Strontian melilite in a nephelinite lava from Etinde, Cameroon

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ABSTRACT. Strontium-rich (up to 16 wt % SrO) melilite oc-curs as microphenocrysts in a nosean–leucite–nephelinite lava from Etinde, Cameroon. Electron microprobe an-alyses show that the melilite is very strongly zoned with Sr, Fe, and Na enrichment towards the crystal rims. Sodium melilite and sodium ferrimelilite are the dominant end-member molecules and together account for up to 76 mole %. The crystals are optically negative and strongly birefringent with birefringence ranging from 0.014 in the cores to 0.032 at the crystal rims. Refractive indices measured at the rim of one crystal gave $\omega = 1.656$, $\varepsilon = 1.628$. The cell dimensions of strontian melilite are $a = 7.765$ Å, $c = 5.054$ Å.

ETINDE is a Quaternary nephelinite volcano on the coast of the Cameroon Republic, West Africa. Its lavas show continuous chemical variation from olivine melanephelinite to a leucocratic nosean–leucite–nephelinite (referred to as 'leucitite' by Esch, 1901). The petrology and geochemistry of the Etinde lavas will be described in a later paper where we shall show that these nosean–leucite nephelinites represent the end product of crystal fractionation of the Etinde nephelinite magma. They plot very close to the nepheline–leucite–diopside cotectic in the system nepheline–sanidine–diopside (Platt and Edgar, 1972). Feldspathic lavas (e.g. phonolites) have not been reported from Etinde. A sample of nosean–leucite–nephelinite (C154) forms the subject of this paper.

Petrography of sample C154. C154 is a green-grey aphanitic rock with sparse phenocrysts of nepheline, nosean, and augite. The augite phenocrysts are zoned from aluminous sahlite cores to aegirine-augite rims. The groundmass is composed of very fine-grained nepheline, leucite, sodalite (identified by X-ray diffraction), aegirine–augite, and magnetite with microphenocrysts of leucite, nepheline, melilite, schorlomite, magnetite, and, rarely, apatite and sphene. A chemical analysis of this rock sample is presented in Table I.

Optical properties of the melilite. Melilite occurs as small (up to 200×50 μm) tabular crystals show-ing slight alteration to a brown material around the edges. The crystals show unusually high bire-fringence for melilite and are strongly zoned optic-ally. Birefringence, measured with a Berek com-pensator, ranges from 0.014 in the cores to 0.032

TABLE I. Chemical composition of sample C154*.

Weight %		CIPW norm, weight %	
SiO$_2$	46.25	orthoclase	35.26
Al$_2$O$_3$	19.46	anorthite	2.60
Fe$_2$O$_3$	4.22	leucite	2.27
FeO	2.18	nepheline	34.17
MgO	1.16	halite	0.80
CaO	6.15	thenardite	0.50
Na$_2$O	7.80	diopside	6.47
K$_2$O	5.98	wollastonite	9.21
TiO$_2$	1.06	magnetite	5.33
MnO	0.36	hematite	0.84
P$_2$O$_5$	0.16	ilmenite	2.09
SrO	0.78	apatite	0.39
BaO	0.39	calcite	0.19
SO$_3$†	0.27		
Cl	0.47		
H$_2$O$^+$	3.22		
CO$_2$	0.08		
	100.12‡		

* FeO, SrO, BaO, Cl, H$_2$O$^+$, and CO$_2$ determined wet-chemically by M. J. Saunders. All other elements determined by XRF techniques.
 † Total S expressed as SO$_3$.
 ‡ Total adjusted for O $\equiv$ Cl.

TABLE II. *Electron microprobe analyses* of strontian melilite from sample C154*

	1	2	3
Weight %			
SiO_2	42.71	41.96	39.89
TiO_2	0.06	0.08	0.10
Al_2O_3	8.23	7.77	6.61
Fe_2O_3†	4.96	6.36	8.73
FeO	1.48	3.12	2.96
MnO	0.33	0.42	0.59
MgO	4.24	2.58	1.13
ZnO	0.10	0.16	0.38
CaO	27.17	23.31	15.73
SrO	3.28	6.29	15.96
BaO	0.05	0.21	0.40
Na_2O	6.85	7.10	7.30
K_2O	0.11	0.14	0.16
	99.57	99.50	99.94

Formula on basis of O = 14

	1		2		3	
Si	3.951		3.982		3.993	
Ti	0.004		0.006		0.007	
Al	0.897		0.869		0.780	
Fe^{3+}	0.346		0.454		0.658	
Fe^{2+}	0.115	5.931	0.247	5.966	0.248	5.932
Mn	0.026		0.033		0.050	
Mg	0.585		0.364		0.168	
Zn	0.007		0.011		0.028	
Ca	2.694		2.370		1.687	
Sr	0.176		0.346		0.926	
Ba	0.002	4.115	0.008	4.047	0.016	4.067
Na	1.230		1.306		1.417	
K	0.013		0.017		0.021	
	10.046		10.013		9.999	

Molecular %

	1	2	3
SM	45.6	44.2	41.0
Fe–SM	17.6	23.1	34.6
Åk	29.7	18.5	8.8
Fe–Åk	7.2	14.2	15.7

* Analyses from a single microphenocryst: 1, core; 2, intermediate position; 3, rim.
† Calculated by assigning $Fe^{3+} = (Na + K) - Al$.

at the rims. The highest birefringence is often seen at the ends of elongate sections. The mineral is optically negative. The strong zoning of the crystals precludes the accurate determination of refractive indices but measurements made at the rim of one crystal gave $\omega = 1.656$, $\varepsilon = 1.628$ (both ± 0.004; $\lambda = 589$ nm).

Composition. Several grains of melilite were analysed using a Cambridge Instruments Microscan 5 electron microprobe operating at 20 kV and a probe current of 30 nA. Wavelength-dispersive

techniques were used for all elements which were measured against simple standards (wollastonite, corundum, periclase, jadeite, orthoclase, rutile, celestine, baryte, and pure Fe, Mn, and Zn). Corrections for dead-time counting losses, atomic number, absorption, and characteristic fluorescence differences between standard and unknown were made and are essentially those of Sweatman and Long (1969). Three analyses from a single melilite crystal are given in Table II. The core and rim analyses were measured at points showing respectively the lowest and highest birefringence. The rim analysis was taken from the end of an elongate section.

A series of analyses for Ca, Sr, Fe, and Mg were made in a traverse across a melilite crystal and the results displayed in fig. 1. The crystal is strongly
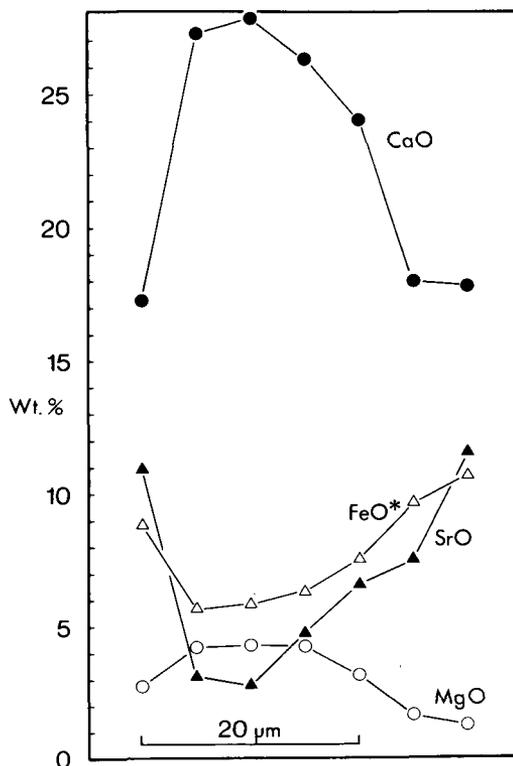

FIG. 1. Variation in Ca, Sr, Fe, and Mg across a melilite crystal from sample C154. FeO* = total Fe as FeO.

zoned in these elements with substitution of Sr for Ca and Fe for Mg towards the rim. The variation in Fe content and birefringence from core to rim are comparable to those described in a melilite crystal from Nyiragongo by Sahama (1967) although the birefringence of the crystals described here is much higher than that measured by Sahama (1967).

Complete substitution of Sr for Ca in melilites has been demonstrated by the synthesis of strontio-gehlenite ($Sr_2Al_2SiO_7$) by Dear (1957) and Brisi and Abbatista (1960) and strontio-åkermanite ($Sr_2MgSi_2O_7$) by Dear (1960). Dear (1969) has shown that strontio-gehlenite is completely iso-morphous with åkermanite. Natural strontium analogues of melilite, however, have not previously been reported. Strontium is seldom determined in melilite analyses and when it is it rarely exceeds 1% (by weight) SrO. Gold (1966), for example, reported 1.59% SrO in a melilite from the Oka carbonatite. Kogarko et al. (1980) have shown that melilite crystals of composition close to $Åk_{70}SM_{30}$, crystallized experimentally from synthetic nephel-inite melts, are only slightly enriched in strontium relative to the liquid ($K_D = 1.2$–1.4).

In the rims of the melilites described here the SrO content (wt. %) exceeds that of CaO although only a little over one-third of the Ca sites have been filled with Sr (Table II, analysis 3). Fig. 1, however, shows that the SrO content increases very rapidly towards the rims of the crystals. The slight alteration around the rims precludes the analysis of the outer 5 μm or so and it is likely, therefore, that these crystals are zoned outwards to a melilite composition in which Sr becomes dominant over Ca. The high strontium content of the host rock (c. 7000 p.p.m.) cannot be accounted for by the observed melilite alone and it is possible that the remainder resides in rim and groundmass strontio-melilite.

Besides its abnormal enrichment in strontium, the melilite described here has a sodium content higher than any previously reported. The data in Table II show that the crystals are enriched in sodium and depleted in aluminium towards the rims. Sodium is always in excess over aluminium in the formula and so the melilite contains substan-tial amounts (up to 35 mole%) of the sodium ferrimelilite molecule ($CaNaFeSi_2O_7$). This mole-cule seldom appears in recalculations of melilite analyses (Velde and Yoder, 1977) and very rarely exceeds 10 mole% of the melilite composition. Donaldson and Dawson (1978) have described meli-lites containing up to 11.1 mole % $CaNaFeSi_2O_7$ in an interstitial soda-rich glass within a pyroxenite nodule from Oldoinyo Lengai.

The unusual composition of the melilites de-scribed here is seen in fig. 2. In this plot the sodium ferrimelilite molecule (Fe–SM) is added to sodium melilite so that this diagram becomes analogous to the diopside–hedenbergite–acmite pyroxene diagram. The marginal enrichment in sodium ferri-melilite described here is analogous to marginal acmite enrichment in pyroxenes. Donaldson and Dawson's (1978) melilite analyses from Oldoinyo
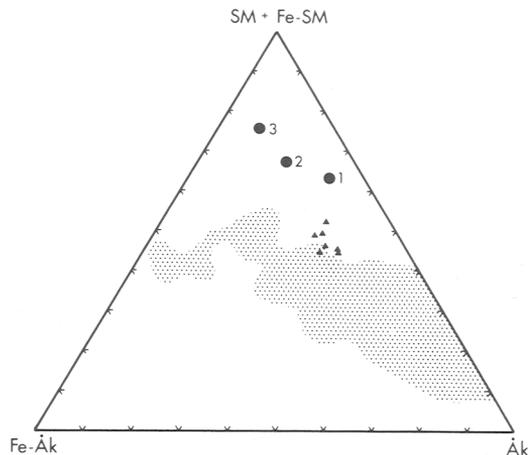

FIG. 2. Melilite analyses from Table II (filled circles) plotted in terms of the end member molecules $CaNaAlSi_2O_7$ (SM), $CaNaFeSi_2O_7$ (Fe–SM), $Ca_2MgSi_2O_7$ (Åk) and $Ca_2FeSi_2O_7$ (Fe–Åk). Strontium has been included with calcium in the recalculation. Melilite analyses from Oldoinyo Lengai (filled triangles; Donaldson and Dawson, 1978) and the field of igneous melilites (stippled area) defined by Velde and Yoder (1977) are shown for comparison.

Lengai and the field of igneous melilites defined by Velde and Yoder (1977) are plotted for comparison. Note that this latter field has been transferred directly from their åkermanite–ferroåkermanite-sodium-melilite diagram since the sodium ferri-melilite molecule appears in very few of their recalculations (Velde and Yoder, 1977).

The extreme composition of these strontian melilites is due to their unusual host rock. Velde and Yoder (1977) have plotted frequency distribu-tions of major elements for 311 melilite-bearing volcanic rocks. The composition of the rock (C154) described here lies at the extreme low end of these distributions for CaO and MgO, at the extreme upper end for SiO_2 and near to it for $Na_2O + K_2O$. C154 must, therefore, represent one of the most fractionated liquids still sufficiently undersaturated to crystallize melilite. The combination of very low Ca and Mg, very high Sr and Na concentrations, and high Fe^{3+}/Fe^{2+} ratios in such an under-saturated liquid have conspired to produce this unusual Sr- and $CaNaFeSi_2O_7$-rich melilite.

The zoning displayed by these melilites points clearly to a $SrNaFeSi_2O_7$ end-member molecule (the strontio-melilite analogue of acmite). The extreme rim and groundmass melilite composition, which, as was noted earlier, could not be analysed because of incipient alteration, may well approach this hypothetical end member.

X-ray data. Attempts to separate strontian meli-lite using heavy liquid techniques were unsuccessful due to the small size and friability of the crystals. However, by extracting, with a fine needle, a number of crystals from a large thin section of C154, enough of the material was separated for powder photography. A faint powder pattern was obtained (using a 114.6 mm diameter camera and Cu-K_α radiation), which included five clear melilite lines (Table III) together with the strongest lines of nepheline, leucite, and sodalite. The melilite lines yielded cell dimensions of $a = 7.765 \pm 0.015$ Å, $c = 5.054 \pm 0.018$ Å ($\pm 2\sigma$).

TABLE III. *X-ray powder data for strontian melilite*

I	d_{obs}	d_{calc}	hkl
m	3.074	3.079	201
s	2.867	2.862	211
vw	2.298	2.304	301
		2.296	112
w	1.760	1.761	312
vw	1.388	1.387	521

REFERENCES

Brisi, C. and Abbatista, F. (1960). Ricerche sulle melilite.—Nota 1. Struttura e proprieta della stronzio-gehlenite. *Ann. Chim. (Roma)* **50**, 1061–5.

Dear, P. S. (1957). Sub-liquidus equilibria for the ternary system SrO-Al$_2$O$_3$-SiO$_2$. *Bull. Va. Poly. Inst. Engrg. Expt. Sta.* **50** (11), 12 pp.

——(1960). Solid state equilibria for the ternary system strontia-magnesia-silica. Ibid. **54** (1), 10 pp.

——(1969). Isomorphism of åkermanite and strontio-gehlenite. *Lithos* **3**, 13–16.

Donaldson, C. H. and Dawson, J. B. (1978). Skeletal crystallisation and residual glass compositions in a cellular alkalic pyroxenite nodule from Oldoinyo Lengai. *Contrib. Mineral. Petrol.* **67**, 139–49.

Esch, E. (1901). Der Vulcan Etinde in Kamerun und seine Gesteine (I). *Sitzungsber. Akad. Wiss. Berlin,* 277–99.

Gold, D. P. (1966). The minerals of the Oka carbonatite and alkaline complex, Oka, Quebec. *Pap. Proc. Int. Mineral. Assoc. 4th Gen. Meeting, New Delhi, 1964,* 109–25.

Kogarko, L. N., Petrova, E. N., and Krigman, L. D. (1980). Fractionation of strontium in the crystallization of melilite in the nepheline-diopside-apatite system. *Dokl. Akad. Nauk SSSR,* **253** (1), 240–2 (in Russian).

Platt, R. G. and Edgar, A. D. (1972). The system nepheline-diopside-sanidine and its significance in the genesis of melilite and olivine bearing alkaline rocks. *J. Geol.* **80**, 224–36.

Sahama, Th. G. (1967). Iron content of melilite. *C.R. Soc. Géol. Finl.* **39**, 17–28.

Sweatman, T. R. and Long, J. V. P. (1969). Quantitative electron-probe microanalysis of rock-forming minerals. *J. Petrol.* **10**, 332–79.

Velde, D. and Yoder, H. S. (1977). Melilite and melilite-bearing igneous rocks. *Carnegie Inst. Washington Yearb.* **76**, 478–85.