

**TRIPARTITE DIVISION OF THE SYSTEM  $2\text{REEPO}_4 - \text{CaTh}(\text{PO}_4)_2 - 2\text{ThSiO}_4$ ,  
 DISCREDITATION OF BRABANTITE, AND RECOGNITION OF CHERALITE  
 AS THE NAME FOR MEMBERS DOMINATED BY  $\text{CaTh}(\text{PO}_4)_2$**

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ABSTRACT

The nomenclature for the system  $2\text{REEPO}_4 - \text{CaTh}(\text{PO}_4)_2 - 2\text{ThSiO}_4$  has been revised, to be consistent with CNMMN principles. Henceforth, only three names will be applied to members dominated by the respective end-member compositions monazite, cheralite, and huttonite. The name *cheralite* has priority over *brabantite*, which hereby is discredited. A six-fold diagram is replaced by a three-fold nomenclature diagram to conform to IMA rules. The parameters of cheralite are redefined. This proposal, IMA 2005/F, was approved by the CNMMN in April 2006.

*Keywords:* monazite, cheralite, huttonite, “brabantite”, classification, nomenclature, discreditation.

SOMMAIRE

La nomenclature de phases dans le système  $2\text{REEPO}_4 - \text{CaTh}(\text{PO}_4)_2 - 2\text{ThSiO}_4$  a été révisée afin d’être conforme aux principes de la Commission de Nouveaux Minéraux et des Noms de Minéraux. Dorénavant, seuls trois noms seront appliqués, monazite, chéralite et huttonite, selon la composante dominante. Le terme *chéralite* a priorité sur “*brabantite*”, qui se trouve donc discrédité. Le diagramme à six divisions est remplacé par un diagramme de nomenclature à trois divisions qui est conforme aux règles de l’IMA. Les paramètres de la chéralite sont redéfinis. Cette soumission, IMA 2005/F, a été approuvée par la Commission en avril, 2006.

(Traduit par la Rédaction)

*Mots-clés:* monazite, chéralite, huttonite, “brabantite”, classification, nomenclature, discréditation.

INTRODUCTION

The ternary system  $2\text{REEPO}_4 - \text{CaTh}(\text{PO}_4)_2 - 2\text{ThSiO}_4$  comprises the phosphates of the monazite group [Strunz ID: 8.AD.35], huttonite [ $\text{ThSiO}_4$ ; Strunz ID: 9.AD.25] (Strunz & Nickel 2001), and their solid solutions. The extent of substitutions of Ca by Sr, and of Th by U, can be significant (Bea 1996, Chakhmouradian & Mitchell 1998, Förster 1998, Mills & Birch 2004). At present, the nomenclature used to describe minerals in this system, as exemplified in Figure 1, does not conform to the rules of the Commission on New Minerals and Mineral Names (CNMMN) of the International Mineralogical Association (IMA). The purpose of this note is to formalize the change that brings the system of nomenclature into conformity.

COMPOSITIONAL VARIATION IN THE SYSTEM

End-member proportions, derived from charge-balanced empirical formulae with eight atoms of oxygen, based on compositions from cited references, are given in Figure 2. In total, 144 data-sets were verified. Twenty-four of these have been discarded, three for having weight totals under 95%, and twenty-one for giving substantially non-stoichiometric formulae. Deviations from the general formula  $[\text{A}^{3+}, \text{A}^{4+}, \text{A}^{2+}]_2[\text{TO}_4]_2$ , marked by  $|\Sigma\text{A} - \Sigma\text{T}| > 0.2$  or  $|\text{A}^{4+} - \text{Si} - \text{A}^{2+}| > 0.2$ , indicating >5% nonstoichiometry, are considered here as being unacceptable. Nevertheless, three nonstoichiometric formulae are considered in the plots, as they are prominent in the history of the nomenclature of these minerals (Pabst 1951, Wang 1978, Rose 1980).

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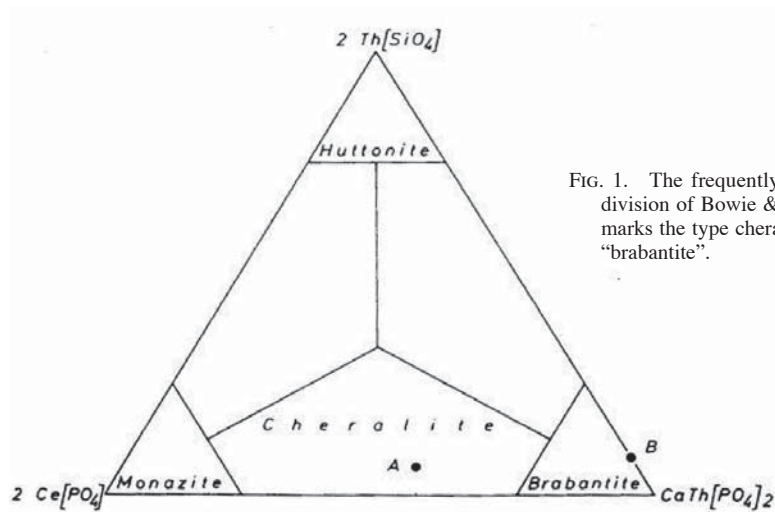


FIG. 1. The frequently used, but now discredited, six-fold division of Bowie & Horne (1953). After Rose (1980). A marks the type cheralite, and B, the now-discredited type "brabantite".

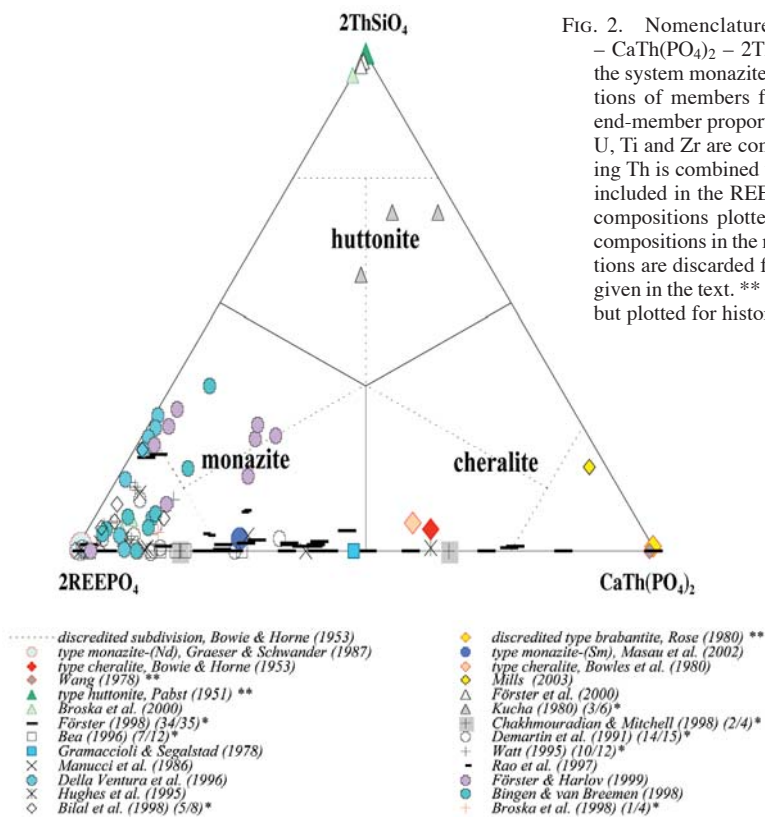


FIG. 2. Nomenclature diagram for the system  $2\text{REEPO}_4 - \text{CaTh}(\text{PO}_4)_2 - 2\text{ThSiO}_4$ . The new tripartite division for the system monazite – cheralite – huttonite, with compositions of members from the literature. In computing the end-member proportions, Pb, Sr,  $\text{Fe}^{2+}$ ,  $\text{Mn}^{2+}$ , Mg, Cu, and U, Ti and Zr are combined with  $\text{CaTh}(\text{PO}_4)_2$ ; any remaining Th is combined with Si in  $\text{ThSiO}_4$ ; Al,  $\text{Fe}^{3+}$ , and Y are included in the  $\text{REEPO}_4$  component. \* The proportion of compositions plotted in this diagram versus the total of compositions in the referred paper; the remaining compositions are discarded for not complying with quality criteria given in the text. \*\* Compositions not meeting the criteria, but plotted for historical reasons (see text).

Complete solid-solution along the  $2\text{REEPO}_4\text{--CaTh}(\text{PO}_4)_2$  join, and along the  $2\text{REEPO}_4\text{--}2\text{ThSiO}_4$  join from the  $2\text{REEPO}_4$  end-member to about 40% of the  $2\text{ThSiO}_4$  end-member, is well documented. Apart from a concentration of data close to the end-member, the  $\text{ThSiO}_4$ -dominated field is poorly represented. In this respect, it must be noted that eight compositions considered to be huttonite by Bilal *et al.* (1998), Kucha (1980) and Broska *et al.* (1998, 2000), are not plotted for failing the criteria for stoichiometry. Recent finds of relatively Si-rich Ca,Th-bearing compositions from the Lake Boga Granite, in Australia, of which one shows 17 mol.%  $2\text{ThSiO}_4$  and 80 mol.%  $\text{CaTh}(\text{PO}_4)_2$  (Mills 2003), and compositions with 51–72 wt.%  $\text{ThO}_2$ , 8–25%  $\text{P}_2\text{O}_5$ , 2–12%  $\text{SiO}_2$ , 3–10%  $\text{CaO}$ , 0.23–2.5% total  $\text{REE}_2\text{O}_3$  found for the first time in India (Vasudevan Rajagopalan, AMD, DAE, Hyderabad, Mindat.org Mineral Messageboard, 13–09–04), suggest the existence of extensive solid-solution between  $\text{CaTh}(\text{PO}_4)_2$  and  $2\text{ThSiO}_4$  as well.

#### CLASSIFICATION OF TERNARY SYSTEMS CONSISTENT WITH IMA–CNMMN PRINCIPLES

Current rules of the IMA's CNMMN prescribe that minerals of a solid-solution series be named according to the dominant end-member in their respective compositions. For a ternary solid-solution series, the nomencla-

ture must comprise no more than three mineral names. Each of the names should apply to the compositional range from the end-member to the nearest right bisectors of the sides of the composition triangle, as shown in Figure 2 (Nickel 1992). Similar brief recommendations were already published in 1977 by the counterpart of the CNMMN, the USSR – All-Union Mineralogical Society of the Academy of Sciences (Nickel 1992). If the mineral contains essential rare-earth elements, its name must be suffixed with the appropriate Levinson modifier indicating the dominant rare-earth element (Levinson 1966, Nickel & Grice 1998).

#### CURRENT CLASSIFICATIONS IN THE SYSTEM $2\text{REEPO}_4\text{--CaTh}(\text{PO}_4)_2\text{--}2\text{ThSiO}_4$

The predominant practice of classifying minerals in the above system is at variance with current CNMMN rules. It follows the six-fold division introduced in 1953 by Bowie & Horne (Fig. 1). Also, the attendant nomenclature has grown into a confusing plethora of mineral names, in particular for intermediate compositions (Table 1). Apparently, this peculiar classification has prevailed for half a century. On the other hand, Chakhmouradian & Mitchell (1998) applied the dominance rule to classify Sr-bearing members of the monazite group.

TABLE 1. MINERAL NAMES USED FOR MEMBERS OF THE TERNARY SYSTEM  
 $2\text{REEPO}_4\text{--CaTh}(\text{PO}_4)_2\text{--}2\text{ThSiO}_4$

A	<b>Monazite-(Ce)</b>	(Ce,La,Nd,Th)PO <sub>4</sub>	Nickel & Mandarino (1987)
A	<b>Monazite-(La)</b>	(La,Ce,Nd)PO <sub>4</sub>	Levinson (1966)
A	<b>Monazite-(Nd)</b>	(Nd,La,Ce)PO <sub>4</sub>	Graeser & Schwander (1987)
A	<b>Monazite-(Sm)</b>	(Sm,Gd,Ce,Th,Ca)PO <sub>4</sub>	Masau <i>et al.</i> (2002)
G	<b>Huttonite</b>	ThSiO <sub>4</sub>	Pabst & Hutton (1951), Förster <i>et al.</i> (2000)
A/D	<i>Brabantite</i>	CaTh(PO <sub>4</sub> ) <sub>2</sub>	Rose (1980)
*	<i>Lingaitukuang</i>	CaTh(PO <sub>4</sub> ) <sub>2</sub>	Wang (1978), cited in Fleischer <i>et al.</i> (1981)
G/A	<b>Cheralite</b>	(LREE,Th,U,Ca,Pb)(P,Si)O <sub>4</sub>	Bowie & Horne (1953), Bowles <i>et al.</i> (1980)
N	<i>Cheralite-(Ce)</i>	(Ce,Ca,Th)(P,Si)O <sub>4</sub>	Hughes <i>et al.</i> (1995), Förster (1998), Mills & Birch (2004)
*	<i>Brabantitic cheralite-(Ce)</i>	(Ce,Sr,Ca,Th)PO <sub>4</sub>	Förster & Harlov (1999)
*	<i>Huttonitic monazite</i>	(REE,Th)(Si,P)O <sub>4</sub>	Förster (1998), Förster & Harlov (1999), Mills & Birch (2004)
D	<i>Cerphosphorhuttonite</i>	(Th,Ce)(SiO <sub>4</sub> ,PO <sub>4</sub> )	Pavlenko <i>et al.</i> (1965), IMA–CNMMN (1968), Della Ventura <i>et al.</i> (1996)

Notes.: Letter-annotated names are extracted from the Mineral Database of Materials Data, Inc. Those entries marked with A and D are from the list of minerals designated respectively as Approved and Discredited and redefined by the IMA Commission on New Minerals and Mineral Names since 1959. The list is an update (February 2004) of the one drawn up in a cooperation between Aleph Enterprises (Ernest H. Nickel, former Vice-Chairman of the CNMMN, and Monte C. Nichols) and the IMA–CNMMN (represented by Giovanni Ferraris, Vice-Chairman). Names marked with G are so-called “grandfathered” minerals, which were described before 1959 and are generally believed to represent valid mineral names. The name marked with N is Not approved by the IMA–CNMMN. Names marked with \* are synonyms, which can be found in the literature but are not listed in the Mineral Database. The April 2006 decisions of the IMA–CNMMN, based on proposal IMA 2005/F, are given in bold.

TOWARD A NOMENCLATURE THAT IS  
IN ACCORDANCE WITH CNMMN RULES

The obvious way to a correct nomenclature for the present system lies in the selection of three mineral names, one for each field of the compositional triangle, as shown in Figure 2. The names of two fields are well established and do not need further discussion. These are monazite [representing all IMA-approved species, namely: monazite-(Ce), monazite-(La), monazite-(Nd), monazite-(Sm)], for compositions dominated by  $2\text{REEPO}_4$ , and huttonite (Pabst 1951), the grandfathered name for compositions dominated by  $2\text{ThSiO}_4$ .

The name for the field adjoining the end-member  $\text{CaTh}(\text{PO}_4)_2$ , however, deserves some deliberation. Two names should be considered: the grandfathered name cheralite (Bowie & Horne 1953) and brabantite (Rose 1980). This same consideration was done before, and by Rose himself. In the very same paper in which he presented *brabantite* as the name for the mineral

with a composition near the end-member  $\text{CaTh}(\text{PO}_4)_2$ , Rose (1980, p. 254-256) stated that: "Although type cheralite contains more than 50%  $\text{CaTh}(\text{PO}_4)_2$ , Bowie & Horne (1953) drew species boundaries at 25 and 75 mol.%  $\text{CaTh}(\text{PO}_4)_2$  in the binary system for  $2\text{Ce}(\text{PO}_4) - \text{CaTh}(\text{PO}_4)_2$  for cheralite. They left the nearly pure end member between 75 and 100 mol.% unnamed on purpose, which now has been described as brabantite. Although there could have been a threefold classification in this system, *there is no reason to change the proposal of Bowie & Horne* (my emphasis) which has been accepted for a quarter of a century." Note that Rose provided a remark of essentially similar content in his original proposal about "brabantite" (IMA 1978-003), and that the compositional diagram accompanying the proposal is the same as that of Bowie & Horne (1953) as well (verified and electronically communicated by Dr. Birch, October 2005).

In hindsight, the view can be taken that if in 1978, the CNMMN had paid due attention to the 1977 recommendations of the authoritative USSR - All-Union Mineralogical Society of the Academy of Sciences, it would have found sufficient reason to disagree with Rose and to prescribe a three-fold classification for this system. On these grounds, it might be suggested that the approval of "brabantite" has been a procedural mistake because the species *cheralite* (published before the CNMMN era) already included the "brabantite" composition (see Table 2). However, it should be noted that the dominance rule was not officially issued by CNMMN until 1992.

In any event, in March 1978, with the approval of IMA 1978-003 (by a vote of 13-2), the Commission made two decisions that are now fundamentally in conflict with CNMMN rules, *viz.*, (i) approval of a name, *brabantite*, that is restricted for minerals with compositions containing more than 75 mol.% of an end-member, and (ii) implicit approval of a six-fold classification for a ternary system. This classification, which tacitly has been condoned since then, can be considered formally outdated since the publication of the recommendations of the CNMMN on mineral nomenclature of solid solutions (Nickel 1992).

A revocation of the IMA decision 1978-003 would seem a simple and effective measure toward a correct nomenclature. However, the 1992 recommendations contain the following relevant clause, which should first be taken into consideration: "... to avoid confusion, mineral names or definitions already in the literature that contravene the recommendations should not be changed unless there are compelling reasons to do so, and then only if approved by a formal vote of members of the CNMMN." Clearly, the use of two different types of classification in the recent literature is confusing in itself. Moreover, both classifications, each in its own way, are in conflict with CNMMN rules. The Bowie & Horne (1953) nomenclature, condoned by the IMA 1978-003 vote, is in conflict with current CNMMN

TABLE 2. COMPOSITIONS OF TYPE CHERALITE AND OF DISCREDITED TYPE BRABANTITE

	1	2	3		1a	2a	3a
$\text{P}_2\text{O}_5$ wt.%	26.8	27.1	27.68	P <i>apfu</i>	1.816	1.836	1.832
$\text{SiO}_2$	2.1	2.08	2.27	Si	0.168	0.166	0.177
$\text{ThO}_2$	31.5	31.64	52.65	Th	0.574	0.576	0.936
$\text{U}_3\text{O}_8$	4.05	4.33		U	0.069	0.074	
$\text{TiO}_2$		n.d.		Ti			
$\text{Al}_2\text{O}_3$	tr.	n.d.	0.74	Al	0	0	0.068
$\text{Fe}_2\text{O}_3$	tr.	n.d.	0.05	Fe	0	0	0.003
$\text{Ce}_2\text{O}_3$	14.21	12.12		Ce	0.416	0.355	
$\text{Y}_2\text{O}_3$	minor*	0.08		Y	*	0.003	
$\text{La}_2\text{O}_3$	major*	5.19		La	*	0.153	
$\text{Pr}_2\text{O}_3$	major*	1.2		Pr	*	0.035	
$\text{Nd}_2\text{O}_3$	major*	5.91		Nd	*	0.169	
$\text{Sm}_2\text{O}_3$	minor*	1.81		Sm	*	0.050	
$\text{Gd}_2\text{O}_3$	minor*	0.45		Gd	*	0.012	
total of *	13.35				0.394		
$\text{Eu}_2\text{O}_3$		0.25		Eu	0	0.007	
$\text{Tb}_2\text{O}_3$		0.05		Tb	0	0.001	
$\text{Dy}_2\text{O}_3$		0.06		Dy	0	0.002	
$\text{Ho}_2\text{O}_3$		0.01		Ho	0	0.000	
$\text{Er}_2\text{O}_3$		0.03		Er	0	0.001	
$\text{Tm}_2\text{O}_3$		0.12		Tm	0	0.003	
$\text{Yb}_2\text{O}_3$		n.d.		Yb	0	0	
$\text{Lu}_2\text{O}_3$		n.d.		Lu	0	0	
CaO	6.3	5.99	11.94	Ca	0.540	0.514	1.000
PbO	0.92	1.15	0.00	Pb	0.020	0.025	0
MnO		n.d.	0.32	Mn	0	0	0.021
MgO			0.56	Mg			0.065
$\text{H}_2\text{O}$	0.06		3.07				
				end-member proportions			
Total	99.23	99.57	96.21	Crl	59.0	55.3	98.9
				Mnz	36.6	39.0	0
				Htn	4.4	5.7	1.1
				excess Ca	--	--	0.17
				excess Si	0.09	0.05	0.16
				excess $M^{3+}$	0.11	0.03	0.07
				excess Th	0.08	--	--

Column 1: cheralite, Kuttakuzhi, Travancore, India, after Bowie & Horne (1953). Column 2: the same, after Bowles *et al.* (1980). Column 3: "brabantite", Karibib, Namibia, after Rose (1980). Symbols: Crl: cheralite, Mnz: monazite, Htn: huttonite. Cation proportions, expressed in atoms per formula unit (*apfu*), were calculated on the basis of eight atoms of oxygen,  $\text{H}_2\text{O}$ -free.

rules by not following the dominance rule. It is true that Chakhmouradian & Mitchell (1998) used a nomenclature that is based on the dominance rule, but they changed “definitions already in the literature” (*cf.* Rose 1980), without the required approval “by a formal vote of members of the IMA–CNMMN”, thereby violating the above specified clause.

Clearly, the Commission’s approval of one unambiguous and unequivocal nomenclature for this system was needed. To establish a nomenclature that obeys the contemporary CNMMN ruling, it sufficed to take two steps that were already indicated a quarter of a century ago:

1. Adhere to one of the anonymous dissenters in the IMA 1978–003 vote who stated that, “the members of this group should be called three names only and intermediate names are unnecessary” (verified and electronically communicated by the secretary of the CNMMN, Dr. Birch, October 2005).

2. Agree with G. Y. Chao (in Fleischer *et al.* 1981), who stated that “both brabantite and lingaitukuang seem to be unnecessary as the intermediate member cheralite (...) in the monazite–CaTh(PO<sub>4</sub>)<sub>2</sub> series could be redefined to include the pure (Ca,Th) end-member. The type cheralite contains more than 50% CaTh(PO<sub>4</sub>)<sub>2</sub>.”

#### CONCLUSIONS

Henceforth, compositions in the ternary system with end-members 2REEPO<sub>4</sub>, CaTh(PO<sub>4</sub>)<sub>2</sub>, and 2ThSiO<sub>4</sub> are classified according to the tripartite division as shown in Figure 2.

Under the current IMA rules, type cheralite (Bowie & Horne 1953, Bowles *et al.* 1980) is accepted as a valid mineral species. As it contains over 50 mol.% of CaTh(PO<sub>4</sub>)<sub>2</sub> (Table 2), its name applies to all members of the 2REEPO<sub>4</sub>–CaTh(PO<sub>4</sub>)<sub>2</sub>–2ThSiO<sub>4</sub> system that are dominated by CaTh(PO<sub>4</sub>)<sub>2</sub>.

The name “brabantite” [Rose (1980); IMA 1978–003; Table 2] is to be discredited for two reasons.

a) As an integral part of an outdated classification, “brabantite” specifically refers to compositions with over 75 mol.% CaTh(PO<sub>4</sub>)<sub>2</sub> only, which is contrary to the CNMMN 50% rule (Nickel 1992).

b) Cheralite (Bowie & Horne 1953), containing more than the required 50 mol.% of CaTh(PO<sub>4</sub>)<sub>2</sub>, has chronological priority. Chakhmouradian & Mitchell (1998) recognized the chronological priority of cheralite, but “favoured the name brabantite as most closely corresponding to the end-member composition CaTh(PO<sub>4</sub>)<sub>2</sub>”. In this matter, however, the accepted criterion of chronological priority overrules personal preference.

As only the names monazite-(Ce), monazite-(La), monazite-(Nd), monazite-(Sm), cheralite and huttonite can be used for minerals with compositions within the respective fields of Figure 2, all other names of Table 1 are rejected.

As shown in Figure 2, a substantial number of compositions of minerals that plot in the cheralite field of the updated classification fall inside the monazite field of the new one and must be renamed accordingly (*e.g.*, Rao 1997, Förster 1998). Similarly, most compositions of formerly named “huttonitic monazite” (Förster & Harlov 1999) are monazite in the new classification.

Authors describing an analogue of cheralite with Sr > Ca from apatite–dolomite carbonatite, Kola Peninsula, Russia (*e.g.*, Chakhmouradian & Mitchell 1998) may apply for a new name.

#### ACKNOWLEDGEMENTS

In reaction to my remark that the currently used nomenclature for the system 2REEPO<sub>4</sub> – CaTh(PO<sub>4</sub>)<sub>2</sub> – 2ThSiO<sub>4</sub> is not in accord with CNMMN rules, editor Robert F. Martin motivated me to do something about it. I thank Ernst Burke for his constructive criticism on an early draft of the proposal, in particular for making very clear that there is no such thing as an end-member name. I am obliged to Bill Birch for retrieving essential information on proposal IMA–CNMMN 1978–003 from the archives, and for mentioning the work of Stuart Mills. The manuscript for proposal IMA–CNMMN 2005/F was essentially improved following a suggestion made by Giovanni Ferraris. The final version benefitted significantly from the pertinent and useful comments by Jeffrey de Fourestier and Robert F. Martin.

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