

THE WODGINITE GROUP. III. CLASSIFICATION AND NEW SPECIES

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ABSTRACT

The minerals constituting the wodginite group are isostructural oxides, with the general formula ABC_2O_8 ($Z = 4$); $A = Mn^{2+}, Fe^{2+}, Li, \square$; $B = Sn^{4+}, Ti, Fe^{3+}, Ta$; $C = Ta, Nb$. A classification system based on the chemistry of the A - and B -cation sites has been devised; it uses chemical modifiers in conjunction with the root name "wodginite". Wodginite itself has the general formula $MnSnTa_2O_8$; two new members of the wodginite group are characterized here: ferrowodginite, $Fe^{2+}SnTa_2O_8$ and titanowodginite, $MnTiTa_2O_8$. Ferrowodginite occurs as 0.01- to 0.2-mm inclusions in cassiterite from a granitic pegmatite near Sukula, southwestern Finland. It is dark brown to black, has a dark brown streak, vitreous luster, is optically anisotropic with all $n > 2$, and is nonfluorescent. The calculated density is 7.02 g/cm^3 ; it is brittle, $H 5\frac{1}{2}$, without cleavage; it has an irregular fracture. The average chemical composition (wt. %) is: MnO 2.8, FeO 9.3, Fe_2O_3 1.9, TiO_2 4.3, SnO_2 10.1, Nb_2O_5 14.8, Ta_2O_5 56.3, total 99.4. The strongest five lines in the X-ray powder pattern are: 4.16(50), 2.97(100), 2.55(30), 2.493(40) and 1.455(30) Å. The unit-cell parameters are $a 9.415(7)$, $b 11.442(6)$, $c 5.103(4)$ Å, $\beta 90.8(1)^\circ$, $V 549.7(6)$ Å³, space group $C2/c$. Titanowodginite occurs as euhedral, diamond-shaped crystals up to 1 cm across at the Tanco pegmatite, Bernic Lake, Manitoba. It is dark brown to black, has a dark brown streak, vitreous luster, is optically anisotropic and biaxial (+) with all $n > 2$, and is nonfluorescent. The density is 6.86 (meas.) and 6.89 g/cm^3 (calc.); it is brittle, $H 5\frac{1}{2}$, with no cleavage and an irregular fracture. The chemical composition (wt. %) is: MnO 9.0, FeO 3.1, Fe_2O_3 0.1, TiO_2 9.2, SnO_2 7.4, Nb_2O_5 11.1, Ta_2O_5 59.9, total 99.7. The strongest five lines in the X-ray powder pattern are: 3.644(46), 2.976(100), 2.966(95), 2.495(36) and 1.715(23) Å. The unit-cell parameters are $a 9.466(2)$, $b 11.431(1)$, $c 5.126(1)$ Å, $\beta 90.31(2)^\circ$, $V 554.6(1)$ Å³; the space group is $C2/c$. The classification, the new species and their names were approved for publication by the I.M.A. Commission on New Minerals and Mineral Names.

Keywords: ferrowodginite, titanowodginite, wodginite, new mineral species, oxide, granitic pegmatite, Finland, Manitoba.

SOMMAIRE

Les minéraux du groupe de la wodginite sont des oxydes isostructuraux ayant la formule générale ABC_2O_8 ($Z = 4$); A représente Mn^{2+}, Fe^{2+}, Li et des lacunes, B représente Sn^{4+}, Ti, Fe^{3+} et Ta , et C , Ta et Nb . Nous proposons un système de classification fondé sur l'occupation des positions A et B ; il se sert de qualificatifs et de la racine "wodginite". La wodginite proprement dite a la formule $MnSnTa_2O_8$. Nous décrivons ici deux nouveaux membres de ce groupe, ferrowodginite, $Fe^{2+}SnTa_2O_8$, et titanowodginite, $MnTiTa_2O_8$. La ferrowodginite forme de petites inclusions (0.01–0.2 mm) dans la cassitérite d'une pegmatite granitique près de Sukula, dans le sud-ouest de la Finlande. Les cristaux sont brun foncé à noir, ont une rayure brun foncé et un éclat vitreux; ils sont optiquement anisotropes, tous les indices n étant supérieurs à 2, et non fluorescents. La densité calculée est de 7.02; la ferrowodginite est cassante (fractures irrégulières); sa dureté est de $5\frac{1}{2}$, et elle est sans clivage. La composition chimique moyenne (% en poids) est: MnO 2.8, FeO 9.3, Fe_2O_3 1.9, TiO_2 4.3, SnO_2 10.1, Nb_2O_5 14.8, Ta_2O_5 56.3, total 99.4. Les cinq raies les plus intenses du cliché de poudre [d en Å(I)] sont: 4.16(50), 2.97(100), 2.55(30), 2.493(40) et 1.455(30). Les paramètres réticulaires sont: $a 9.415(7)$, $b 11.442(6)$, $c 5.103(4)$ Å, $\beta 90.8(1)^\circ$, $V 549.7(6)$ Å³, groupe spatial $C2/c$. La titanowodginite forme des cristaux idiomorphes en losanges d'un cm dans la pegmatite de Tanco, lac Bernic, au Manitoba. Les cristaux sont brun foncé à noir, la rayure, brun foncé, et l'éclat, vitreux; elle est optiquement anisotrope et biaxe positive, avec tous les indices de réfraction supérieurs à 2, et non fluorescente. La densité est 6.86 (mesurée) et 6.89 (calculée). Elle est cassante; sa dureté est de $5\frac{1}{2}$. Elle ne montre aucun clivage, et les fractures sont irrégulières. La composition chimique (% en poids) est: MnO 9.0, FeO 3.1, Fe_2O_3 0.1, TiO_2 9.2, SnO_2 7.4, Nb_2O_5 11.1, Ta_2O_5 59.9, total 99.7. Les cinq raies les plus intenses du cliché de poudre [d en Å(I)] sont: 3.644(46), 2.976(100), 2.966(95), 2.495(36) et 1.715(23). Les paramètres réticulaires sont $a 9.466(2)$, $b 11.431(1)$, $c 5.126(1)$ Å, $\beta 90.31(2)^\circ$, $V 554.6(1)$ Å³, groupe spatial $C2/c$. Le schéma de classification, les espèces nouvelles et leur nom ont reçu l'approbation de la Commission des nouveaux minéraux et des noms de minéraux de l'Association Internationale de Minéralogie.

(Traduit par la Rédaction)

Mots-clés: ferrowodginite, titanowodginite, wodginite, nouvelle espèce minérale, oxyde, pegmatite granitique, Finlande, Manitoba.

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INTRODUCTION

Although wodginite was first encountered by Simpson (1909) at Wodgina, Western Australia, recognition of its status as a new mineral species came only when Nickel *et al.* (1963) showed it to be distinct from tantalite. Recognition of this distinction led to the discovery of wodginite at a variety of localities, which today total 37 in number.

Nickel *et al.* (1963) correctly inferred wodginite to be a superstructure of ixiolite; however, it was not until much later that the details of the structure of wodginite and its formula were deciphered (Ferguson *et al.* 1976). Wodginite has the general formula ABC_2O_8 , ideally $A = Mn$, $B = Sn$ and $C = Ta$, with $Z = 4$ and space group $C2/c$. Wodginite shows considerable solid-solution at all structural sites (*e.g.*, von Knorring *et al.* 1969, Kornetova *et al.* 1978). We have found some samples to deviate by more than 50% from the ideal formula; hence "wodginite" as previously defined inadequately describes these samples. As previously defined, "wodginite" consists of a group of mineral species. The classification and two new members of the group are the subject of the present paper; the structural crystallography and crystal chemistry of the group are described in companion papers (Ercit *et al.* 1992a, b).

CLASSIFICATION

The name *wodginite*, as introduced by Nickel *et al.* (1963) and defined by Ferguson *et al.* (1976), is associated with the composition $MnSnTa_2O_8$. As such, the name is inappropriate for several natural examples of wodginite that deviate by more than 50% at individual cation sites from this ideal composition. These examples of wodginite most closely approach the hypothetical end-members $FeSnTa_2O_8$, $MnTiTa_2O_8$ or $LiTaTa_2O_8$.

Subdivision and classification of wodginite-group minerals are complicated by a number of factors. 1) Cation substitutions involve three distinct sites, making a nomenclature based on the generic name *wodginite* difficult. However, because of the limited extent of Nb substitution at the C site ($\langle C\text{-site Nb} \rangle = 15\%$, maximum C-site Nb = 35%), substitutions at this site can be ignored for purposes of nomenclature. Classification can be based simply on the nature of the occupant of the A and B sites; the reduced dimensionality of the problem makes a nomenclature involving a generic name plus chemical prefixes possible. 2) The degree of cation order is variable; the calculation of fully ordered formulae may not exactly reflect the disorder-modified site occupancies of some samples. However, because of the

difficulty involved in obtaining actual site-occupancies by means other than crystal-structure analysis or highly precise powder diffractometry, a classification based on the fully ordered formulae seems most practical (*cf.* the columbite group). 3) Coupled substitutions involving more than one site result in further complexity, as does the introduction of some substituents by more than one mechanism (*e.g.*, B-site Ta). However, these mechanisms are well known (Ercit *et al.* 1992a), so that by applying constraints to the rules of nomenclature, a solution should be possible. Table 1 summarizes all known operators.

Taking all of the above factors into consideration, the following scheme is proposed for the classification and nomenclature of wodginite-group minerals based on A- and B-site chemistries:

1. The set of species with the wodginite structure (partially to completely ordered, Ercit *et al.* 1992a, b) is referred to as the *wodginite group*.
2. For historical reasons, the name *wodginite* is used for end-member $MnSnTa_2O_8$, which is closest to the composition of most natural wodginite-group minerals.
3. Species names are to consist of the root "wodginite" modified by prefixes reflecting A- and B-site chemistries.
4. Such prefixes are to be used only in cases where one or more of the operators in Table 1 are more than 50% effective.
5. No more than one prefix per site should be used to construct the name, in which case the A-site prefix should precede the B-site prefix. In cases where more than one constituent is introduced to a single site by the operation, the prefix chosen should reflect the unique constituent only.

The following examples should serve to illustrate the application of point 5. Ta is a non-unique B-site constituent in that it can be introduced to the site by as many as four different mechanisms of substitution (operators 4 to 7 of Table 1). One of these operators is always insignificant from a taxonomic point of view, and thus it can be ignored (operator 7). Of the remaining operators, (5) represents the only one by which Fe^{3+} can be introduced to the B site. Fe^{3+} is the unique

TABLE 1. SIGNIFICANT SUBSTITUTION OPERATORS FOR THE WODGINITE GROUP

Operator	End-member
(1) $Fe^{2+} Mn^{2+}_{-1}$	$Fe^{2+}_2Sn_4Ta_8O_{32}$
(2) $Ti^{4+} Sn^{4+}_{-1}$	$Mn_2Ti_4Ta_8O_{32}$
(3) $Nb^{5+} c[Ta^{5+}]_{-1}$	$Mn_2Sn_2Nb_8O_{32}$
(4) $A[L^{i+}]_B[Ta^{5+}]_A[Mn^{2+}]_{-1}_B[Sn^{4+}]_{-1}$	$Li_4Ta_4Ta_8O_{32}$
(5) $Fe^{3+}_B[Ta^{5+}]_B[Sn^{4+}]_{-2}$	$Mn_2Fe^{3+}_2Ta_8O_{32}$
(6) $A_c[B[Ta^{5+}]_2]_A[Mn^{2+}]_{-1}_B[Sn^{4+}]_{-2}$	$Mn_2Ta_4Ta_8O_{32}$
(7) $B_c[B[Ta^{5+}]_4]_B[Sn^{4+}]_{-5}$	$Mn_4Ta_{5.2}Ta_8O_{32}$

TABLE 2. CLASSIFICATION OF THE WODGINITE GROUP

Criteria		Name	End Member
A site	B site		
≤50% Li, ≤50% Fe ²⁺	≤50% Ti ≤25% Fe ³⁺	WODGINITE	Mn ₄ Sn ₄ Ta ₈ O ₃₂
	>50% Ti	TITANOWODGINITE	Mn ₄ Ti ₄ Ta ₈ O ₃₂
>50% Fe ²⁺	>25% Fe ³⁺ (>25% Ta)	(unnamed)	Mn ₄ (Fe ³⁺ ₂ Ta ₂)Ta ₈ O ₃₂
	≤50% Ti ≤25% Fe ³⁺	FERROWODGINITE	Fe ²⁺ ₄ Sn ₄ Ta ₈ O ₃₂
	>50% Ti	(unnamed)	Fe ²⁺ ₄ Ti ₄ Ta ₈ O ₃₂
>50% Li	>25% Fe ³⁺ (>25% Ta)	(unnamed)	Fe ²⁺ ₄ (Fe ³⁺ ₂ Ta ₂)Ta ₈ O ₃₂
	>50% Ta	LITHIOWODGINITE	Li ₄ Ta ₄ Ta ₈ O ₃₂

constituent of this operation, thus the appropriate prefix for greater than 50% effectiveness of (5) is *ferri*. As already correctly applied by Voloshin *et al.* (1990), *lithio* is the prefix associated with operator (4). And so, by deduction, *tantalio* would be the prefix associated with greater than 50% efficiency of operator (6).

Table 2 gives actual and hypothetical names of species and end-member compositions generated by operators (1), (2), (4) and (5), the most significant operators involved in the crystal chemistry of the group. Criteria for classification follow the rules given above. The table is divided into three segments on the basis of A-site chemistry. The uppermost segment contains species with Mn end-members. The middle segment contains species with Fe²⁺ end-members. The bottom segment contains the only species possible with Li end-members. Three new members of the wodginite group have been recognized: ferrowodginite and titanowodginite (present study) and lithiowodginite (Voloshin *et al.* 1990). At an earlier stage of this work (Ercit *et al.* 1984), a fourth species was proposed: tantalowodginite. *We have since formally retracted the species status of tantalowodginite*, as we now recognize the type samples to be Ta-rich wodginite and lithiowodginite. Greater than 50% effectiveness of operator (6) (Table 1) is shown only by sample L-15 (Ercit *et al.* 1992a); however, the minute size of the crystals and the limited quantities of the mineral do not allow for measurement of Li or the X-ray properties of the sample; hence it is *not* presently possible to use "tantalowodginite" as a species name. Two samples examined in the present study (TSE-82, TSE-94) have more than 50% of the end-member FeTiTa₂O₈; however, because of the minute size of each sample, adequate material is not available for characterization of the hypothetical species "ferrotitanowodginite". As a final note, both the synthesis work of Turnock

(1966) and the existence of some natural samples with Fe³⁺ contents approaching 50% efficiency of the operator (5) suggest that operator (5) may generate new species in the future.

The classification scheme was approved for publication by the International Mineralogical Association in 1984, and is presented here, in its original systematics, with only minor additions (Table 1) imposed by more recent studies (Voloshin *et al.* 1990).

FERROWODGINITE

Ferroan "varieties" of wodginite were first encountered by Vormá & Siivola (1967) and von Knorring *et al.* (1969) soon after wodginite was first established as a species. The latter of these two samples is only a variety of wodginite, but the sample of Vormá & Siivola (1967) is wodginite with more than 50% of its Mn²⁺ replaced by Fe²⁺. We obtained samples of this material from the research collection of J. Siivola (sample A5234, renumbered SK-1 in the present study), and found that it is a new species, the Fe²⁺ analogue of wodginite; in allusion to the chemistry, we name the species *ferrowodginite*. The new species and its name have been approved for publication by the I.M.A. Commission on New Minerals and Mineral Names.

Ferrowodginite occurs in a granitic pegmatite near the village of Sukula in the Tammela-Somero pegmatite province, southwestern Finland (Vormá & Siivola 1967), the regional geology of which was described by Aurola (1963). Because of the number of pegmatites in the vicinity of Sukula, and owing to imprecise labeling of the samples (collected over 100 years ago), the exact location is not known. However, Vormá & Siivola (1967) indicated that samples containing the mineral probably originated from a quarried pegmatite near the Makitulokas farm house in Sukula, where tantalian cassiterite ("ainalite"), an associate of the ferrowodginite, was originally found.

Samples consist predominantly of granular aggregates of strongly color-zoned tantalian cassiterite, with individual grain-sizes ranging from 1 mm to a few cm. Topiolite, native bismuth and ferrowodginite occur as inclusions in the cassiterite. Stannomicrolite (originally "sukulaite"; Vormá & Siivola 1967) occurs as a replacement of the ferrowodginite (Ercit *et al.* 1987).

The ferrowodginite inclusions in cassiterite are typically 0.01 to 0.2 mm long; however, grains as large as 0.3 mm have been found. The inclusions we observed are irregular in shape; however, Vormá & Siivola (1967) also observed inclusions with lath-like outlines. Stannomicrolite rims about the ferrowodginite inclusions are typically in the order of 10 μm thick.

Ferrowdginite is dark brown to black, and has a dark brown streak. It is transparent to translucent, nonfluorescent, and has a vitreous luster. It is anisotropic, and is assumed to be biaxial; all of its indices of refraction are greater than 2.0, and could not be measured with available immersion oils. It is brittle and has a hardness of 5½; it shows no prominent cleavage, but has an irregular fracture. Because of the small grain-size and intimate association with stannomicroolite, the density of ferrowdginite could not be measured; the calculated density is 7.02 g/cm³.

Energy-dispersion (ED) X-ray spectra were obtained with a MAC 5 electron microprobe using a Kevex Micro-X 7000 spectrometer. Spectra were collected for 200 live seconds with an operating voltage of 15 kV and a sample current of 5 nA (measured on synthetic fayalite), and were corrected for current and voltage drift. Line overlaps such as TaMδ and TaMη on NbLα, SnLβ on TiKα, and MnKβ on FeKα were dealt with by noniterative techniques of spectral stripping involving library spectra of individual elements. Manganotantalite (Mn, Ta), chromite (Fe), titanite (Ti), cassiterite (Sn) and CaNb₂O₆ (Nb) were used as standards. Data were reduced with Kevex software using the program MAGIC V (Colby 1980).

Qualitative investigation of ED spectra and two quantitative analyses showed no significant core-to-rim or grain-to-grain variations. The average of the two chemical compositions is given in Table 3. The Fe²⁺:Fe³⁺ ratios were calculated according to the method of Ercit *et al.* (1992a). The average unit-cell contents are: (Fe²⁺_{3.04}Mn_{0.93}□_{0.03})Σ₄(Sn_{1.58}Ti_{1.27}Fe³⁺_{0.55}Ta_{0.60})Σ₄(Ta_{5.38}Nb_{2.62})Σ₈O₃₂

TABLE 3. CHEMICAL COMPOSITIONS OF NEW WODGINITE-GROUP MINERALS

	Ferrowdginite* (SK-1)		Titanowdginite (A-25)	
		(core)	(rim)	
MnO	wt.%	2.8	9.0	9.6
FeO		9.3	3.1	2.5
Fe ₂ O ₃		1.9	0.1	0.5
TiO ₂		4.3	9.2	8.0
SnO ₂		10.1	7.4	8.3
Nb ₂ O ₅		14.8	11.1	11.1
Ta ₂ O ₅		56.3	59.9	60.3
		99.4	99.7	100.3
Cations per 32(O)				
Mn		0.93	2.93	3.15
Fe ²⁺		3.04	0.99	0.79
Fe ³⁺		0.55	0.02	0.14
Ti		1.27	2.66	2.32
Sn		1.58	1.14	1.28
Nb		2.62	1.93	1.94
Ta		5.98	6.26	6.32
		15.97	15.91	15.94

Fe²⁺:Fe³⁺ calculated according to Ercit *et al.* (1991b).

* Average of 2 analyses.

TABLE 4. X-RAY POWDER-DIFFRACTION DATA FOR NEW WODGINITE-GROUP MINERALS

hkl	Ferrowdginite (SK-1)			Titanowdginite (A-25)		
	d (Å) (calc)	d (obs)	I	d (calc)	d (obs)	I
200	4.71	---	--	4.73	4.73	2
111	4.20	---	--	4.20	---	--
111	4.16	4.16	50	4.18	---	--
220	3.64	3.64	20	3.645	3.644	46
130	3.53	---	--	3.535	3.530	2
221	2.98	---	--	2.977	2.976	100
221	2.95	2.97	100	2.965	2.966	95
040	2.86	2.86	20	2.858	2.858	15
002	2.55	2.55	30	2.563	2.563	15
041	2.495	2.493	40	2.496	2.495	36
400	2.354	2.352	20	2.366	2.366	8
202	2.256	---	--	2.259	2.260	3
241	2.198	---	--	2.205	2.203	5
222	2.099	---	--	2.101	2.101	8
222	2.078	---	--	2.092	2.094	7
042	1.905	1.905	10	1.908	1.907	8
440	1.817	---	--	1.823	1.822	7
260	1.767	1.768	20	1.767	1.767	17
402	1.742	1.742	20	1.743	1.743	8
441	1.718	1.720	20	1.720	1.720	16
402	1.718	---	--	1.734	1.733	7
441	1.706	---	--	1.715	1.715	23
223	1.547	---	--	1.550	---	---
223	1.534	---	--	1.545	1.547	8
442	1.488	---	--	1.488	1.489	2
442	1.473	---	--	1.482	1.481	3
621	1.456	1.455	30	1.460	1.462	16
262	1.456	---	--	1.456	---	---
262	1.449	1.449	10	1.454	1.455	18
080	1.430	---	--	1.429	1.430	2
081	1.377	1.378	10	1.376	1.377	7
a (Å)		9.415(7)			9.466(2)	
b		11.442(6)			11.431(1)	
c		5.103(4)			5.126(1)	
β (°)		90.8(1)			90.31(2)	
V (Å ³)		549.7(6)			554.6(1)	

Ferrowdginite: 114.6 mm Gandolfi camera, Ni-filtered CuKα radiation, corrected for shrinkage.

Titanowdginite: Philips PW1050 diffractometer, Ni-filtered CuKα radiation, CaF₂ internal standard.

Ferrowdginite is ideally Fe²⁺SnTa₂O₈, Z = 4, and is the ferrous iron analogue of wodginite.

The ferrowdginite is anhedral. Optical examination shows it to be polysynthetically twinned; a X-ray precession study shows that the twin plane is {100}.

X-ray precession and powder-diffraction studies show ferrowdginite to be isostructural with wodginite; the powder pattern is given in Table 4. The data were obtained on the same crystal as was used for microprobe analysis; because of the small size of the crystal, the mean ratio of line intensity to background was found to be low; hence several weak lines normally found in wodginite patterns were not observed. The unit-cell parameters were refined using the program CELREF (Appleman & Evans 1973): a 9.415(7), b 11.442(6), c 5.103(4) Å, β 90.8(1)°, V 549.7(6) Å³. In general type ferrowdginite has smaller a and b cell edges and β angle, and a larger c cell edge than wodginite. On the basis of the results of Ercit *et al.* (1992a), the type sample is fully ordered.

TITANOWODGINITE

Titanium is largely a ubiquitous component in wodginite-group minerals; however, Ti contents are typically low, generally less than 1 wt.% TiO₂. The first Ti-rich variety of wodginite encountered was the type ferrowodginite sample, with an average of 3% TiO₂ (Vorma & Siivola 1967). Grice *et al.* (1972) described wodginite with up to 4% TiO₂ from the Tanco pegmatite, Manitoba. This remained the maximum Ti content of wodginite until a re-examination of the Ta-, Nb-oxide minerals at Tanco led to the discovery of wodginite with TiO₂ contents as high as 10.4% (Ercit 1986). In this material, up to 73 at.% of the Sn is replaced by Ti; hence it represents a new species which, in allusion to its composition, we have named *titanowodginite*. The new species and its name have been approved for publication by the I.M.A. Commission on New Minerals and Mineral Names.

Type titanowodginite occurs in a sample of Ta ore from the research collection of P. Černý, sample A-25. The sample comes from the workings of the Tanco pegmatite, Bernic Lake, Manitoba; the regional geology of the area and the internal structure of the pegmatite were reviewed by Černý (1982). From the mineralogy of the host rock and the chemistry of its oxide minerals, the sample is inferred to come from exposures of the saccharoidal albite unit [unit (3) of Černý (1982)] in the eastern workings of the pegmatite. The mineral occurs with microlite and manganocolumbite as disseminations in a silicate matrix consisting of saccharoidal albite plus quartz with minor muscovite and beryl. Since the discovery of the type sample, titanowodginite has been found in several exposures of the saccharoidal albite unit in the eastern workings of the pegmatite, and in one exposure of the central intermediate unit [unit (6) of Černý (1982)] in the northwestern workings of the pegmatite.

Type titanowodginite occurs as euhedral, bipyramidal crystals ranging from a few mm to 1 cm long. It occurs most often in irregular clusters of crystals, but also occurs as individual crystals.

Titanowodginite is dark brown to black and has a dark brown streak. It is transparent to translucent, nonfluorescent and has a vitreous luster. It is anisotropic, biaxial (+); all of its indices of refraction are greater than 2.0 and could not be measured with immersion oils available. It is brittle, hardness 5½, and shows no prominent cleavage, but has an irregular fracture. The density was measured with a Berman balance using toluene as an immersion liquid. Three repeated weighings of an 11-mg fragment gave a density of 6.86(3) g/cm³, which compares well with the calculated density of 6.89 g/cm³.

The methods used to analyze type titanowodginite are identical to those used for ferrowodginite. Results of the chemical analyses are given in Table 3. Type titanowodginite shows slight core-to-rim variation in chemistry. The rim has higher Mn/Fe and Sn/Ti than the core, typical of normal chemical zoning in oxide minerals from granitic pegmatites (Černý & Ercit 1985). In accordance with the procedure of formula calculation of Ercit *et al.* (1992a), the formula contents per unit cell are: $(\text{Mn}_{3.04}\text{Fe}^{2+}_{0.89}\square_{0.07})_{\Sigma 4}(\text{Ti}_{2.49}\text{Sn}_{1.21}\text{Ta}_{0.22}\text{Fe}^{3+}_{0.08})_{\Sigma 4}(\text{Ta}_{6.06}\text{Nb}_{1.94})_{\Sigma 8}\text{O}_{32}$. Titanowodginite is ideally $\text{MnTiTa}_2\text{O}_8$, $Z = 4$, and is the titanium analogue of wodginite.

Titanowodginite is euhedral. Predominance of the form {111} results in the characteristically bipyramidal crystals; occasionally the {101} and {100} forms are prominent. Penetration twins are typical, with {001} and {100} as the composition planes.

X-ray precession and powder-diffraction studies show titanowodginite to be isostructural with wodginite; the powder pattern is given in Table 4. Using the CELREF program, the refined unit-cell parameters are a 9.466(1), b 11.431(1), c 5.126(1) Å, β 90.31(2)°, V 554.6(1) Å³. In general, type titanowodginite has smaller a and b cell edges and β angle, and a larger c cell edge than wodginite. On the basis of the results of Ercit *et al.* (1992a), the type sample is only 35% ordered; the absence of several high- d lines in the diffraction pattern is in part due to this disorder.

SUMMARY

- (1) The wodginite group consists of isostructural minerals of the general form ABC_2O_8 ($Z = 4$), $A = \text{Mn}^{2+}$, Fe^{2+} , Li , \square ; $B = \text{Sn}^{4+}$, Ti , Fe^{3+} , Ta ; $C = \text{Ta}$, Nb .
- (2) A scheme of classification and nomenclature is introduced whereby species are described by names involving chemical modifiers used in conjunction with the root name "wodginite".
- (3) There are four wodginite-group minerals known: (i) wodginite (*sensu stricto*), ideally $\text{MnSnTa}_2\text{O}_8$, (ii) ferrowodginite, ideally $\text{Fe}^{2+}\text{SnTa}_2\text{O}_8$, (iii) titanowodginite, ideally $\text{MnTiTa}_2\text{O}_8$, and (iv) lithiowodginite, ideally $\text{LiTaTa}_2\text{O}_8$.
- (4) There is extensive solid-solution toward the hypothetical end-members ferriwodginite, $\text{Mn}_4(\text{Fe}^{3+}_2\text{Ta}_2)\text{Ta}_8\text{O}_{32}$, and ferroferriwodginite, $\text{Fe}^{2+}_4(\text{Fe}^{3+}_2\text{Ta}_2)\text{Ta}_8\text{O}_{32}$, and other species seem probable.

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