Clinozoisite from Camaderry Mountain, Co. Wicklow.

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1. *Nature of the occurrence.*

THE clinozoisite to be described is found in veins traversing a metamorphosed basic intrusion exposed at the top of Camaderry Mountain, Glendalough, Co. Wicklow. This intrusion is a small boss of Lower
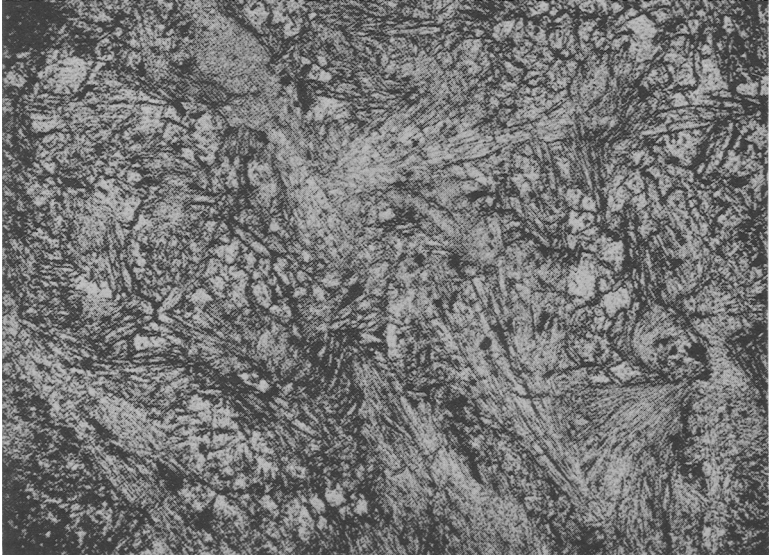

FIG. 1. Zoisite-amphibolite. ×25. This is the metamorphosed igneous rock through which the veins of clinozoisite and albite run. Small grains of zoisite and clinozoisite are enfolded by radiating fibres of tremolite. Sphene is a common accessory mineral.

Palaeozoic age which has been metamorphosed both by earth movement and by the intrusion of the Leinster granite. The rock exposed is now an amphibolite (fig. 1) within which are found the veins carrying clinozoisite with albite and a little prehnite, sphene, and tremolite.

These veins, which are up to an inch in width, were probably introduced during the late stages of the basic intrusion as veins of lime-rich plagioclase.

Preliminary examination under the microscope shows that the clinozoisite is well crystallized, fresh, and free from inclusions. The colour in the hand-specimen is grey-white; in thin section it is colourless. Individual crystals are found up to 5 mm. in length. Twinning and intricate zoning are common.

2. *Specific gravity and separation.*

The clinozoisite was separated from the other minerals of the vein by the use of heavy liquids and the centrifuge. A section of the vein was first broken down and passed through a 90-mesh sieve, then panned to remove the dust. Methylene iodide diluted to a specific gravity of 3·00 floated off the albite, prehnite, and amphibole. Next a liquid of specific gravity 3·40 was used to separate the clinozoisite from the sphene.

By a gradual reduction of the specific gravity of this last liquid it was found possible to separate the grains of clinozoisite into two fractions. The specific gravity of the liquid which effected this separation was determined as 3·372 at 18° C. The average specific gravities of the two fractions were 3·370 and 3·375 at 18° C.

3. *Optical properties.*

The intricate zoning of many of the crystals presents a variety of optical properties within a single specimen. Values for the refractive indices, double refraction, optic axial angle, and extinction angle $\alpha:c$ were measured for the central and outside zones.

TABLE I. Optical data.

	Central zones.			Outer zones.
α	...	1·710	α	...	1·712
β	...	1·712–1·713	β	...	1·715–1·716
γ	...	1·716	γ	...	1·719
$\gamma-\alpha$	...	0·006	$\gamma-\alpha$	...	0·007
$2V\gamma$	...	14–20°	$2V\gamma$	...	68–78°
$\alpha:c$	...	50–60°	$\alpha:c$	...	3–10°

These readings were made in monochromatic mercury yellow light (579 $\mu\mu$). The refractive indices are subject to an error of $\pm0\cdot002$. The central zones correspond to the lighter fractions (sp. gr. 3·370) and the outer zones to the heavier (sp. gr. 3·375). Values for 2V and $\alpha:c$ were measured on a Fedorov stage.

Values of $\alpha:c$ in the crystal shown in fig. 2 were measured for both

halves of the twin, using a mercury lamp with filters for yellow (579 $\mu\mu$) and blue (436 $\mu\mu$). These values for the direction α are represented diagrammatically in fig. 3. In all cases α is in the obtuse angle β.

Figs. 4 and 5 are illustrations of zoned twins similar to that in fig. 3. Note that the boundaries between the zones are sometimes parallel with a crystallographic direction, sometimes irregular.
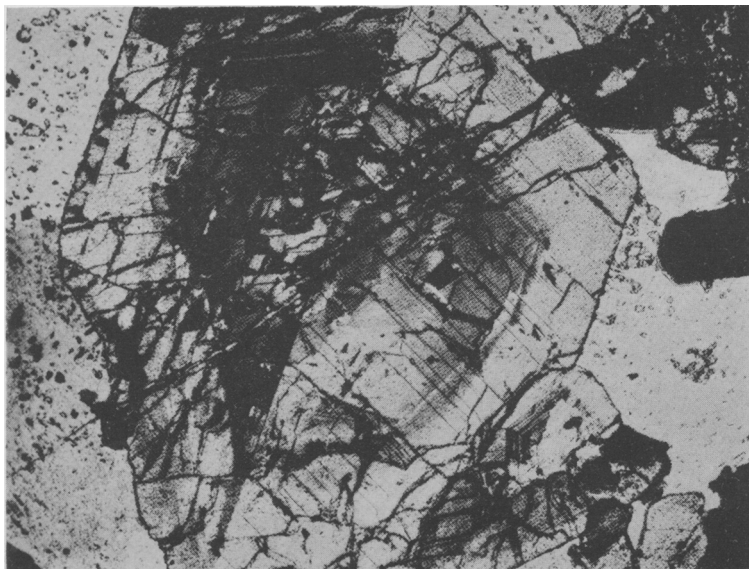

Fig. 2. Clinozoisite from vein. ×25. Crossed nicols. Wratten A (red) filter. A well-developed crystal of clinozoisite surrounded by albite. The twinning, zoning, and cleavages stand out clearly. The interference colours are anomalous—browns, blues, and yellow-blues.

TABLE II. Measured values for the extinction angle $\alpha : c$.

Fig. 3.—	Left half.			Right half.	
	Yellow.	Blue.		Yellow.	Blue.
	62°	35°	central zone	—	—
	53	30	⏐	51°	29°
	44	22	⏐	43	21
	11	9	⏐	3	3
	17	13	outwards	10	7
	11	9	↓	3	3

Note that the small central area with the high-extinction values is not present in the right half of the crystal. Note also the reversal of the trend in the one from outermost zone.
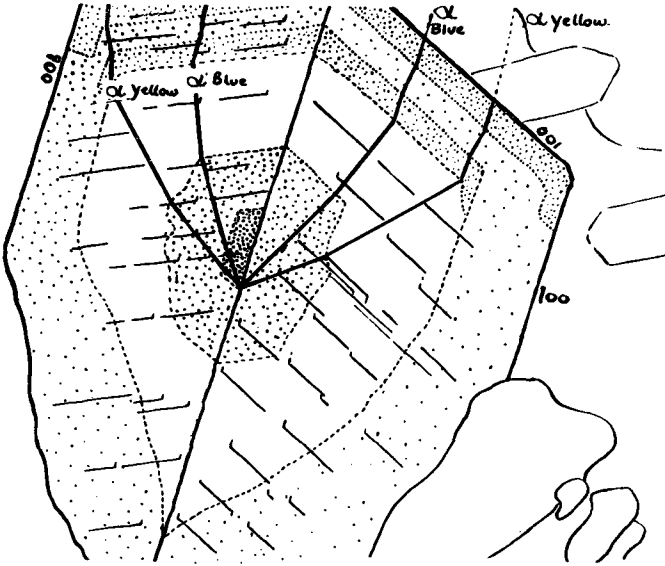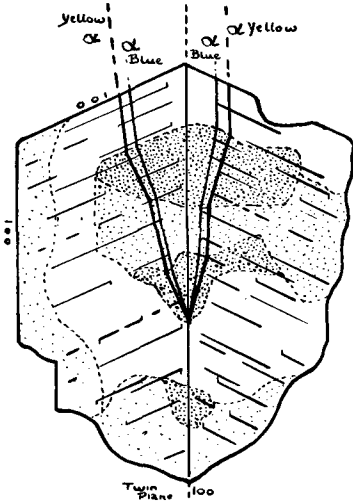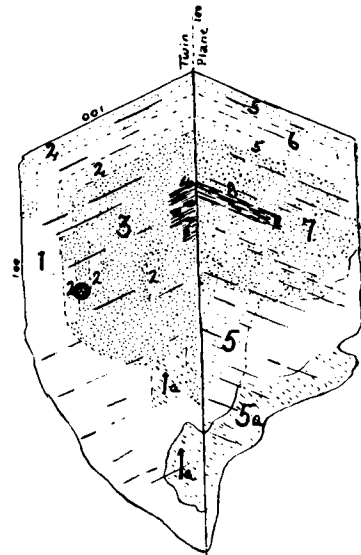
FIG. 3.

FIG. 4.   FIG. 5.

FIGS. 3–5. Twinned and zoned crystals of clinozoisite, showing
extinction directions.

TABLE II (cont.).

Fig. 4.—	Left half.			Right half.	
	Yellow.	Blue.	Zone.	Yellow.	Blue.
	23°	20°	Heavy stipple	16°	10°
	11	11	Light stipple	3	3
	8	8	Plain	—3	—1

Fig. 5.—	Left half.			Right half.	
Zone.	Yellow.	Blue.	Zone.	Yellow.	Blue.
1a,	7°	7°	5a,	—3°	—5°
1,	11	10	5,	1	0
2,	17	13	6,	5	4
3,	41–51	22–27	7,	15–30	12–17
4,	67	47	8,	42	28

The graph (fig. 6) shows that the values for 2V and $\alpha:c$ are related to one another in a definite manner. Since the data are drawn from
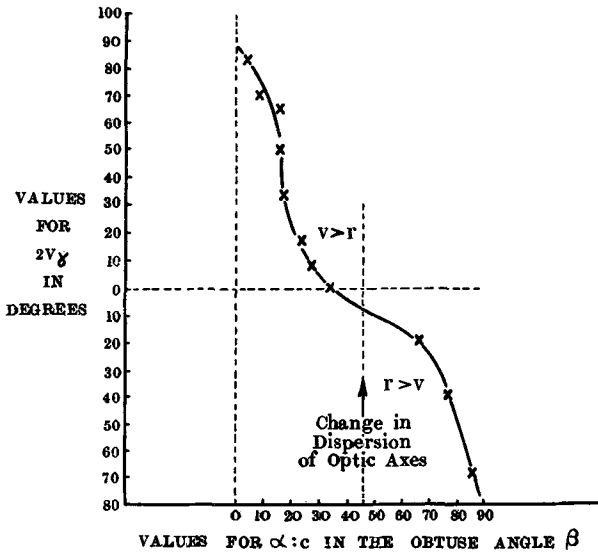

FIG. 6. Graph showing the trend in the relationship between 2V and $\alpha:c$ in clinozoisite.

only two sources, Orlov and this paper, the curve must be regarded as provisional and indicative of the trend of the relationship only.

When the physical and optical properties of the clinozoisites are plotted (fig. 7) against the total iron content expressed as Fe_2O_3 it is

found that the values for the refractive indices, double refraction, and specific gravity respond regularly to a change in the percentage of Fe_2O_3, but that the values for 2V and α:c behave in an irregular manner when
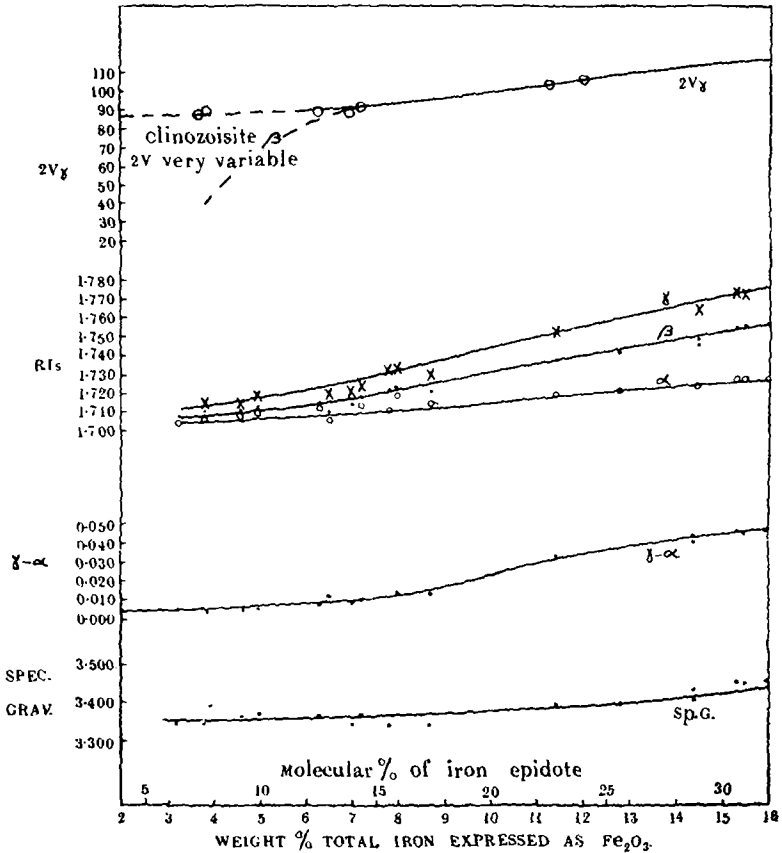

FIG. 7. The physical properties of the epidote-clinozoisite series plotted against the total content of iron expressed as Fe_2O_3.

the tenor of Fe_2O_3 drops below about 5 %. Possibly the physical conditions prevailing at the time of crystallization exerted a greater influence on these properties than a change in the content of iron.

Dispersion of the optic axes.—The dispersion of the optic axes is very variable. Observations on the Camaderry material show that it is feeble $v > r$ in the outer zones where the α:c angle is small, but that it

becomes strong in the central zones as the extinction angle increases, changing in character to $r > v$. Accurate observations were made by Orlov who stated that the maximum dispersion occurs when $2V_\gamma$ is about zero. It reaches a maximum value of about $20°$. The change from $v > r$ to $r > v$ takes place when $\alpha:c$ reaches about $45°$.

Elongation.—The crystals of clinozoisite are normally elongated parallel with the crystallographic axis b. Examples which show a marked zonary structure sometimes display a difference in the sign of elongation for the centre and outer zones. This is caused by the rotation of the ellipsoid bringing α or γ more nearly transverse to the elongation.

4. Chemical analyses.

The chemical analyses of the two fractions presented no unusual features. The H_2O content was tenacious but came off successfully when heated with an oxy-coal-gas blow-lamp. The results are given in table III.

TABLE III. Chemical analyses of clinozoisite.

1. Fraction of average specific gravity 3·370 representing the inner portion of the zoned crystals.
2. Fraction of average specific gravity 3·375 representing the outer portions of the zoned crystals.

	1.	Mol. props.	Metal atoms.	2.	Mol. props.	Metal atoms.
SiO_2	39·08	0·651	6·01	38·01	0·633	5·84
TiO_2	trace	—		trace	—	
Al_2O_3	30·96	0·303	5·59 ⎫	31·71	0·311	5·74 ⎫
Fe_2O_3	4·13	0·026	0·48 ⎬ 6·12	4·68	0·029	0·53 ⎬ 6·30
FeO	0·42	0·006	0·05 ⎭	0·23	0·003	0·03 ⎭
MnO	0·01	—		trace	—	
MgO	0·01	—		0·01	—	
CaO	23·32	0·416	3·86	23·86	0·427	3·94
H_2O+... ...	1·86 ⎫			1·83 ⎫		
H_2O-... ...	0·01 ⎬ 0·104	1·94 1·94		0·01 ⎬ 0·103	1·90	
Total	99·80			100·34		

The metal atoms are calculated on the basis of 26(O,OH), this being the content of the unit cell. It will be seen that the ratios of the metal atoms agree reasonably well with the accepted empirical formula for the epidote-clinozoisite series $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$.

The structural formula has been studied by L. Waldbauer and D. C. McCann and by T. Ito. The latter gives the following structural formula: $Ca_2O.(Al,Fe)O_2OH.Al.AlSi_3O_9$.
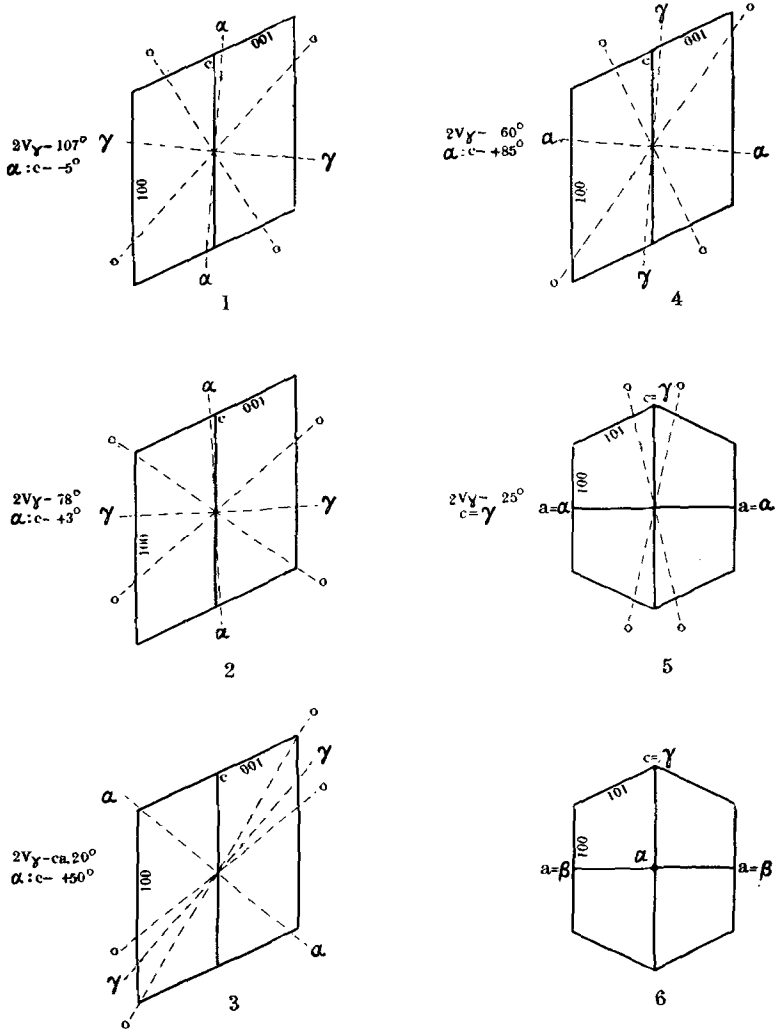
FIG. 8. A comparison of optical orientations.

1. Epidote of Weinschenk (1907).
2. Clinozoisite from Camaderry. Values from the outer portions of zoned crystals. Following Orlov this is clinozoisite-α.
3. Clinozoisite from Camaderry. Values from the inner portions of zoned crystals. Following Orlov this is clinozoisite-β, in which the angle α:c exceeds 45°.
4. Clinozoisite-β of Orlov (1926). Note the similarity to zoisite-β. Any further rotation of the ellipsoid would make the two indistinguishable.
5. Zoisite-β. Weinschenk (1907). This could be regarded as a special case of clinozoisite.
6. Zoisite-α. Weinschenk (1907).

The epidote end-member has a limiting content of Fe_2O_3 of about 16 %, since Fe replaces Al to the fullest possible extent in the formula $Ca_2O.FeO_2OH.Al.AlSi_3O_9$.

5. Data on the iron-poor members of the epidote-clinozoisite series.

Fourteen analyses extracted from the literature are listed with the analyses of the Camaderry material for comparison in table IV.

TABLE IV. Data on the iron-poor members of the epidote-clinozoisite series.

Author ...	Wein-schenk.	Hietanen.	Orlov.	Zambo-nini.	Zambo-nini.	Orlov.	Orlov.	Wein-schenk.
Locality ...	Gosler-wand.	Finland.	Horky.	Chiamper-notto.	Monte-Tovo.	Proseč.	Horky.	Zillerthal.
	%	%	%	%	%	%	%	%
SiO₂ ...	39·06	40·36	38·66	39·16	—	38·61	38·27	38·60
TiO₂ ...	—	0·09	trace	—	—	trace	trace	—
Al₂O₃ ...	32·57	30·67	31·94	30·93	—	31·22	31·69	31·71
Fe₂O₃ ...	1·68	0·61	2·58	3·18	3·01	2·80	3·01	3·52
FeO ...	0·29	1·77	0·61	0·32	0·64	0·96	0·79	0·35
MnO ...	trace	—	0·06	0·17	—	0·07	0·07	trace
MgO ...	—	0·74	0·10	0·08	—	0·10	0·14	—
CaO ...	24·53	22·62	24·39	24·11	—	24·42	24·19	24·22
Na₂O ...	—	—	—	—	—	0·03	—	—
K₂O ...	—	—	—	—	—	trace	—	—
H₂O+ ...	}2·01	3·50	1·72	2·18	—	1·69	1·65	}1·95
H₂O− ...		—	0·10	0·21	—	0·05	0·09	
F ...	—	—	0·03	—	—	0·02	—	—
Total ...	100·14	100·36	100·19	100·34	—	99·97	99·90	100·35
% Total iron as Fe₂O₃...	2·00	2·56	3·25	3·53	3·71	3·86	3·88	3·90
α ...	1·7176	min. 1·670	1·706	—	—	>1·710	>1·707	1·7238
β ...	1·7195	1·674	1·708–1·710	1·7153	—	1·711–1·711	1·709–1·711	1·7291
γ ...	1·7232	max. 1·681	1·712	—	—	<1·716	<1·712	1·7343
γ−α ...	0·0056	0·013	0·006	—	—	0·006	0·005	0·0105
2Vγ ...	81° 40′	31–55°	very variable	—	88° 50′	very variable	89° 16′
α:c ...	2°	—	see graph	2·5–8°	3–6°	see graph	0°
Sp. gr. ...	3·372	3·215–3·230	3·343–3·366	—	—	3·343–3·366	3·3985

Author ...	Johnston.	Johnston.	Forbes.	Shannon.	Lacroix.	Thomas.	Tempel.	Forbes.
Locality ...	Cama-derry.	Cama-derry.	Hunting-ton.	Trumbull.	Ariège.	Inverness.	Zillerthal.	Zillerthal.
SiO₂ ...	39·08	38·01	37·99	36·89	38·95	39·02	37·80	—
TiO₂ ...	trace	trace	—	—	—	trace	0·10	—
Al₂O₃ ...	30·96	31·71	29·53	28·50	28·90	28·64	27·63	—
Fe₂O₃ ...	4·13	4·68	5·67	5·92	5·75	6·81	7·62	6·97
FeO ...	0·42	0·23	0·53	0·52	1·08	0·34	0·19	0·89
MnO ...	0·02	trace	0·21	0·02	—	trace	0·04	—
MgO ...	0·01	0·01	—	0·21	0·35	trace	0·29	—
CaO ...	23·32	23·86	23·85	27·26	22·80	23·73	24·56	—
Na₂O ...	—	—	—	—	—	—	—	—
K₂O ...	—	—	—	—	—	—	—	—
H₂O+ ...	1·86	1·83	}2·04	}1·29	}1·90	}1·76	}1·83	—
H₂O− ...	0·01	0·01						—
F ...	—	—	—	0·60	—	—	—	—
Total ...	99·80	100·34	99·82	101·21	99·73	100·30	100·06	—
% Total iron as Fe₂O₃...	4·60	4·93	6·25	6·49	6·94	7·18	7·83	7·95

TABLE IV (*cont.*).

Author. Locality.	Johnston. Cama- derry.	Johnston. Cama- derry.	Forbes. Hunting- ton.	Shannon. Trumbull.	Lacroix. Ariège.	Thomas. Inverness.	Tempel. Zillerthal.	Forbes. Zillerthal.
α ...	1·710	1·712	1·714	1·706	1·7091– 1·7103	1·714	1·712	1·720
β ...	1·712– 1·713	1·715– 1·716	1·716	1·710	1·7143– 1·7149	1·7196	1·723	1·724
γ ...	1·716	1·719	1·724	1·720	1·7200– 1·7202	1·725	1·735	1·734
γ–α ...	0·006	0·007	0·010	0·014	0·0097– 0·0111	0·011	0·023	0·014
2Vγ ...	14–20°	68–78°	89° 28′	—	86° 29′	90° 25′	—	92° 14′
α:c ...	50–60°	3–10°	2° 9′	—	—	1°	—	0°
Sp. gr. ...	3·370	3·375	3·367	—	3·344	3·37	3·324	—

6. *Conclusion.*

The clinozoisite from Camaderry Mountain is interesting for the variety of optical properties it displays. Whilst these properties have been noted before, especially by Orlov, such large values for $\alpha:c$ and small values for 2V are not usually associated with clinozoisite.

The rapid changes in these values are the result of the rotation of the ellipsoid in the optic axial plane. When the content of iron drops below about 5 %, this rotation of the ellipsoid appears to be much freer and not entirely dependent on the chemical composition. Or if it is the result of chemical change, then the sensitivity to such change must be very much greater in the iron-poor members of the series. Unfortunately the data available are insufficient to be definite about this, but it seems more probable that when the content of iron is low, other factors, such as the temperatures and pressures prevailing during the period of crystallization, may exert a greater influence on the optics than the chemical composition alone.

The similarity between clinozoisite-β with a large $\alpha:c$ extinction angle and zoisite-β as described by Termier is very marked.

In conclusion I should like to thank Professor C. E. Tilley for his very able supervision of my work and Dr. S. R. Nockolds for his encouragement and suggestions.

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