Module 7
Igneous Rocks

IGNEOUS ROCKS

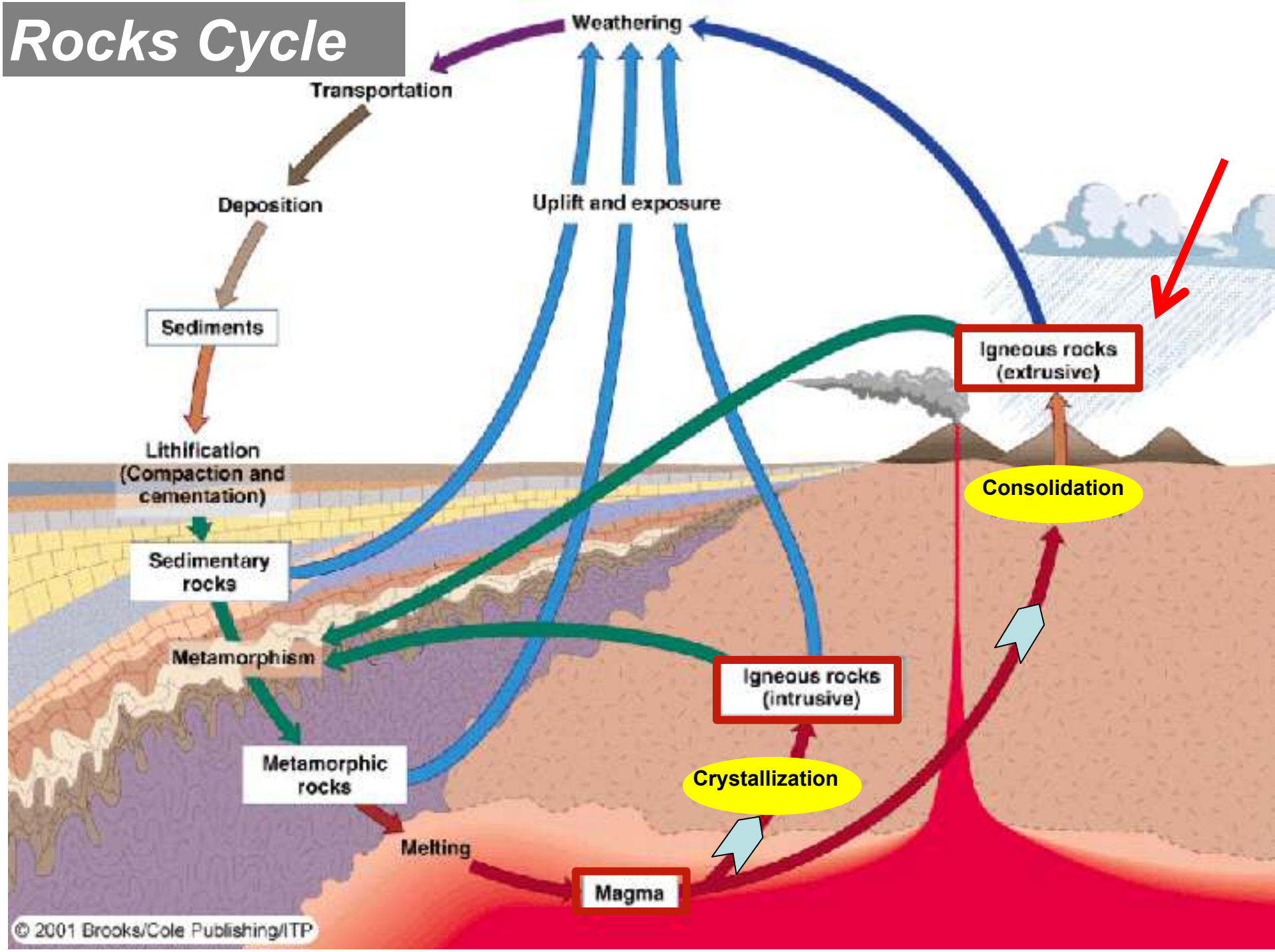
- ***Igneous Rocks form by crystallization of molten rock material***

Igneous rocks form from magma—molten rock material consisting of liquid, gas, and crystals. A wide variety of magma types exists, but important end members are (1) basaltic magma, which is typically very hot (from 900° to 1200°C) and highly fluid, and (2) silicic magma, which is cooler (less than 850°C) and highly viscous.

IGNEOUS ROCKS

- ***Igneous Rocks form by crystallization of molten rock material***
  - **Molten rock material below Earth's surface is called *magma***
  - **Molten rock material erupted above Earth's surface is called *lava***
  - **The name changes because the composition of the molten material changes as it is erupted due to escape of volatile gases**

Rocks Cycle


Weathering
Transportation
Deposition
Uplift and exposure
Sediments
Lithification
(Compaction and
cementation)
Sedimentary
rocks
Metamorphism
Metamorphic
rocks
Melting
Magma
Igneous rocks
(extrusive)
Consolidation
Igneous rocks
(intrusive)
Crystallization
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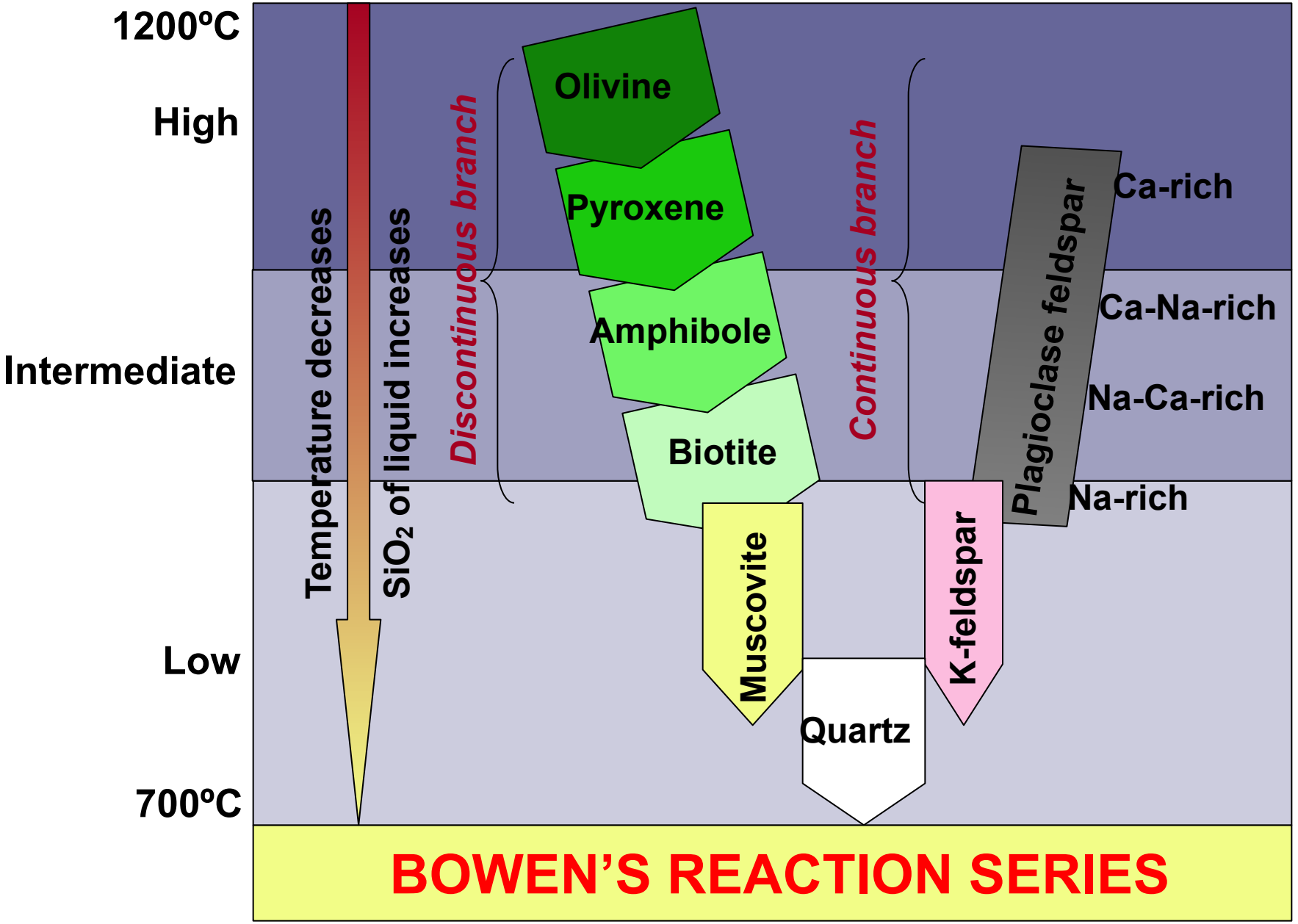
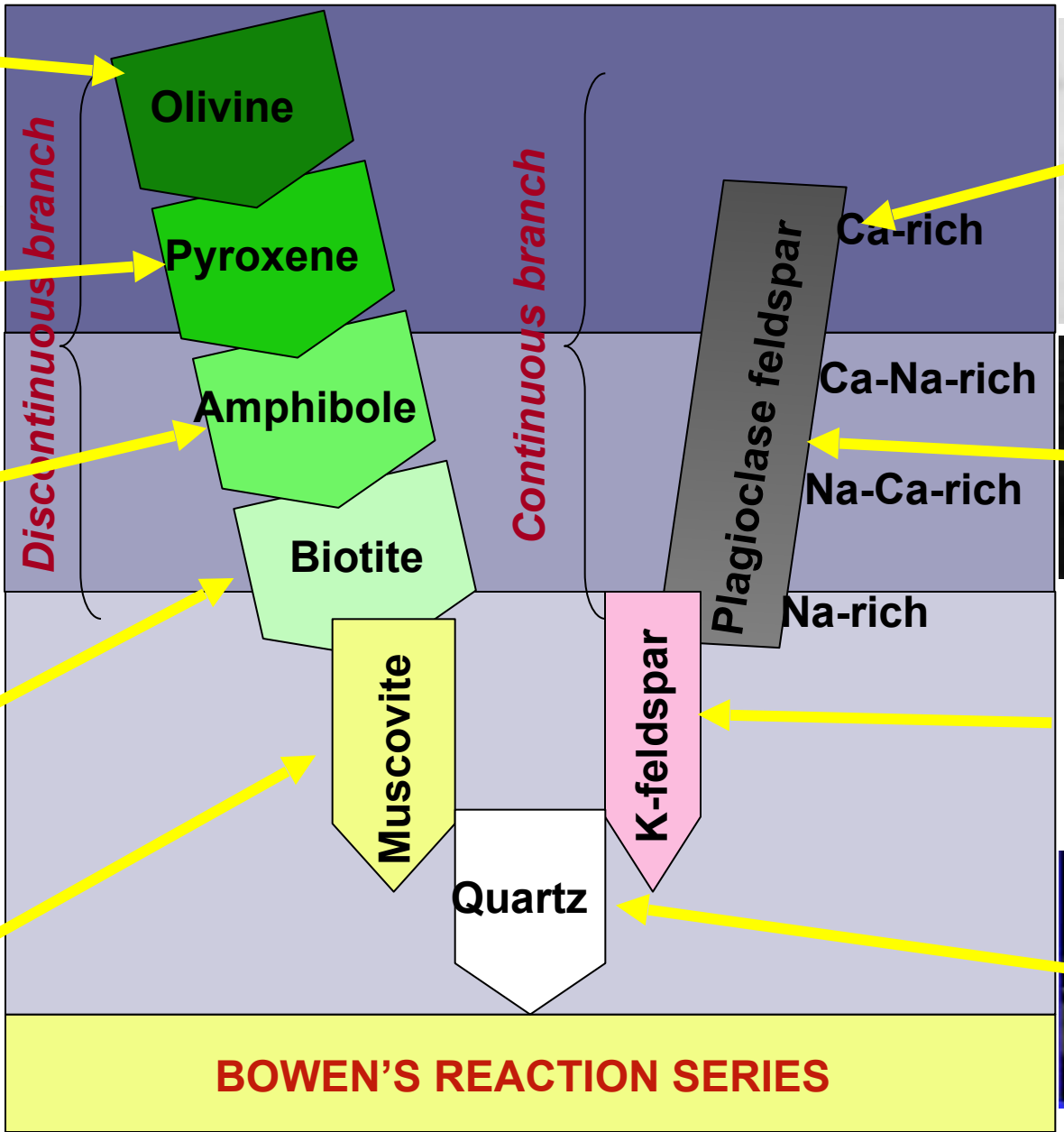
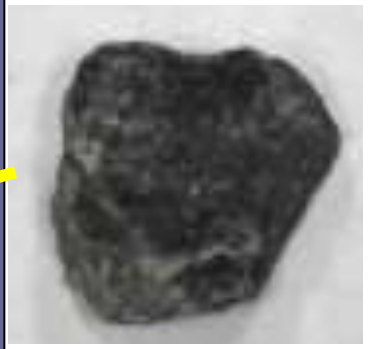
Rock Forming Minerals



Rock Forming Minerals





Rock Forming Minerals

High Temperature Mineral Suite

Olivine

- Isolated Tetrahedra Structure
- Iron, magnesium, silicon, oxygen
- Bowen's Discontinuous Series

Augite

- Single Chain Structure (Pyroxene)
- Iron, magnesium, calcium, silicon, aluminium, oxygen
- Bowen's Discontinuos Series

Calcium Feldspar

- Framework Silicate Structure (Plagioclase)
- Calcium, silicon, aluminium, oxygen
- Bowen's Continuous Series

Rock Forming Minerals

Intermediate Temperature Mineral Suite

Hornblende

- Double Chain Structure (Amphibole)
- Iron, magnesium, calcium, silicon, aluminium, oxygen
- Bowen's Discontinuos Series

Biotite

- Sheet Silicate Structure (Mica)
- Iron, magnesium, potassium, silicon, aluminium, oxygen
- Bowen's Discontinuos Series

Sodium Feldspar

- Framework Silicate Structure (Plagioclase)
- Sodium, silicon, aluminium, oxygen
- Bowen's Continuous Series

Rock Forming Minerals

Low Temperature Mineral Suite

Muscovite

- Sheet Silicate Structure (Mica)
- Calcium, potassium, silicon, aluminium, oxygen
- Bowen's Discontinuos Series

Potassium Feldspar

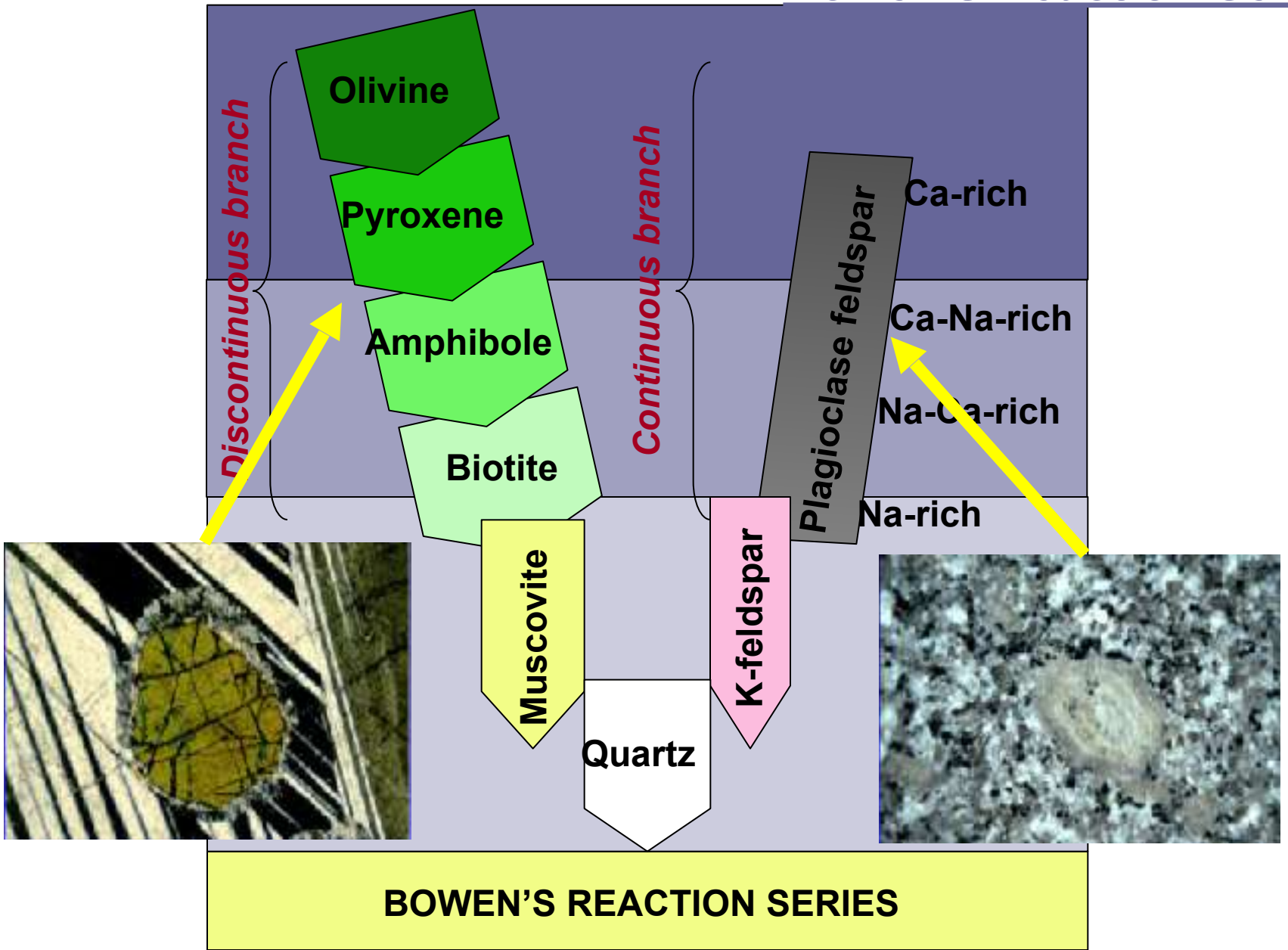
- Framework Silicate Structure (Orthoclase)
- Potassium, silicon, aluminium, oxygen
- Bowen's Continuous Series

Quartz

- Framework Silicate Structure
- Silicon, oxygen
- Last to crystallize from magma

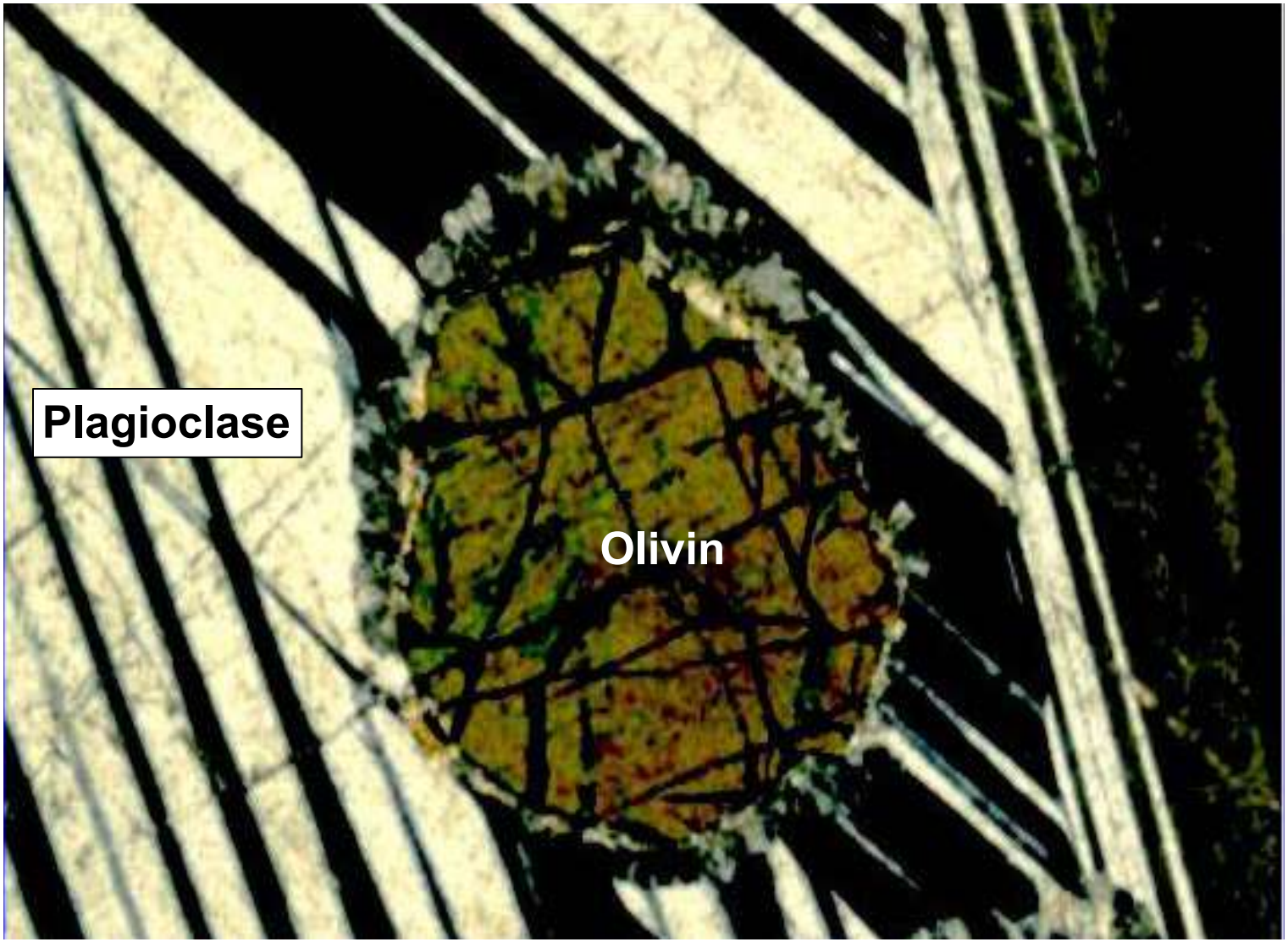
Rock Forming Minerals

Bowen's Reaction Series



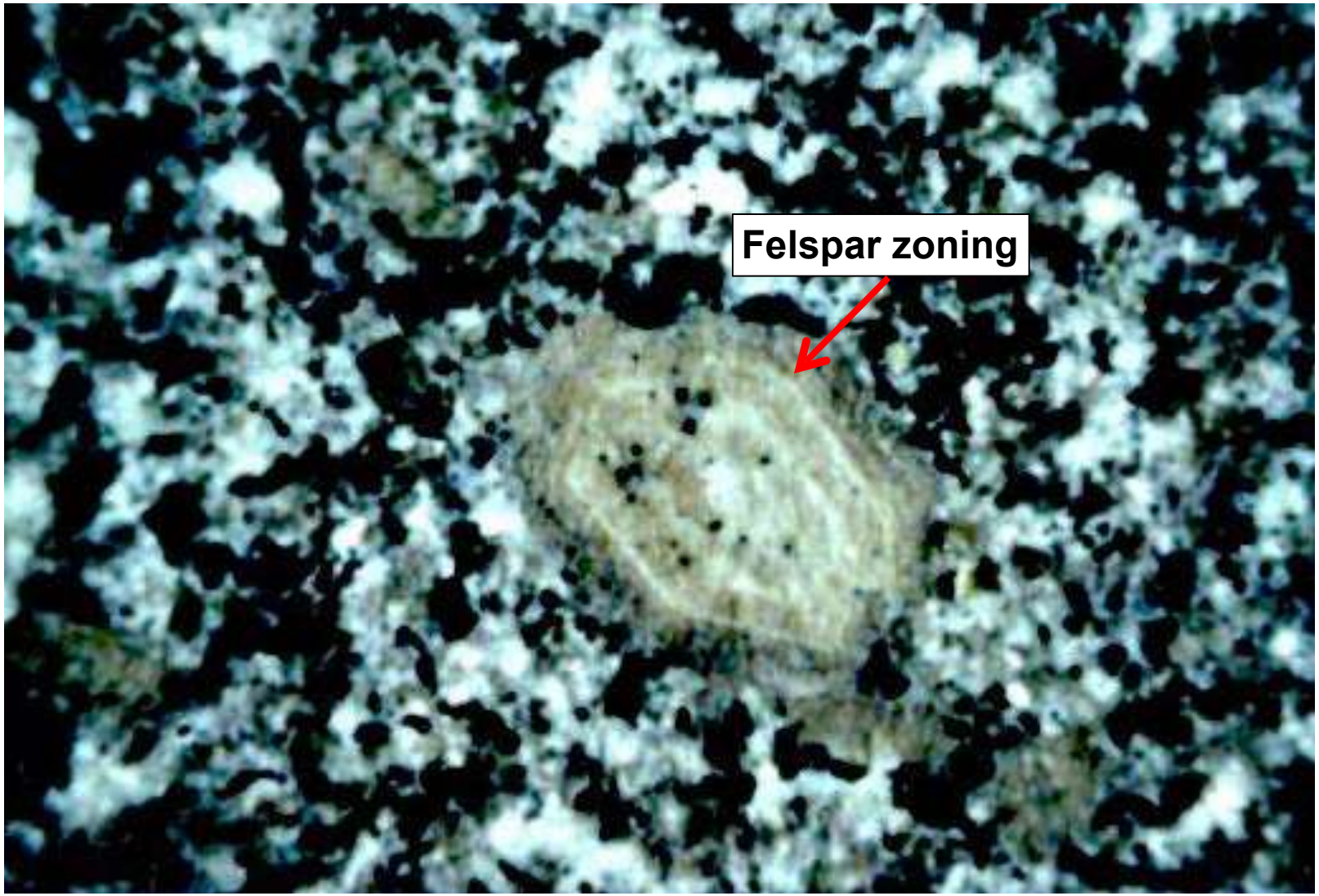
Rock Forming Minerals

Bowen's Reaction Series



Rock Forming Minerals

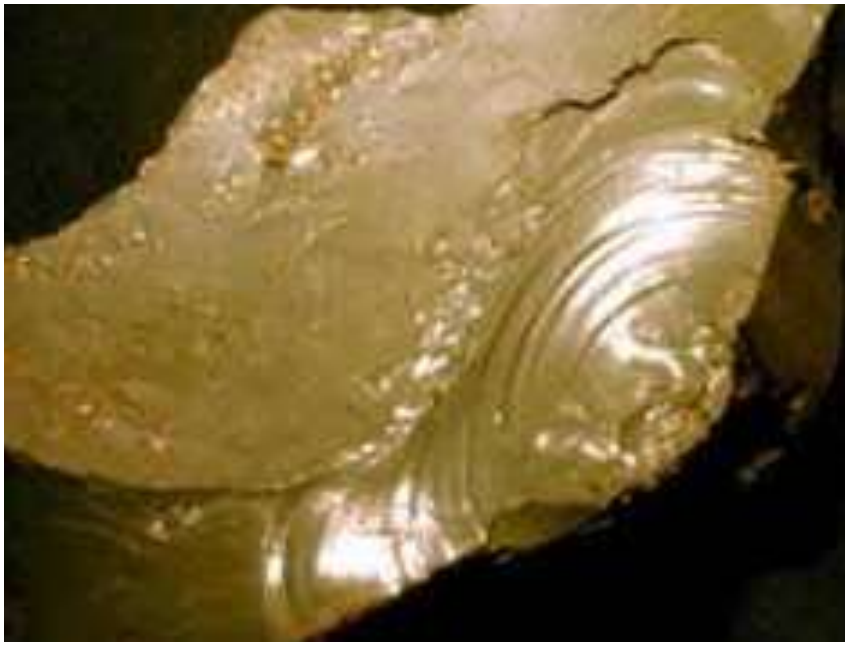
Bowen's Reaction Series



Effect of Cooling Rate on Crystal Size

- **Crystals are formed by ions arranged in orderly patterns**
- **Crystal size is determined by the rate of cooling**
  - ➢ ***Extremely fast cooling***
  - ➢ ***Fast cooling***
  - ➢ ***Slow cooling***

Effect of Cooling Rate on Crystal Size



Extremely fast cooling

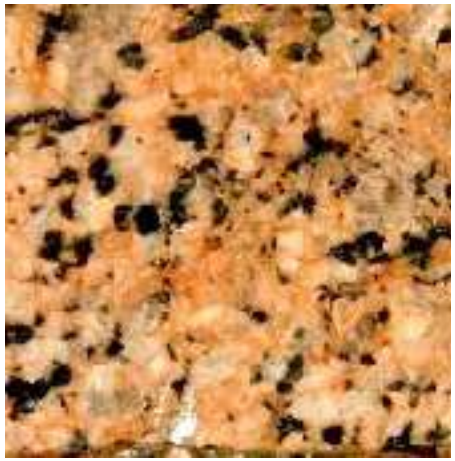
- Forms glass, not crystals
- Occurs above Earth's surface under water or ice
- Yields obsidian, volcanic glass

Effect of Cooling Rate on Crystal Size

Fast cooling

- Forms very small invisible crystals
- Crystallized out less slowly
- Magma moved more rapidly
- Occurs closer to Earth's surface
- Typical in small intrusions and conduit

Effect of Cooling Rate on Crystal Size

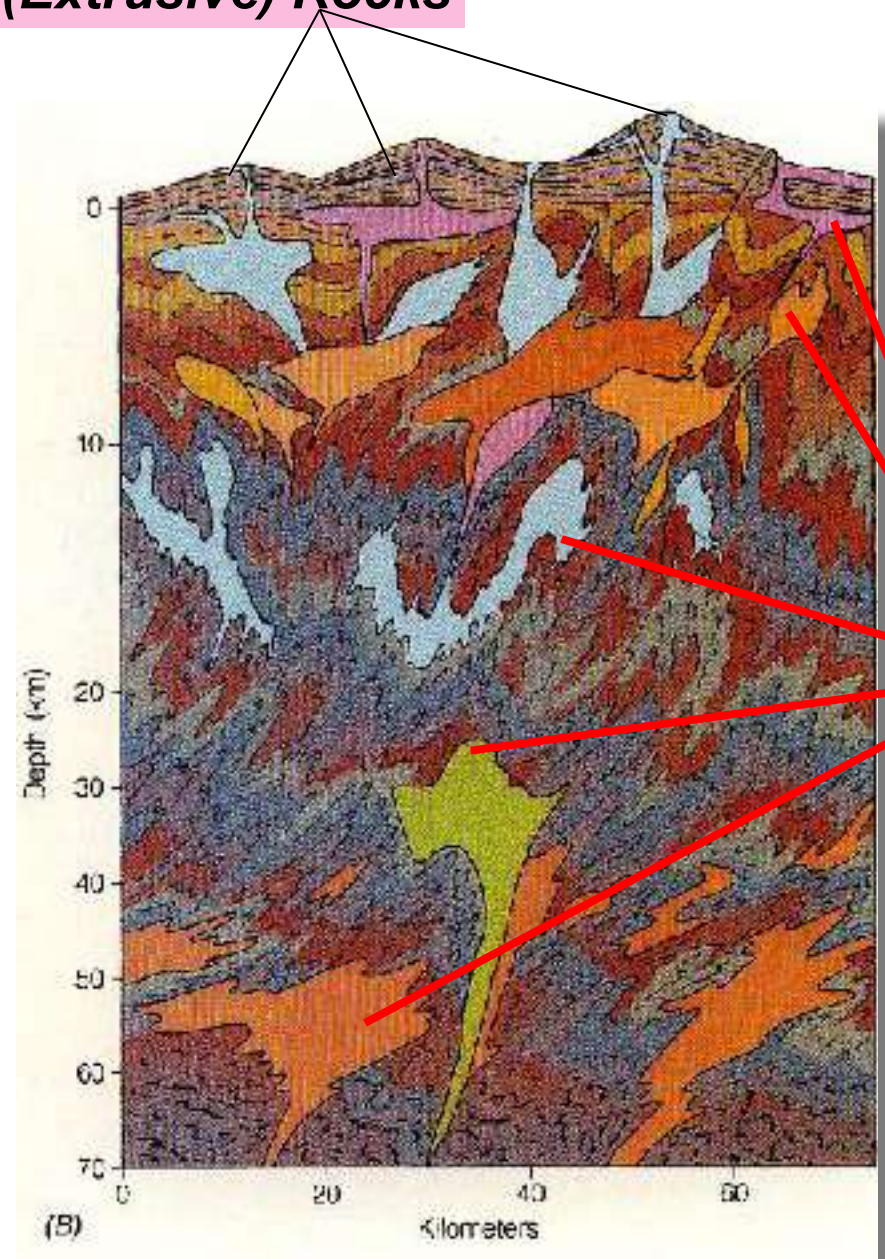


Slow cooling

- Forms large, visible crystals
- The slower the cooling rate, the larger the crystals formed
- Occurs below Earth's surface
- Typical of plutonic rocks

Where do the igneous rocks form?

Volcanic (Extrusive) Rocks



Plutonic (intrusive) Rocks

Where do the igneous rocks form?

Plutonic (intrusive) Igneous Rocks

Plutonic (intrusive) Rocks

Form by crystallization of molten rock material below Earth's surface

Coarse-grained plutonic rocks

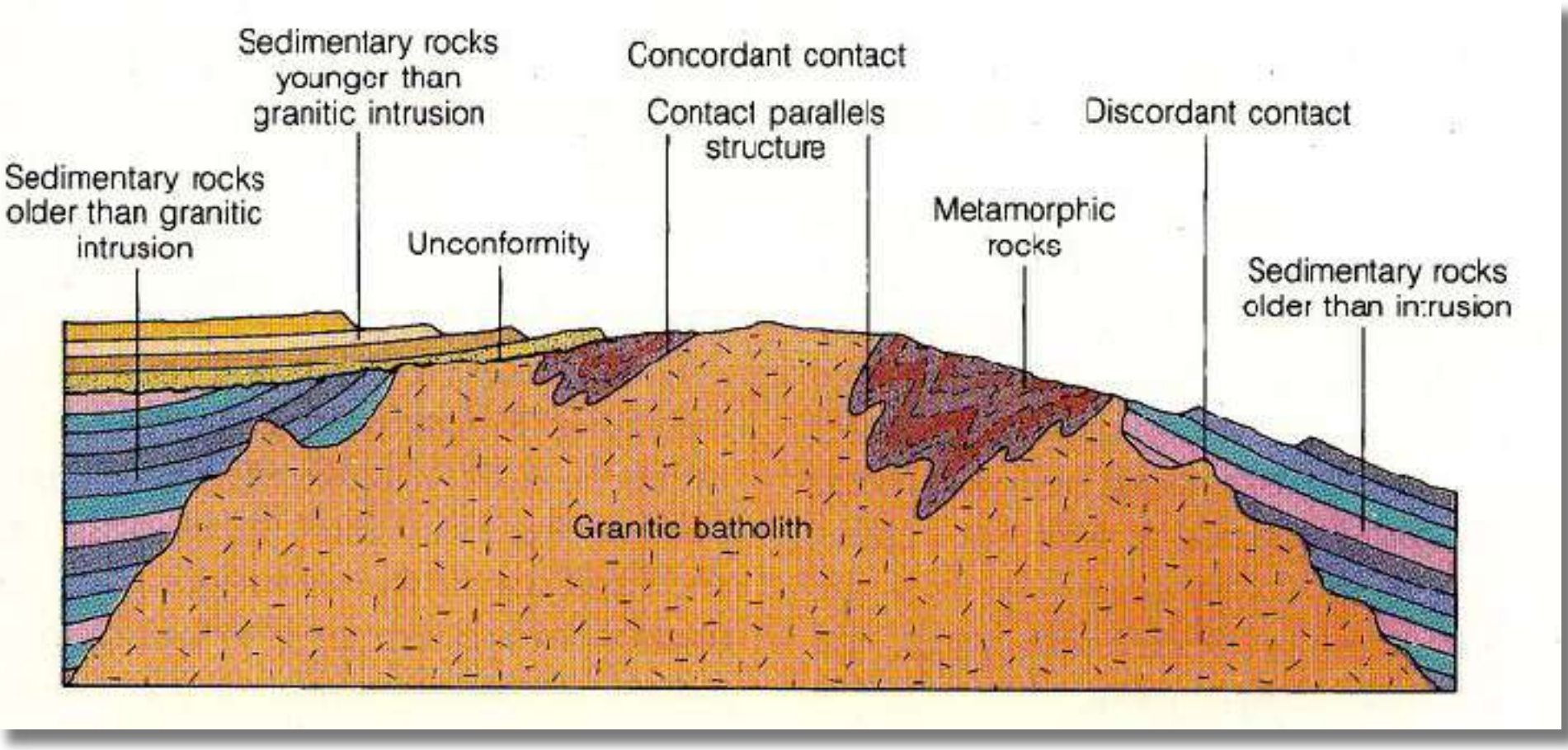
Crystallized out very slowly in large magma chambers 12-20 km beneath Earth's surface

Fine-grained plutonic rocks

Crystallized out less slowly, more rapidly, in small intrusions and conduits closer to Earth's surface

Where do the igneous rocks form?

Plutonic (intrusive) Igneous Rocks

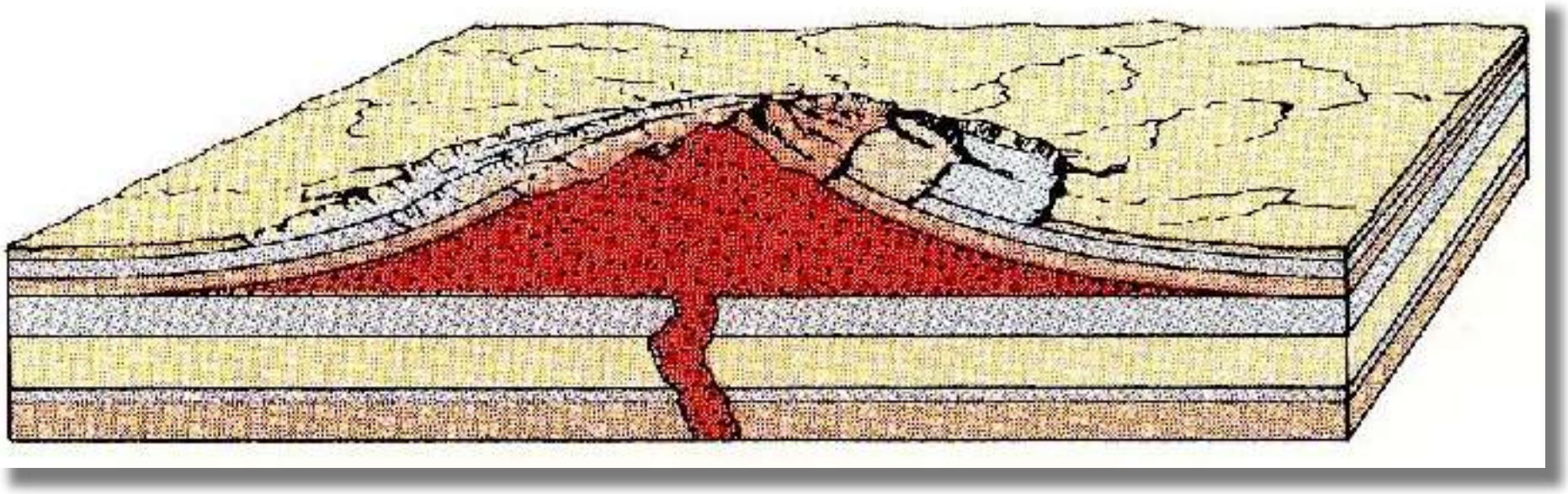


Where do the igneous rocks form?

Plutonic (intrusive) Igneous Rocks

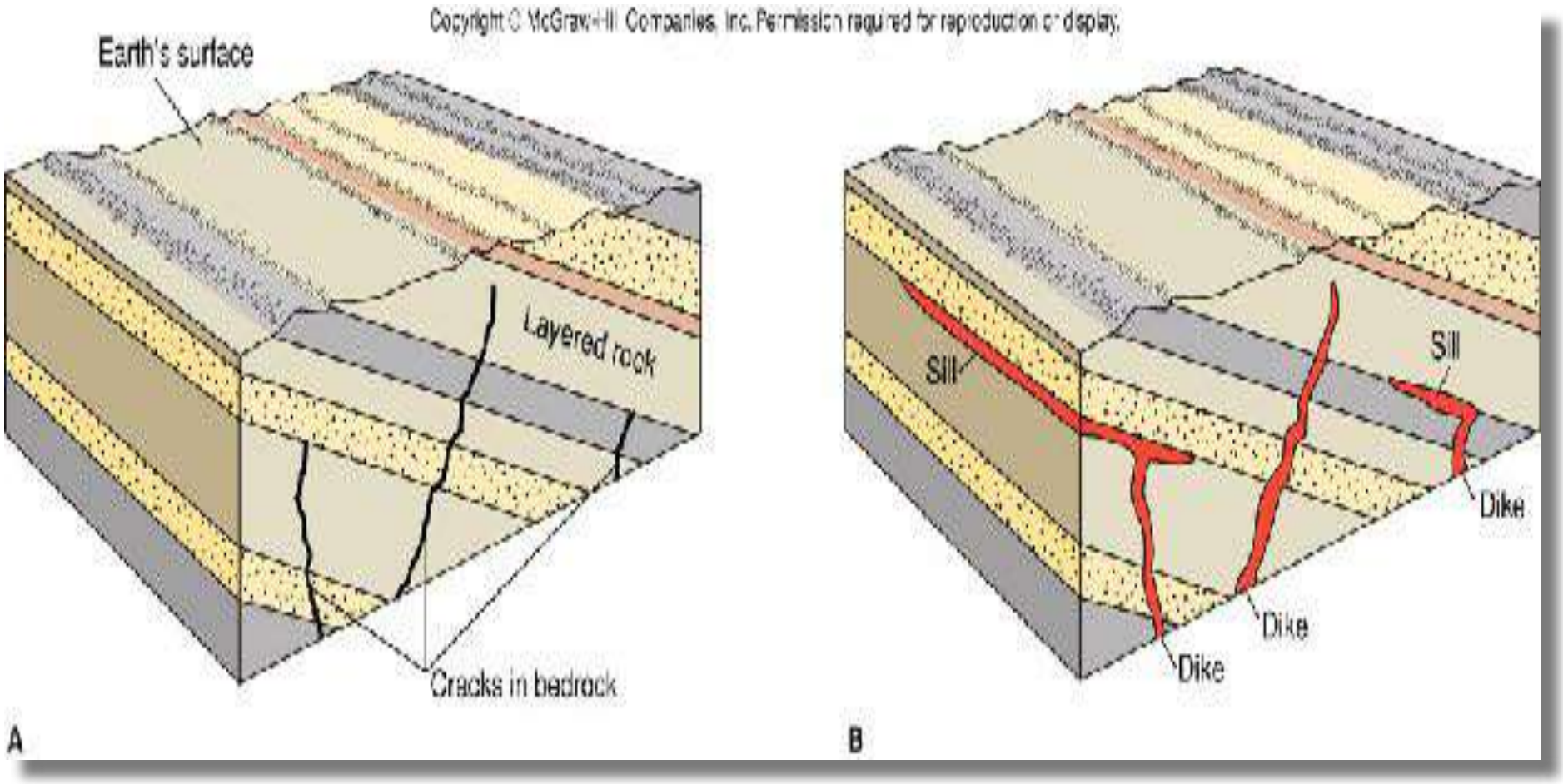
Laccolith

- **are masses of igneous rock between layers of the surrounding rock**



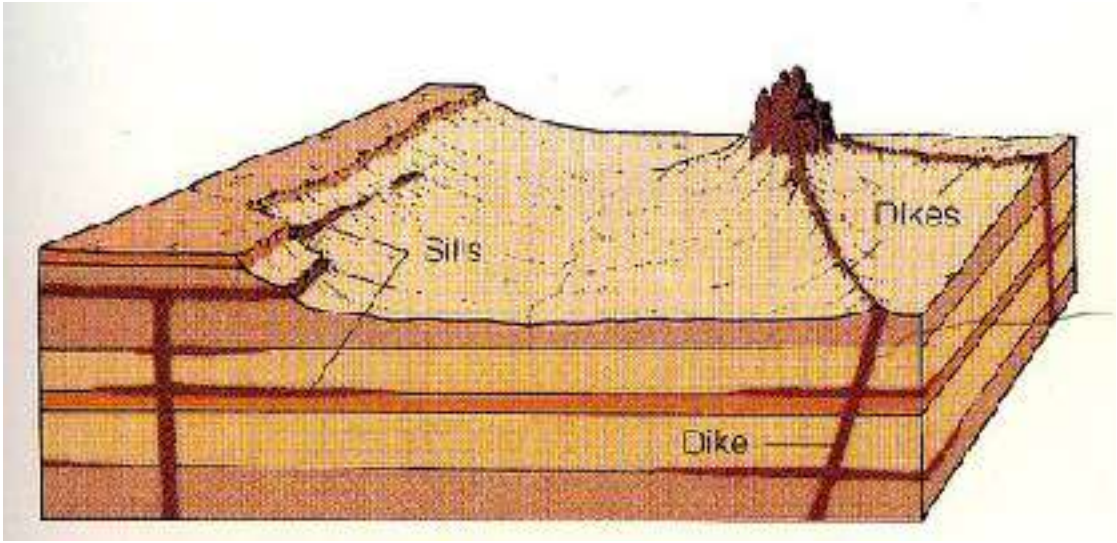
Where do the igneous rocks form?

SILL & DIKE



Where do the igneous rocks form?

Plutonic (intrusive) Igneous Rocks



Dike & Sill

- are tabular intrusive bodies.
- Dikes cut across layer of the surrounding rock
- Sills are injected between layers of strata

Where do the igneous rocks form?

Volcanic (Extrusive) Igneous Rocks

Form by crystallization of molten rock material above Earth's surface

Lavas
are flowing out (extruded)

Pyroclastic volcanic rocks
are blasted out

Ash
is very fine-grained pyroclastic material

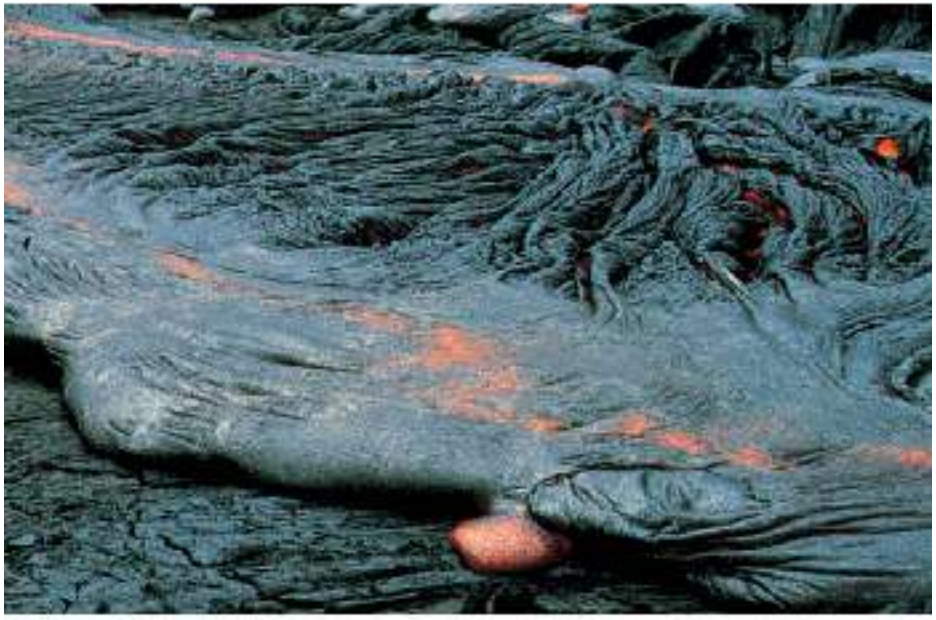
Blocks
are large *solid* blocks that are blasted out

Bombs
are large *molten* blocks that are blasted out

Where do the igneous rocks form?

Volcanic (extrusive) Igneous Rocks

A lava fountain and rapidly flowing basalt



Pahoehoe, a smooth-surfaced, ropy form of basalt that crystallizes out near the beginning of a basalt flow

AA, a jagged-surfaced form of basalt that crystallizes out at the end of a basalt flow

Basalt, a mafic composition lava

Where do the igneous rocks form?

Volcanic (extrusive) Igneous Rocks

Andesite flow,
Mexico

Andesite flow,
Cascade Range, Oregon

Andesite, an intermediate composition lava

Where do the igneous rocks form?

Volcanic (extrusive) Igneous Rocks

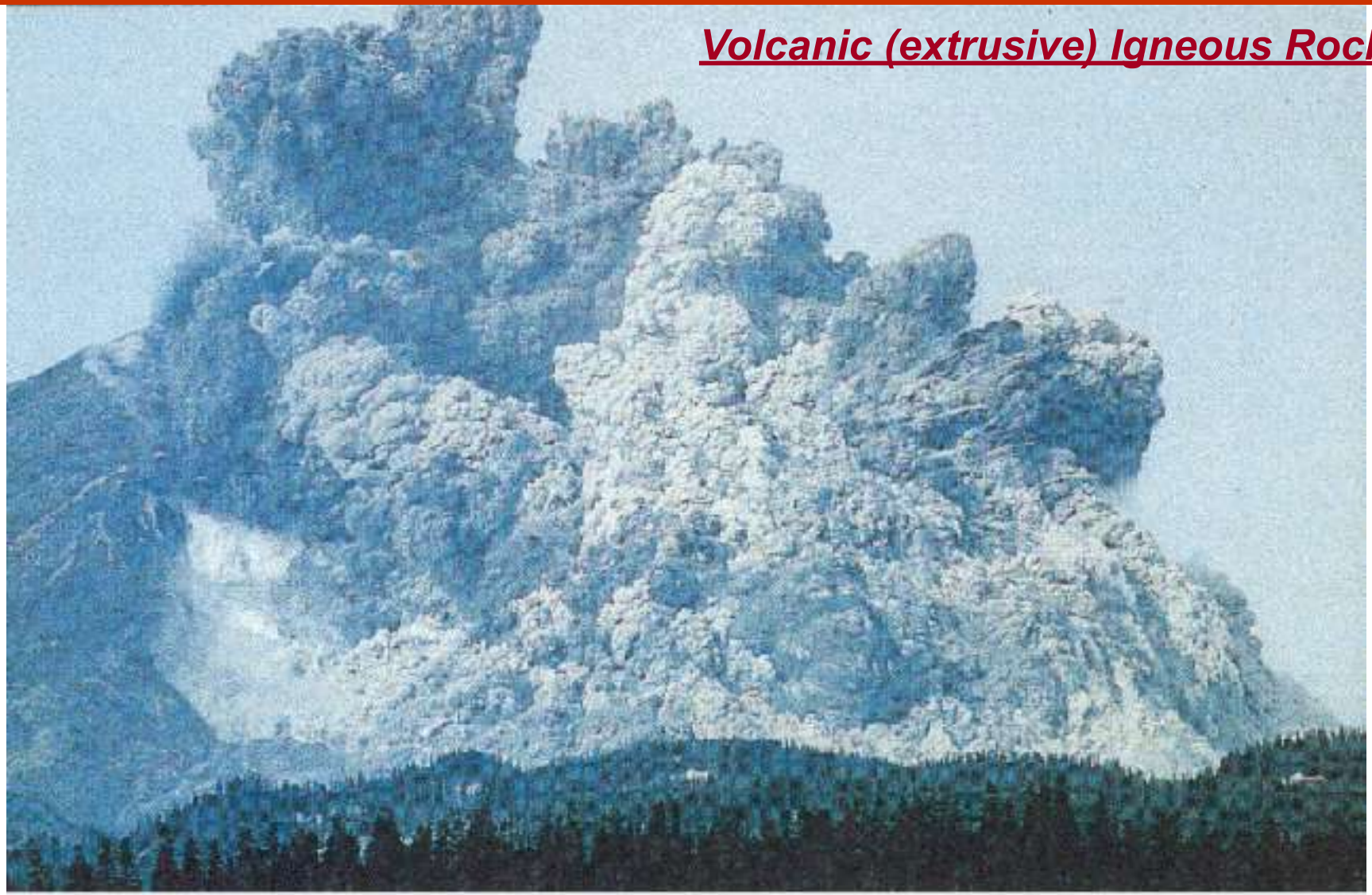
Rhyolite dome,
Mono Craters, California

Rhyolite flow showing columnar jointing, MacDougalls Island, New Brunswick

Rhyolite, a felsic composition lava

Where do the igneous rocks form?

Volcanic (extrusive) Igneous Rocks

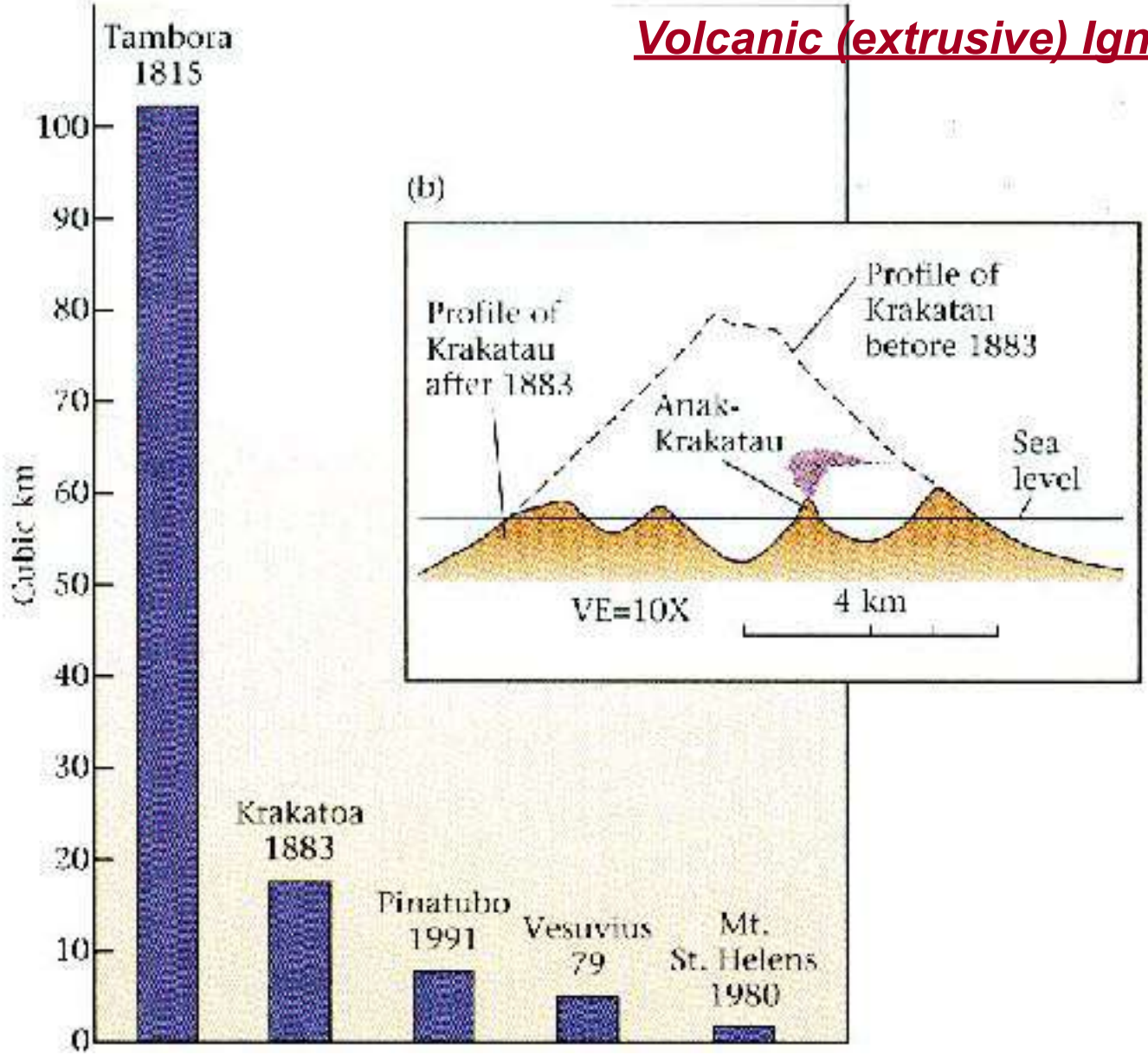


May 18, 1980 eruption of Mount St. Helens (photo by Keith Ronnholm)

Pyroclastic Eruption, **Eruption of Mount St. Helens, Washington, 1980**

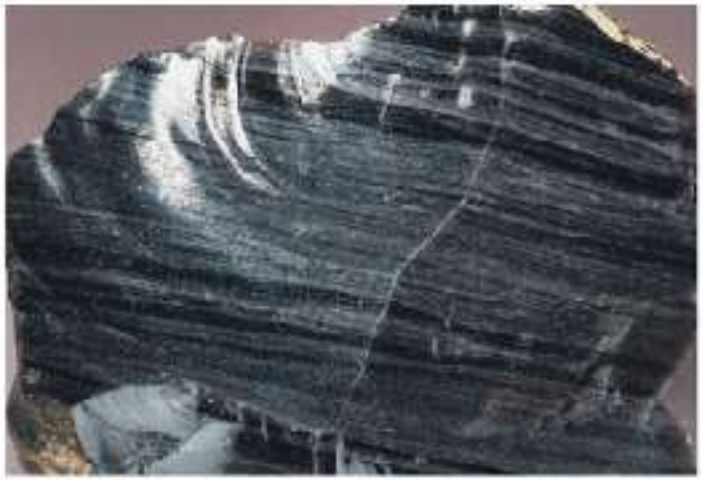
Where do the igneous rocks form?

Volcanic (extrusive) Igneous Rocks



Other Notable Pyroclastic Volcanic Eruptions

Igneous Rocks Texture (4 textures)



(A) **A glassy texture** develops when molten rock cools so rapidly that the migration of ions to form crystal grains is hampered. Glassy texture typically forms on the crust of lava flows and in viscous magma. The sample shown here is obsidian.

(B) An aphanitic texture consists of mineral grains too small to be seen without a microscope. The sample shown here is rhyolite. Only a few grains are large enough to be seen. Most are microscopic. Aphanitic texture results from rapid cooling.

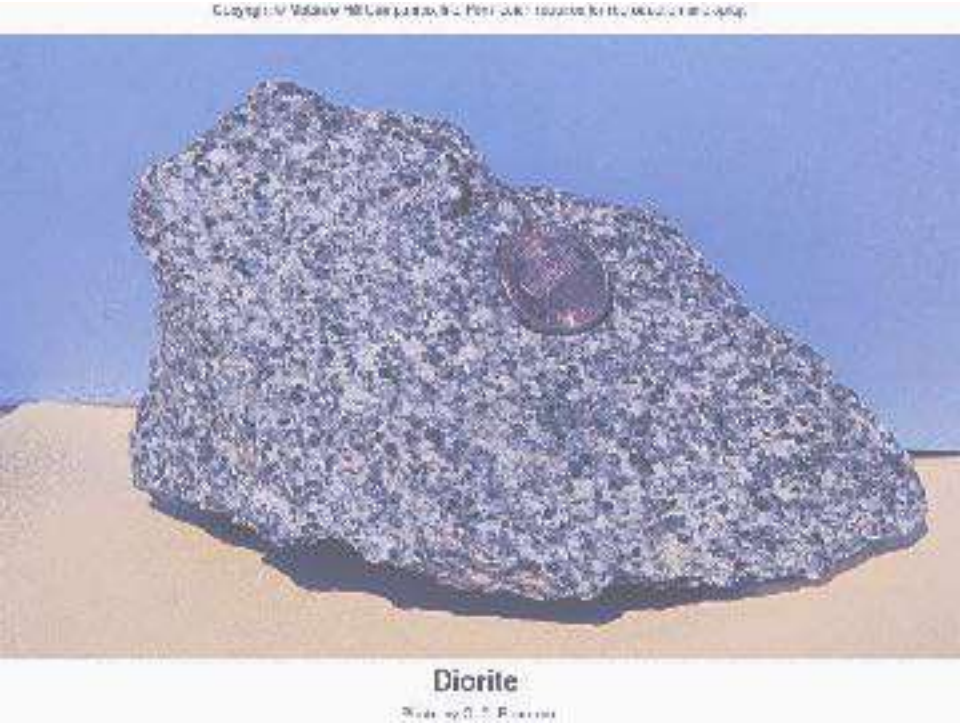
(C) **A phaneritic texture** consists of grains large enough to be seen with the unaided eye. All grains are roughly the same size, and they interlock to form a tight mass. The large crystals suggest a relatively slow rate of cooling.

(D) A pyroclastic texture forms when crystals, fragments of rock, and glass are blown out of a volcano as hot ash. The material may accumulate as an ash fall or as an ash flow. The black lenses of glass were pumice fragments that were squashed during welding of the hot ash.

FIGURE 4.3 Textures of igneous rocks provide important information concerning rock genesis. All of the silicic rocks presented here have roughly the same chemical composition but extremely different textures. The photographs show the actual size of the specimens.

Igneous Rocks Texture

IGNEOUS ROCK TEXTURE PROVIDES INSIGHT INTO THE COOLING HISTORY OF THE ROCK



Diorite

A phaneritic texture

- Consists of visible grains
- Is formed by very slow cooling below Earth's surface
- Characteristic of plutonic igneous rocks *i.e.* gabbro, diabase, diorite, granite

Igneous Rocks Texture

Photo by C.C. Plummer

Aphanitic texture

- Consists of invisible grains formed by fast rate of cooling
- Characteristic of the lavas: ***basalt, andesite, rhyolite***

Igneous Rocks Texture

Glassy texture

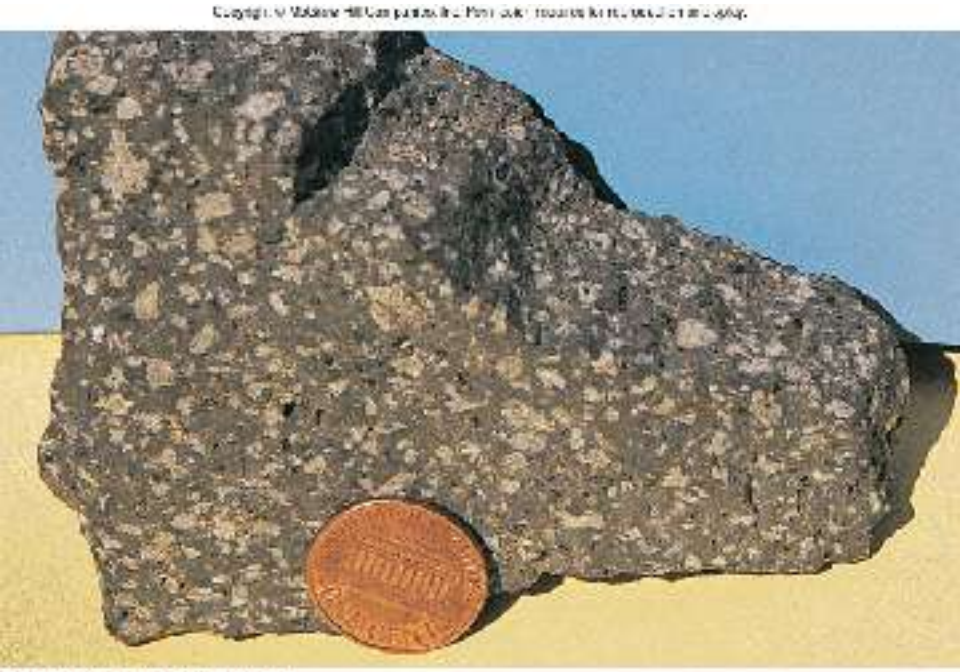
- **Consists of visible grains**
- **Is not crystalline, is formed by extremely rapid cooling**
- **Characteristic of *Obsidian***

Igneous Rocks Texture

Vesicular texture

- Is bubbly, formed by trapped bubbles of gas
- Characteristic of *scoria* (vesicular basalt) and *pumice* (vesicular rhyolite)

Igneous Rocks Texture



Andesite (porphyritic)

Porphyritic texture

- Consists of phaneritic (visible) grains in an aphanitic matrix
  - Phaneritic crystals form by very slow cooling below Earth's surface
  - Aphanitic crystals form by very rapid cooling above Earth's surface
- Characteristic of the lavas: *basalt*, *andesite*, *rhyolite*
- Formed when a lava is erupted as a crystal mush

Texture and where they form

ABOVE EARTH'S SURFACE

Based on Where They Form and Their Texture

Glassy Texture

Vesicular Texture

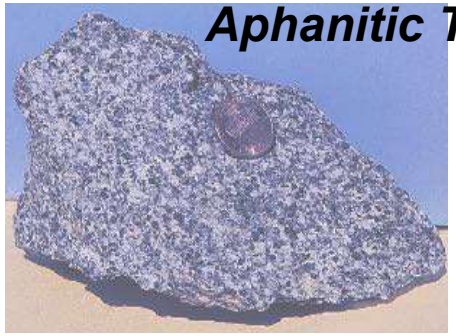
Plutonic (intrusive) Igneous Rocks

Volcanic (Extrusive) Igneous Rocks

CLOSER EARTH'S SURFACE

Aphanitic Texture

Porphyritic Texture



Phaneritic Texture

BELOW EARTH'S SURFACE

Igneous Rocks Composition

Dunit (Olivine rich)

Harzburgit (Pyroxene rich)

Ultramafic

- ***Means rich in magnesium and iron***
- **Is the average composition of Earth's mantle**
- **Composed of olivine and augite**
- **Example: *peridotite***

Igneous Rocks Composition

Gabbro

Mafic

- ***Means rich in magnesium, iron, and/or calcium***
- **Is the average composition of oceanic crust**
- **Composed of olivine, augite, and calcium, plagioclase feldspar**
- **Examples: *basalt, diabase, and gabbro***

Igneous Rocks Composition

Intermediate

- ***Means half mafic, half felsic***
- **Is the composition of a mixture of oceanic and continental crust?**
- **Composed of hornblende and calcium-sodium plagioclase feldspar**
- **Examples: *andesite* and *diorite***

Igneous Rocks Composition


Rhyolite

Felsic

- ***Means rich in feldspar and silica***
- **Is the average composition of continental crust**
- **Composed of potassium feldspar, sodium plagioclase feldspar, quartz**
- **Examples: *rhyolite* and *granite***

Classification and naming of igneous rocks

Identification of Plutonic Igneous Rocks

Plutonic Rocks

Phaneritic texture

Mafic composition
Dark gray

Diabase
(fine-grained)

Gabbro
(coarse-grained)

Intermediate composition
Medium gray,
~ 50:50 black and white

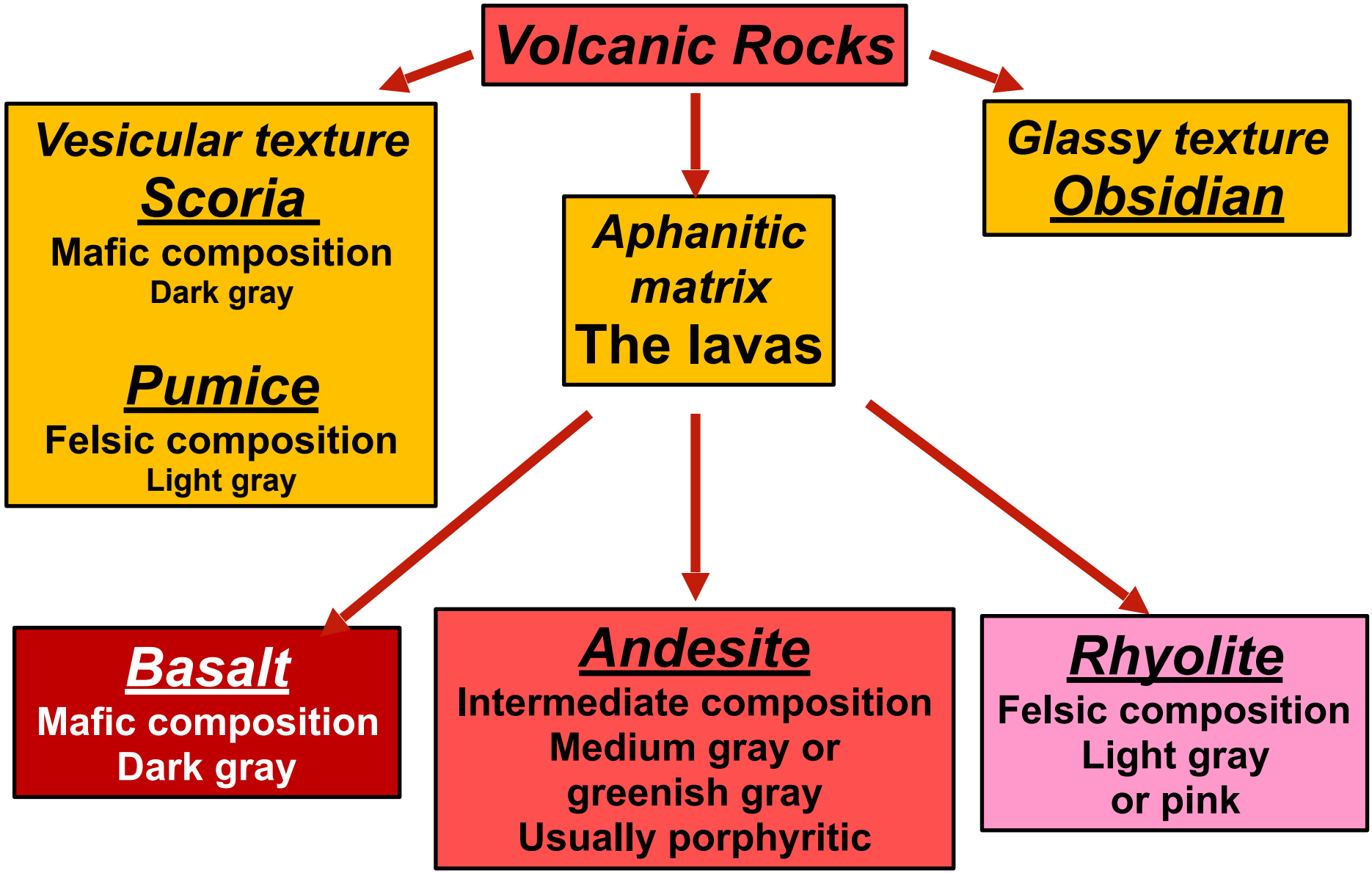
Diorite

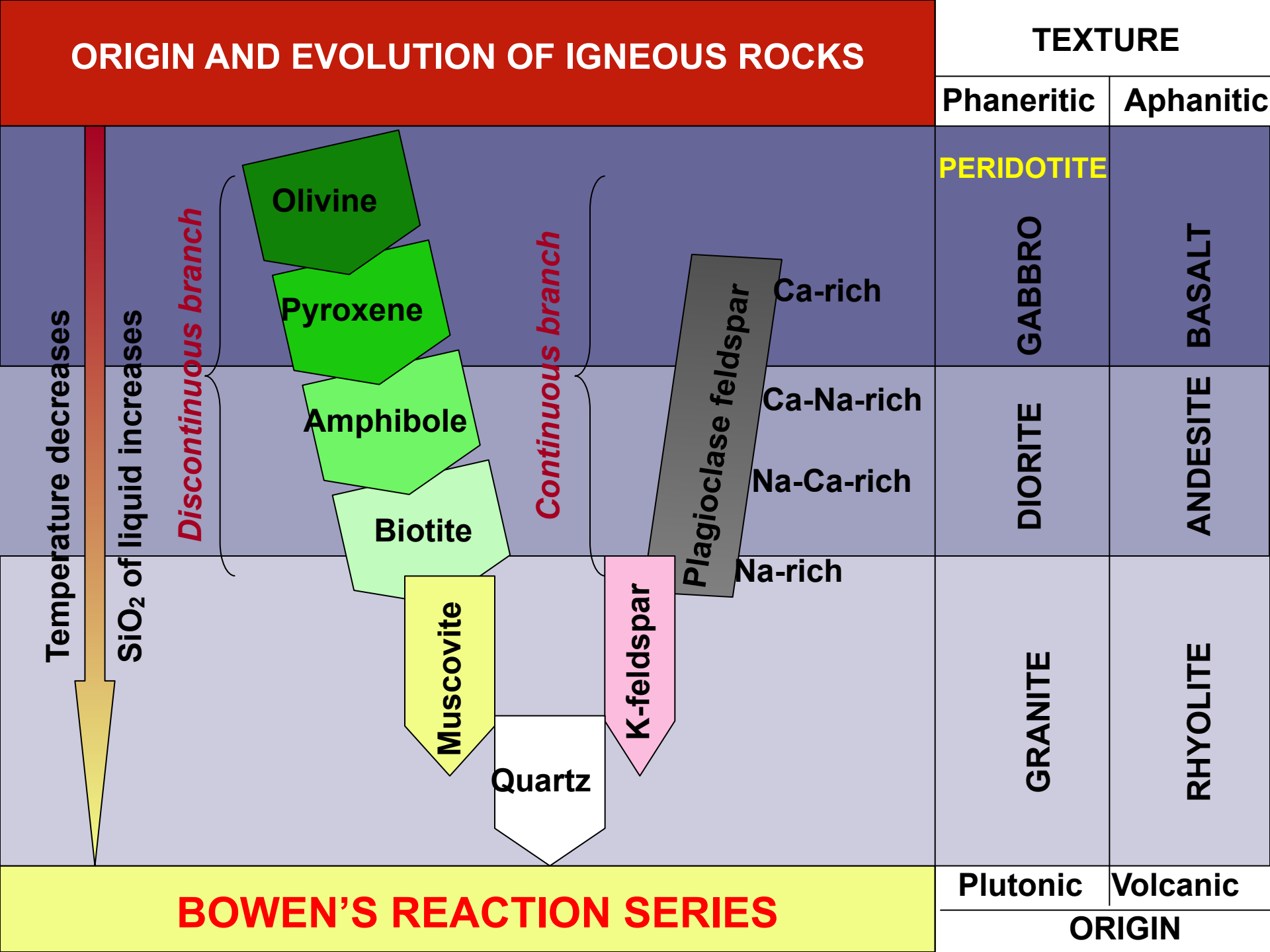
Felsic composition
Light gray
or pink

Granite

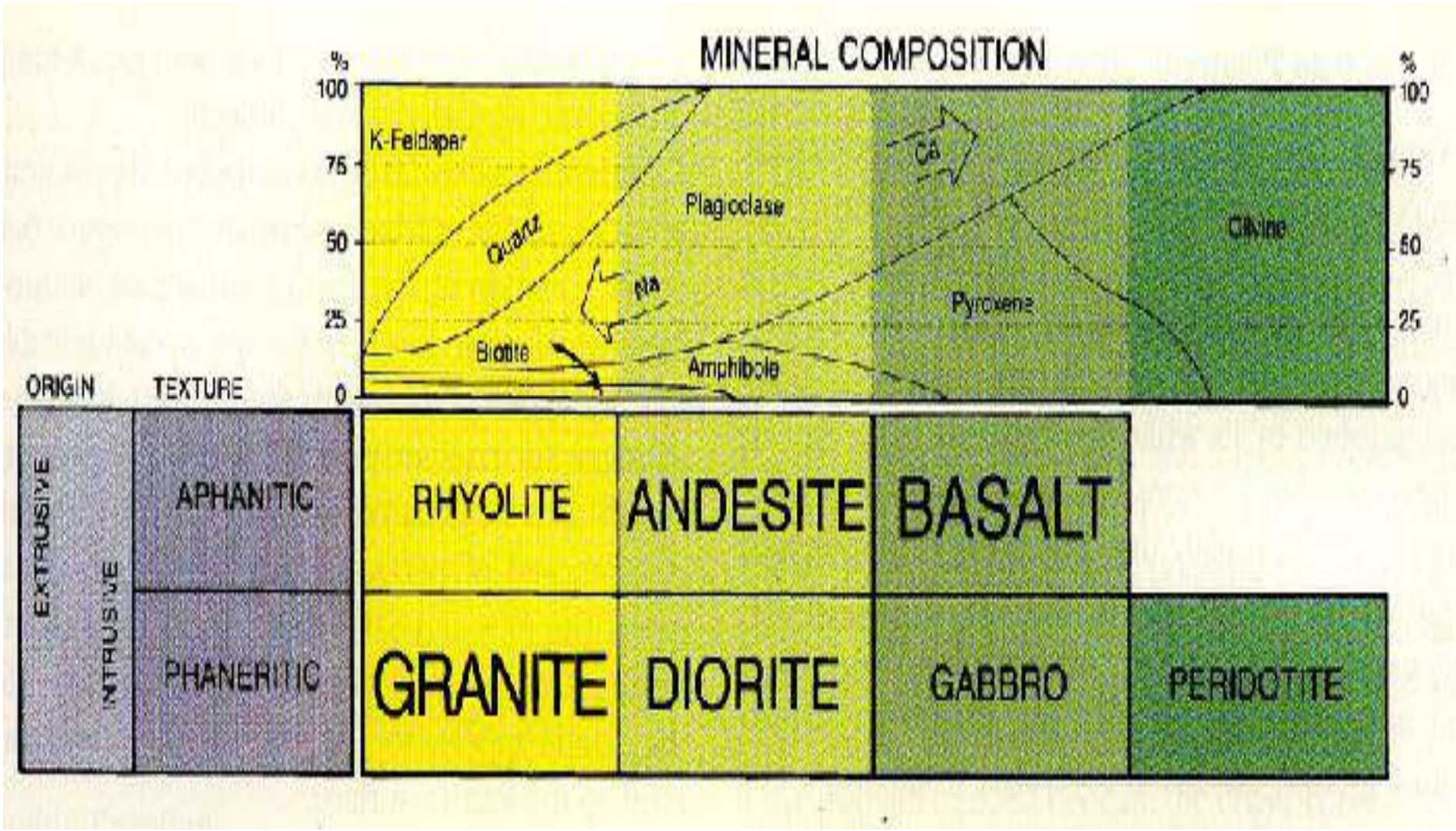
Classification and naming of igneous rocks

Identification of Volcanic Igneous Rocks




ORIGIN AND EVOLUTION OF IGNEOUS ROCKS
TEXTURE
Phaneritic
Aphanitic
PERIDOTITE
GABBRO
BASALT
DIORITE
ANDESITE
GRANITE
RHYOLITE
Temperature decreases
SiO2 of liquid increases
Discontinuous branch
Continuous branch
Olivine
Pyroxene
Amphibole
Biotite
Muscovite
Quartz
K-feldspar
Plagioclase feldspar
Ca-rich
Ca-Na-rich
Na-Ca-rich
Na-rich
BOWEN'S REACTION SERIES
Plutonic
Volcanic
ORIGIN

Classification and naming of igneous rocks



IGNEOUS ROCK CLASSIFICATION

MINERAL COMPOSITION

OLIVINE

AUGITE

CALCIUM FELDSPAR

ROCK TEXTURE

PHANERITIC

GABBRO

APHANITIC

BASALT

IGNEOUS ROCK CLASSIFICATION

MINERAL COMPOSITION

HORNBLENDE

BIOTITE

SODIUM FELDSPAR

ROCK TEXTURE

PHANERITIC

DIORITE

APHANITIC

ANDESITE

IGNEOUS ROCK CLASSIFICATION

MINERAL COMPOSITION

MUSCOVITE

POTASSIUM FELDSPAR

QUARTZ

ROCK TEXTURE

PHANERITIC

GRANITE

APHANITIC

RHYOLITE

Obsidian (volcanic glass)

Photo by C. C. Plummer

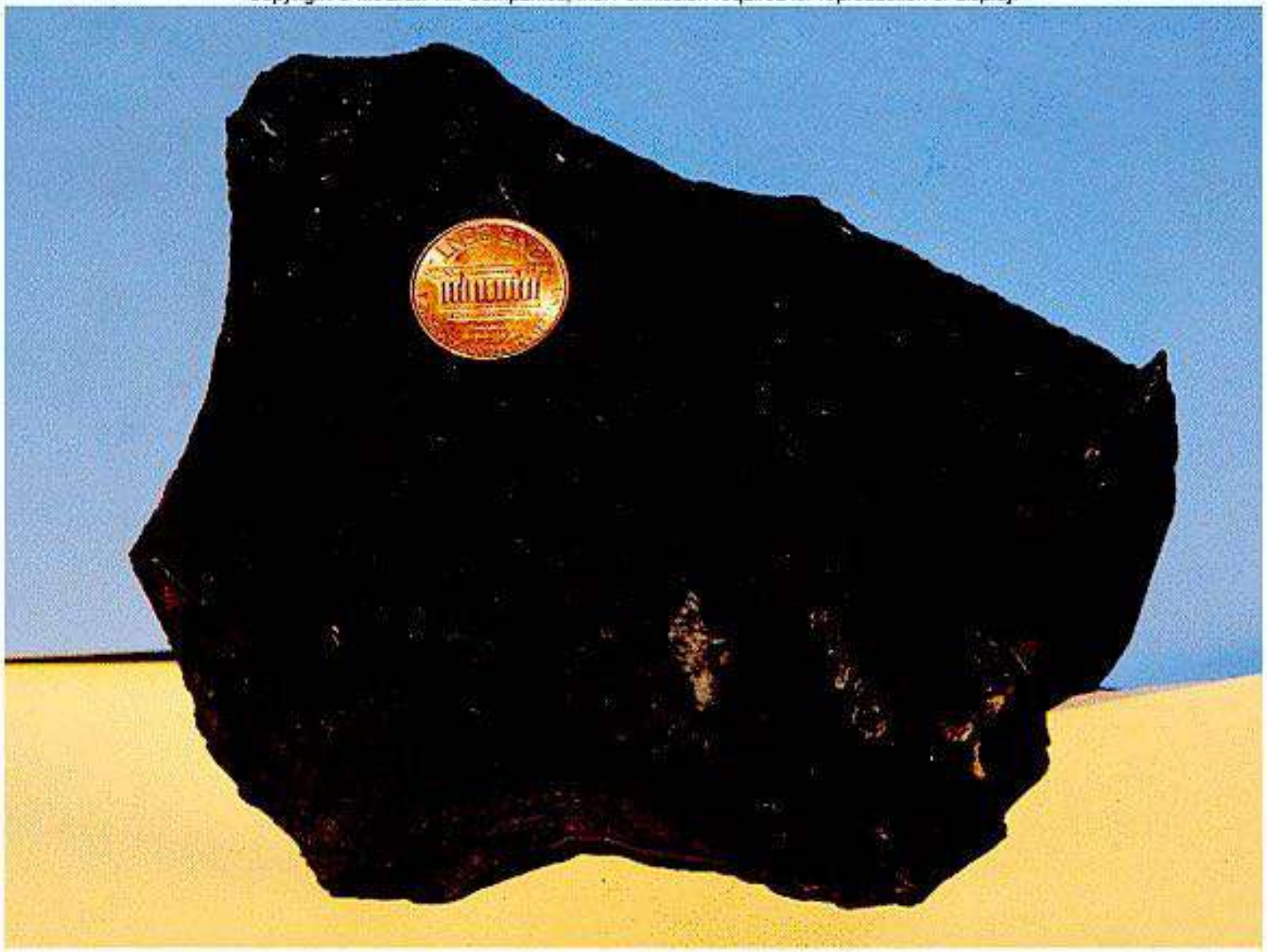
Scoria (vesicular basalt)

Photo by C. C. Plummer

Pumice (vesicular rhyolite)

Photo by C. C. Plummer

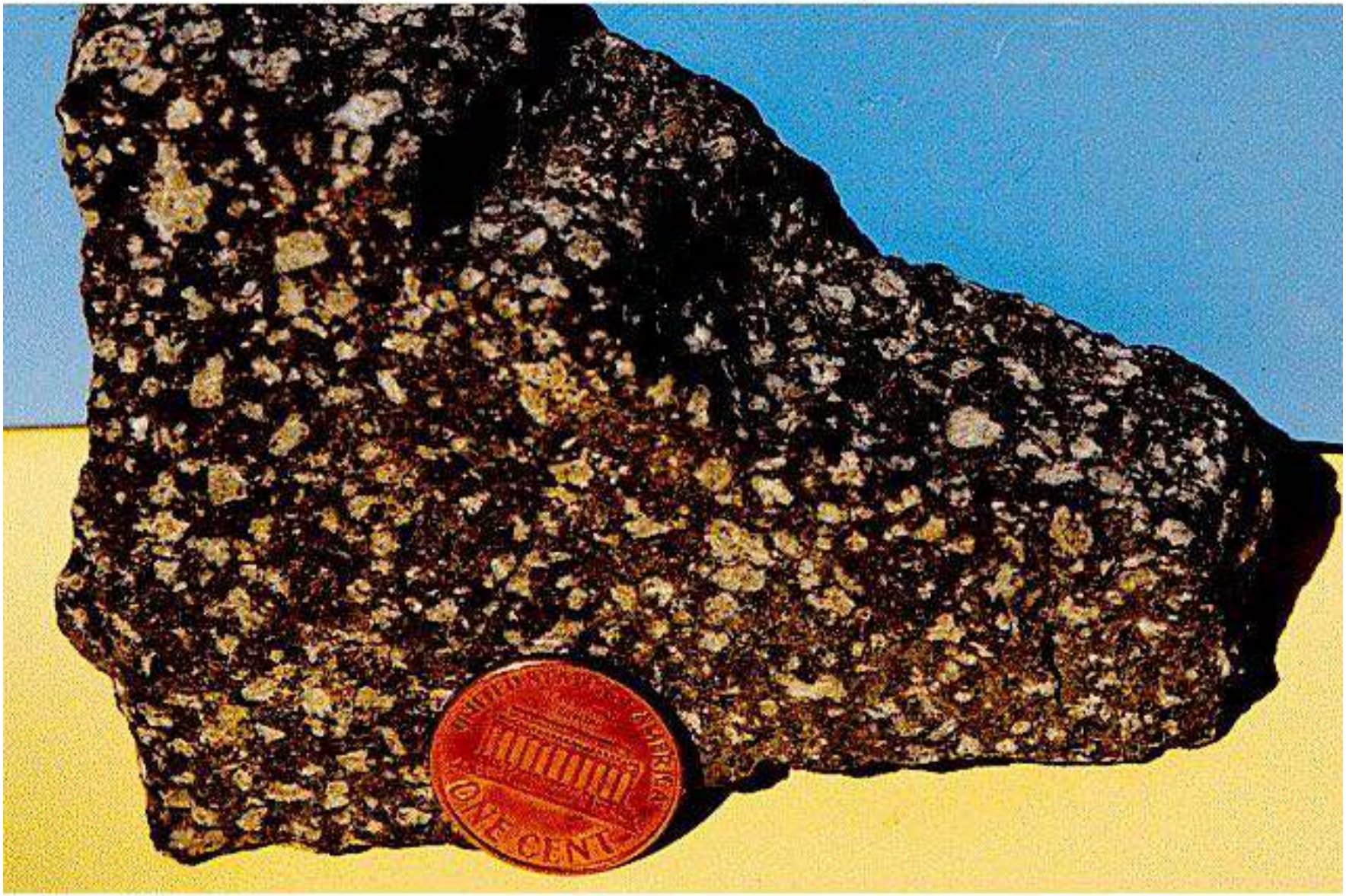
Basalt



Basalt

Photo by C. C. Plummer

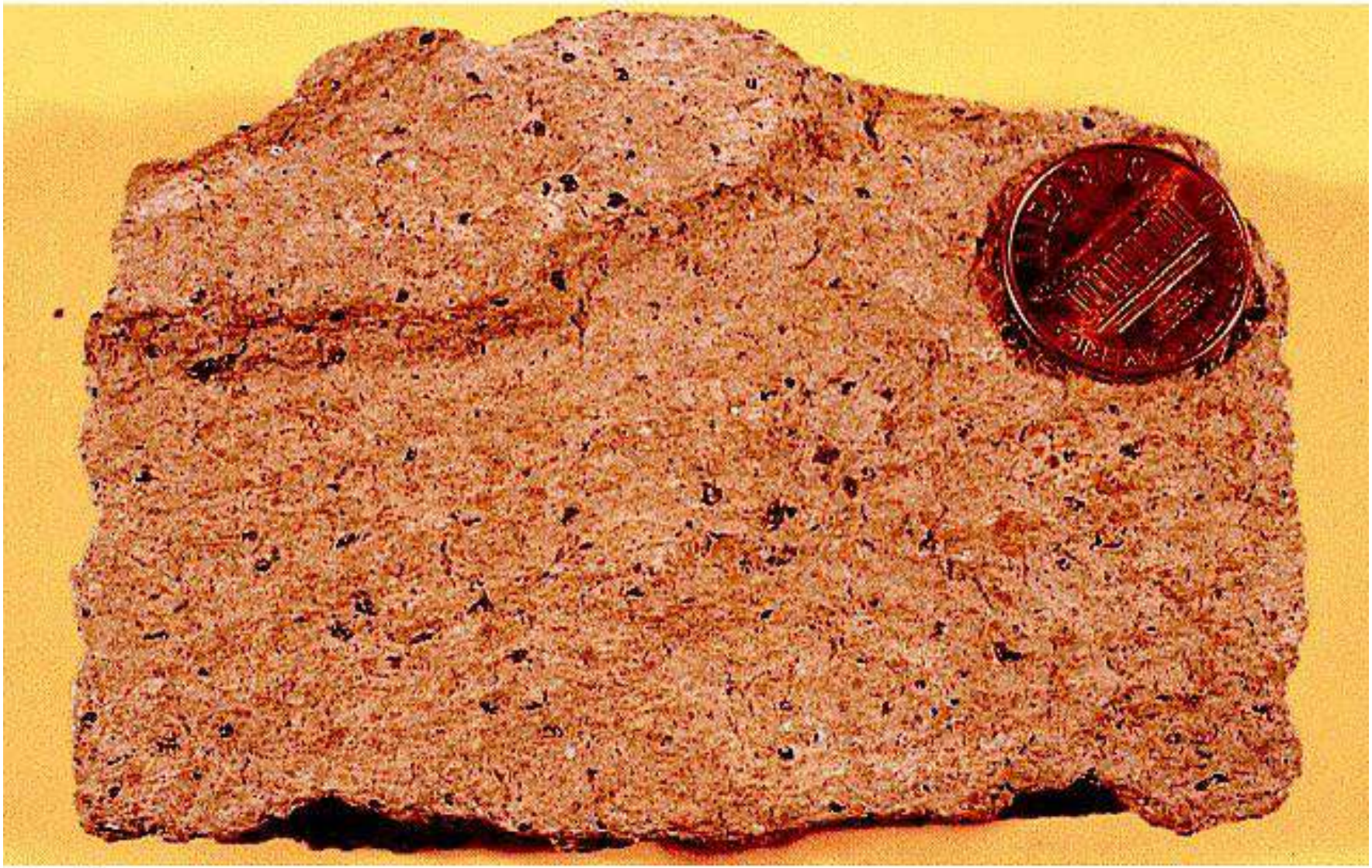
Porphyritic Andesite



Andesite (porphyritic)

Photo by C. C. Plummer

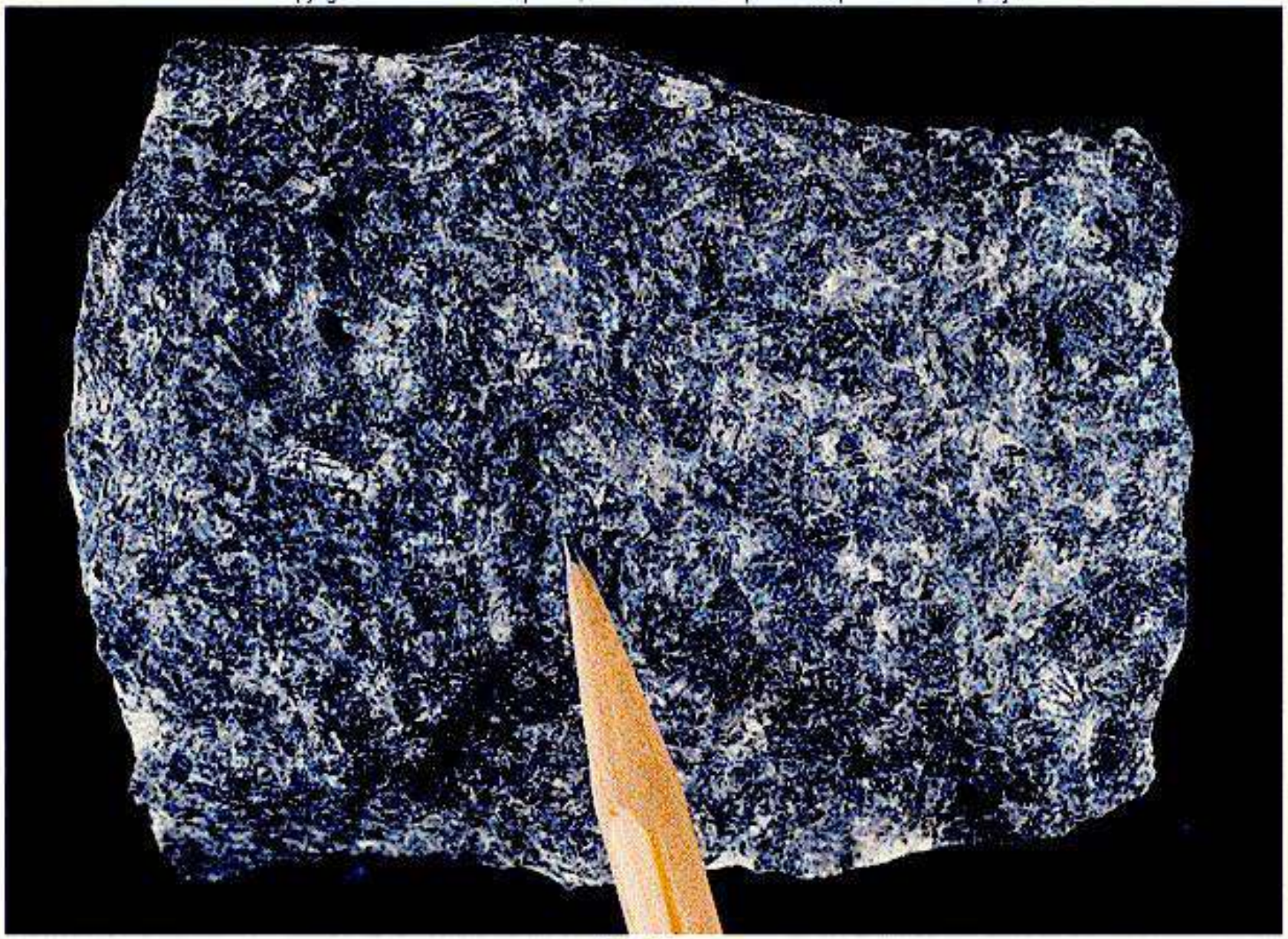
Rhyolite



Ryolite

Photo by C. C. Plummer

Gabbro



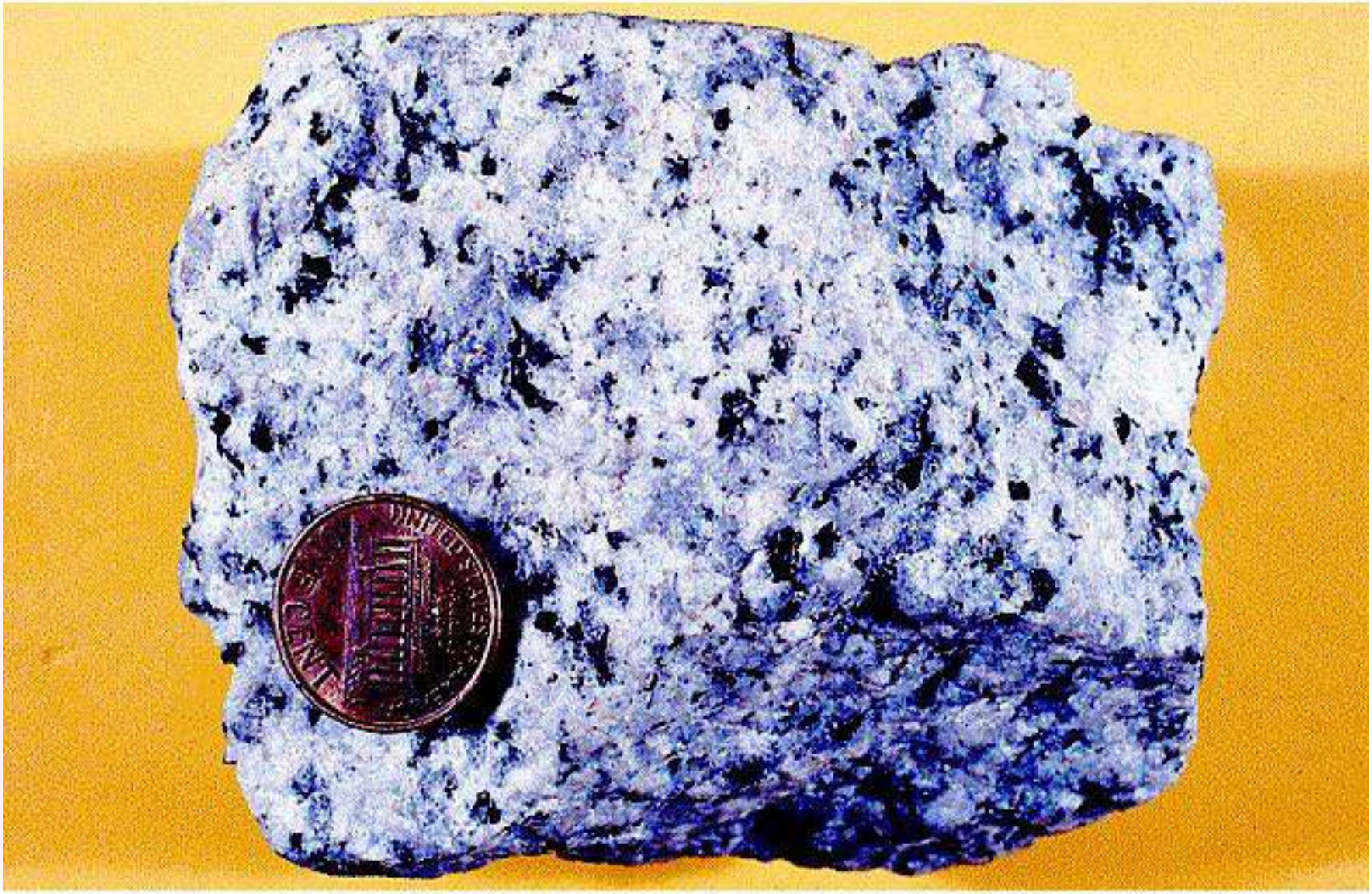
Gabbro

Diorite

Diorite

Photo by C. C. Plummer

Granite



Granite

Photo by C. C. Plummer

MAJOR CONCEPTS

1. Magma is molten rock that originates from the partial melting of the lower crust and the upper mantle, usually at depths between 10 and 200 km below the surface.
2. The texture of a rock provides important insight into the cooling history of the magma. The major textures of igneous rocks are (a) glassy, (b) aphanitic, (c) phaneritic, (d) porphyritic, and (e) pyroclastic.
3. Most magmas are part of a continuum that ranges from mafic magma to silicic magma.
4. Silicic magmas produce rocks of the granite-rhyolite family, which are composed of quartz, K-feldspar, Na-plagioclase, and minor amounts of biotite or amphibole.
5. Basaltic magmas produce rocks of the gabbro-basalt family, which are composed of Ca-plagioclase and pyroxene with lesser amounts of olivine and little or no quartz.
6. Magmas with composition intermediate between mafic and silicic compositions produce rocks of the diorite-andesite family.

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MAJOR CONCEPTS

7. Basalt, the most abundant type of extrusive rock, typically either erupts from fissures to produce relatively thin lava flows that cover broad areas or erupts from central vents to produce shield volcanoes and cinder cones. Volcanic features developed by intermediate to silicic magmas include viscous lava flows, ash-flow tuff, composite volcanoes, and collapse calderas. The abundance of water in silicic magma is critical to its development and eruption.
8. Masses of igneous rock formed by the cooling of magma beneath the surface are called intrusions or plutons. The most important types of intrusions are batholiths, stocks, dikes, sills, and laccoliths.
9. The wide variety of magma compositions is caused by variations in (a) the composition of the source rocks, (b) partial melting, (c) fractional crystallization, (d) mixing, and (e) assimilation of solid rock into the molten magma.
10. Most basaltic magma is generated by partial melting of the mantle at divergent plate boundaries and in rising mantle plumes. Most intermediate to silicic magma is produced at convergent plate boundaries. Partial melting of continental crust at rifts and above plumes can also produce silicic magma.

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