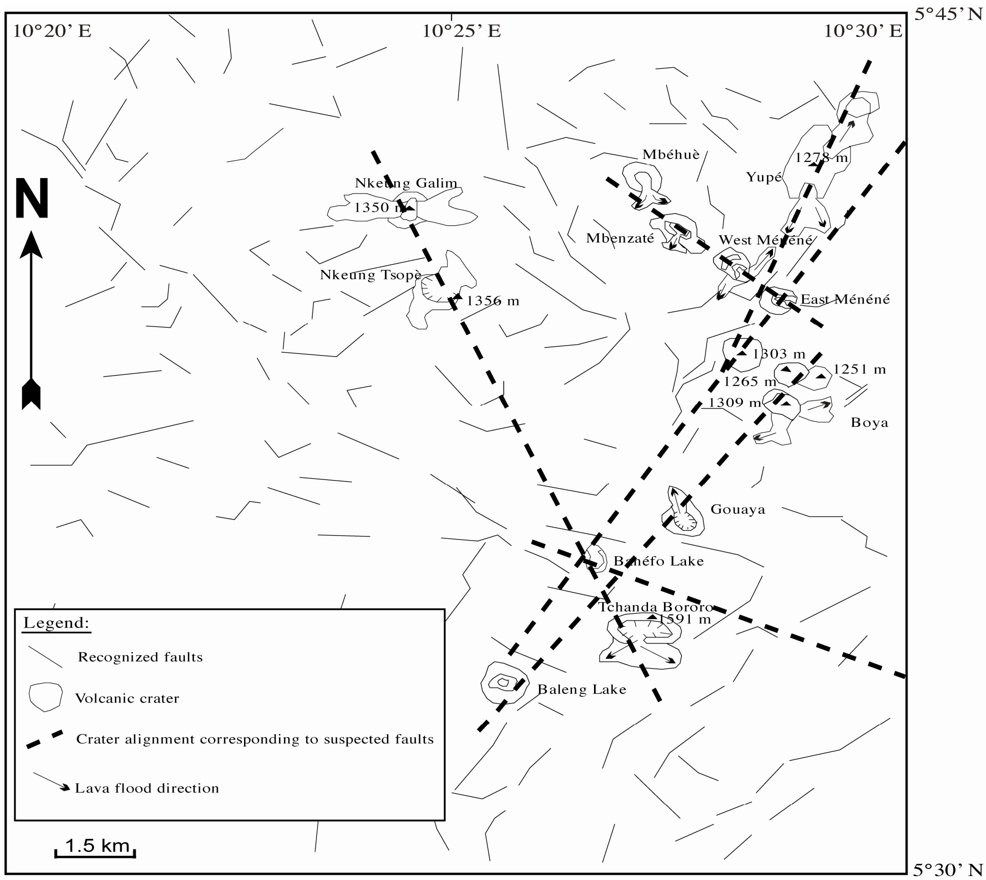

Fig. 2. Volcanotectonic map of the western side of Noun

to 1.70 Ma and in recent times (0.40 Ma), that built monogenetic volcanoes, today well conserved as exemplified by the Tchanda Bororo volcano.

More generally, lavas of the Bamileke and Bamoun plateaus show a great range of ages. Three important periods of volcanism are evidenced: (1) 51.8–38 Ma (Tchoua 1974; Moundi 2004; Moundi et al. 2007; Wandji et al. 2008); (2) 15–10 Ma (Youmen 1994; Wotchoko et al. 2005); (3) 7–4 Ma (Nana 1988; Wotchoko et al. 2005). The ages of 10.43 Ma and 4.59 Ma (Itiga et al. 2004; Wotchoko 2005) as well as a new age of 4.15 Ma obtained in the Noun Plain, correspond to period 2 and period 3. These ages concern the volcanism located at the boundary between the Bamileke plateau and the west side of Noun. Moreover, we have evidenced a more recent volcanism in the centre of the Noun Plain.

Petrography and mineralogy

The lavas

Three petrographic types of mafic lavas are identified according to geochemical data: picrites, alkali basalts and hawaiites (Table 2).

Picrites (Y11, BS2) have a porphyritic microlitic dominant texture and sometimes present a fluidality. Their homogeneous mineralogical composition includes: olivine, clinopyroxene, plagioclase and Fe-Ti oxides as

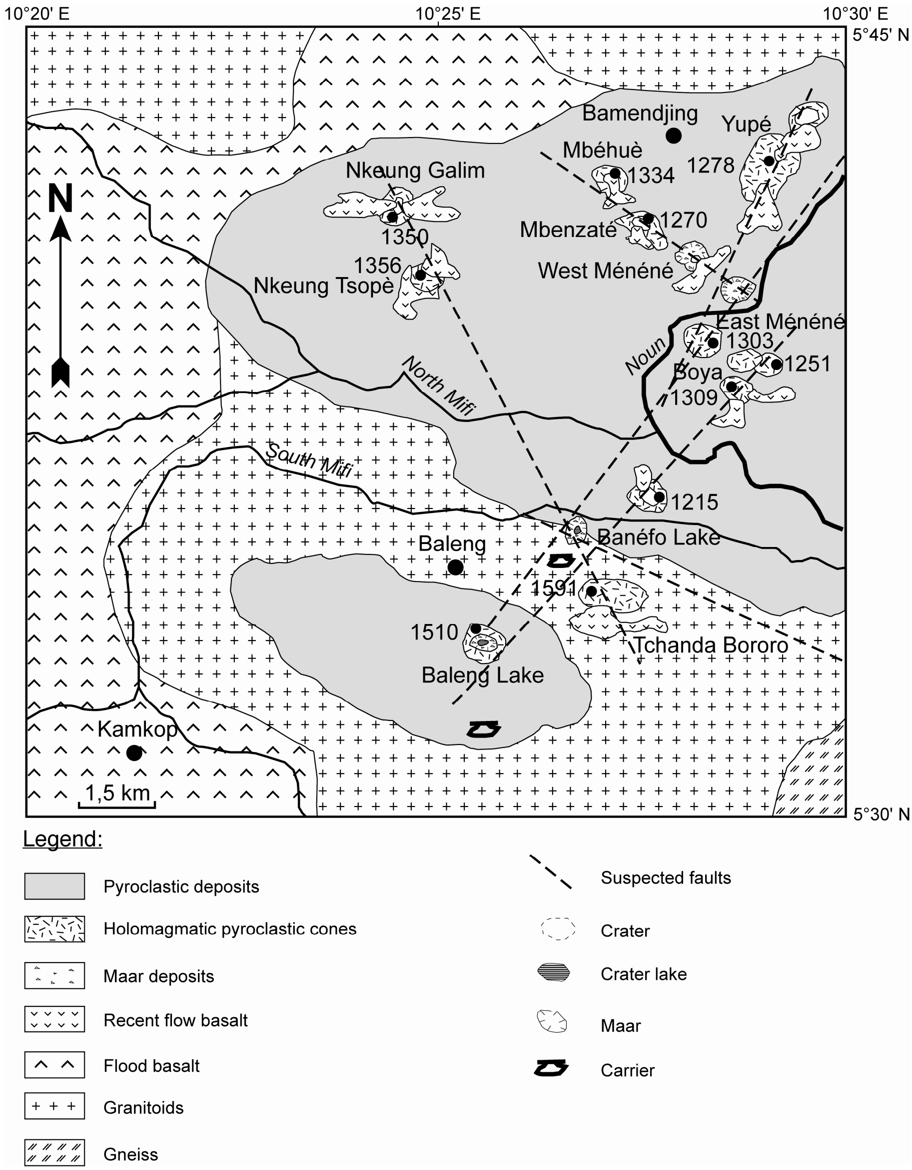

Fig. 3. Geological map of the western side of Noun

phenocrysts (nearly 20 vol.%) as well as microcrysts (75 vol.%). Nepheline microcrysts exist in the microcrystalline phase with less than 4 vol.% of glass.

Alkali basalts (T10, BK5) have a porphyritic microlitic to subdoleritic texture, and homogeneous mineralogical composition of olivine, clinopyroxene, plagioclase, Fe-Ti oxides and rare apatite. Olivine, clinopyroxene and plagioclase phenocrysts account for 20 to 50 vol.% of the rock. The groundmass, that is made up of same minerals that the phenocrysts, constitutes a significant fraction and represents on average 65 vol.% of the rock. The glass

Table 1. *K-Ar ages of basalts from the western side of Noun*

Rock	Location	Petrographic types	Volcanic style	Weight (g)	^{36}Ar Exp (10^{-9} cm^3)	$^{40}Ar^*$ (%)	$^{40}Ar^*/g$ (10^{-7} cm^3)	K_2O (wt.%)	Age (Ma)
BK5	Baleng (around Mifi river)	alkali basalt	fissural	1.20	1.82	47.6	4.06	1.20	10.43± 0.28
Y11	Bamendjing (Yupé volcano)	picrite	fissural	3.01	1.82	49.5	1.75	1.18	4.59± 0.12
BK3	Baleng (Kamkop)	alkali basalt	fissural	1.01	0.78	45.3	1.89	1.41	4.15± 0.11
D120	Galim (Mbéhuè)	alkali basalt	explosive	1.01	1.28	21.5	1.04	1.58	2.04± 0.20
BO1	Boya	alkali basalt	explosive	1.00	1.44	18.3	9.48	1.73	1.70± 0.19
T10	Baleng (Tchanda Bororo volcano)	alkali basalt	explosive	1.01	1.03	6.80	0.22	1.69	0.40± 0.10

fractions vary from 3 vol.% in BK5 to 53 vol.% in T10.

Hawaiites (MN8, D11) display a porphyritic microlitic texture, and show a rather homogeneous mineralogical composition of olivine, clinopyroxene, plagioclase, Fe-Ti oxides, and sometimes calcite and apatite. The groundmass represents nearly 60 vol.% of the modal volume of the rock and contains more clinopyroxene (nearly 20 vol.%) than other mineral species. The clear brown coloured glass is well represented (5–10 vol.%). These lavas contain many vacuoles which are generally filled by zeolites.

Mineralogy

Olivine of the series has a composition of chrysolite and hyalosiderite varying from Fo_{86} in phenocrysts of picrites to Fo_{67} in the microphenocrysts of hawaiites (Table 3). In all the petrographic types, there is a normal zoning, with a core more magnesian than the rim. In picrites, the forsterite content of phenocrysts varies from $Fo_{86–76}$ (core) to $Fo_{84–82}$ (rim). The microphenocrysts have forsterite content from Fo_{86} to Fo_{76}. In alkali basalts, this value decreases from $Fo_{84.5}$ to Fo_{67}. Phenocrysts have a varying content from Fo_{85} in the core to Fo_{77} in the rim. The microphenocrysts also show a decrease from Fo_{79} in the core to Fo_{67} in the rim with an intermediate part which could be more magnesian (Fo_{84}). In the hawaiites, there is a reduction in the rate of forsterite: it varies from Fo_{76} in phenocryst to Fo_{67} in the microcryst. Phenocrysts display only few varying contents: i.e. $Fo_{75.8}$ in the core and $Fo_{75.5}$ in the rim. NiO contents vary between 0 and 1.7 wt.% in all lavas. In the picrites, these values rise up to 1.7 wt.% in phenocrysts and up to 0.6 wt.% in the microphenocrysts. In alkali basalts, NiO contents in phenocrysts decrease from core (0.43 wt.%) to rim (0.27 wt.%). In the microphenocrysts, NiO contents are only between 0.21 wt.% and 0.09 wt.%. In the same way, we note in the hawaiites a decrease from core (0.16 wt.%) to rim (0.11 wt.%) of phenocrysts.

Table 2. *Modal analyses of some lavas from the Galim, Bamendjing and Baleng areas (western side of Noun). (Ol) olivine; (Cpx) clinopyroxene; (Opx) orthopyroxene; (Pl) plagioclase; (Ox) oxide; (Ne) nepheline; (Qtz) quartz; (Ca) calcite; (F) flow; (T) tephra*

Rock		Picrite				Alkali basalt							Hawaiite								
Sample		Y11	BS2	Y1	B11	M8	TA1	T10	BK5	BO6	BL2	N2	BO1	MN8	D11	D2X	KPM	NM5	NB1	M12
Type		F	F	F	F	F	F	F	F	F	F	F	F	F	F	T	T	T	F	F
Phenocrysts	Ol	15.7	25.5	8.4	10.2	12.5	8.3	5.0	37.6	24.0	4.5	12.2	12.0	13.0	14.2	0.9	10.5	20.6	18.7	10.0
	Cpx	8.3	10.8	8.8	6.4	7.0	3.6	12.0	11.3	-	3.3	3.2	36.1	1.0	16.8	27.5	37.4	30.6	25.5	19.0
	Pl	-	-	2.6	1.2	-	37	-	-	-	-	-	0.5	17.0	-	2.0	-	-	-	-
	Ox	0.4	-	1.0	2.0	-	5.4	1.0	1.1	-	-	-	1.1	2.0	0.4	1.0	1.0	-	-	0.2
	Total	24.4	36.3	20.8	19.8	19.5	54.3	18.0	50.0	24.0	7.8	15.4	49.7	33.0	31.4	31.4	48.9	51.2	44.2	29.2
Groundmass	Ol	14.4	14.2	15.4	11.2	17.5	3.2	3.0	16.8	16.0	30.8	26.9	7.1	8.0	6.0	1.0	3.5	8.2	1.0	15.0
	Cpx	12.1	8.8	11.8	5.3	26.5	1.1	6.0	8.3	3.0	20.1	15.3	21.2	7.0	17.6	30.0	28.1	20.2	31.4	23.5
	Pl	20.6	20.9	32.6	42.5	30.0	18.0	3.7	13.1	29.5	17.2	17.3	16.5	40.0	31.8	11.5	2.0	2.0	2.0	21.3
	Ox	22.4	15.3	14.1	17.7	3.0	23.4	10.5	9.3	26.5	21.1	15.5	3.3	12.0	7.0	13.5	12.0	15.0	17.3	5.0
	Ne	2.0	1.5	1.1	Tr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	glass	1.2	3.0	4.2	3.5	3.5	-	52.6	2.5	1.0	2.0	9.6	2.2	-	6.2	11.2	5.5	3.4	2.8	6.0
	Total	72.7	63.7	79.2	80.2	80.5	45.7	75.8	50.0	76.0	91.2	84.6	50.3	67.0	68.6	67.2	51.1	48.8	54.5	70.8
Xenocrysts	Opx	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-
	Pl	-	-	-	-	-	-	2	-	-	-	-	-	-	-	0.1	-	-	-	-
	Qtz	1.4	-	-	-	-	-	4.2	-	-	1	-	-	-	-	1.2	-	-	-	-
	Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	-
Vacuole		4.0	2.0	-	1.0	2.5	-	9.2	-	-	-	3.0	2.0	-	1.7	-	5.0	7.0	-	-

Table 3. *Chemical analyses of olivine in wt.%, c - core, m - middle, r - rim. Analyses in brackets belong to one and the same grain*

Rock	Picrite						Alkali basalt							
Sample	Y11	Y11	Y11	Y11	Y11	BS2	T10	T10	T10	T10	T10	BK5	BK5	BK5
Analysis	1c	2c	4r	6r	7	10	14c	15m	22r	26	27c	33	34	38c
SiO_2	38.07	40.10	39.71	39.46	38.69	37.24	39.72	39.41	39.91	39.50	40.57	39.63	38.93	39.38
TiO_2	0.00	0.03	0.06	0.01	0.08	0.04	0.00	0.04	0.06	0.01	0.05	0.00	0.00	0.00
FeO	19.94	13.60	15.82	16.15	17.68	22.13	14.70	15.26	18.22	17.03	15.40	15.90	16.28	15.71
MnO	0.22	0.31	0.08	0.46	0.48	0.51	0.10	0.41	0.25	0.25	0.25	0.02	0.45	0.32
MgO	41.23	46.44	45.38	43.43	42.93	38.30	44.95	44.57	39.91	42.30	44.10	43.78	43.54	43.42
NiO	0.58	0.43	0.43	1.59	0.00	0.00	0.43	0.35	0.18	0.20	0.16	0.25	0.09	0.21
CaO	0.15	0.19	0.32	0.32	0.44	0.28	0.28	0.24	0.38	0.38	0.38	0.30	0.21	0.32
Total	100.19	101.10	101.80	101.42	100.30	98.50	100.18	100.28	98.91	99.67	100.91	99.88	99.50	99.36
Formulae based on 4 oxygens														
Si	0.98	0.99	0.98	0.99	0.98	0.98	1.00	0.99	1.04	1.01	1.01	1.00	0.99	1.00
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.43	0.28	0.33	0.34	0.37	0.49	0.31	0.32	0.40	0.36	0.32	0.34	0.35	0.33
Mn	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01
Mg	1.58	1.71	1.67	1.62	1.62	1.51	1.68	1.67	1.55	1.61	1.64	1.65	1.65	1.65
Ni	0.01	0.01	0.01	0.03	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Ca	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fo (%)	78.65	85.89	83.63	82.73	81.23	75.51	84.49	83.88	79.60	81.57	83.61	83.07	82.66	83.13
Rock	Alkali basalt									Hawaiite				
Sample	BK3	BK3	BK3	BK3	BK3	BK3	BK3	BK3	BK3	MN8	MN8	P1B	P1B	P1B
Analysis	(39c	40r)	(41r	42c)	(43c	44r)	(45c	46m	47r)	50	52	57	(58c	59r)
SiO_2	37.21	37.37	37.35	36.55	36.81	36.80	37.58	37.59	37.14	37.24	37.09	37.12	38.02	37.88
TiO_2	0.05	0.00	0.11	0.06	0.02	0.07	0.08	0.04	0.06	0.19	0.17	0.08	0.04	0.00
FeO	27.68	29.12	28.53	29.30	29.32	29.47	25.28	26.48	28.16	28.58	27.39	27.49	22.01	22.18
MnO	0.81	0.64	0.64	0.71	0.62	0.71	0.50	0.54	0.47	0.32	0.61	0.90	0.24	0.27
MgO	33.93	34.33	32.32	32.95	33.52	33.19	35.69	35.18	34.45	34.73	34.32	33.65	38.78	38.35
NiO	0.07	0.04	0.01	0.01	0.12	0.08	0.10	0.11	0.00	0.03	0.21	0.03	0.16	0.11
CaO	0.36	0.37	0.41	0.43	0.33	0.38	0.31	0.31	0.41	0.45	0.41	0.38	0.12	0.28
Total	100.11	101.87	99.37	100.01	100.74	100.70	99.54	100.25	100.69	101.54	100.20	99.65	99.37	99.07
Formulae based on 4 oxygens														
Si	1.00	0.98	1.01	0.99	0.98	0.99	1.00	1.00	0.99	0.98	0.99	1.00	0.99	1.00
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.62	0.64	0.65	0.66	0.66	0.66	0.56	0.59	0.63	0.63	0.61	0.62	0.48	0.49
Mn	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Mg	1.35	1.35	1.31	1.32	1.33	1.32	1.41	1.39	1.36	1.36	1.37	1.35	1.51	1.50
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Fo (%)	68.60	67.75	66.87	66.71	67.08	66.74	71.56	70.30	68.56	68.41	69.07	68.57	75.85	75.50

Most clinopyroxenes (Table 4) are zoned; their compositions vary slightly in the different rocks that is to say between diopside and augite (Fig. 4). In the picrites (Fig. 4a), the clinopyroxene compositions display a rather large composition range. Some of them are characterized by SiO_2 impoverishment (42 to 47 wt.%), but TiO_2 (up to 4.4 wt.%), Al_2O_3 (up to 10 wt.%) and CaO (up to 23 wt.%) enrichments. Moreover, these enrichments are witnessed by the green colour of the core of the crystals. Their compositions ($Wo_{52–50.2}En_{39–35}Fs_{13–11}$) are close to those ($Wo_{51.9–50.3}En_{36.8–32.5}Fs_{16.4–12.5}$) of some ankaramites of the eastern side of Noun (Wandji et al. 2000). The $Mg^{\#}$ values are lower (0.78) than in other diopsides and augites (0.85). In the alkali basalts (Fig. 4b), the clinopyroxenes have typical diopsidic compositions ($Wo_{48}En_{39}Fs_{13}$). These clinopyroxenes resemble those of alkali

Table 4. *Chemical analyses of clinopyroxene in wt.%*

Rock	Picrite							Alkali basalt					Hawaiite					
sample	Y11	Y11	Y11	BS2	BS2	BS2	BS2	T10	T10	T10	T10	T10	P1B	P1B	P1B	P1B	P1B	P1B
SiO_2	49.40	48.52	45.62	48.73	42.61	46.71	42.98	45.31	44.32	48.22	42.79	49.59	48.33	48.15	48.86	50.31	48.25	47.45
TiO_2	1.36	1.36	3.00	1.46	4.43	3.05	4.22	2.29	2.75	1.62	3.01	1.11	1.71	2.17	1.04	0.31	1.47	1.41
Al_2O_3	4.81	5.43	7.67	6.14	9.00	5.40	9.93	8.25	9.27	5.79	9.77	4.72	4.76	4.68	6.61	2.96	6.76	7.57
Cr_2O_3	0.19	0.10	0.00	0.20	0.00	0.14	0.10	0.04	0.24	0.06	0.00	0.00	0.38	0.00	0.63	0.00	0.51	0.25
ZrO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeOt	5.66	6.16	7.42	5.61	7.41	7.31	7.21	8.50	8.21	8.18	8.53	6.80	7.33	8.33	5.28	13.57	6.88	6.76
MnO	0.00	0.00	0.00	0.19	0.00	0.13	0.07	0.13	0.13	0.14	0.12	0.13	0.00	0.19	0.03	0.18	0.16	0.22
MgO	14.39	14.72	11.95	14.52	10.93	13.38	10.70	11.79	11.62	13.30	10.99	14.25	13.28	13.27	15.33	10.83	13.05	12.81
ZnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	22.68	20.25	22.31	21.70	22.85	22.04	21.89	22.22	21.93	21.43	22.15	21.91	22.67	21.93	20.28	20.21	21.29	22.09
Na_2O	0.38	0.65	0.46	0.70	0.56	0.38	0.66	0.59	0.73	0.47	0.63	0.58	0.65	0.73	0.86	0.70	0.52	0.55
K_2O	0.02	0.96	0.00	0.00	0.00	0.00	0.02	0.96	0.96	0.96	0.96	0.96	0.04	0.03	0.96	0.96	0.02	0.03
Total	98.89	98.15	98.43	99.25	97.79	98.54	97.78	100.08	100.16	100.17	98.95	100.05	99.15	99.48	99.88	100.03	98.91	99.14
Formulae based on 6 oxygens																		
Si	1.84	1.81	1.73	1.80	1.63	1.76	1.64	1.68	1.64	1.78	1.61	1.82	1.81	1.80	1.78	1.90	1.81	1.77
Al^{IV}	0.16	0.19	0.27	0.20	0.37	0.24	0.36	0.32	0.36	0.22	0.39	0.18	0.19	0.20	0.22	0.10	0.19	0.23
T	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Ti	0.04	0.04	0.09	0.04	0.13	0.09	0.12	0.06	0.08	0.05	0.09	0.03	0.05	0.06	0.03	0.01	0.04	0.04
Al^{VI}	0.05	0.05	0.07	0.07	0.03	0.00	0.09	0.04	0.05	0.04	0.04	0.03	0.02	0.00	0.06	0.03	0.10	0.10
Cr	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.01
Zr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fet	0.18	0.19	0.23	0.17	0.24	0.23	0.23	0.26	0.25	0.25	0.27	0.21	0.23	0.26	0.16	0.43	0.22	0.21
Mn	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01
Mg	0.80	0.82	0.67	0.80	0.62	0.75	0.61	0.65	0.64	0.73	0.62	0.78	0.74	0.74	0.83	0.61	0.73	0.71
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.90	0.81	0.90	0.86	0.94	0.89	0.90	0.88	0.87	0.85	0.89	0.86	0.91	0.88	0.79	0.82	0.85	0.88
Na	0.03	0.05	0.03	0.05	0.04	0.03	0.05	0.04	0.05	0.03	0.05	0.04	0.05	0.05	0.06	0.05	0.04	0.04
K	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.04	0.00	0.00	0.04	0.05	0.00	0.00
M1+M2	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Charges cat.	11.94	11.84	11.93	11.90	11.88	11.92	11.93	11.77	11.75	11.83	11.73	11.82	11.88	11.87	11.81	11.85	11.97	11.92
Fe^{3+}	0.06	0.16	0.07	0.10	0.12	0.08	0.07	0.23	0.25	0.17	0.27	0.18	0.12	0.13	0.16	0.15	0.03	0.08
Fe^{2+}	0.12	0.04	0.17	0.08	0.12	0.15	0.16	0.03	0.01	0.08	0.00	0.03	0.11	0.13	0.00	0.28	0.18	0.13
FeO*	3.82	1.13	5.25	2.49	3.60	4.63	4.88	0.96	0.22	2.73	0.00	1.09	3.50	4.14	0.00	8.89	5.84	4.06
Fe_2O_3*	2.03	5.59	2.41	3.47	4.24	2.97	2.59	8.37	8.89	6.06	9.48	6.34	4.25	4.66	5.87	5.20	1.15	3.00
Total*	99.08	98.71	98.67	99.58	98.21	98.84	98.04	100.92	101.05	100.77	99.89	100.67	99.58	99.94	100.47	100.55	99.04	99.42
Mg/Mg+Fet	0.82	0.81	0.74	0.82	0.72	0.77	0.73	0.71	0.72	0.74	0.70	0.79	0.76	0.74	0.84	0.59	0.77	0.77

Table 4. (continuation)

Rock sample	Picrite							Alkali basalt					Hawaiite					
	Y11	Y11	Y11	BS2	BS2	BS2	BS2	T10	T10	T10	T10	T10	P1B	P1B	P1B	P1B	P1B	P1B
ac: $NaFeSi_2O_6$	0.03	0.05	0.03	0.05	0.04	0.03	0.05	0.04	0.05	0.03	0.05	0.04	0.05	0.05	0.06	0.05	0.03	0.04
$CaFeAlSiO_6$	0.03	0.11	0.03	0.05	0.08	0.06	0.03	0.19	0.20	0.14	0.22	0.13	0.07	0.08	0.10	0.10	0.00	0.04
$CaCrAlSiO_6$	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.01
$CaTiAlAlO_6$	0.04	0.04	0.09	0.04	0.13	0.09	0.12	0.06	0.08	0.05	0.09	0.03	0.05	0.06	0.03	0.00	0.04	0.04
$CaAlAlSiO_6$	0.05	0.00	0.07	0.07	0.03	0.00	0.09	0.00	0.00	-0.01	0.00	-0.02	0.01	0.00	0.05	0.00	0.10	0.10
Wo $Ca2Si_2O_6$	0.39	0.33	0.36	0.35	0.35	0.37	0.33	0.31	0.29	0.34	0.29	0.36	0.38	0.37	0.30	0.36	0.35	0.35
En $Mg_2Si_2O_6$	0.40	0.41	0.34	0.40	0.31	0.38	0.30	0.33	0.32	0.37	0.31	0.39	0.37	0.37	0.42	0.30	0.36	0.36
Fe $Fe_2Si_2O_6$	0.06	0.02	0.08	0.04	0.06	0.08	0.08	0.02	0.01	0.04	0.00	0.02	0.05	0.07	0.00	0.14	0.09	0.07
Components total	1.00	0.95	1.00	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.96	1.00	1.00	0.97	0.96	1.00	1.00
Wollastonite	0.46	0.43	0.46	0.44	0.48	0.45	0.46	0.48	0.47	0.45	0.49	0.47	0.47	0.46	0.42	0.45	0.43	0.45
Enstatite	0.47	0.54	0.43	0.51	0.44	0.46	0.43	0.50	0.52	0.49	0.51	0.51	0.46	0.46	0.58	0.38	0.45	0.46
Aegyrine	0.06	0.10	0.07	0.10	0.10	0.06	0.11	0.11	0.14	0.08	0.13	0.09	0.10	0.11	0.13	0.10	0.07	0.09
Ferrosilite	0.12	0.04	0.18	0.08	0.14	0.16	0.18	0.04	0.01	0.10	0.01	0.04	0.12	0.14	0.00	0.29	0.19	0.14
$Q=Ca+Mg+Fe^{2+}$	1.821	1.66	1.744	1.735	1.67	1.789	1.66	1.57	1.52	1.67	1.51	1.68	1.76	1.74	1.62	1.71	1.76	1.72
J=2Na	0.05	0.09	0.07	0.10	0.08	0.06	0.10	0.08	0.10	0.06	0.10	0.08	0.09	0.11	0.12	0.10	0.08	0.08
"Wo"	47.88	45.50	49.86	46.91	52.12	47.55	51.64	48.89	49.15	46.20	50.00	46.49	48.40	46.56	44.16	44.08	47.49	48.86
"En"	42.55	44.05	37.17	43.64	34.69	40.13	35.10	36.11	36.16	39.67	34.83	42.16	39.39	39.15	46.40	32.80	40.54	39.45
"Fs"	9.57	10.45	12.97	9.45	13.19	12.32	13.26	15.00	14.69	14.13	15.17	11.35	12.21	14.29	9.44	23.12	11.97	11.69

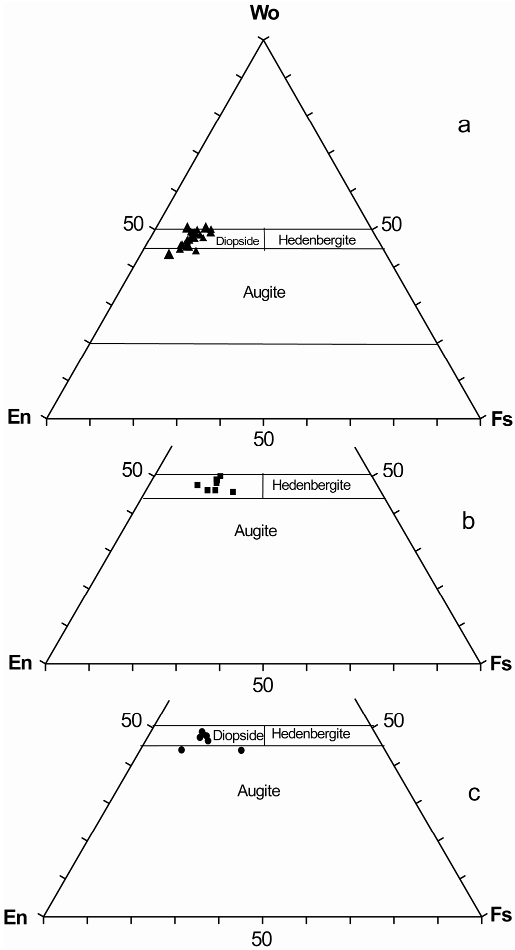

Fig. 4. Wo–En–Fs clinopyroxene diagrams of the lavas from the western side of Noun: (a) picrites; (b) alkali basalts; (c) hawaiites

basalts ($Wo_{50}En_{34}$ Fs_{14}) of the eastern side of Noun (Wandji 1995). In the hawaiites (Fig. 4c), the clinopyroxene phenocrysts ($Wo_{49–44}En_{39–33}Fs_{12–23}$) are Ti-, Ca- and Fe- richer than the microcrysts ($Wo_{48–46}En_{39}Fs_{14–12}$).

Plagioclases (Table 5) are present in all lavas. However, this mineral phase exists mainly in the hawaiites where it confers to the rock an intergranular or glomeroporphyric texture. Plagioclases have compositions from labradorite to andesine ($An_{69–34}$). In the picrites, the anorthite contents vary from An_{66} to An_{44}. The phenocryst cores are more basic than those of alkali basalts. Most phenocrysts of hawaiites show a normal zoning, but sometimes a slight oscillatory zoning too. We observed a decrease of anorthite content from the core (An_{69}) to the rim (An_{60}). This diminution reflects the equilibrium with a residual liquid during the growing stage when the lava is cooling. Diminution in anorthite content is accompanied by a light enrichment in orthoclase component from labradorite ($An_{69}Or_1$) to potassic andesine ($An_{45}Or_{10}$). As a comparison, these values are higher than those of alkali basalts ($An_{56–48}$) of the eastern side of Noun (Wandji 1995). In the hawaiites, the anorthite contents mostly decrease from An_{60} to An_{38}. These values, moderately low, are linked to the slight degree of differentiation of these lavas. The BaO contents vary from one lava to another: 0.12 to 0.6 wt.% in the picrites, 0 to 0.33 wt.% in alkali basalts and 0 to 0.24 wt.% in hawaiites. The Sr contents are also very low and the highest contents are found in the picrites (0.90 wt.% SrO). It is significant to note that the contents of Fe^{3+} are rather important as they vary between 0.2 and 1.3 wt.% and are thus more easily incorporated in the structure of plagioclase while Mg^{2+} exists only in traces. Al^{IV} occupies the tetrahedral sites, but its amount is insufficient to fill them completely. The incorporation of Fe^{3+} will complete the deficit of Al^{IV} ($Si + Al^{IV} < 4$) in the tetrahedral site. The Fe^{3+} in the crystalline pattern of feldspars would be in relation to the speed of lava cooling (Bottinga et al. 1966; Brown & Carmichael 1971). However, in some alkali basalts and hawaiites, the representative points of plagioclases are plotted on the $Si + Al^{IV} = 4$ line representing the saturation of the tetrahedral site. The plagioclase – liquid geothermometer of Kudo and Weill (1970) gives temperatures 1077 to 1178°C for the picrites, 1120 to 1189°C for the alkali basalts and 1168 to 1202°C for the hawaiites for a water pressure of 1 kbar.

Fe–Ti oxides (Table 6) are present during the crystallization either as inclusions in

Table 5. *Chemical analyses of plagioclase in wt.%, c - core, m - middle, r - rim. Analyses in brackets belong to one and the same grain*

Rock	Picrite					Alkali basalt							Hawaiite										
Sample	BS2	BS2	BS2	BS2	BS2	T10	T10	T10	BK3	BK3	BK5	BK5	MN8	MN8	MN8	MN8	MN8	MN8	MN8	P1B	P1B	P1B	P1B
Anal-ysis	13c	14r	16c	17	19	20	42	50	48	51	30	31	(9r	10m	11c)	1c	(4c	5r)	6c	26	27	28	29
SiO_2	51.04	50.86	50.70	50.65	50.78	54.12	52.57	54.76	54.04	54.42	52.87	51.77	52.77	52.41	50.31	53.22	53.62	55.46	52.45	56.34	53.46	54.72	52.68
Al_2O_3	31.07	30.42	30.35	29.92	31.21	27.82	29.59	27.97	28.58	28.34	30.01	29.84	28.84	28.77	30.50	28.47	29.66	27.00	28.32	26.56	29.31	28.45	28.61
FeOt	0.64	0.46	0.44	0.70	0.51	0.97	1.05	1.10	0.28	0.62	0.43	0.75	0.53	0.39	0.24	0.94	0.60	1.29	0.78	0.59	0.19	0.81	0.56
CaO	12.93	12.54	12.86	11.95	13.61	9.80	12.62	10.85	11.18	11.06	11.38	12.47	12.09	12.21	13.85	10.41	10.61	9.64	10.97	7.88	11.23	10.27	11.65
Na_2O	3.93	4.01	3.66	4.21	3.66	5.27	4.46	5.52	4.97	5.13	4.45	3.99	4.30	4.43	3.25	4.90	4.78	5.34	4.44	6.70	4.75	5.24	4.20
K_2O	0.27	0.28	0.31	0.33	0.22	1.85	0.42	0.50	0.41	0.41	0.26	0.24	0.11	0.13	0.21	0.51	0.36	1.10	1.12	0.61	0.32	0.41	0.26
SrO	0.59	0.65	0.38	0.66	0.55	0.25	0.23	0.02	0.00	0.00	0.75	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.19	0.38	0.38
BaO	0.06	0.07	0.25	0.12	0.34	0.11	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.02	0.23
Total	100.53	99.29	98.95	98.54	100.88	100.19	100.94	100.72	99.46	99.98	100.23	99.59	98.64	98.34	98.36	98.45	99.63	99.83	98.08	99.01	99.45	100.3	98.57
Formulae based on 8 oxygens																							
A	2.73	2.76	2.77	2.79	2.73	2.74	2.72	2.71	2.73	2.72	2.72	2.75	2.76	2.77	2.78	2.76	2.72	2.72	2.78	2.73	2.73	2.71	2.77
Si	2.32	2.34	2.34	2.35	2.31	2.47	2.38	2.47	2.46	2.46	2.40	2.37	2.42	2.41	2.33	2.44	2.43	2.51	2.43	2.56	2.43	2.47	2.43
Al	1.66	1.65	1.65	1.63	1.67	1.49	1.58	1.48	1.53	1.51	1.60	1.61	1.56	1.56	1.66	1.54	1.58	1.44	1.55	1.42	1.57	1.51	1.55
Fe^{3+}	0.02	0.02	0.02	0.03	0.02	0.04	0.04	0.04	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.04	0.02	0.05	0.03	0.02	0.01	0.03	0.02
Ca	0.63	0.62	0.64	0.59	0.66	0.48	0.61	0.52	0.54	0.54	0.55	0.61	0.59	0.60	0.69	0.51	0.51	0.47	0.54	0.38	0.55	0.50	0.57
Na	0.35	0.36	0.33	0.38	0.32	0.47	0.39	0.48	0.44	0.45	0.39	0.35	0.38	0.40	0.29	0.44	0.42	0.47	0.40	0.59	0.42	0.46	0.37
K	0.02	0.02	0.02	0.02	0.01	0.11	0.02	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.02	0.06	0.07	0.04	0.02	0.02	0.02
Sr	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Ba	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.02	5.01	5.00	5.02	5.02	5.06	5.02	5.03	5.00	5.01	5.00	5.00	4.98	5.00	4.99	5.00	4.99	5.01	5.01	5.03	5.00	5.00	4.98
Or	1.60	1.64	1.87	1.97	1.28	10.21	2.35	2.80	2.34	2.35	1.59	1.45	0.66	0.74	1.24	3.03	2.15	6.34	6.58	3.52	1.89	2.38	1.60
Ab	34.94	36.03	33.39	38.17	32.32	44.28	38.08	46.58	43.56	44.56	40.77	36.12	38.89	39.34	29.45	44.62	43.95	46.91	39.47	58.49	42.52	46.88	38.84
An	63.46	62.33	64.74	59.86	66.40	45.51	59.57	50.62	54.10	53.09	57.64	62.43	60.45	59.92	69.31	52.35	53.90	46.75	53.95	37.99	55.59	50.74	59.56

Table 6. *Chemical analyses of Fe-Ti oxides in wt.%*

Rock	Picrite				Alkali basalt		Hawaiite				
Sample	Y11	Y11	BS2	BS2	T10	T10	MN8	MN8	MN8	P1B	P1B
SiO_2	1.14	0.14	0.10	0.06	0.07	0.20	0.78	0.07	0.05	0.15	0.50
TiO_2	18.49	1.09	26.71	27.17	20.98	21.70	24.55	24.73	25.77	21.93	24.95
Al_2O_3	7.11	26.75	2.60	3.71	4.33	3.93	1.46	1.50	1.52	0.81	2.85
Cr_2O_3	3.40	28.31	0.49	0.64	1.72	0.35	0.00	0.21	0.10	0.33	0.21
FeOt	60.85	26.97	60.98	61.37	63.94	65.46	63.87	65.75	65.69	67.85	63.60
MnO	0.55	0.23	0.74	0.81	0.87	0.63	1.01	0.57	0.69	1.15	0.64
MgO	3.87	11.64	3.49	3.65	2.52	1.85	3.08	2.19	2.40	1.91	2.27
CaO	0.31	0.00	0.18	0.09	0.14	0.27	0.03	0.00	0.11	0.17	0.22
NiO	0.41	0.83	0.00	0.06	0.00	0.09	0.00	0.27	0.14	0.06	0.00
Total	96.13	95.96	95.29	97.56	94.57	94.48	94.78	95.29	96.47	94.36	95.24
Formulae based on 32 oxygens and 24 cations											
Si	0.33	0.03	0.03	0.02	0.02	0.06	0.23	0.02	0.01	0.05	0.15
Ti	3.98	0.21	5.98	5.91	4.71	4.91	5.55	5.61	5.77	5.03	5.62
Al	2.40	7.91	0.91	1.27	1.52	1.39	0.52	0.53	0.53	0.29	1.01
Cr	0.77	5.61	0.12	0.15	0.40	0.08	0.00	0.05	0.02	0.08	0.05
Fet	14.56	5.66	15.17	14.85	15.96	16.46	16.05	16.59	16.35	17.32	15.93
Mn	0.13	0.05	0.19	0.20	0.22	0.16	0.26	0.15	0.17	0.30	0.16
Mg	1.65	4.35	1.55	1.57	1.12	0.83	1.38	0.98	1.06	0.87	1.01
Ca	0.10	0.00	0.06	0.03	0.05	0.09	0.01	0.00	0.03	0.05	0.07
Ni	0.09	0.17	0.00	0.01	0.00	0.02	0.00	0.07	0.03	0.02	0.00
Fe^{3+}	4.23	1.99	2.96	2.73	4.61	4.59	3.92	4.15	3.88	5.47	3.40
Fe^{2+}	10.33	3.67	12.21	12.1	11.34	11.87	12.13	12.44	12.48	11.84	12.53
FeO*	43.18	17.48	49.08	50.07	45.45	47.19	48.28	49.29	50.12	46.40	50.01
Fe_2O_3*	19.64	10.55	13.22	12.56	20.55	20.30	17.33	18.29	17.30	23.83	15.10
Total*	98.09	97.01	96.62	98.82	96.63	96.50	96.52	97.12	98.20	96.72	96.75
$Mg/Mg+Fe^{2+}$	0.14	0.54	0.11	0.12	0.09	0.07	0.10	0.07	0.08	0.07	0.07
Cr/Cr+Al	0.24	0.41	0.11	0.10	0.21	0.06	0.00	0.09	0.04	0.21	0.05
F2	9.95	0.86	12.16	12.04	11.1	11.82	12.13	12.41	12.47	11.80	12.50
F3	3.96	1.90	2.59	2.34	4.17	4.27	3.40	3.86	3.53	4.88	3.08
MG	0.45	0.40	1.09	0.94	0.36	0.14	1.12	0.72	0.80	0.72	0.51
Chr	0.05	0.35	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Mg-Fe	0.06	0.05	0.14	0.12	0.04	0.02	0.14	0.09	0.10	0.09	0.06
Mag	0.25	0.06	0.03	0.03	0.22	0.25	0.13	0.15	0.12	0.22	0.16
Sp	0.15	0.49	0.06	0.08	0.10	0.09	0.03	0.03	0.03	0.02	0.06
Ul	0.50	0.03	0.75	0.74	0.59	0.61	0.69	0.70	0.72	0.63	0.70
Ja	0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.04	0.02
T	1.02	0.98	1.00	1.00	1.00	0.99	1.03	0.99	0.99	1.00	1.01
Chromite	0.05	0.36	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Mg-ferrite	0.06	0.05	0.14	0.12	0.05	0.02	0.14	0.09	0.10	0.09	0.06
Magnétite	0.24	0.06	0.03	0.03	0.22	0.25	0.13	0.15	0.12	0.22	0.16
Spinelle	0.15	0.50	0.06	0.08	0.10	0.09	0.03	0.03	0.03	0.02	0.06
Ulvospinelle	0.49	0.03	0.75	0.74	0.59	0.62	0.67	0.71	0.73	0.63	0.70
Jacobsite	0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.04	0.02

clinopyroxene and olivine phenocrysts, or as microphenocrysts or microcrystals in the groundmass. They are titanomagnetite containing 49 to 75 % of ulvöspinel (Fig. 5). Moreover, an aluminous (26.8 wt.% Al_2O_3) and chromian (28.3 wt.% Cr_2O_3) spinel is described in the picrites (Table 6). This could witness of two phases of crystallization for the oxides:

- the first phase corresponds to the Al–Cr spinel;
- the second phase corresponds to titanomagnetite, first as inclusions and later as microphenocrysts.

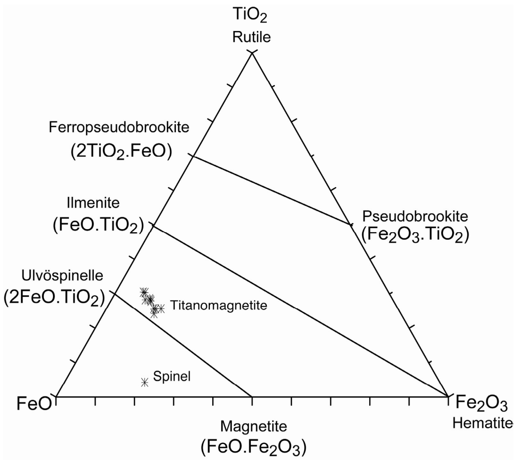

Fig. 5. FeO–Fe_2O_3–TiO_2 diagram for the lava from the western side of Noun

Geochemistry

Lavas from the western side of the Noun River show only a slight differentiation as their differentiation indexes (DI) (Thornton & Tuttle 1960) vary from 18.6 to 39.2 (Table 7). Rocks are picrites, alkali basalts and hawaiites (Fig. 6a). They globally define an alkaline trend mainly sodic, but sometimes potassic, with Na_2O/K_2O ratio between 1.8 and 3.2. They contain 0 to 15 wt.% of normative nepheline or 0.5 to 0.8 wt.% of normative hypersthene. The Mg# ratio normally decreases from the picrites (0.78) to the hawaiites (0.5). These lavas are ultrabasic (SiO_2 < 45 wt.%) or basic (45 wt.% < SiO_2 < 50 wt.%). Total $Na_2O + K_2O$ contents witness of a continuous evolution of the picrites to the hawaiites, the representative points of which plot in the field of alkaline series (according to Macdonald & Katsura 1964) (Fig. 6b).

The major elements variations versus DI present 3 tendencies (Fig. 7):

1) Some element contents increase from picrites to hawaiites:

- SiO_2 contents (41 to 46 wt.%) present a continuous increase from picrites to hawaiites;
- Al_2O_3 contents regularly increase from picrites (11.5 wt.%) to hawaiites (17.1 wt.%);
- Na_2O and K_2O increase gradually in the series. The highest contents are in hawaiites (up to 3.7 wt.% Na_2O and up to 1.9 wt.% K_2O).

2) Some element contents decrease from

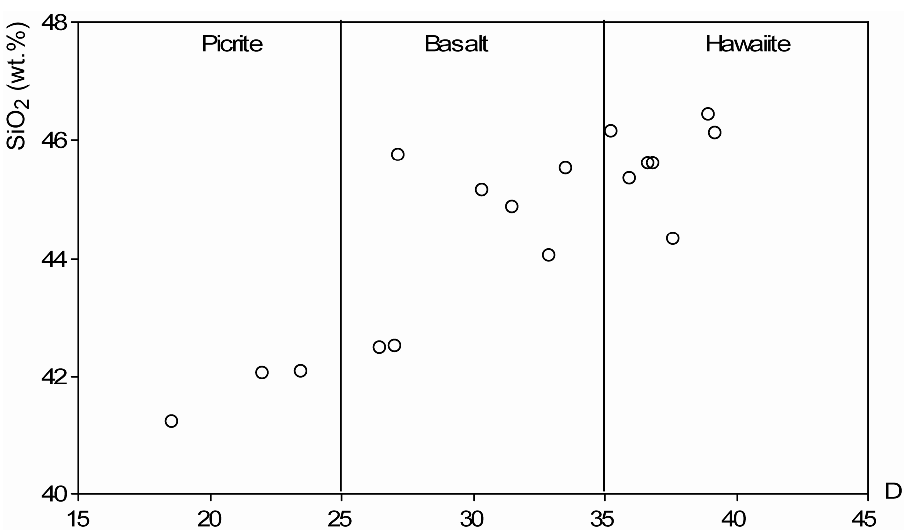

Fig. 6a. The lavas nomenclature from the western side of Noun (Thornton &Tuttle 1960)

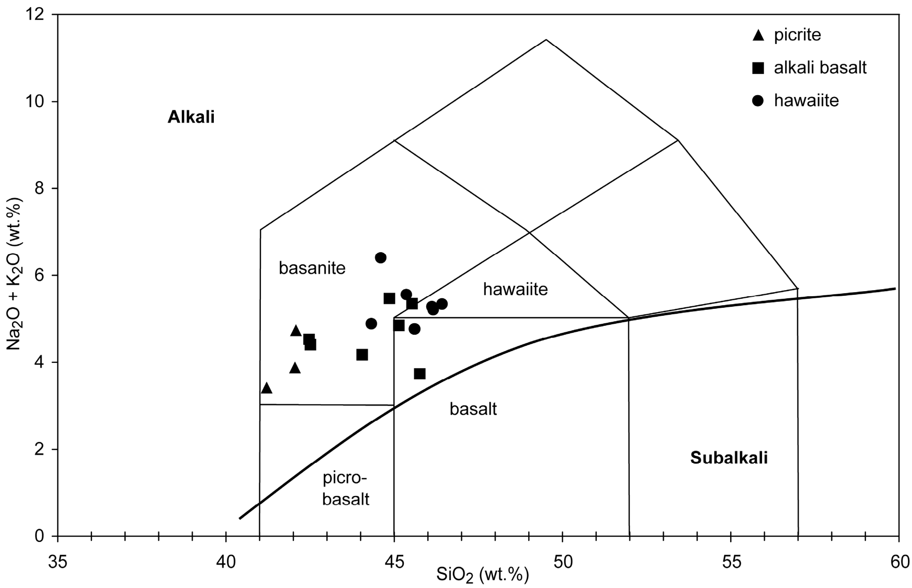

Fig. 6b. Plot of lavas from the western side of Noun in the total alkalis *vs.* silica (TAS) diagram of Le Bas et al. (1986). Alkali and subalkali fields according to Miyashiro (1978)

picrites to hawaiites: the CaO and MgO contents decrease in the series. In the picrites, these contents vary from 11.2 to 11.9 wt.% CaO and 11.5 to 13.8 wt.% MgO; in alkali basalts, from 8 to 12 wt.% CaO and 5.5 to 11.5 wt.% MgO; in the hawaiites, they evolve from 7.6 to 9.8 wt.% CaO and 5.2 to 6.7 wt.% MgO. This global evolution can be explained by the incorporation of the CaO during the fractionation of clinopyroxenes and MgO in the olivines, from picrites to the hawaiites. P_2O_5 contents show a slight decrease from the picrites to the hawaiites, in relation with the apatite fractionation.

3) Some element contents remain constant like MnO (average of 0.2 wt.%) or show a great dispersion like Fe_2O_3. This is related to the crystallization of some minerals such as Fe-Ti oxides which are present in variable proportions in the lavas.

Incompatible elements variations during differentiation process are related to their hygromagmatophile affinity. The diagrams in Fig. 8 indicate a positive correlation of some trace element contents (U, Nb, Yb, Hf, Ta, La, Zr, Y) with Th. U contents show some variations in picrites (0.9–2.1 ppm), alkali basalts (0.8–1.8 ppm) and hawaiites (1–1.6 ppm). Ba contents are relatively constant in the picrites (646 to 683 ppm). We note an increase (up to 1242 ppm) in the hawaiite NG1. Rb contents increase during differentiation, from 24 ppm in the picrites to 70 ppm in the hawaiites.

Variations of the compatible elements versus DI (Fig. 9) show negative correlations all along the magmatic differentiation. Sr contents decrease during the magmatic differentiation, from 1370 ppm in picrites to 700 ppm in alkali basalts and hawaiites. This decrease is related to the plagioclase fractionation. Ni and Cr contents in picrites are 260–360 ppm and 582–710 ppm respectively. These contents are relatively close to the typical values of the primary basaltic liquids resulting from the partial melting ($0 < PM < 30$ %) of the peridotitic mantle: 250 to 500 ppm for Ni (Allègre & Minster 1978; Villemant et

Table 7. *Representative analyses of lavas (CRPG-CNRS, Nancy, France) by ICP for major and minor elements and by ICP-MS for trace elements and rare earth elements. (DI) Differentiation Index (Thornton & Tuttle, 1960); ($Mg^{\#}$) $Mg/(Mg+Fe^{2+})$; (P) picrite; (B) basalt; (H) hawaiite*

Rock	BS2	Y11	Y1	BK5	B11	TA1	T10	BO6	D11	N2	NG1	P1B	G15	BL2	MN8	B1	BK4	W240
type	P	P	P	B	B	B	B	B	B	B	H	H	H	H	H	H	H	H
SiO_2	41.21	42.05	42.08	42.47	42.51	44.05	44.86	45.14	45.53	45.76	44.32	45.36	45.60	45.61	46.12	46.16	46.42	44.60
TiO_2	3.37	2.68	2.76	3.72	2.53	4.32	2.90	2.85	2.91	2.74	3.15	2.50	3.42	3.54	3.37	2.75	2.88	2.60
Al_2O_3	11.46	12.28	12.68	13.62	12.83	15.87	14.69	14.41	15.37	12.99	15.12	15.66	16.75	16.92	16.90	15.96	17.08	14.81
Fe_2O_3tot	13.32	12.95	13.06	12.49	13.21	15.21	13.28	12.45	12.16	13.03	15.87	12.08	13.91	13.64	13.40	12.17	12.92	12.52
MnO	0.18	0.21	0.20	0.19	0.22	0.19	0.20	0.19	0.17	0.17	0.20	0.22	0.19	0.18	0.17	0.21	0.25	0.20
MgO	13.77	12.35	11.46	9.75	11.01	5.55	8.56	8.50	6.63	10.02	5.18	6.68	5.14	5.10	5.10	5.88	4.58	7.50
CaO	11.20	11.91	11.69	10.89	12.24	8.04	10.21	10.57	10.65	10.34	7.86	9.40	7.90	7.89	7.62	9.79	8.43	9.73
Na_2O	2.36	2.70	3.33	3.09	3.35	2.99	3.81	3.37	3.75	2.72	3.12	3.86	3.17	3.21	3.55	3.36	3.69	4.44
K_2O	1.05	1.18	1.41	1.44	1.05	1.18	1.66	1.48	1.60	1.01	1.77	1.70	1.60	1.56	1.73	1.85	1.65	1.96
P_2O_5	0.86	0.71	0.77	0.85	0.90	0.54	0.57	0.71	0.76	0.62	1.61	0.64	0.59	0.60	0.59	0.64	0.71	0.61
LOI	1.57	1.26	0.61	1.41	0.49	2.02	-0.35	0.23	0.51	-0.05	1.84	2.07	1.71	1.73	1.42	1.65	1.34	-0.40
Total	100.35	100.28	100.05	99.92	100.34	99.96	100.39	99.90	100.04	99.35	100.04	100.17	99.98	99.98	99.97	100.42	99.95	99.57
$Mg^{\#}$	0.78	0.75	0.73	0.74	0.45	0.27	0.67	0.69	0.64	0.71	0.25	0.63	0.55	0.27	0.56	0.33	0.53	0.65
DI	18.58	22.00	23.48	27.07	27.07	32.92	31.50	30.38	33.52	27.17	37.6	35.95	36.65	36.86	39.19	35.25	38.93	36.90
Nepheline (CIPW)	9.34	11.97	15.34	10.30	14.22	0.00	12.07	8.23	9.25	2.33	0.00	8.94	0.27	0.17	1.92	5.42	3.06	14.45

Rock	BS2	Y11	Y1	BK5	B11	TA1	T10	BO6	D11	N2	NG1	P1B	G15	BL2	MN8	B1	BK4	W240
As	0.66	1.24	1.35	1.21	0.81	0.00	0.86	0.00	0.82	0.00	0.82	0.89	0.75	0.67	n.d.	0.99	0.82	n.d.
Ba	665	646	683	712	714	481	628	795	944	459	1242	529	662	552	730	496	545	693
Be	1.13	1.70	1.60	2.06	1.83	0.00	1.52	1.45	1.65	0.00	1.07	2.68	1.38	1.63	1.64	2.66	2.67	1.75
Cd	0.00	0.33	0.00	0.00	0.37	0.00	0.00	0.33	0.33	0.33	0.39	0.37	n.d.	n.d.	0.38	n.d.	0.33	n.d.
Ce	83.3	125.0	136.0	102.0	145.0	78.0	111.0	102.0	113.0	65.5	133.0	104.0	90.0	96.2	96.6	101.0	96.0	152.7
Co	70.5	59.9	56.8	59.7	55.7	53.7	50.8	43.1	40.3	52.7	41.8	36.9	41.6	39.1	41.1	37.3	33.4	39.6
Cr	582.0	710.0	627.0	337.0	459.0	12.4	204.0	282.0	180.0	456.0	70.0	160.0	6.2	n.d.	5.1	124.0	10.3	238.0
Cs	0.30	0.65	0.57	26.80	0.61	0.30	0.74	0.28	0.49	0.31	n.d.	0.41	n.d.	n.d.	0.51	0.56	0.20	n.d.
Cu	82.5	76.3	71.5	49.5	61.2	22.4	58.0	55.6	50.1	55.1	25.7	37.5	20.5	23.9	21.5	42.1	29.9	44.8
Dy	4.42	5.66	5.60	5.50	5.72	4.95	5.23	5.35	5.46	4.83	7.20	5.82	5.51	5.73	5.37	6.09	6.52	6.14
Er	1.90	2.31	2.45	2.53	2.51	2.19	2.24	2.19	2.35	1.99	2.94	2.78	2.61	2.59	2.63	2.99	3.06	2.70
Eu	2.95	3.11	3.46	3.25	3.67	3.03	2.91	3.12	3.49	2.56	5.03	2.82	2.84	3.01	2.89	3.04	3.08	3.42
Ga	17.4	19.0	20.0	20.9	20.3	21.9	21.1	21.4	23.6	20.4	23.4	24.6	23.1	22.1	23.0	24.7	24.5	21.3
Gd	7.36	7.75	8.38	8.53	9.01	6.37	7.38	7.73	7.93	6.33	11	7.34	7.66	7.90	7.62	8.24	9.03	9.10
Ge	1.19	1.50	1.43	1.40	1.43	1.41	1.44	1.31	1.16	1.50	1.47	1.59	1.30	1.20	1.29	1.22	1.27	n.d.

Table 7. (Continuation)

Rock	BS2	Y11	Y1	BK5	B11	TA1	T10	BO6	D11	N2	NG1	P1B	G15	BL2	MN8	B1	BK4	W240
Hf	3.67	5.36	5.46	5.93	4.91	4.81	4.89	4.75	5.12	3.91	5.46	6.67	5.96	6.26	5.87	6.80	6.50	n.d.
Ho	0.85	0.97	0.99	0.94	0.97	0.84	0.94	0.92	0.92	0.85	1.32	1.03	1.04	1.04	0.98	1.04	1.44	1.21
In	0.00	0.00	0.00	0.00	0.11	0.00	0.10	0.00	0.00	0.00	0.11	n.d.	n.d.	0.13	n.d.	0.12	0.11	n.d.
La	39.80	65.00	72.30	52.00	77.10	36.20	58.60	51.80	59.60	33.00	60.10	53.40	42.40	45.50	45.60	50.60	46.40	82.92
Lu	0.22	0.29	0.29	0.30	0.31	0.25	0.24	0.25	0.27	0.22	0.33	0.37	0.31	0.33	0.29	0.32	0.37	0.35
Mo	2.39	2.93	3.66	3.65	2.22	1.71	3.01	1.78	2.56	1.31	1.89	2.70	1.60	1.39	1.16	2.78	3.93	n.d.
Nb	46.8	88.3	98.6	70.1	88.2	48.0	79.7	67.7	73.9	41.7	50.1	69.5	50.9	56.8	52.0	66.2	59.3	102.0
Nd	43.8	53.0	57.6	50.3	62.1	39.7	47.3	46.8	51.1	34.4	72.1	48.8	43.9	47.0	49.3	45.4	46.2	62.8
Ni	360.0	296.0	260.0	202.0	265.0	19.8	127.0	145.0	81.5	200.0	27.2	91.2	8.7	10.6	10.6	66.7	13.3	109.0
Pb	1.82	3.48	3.39	3.76	3.14	2.09	3.68	2.90	3.21	1.73	3.42	4.32	4.01	3.35	4.12	3.95	3.71	n.d.
Pr	10.50	14.10	15.70	12.40	16.40	9.86	12.60	12.10	13.20	7.88	16.30	12.20	11.00	11.90	12.20	11.80	11.70	16.37
Rb	24.4	50.2	43.1	43.7	53.0	47.4	45.5	31.3	41.9	22.7	25.7	51.4	27.3	25.8	40.4	48.8	33.8	69.8
Sb	0.00	0.12	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	n.d.	n.d.	n.d.	n.d.	n.d.	0.13	0.11	n.d.
Sm	8.42	9.88	10.50	9.70	11.00	7.63	8.75	9.17	9.47	7.68	13.9	9.41	8.74	9.37	9.41	9.30	10.20	10.93
Sn	1.15	1.74	1.60	1.99	1.32	1.48	1.81	1.61	1.74	1.56	1.75	1.87	1.86	1.97	2.06	2.35	2.11	n.d.
Sr	1370	1028	1043	1188	1156	1128	896	994	1140	702	967	768	1024	930	984	771	850	1085
Ta	3.27	5.63	6.05	4.96	5.61	3.39	4.93	4.70	5.17	2.81	3.41	4.72	3.78	4.16	3.71	4.68	4.54	n.d.
Tb	0.95	1.02	1.13	1.18	1.15	0.87	1.02	1.06	1.06	0.90	1.44	1.07	1.05	1.06	1.07	1.19	1.21	1.22
Th	3.41	7.38	7.69	6.38	7.32	3.07	6.43	5.55	6.05	3.00	3.78	5.28	3.87	4.22	3.94	5.46	5.00	9.27
Tm	0.25	0.31	0.31	0.33	0.33	0.27	0.30	0.28	0.31	0.24	0.38	0.39	0.34	0.36	0.34	0.36	0.43	0.39
U	0.90	2.08	2.02	1.79	1.75	0.86	1.48	1.11	1.49	0.81	1.01	1.43	1.11	1.22	1.21	1.59	1.31	n.d.
V	264	246	253	257	231	259	241	206	217	214	149	200	226	204	217	197	169	212
W	0.36	0.66	1.31	0.56	0.45	0.25	1.02	0.59	0.92	0.31	0.16	0.64	0.18	0.11	n.d.	0.51	0.35	n.d.
Y	22.9	27.2	28.6	27.2	27.0	24.9	26.8	23.6	27.9	23.1	38.2	31.5	27.8	27.7	27.5	30.0	30.3	30.3
Yb	1.56	1.89	1.97	1.96	2.07	1.84	1.79	1.69	1.98	1.50	2.44	2.56	2.27	2.25	2.21	2.31	2.50	2.33
Zn	124	122	127	127	136	139	131	125	138	128	157	143	143	133	137	134	142	121
Zr	165	262	287	270	235	225	250	214	229	171	282	332	265	291	268	327	286	298

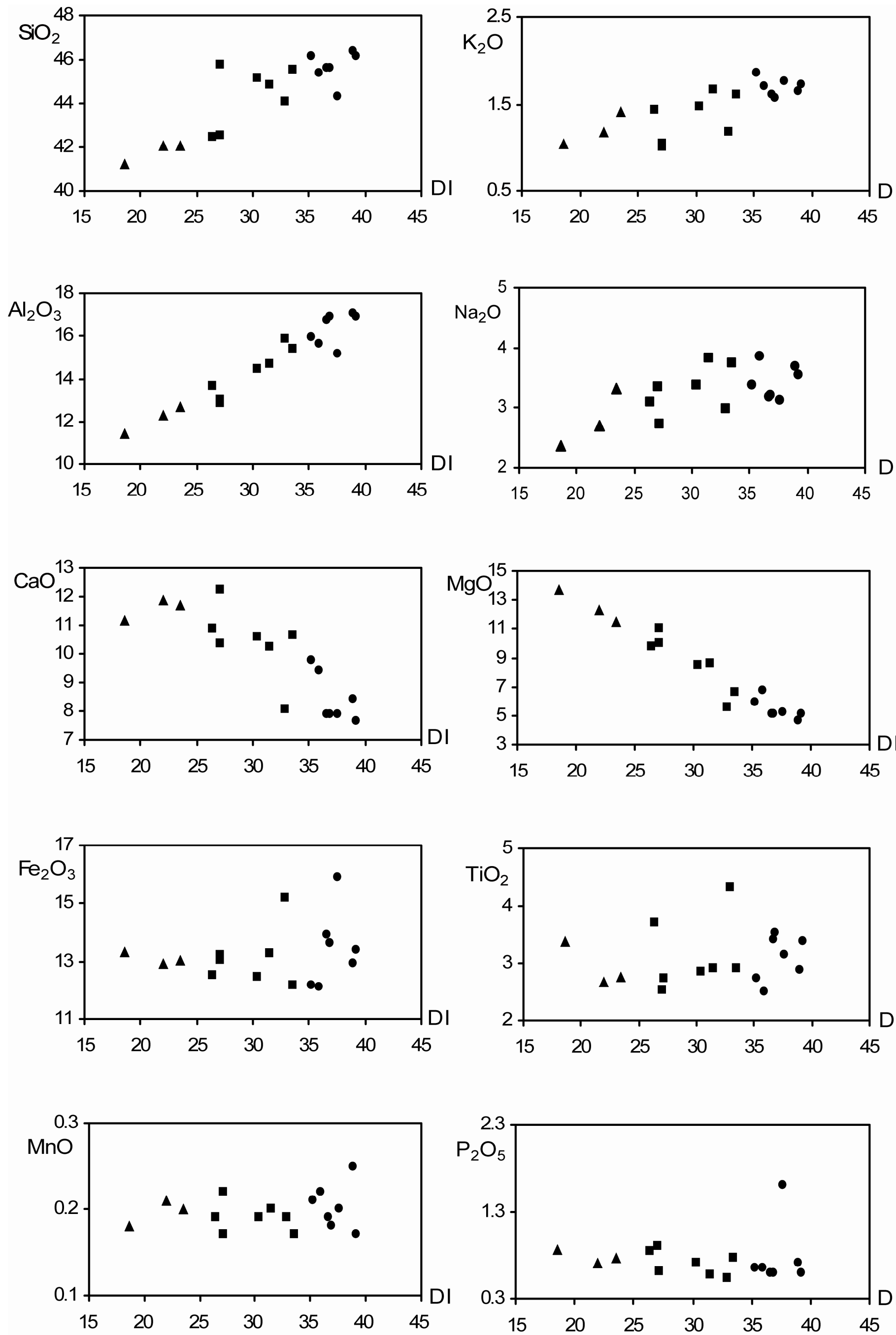

Fig. 7. Major elements amounts (wt.%) of lavas *vs.* DI. Symbols as on Fig. 6b

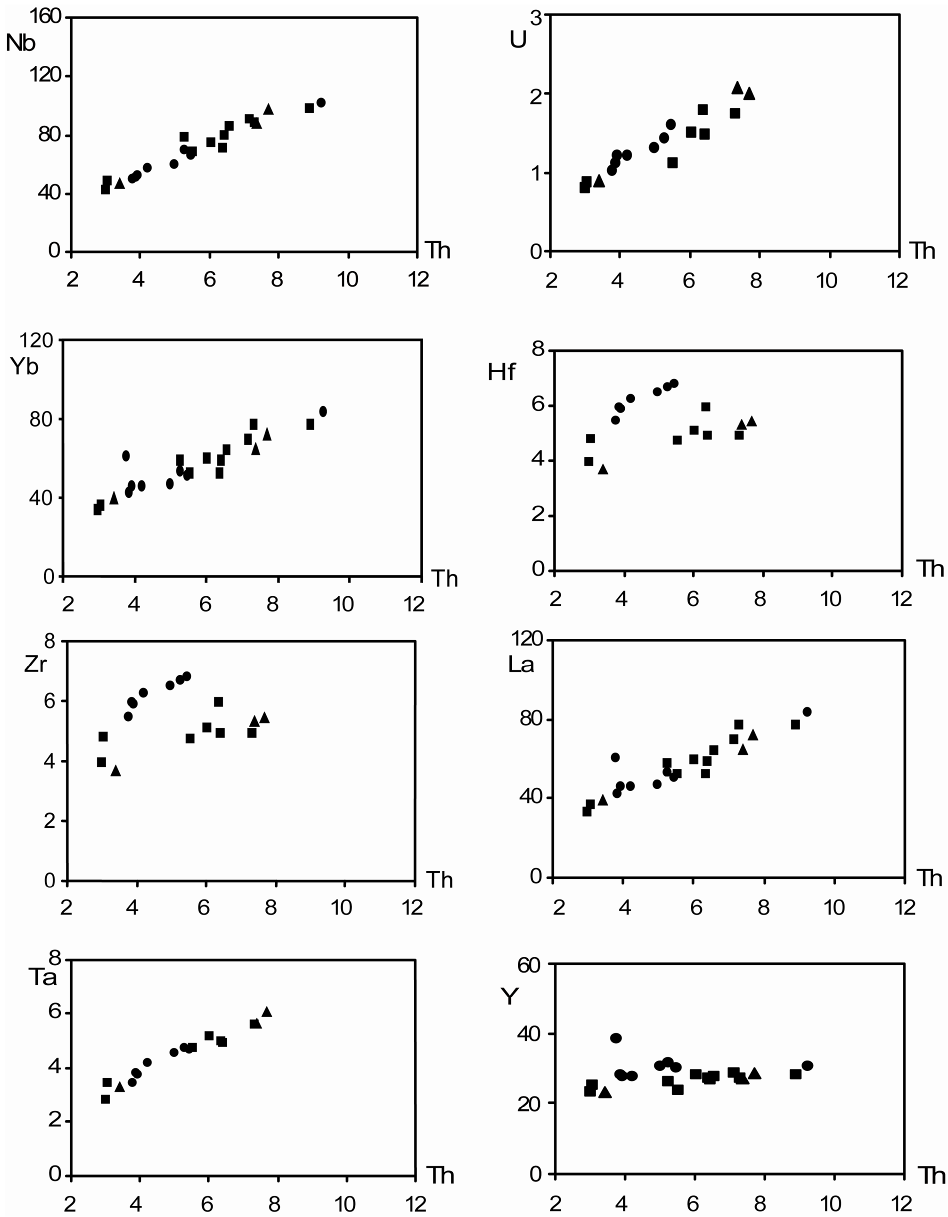

Fig. 8. Trace elements incompatible amounts (ppm) of lavas *vs.* Th. Symbols as on Fig. 6b

al. 1981) and higher than 600 ppm for Cr (Bougault 1980; Green 1980; Villemant et al. 1981; Clague & Frey 1982). The decreases of Ni and Cr contents all along the series (up to 9 ppm Ni and 5 ppm Cr in hawaiites) are related with the important fractionation of olivine and clinopyroxenes. Co contents decrease from the picrites (71 ppm) to the hawaiites (33 ppm), simultaneously with Cr during differentiation. The variations in Co and Cr are correlated to

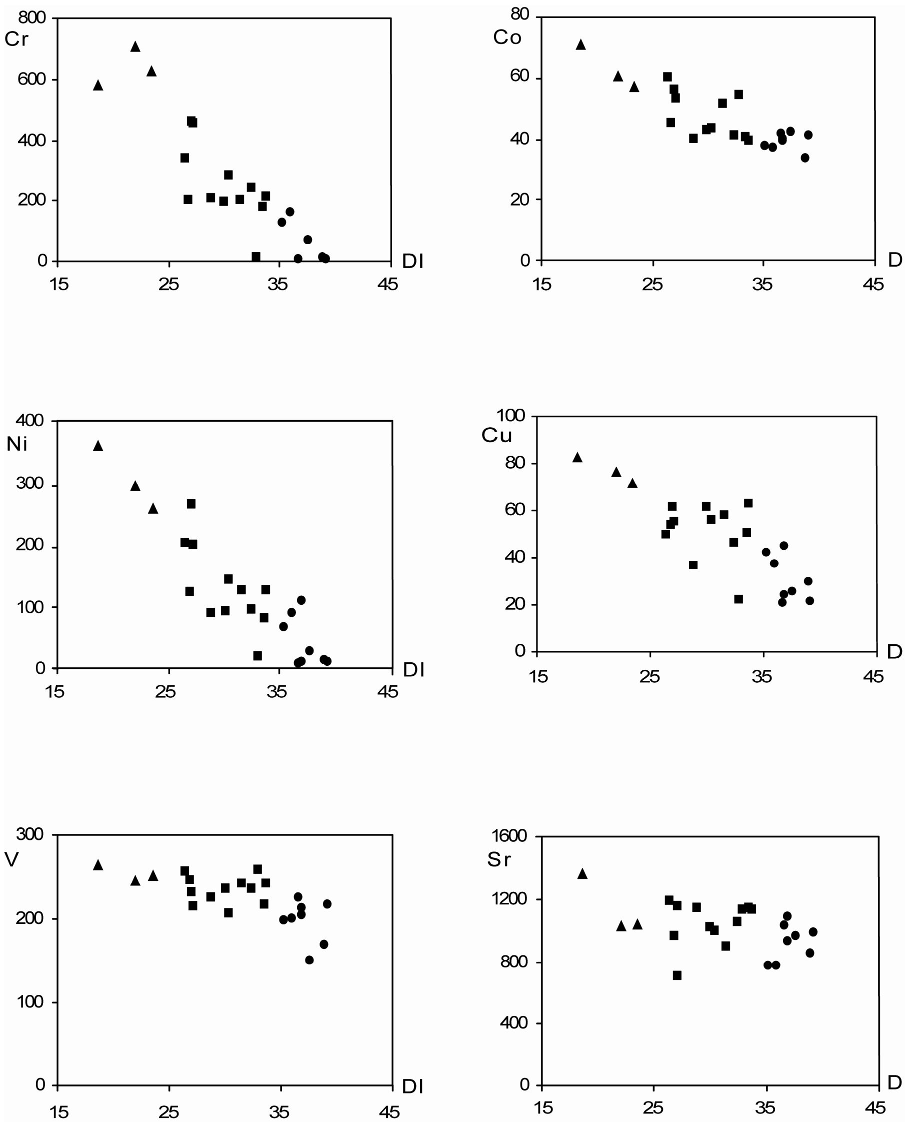

Fig. 9. Trace elements compatible amounts (ppm) of lavas *vs.* DI. Symbols as on Fig. 6b

the crystallization of clinopyroxenes. Ni and Co mainly indicate the fractionation of olivines (Wilson 1989) and clinopyroxenes (Joron et al. 1980; Käkhönen 1989). Vanadium presents a linear correlation and decreases moderately from picrites to hawaiites. This behaviour is in relation with its incorporation in the Fe-Ti oxides.

The spectra of *RRE*, normalized to chondrites (McDonough & Sun 1995) (Fig. 10), show *LREE* enrichment versus *HREE* in picrites, alkali basalts and hawaiites. These

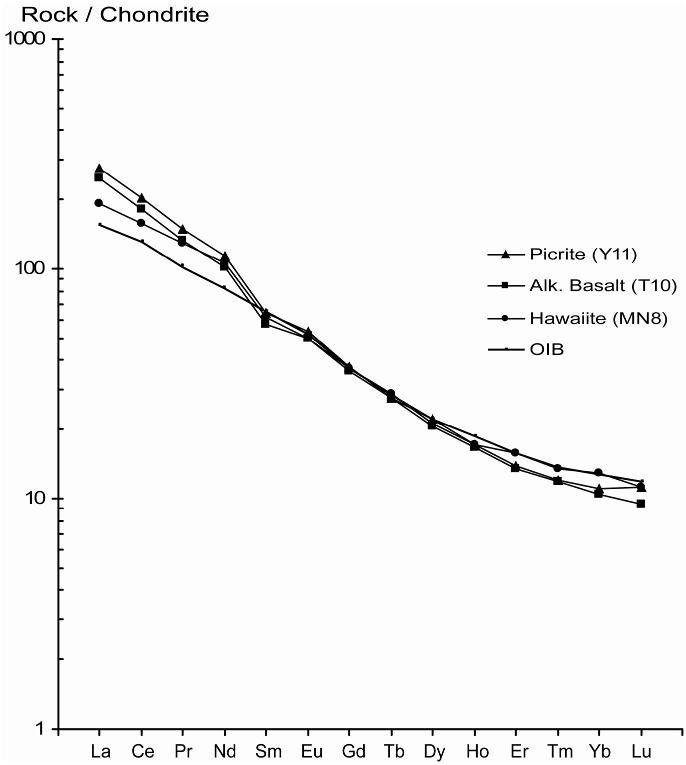

Fig. 10. Chondrite-normalized spidergram compared with OIB (normalizing values from McDonough & Sun 1995)

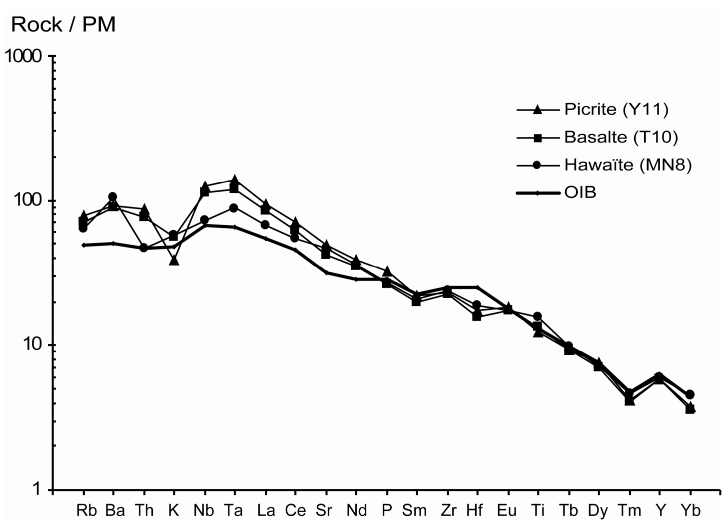

Fig. 11. Primitive mantle normalized spidergram compared with OIB (normalizing values from Sun & McDonough 1989)

Table 8. *Comparison of the ratios of some traces elements of the lavas of west side of the Noun with those of some other volcanic series*

Locality	References	Zr/Nb	La/Nb	Ba/Nb	Rb/Nb	Ba/La	Zr/Ta	La/Ta	Ba/Ta	Th/Ta	La/Th	Th/U	Ba/Th
Western side of Noun	Wotchoko 2005; Wotchoko et al. 2005	2.7-5.6	0.7-1.2	6.9-14	0.4-1	9-21	42-72	10-18	106-364	0.9-1.3	8-16	3.5-5	88-329
Eastern side of Noun	Wandji 1995	3.4	-	10.7	0.6	15.5	-	-	-	-	7.7	-	119
Tombel graben	Nkouathio 1997; Nkouathio et al. 2008	4-5.3	0.7-0.9	6.2-9.3	0.34-0.6	8.5-12	55-70	9.5-10.7	81-122	1-1.2	8-10	2.1-4.6	68-151
1982 Mount Cameroon	N'ni 1984	3.9-5.2	-	5.5-10	-	6.7	-	10.4	66.8	1.1	9.2	3.7	60
1999 Mount Cameroon	Déruelle et al. 2000	3.9	0.83	5.2	0.44	6.3	54.8	11.7	74.2	1.6	7.3	5.2	46.4
Manengouba	Kagou Dongmo et al. 2001	3.6-5.8	0.7-0.9	6.1-10	0.5-1.1	7.8-12	49-82	9.0-13	81-123	1-1.3	6.8-11.2	2.0-7	53-115
Kapsiki	Tamen 1998	4.4	0.74	6.4	0.55	8.8	56.6	9.7	83.9	0.9	10.4	3.8	92.4
Mount Bambouto	Youmen 1994; Nkouathio et al. 2008	3.1-5	0.71-0.94	11.6-21.8	0.3-1.4	14.3-27.5	-	-	-	-	-	-	172-315
OIB	McDonough & Sun 1995	5.8	0.77	7.3	0.65	9.46	104	13.7	129.6	1.48	9.25	3.92	87.5
Bioko	Fitton 1987	-	-	-	-	7.8-7.9	68-80	11.6-11.7	101-98	1.1-1.17	11.6-9.2	3.8-3.9	80-94
St. Helene	Nkouathio 1997	4.5	-	5.9	-	8.7	62.5	9.56	85.5	1.07	8.9	3.78	77
Ascension	Nkouathio 1997	-	-	-	-	1.3	75.8	6.59	96.7	1.06	8.7	3.54	92
Tristan da Cunha	Nkouathio 1997	4.2	-	11.4	-	13.2	63.1	12.2	159.4	1.28	7.8	4.5	103
Kerguelen	Nkouathio 1997	5.3	1.14	14.4	1.17	13.5	-	-	-	-	-	-	126
Mururoa atoll	Maury et al. 1992	-	-	-	-	5.85	68.27	8.07	47.21	0.85	2.82	-	55.36

spectra are more or less identical that witness of the comagmatic origin of all the lavas.

The ratio Eu/Eu* (Taylor & Mc Lennan 1985) varies from 2.7 to 3.1 in picrites, 2.3 to 3.3 in alkali basalts and 2.5 to 4.5 in hawaiites. These positive values characterize an accumulation of plagioclases during the magmatic processes (Macdonald et al. 1995). For the lava of western side of Noun, the values of the La/Yb ratio are high and typical of the alkaline basic lavas. These ratios, which decrease from the picrites (31 on average) to the hawaiites (22 on average) can be related to the presence of garnets in the mantel source (Rollinson 1993). Spectra of the trace elements (Fig. 11) normalized to the primitive mantle (Sun and McDonough 1989) are very similar to those of the 1999 lavas of the Mount Cameroon (Déruelle et al. 2000; Tsafack 2009), of the hawaiites of the Tombel graben and of the OIB (Fitton & Dunlop 1985).

Two processes could be successively invoked: a very weak partial melting for the formation of the picrites following by a starting fractional crystallization at the origin of basalts and hawaiites The picrites of the western Noun Plain could derive from a primary magma at a weak rate of partial melting of about 5 %, near to that calculated by Sun & Hanson (1975) and coming from a mantel source near the OIB.

Discussion and concluding remarks

The location of the different volcanic edifices in the western Noun Plain, one of the links of the CVL, has been controlled by extensional tectonic regime, recorded in two main directions: N35 and N135. Volcanism was active during several events, mainly effusive at 10.43 Ma, 4.60 to 4.15 Ma, and mainly explosive at 2.04 to 1.70 Ma and in more recent times (0.40 Ma), as indicated by whole-rock K-Ar ages.

Incompatible elements ratios (Table 8) in the lavas of the western side of Noun are compared to those of some other volcanic areas along the CVL (recent lavas of the Mount Cameroon, Déruelle et al. 2000; recent basalts

Table 9. *Rb-Sr and Sm-Nd isotope data of lavas from the Noun Plain (analyses: D. Demaiffe, Laboratoire de Géochimie Isotopique, Université Libre de Bruxelles, Belgium)*

Sample	Rock	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$	2σ	Sm ppm	Nd ppm	$^{143}Nd/^{144}Nd$	2σ
Y11	picrite	50.2	1028	0.703157	0.000008	9.88	53.0	0.512926	11E-06
BK5	alkali basalt	43.7	1188	0.703218	0.000010	9.70	50.3	0.512887	7E-06
T10	alkali basalt	45.5	896	0.703494	0.000005	8.75	47.3	0.512875	9E-06

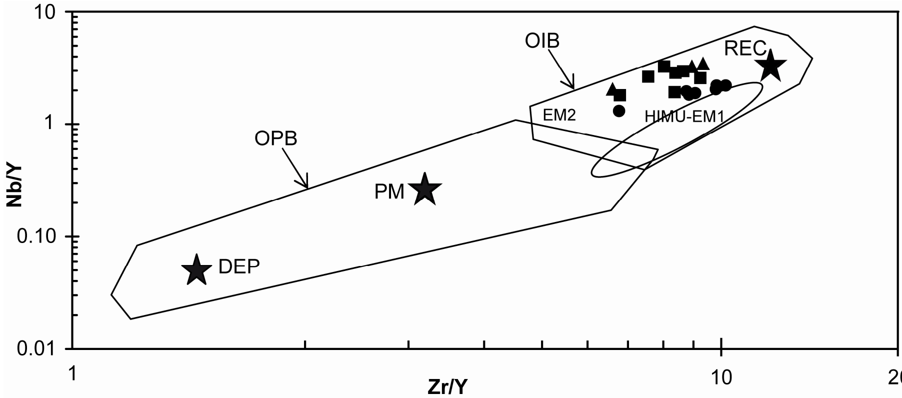

Fig. 12. Nb/Y *vs.* Zr/Y isotopic diagram (adapted from Kuepouo et al. 2006 and Weaver, 1991, modified and completed). New analyses: picrite (triangle), alkali basalt (square) and hawaiite (circle). (OIB) oceanic island basalts; (OPB) oceanic plateau basalts; (PM) primitive mantle; (DEP) deep depleted mantle; (REC) recycled component; mantle poles HIMU (high $^{238}U/^{204}Pb$ ratio), EM1 and EM2 (enriched)

of the Mount Manengouba, Kagou et al. 2001; recent lavas of the Tombel graben, Nkouathio et al. 2002) and to those of some other alkaline intraplate series (French Polynesia, Th/La = 0.12; Th/Ta = 0.85; Ta/La = 0.12; Th/Hf = 0.66, Maury et al. 1992). This study shows the similitude of these ratios, indicating the existence of a homogeneous magmatic source and their derivation from partial melting (Villemant & Treuil 1983; Gisbert 1989). Compared to other alkaline series, the lavas in the western side of Noun are similar to those of the islands of Sainte Helene and Tristan da Cunha (Zr/Nb: 4.2–4.5; Ba/La: 8.7–13.2, La/Ta: 9.6– 12.2, Th/U: 3.8–4.5, and Ba/Ta: 85.5–159.4 respectively). The primary liquids have the characteristics of the OIB. Indeed Sato et al. (1990) argue that monogenic and polygenic volcanoes do not present the same source along the Cameroon volcanic line. These authors confirm that the monogenic volcanoes derive from the OIB (Fig. 12) (while the polygenic volcanoes show the same characteristics of the MORB). These results are in conformity with the patterns of the trace elements and those of the rare earths which present similarities with the OIB for *MREE* and *HREE*.

Three isotopic analyses were performed by D. Demaiffe (Table 9). Sr isotopic ratios are corrected for mass fractionation with normalization to $^{86}Sr/^{88}Sr$ = 0.1194. Nd isotopic data are corrected for mass fractionation by normalization to ratio $^{146}Nd/^{144}Nd$ = 0.7219. The isotopic analyses carried out on two alkali basalts and one picrite have yielded Sr isotopic ratios ranging between 0.703157 and 0.703494, and for Nd between 0.512875 and 0.512926. These Sr ratios are close to those of the recent lavas of the Mount Cameroon ($^{87}Sr/^{86}Sr$ = 0.703198–0.703344) (Wandji et al. 2009). Although these values are little lower than those lavas of the Bamoun plateau ($^{87}Sr/^{86}Sr$ = 0.703343–0.704472) (Moundi et al. 2007), than those of the Tombel graben ($^{87}Sr/^{86}Sr$ = 0.703420–0.703640) (Nkouathio et al. 2008), than the mafic lavas from mounts Bambouto ($^{87}Sr/^{86}Sr$ = 0.703248–0.704250) (Nkouathio et al. 2008), while the felsic lavas from the Mbépit massif present rather high ratios ($^{87}Sr/^{86}Sr$ = 0.7047–0.7050) (Wandji et al. 2008), all these values are rather similar to those obtained for the whole CVL (Halliday et al. 1988; Lee et al. 1994) and the results indicate that the recent basaltic lavas of the Noun Plain display characteristics of a mantle source.

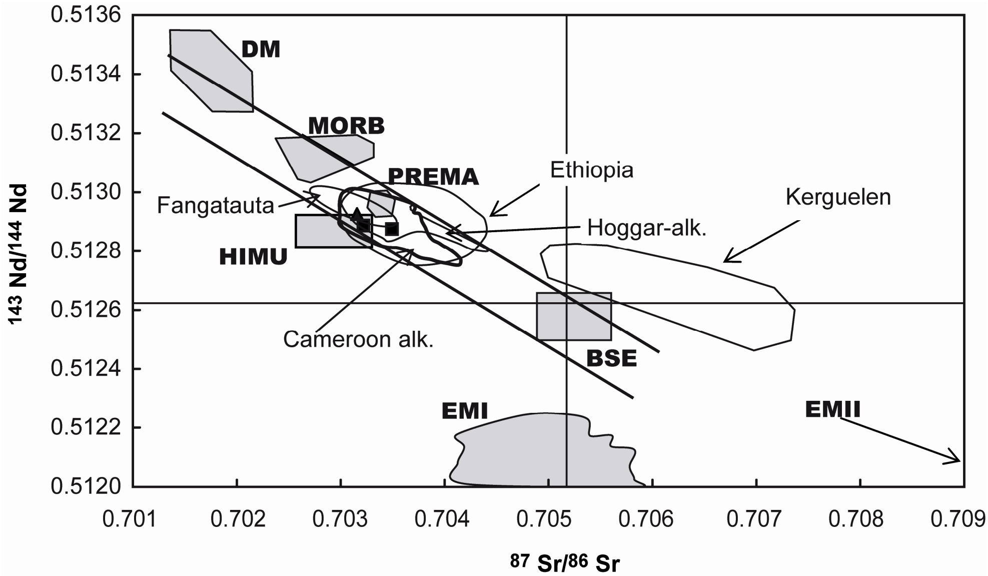

Fig. 13. $^{143}Nd/^{144}Nd$ *vs.* $^{87}Sr/^{86}Sr$ isotope correlation diagram (adapted from Rollinson 1993, modified and completed). New analyses: picrite Y11 (triangle), alkali basalts T10 and BK5 (square). Fields of the other lavas from CVL (Mount Cameroon and Mount Manengouba, adapted from Halliday et al. 1990); fields of Fangataufa (Bardintzeff et al. 1994), of alkali lavas of Hoggar (Aït-Hamou et al. 2000), of Ethiopia (Pik et al. 1999), of Kerguelen (Bardintzeff et al. 1994; Gautier et al. 1990), MORB and mantle compositions DM (depleted), EMI and EMII (enriched), HIMU, PREMA and BSE defined by Zindler & Hart (1986)

The chemical characteristics (major, trace and rare earths elements) of the lavas allow us to precise the chemical nature and magmatic affinities of the series. The rocks belong to an undersaturated alkaline domain, weakly differentiated. The primary magma of the picrite type resulted from the partial melting at a low rate (5 %) of mantle source similar to those of the OIB. The isotopic $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios show that the recent basaltic lavas of the Noun Plain derive from a mantle source very close to the prevalent mantle type (PREMA) in which HIMU (high $^{238}U/^{204}Pb$ ratio) plays the major role.

$^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopic ratios of the alkali basalts and hawaiites show some similarities with those of the alkali districts of the Hoggar (Aït-Hamou et al. 2000), of Ethiopia (Pik et al. 1999) and of the relative fields in Fangataufa (Bardintzeff et al. 1994) (Fig.13).

Acknowledgements: This study has been supported by EGIDE (Centre français pour l'accueil et les échanges internationaux) and the Campus-Corus project "L'évolution volcano-structurale, du Crétacé à l'Actuel, de la Ligne du Cameroun". Chemical analyses have been carried at Université Paris-Sud Orsay, at CRPG Nancy, and at CAMPARIS Paris, France. J.C. Philippet did the K-Ar datings at the Université de Bretagne Occidentale, France. Isotopic data have been measured by D. Demaiffe at the Laboratoire de Géochimie Isotopique, Université Libre de Bruxelles, Belgium. Figures have been drawn by L. Daumas. We thank also the "Coopération Française" of Yaoundé (SCAC) for a financial help through 3 travel supports and living expenses in France during our research in 2001, 2003 and 2005.

References

Aït-Hamou F, Dautria JM, Cantagrel, Dostal J, Briqueu L (2000) Nouvelles données géochronologiques et isotopiques sur le volcanisme cénozoïque de l'Ahaggar (Sahara algérien): Des arguments en faveur de l'existence d'un panache. *Comptes Rendus Académie Sciences Paris, IIa,* **330**, 12, 829-836

Allègre CJ, Minster JL (1978) Quantitative models of traces elements behaviour in magmatic processes. *Earth and Planetary Science Letters*, **38**, 1-25

Bardintzeff JM, McBirney AR (2000) *Volcanology*. Jones and Bartlett, Sudbury, USA, 288 p.

Bardintzeff JM, Leyrit H, Guillou H, Guille G, Bonin B, Giret A, Brousse R (1994) Transition between tholeiitic and alkali basalts: Petrographical and geochemical evidence from Fangataufa, Pacific Ocean, and Kerguelen, Indian Ocean. *Geochemical Journal*, **28**, 489-515

Bellon H, Rangin C (1991) Geochemistry and isotopic dating of Cenozoic volcanic arc sequences around the Celebes and Sulu seas. In: Silver EA, Rangin C., Breymann MT et al. (Editors). *Proc. Ocean Drilling Program Scientific Results*, **124,** 321-338

Bottinga Y, Kudo A, Weill D (1966) Some observations on oscillatory zoning and crystallization of magmatic plagioclase. *American Mineralogist*, **51**, 792-806

Bougault H (1980) *Contribution des éléments de transition à la compréhension de la genèse des basaltes océaniques. Analyse des éléments en traces dans les roches par spectrométrie de fluorescence X.* Thèse d'Etat, Université Paris VII, 221 p.

Brown FH, Carmichael ISE (1971) Quaternary volcanoes of the Lake Rudolf region: II. The lavas of North Island, South Island and the Barrier. *Lithos,* **4**, 305-323

Clague DA, Frey AF (1982) Petrology and trace element geochemistry of the Honolulu volcanics, Oahu: Implications for the oceanic mantle below Hawaii. *Journal of Petrology*, **23**, 447-501

Déruelle B, Moreau C, Nkoumbou C, Kambou, Lissom J, Njonfang E, Ghogomu RT, Nono A (1991) The Cameroon line: A review. In: Kampunzu AB, Lubala RT (Editors) *Magmatism in Extensional Structural Settings*, p. 274-327, Springer-Verlag, Berlin

Déruelle B, Bardintzeff JM, Cheminée JL, Ngounouno I, Lissom J, Nkoumbou C, Etamé J, Hell JV, Tanyileke G, N'ni J, Ateba B, Ntepe N, Nono A, Wandji P, Fosso J, Nkouathio DG (2000) Eruptions simultanées de basalte alcalin et de hawaiite au mont Cameroun (28 mars–17 avril 1999). *Comptes Rendus Académie Sciences Paris*, **331**, 525-531

Déruelle B, Ngounouno I, Demaiffe D (2007) The Cameroon hot line (CHL): A unique example of active alkaline intraplate structure in both oceanic and continental lithosphere. *Comptes Rendus Geoscience* **339**, 9, 589-600

Fitton JC (1987) The Cameroon line, West Africa: A comparison between oceanic and continental alkaline volcanism. *Geological Society Special Publication*, **30,** 273-291

Fitton JC, Dunlop HM (1985) The Cameroon Line, West Africa and its bearing on the origin of oceanic and continental alkali basalt. *Earth and Planetary Science Letters*, **72**, 23-38

Gautier I, Weis D, Mennessier JP, Vidal P, Giret A, Loubet M (1990) Petrology and geochemistry of the Kerguelen Archipelago basalts (South Indian Ocean): Evolution of the mantle sources from ridge to intraplate position. *Earth and Planetary Science Letters*, **100**, 59-76

Gisbert T (1989) *Volcanologie de l'île de Taha'a (Archipel de la Société) son enrichissement en terres rares*. Thèse Université Paris-Sud, 248 p.

Green TH (1980) Island arc and continental building magmatism: A review of petrogenetic models based on experimental petrology and geochemistry. *Tectonophysics*, **63**, 367-385

Halliday AN, Davidson JP, Holden P, Dewolf C, Lee DC, Fitton JG (1990) Trace element fractionation in plumes and the origin of HIMU mantle beneath the Cameroon Line. *Nature,* **347**, 6293, 523-528

Halliday AN, Dickin AP, Fallick AE, Fitton JG (1988) Mantle dynamics and, Sr, Pb and O isotopic Study of the Cameroon Line volcanics chain. *Journal of Petrology*, **29**, 181-211

Itiga Z, Chakam Tagheu PJ, Wotchoko P, Wandji P, Bardintzeff JM, Bellon H (2004) La Ligne du Cameroon: Volcanologie et géochronologie de trois régions (mont Manengouba, plaine du Noun et Tchabal Gangdaba). *Géochronique*, **91**, 13-16

Joron JL, Treuil M, Jaffrezic H, Villemant B (1980) Etude géochimique des éléments en traces dans les séries de roches volcaniques du rift d'Asal. Identification et analyse des processus d'accrétion. *Bulletin Société Géologique de France*, **7**, XXII, 6, 851-861

Kagou Dongmo A, Wandji P, Pouclet A, Vicat JP, Cheilletz A, Nkouathio DG, Alexandrov P, Tchoua FM (2001) Evolution volcanologique du mont Manengouba (Ligne du Cameroun), nouvelles données pétrographiques, géochim-

iques et géochronologiques. *Comptes Rendus Académie Sciences Paris*, **333**, II A, 155-162
Kähkönen Y (1989) Geochemistry and petrology of the metavolcanic rocks of the early Proterozoic Tampere schist belt, southern Finland. *Geological Survey Finland*, **345**, 1-107
Kudo AM, Weill DF (1970) An igneous plagioclase thermometer. *Contributions to Mineralogy and Petrology*, **25**, 52-65
Kuepouo G, Tchouankoue JP, Nagao T, Sato H (2006) Transitional tholeiitic basalts in the Tertiary Bana volcano-plutonic complex, Cameroon Line. *Journal of African Earth Sciences*, **45,** 3, 318-332
Le Bas MJ, Le Maitre RW, Streckeisen A, Zanettin B (1986) A chemical classification of volcanic rocks based on the total alkali-silica diagram. *Journal of Petrology,* **27**, 3, 745-750
Lee DC, Halliday AN, Fitton JG, Poli G (1994) Isotopic variations with distance and time in the volcanic islands of the Cameroon Line: Evidence for a mantle plume origin. *Earth and Planetary Science Letters*, **123**,119-138
Mahood GA, Drake RE (1982) K-Ar dating young rhyolitic rocks: A case study of the Sierra la Primavera, Mexico. *Geological Society American Bulletin*, **93**, 1232-1241
Macdonald GA, Katsura T (1964) Chemical composition of Hawaiian lavas. *Journal of Petrology*, **5**, 82-133
Macdonald R, Davies GR, Upton BGJ, Dunkley PN, Smith M, Leat PT (1995) Petrogenesis of Silali volcano, Gregory Rift, Kenya. *Journal of the Geological Society*, **152**, 703-720
McDonough WF, Sun SS (1995) The composition of the Earth. *Chemical Geology*, **120**, 22 -253
Maury RC, Caroff M, Achard S, Guille G, Joron JL, Gachon A, Rocaboy A, Letterier J (1992) L'atoll de Mururoa (Polynésie française) II–La série magmatique. *Bulletin Société Géologique France*, **163,** 5, 659-679
Miyashiro A (1978) Nature of alkalic volcanic rocks series. *Contributions to Mineralogy and Petrology,* **66**, 91-104
Moreau C, Regnoult JM, Déruelle B, Robineau B (1987) A new tectonic model for the Cameroon Line, central Africa. *Tectonophysics*, **139**, 317-34
Morin S (1989) *Hautes terres et bassins de l'Ouest Cameroun. Etude géomorphologique*. Thèse Université Bordeaux III, I.G.E.R., 1190 p.
Moundi A (2004) *Les basaltes des plateaux du plateau Bamoun: pétrologie, géochimie et géochronologie. Implications sur les sources des magmas, contexte et évolution géodynamiques*. Thèse Doctat d'Etat Université Yaoundé I, Cameroun, 254 p.
Moundi A, Wandji P, Bardintzeff JM, Ménard JJ, Atouba Okomo LC, Mouncherou Farouk O, Reusser E, Bellon H, Tchoua MF (2007) Les basaltes éocènes à affinité transitionnelle du plateau Bamoun, témoins d'un réservoir mantellique enrichi sous la ligne volcanique du Cameroun. *Comptes Rendus Geoscience*, **339**, 396-406
Nana JM (1988) *Le complexe volcano-plutonique de Bana (Ouest Cameroun): géologie et pétrologie.* Thèse de l'Université Paris XI-Orsay, 131 p.
Nkouathio DG (1997) *Le volcanisme récent du graben de Tombel (Province du Littoral et du Sud-Ouest Cameroun)*. Thèse Doctorat 3[e] cycle, Université Yaoundé I, 179 p.
Nkouathio DG, Ménard JJ, Wandji P, Bardintzeff JM (2002) The Tombel graben (West-Cameroon): A recent monogenetic volcanic field of the Cameroon Line. *Journal of African Earth Sciences*, **35**, 285-300
Nkouathio DG, Kagou Dongmo A, Bardintzeff JM, Wandji P, Bellon H, Pouclet A (2008) Evolution of volcanism in graben and horst structures along the Cenozoic Cameroon Line (Africa): Implications for tectonic evolution and mantle source composition. *Mineralogy and Petrology*, **94**, 287-303
N'ni J. (1984) *Le volcan actif du mont Cameroun (Ligne du Cameroun): Géologie et pétrologie du volcan*. Thèse doctorat 3[e] cycle, Université Paris-Sud, Orsay, 260 p.
Pik R, Deniel C, Coulon C, Yirgu G, Marty B (1999) Isotopic and trace element signatures of Ethiopian flood basalts: Evidence for plume-lithosphere interactions. *Geochimica et Cosmochimica Acta*, **63**, 15, 2263-2279
Rollinson HR (1993) *Using Geochemical Data: Evolution, Presentation, Interpretation, Geochemistry Series.* Longman Scientific and Technical, New York, 352 p.
Sato H, Aramaki S, Kusakabe M, Hirabayashi JI, Sano Y, Nojiri Y, Tchoua FM (1990) Geochemical difference of basalts between polygenetic and monogenetic volcanoes in the central part of the Cameroon volcanic line. *Geochemical Journal*, **24**, 6, 357-370
Steiger RH, Jäger E (1977) Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. *Earth and Planetary Science Letters*, **36,** 359-362

Sun SS, Hanson GN (1975) Origin of Ross Island basanitoids and limitations upon the heterogeneity of mantle sources for alkali basalts and nephelinites. *Contributions to Mineralogy and Petrology*, **52**, 77-106

Sun SS, McDonough WF (1989) Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes. In: Saunders AA, Norry MJ (Editors), *Magmatism in Ocean Basins*. *Geological Society Special Publication*, **42**, 313-345

Tamen J. (1998) *Contribution à l'étude géologique du plateau Kapsiki (Extrême-Nord, Cameroun): volcanologie, pétrologie et géochimie*. Thèse Doctorat 3^{e} cycle Université Yaoundé I, 127 p.

Taylor SR, Mc Lennan SM (1985) *The Continental Crust: Its Composition and Evolution*. Blackwell, Oxford

Tchoua MF (1974) *Contribution à l'étude géologique et pétrologique de quelques volcans de la "Ligne du Cameroun" (Monts Manengouba et Bambouto)*. Thèse Doctorat Etat, Université Clermont-Ferrand, 337 p.

Thornton CP, Tuttle OF (1960) Chemistry of igneous rocks. Differentiation index. *American Journal of Science*, **258**, 664 - 684

Tsafack JPF (2009) *Volcanisme plio-quaternaire du mont Cameroun: Pétrologie, minéralogie, géochimie isotopique, géochronologie et évolution de la bordure côtière*. Thèse Ph.D, Université Yaoundé I, Cameroon, 188 p.

Villemant B, Jaffrezic H, Joron JL, Treuil M (1981) Distribution coefficients of major and traces elements: fractional crystallisation in the alkali basalt series of Chaîne des Puys (Massif Central, France). *Geochimica et Cosmochimica Acta*, **45**, 1997-2016

Villemant B, Treuil M (1983) Comportement des éléments traces et majeurs dans la série alcaline du Velay; comparaison avec la Chaîne des Puys (Massif Central France). *Bulletin de Minéralogie*, **106**, 465-486

Wandji P (1995) *Le volcanisme récent de la plaine du Noun (Ouest-Cameroun). Volcanologie, pétrologie, géochimie et pouzzolanicité*. Thèse Doctorat Etat, Université Yaoundé I, 295 p.

Wandji P (1998) Données nouvelles sur les quatre types de volcans de la plaine du Noun (Ligne du Cameroun, Ouest-Cameroun). In: Vicat JP, Bilong P (Editors), *Géosciences au Cameroun*. Collection Géocam, Presses Universitaires Yaoundé I, 1, 213-224

Wandji P, Bardintzeff JM, Ménard JJ, Tchoua MF (2000) The alkaline fassaite-bearing volcanic province of the Noun Plain (West-Cameroon). *Neues Jahrbuch für Mineraloge Monatshefte*, **1**, 1-14

Wandji P, Ménard JJ, Tchoua FM (1994) L'activité hydromagmatique récente dans la plainte du Noun (Ouest-Cameroun) et les aléas volcaniques associés. *Comptes Rendus de l'Académie des Sciences,* Paris, **319**, II, 417-422

Wandji P, Tchokona Seuwui D, Bardintzeff JM, Bellon H, Platevoet B (2008) Rhyolites of the Mbépit Massif in the Cameroon Volcanic Line: an early extrusive volcanic episode of Eocene age. *Mineralogy and Petrology*, **94**, 271-286

Wandji P, Tsafack JPF, Bardintzeff JM, Nkouathio DG, Kagou Dongmo A, Bellon H, Guillou H (2009) Xenoliths of dunites, wehrlites and clinopyroxenites in the basanites from Batoke volcanic cone (Mount Cameroon, Central Africa): petrogenetic implications. *Mineralogy and Petrology*, **96**, 81-98

Weaver BL (1991) The origin of ocean basalt end-member compositions: Trace element and isotopic constraints. *Earth and Planetary Science Letters*, **104**, 381-397

Wilson M (1989) *Igneous Petrology*. Wilson and Collins Academics Eds., London 466 p.

Wotchoko P (2005) *Le volcanisme néogène a récent des régions de Galim, Bamendjing et Baleng (Ouest–Cameroun): Volcanologie, pétrologie, géochimie et approche environnementale*. Thèse Ph.D, Université Yaoundé I, Cameroon, 198 p.

Wotchoko P, Wandji P, Bardintzeff JM, Bellon H (2005) Données pétrologiques et géochronologiques nouvelles sur le volcanisme alcalin néogène à récent de la rive ouest du Noun (plaine du Noun, Ligne du Cameroun). *Review of the Bulgarian Geological Society*, **66**, 1-3, 97-105

Youmen D (1994) *Evolution volcanologique, pétrologique et temporelle de la caldeira des monts Bambouto (Cameroun)*. Thesis University Kiel. 273 p.

Zindler A, Hart SR (1986) Chemical geodynamics. *Annual Review Earth and Planetary Sciences,* **14**, 493-571

Accepted September 15, 2010