SECONDARY URANIUM MINERALS AT THE W. WILSON MINE IN THE BOULDER BATHOLITH, MONTANA*

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Abstract

Secondary uranium minerals found in the W. Wilson mine, near Clancy, Montana, include meta-autunite, meta-uranocircite, meta-torbernite, meta-zeunerite, uranophane, beta-uranophane, phosphuranylite, gummite, and an unidentified mineral, possibly a complex uranium silicate. Uraninite in this "siliceous reef" deposit has been leached and altered by ground water to form the secondary minerals. The deposition of autunite and torbernite as the meta-I hydrate, apparently at normal ground water temperatures, would appear to lower the range of temperature stability previously reported for these minerals. Isomorphous substitution among the four minerals of the meta-torbernite group may be responsible for this difference in stability. Although isostructural with uranophane, the W. Wilson material of this composition has minor discrepancies in its optical character which may be due to the extra Cu, Ba, or Pb in the mineral.

Introduction

The W. Wilson mine, near Clancy, Montana, provided an excellent opportunity to study the secondary uranium mineralization in a uraninite-bearing sulfide vein deposit close to the surface. Field investigations were begun during the summer of 1952 as part of a program of mineralogical studies of vein uranium deposits in the Boulder batholith, undertaken at The Pennsylvania State University on behalf of the U. S. Atomic Energy Commission. This paper summarizes the chemical, crystallographic, optic, and *x*-ray data on the secondary uranium minerals identified. Their distribution and zoning relative to the primary uranium minerals, the land surface, and the ground water table are discussed in a separate paper. (Wright and Emerson, 1957)

The W. Wilson mine, the largest of several small uranium producers in the northern part of the Boulder batholith, lies about 15 miles south of Helena, Montana. It is a "siliceous reef" type vein deposit in quartz monzonite. The gangue of vari-colored microcrystalline quartz contains small amounts of pyrite, galena, sphalerite, argentite, chalcopyrite, covellite, and uraninite, chiefly as microscopic inclusions.

Uraninite is the only uranium mineral recognized as primary. Although all of the uranium is thought to have been deposited originally as uraninite, nearly all of it is now in the form of secondary minerals. These are found both in scattered patches in the vein proper, and disseminated in the wall rock.

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RECENT WORK

The geology of the area west of Clancy was mapped by Roberts and Gude (1951) of the U. S. Geological Survey. They reported the occurrence of pitchblende, rutherfordine, uranophane, volgite, torbernite-zeunerite, autunite-uranocircite and gummite in the outcrop of the reef now being developed by the W. Wilson mine. A more recent study, made after considerable underground development, was conducted by Meschter (1953) of the U. S. Geological Survey. He found pitchblende, meta-torbernite, meta-zeunerite, autunite, uranophane, gummite, uranocircite, and phosphuranylite.

Thurlow and Reyner (1951) of the U. S. Atomic Energy Commission noted the presence of pitchblende, autunite, torbernite, gummite and possibly zeunerite, phosphuranylite and uranophane in the open cuts along the reef.

SPECTROSCOPIC ANALYSIS

Quantitative analysis of compounds rich in uranium by the spectrographic method is difficult due to the masking effect of the numerous lines of the complex uranium atom. The carrier-distillation method, as described by Scribner and Mullin (1946), was used to suppress the uranium spectrum. This method makes use of the order of volatilization of elements in the arc. Zirconium, hafnium, and most of the rare earths are the only elements reported to be less volatile than uranium. A carrier —in this case Ga_2O_3—mixed with the sample "sweeps out" the more volatile elements and the majority of the uranium remains in the electrode.

Since information could not be found in the literature on the application of the carrier-distillation method to the analysis of uranium phosphates, arsenates and silicates, some experimentation was carried out by Dr. H. L. Lovell and Mr. H. Grendon in the spectroscopic laboratories of the University to develop a suitable procedure for these minerals. A standard exposure (120 seconds at a 13 amp. spark current, using five milligrams of a uranium mineral sample mixed with five milligrams of graphite) was found to produce, as expected, an extremely heavy response of uranium lines and was not usable for semi-quantitative studies.

Exposure tests were made on the 1:1 mixture of Ga_2O_3 and sample. The uranium interference in exposures of 60 seconds and longer was too great for semi-quantitative analysis. When 30-second exposures were made the uranium lines were present but were confined to the 5th to 7th sector steps. The other elements in the sample showed clearly above this low uranium background. This 30-second exposure time was chosen, and five samples and a standard mineral were exposed. The senior author read these first plates and found the concentration estimates of some of the elements too low when compared with the usual graphite standards.

A set of synthetic uranium standards with known amounts of 25 elements was prepared, mixed in 1:1 ratio with Ga_2O_3, and exposed for 30 seconds. The density values obtained from these plates were used to estimate the element concentration in the uranium minerals. The ratio of Ga_2O_3 to sample was varied from 1:1 to 1:5 and uranium interference was found least objectionable at the 1:1 ratio.

Both major and trace elements were sought in each sample. The standardization samples contained Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, N, P, Pb, Sb, Si, Sn, Ti, U, V, and Zn. The amounts of these and 12 others, Au, B, Ca, Ge, K, Li, Na, Rb, Th, W, Y and Zr, were semi-quantitatively determined. In the study of the synthetic oxide mixtures in uranium matrix, serious variations from the expected intensities appeared in Ca, P, and Cu, when their concentration was greater than 0.1 per cent. This suggests that elements present in the larger concentrations tend to be held back with the uranium. It is not clear whether the effect is due to the nature of these particular elements or to their concentration, but the study of synthetic mixtures indicates that concentration is the major factor. Ti was found to be distinctly retarded and As, H, Ni and Sb showed a reduced sensitivity.

It appears that for trace element studies the method described above produces fairly reliable information. For major elements the percentages reported tend to be low and ratios of the major elements cannot be closely relied upon. Further standardization of this spectroscopic technique is needed and the standards should be prepared in a matrix more nearly like the uranium minerals.

SECONDARY URANIUM MINERALS

The brightly colored yellow, green, and orange secondary uranium minerals occur in pseudomorphous replacements of uraninite deposits along fractures and cleavages of the wall rock minerals, and well formed crystals growing in open fractures in veins and wall rock. The mineralogy is complex due to the compositional and structural variability and the abundance of fine-grained intergrown mixtures. Hydrous oxides, arsenates, phosphates, and silicates of uranium are present. Most of the minerals have variable water content and two or three structural changes which accompany dehydration.

The chemical formulas used for the minerals are taken from the *Glossary of Uranium- and Thorium-Bearing Minerals* (Frondel and Fleischer, 1955). The 6th and 7th editions of *Dana's System of Mineralogy*

(Palache, et al, 1951) and the *Tables of Uranium and Vanadium Minerals Which are Largely of Secondary Origin* (Gruner and Gardiner, 1952) provided optical and crystallographic data. Much of the systematic study of the uranium minerals has taken place during the past 10 years. New data are accumulating constantly, and continual revisions are necessary. Many of the earlier names and descriptions have been discarded, and several new species have been described. Descriptions in older publications are often incomplete or contain inaccuracies. The authors were fortunate to be able to compare their mineral descriptions with those tabulated by Dr. Clifford Frondel, which are in preparation for publication and represent the latest and most comprehensive compilation of this information available.

The minerals identified in samples from the W. Wilson mine are meta-autunite, meta-uranocircite, meta-torbernite, meta-zeunerite, phosphuranylite, uranophane, and beta-uranophane. The species contained in the fine-grained "gummite" (please refer to the terminology of "gummite" below), other than varying amounts of the last three minerals named above, have not been positively identified but are probably of the hydrous oxide group.

Rutherfordine and volgite, reported by Roberts and Gude (1951), were not found.

META-TORBERNITE GROUP

Four members of the meta-torbernite isostructural group are common in the W. Wilson deposit. These fit the general formula $A(UO_2)_2 (XO_4)_2 \cdot nH_2O$ and are the Cu, Ca, and Ba phosphates, meta-torbernite, meta-autunite and meta-uranocircite, and the Cu arsenate, meta-zeunerite. A good summary of the structure and the various transitions due to hydration is given by Palache, et al (1951). One problem in the study of these minerals is that the transitions from one form to another occur near room temperature. The transition from the meta-I structure to the fully hydrated form is reversible in the case of autunite but may not be so in torbernite, zeunerite, and uranocircite. With the large number of samples collected, it was impractical to take the precautions in sampling and shipping necessary to preserve the natural hydration state of the minerals, and in all cases the meta-I structure was the only one found during the laboratory study. However, distortions and cracks due to dehydration were not observed and all of the species may occur in the mine in the meta-I state of hydration. The ease of base exchange in this type of structure was shown by Fairchild (1929) who replaced the Ca of autunite with Na, K, Ba, Mn, Ca, Ni, Pb and Mg by soaking the autunite flakes in solutions containing these elements.

Because of the difficulty of determining the refractive index of the vibration direction perpendicular to the cleavage in these platy minerals, the values listed for the extraordinary ray and the birefringence were obtained from only one sample.

Meta-autunite I $Ca(UO_2)_2(PO_4)_2\cdot 2\frac{1}{2}$ to $6\frac{1}{2}$ H_2O

Color: Yellow to greenish yellow.

System: Tetragonal.

Habit: Thin tabular (001), usually square in outline. Subparallel growth gives rise to micaceous aggregates. See Fig. 1.

Oriented growth: Parallel growth with meta-torbernite is common.

Forms: (001) and (110) common, (010), (120)?

Cleavage: (001) perfect, (110) good, (010) and (100) traces seen.

Inclusions: Irregular red-brown masses of high positive relief are common. Colorless needles of high positive relief are parallel to (010) and (100). Some iron stains.

Fluorescence: Bright yellow-green

Optics Anomalously biaxial due to strain.

$n_{\text{Na and white}}$	Orientation	Pleochroism
α 1.594 ±0.002*	c	colorless
β 1.604–1.608 ±0.002		light yellow
γ 1.605–1.610 ±0.002		light yellow

Birefringence: $\gamma-\alpha=0.011$.

Biaxial negative: $2V=0$–$5°$.

X-ray: Yellow meta-autunite $n_\gamma=1.606$.

$d_{(\text{meas})}$ Å	8.33	3.60	3.48	3.22
I	10	9	9	8

Green meta-autunite n_γ 1.606

$d_{(\text{meas})}$ Å	8.42	3.63	3.58	3.20
I	10	10	10	9

Analysis: Semi-quantitative spectroscopic analysis

Yellow meta-autunite

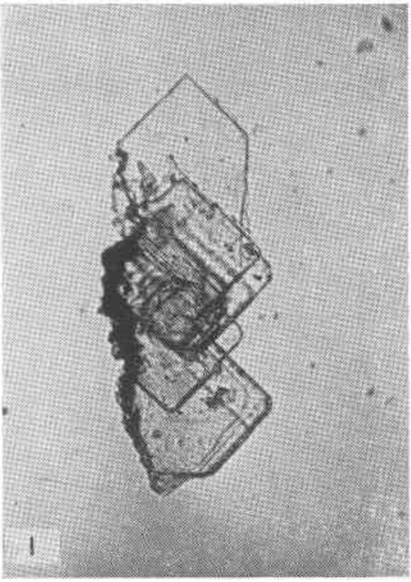
>10%	U, P
1–10%	Ca
0.1–1%	Si, K
0.01–0.1%	Al, Ba, Co, Cu, Fe, Ge, Li, Pb, Na, Sr
0.001–0.01%	Ag, B, Mg

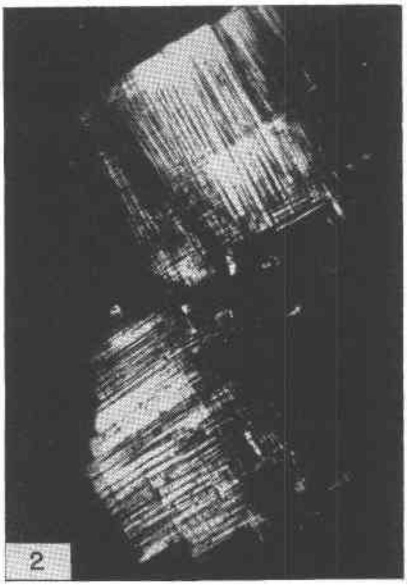
Green meta-autunite

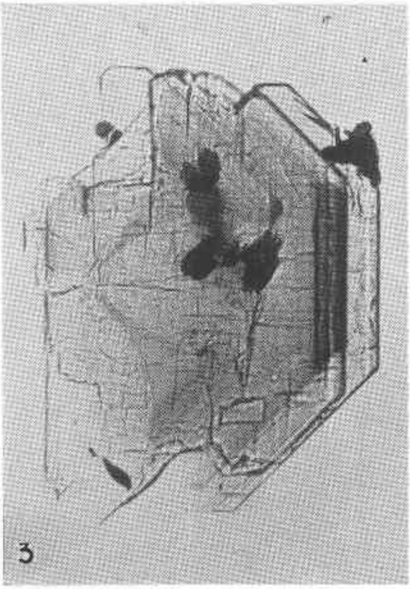
>10%	U, P
1–10%	Ca
0.1–1%	Ba, Cu, K, Si
0.01–0.1%	Al, Co, Fe, Li, Na, Pb
0.001–0.01%	Ag, B, Ge, Mg, Mo

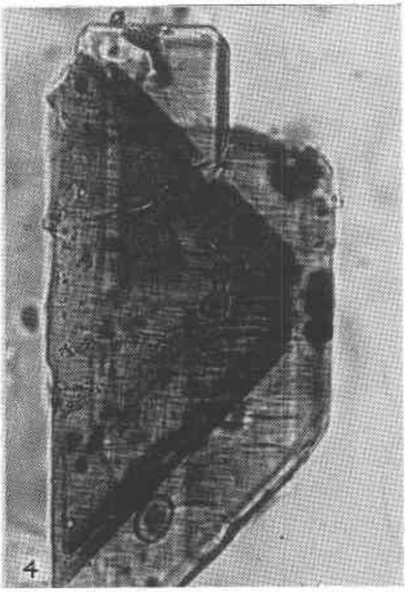
* ±0.002 indicates the precision of a single measurement.

X-ray and spectroscopic data on minerals from the W. Wilson mine indicate that isomorphous substitution may occur among the members of the meta-torbernite group.









Photomicrographs of Meta-torbernite Group Minerals
The (001) plane is parallel to the photograph

FIG. 1. Aggregate of yellow meta-autunite crystals. The group is 0.7 mm. long. Magnified about 80×.

FIG. 2. Aggregate of greenish-yellow meta-uranocircite crystals in crossed polarized light showing the "gridiron" twinning. The group is 1.6 mm. long. Magnified about 50×.

FIG. 3. Aggregate of green meta-torbernite crystals. The group is 0.78 mm. long. Magnified about 80×.

FIG. 4. A crystal of green meta-zeunerite showing phantom outlines. The crystal is 0.81 mm. long. Magnified about 100×.

Most of the meta-autunite has n_γ near 1.605 in the basal section, but some grains approached 1.610. This variation is well within the range recorded in the literature (Palache, et al, 1951). It is not possible to distinguish meta-autunite from meta-uranocircite visually or optically except by the use of index oils. The green color of some of the meta-autunite is probably due to the isomorphous subsitution of Cu or Ba, as suggested by the analysis.

Meta-uranocircite $Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$.
Color: Yellow-green to yellow.
System: Tetragonal.
Habit: Thin flakes parallel to the fracture surface and in radiating clumps, in the middle of which the flakes are perpendicular to the surface of deposition. Also as individual flakes around grains in the wall rock.
Forms: (001), (110), (010)
Cleavage: (001) perfect, (100) and (010) distinct
Fluorescence: Strong yellow-green
Optics: Anomalously biaxial due to strain

	$n_{\text{Na and white}}$	Orientation	Pleochroism
ϵ or X	1.610 ±0.002	c	colorless
ω or Y	1.612–1.624±0.002		pale yellow
ω or Z	1.612–1.624±0.002		pale yellow

Birefringence: $\omega-\epsilon=0.012$
Biaxial negative: $2V=0-5°$
Shows sets of twin lamelle parallel to (100) and (010); these resemble the "gridiron" twinning of microcline (Fig. 2). Nuffield and Milne (1953) suggest that this is due to variation in the zeolite-type hydration of the mineral and is not a structural twinning

X-ray:

$d_{(\text{meas})}$Å	8.52	3.61	3.22
I	10	10	9

Analysis: Semi-quantitative spectroscopic analysis

>10%	U, P
1–10%	Ca, Ba
0.1–1%	Si, Fe, Al, As, Pb, Cu
0.01–0.1%	Mn, Cr, Mo, Ni
0.001–0.01%	Mg, Ag, Be

Samples which were greenish-yellow and showed the twinning had an ordinary index as low as 1.612. For the purpose of this study, all flakes which fit the properties of the meta-autunite to meta-uranocircite series and had an index below 1.612 were classified as meta-autunite regardless of color. The sample submitted for analysis was homogeneous to *x*-rays and the Ca, present in significant amount, may be present in Ba positions.

Meta-torbernite $Cu(UO_2)_2(PO_4)_2 \cdot 4-8H_sO$
Color: Green
System: Tetragonal

Habit: Well formed crystals, thin to thick tabular (001), usually square in outline; rarely pyramidal. Subparallel growth in micaceous aggregates is common. See Fig. 3.

Forms: (001), (010)?, (111)?, (101)?

Cleavage: (001) perfect, (100) distinct.

Inclusions: Irregular colorless inclusions of $n=1.616$ are common. Also iron stains.

Fluorescence: None.

Optics:

	n_{Na}	Orientation	Pleochroism
	ω 1.626±0.002		green
	ϵ about 1.625	c	blue

Birefringence: $\epsilon-\omega$ about 0.001. In white light the indices are slightly higher and there is an abnormal purple interference color. Uniaxial positive or negative.

X-ray: Sample No. 2764, 120 foot level.

$d_{(meas)}$Å	8.26	8.93	3.63	3.45	3.21
I	10	9	10	9	9

Sample No. 425.

$d_{(meas)}$Å	8.76	3.66	3.23
I	10	10	9

Analysis: Semi-quantitative spectroscopic analysis.

Sample No. 2764, 120 foot level.

>10%	U, P
1–10%	Cu
0.1–1%	Al, Ca, Si
0.01–0.1%	Ba, Co, Fe, Mg, Pb
0.001–0.01%	Ag, Mn

Sample No. 425, 70 foot sub-level.

In *Dana's System of Mineralogy*, (Palache *et al.*, 1951), the pleochroism of meta-torbernite (ω=sky blue, ϵ=green) is reversed. This error has persisted from the earlier literature and should be corrected.

Interlayered parallel growth of meta-torbernite and meta-autunite is often seen. Thus the calcium found in meta-torbernite by spectroscopic analysis may be due to intermixed meta-autunite rather than isomorphous substitution. Meta-torbernite overgrowths on meta-uranocircite were noted in several samples.

Isomorphism between meta-zeunerite and meta-torbernite is suggested by Frondel (1955). Spectroscopic analysis of one sample (no. 425) of meta-torbernite, which appears homogeneous from optics and *x*-ray, shows the presence of considerable As which appears to have substituted for P. The mineral with the relatively high As content is optically negative and has $n_\omega=1.624$.

Experiments carried out by Hallimond (1920) showed that meta-torbernite formed from aqueous solutions only above 75° C. Although the crystals from the W. Wilson deposit may have become dehydrated on removal, this seems unlikely due to the lack of cracks and turbidity which normally are found when natural torbernite is dehydrated to the meta-I structure. It also seems unlikely that these crystals were deposited from solutions as warm as Hallimond suggests because all evidence strongly indicates movement and deposition by shallow-circulating ground water. It is possible that impurities in the crystals studied forced the meta-I structure to form, and more recent experimental work may already have lowered the formation temperature reported by Hallimond.

Meta-zeunerite $Cu(UO_2)_2(AsO_4)_2\cdot 8H_2O$.
Color: Green.
System: Tetragonal.
Habit: Tabular to scaly (001). Some rectangular outlines. Shows phantom outlines (Fig. 4) and occasionally appears as a parallel (001) overgrowth on meta-uranocircite.
Forms: (001), (010), (110).
Cleavage: (001) perfect, (100) distinct.
Fluorescence: None to weak yellow-green.

	n_{Na}	n_{white}	Pleochroism
ω	1.634 ±0.002	1.634	green.
ε	1.624–1.628±0.002	1.624	colorless.

Birefringence: $\omega-\epsilon=0.008$.
Uniaxial negative.

X-ray:

$d_{(meas)}$ Å	8.36	8.86	3.64	3.45	3.20
I	10	9	10	9	9

Analysis: Semi-quantitative spectroscopic analysis.

>10%	U, P
1–10%	Ca, As, Ba, Cu
0.1–1%	Si, Fe, Al, Pb
0.01–0.1%	Cr, Mo, Ni
0.001–0.01%	Mg, Mn, Ag, Be

According to Frondel (1951), meta-zeunerite is the expected form of the material. Meta-zeunerite and meta-uranocircite were noted to have developed, intermixed, on the iron-stained fracture surfaces of several samples.

Fine-Grained Secondary Minerals

Well crystallized samples of the fine-grained yellow minerals are rare, and the largest crystals seldom exceed 0.5 mm. in length. Some of these minerals, uranophane, beta-uranophane and phosphuranylite commonly occur as fine-grained aggregates and form a significant part of the "gummite" (see discussion of "gummite" below).

Uranophane $Ca(UO_2)_2(SiO_3)_2(OH)_2\cdot 5H_2O$.
Color: Yellow.
System: Orthorhombic.

Habit:	Well formed, very small radiating laths. Average crystal size 0.1 mm.×0.005 mm.×0.004 mm. Also shown by *x*-ray identification to form as a yellow powder, amorphous under the microscope. See Fig. 5.
Forms:	(100), (010), (011)?
Cleavage:	(100) and (010), one perfect, the other fair.
Inclusions:	Irregular opaque inclusions occur rarely.
Fluorescence:	None.

Optics:

$n_{\text{Na and white}}$	Orientation	Pleochroism
α 1.627 ± 0.002		colorless.
β 1.649 ± 0.002	c	yellow.
γ 1.660 ± 0.002		yellow-green.

Birefringence: $\gamma - \alpha = 0.033$.

Biaxial negative: $2V = 60°$.

Dispersion: $r > v$ moderate. Abnormal blue interference color due to dispersion.

X-ray:

$d_{(\text{meas})}$Å	7.89	3.95	2.98	2.90
I	10	10	9	9

(For greater detail see Table 1).

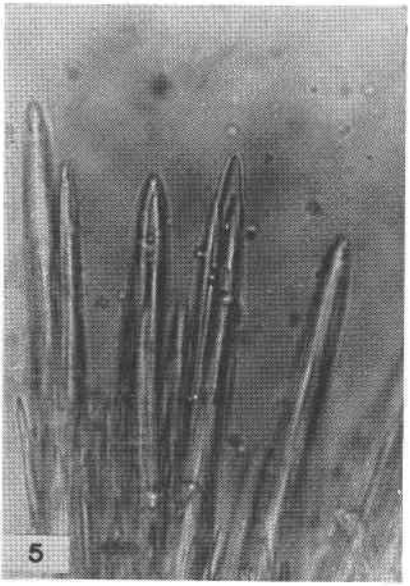
Analysis: Semi-quantitative spectroscopic analysis.

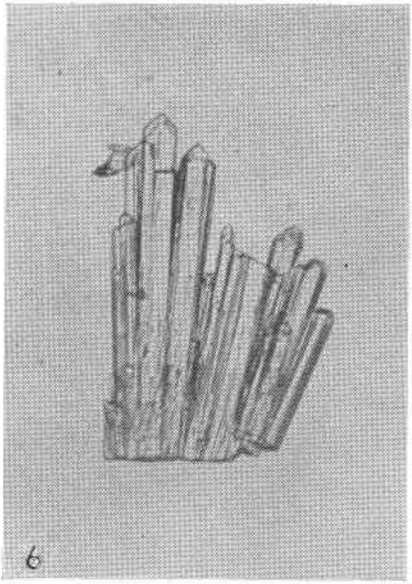
>10%	Si, U
1–10%	Ca, Ba, P, Cu
0.1–1%	Fe, Al, Pb
0.01–0.1%	Mn, Cr, Mo
0.001–0.01%	Mg, Ag, Be

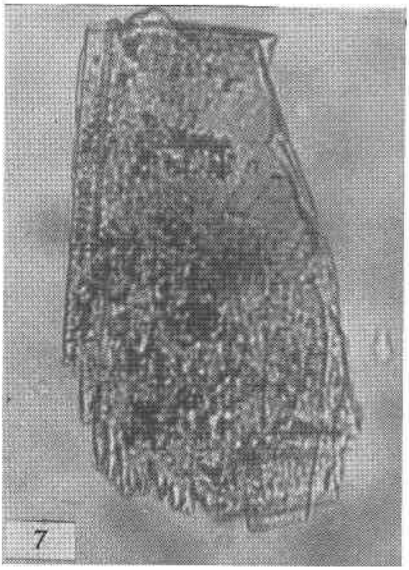
Published information on uranophane, such as Larsen *et al.* (1926), includes optical data which as shown below are incompatible with the optical character of the W. Wilson uranophane.

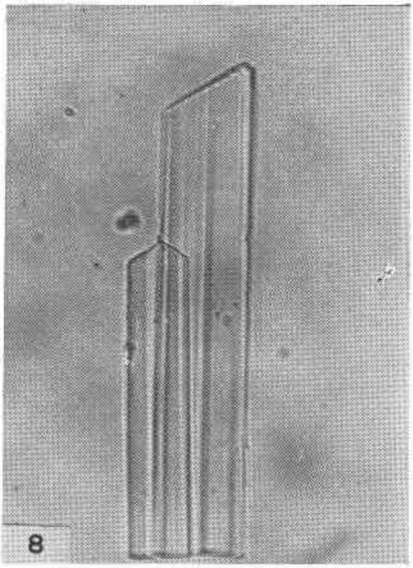
	Uranophane from Lusk, Wyo. (Larsen et al, 1926)	W. Wilson uranophane
α	1.642	1.627
β	1.665	1.649
γ	1.672	1.660
	$r < v$	$r > v$
2V	37–45°	60°
Orientation	Elongated parallel to Z.	Elongated parallel to Y.

The reason for the optical discrepancy is not known. It may conceivably be related to the extra Cu, Ba or Pb indicated by the analysis of W. Wilson uranophane. The *x*-ray powder photograph of the W. Wilson mineral is identical to the pattern from the spindle of the U. S. Geological Survey's uranophane sample #1313, and Dr. Frondel (personal communication) reported that the W. Wilson uranophane is identical structurally with uranophane in the Harvard University collection.









Photomicrographs of Secondary Uranium Minerals

FIG. 5. A cluster of uranophane needles showing their terminations. The (001) plane is parallel to the photograph. The field of the photograph is 0.1 mm. long. Magnified about 750×.

FIG. 6. A cluster of beta-uranophane laths. The (010) plane is parallel to the photograph. The field of the photograph is 0.5 mm. long. Magnified about 150×.

FIG. 7. A basal fragment of phosphuranylite showing crude crystal outlines and cleavage traces. The (001) plane is parallel to the photograph. The field of the photograph is 0.2 mm. long. Magnified about 375×.

FIG. 8. Parallel crystals of mineral "*X*". This orientation gives a centered Bx_a figure. The field of the photograph is 0.2 mm. long. Magnified about 375×.

Beta-uranophane $Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$.

Color: Yellow.

System: Monoclinic, β = about 94°.

Habit: Well formed crystals, moderately thick, tabular parallel to (010). Aggregate growth parallel to (010) is common. Average single crystal size 0.1 mm.×0.04 mm.×0.02 mm. Commonly in radial aggregates. See Fig. 6.

Twinning: Occasional twinning on the c axis.

Zoning: Crystal zoning is seen in (010) section with zone boundaries parallel to (100) and (001).

Forms:

(100)	(001)	(100) very small.
(010)	(011)	(101)

Cleavage: (010) perfect, (100) poor.

Inclusions: Rare, some iron stains.

Fluorescence: None.

Optics

	n_{Na}	n_{white}*	Pleochroism
α	$(1.652–1.656) \pm 0.002$	1.652	colorless.
β	$(1.678–1.682) \pm 0.002$	1.680	light yellow.
ω	$(1.682–1.686) \pm 0.002$	1.683	light yellow.

Orientation: $b = X$, $c \wedge Y_{Na} = 30° - 40°$.

Birefringence: $\gamma - \alpha$ about 0.030.

Biaxial negative: $2V = 10 - 20°$

Absorption: $Z = Y > X$.

Dispersion: $r > v$ very strong, crossed, abnormal interference colors.

X-ray:

$d_{(meas)}$Å	7.78	3.84	3.47	3.16
I	10	9	8	8

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* These are approximate values because of strong dispersion.

The zoning, similar to that reported by Steinocher and Novacek (1939) for beta-uranotile (= beta-uranophane), is attributed to compositional variations and is probably not due to a change in the hydration state.

A ten milligram sample for spectrographic analysis could not be obtained.

Phosphuranylite $Ca(UO_2)_4(PO_4)_2(OH)_4 \cdot 7H_2O$.

Color: Dark yellow.

System: Orthorhombic (Hogarth and Nuffield, 1954).

Habit: Microscopic rectangular basal plates. Crystal outlines are not well formed. See Fig. 7.

Fluorescence: None.

Optics:

	n_{Na}	n_{white}	Pleochroism
α	1.672 ± 0.002	1.668	colorless.
β	$1.688–1.696 \pm 0.002$	1.684–1.692	dark yellow.
γ	$1.688–1.696 \pm 0.002$	1.684–1.692	dark yellow.

Birefringence: $\gamma - \alpha = 0.016 - 0.024$.

Biaxial negative: $2V = 10–35°$ $r > v$ strong.

X-ray:

$d_{(meas)}$Å	7.83	3.95	5.80	2.87
I	10	9	8	8

TABLE 1. *X*-RAY DIFFRACTION POWDER PATTERN OF URANOPHANE CORRECTED FOR FILM SHRINKAGE. CuKα RADIATION

d(meas.) Å	*I*	*d*(meas.) Å	*I*	*d*(meas.) Å	*I*
7.89	10	2.185	5	1.446	2
6.58	7	2.096	5	1.3849	1
5.40	7	2.036	2	1.3662	1
4.78	8	1.967	5	1.3467	1
4.26	3	1.908	4	1.3221	1
3.948	10	1.864	4	1.2630	1
3.579	5	1.821	2	1.2423	2
3.489	5	1.771	4	1.1859	1b
3.414	2	1.742	4	1.1487	1b
3.200	8	1.716	1	1.0811	1
3.075	2	1.688	1	1.0702	1
2.981	9	1.654	2	1.0515	1
2.898	9	1.606	1	1.0242	1
2.682	7	1.583	1	0.9536	1
2.625	7	1.563	1	0.9110	1
2.564	2	1.533	2	0.8914	1
2.511	3	1.488	2	0.8663	1
2.411	2	1.464	1	0.8544	1

Contrary to the data of Frondel (1950) and Palache *et al.* (1951), who report Z perpendicular to the tablets, X is perpendicular to the plates in the W. Wilson material. The orientation found by the authors agrees with the two determinations made by Larsen (1921), and considering the pleochroism, optic sign, and pseudo-tetragonal nature of the mineral, the orientation with X perpendicular to the plates appears more consistent to the authors.

A ten milligram sample for spectroscopic analysis could not be obtained.

Mineral "X"

Color:	Yellow.
System:	Orthorhombic?
Habit:	Well formed, very small radiating laths. Crystal size about 0.3 mm.×0.02 mm×0.01 mm. Parallel growths are common. See Fig. 8.
Forms:	If the length=*c*, width=*b*, and thickness=*a* then (100) (010) (011)? are present.
Cleavage:	(100) and (010) perfect.
Inclusions:	Rare.
Fluorescence:	None.

Optics:

n_{Na}	Orientation	Pleochroism
α 1.71±0.01		colorless.
β 1.87±0.01		colorless.
γ 1.92±0.01	c	light yellow.

Birefringence: $\gamma-\alpha=0.21$.
Biaxial negative: $2V=55°$
Dispersion: $r>v$ moderate.

X-ray:

$d_{(meas)}$Å	7.67	3.37	3.83
I	10	8	7

(For additional *x*-ray data see Table 2.)

Analysis: Semi-quantitative spectroscopic analysis.

>10%	U
1–10%	Si, Ca, Cu, Mo
0.1–1%	Fe, Al, Pb, Ba
0.01–0.1%	Cr
0.001–0.01%	Mg, Ag

Only one specimen of this mineral was found in the W. Wilson mine. The sample was collected by Mr. Buford Miles while he was working in the mine near the 50 foot sub-level. Radiating clusters of the lath-like crystals occur in open fractures with a few crystals of meta-torbernite.

The mineral lost about 5% of its weight when heated at 75° C., and no further loss occurred at 110° C. The *x*-ray powder photograph did not match anything, known or unidentified, in the file of uranium minerals at Harvard University (C. Frondel, personal communication). Mineral "*X*" is apparently a new species and the spectroscopic analysis indicates that it is possibly a complex uranium silicate. More accurate chemical data are needed to determine the composition of this mineral and establish it as a new species.

The authors have identified this same mineral in a sample from Marysvale, Utah.

TABLE 2. *X*-RAY DIFFRACTION POWDER PATTERN OF MINERAL "X"

Not corrected for film shrinkage. CuKα radiation

d(meas.)	I	d(meas.)	I	d(meas.)	I
7.67	10	2.903	5	1.696	1b
6.60	5	2.710	1	1.612	2
4.98	5	2.128	4	1.566	5
4.49	5	2.075	4	1.540	1
3.834	7	2.031	4	1.497	1
3.369	8	1.956	6	1.433	1
3.220	6	1.884	6	1.3139	1
3.139	6	1.800	1b	1.2642	1
2.978	5				

Gummite and "Gummite"

Gummite is a loosely defined generic term referring to the alteration products about uraninite. It represents the final stages of oxidation and hydration, and its mineral composition has been shown by Frondel (1956) to vary widely. Frondel (1956, p. 542) found that it was possible, using *x*-ray, optical, and thermal methods, to identify the components of nearly all of about 100 specimens of gummite examined with already known uranium minerals, and that "gummite and its analogues virtually disappear as units of description" if these methods are applied. Geologists in the Boulder batholith have used the term as a convenient field name to describe all amorphous or very fine-grained yellow secondary minerals, whether or not they appear to have replaced uraninite directly. Closely associated with some of the uraninite fragments is a glassy orange to yellow material which fits the more common usage of gummite. The field term "gummite," used in quotation marks, has been retained by the present authors in the study of the distribution of the uranium secondaries (Wright and Emerson, 1957), to refer to the fine-grained yellow material lacking a vitreous luster and commonly occurring at some distance from original uraninite sites.

The orange-yellow vitreous gummite occurs very sparingly in the W. Wilson deposit and little material could be collected. This material gave a poor *x*-ray pattern with faint lines at 3.21 and 3.34 Å and very weak, broad lines at 4.02, 4.12 and 7.83 Å. When the material was heated at 500° to 600° C. for several hours in an attempt to crystallize it and sharpen the *x*-ray lines it turned a deep red but did not melt. No clear powder pattern could be obtained and only one weak line with a spacing of 3.32 Å remained. This gummite is anisotropic with indices of refraction around 1.70. A spectroscopic analysis shows a significant amount of Si, Sb, and As.

Much of the fine-grained yellow "gummite" is a mixture of uranophane, beta-uranophane and phosphuranylite. However, a number of lines which cannot be attributed to these minerals appear in the *x*-ray patterns. The wide variation in the peak positions and heights of the *x*-ray diffractometer patterns indicate a great variability in the composition of the "gummite." Spacings which could be due to clarkeite ($UO_3 \cdot nH_2O$?), fourmarierite ($PbO \cdot 4UO_3 \cdot nH_2O$) and epiianthinite ($UO_3 \cdot 2H_2O$) were found in some of the patterns. The high refractive indices of some components in the "gummite" are in the proper range for these minerals (1.8–2.0), but positive identifications could not be made. Two samples were spectroscopically analyzed and these yielded the following results:

	#1	#2
>10%	U	U
1–10%	Ca, P, Si, W	Ca, P, Si
0.1–1%	Ba, Pb, Sb, K	K, Pb, W
0.01–0.1%	Al, Co, Cu, Fe, Mn, Mo, Na, Rb	Al, Ba, Co, Cu, Fe, Mo, Na, Rb, Sb
0.001–0.01%	Ag, Mg	Ag, Mg, Mn

The analyses show the variability in the gummite and indicate that it is composed primarily of hydrous uranium oxides, silicates, and phosphates. The surprising abundance of tungsten cannot be explained by the authors.

A brief study of the fine-grained yellow "gummite" material was made with the electron microscope. Both powder and surface replica techniques were used for the fine-grained secondaries and in both cases the majority of the material showed no distinct crystal outlines. An occasional grain showed parallel edges, probably due to cleavage, and a few 90 degree crystal or cleavage corners could be seen. The surface replicas showed cleavage in poorly developed crystal laths. The larger grains are about two to six microns across.

Surface replicas of the gummite were difficult to obtain because of the small size of the samples. The largest continuous fracture surface of this glassy material measured two millimeters across. On this surface the electron microscope showed areas of irregular fractures and a few pockets of lath-like needles which are about 0.5 to 1.0 microns long and 0.1 micron thick.

CONCLUSIONS

Four members of the meta-torbernite structural group, meta-autunite, meta-uranocircite, meta-torbernite and meta-zeunerite, occur in the W. Wilson deposit. Uranophane, beta-uranophane, phosphuranylite, gummite and an unidentified mineral occurring in yellow needles of high refractive index are also found. All of the minerals for which chemical data could be obtained show variations from the ideal formulas, due probably to one or more of three factors: contamination, interlayering, and isomorphism. Contamination is the probable source of iron in the uranophane. Interlayering of meta-autunite and meta-torbernite was observed, and may occur in many more cases than were recognized, since it can be observed only under unusual circumstances. Isomorphous substitution is suggested as the main cause of the variation in Ba, Ca, and Cu as well as P and As in the meta-torbernite structure minerals.

This deposit is possibly unique in that no minerals of the hydrated torbernite structure were found and evidence suggests that only the meta-torbernite type minerals were deposited. This may be due to the isomorphous compositional variations in the meta-autunite and meta-torbernite, although there may have been recent unpublished experimental work, unknown to the authors, demonstrating temperatures for the stability field lower than those reported earlier.

The discrepancy between the optical data on the W. Wilson uranophane and the published data on that mineral may be due to the extra Cu, Ba or Pb. The structural identity with normal uranophane is shown by the *x*-ray powder patterns.

Optical study of the meta-torbernite showed the pelochroism to be the reverse of that listed in the seventh edition of *Dana's System of Mineralogy* (Palache, 1951). Also, phosphuranylite is described as having Z perpendicular to the tabular development while the W. Wilson material has X perpendicular to the tablets.

Mineral "*X*", the yellow needles of high refractive index, is probably a complex hydrated uranium silicate on the basis of one spectrographic analysis. Its structure is not similar to any of the known uranium minerals. More accurate chemical data needed to establish this mineral as a new species will be difficult to obtain with the very limited amount of material available.

The "gummite" of the W. Wilson deposit is a mixture of various amounts of uranophane, beta-uranophane and phosphuranylite with several unidentified minerals. The material is composed of significant amounts of Ba, Ca, K, P, Pb, Si, W, and U.

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