

Earth Rocks 1: Igneous Environments

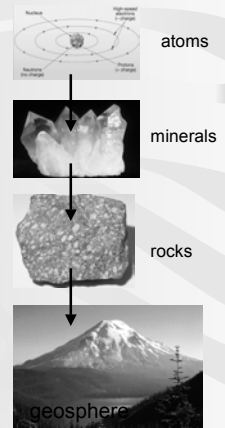


So far, we have looked at the relationship of atoms to minerals.

We will now look at the relationship of rocks to stated in the last couple lectures processes that act within the geosphere.

Simply put,

ROCKS are solid aggregates of minerals and mineral-like materials.



Importance of Rocks

Rocks are the ultimate source of materials that living things require; mineral-derived nutrients and materials for skeletal construction are constantly supplied to the biosphere through the weathering of rock.

Most of our knowledge about Earth's processes and deep history comes from rocks – rocks are our time capsules.

For example:

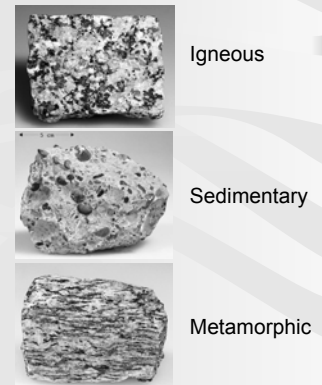
1. Rocks are preservational media for fossils. Fossils, in turn, reveal patterns of evolutionary change.
2. Rocks provide information on processes that have acted both on and within the Earth.
3. Rocks contain minerals that can be dated (thus allowing absolute ages of rocks to be obtained).

Three Basic Classes of Rocks

Just as organisms are classified into groups according to shared characteristics, rocks can be divided into categories.

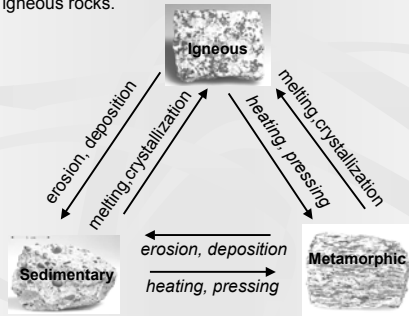
At the most basic level, rocks are considered to belong to three *classes*, each of which have characteristics that indicate how they were formed.

Within each class, rocks are given more specific names.



The Rock Cycle

Rocks of each class have the potential to change into members of other rock classes. This ultimate rock recycling system is called the *rock cycle*. We will look at this in detail a little later on. Today we will look at igneous rocks.



How Are Igneous Rocks Formed ?

The term "igneous" gets its name from the Latin *ignis* = "fire"

The hot, molten, material from which of igneous rocks are formed is called *magma*.

Magma results from the melting of rock in the mantle or crust, or both.

Magma is mostly liquid, but can also contain gases such as water vapour and carbon dioxide and mineral crystals.



When magma reaches the surface and loses its gases (thus changing in composition), it becomes lava.

How are Igneous Rocks Classified ?

Igneous rocks are classified based on two major things:

Texture: including relative sizes of mineral crystals, and/or distinct features such as bubbles and fragmented material. Texture is useful for determining the cooling history of an igneous rock.

Composition: the mineral content of a rock (often indicated by colour or shade) is useful in determining the chemical characteristics of the magma.

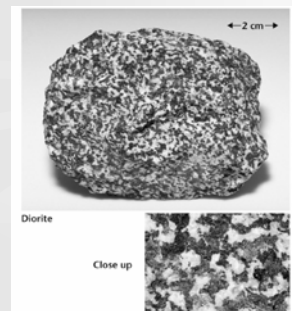
In general, we refer igneous rocks as being

Phaneritic Texture

Mineral crystals in this rock are large enough to be observed with the unaided eye.

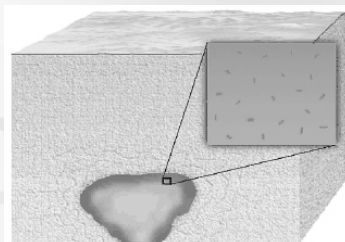
This texture is called *phaneritic* texture. (*phaner* = visible)

Large crystals means that the magma cooled very slowly, deep underground.



Example of phaneritic texture

Origin of Phaneritic Texture



Magma ascends due to being less dense than the surrounding rock.

The magma starts to cool, allowing minerals to crystallize from chemical components of the melt.

If magma remains trapped in a magma chamber, it cools very slowly, allowing the crystals to grow to large sizes.

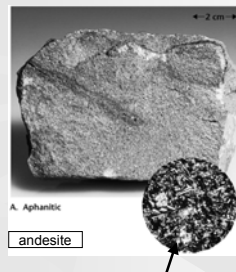
Rocks formed in this environment are called *intrusive* or *plutonic* igneous rocks

Aphanitic Texture

Mineral crystals in this igneous rock are too small to be observed with the unaided eye.

This texture is called *aphanitic* texture.
(a= not, *phaner* = visible)

Tiny crystals indicate rapid cooling of magma at the Earth's surface.

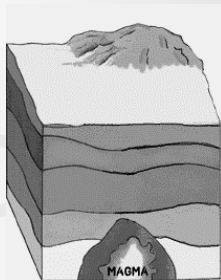


A. Aphanitic

andesite

Magnified about 30 x under cross-polarized light

Origin of Aphanitic Texture



Magma that escapes a magma chamber and reaches Earth's surface can erupt from a volcanic centre. The extruded material is called *lava*.

Lava is extruded from a volcanic vent due to the expansion of volatiles (gases) as they escape to the surface in response to a decrease in pressure (similar to what happens when you open a pop bottle that has been shaken).

If the eruption is explosive the volcanic material may become airborne (more on this later).

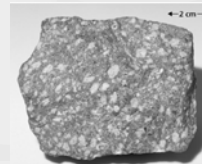
Rocks formed in this way are called *extrusive* or *volcanic* igneous rocks

Porphyritic Texture

Some igneous rocks have a texture showing large mineral crystals (phenocrysts) imbedded in a "groundmass" of much smaller crystals (commonly aphanitic).

The resulting texture is called a *porphyritic* texture.

This texture is produced when the magma initially cools very slowly (forming large crystals), but later moves closer to the surface (or is extruded), cooling more quickly and producing smaller crystals



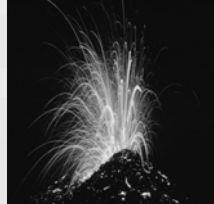
Igneous rock, in this case a volcanic rock, showing porphyritic texture

Eruptions

The nature of a lava eruption is linked to the temperature, melt composition, and volatile content of the magma (we will discuss this in greater detail later in the term).



Lava can be extruded quietly...



...or violently

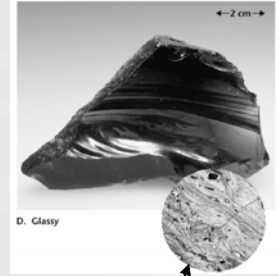
Special Textures: Glassy

In some instances, lava solidifies too quickly (is “quenched”) for any significant crystallization to occur.

Unordered ions remain essentially “frozen” before they can unite to form crystals.

The result is a *glassy texture*.

Obsidian is a common rock exhibiting such a texture.



D. Glassy

Magnified about 30 x under cross-polarized light

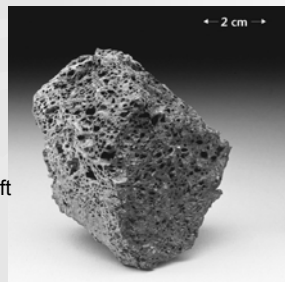
Special Textures: Vesicular

On reaching the surface, gases separate from the melt – much of these escape.

But some gas remains in the melt as bubbles.

A rock riddled with holes left by gas bubbles is said to have a *vesicular texture*.

Scoria is a rock that has a vesicular texture



Special Textures: Frothy

A frothy texture can be considered an extreme version of vesicular texture.

Due to the huge number of holes left by escaping gas, a rock with a frothy texture can float in water.

Pumice shows such a frothy texture exceptionally well.



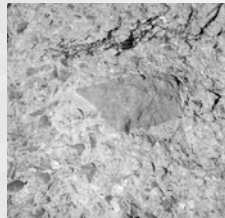
Special Textures: Pyroclastic

Lava is not the only material produced by volcanoes.

Eruptions that are exceptionally violent can eject dust-sized particles (ash) to fist- or even car-sized bodies (bombs).

These particles include blobs of molten material and pulverized bits of rock.

Rocks composed of this fragmented material are said to have a *pyroclastic texture* (*pyro*= fire, *klastos*= broken)



A rock showing pyroclastic texture (note large angular fragments of rock surrounded by fine-grained ash)

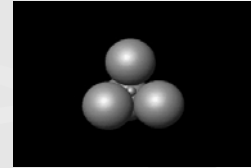
Back to Minerals; Review

Most igneous rocks are principally made of silicate minerals (although types of minerals do occur in smaller quantities).

As their name implies, silicate minerals all contain the substance called silica.

Silica can be thought of as a complex ion made of 1 silicon atom bonded to 4 oxygen atoms (SiO_4)⁴⁻

The silica "unit" occurs in the form of a tetrahedron.



Silica unit
(small blue ball: silicon)
(large red balls: oxygen)

Note: only one bond of each oxygen atom are connected to silicon, so silica has a net -4 charge

Common Minerals of Igneous Rocks

Ferromagnesian silicates
(basically iron and/or magnesium ions ionically bonded with silica units – other additional ions in some varieties)
Tend to be dark-coloured



Olivine
 $(\text{Mg,Fe})_2\text{SiO}_4$



Pyroxene
 $(\text{Mg,Fe})\text{SiO}_3$



Amphibole
 $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$



Biotite Mica
 $\text{K}(\text{Mg,Fe})_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$

Silica units



Single tetrahedra

No cleavage



Single chains

2 cleavages
(90°)



Double chains

2 cleavages
(60° and 120°)



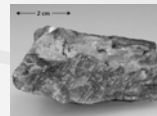
Sheets

1 cleavage

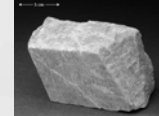
Common Minerals of Igneous Rocks

Feldspars

(silica framework plus light cations (K^+ , Na^+ , Ca^{2+}))
Ca-rich plagioclase dark coloured, Na-rich plagioclase light coloured
K-feldspar and Quartz light coloured



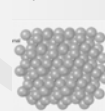
Plagioclase feldspar



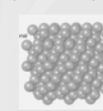
Potassium feldspar (Orthoclase)

Both minerals have two sets of cleavage meeting at 90°, reflecting the same pattern of bonding weakness within the crystal structure of the feldspar mineral group.

Silica units



3-D framework



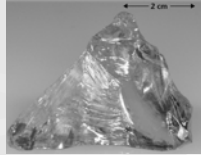
3-D framework

Common Minerals of Igneous Rocks

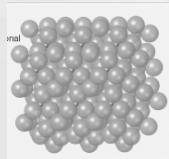
Quartz

Quartz, one of the most common minerals in igneous rocks consists of only silica (again, silicon plus oxygen).

Because of the complete sharing of oxygen by adjacent silicon atoms, all of the bonds in quartz are equally strong. As a consequence, quartz does not have cleavage and generally shows a conchoidal fracture. Pure quartz is clear and colourless.



Quartz



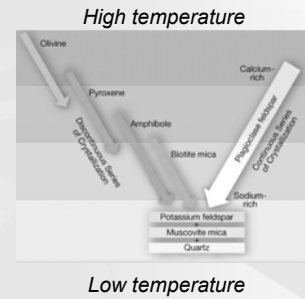
3-D silica framework (no extra ions)

Crystallization Sequence of Common Silicate Minerals

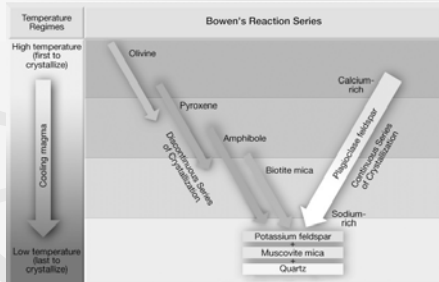
Different minerals crystallize at different temperatures. Thus, as a magma cools, minerals crystallize in a distinct sequence (expressed as Bowen's Reaction Series).

The ferromagnesium minerals crystallize in a discontinuous sequence.

Plagioclase changes gradually in composition with changing temperature, crystallizing in a continuous sequence.



Note that during each stage in cooling, the resulting rock will preserve a different suite of minerals.



Dark-coloured

Light-coloured

Also note that the dark coloured ferromagnesian minerals and Ca-rich plagioclase crystallize at higher temperatures than light-coloured K-feldspar and quartz

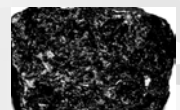
Igneous Rock Types: Composition

On a very basic level, the composition of igneous rocks can be estimated on the basis of colour.

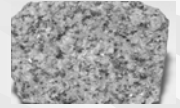
Mafic rocks: Igneous rocks containing a high concentrations of dark-coloured minerals (especially ferromagnesian minerals) are called *mafic rocks* ("ma" referring to magnesium and "fi" referring to iron). These rocks are generally very dark in colour.

Felsic rocks: Igneous rocks containing high concentrations of light-coloured minerals with only minor amounts of dark minerals (especially ferromagnesian minerals) are called *felsic rocks* ("fel" referring to the abundance of light-coloured feldspar, and the "si" referring to silica (quartz)). These rocks are generally light in colour.

Intermediate rocks: These are rocks that have a colour in-between mafic and felsic.



Mafic igneous rock



Felsic igneous rock

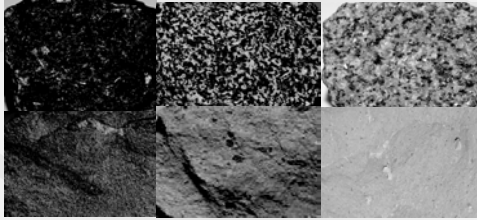


Intermediate igneous rock

Naming Igneous Rocks

Note: The terms "felsic," "intermediate," and "mafic" only reflect the composition of an igneous rock, whereas "phaneritic" and "aphanitic" refer to texture, but not composition.

A rock name is extremely informative as it tells something about a rock's composition and texture (without the user having to spell out the details every time he/she refers to that specific rock).

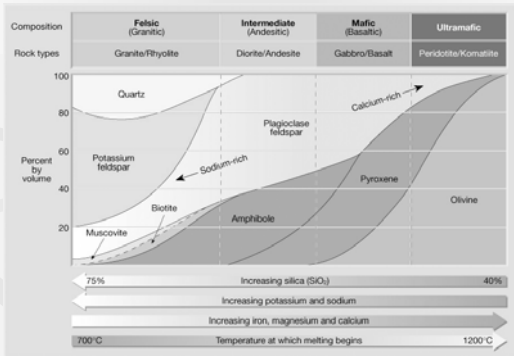


Naming igneous rocks

Here is a very basic scheme on how 6 common igneous rock names relate to their composition and texture.

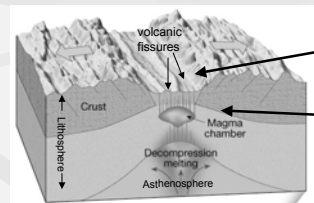
		<i>composition</i>		
		Mafic (dark coloured)	Intermediate (in-between colour)	Felsic (light coloured)
<i>texture</i>	Phaneritic (large crystals)	 Name: Gabbro	 Name: Diorite	 Name: Granite
	Aphanitic (very small crystals)	 Name: Basalt	 Name: Andesite	 Name: Rhyolite

Another way of looking at composition



Igneous Rocks and Plate Tectonics

Magmas generated in places where plates are spreading apart are produced by the melting of both low and high temperature minerals, and therefore the magma contains silica, but a large amount of iron and magnesium. Cooling of such magma produces a dark-coloured rock.

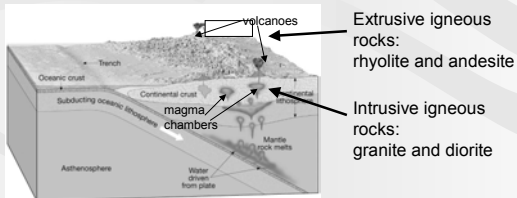


Extrusive igneous rock: basalt
Intrusive igneous rock: gabbro

Igneous Rocks and Plate Tectonics

Magma produced by melting of a descending tectonic plate tends to be formed at lower temperatures than those produced at sites where plates are spreading apart (water contained in the descending slab turns to steam and lowers the melting point of rock).

Under relatively low temperatures, low-temperature (and light coloured) minerals are preferentially melted, enriching the magma in silica. Magma can also be "contaminated" by silica-rich rocks in the crust, further increasing its silica content.



Can Fossils found in Igneous Rocks ?

As a general rule, no.

Plutonic rocks are formed well below the surface, where nothing live anyway !

One would also not expect to find fossils in extrusive igneous rocks - lava is generally hot enough to incinerate pretty much all organic tissue (plant or animal) that it encounters.

...But rare examples are known.



Fossils in Lava Flows

In the example shown here, lava flowed around a tree that was still in vertical position.

Moisture in the wood was sufficient to prevent the wood from immediately incinerating, and helped cool the lava directly surrounding the tree.

The wood did eventually burn away (indicated by some charred residue), but molds made in the lava remained.



Mould of a tree in lava flow:
Craters of the Moon National Monument, Idaho, U.S.A
Age: Less than 10,000 years

Fossils Found in Pyroclastic Deposits

Fine-grained pyroclastic debris (as volcanic ash) cools very quickly in the air.

When it falls to the ground, it can cover the remains of organisms. Where lots of ash is deposited in a short period of time, remains or traces of activity can be sufficiently protected to be well preserved as fossils.



Butterfly preserved in volcanic ash
(Florissant, Colorado)
Age: about 35 million years



Rhino skeletons in volcanic ash
(Ashfall Fossil Beds, Nebraska)
Age: about 10 million years

Why do we care about igneous rocks if this course is about fossils ?

Igneous rocks (with the exception of volcanic ash, which could be argued to technically be sedimentary) very rarely preserve organic remains.

However, along with metamorphic rocks (which we will talk about soon), igneous rocks, when weathered are important sources of sediment.

Sediment is ultimately transformed into sedimentary rock, within which the vast majority of fossils are found.

END OF LECTURE

Next Lecture: Sedimentary and Metamorphic Environments