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Barium-felspars (celsian and paracelsian) from Wales.

By L. J. SPENCER, C.B.E., M.A., Sc.D., F.R.S.

Formerly Keeper of Minerals in the British Museum.

[Read November 6, 1941.]

IN 1911 an interesting find of barium-felspars was made in the Benallt manganese mine near Rhiw in the Lleyn peninsula of Carnarvonshire. A brief preliminary note on the occurrence was given by Mr. Arthur Russell in the same year.¹ At the same time he very generously handed over to me for crystallographic and optical description a selection of the material he had collected, while he himself made a start on the chemical analysis of the material. Chemical analyses have now, at last, been made by Miss Hilda Bennett in the Mineral Department of the British Museum, and it therefore seems time to collect together the large volume of notes on the work done in 1911.

The material was found in some abundance in a band in shales and sandstones of Ordovician age with associated lava flows and beds of volcanic tuff, and beds of black manganese ore. The unoxidized ore is mainly carbonate with some silicate.² Nearby there is an intrusive sill of dolerite, and probably the barium-felspars are the result of metamorphic action. The geology of the district has been described by Dr. C. A. Matley³ and the petrography by Dr. A. W. Woodland.⁴ From the same mine came fine crystals of natrolite, which have been further examined by Dr. M. H. Hey.⁵ In none of these publications has any mention been made of the barium-felspars.

The crystals of the barium-felspar are of two totally distinct types. One of them, described under celsian, presents the form of monoclinic crystals of typical felspar (adularia) habit. The other, paracelsian, is pseudo-orthorhombic and is the more interesting and puzzling of the two.

¹ A. Russell, An occurrence of the barium-felspar celsian in north Wales. *Nature*, London, 1911, vol. 86, p. 180.

² H. Dewey and others, Tungsten and manganese ores. *Mem. Geol. Surv., Special Reports on the Mineral Resources of Great Britain*, 1915, vol. 1, p. 49; 3rd edit., 1923, p. 71. A. W. Groves, *Manganese. Reports on the Mineral Industry of the British Empire and foreign countries*, Imperial Institute, London, 1938, 2nd edit., p. 31.

³ C. A. Matley, *Quart. Journ. Geol. Soc. London*, 1932, vol. 88, pp. 245, 246, 248, 249, 263; *Proc. Geol. Assoc. London*, 1939, vol. 50, p. 99.

⁴ A. W. Woodland, The petrography and petrology of the manganese ore of the Rhiw district (Carnarvonshire). *Proc. Geol. Assoc. London*, 1939, vol. 50, pp. 205-222. [M.A. 8-250.]

⁵ M. H. Hey, *Min. Mag.*, 1932, vol. 23, pp. 246, 248, 251-253, 257-260, 273.

PARACELSIAN.

The crystals of paracelsian have the form of simple orthorhombic crystals from which they cannot be distinguished by goniometric measurements. But when examined optically in thin sections they show complex twinning of more than one kind. The name 'paracelsian' (of E. Tacconi, 1905) was provisionally

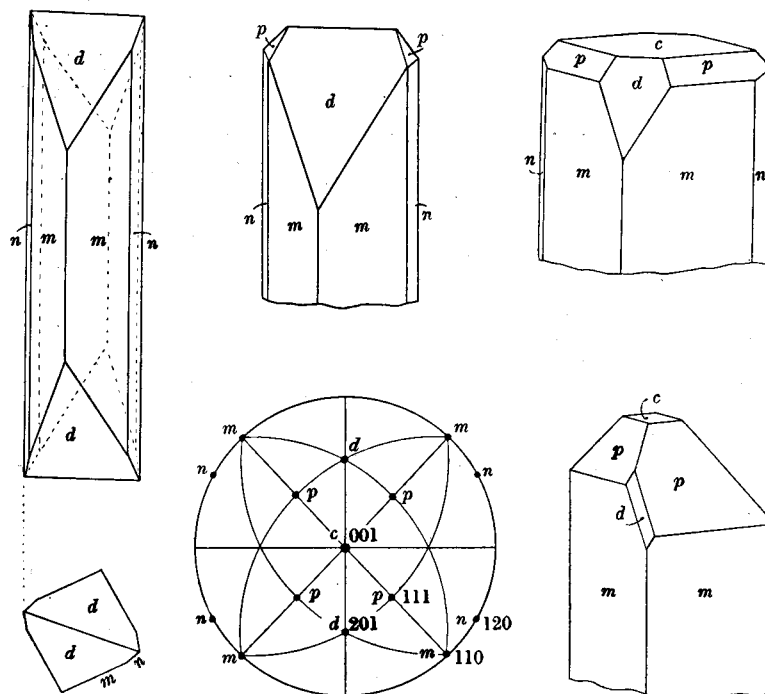


FIG. 1. Paracelsian crystals of simple orthorhombic habit from Benallt mine, Carnarvonshire; and stereographic projection of the few crystal-forms.

adopted for these crystals in 1911 and it may be retained here. The prefix para (*παρά* near) may suitably be applied to apparently dimorphous forms which can be explained by complex twinning, especially when there is no difference in specific gravity, as, for example, paracoquimbite, parahilgardite, paralaurionite, pararammelsbergite, parawollastonite, paratacamite.

The crystals (fig. 1) are prismatic in habit with very few crystal-forms, and with very much the aspect of crystals of topaz. They range from colourless and transparent to white and cloudy, and have a vitreous lustre. Clusters of crystals are confusedly aggregated together in open or more or less compact masses, and they are in part coated with oxides of iron and manganese. The largest crystals measure 5 cm. in length with a thickness of about 1 cm.; others are only a few millimetres. The specific gravity is 3.31–3.32, and the hardness rather less than 6.

In the orientation shown in fig. 1 the orthorhombic axial ratios are:

$$a : b : c = 0.9470 : 1 : 0.8956,$$

calculated from the measured angles mm^m (110) ($\bar{1}\bar{1}0$) = $86^\circ 53'$ (limits $86^\circ 36' - 87^\circ 9'$) and cd (001)(201) = $62^\circ 8'$ (limits $61^\circ 55' - 62^\circ 26'$). The calculated angles of the very few crystal-forms to the three axial planes (only one of which is actually present) are:

TABLE I. Crystal-forms and calculated angles of paracelsian.
 $a : b : c = 0.9470 : 1 : 0.8956$

Forms.	Angles to:		
	$a(100).$	$b(010).$	$c(001).$
$c(001)$	$90^\circ 0'$	$90^\circ 0'$	—
$m(110)$	$43^\circ 26\frac{1}{2}'$	$46^\circ 33\frac{1}{2}'$	$90^\circ 0'$
$n(120)$	$62^\circ 10'$	$27^\circ 50'$	$90^\circ 0'$
$d(201)$	$27^\circ 52'$	$90^\circ 0'$	$62^\circ 8'$
$p(111)$	$54^\circ 50'$	$56^\circ 57'$	$52^\circ 29'$

The faces in the prism zone are striated vertically and between m and n gave a series of measurements ranging from $3^\circ 6'$ to $16^\circ 30'$ from m , corresponding to a range of vicinal faces from (780) to (7.13.0). The crystals are usually symmetrically developed, as shown in the three upper drawings in fig. 1, and they are often doubly terminated. Some show an irregular development; e.g. one crystal with d faces at one end and a c face at the other end. Sub-parallel growth in the crystals gives rise to scattered reflections. A side-growth can sometimes be readily detached, showing a contact surface parallel to (100), which is striated horizontally.

The fracture is sub-conchoidal. Cleavage is not conspicuous and seems to be quite erratic. It was sometimes noticed parallel to $m(110)$. One crystal showed a bright and smooth cleavage parallel to (110) but a less good and interrupted cleavage parallel to ($\bar{1}\bar{1}0$). On another crystal cleavages could be developed parallel to only three of the four m faces (suggesting that the crystal is twinned). Another showed good cleavages with pearly lustre parallel to all four faces.

The axial ratios and a glance at the stereographic projection in fig. 1 at once suggest a pseudo-cubic arrangement, and the angles are not far from the corresponding cubic angles, as shown below. The agreement here is much closer than in the 'hypocubic' orientation of the feldspars.¹

	Cubic		Cubic
$(100)(110) = 43^\circ 26\frac{1}{2}'$	} $45^\circ 0'$	$(001)(111) = 52^\circ 29'$	} $54^\circ 44'$
$(001)(101) = 43^\circ 24'$		$(100)(111) = 54^\circ 50'$	
$(001)(011) = 41^\circ 51'$		$(010)(111) = 56^\circ 57'$	
$(111)(\bar{1}\bar{1}1) = 70^\circ 20'$		$(100)(201) = 27^\circ 52'$	
$(111)(1\bar{1}\bar{1}) = 66^\circ 6'$		$(010)(120) = 27^\circ 50'$	
	} $70^\circ 32'$		} $26^\circ 34'$

There is, however, a much closer and very remarkable agreement between the angles of paracelsian and those of topaz and danburite.² Interchanging the a and b axes of paracelsian and taking $p(111)$ as (121), the axial ratios and the corresponding angles are:

¹ Tables comparing the angles of feldspars with cubic angles are given by P. Niggli, *Lehrb. Min.*, 2nd edit., 1926, vol. 2, p. 548; and E. Schiebold (1931, pp. 256, 258).

² A relationship between the crystal-structure of feldspar and danburite has been described by E. Schiebold (1931, p. 305), and by W. H. Taylor (*Zeits. Krist.*, 1933, vol. 85, p. 439). [M.A. 5-473.]

Paracelsian.	Topaz.	Danburite.
$\text{BaAl}_2\text{Si}_2\text{O}_8$	$[\text{Al}(\text{F}, \text{OH})_2]_2\text{Al}_2\text{Si}_2\text{O}_8$	$\text{CaB}_2\text{Si}_2\text{O}_8$
0.5280 : 1 : 0.4728	0.5285 : 1 : 0.4770	0.5444 : 1 : 0.4807
(100) n = 27° 50'	$am(100)(110)$ = 27° 51½'	$am(100)(110)$ = 28° 34'
(100) m = 46 33½	$al(100)(120)$ = 46 35½	$al(100)(120)$ = 47 26
cd = 62 8	$cy(001)(041)$ = 62 20½	$cv(001)(041)$ = 62 31½
cp = 52 29	$cv(001)(121)$ = 52 42½	$cr(001)(121)$ = 52 33

It has not been possible to trace any relationship between the angles of paracelsian and those of normally developed felspar. As shown by the optical characters, the apparently simple orthorhombic crystals are in reality complex twins according to more than one law. But, again, it has not been possible to correlate these with the twins of normal felspar. No re-entrant angles between external faces due to twinning have been observed.

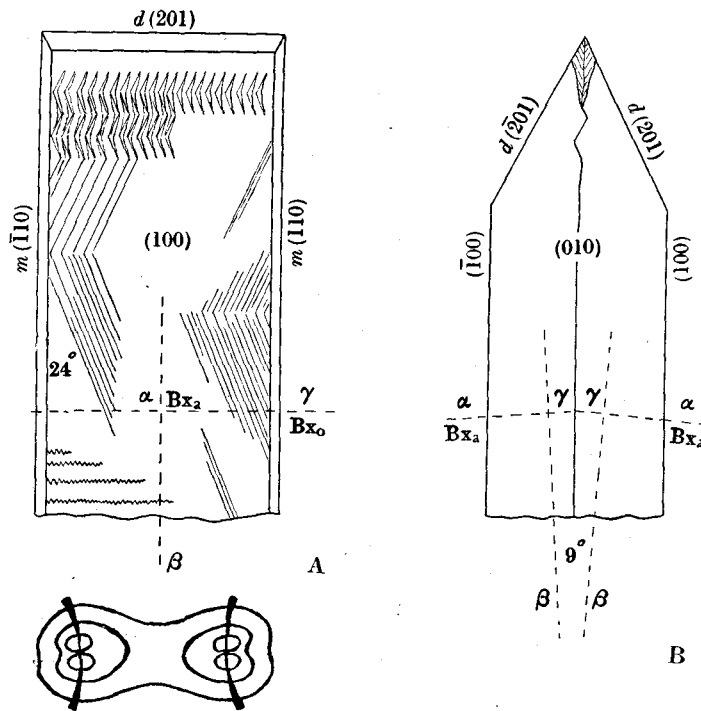


FIG. 2. Paracelsian from Benallt mine, Carnarvonshire.

A. Section parallel to (100) and nearly perpendicular to the acute bisectrix of the optic axes, showing complex lamellar twinning.

B. Section parallel to (010) and perpendicular to the obtuse bisectrix, showing a simple contact twin on (100) and lamellar twinning parallel to (201).

Fig. 2 gives diagrammatic representations of sections cut parallel to the pinakoids (100) and (010). The (010) section (fig. 2B) shows a simple twinning on (100) with an angle of 9° between the directions of optical extinction in the two halves. The (100) section (fig. 2A) gives straight extinction (parallel to the prism edge) and is nearly normal to the acute bisectrix of the optic axes. It shows a peculiar overlapping optic picture with double eyes about the horizontal line.

The acute bisectrices of the two portions of the twin are thus not quite normal to (100), and the two nearly coincident optic axial planes are not quite parallel to (001), being slightly tilted in opposite directions. The optical sign is negative. A positive figure about the obtuse bisectrix is seen in oil through (010). Moving these sections about on the microscope stage, these optic pictures perform strange antics. Passing over the twin junction in the (010) section, the picture is suddenly jerked sideways. In the (100) section the two sets of coloured rings are constantly changing in size and number, and one set may gradually pass out completely, leaving a normal picture not quite in the centre of the field. This results from a varying relative thickness in the two halves of the twin: in the (010) sections the junction line is not always parallel to the prism edge (as represented in fig. 2B).

The (100) section (fig. 2A) shows another peculiarity. When near the position of optical extinction between crossed nicols, a complex herring-bone structure becomes evident for the first time, together with longer bands and serrated lines. These indicate lamellar twinning in two directions, apparently on the dome (083). Sections parallel to (010) showed little evidence of this lamellar twinning, except occasionally at the tip of the crystal (fig. 2B). Sections parallel to (001) showed some faint twin lamellae when near the position of optical extinction (the extinction direction bisecting the angles between the prism edges). On the sub-conchoidal fracture of the crystals ripple markings, resembling those shown by amethyst, are sometimes seen. One clear and transparent crystal examined with a magnifying lens showed, at certain inclinations of the light, internal reflections from this lamellar structure.

With these complications it was not possible to cut from the crystals correctly and accurately oriented plates for the measurement of the optic axial angle and prisms for determining the refractive indices. Several prisms were cut with the refracting edges parallel to [010], [100], and [001], but somewhat variable results were obtained.

Two prisms cut from the same crystal gave:

			$\alpha.$	$\gamma.$	$\beta.$	$\gamma.$	$\gamma-\alpha.$
Li	...	...	1.5679	1.5832	1.5806	1.5835	0.0153
Na	...	...	1.5712	1.5866	1.5839	1.5869	0.0154
Tl	...	...	1.5744	1.5899	1.5871	1.5901	0.0155

Measured pairs on other crystals were:

			$\alpha.$	$\gamma.$	$\beta.$	$\gamma.$	$\beta.$	$\gamma.$	$\alpha.$	$\beta.$
Li	...	...	1.5682	1.5833	1.5836	1.5843	1.5812	1.5870	1.5634	1.5793
Na	...	...	1.5717	1.5872	1.5840	1.5869	1.5843	1.5848	1.5702	1.5824
Tl	...	...	1.5747	1.5904	1.5870	1.5901	1.5876	1.5905	1.5734	1.5867

The best values from this selection of measurements seem to be:

			$\alpha.$	$\beta.$	$\gamma.$	$\gamma-\alpha.$
Li	...	...	1.5634	1.5793	1.5843	0.0209
Na	...	...	1.5702	1.5824	1.5869	0.0167
Tl	...	...	1.5734	1.5867	1.5901	0.0167

Measurements with the optic axial angle apparatus also gave varying results in different parts of the plates. In one (100) plate the mean value in sodium-light was $2E\ 85^\circ\ 11'$ (limits $83^\circ\ 29'$ – $86^\circ\ 22'$), corresponding to $2V_a\ 50^\circ\ 35'$. In another (100) plate $2E\ 85^\circ\ 48'$ (limits $85^\circ\ 8'$ – $86^\circ\ 24'$). Other measurements were: $2E_{Li}\ 82^\circ\ 50'$, $2E_{Na}\ 83^\circ\ 31'$, $2E_{Ti}\ 84^\circ\ 29'$; $v > r$. A (010) plate measured in oil gave $2H_o\ 144^\circ\ 25'$, corresponding to $2V_o\ 129^\circ\ 52'$ (Na), and $2V_a + 2V_o = 180^\circ\ 27'$.

The chemical analysis of paracelsian made by Miss Hilda Bennett is given under I (table II) with the molecular proportions under Ia. It agrees closely with the formula $BaAl_2Si_2O_8$, analogous to that of anorthite. A spectroscopic analysis of paracelsian kindly made in the Research Laboratories of the General Electric Company at Wembley showed, in addition to Ba, Al, Si, the presence of traces of Fe, Mn, Cu, Mg, Ca, and B.

TABLE II. Chemical analyses of paracelsian and celsian.

	I.	Ia.	II.	IIa.	$BaAl_2Si_2O_8$.
SiO ₂	33.01	0.5496	32.68	0.5441	32.00
TiO ₂	trace	—	0.08	—	—
Al ₂ O ₃	27.16	0.2664	27.28	0.2676	27.15
Fe ₂ O ₃	0.28	—	0.40	—	—
MnO	trace	—	0.13	—	—
BaO	38.53	0.2512	38.94	0.2539	40.85
SrO	nil	—	nil	—	—
CaO	0.06	0.0011	0.08	0.0014	100.00
MgO	0.14	0.0035	0.26	0.0065	
Na ₂ O	0.15	0.0024	nil	—	
K ₂ O	0.54	0.0057	0.18	0.0019	
SO ₃	—	—	0.15	—	
H ₂ O+	0.05	—	0.08	—	
H ₂ O-	nil	—	0.05	—	
	99.92		100.31		
Sp. gr.	3.29		3.31		

I. Paracelsian, Benallt mine, Rhiw, Carnarvonshire. Weight used 5 grams. Analyst, Miss Hilda Bennett, 1941. Ia, molecular proportions.

II. Celsian, same locality. Weight used 4 grams. Analyst, Miss Hilda Bennett, 1941. IIa, molecular proportions.

CELSIAN.

A massive granular rock consists entirely of celsian showing bright cleavage surfaces. It is reddish-brown in colour with a somewhat greasy lustre, and is speckled and veined with red iron oxide and black manganese oxide. In cavities there are two distinct habits of crystals:

- (1) Larger, stout, short-prismatic crystals of adularia habit, rich in crystal-forms, and usually twinned on the Manebach and Baveno laws. They average 1 cm. across, the largest being $1\frac{1}{2}$ cm.
- (2) Long, slender to acicular, prisms with few crystal-forms, usually simple, but occasionally twinned on the Carlsbad law. They measure 1–5 mm. in length with a thickness of 0.05–1 mm. Shorter and thicker crystals of this type may show a gradation to smaller crystals of type (1).

The crystals of both kinds are colourless and transparent, but are partly coated with black and white powdery material that can usually be easily rubbed off, while the larger crystals enclose films of iron and manganese oxides. They

occur together in the cavities of the rock, and they appear to have grown together at the same period, though in some cases crystals of habit (2) are deposited on those of habit (1). While in each cavity there are only a few of the larger twinned crystals (habit 1), the walls of the cavity may be encrusted with thick clusters of acicular crystals (habit 2). This association of a few large twinned crystals with a crowd of small slender prisms is similar to that shown by calcite on specimens from Egremont in Cumberland and Wheal Wrey in Cornwall. No crystals of paracelsian were found in this celsian-rock. Of the many specimens of paracelsian examined only a few showed the presence of celsian crystals of habit 2 (none of habit 1) deposited on the paracelsian crystals. Apart from the staining of iron and manganese oxides, the only other mineral found on the celsian specimens was one crystal of green baryte.

In marked contrast with the crystals of paracelsian, those of celsian always show a prominent $c(001)$ cleavage with pearly lustre, and also a less perfect $b(010)$ cleavage.

Approximate determinations of the specific gravity were made by floating the measured crystals in methylene iodide. Crystals of habit 1 gave 3.31-3.33, while those of habit 2 gave 3.17-3.19. The difference may perhaps be due to attached impurities on the very slender prisms.

Several crystals were measured in many zones on the goniometer, and from a selection of the better readings the following axial ratios were calculated. These ratios are compared with previous results obtained on allied minerals:

	Limits.	No.	Mean.
$cm(001)(110)$	68° 30'-68° 41'	26	68° 37'
$co(001)(\bar{1}11)$	54 27-54 34	15	54 31
$oo'(\bar{1}11)(\bar{1}\bar{1}1)$	53 20-54 26	6	53 23
		$a : b : c.$	$\beta (ac).$
Celsian (Spencer) ... ..	...	0.6613 : 1 : 0.5518	64° 51'
Celsian (Strandmark, 1903) ... ..	...	0.657 : 1 : 0.554	64 58
Hyalophane (Baumhauer, 1903) ... ..	...	0.6582 : 1 : 0.5523	64 16
Orthoclase (Koksharov, 1866) ... ..	...	0.6585 : 1 : 0.5554	63 57

Eighteen crystal-forms were identified, eleven of which are new for celsian; but most of these correspond to forms already known on orthoclase and hyalophane, and for them Dana's letters for orthoclase have been adopted. The following particulars are given for the three forms not recorded on orthoclase or hyalophane.

$J(\bar{4}23)$, small face on five crystals; dull, although adjacent faces are bright. Measured Jc 63° 35'; Jb 73° 17', 73° 32'; Jy (in the zone $[ym]$) 23° 13', 23° 16', 23° 28', 23° 26' (calculated 23° 13').

$F(112)$, long narrow face on the edge ce , on two crystals. Measured Fc 21° 2', 21°.

$G(131)$, narrow on edge eb , two faces on one crystal. Measured Gb 45°, 46°.

In addition to the eighteen crystal-forms found on the Welsh crystals, there are included in the table of calculated angles (table III) and on the stereographic projection (fig. 5A) the forms $(\bar{1}14)$, (311) , and (331) found by J. E. Strandmark (1903) on celsian from Jakobsberg, Sweden, and (310) found by E. Tacconi (1911) on celsian from Candoglia, Piedmont; these are here lettered U , V , W , Y , respectively.

TABLE III. Crystal-forms and calculated angles of celsian.

$$a : b : c = 0.6613 : 1 : 0.5518, \beta = 64^\circ 51'.$$

Forms.	Angles to:		
	$a(100)$.	$b(010)$.	$c(001)$.
$a(100)$ narrow	—	$90^\circ 0'$	$64^\circ 51'$
$b(010)$ „	$90^\circ 0'$	—	$90^\circ 0'$
$c(001)$ large... ..	$64^\circ 51'$	$90^\circ 0'$	—
$Y(310)$ (Tacconi)	$11^\circ 17'$	$78^\circ 43'$	$65^\circ 22'$
$m(110)$ large	$30^\circ 54\frac{1}{2}'$	$59^\circ 5\frac{1}{2}'$	$68^\circ 37'$
$L(120)$ narrow	$50^\circ 8'$	$39^\circ 52'$	$74^\circ 12'$
$z(130)$ „	$60^\circ 53\frac{1}{2}'$	$29^\circ 6\frac{1}{2}'$	$78^\circ 4'$
$x(101)$ small	$114^\circ 20'$	$90^\circ 0'$	$49^\circ 29'$
$y(201)$ medium	$143^\circ 57'$	$90^\circ 0'$	$79^\circ 6'$
$h(023)$ small	$66^\circ 13'$	$61^\circ 35'$	$18^\circ 25'$
$n(021)$ „	$72^\circ 30'$	$45^\circ 2'$	$44^\circ 58'$
$e(111)$ „	$39^\circ 9'$	$72^\circ 9'$	$33^\circ 46'$
$F(112)$ narrow	$48^\circ 7'$	$78^\circ 35'$	$21^\circ 2'$
$G(131)$ „	$54^\circ 31'$	$45^\circ 59'$	$51^\circ 5'$
$U(\bar{1}14)$ (Strandmark)	$76^\circ 41'$	$82^\circ 21'$	$13^\circ 3'$
$g(\bar{1}12)$ small	$89^\circ 31'$	$74^\circ 34'$	$28^\circ 49'$
$o(\bar{1}11)$ medium	$111^\circ 36'$	$63^\circ 18\frac{1}{2}'$	$54^\circ 31'$
$s(131)$ „	$103^\circ 10'$	$33^\circ 33'$	$68^\circ 58'$
$J(\bar{4}23)$ small	$125^\circ 29'$	$73^\circ 40'$	$63^\circ 34'$
$v(241)$ medium	$119^\circ 33'$	$37^\circ 36'$	$88^\circ 22'$
$V(\bar{3}11)$ (Strandmark)	$153^\circ 33'$	$77^\circ 34'$	$91^\circ 23'$
$W(\bar{3}31)$ „	$139^\circ 53'$	$56^\circ 32'$	$91^\circ 20'$

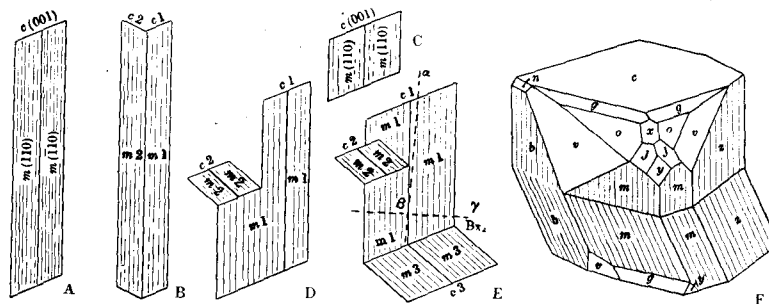


FIG. 3. Celsian crystals from Benallt mine, Carnarvonshire.

A-E, Orthographic projections on (010).

- A. Simple crystal of long-prismatic habit.
- B. Carlsbad twin of long-prismatic habit.
- C. Simple crystal of rhombohedral habit.
- D. Manebach twin with unsymmetrical development.
- E. Manebach twin with parallel repetition. The optical orientation is indicated in the main individual.
- F. Manebach twin, usual habit, showing many small faces.

The habit of the crystals is controlled by the predominating forms $c(001)$ and $m(110)$. When these are equally developed the habit is pseudo-rhombohedral (fig. 3c), the angles being cm $68^\circ 37'$ and mm $61^\circ 49'$. A short-prismatic habit, as in adularia, is shown in fig. 4A and a long-prismatic habit in fig. 3A. On the larger crystals the edges and corners of these forms are usually replaced by faces

of variable size, but usually small, of the common forms *zxynegov*. The forms $a(100)$ and $b(010)$ are rarely present as narrow faces in the deeply striated prism zone. The crystal represented in fig. 3F shows eleven forms; others showed 14 or 15.

Manebach twins on (001) are common and of various odd shapes (figs. 3D, E, and F; 4B). These combined with Baveno twins on (021) and (0 $\bar{2}$ 1) give fourlings (fig. 4D). Similar fourlings could also result by repeated twinning on the Baveno

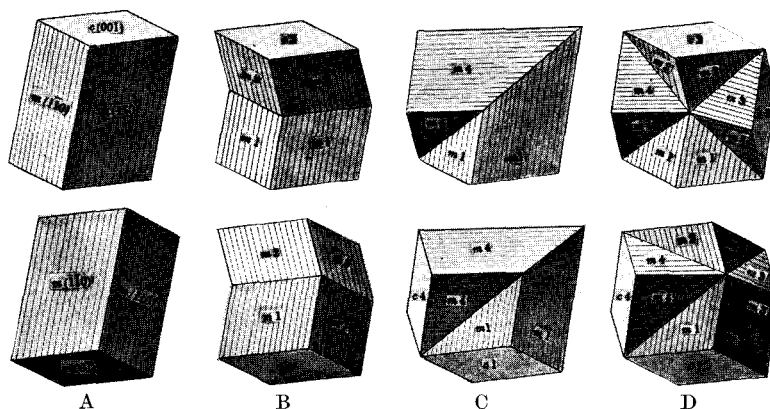


FIG. 4. Celsian crystals from Benallt mine, Carnarvonshire.

Upper row showing front view, lower row showing back view.

- A. Simple crystal of short-prismatic habit.
- B. Manebach twin of A. Re-entrant angle in front, salient angle at back, $m\bar{m}$ $42^{\circ} 46'$.
- C. Baveno twin of A. In front, re-entrant angle $m\bar{m}$ $76^{\circ} 46'$ and salient angle $m\bar{m}$ $12^{\circ} 5'$; at back, re-entrant angle $12^{\circ} 5'$ and salient angle $76^{\circ} 46'$.
- D. Manebach-Baveno fourling. In front, four re-entrant angles of $76^{\circ} 46'$; at the back, four re-entrant angles of $12^{\circ} 5'$; all the salient angles between adjacent individuals being cut out by the overlap.

law, but, since Manebach twins are here common, it is more natural to regard them as Manebach-Baveno twins. These are illustrated in fig. 4, the upper row showing the front view and the lower row the back. Carlsbad twins were found only on the long slender prisms¹ of type 1 (fig. 3B).

The re-entrant and salient angles at opposite ends of the twinned crystals are:

Manebach	...	...	cm''	$111^{\circ} 23'$	—	cm	$68^{\circ} 37'$	=	$m\bar{m}$	$42^{\circ} 46'$		
Baveno	...	...	nm''	128	23 —	nm	51	37	=	$m\bar{m}$	76	46
			nm'	96	2 —	nm''	83	57	=	$m\bar{m}$	12	5
Carlsbad	...	...	$a'c$	115	9 —	ac	64	51	=	$c\bar{c}$	50	18

In the complete Baveno twin (fig. 4C) there is in front (upper figure) a re-entrant angle of $76^{\circ} 46'$ and a salient angle of $12^{\circ} 5'$, and at the back (lower figure) a re-entrant angle of $12^{\circ} 5'$ and a salient angle of $76^{\circ} 46'$. In the fourling (fig. 4D) some of these angles are cut out, and there remains in front (upper figure) four re-entrant angles of $76^{\circ} 46'$ and at the back (lower figure) four re-entrant angles of $12^{\circ} 5'$. A stereographic projection of this fourling is given in fig. 5B.

¹ J. E. Strandmark (1903) on celsian from Jakobsberg, Sweden, mentions that Carlsbad twins are common, and he found only one each of Manebach and Baveno twins. His drawing of a Carlsbad twin shows an enormously elongated prismatic crystal.

The optical extinction of celsian on (100) is straight, i.e. parallel to the prism edge [001], and the prismatic crystals show negative elongation. The extinction on (010) referred to the same direction is 3° in the acute axial angle β , i.e. $\alpha : c = -3^\circ$. Extinction on (001) bisects the angle between the edges cm . The optic axial plane is in the plane of symmetry and the acute positive bisectrix at 3° to the normal to (100) (fig. 3E). Through the front prism edge a good optic picture is seen in oil with $2V$ nearly 90° (from approximate measurements without cutting

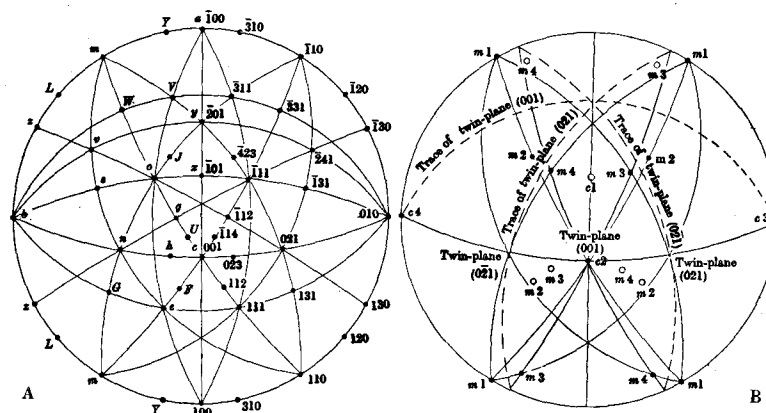


FIG. 5. Stereographic projections of celsian.

A. All the known (22) forms, including U , V , W , Y not found on crystals from Wales.
B. Manebach-Baveno fourling.

a plate). Through the perfect cleavage (001) one optic axis emerges obliquely. With this optical orientation (which agrees completely with that of Strandmark for celsian from Sweden), the refractive indices measured through the natural prism (110)($\bar{1}10$) will be β and very near α . But the results obtained, $\alpha' 1.5868$, $\beta 1.5917$ (Na), were not good, owing to the striation of the prism zone. The fine needles show the same optical orientation as the larger crystals. Refractive indices recently determined by Mr. F. A. Bannister by the immersion method on a (010) cleavage flake are $\alpha 1.580$, $\gamma 1.590 \pm 0.003$.

The results of Miss Hilda Bennett's analysis of celsian are given under II in table II (p. 236). Her first analysis was complicated by the unexpected presence of baryte, a single crystal of which must have been inadvertently included amongst the cleavage fragments collected. In this material the presence of baryte was shown by an X-ray powder photograph taken by Mr. F. A. Bannister. A sample submitted to the Research Laboratories of the General Electric Company at Wembley for spectroscopic analysis showed, in addition to Ba, Al, Si, appreciable amounts of Fe and Mn, and traces of Cu, Ni, Sb, Mg, Ca, and B. Miss Bennett's complete analysis leads to the same formula, $BaAl_2Si_2O_8$, as that given by her analysis of paracelsian.

X-ray powder photographs of celsian and paracelsian taken by Mr. F. A. Bannister show different patterns; that of celsian being similar to adularia, while that of paracelsian is quite distinct. It is hoped that later a more detailed X-ray

examination may help to solve the perplexing relationship between these minerals.

BARIUM-FELSPARS.

Hyalophane was the first barium-felspar to be recognized and was named by W. Sartorius von Waltershausen in 1855. It came from the dolomite of the Binnenthal in Switzerland, and had previously been mistaken for adularia, which it much resembles in the monoclinic crystals. Chemical analyses show BaO 12–15 %, but the crystals are zoned and one analysis shows only 1.84 %. The composition can be expressed as an isomorphous mixture of the orthoclase (KAlSi_3O_8) and celsian ($\text{BaAl}_2\text{Si}_2\text{O}_8$) molecules. Hyalophane containing BaO 7–12 % was later found in the manganese mines at Jakobsberg and Sjögrufvan in Sweden (L. J. Igelström, 1868, 1883, 1888; G. Flink, 1914). Other localities for hyalophane are Kongsberg in Norway (C. Bugge, 1917), Franklin Furnace in New Jersey (L. H. Bauer and C. Palache, 1926), the Kaso manganese mine in Japan (T. Yosimura, 1939), and the Slyudyanka river in Siberia (P. V. Kalinin, 1939). Several analyses of orthoclase from various localities have shown the presence of small amounts of barium (A. Mitscherlich, 1860; S. L. Penfield and E. S. Sperry, 1888, and others). A tabulation of 329 chemical analyses of potash-felspars (orthoclase and microcline) in C. Hintze's 'Handbuch der Mineralogie' (vol. 2, 1897) shows the presence of barium (BaO 0.10–3.95 %) in 21 analyses. J. E. Strandmark in 1904 proposed to restrict the term hyalophane to members of the series from Or_2Cn_1 (BaO 16.4 %) to Or_6Cn_1 (BaO 7.5 %), referring to still lower members as barytiferous potash-felspar; and there was a gap in the upper part of the series to celsian. A barium-sanidine containing BaO 5 % has been described from the Highwood Mountains, Montana (E. S. Larsen and others, 1941).

Kasoite with BaO 25.50 %, described by T. Yosimura (1936), from the Kaso manganese mine in Japan, now falls in this gap. This author has made an intensive study of the barium-felspars. Chemical, optical, and specific gravity data collected from the literature, together with many new determinations on Japanese material, are tabulated and plotted on diagrams. These show a division into two groups still with an intervening gap: (1) adularia to hyalophane, and (2) kasoite to celsian. In (1) the optical orientation remains that of adularia, with the optic axial plane normal to the plane of symmetry (010) and $\gamma = b$. In (2) the optic axial plane lies in (010) with $\beta = b$ and $\alpha : c = -3^\circ$, thus differing from the orientation in sanidine. Yosimura points out that several of the analyses show a deficiency in silica, and he assumes the presence of the nepheline and kaliophilite molecules, $\text{Ne} = \text{NaAlSi}_3\text{O}_8$ and $\text{Kp} = \text{KAlSi}_3\text{O}_8$. The presence of these molecules may be the cause of the discontinuity in the plotted curves. One of the possible alternatives for the composition of kasoite is given as $\text{Cn}_{49.6}, \text{Ab}_{8.5}, \text{Ne}_{9.4}, \text{Kp}_{32.5}$.

Celsian,¹ the end-member of the series, was described by H. Sjögren in 1895 from the manganese mines at Jakobsberg, Sweden. From the chemical analysis (BaO 39.72 %) he deduced the formula $\text{BaAl}_2\text{Si}_2\text{O}_8$, but from the angles and optical orientation of cleavage flakes he considered the mineral to be triclinic

¹ Named after the Swedish astronomer Anders Celsius (1701–1744), who devised the Celsius or centigrade thermometer scale.

and a barium-anorthite. Well-developed crystals containing BaO 36.45 % from the same locality were later described by J. E. Strandmark (1903) and shown to be monoclinic. Since then celsian has been recorded from Alaska (BaO 37.7 %, W. T. Schaller, 1929), California (A. F. Rogers, 1932), and Japan (BaO 34.5 %, T. Yosimura, 1939).

Paracelsian, of abundant occurrence as grains and granular masses in calciphyre at Candoglia in Piedmont, was described by E. Tacconi in 1905. From his analysis (BaO 34.47 %) he deduced the formula as $Ba_3Al_8Si_8O_{31}$, and from the optical characters (determined in thin sections without any crystal outlines or distinct cleavage directions) he considered the mineral to be probably monoclinic or perhaps triclinic. A careful comparison was made with celsian, and indeed a new complete chemical analysis (BaO 39.71 %, yielding the formula $BaAl_2Si_2O_8$) and optical determinations were made on material from the original Swedish locality. The main difference was in the absence of any distinct cleavage in paracelsian; and mention is also made of a difference in specific gravity, paracelsian floating, and celsian sinking, in methylene iodide, although the actual difference, 3.325 and 3.37, is not really significant. These are just the points that I noticed in the Welsh crystals. Later, Tacconi (1908, 1911) found a single minute ($\frac{1}{2}$ mm.) crystal from Candoglia which gave goniometric measurements agreeing with those of Strandmark on celsian from Sweden, and he then admitted that his paracelsian was identical with celsian, although no mention was made of any cleavage. In this conclusion he appears to have been unduly influenced by Strandmark's paper, which apparently he had not previously seen. It is more probable that at Candoglia, as at the Welsh locality, both celsian and paracelsian occur together. Tacconi makes no mention of any lamellar twinning in paracelsian. In the Welsh crystals this was only faintly seen when the sections were near the position of optical extinction. His angle of 92° between indistinct cleavages perhaps corresponds to my angle $93^\circ 7'$ between the variable prismatic cleavage. His optic axial angle $2V 82^\circ 33' - 84^\circ 44'$ is near to my value $2E 83^\circ 29' - 86^\circ 22'$, suggesting possibly a misprint.

In the plagioclase-felspars barium is much less frequently present. In a tabulation of 637 chemical analyses of plagioclases in C. Hintze's 'Handbuch der Mineralogie' (vol. 2, 1897) barium appears only once, in an andesine from Bodenmais, Bavaria, with BaO 0.24 %. In 30 analyses of K-Na-felspars (anorthoclase) none shows any barium. A barium-plagioclase containing BaO 7.30 % was described from an unknown locality by A. Des Cloizeaux in 1877; and one containing BaO 5.7 % from Broken Hill, New South Wales, by S. R. Nockolds and E. G. Zies in 1933. A 'barium-albite' is mentioned by T. Yosimura (1939, p. 385) as an impurity in mangan-hedenbergite from the Kaso mine, Japan, one analysis of which shows BaO 1.28 %, and the composition of the felspar is calculated as $Ab_{44}An_{42}Cn_{14}$.

Artificial barium-felspar, $BaAl_2Si_2O_8$, has been prepared by different workers but with varying results. The earliest experiments were by F. Fouqué and A. Michel-Lévy (1880), who by fusing a mixture of the oxides obtained microliths which were apparently orthorhombic and free from twinning. E. Dittler (1911) by simple fusion obtained plates, also apparently orthorhombic and free from twinning. A. S. Ginzberg (1915) prepared mixed triclinic crystals of anorthite containing up to 20 % $BaAl_2Si_2O_8$, the excess of $BaAl_2Si_2O_8$ crystallizing as

hexagonal plates which were optically uniaxial with positive sign and called 'barium-nepheline'.¹ Hexagonal mixed crystals containing 15% KAlSi_3O_8 were also obtained. P. Eskola (1922) using a barium vanadate flux also obtained apparently orthorhombic crystals, but in reality these were Carlsbad twins with optical characters agreeing with those of natural celsian. E. Dittler and H. Lasch (1930, 1931) obtained hexagonal plates of $\text{BaAl}_2\text{Si}_2\text{O}_8$ up to 10 mm. across, which were optically uniaxial with negative sign; this was called ' α -celsian', and similar but smaller mixed crystals containing up to 30% KAlSi_3O_8 were also obtained. ' α -Celsian' has been recorded from a lead slag (W. Faber, 1935).

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¹ This high-temperature hexagonal modification of $\text{BaAl}_2\text{Si}_2\text{O}_8$ had been previously obtained by Z. Weyberg (1904) by fusing kaolin with BaCl_2 .

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