STUDIES OF RADIOACTIVE COMPOUNDS:

V—SODDYITE[1]

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ABSTRACT

New observations are made on the rare uranium silicate mineral soddyite. The formula $5UO_3 \cdot 2SiO_2 \cdot 6H_2O$ is established as the most plausible. New crystallographic data are recorded: orthorhombic, $a=8.32$, $b=11.21$, $c=18.71$ A; space group *Fddd*. Powder data are presented which are in agreement with cell dimensions. Soddyite is optically negative, $2V=84°$, $\alpha=1.650$, $\beta=1.685$, $\gamma=1.712$, $X=c$, $Y=b$, $Z=a$, pleochroic, X colorless, Y very pale yellow, Z pale yellow-green; dispersion negligible, in disagreement with previous ob-observations of $r>v$ strong.

Soddyite is a rare hydrous uranium silicate mineral, having an extremely limited geographical distribution. It was first described by Schoep (1922) from Kasolo, Belgian Congo. In subsequent papers, Schoep (1923a, b; 1927, 1930) gave more detailed descriptions, and nothing more on it appeared in the mineralogical literature until Gevers, Partridge & Joubert (1937) reported its occurrence in Namaqualand, Africa. Namaqualand material was not available to the author. Five specimens of soddyite from Kasolo served as material for this study.

PHYSICAL PROPERTIES

Soddyite occurs as idiomorphic crystals often in groups or clusters, which are sometimes divergent. It also occurs as flat blades or fibres of the cross-fibre type in fissures; also massively intergrown with curite. Larger crystals up to a millimeter in length are generally mosaical, and usually totally opaque, or have at the most a mere selvage of transparent material. Smaller crystals, which are usually tabular are translucent and sometimes quite transparent except for a cloudiness towards the centre. Zoning of the transparent and opaque material, as shown in Fig. 1, is common.

The color is greenish-yellow for the cross-fibre type, canary yellow for the opaque material and amber yellow for the transparent crystals. It is readily distinguished from the orange-red of curite and the slightly brownish hue of kasolite. The streak is pale yellow. The transparent selvages on opaque crystals have a vitreous to adamantine lustre. The opaque varieties are sub-vitreous to dull. Massively it is earthy. The hardness is between 3 and 4 on Mohs' scale. The density of a clean cluster of crystals weighing approximately 18 mg. gave 4.70±0.01 as measured on

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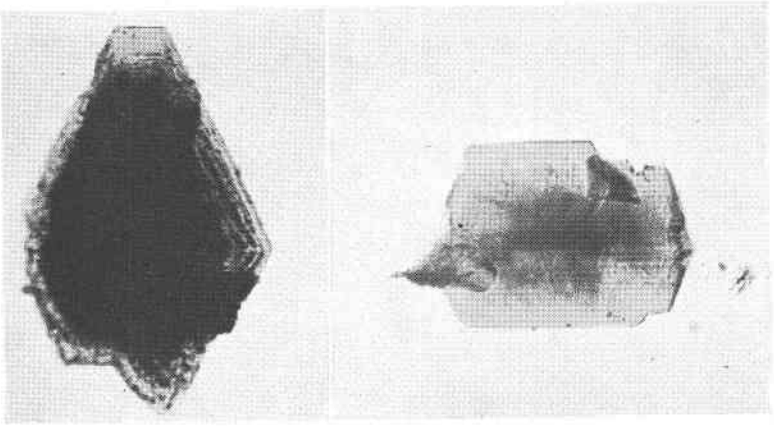
A B

FIG. 1. Soddyite. A—Crystal elongated in [001] showing zoning of transparent and opaque material. B—Crystal elongated in [110] showing murkiness toward the centre. Both photomicrographs taken with plane polarized light, ×112.

the Berman balance. This compares well with Schoep's determination of 4.627 by the pycnometer method. Two cleavages were noted: (001) perfect, (111) good. No visible fluorescence was observed from soddyite under long or short wave ultraviolet excitation.

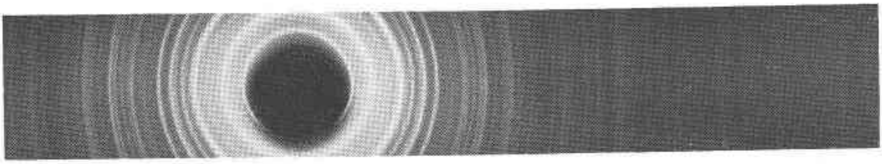

FIG. 2. Soddyite. *X*-ray powder photograph using Cu/Ni radiation ($\lambda = 1.5418$ A); camera radius 57.3 mm; actual size print.

X-RAY CRYSTALLOGRAPHY

For the *x*-ray powder photography a camera of radius 57.3 mm. and nickel filtered copper radiation were used. Spacing was based on $\lambda = 1.5418$ A. Powder photographs obtained from all types of euhedral crystals both translucent and opaque and from the cross-fibre type of soddyite proved to be identical. A print of the pattern, actual size, is shown in Fig. 2, and the powder data are presented in Table 1.

A single crystal, with no visible mosaic texture, was selected and mounted so as to rotate about the *c* axis. A sharp rotation photograph showed a large *c* period with a strong pseudo-period of $\frac{1}{3}c$. When the *Z* factor was subsequently calculated as 3, a tentative explanation of the

TABLE 1. SODDYITE—$5UO_3 \cdot 2SiO_2 \cdot 6H_2O$: *X*-RAY POWDER DATA

Orthorhombic, *Fddd*; $a=8.32$, $b=11.21$, $c=18.71$A; $Z=3$

I (Cu)	*d* (meas)	*hkl*	*d* (calc)	*I* (Cu)	*d* (meas)	*hkl*	*d* (calc)	*I* (Cu)	*d* (meas)	*hkl*	*d* (calc)
9	6.28	111	6.28	7	3.00	133	2.99	5	2.10	333	2.11
3	4.79	022	4.81	5	2.82	040	2.80	3	2.05	153	2.04
10	4.57	004	4.67	8	2.73	224	2.71	5	1.990	119	1.985
		113	4.56	8	2.49	206	2.49	5	1.918	422	1.917
2	3.80	202	3.80	1	2.33	008	2.34	6	1.867	155	1.867
9	3.36	131	3.37	2	2.28	226	2.28			246	1.864
		220	3.34	½	2.22	311	2.21				

I (Cu)	*d* (meas)	*I* (Cu)	*d* (meas)	*I* (Cu)	*d* (meas)	*I* (Cu)	*d* (meas)
3	1.771	½	1.386	4	1.088	½	0.903
3	1.710	4	1.365	1	1.046	½	0.892
2	1.681	½	1.344	1	1.022	2	0.875
4	1.654	3	1.275	½	0.999	½	0.861
2	1.606	4	1.228	½	0.984	½	0.833
½	1.557	4	1.155	3	0.946	2	0.819
3	1.524	½	1.142	½	0.931	1	0.803
½	1.502	½	1.121	1	0.912	½	0.796
4	1.412						

pseudo-period presented itself. It is conjectured that there is a threefold disposition of the heavy uranium atoms or uranium groupings along the *c* axis.

The *a* and *b* lengths were obtained from excellent Weissenberg photographs, which also showed clearly orthorhombic symmetry. The space group proved to be the rather unusual *Fddd*. The extinction conditions imposed by such a space group are (*hkl*) present only with *h*, *k*, *l*, all odd or all even; (00*l*), (0*k*0), (*h*00), (*hk*0), (0*kl*), (*h*0*l*) present only with all indices even and half the sum even. In Table 2 the single crystal data are presented.

TABLE 2. SODDYITE: *X*-RAY SINGLE CRYSTAL DATA

a 8.32 A ± .01	orthorhombic 2/m 2/m 2/m	space group *Fddd*
b 11.21	$a:b:c=0.742:1:1.669$	$Z=3$
c 18.71	$p_0:q_0:r_0=2.249:1.669:1$	

A rotation photograph was also taken about [110], the elongation direction of some crystals. The period determined was 7.00 A, which is in good agreement with 6.99 A calculated from *a* and *b*. As a further check on cell dimensions and space group the first 17 lines of the powder photograph were indexed and their spacings calculated. The excellent agreement of measured and calculated spacings may be seen in Table 1.

Morphological Crystallography

Schoep has noted in all his papers that soddyite crystals were not amenable to accurate goniometric work. Nevertheless he was able to determine the orthorhombic symmetry and an axial ratio of $a:b:c = 0.7959:1:1.6685$. This is only in fair agreement with the axial ratio obtained in this study by *x*-ray work. Undoubtedly this discrepancy is due to the poor quality of the crystals which both Schoep and the present writer have observed. It is evident from the variation in measured angles for the form (111) as shown in Table 3 that an axial ratio calculated from goniometric measurements cannot be as accurate as that calculated from excellent *x*-ray measurements.

Table 3. Soddyite: Measured and Calculated Two Circle Angles

	$\phi(111)$	$\rho(111)$	$\phi(111)-\phi(\bar{1}11)$
Schoep (1923a)			107°
Schoep (1923b)	52° 02′	67° 01′	
Schoep (1930)	51° 29′	69° 32′	
Gorman	53° 07′ (meas)	70° 21′ (meas)	106° 14′ (meas)
	53° 25′ (calc)	70° 44′ (calc)	106° 50′ (calc)

Individual crystals of soddyite invariably have an acute dipyramid form. They show a change in habit from an elongation in [001], through equidimensional, to a platy type elongated in the [110] direction, but nevertheless dipyramidal. It appears as if opposite faces of the dipyramid have been compressed and the crystal attenuated in [110]. It is this platy, elongated habit, thought by Schoep (1922) to show a prism form, that has led George (1949) and other observers to describe this elongation as [001]. The transition in habit is clearly shown in Fig. 3.

The dominant form is the dipyramid (111) which on some crystals is terminated by the basal pinacoid (001). Other faces with ϕ values the same as that of (111) and ρ values varying from 74° 25′ to 79° 04′ were observed, although their goniometric signals were poor. These faces when plotted on the gnomonic projection could not be given simple indices, and the writer hesitates to impute any indices, regardless of complexity to faces giving such poor signals, especially when aberration caused by striations had to be considered. The crystals are heavily striated parallel to the trace of the basal pinacoid (001). These striations are due in part to an oscillation between dipyramids with varying ρ angles, but in the main to oscillation between (111) and (11$\bar{1}$).

The platy crystals less frequently exhibit (111) but rather are formed by dipyramids with ρ values greater than that of (111). Of these ρ values 74° 45′ occurs most frequently. When the less platy types possess these possibly vicinal faces, barrel shaped crystals result from the continuous change in ρ angles.

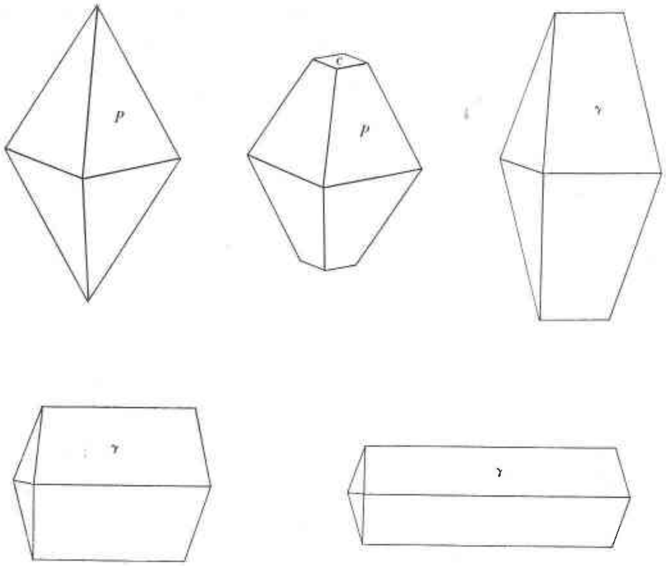

FIG. 3. Soddyite. Showing habit change from elongation in [001] to [110]; and forms: *c*(001), *p*(111), γ (dipyramid with φ the same as 111, and ρ varying from 74°25′ to 79°04′).

Schoep (1930) records the forms (113) and (114), neither of which appeared on the score of crystals measured in this study; nor was any indication of such faces seen when myriads of crystals were observed under the binocular microscope.

Schoep (1930) observed no cleavage, nor does he mention cleavage in any of his other papers. George (1949) records (010) and (100). Gevers, Partridge and Joubert (1937) describe a perfect (100) and a good domal cleavage, assuming that the bladed crystals are elongated in [001]. In the new orientation, with the bladed crystals elongated in [110], the cleavages become perfect (001) and good (111), both of which were observed here. It was difficult to distinguish between a crystal and a cleavage fragment since the cleavage planes are equivalent to the prominent crystal faces, and very few incipient cracks are present.

Optical Properties

Some difficulty was encountered in determining the optical constants of soddyite because of the murky, pebbly appearance of the more abundant material. This may account for the discrepancy between the indices of refraction originally given by Schoep (1923a) and those recorded by more recent workers. However, there is good agreement among the recent workers, and Professor Schoep does indicate in his own hand on a copy of his original article in the University of Toronto Library that his indices are within wide limits. Some of the optical data as determined by various observers are given in Table 4.

Table 4. Soddyite: A Comparison of Some Optical Data

	α	β	γ	Sign	2V
Kasolo					
Schoep (1923a)	1.645	1.662	—	Pos.	Large
Larsen & Berman (1934)	1.650	1.68	1.71	Neg.	Near 90°
George (1949)	1.650	1.685	1.715	Neg.	Large
Gorman (1952)	1.650	1.685	1.712	Neg.	84° (calc)
Namaqualand					
Gevers, etc. (1937)	1.654	1.685	1.699	Neg.	Near 70°

The correct optical orientation $X=c$, $Y=b$, $Z=a$ follows from the new morphological setting. Most of the material available was weakly pleochroic: X colorless, Y very pale yellow, Z pale green-yellow. There was a stronger pleochroism in some of the cross-fibre type. In Becke line tests no appreciable dispersion was observed, in contrast with the other authors listed in Table 4, who report strong dispersion $r>v$.

Chemistry and Mode of Occurrence

Table 5 shows three analyses made by Schoep on soddyite from Kasolo. Also given are the average of the three analyses according to Schoep, the theoretical compositions calculated for two suggested chemical formulae along with the molecular ratios derived therefrom. Schoep chose $12UO_3 \cdot 5SiO_2 \cdot 14H_2O$ as more likely than $5UO_3 \cdot 2SiO_2 \cdot 6SiO_2$ (advocated by Wherry, 1922) since the weight percentages calculated for it are in slightly better agreement with his average analysis.

The weight of the cell contents was calculated from the cell dimensions and the measured density. This figure, with the atomic proportions derived from analysis 3 in Table 5 led to $3[5UO_3 \cdot 2SiO_2 \cdot 6H_2O]$ as the cell contents most compatible with the chemical data. The derivation of the cell contents is presented in Table 6. The calculated Z factor of 3 is ap-

TABLE 5. CHEMICAL DATA ON SODDYITE (After Schoep)

	1	2	3	4	5	6	7	8
UO_3	85.53	85.13	85.79	85.87	86.10	86.25	0.300	0.300
SiO_2	7.86	7.88	7.61	7.87	7.50	7.30	0.131	0.125
H_2O	—	—	6.16	6.26	6.30	6.50	0.350	0.350
			99.56	100.00	99.90	100.05		

1, 2, 3. Soddyite, Kasolo; anal. Schoep (1930). 4. Schoep's average of analyses 1, 2 and 3. 5, 6. Schoep's calculated weight percentages for $12UO_3 \cdot 5SiO_2 \cdot 14H_2O$ and $5UO_3 \cdot 2SiO_2 \cdot 6H_2O$ respectively. 7, 8. Schoep's molecular proportions for 5 and 6 respectively.

parently related to the pseudo-period of $\frac{1}{3}$ which was previously noted. The calculated specific gravity of 4.75 compares well with the measured value of 4.70.

Wildish (1930) has reported the U^6 content of soddyite as 43.98% determined by the emanation method, and 44% by the gravimetric method The material analysed was certainly not soddyite, but quite possibly kasolite, which has a U^6 content of roughly 40%. These two minerals are similar in color and not easily distinguished in the hand specimen, by those not familiar with their crystal morphology.

As noted at the beginning of this paper, soddyite is both rare and limited in occurrence. It has been reported from only two localities: Kasolo, in the Belgian Congo of Africa, and the Norrabees pegmatite area south of the Orange River, Namaqualand, Africa. At Kasolo it forms a massive intimate mixture with curite. The cross-fibre or cross-bladed type always occurs as fissure fillings in the soddyite-curite complex. Euhedral crystals and crystal clusters are found associated with needles of sklodowskite on curite, the soddyite seemingly formed after

TABLE 6. ANALYSIS AND CELL CONTENT OF SODDYITE

	1		2	3	4
UO_3	85.79	U	14.88	14.94	15
SiO_3	7.61	Si	6.26	6.29	6
H_2O	6.16	O	56.79	57.00	57
	99.56	H_2O	18.52	18.60	18
			96.45	96.83	96

[1] Analysis by Schoep on Kasolo material. 2. Atoms per unit cell. 3. Atoms per unit cell based on O=57. 4. Ideal cell content for $3[5UO_3 \cdot 2SiO_2 \cdot 6H_2O]$.

the curite and before the sklodowskite. Kasolite, the lead bearing hydrous uranium silicate is another associated mineral.

Schoep has pointed out that there seems to be an intimate association of lead and non-lead species at Kasolo, for example curite-soddyite, curite-becquerelite, and kasolite-soddyite, the lead bearing species having formed first as an alteration of uraninite. The paragenesis at the Nicholson Mine, Lake Athabaska, Canada appears analogous, although no soddyite has as yet been found there.

The Namaqualand soddyite as reported by Gevers, Partridge and Joubert (1937) occurs in pegmatites, as a bladed incrustation on quartz, associated with malachite.

Soddite was the original name given to this mineral by Schoep in honor of Professor F. Soddy of Oxford University. Billiet (1926) changed it to soddyite, the change being approved by Schoep, who used this more euphonious synonym in all his later publications.

Acknowledgements

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