

Silicate Minerals

GLY 4310
Spring, 2006

1

Crustal Chemistry

- The earth's crust is composed of three common elements, on an atom percent basis
 - ❖ Oxygen, 62.5%
 - ❖ Silicon, 21.2%
 - ❖ Aluminum, 6.47%
- Silicates are the most common minerals on the planet
- They are called "rock-forming" minerals for this reason

2

Other Common Cations

- Metal cations also contribute to minerals
- On an atom % basis:
 - ❖ Sodium, 2.64
 - ❖ Calcium, 1.94
 - ❖ Iron, 1.92
 - ❖ Magnesium, 1.84
 - ❖ Potassium, 1.42

3

Types of Silicate Minerals in the Earth's Crust

- Silicates make up 92% of the crust
 - ❖ Plagioclase, 39%
 - ❖ Alkali feldspar, 12%
 - ❖ Quartz, 12%
 - ❖ Pyroxene, 11%
 - ❖ Amphiboles, 5%
 - ❖ Micas, 5%
 - ❖ Clays, 5%
 - ❖ Other silicates, 3%

4

Whole Earth

- When the mantle and core are included, the compositional picture changes
- Olivine is the main constituent of the upper mantle, and may be the most common mineral on earth
- The lower mantle is composed of other silicates
- The core is believed to be an Fe-Ni mix

5

Mineral Nomenclature

- Minerals are classified into classes, such as oxides, carbonates, and silicates
- The silicates are divided into subclasses
- Within a class or subclass, we may have divisions into groups, such as the garnet group of the subclass nesosilicate or the spinel group of the oxides
- Minerals may also be classified as series, such as the olivine series of the nesosilicates

6

Mineral Nomenclature 2

- Individual minerals are known as species, such as forsterite or fayalite of the olivine series
- A species may have varieties, such as Iceland Spar, tufa, or travertine of the mineral calcite

7

Silicate Nomenclature

Silicate Subclass	Alternative Name
Neso – (or Ortho) Silicates	Island
Sorosilicates	Couplet
Cyclosilicates	Ring
Inosilicates	Chain
Phyllosilicates	Layer
Tectosilicates (or Tekto-)	Framework

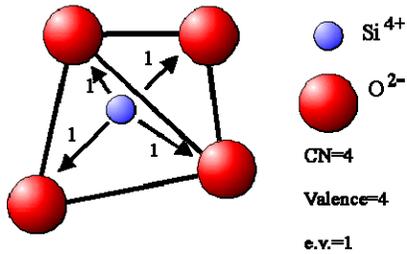
8

Silicate Anionic Group

- The silica tetrahedron is the basis for all the silicate structures
- The SiO_4 tetrahedron has a charge of ?

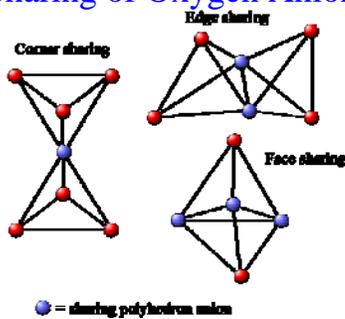
9

Silicon Tetrahedron Silicate anion



10

Sharing of Oxygen Anions



11

Nesosilicates

- Characterized by independent SiO_4 tetrahedra, which are not linked together directly
- They are bonded together by ionic bonds to interstitial cations
- The structures of the nesosilicates are therefore, very dependent on the size and charge of the interstitial cations
- Because the tetrahedra do not share oxygen, the Si:O ratio is 1:4.

12

Interstitial Cations

- Since the SiO_4 tetrahedron has a charge of 4, two divalent cations, a trivalent and a monovalent, or a quadrivalent cation are required to maintain electrical neutrality
- Several structure types are possible – in the silicate structures the letter A = non-silicon cations with lower valency than Si^{4+} , B = Si or Al or other higher valent cations, O = oxygen

13

A_2SiO_4

- This group includes the olivine series
- Structure is based on an nearly HCP arrangement of the O^{2-} ions
- A ions are in octahedral voids
- B ion in a tetrahedral void
- $\frac{1}{2}$ of the octahedral voids are occupied, $\frac{1}{8}$ of the tetrahedral voids are occupied

14



Olivine Series

- Olivine itself is the compound $(\text{Fe}, \text{Mg})_2 \text{SiO}_4$ with a complete solid solution series
- As with other solid solution series the two end members are the most important
 - ❖ Fayalite – Fe_2SiO_4 Fa
 - ❖ Forsterite – Mg_2SiO_4 Fo

15

Olivine Solid Solution Ranges

- Fosterite 0-10% Fe
- Chrysolite 10-30% Fe
- Hyalosiderite 30-50% Fe
- Mortonolite 50-70% Fe
- Ferrohortonolite 70-90% Fe
- Fayalite 90-100% Fe

16

Solid Solution Nomenclature

- As with some other important series an abbreviation is used for the end members – compositions can be expressed using abbreviated symbols
- Example $\text{Fe}_{0.6}\text{Mg}_{1.4}\text{SiO}_4 = \text{Fa}_{30}\text{Fo}_{70}$

17

Other Olivine Group Minerals

- CaMgSiO_4 Monticellite
- Mn_2SiO_4 Tephroite
- CaMnSiO_4 Glaucocroite
- CaFeSiO_4 Kirschsteinite

18

ASiO₄

- The most common mineral of this group is the mineral zircon, ZrSiO₄
- In zircon, the A ions are in distorted cubic coordination with 4 oxygens at one distance, 4 further away
- Zircon always contains some Hf and sometimes Th or U (may be metamict)
- Thorite, ThSiO₄, is isostructural but is often metamict because of radioactive decay

19

Garnets, A₃B₂(SiO₄)₃

- Larger A site is occupied by divalent cations which are relatively large, with a coordination number of VIII
 - ❖ Typical cations are Ca²⁺, Mg²⁺, Fe²⁺, Mn²⁺, and some trivalent lanthanides
- The smaller B site is occupied by trivalent cations which are smaller, with a CN of VI
 - ❖ Typical cations Al³⁺, Cr³⁺, Fe³⁺, and Ti⁴⁺

20

Garnet Structure

- Silica tetrahedra are linked by the VI coordinated cations to form a three dimensional array
- VIII coordinated ions are distributed within this structure
- All garnets have isometric hexoctahedral symmetry

21

Calcium and Noncalcium Garnets

- Ca^{2+} is larger than Mg^{2+} , Fe^{2+} and Mn^{2+}
- Garnets can be split into two groups, the Ca and non-Ca garnets
- A similar division may be made for the B ions into Al, Fe^{3+} and Cr^{3+} garnets.

22

Ca Garnets

Name	Formula	Color
Uvarovite	$\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$	Emerald green
Grossularite, also called cinnamon stone, essonite	$\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$	White green, yellow, cinnamon brown, pale red
Andradite	$\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$	Yellow, green, brown, black

23

Non-Ca Garnets

Name	Formula	Color
Pyrope	$\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$	Deep red to black
Almandine	$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$	Deep red to brown
Spessartite	$\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$	Brownish to red

24

Garnet Photos



Uvarovite Garnet (above)



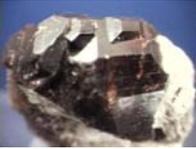
Grossular garnet (above)



Grossular, variety hessonite (left)

25

Garnet Photos



Andradite garnet (above)



Almandine garnet (left and right)

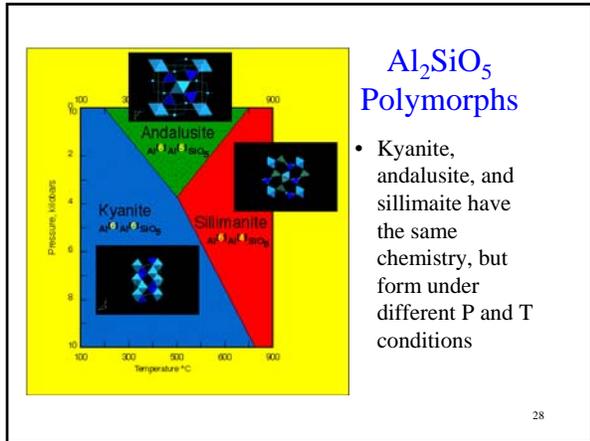


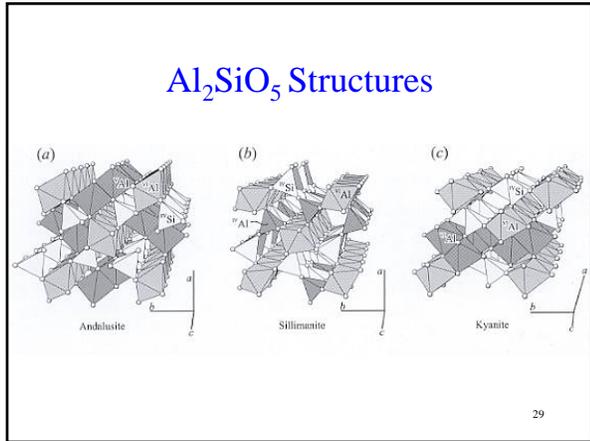
26

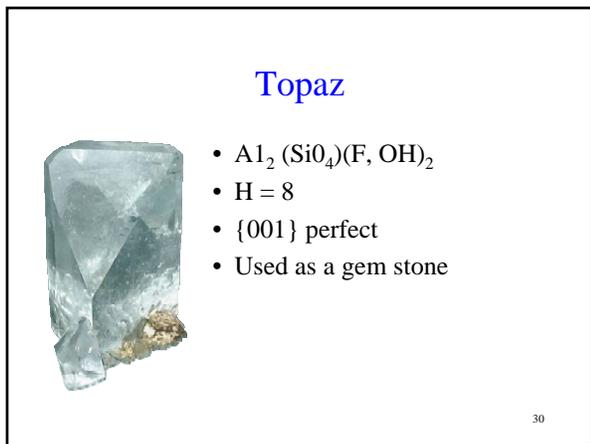
Aluminosilicates

- Aluminosilicates have aluminum in addition to silicon in the structure
- They may belong to any silicate subclass

27









Stauroilite

- $\text{Fe}_2\text{Al}_9\text{O}_6(\text{SiO}_4)_4(\text{O},\text{OH})_2$
- Crystals are prismatic
- Often twinned (penetration twins), with two varieties of cruciform twins



31

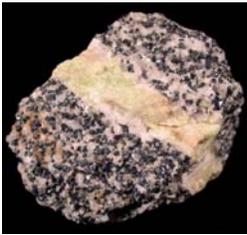


Titanite

- $\text{CaTiO}(\text{SiO}_4)$
- Formerly known as sphene
- An example of a titanosilicate
- $N = 1.91$ – luster resinous to adamantine

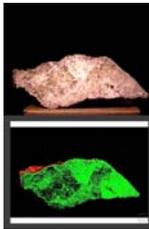
32

Willimite



Willimite with Franklinite and Quartz
New Jersey

- Zn_2SiO_4
- Associated with other Zn ores
- Mn may replace Zn
- Often fluorescence



33

Sorosilicates

- Characterized by two SiO₄ tetrahedra joined through a single oxygen to give an Si:O ratio of 2:7

34



Epidote Group

- Contains both SiO₄ and Si₂O₇ groups
- General formula is X₂^{viii}Y₃^{vi}(SiO₄)O(OH)
- X = Ca²⁺, Na⁺
- Y = Al³⁺, Fe³⁺, Mn³⁺, Cr³⁺

- Epidote: Ca₂(Al,Fe)Al₂O(Si₂O₇)(SiO₄)(OH)
- Clinozoisite: Ca₂Al₃O(Si₂O₇)(SiO₄)(OH)

35

Vesuvianite



- Formerly called Idocrase
- Ca₁₀(Mg, Fe)₂Al₄(SiO₄)₅(Si₂O₇)₂(OH)₇
- Tetragonal H = 6 ½
- Brown or green

36



Hemimorphite

- $Zn_4(Si_2O_7)(OH)_2H_2O$ is one mineral of the sorosilicate group with isolated Si_2O_7 groups, cross linked by Zn cations
- Formed as a secondary mineral in the oxidized portions of zinc deposits

37

Lawsonite



- $CaAl_2(OH)_2Si_2O_7H_2O$
- Found only in metamorphic blue (glaucophane)-schist or similar low temperature, moderate to high pressure environments.

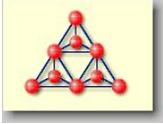
38

Cyclosilicates

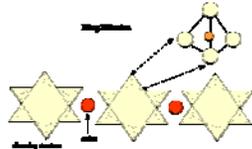
- When three or more Si tetrahedral groups are linked, a cyclical structure is possible
- The Si:O ratio is 1:3
- Rings containing 3, 4, or 6 Si are possible, but only the rings with 6 Si are at all common

39

Cyclic Silicates

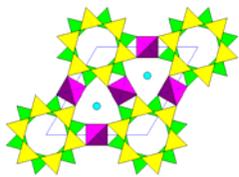


3 membered ring



6 membered rings

40



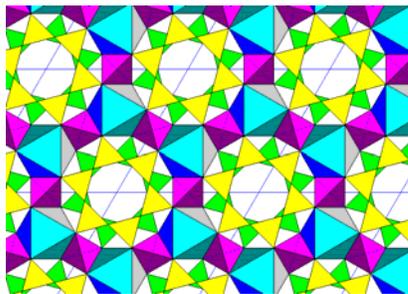
Beryl Structure

A single unit cell of beryl

- Yellow Si tetrahedra are in the upper layer, the green ones in the lower layer
- The outer points of the tetrahedra are actually edges viewed along their length
- Purple tetrahedra contain Be and are viewed down their four-fold inversion axes
- They connect the bottom corners of the tetrahedra in the upper ring with the top corners of the tetrahedra in the lower ring
- Solitary blue atoms are Al, in VI-fold coordination with the adjacent tetrahedral oxygens

41

Complete Beryl Lattice



- Shows the octahedral coordination of Al in blue

42

Gem Beryl









- Upper left, emerald
- Lower left, morganite
- Upper right, aquamarine
- Lower right, golden beryl

43

Tourmaline





- Elbaite, a gem variety of tourmaline
- Schorl crystal, with striations, typical of tourmaline

44

Chrysocolla



- Amorphous but similar to diopside, a six-membered cyclosilicate
- May contain Si_4O_{10} units, which would make it a phyllosilicate

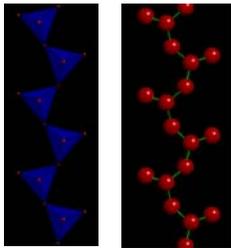
45

Inosilicates

- Inosilicates include two very important groups of silicates, the pyroxenes and the amphiboles
- Both have chain structures
- SiO_4 tetrahedra link together to form either a single chain or a double chain composed of two linked, parallel single chains

46

Pyroxene Chain



- Single chain of SiO_4 tetrahedra connected by sharing a corner

47

Orthopyroxenes

- Enstatite MgSiO_3
- Hypersthene $(\text{Mg, Fe})\text{SiO}_3$
- Orthoferrosilite Fe SiO_3

48



Enstatite

- Brownish orthopyroxene (opx)
- Lower photo is of Bronzite, an opx containing some Fe, and displaying an iridescence known as Schiller luster



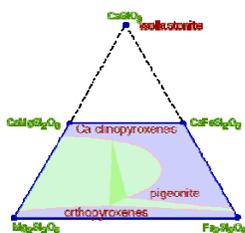
49

Clinopyroxenes

	X	Y	
• Diopside	Ca	Mg	Si ₂ O ₆
• Hedenbergite	Ca	Fe ²⁺	Si ₂ O ₆
• Augite	Ca	(Mg, Fe ²⁺) (Al, Fe ³⁺ , Ti)	Si ₂ O ₆
• Pigeonite	(Mg, Fe ²⁺ , Ca)	(Mg, Fe ²⁺) (Al, Fe ³⁺)	Si ₂ O ₆
• Aegirine	Na	Fe ³⁺	Si ₂ O ₆
• Jadeite	Na	Al	Si ₂ O ₆
• Spodumene	Li	Al	Si ₂ O ₆

50

Pyroxene "Quad"



- The pyroxene quadrilateral forms part of a larger ternary system (CaSiO₃-MgSiO₃-FeSiO₃), that includes another single chain silicate wollastonite
- The Ca-rich clinopyroxenes are separated from the orthopyroxenes, and from the Ca-poor clinopyroxene pigeonite by a solvus (shown in green in the figure)

51

Augite



- Augite is distinguished by 2D cleavage @ 90°
- Al occurs at tetrahedral sites, so trivalent cations are present at normally divalent sites

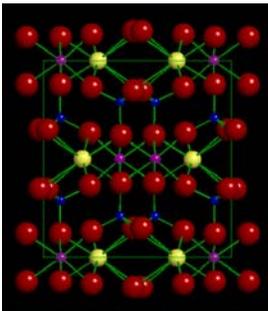
52

Pyroxene Structure

- X: VIII coordination Na^+ or Ca^{2+}
- Y: VI coordination Mg , Fe^{2+} , Fe^{3+} , Al^{3+} , Mn^{2+} , Mn^{3+} , Li^+ , Ti^{4+}
- Si: IV coordination Si^{4+} or Al^{3+}

53

Diopside Structure



- Diopside (001) view
- Blue = Si
- Purple = M1 (Mg)
- Yellow = M2 (Ca)

54

Spodumene Series

- The spodumene series of pyroxenes involves X sites occupied by moderate to large size cations, Y by small trivalent cation
- Spodumene Li Al Si₂O₆
- Jadeite Na Al Si₂O₆
- Aegerine Na Fe³⁺ Si₂O₆

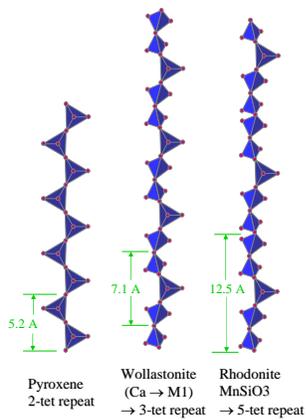
55

Pyroxenoid Structure

- Large cations occupy both X and Y, producing the triclinic structure of the pyroxenoids
- Chains made of Si₂O₇ and SiO₄ groups linked together are present, and the chains are parallel to **b**
- Si:O = 1:3

56

Pyroxene vs. Pyroxenoid



57

- “Ideal” pyroxene chains with 5.2 Å repeat (2 tetrahedra) become distorted as other cations occupy VI sites
- Note presence of Si₂O₇ couplets

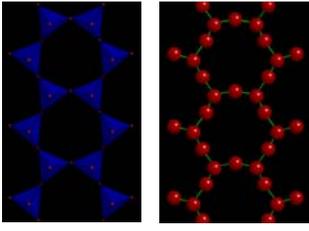
Pyroxenoids



- Top, pectolite
- Middle, wollastonite
- Bottom, rhodonite

58

Amphibole Chain



- Double chain of SiO_4 tetrahedra connected by corner sharing

59

Amphibole Structure

- Amphiboles have a double chain structure formed by sharing three corners
- All have the basic Si_4O_{11} double chains, with larger X ions are in VIII coordination, while smaller Y cations are in VI coordination
- Si:O = 1:2.75

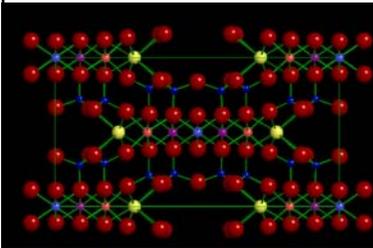
60

Amphibole Formula

- The general formula is:
- $W_{0-1}X_{0-7}Y_{7-14}Z_{16}O_{44}(OH)_4$
- X: Na^+ , Ca^{2+} , minor K^+ , Mn^{2+} , Fe^{2+} , Mg^{2+} , Li^+
- Y: Mg^{2+} , Fe^{2+} , Fe^{3+} , Al^{3+} , Mn^{2+} , Mn^{3+} , Ti^{4+}
- Z: Si^{4+} , Al^{3+}

61

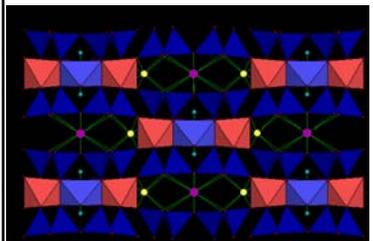
Amphibole Double Chain - Tremolite



- $Ca_2Mg_5[Si_8O_{22}](OH)_2$
- (001) view
- Blue = Si
- Purple = M1
- Rose = M2
- Gray = M3 (all Mg)
- Yellow = M4 (Ca)

62

Amphibole Double Chain - Hornblende



- $(Ca, Na)_{2,3}(Mg, Fe, Al)_5[(Si, Al)_8O_{22}](OH)_2$
- (001) view
- Dark blue = Si, Al
- Purple = M1
- Rose = M2
- Light blue = M3 (all Mg, Fe)
- Yellow ball = M4 (Ca)
- Purple ball = A (Na)
- Little turquoise ball = H

63

Amphibole Site Size



Hornblende (001) view
Dark blue = Si, Al, Purple = M1,
Rose = M2, Light blue = M3 (all Mg, Fe)
Yellow ball = M4 (Ca)
Purple ball = A (Na)
Little turquoise ball = H

- M1-M3 are small sites
- M4 is larger (Ca)
- A-site is really big
- Variety of sites → great chemical range

64

Pyroxene Cleavage

2 at 90°



65

Amphibole Cleavage

- Hornblende



66

Orthoamphibole

Orthoamphibole X,Y Z

Anthophyllite (Mg, Fe²⁺)₇ (Si₈O₂₂) (OH, F)₂

67

Clinoamphiboles

Clinoamphiboles W X,Y Z

Cumingtonite Fe²⁺₃Mg₂ (Si₈O₂₂)(OH, F)₂

Grunerite Fe₇ (Si₈O₂₂)(OH, F)₂

Tremolite Ca₂Mg₅ (Si₈O₂₂)(OH, F)₂

Actinolite Ca₂(Mg, Fe²⁺)₃ (Si₈O₂₂)(OH, F)₂

Hornblende (Na, K)₀₋₁ (Ca, Na)₂ (Mg, Fe²⁺, Al, Fe³⁺)₃ (Al, Si)₂Si₆O₂₂(OH, F)₂

Glaucophanes Na₂ Mg₃Al₂ Si₈O₂₂(OH)₂

Riebeckite Na₂ Fe²⁺Fe³⁺ (Si₈O₂₂)(OH, F)₂

68

Phyllosilicates

- Phyllon is the Greek word for leaf – phyllosilicates are thus "leaf-like", platy or flaky minerals which have a layered structure
- The basic silicate sheet structure is composed of a hexagonal grouping of tetrahedra

69

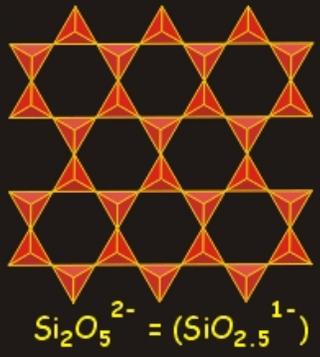
Micas



- Micas are the chief minerals of schists and are also commonly found in igneous rocks
- They form at lower temperatures than the inosilicates (pyroxenes and amphiboles) and are frequently formed as replacement minerals after hydrothermal alteration
- Ratio of Si:O is 2:5

70

Sheet

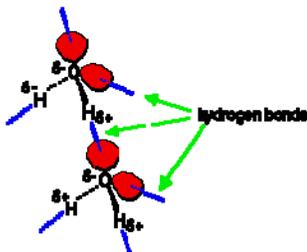


Siloxane Sheet

- Sheet stretches indefinitely in two dimensions

71

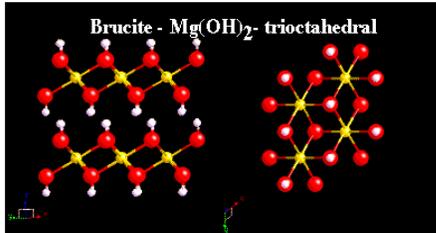
Hydrogen Bonding



- Hydrogen bonds help to hold siloxane sheets together

72

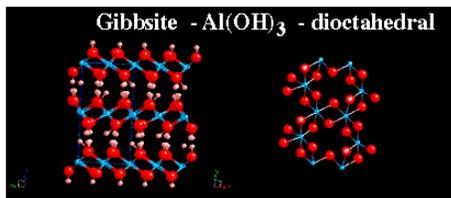
Brucite Structure



- All cation positions filled by divalent ions

73

Gibbsite Structure



- Two-thirds of the cation positions filled by divalent ions

74

Diphormic Phyllosilicates

- One t-layer, one o-layer
- 0.7nm repeat distance
- Kaolinite - dioctahedral $Al_4[Si_4O_{10}](OH)_8$
- Serpentine – trioctahedral $Mg_6[Si_4O_{10}](OH)_8$

75

Chrysotile



- Fibrous diphormic phyllosilicate

76

Triphormic Phyllosilicates

- In this phyllosilicate the ratio of tetrahedral : octahedral layers is 2:1
- Basal spacing is generally around 0.9nm
- The structure is a t-o-t sandwich, with apical oxygens pointing inward
- Pyrophyllite – dioctahedral $\text{Al}_2\{\text{Si}_4\text{O}_{10}\}(\text{OH})_2$
- Talc - trioctahedral $\text{Mg}_3\{\text{Si}_4\text{O}_{10}\}(\text{OH})_2$

77

Micas

- Another example of triphormic phyllosilicates
- The t-o-t layers are held together by layers of K^+ cations, in the holes of the rings
- To balance the plus charge of the K ion, one quarter of the Si^{4+} are replaced by Al^{3+}

78

Brittle Miccas

- Half of the Si^{4+} ions are replaced by Al^{3+}
- This means the interlayer cations be divalent, like Ca^{2+}
- Ca^{2+} bonds are stronger and consequently the cages are not flexible
- Margite - dioctahedral $\text{CaAl}_2\{\text{Al}_2\text{Si}_2\text{O}_{10}\}(\text{OH})_2$
- Clintonite - trioctahedral $\text{CaMg}_3\{\text{Al}_2\text{Si}_2\text{O}_{10}\}(\text{OH})_2$

79

Swelling Clays



- Building damaged by expansion and contraction of clay minerals in the soil

80

Tetraphormic Phyllosilicates

- t-o-t layers of either the pyrophyllite or talc type are joined by octahedral layers
- tot o tot o tot o tot Repeat distance is 1.4nm
- These minerals are chlorites
 - ❖ Leptochlorites $\text{Fe}^{2+} + \text{Fe}^{3+}$
 - ❖ Orthochlorites Fe^{2+} only
- $[(\text{Fe},\text{Mg},\text{Al})_{2,3}(\text{OH})_6(\text{Mg},\text{Fe},\text{Al})_{2,3}\{\text{Al},\text{Si}\}_4\text{O}_{10}\}(\text{OH})_2]$

81

Tectosilicates

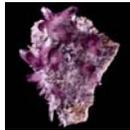
- The tectosilicates are three – dimensional, or framework, silicates
- They involve linkage of SiO_4 tetrahedra through all four oxygen atoms
- The resulting structure is stable and strongly bonded
- Si:O ratio is 1:2

82

Varieties of Crystalline Quartz



Blue



Amythyst



Milky



Citrine



Rose

83

Varieties of Cryptocrystalline Quartz



Jasper



Chalcedony



Chert



Chrysoprase

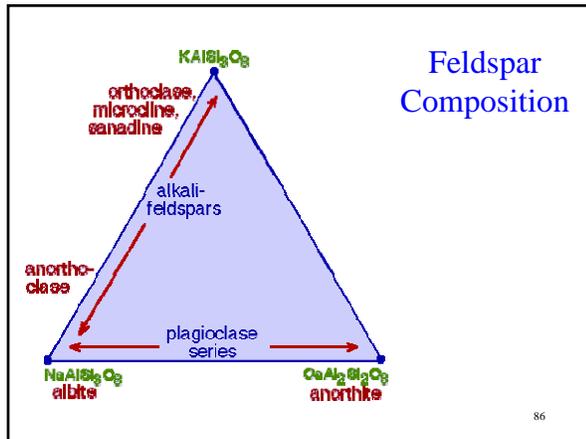
84

Feldspars

- Alkali – Potassium and Ab_{95-100}
- Plagioclase An_{5-100}
- Barium
 - ❖ Celsian $BaAl_2Si_2O_8$
 - ❖ Hyalophane $(K, Ba)(Al, Si)_2Si_2O_8$

85

Feldspar Composition



86

Alkali Feldspars

- K-spar shows a variety of polymorphic forms
 - ❖ Sanidine
 - ❖ Orthoclase
 - ❖ Microcline

87

Perthite and Antiperthite

- Albite in K-spar host = perthite
- K-spar in plagioclase host = antiperthite

88

Plagioclase Name

- Plagioclases are triclinic
- Their a-b and b-c angles are a bit more oblique than microcline
- Hence the name: *plagio-*, oblique and *clase*, break

89

Plagioclase Feldspars

- **Albite**
 - ❖ An_{0-10} - Found only in very sodic rocks, hence usually metamorphic or formed in marine conditions as a sedimentary cement, or by ion exchange with more calcic plagioclase.
- **Oligoclase**
 - ❖ An_{10-30} - The dominant plagioclase in granitic rocks
- **Andesine**
 - ❖ An_{30-50} - Found in intermediate igneous rocks
- **Labradorite**
 - ❖ An_{50-70} - The dominant plagioclase in gabbro and basalt. Also, despite their name, most anorthosites are made up of labradorite.
- **Bytownite**
 - ❖ An_{70-90} - The rarest. Requires both a lot of calcium and also significant sodium. Most igneous settings have too much sodium, most calc-silicate metamorphic settings have too little sodium.
- **Anorthite**
 - ❖ An_{90-100} - Generally a metamorphic mineral in calc-silicate rocks.

90

Charge Balance

- Since Na and Ca differ in valence, Al has to substitute for Si to compensate
- The Al-Si orderings of albite and anorthite are different, and at low temperatures, plagioclases in the middle of the composition range also exsolve, but on a submicroscopic scale
- These submicroscopic textures are probably responsible for the iridescence of some plagioclases

91

Feldspathoids

- Alumino – silicates but contain less SiO_2 than feldspars
- They are rich in alkalis
- The feldspathoids often include unusual anions such as Cl^- , CO_3^{2-} , etc.

92

Important Feldspathoids

Nepheline	$(\text{Na}, \text{K})\text{AlSi}_3\text{O}_8$	
Leucite	$\text{K}(\text{AlSi}_2\text{O}_6)$	K
Sodalite	$\text{Na}_8(\text{AlSi}_4\text{O}_{14})_6\text{Cl}_2$	Cl
Lazurite	$(\text{Na}, \text{Ca})_3(\text{AlSi}_5\text{O}_{14})_2(\text{SO}_4, \text{S}, \text{Cl})_2$	$\text{SO}_4, \text{S}, \text{Cl}$
Petalite	$\text{Li}(\text{AlSi}_4\text{O}_{10})$	

93

Scapolites

- Metamorphic rock minerals probably derived from feldspars
- The alumino-silicate framework forms chains in the c-direction and has large open spaces which can accommodate large anions such as Cl, CO₃, SO₄

94

Scapolite Minerals

- Marialite $\text{Na}_4(\text{AlSi}_3\text{O}_8)_3(\text{Cl}_2, \text{CO}_3, \text{SO}_4)$
- Meionite $\text{Ca}_4(\text{Al}_2\text{Si}_2\text{O}_8)_3(\text{Cl}_2, \text{CO}_3, \text{SO}_4)$

95

Zeolites

- Hydrous alumino-silicates with very open structures.
- Rings of AlO₄ and SiO₄ tetrahedra are penetrated by open channels in the structure
- Non-silicon cations hold the structure together.

96

Cation Exchange

- Water can easily pass through these channels and dissolve and replace the cations present in the structure
- This process is known as cation exchange and is reversible
- Thus, the zeolites can serve as catalysts and water-softening agents
- Petroleum companies have been particularly interested in zeolites for this reason

97

Important Natural Zeolites

- Chabazite $\text{Ca}_2(\text{Al}_2\text{Si}_4\text{O}_{12}) \cdot 6\text{H}_2\text{O}$
- Heulandite $\text{Ca}(\text{Al}_2\text{Si}_7\text{O}_{18}) \cdot 6\text{H}_2\text{O}$
- Stibnite $\text{Ca}_2\text{Na}(\text{Al}_5\text{Si}_{13}\text{O}_{36}) \cdot 14\text{H}_2\text{O}$
- Natrolite $\text{Na}_2(\text{Al}_2\text{Si}_3\text{O}_{10}) \cdot 2\text{H}_2\text{O}$
- Analcime $\text{Na}(\text{AlSi}_2\text{O}_6) \cdot \text{H}_2\text{O}$

98
