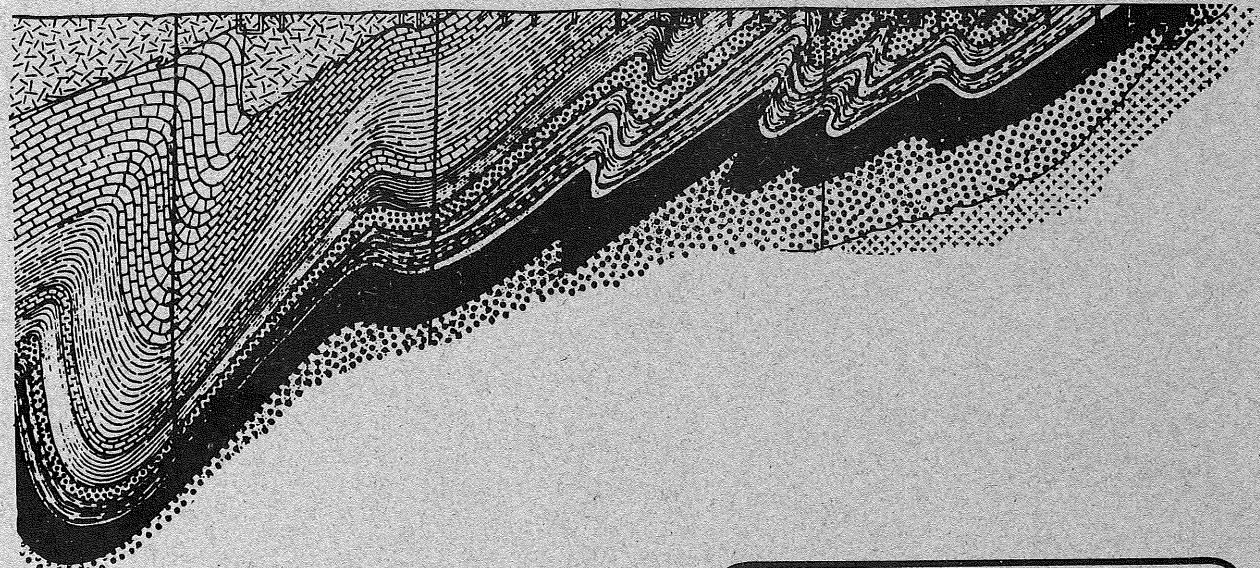




UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG



ECONOMIC GEOLOGY
RESEARCH UNIT

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THE ALTERATION OF BERYL IN THE DERNBURG PEGMATITE,
KARIBIB, SOUTH WEST AFRICA

by

C. ROERING
Research Fellow

and

R. O. HECKROODT
Research Officer
Ceramics Unit
Council for Scientific and Industrial Research
Pretoria

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THE ALTERATION OF BERYL IN THE DERNBURG PEGMATITE,
KARIBIB, SOUTH WEST AFRICA

A B S T R A C T

An altered form of beryl, containing up to 15 per cent BeO, has been found in the Demburg pegmatite approximately four miles west of Karibib. The alteration product consists of a mixture of scattered colourless glassy fragments and clay material, the whole mass being pseudomorphic after hexagonal beryl crystals. The high BeO content is contributed by the "clay fraction". Alteration caused by deuteritic pegmatite solutions has produced replacement zones of lithium-bearing mica and albite which cut across the normal zonal arrangement of the bodies, and which have narrow cleavelandite-rich borders. The altered beryl occurs where such borders are in contact with the normal beryl contained in the central core of the pegmatite. The glassy fragments of the alteration product have been identified as beryl. The cryptocrystalline "clay fraction" is composed of extremely fine-grained aggregates of bertrandite, which is responsible for the high BeO content, and of dioctahedral aluminous mixed-layer chlorite-swelling chlorite.

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THE ALTERATION OF BERYL IN THE DERNBURG PEGMATITE,
KARIBIB, SOUTH WEST AFRICA

INTRODUCTION

While engaged in prospecting the pegmatites of the Karibib area, South West Africa, Mr. J. Henckert found a peculiar "beryl" which contained up to 15 per cent BeO. Macroscopically, it can be seen that specimens of this "beryl" consist of a mixture of clay material and scattered colourless glassy fragments, the whole mass being pseudomorphic after well-defined hexagonal beryl crystals (Plate 1A).

Preliminary investigations proved that the glassy fragments are beryl, and that the "clay fraction" contributes to the high beryllia content. Chemical analysis of this "clay fraction", which was obtained by simple separation under the binocular microscope, gave a surprisingly high value of 24 per cent BeO. X-ray investigations of an identical portion of this sample indicated the presence of bertrandite - $\text{Be}_4(\text{OH})_2\text{Si}_2\text{O}_7$ - as well as of a mineral giving a well-defined reflection at about 30° . It was considered desirable to separate the bertrandite from the "clay fraction", and to identify the remaining phase(s) in order to establish whether the latter contained any beryllium.

Vernon and Williams (1960) described a micaceous pseudomorphic mixture after beryl from Queensland, Australia, which assayed 13.1 per cent BeO. The beryllia content was attributed to the presence of residual beryl and bertrandite, the grains of the latter being large enough for microscopic examination. In contrast, the South West African occurrence contains bertrandite in extremely fine-grained aggregates which do not differ much in appearance from the clay material constituting the rest of the altered beryl mass.

The altered beryl occurs in a pegmatite on the farm Dernburg, four miles west of the town of Karibib, which, itself, is approximately 90 miles west-northwest of Windhoek. The steeply-dipping pegmatite is located in quartzites of the Damara System, strikes northwestwards, has an exposed length of 1200 feet, and is 30-40 feet wide. It has been mined for beryl, amblygonite, and tantalite. Lithium-bearing mica also occurs. Zoning of the pegmatite is systematic and, the pattern of the particular section in which the altered mineral is developed is as follows :

Plan thickness

1'	-	wall zone of quartz and muscovite
1' - 10'	-	zone of albite, quartz, and muscovite
15' - 20'	-	{ coarse-grained perthite with scattered crystals of beryl and irregular crystals of quartz; beryl crystals are up to six feet in length; this zone occupies the core of the pegmatite, and is enveloped by the above two zones.

Quartz lenses with amblygonite have a tendency to occur near the perthite and albite-quartz-muscovite contact, and generally have an irregular shape and are several feet in their maximum dimensions. Replacement zones consisting of lithium-bearing mica and albite cut across all other zones in an irregular manner. Tantalite-columbite may accompany these rocks, and they may also be

surrounded by a narrow border of cleavelandite with or without spodumene. The altered beryl occurs where the cleavelandite-rich borders abut against the beryl in the central zone. The cleavelandite reveals a clear corrosive textural relationship with the perthite. From field relationships it would appear that this alteration was caused by deuterian pegmatite solutions intimately associated with the formation of the lithium mica-bearing replacement zones and their cleavelandite-rich margins.

* * * * *

LABORATORY PROCEDURE

A. PREPARATION OF SAMPLES

The following five sample types were selected from a specimen which showed a transition from pure beryl to highly altered material:

- Sample 1 : pure beryl (unaltered)
- Sample 2 : partially altered beryl
- Sample 3 : highly altered beryl
- Sample 4 : opaque white cryptocrystalline grains selected under a binocular microscope from a crushed fraction (+24 mesh) of Sample 3
- Sample 5 : -5 micron "clay" fraction

To separate the clay mineral from the other phases present in the alteration products, two small specimens of highly altered beryl were crushed in an iron pestle and mortar. Any iron contamination was removed by means of a hand magnet. The crushed sample was dispersed in a "Waring Blender" for 20 minutes to facilitate the separation of the clay particles adhering to other mineral grains, and to disintegrate the clay aggregates into particles finer than the bertrandite. The -5 micron fraction was then obtained by sedimentation. Twenty-two grams of material were recovered for subsequent investigations.

B. CHEMICAL ANALYSES

The chemical analyses in Table 1 show the main trends in the alteration of beryl. The overall chemical changes in one hand specimen, which take place from unaltered beryl to the highly altered beryl, are clearly shown by comparing Analyses 1, 2 and 3. The most obvious phenomena are a decrease in SiO_2 with an increase in BeO , H_2O , CO_2 , and MgO . The other other components remain remarkably constant, except Na_2O and Cs_2O which tend to decrease. These changes in chemical composition are related to the formation of bertrandite and a clay mineral at the expense of beryl.

Analysis 4 represents the white opaque cryptocrystalline alteration products which contain an excessively high percentage of beryllia. Macroscopically, this aggregate appears similar to a "clay", but X-ray analysis revealed the presence of both bertrandite and a clay mineral. Bertrandite is obviously enriched in this white aggregate, as indicated by the high beryllia content, and by the relative intensities of the bertrandite reflections in the X-ray diffraction pattern of Sample 4 (Table 4).

C. X-RAY ANALYSES

A Norelco X-ray diffractometer was employed using Co-K alpha radiation (Fe filter). The goniometer was calibrated with a silicon standard, and diffraction patterns were recorded at a speed of $\frac{1}{2}^{\circ}$ per minute.

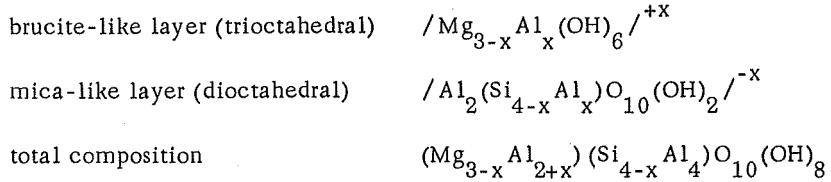
In Table 2 the d-values of the macroscopically unaltered beryl are given (Sample 1). The values correspond with those published by the American National Bureau of Standards (1960). No other phases could be detected. In Table 3 the d-values of the partially altered beryl are given (Sample 2). Beryl reflections are present, together with those of bertrandite. A few reflections belonging to the clay mineral are also developed. The d-values of the opaque white cryptocrystalline grains (Sample 4) are given in Table 4. Beryl and bertrandite are present, but some unidentified reflections still occur, and one particular reflection at 14.6 \AA suggests the presence of a clay mineral. The X-ray data indicate that the cryptocrystalline alteration product consists of bertrandite and an associated clay material containing scattered grains of remnant beryl. The fact that bertrandite occurs in a form that makes it indistinguishable from the clay material in the hand specimen and under the microscope might easily cause it to be overlooked.

The d-values obtained on the -5 micron fraction (Sample 5) are listed in Table 5. The random orientation of the sample was obtained by mixing with an equal part by volume of -100 mesh cork powder, and by side-loading this mixture into an aluminium specimen holder. The orientated specimen was prepared by allowing a Mg-ion saturated suspension of the fine fraction to dry on a microscope glass-slide (Kittrick, 1961). Beryl has its strongest reflections at 2.867 \AA , 3.25 \AA , and 7.98 \AA . As there are no reflections corresponding to the latter two in the diffraction pattern of the -5 micron fraction, it appears that any remaining beryl is well below the limit of detection. The X-ray pattern indicates that a certain amount of cryptocrystalline bertrandite is still present. Most of the reflections given in Table 5 must therefore be ascribed to the clay mineral. The 30 \AA reflection suggests that the clay mineral is of a mixed-layer type. From Table 5 it is apparent that the 4.78 \AA line is characteristic of the clay mineral, and that it must be a 001-type reflection. Indexing this line as (006), the d-values of the other 001 reflections were calculated according to Ito's method (Azaroff and Buerger, 1958), and compared with the observed values in Table 6. As an integral series of basal reflections exists, the clay mineral is of the regular mixed-layer type (MacEwan, Ruiz Amil, and Brown, 1961).

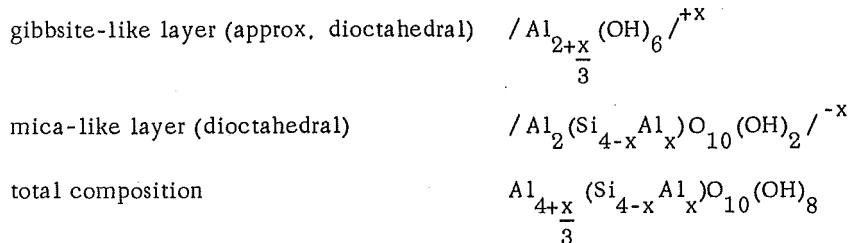
The responses of the 001 reflections of the -5 micron fraction to various treatments are given in Table 7. Regular mixed-layer minerals showing similar responses to these treatments are a mixed-layer chlorite-swelling chlorite, reported by Stephen and MacEwan (1951), corrensite from Zaisersweiher (Lippmann, 1954), some minerals from the Jura described by Martin Vivaldi and MacEwan (1957), and a swelling chlorite mineral (1 : 1 chlorite-swelling chlorite interstratification), described by Sutherland and MacEwan (1960). The medium-strong reflection at 1.49 \AA was indexed as (060), and the b-parameter is therefore 8.94 \AA . This classifies the mineral as dioctahedral (Brindley and Gillery, 1956; Brindley and de Kimpe, 1961), and is in keeping with the chemical analyses which reveal a high alumina content. A b-value of 8.94 \AA is also strongly suggested by electron diffraction (see below).

The clay mineral in Sample 5 appears, therefore, to be a dioctahedral mixed-layer chlorite-swelling chlorite.

The possibility that one or both of the octahedral layers in a chlorite structure may be dioctahedral has been considered by Brindley and Gillery (1956). They gave the possible combinations as follows :



The double dioctahedral case was believed to embrace the following :



Examples of Al-rich dioctahedral chlorites are given by Müller (1963) in his discussion of the sudoite members of the sudoite-chlorite group. Sudoite is characterized by a basal reflection of approximately 14.2 \AA which, however, is not influenced by glycol treatment, and by a b-parameter of $8.95 - 9.06 \text{ \AA}$.

D. ELECTRON DIFFRACTION

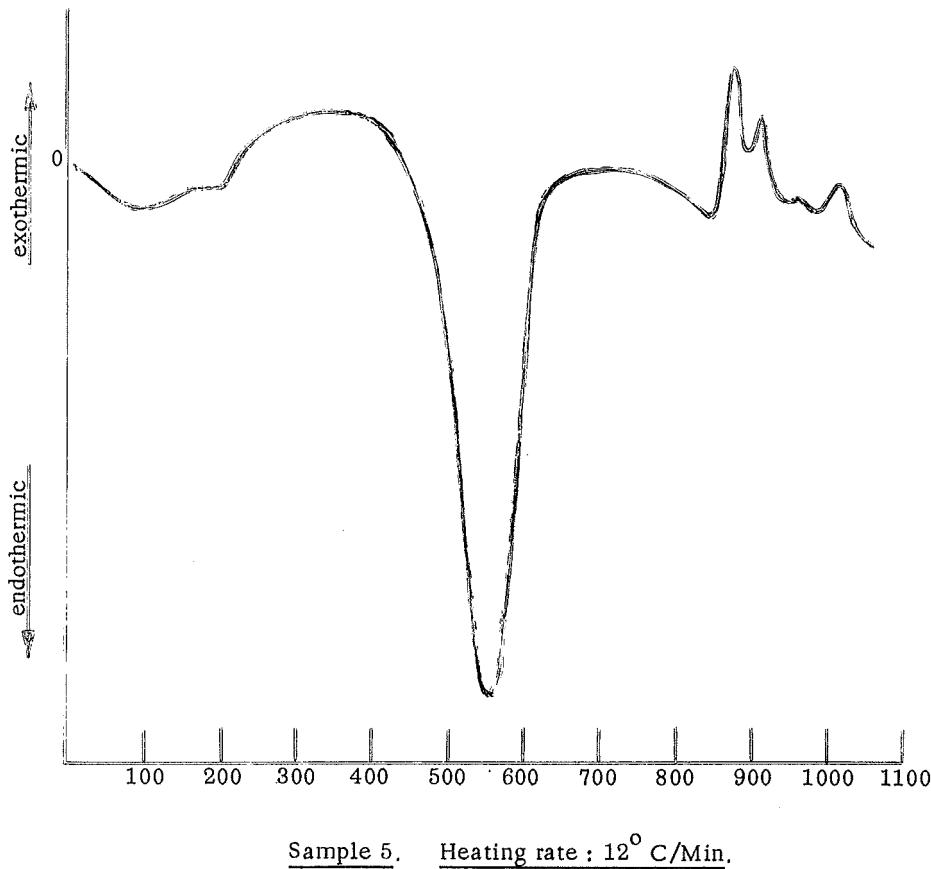
Single crystal electron diffraction was used to confirm the dioctahedral nature of the clay mineral, as well as the relative pureness of the -5 micron fraction. In the discussion of the identification of clay minerals by single crystal electron diffraction, Brindley and de Kimpe (1961) pointed out some limitations of this method. Using an internal standard, however, they suggested that the b-parameter can be accurately determined, and that such data can help in the partial identification of clay minerals.

Plate 1B reveals the platy nature of the mineral, while Plate 1C is a typical diffraction pattern of hexagonal symmetry commonly obtained from clay minerals lying flat on the basal substrate without precise tilt adjustment (Brindley and de Kimpe, 1961). Gold was employed as an internal standard, and the apparatus used was a Siemens Emiskop I Electron Microscope. Unfortunately, the $0k0$ zone could not be identified. Three zones occurring at 120° to each other may well represent the $0k0$ zone, but all gave a b-value of $8.94 \pm 0.02 \text{ \AA}$. This result confirms the b-value obtained by X-ray diffraction methods.

Several diffraction patterns of single crystals and of polycrystalline aggregates were taken, and it was found that the single hexagonal pattern could account for all the patterns, even when they were slightly inclined, or if they were polycrystalline aggregates. This gave a certain amount of confidence that the -5 micron fraction was relatively pure.

E. DIFFERENTIAL THERMAL ANALYSES

The D.T.A. curve of the -5 micron fraction material is given below. The material was dried at 74°C for $1\frac{1}{2}$ hours, and cooled in a desiccator prior to analysis. The D.T.A. apparatus was calibrated with pure quartz, and the maximum temperature error was 5°C .



Two weak endothermic reactions occur at 100°C and 200°C , a major reaction at 555°C , and another weak reaction at about 850°C . Exothermic reactions occur at 880°C , 915°C , and 1020°C . The curve resembles those obtained for pseudo-chlorites (Caillere and Henin, 1957), and for some swelling chlorites described by Honeyborne (1951). Owing to the nature of these materials, variations in the D.T.A. curves are to be expected.

* * * * *

CONCLUSIONS

The glassy fragments in the altered material were identified as beryl. The X-ray diffraction pattern (Table 2) agrees well with the data published by the National Bureau of Standards (1960), and the refractive index was found to be 1.586 ± 0.003 . The surprising feature of the chemical analysis of this sample (Table 1) is the high CO_2 content (2.32 per cent). On examination of the molecular proportions, it can be readily seen that the CaO and MgO content is too small to account for the CO_2 by assuming the presence of a carbonate. A possible explanation is that the CO_2 occurs as liquid inclusions, or that carbon or CO_2 is enclosed in the beryl structure.

The occurrence of bertrandite in the cryptocrystalline alteration products of the beryl was proved by X-ray diffraction.

The X-ray diffraction and D.T.A. results strongly suggest that the clay mineral is a dioctahedral mixed-layer chlorite-swelling chlorite. The chemical analysis indicates the aluminous nature of the material, but further work is necessary before the exact nature of the mineral can be given.

The investigation indicates that the peculiar "beryl" containing up to 15 per cent BeO is a deutereric alteration pseudomorph consisting of cryptocrystalline bertrandite and clay material in which are dispersed remnant beryl fragments. The clay material is probably an aluminous mixed-layer chlorite-swelling chlorite.

* * * * *

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* * * * *

TABLE 1
CHEMICAL ANALYSES

Sample No.	1	2	3	4	5
SiO ₂	60.74	52.70	44.74	43.80	38.24
Al ₂ O ₃	21.11	21.46	20.58	18.74	33.95
BeO	13.50	15.95	21.85	23.70	6.05
K ₂ O	0.04	0.03	0.04	0.04	0.07
Na ₂ O	0.24	0.17	0.08	0.00	0.07
Rb ₂ O	0.00	0.00	0.00	0.00	nd
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.60
TiO ₂	0.09	0.09	0.07	0.06	0.20
FeO	0.00	0.00	0.00	0.00	nd
CaO	1.01	1.70	0.95	1.10	1.75
MgO	0.00	0.22	0.42	0.23	1.73
Li ₂ O	0.36	0.32	0.39	0.50	1.00
Cs ₂ O	0.39	0.22	0.03	0.00	nd
H ₂ O+	0.70	1.74	4.58	6.44	12.40
H ₂ O-	0.00	0.20	0.40	0.50	2.80
CO ₂	2.32	4.74	6.30	4.50	nd
F	0.05	0.08	0.09	0.08	nd
MnO	0.003	0.006	0.001	0.07	0.05
P ₂ O ₅	nd	nd	nd	nd	0.64
Total	100.55	99.62	100.52	99.76	99.55

- Sample 1 : pure beryl (unaltered)
Sample 2 : partially altered beryl
Sample 3 : highly altered beryl
Sample 4 : opaque white cryptocrystalline grains selected from Sample 3
Sample 5 : -5 micron "clay" fraction obtained from altered beryl

(Analysts : P. J. Fourie and C. E. G. Schutte, Chemical Services Division, Department of Agriculture)

TABLE 2

X-RAY PATTERN OF SAMPLE 1 (UNALTERED BERYL)
GROUND IN ALCOHOL FOR 1 HOUR

Sample 1		Beryl ^x	
d-value	intensity	d-value	intensity
8.0	VS	7.98	93
4.61	S	4.60	51
4.00	S	3.99	46
3.26	VS	3.254	95
3.02	S	3.015	34
2.86	VS	2.867	100
		2.660	2
2.53	M	2.523	30
2.31	W	2.293	10
2.22	W	2.213	6
		2.208	2
2.15	W	2.152	14
		2.060	3
		2.056	4
2.00	W	1.9926	22
		1.8308	6
1.80	W	1.7954	17
1.74	M	1.7397	19
1.71	W	1.7110	12
		1.7007	2
1.63	W	1.6265	17
1.60	VW	1.5953	6
1.57	VW	1.5710	9
		1.5690	7
1.54	VW	{ 1.5349	5
		{ 1.5320	7
1.51	W	1.5138	15
		1.4882	1
1.46	W	{ 1.4566	9
		{ 1.4535	10
1.43	W	1.4324	13
		1.4148	1
1.37	W	{ 1.3682	7
		{ 1.3656	6
1.28	M	1.2774	11
1.27	W	{ 1.2657	13
		{ 1.2628	9

VS = very strong; S = strong; M = medium; W = weak; VW = very weak

^xStandard X-ray Diffraction Powder Patterns, NBS Circular 539, Vol. 9,
(1960) p. 14.

TABLE 3

X-RAY PATTERN OF SAMPLE 2 (PARTIALLY ALTERED BERYL
GROUND IN ALCOHOL FOR 1 HOUR)

Sample 2		Beryl ^x		Bertrandite ^{xx}	
d-value	intensity	d-value	intensity	d-value	intensity (est.)
14.6	S				
7.99	VS	7.98	93		
7.67	W			7.56	1
				4.85	0.2
4.61	S	4.60	51		
4.38	M			4.38	10
3.98	M	3.99	46		
3.92	W			3.94	4
3.83	VW			3.80	0.7
3.6	VW				
3.26	VS	3.254	95		
3.17	S			3.19	9
3.02	S	3.015	34		
2.87	VS	2.867	100	{ 2.93	1
				{ 2.88	1
2.53	S	2.523	30	2.54	8
				2.42	0.5
2.31	M				
2.29	M	2.293	10	2.28	6
2.22	M	2.213	6	2.22	6
				2.18	0.2
2.15	W	2.152	14		
				2.10	0.3
2.03	VW			2.02	0.5
1.99	M	1.9926	22	1.983	2
				1.923	0.5
1.83	VW	1.8308	6		
1.80	W	1.7954	17	1.787	0.5
1.74	M	1.7397	19		
1.71	W	1.7110	12	1.698	1.5
				1.650	1
1.63	M	1.6265	17	1.628	0.2
1.60	VW	1.5953	6		
1.57	W	1.5710	9	1.579	0.3
				1.555	3
1.51	W	1.5138	15		
1.49	VW	1.4882	1	1.491	0.2
1.456	W	1.4566	9	1.465	3
1.43	W	1.4324	13	1.440	1
1.37	W	1.3682	7	1.363	0.2
				1.338	0.3
1.31	W			1.305	4
1.28	M	1.2774	11		
1.27	W	1.2657	13		
				1.251	1

TABLE 4

X-RAY DATA OF SAMPLE 4 (HAND SORTED + 24 MESH
OPAQUE WHITE CRYPTOCRYSTALLINE AGGREGATE)

Sample 4		Beryl ^x		Bertrandite ^{xx}	
d-value	intensity	d-value	intensity	d-value	intensity
14.6	VS				
8.02	W	7.98	93		
7.59	W			7.56	1
7.24	W				
4.77	M	4.60	51		
4.39	VS			4.38	10
3.93	S	3.99	46	3.94	4
3.83	M				
3.60	W				
3.18	VS	3.254	95	3.19	9
2.92	M			2.93	1
2.87	M	2.867	100	2.88	1
2.54	S			2.54	8
2.53	S	2.523	30		
2.43	M			2.42	0.5
2.29	S	2.293	10	2.28	6
2.23	S			2.22	6
2.21	M	2.213	6		
2.11	VW	2.152	14	2.10	0.3
2.03	W			2.02	0.5
		1.9926	22		
1.98	M			1.983	2
1.91	W			1.923	0.5
1.79	VW	1.7954	17	1.787	0.5
1.70	W	1.7110	12	1.698	1.5
1.65	W	1.6265	17	1.650	1.0
1.58	VW	1.5953	6	1.579	0.3
		1.5710	9		
1.55	W	1.5690	7	1.555	3
1.49	M	1.5138	15		
1.46	W	{ 1.4566	9	1.465	3
		{ 1.4535	10		
1.44	W	1.4324	13	1.440	1
1.31	M	{ 1.2774	11	1.305	4
1.27	W	{ 1.2657	13		

^xNBS Circular 539 Vol. 9 (1960) p. 14

^{xx}Vernon and Williams (1960)

TABLE 5
X-RAY DATA OF SAMPLE 5 (-5 MICRON FRACTION)

Random Orientation		Preferred Orientation (Mg-saturated)		Unidentified Lines (Tables 3 and 4)	Bertrandite ^x (strongest lines)		Beryl ^{xx} (three strongest lines)	
d-value	intensity	d-value	intensity	d-value	d-value	intensity	d-value	intensity
Not resolved		30	M					
15	VS	14.44	VS	15				
		9.68	VW					
7.2	M	7.20	M	7.2	7.56	1	7.98	93
4.79	S	4.78	S	4.79				
4.47	S				4.38	10		
4.41	M							
4.20	M							
3.95	W				3.94	4		
3.84	VW			3.83	3.80	0.7		
3.58	M	3.59	S	3.59				
3.18	W				3.19	9	3.254	95
2.86	M	2.86	M		2.88	1	2.867	100
2.71	VW							
2.56	S							
2.52	S			2.53	2.54	8		
2.33	S			2.33				
2.29	W	2.29	W		2.28	6		
2.22	VW				2.22	6		
2.03	W				2.02	0.5		
1.98	W				1.983	2		
1.65	W				1.698	1.5		
1.49	MS				1.491	0.2		
1.47	VW				1.465	3		
1.45	VW							
1.43	VW							

^xVernon and Williams (1960)^{xx}NBS Circular 539, Vol. 9 (1960) p. 14

TABLE 6

AGREEMENT OF COMPUTED AND OBSERVED Q_{001's}
OF THE Mg-CATION SATURATED CLAY MINERAL

$$Q_{001} = \frac{1}{d_{001}^2}$$

d obs	I ^x	001	Q ₀₀₁		Difference	d calc
			Computed	Observed		
30	W	001	.00012	.00011	-.00001	28.68
14.44	VVS	002	.00486	.00480	-.00006	14.34
9.68	W	003	.01094	.01067	-.00027	9.56
7.20	S	004	.01945	.01929	-.00016	7.17
4.78	VS	006	-	.04377	-	4.78
3.58	S	008	.07781	.07803	+.00022	3.585
2.86	M	00,10	.12157	.12226	+.00069	2.868

^x Intensities as for an orientated specimen

TABLE 7

RESPONSE OF 001-REFLECTIONS TO VARIOUS TREATMENTS

001	Untreated ⁽¹⁾		Ethylene ⁽²⁾ glycol	Glycerol ⁽³⁾	Heat-treated		NH ₃ -ion saturated
	Obs	Calc.			300° ⁽⁴⁾	500° ⁽⁵⁾	
001	30 W	28.68	31 M	32 W	30 VW	-	-
002	14.4 VS	14.34	15.0 VS	15.7 S	14.3 VS	13.64 VS	14.2 VS

(1) Mg-ion saturated

(2) Walker (1958)

(3) Mg-ion saturated, then treated with 10 per cent glycerol solution
(Kittrick, 1961; Walker, 1958)

(4) Natural sample orientated and heated to 300°C for 1 hour

(5) Mg-ion saturated sample orientated and heated to 500°C for $\frac{1}{2}$ hour

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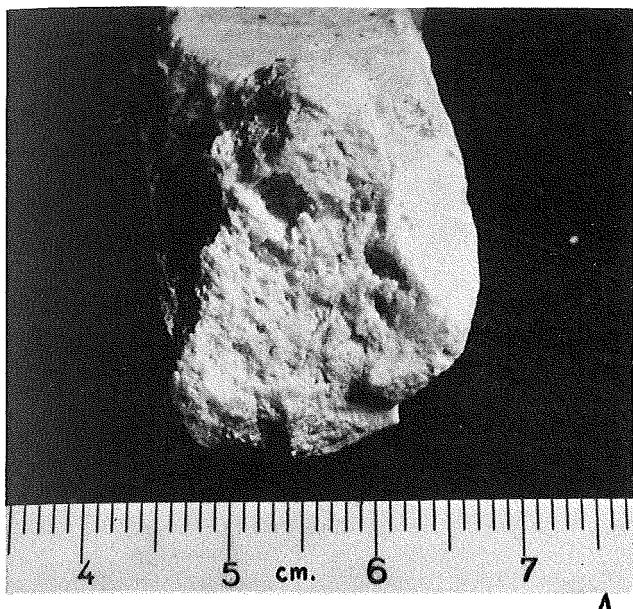
LIST OF REFERENCES

- Azaroff, L. V., and Buerger, M. J.
- Brindley, G. W., and de Kimpe, C.
- Brindley, G. W., and Gillery, F. H.
- Caillere S., and Henin, S.
- Foster, M. D.
- Honeyborne, D. B.
- Kittrick, J. A.
- Lippman, F.
- MacEwan, D. M. C., Ruiz Amil, A., and Brown, G.
- Martin Vivaldi, J. L., and MacEwan, D. M. C.
- Müller, G.
- National Bureau of Standards
- 1958 The Powder Method in X-ray Crystallography
McGraw-Hill Co., New York.
- 1961 Identification of Clay Minerals by Single Crystal
Electron Diffraction
Amer. Miner. 46 (9, 10) p. 1005.
- 1956 X-ray Identification of Chlorite Species
Amer. Miner. 41 (3, 4) p. 169.
- 1957 The Differential Thermal Investigation of Clays
- edited by Robert C. MacKenzie
Mineralogical Society, London.
- 1962 Interpretation of the Composition and a
Classification of the Chlorites
Prof. Paper 414-A, U.S.G.S.,
Washington.
- 1951 The Clay Minerals in the Keuper Marl
Clay Min. Bull. 1 (5) p. 150.
- 1961 A Comparison of the Moving-Liquid and Glass-
Slide Methods for the Preparation of Oriented
X-ray Diffraction Specimens
Soil Science, 92 (3) p. 155.
- 1954 Über Einen Keuperton von Zaisersweiher bei
Maulbronn
Heidelb. Beitr. Min. Petr. 4, p. 130.
- 1961 The X-ray Identification and Crystal Structures
of Clay Minerals - edited by G. Brown
Mineralogical Society, London.
- 1957 Triassic Chlorites from the Jura and Catalan
Coastal Range
Clay Min. Bull. 3 (18) p. 177.
- 1963 Zur Kenntnis Dioktaedrischer - Vierschicht
Phyllosilikate (Zudoit - Reihe der Zudoit-
Chlorit-Gruppe)
Proc. of Int. Clay Conference - Aug. 1963,
Stockholm, Sweden.
- 1960 Circular 539, Vol. 9, in American Society for
Testing Materials : Index to the X-ray Powder
Data File (ed. J. V. Smith)
A.S.T.M. Special Technical Publication
48-L.

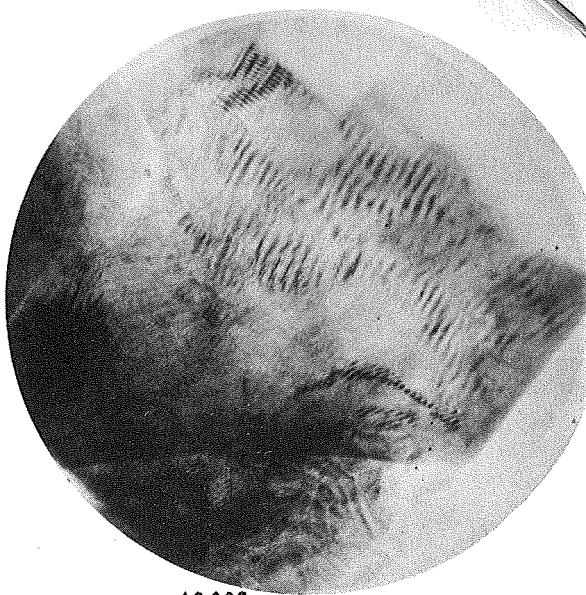
- Stephen, I., and MacEwan, D. M. C. 1951 Some Chlorite Clay Minerals of Unusual Type
Clay Min. Bull. 1 (5) p. 157.
- Sutherland, H. H., and
MacEwan, D. M. C. 1960 A Swelling-Chlorite Mineral
9th Nat. Conf. on Clays and Clay Min.,
U.S.A., p. 451.
- Vernon, R. H., and
Williams, K. L. 1960 Bertrandite from Mica Creek, Queensland
Amer. Miner. 45 (11, 12) p. 1300.
- Walker, G. F. 1948 Reactions of Expanding Lattice Clay Minerals
with Glycerol and Ethylene Glycol
Clay Min. Bull. 3 (20) p. 302.

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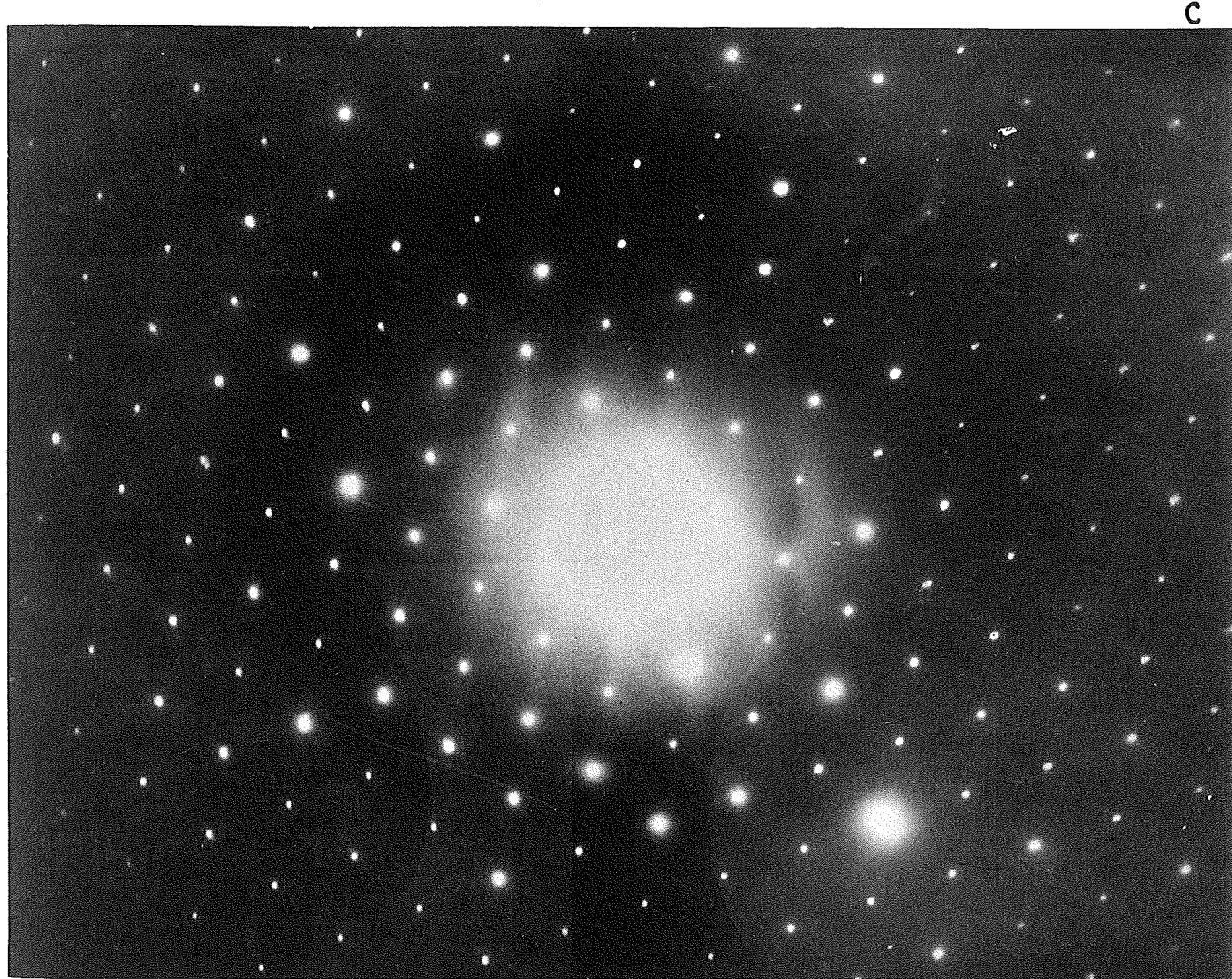
PLATE 1



A



B



C