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Classification and nomenclature of the pyrochlore group

D. D. HOGARTH[1]

Department of Geology, University of Ottawa
Ottawa, Canada K1N 6N5

Abstract

The IMA Subcommittee on Nomenclature of the Pyrochlore Group recommends the following classification and nomenclature:

Group	pyrochlore $[A_{2-m}B_2O_6(O,OH,F)_{1-n}\cdot pH_2O]$
Subgroups	pyrochlore, microlite, betafite
Species	pyrochlore, kalipyrochlore, bariopyrochlore, yttropyrochlore, ceriopyrochlore, plumbopyrochlore, uranpyrochlore (pyrochlore subgroup); microlite, stannomicrolite, bariomicrolite, plumbomicrolite, bismutomicrolite, uranmicrolite (microlite subgroup); yttrobetafite, plumbobetafite, betafite (betafite subgroup).

Subgroups are divided according to *B*-atoms (Nb, Ta, Ti) and species according to *A*-atoms (K, Sn, Ba, REE, Pb, Bi, U). Forty-eight names related to the pyrochlore group should be dropped, and five type specimens should be reinvestigated.

Introduction

The pyrochlore group comprises a series of cubic oxides containing essential amounts of niobium, tantalum, or titanium. Pyrochlore itself was described by Wöhler in 1826, microlite by Shepard in 1835, and "hatchettolite" by Smith in 1877. The remaining members were all described in the present century.

Prior to the late 1950's, *Dana's System of Mineralogy* (Palache *et al.*, 1944, p. 747–757) provided the accepted classification of the pyrochlore minerals. In this classification pyrochlore–microlite was described as a series, and nine similar minerals were appended as "likely members" of this series. Betafite and "djalmaite" (*ibid*, p. 803–805) were excluded, but with the cautionary statement that "considerable uncertainty" exists concerning their relationship with pyrochlore and microlite. These two minerals were later shown, chemically and structurally, to retain the pyrochlore structure with many of the larger cation sites unfilled (Borodin and Nazarenko, 1957; Hogarth, 1961).

In the 1960s and 1970s many new analyses of pyrochlore minerals were published, revealing a wide range of compositions and leading to many new mineral names. In the same period several schemes of classification were proposed including those of Ginzburg *et al.* (1960), van der Veen (1963), and Bonshtedt-Kupletskaya (1966). Adding to this growing complexity, the literature continued to perpetuate mineral "species" of questionable validity, such as blomstrandite, ellsworthite, and chalcolamprite, and synonyms such as mendeleevite and betafite, neotantalite and microlite, koppite and pyrochlore. Clearly a need existed for a universally accepted, rational classification and a revised nomenclature.

In view of this need, the IMA Commission on New Minerals and Mineral Names, at the request of the chairman Dr. Michael Fleischer, established a Subcommittee on Pyrochlore Nomenclature. A. H. van der Veen, Arnhem, Netherlands, was appointed chairman in August, 1966, and he, in turn, selected the following members:

(1) Subcommittee, voting members

E. M. Bonshtedt-Kupletskaya, Moscow, U.S.S.R.[2]
T. Deans, London, England (Secretary)[3]
M. Gasperin, Paris, France
D. D. Hogarth, Ottawa, Canada
Akira Kato, Tokyo, Japan
L. Van Wambeke, Brussels, Belgium

[1] For the IMA Subcommittee on Nomenclature of the Pyrochlore Group.

[2] Died July, 1974

[3] Retired Feb., 1976

(2) Commission observers, non-voting

M. Fleischer, Washington, D.C., U.S.A. until Feb., 1968

C. Guillemin, Orléans, France

M. H. Hey, London, England since Feb., 1968

The Subcommittee functioned almost entirely by correspondence. In general, their criteria were based on published information, but in two cases, members re-examined type specimens. Certain decisions required a vote, and in the few instances when opinions of members were equally divided, the chairman cast the deciding vote.

At the outset, members were faced with the choice of recommending "orthodox" names, often well-established and of deserving origin, or appropriate chemical names. After detailed consideration, the Subcommittee and later the Commission ruled in favor of a chemical nomenclature.

The Subcommittee submitted its first complete report to Dr. Fleischer in December 1971. He, in turn, distributed copies to affiliated societies for comments and suggestions, which were forwarded to the Subcommittee in November 1973. A revised report was then submitted in August 1974, and its recommendations were ratified by the Commission in 1975 and 1976. The present report summarizes the reports of the Subcommittee (unpublished, prepared by T. Deans), incorporates suggestions and decisions taken by the Commission, and represents the final conclusions of the Subcommittee.

Classification

The pyrochlore group comprises those multiple cubic oxides having the following characteristics:

(a) essential amounts of niobium, tantalum, and titanium, either individually or in combination,

(b) the space group *Fd*3*m*,

(c) the pyrochlore structure as defined by Gaertner (1930) and Brandenberger (1931), and

(d) the general formula $A_{2-m}B_2O_6(O,OH,F)_{1-n} \cdot pH_2O$.

In the case of metamict minerals, compositional equivalents which produce the pyrochlore phase on ignition (preferably in vacuum or inert atmosphere) are admitted to the scheme. Isostructural minerals, such as antimonates of the stibiconite series and tungstates related to ferritungstite, are excluded.

Three subgroups are recommended, based on the atomic proportions of the *B*-atoms Nb, Ta, and Ti. The recommended subgroups are:

Pyrochlore Subgroup in which Nb + Ta > 2Ti and Nb > Ta,

Microlite Subgroup in which Nb + Ta > 2Ti and Ta ≥ Nb,

Betafite Subgroup in which 2Ti ≥ Nb + Ta.

The above compositional limits for the subgroups were adopted because of a natural clustering of compositions and a relative scarcity of titanium-rich analyses (see Fig. 1). Titanium-rich species range from 33 to 55 percent Ti, where Nb + Ta + Ti = 100 atom percent. Analyses reporting larger amounts of titanium may represent mixtures. In contrast, most pyrochlores and microlites fall in the range 70–100 percent Nb and Ta, respectively. Subdivision of the pyrochlore group according to the predominance of Nb, Ta, and Ti atoms would therefore restrict the titanium subgroup to few examples, and would cause wide variations of compositions in the pyrochlore subgroup. Accordingly, it was eventually ruled that any mineral with 2 Ti ≥ Nb + Ta belongs to the betafite subgroup.

Within the subgroups, individuals species are defined with respect to *A*-atoms (*viz* Na, Ca, K, Sn, Ba, REE, Pb, Bi, U) in the following manner:

(a) Na–Ca members. Sodium or calcium, but no other *A*-atom, shall exceed 20 percent of the total *A*-atoms present, and

(b) other members. One or more *A*-atoms other than Na or Ca shall exceed 20 percent of the total *A*-atoms present.

The figure 20 percent corresponds favorably with recent practice in describing betafite, uranpyrochlore, and uranmicrolite, the most common species after pyrochlore and microlite.

The proposed classification is based on total *A*-ions (excluding oxonium), not on *A*-sites available. Thus deficiency of *A*-cations or filling of vacant *A*-sites by oxonium does not affect the classification.

Special rules apply in the case of lanthanides and yttrium. Although no example is known in the pyrochlore group of a single rare-earth element exceeding 20 percent of the *A*-atoms, several rare earths may occur together in significant amounts. When their total exceeds 20 percent of the total *A*-atoms, the Subcommittee recommends that the mineral be given separate species status. The well-known tendency for the rare earths to be predominantly of the cerium group (light lanthanides La → Eu, styled ΣCe), or the yttrium group (Y + heavier lanthanides Ga → Lu, styled ΣY), also prevails, and has created a further twofold subdivision.

Nomenclature and species

The current 16 species of the pyrochlore group recommended in this study are listed and defined in

Table 1. Their names reflect the decision to adopt chemical names in preference to "orthodox" names. Thus uranpyrochlore replaces hatchettolite, uranmicrolite replaces djalmaite, *etc.* Applicability of the Levinson nomenclature (Levinson, 1966) was referred to, but not recommended by the Commission.

The root names for species of the Nb- and Ta-rich subgroups, as also the names of the subgroups themselves, are derived from the "orthodox" names of the Na–Ca members. However, as no Na–Ca member has been definitely established for the Ti-rich subgroup, the Subcommittee recommends that betafite, the most common member, be used as root name for this subgroup.

The bismuthomicrolite of Zalashkova and Kukharchik (1957) was considered as a new species but rejected by the Subcommittee because it contained insufficient Bi(4 atom % of the *A*-ions). The Subcommittee recommends this name be used for the bismuth member of the microlite subgroup as defined in the preceding section and first described (as westgrenite) by Knorring and Mrose (1963).

The use of additional adjectival prefixes is optional, and should normally be restricted to the *A*-atom next in abundance after the principal constituent, following Palache *et al.* (1944, p. 43). Thus bariopyrochlore from the type locality can be called strontian bariopyrochlore (Ba 44%; Sr 32% of the *A*-atoms present).

Recommended names are given below. Note that, with the approval of the Commission, six new names are introduced: kalipyrochlore, bariopyrochlore, yttropyrochlore, ceriopyrochlore, stannomicrolite, and bariomicrolite. Bismutomicrolite is redefined.

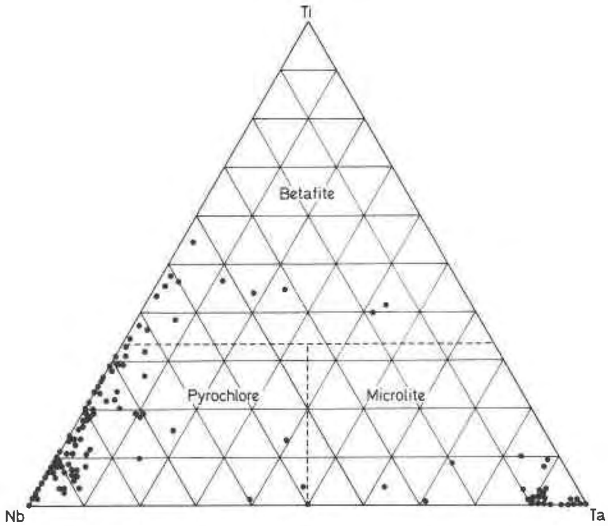

Fig. 1. The three subgroups of the pyrochlore group. Compositions are plotted atomically from data in Bonshtedt-Kupletskaya (1966). Minerals no longer included in the group (minerals with the samiresite phase, "hatchettolite" from Hybla, Ontario, and "titanpyrochlore" from Tangen, Norway) are not plotted.

Species of the pyrochlore group

Pyrochlore (Wöhler, 1826)

Table 1. The pyrochlore group

SUBGROUPS defined by B atoms *viz* Nb, Ta, Ti			PYROCHLORE Nb+Ta>2Ti Nb>Ti	MICROLITE Nb+Ta>2Ti Ta≥Nb	BETAFITE 2Ti≥Nb+Ta
SPECIES defined by A-atoms *viz* K, Sn, Ba, REE, Pb, Bi, U	Na+Ca, but no other A-atoms >20% total A-atoms		pyrochlore	microlite	
	One or more A-atoms, other than Na or Ca, >20% total A-atoms. Species named by most abundant A-atom, other than Na or Ca	K	kalipyrochlore		
		Sn		stannomicrolite	
		Ba	bariopyrochlore	bariomicrolite	
		REE*	yttropyrochlore(ΣY>ΣCe)** ceriopyrochlore(ΣCe>ΣY)		yttrobetafite(ΣY>ΣCe)
		Pb	plumbopyrochlore	Plumbomicrolite	Plumbobetafite
		Bi		bismutomicrolite	
		U	uranpyrochlore	uranmicrolite	betafite

*REE = Y + (La → Lu), *and for purposes of species definition,* REE *counts as one* A-*atom.*
** ΣY = Y + (Gd → Lu); ΣCe = La → Eu.

Kalipyrochlore (described but not named by Van Wambeke, 1965, p. 9–15)

Bariopyrochlore (name replaces pandaite, *q.v.*)

Yttropyrochlore (Kupriyanova, unpublished; described as obruchevite by Kupriyanova *et al.*, 1964, anal. 63)

Ceriopyrochlore (name replaces marignacite, *q.v.*)

Plumbopyrochlore (Skorobogatova *et al.*, 1966)

Uranpyrochlore (Holmquist, 1896; name replaces hatchettolite, *q.v.*)

Species of the microlite subgroup

Microlite (Shepard, 1835)

Stannomicrolite (name replaces sukulaite, *q.v.*)

Bariomicrolite (name replaces rijkeboerite, *q.v.*)

Plumbomicrolite (Hey, 1964, p. 1147; based on Safiannikoff and Van Wambeke, 1961)

Bismutomicrolite (name replaces westgrenite, *q.v.*)

Uranmicrolite (Strunz, 1957; name replaces djalmaite, *q.v.*)

Species of the betafite subgroup

Yttrobetafite (Kalita, 1959)

Plumbobetafite (Ganzeev *et al.*, 1969)

Betafite (Lacroix, 1912b)

Synonyms, doubtful and discredited names, and species not belonging to the pyrochlore group

The many synonyms and other names associated with the pyrochlore group are listed alphabetically below, and discussed in light of the proposed nomenclature.

Aluminobetafite (Kawai, 1960) may possibly belong to the pyrochlore group and betafite subgroup, with unusual gross substitution of Al and some Sn and U. More data are needed.

Azorpyrrhite (Hubbard, 1886) probably belongs to the pyrochlore group, but as quantitative analyses are lacking, the mineral cannot be classified or renamed at this time.

Blomstrandite (Lindström, 1874) has been assumed to belong to the pyrochlore group. It is possibly *uranpyrochlore,* but adequate analyses are lacking, and new data are desirable.

Calciosamarskite (Ellsworth, 1928) has the composition of *uranian yttropyrochlore,* but the mineral is metamict, and proof that it belongs to the pyrochlore group is lacking. Van Wambeke (1970) suggests that a somewhat similar metamict mineral from Zaire may be *yttrian uranpyrochlore* with a high proportion of Fe^{3+} in the *B*-positions. Further study seems desirable before deciding the status of this mineral.

Ceruranopyrochlore (Lin *et al.*, 1973) is a *cerian pyrochlore.* The name should be dropped.

Chalcolamprite (Flink, 1898; 1901) contains a "large number of microscopical inclusions" (Flink, 1901, p. 163) and apparently represents an impure *pyrochlore.* The 10.86 percent SiO_2 may be due to impurities. The name should be dropped.

Columbomicrolite (Villiers, 1941) is an unnecessary synonym of *pyrochlore.* The name should be dropped.

Djalmaite (Guimarães, 1939) is a synonym for *uranmicrolite.* The name should be dropped.

Ellsworthite (Walker and Parsons, 1923a) conforms to the new definition of *uranpyrochlore.* The name should be dropped.

Endeiolite (Flink, 1901) is probably an impure *pyrochlore.* The few tiny analysed crystals "were scraped" from aegirine. The 11.48 percent weight loss in HF and H_2SO_4 was assumed to be SiO_2, essential to the composition of the mineral. The name should be dropped.

Fluochlore (Hermann, 1850) is an early synonym of *pyrochlore,* not used by later writers. The name should be dropped.

Haddamite (Shepard, 1870) is assumed to be a synonym of *microlite,* but analyses are lacking. The name should be dropped.

Hatchettolite (Smith, 1877) is a synonym of *uranpyrochlore*. The name should be dropped.

Hydrochlore (Hermann, 1850) is an early synonym of *pyrochlore,* not used by later writers. The name should be dropped.

Hydropyrochlore (Ivanov *et al.*, 1944) is probably an altered metamict *pyrochlore.* The name should be dropped.

Koppite (Knop, 1875) is a poorly defined variety of *pyrochlore*. The type specimen is not available, but most specimens from the type locality are *pyrochlore* (see Van Wambeke, 1964, p. 67 for analyses). Jakob's analysis (Brandenberger, 1931) shows 9.73 percent Fe_2O_3, and contamination is suspected. The name should be dropped.

Marignacite (Weidmann and Lenher, 1907) is a synonym of *ceriopyrochlore.* The name should be dropped.

Mendelyeevite or *mendelejevite* (Vernadskii, 1914; 1923) is a synonym of *betafite,* the accepted analysis (see Chukhrov and Bonshtedt-Kupletskaya, 1967, p. 175–176, anal. 9) conforming to the redefinition of this species, although the proportion of uranium is little above the necessary minimum. The name should be dropped.

Metasimpsonite (Simpson, 1938, p. 88; Bowley, 1939; Taylor, 1939, p. 93) is a synonym of *microlite*. The name should be dropped.

Mumbite (Van Wambeke, 1970) is a synonym of *plumbomicrolite*. The name should be dropped.

Neotantalite (Termier, 1902) has long been recognized as either *microlite* or a closely-related mineral. The original analysis (by Pisani) showed Fe and Mn as the principal *A*-atoms and the absence of Ca. Reexamination of Termier's type material by Gasperin (1972) showed the mineral to be metamict *microlite* with large deficiencies in the *A*-ions, which may be filled by Ba, Pb, U, and Ca. Fe and Mn were present as impurities. The name should be dropped.

Niobpyrochlore (Machatschki, 1932) is an unnecessary synonym for *pyrochlore*. The name should be dropped.

Niobtantalpyrochlore (Machatschki, 1932), implying a composition with Nb $\approx$ Ta, must be renamed either *pyrochlore* or *microlite*, according to the analysis. The name should be dropped.

Nuolaite (Lokka, 1928), a mixture of yttropyrochlore and other niobium oxide minerals relates to *wiikite* (*q.v.*), must be discredited as a species.

Obruchevite (Kalita, 1957) is a name later shown to have been given to two different species (Gorzhevskaya and Sidorenko, 1969). One of these, brown obruchevite, after heating to 700°C, crystallized to the *samiresite S* phase (*q.v.*). The other, black obruchevite, was subsequently renamed *yttropyrochlore* (Kupriyanova, 1970, unpublished). The Soviet Union's Commission of New Minerals (KNM) and Mineralogical Terminology have recommended the name *yttropyrochlore* replace this type of *obruchevite*.

Pandaite (Jäger *et al.*, 1959) is a synonym for *bariopyrochlore*. The name should be dropped.

Priazovite (Yurk, 1941; 1956, p. 24), previously regarded as an altered pyrochlore (Dzhun, 1963), has been shown to belong to the *samarskite* group (Gorzhevskaya and Sidorenko, 1974) and must be excluded from the pyrochlore group.

Pyrochlore–microlite (Beus *et al.*, 1962), implying a composition with Nb $\approx$ Ta must be renamed either *pyrochlore* or *microlite*, according to the analysis.

Pyrochlore–wiikite (Strunz, 1957), being a mixture, must be discredited; see *wiikite*, below.

Pyrrhite (Rose, 1839, p. 562; 1842, p. 383–385) belongs to the *pyrochlore* group, but cannot be classified because the type material has not been analyzed. The name should be dropped.

Rijkeboerite (van der Veen, 1963) is a synonym for *bariomicrolite*. The name should be dropped.

Samiresite (Lacroix, 1912a) has the composition of a *plumbian uranpyrochlore* (see Van Wambeke, 1970, p. 138). However, although this mineral is metamict, apparently with octahedral habit, it recrystallizes on heating (Gorzhevskaya *et al.*, 1966; Gorzhevskaya and Sidorenko, 1971) to a phase, "*S*", related to synthetic UTa_3O_{10} (Gasperin, 1965) and lesser amounts of a pyrochlore phase. The name should be dropped.

Scheteligite (Bjørlykke, 1937) may possibly belong to the betafite subgroup, with complex substitution by Y, Mn, Sb, W, Bi, but more data are needed.

Silicate–wiikite (Strunz, 1957) must be discredited, being a mixture; see *wiikite*.

Stibiomicrolite (Quensel and Berggren, 1938) must be discredited, being a mixture of *microlite, stibiotantalite*, and *stibnite* (see Rosén and Westgren, 1938)

Sukulaite (Vorma and Siivola, 1967) is a synonym for *stannomicrolite*. The name should be dropped.

Tangenite (Gagarin and Cuomo, 1949) was a name presumptuously given to titanium-rich "*betafites*" from Norway (Tangen quarry near Kragerø). Two of the analyses correspond to *betafite*, and one to the titanian equivalent of pyrochlore. Recently W. L. Griffin, of the Mineralogisk Museum, Oslo, has shown that the specimens analyzed were mixtures (see *titanopyrochlore*). The name is discredited.

Tantalbetafite (Kalita and Bykova, 1961) is a synonym for *betafite*. The name should be dropped.

Tantalohatchettolite (Villiers, 1941) is a synonym for *uranmicrolite*. The name should be dropped.

Tantalo–obruchevite (van der Veen, 1963), intended for the yttrium-rich member of the microlite group, has not been found.

Tantalpyrochlore (Machatschki, 1932) is a synonym of *microlite*. The name should be dropped.

Titanbetafite (Ginzburg *et al.*, 1960) is a synonym of *betafite* as redefined above. The name should be dropped.

Titanmicrolite (Strunz, 1966, erroneously ascribed to van der Veen, 1963), with Ti > Ta > Nb, has not been found.

Titano–obruchevite (van der Veen, 1963) is a synonym of *yttrobetafite*, and the name must be discarded.

Titanopyrochlore (Machatschki, 1932) was named as a hypothetical titanian equivalent of *pyrochlore*. One of the analyses of Bjørlykke (1931, anal. 3), from the Tangen Quarry near Kragerø, Norway, conforms to a dominantly calcian member of the betafite subgroup. W. L. Griffin (correspondence, April 1974) made a microprobe analysis of Bjørlykke's specimen and found it to be composed of at least five different phases. A "*hatchettolite*" from Hybla, Ontario (Walker and Parsons, 1923b, anal. 1) approaches *titanpyrochlore* in bulk, but the material is inhomogeneous (Hogarth, unpublished data). The name should be dropped.

Westgrenite (Knorring and Mrose, 1963) is a synonym of *bismutomicrolite.* The name should be dropped.

Wiikite (Ramsay, 1899, p. 379) and α- and β-*wiikite* (Ant-Wuorinen, 1936) are mixtures of *yttropyrochlore* or other members of the pyrochlore group with *euxenite* and silicates (Fauquier, 1960; Beus and Kalita, 1961) and must be discredited (see also *pyrochlore–wiikite* and *silicate–wiikite*).

Yttrohatchettolite (Kalita, 1959) has insufficient uranium to be classified as *uranpyrochlore.* It is synonymous with *yttropyrochlore.* The name should be dropped.

Zirconolite and *niobozirconolite* from U.S.S.R. (Borodin *et al.*, 1956; 1960) are synonymous with *zirkelite* (Hussak and Prior, 1895). Parker and Fleischer (1968, p. 31) have listed *niobozirconolite* as a member of the "pyrochlore-betafite-microlite series," but its monoclinic symmetry excludes it from the pyrochlore group (Pudovkina *et al.*, 1974).

Conclusions

The proposed scheme of classification permits the addition of new species to the group when data become available. In naming these minerals, we recommend a chemical nomenclature, as outlined above. The following minerals or variants are poorly defined: aluminobetafite, azorpyrrhite, blomstrandite, calciosamarskite, scheteligite. Type materials should be reinvestigated, and their mineralogical status confirmed.

Acknowledgments

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