

## STUDIES OF RADIOACTIVE COMPOUNDS: VIII— URANOPHANE AND BETA-URANOPHANE<sup>1</sup>

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### ABSTRACT

Uranophane and beta-uranophane are dimorphous with composition  $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$  as found by Nováček (1935). Uranophane: Monoclinic,  $a=15.87$ ,  $b=7.05$ ,  $c=6.66$  Å,  $\beta=97^\circ 15'$ ; space group  $P2_1/a$  or  $P2/a$ ;  $Z=2$ ;  $\text{SG}=3.83$  (meas.), 3.85 (calc.); needle-like crystals elongated  $b[010]$ . Beta-uranophane: Monoclinic,  $a=6.64$ ,  $b=15.55$ ,  $c=14.01$  Å,  $\beta=91^\circ$ ; space group  $P2_1/c$ ;  $Z=4$ ;  $\text{SG}=3.90$  (meas.), 3.93 (calc.); needle-like crystals elongated  $c[001]$ .

### URANOPHANE

Uranophane  $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ , is by far the most common uranium silicate mineral. Billiet (1936) gives an account of the history of the species. It was first described by Websky in 1853 from Kupferberg, Silesia. Bořický described the same species from Wölsendorf in 1870 and called it uranotil. Since that time the two names have been synonymous, although in 1892, Pjatnitzky proposed uranotil for the well crystallized material, and uranophane for that material which could not be studied goniometrically. Subsequently uranophane, which occurs at practically every locality where pitchblende is found, was described by a number of investigators whose studies were concerned with the optics, chemistry and the goniometry of the species.

Billiet made the first  $x$ -ray study of the mineral. Powder photographs were taken, and unit cell dimensions determined from a series of single crystal rotation photographs. The chemical formula was then established from the  $x$ -ray data and existing chemical analyses. Since 1936 no further detailed work has been done, although uranophane has been reported from several localities not previously recorded.

In the course of a re-examination of all the uranium silicate minerals, the present authors, realizing the  $x$ -ray techniques employed by Billiet might have led to erroneous interpretation, undertook a more detailed  $x$ -ray examination of uranophane. Observations on physical properties and optics were also made, and are included in summary with those of previous investigators.

#### *Physical properties*

Uranophane occurs as idiomorphic crystals which are prismatic or acicular, sometimes reticulate, but more often in divergent clusters or

<sup>1</sup> Extracted from Gorman's thesis for the Ph.D. degree, University of Toronto.

tufts. Crystals are found most frequently in small vugs, and rarely exceed 1 mm. in length. More commonly the mineral is compact, massive or powdery, and often is seen as scaly incrustations or films on primary minerals, and not infrequently as paper thin sheets in minute cracks.

The color is rather variable, lemon yellow, canary yellow, orange yellow, and very often very pale yellow. The massive varieties exhibit the greatest variation in color. Various authors have described the luster of the crystals as pearly or greasy, probably an accurate assessment, although the material we studied was so minutely acicular as to appear silky. The massive varieties are earthy to resinous, or waxy for the more compact, scaly type.

Crystals have perfect pinacoidal cleavage, reasonably assumed to be (100) by analogy with that more precisely determined for beta-uranophane. The hardness, as far as can be ascertained, is 2-3 as expressed on Mohs' scale. The massive varieties can be scratched easily with a needle.

Billiet (1936) lists specific gravities of 2.6, 2.7, 3.81, 3.89, 3.96 and 4.17 recorded by various observers. He calculated a specific gravity of 3.81 and measured it as 3.809 using Clerici solution. We also found a variation in specific gravity for non-crystallized material, due in part we think, to the porosity of the material or admixed impurities. On clean, crystallized material from Wölsendorf, Bavaria, Gorman determined the gravity to be 3.83. It is interesting to note that this is the value used by Billiet in calculating his cell contents. The gravity calculated from our cell dimensions is 3.85.

As in a great many descriptions of secondary uranium minerals, those concerning uranophane are replete with "possibles" and "maybes" regarding fluorescence. On both massive and crystallized varieties previous determinations have been recorded as "some" and "faint green." The present authors found that under both long and short wave ultraviolet light the massive material showed no fluorescence, and the crystallized variety a faint green emission.

The optical properties of uranophane are well established. Table 1 is a summary of those properties compiled from data by Larsen, Hess & Schaller (1926) with our determinations shown in the second column. George (1949) states that for all the uranophane sent to him by field engineers the optical properties have always fallen within the limits recorded in the literature.

### *Crystallography*

Billiet (1936) made an x-ray examination of uranophane, obtaining a powder photograph of the material from Chinkolobwe, and unit cell dimensions from a series of rotational photographs—a remarkable feat

TABLE 1. THE OPTICAL PROPERTIES OF URANOPHANE

	Larsen, Hess & Schaller (1926)	Gorman & Nuffield (1955)
$\alpha$	1.642-1.645	1.642
$\beta$	1.665-1.667	1.666
$\gamma$	1.667-1.672	1.668
Sign	negative	negative
$2V$	32-45 (Na)	small
Dispersion	strong $r < v$	marked
Opt. orient.	$Z = \text{elongation}$	$Z = \text{elongation}$
Pleochroism	$\alpha$ nearly colorless	$\alpha$ nearly colorless
	$\beta$ pale canary yellow	$\beta$ nearly colorless
	$\gamma$ canary yellow	$\gamma$ pale yellow

considering the size of the crystals with which he worked. His cell dimensions were recorded as

$$a = 6.68 \text{ \AA} \text{ (probably kX)}, \quad b = 15.28, \quad c = 7.3 = \text{elongation.}$$

No powder data were given.

The present authors obtained  $x$ -ray powder patterns of several types of uranophane, powdery, waxy and crystallized. All patterns were identical except one of material from Mexico, which indicated a slightly smaller cell. The powdery or waxy material did not give such sharp patterns as the well crystallized type. A print of the powder photograph of well crystallized material from Nabburg, Bavaria is shown in Figure 1. Powder data for uranophane from Nabburg are given in Table 2.

Rotation and Weissenberg photographs were taken of a minute needle of uranophane from Nabburg. From these photographs the following data were obtained:

$$a = 15.87 \text{ \AA}, \quad b = 7.05 = \text{elongation}, \quad c = 6.66, \quad \beta = 97^\circ 15'$$

Some months later these constants were confirmed by Lipscomb.<sup>1</sup> The space group is  $P2_1/a$  or  $P2/a$ .

Uranophane has always been described as orthorhombic, except by Pjatnitzky (1892, in Billiet, 1936) who reported it as triclinic. Billiet gives an exceedingly complete summary of the goniometry of this species, listing all the observed forms and angular measurements for an orientation  $c = \text{axis of elongation}$ . In his conclusion he appears to make the majority of observations fit an orthorhombic symmetry. In reading his paper it is noticeable that he stresses over and over that most observers reported that goniometric measurements were poor. Because,

<sup>1</sup> Private communication, Prof. J. Gruner, University of Minnesota.

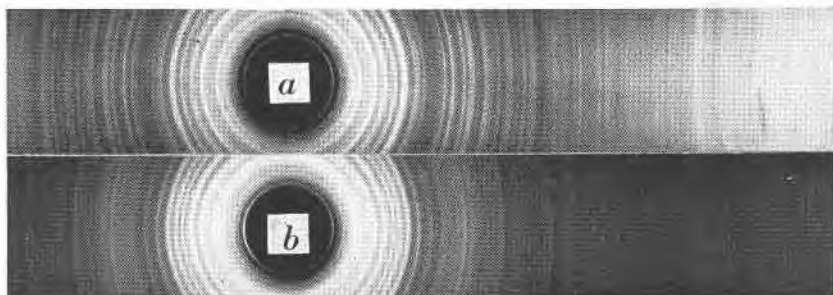


FIG. 1. (a) Uranophane, Nabburg, Bavaria; (b) beta-uranophane, Jachymov, Bohemia. X-ray powder photographs using Cu/Ni radiation ( $\lambda = 1.5418 \text{ \AA}$ ); camera diameter 57.3 mm; actual size prints.

in his  $x$ -ray study, he used rotation photographs only, Billiet had no means of assessing properly the true symmetry, and merely conjectured it to be orthorhombic from previous goniometric measurements.

Uranophane is proved by the present authors to be monoclinic,  $2/m$ , with crystals elongated in the  $b[010]$  direction.

$$\begin{aligned} a:b:c &= 2.252:1:0.945, & \beta &= 97^{\circ}15' \\ p:q:r &= 0.448:1:1.067, & \mu &= 82^{\circ}45' \end{aligned}$$

The axial ratios were calculated from the cell dimensions.

It is interesting to note from Billiet's summary of goniometric studies,

TABLE 2. URANOPHANE, NABBURG, BAVARIA. X-RAY POWDER DATA  
Cu/Ni radiation;  $\lambda = 1.5418 \text{ \AA}$

$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$
10	7.55	8	2.08	$\frac{1}{2}$	1.364	$\frac{1}{2}$	0.956
3	6.41	5	1.947	$\frac{1}{2}$	1.326	4	0.951
4	5.21	5	1.901	$\frac{1}{2}$	1.288	1	0.935
6	4.67	5	1.859	3	1.256	1	0.918
$\frac{1}{2}$	4.23	$\frac{1}{2}$	1.816	5	1.226	2	0.909
9	3.83	5	1.764	3	1.171	2	0.897
4	3.48	5	1.733	3	1.151	$\frac{1}{2}$	0.886
5	3.17	$\frac{1}{2}$	1.708	$\frac{1}{2}$	1.133	$\frac{1}{2}$	0.877
9	2.94	3	1.646	1	1.109	3	0.870
5	2.86	4	1.589	1	1.099	3	0.837
4	2.64	4	1.564	$\frac{1}{2}$	1.041	$\frac{1}{2}$	0.825
3	2.57	2	1.531	$\frac{1}{2}$	1.024	2	0.811
2	2.49	4	1.491	1	1.016	1	0.805
$\frac{1}{2}$	2.24	1	1.454	$\frac{1}{2}$	1.001	2	0.798
7	2.17	3	1.434	$\frac{1}{2}$	0.986	$\frac{1}{2}$	0.790
						2	0.786

that Zepharovich in his *Mineralogisches Lexicon* lists the angle between the largest pinacoidal faces as  $82^\circ$ , and that Schrauf in 1873 gave

$$(110)(\bar{1}10) = 97^\circ \quad \text{and} \quad (110)(1\bar{1}0) = 82\frac{1}{2}^\circ$$

All three of these goniometric measurements are in rigorous harmony with  $\beta = 97^\circ 15'$  as determined by our *x*-ray analysis.

Owing to the size of the crystals available to us, their amenability to optical goniometry, and after a perusal of the existing literature on the measurements of uranophane crystals, we offer only this—that the crystals are elongated in the *b*[010] direction, there are basal and front pinacoids, and other smaller faces in the  $\{hOl\}$  zone, with minute terminations of  $\{0kl\}$  and possible  $\{hkl\}$ , all of simple indices.

### Chemistry

In Table 3 are listed 11 analyses of uranophane from various localities. The sources of these analyses are appended. In fairness it must be admitted that analyses were selected that were in close conformity with

TABLE 3. CHEMICAL ANALYSES OF URANOPHANE

	1	2	3	4	5	6	7	8	9	10	11
SiO <sub>2</sub>	17.08	13.78	13.02	14.48	13.72	13.24	13.47	13.24	14.23	13.9	13.3
UO <sub>3</sub>	53.33	66.75	63.93	62.84	66.67	65.87	64.36	65.96	69.32	67.2	61.0
Al <sub>2</sub> O <sub>3</sub>	6.10	0.51	trace	trace	trace	—	—	—	—	—	—
Fe <sub>2</sub> O <sub>3</sub>	—	—	3.03	2.88	trace	0.14	0.47	trace	—	—	—
CaO	5.07	5.27	5.13	5.49	6.67	7.05	7.49	7.00	2.86	6.5	10.3
H <sub>2</sub> O	15.11	12.67	14.55	13.79	12.02	13.11	13.33	13.17	12.28	12.6	13.9
MgO	1.46	—	—	—	—	—	—	—	—	—	—
K <sub>2</sub> O	1.85	—	—	—	—	—	—	—	—	—	—
P <sub>2</sub> O <sub>5</sub>	—	—	—	—	0.29	—	—	—	1.10	—	—
PbO	—	0.45	—	—	0.60	—	—	—	—	—	—
BaO	—	—	—	—	0.28	—	—	—	—	—	—
SrO	—	—	—	—	0.13	—	—	—	—	—	—
S.G.	—	3.96	—	3.856	3.834	—	—	—	3.78	—	—
Totals	100.00	99.43	99.66	99.48	100.38	99.41	99.11	99.37	99.79	100.2	98.5

1. Uranophane, Kupferberg, Silesia; anal. Grundman (1859), recalcd. Websky (1870) after deducting 7% impurities. 2. Uranotil, Wölsendorf, Bavaria; anal. Bořický (1870). 3, 4. Uranotil, Neustadt, Saxony; anal. Winkler (1880). 5. Uranophane, Mitchell Co., N. C.; anal. Genth (1879). 6, 7, 8. Uranophane, Mitchell Co., N. C.; anal. von Foullon (1883). 9. Uranotil, Luiswishi, Katanga; anal. Schoep (1921). 10. Uranotil, Lusk, Wyoming; anal. Larsen, Hess & Schaller (1926). 11. Uranophane, Yancy, N. C.; anal. Sherwood (1952, priv. comm.). Note: analyses 1-7 taken from Dana (1892), analysis 8 from von Foullon (1885).

those published with the original description of the mineral. Other analyses showing appreciable amounts of Cu, Co, Ni, Fe exist and will be included in further papers on sklodowskite and cuprosklodowskite, when the isomorphism of these minerals with uranophane will be discussed.

The analyses listed show a reasonable uniformity considering the nature of the material used, i.e. impure powdery or massive, and the small

amounts available for analyses of the crystallized variety. Billiet (1936) lists all the formulae, in oxide form, that have been suggested, and in conclusion agrees with Nováček that the most reasonable choice is  $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ . There appeared some justification for a deviation from  $6\text{H}_2\text{O}$  and Schoep (1927) maintained a water content of  $7\text{H}_2\text{O}$ . However, it will be shown in the following discussion of the calculation of the cell contents that  $6\text{H}_2\text{O}$  is the better choice, and particularly so since unpublished data (Gorman) indicate that  $6\text{H}_2\text{O}$  is the best choice for the water content of sklodowskite, the magnesium analogue of uranophane.

Billiet (1936) chose 4 representative analyses (5, 6, 7 & 8 of Table 3) and calculated the cell contents for his dimensions and a gravity of 3.834. His results are noted in the first 4 columns of Table 4. Column V shows

TABLE 4. THE CELL CONTENTS OF URANOPHANE

	I	II	III	IV	V	VI	VII
U	4.04	3.98	4.00	3.90	3.98	3.91	4
Si	3.95	3.82	3.82	3.88	3.87	3.80	4
Ca	2.06	2.19	2.16	2.31	2.18	2.14	2
O	22.08	21.77	21.80	21.77	21.86	21.49	22
H <sub>2</sub> O	11.57	12.56	12.68	12.82	12.41	12.20	12
Totals	43.70	44.32	44.56	44.68	44.30	43.44	44

I-IV. Billiet's (1936) calculated cell contents for 4 analyses using his dimensions and SG 3.834. V. Aver. of I-IV. VI. Billiet's aver. recal. using Gorman & Nuffield cell dimensions and SG 3.83. VII. Ideal cell contents for  $2[\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}]$ .

the averages as calculated by the present authors. Thus Billiet justified the formula  $2[\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}]$ .

The newly proposed cell dimensions with a measured specific gravity of 3.83 gave a cell content weight that is related to Billiet's by a factor of 0.983. It seemed superfluous to calculate the cell contents for each analysis, and consequently the conversion factor was applied to Billiet's calculated averages. The resultant atomic proportions are shown in Table 4, column VI with the ideal contents for  $2[\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}]$  given in column VII. The calculated specific gravity using this formula is 3.85, which is in close agreement with our measured value, 3.83.

#### *Mode of occurrence*

Of the several uranium silicates, uranophane is the most abundant and has the widest geographical distribution. Moreover it is being identified from so many localities now that *x*-ray powder photography is used so extensively, that it appears to be one of the most common secondary

uranium bearing minerals. It is found associated with other secondary uranium minerals, notably autunite, torbernite, beta-uranophane, kasolite, schoepite and sklodowskite and is an important constituent of gum-mite (as defined in Dana's System of Mineralogy, 1944).

There is no doubt that it is secondary after primary uranium minerals, but there is some disagreement as to whether it is of supergene or deuteritic origin. Ross, Henderson & Posnjak (1931) favor a hydrothermal or deuteritic origin for the occurrence at Spruce Pine, New Jersey where it is associated with fresh feldspar. George (1949) notes a similar type of occurrence at the Ruggles Mine, New Hampshire. In several Ontario localities uranophane is invariably associated with feldspar, and could have had a deuteritic origin.<sup>1</sup> George further states that a deuteritic origin is not universal, and gives evidence for a supergene origin of uranophane in Portugal, in Stone Mountain, Virginia, and in Lusk, Wyoming. In the famed Chinkolobwe, Katanga deposits, where uranophane is abundant, Néve (1915) points out that it is the last radioactive mineral save the phosphates, and postulates a supergene origin. Hogarth (1951) describes a similar but smaller zone of uranophane at the Nicholson mine, Saskatchewan, placing this mineral very late in his paragenetic sequence.

In addition to the above mentioned localities, uranophane occurs at Wölsendorf and Nabburg, Bavaria; Kupferberg, Silesia; Schneeberg and Neustadt, Saxony; Jachymov, Bohemia; Namaqualand, Africa; Yancy, North Carolina; Great Bear Lake, Wilberforce and Kenora districts, Canada. Uranophane from Villeneuve, Quebec (Hoffman, 1901) the earliest reference to Canadian material, is not uranophane, but is as yet unidentified.

#### BETA-URANOPHANE

Nováček (1935) proposed the name beta-uranotile for greenish-yellow needle-like crystals from Jachymov, which gave by chemical analysis the same formula as uranophane, but distinctly higher indices of refraction. Billiet (1936) attempted single crystal *x*-ray studies of the Jachymov material but because of the quality of the crystals, only powder work was possible. This confirmed however, the distinction between uranophane and beta-uranotile. Steinocher & Nováček (1939) published the results of a detailed optical study of beta-uranotile. They showed that material labelled schroeckerite from Bedford, New York and Mitchell county, North Carolina was in fact beta-uranotile and discovered the mineral in specimens from Wölsendorf. Precise goniometric measurements were not possible. Meixner (1949) observed the mineral on samarskite from San-

<sup>1</sup> Private communication, Dr. J. Satterly, Ontario Dept. Mines.

kara, Nellore, India. Satterly (1955) found an occurrence in MacNicol township, Kenora district, Ontario.

We too found that the Jachymov beta-uranotile offered no opportunities for single crystal studies. Similarly a new occurrence from Quebec proved unsuitable. This material, sent to us by Mr. G. R. Forbes, an engineer with Yates Uranium Mines, was said to occur in lot 20, range 4, Huddersfield township, Pontiac county. It is found as tiny intergrown needles on orange-colored crystalline limestone which also contains uranoan thorianite. This study was finally made possible by another occurrence, in Faraday township, Hastings county, Ontario which was discovered by Dr. J. Satterly (Satterly & Hewitt, 1955) of the Ontario Department of Mines. Beta-uranotile occurs here sparingly in pegmatite dikes with other radioactive minerals such as uranothorite, uraninite, allanite and secondary uranophane. Our specimen consists of a piece of split drill core containing a 3 mm. cavity in plagioclase which is filled with radiating groups of well-crystallized needles.

#### *Physical properties*

Beta-uranotile commonly occurs as minute acicular crystals in radial tufts, or as stubby, flattened prismatic crystals in reticulate groups. Unlike uranophane, the massive variety is less common, but it does occur as thin coatings and scales. The color varies from greenish yellow to orange yellow, unlike uranophane which is often a bright canary yellow. The highly acicular variety exhibits a silky luster, becoming more sub-adamantine to greasy for larger crystals, and waxy for the scaly type. The cleavage as recorded by Nováček (1935) and confirmed in this study is parallel to  $b(010)$ . The hardness is 2–3 on the Mohs' scale. Steinocher & Nováček (1939) list specific gravities of 3.953, 3.85 and 3.8. On clean, acicular crystals from Faraday township, Gorman determined the value 3.90. The calculated gravity, as shown below, is 3.93.

The degree of fluorescence has been reported as "questionable" or "none," yet all of the specimens examined by us show a definite though weak green emission under both short and long wave ultraviolet excitation. Satterly (1955) reports that a scaly beta-uranophane (identified by x-ray powder pattern) from the Kenora district, Ontario fluoresces bright green.

Steinocher & Nováček (1939) made an exceedingly detailed study of the optical properties. In summary they report for Na light:  $a$  1.661–1.668,  $\beta$  1.682–1.695,  $\gamma$  1.689–1.702, negative,  $2V$  small to  $66^\circ$ ,  $z \wedge c = 36$ – $62^\circ$ ,  $X$  colorless,  $Y$  and  $Z$  lemon yellow. Subsequent reports, including determinations made by the present authors confirmed their data. The



"superbly crystalline" Urgeirica material of George (1949) which gave indices not in conformity with those of beta-uranotile was proved by Hogarth & Nuffield (1954) to be phosphuranylite.

### Crystallography

The Faraday crystals measure less than 1 mm. in length and closely resemble the Jachymov crystals described by Nováček (1935, Fig. 3). In Nováček's orientation they are elongated parallel to  $c[001]$ , somewhat flattened on  $b(010)$  and also show  $a(100)$ . Two faces,  $(h0l)$  and  $(\bar{h}0l)$  terminate the crystals. The small face  $c(001)$  noted by Nováček is not present and the  $(100)$  twinning which is common on Jachymov crystals, was not observed. The luster is vitreous, although sometimes pearly on the broad  $(010)$  cleavage faces.

A typical crystal mounted about the axis of elongation on a two-circle goniometer gave weak but distinct signals from  $a(100)$  and  $b(010)$  and a less distinct signal corresponding to a  $\rho$  angle of  $46 \pm 1^\circ$  for one of the  $(h0l)$  faces. Sharp rotation and Weissenberg films were obtained about  $c[001]$  and zero and first level precession films about  $a[100]$  and  $b[010]$ . The films showed monoclinic symmetry and gave the constants:

$$a = 6.64 \text{ \AA}, \quad b = 15.55, \quad c = 14.01 = \text{elongation}, \quad \beta = 91^\circ; \quad \text{space group } P2_1/c$$

The rotation film about  $c[001]$  showed alternate weak and strong layer lines indicating a pseudo-period with  $c' = c/2$ .

It is interesting to observe that Nováček detected the slight departure from orthorhombic geometry with two-circle measurements on imperfect crystals. He gave the  $\rho$  angle of  $(001)$  as "no larger than  $2^\circ$ ". Later Steinocher (Steinocher & Nováček, 1939) reported  $\beta$  about  $94^\circ$  from measurements under the microscope.

Nováček obtained  $\rho = 48^\circ 36'$  (aver. of 7 from  $49^\circ 0'$  to  $48^\circ 19'$ ) from the one measurable  $(h0l)$  face on his crystals. This compares with  $46 \pm 1^\circ$  measured on our material and corresponds to  $(102)$  or  $(\bar{1}02)$  (calc.  $47^\circ 1'$  and  $46^\circ 5'$  respectively for our lattice constants). The  $(h0l)$  termination which did not give a signal appears by inspection to have about the same  $\rho$  angle and therefore it can be safely assumed that both  $(102)$  and  $(\bar{1}02)$  are present on the Faraday crystals. The appearance of these faces in preference to  $(101)$  is compatible with the space group extinction condition:  $(h0l)$  present only with  $l$  even.

The usual  $x$ -ray powder print (Fig. 1) and powder data (Table 5) are presented to aid in the future identification of beta-uranophane.

### Chemistry

The only two complete analyses of beta-uranotile, both by Nováček, are presented in Table 6, together with the cell contents calculated for

TABLE 5. BETA-URANOPHANE, JACHYMOV, BOHEMIA. X-RAY POWDER DATA

Cu/Ni radiation;  $\lambda = 1.5418 \text{ \AA}$ 

$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$	$I_{\text{Cu}}$	$d$
10	7.49	4	2.00	4	1.347	1	0.957
2	6.50	2	1.971	2	1.298*	3	0.947
5	5.98	5	1.924	4	1.263*	1	0.934
8	5.04	4	1.872	1	1.240	3	0.920
8	4.53	2	1.823	2	1.183	3	0.908
3	4.11	2	1.783	4	1.158	1	0.896
9	3.83	3	1.727	2	1.138	1	0.884
8	3.51	2	1.690	2	1.115	3	0.873
7	3.17	1	1.651	3	1.085	1	0.864
8	3.02	5	1.614	2	1.064	1	0.850
9	2.80	$\frac{1}{2}$	1.579	1	1.045*	2	0.841
6	2.58	2	1.540	1	1.032*	1	0.831
4	2.36	2	1.518	1	1.013*	2	0.825
$\frac{1}{2}$	2.27	1	1.478	2	1.000*	2	0.802
4	2.19	$\frac{1}{2}$	1.458	1	0.990		
2	2.13	$\frac{1}{2}$	1.442	1	0.976		
2	2.07	$\frac{1}{2}$	1.411	2	0.967		

\* Diffuse.

our lattice constants and the measured gravity, 3.90. The calculations suggest the cell contents  $4[\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}]$  which are compatible with the formula derived by Nováček. The departure of  $\text{SiO}_2$  and  $\text{CaO}$  from the ideal may be attributed to the small quantity of material which was available for the analyses.

At this time there is insufficient data to propose structural formulae for uranophane and beta-uranophane. A determination of the character of the water would be helpful but unfortunately the problem of obtaining enough material for this purpose has not been overcome.

TABLE 6. CHEMICAL ANALYSES AND CELL CONTENTS OF BETA-URANOPHANE

	1	2	3	4	5	6
$\text{SiO}_2$	13.11	12.9	14.02	7.5	7.3	8
$\text{UO}_3$	66.29	66.9	66.8	7.9	8.0	8
$\text{CaO}$	7.32	7.1	6.55	4.5	4.3	4
$\text{H}_2\text{O}$	12.87	12.6	12.62	24.4	23.9	24
Totals	99.59	99.5	100.00	44.3	43.5	44
S.G.	3.953	3.85				

1. Jachymov, on 7.5 mgs.; anal. Nováček (1953) 2. Wölsendorf, Bavaria on 2 mgs.; anal. Nováček (1939) 3. Ideal composition based on  $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ . 4. Cell contents calculated for 1. 5. Cell contents calculated for 2. 6. Ideal cell contents.

*Synonymy*

Although precedent has already been set for the use of varietal names in describing various forms of a single species, i.e. pitchblende and uraninite, brucite and nemalite, this is a practice that should be discouraged to the point of elimination. Uranophane has precedence over uranotile, and Nováček (1935) merely called his newly identified material beta-uranotile because specimens on which he worked were labelled uranotile. It is therefore proposed that the two species described in this paper be called uranophane and beta-uranophane.

## SUMMARY

This study has confirmed the dimorphic character of uranophane and beta-uranophane. The constants for the cell of uranophane and the pseudo-cell of beta-uranophane are compared in Table 7. The comparison

TABLE 7. COMPARISON OF URANOPHANE AND BETA-URANOPHANE

<i>Uranophane</i>	<i>Beta-uranophane</i>
$a = 15.87 \text{ \AA}$	$b = 15.55 \text{ \AA}$
$b = 7.05$ (elongation)	$c' = 7.005 = c/2$ (elongation)
$c = 6.66$	$a = 6.64$
$\beta = 97^{\circ}15'$	$\beta = 91^{\circ}$
SG (calc.) = 3.85	SG (calc.) = 3.90

shows the remarkable similarity of two of the cell edges, namely  $7 \text{ \AA}$  and  $6.6 \text{ \AA}$ , which it will be shown in a future paper, are a feature of several uranium silicate minerals. It was found that cleavage occurs in the plane of these two periods in beta-uranophane. Although the cleavage orientation could not be determined in our uranophane crystals, it may be assumed that uranophane cleaves in a similar, i.e. parallel to (100) as has already been proposed in various reports. Thus cleavage takes place in a plane which is normal or nearly normal to the longest and most variable of the three cell dimensions. It is further worth noting that the axis of crystal elongation is along the  $7 \text{ \AA}$  period in both species.

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