

CLASSIFICATION OF THE NATURAL SILICATES

PART II. COMPOSITION OF THE NATURAL SILICATES

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(Continued from page 1087)

The following tables give the composition of the natural silicates thus far determined by x-ray investigations. The species are arranged according to the classification proposed in the preceding part of the discussion.

The complex silicates are indicated by printing their names in italics. The roman figures beneath the names indicate their constituent types, thus $\frac{\textit{Vesuvianite}}{\text{I-II}}$ signifies a complex silicate of types I and II. The complex silicates are placed in the table with the simplest type entering into the composition of each.

A few species have been included in the tables whose structures are not adequately known. Such species (or families) are indicated by an asterisk * following their names. The figures enclosed in brackets after the names refer to the literature citations at the end.

CLASSIFICATION OF THE NATURAL SILICATES

I. SiO_4 GROUPS UNCOMBINED. ORTHOSILICATES, $\text{R}'_4\text{SiO}_4$.

1. *Bivalent Silicates*, $\text{R}''_2\text{SiO}_4$.

a. Anhydrous.

1. Olivine family (1). Orthorhombic

a. Mg, Fe section

Fosterite Mg_2SiO_4

Olivine (1) $(\text{Mg, Fe})_2\text{SiO}_4$

Fayalite Fe_2SiO_4

b. Ca section¹

Monticellite (2) CaMgSiO_4

2. Phenacite family. Trigonal

Phenacite (3) Be_2SiO_4

Willemite (4) Zn_2SiO_4

Troostite $(\text{Zn, Mn})_2\text{SiO}_4$

b. Hydrus.

1. Chondrodite series (5), $n \text{Mg}_2\text{SiO}_4 + \text{Mg}(\text{OH, F})_2$, n even monoclinic, n odd orthorhombic

Norbergite (6) $\text{Mg}_2\text{SiO}_4 \cdot \text{Mg}(\text{OH, F})_2$. Orthorhombic

¹ A Mn, Fe section may, possibly, be added here. It embraces the minerals

Tephroite Mn_2SiO_4

Knebellite $(\text{Fe, Mn})_2\text{SiO}_4$.

- Chondrodite $2 \text{Mg}_2\text{SiO}_4 \cdot \text{Mg}(\text{OH}, \text{F})_2$. Monoclinic
 Humite $3 \text{Mg}_2\text{SiO}_4 \cdot \text{Mg}(\text{OH}, \text{F})_2$. Orthorhombic
 Clinohumite $4 \text{Mg}_2\text{SiO}_4 \cdot \text{Mg}(\text{OH}, \text{F})_2$. Monoclinic
2. Complex division
 $\frac{\text{Bertrandite (7) Be}_2(\text{BeOH})_2}{\text{I-III}} \left\{ \begin{array}{l} \text{SiO}_4 \\ \text{SiO}_3 \end{array} \right. \text{Orthorhombic}$
2. *Trivalent Silicates*, $\text{R}'''\text{}_4(\text{SiO}_4)_3$.
- a. Anhydrous.
1. Garnet family (8) $\text{R}''_3\text{R}'''\text{}_2(\text{SiO}_4)_3$. Isometric
 2. Cyanite series (9) Al_2OSiO_4
 Sillimanite (10) Coordination $\frac{1}{2}\text{Al} = 4$, $\frac{1}{2}\text{Al} = 6$. Orthorhombic
 Andalusite (11) Coordination $\frac{1}{2}\text{Al} = 5?$, $\frac{1}{2}\text{Al} = 6$. Orthorhombic
 Cyanite (12) Coordination $\text{Al} = 6$. Triclinic
 3. Eulytite series $\text{Bi}_4(\text{SiO}_4)_3$
 Eulytite (13) Isometric
 Agricolite *Monoclinic
 4. Complex division.
 $\frac{\text{Mullite (14)*}_2 (\text{Al}_2\text{O})_8}{\text{I-II}} \left\{ \begin{array}{l} (\text{SiO}_4)_6 \\ \text{Al}_2\text{O}_7 \end{array} \right. \text{Orthorhombic}$

b. Hydrous.

1. Staurolite (15) $2 \text{cyanite} + \text{Fe}(\text{OH})_2$. Orthorhombic
 2. Topaz (16) $\text{Al}_2(\text{OH}, \text{F})_2\text{SiO}_4$. Orthorhombic
 3. Euclase (17) $\text{Al}(\text{BeOH})\text{SiO}_4$. Monoclinic
 4. Complex division
 $\frac{\text{Yesuvianite (18) Ca}_{10}\text{Al}_4}{\text{I-II}} \left\{ \begin{array}{l} (\text{SiO}_4)_5 \\ (\text{Si}_2\text{O}_7)_2 \end{array} \right. \cdot 2\text{Mg}(\text{OH})_2$. Tetragonal

3. *Quadrivalent Silicates* $\text{R}^{\text{IV}}\text{SiO}_4$.

a. Anhydrous.

1. Zircon family $\text{R}^{\text{IV}}\text{SiO}_4$. Tetragonal
 Zircon (19) ZrSiO_4
 Thorite* ThSiO_4
 2. Titanite (20) $\text{Ca}(\text{TiO})\text{SiO}_4$. Monoclinic

II. SiO_4 GROUPS COMBINED BY ONE SOLID ANGLE. ORTHODISILICATES. $\text{R}'_6\text{Si}_2\text{O}_7$.PAIRS1. *Bivalent Silicates* $\text{R}''_3\text{Si}_2\text{O}_7$.

b. Hydrous.

Calamine (21) $\text{Zn}_2(\text{ZnOH})_2\text{Si}_2\text{O}_7 \cdot \text{H}_2\text{O}$. Orthorhombic

2. *Trivalent Silicates*, $\text{R}'''\text{}_2\text{Si}_2\text{O}_7$.a. Anhydrous.³

1. Thortveitite (22) $\text{Sc}_2\text{Si}_2\text{O}_7$. Monoclinic

² The empirical formula of mullite is $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$. Taylor showed that the x-ray patterns of mullite and sillimanite are similar and suggests that their structures are analogous. He derives mullite from 8 molecules of sillimanite by removing one atom of O and replacing two Si by two Al. The result suggests a formula of the above type, but the true structure of mullite is unknown.

³ For danburite see type V.

2. Aenigmatite (23)⁴ X₄Y₁₃(Si₂O₇)₆. X=(Na, Ca, K). Y=(Fe'', Ti, Fe''', Mg, Al).
Triclinic

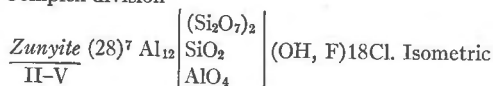
3. Bivalent to Quadrivalent Silicates.

a. Anhydrous.

1. Melilite family (24)⁵ X₂Y(Si, Al)₂O₇. X=(Ca, Na). Y=(Mg, Fe, Zn, Si, Al).
Tetragonal
- a. Bivalent section Ca₂(Mg, Zn)
Akermanite (24) Ca₂MgSi₂O₇
Hardystonite (25) Ca₂ZnSi₂O₇
- b. Trivalent section
Melilite (24) (Ca, Na)₂(Mg, Al) (Si, Al)₂O₇
- c. Quadrivalent section
Na-melilite (26) Na₂SiSi₂O₇
Gehlenite (26) Ca₂SiAl₂O₇

b. Hydrous.

1. Meliphanite family⁶ (Ca, Na)₂Be(Si, Al)₂(O, OH, F)₇
Leucophanite (27) (Ca, Na)₂BeSi₂(O, OH, F)₇ Orthorhombic
Meliphanite (27) (Ca, Na)₂Be(Si, Al)₂(O, OH, F)₇ Tetragonal
2. Complex division



⁴ M. Fleischer gives the above formula for aenigmatite, basing it upon chemical analyses and the dimensions and density of the unit cell. The structure has not been adequately determined.

⁵ The members of the melilite family can be referred, for classification, with almost equal propriety to two different types. If the Y(Mg, Fe, Zn, Si, Al) atoms be viewed as kations, the (Al, Si)₂O₇ groups being considered the only anions, the formula becomes X₂Y(Si, Al)₂O₇, as written above, and the family is a member of the orthodisilicates of type II. If, however, both the paired (Si, Al)₂O₇ and the YO₄ tetrahedra (see Figure 3), are considered anions, then, since they are united by their solid angles, they form sheet-like structures and the formula becomes X₂ $\left| \begin{array}{l} \text{Si}_2\text{O}_5 \\ \text{YO}_2 \end{array} \right|$. In the latter case the melilites may be viewed

as complex silicates related structurally to epididymite Na(BeOH) $\left| \begin{array}{l} \text{Si}_2\text{O}_5 \\ \text{SiO}_2 \end{array} \right|$.

The original investigators of the structures wrote their formula in the first way, as we do. C. Hermann and his associates, in the second volume of the *Strukturbericht* (1936, pp. 541-543) classify them as forming two-dimensional sheets.

⁶ The constitution of the meliphanite family has been studied by W. H. Zachariasen, who derives the formula given above from chemical analyses, the dimensions and densities of the unit cells and the similarity of their x-ray patterns to those of the melilites. The structure suggested, though not determined, is interesting in that it seems to place O, OH and F, interchangeably, upon the solid angles of the SiO₄ tetrahedra, a condition seemingly not recognized, hitherto, in other adequately studied silicates.

⁷ Zunyite may also be regarded as combining types I, II, V, if the AlO₄ tetrahedra be regarded as replacing SiO₄.

III. SiO_4 GROUPS COMBINING BY TWO SOLID ANGLES. METASILICATES, $\text{R}'_2\text{SiO}_3$.
RINGS AND CHAINS.

A. Rings

1. Three-fold rings, $\text{R}'_6(\text{SiO}_3)_3$
a. Anhydrous.

1. Wollastonite family
 - a. Monoclinic section⁸
Wollastonite (29) $\text{Ca}_3(\text{SiO}_3)_3$
2. Benitoite (30) $\text{BaTi}(\text{SiO}_3)_3$ Hexagonal
 - b. Hydrous.
1. Pectolite family (31)⁹ Triclinic-Pseudomonoclinic
Pectolite* $\text{NaHCa}_2(\text{SiO}_3)_3$
Schizolite* $\text{NaH}(\text{Ca}, \text{Mn})_2(\text{SiO}_3)_3$
2. Tourmaline family (32)^{*10} $\text{XY}_3\text{B}_3\text{Si}_6\text{O}_{27}(\text{O}, \text{OH}, \text{F})_4$ Trigonal
 $\text{X} = (\text{Ca}, \text{Na}, \text{K}, \text{Mn})$ $\text{Y} = (\text{Mg}, \text{Fe}, \text{Al}, \text{Cr}, \text{Mn}, \text{Ti}, \text{Li})$
 2. Six-fold rings, $\text{R}'_{12}(\text{SiO}_3)_6$.
 - a. Anhydrous.

1. Beryl (33) $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$. Hexagonal
2. Cordierite (34) $(\text{Mg}, \text{Fe})_2\text{Al}_3(\text{Si}_5\text{Al})\text{O}_{18} \mp \text{H}_2\text{O}$. Orthorhombic

B. Chains.

1. Chains unilateral, $\text{R}'_2\text{SiO}_3$.

1. Pyroxene family $(\text{X}, \text{Y})_2(\text{Si}, \text{Al})_2\text{O}_6$
 $\text{X} = (\text{Ca}, \text{Na}, \text{K}, \text{Mn})$ $\text{Y} = (\text{Mg}, \text{Fe}, \text{Al}, \text{Ti}, \text{Li}, \text{Mn})$
 - a. Orthorhombic system (35) Mg, Fe series
Enstatite MgSiO_3
Bronzite (36) $(\text{Mg}, \text{Fe})\text{SiO}_3$
Hypersthene $(\text{Fe}, \text{Mg})\text{SiO}_3$
 - b. Monoclinic system (37)
 1. Bivalent section
 - a. Mg, Fe series
Clinoenstatite $\text{Mg}_2\text{Si}_2\text{O}_6$
 - b. Ca, Mg series $\text{Ca}(\text{Mg}, \text{Fe})\text{Si}_2\text{O}_6$
Diopside (38) CaMg
Hedenbergite CaFe

⁸ The wollastonite family occurs in both monoclinic and triclinic sections. M. Barnick, who has determined the ring structure of monoclinic wollastonite, suggests that the triclinic form may have a similar structure, but differs in the lesser symmetry of its cells. Vogtite is a Mn bearing variety $(\text{Ca}, \text{Mn})\text{SiO}_3$ of the triclinic section.

⁹ The work of M. A. Peacock has shown so close a relation between the triclinic wollastonite and pectolite families as to suggest similarity of structures. As stated above, M. Barnick has established the ring structure of monoclinic wollastonite and suggests a similar structure for the triclinic form. The true structure of the pectolite family, however, is not definitely known.

¹⁰ F. Machatschki gives the above formula for tourmaline, save that he unites the $(\text{O}, \text{OH}, \text{F})_4$ group with the O, the latter thus becoming $(\text{O}, \text{OH}, \text{F})_{31}$. He derives the formula from chemical analyses and the dimensions and density of the unit cells. The formula suggests a possible position of tourmaline in this division, but its structure and place in the classification are unknown. The work of Machatschki is interesting as an effort to unravel somewhat of the complexity of this difficult family.

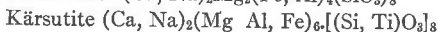
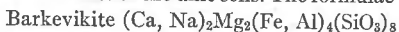
2. Trivalent section¹¹ (Ca, Na) (Mg, Fe, Al) (Si, Al)₂O₆
- a. Ca, Mg series
Augite¹² X_mY_{2-m}(Si, Al)₂O₆
X = (Ca, Na, Al, Mn). Y = (Mg, Fe, Al, Ti, Mn).
 - b. Ca, Na, Li series R'₄Si₂O₆
Acmite NaFe'''
Jadeite NaAl
Spodumene LiAl
2. Complex division. Bilateral chains, R'₆ $\left\{ \begin{array}{l} \text{Si}_2\text{O}_6 \\ \text{Si}_2\text{O}_5 \end{array} \right.$
- b. Hydrous.
1. Serpentine family
Chrysotile (39) (MgOH)₆Si₂O₆, Si₂O₆ · H₂O Monoclinic
 2. Amphibole family R''₇₋₈(Si, Al)₄O₁₂, (Si, Al)₄O₁₀(OH, F)₂
 - a. Orthorhombic system
 1. Mg, Fe series
Anthophyllite (40) (Mg, Fe)₇Si₄O₁₂, Si₄O₁₀(OH)₂
 - b. Monoclinic system (41)
 1. Bivalent section
 - a. Mg, Fe series (Mg, Fe)₇Si₄O₁₂, Si₄O₁₀(OH)₂
Kupfferite Mg₇
Cumingtonite (42) (Mg, Fe)₇
Grunerite Fe₇''
 - b. Ca, Mg series Ca₂(Mg, Fe'')₅Si₄O₁₂, Si₄O₁₀(OH, F)₂
Tremolite (43) Ca₂Mg₅
Actinolite Ca₂(Mg, Fe'')₅
 2. Trivalent section (42) X₂₋₃Y₅(Si, Al)₄O₁₂, (Si, Al)₄O₁₀(OH, F)₂
X = (Ca, Na, K, Mn), Y = (Mg, Fe, Al, Mn, Ti)
- a. Na rich series¹³ R'₁₄Si₈O₂₂(OH)₂
*Glaucophane** Na₂(Mg, Fe'')₃(Al, Fe''')₂
*Riebeckite** Na₂Fe''₃Fe'''₂
*Arfvedsonite** Na₂Fe''₄Fe'''₁
 - b. Na poor series R'₁₅₋₁₆(Si, Al)₈O₂₂(OH, F)₂
*Hornblende*¹⁴ X₂₋₃Y₅

¹¹ Formulae have been proposed for various other members of the pyroxene family but the results seem too insecure to render it desirable to present them at this place.

¹² B. E. Warren and J. Bischof cite the presence of H₂O in some augites and write the formula X_mY_{2-m}(Si, Al)₂(O, OH, F)₆.

¹³ The species here listed have had formulae assigned to them by Winchell, Bragg and others, based upon their analogies to the studied amphiboles, but their structures are not adequately known. The formulae here given are those of Winchell. (A. N. Winchell, *Elements of Optical Mineralogy*, pt. II, p. 239, 1933, W. L. Bragg, *Atomic Structure of Minerals*, p. 185, 1937.) See also B. Gossner, F. Spielberger, *Zeits. Krist.*, **72**, 111, 1929, B. Gossner, F. Muschnug, *N. Jb. Min., A. Beil. Bd.*, **58**, 213, 1928.

¹⁴ Osannite (44) is a variety of hornblende with abnormally high O content and high Na. Additional varieties of hornblende have been examined by B. Gossner and F. Spielberger (*Zeits. Krist.*, **72**, 111, 1929) who derived their formulae from chemical analyses and measurements of the unit cells. The formulae they propose may be written as follows—



IV. SiO_4 GROUPS COMBINED BY THREE SOLID ANGLES. METADISILICATES, $\text{R}'_2\text{Si}_2\text{O}_5$
SHEETS
1. *Bivalent and Trivalent Silicates. Hydrous.*A. Si_2O_5 series

1. Apophyllite (45) $4\text{CaSi}_2\text{O}_5 \cdot \text{KF} \cdot 8\text{H}_2\text{O}$. Tetragonal
2. Kaolin family (46) $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. Monoclinic
 Kaolinite (47)¹⁵ $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot \beta = 101^\circ 30'$
 var. Anauxite (48)¹⁶ $\text{AlSi}_2(\text{O}, \text{OH})_5(\text{OH})_{1-2}$
 Dickite (49) $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot \beta = 96^\circ 50'$
 Nacrite (50)¹⁷ $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot \beta = 91^\circ 43'$
3. Halloysite (51) $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \cdot 2\text{H}_2\text{O}$ Monoclinic

B. Si_4O_{10} seriesa. $\text{R}'_{6-8}(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2$ division

1. Montmorillonite family (52)¹⁸ $(\text{Mg}, \text{Al}, \text{Fe})_{2-3}(\text{Si}, \text{Al}, \text{Fe})_4\text{O}_{10}(\text{OH})_2 \cdot n\text{H}_2\text{O}$.
 Orthorhombic
 Montmorillonite $(\text{Mg}, \text{Al})_{2-3}4\text{H}_2\text{O}$. Little or no Si replaced by (Al, Fe)
 Nontronite $(\text{Mg}, \text{Al}, \text{Fe})_{2-3}n\text{H}_2\text{O}$. Up to 1 Si replaced by (Al, Fe)
2. Talc—Pyrophyllite group (53) $(\text{Mg}, \text{Al})_{2-3}(\text{Si}_4\text{O}_{10})(\text{OH})_2$. Monoclinic
 Talc Mg_3
 Pyrophyllite Al_2
3. Mica families (54) $\text{R}'_{7-8}(\text{Si}, \text{Al})_4\text{O}_{10}(\text{OH})_2$. Monoclinic
 a. Elastic micas¹⁹. One Al replacing Si. $\text{R}'_7(\text{Al}_1\text{Si}_3)\text{O}_{10}(\text{OH}, \text{F})_2$
 Muscovite (55) $\text{KAl}_2(\text{Al}_1\text{Si}_3)\text{O}_{10}(\text{OH}, \text{F})_2$
 var. Phengite. Muscovite + $\text{KAl}(\text{Mg}, \text{Fe})\text{Si}_4\text{O}_{10}(\text{OH}, \text{F})_2$
 Paragonite $\text{NaAl}_2(\text{Al}_1\text{Si}_3)\text{O}_{10}(\text{OH}, \text{F})_2$

¹⁵ The formula given is based upon the structure determined by L. Pauling (*Proc. Nat. Acad. Sci.*, **16**, 578, 1930) developed further by J. W. Gruner (*Zeits. Krist.*, **83**, 75, 1932). C. J. Ksanda and T. F. W. Barth pointed out certain difficulties based upon a study of dickite (*Am. Mineral.*, **20**, 631, 1935). The structure given by Gruner has been confirmed by S. B. Hendricks (*Zeits. Krist.*, **95**, 247, 1936) with a slight modification in the value of β .

¹⁶ Anauxite forms an isomorphous series with kaolinite. It may be considered derived from kaolinite by the removal of either $\text{Al}(\text{OH})_3$ or $\text{AlO}(\text{OH})$ from kaolinite. In the latter case an OH group is substituted for one O atom in a Si_2O_5 group. (S. B. Hendricks, *Zeits. Krist.*, **95**, 247, 1936).

¹⁷ Allophane is an amorphous body with approximately the composition of kaolinite. (C. S. Ross, P. F. Kerr, *U. S. G. S., Prof. Paper 185 G*, 1934.)

¹⁸ J. W. Gruner makes the formula of this family $(\text{Al}, \text{Fe})_8(\text{Al}, \text{Fe})_n\text{Si}_{16-n}\text{O}_{40}(\text{OH})_8 \cdot m\text{H}_2\text{O}$ and regards montmorillonite, beidellite and nontronite as a continuous isomorphous series with n varying in value from 0 to 4. In montmorillonite $n=0$ or <1 , in nontronite $n=2$ to 4. In beidellite and other varieties n lies between these limits.

¹⁹ The species of elastic micas are subject to wide variation in composition. The following replacements occur in them according to J. Holzner (*Zeits. Krist.*, **95**, 435, 1936), $\text{R}'_7 = \text{X}_1\text{Y}_{2-3}$ where $\text{X} = (\text{K}, \text{Na}, \text{Ca})$, $\text{Y} = (\text{Mg}, \text{Fe}, \text{Al}, \text{Mn}, \text{Li})$. Fe''' may replace Al in $(\text{Al}_1\text{Si}_3)\text{O}_{10}$. Holzner also suggests certain other replacements that seem less assured, i.e. (X, Y') and (Ti, Si) in some micas and (Na, Li) in lepidolite and zinnwaldite.

Holzner recognizes two structural types of elastic micas, muscovite Y_2 and phlogopite Y_3 , and regards biotite as an intergrowth of sheets of both.

- Phlogopite $KMg_3(Al_1Si_3)O_{10}(OH, F)_2$
 Biotite (56)²⁰ $K(Mg, Fe, Al)_{2-3}(Al, Si)_4O_{10}(OH, F)_2$
 b. Brittle micas. Two Al replacing Si. $R'_3(Al_2Si_2)O_{10}(OH)_2$
 Margarite $CaAl_2(Al_2Si_2)O_{10}(OH)_2$
4. Vermiculites (57) $(Mg, Fe)_{2-3}(Si, Al, Fe''')_4O_{10}(OH)_2 \cdot 4H_2O$. Monoclinic
- b. $R'_{13-14}(Si, Al)_4O_{10}(OH)_8$ division
1. Chlorite group (58) $R'_{13-14}(Si, Al)_4O_{10}(OH)_8$ Monoclinic
- a. Clinocllore family. One Al replacing Si
 $R'_{13}(Al_1Si_3)O_{10}(OH)_8$. $R'_{13} = (Mg, Fe, Mn)_5(Al, Fe''')$
- b. Amesite family. Two Al replacing Si
 $R'_{14}(Al_2Si_2)O_{10}(OH)_8$. $R'_{14} = (Mg, Fe'', Mn'')_4(Al, Fe''')$

2. Complex division

1. Epididymite (59) $Na(BeOH) \left| \begin{array}{l} Si_2O_5 \\ SiO_2 \end{array} \right.$ Orthorhombic
 IV-V

V. SiO_4 GROUPS COMBINED BY FOUR SOLID ANGLES. DIOXIDE TYPE, SiO_2 . NET-WORKS

A. R''' free. SiO_2

1. Three-fold. Quartz (60) $(SiO_2)_3$ Trigonal
2. Six-fold. $(SiO_2)_6$
 Cristobalite (61) Cubic packing. Orthorhombic? Isometric
 Tridymite (62) Hexagonal packing. Orthorhombic, Hexagonal

B. Trivalent Silicates

1. Anhydrous.

a. Silicates without other anions. Monanionic.

1. Feldspar family (63) $R'_{1-2}(Si, Al)_4O_8$
- a. Monoclinic system
 Orthoclase (64) $KAlSi_3O_8$
 Hyalophane $KAlSi_3O_8 \cdot BaAl_2Si_2O_8$
 Celsian $BaAl_2Si_2O_8$
- b. Triclinic system
 Microcline $KAlSi_3O_8$
 Albite (65) $NaAlSi_3O_8$
 Anorthite $CaAl_2Si_2O_8$
2. Danburite (66)²¹ $CaB_2Si_2O_8$. Orthorhombic

²⁰ The above formula is that of J. Holzner. A. N. Winchell writes $K(Mg, Fe, Al)_3(Al, Si)_4O_{10}(OH)_2$ (*Am. Mineral.*, **20**, 773, 1935).

²¹ Danburite consists of pairs of SiO_4 tetrahedra joined by one solid angle, with the formula Si_2O_7 and similarly joined pairs of BO_4 tetrahedra with the formula B_2O_7 . Both the Si_2O_7 and B_2O_7 pairs are further united by their solid angles to form a net-work. If the Si_2O_7 pairs alone be viewed as anions, danburite is clearly an orthosilicate, $CaB_2OSi_2O_7$. If boron is viewed as replacing Si, in a manner analogous to the replacement of Si by Al, the structure is of the dioxide type and the formula becomes $CaB_2Si_2O_8$ as here written. The small size and trivalent valency of the B atom has led us to treat the subject in the latter way.

3. Leucite family (67)^{*22} $R'AlSi_2O_6$ Tetragonal—Pseudo-isometric
Leucite $KAlSi_2O_6$
Na-Leucite $(K, Na)AlSi_2O_6$
 4. Nepheline family (68) $R'AlSiO_4$. Hexagonal
Nepheline (α carnegite) $NaAlSiO_4$
Kaliophilite $KAlSiO_4$
- b. Silicates with other anions. Polyanionic.
1. Scapolite family (69) $3(Na, Ca)(Al, Si)_3O_8 + [NaCl, Ca(CO_3, SO_4)]$
Tetragonal
Marialite. 3 albite + NaCl
Wernerite | Marialite + Meionite
Mizzonite |
Meionite. 3 Anorthite + $Ca(CO_3, SO_4)$
 2. Sodalite family (70) $(Na, Ca)_{6-3}(AlSiO_4)_6 + 2X$. Isometric
Sodalite $Na_6(AlSiO_4)_6Na_2Cl_2$
Noselite (71) $Na_6(AlSiO_4)_6Na_2SO_4$
Haüynite (71) $(Ca, Na)_{3-6}(AlSiO_4)_6(CaSO_4)_{1-2}$
 3. Cancrinite family (72) $3NaAlSiO_4 + Ca(Cl_2, CO_3, SO_4) \cdot \pm H_2O$. Hexagonal
Cancrinite $3NaAlSiO_4 + CaCO_3 \pm H_2O$
Davynite $3NaAlSiO_4 + Ca(Cl_2, SO_4)$
 4. Helvite—Danalite group (73). Isometric
Helvite $3(Mn, Fe)(Be, Si)O_4 + (Mn, Fe, Zn)S$
Danalite $3(Zn, Fe, Mn)(Be, Si)O_4 + (Zn, Fe)S$
2. Hydrous.
1. Epidote family (74)^{*23} $Ca_2(Al, Fe, R'')_3Si_3O_{12}(OH)$
 2. Zeolites (75)²⁴ $R'_m(Al_mSi_n)O_2(2+n) \cdot xH_2O$

²² No adequate study has been made of the structure of leucite but its composition and relations are such as to suggest its position in this group. Recent studies of J. Wyart show its true tetragonal character.

²³ The structure of the epidote family is not adequately known. D. J. Bujor studied epidote and clinozoisite and published his roentgenographic data in 1931, in the first of two articles. The second part, embracing his interpretation of the data, has not yet appeared. A. N. Winchell has referred the family to the division of three-dimensional lattices. This has a certain plausibility because of the relation of epidote to feldspar. Waldbauer and McCann have shown that orthorhombic zoisite is probably formed by the submicroscopic twinning of clinozoisite.

²⁴ Different views have been held concerning the composition of the zeolites due to their complexity, variable hydration, isomorphous intergrowths and replacements seemingly taking place after their crystallization. One view, widely held, assigns to most of them two Al atoms (or some multiple of two), a fixed Al:Si ratio, the isomorphous replacement of Ca by Na_2 in many, and a resulting variable number of kations. A second view, suggested by A. N. Winchell, is that CaAl and NaSi mutually replace each other resulting in isomorphous intergrowths, a variable Al:Si ratio and a constant number of kations in each species. Winchell denies the primary replacement of Ca by Na_2 though he believes it may occur subsequent to crystallization. M. H. Hey and J. Wyart believe, on the contrary, that both types of replacement occur.

- a. Al_2 section. $R'_2Al_2Si_nO_{2(2+n)} \cdot xH_2O$
- Si_2O_8 series
Thomsonite (76)²⁶ $Na_2Ca_4(Al_2Si_2O_8)_6 \cdot 12H_2O$. Orthorhombic
 - Si_3O_{10} series
Natrolite (77) $Na_2Al_2Si_3O_{10} \cdot 2H_2O$. Orthorhombic
Scolecite (78) $CaAl_2Si_3O_{10} \cdot 3H_2O$. Monoclinic
Mesolite (79)^{*26} $Na_2Ca_2(Al_2Si_3O_{10})_3 \cdot 8H_2O$. Monoclinic
Gonnardite (80)^{*27} $Na_2Ca(Al_2Si_3O_{10})_2 \cdot 7H_2O$. Orthorhombic or Tetragonal
Edingtonite (81) $BaAl_2Si_3O_{10} \cdot 4H_2O$. Tetragonal
 - Si_4O_{12} series
Analcite (82) $Na_2Al_2Si_4O_{12} \cdot 2H_2O$ Tetragonal? Pseudo-isometric
Chabazite (83)²⁸ $CaAl_3Si_4O_{12} \cdot 6H_2O$. Rhombohedral
Pollucite (84)^{*} $CsAl_2Si_4O_{12} \cdot 1H_2O$. Isometric
 - Si_7O_{18} series
Heulandite (85)^{*29} $CaAl_2Si_7O_{18} \cdot 6H_2O$ Monoclinic
 - Si_8O_{20} series
Mordenite (86)^{*30} $Na_2Ca(Al_2Si_8O_{20})_2 \cdot 12\frac{1}{2}H_2O$. Monoclinic
- b. Al_m section
Ashcroftine (87)^{*31} $NaK(Ca, Mn, Mg)Al_4Si_6O_{18} \cdot 8H_2O$. Tetragonal

²⁵ Subject to replacements of $CaAl \rightleftharpoons NaSi$ and $Ca \rightleftharpoons Na_2$, according to M. H. Hey.

²⁶ Composition doubtful, perhaps $Na_4Ca_6(Al_2Si_3O_{10})_8 \cdot 21H_2O$, (W. H. Taylor et al., *Zeits. Krist.*, **84**, 384, 1933, footnote.)

²⁷ M. H. Hey gives the above formula and states that $CaAl$ and $NaSi$ replace each other, more rarely Ca and Na_2 .

²⁸ The structure of chabazite was determined by J. Wyart who gives the above formula, subject to various replacements of $Ca \rightleftharpoons Na_2$, $CaAl \rightleftharpoons NaSi$, etc. A. N. Winchell's formula is $(Na, K, Ca)_7(Al, Si)_{40}O_{80} \cdot 40H_2O$.

²⁹ The composition of heulandite varies widely. J. Wyart studied its structure but did not determine the parameters. He gives the above formula subject to various replacements of Ca, Al, Si , especially $Si \rightleftharpoons NaAl$. M. H. Hey gives the formula $Na_xCa_yAl_{(x+y)}Si_{36-(x+2y)}O_{72} \cdot 24H_2O$.

³⁰ The above formula is by A. N. Winchell, who bases it upon chemical analyses.

³¹ A. N. Winchell adds the following formula of additional species of zeolites, basing them upon selected chemical analyses (*Am. Mineral.*, **10**, 170, 1925. See also *ib.* **22**, 85, 1937). His kation number ("alkali number") is recalculated for 80 oxygen atoms.

- Al:Si ratio and composition constant

Levynite $NaCa_4Al_9Si_{16}O_{50} \cdot 25H_2O$	Kation number 8
Stilbite $Na_3Ca_9Al_{12}Si_{19}O_{160} \cdot 60H_2O$	Kation number 6
Epistilbite $NaCa_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$	Kation number 6
Brewsterite $Na(Ca, Sr, Ba)_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$	Kation number 6
Harmatome $KBa_5Al_{11}Si_{29}O_{80} \cdot 25H_2O$	Kation number 6
Ptilotite $Na_3Ca_2Al_7Si_{30}O_{80} \cdot 25H_2O$	Kation number 5?
- Al:Si ratio and composition variable. Isomorphous intergrowths

Gmelinite $(Na, Ca)_{12}(Al, Si)_{40}O_{80} \cdot 40H_2O$	Kation number 12 (11 $\frac{2}{3}$?)
Gismondite $(K, Ca)_{11}(Al, Si)_{40}O_{80} \cdot 36-40H_2O$	Kation number 11
Phillipsite $(K, Ca)_{11}(Al, Si)_{40}O_{80} \cdot 30-40H_2O$	Kation number 11
Laumontite $(Na, Ca)_7(Al, Si)_{40}O_{80} \cdot 25H_2O$	Kation number 7

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³² The usual abbreviations are used, save in the following publications—

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 Zunyite, 1163