CHAPTER 3: ROCKS

Rocks as Mineral Aggregates

_____ is the study of rocks and their formation. A _____ is simply one or more minerals attached in some manner; it is usually a mixture.

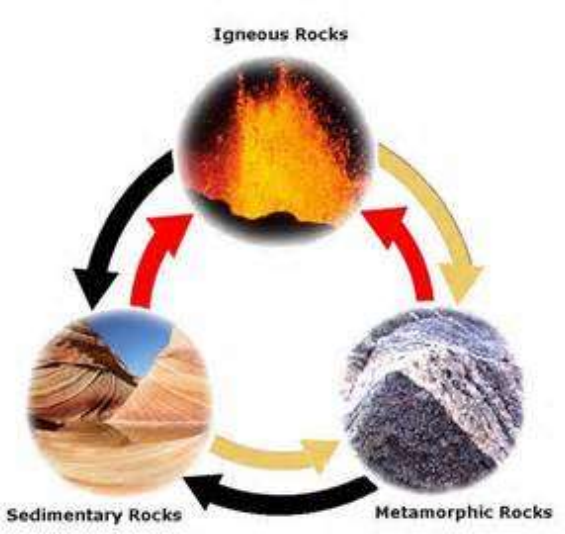
According the principles of _____, the geologic processes now at work were also active in the past, and the physical features of the earth were formed from these processes over long periods of time. From this, we can surmise that the rocks we see around us were also formed in the past by the same geological processes we see around us today.

There are **three** broad classes of rock:

1) _____ _____ – formed when molten _____ or _____ cools

2) _____ _____ – formed either from eroded _____ (mud, sand, gravel, etc) that is deposited and cemented together into new rock, or forms by _____ out of solution.

3) _____ _____ – formed when a rock experiences intense _____ and _____, altering the rock's mineralogy and characteristics.



3.1 Igneous Rocks

Melting and Crystallization

The **Igneous** Family includes a wide range of rocks that can form either _____ the planet or on the _____. However, at some point all **igneous** rocks were in a *molten* (melted) form. If the liquid rock is underground, it is called _____. If the liquid rock is found at the surface, it is called _____.

In this section of the course we will study the processes of how magma forms and how it cools and crystallizes into different types of rocks. Igneous rocks compose more than _____ of the Earth's crust.

Origin and Crystallization of Magma:

There is a lot of heat in the interior of the Earth. Some of this heat comes from the _____ of the Earth. Some of it is also from _____ _____ of certain elements, such as _____ and _____. The interior of the Earth is up to several _____ degrees Celsius. At these temperatures, most elements and compounds are above their melting point. The immense pressure in this setting, however, keeps the _____ from being a 'true' liquid.

When _____ (cracks, faults, etc.) in the crust allow this material to get closer to the surface, the _____ becomes less extreme, and the material can change into a _____ form. This material is technically called _____, but is more commonly called _____.

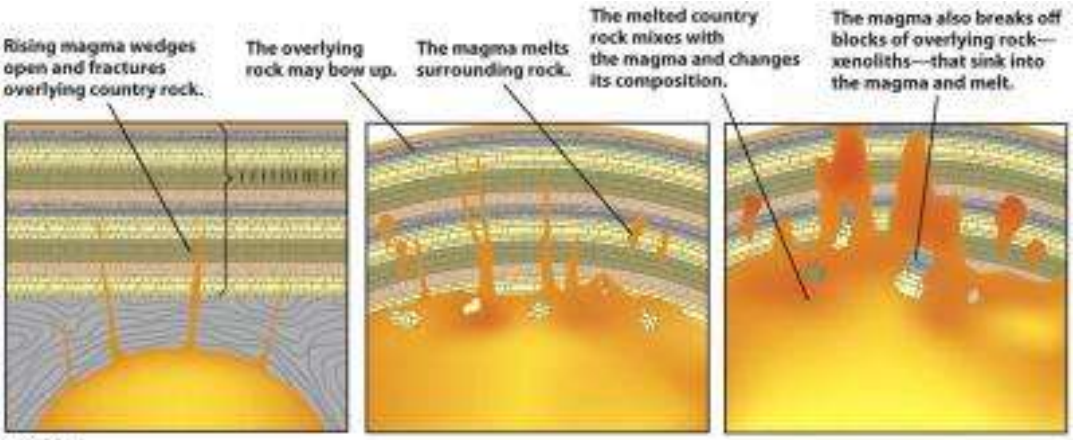


Figure 5.10
The Essential Earth, Second Edition
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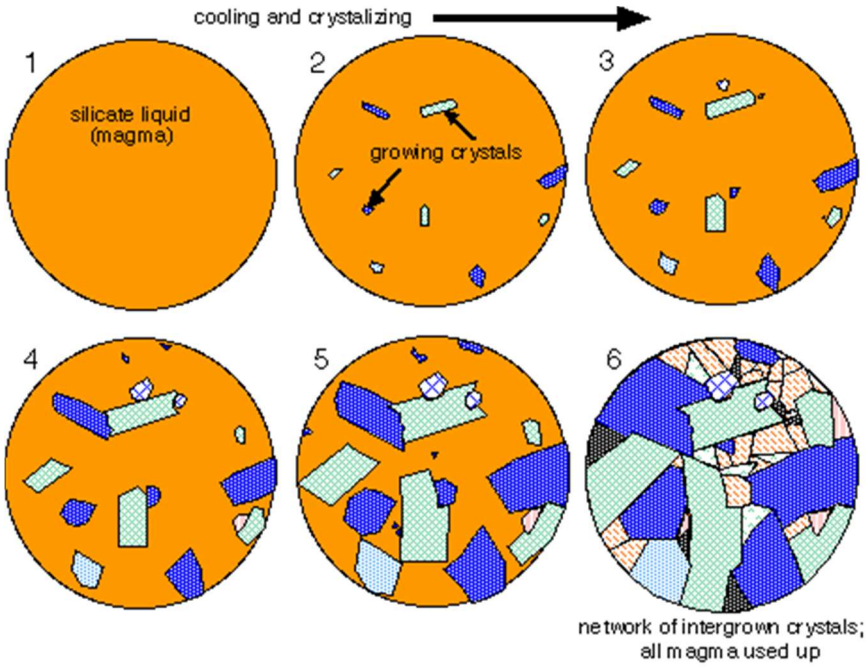
As the material migrates upwards heat energy is lost to the surrounding rock (_____ _____). As the _____ drops, in atoms will slow down and begin to interact with each other. They can react and form new compounds. These compounds will be _____ for new mineral crystals to grow.

Not all minerals form at the same time since each one has a unique _____/_____ point. There is an order to the process, called the _____ _____ _____. The basic principle is that certain minerals _____ out of the melt first, and then react with the remaining melt, forming new and/or altered minerals, until all the magma is crystallized.



Plutonic vs. Volcanic Rocks

The major division for igneous rocks is based on rate of cooling. _____ rocks or _____ rocks cool _____ within the earth. They produce relatively _____ and interlocking crystals.

_____ rocks or _____ rocks form when lava cools on the Earth's surface. They cool _____ and the crystals that form are relatively _____.

Once it has been determined whether the rock is plutonic or volcanic, the name given is on the basis of colour and mineralogy.

Magmas that form _____ form _____.
Magmas that form _____ form _____.

Plutonic and volcanic rocks have different names. They are classified by their percentage of _____ minerals. Dark minerals typically contain more iron and magnesium.

Terminology:

Chemistry Terminology:

- ***Mafic***: -Magma that is rich in iron-magnesium (_____)
  -Forms minerals that are (generally) _____ in color
  -Magma/Lava has _____ (low silica = 'runnier')
  -Resulting rock is _____ in quartz, rich in ferromagnesian minerals

- ***Felsic***: -Magma that is silica-rich (_____)
  -Forms minerals that are (generally) _____ in color
  -Magma/Lava has _____ (silica = 'stickier')
  -Resulting rock is _____ in quartz and feldspar

Textural Terminology:

- **Grain Size**: -Size of _____ _____ _____ (fine vs. coarse)
  →depends on cooling history/conditions

- **Aphanitic**: -When mineral crystals are very _____ ('fine')
  →magma cooled _____ = little time to form

- **Phaneritic**: -When mineral crystals are _____ ('coarse')
  →magma cooled _____ = lots of time to form/grow

- **Glassy**: -When _____ crystals are present
  →magma cooled _____ = no time for growth

- **Vesicular**: -When '_____ are present in a rock
  →_____ were _____ during cooling

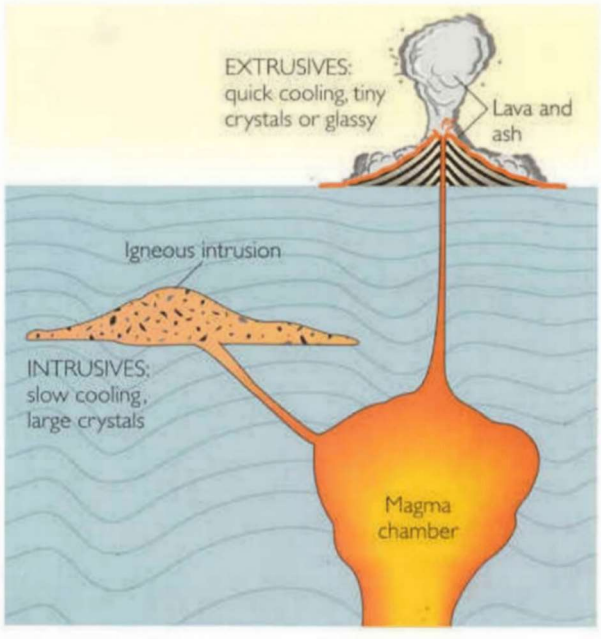


Figure 3.2
Press and Siever: *Understanding Earth*

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Classification:

Igneous rocks are generally classified by the chemistry and where they form. These manifests through the mineral composition (_____) and crystal size (_____).

Chemical Classification:

-a _____ scale, using the terms described earlier:

Felsic	→	**Intermediate**	→	**Mafic**
High Silica content		→		Low Silica content
Light colored minerals		→		Dark colored minerals

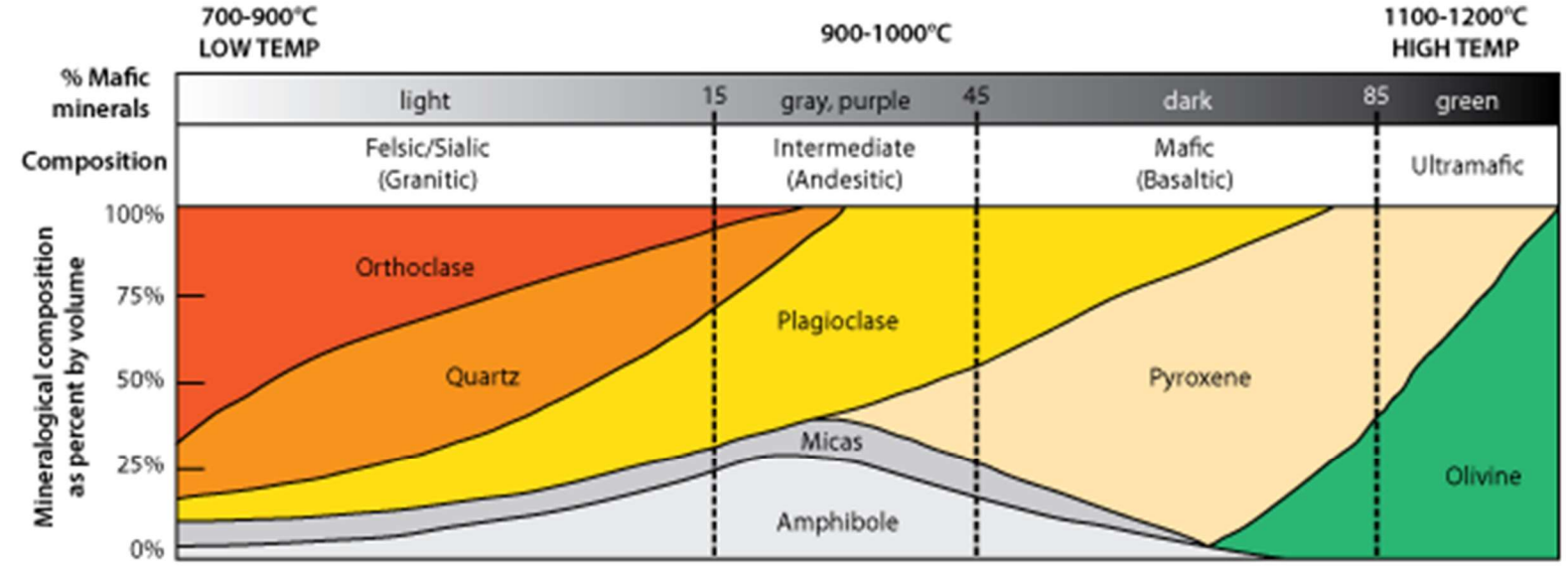
Physical Classification:

-grain (crystal) size tells you location of formation:

Plutonic/Intrusive	**Volcanic/Extrusive**
_____	_____
_____	_____

→Once you have described a rock by its color (~mineralogy) and crystal size, you can use a chart to determine specific rock name.

Colour of Rock	**Volcanic Name (fine-grained)**	**Plutonic Name (course-grained)**
Very Dark (ultramafic)		Peridotite
Dark (mafic)	Basalt	Gabbro
Medium (intermediate)	Andesite	Diorite
Light (felsic or silicic)	Rhyolite	Granite

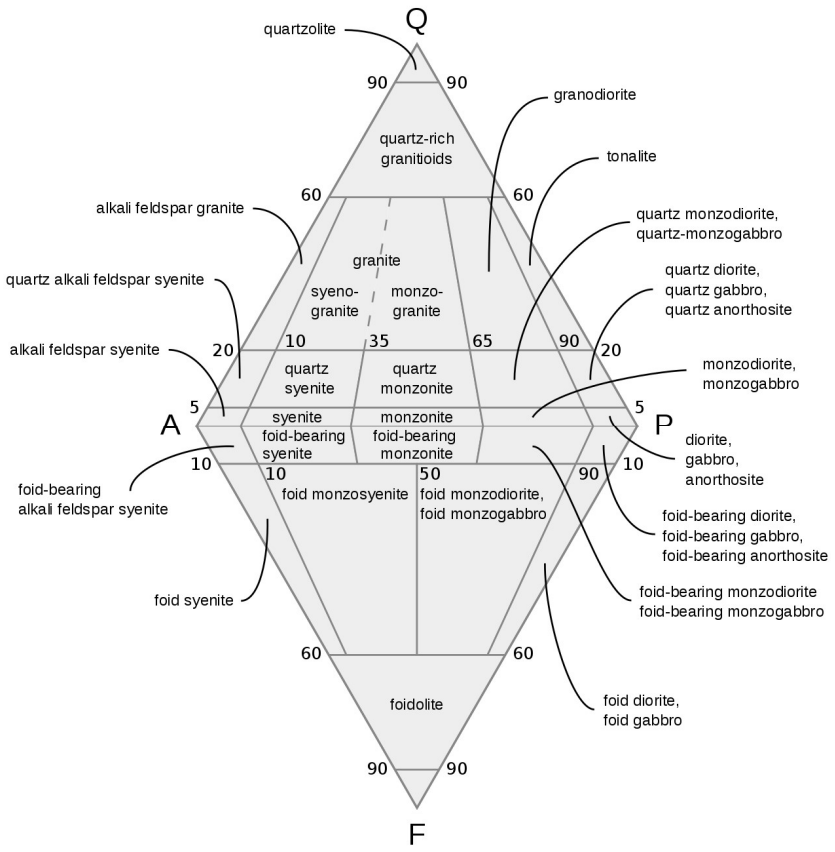


Texture	Rock names			
Coarse-grained	Granite	Diorite	Gabbro	Peridotite
Fine-grained	Rhyolite	Andesite	Basalt	Uncommon (rarely encountered)
Pyroclastic	Rhyolite Tuff	Andesite Tuff	Basalt Tuff	
Glassy	Obsidian			
Vesicular	Pumice (like meringue)		Scoria	

Plutonic Rock	Overall Colour	Major Minerals Present
Granite	Light, few dark minerals	Noticeable _____ and light orthoclase (K) or albite (Na) _____ (felsic/ acidic). The few dark minerals are _____ or _____.
Pegmatite	Light, few dark minerals	An extremely coarse grained light coloured _____ rock, similar composition to _____.
Syenite	Light, few dark minerals	Pink, grey and white orthoclase (K) and plagioclase (Na) feldspars (felsic), and _____ quartz The few dark minerals are biotite or hornblende.

Quartz Diorite (Tonalite)	Medium, similar proportions of light and dark minerals	_____ minerals, mostly albite (Na) feldspars with _____ quartz and plagioclase feldspar. Dark minerals are hornblende or biotite.
Diorite	Medium to dark, more dark minerals	_____, mostly grey Ca plagioclase. Dark minerals commonly hornblende, _____ pyroxene.
Gabbro	Dark grey to black	_____ dark magnesium and iron minerals, _____ quartz and some calcium feldspar (mafic).
Peridotite	Dark Black	_____ pyroxene and olivine with a _____ calcium plagioclase (ultramafic).

Volcanic Rock	**Overall Colour**	**SiO_2**	**Viscosity**
Rhyolite	Light – pale grey, cream	High	High
Dacite	Greenish grey, grey	Medium	Med-High
Andesite	Grey, light brown	Medium	Med-Low
Basalt	Dark – brown, black	Low	Low



You do not need to memorize this diagram. It is for your own reference

Other Igneous Rocks:

1) **Porphyry** is a rock which has both _____ and _____ crystals. It has a _____ cooling history: magma started out cooling slowly so large crystals form/grow (called _____). A sudden change (like an eruption) brings magma closer to or on surface, and the remaining melt cools quickly (into a fine-grained 'cement' called _____),

2) **Obsidian** is very _____. Although it is usually black in colour, it is usually _____ in composition. Forms from lava with very high water content.

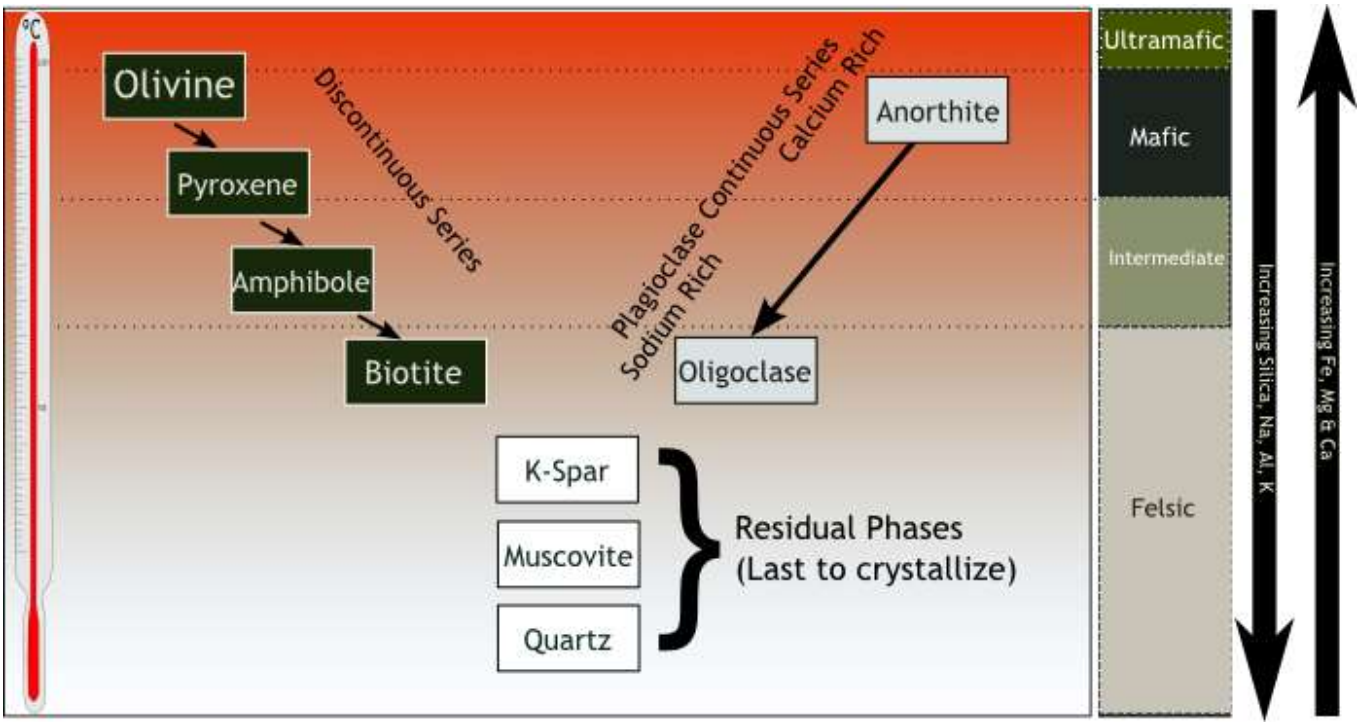
3) **Pumice** is a low _____, frothy, _____, light-coloured rock formed from gassy rhyolite. **Scoria** forms from basalt with a _____ content, creating a very open network of _____. It is denser and darker than pumice.

4) **Pyroclastics** are broken up _____ of igneous volcanic rock. Tuff is a rock formed from volcanic _____ less than 4 mm wide. Volcanic breccia is formed from _____ greater than 4 mm wide.

Bowen's Reaction Series

Norman Bowen found that _____ _____ _____

There are three parts to BRS: The _____ series (including olivine, pyroxene, amphibole, and biotite); the _____ plagioclase feldspar series; and the _____ phases (including quartz, muscovite, and potassium feldspar).



Continuous Series – right side of Bowen's Reaction Series

- Ca^{+2} and Na^{+} can _____ in the mineral plagioclase feldspar.
- At _____ temperatures plagioclase only has _____, while at _____ temperatures, plagioclase only has _____.
- In between, these ions mix in a continues series from 100% Ca and 0% Na at the high end of the series to 50% Ca and 50% Na at the middle temperatures to 0%Ca and 100% Na at the lowest temperatures.
- During this continuous reaction, the _____ formed plagioclase crystals _____ continuously with the melt to become _____ in silica and sodium and depleted in calcium.

Discontinuous Series

- On the left side of the reaction series are a group of mafic (or iron-magnesium-rich) minerals - olivine, pyroxene, amphibole and biotite
- In igneous magmas, if there is enough _____ in the melt, each mineral will change to the next mineral lower in the series as the temperature drops.
- For example, _____ is the first mineral to form. When the temperature is low enough, all of the olivine will react with the melt to form _____.
- As the temperature drops, all the pyroxene will react with the melt to form _____; if it continues to drop, all the amphibole will react with the melt to form _____.
- If these minerals react to form other minerals, then how do we find these mafic minerals at the Earth's surface?
- _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Residual Phases

- At the bottom of BRS are the felsic minerals of _____, _____, and _____.
- These minerals have _____ aluminum and potassium, and higher amounts of silica than the mafic minerals earlier in the series. In fact, quartz is 100% silica.

NOT EVERY MAGMA GOES THROUGH ALL STEPS IN BOWEN'S SERIES

- _____ _____ _____. If you are crystallizing olivine and there is not enough silica to form pyroxene, then the reaction will not occur and olivine will remain.

- A mafic magma (rich in iron and magnesium) will completely crystallize before it reaches the lower temperature stages of the discontinuous reaction.

- A silicic magma is rich in silica and poor in magnesium and iron. So, olivine and pyroxene will be reabsorbed and will be absent from the resulting rock.

- If you are crystallizing a mineral and the temperature drops rapidly, then the BRS will stop at that point, and further reactions will not occur.

3.1 Review Questions

1. Explain the differences between magma, lava, intrusive (plutonic) rock, and extrusive (volcanic) rock.

2. What are the differences between aphanitic, phaneritic, and porphyritic crystal structures?

3. Relate texture to the rate of crystallization for intrusive and extrusive igneous rocks.

4. Describe the major characteristics used in the identification and naming of igneous rocks. What factors determine each of these characteristics?

5. How is colour index useful in the identification of plutonic rocks?

6. Why is the colour index not generally as useful when describing volcanic rocks?

7. Compare each of the following pairs of igneous rocks in terms of crystal size, colour, composition, felsic or mafic, plutonic or volcanic.

    a. Granite and rhyolite

    b. Gabbro and granite

    c. Rhyolite and basalt

    d. Pumice and obsidian

    e. Basalt and granite

f. Pumice and scoria

g. Peridotite and basalt

8. Describe and explain the order of crystallization of minerals from a magma (Bowen's reaction series).

9. Describe how felsic and mafic rocks are different. Give a plutonic and volcanic example of each.

10. Using the Composition of Igneous Rocks diagram, identify the following rocks from their compositions:

    a. A volcanic rock containing 25% quartz

b. A volcanic rock containing 50% pyroxene plus olivine

c. A plutonic rock containing 20% quartz

d. A plutonic rock containing 10% pyroxene, 20% amphiboles and 0% quartz

e. A plutonic rock containing 60% olivine

Intrusive Rock Structures

When magma enters the crust, it intrudes on other rocks. This rock is called the _____. When magma erupts onto the Earth's surface, it becomes _____e. We will only look at intrusive igneous bodies, or plutons, in this chapter.

We can only hypothesize how plutons form - we cannot reproduce the pressure and temperature conditions necessary for their formation in a lab setting, except on a small scale. However, erosion of the earth's surface has exposed plutons, allowing geologists to make conjectures about the processes involved.

Geometry of Intrusions:

There are several types of plutons, which are defined by their shape and their relationship to the country rock. They may be described as _____, _____, _____, _____, or _____.

Factors affecting the geometry of intrusions include:

1) _____ – mafic magmas are denser than felsic magmas, and therefore less buoyant.

2) _____ – How well does the magma flow? (eg. Water vs maple syrup) Mafic magmas are less viscous than felsic magmas, so they flow more easily.

3) _____ – magma, especially if it has gases in it, can exert pressure on the country rock. This pressure can cause the country rock to fracture and break. Magma can then flow through these fractures.

4) _____ _____ – if the country rock is weak and fractures, magma can pass up through it more easily.

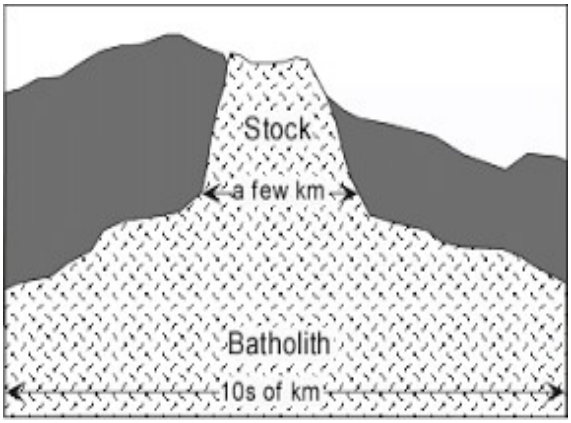
Common Intrusive Rock Terms:

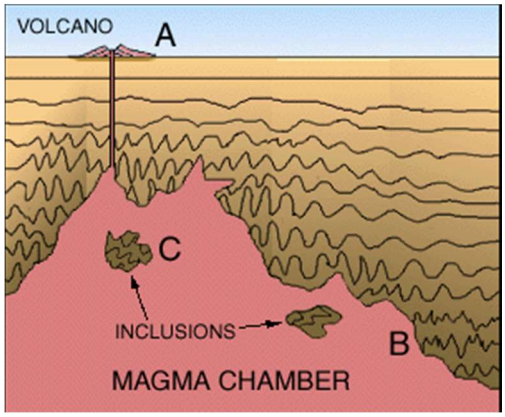
- _____ – any plutonic rock that has cooled below the Earth's surface.
- _____ – a pluton that is parallel to the folds or layers of the country rock.
- _____ – a pluton that is perpendicular to the folds or layers of the country rock.

Types of Intrusions

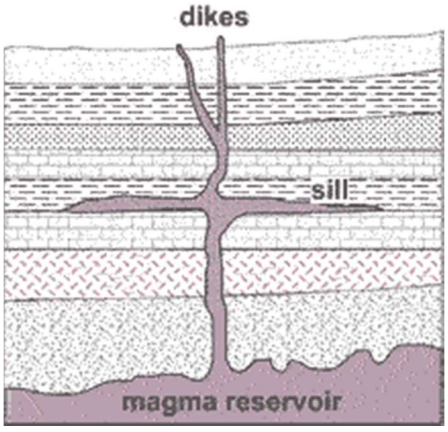
Massive Intrusions

- _____ are exposed plutons that have at least _____ of surface area. The largest of plutons, they may contain hundreds or thousands of cubic kilometres of rock. Most batholiths are made up of _____ or _____ rock.
- _____ are exposures of plutonic rock with a surface area _____ than 100 km^2 – basically just small batholiths.
    - _____ are an un-melted portion of country rock (inclusions) embedded within a pluton.





Sheet-like Intrusions



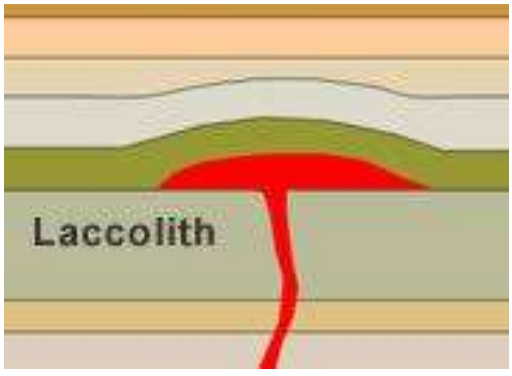
- _____ appear as bands of igneous rock slicing across rock layers. They are very common, and range from a few centimetres to more than 100 m thick. They form in existing fractures within the country rock, or they may form in fractures caused by pressure within the magma itself. Usually mafic.

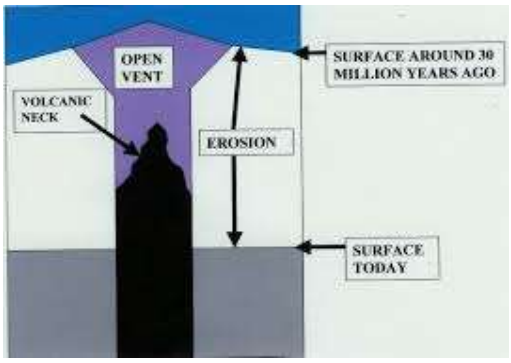
- _____ appear as bands of igneous rock lying between layers of country rock. They are usually have a thickness of a metre or less. Sills are emplaced when the fluid pressure of the magma is so great that the intruding magma lifts the overlying rocks. They are usually shallow intrusive bodies. Usually mafic.

- _____ are very thin (<2cm), irregular, sheet-like intrusions that may be either concordant or discordant. Commonly felsic, often exclusively quartz.

- _____ form when shallow sills inflate into _____ as magma pressure increases. Eventually, the overlying crust is lifted. They usually form when the magma is very stiff and unable to flow easily. The overlying surface rises into a dome-like hill or even a mountain.

- _____ _____ are the central intrusive conduits of ancient volcanoes, exposed during deep erosion. They are thought to form where magma rises through the crust by exploiting a vertical path of weakness.

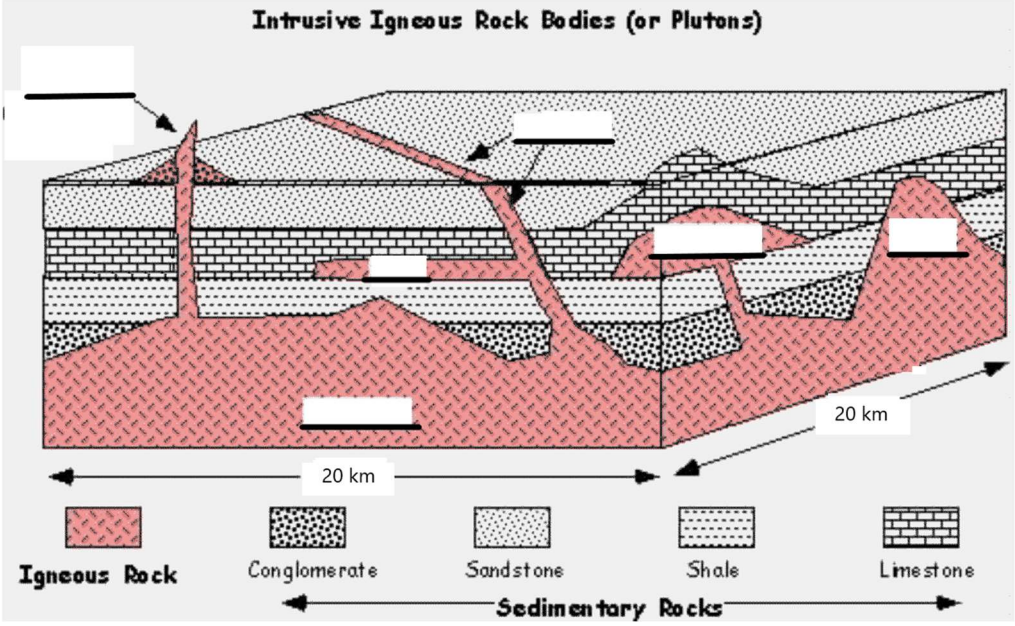




Plutonic Rock Formations

I. Label the following diagram with the following terms:

Batholith Dike Laccolith Neck Sill Stock



II. Match the following terms with their definitions:

1.	____	Hardened lava in the vent of an eroded volcano	a) Batholith
2.	____	Sill that forms a domelike mass	b) Dike
3.	____	largest of all igneous intrusions	c) Laccolith
4.	____	Flat sheet of igneous rock parallel to the intruded rock layer	d) Neck
5.	____	Pluton less than 100 square kilometers	e) Sill
6.	____	Flat sheet of igneous rock that cuts across rock layers	f) Stock

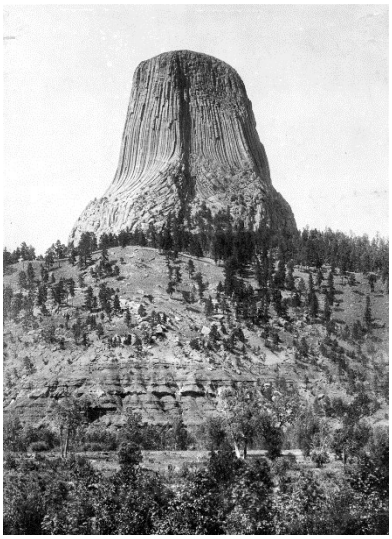
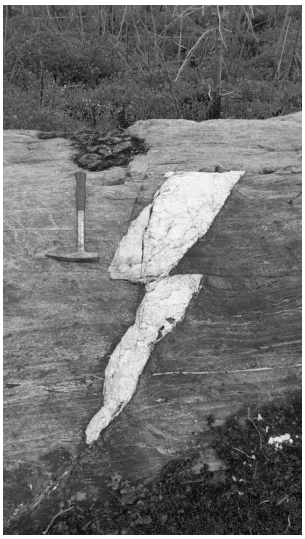
III. Identify the structures in the following photos:

PHOTO 1: _____

PHOTO 2: _____

PHOTO 3: _____

PHOTO 4: _____

1. 	2. 
3. 	4. 

Questions:

1) What is a pluton?

2) How does the presence of gases in a magma affect pluton formation?

3) How does the strength of the country rock affect pluton formation?

4) Differentiate between:
    a. Concordant and Discordant

    b. Sill and Dike

    c. Batholith and Stock

    d. Dyke and Vein

5) What type of intrusive structures are most apt to be formed from:
    a. Felsic magma?

    b. Mafic magma?

6) Describe how each of the following structures form. Include a sketch.
    a. Sill:

    b. Dike

    c. Laccolith

    d. Volcanic Neck

Key Terms

Aphanitic
Batholith
Bowen's Reaction Series
Concordant
Dike
Disconcordant
Extrusive
Felsic
Glassy
Grain size
Intrusive
Laccolith
Lava
Mafic
Magma
Mantle
Neck
Nuclei
Phaneritic
Pipe
Plutonic
Plutons
Pressure
Sill
Stock
Uniformitarianism
Vein
Vesicular
Volcanic
Xenolith

Key Rocks

Granite
Rhyolite
Diorite
Andesite
Gabbro
Basalt
Peridotite
Obsidian
Porphyry
Pumice