Mineralogy. — *On the relation between the optical properties and the chemical composition of glaucophane.* By H. W. V. WILLEMS. (Communicated by Prof. H. A. BROUWER).

(Communicated at the meeting of September 25, 1937.)

The chemical composition of the alkali-amphiboles can, according to WARREN (1 p. 493), be expressed by the general formula $(Ca, Na, K, Mn)_{2-3}$ $(Mg, Fe, Ti, Al, Mn)_5\,(Si, Al)_8\,O_{22}\,(OH, F)_2$. Calculated according to this formula, the different glaucophanes and related minerals, of which in the literature the chemical composition as well as the optical properties are mentioned, give:

	n_α	n_β	n_γ	2 V	Optical orient.	Ca	Na	K	Mg	Fe^{II}	Mn^{II}	Fe^{III}	Ti	Al	Si
1	1.606	—	1.627	—	y = b	0.15	1.83	0.12	2.62	0.61	—	0.12	—	1.91	7.79
2	1.615	—	1 634	41°	,,	0.10	1.81	0.11	2.14	0.95	—	0.30	—	1.76	7.86
3	1.618	—	1.637	—	,,	0.19	1.74	0.11	1.85	1.26	—	0.20	—	1.85	7.91
4	1.619	—	1.640	—	,,	0.49	1.50	0.10	2.32	1.24	—	0.25	—	1.47	7.86
5	1.621	1.633	1 640	76—80°	,,	1.16	1.46	0.05	3.71	—	—	0.88	0.12	0.64	7.58
6	1.622	—	1.640	—	,,	0.06	1.82	0.15	1.54	1.61	—	0.17	—	2.04	7.78
7	1.629	—	1.651	—	,,	1.67	0.19	0.02	4.08	0.78	0.03	0.15	—	0.10	7.88
8	1.640	—	1.652	—	,,	0.24	1.75	0.07	1.55	1.42	0.04	0.76	—	1.40	7.84
9	1.655	1.664	1.668	42°	,,	0.33	1.67	0.13	1.99	0.99	—	1.69	0.04	0.63	7.67

	$\frac{Na+K}{Al+Fe^{III}}$	$\frac{Al+Fe^{III}}{Ca+Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$	$\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Ca+Mg+Al}$	$\frac{Ca}{Ca+Fe^{III}+Al}$	$\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$
1	0.96	0.37	0.16	0.07	0.14
2	0.93	0.39	0.31	0.05	0.24
3	0.90	0.38	0.38	0.08	0.28
4	0.93	0.30	0.35	0.22	0.28
5	0.99	0.24	0.16	0.43	0.17
6	0.89	0.41	0.49	0.03	0.33
7	0.84	0.04	0.16	0.87	0.19
8	0.84	0.40	0.70	0.10	0.43
9	0.78	0.41	0.91	0.12	0.51

1. glaucophane, Zermatt (2. p. 198).
2. „ Champ de Praz (2. p. 198).
3. „ Smyrna (2. p. 198).
4. „ Mt. Salève (2. p. 202).
5. tremolite-glaucophane, Krivoi Rog (3. p. 234).
6. glaucophane, Cyclades (2. p. 198).
7. actinolite, Comet Vale (4. p. 1).
8. crossite, Berkeley (2. p. 198).
9. ternovskite, Krivoi Rog (3. p. 233).

In all these analyses the replacement of Si by Al + Na is of very subsidiary importance, for Si differs only slightly from the theoretical amount = 8. Also in all of them $Na + K < Al + Fe^{III}$, but the difference never amounts to very much, for the proportion $\frac{Na + K}{Al + Fe^{III}} = 0.78—0.99$ as is shown in fig. 1. The amount of glaucophane-riebeckite is therefore

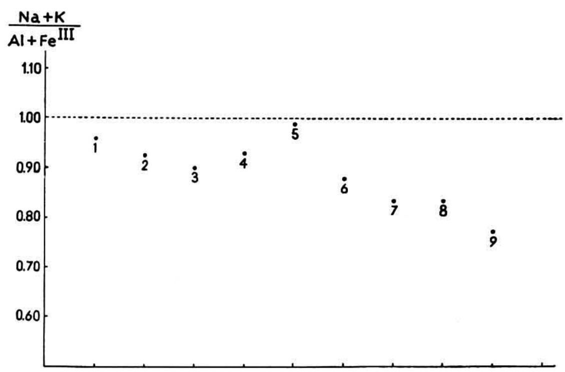

Fig. 1. Graphic representation of the proportion $\frac{Na+K}{Al+Fe^{III}}$ (the numbers refer to those of the analyses).

mainly determined by $Al + Fe^{III}$, the more so because in the determination of Al_2O_3 and Fe_2O_3 the general tendency is to find these too high, on account of:

1. non- or partial determination of SiO_2 in the R_2O_3 precipitate.
2. non-determination of MnO, TiO_2, P_2O_5, ZrO_2, rare earths, etc.
3. oxidation of Fe^{II} to Fe^{III} while in the determination of Na_2O and K_2O there is a tendency to low results. Furthermore the proportion

$$\frac{Al + Fe^{III}}{Ca + Mg + Fe^{II} + Mn^{II} + Fe^{III} + Al} \leqq \pm 0.40,$$

as is shown in fig. 2, which is in agreement with the formulas for glaucophane = $Na_4Mg_6Al_4Si_{16}O_{44}(OH, F)_4$ and riebeckite = $Na_6Fe^{II}_6Fe^{III}_4$

$Si_{16}O_{46}(OH)_2$ given by BERMAN (5. p. 359) and with the conceptions of

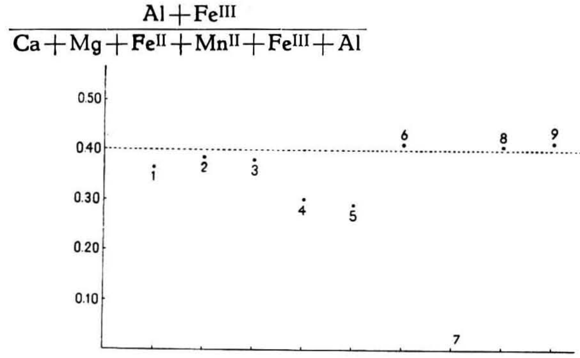

Fig. 2. Graphic representation ot the proportion $\frac{Al+Fe^{III}}{Ca+Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$ (the numbers refer to those of the analyses).

KUNITZ (2. p. 204) concerning the miscibility between glaucophane-riebeckite and tremolite-actinolite. It is possible that the proportion

$$\frac{Al + Fe^{III}}{Ca + Mg + Fe^{II} + Mn^{II} + Fe^{III} + Al}$$

amounts to more than 0.40 on account of:

1. replacement of Si by Al + Na.
2. determinations of Al_2O_3 and Fe_2O_3 being apt to be high, as already set forth.
3. FeO being frequently found too low.
4. non-determination of MnO.

Those analyses also show that it is impossible to express the chemical composition in what are usually called endmembers as glaucophane = $Na_2Mg_3Al_2Si_8O_{22}(OH, F)_2$, riebeckite = $Na_3Fe^{II}_3Fe^{III}_2Si_8O_{23}(OH)$, tremolite = $Ca_2Mg_5Si_8O_{22}(OH)_2$ and actinolite = $Ca_2Fe^{II}_5Si_8O_{22}(OH)_2$. Then for instance Mg $\geqq$ 1.5 Al, while glaucophane of Smyrna contains only 1.54 Mg and 2.04 Al. Therefore the relation between the optical properties and the chemical composition cannot be plotted in the familiar diagrams. Careful examination of those analyses, however, shows that both refractive indices, n_α and n_γ, increase rather gradually with increasing content of $Fe^{II} + Mn^{II} + Fe^{III}$, as is graphically represented in fig. 3, in which is plotted the relation between the refractive indices n_α and n_γ and the proportion $\frac{Fe^{II} + Mn^{II} + Fe^{III}}{Mg + Ca + Al}$. Though it is possible to draw a smooth curve through the analyses 1, 2, 3, 6, 8 and 9, the remaining ones, 4, 5 and 7, deviate very much, but those are the very analyses for which according to fig. 2 the proportion $\frac{Al + Fe^{III}}{Ca + Mg + Fe^{II} + Mn^{II} + Fe^{III} + Al}$ amounts to much less than 0.40. The lower this proportion, the more the refractive indices will deviate from the curves, as will be easily seen from combining with each other the figs 2 and 3. Apparently the optical

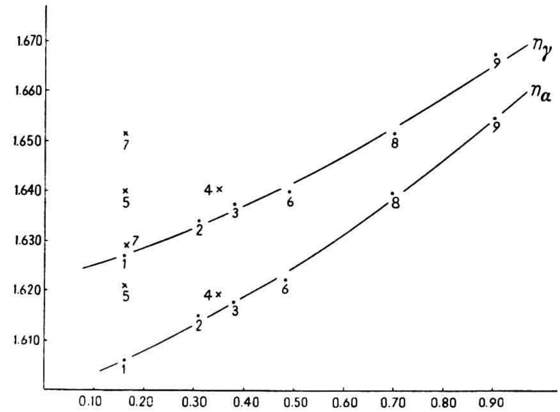

Fig. 3. Relation between the refractive indices and the proportion $\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Mg+Ca+Al}$ (the numbers refer to those of the analyses).

properties are not only dependent on the amount of $Fe^{II}+Mn^{II}+Fe^{III}$ but also on the amount of Ca that is present; in other words they seem to be largely controlled by the relation of glaucophane to riebeckite, as

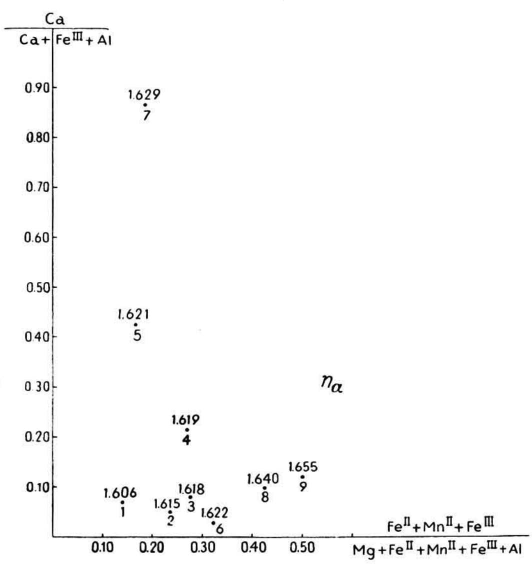

Fig. 4. Graphic representation of n_α (the numbers refer to those of the analyses).

well as by the proportion of glaucophane + riebeckite to tremolite + actinolite. The proportion of tremolite + actinolite to glaucophane + riebeckite can be expressed by $\frac{Ca}{Ca+Fe^{III}+Al}$ and the proportion of riebeckite to glaucophane as well as the proportion of actinolite to tremolite by $\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$. Plotting the optical constants against these two proportions gives the figs 4 and 5, from which can

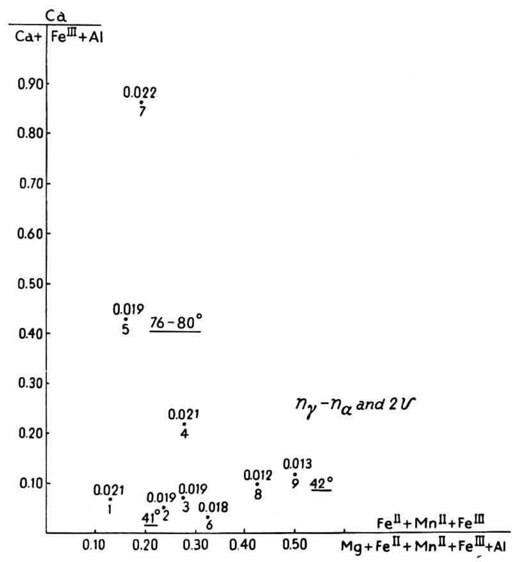

Fig. 5. Graphic representation of $n_\gamma - n_\alpha$ and 2V (the numbers refer to those of the analyses).

be seen that the refractive indices increase rapidly with increasing $\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$, but slowly with increasing $\frac{Ca}{Ca+Fe^{III}+Al}$. On the other hand, the birefringence decreases with increasing $\frac{Fe^{II}+Mn^{II}+Fe^{III}}{Mg+Fe^{II}+Mn^{II}+Fe^{III}+Al}$ and probably increases slightly with increasing $\frac{Ca}{Ca+Fe^{III}+Al}$, as probably does also 2V, so that, as far as our present knowledge of glaucophane is concerned, it seems possible to some extent to predict the chemical composition of a glaucophane, when its refractive indices and 2V are known.

LITERATURE.

1. B. E. WARREN: The crystal structure and chemical composition of the monoclinic amphiboles. Zt. f. Krist. **72**, p. 493, 1930.
2. W. KUNITZ: Die Isomorphieverhältnisse in der Hornblendegruppe. N. J. Min. Geol. Pal. BB, **60** A, p. 171, 1930.
3. I. POLOVINKINA: On some interesting amphiboles from the rocks of Krivoi Rog. Mém. Soc. Russe. Min. **53**, p. 199, 1924.
4. E. S. SIMPSON: Contributions to the mineralogy of Western Australia. Journ. Roy. Soc. W. Australia, **22**, p. 1, 1936. Min. Mag. Abstracts **6**, p. 362, 1936.
5. H. BERMAN: Constitution and classification of the natural silicates. Am. Min. **22**, p. 342, 1937.