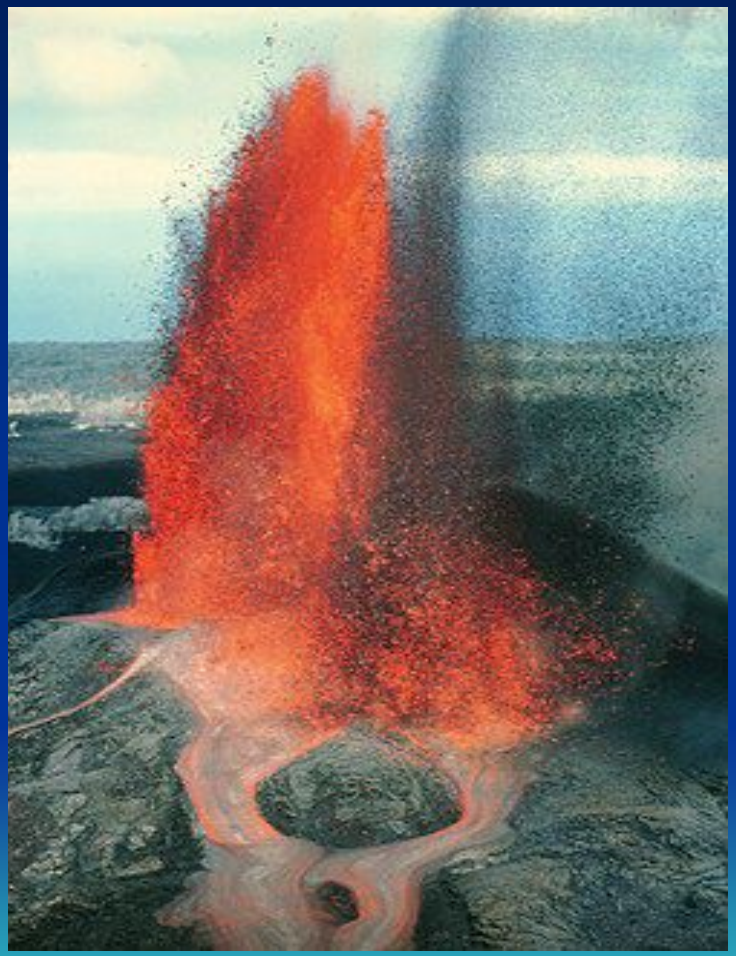
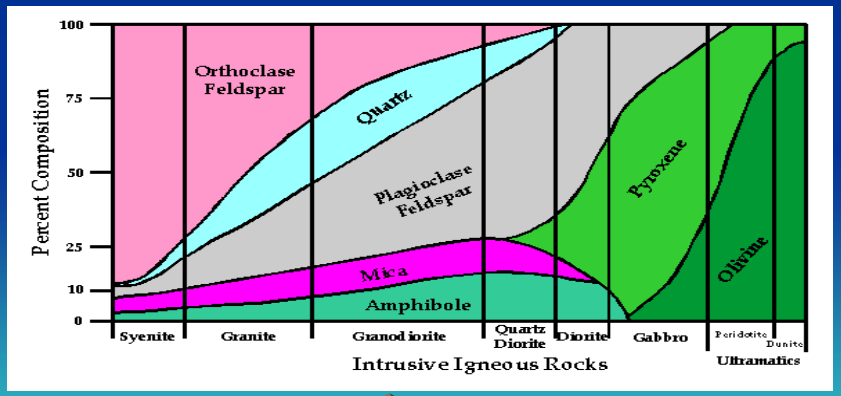
# Igneous Rock Processes and Identification






http://www.rockhounds.com/rockshop/rockkey/index.html

http://earthsci.org/education/teacher/basicgeol/igneous/igneous.html#KindsofIgneousRocks

# Major Concepts

1) Igneous rocks form directly from the crystallization of a magma or lava
2) Three primary tectonic settings of global-scale magmatization are divergent boundaries, subduction-related convergent boundaries, and hot spots.
3) Tectonic environment controls the type of magmas generated, and hence the types of igneous rocks that form at each of the three tectonic settings.
4) Magma reaching the surface is termed lava, typically forming a volcano.
5) The type of igneous rock formed is controlled by two factors: magma composition and cooling history; also determines naming of igneous rocks
6) Magma compositions vary from mafic to intermediate to silicic-felsic.
7) Texture controlled by cooling history; Mineralogy by magma composition
8) Coarse-grained igneous rocks that cooled very slowly at depth are termed intrusive or plutonic
9) Fine-grained igneous rocks that cooled quickly at or near surface are termed extrusive or volcanic.
10) Identification of igneous rocks based on two criteria: texture and composition

# Types of Rocks

Igneous Rocks

Sedimentary Rocks

Metamorphic Rocks

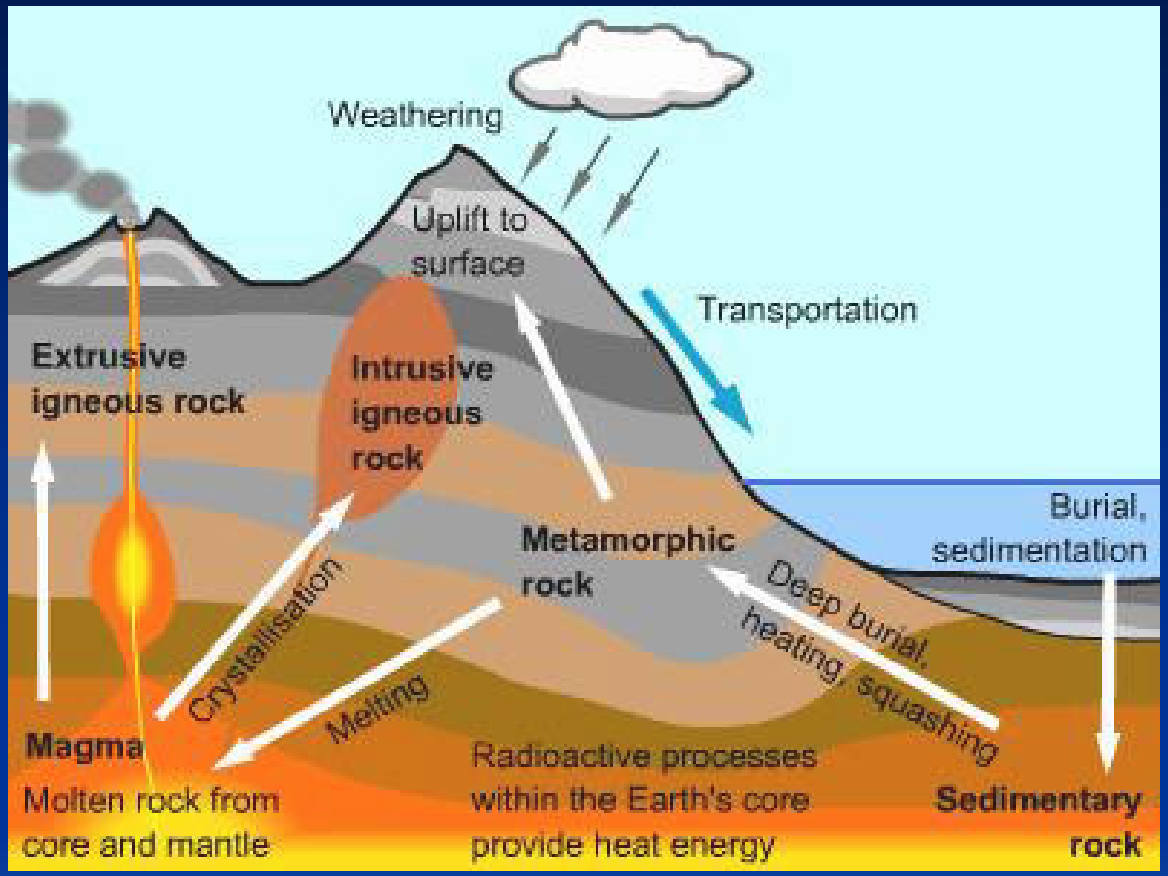
# The Rock Cycle

**Three Primary Rock Types**

1) **Igneous**

2) **Metamorphic**

3) **Sedimentary**

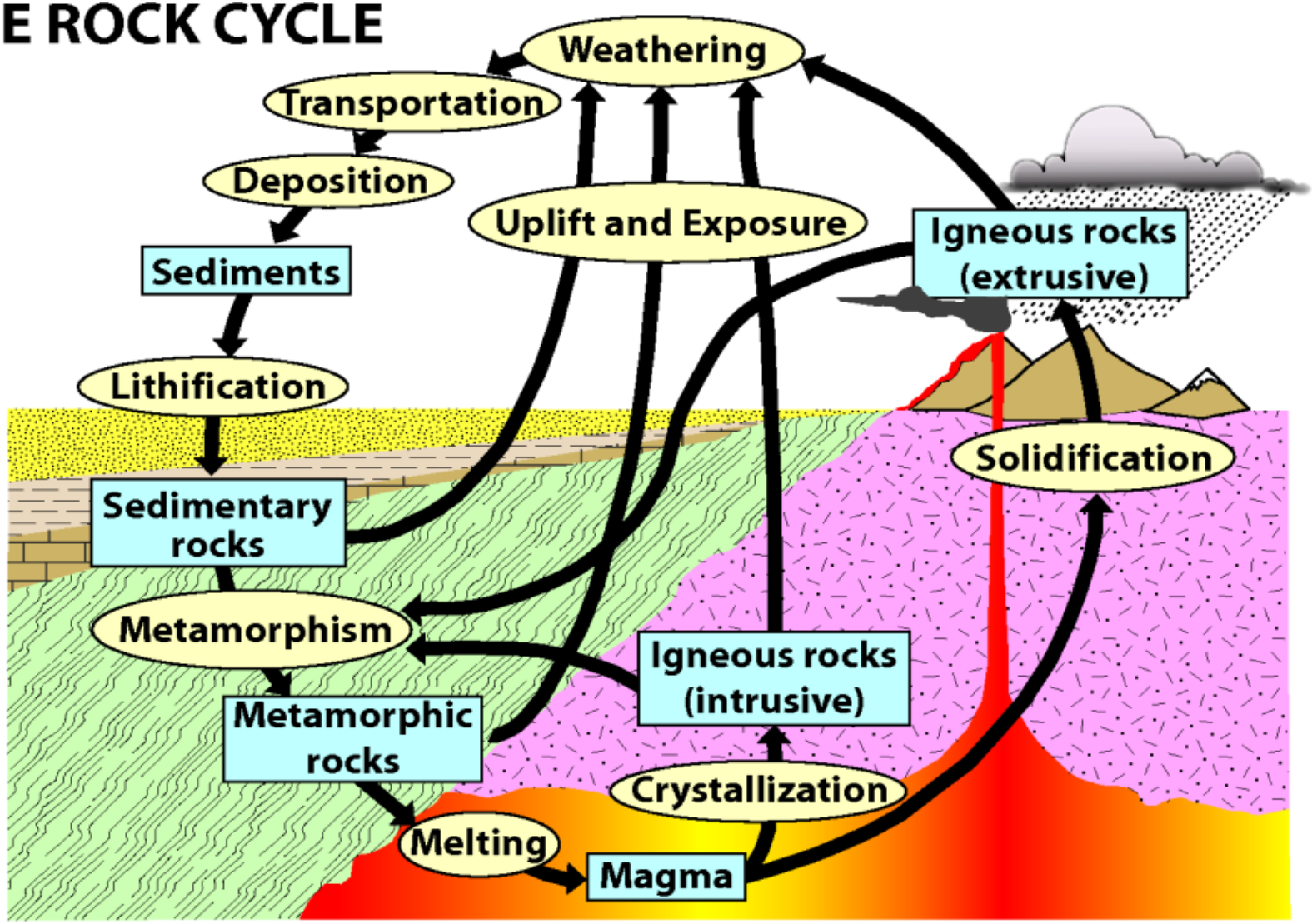



**Key Concept:**

**The Rock Cycle is Perpetuated by Several Major Processes**

1) Magmatic Activity
2) Uplift and Mountain Building
3) Weathering, Erosion, Deposition, and Burial of Sediment

# THE ROCK CYCLE




**Igneous Rocks -**
Rocks that form from the cooling of motlen rock (magma), Example: granite and basalt

**Sedimentary Rocks -**
Rocks that are fromed from pieces of other rocks, Example: sandstone, or that are deposited from the ocean by chemical processes, Example: limestone

**Metamorphic Rocks -**
Rocks that are changed by heat and pressure without melting, Example: gneiss

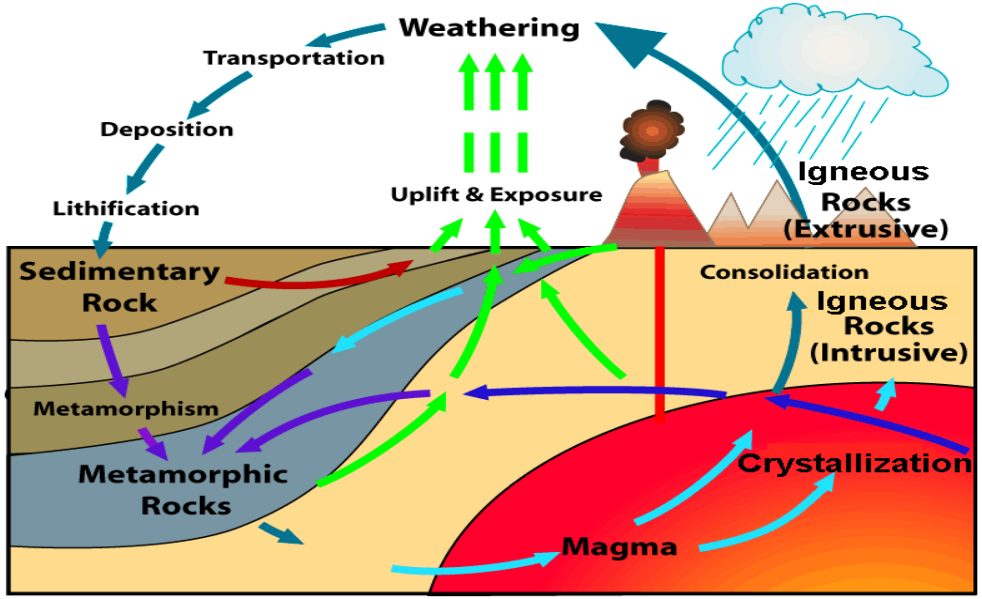
# The Rock Cycle

**Three Primary Rock Types**

1) **Igneous**

2) **Metamorphic**

3) **Sedimentary**




Igneous rocks form by the *cooling* and *crystallization* of underground *magmas* and erupted *lavas*.

Igneous rocks are classified by two mineral criteria:

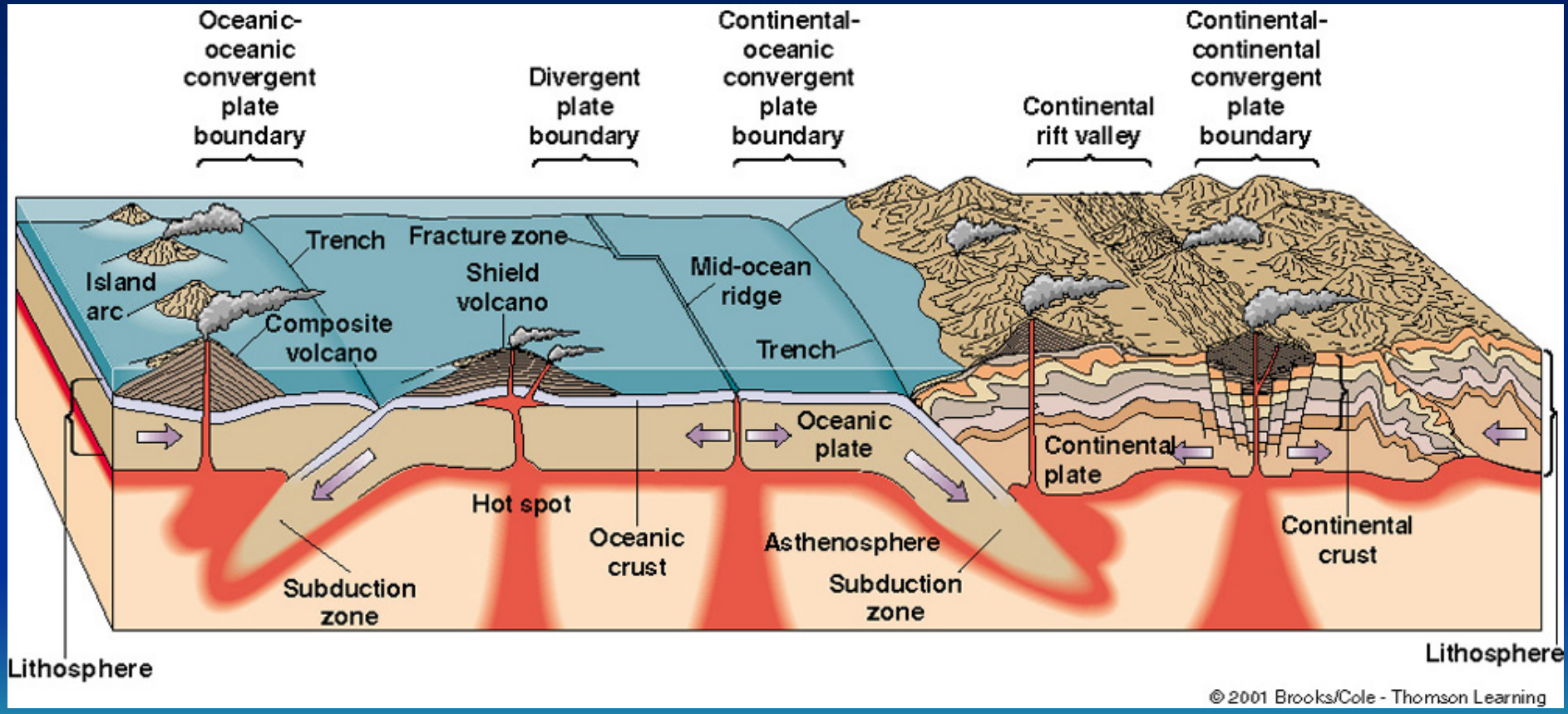
1) *Type and % of minerals* 2) *Crystal size & arrangement*

# Magma and Lava = Mother Igneous

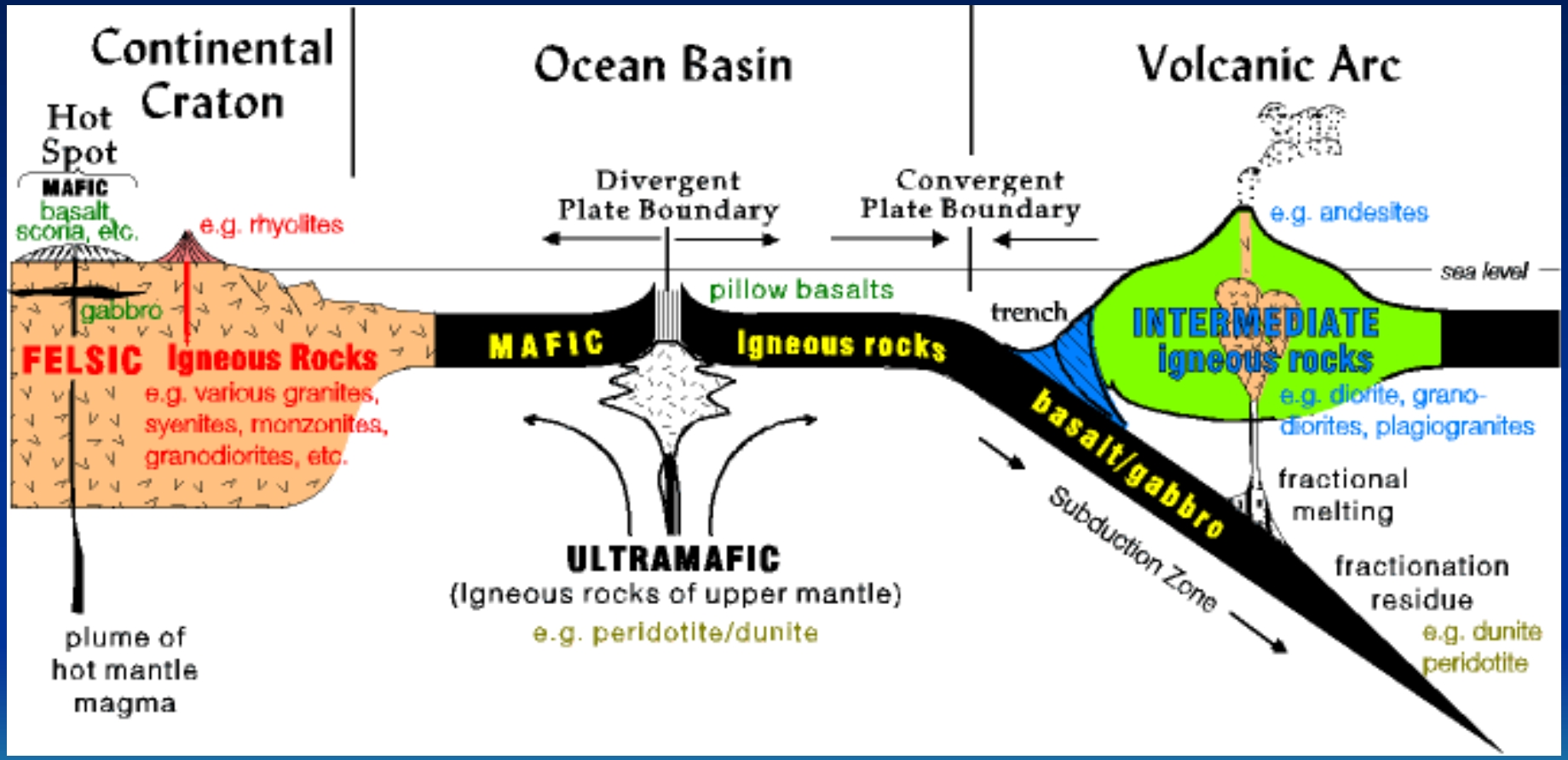
The mineralogy of an igneous rock is *primarily controlled* by the composition of the magma or lava that it cooled from.

The texture of an igneous rock is *primarily controlled* by the cooling rate of its parent crystallizing magma or lava.

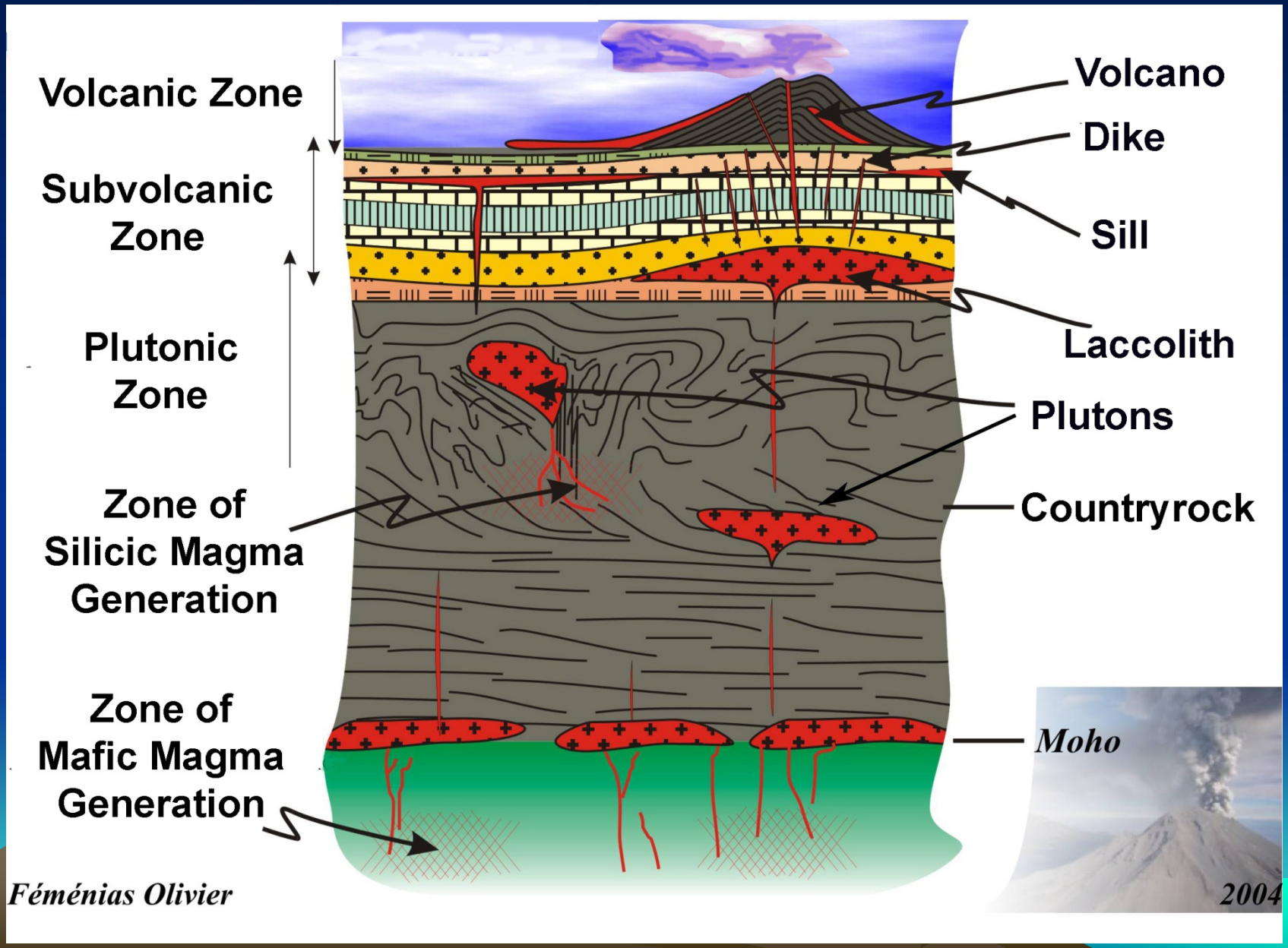
# Tectonic Environments for Magma Generation



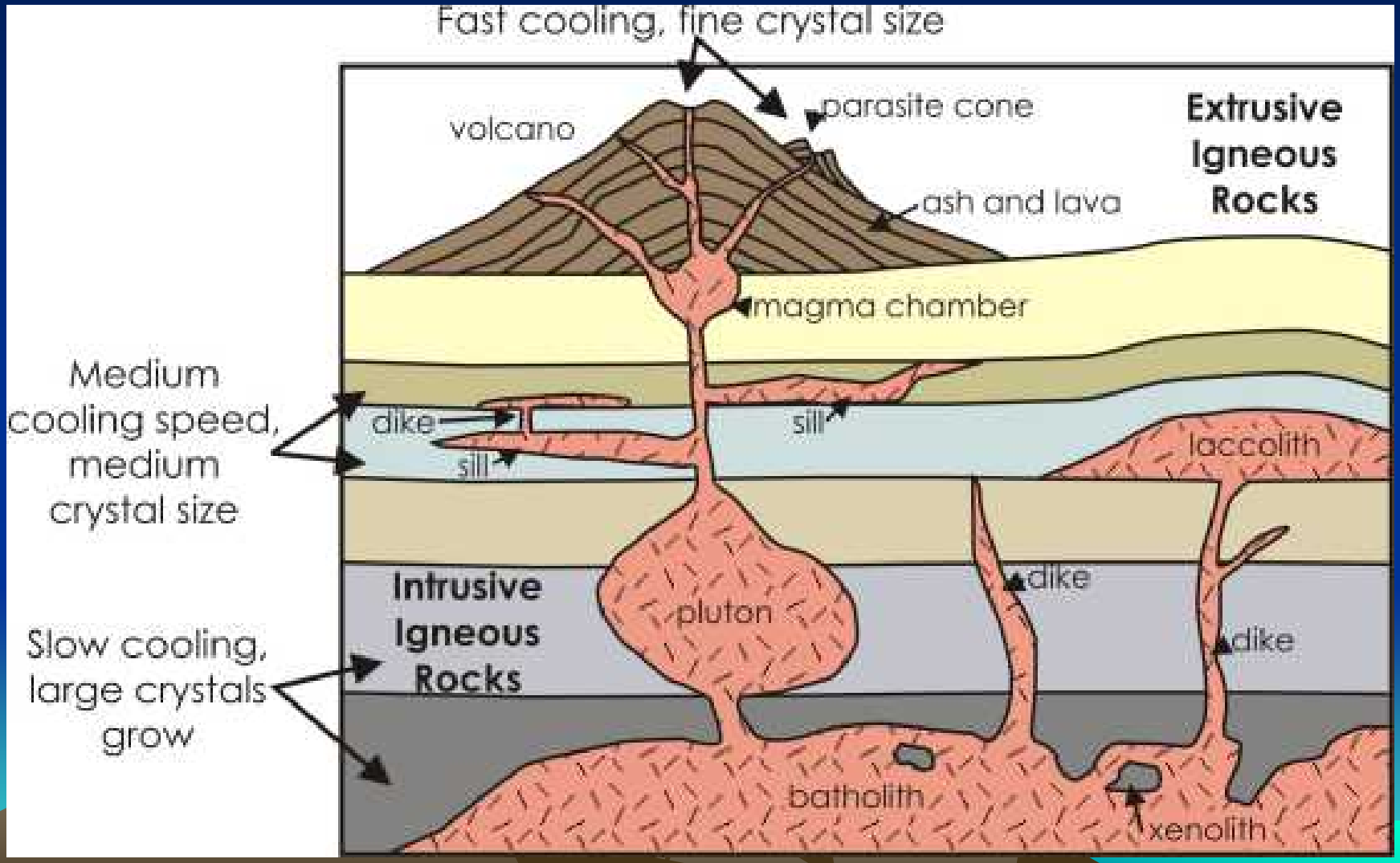
# Predominant Igneous Rock Types at Specific Tectonic Settings



# Igneous Environments



# Affects of Cooling Rates on Crystal Size in Various Igneous Environment



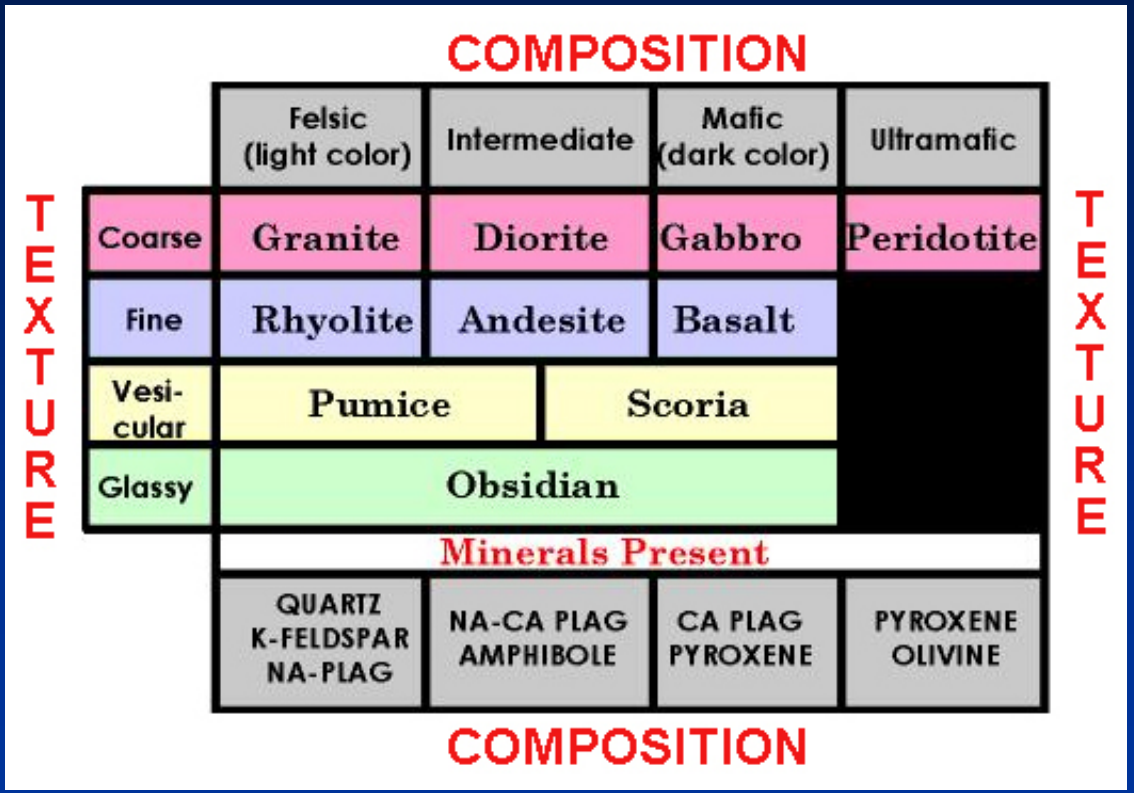
# Common Igneous Rock-Forming Minerals

1) Plagioclase
2) Potassium Feldspar
3) Quartz
4) Muscovite
9) Biotite
10) Hornblende
11) Augite (pyroxene)
12) Olivine
13) Tourmaline
14) Garnet
15) Magnetite

# Igneous Rock Classification

The mineralogy of an igneous rock is *primarily controlled* by the composition of the magma or lava that it cooled from.

The texture of an igneous rock is *primarily controlled* by the cooling rate of its parent crystallizing magma or lava.




- http://geology.csupomona.edu/alert/igneous/igclass.htm

# Igneous Compositions

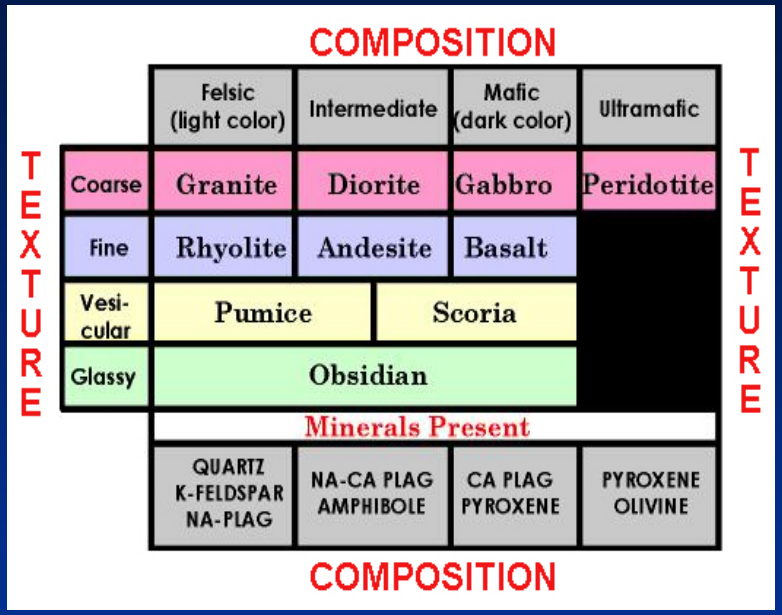
**Ultramafic:**
- ✓ Very Iron – Magnesium Rich
- ✓ Super undersaturated in silica
- ✓ Mantle rocks = **Peridotite**

**Mafic:**
- ✓ Iron–Magnesium-Calcium Rich
- ✓ Undersaturated in silica
- ✓ Oceanic rocks = **Gabbro and Basalt**

**Sub-Mafic:**
- ✓ Between Mafic and Sub-Felsic/Silicic
- ✓ Saturated in silica
- ✓ Volcanic Arc rocks = **Diorite and Andesite**

**Sub-Felsic/Silicic:**
- ✓ Between Sub-Mafic and Felsic/Silicic
- ✓ Saturated in silica
- ✓ Volcanic Arc rocks = **Granodiorite and Dacite**

**Felsic/Silicic:**
- ✓ Sodium – Potassium - Aluminum Rich
- ✓ Very Oversaturated in silica
- ✓ Continental rocks = **Granite** and **Rhyolite**

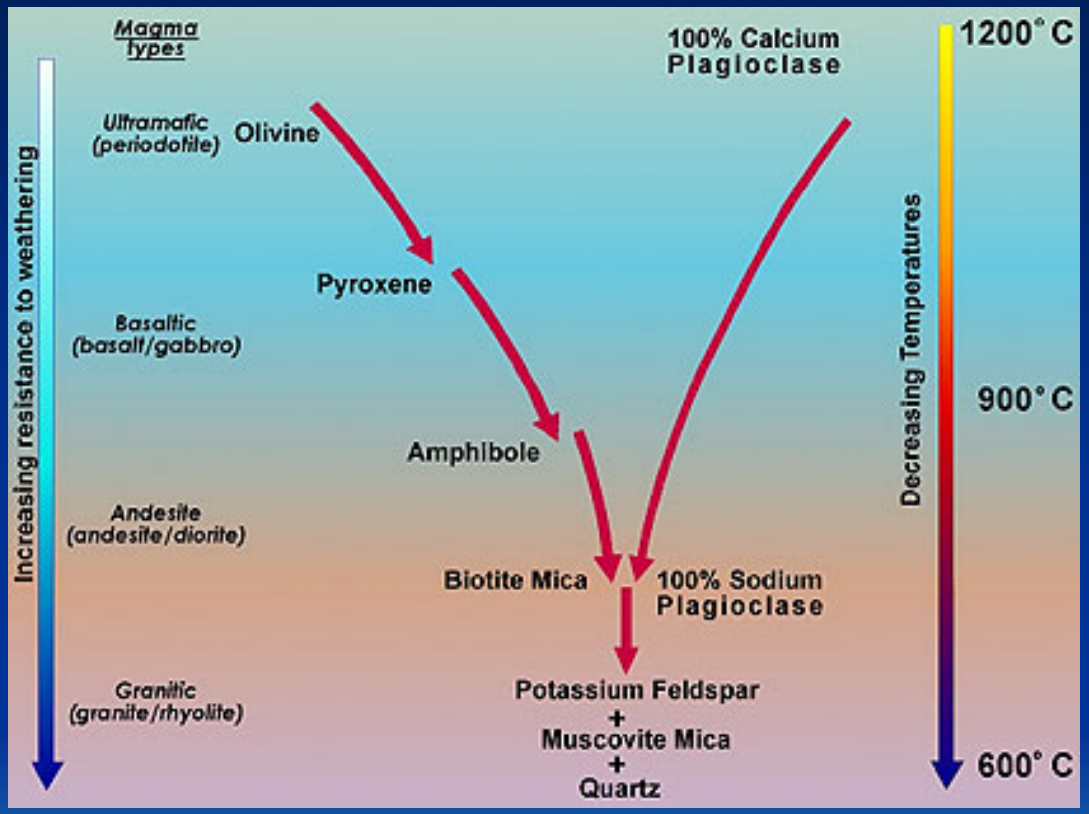



- http://www.rockhounds.com/rockshop/rockkey/index.ht

# Cooling and Crystallization of a Magma

## Bowen's Reaction Series

- ✓ Early forming minerals are Fe-Mg-Ca rich and silica poor @ high temps
- ✓ Later forming minerals become more richer in Na and silica @ mod temps
- ✓ Last forming minerals are most rich in K and silica @ low temps



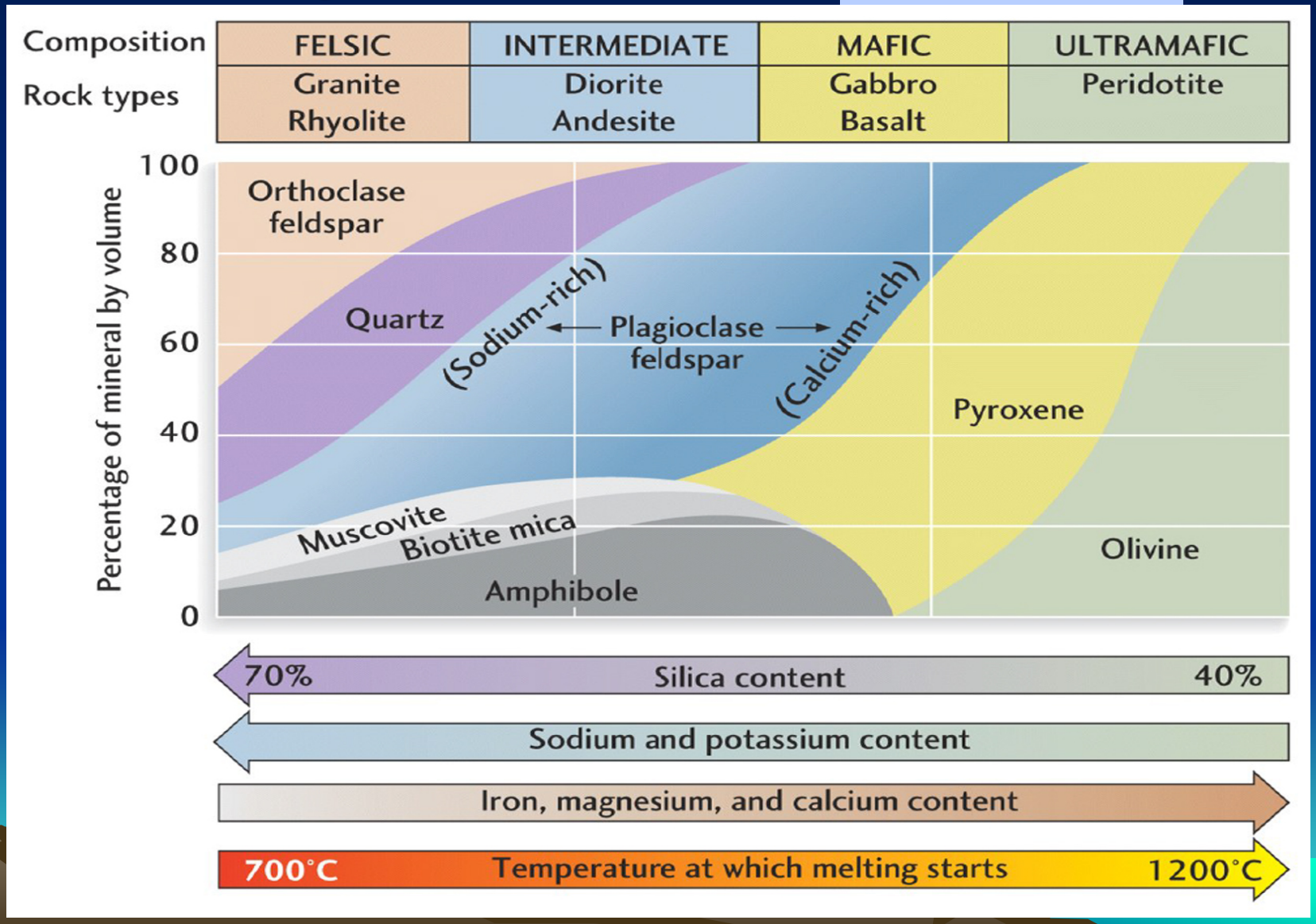

- ✓ Final rock type depends mostly on initial magma composition
- ✓ Crystal fractionation processes can also affect magma comp.

- http://www.rockhounds.com/rockshop/rockkey/index.html

# Mineral Assemblages of Igneous Rock

Light-Colored

Dark-Colored



# Igneous Rock Textures

## Phaneritic Texture:

- ✓ **Coarse Grain Size =** Slow Cooling
- ✓ **Plutonic Rocks** = Coarse-grained

## Aphanitic Texture:

- ✓ **Fine Grain Size =** Fast Cooling
- ✓ **Volcanic Rocks** = Fine-grained

## Porphyritic Texture:

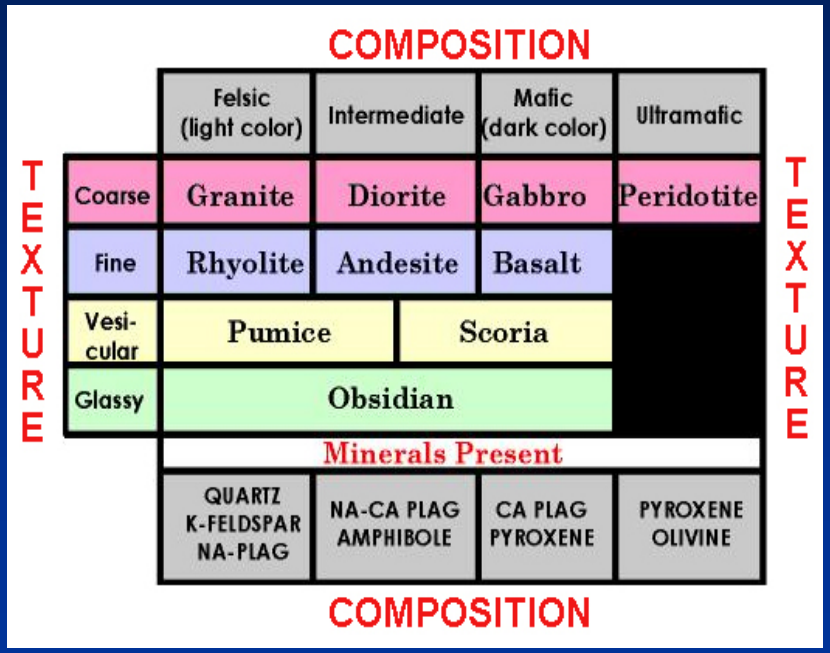
- ✓ Large crystals in aphanitic groundmass = slow cooling followed by rapid cooling
- ✓ **Porphyry Rocks** = Mixed-grain

## Vesicular Texture:

- ✓ Fine-grained to glassy with Cavities
- ✓ Lots of tiny vesicles = pumice
- ✓ Fewer larger vesicles = scoria

## Glassy Texture:

- ✓ Little to no crystals = natural glass
- ✓ Super rapid cooling
- ✓ Obsidian is dark in color
- ✓ Pumice is light in color




- http://www.rockhounds.com/rockshop/rockkey/index.html

# Igneous Rock Pairs

| Classification by texture | |
|---|---|
| *Extrusive* | *Intrusive* |
| *Fine grained* | *Coarse grained* |
| Basalt | gabbro |
| Andesite | diorite |
| Rhyolite | granite |

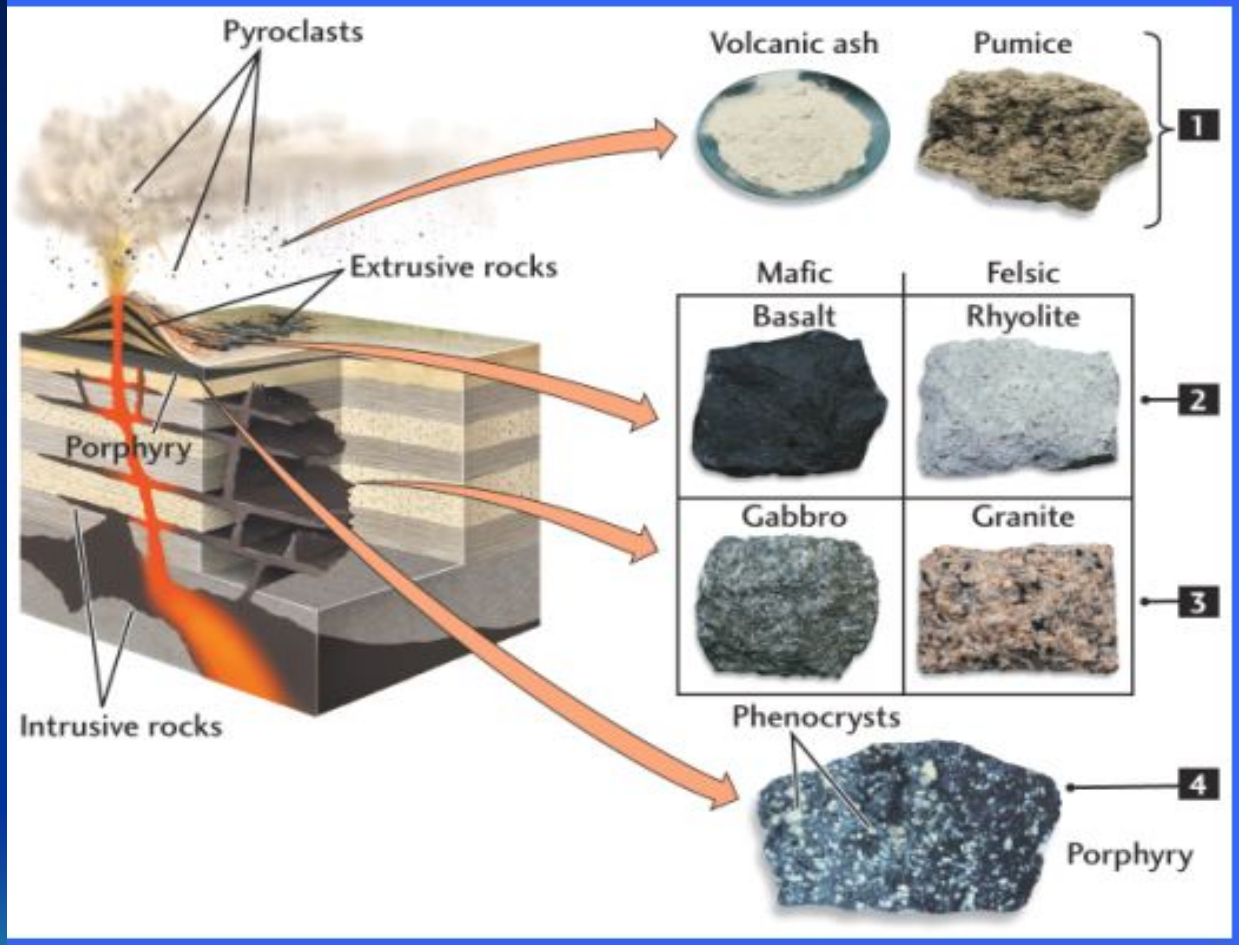
**Classification by composition**

- magnesium (Mg) + iron (Fe) = mafic
- feldspar + quartz (Si) = felsic

Fast Cooling


Slow Cooling

# Formation and texture



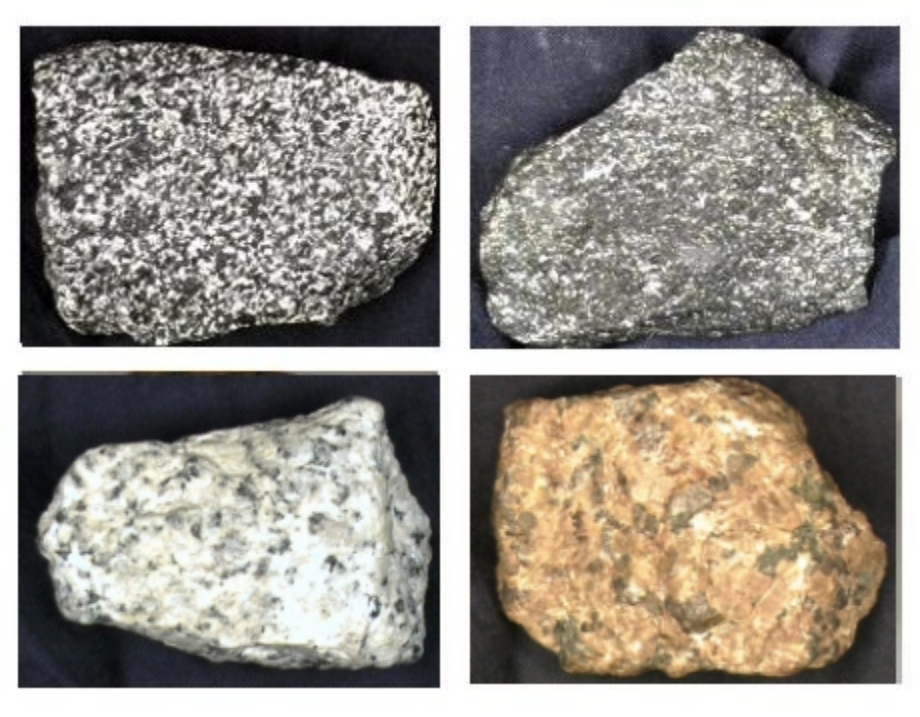

1. **Pyroclasts** form from airborne lava in violent eruption

2. **Extrusive igneous rocks**. Cool rapidly on the Earth's surface

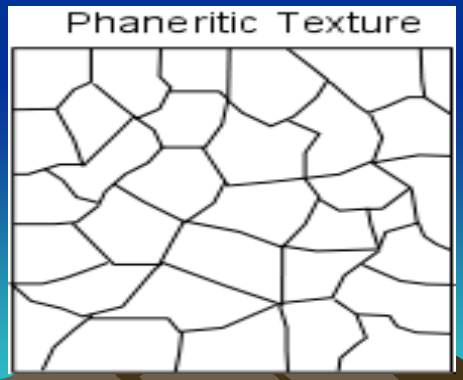
3. **Intrusive igneous rocks**. Cool slowly in the Earth's interior allowing large crystals to form

4. **Porphyry** starts to grow below the surface but before solidification is brought to the surface

# Plutonic Rock Textures



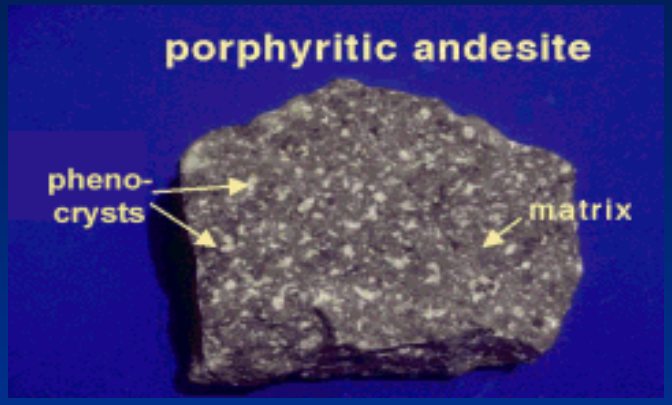
Field Outcrops of Plutonic Rocks



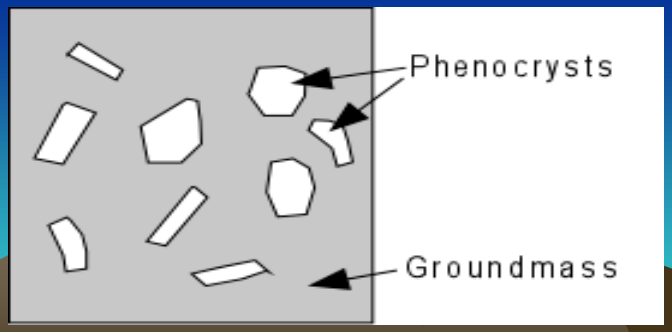

- ✓ Intrusive -Plutonic
- ✓ Coarse-grained
- ✓ Cooled Slowly

# Volcanic Rock Textures

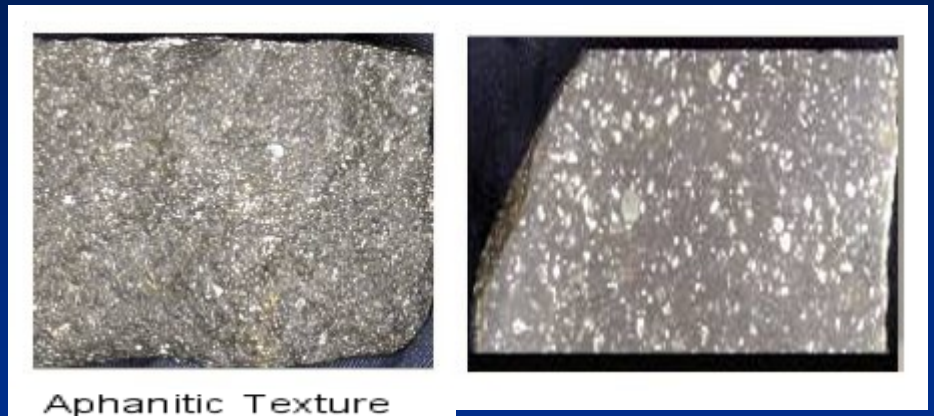
## Porphyritic








## Aphanitic

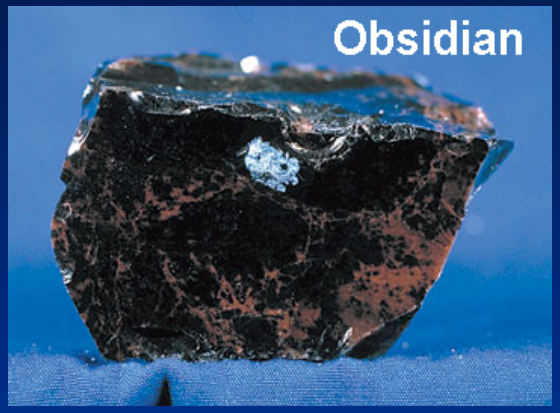



- ✓ Extrusive -Volcanic
- ✓ Fine-grained
- ✓ Cooled Rapidly

- ✓ Combo Plutonic -Volcanic
- ✓ Coarse-grained phenocrysts in a fine-grained groundmass
- ✓ First cooled Slow, then Fast

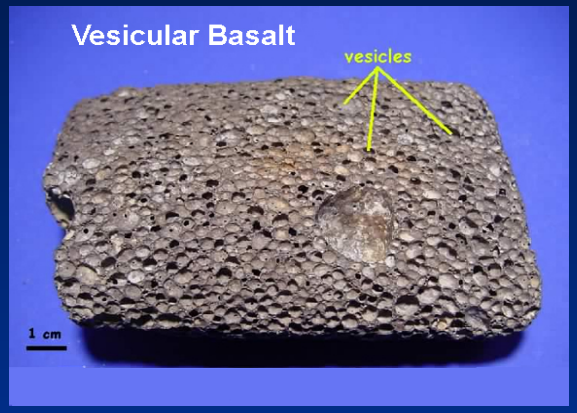
# Other Volcanic Rock Textures

## Glassy





## Vesicular

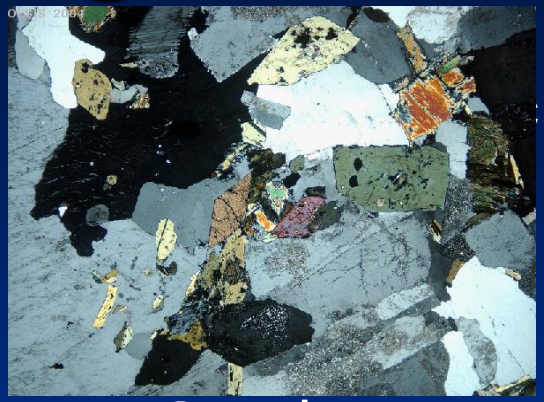





## Fragmental

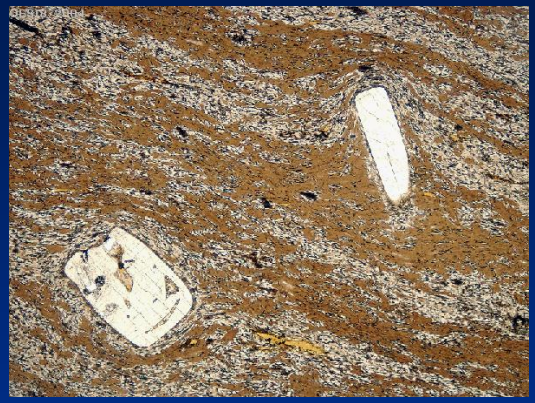


# Igneous Rocks Under a Microscope

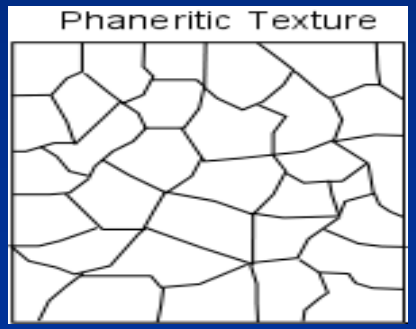


Granite

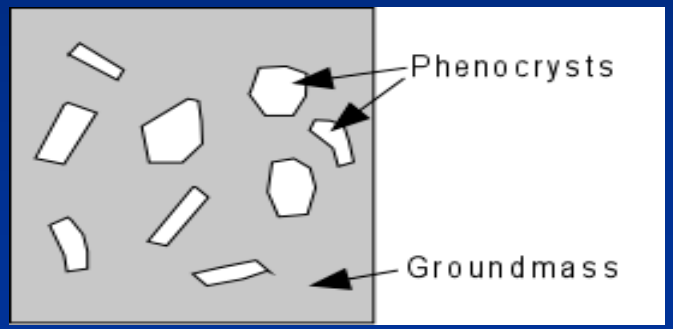
Rhyolite



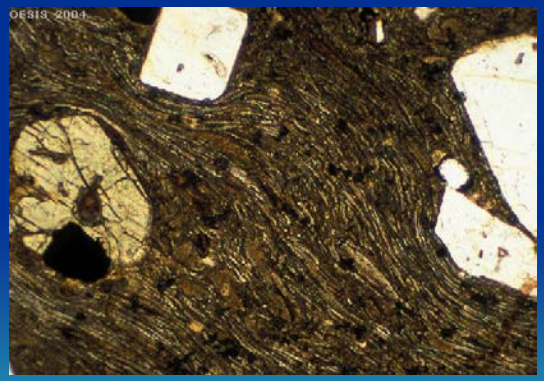
Obsidian



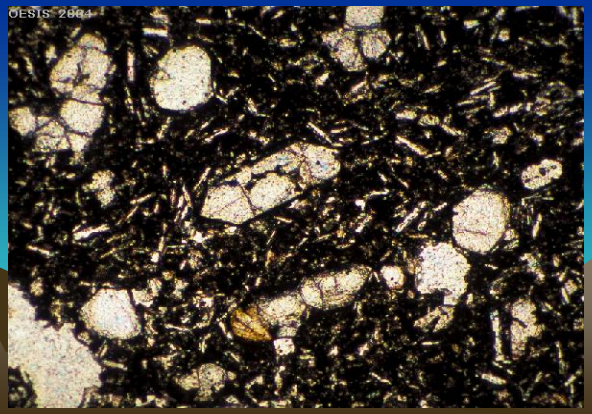

Gabbro




Basalt



Welded Tuff

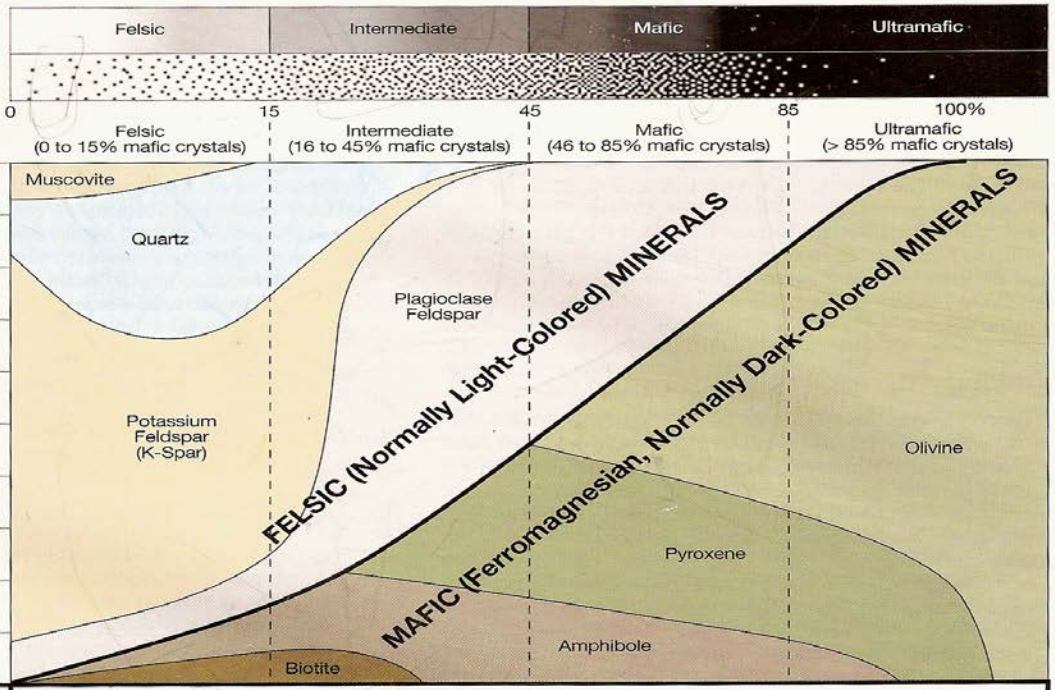


# Color Index of Plutonic Rocks

# Igneous Rock Classification

## IGNEOUS ROCKS CLASSIFICATION

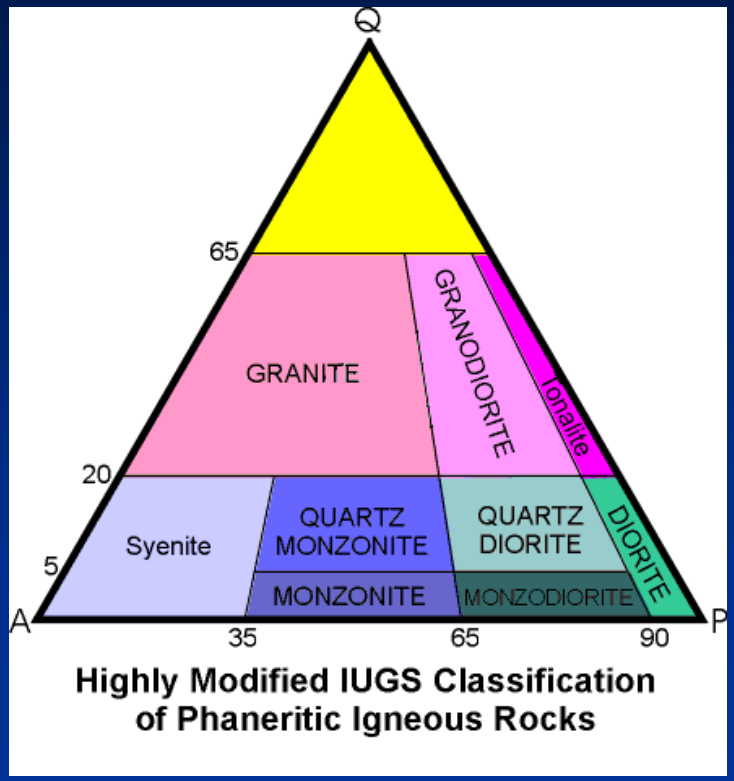
**1. Color Index**
Estimate the rock's color index (CI): % of mafic mineral crystals or darkness of the rock.



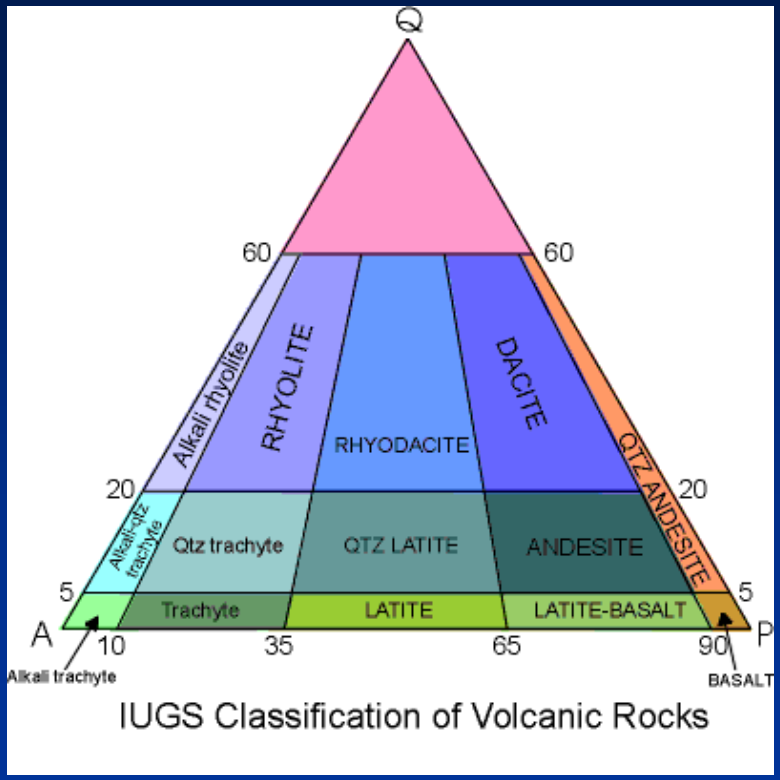

**2. Minerals**
Identify minerals in the rock, if possible, and their percent (by volume) of the whole rock. Skip this step if mineral crystals are not visible or are too small to identify.

| 3. Texture(s) Identify the rock's texture(s). | | 4. Rock Name: Select name below, based on data from steps 1–3. | | | |
|---|---|---|---|---|---|
| INTRUSIVE ORIGIN | Pegmatitic: very coarse-grained | PEGMATITIC GRANITE | PEGMATITIC DIORITE | PEGMATITIC GABBRO | PEGMATITIC PERIDOTITE |
| | Phaneritic: coarse-grained | **GRANITE** (SYENITE, if no quartz) | **DIORITE** | **GABBRO** | **PERIDOTITE** |
| | Phenocrysts[1] in a phaneritic groundmass | PORPHYRITIC GRANITE | PORPHYRITIC DIORITE | PORPHYRITIC GABBRO | PORPHYRITIC PERIDOTITE |
| EXTRUSIVE ORIGIN | Phenocrysts[1] in an aphanitic groundmass | PORPHYRITIC RHYOLITE | PORPHYRITIC ANDESITE | PORPHYRITIC BASALT | Cannot be distinguished from basalt in hand samples (KOMATITE) |
| | Aphanitic: fine-grained | **RHYOLITE** | **ANDESITE** | **BASALT** | |
| | Glassy | OBSIDIAN | | | |
| | Vesicular | PUMICE (abundant tiny vesicles–like meringue; very lightweight; white or gray; floats in water) | | SCORIA (resembles a sponge) VESICULAR BASALT (has few scattered vesicles) | |
| | Pyroclastic or Fragmental | VOLCANIC TUFF (fragments ≤ 2 mm) VOLCANIC BRECCIA (fragments > 2 mm) | | | |

# Igneous Rock Classification




**Granitic Plutonic Rocks**




**Volcanic Rocks**

## Ternary Diagrams:

1) Top corner = quartz; Bottom L. corner = K-spar; Bottom R. corner = Plag

2) Fields indicate tri-mineral proportions in terms of percentages totally 100%

# Igneous Rock Classification

## A Three Step Process

### 1) Determine Composition

- ✓ Color Index (plutonic only)
- ✓ Color darkness (volcanic)
- ✓ Mineralogy (observable)

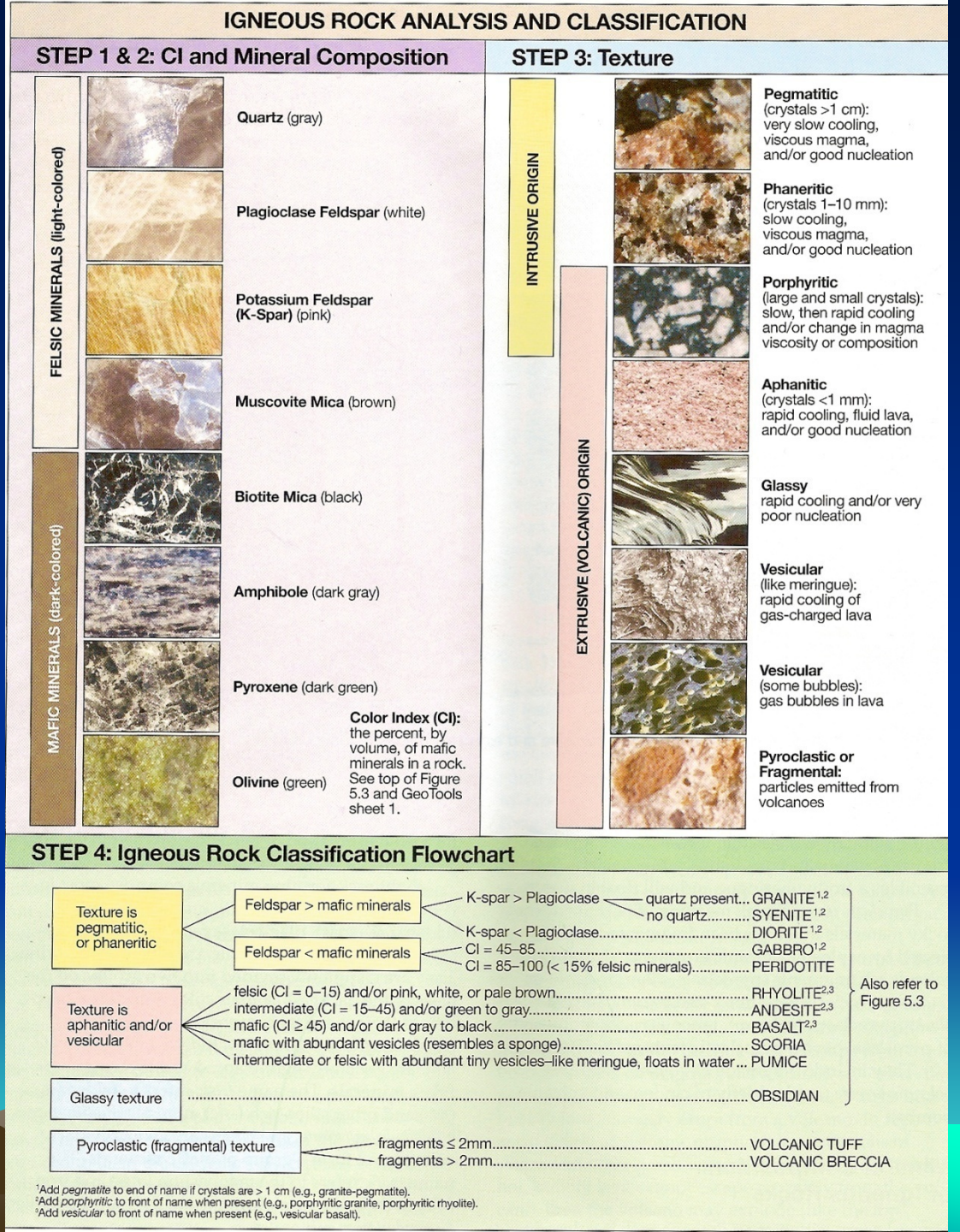
### 2) Determine Texture

- ✓ Specific intrusive texture?
- ✓ Specific extrusive texture?

### 3) Name the Rock

- ✓ Use Flowchart

**Practical Use for Rock?**



# Igneous Rock Classification

A Three Step Process

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- ✓Color Index min % (plutonic only)
- ✓Color index darkness (volcanic)
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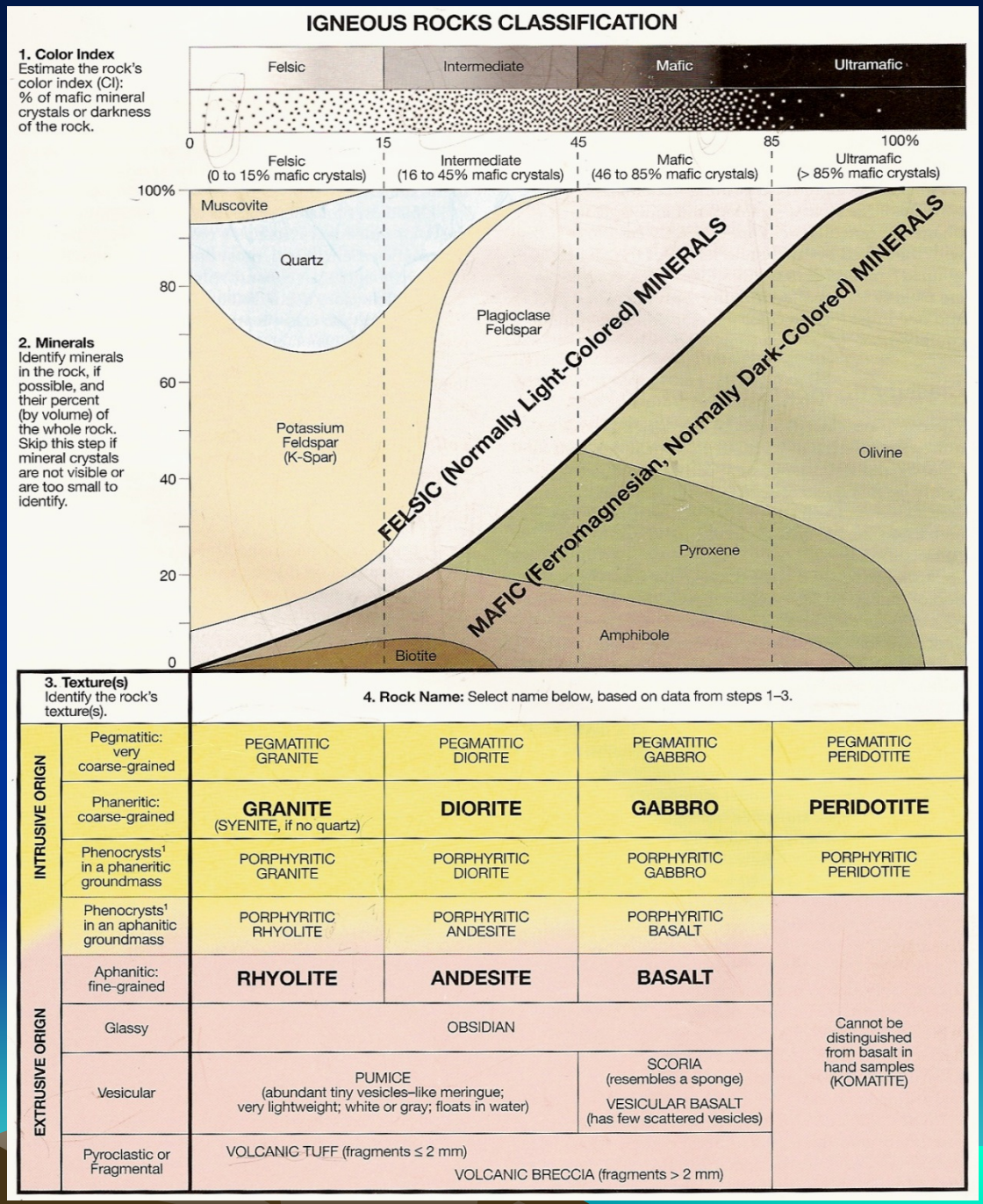


# Igneous Rock Identification Procedure

**Step 1:** Observe and record the rock's **TEXTURE**

- ✓ **Pegmatitic**
- ✓ **Phaneritic**
- ✓ **Aphanitic**
- ✓ **Porphyritic**
- ✓ **Fragmental**
- ✓ **Others = vesicular or glassy**

**Step 2:** IF ***Phaneritic* or *Pegmatitic*-** Identify and record the minerals and the volume % of dark minerals = ***COLOR INDEX*.**

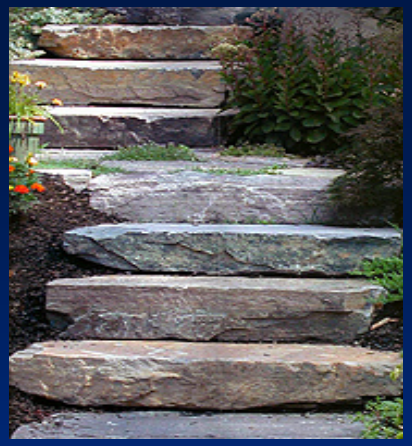
**Note: Color index** applicable for **course-grained rocks ONLY**! **OR**

IF ***Aphanitic*** or ***Porphyritic*** = no to some observable minerals, then estimate composition by the **OVERALL ROCK COLOR**.

**Note:** ("light" = felsic/silisic, "medium" = intermediate, and "dark" = mafic).

**Step 3:** **NAME the ROCK – based on texture/composition combo**

# Applications

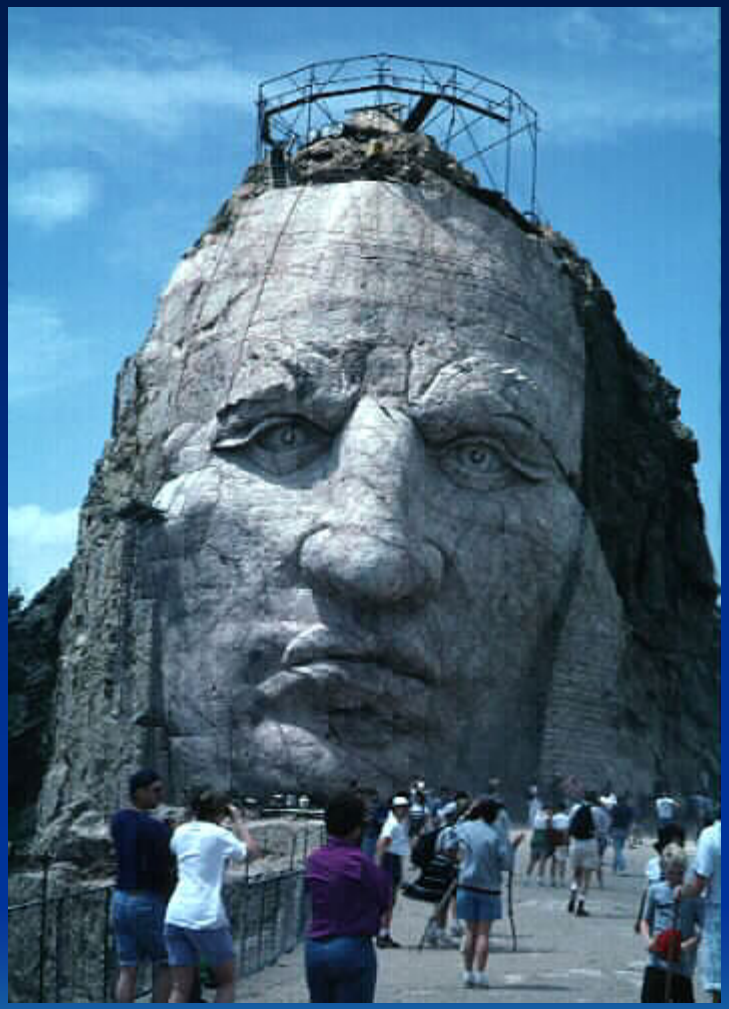


Granite, Diorite and Gabbro - used for flooring, countertops, walls, steps, cobblestone paving, gravestones, and various landscaping applications

Volcanic Rock - used for various landscaping applications


http://www.stonecontact.com/library.asp

# Igneous Rock References

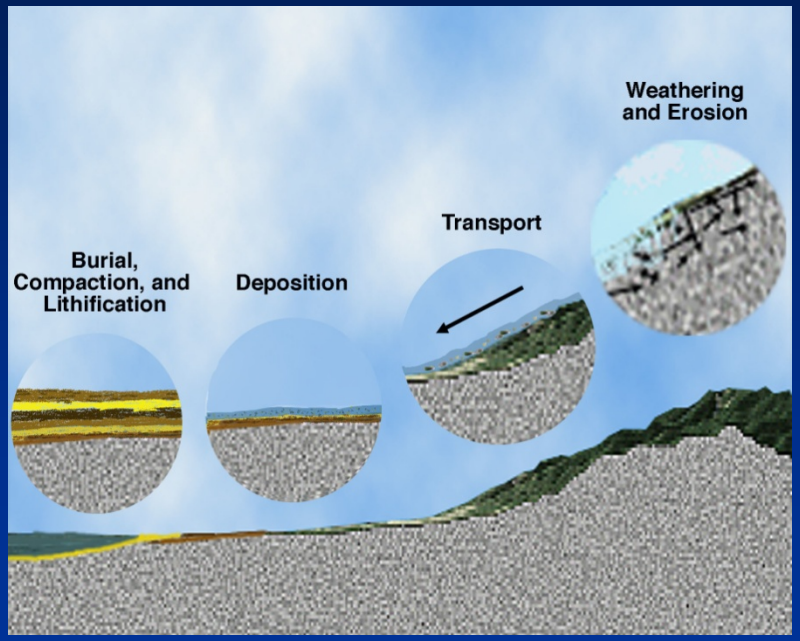


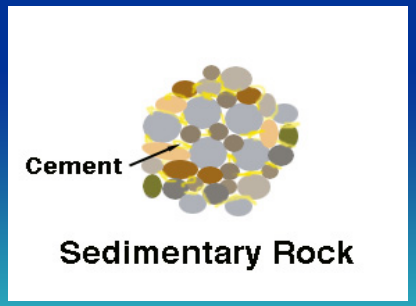
http://www.cobweb.net/~bug2/mineral.htm
http://www.rockhounds.com/rockshop/rockkey/index.html
http://www.union.edu/PUBLIC/GEODEPT/COURSES/geo-10/mineral.htm

- http://academic.brooklyn.cuny.edu/geology/grocha/mineral/mineral.html

# Sedimentary Rocks

## Origin, Properties and Identification

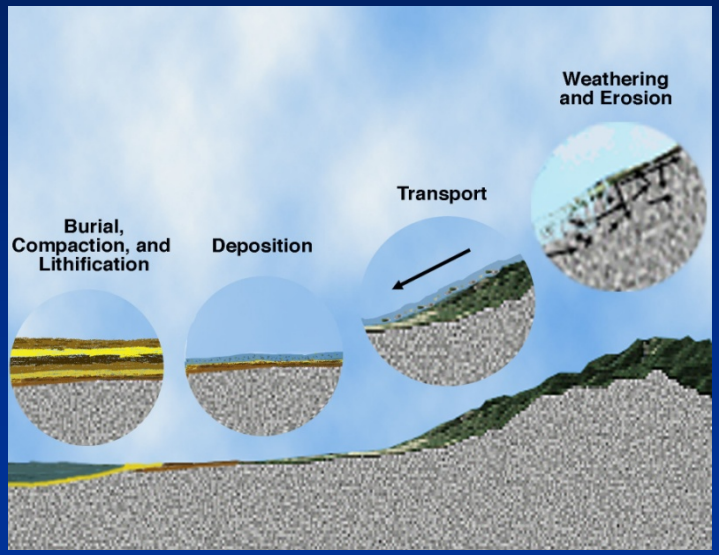



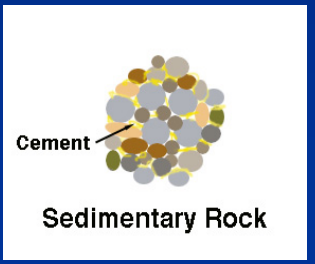

**Intro to Earth Systems**

**ENVI 110 Lab**

Ray Rector - Instructor

# Sedimentary Rock Origin and Identification Lab




Pre-Lab Internet Link Resources

1) http://www.rockhounds.com/rockshop/rockkey/index.html

2) http://earthsci.org/education/teacher/basicgeol/sed/sed.html#top

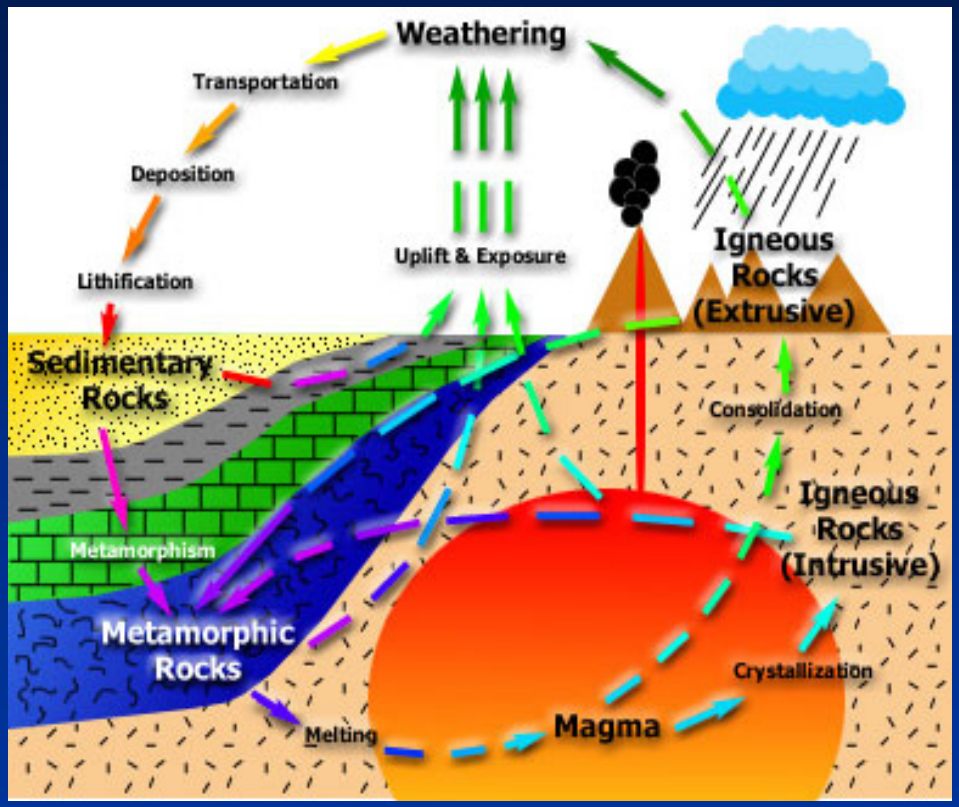
# Major Sedimentary Concepts

1) Sedimentary rocks form by depositing, compaction, and cementing of sediment grains, and/or precipitation of crystals from an aqueous solution
2) The type of sedimentary rock formed is controlled by two factors: **1)** type of sediment and **2)** depositional environment
3) The ***five primary depositional environments*** of sedimentation worldwide are **1)** lakes and river systems, **2)** alluvial fans and deserts, **3)** shorelines, **4)** continental margins (shelves, slopes and rises) , and **5)** deep ocean floor.
4) Source rock, climate, weathering, erosion, and deposition conditions control the nature of the deposited sediments, and hence the types of sedimentary rocks that form at each of the five sedimentary sites described above.
5) Sedimentary rocks formed by cementing of clastic grains are called ***detrital*** rocks.
6) Sedimentary rocks formed by the precipitation and/or cementing of shell, skeleton, or plant material are called ***biochemical*** rocks.
7) Sedimentary rocks formed by the precipitation and cementing of material directly from an aqueous solution like seawater are called ***chemical*** rocks**.**
8) Identification of sedimentary rocks based on two criteria:
   - ✓ **Texture**
   - ✓ **Composition**

# Sedimentary Rocks in The Rock Cycle

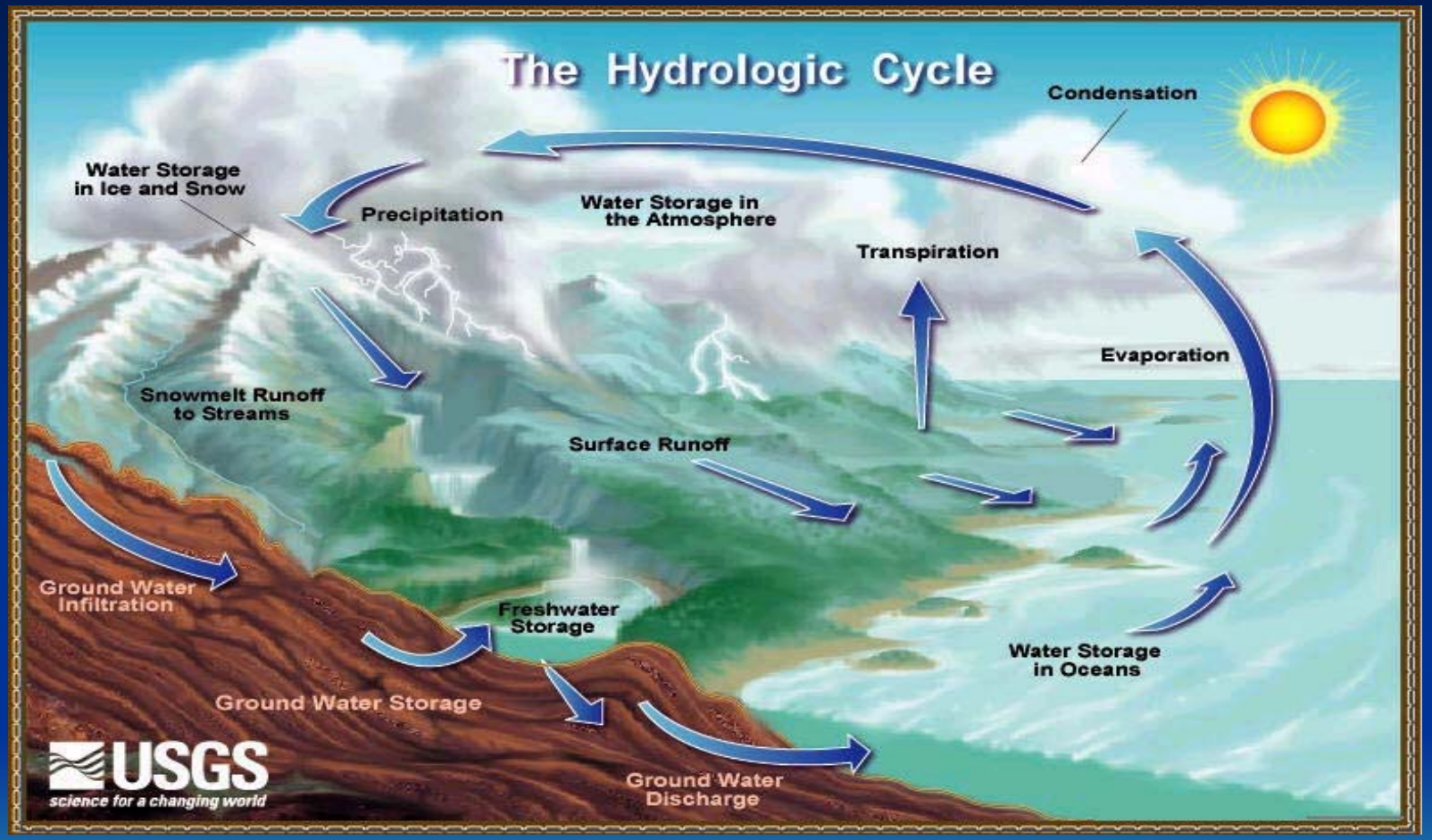
**Key Points:**

1) Part of rock cycle involving materials, conditions and processes *at or near Earth's surface*
2) Begins with weathering of uplifted, exposed rock
3) Continues with the erosion (removal and transportation) of weathered sediment
4) Finishes with the deposition and lithification of sediment




The Rock Cycle

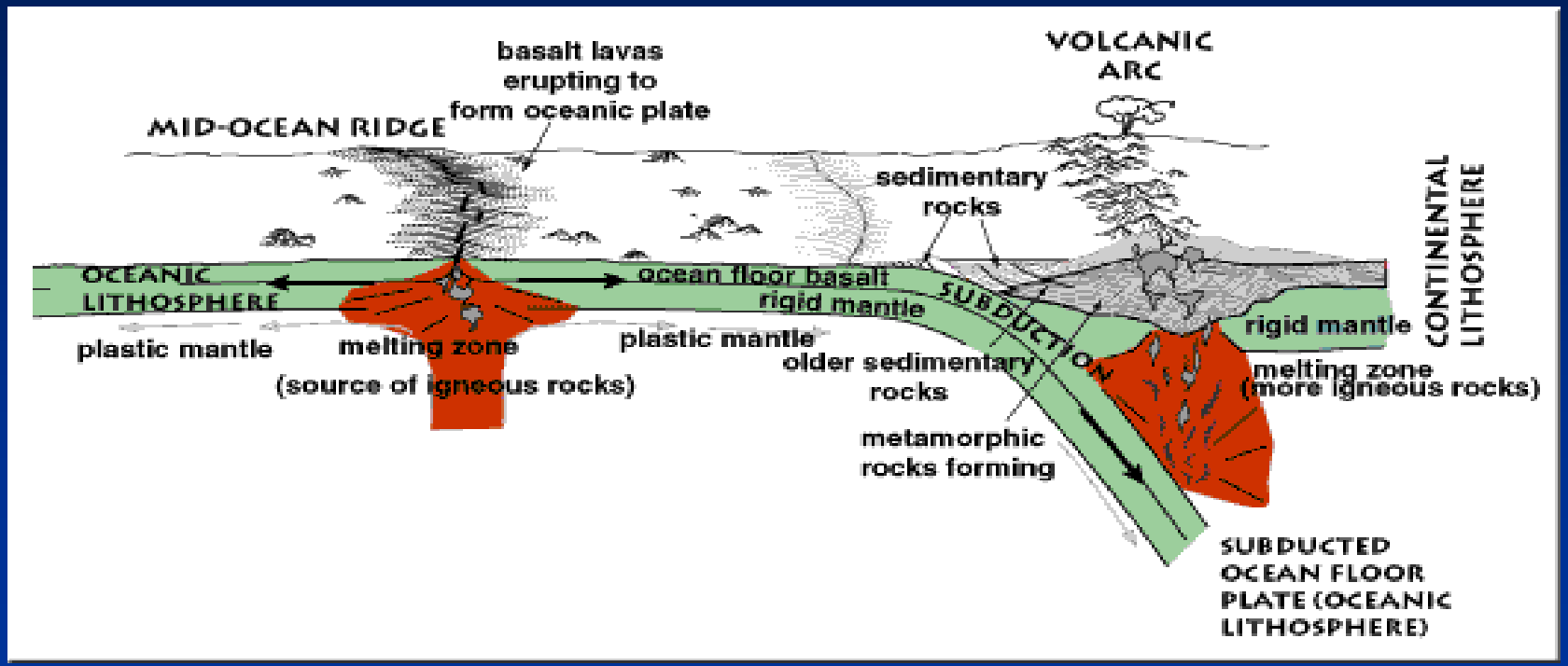
# Water Cycle = Mother Sedimentary




1) **Agents** = Sun, Water, Air and Gravity

2) **Processes** = Weathering, Erosion and Deposition

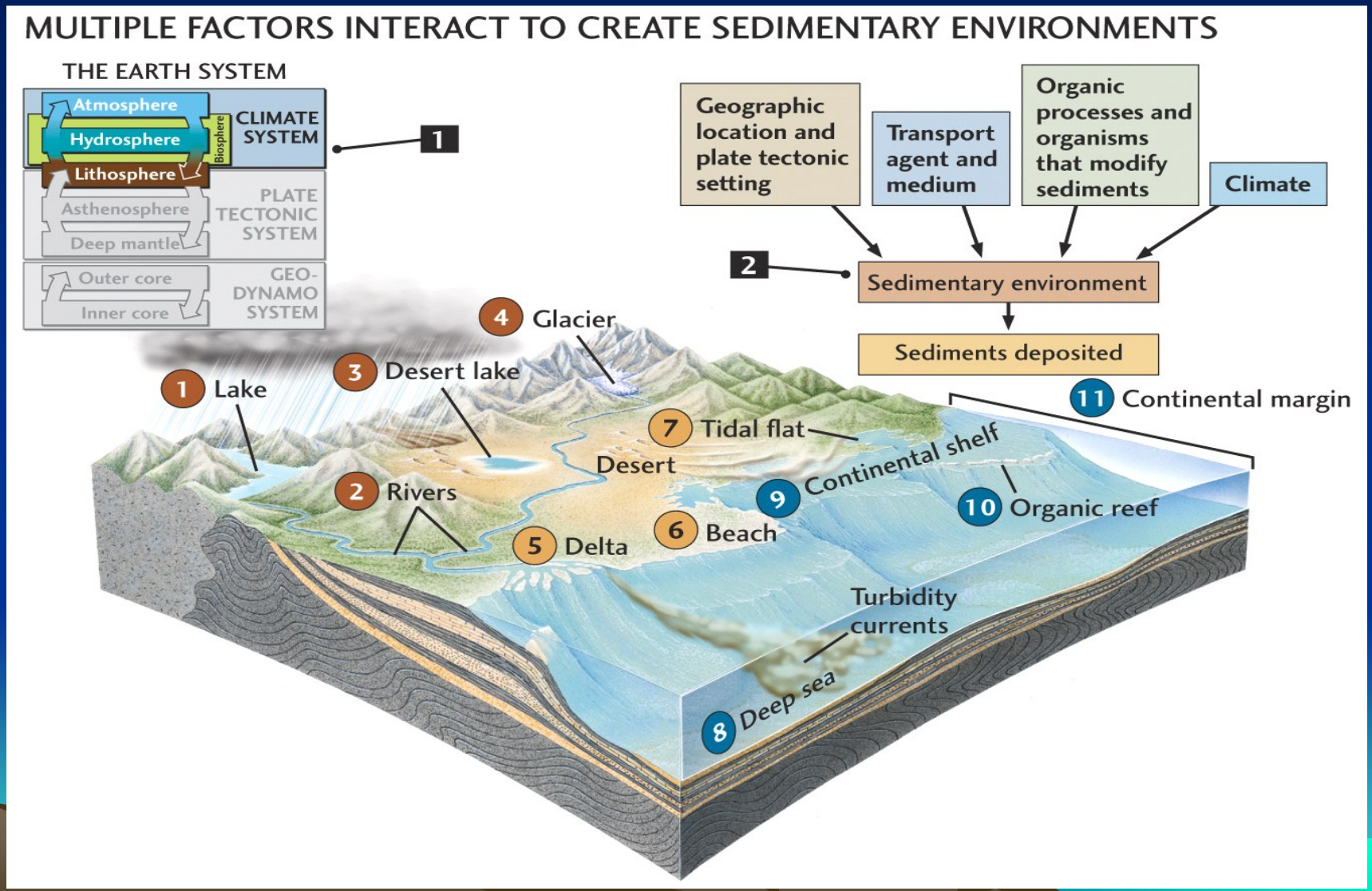
# Tectonic Environments and Sedimentary Rock Formation




1) ***Source regions*** for sediments are primarily convergent plate boundaries

2) ***Depositional sites*** for sediments are primarily the edges of ocean basins

# Sedimentary Environments Where Sedimentary Rocks Form

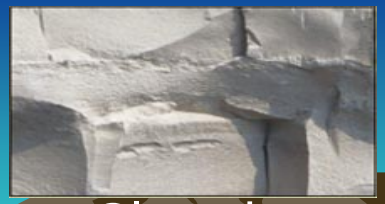


# Predominant Sediment Clast Types at Specific Depositional Settings

Gravel-size

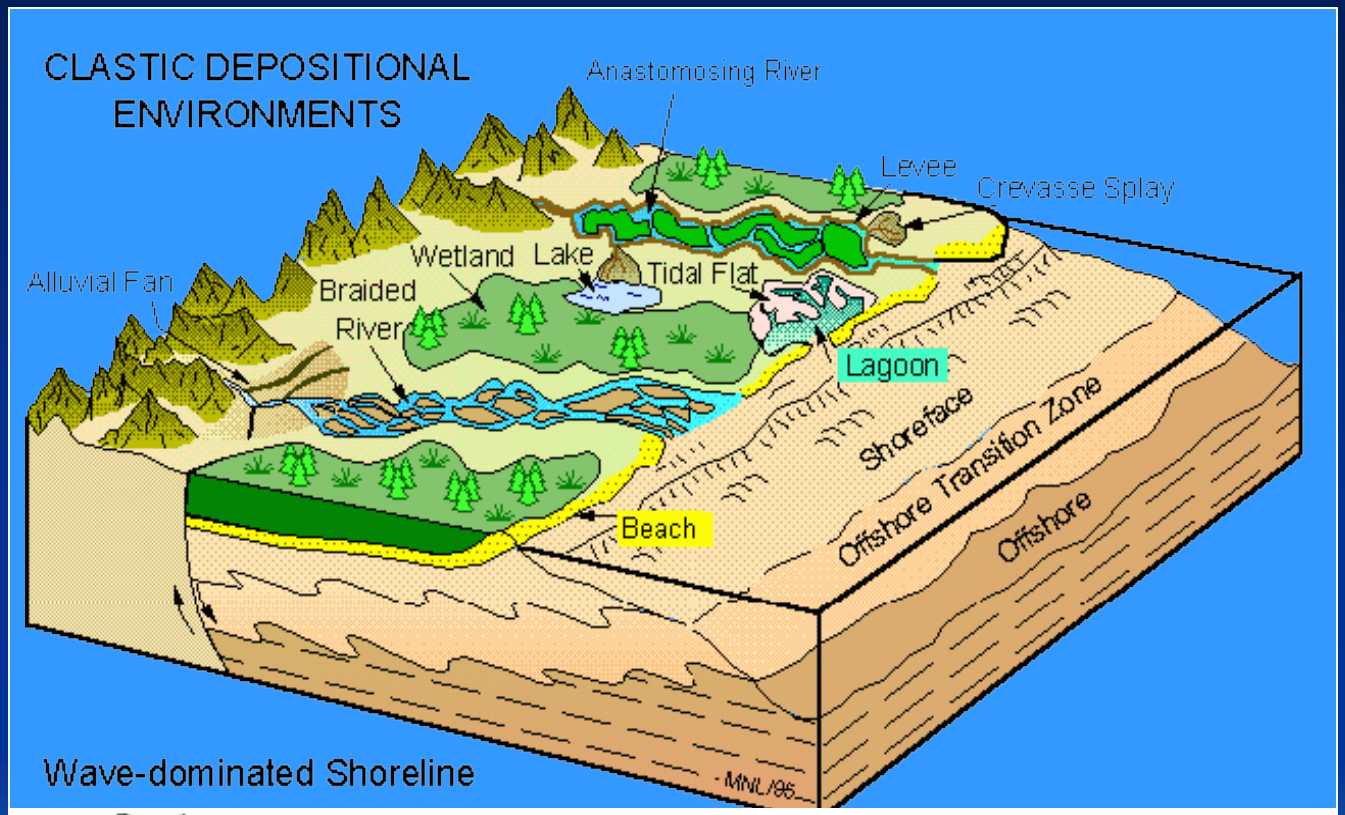
Sand-size

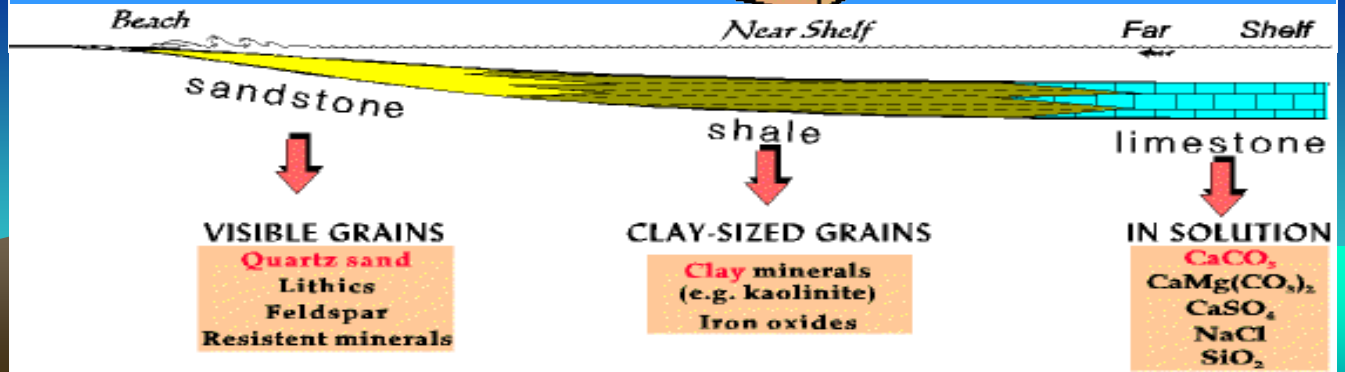
Silt-size



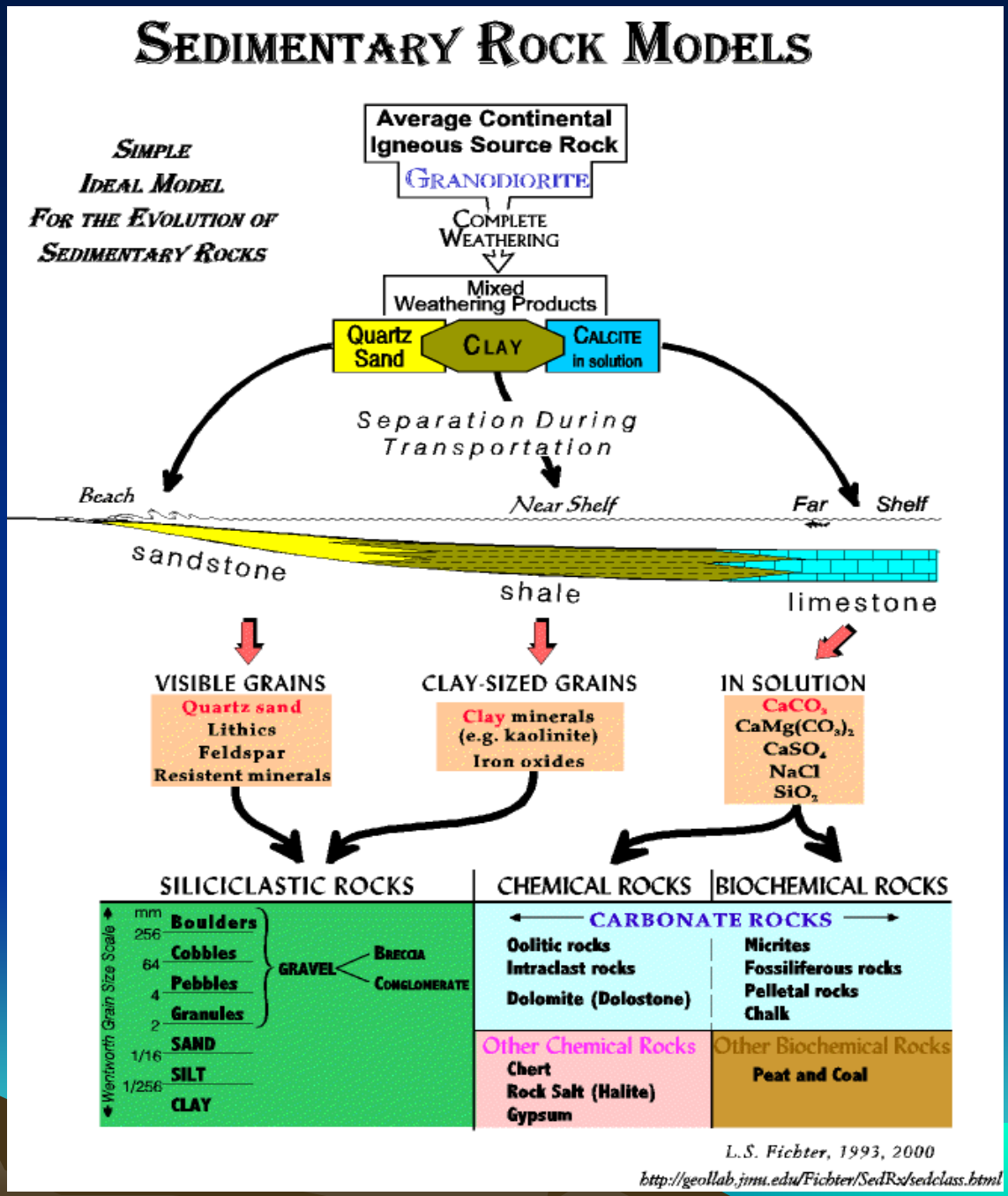
Clay-size

**Clast Size**



# Sedimentary Rock Models



# Sediment Clast Types

## Clast Size

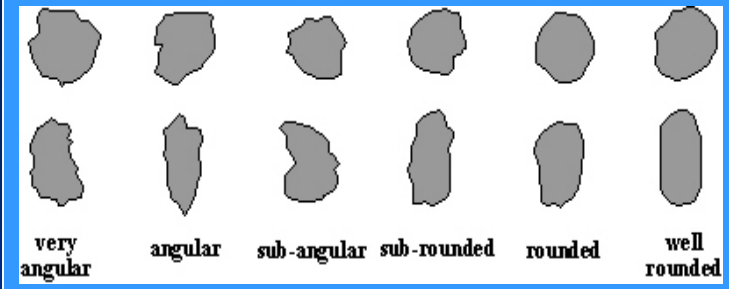
Gravel-size

Sand-size

Silt-size

Clay-size

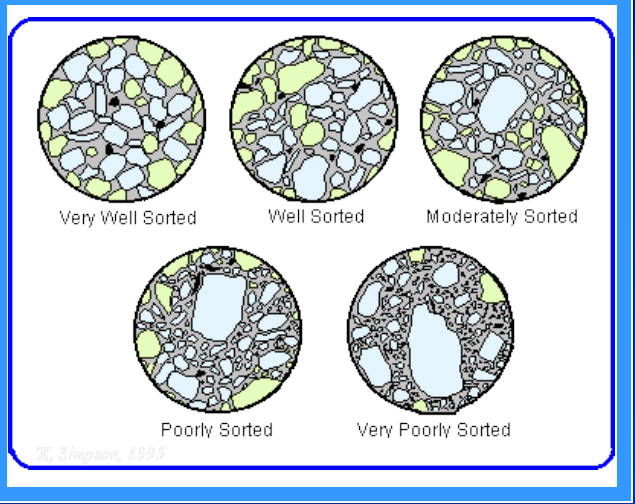
## Clast Shape




Near-to-source

Far-from-source

## Clast Sorting




1) **Clast size** is a function of transport time and medium

- ✓ An indicator of depositional environment

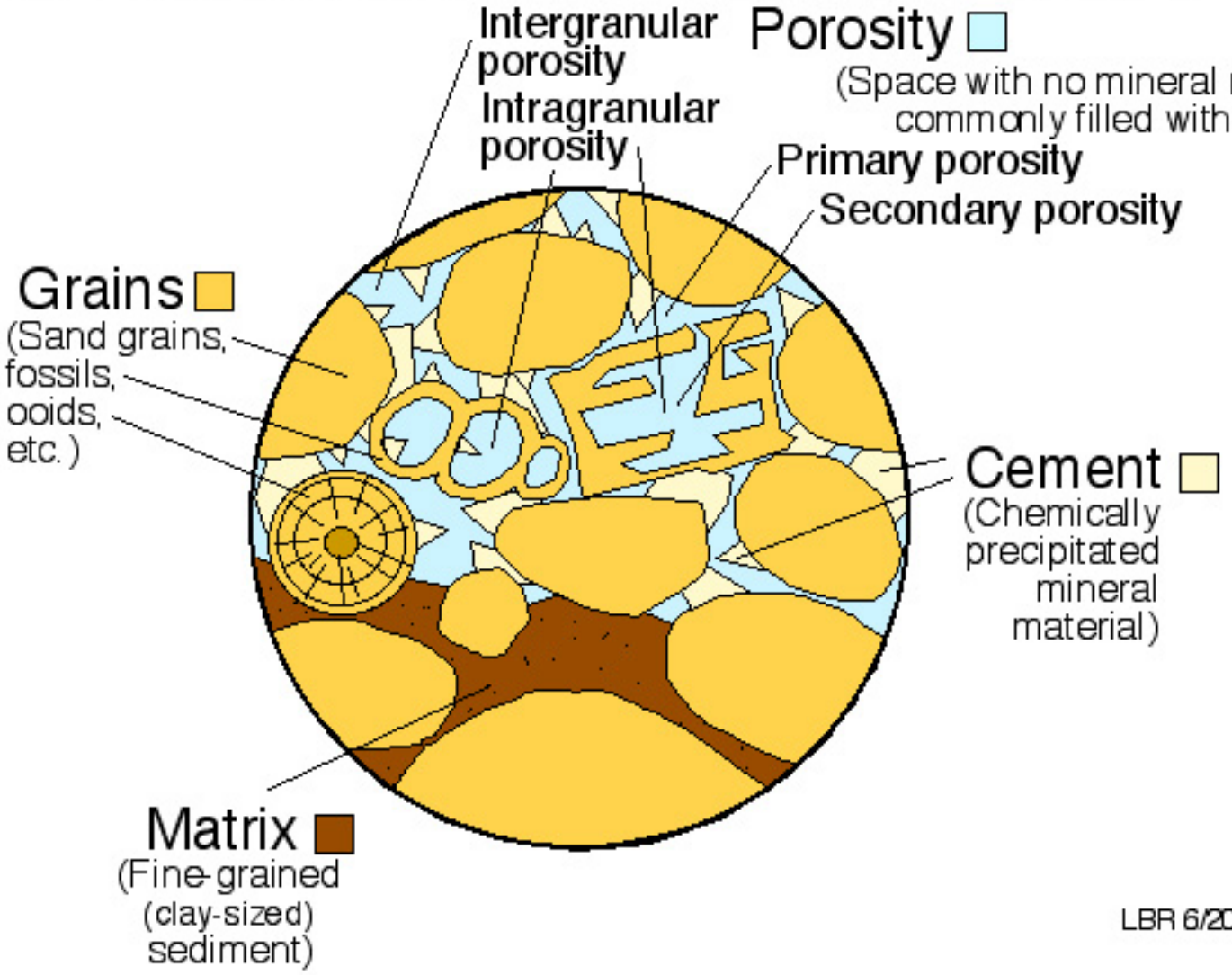
2) **Clast shape** is a function of transport distance and time

- ✓ An indicator of sediment “maturity”

3) **Clast sorting** is a function of transport medium

- ✓ An indicator of depositional environment

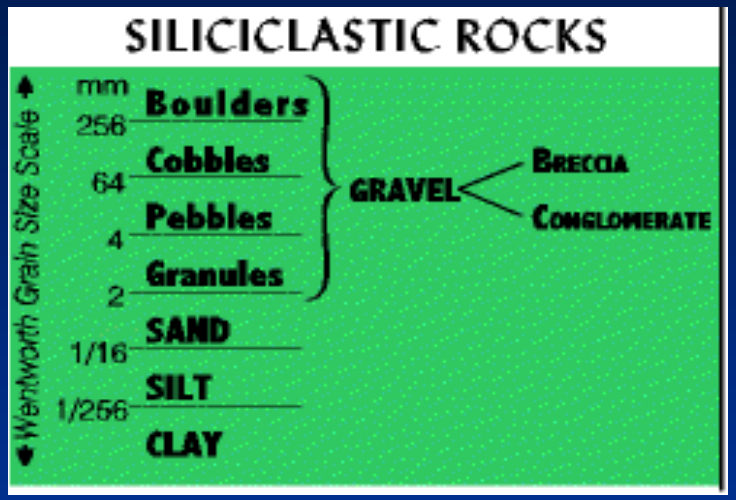
# Four Fundamental Components of Sedimentary Rocks



# Three Major Groups of Sedimentary Rocks

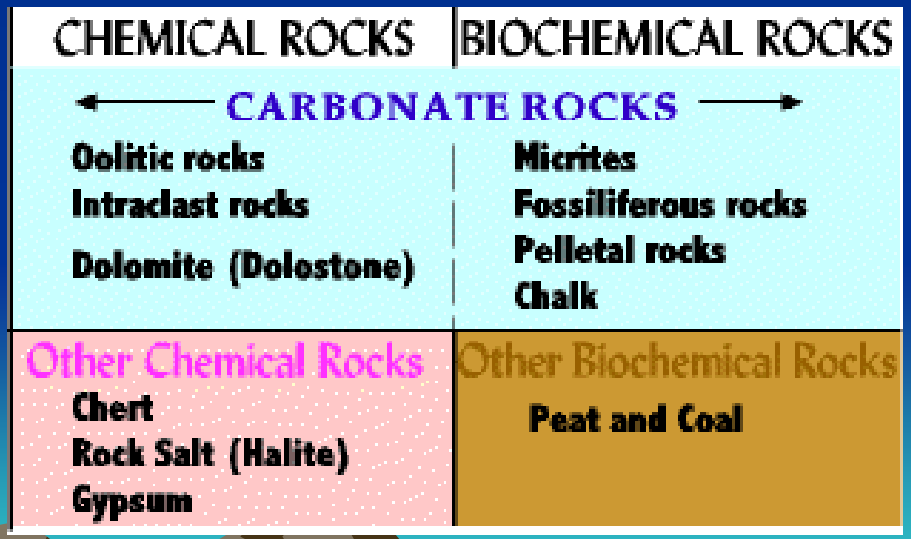
**1)** Siliciclastic

- ✓ Breccia and Conglomerate
- ✓ Sandstone
- ✓ Siltstone
- ✓ Shale




**2)** Biochemical

- ✓ Limestone and Coal
- ✓ Biogenic origin
- ✓ Clastic and Crystalline




**3)** Chemical

- ✓ Chert, Rock Salt, and Gypsum
- ✓ Inorganic origin
- ✓ Crystalline

http://earthsci.org/mineral/mineral.html

# Sedimentary Detrital Rock Textures

## Breccia Texture:

- ✓ Very coarse-grained
- ✓ Angular fragments
- ✓ Deposits lose to source region

## Conglomerate Texture:

- ✓ Very coarse-grained
- ✓ Rounded Fragments
- ✓ Deposits far from source reg

## Sandstone Texture:

- ✓ Coarse to medium-grained
- ✓ Mostly quartz and feldspar
- ✓ Deposits in moving waters

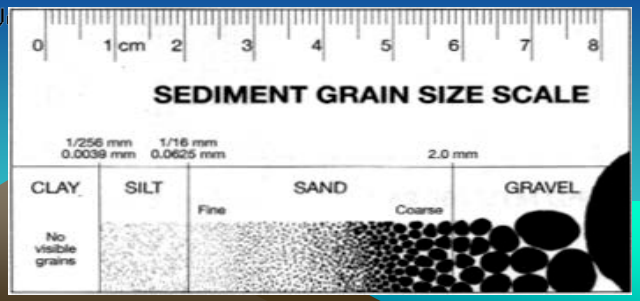
## Siltstone texture:

- ✓ Fine-grained = silt-sized
- ✓ Mostly quartz and feldspar
- ✓Deposits in fairly quiet waters

## Shale Texture:

- ✓ Very fine-grained = clay-sized
- ✓ Mostly clay
- ✓ Deposits in very quiet waters

| Phi Units* | Size | Wentworth Size Class | Sediment/Rock Name |
|---|---|---|---|
| -8 | 256 mm | Boulders | Sediment: GRAVEL<br>Rock RUDITES: (conglomerates, breccias) |
| -6 | 64 mm | Cobbles | |
| -2 | 4 mm | Pebbles | |
| -1 | 2 mm | Granules | |
| 0 | 1 mm | Very Coarse Sand | Sediment: SAND<br>Rocks: SANDSTONES (arenites, wackes) |
| 1 | 1/2 mm | Coarse Sand | |
| 2 | 1/4 mm | Medium Sand | |
| 3 | 1/8 mm | Fine Sand | |
| 4 | 1/16 mm | Very Fine Sand | |
| 8 | 1/256 mm | Silt | Sediment: MUD<br>Rocks: LUTITES (mudrocks) |
| | | Clay | |



# Sedimentary (Bio)Chemical Textures

## Clastic and Crystalline

### Sparite Texture:

- ✓ Coarse-grained crystalline
- ✓ Carbonate minerals
- ✓ Halite and Gypsum
- ✓ With or without fossils

### Micrite Texture:

- ✓ Fine-grained crystalline
- ✓ Carbonate minerals
- ✓ With or without fossils


### Coquina Texture:

- ✓ Coarse-grained
- ✓ Mostly shell material
- ✓ Carbonate minerals

### Microcrystalline texture:

- ✓ Extremely fine-grained
- ✓ Smooth, massive looking
- ✓ Deposits in quiet waters
- ✓ Chert and Travertine

### Fossiliferous Texture:

- ✓ Abundant fossils
- ✓ Either crystalline or clastic groundmass
- ✓ Usually carbonate rich

# Sedimentary Rock Structures

Mud Cracks

Ripple Marks

Cross Bedding

Graded Bedding

Layering


Bioturbation

# Sedimentary Rock Classification

- **A Three Step Process**

**1) Find Rock Composition**

- ✓ Detrital? Crystalline?
- ✓ Mineralogy?

**2) Find Texture**

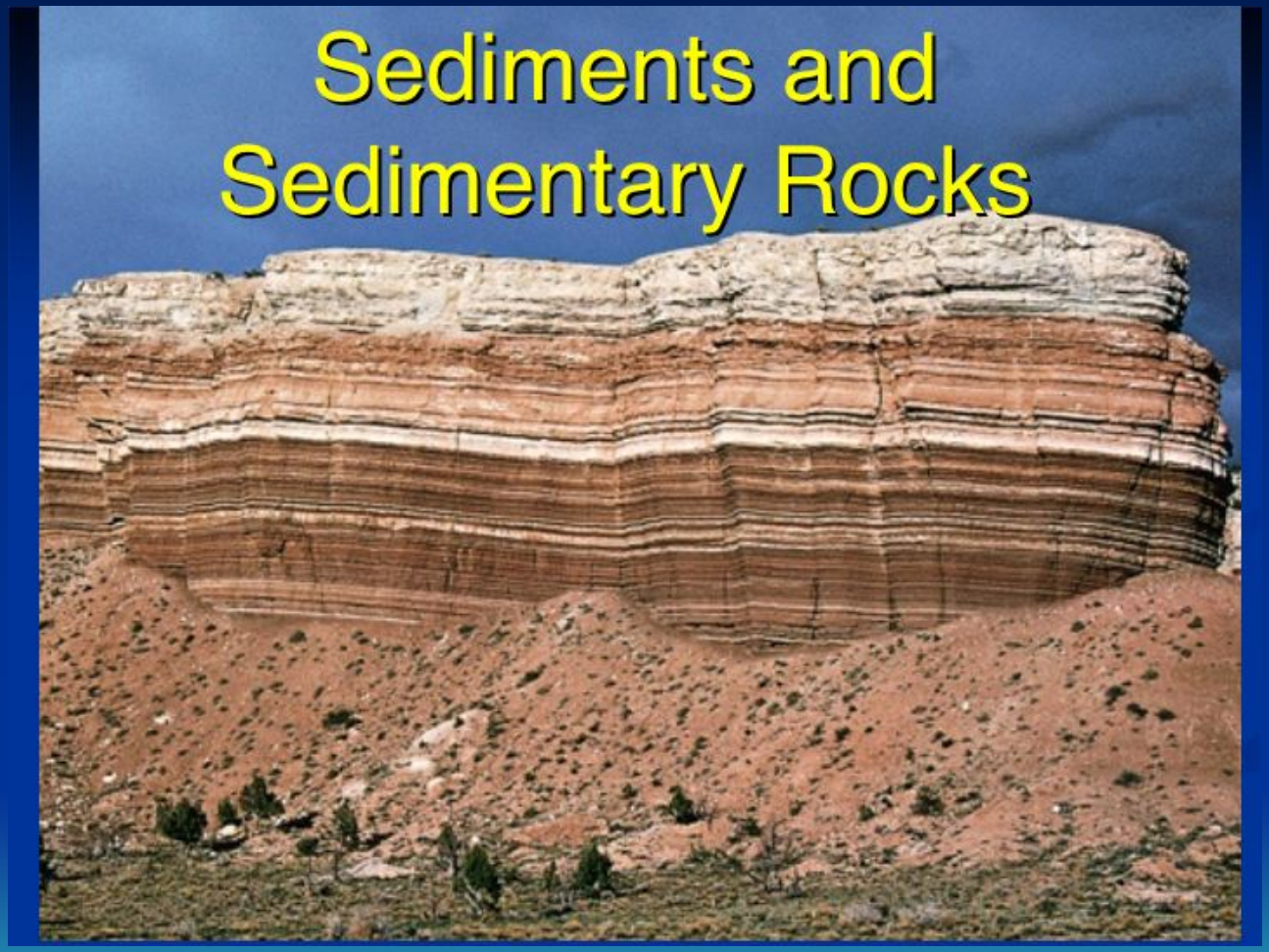
- ✓ Grain size?
- ✓ Shape?
- ✓ Fossils?

**3) Name the Rock**

## SEDIMENTARY ROCK ANALYSIS AND CLASSIFICATION

| STEP 1: What is the rock's composition? | | STEP 2: What are the rock's textural and other distinctive properties? | | STEP 3: Rock Name(s) | |
|---|---|---|---|---|---|
| DETRITAL (CLASTIC) | Mainly rock fragments or mineral grains (quartz, feldspar, clay) weathered from other rocks | Mainly gravel (≥ 2 mm) | Rounded grains | CONGLOMERATE | |
| | | | Angular grains | BRECCIA | |
| | | Mainly sand (1/16 – 2 mm) | Mostly quartz grains | QUARTZ SANDSTONE | SANDSTONE |
| | | | Mainly feldspar and quartz | ARKOSE | |
| | | | Sand is mixed with much silt and/or clay (mud) | GRAYWACKE | |
| | | Mainly Mud (< 1/16 mm) — Mostly silt (1/256 – 1/16 mm) | Breaks into blocks or layers | SILTSTONE | MUDSTONE |
| | | Mainly Mud (< 1/16 mm) — Mostly clay (< 1/256 mm) | Crumbles or breaks into blocks | CLAYSTONE | |
| | | | Fissile (splits easily) | SHALE | |
| BIOCHEMICAL: Mainly fossil shells or plant fragments | Mainly plant fragments or charcoal | Dull brown with visible plant fragments | Porous and easy to break apart the plant fragments | PEAT | |
| | | Black | Dense and brittle or porous and sooty | BITUMINOUS COAL | |
| | Mainly fossil shells, shell fragments, or microfossils. Effervesces in dilute HCl | Mostly visible shells and shell fragments cemented into a dense mass | | CALCIRUDITE | LIMESTONE |
| | | Mostly sand-sized fragments. May have a few larger shells. | | CALCARENITE | |
| | | Mostly very fine grained to microcrystalline mass of calcite and microfossils | | MICRITE | |
| | | Porous, poorly cemented mass of shells and shell fragments | | COQUINA | |
| | | Mostly very fine grained, earthy, chalky, light-colored mass of microfossils | | CHALK | |
| CHEMICAL (INORGNIC): Chemically precipitated crystals | Mainly crystals of calcite or aragonite, $CaCO_3$. Effervesces in dilute HCl | Crystalline to microcrystalline bands of calcite crystals | | TRAVERTINE | |
| | | Spherical grains like tiny beads (< 2 mm) with concentric laminations | | OOLITIC LIMESTONE | |
| | Mainly dolomite $CaMg(CO_3)_2$ | Microcrystalline | Effervesces in dilute HCl only if powdered | DOLOSTONE | |
| | Mainly varieties of quartz, $SiO_2$ (chalcedony, flint, chert, opal, jasper, etc.) | Microcrystalline, conchoidal fracture | Scratches glass | CHERT | |
| | Mainly halite, NaCl | Crystals formed as inorganic chemical precipitates | Salty taste | ROCK SALT | |
| | Mainly gypsum, $CaSO_4 \cdot 2H_2O$ | Crystals formed as inorganic chemical precipitates | Can be scratched with your fingernail | ROCK GYPSUM | |
| | Mostly iron-bearing minerals, like limonite and hematite | Amorphous or microcrystalline | Dark-colored, usually brown or red-gray | IRONSTONE | |

# Discussion and Examination

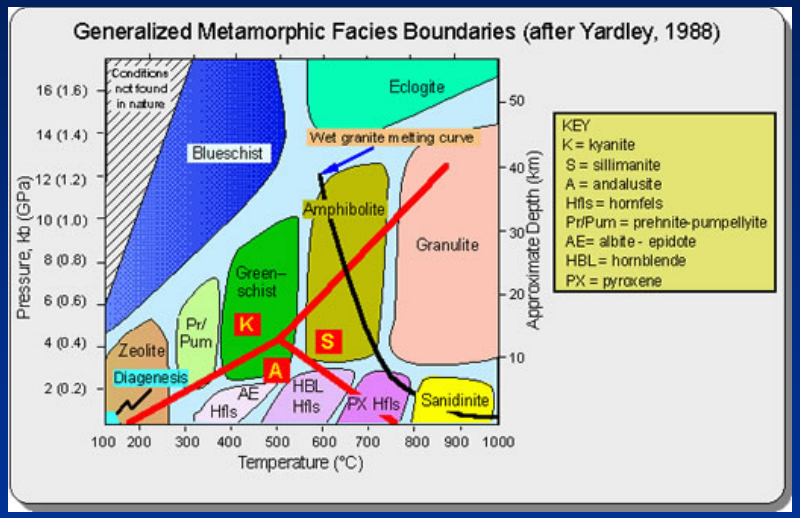



http://www.cobweb.net/~bug2/mineral.htm

http://www.rockhounds.com/rockshop/rockkey/index.html

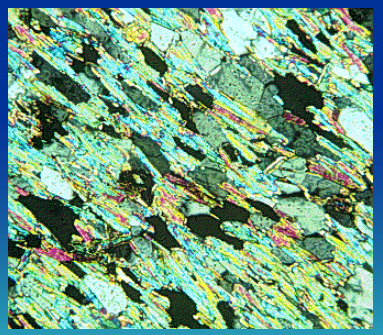
http://www.union.edu/PUBLIC/GEODEPT/COURSES/geo-10/mineral.htm

# Metamorphic Rock Origin and Identification




## Intro to Earth Systems
## ENVI 110 Lab

Ray Rector - Instructor



http://www.rockhounds.com/rockshop/rockkey/index.html

http://earthsci.org/education/teacher/basicgeol/meta/meta.html

http://csmres.jmu.edu/geollab/Fichter/MetaRx/Metaalphab.html

# Major Concepts

1) Metamorphic rocks form by recrystallization and/or neocrystallization of preexisting rock (parent rock) in the solid state.
2) Most cases of metamorphism occur at or near tectonic plate boundaries.
3) Agents of metamorphism include heat, pressure, reactive fluids, and stress.
4) Two metamorphic processes are recrystallization and neocystallization.
5) Three major types of metamorphism is regional, contact and dynamic.
6) The two primary criteria for classifying and identifying metamorphic rocks are composition (mineralogy) and texture (grain size and grain orientation).
7) Two major metamorphic rock groups are 1) foliated and 2) nonfoliated.
8) Metamorphic rock composition controlled by parent rock composition.
9) Texture controlled by combination of metamorphic agents (foliated includes. stress; nonfoliated no stress involved).
10) Slate, phyllite, schist and gneiss are the foliated metamorphic rocks.
11) Marble, quartzite, hornfels, and granofels are the nonfoliated meta rocks.

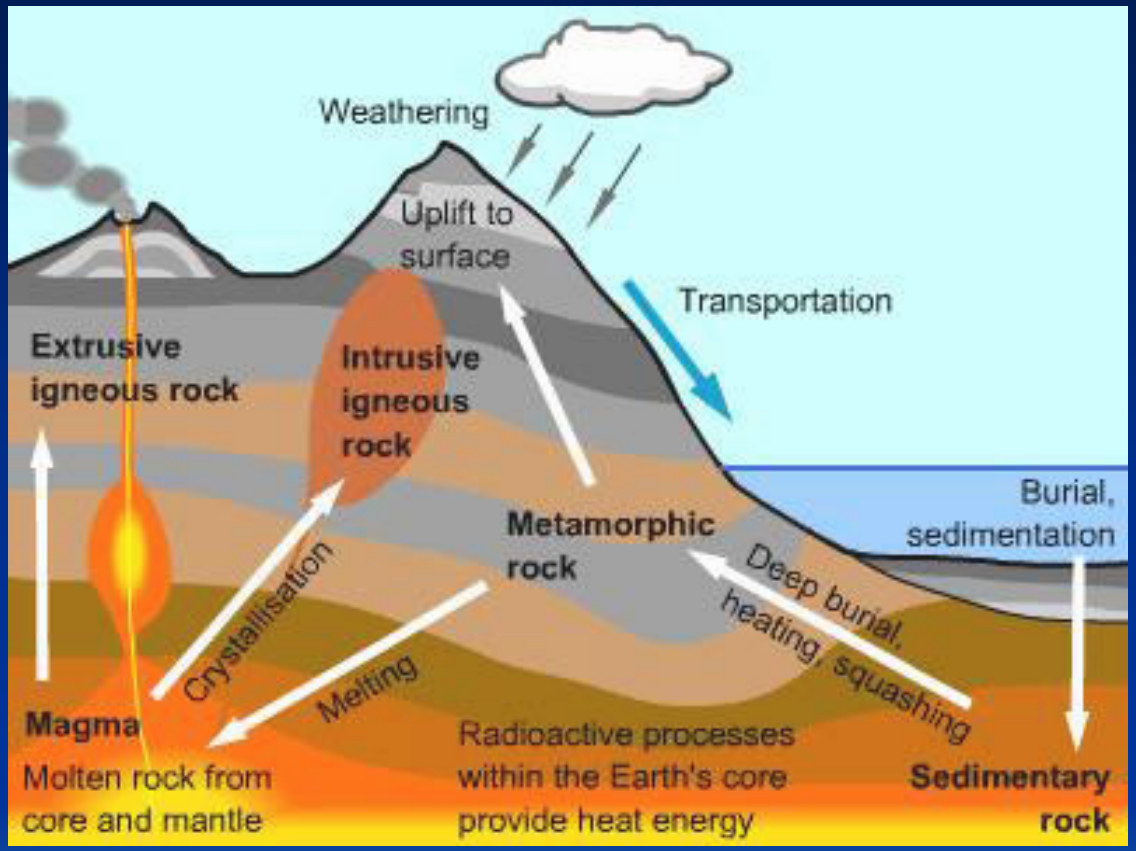
# The Rock Cycle

**Three Primary Rock Types**

1) **Igneous**

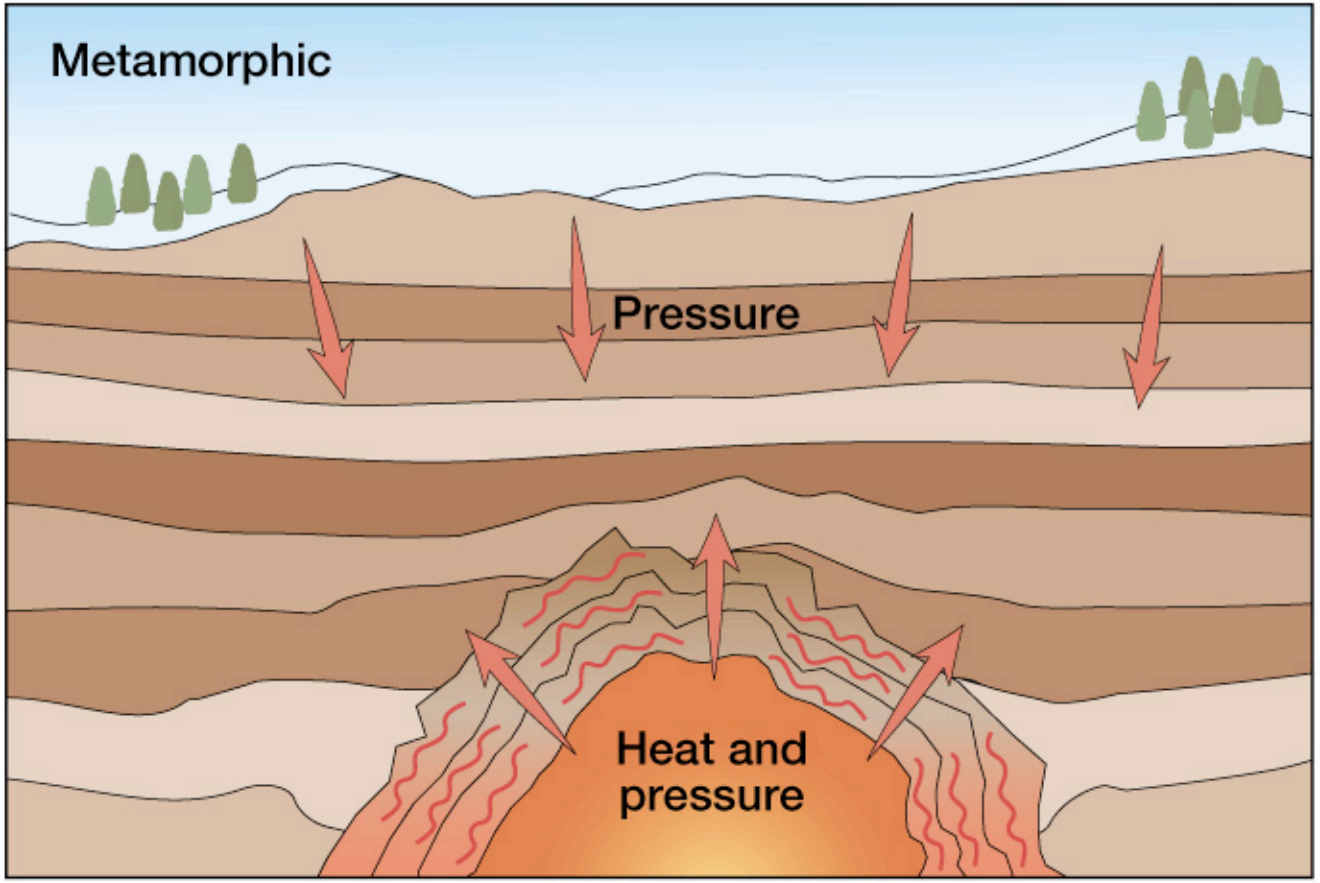
2) **Metamorphic**

3) **Sedimentary**



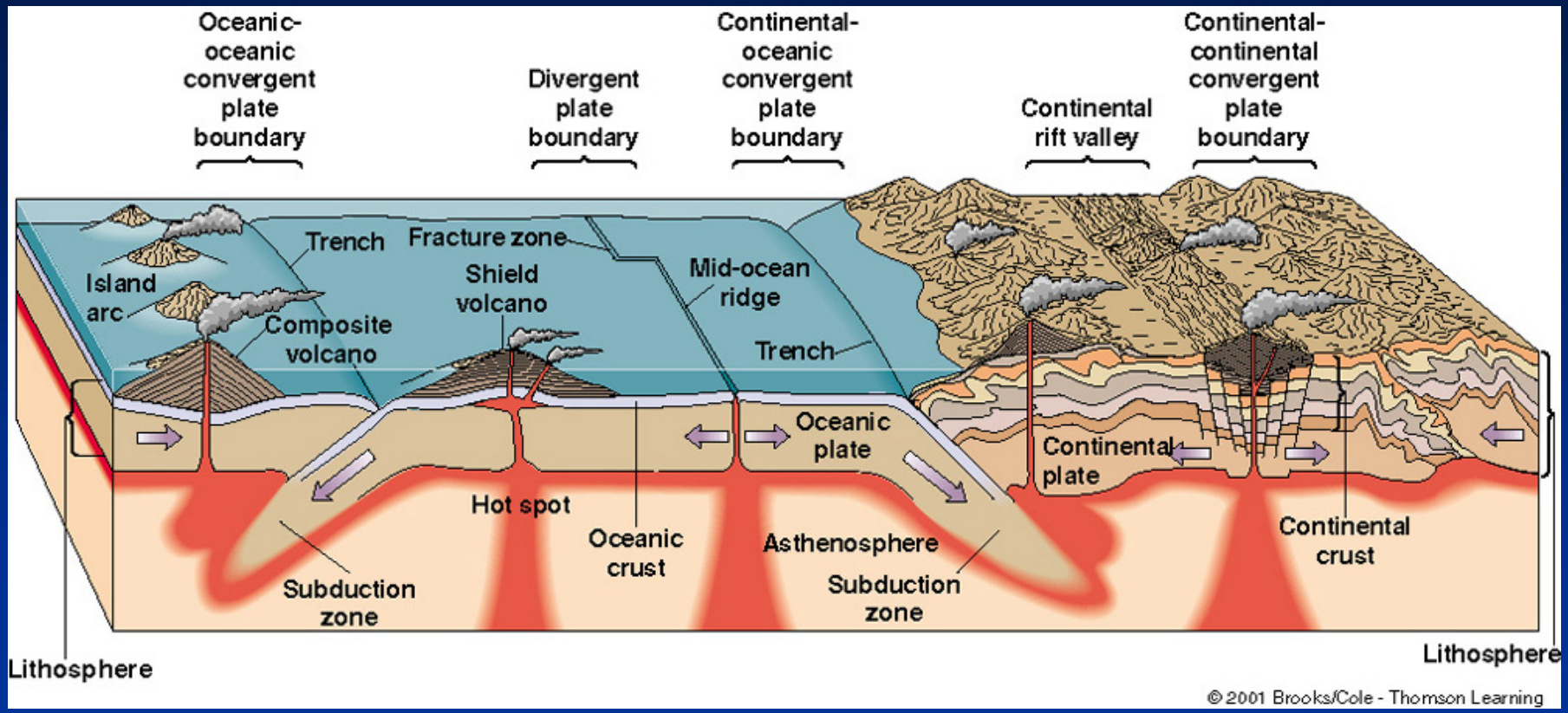

Focus of this presentation is on Metamorphic Rocks

# Heat + Pressure = Mother Metamorphic




Hot Chemically-Reactive Fluids and Tectonic Stresses Too!

# Environments for Metamorphism



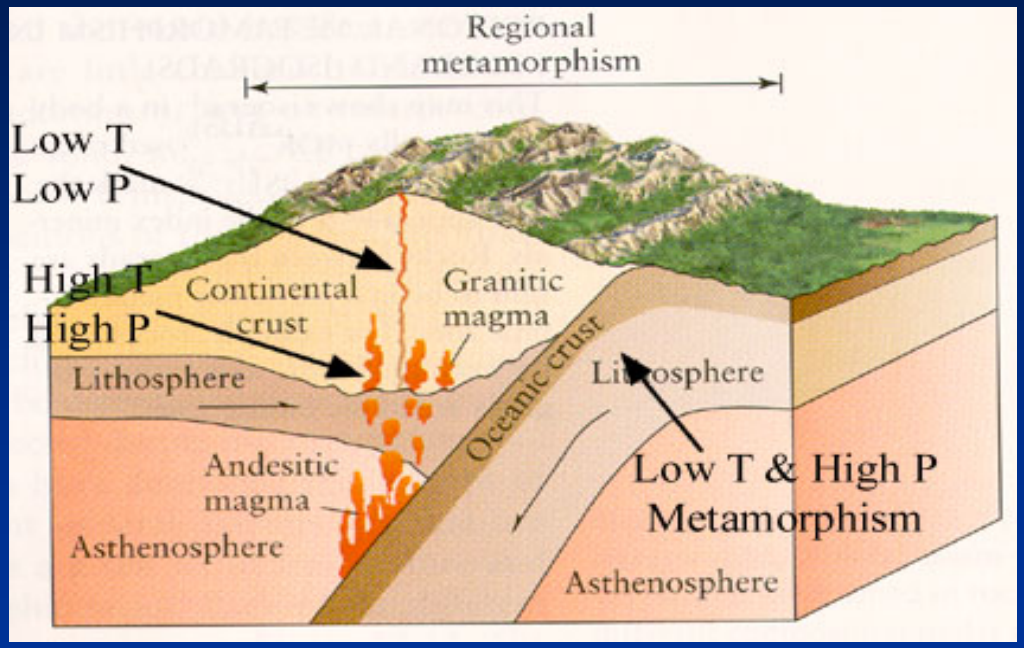

**Vast majority of metamorphism takes place at plate boundaries – Why?**

1) Heat 2) Elevated Pressure 3) Magma and Hot Fluids 4) Tectonic Stresses

# Tectonic Settings and Types of Metamorphism

## Tectonic Settings of Metamorphism

1) All types of plate boundaries
2) Hot spots
3) Any other region undergoing mountain building and/or magmatic activity




## Types of Metamorphism

**1) Regional Metamorphism (RM)**

- ✓ Due to deep burial
- ✓ From Low T + Low P to High T + High P

**2) Contact Metamorphism (CM)**

- ✓ Caused by close proximity to magma and/or very hot fluids
- ✓ From High T + Low P to High T + High P

**3) Dynamic Metamorphism (DM)**

- ✓ Caused by shearing forces in active fault zones
- ✓ From Low T + Low P to Mod T + Mod P

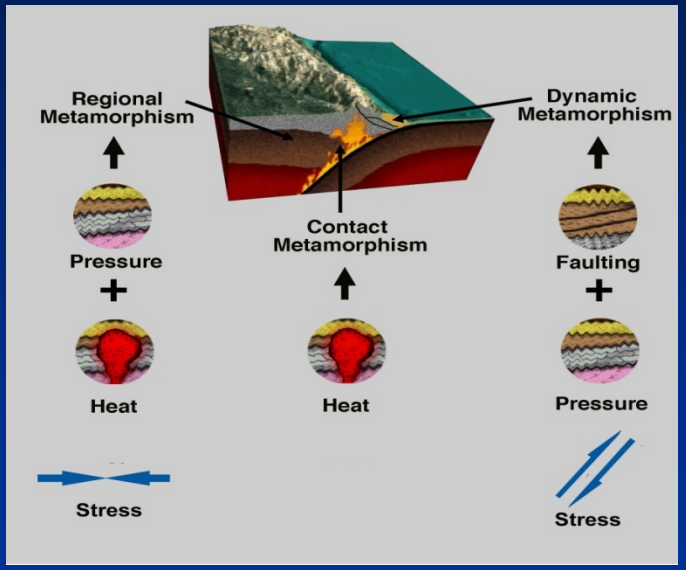
# Metamorphic Processes and Grade

## 1) Deep Burial = Pressure + Heat + Tectonic Stresses

- ✓ Process termed **Regional Metamorphism**
- ✓ Metamorphic conditions = Low to High grade
- ✓ Produces foliated textures
- ✓ Slates, schist, and gneisses

## 2) Magma Contact = High Heat + Fluids

- ✓ Process termed **Contact Metamorphism**
- ✓ Metamorphic conditions = Low to High grade
- ✓ Produces non-foliated textures
- ✓ Quartzite, Marble, and Hornfels




Metamorphic Grade

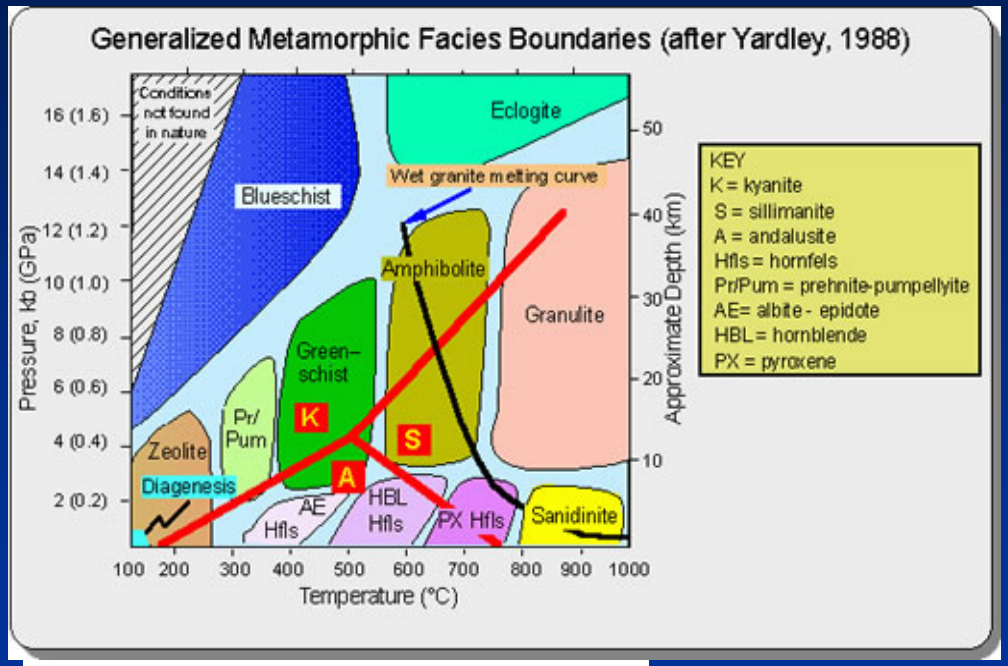
| Parent | Low Grade | | High Grade |
|---|---|---|---|
| Limestone | Marble | | Marble |
| Sandstone | Quartzite | | Quartzite |
| Shale | Slate | Schist | Gneiss |
| Granite | ----- | Schist | Gneiss |
| Basalt | Greenschist | | Amphibolite |

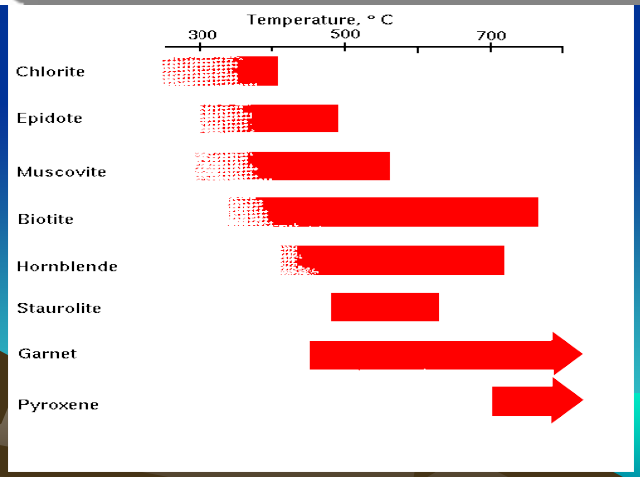
# Metamorphic Grade and Mineral Facies

## Temperature-Pressure Chart

### The Facies Concept

1) The presence of a Key Mineral in a metamorphic rock indicates a unique set of Temperature-Pressure conditions
2) A specific range of temperature-pressure values constitutes a given Metamorphic Facies
3) Each Metamorphic Facies is associated with a unique tectonic setting
4) Low-grade metamorphism occurs at low temperatures and pressures
5) High-grade metamorphism occurs at high temperatures and pressures



# Metamorphic Rock Classification

| Original Rock | Texture | Rock Name | Metamorphic Process | Metamorphic Grade | Comments |
|---|---|---|---|---|---|
| mudstone | Foliated | slate | regional | lower | breaks into plates (slaty cleavage) |
| mudstone | Foliated | phyllite | regional | moderate | more shiny and crenulated than slate |
| mudstone | Foliated | schist | regional | mod-high | different schists recognized on the basis of mineral content |
| mudstone granite | Foliated | gneiss | regional | high | well-developed light and dark banding |
| quartz sandstone | Non-foliated | quartzite | contact | low-high | sugary texture composed of interlocking quartz grains; relatively hard; won't fizz with acid |
| limestone | Non-foliated | marble | contact | low-high | sugary texture composed of interlocking calcite grains; relatively soft; may fizz with acid |
| basalt | Non-foliated | metabasalt | contact | low | greenish color due to chlorite |

**Metamorphic rocks are classified according to several criteria:**

1) Origin = parent rock

2) Texture-Fabric

3) Composition-Mineralogy

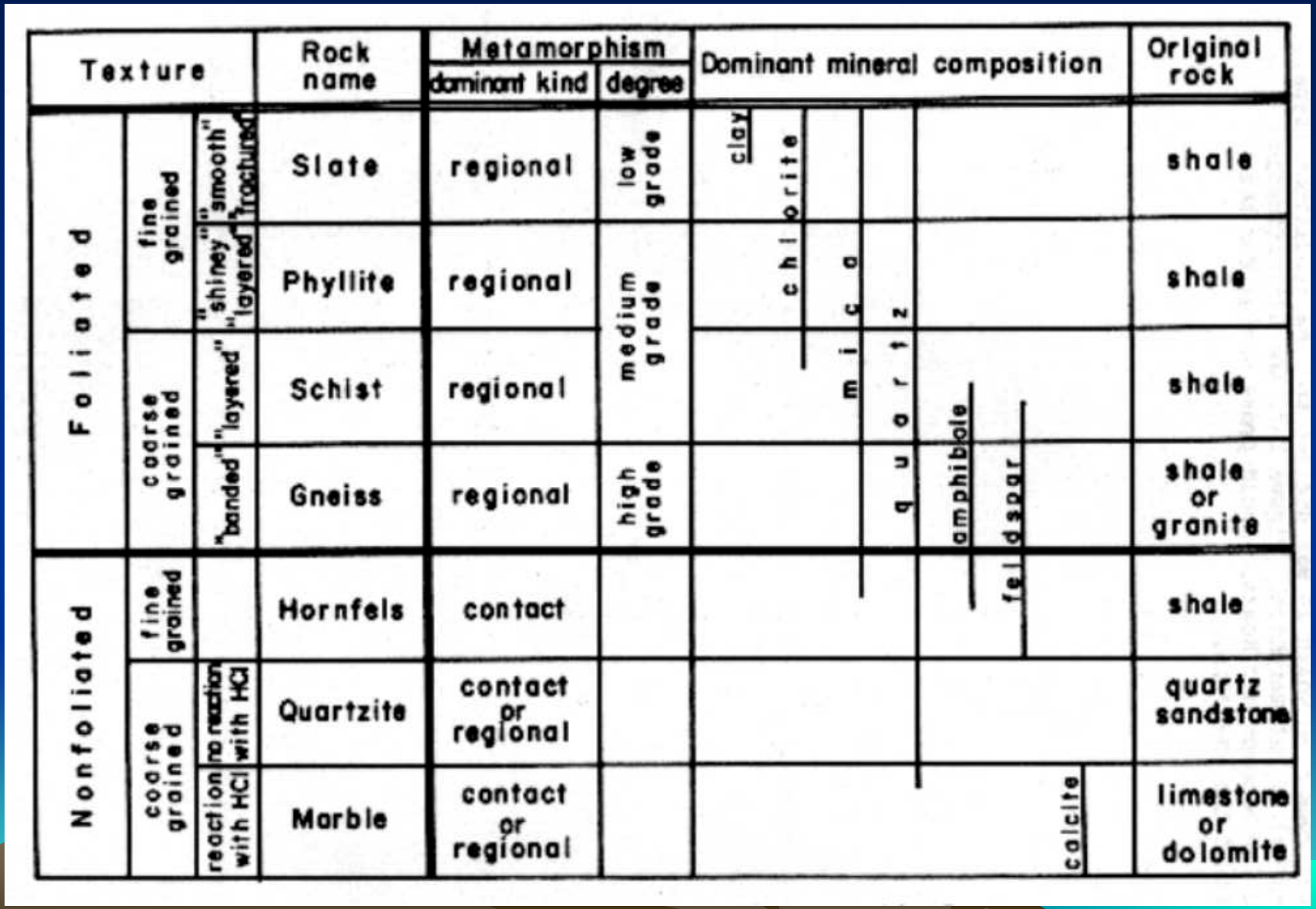
4) Metamorphic process

5) Grade of metamorphism

# Parent Rock → Metamorphic Rock Pairs

| Parent | Grd | Rock | Foliation | Comments |
|---|---|---|---|---|
| Shale | Low | Slate | cleavage | v fine |
| | | Phyllite | cleavage | 'sheen' from fine mica |
| | | Schist | schistocity | mica coarse/visible |
| | Hi | Gneiss | banding | v coarse |
| Basalt | Med | Green schist | schistocity | green chlorite |
| | | Ampholite | Banding | black amphibole |
| | Hi | Blue-schist | schistocity | blue amphibole |
| Lime-stone | All | Marble | None/ Banding | Calcite dominates minors give color |
| Sand-stone | All | Quartzite | None | Quartz dominates minors give color |

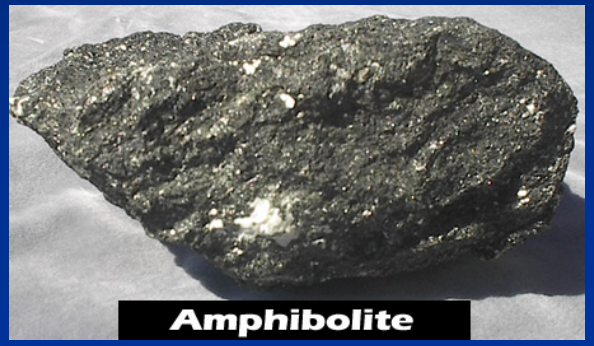
# Metamorphic Rock Classification



# Common Metamorphic Rocks In Hand Samples











# Foliated Metamorphic Textures

## Slaty

- ✓ Foliated = Flat, tight-layered sheets
- ✓ Very Fine Grained
- ✓ Little to minerals observable

Red Slate

Close-Up

## Phyllitic

- ✓ Foliated = Mildly wavy, sheets
- ✓ Fine-grained
- ✓ Sheen-like luster = mica minerals

Mica Schist

Close-Up

## Schistose

- ✓ Foliated = wavy, flaky layers
- ✓ Medium to course grained
- ✓ Observable mineralogy
- ✓ Lots of mica and quartz

## Gneissic

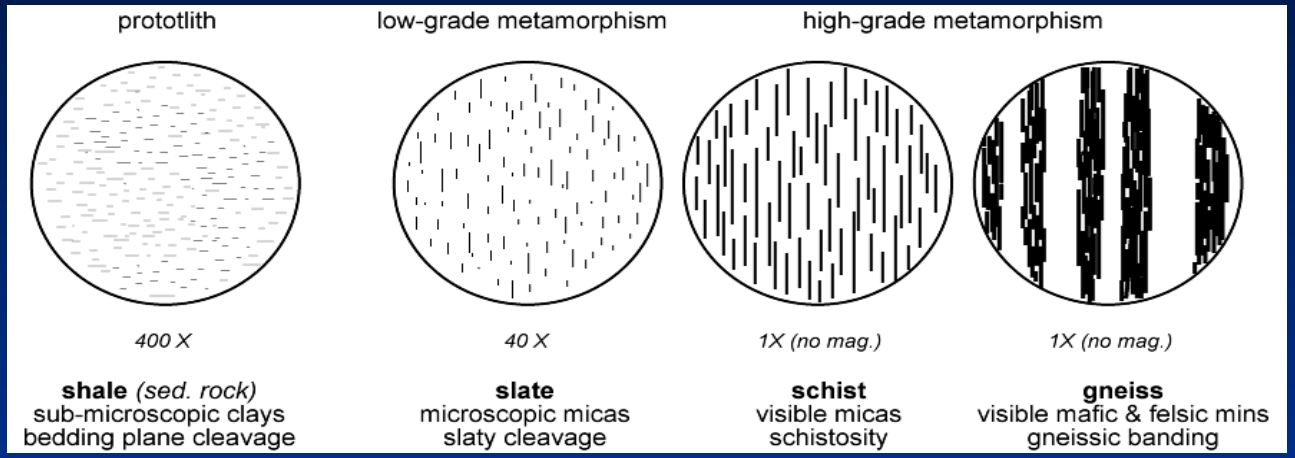
- ✓ Foliated = dark and light mineral bands
- ✓ Medium to course grained
- ✓ Observable mineralogy
- ✓ Quartz, feldspar, biotite, and amphibole

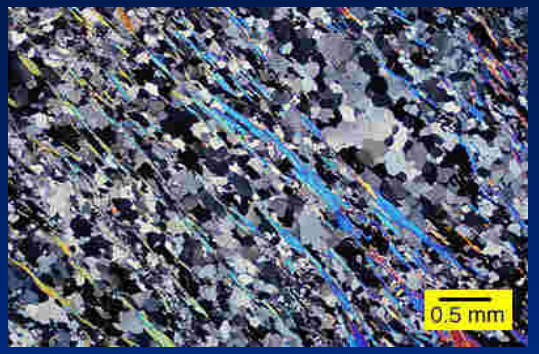
Garnet Gneiss

Close-Up

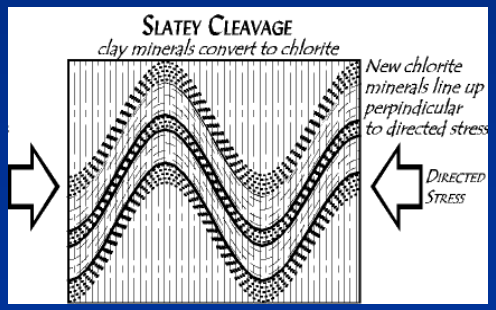
- http://www.rockhounds.com/rockshop/rockkey/index.html

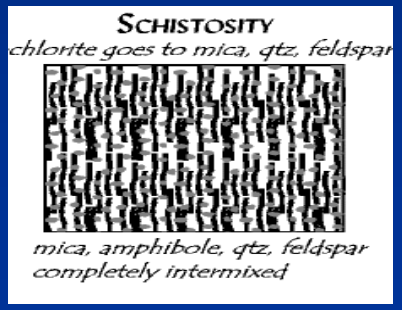
# Foliated Metamorphic Textures

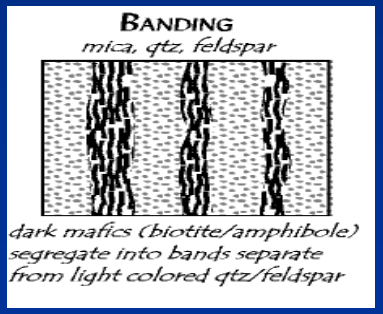



**Foliated Textures**




**1) Foliated textures result from deviatoric tectonic stresses**

**2) The type of foliated rock fabric is a function of metamorphic grade**

- ✓ Foliation character changes with intensity and duration of metamorphism

**3) The type of foliated rock fabric is also a function of rock composition**

# Non-Foliated Metamorphic Textures

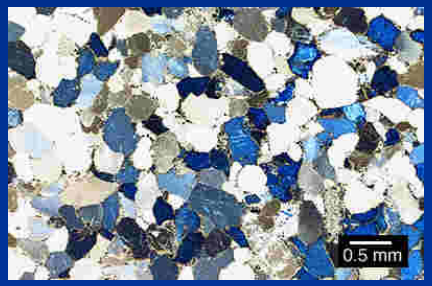
## Microgranular

- ✓ **Crystalline**
- ✓ Nonfoliated = Equant-shaped grains
- ✓ Very fine- to fine-grained
- ✓ Massive-looking rock
- ✓ Little to no minerals observable
- ✓ Example = Hornfels

## Macrogranular

- ✓ **Crystalline**
- ✓ Nonfoliated = Equant-shaped grains
- ✓ Medium to coarse-grained
- ✓ Massive-looking rock
- ✓ Identifiable minerals
- ✓ Example: Marble

Hornfels

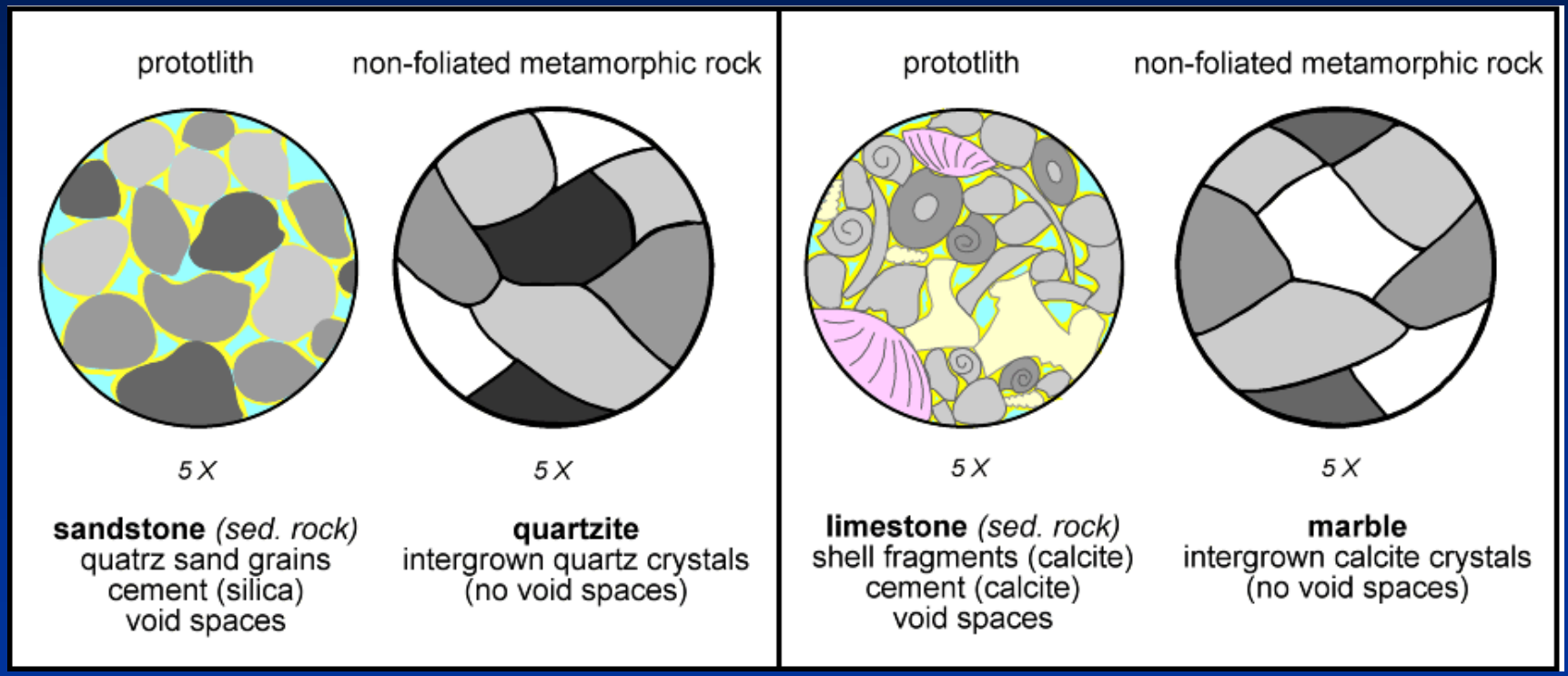



Granular Fabric

Marble

# Metamorphism of Parent Rocks

## Textural Changes in Mono-Minerallic Metamorphism




Quartz-rich Rocks

Calcite-rich Rocks

- ✓ **Mono-minerallic rocks are typically non-foliated.**
- ✓ **Texture described as “polygonal granular”**

# Most Common Types of Metamorphic Rocks

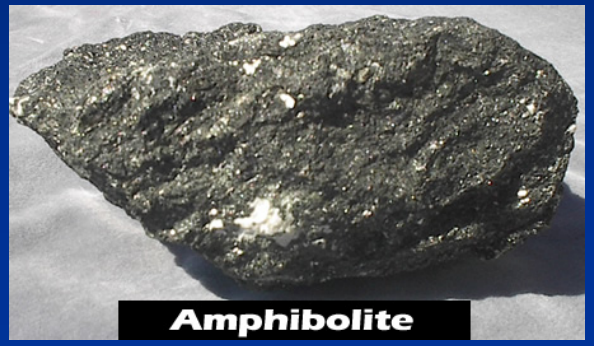
**Questions:**

1) Which are foliated?
2) Which are nonfoliated?
3) Which are monomineralic?
4) Which are high grade?
5) Which are low grade?
6) Which looks mica-rich?
7) Which are hard?
8) Which are soft?

# Common Metamorphic Rocks In Hand Samples



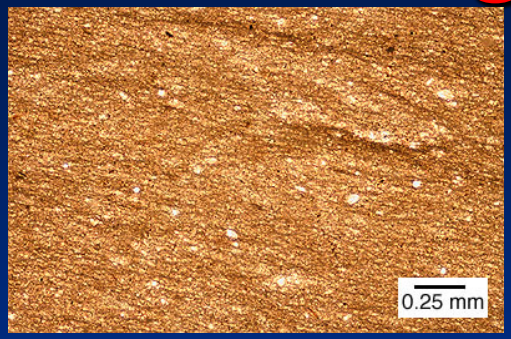




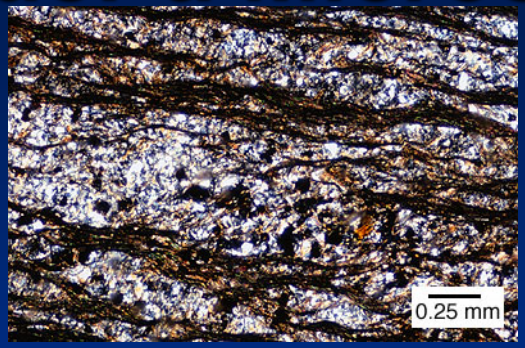




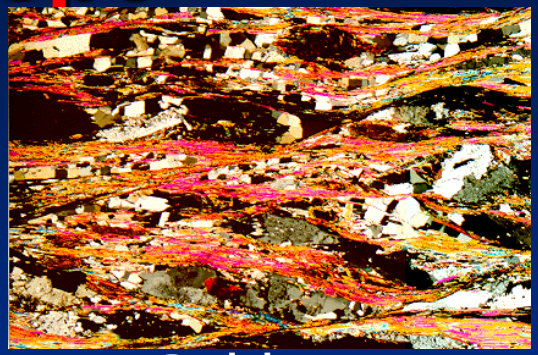
# Common Metamorphic Rocks Under a Microscope



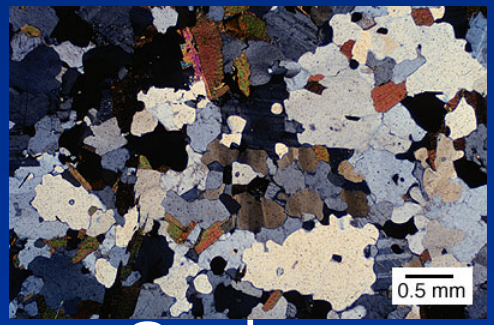

Slate




Phyllite

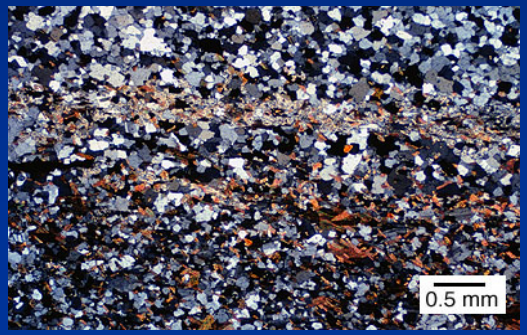


Schist

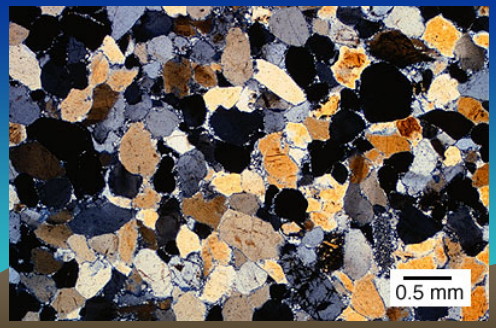



Gneiss

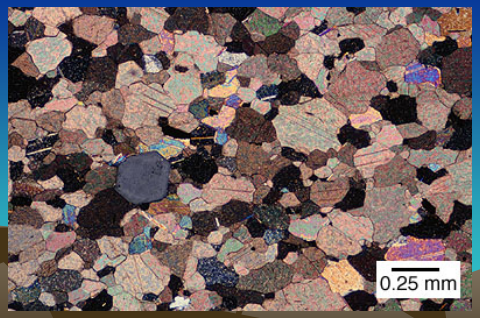

Amphibolite



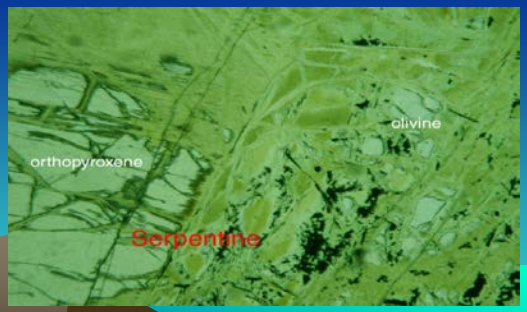

Hornfels




Quartzite




Marble




Serpentinite

# Metamorphic Rock Classification

## A Three Step Process

### 1) Determine Texture

- ✓ Foliated or Nonfoliated?
- ✓ Type of foliation?
- ✓ Grain size?

### 2) Determine Composition

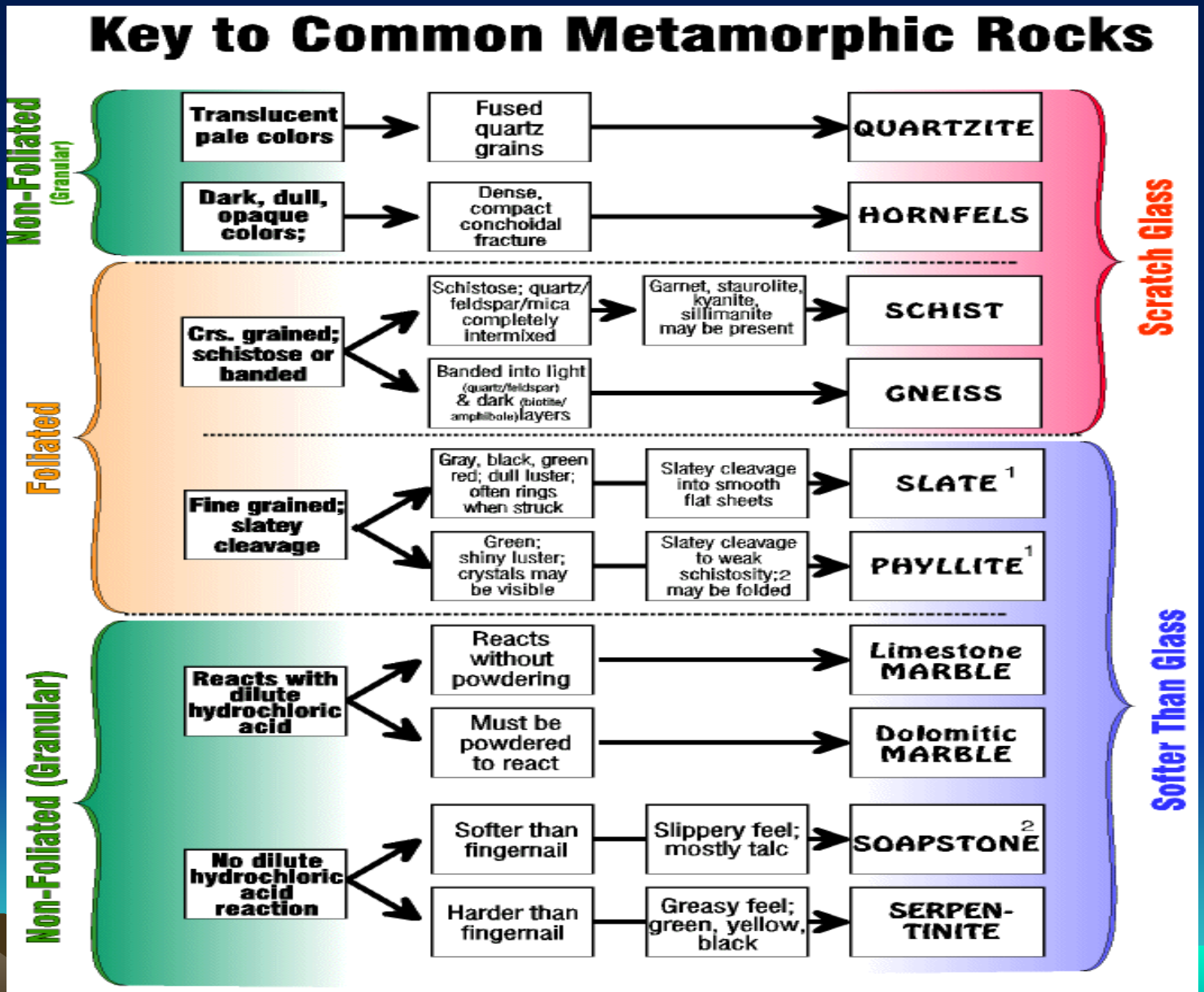
- ✓ Mineralogy?

### 3) Name the Meta Rock and its Parent Rock

**Scheme for Metamorphic Rock Identification**

| TEXTURE | GRAIN SIZE | COMPOSITION | TYPE OF METAMORPHISM | COMMENTS | ROCK NAME | MAP SYMBOL |
|---|---|---|---|---|---|---|
| FOLIATED – MINERAL ALIGNMENT | Fine | MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE | Regional (Heat and pressure increase with depth) | Low-grade metamorphism of shale | Slate | |
| FOLIATED – MINERAL ALIGNMENT | Fine to medium | MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE | Regional (Heat and pressure increase with depth) | Foliation surfaces shiny from microscopic mica crystals | Phyllite | |
| FOLIATED – MINERAL ALIGNMENT | Fine to medium | MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE | Regional (Heat and pressure increase with depth) | Platy mica crystals visible from metamorphism of clay or feldspars | Schist | |
| FOLIATED – BAND-ING | Medium to coarse | MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE | Regional (Heat and pressure increase with depth) | High-grade metamorphism; some mica changed to feldspar; segregated by mineral type into bands | Gneiss | |
| NONFOLIATED | Fine | Variable | Contact (Heat) | Various rocks changed by heat from nearby magma/lava | Hornfels | |
| NONFOLIATED | Fine to coarse | Quartz | Regional or Contact | Metamorphism of quartz sandstone | Quartzite | |
| NONFOLIATED | Fine to coarse | Calcite and/or dolomite | Regional or Contact | Metamorphism of limestone or dolostone | Marble | |
| NONFOLIATED | Coarse | Various minerals in particles and matrix | Regional or Contact | Pebbles may be distorted or stretched | Metaconglomerate | |

# Classification of Metamorphic Rocks




1 (Shale), slate, and phyllite complete intergrade with each other. Distinctions may be difficult.

2 Soapstone may be weakly foliated.

# Metamorphic Rocks

Discussion and Examination