Earth's Changing Landscape Systems

The Geologic Cycle and Minerals

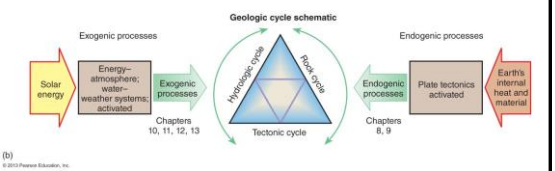
The Geologic Cycle

- **Two systems operating at the Earth-atmosphere interface:**
  - **Endogenic (internal system) builds land forms**
  - **Exogenic (external system) wears down the land forms**
- **The overall cycle is fueled by Earth's internal heat and solar energy**

The Geologic Cycle

- **Composed of three principal cycles:**
  - **The hydrologic cycle:**
    - **Involves erosion, transportation and depositional processes**
  - **The rock cycle:**
    - **Produces the three basic rock types found in the crust**
  - **The tectonic cycle:**
    - **Brings heat energy and new material to the surface**
    - **Recycles crustal material**
    - **Causes movement and deformation of the crust**

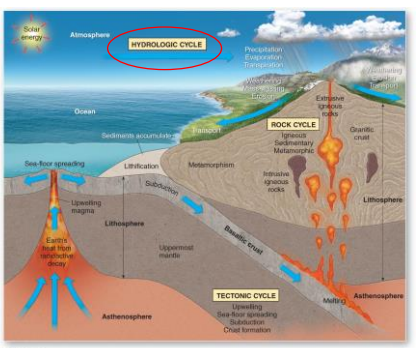
Exogenic And Endogenic Processes



Exogenic wears down land forms:
- Weathering
- Erosion
- Mass wasting

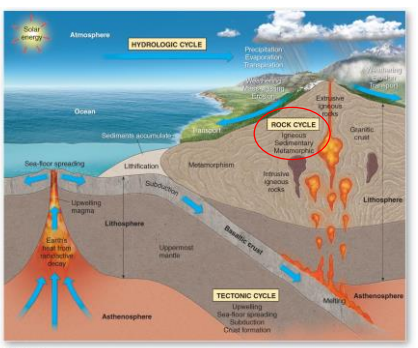
Endogenic builds land forms:
- Igneous activity
- Sedimentation
- Crustal deformation and uplift

The Geologic Cycle



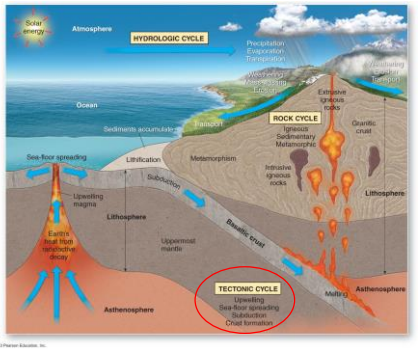
Hydrologic Cycle, powered by solar energy, transfers and stores water in various reservoirs

The Geologic Cycle



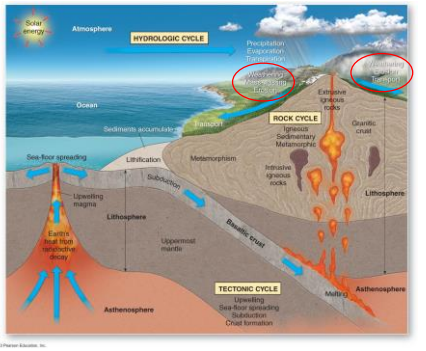
Rock Cycle, powered by Earth's internal heat energy, produces the three basic rock types found in the crust

The Geologic Cycle



Tectonic Cycle, also powered by Earth's internal heat energy, brings internal heat to surface, generates new crust, moves and deforms crust, and recycles crustal material

The Geologic Cycle



Interactions among the atmosphere, hydrosphere and lithosphere at Earth's surface result in weathering, mass wasting, erosion, and sediment transport

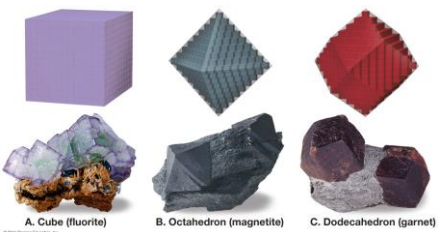
Minerals

The Basic Building Blocks Of Rocks

Definition of a Mineral

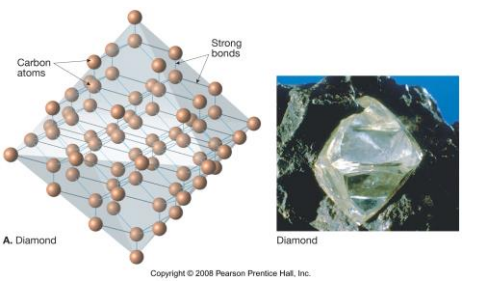
- Naturally occurring and therefore generally found in nature
- Solid within temperature range normally found at Earth's surface
- Orderly crystalline structure where atoms are arranged in an orderly, repetitive manner
- Well-defined chemical composition
- Generally inorganic even though some may contain carbon

Atoms Within Minerals Are Arranged In Orderly Crystalline Structures

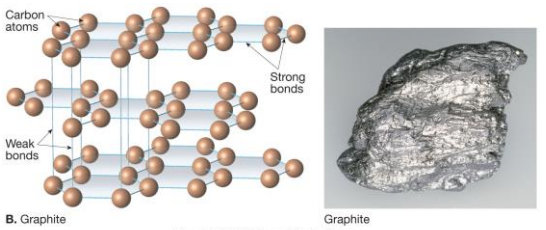


- Different minerals have different crystal forms due to differences in the internal arrangement of atoms
- We cannot see the atomic arrangement of a mineral directly, but we can view the overall shape of the crystal

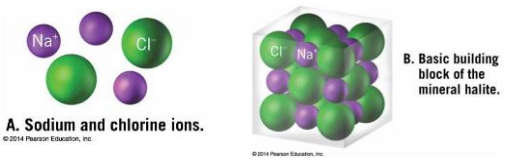
In diamond, each carbon atom shares electrons with four adjacent carbon atoms (covalent bonds) in a tetrahedral arrangement

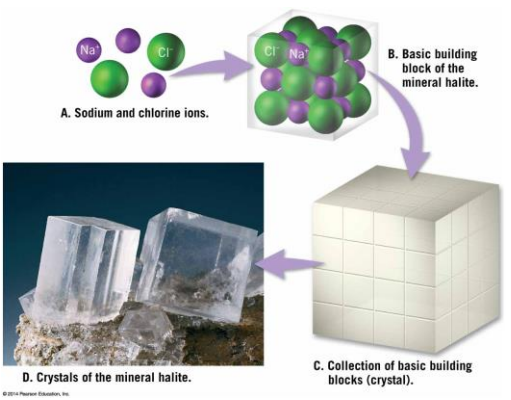


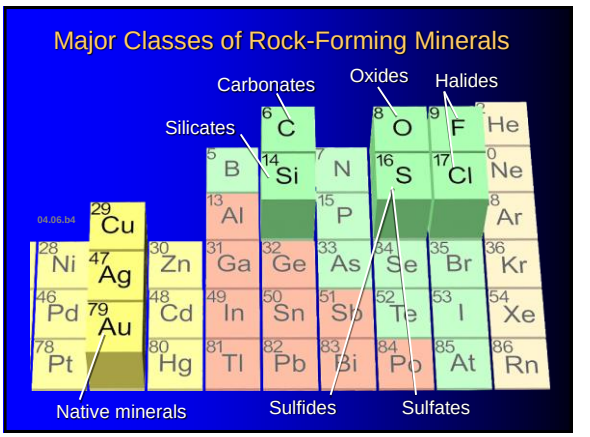
The arrangement of carbon atoms in graphite is different from that of diamonds, resulting in very different properties for the two minerals



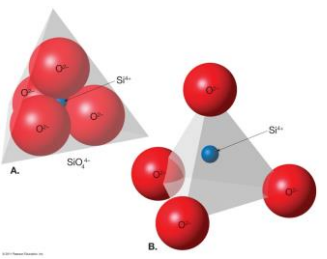
In Halite (NaCl), each Na atom is bonded to six Cl atoms and each Cl atom is bonded to six Na atoms. This arrangement results in the atomic structure of a cube





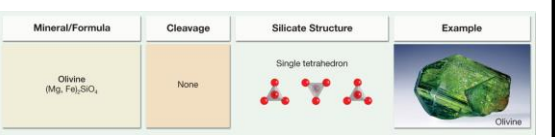


Silicate Minerals



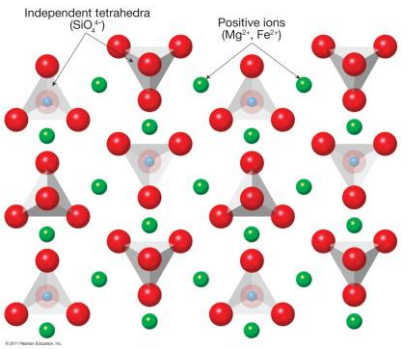
- Silicon ion (Si^{4+}) surrounded by four oxygen ions (O^{2-}) and represented by the formula $(SiO_4)^{4-}$
- General formula for silicates:
  $(SiO_4)^{4-}$ $\pm$ cations (Mg^{2+}, Fe^{2+}, Ca^{2+}, Na^{+}, K^{+})
- The basic building block is the Silicon-Oxygen Tetrahedron

Silicate Structures: Independent Tetrahedron

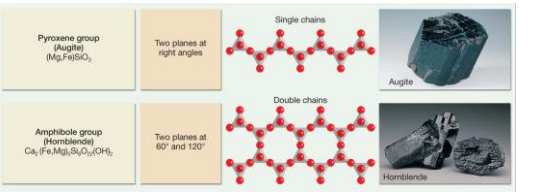


Cations link individual tetrahedra in the crystal structure

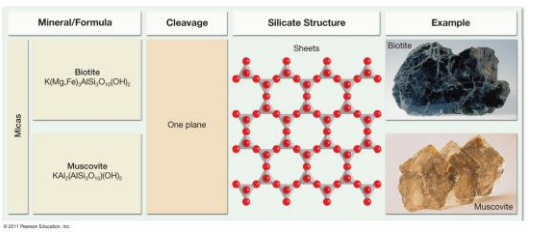
Structure of the Mineral Olivine



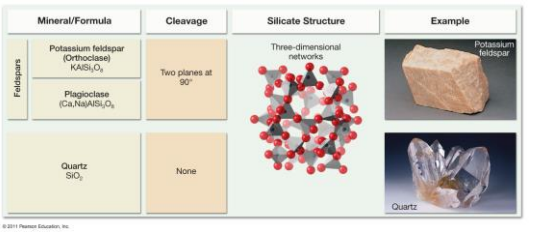
Silicate Structures: Single And Double Chains of Tetrahedra



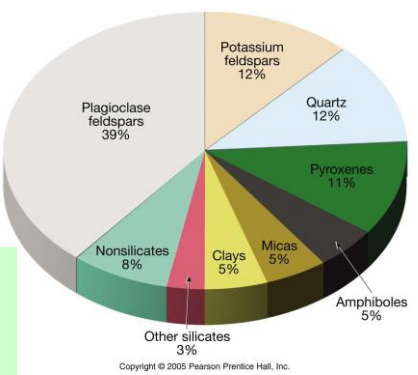
Silicate Structures: Sheets of Tetrahedra



Silicate Structures: Three Dimensional Networks of Tetrahedra



Silicates are the most common minerals in Earth's crust



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Non-silicate minerals are minor, but important components of Earth's crust

TABLE 3.2 Common Nonsilicate Mineral Classes

Mineral Groups (Key ions or elements)	Mineral Name	Chemical Formula	Economic Use
Carbonates (CO_3^{2-})	Calcite	$CaCO_3$	Portland cement, lime
	Dolomite	$CaMg(CO_3)_2$	Portland cement, lime
Halides (Cl^{1-}, F^{1-}, Br^{1-})	Halite	NaCl	Common salt
	Fluorite	CaF_2	Used in steelmaking
	Sylvite	KCl	Fertilizer
Oxides (O^{2-})	Hematite	Fe_2O_3	Ore of iron, pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
Sulfides (S^{2-})	Galena	PbS	Ore of lead
	Sphalerite	ZnS	Ore of zinc
	Pyrite	FeS_2	Sulfuric acid production
	Chalcopyrite	$CuFeS_2$	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates (SO_4^{2-})	Gypsum	$CaSO_4 \cdot 2\,H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements (single elements)	Gold	Au	Trade, jewelry
	Copper	Cu	Electrical conductor
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst

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Carbonates

- Basic unit is the $(CO_3)^{2-}$ complex
- There are different carbonate minerals depending on which cation is attached to the carbonate complex:

  $(CO_3)^{2-}$ + cations

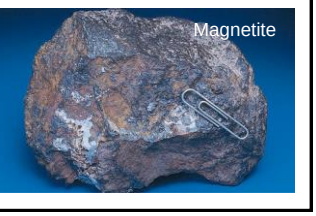
- Two most important carbonates are calcite [$CaCO_3$] and dolomite [$CaMg(CO_3)_2$]

Oxides

- Cations are bounded to oxygen

  O^{2-} + cations

- Two important oxides:
  - Hematite (Fe_2O_3)
  - Magnetite (Fe_3O_4)



Halides

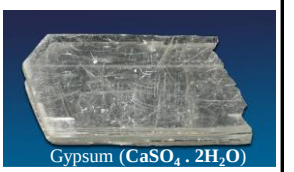
- Generally form ionic bonds
- Some precipitate from salty water (seawater)
- Important halides:
  - Halite (NaCl)
  - Sylvite (KCl)
  - Fluorite (CaF_2)

Sulfates

- Sulfur is present as the sulfate ion $(SO_4)^{2-}$

  $(SO_4)^{2-}$ + cations

- Two important sulfates:
  - Anhydrite ($CaSO_4$)
  - Gypsum ($CaSO_4 \cdot 2H_2O$)

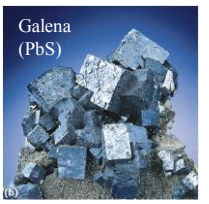


Sulfides

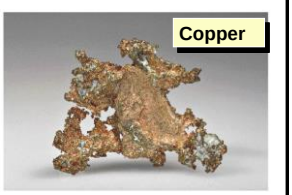
- Many important ore deposits exist as sulfides

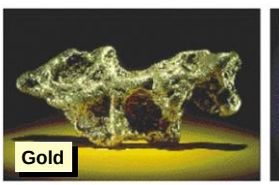
  S^{2-} + cations

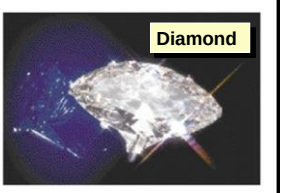
- Two important sulfides:
  - Pyrite (FeS_2)
  - Galena (PbS)



- Native Element Minerals are composed of only one element:
  - Graphite (C)
  - Diamond (C)
  - Copper (Cu)
  - Gold (Au)
  - Sulfur (S)







Earth's Changing Landscape Systems

The Rock Cycle

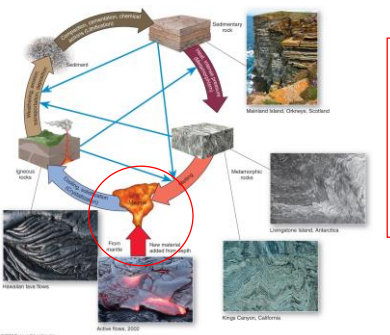
Solid Earth Materials

- **Minerals:**
  - **Minerals are composed of chemical elements.**
  - **Chemical elements are held together by bonds.**
  - **Minerals are the building blocks of the solid Earth**
- **Rocks:**
  - **Rocks are composed of minerals**

Categories of Rocks

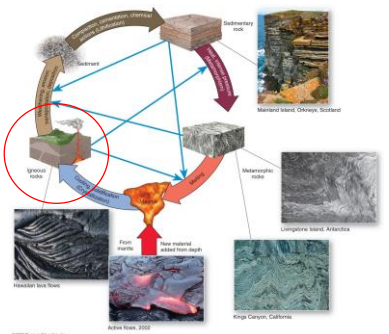
- **Igneous Rocks (Crystallize from magma and lava)**
- **Sedimentary Rocks (Lithification of sediment; Precipitation of ions)**
- **Metamorphic Rocks (Formed when original parent rocks undergo changes due to changing temperature and pressure conditions)**

The Rock Cycle



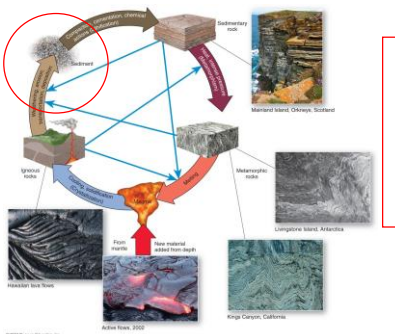
Because of heating within the Earth, deep rocks are melted to produce magma

The Rock Cycle



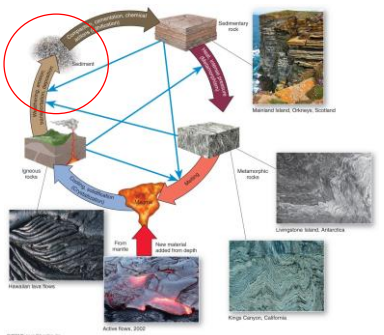
Rising magma cools and crystallizes at shallower depth or erupts on the surface to form igneous rocks

The Rock Cycle



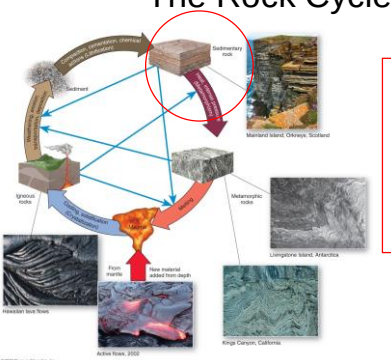
Igneous rocks brought to the surface are weathered by water, ice and air under the influence of gravity to form sediment

The Rock Cycle



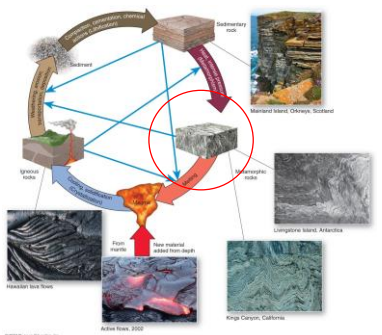
Glaciers, running water and wind transport and deposit sediment in valleys, lakes, deserts and oceans

The Rock Cycle



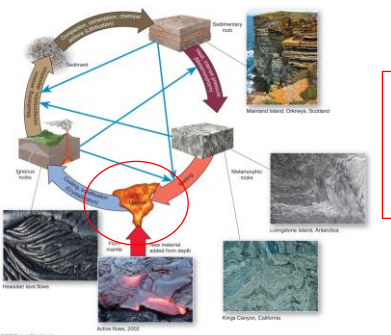
Deposited sediments slowly get buried, compacted and lithified into sedimentary rocks

The Rock Cycle



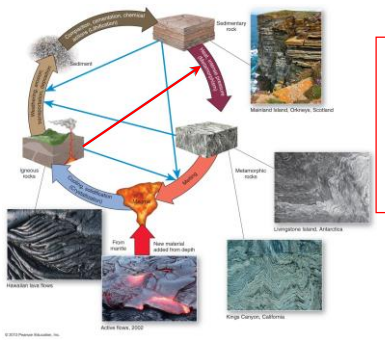
Deep burial of sedimentary rocks to higher temperatures and pressures results in metamorphism

The Rock Cycle



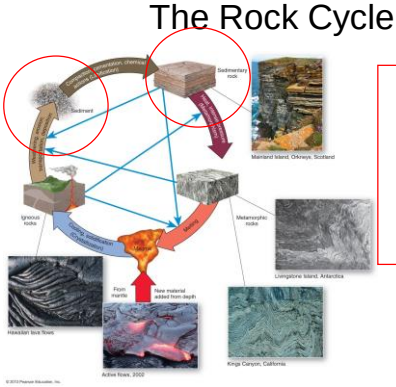
Metamorphic rocks can be heated further and eventually melted to form magma

The Rock Cycle



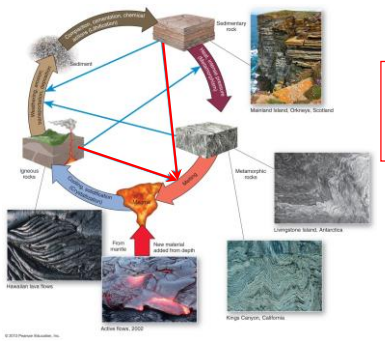
Igneous rocks at depth can bypass the weathering stage, converting directly into metamorphic rocks

The Rock Cycle



Any rock type can be uplifted and exposed at any stage and weathered to produce sediments and sedimentary rocks

The Rock Cycle



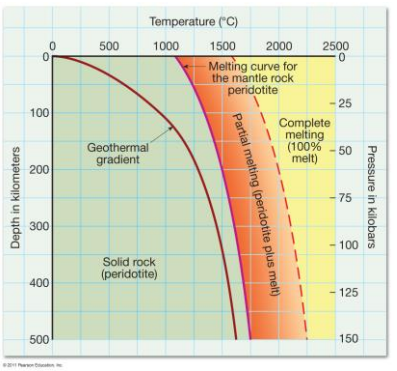
Any rock type can be heated and melted to form magma

Origin of Magma

- Generating magma from solid rock
- Role of heat:
  - Temperature increase in the upper crust (geothermal gradient) averages between 20°C to 30°C per kilometer depth
  - Rocks in the lower crust and upper mantle are near their melting points
  - Any additional heat may induce melting

The geothermal gradient shows how temperature increases with depth in the Earth

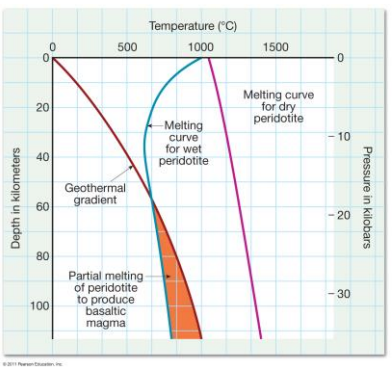
Melting temperatures of dry peridotite are everywhere higher than geothermal gradient



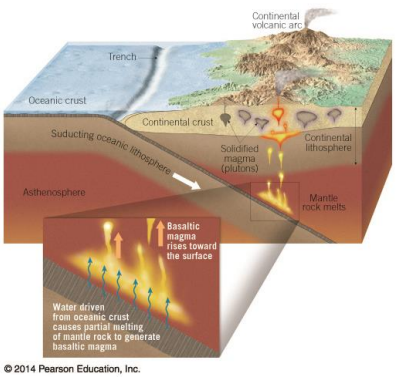
Origin of Magma

- Role of volatiles:
  - Volatiles (primarily water) cause rocks to melt at lower temperatures
  - Important factor where oceanic lithosphere descends into the mantle

Wet peridotite partially melts at depths below ~60 km (upper mantle) to produce basaltic magma

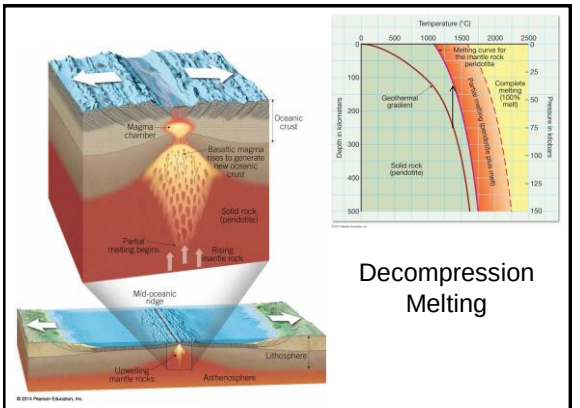


Mantle Melting Through The Release of Volatiles

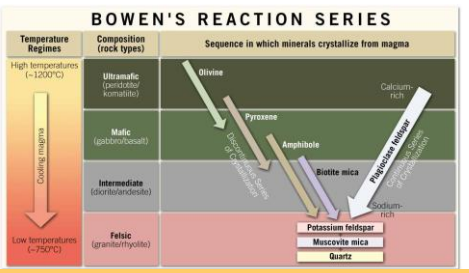


Origin of Magma

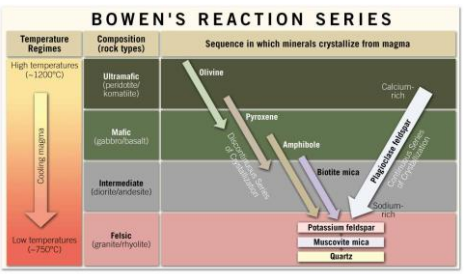
- **Role of pressure:**
  - **An increase in confining pressure with depth increases a rock's melting temperature (e.g. higher temperatures are required to melt deeper rocks)**
  - **Conversely, mantle material rising towards the surface experiences a decrease in confining pressure**
  - **When confining pressure drops, decompression melting occurs**



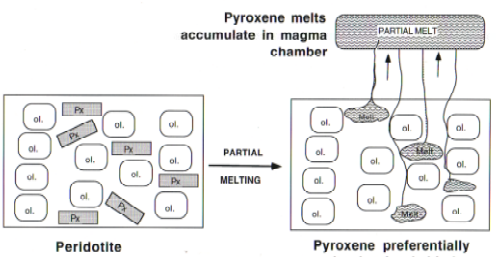
Decompression Melting



- Different silicate minerals melt or crystallize at different temperatures
- The types of minerals comprising an igneous rock depend on its composition:
  - Ultramafic (e.g. mantle peridotite); high temp. olivine and pyroxene
  - Mafic (basaltic); olivine, pyroxene and Ca-rich feldspar
  - Intermediate and felsic compositions are richer in silica, Na, and K; consist of lower temp. minerals further down Bowen's reaction series

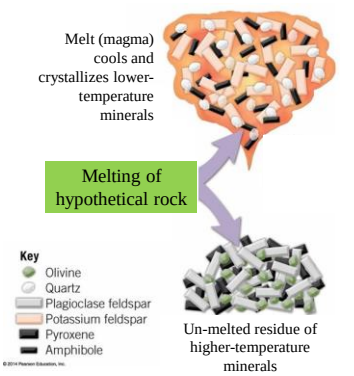


- Magma forms as a hot liquid produced when pre-existing rock melts
- When a rock is heated, lower-temperature minerals may begin to melt while higher-temperature minerals remain solid:
  - This process is termed partial melting
  - The resulting liquid is called a partial melt



Partial Melting

- The partial melt formed through the melting of certain minerals takes on the composition of the melted minerals
- The solid minerals remaining behind define the composition of the residual solid



Magma then rises towards the surface and compositionally evolves as it cools and crystallizes minerals to form igneous rocks