Götzenite and combeite, two new silicates from the Belgian Congo.

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Summary. A nephelinite from the extinct volcano Mt. Shaheru, North Kivu, Belgian Congo, contains two new minerals: *Götzenite* is triclinic with a 10·93, b 7·32, c 5·74 Å., α 90°, β 100°, γ 120°; the unit-cell contents approximate to $(Ca,Na,Al)_7$ $(Si,Ti)_5O_{15}F_{3.5}$, and the optical constants are a 1·660, β 1·662, γ 1·670, $2V_\gamma$ 52°; sp.gr. 3·138. Götzenite is related to the rinkite series, and, less closely, to wollastonite and pectolite. *Combeite* is rhombohedral, space-group $R3m$, $R32$, or $R\bar{3}m$, a 10·43, c 13·14 Å., the unit cell containing approximately $3[Na_4(Ca,Al,Fe)_3Si_6O_{16}(O,OH,F)_2]$; optically uniaxial positive, $\epsilon = \omega = 1·598\pm0·002$; sp.gr. 2·844.

IN 1954, together with Mr. André Meyer, of the Geological Survey of the Belgian Congo, the authors had the privilege of making a joint excursion to the active volcano Mt. Nyiragongo and to its extinct southern tributary Mt. Shaheru in North Kivu, Belgian Congo. On that excursion a specimen was collected from the north-eastern inner wall of the Shaheru crater and numbered S. 80 = M. 2 and 3. Later microscopic study of the rock showed that it represents a nephelinite with a rather complicated mineralogical composition. Among the principal constituents of the rock two were found that could not be identified microscopically. A detailed investigation of these two minerals proved them to be new species, now named götzenite and combeite, the description of which is given in this paper. The petrography of the rock itself will be published later in connexion with the general mineralogy and petrology of the Nyiragongo area lavas by the senior author in the papers by the Institut des Parcs Nationaux du Congo Belge, Brussels.

Götzenite.

This mineral occurs as prismatic crystals that may reach a length of $\frac{1}{2}$ mm. The crystallographic axes were chosen in such a way that they

correspond to the conventional setting of wollastonite; accordingly, the axis of the prism zone was taken as b. Fig. 1 shows a section perpendicular to this b-axis. The faces shown were collected from two individual crystals and were indexed on the basis of the unit-cell data. The angles between the faces were measured with the optical goniometer with the following results: (100):(403) = 138°, (403):(001) = 143°, (001):($\bar{1}$01) = 145°, ($\bar{1}$01):($\bar{1}$00) = 113°, ($\bar{1}$00):($\bar{2}$0$\bar{1}$) = 147°, ($\bar{2}$0$\bar{1}$):(00$\bar{1}$) = 135°,
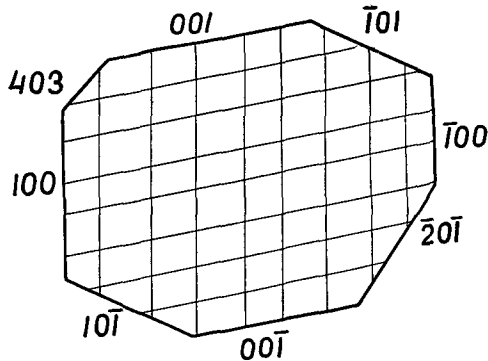

FIG. 1. Götzenite crystal. Section perpendicular to the b-axis.

(00$\bar{1}$):(10$\bar{1}$) = 146°, (10$\bar{1}$):(100) = 113°. Owing to the small size and poor quality of the crystals and the goniometer available for their measurement, these interfacial angles are only accurate to $\pm\frac{1}{2}$°. Faces outside the [010] zone are extremely rare and were detected only in a few crystals; and these pyramidal faces are too poorly developed to be accurately measured and indexed. There is a perfect cleavage || (100), and a good one || (001). Almost every crystal shows lamellar twinning, with twin axis b; the composition plane is perpendicular to (001).

The mineral is colourless in thin section. Under the binocular microscope with low power, the crystals lying on the surface of the specimen are glass clear. The refractive indices measured with the immersion method are: α = 1·660, β = 1·662, γ = 1·670. Birefringence weak: $\gamma - \alpha$ = 0·010 (calculated). Optically positive. $2V_\gamma$ = 52° (measured). The refractive indices given yield a value $2V_\gamma$ = 53$\frac{1}{2}$° (calculated). The optic axial angle is somewhat greater for red than for blue. Dispersion strong. The optical orientation for sodium light is indicated in fig. 2: the optic axial plane makes an angle of 29° with the b-axis, and on (010) the extinction direction γ' makes an angle of ca. 58° with the trace of the c-axis in the obtuse angle β.

A pycnometric measurement of the specific gravity yielded $D_{4°}^{20°} =$ 3·138.

The mineral is triclinic. The lengths of the axes of the unit cell were measured from rotation photographs with the crystal rotated about the
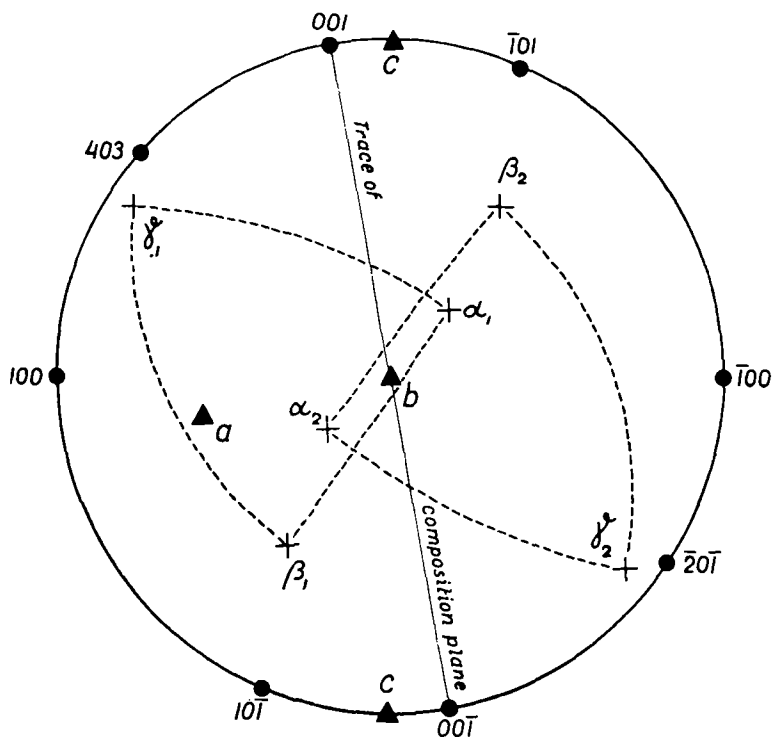

FIG. 2. Optical orientation of a götzenite twin in stereographic projection.

three axes. The interaxial angles of the reciprocal cell were measured from the three corresponding zero-layer Weissenberg photographs with the following results: $\alpha^* = 84°$, $\beta^* = 78\frac{1}{3}°$, $\gamma^* = 59\frac{1}{3}°$. To test the interaxial angle α of the direct cell, a first and second layer equi-inclination Weissenberg photograph was taken rotating the crystal about the b-axis. No deviation from 90° was detected for α. The data obtained lead to the unit-cell dimensions (assuming $\lambda = 1·54050$ Å. for Cu-$K\alpha_1$):

a 10·93±0·05 Å., $\quad b$ 7·32±0·03, $\quad c$ 5·74±0·03,

α 90°, $\quad\quad\quad \beta$ 100°±1°, $\quad\quad \gamma$ 120°±1°,

Volume 389 Å³., $a:b:c::1·493:1:0·784.$

The rotation photograph about the b-axis shows very weak layer lines with n odd. Hence there is a pronounced sub-cell with $b = 3\cdot66$ Å.

The powder pattern of götzenite was recorded with the Philips Norelco diffractometer using copper radiation and nickel filter. The result is presented in table I.

Götzenite was separated for chemical analysis by centrifuging the powdered rock in Clerici's solution. The material used for the analysis was tested under the microscope and found to be of a very high purity.

TABLE I. Powder pattern of götzenite. Filtered copper radiation.

2θ	d	I	2θ	d	I
22·24	3·994	15	43·935	2·059	5
24·70	3·601	5	*45·575	1·989	7
28·775	3·100	100	47·535	1·911	50
29·90	2·986	100	48·495	1·876	15
31·26	2·859	10	49·685	1·833	15
31·68	2·822	7	50·72	1·798	10
33·815	2·648	40	54·24	1·690	25
35·725	2·511	25	*55·815	1·646	7
38·725	2·323	10	57·81	1·594	10
39·83	2·261	15	58·635	1·573	10
40·71	2·214	7	*59·88	1·543	10
*41·945	2·152	5	62·635	1·482	15

* Line broad.

The result of the chemical analysis and the unit-cell content, calculated on the basis of the density and X-ray data, is summarized in table II. Neglecting the minor constituents, the stoichiometric net formula of götzenite may be written as $5Ca(Si,Ti)O_3.(Na,Ca,Al)_2F_{3\cdot5}$. The structural interpretation of this empirical formula must be left till the crystal structure of the mineral has been worked out. A qualitative spectrographic test revealed the absence of Ce, Yt, and Cb in the mineral.

Experiments made with the Leitz heating microscope (1954 model) revealed the fact that the birefringence of götzenite is strongly decreased on heating. At a temperature of $955° \pm 10°$ C. the mineral becomes isotropic and loses its transparency. A powder pattern of the heated material showed the mineral to be decomposed. The decomposition product consists apparently of a mixture of phases the identification of which is difficult.

Götzenite is easily soluble in hot diluted hydrochloric acid.

In chemical composition, götzenite is closely related to calcium rinkite from Yukspor, Kola. Calcium rinkite may be derived from rinkite by replacing most of the rare earths by calcium. Rare earths are not present

at all in götzenite. Accordingly, the following series with decreasing rare-earth content may be established: rinkite–calcium-rinkite–götzenite. The optical and unit-cell data for rinkite and calcium rinkite being incomplete so far, an accurate comparison of these three minerals with each other is not possible. However, the entire absence of the rare

TABLE II. Chemical composition and unit-cell content of götzenite.

	%		Atomic ratio $\times 10^4$	Unit-cell content
SiO_2	32·50	Si	5409	3·98
TiO_2	9·72	Ti	1217	0·90
Al_2O_3	4·26	Al	836	0·62
Fe_2O_3	0·35	Fe^{3+}	44	0·03
FeO	0·45	Fe^{2+}	63	0·05
MnO	0·07	Mn	10	0·01
MgO	0·29	Mg	72	0·05
CaO	41·80	Ca	7454	5·49
BaO	0·09	Ba	6	0·00
SrO	0·00	Na	1565	1·15
Na_2O	4·85	K	30	0·02
K_2O	0·14	F	4384	3·23
P_2O_5	0·01	Cl	42	0·03
CO_2	0·00	SO_4	24	0·02
F	8·33	OH	287	0·21
Cl	0·15	O	20546	15·11
SO_3	0·19			
H_2O+	0·26			
H_2O-	0·14			
	103·60			
−O	3·54			
Total	100·06			

earths (and Cb, Sr) and the somewhat higher fluorine content of götzenite as well as its slightly differing optical properties seem to justify the mineral being distinguished from calcium rinkite. Götzenite is also formally related to wollastonite and pectolite.

The mineral is named after the German traveller, Count G. A. von Götzen, who was the first white man to climb Mt. Shaheru and Mt. Nyiragongo in 1894, together with a German companion.

Combeite.

Crystals are poorly developed; in some instances stout hexagonal prisms were found, a few tenths of a millimetre in length. No terminal faces are visible, and there is no cleavage. The mineral is colourless, optically uniaxial, positive; birefringence very low. Refractive indices

by the immersion method: $\epsilon \approx \omega = 1 \cdot 598 \pm 0 \cdot 002$. $D_{4°}^{20°} = 2 \cdot 844$ (pycnometer).

A series of Weissenberg photographs proved the mineral to be rhombohedral. The unit-cell dimensions were determined from rotation photographs about the a- and c-axis, respectively. The results are:

$$c = 13 \cdot 14 \pm 0 \cdot 03 \text{ Å}. \qquad c/a = 1 \cdot 260.$$
$$a = 10 \cdot 43 \pm 0 \cdot 03 \text{ Å}. \qquad \text{Volume} = 1238 \text{ Å}^3.$$

Diffraction symbol $\overline{3}mR$—. Possible space-groups $R3m$, $R32$, and $R\overline{3}m$. The powder pattern recorded with the Philips Norelco diffractometer

TABLE III. Powder pattern of combeite. Filtered copper radiation. Indices given in hexagonal notation.

$hkil$	I	2θ	d	$Q_{obs.}$	$Q_{calc.}$	$hkil$	I	2θ	d	$Q_{obs.}$	$Q_{calc.}$
$10\overline{1}1$	10	11·87	7·449	0·0180	0·0180	$20\overline{2}5$	15	39·625	2·72	0·1937	0·1938
0003	30	20·255	4·380	0·0521	0·0521	*$\overline{4}042$	15	42·28	2·136	0·2192	0·2192
$20\overline{2}2$	50	23·89	3·722	0·0722	0·0722	*$3\overline{2}15$	10	43·415	2·083	0·2305	0·2305
$11\overline{2}3$	40	26·555	3·354	0·0889	0·0889	$40\overline{4}4$	40	48·91	1·861	0·2887	0·2886
$21\overline{3}1$	70	26·96	3·304	0·0916	0·0915	$\left\{ \begin{matrix} 41\overline{5}3 \\ 5051 \end{matrix} \right.$	10	50·805	1·795	0·3104	$\left\{ \begin{matrix} 0·3094 \\ 0·3120 \end{matrix} \right.$
*$30\overline{3}0$	10	29·585	3·017	0·1099	0·1103	$\overline{2}027$	10	52·735	1·734	0·3326	0·3327
$\overline{2}024$	100	33·70	2·657	0·1417	0·1416	$20\overline{2}8$	20	59·825	1·544	0·4195	0·4196
$22\overline{4}0$	80	34·375	2·607	0·1471	0·1470	$6\overline{4}\overline{2}4$	20	61·125	1·515	0·4357	0·4356
$\overline{1}015$	10	35·52	2·525	0·1568	0·1570	*$60\overline{6}0$	20	61·575	1·505	0·4415	0·4410
$31\overline{4}2$	10	38·43	2·340	0·1826	0·1824						

* Line broad.

(filtered copper radiation) is summarized in table III. The indexing is based on the unit-cell dimensions given above.

Combeite was separated from the rock for chemical analysis by centrifuging in Clerici's solution. A microscopic test revealed that the material to be analysed was of a somewhat lower purity than the analysed material for götzenite. However, the contamination consisted mostly of the alteration product of combeite to be described below. The result of the chemical analysis and the unit-cell content, calculated on the basis of the density and X-ray data, is summarized in table IV. The following simplified formula may be tentatively written for combeite: $Na_4(Ca,Al,Fe)_3Si_6O_{16}(OH,F)_2$. The unit cell contains three formula weights. A structural formula cannot be established as long as the type of the crystal structure has not been determined.

Combeite is easily soluble in hot diluted hydrochloric acid. Much of the mineral has undergone alteration, as illustrated in fig. 3. The crystals consist mostly of an alteration product in which unaltered combeite forms irregularly shaped relics resembling olivine relics in serpentine. The alteration product has a birefringence higher than that of combeite and a wavy extinction. It is uniaxial negative with the optic axis parallel to that of unaltered combeite. The refractive indices

TABLE IV. Chemical composition and unit-cell content of combeite.*

	%		Atomic ratio $\times 10^4$	Unit-cell content
SiO_2	49·78	Si	8284	17·69
TiO_2	0·32	Ti	40	0·09
ZrO_2	0·44	Zr	35	0·07
Al_2O_3	2·45	Al	480	1·02
Fe_2O_3	1·86	Fe^{3+}	233	0·50
FeO	0·54	Fe^{2+}	75	0·16
MnO	0·58	Mn	82	0·18
MgO	0·41	Mg	102	0·22
CaO	22·68	Ca	4044	8·63
BaO	0·09	Ba	6	0·01
SrO	0·00	Na	5207	11·12
Na_2O	16·14	K	250	0·53
K_2O	1·18	F	984	2·10
P_2O_5	0·02	Cl	85	0·18
CO_2	0·00	SO_4	24	0·05
F	1·87	OH	1543	3·29
Cl	0·30	O	23423	50·02
SO_3	0·19			
H_2O+	1·39			
H_2O-	0·42			
	100·66			
−O	0·86			
Total	99·80			

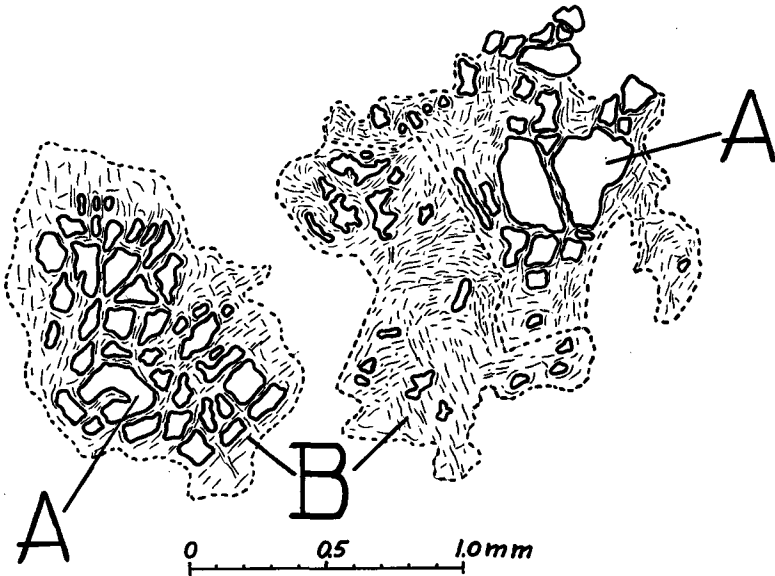* A spectrographic test showed the material to be free from rare earths.

FIG. 3. Unaltered combeite relics (A) surrounded by alteration product (B) in parallel growth.

are lower than those of combeite and vary within the range of *ca.* 1·56–1·57. No noticeable difference was found in powder pattern between pure combeite and a combeite material in which the alteration product was strongly enriched. The similarity in powder pattern and homoaxial growth of combeite and alteration product indicates that the latter is structurally and probably also chemically closely related to the former.

The data for combeite given above are not consistent with any known species. Formally, it represents an analogue to eudialyte.

The mineral is named after the late Mr. A. D. Combe, of the Geological Survey of Uganda, who contributed much to the geology of the Virunga volcanic field; the name should be pronounced kōombite.