CLASSIFICATION OF THE NATURAL SILICATES

PART II. COMPOSITION OF THE NATURAL SILICATES

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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, R'_4SiO_4.

1. *Bivalent Silicates*, R''_2SiO_4.

a. Anhydrous.

1. Olivine family (1). Orthorhombic
   a. Mg, Fe section
      Fosterite Mg_2SiO_4
      Olivine (1) $(Mg, Fe)_2SiO_4$
      Fayalite Fe_2SiO_4
   b. Ca section[1]
      Monticellite (2) $CaMgSiO_4$
2. Phenacite family. Trigonal
   Phenacite (3) Be_2SiO_4
   Willemite (4) Zn_2SiO_4
   Troostite $(Zn, Mn)_2SiO_4$

b. Hydrous.

1. Chondrodite series (5), $n\ Mg_2SiO_4 + Mg(OH, F)_2$, n even monoclinic, n odd orthohombic
   Norbergite (6) $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Orthorhombic

[1] A Mn, Fe section may, possibly, be added here. It embraces the minerals
Tephroite Mn_2SiO_4
Knebellite $(Fe, Mn)_2SiO_4$.

Chondrodite 2 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Monoclinic
Humite 3 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Orthorhombic
Clinohumite 4 $Mg_2SiO_4 \cdot Mg(OH, F)_2$. Monoclinic

2. Complex division
$\frac{\textit{Bertrandite}}{\text{I–III}}$ (7) $Be_2(BeOH)_2 \left| \begin{matrix} SiO_4. \\ SiO_3. \end{matrix} \right.$ Orthorhombic

2. *Trivalent Silicates*, $R'''_4(SiO_4)_3$.

a. Anhydrous.

1. Garnet family (8) $R''_3R'''_2(SiO_4)_3$. Isometric
2. Cyanite series (9) Al_2OSiO_4
   Sillimanite (10) Coordination $\frac{1}{2}Al=4$, $\frac{1}{2}Al=6$. Orthorhombic
   Andalusite (11) Coordination $\frac{1}{2}Al=5?$, $\frac{1}{2}Al=6$. Orthorhombic
   Cyanite (12) Coordination $Al=6$. Triclinic
3. Eulytite series $Bi_4(SiO_4)_3$
   Eulytite (13) Isometric
   Agricolite *Monoclinic
4. Complex division.
   $\frac{\textit{Mullite}}{\text{I–II}}$ (14)*[2] $(Al_2O)_8 \left| \begin{matrix} (SiO_4)_6 \\ Al_2O_7 \end{matrix} \right.$ Orthorhombic

b. Hydrous.

1. Staurolite (15) 2 cyanite$+Fe(OH)_2$. Orthorhombic
2. Topaz (16) $Al_2(OH, F)_2SiO_4$. Orthorhombic
3. Euclase (17) $Al(BeOH)SiO_4$. Monoclinic
4. Complex division
   $\frac{\textit{Vesuvianite}}{\text{I–II}}$ (18) $Ca_{10}Al_4 \left| \begin{matrix} (SiO_4)_5 \\ (Si_2O_7)_2 \end{matrix} \right| \cdot 2Mg(OH)_2$. Tetragonal

3. *Quadrivalent Silicates* $R^{IV}SiO_4$.

a. Anhydrous.

1. Zircon family $R^{IV}SiO_4$. Tetragonal
   Zircon (19) $ZrSiO_4$
   Thorite* $ThSiO_4$
2. Titanite (20) $Ca(TiO)SiO_4$. Monoclinic

II. SiO_4 GROUPS COMBINED BY ONE SOLID ANGLE. ORTHODISILICATES. $R'_6Si_2O_7$ .PAIRS

1. *Bivalent Silicates* $R''_3Si_2O_7$.

b. Hydrous.

Calamine (21) $Zn_2(ZnOH)_2Si_2O_7 \cdot H_2O$. Orthorhombic

2. *Trivalent Silicates*, $R'''_2Si_2O_7$.

a. Anhydrous.[3]

1. Thortveitite (22) $Sc_2Si_2O_7$. Monoclinic

[2] The empirical formula of mullite is $3Al_2O_3 \cdot 2SiO_2$. 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] $X_4Y_{13}(Si_2O_7)_6$. X=(Na, Ca, K). Y=(Fe'', Ti, Fe''', Mg, Al). Triclinic

3. *Bivalent to Quadrivalent Silicates.*

a. Anhydrous.

1. Melilite family (24)[5] $X_2Y(Si, Al)_2O_7$. X=(Ca, Na). Y=(Mg, Fe, Zn, Si, Al). Tetragonal
   a. Bivalent section Ca_2(Mg, Zn)
      Akermanite (24) $Ca_2MgSi_2O_7$
      Hardystonite (25) $Ca_2ZnSi_2O_7$
   b. Trivalent section
      Melilite (24) $(Ca, Na)_2(Mg, Al)(Si, Al)_2O_7$
   c. Quadrivalent section
      Na-melilite (26) $Na_2SiSi_2O_7$
      Gehlenite (26) $Ca_2SiAl_2O_7$

b. Hydrous.

1. Meliphanite family[6] $(Ca, Na)_2Be(Si, Al)_2(O, OH, F)_7$
   Leucophanite (27) $(Ca, Na)_2BeSi_2(O, OH, F)_7$ Orthorhombic
   Meliphanite (27) $(Ca, Na)_2Be(Si, Al)_2(O, OH, F)_7$ Tetragonal
2. Complex division

<u>*Zunyite*</u> (28)[7] $Al_{12}\left|\begin{matrix}(Si_2O_7)_2\\ SiO_2\\ AlO_4\end{matrix}\right|$(OH, F)18Cl. Isometric
II–V

[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 $(Al, Si)_2O_7$ groups being considered the only anions, the formula becomes $X_2Y(Si, Al)_2O_7$, as written above, and the family is a member of the orthodisilicates of type II. If, however, both the paired $(Si,Al)_2O_7$ and the YO_4 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 $X_2\left|\begin{matrix}Si_2O_5\\ YO_2.\end{matrix}\right.$ In the latter case the melilites may be viewed as complex silicates related structurally to epididymite $Na(BeOH)\left|\begin{matrix}Si_2O_5\\ SiO_2.\end{matrix}\right.$

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 *Structurbericht* (**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 SiO_4 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 AlO_4 tetrahedra be regarded as replacing SiO_4.

III. SiO_4 GROUPS COMBINING BY TWO SOLID ANGLES. METASILICATES, R'_2SiO_3. RINGS AND CHAINS.

A. Rings

1. Three-fold rings, $R_6(SiO_3)_3$

a. Anhydrous.

1. Wollastonite family
   a. Monoclinic section[8]
   Wollastonite (29) $Ca_3(SiO_3)_3$
2. Benitoite (30) $BaTi(SiO_3)_3$ Hexagonal

b. Hydrous.

1. Pectolite family (31)[9] Triclinic-Pseudomonoclinic
   Pectolite* $NaHCa_2(SiO_3)_3$
   Schizolite* $NaH(Ca, Mn)_2(SiO_3)_3$
2. Tourmaline family (32)*[10] $XY_9B_3Si_6O_{27}(O, OH, F)_4$ Trigonal
   X=(Ca, Na K, Mn) Y=(Mg, Fe, Al, Cr, Mn, Ti, Li)

2. Six-fold rings, $R'_{12}(SiO_3)_6$.

a. Anhydrous.

1. Beryl (33) $Be_3Al_2(SiO_3)_6$. Hexagonal
2. Cordierite (34) $(Mg, Fe)_2Al_3(Si_5Al)O_{18} \mp H_2O$. Orthorhombic

B. Chains.

1. Chains unilateral, R'_2SiO_3.

1. Pyroxene family $(X, Y)_2(Si, Al)_2O_6$
   X=(Ca, Na, K, Mn) Y=(Mg, Fe, Al, Ti, Li, Mn)
   a. Orthorhombic system (35) Mg, Fe series
      Enstatite $MgSiO_3$
      Bronzite (36) $(Mg, Fe)SiO_3$
      Hypersthene $(Fe, Mg) SiO_3$
   b. Monoclinic system (37)
      1. Bivalent section
         a. Mg, Fe series
            Clinoenstatite $Mg_2Si_2O_6$
         b. Ca, Mg series $Ca(Mg, Fe)Si_2O_6$
            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 $(Ca, Mn)SiO_3$ 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 $(O, OH, F)_4$ group with the O, the latter thus becoming $(O, OH, F)_{31}$. 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 section[11] (Ca, Na) (Mg, Fe, Al) $(Si, Al)_2O_6$
   a. Ca, Mg series
      Augite[12] $X_mY_{2-m}(Si, Al)_2O_6$
      X = (Ca, Na, Al, Mn). Y = (Mg, Fe, Al, Ti, Mn).
   b. Ca, Na, Li series $R'_4Si_2O_6$
      Acmite NaFe'''
      Jadeite NaAl
      Spodumene LiAl

2. Complex division. Bilateral chains, $R'_6 \left| \begin{matrix} Si_2O_6 \\ Si_2O_5 \end{matrix} \right.$

b. Hydrous.

1. Serpentine family
   Chrysotile (39) $(MgOH)_6Si_2O_6, Si_2O_5 \cdot H_2O$ Monoclinic
2. Amphibole family $R''_{7-8}(Si, Al)_4O_{12}, (Si, Al)_4O_{10}(OH, F)_2$
   a. Orthorhombic system
      1. Mg, Fe series
         Anthophyllite (40) $(Mg, Fe)_7Si_4O_{12}, Si_4O_{10}(OH)_2$
   b. Monoclinic system (41)
      1. Bivalent section
         a. Mg, Fe series $(Mg, Fe)_7Si_4O_{12}, Si_4O_{10}(OH)_2$
            Kupfferite Mg_7
            Cummingtonite (42) $(Mg, Fe)_7$
            Grunerite Fe_7''
         b. Ca, Mg series $Ca_2(Mg, Fe'')_5Si_4O_{12}, Si_4O_{10}(OH, F)_2$
            Tremolite (43) Ca_2Mg_5
            Actinolite $Ca_2(Mg, Fe'')_5$
      2. Trivalent section (42) $X_{2-3}Y_5(Si, Al)_4O_{12}, (Si, Al)_4O_{10}(OH, F)_2$
         X = (Ca, Na, K, Mn), Y = (Mg, Fe, Al, Mn, Ti)
         a. Na rich series[13] $R'_{14}Si_8O_{22}(OH)_2$
            *Glaucophane** $Na_2(Mg, Fe'')_3(Al, Fe''')_2$
            *Riebeckite** $Na_2Fe''_3Fe'''_2$
            *Arfedsonite** $Na_2Fe''_4Fe'''_1$
         b. Na poor series $R'_{15-16}(Si, Al)_8O_{22}(OH, F)_2$
            Hornblende[14] $X_{2-3}Y_5$

[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. Biscoe cite the presence of H_2O 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. Mussgnug, *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—

Barkevikite $(Ca, Na)_2Mg_2(Fe, Al)_4(SiO_3)_8$

Kärsutite $(Ca, Na)_2(Mg\ Al, Fe)_6.[(Si, Ti)O_3]_8$

IV. SiO_4 Groups combined by three solid angles. Metadisilicates, $R'_2Si_2O_5$ Sheets

1. *Bivalent and Trivalent Silicates. Hydrous.*

A. Si_2O_5 series

1. Apophyllite (45) $4CaSi_2O_5 \cdot KF \cdot 8H_2O$. Tetragonal
2. Kaolin family (46) $Al_2Si_2O_5(OH)_4$. Monoclinic
   Kaolinite (47)[15] $Al_2Si_2O_5(OH)_4 \cdot \beta=101°30'$
   var. Anauxite (48)[16] $AlSi_2(O, OH)_5(OH)_{1-2}$
   Dickite (49) $Al_2Si_2O_5(OH)_4 \cdot \beta=96°50'$
   Nacrite (50)[17] $Al_2Si_2O_5(OH)_4 \cdot \beta=91°43'$
3. Halloysite (51) $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$ Monoclinic

B. Si_4O_{10} series

a. $R'_{6-8}(Si, Al)_4O_{10}(OH)_2$ division

1. Montmorillonite family (52)[18] $(Mg, Al, Fe)_{2-3}(Si, Al, Fe)_4O_{10}(OH)_2 \cdot nH_2O$. Orthorhombic
   Montmorillonite $(Mg, Al)_{2-3}4H_2O$. Little or no Si replaced by (Al, Fe)
   Nontronite $(Mg, Al, Fe)_{2-3}nH_2O$. Up to 1 Si replaced by (Al, Fe)
2. Talc—Pyrophyllite group (53) $(Mg, Al)_{2-3}(Si_4O_{10})(OH)_2$. Monoclinic
   Talc Mg_3
   Pyrophyllite Al_2
3. Mica families (54) $R'_{7-8}(Si, Al)_4O_{10}(OH)_2$. Monoclinic
   a. Elastic micas[19]. One Al replacing Si. $R'_7(Al_1Si_3)O_{10}(OH, F)_2$
      Muscovite (55) $KAl_2(Al_1Si_3)O_{10}(OH, F)_2$
      var. Phengite. Muscovite+$KAl(Mg, Fe)Si_4O_{10}(OH, F)_2$
      Paragonite $NaAl_2(Al_1Si_3)O_{10}(OH, F)_2$

[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 $Al(OH)_3$ or $AlO(OH)$ 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 $(Al, Fe)_8$ $(Al, Fe)_nSi_{16-n}O_{40}(OH)_8 \cdot mH_2O$ 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), $R'_7=X_1Y_{2-3}$ where X=(K, Na, Ca), Y=(Mg, Fe, Al, Mn, Li). Fe''' may replace Al in $(Al_1Si_3)O_{10}$. 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. $R'_8(Al_2Si_2)O_{10}(OH)_2$
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. Clinochlore 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
      $R'_{14}(Al_2Si_2)O_{10}(OH)_8$. $R'_{14}=(Mg, Fe'', Mn'')_4(Al, Fe''')_2$

2. *Complex division*

1. $\frac{\textit{Epididymite}}{\text{IV–V}}$ (59) Na(BeOH) $\left|\begin{matrix} Si_2O_5 \\ SiO_2 \end{matrix}\right.$ Orthorhombic

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 orthodisilicate, $CaB_2OSi_2O_7$. 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 carnegeite) $NaAlSiO_4$
   Kaliophilite $KAlSiO_4$

b. Silicates with other anions. Polyanionic.

1. Scapolite family (69) 3 (Na, Ca) $(Al, Si)_4O_8$+[NaCl, $Ca(CO_3, SO_4)$]
   Tetragonal
   Marialite. 3 albite+NaCl
   Wernerite / Mizzonite | Marialite+Meionite
   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. $R'_2Al_2Si_nO_{2(2+n)} \cdot xH_2O$

1. Si_2O_8 series
   Thomsonite (76)[25] $Na_2Ca_4(Al_2Si_2O_8)_5$. $12H_2O$. Orthorhombic
2. Si_3O_{10} series
   Natrolite (77) $Na_2Al_2Si_3O_{10}$. $2H_2O$. Orthorhombic
   Scolecite (78) $CaAl_2Si_3O_{10}$. $3H_2O$. Monoclinic
   Mesolite (79)*[26] $Na_2Ca_2(Al_2Si_3O_{10})_3$. $8H_2O$. Monoclinic
   Gonnardite (80)*[27] $Na_2Ca(Al_2Si_3O_{10})_2$. $7H_2O$. Orthorhombic or Tetragonal
   Edingtonite (81) $BaAl_2Si_3O_{10}$. $4H_2O$. Tetragonal
3. Si_4O_{12} series
   Analcite (82) $Na_2Al_2Si_4O_{12}$. $2H_2O$ Tetragonal? Pseudo-isometric
   Chabazite (83)[28] $CaAl_2Si_4O_{12}$. $6H_2O$. Rhombohedral
   Pollucite (84)* $CsAl_2Si_4O_{12} \cdot 1H_2O$. Isometric
4. Si_7O_{18} series
   Heulandite (85)*[29] $CaAl_2Si_7O_{18}$. $6H_2O$ Monoclinic
5. Si_8O_{20} series
   Mordenite (86)*[30] $Na_2Ca(Al_2Si_8O_{20})_2$. $12\frac{1}{2}H_2O$. Monoclinic

b. Al_m section

Ashcroftine (87)*[31] $NaK(Ca, Mn, Mg)Al_4Si_5O_{18}$. $8H_2O$. Tetragonal

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

[26] Composition doubtful, perhaps $Na_4Ca_6(Al_2Si_3O_{10})_8$. $21H_2O$, (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 $Ca \rightleftarrows Na_2$, $CaAl \rightleftarrows NaSi$, etc. A. N. Winchell's formula is $(Na, K, Ca)_7(Al, Si)_{40}O_{80}$. $40H_2O$.

[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 $Si \rightleftarrows NaAl$. M. H. Hey gives the formula $Na_xCa_yAl_{(x+2y)}Si_{36-(x+2y)}O_{72}$. $24H_2O$.

[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.

1. Al:Si ratio and composition constant

Levynite $NaCa_4Al_9Si_{16}O_{50}$. $25H_2O$	Kation number 8
Stilbite $Na_3Ca_9Al_{21}Si_{59}O_{160}$. $60H_2O$	Kation number 6
Epistilbite $NaCa_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Brewsterite $Na(Ca, Sr, Ba)_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Harmatome $KBa_5Al_{11}Si_{29}O_{80}$. $25H_2O$	Kation number 6
Ptilotite $Na_3Ca_2Al_7Si_{33}O_{80}$. 25? H_2O	Kation number 5?

2. Al:Si ratio and composition variable. Isomorphous intergrowths

Gmelinite $(Na, Ca)_{12}(Al, Si)_{40}O_{80}$. $40H_2O$	Kation number 12 ($11\frac{1}{3}$?)
Gismondite $(K, Ca)_{11}(Al, Si)_{40}O_{80}$. 36–$40H_2O$	Kation number 11
Phillipsite $(K, Ca)_{11}(Al, Si)_{40}O_{80}$. 30–$40H_2O$	Kation number 11
Laumontite $(Na, Ca)_7(Al, Si)_{40}O_{80}$. $25H_2O$	Kation number 7

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

P. P. Ewald, C. Hermann, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, I, **1931.** Abbreviation, *SB* I **1931.**

C. Hermann, O. Lohrmann, H. Philipp, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, II, **1936.** Abbreviation, *SB* II **1936.**

G. Gottfried, F. Schlossberger, *Zeits. Krist.*, *Ergänzungsband*, *Strukturbericht*, III, **1936.** Abbreviation, *SB* III **1936.**

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