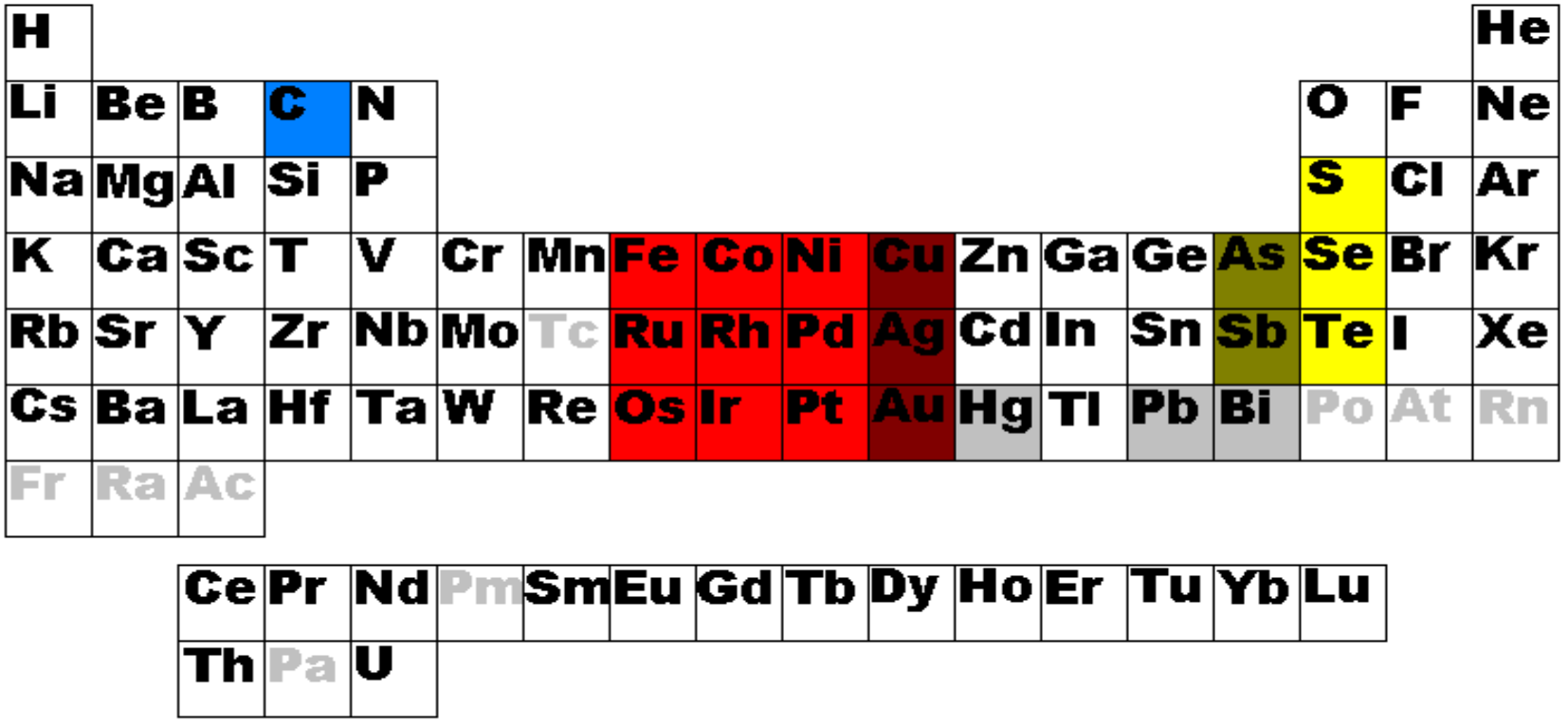
Descriptive Mineralogy

Classification of Minerals

Classification of Minerals

- Non-Silicates
  - Native Elements
  - Halides
  - Sulphides
  - Oxides
  - Hydroxides
  - Carbonates
  - Sulphates
  - Phosphates
- Silicates
  - Orthosilicates
  - Sorosilicates
  - Cyclosilicates
  - Chain Silicates
  - Layer Silicates
  - Tektosilicates

Native Elements



Native Elements

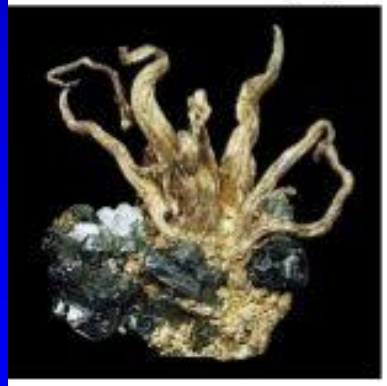
Native elements are minerals composed of only one element.

Sulfur (S)

Diamond (C)

Graphite (C)

Gold(Au)



Silver (Ag)

Copper (Cu)

Platinum (Pt)

Native Elements: Metals

- *Fe, Co & Ni in Meteorites*
- *Platinum Group (Ru, Rh, Pd, Os, Ir, Pt) in Mafic Igneous Rocks*
- *Formation environment*
  - *Cu, Ag: Supergene Enrichments (Sulphide Oxidation)*
  - *Au: Low Temperature Hydrothermal, Placer*

Uses: Coinage metals - Cu, Ag, Au, Pt & Cu-alloys (bronze, brass)

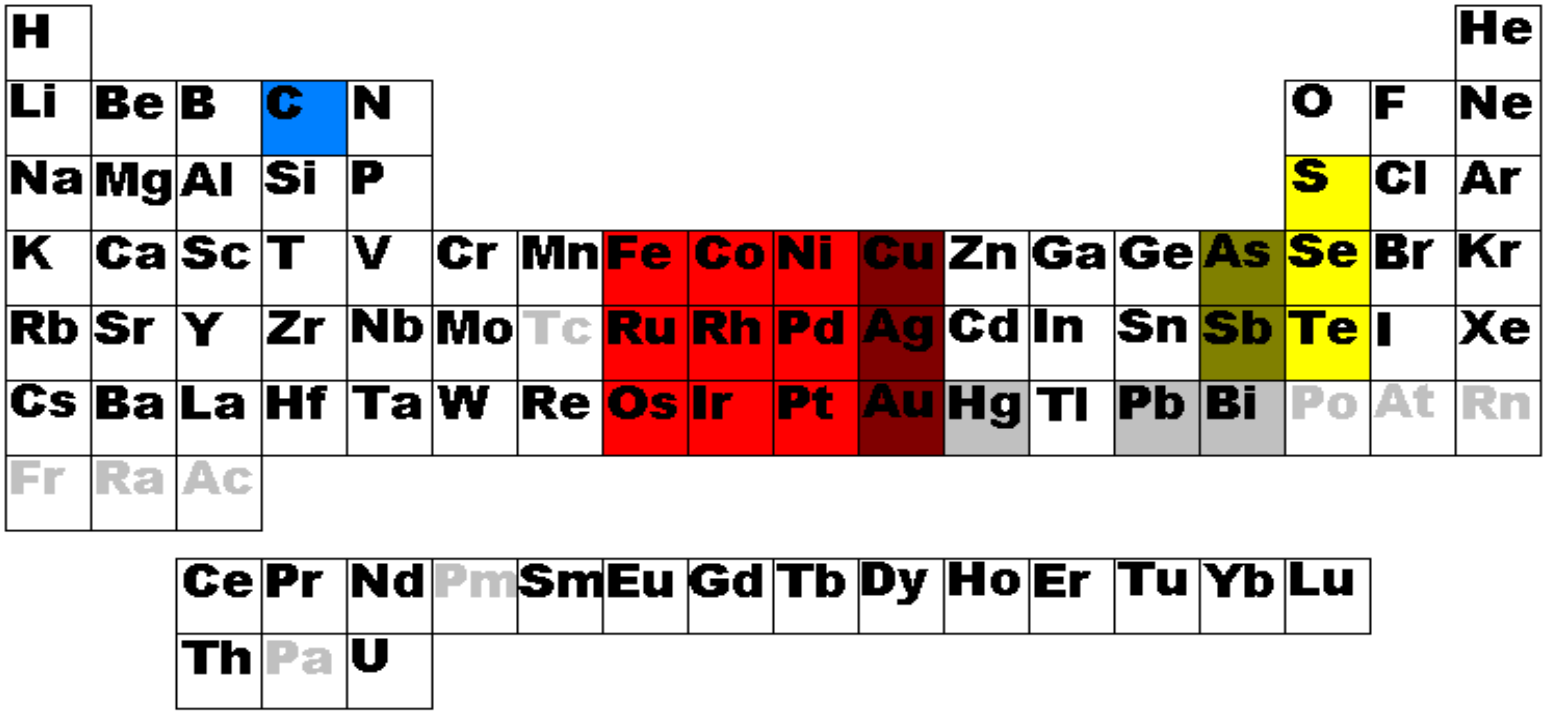
Native Elements: non-metals

- **Carbon:**
  - Graphite in Metamorphic Rocks
  - Diamond in Kimberlites, Lamprophyres etc

- **Sulphur (+Se):**
  - In Salt Domes (Sulphate reduction),
  - in Volcanos (H_2S oxidation)

Halides

Minerals with halogen anions



Halides

- **Halite** (NaCl) & **Sylvite** (KCl) formed in evaporites
- **Fluorite** (CaF_2) formed in Low temperature hydrothermal
- **Cryolite** (Na_3AlF_6) crystallised in pegmatites

The Halides

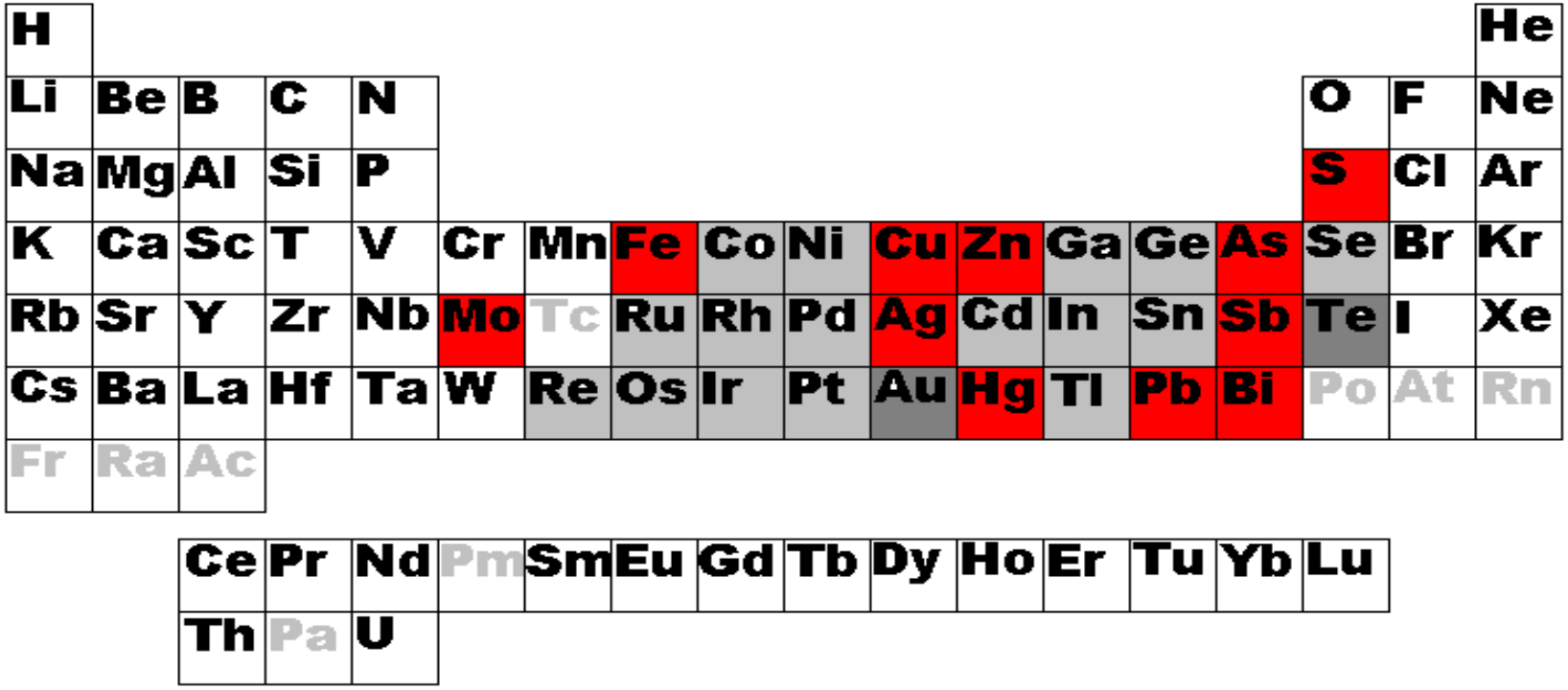
Halite, Rock Salt

Green Fluorite

Dry Lake Bed in Death Valley
Filled with Halite

Purple Fluorite

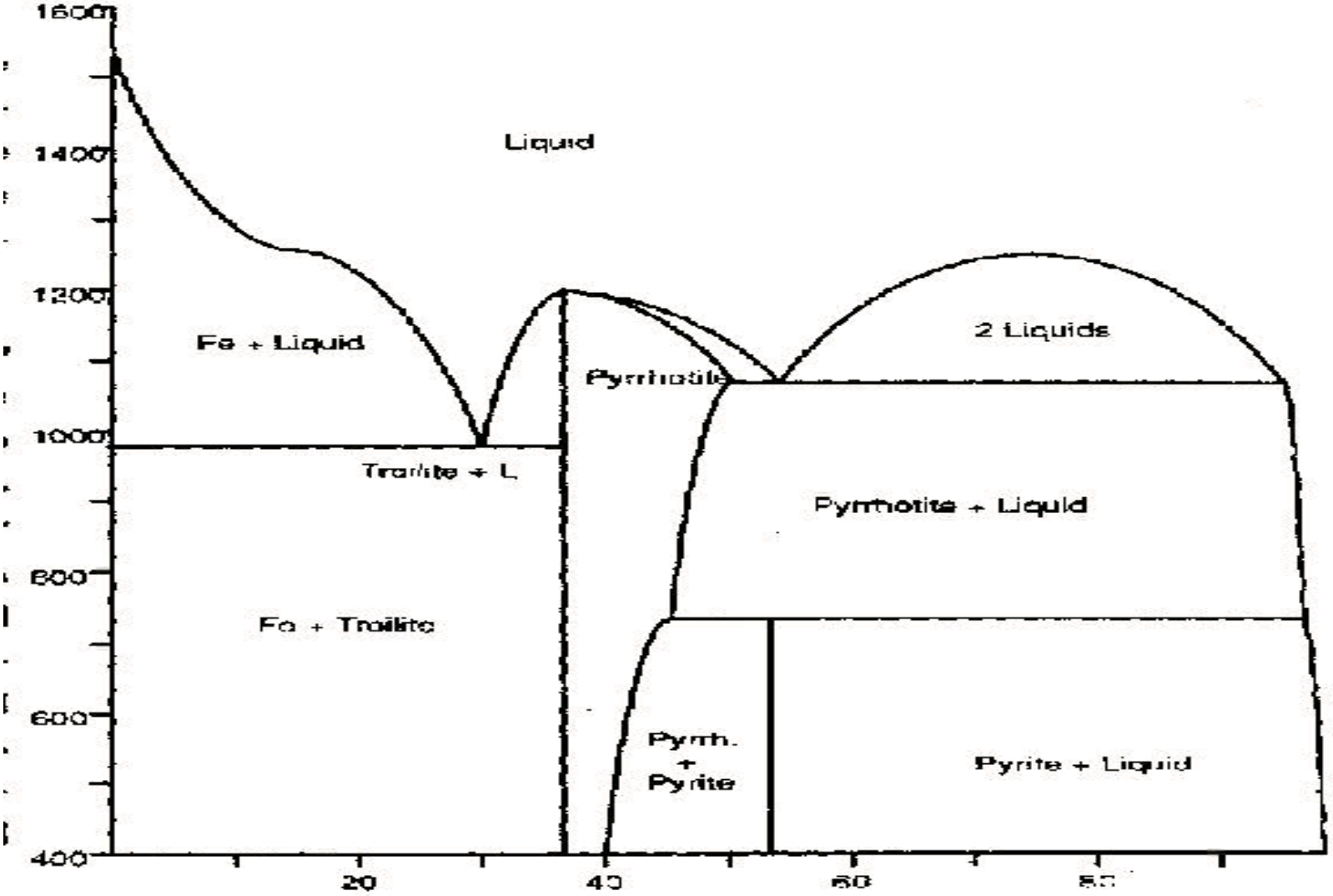
Sulphides

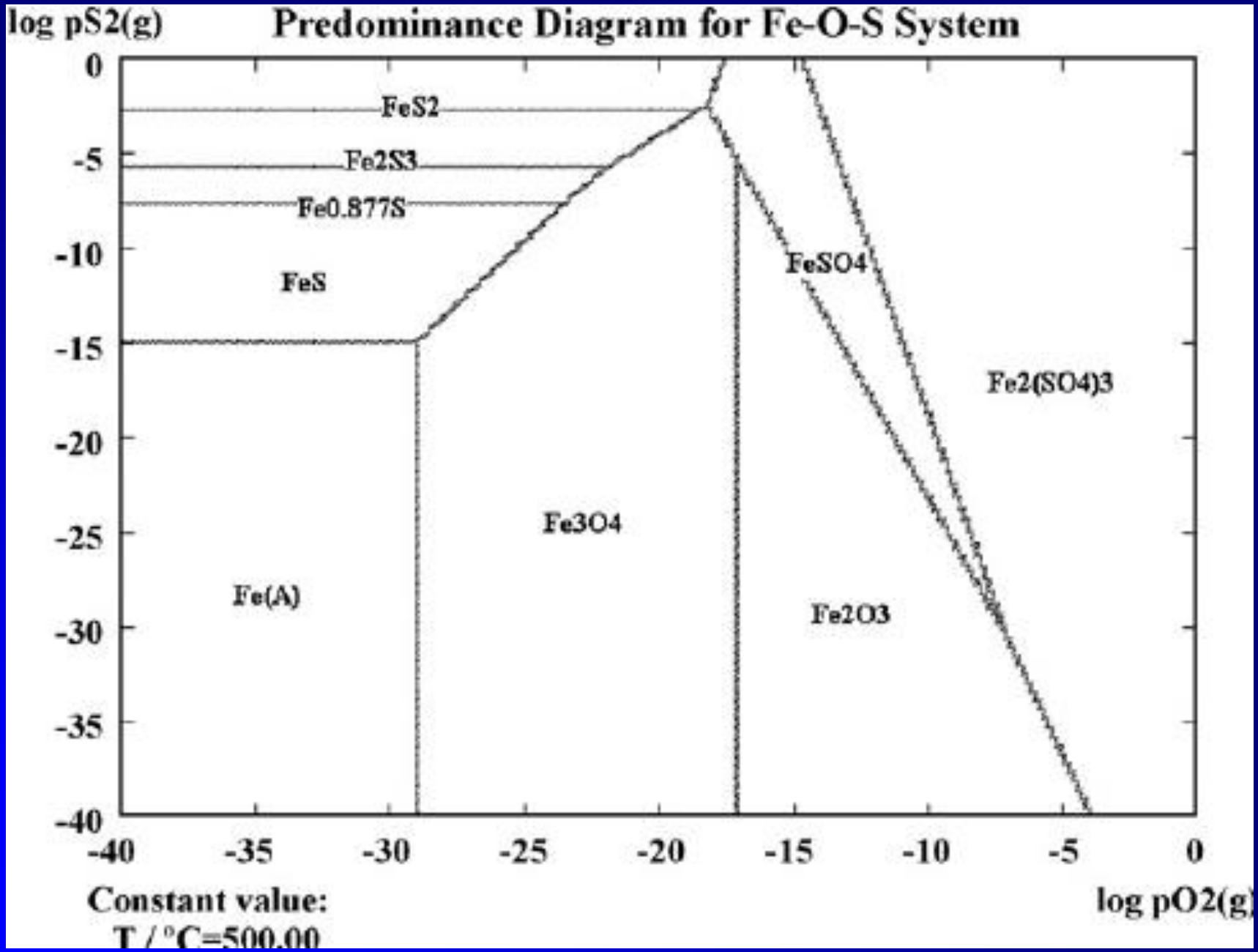

H
He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc T V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Ac
Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tu Yb Lu
Th Pa U

Fe Sulphides

- **Fe:**
  - **Pyrite FeS_2**
  - **Marcasite FeS_2**
  - **Pyrrhotite $Fe_{1-x}S$**
  - **Troilite FeS**
  - **Arsenopyrite FeAsS**

Fe-S Diagram


1600
1400
1200
1000
800
600
400
20
40
60
Liquid
Fe + Liquid
Troilite + L
Fe + Troilite
Pyrrhotite
2 Liquids
Pyrrhotite + Liquid
Pyrh.
+
Pyrite
Pyrite + Liquid


log pS2(g)
Predominance Diagram for Fe-O-S System
0
-5
-10
-15
-20
-25
-30
-35
-40
FeS2
Fe2S3
Fe0.877S
FeS
FeSO4
Fe2(SO4)3
Fe3O4
Fe(A)
Fe2O3
-40
-35
-30
-25
-20
-15
-10
-5
0
Constant value:
T / °C=500.00
log pO2(g)

Cu Sulphides

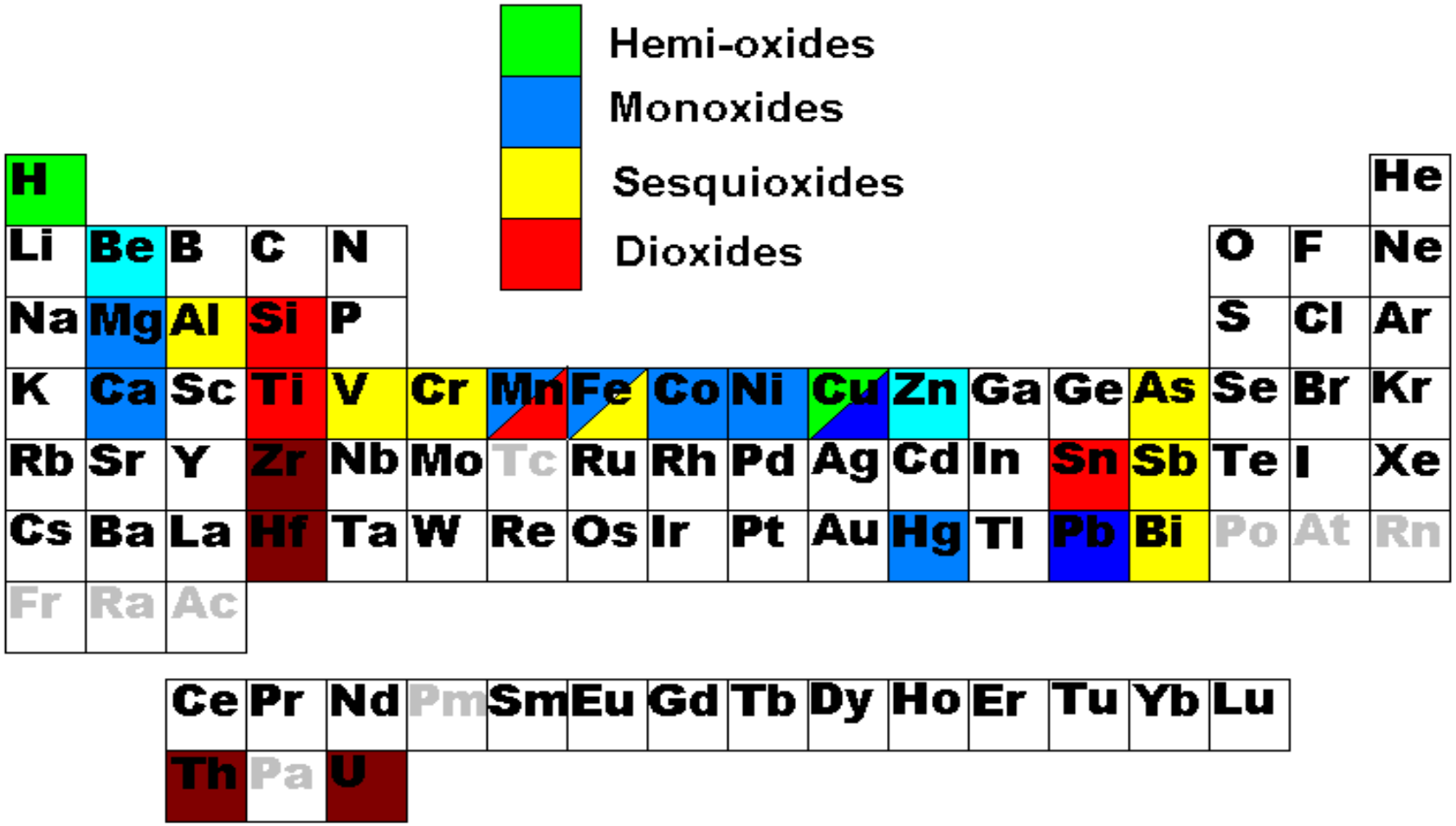
- **Cu Sulphides**
  - **Chalcocite Cu_2S**
  - **Covellite CuS**

- **Cu-Fe Sulphides**
  - **Chalcopyrite $CuFeS_2$**
  - **Bornite Cu_5FeS_4**

Other Sulphides

- Sphalerite ZnS
- Molybdenite MoS_2
- Galena PbS
- Arsenopyrite FeAsS
- Stibnite Sb_2S_3
- Cinnabar HgS

Oxides


Hemi-oxides
Monoxides
Sesquioxides
Dioxides
H
He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Ac
Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tu Yb Lu
Th Pa U

Simple Oxides

- Hemioxides
  - Cuprite (Cu_2O)
  - Ice (H_2O)
- Monoxides
  - Periclase (MgO)
  - Wüstite (FeO)
  - Manganosite (MnO)
  - Lime (CaO)
  - Zincite (ZnO)
  - Bromellite (BeO)
  - Tenorite (CuO)
- Sesquioxides
  - Corundum (Al_2O_3)
  - Hematite (Fe_2O_3)
  - Bixbyite (Mn_2O_3)
- Dioxides
  - Rutile (TiO_2)
  - Anatase (TiO_2)
  - Brookite (TiO_2)
  - Cassiterite(SnO_2)
  - Pyrolusite(MnO_2)

Hemi-Oxides (M_2O)

- Ice (H_2O) Hexagonal
- Cuprite (Cu_2O)
- Why not Na_2O?
  - (Na radius too large)

Monoxides (MO)

- Rocksalt oxides MgO, FeO, MnO, CaO, NiO
  - Periclase MgO - Wuestite FeO
  - Manganosite MnO
  - Lime CaO
  - Bunsenite NiO
- Zincite oxides: Zincite ZnO, bromellite BeO
- Other monoxides:
  - Tenorite CuO, Montroydite HgO

Sesquioxides (M_2O_3)

- **Corundum Group**
  - **Corundum Al_2O_3**
  - **Hematite Fe_2O_3**
  - **Karelianite V_2O_3 and Eskolaite Cr_2O_3**
- **Other Sesquioxides**
  - **Bixbyite Mn_2O_3**

Dioxides

- ***Rutile Group***
  - ***Rutile TiO_2; Anatase; Brookite***
  - ***Cassiterite SnO_2***
  - ***Pyrolusite MnO_2***
  - ***Stishovite SiO_2***
- ***Uraninite (UO_2) & Thorianite (ThO_2)***
- ***Baddeleyite ZrO_2***

Complex Oxides

- Two or more different cations
  - Spinel Group: M_2TO_4
  - Ilmenite Group : $FeTiO_3$
  - Pseudobrookite Group : A_2BO_5
  - Perovskite Group : $CaTiO_3$
- High Pressure silicate analogues

- **Spinels** are any of a class of minerals with a general formula **AB_2X_4**

- A & B are cations that occupy some or all of the **octahedral & tetrahedral sites** in the lattice

- X - anions (oxygen & sulphur) arranged in a **cubic close-packed lattice**

- Spinels crystallise in the **cubic crystal system**

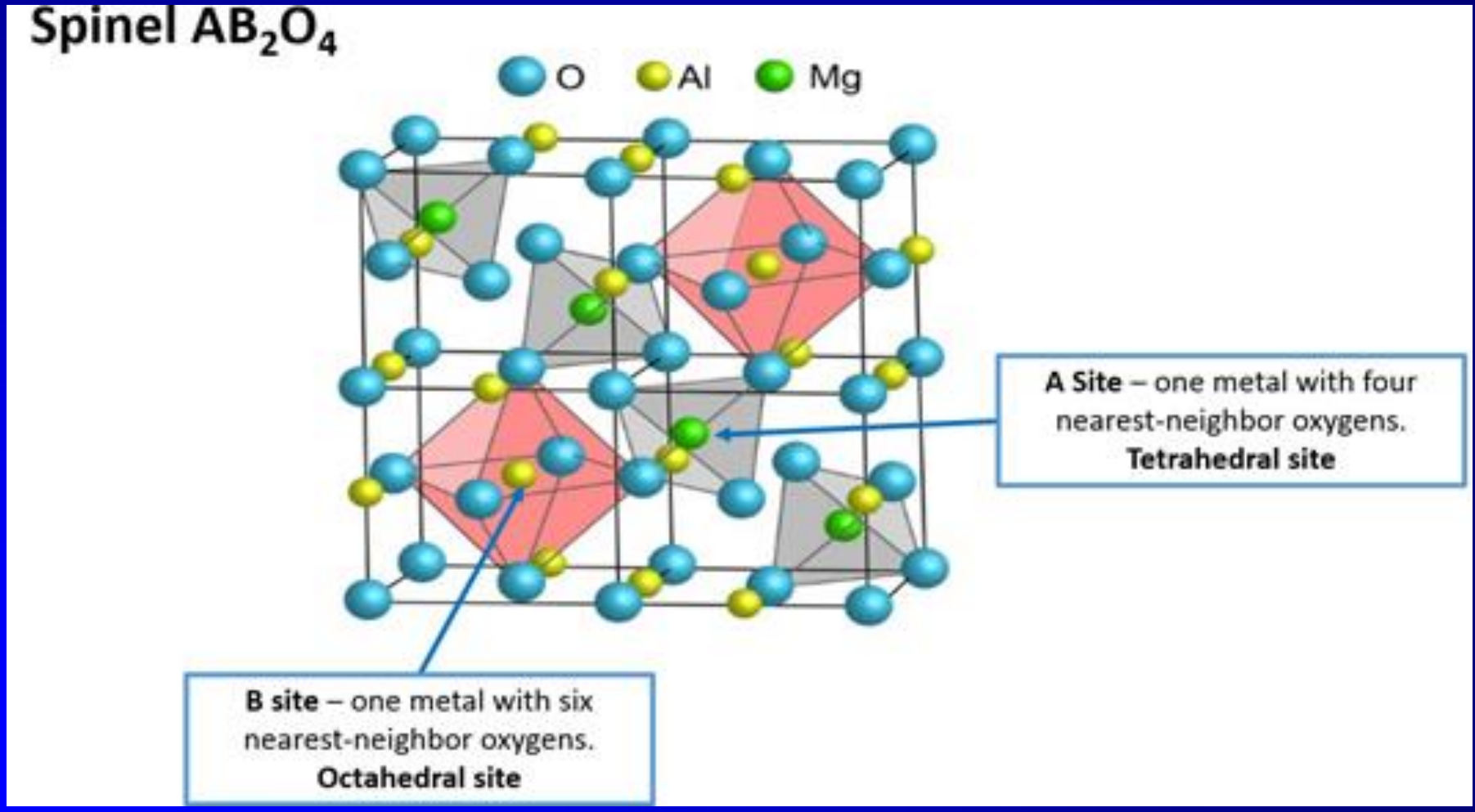
Spinel Group

- Spinel $MgAl_2O_4$
- Hercynite $FeAl_2O_4$
- Chromite $FeCr_2O_4$
- Magnesiochromite $MgCr_2O_4$
- Magnetite $Fe^{2+}Fe^{3+}{}_2O_4$
- Magnesioferrite $MgFe_2O_4$
- Gahnite $ZnAl_2O_4$
- Ulvospinel $TiFe_2O_4$
- Ringwoodite Mg_2SiO_4

Spinel Structure

Two octahedra per Tetrahedron

Mg Al_2O_4 (Normal) or $Al(Mg,Al)O_4$ (Inverse)



Normal spinel structures are usually cubic close-packed oxides with **8 tetrahedral & 4 octahedral sites per formula unit**

Tetrahedral sites are **smaller** than the octahedral sites

B^{3+} ions occupy 1/2 the octahedral sites, while **A^{2+} ions occupy 1/8** of the tetrahedral sites

Spinel $MgAl_2O_4$ has a **normal spinel structure**.

Inverse spinel structures have a different cation distribution

All of the **A cations and half of the B cations occupy octahedral sites**, while the **other half of the B cations occupy tetrahedral sites**

An example of an inverse spinel is **Fe_3O_4**, if the Fe^{2+} (A^{2+}) ions are d^6 high-spin & the Fe^{3+} (B^{3+}) ions are d^5 high-spin

Ilmenite Group

- Ilmenite $FeTiO_3$
- Geikielite $MgTiO_3$
- Akimotoite $MgSiO_3$

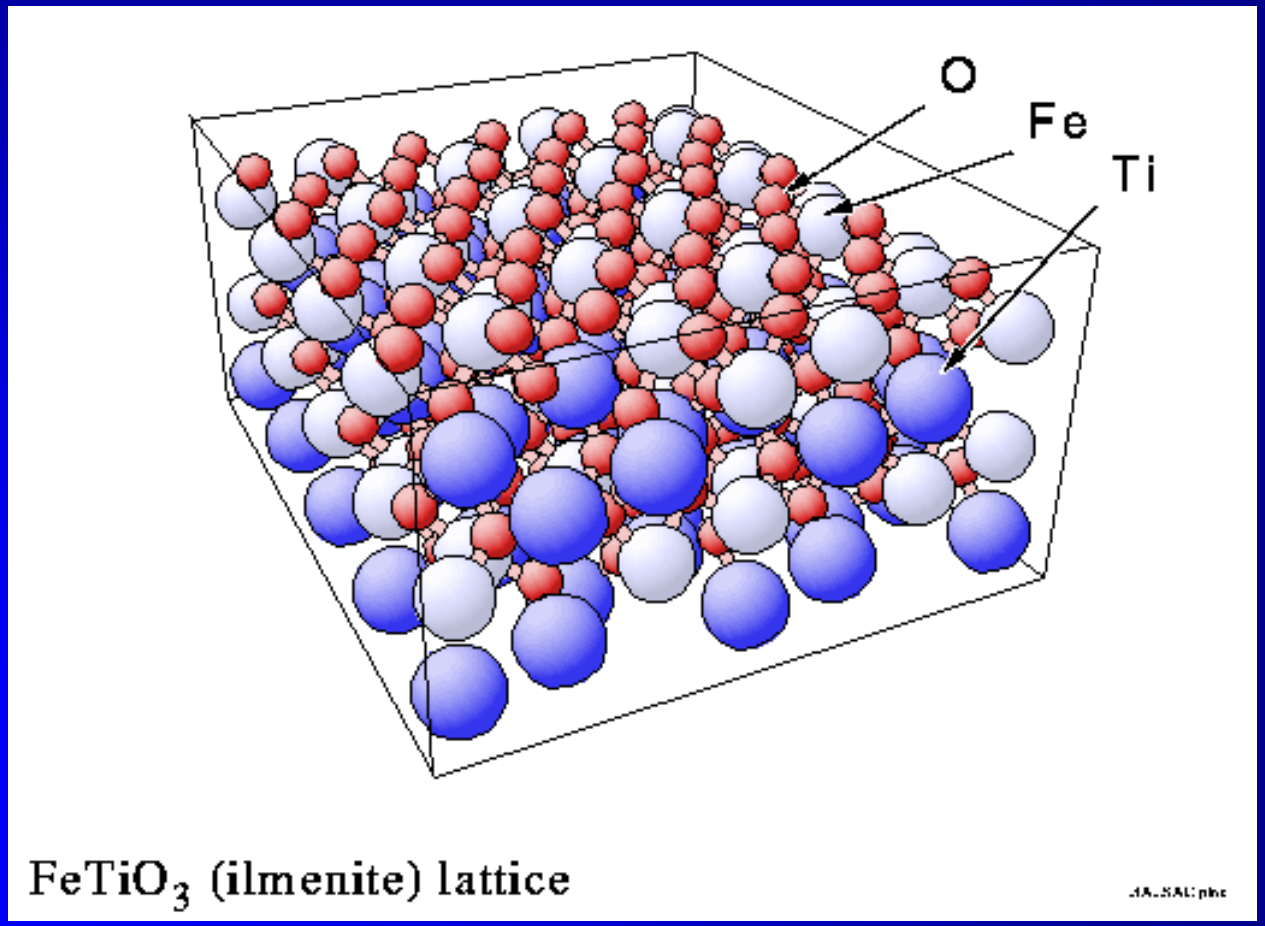
ilmenite is the most important ore of titanium

Ilmenite is the main source of titanium dioxide, which is used in paints, printing inks, fabrics, plastics, paper, sunscreen, food and cosmetics

Ilmenite Structure

- ***Similar to Corundum Structure***

- ***Alternating layers of Fe and Ti Octahedra***



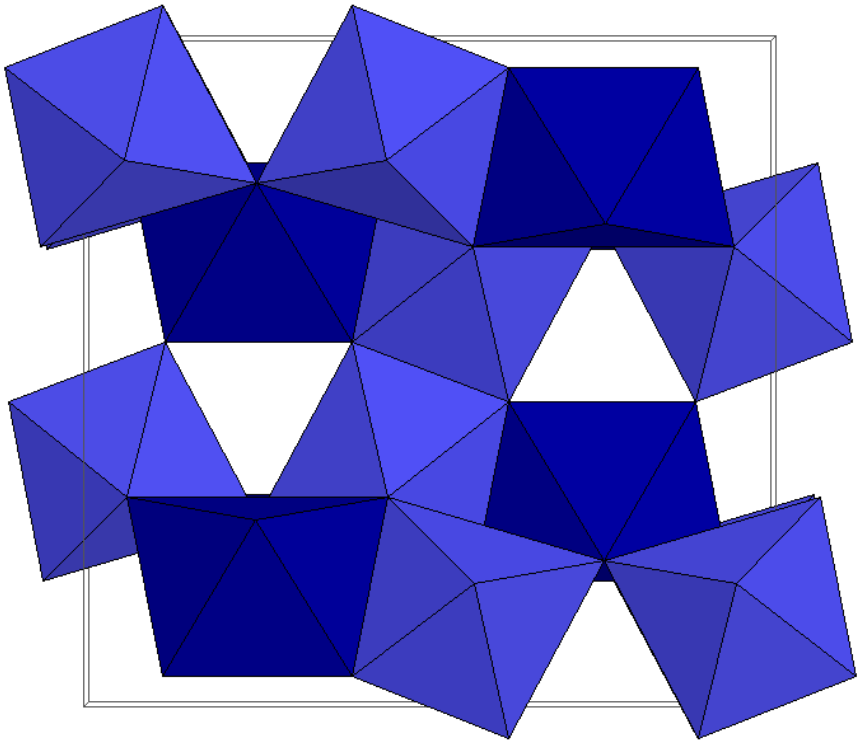
- Ilmenite crystallizes in the trigonal system
  - Ilmenite crystal structure consists of an ordered derivative of the corundum structure
  - In corundum all cations are identical but in ilmenite Fe^{2+} & Ti^{4+} ions occupy alternating layers perpendicular to the trigonal z-axis

Pseudobrookite Group

- Pseudobrookite $Fe^{2+}Ti_2O_5$
- Ferro-pseudobrookite $TiFe^{3+}{}_2O_5$
- Armalcolite $(Mg,Fe^{2+})Ti_2O_5$

Pseudobrookite Structure

- M1 dark
- M2 lighter

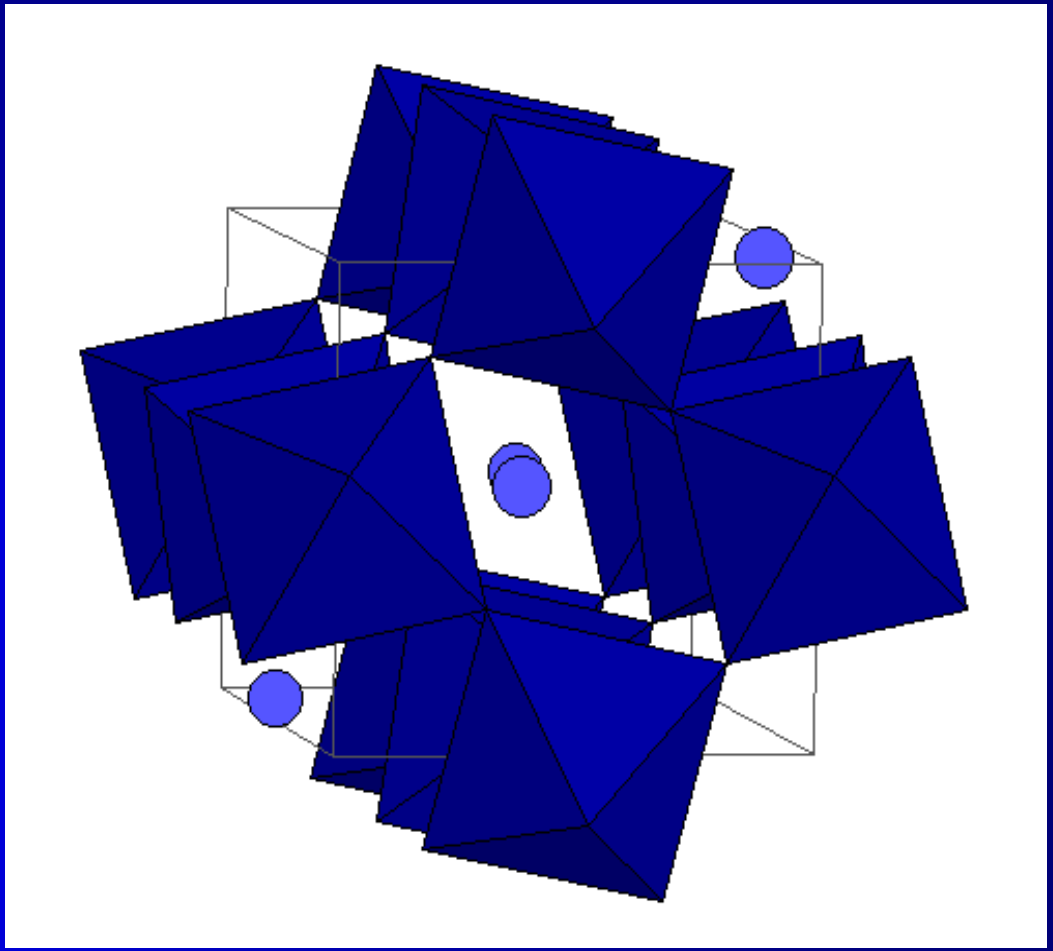


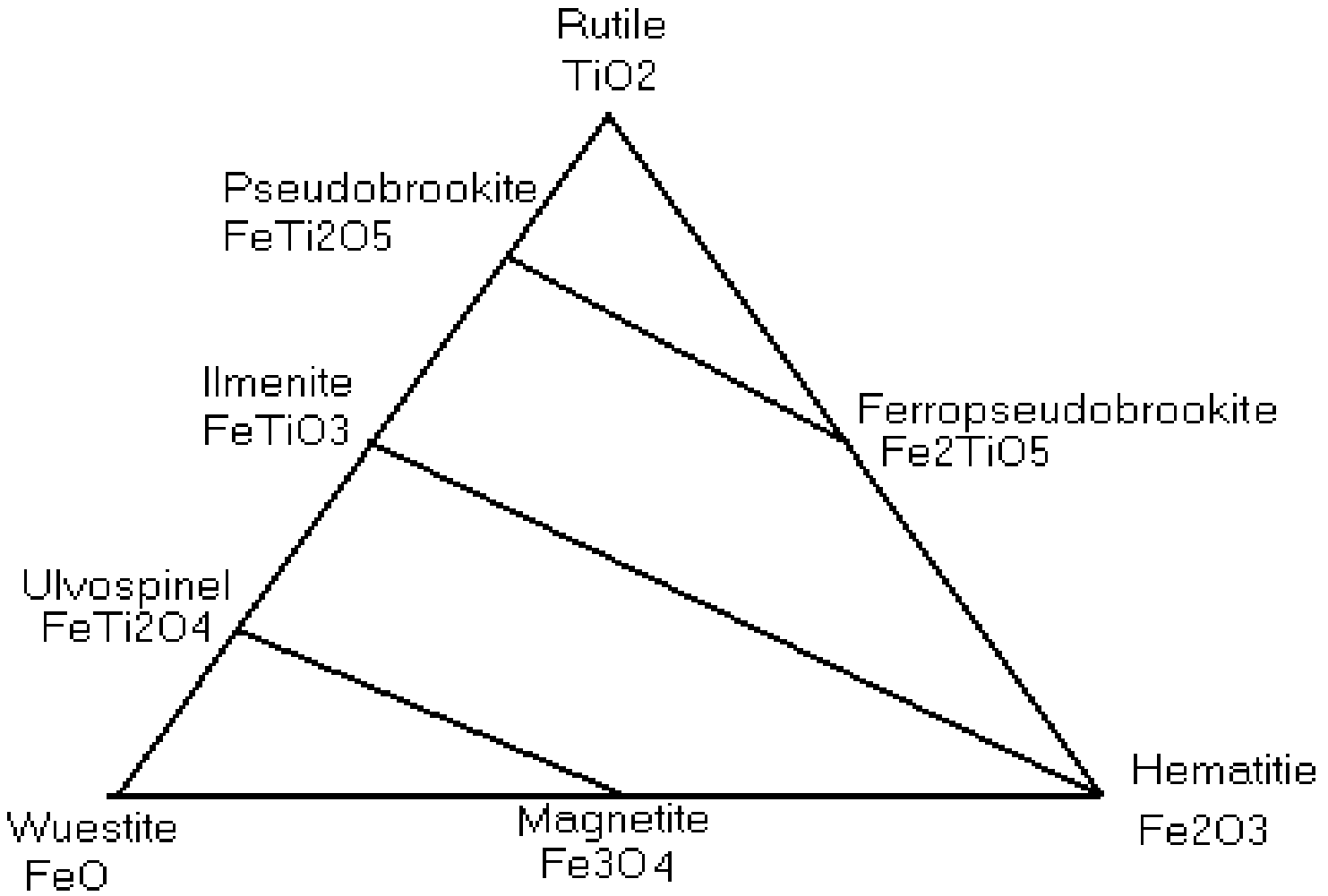
Perovskite

- Perovskite $CaTiO_3$
- $MgSiO_3$ (Lower mantle phase)

Perovskite Structure

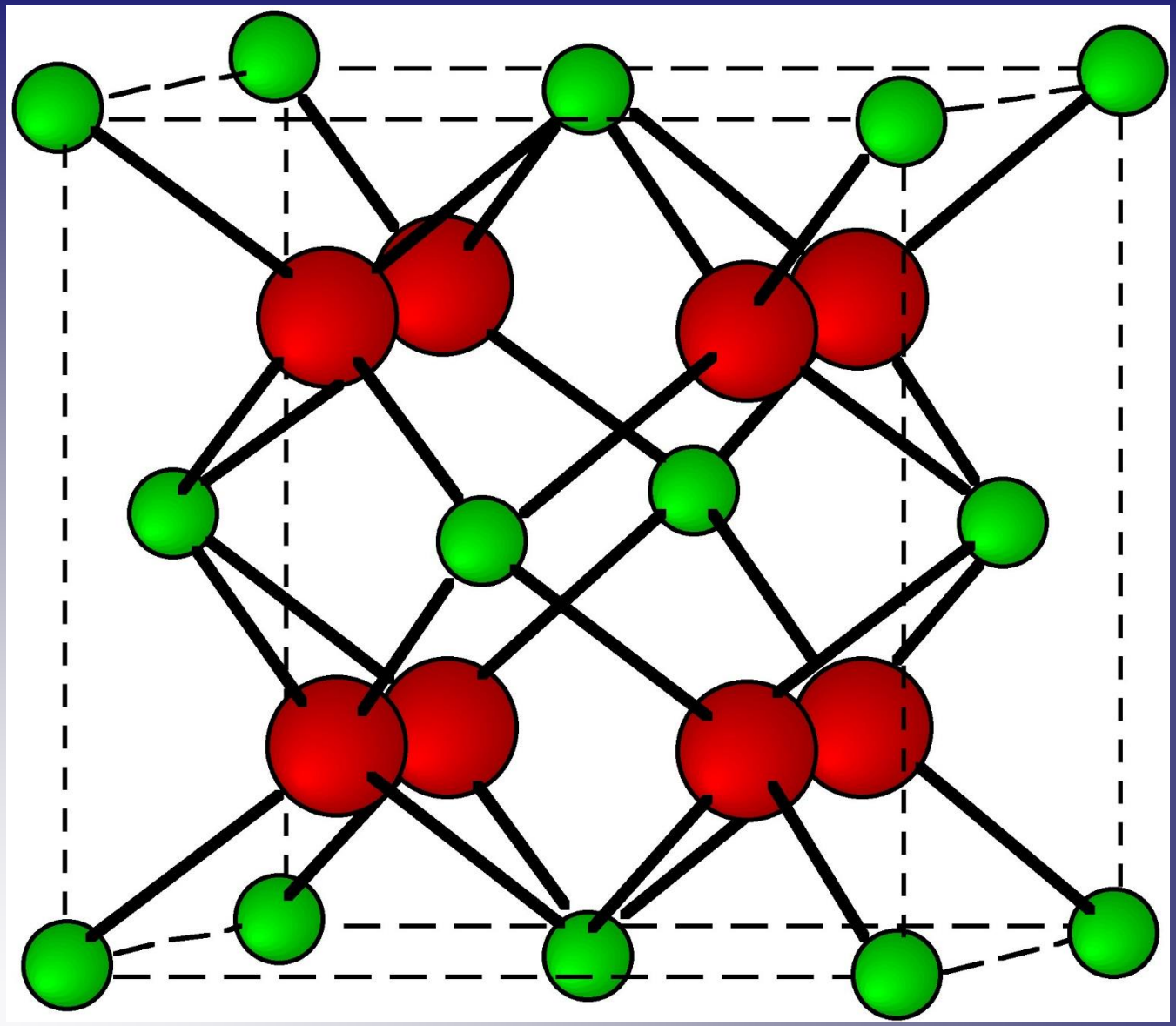
- *Pseudo-cubic*
- *Orthorhombic*




Rutile
TiO2
Pseudobrookite
FeTi2O5
Ilmenite
FeTiO3
Ferropseudobrookite
Fe2TiO5
Ulvospinel
FeTi2O4
Hematitie
Fe2O3
Wuestite
FeO
Magnetite
Fe3O4

Hydroxides

- Brucite $Mg(OH)_2$
- Bauxite (Mixed Al hydroxides)
  - Gibbsite $Al(OH)_3$
  - Boehmite and Diaspore $AlO(OH)$
- Goethite $FeO(OH)$ (+Lepidochrosite)
- Limonite $Fe(OH)_3$

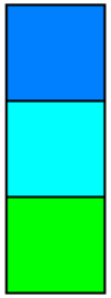


Al – Green; OH - Red

Carbonates

- Calcite Group
- Aragonite Group
- Dolomite Group
- Other carbonates

Carbonate Minerals



Calcite Group

Aragonite Group

Other

H																	He
Li	Be	B	C	N											O	F	Ne
Na	Mg	Al	Si	P											S	Cl	Ar
K	Ca	Sc	T	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

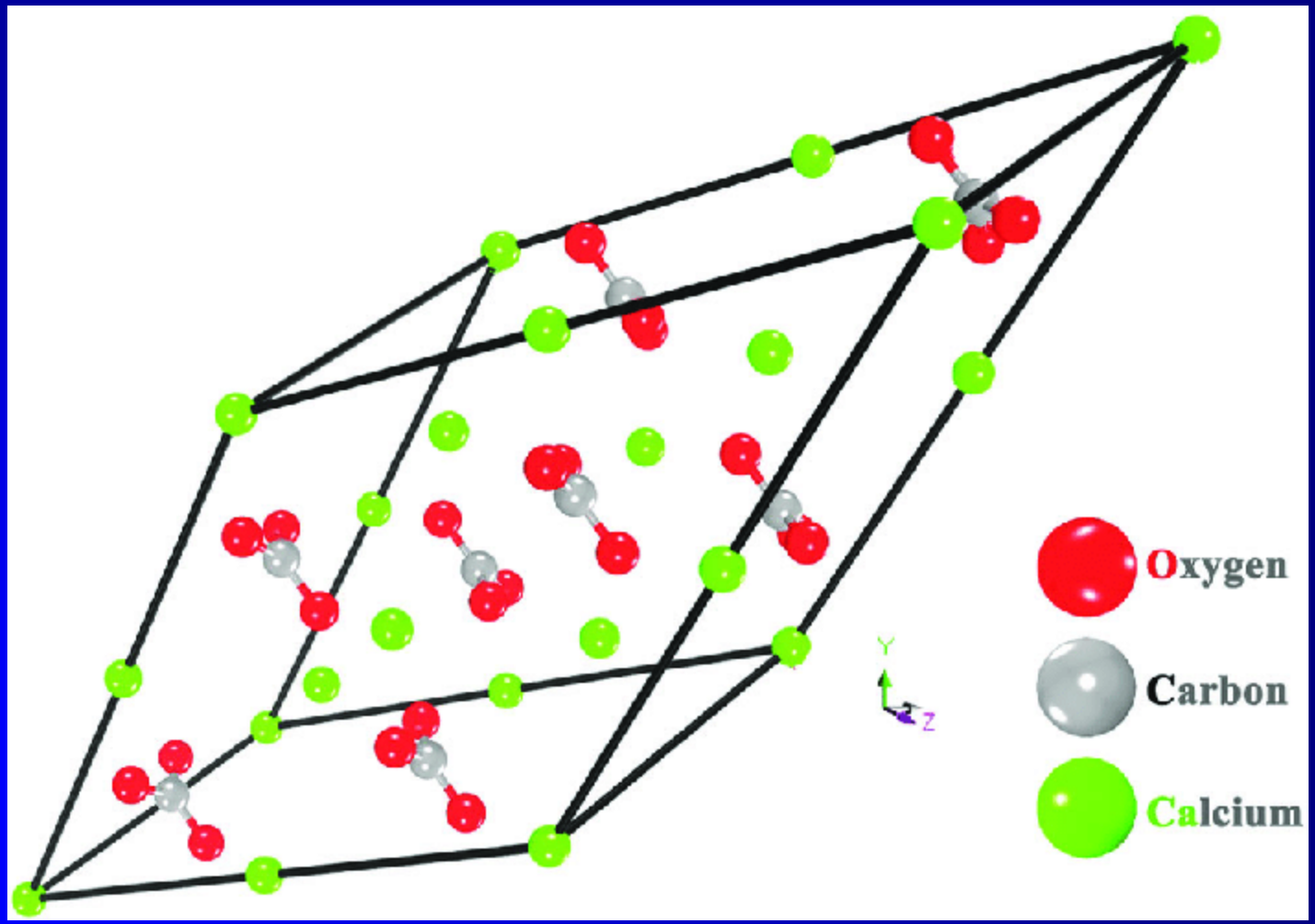
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tu	Yb	Lu
Th	Pa	U											

Calcite Group

- Calcite $CaCO_3$
- Magnesite $MgCO_3$
- Siderite $FeCO_3$
- Rhodochrosite $MnCO_3$
- Smithsonite $ZnCO_3$

Calcite Structure

- Divalent cation radius < 1.00Å

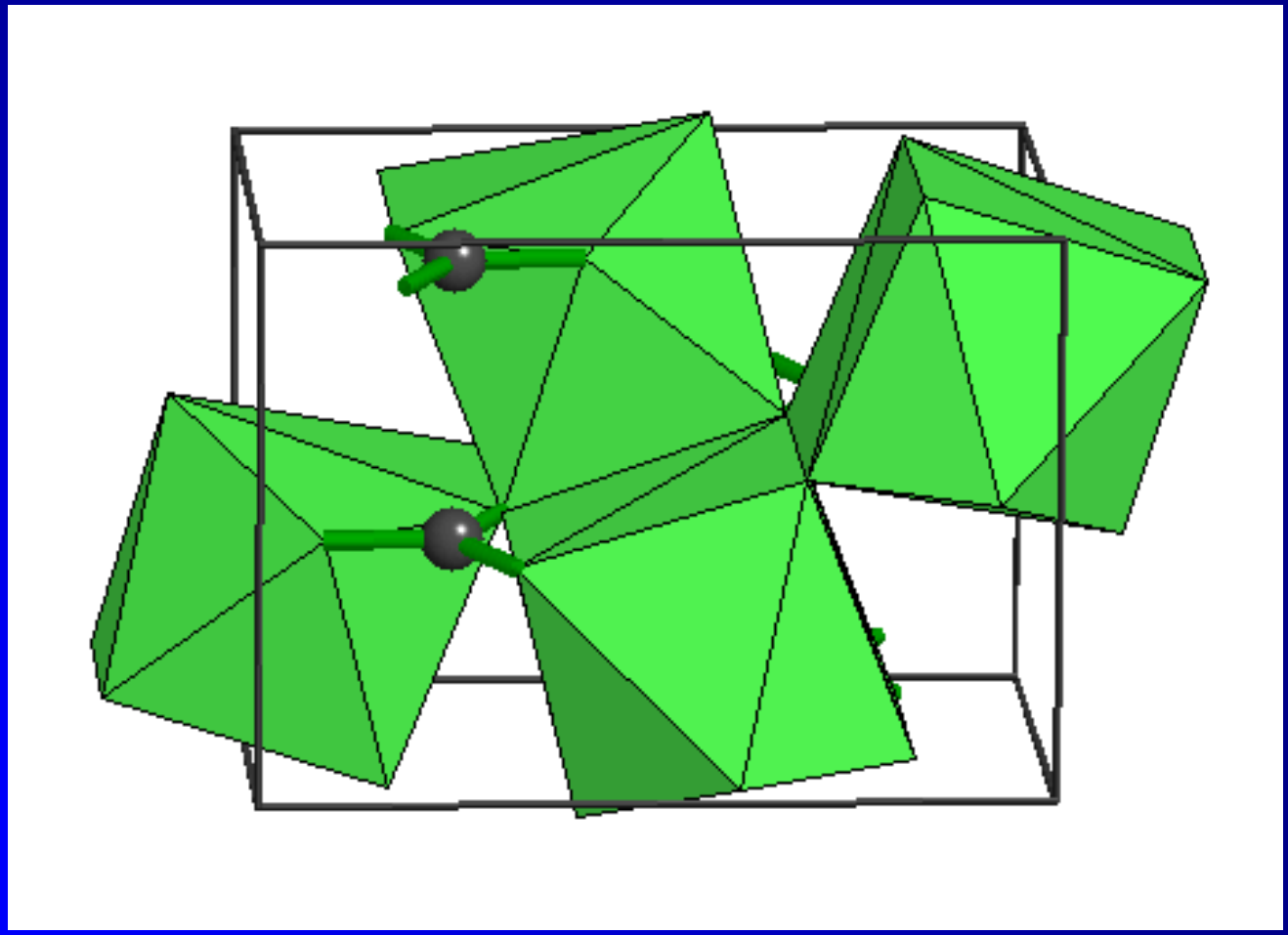


Aragonite Group

- Aragonite $CaCO_3$
- Strontianite $SrCO_3$
- Witherite $BaCO_3$
- Cerussite $PbCO_3$

Aragonite Structure

- Cation Radius > 1.00Å



Dolomite Group

- Dolomite $CaMg(CO_3)_2$
- Ankerite $CaFe(CO_3)_2$

Other Carbonates

- Malachite (Green) $Cu_2(OH)_2CO_3$
- Azurite (Blue) $Cu_3(OH)_2(CO_3)_2$
  - Cu^{1+} or Cu^{2+}?
- Bastnasite $REECO_3F$

Sulphates

- Gypsum $CaSO_4 \cdot 2H_2O$
- Anhydrite $CaSO_4$
- Celestine $SrSO_4$
- Barite $BaSO_4$
- Anglesite $PbSO_4$
- Alunite $KAl_3(OH)_6(SO_4)_2$

Sulfate Minerals

Gypsum/Anhydrite

Barite Group

Alunite

H																	He
Li	Be	B	C	N											O	F	Ne
Na	Mg	Al	Si	P											S	Cl	Ar
K	Ca	Sc	T	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tu	Yb	Lu
Th	Pa	U											

Gypsum

- $CaSO_4 \cdot 2H_2O$
- Hardness 2
- Evaporite
- Contains water

Anhydrite

- $CaSO_4$
- Hardness 3-3.5
- Evaporite
- Contains no water

- ***Celestine $SrSO_4$***
  - ***Hydrothermal***
- ***Barite $BaSO_4$***
  - ***Hydrothermal***
- ***Anglesite $PbSO_4$***
  - ***OxHydrothermal***