Geology 284 - Mineralogy, Fall 2007
Dr. Helen Lang, West Virginia University

Igneous Rocks and their Minerals:

What are IGNEOUS rocks?

- Rocks that are formed by solidification of a MAGMA
- Magma is "a naturally occurring molten rock material" (see glossary in textbook)

Some General Terms about Igneous Rocks

• intrusive	extrusive
• plutonic	volcanic
• magma	lava
• usually phaneritic	usually aphanitic or porphyritic

Most Magmas are silicate magmas (containing 40 to 75 wt.% SiO_2)

- Felsic (silicic or sialic) magmas are high in SiO_2 and Al_2O_3 and low in MgO and FeO
- Mafic magmas contain <50 wt.% SiO_2 and higher MgO, FeO and Fe_2O_3

- Ultramafic magmas are even more SiO_2 poor and MgO/FeO rich
- Intermediate magmas are between Felsic and Mafic magmas
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- <u>Sample Chemical Analyses</u>

Wt. % Oxide	Granite (felsic)	Gabbro (mafic)
SiO_2	72.08	50.78
TiO_2	0.37	1.13
Al_2O_3	13.86	15.68
Fe_2O_3	0.86	2.26
FeO	1.67	7.41
MnO	0.06	0.18
MgO	0.52	8.35
CaO	1.33	10.85
Na_2O	3.08	2.14
K_2O	5.46	0.56
H_2O	0.53	0.48
P_2O_5	0.18	0.18

Magmas contain Volatiles

- Elements or compounds that "prefer" to be in gaseous form
- Mostly H_2O and CO_2 in magmas
- Also S, Cl and F
- Contribute to formation of hydrous minerals
- like Biotite $K(Fe,Mg)_3(AlSi_3O_{10})(OH)_2$
- May separate and form bubbles or vesicles

Escape of gases from a magma may cause explosive eruptions like this

October 1, 2004, eruption of Mount St. Helens

Magmas may crystallize in stages with the remaining liquid separating from the Crystals

- Many igneous minerals are more dense than the magma and fall to the bottom of the chamber
- Called partial or fractional crystallization
- The last liquid to crystallize may contain volatiles and incompatible elements (K, Rb, Li, Be, B, and REEs)
- Pegmatites form from these residual liquids, large crystals because H_2O acts as a flux

Bowen's Reaction Series - see handout

- Idealized model for crystallization of magmas
- Shows order in which minerals crystallize from a typical mafic or basaltic magma
- Left side is called Discontinuous Side
- Mafic minerals change abruptly
- Right side is called Continuous Side
- Plagioclase changes composition gradually

Most of the Minerals in Igneous Rocks are Silicate Minerals

- Felsic (high in SiO_2 and alkalis) Silicate Minerals
    - Quartz and Feldspars (framework silicates)
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- Mafic (high in Mg and Fe) Silicate Minerals
    - Pyroxenes, Amphiboles and Micas (chain and sheet silicates)

We'll start with Felsic Minerals (framework silicates)

- Right-hand side of Bowen's Reaction Series
- Quartz SiO_2
- Alkali Feldspars $(K,Na)AlSi_3O_8$
- Plagioclase Feldspars $(Ca,Na)(Al,Si)_4O_8$
- Important in all igneous rocks
- Especially in Granites

SiO_2 like many other minerals comes several different structures

- Called Polymorphs (many shapes)
- Minerals with the same composition, but different structures
- Quartz - stable form of SiO_2 at most conditions found on Earth
- High Temperature (low P) forms: tridymite, cristobalite
- Very high Pressure forms: coesite, stishovite

SiO_2 P-T Phase Diagram - see handout

Each Polymorph has a completely different 3D framework of SiO_4 tetrahedra

Quartz Structure

Tridymite Structure

Compare Low- and High-Quartz Structures

Compare High Quartz and Tridymite Structures

View Crystal Structure Movies

Quartz - http://socrates.berkeley.edu/~eps2/wisc/geo360/Quartz.mov

Tridymite - http://socrates.berkeley.edu/~eps2/wisc/geo360/tridymite.mov

Cristobalite - http://socrates.berkeley.edu/~eps2/wisc/geo360/cristobalite.mov

Higher Density Minerals are Stable at Higher Pressures

Newsflash! Coesite has been found in Crustal Rocks!

- Coesite, formerly known only from impact craters, has been found in rocks that were once at the surface (first found in 1984)
- This means that in continent-continent collision zones (like the Himalayas and Alps), rocks somehow get from the surface down to >100km (~60mi) and back fast enough to preserve coesite

Quartz Properties

- H=7, G=2.65
- Generally clear and glassy, may have a variety of colors (clear, smoky, brown, rose; it’s allochromatic)
- Conchoidal fracture, no cleavage
- Habit: hexagonal (6-sided prisms) or massive
- Optical: low relief and low birefringence

Examples of Quartz

Quartz Crystals (variety amethyst)

Feldspars

- Also framework silicates
- Most abundant minerals in the Earth’s crust

- Also common in igneous rocks
- Almost all igneous rocks have feldspars (not true for quartz)

How do we get other framework silicates with formulas different from SiO_2?

- When all SiO_4^{4-} tetrahedra share all corners with other tetrahedra, formula is $(SiO_2)^0$, no need for other cations
- If Al^{3+} substitutes for Si^{4+} in some tetrahedra, there is a net negative charge and other cations are needed to balance the charge
- That's how we get **Feldspars!**

Feldspars

- If Al^{3+} substitutes for $^1/_4$ of the Si^{4+} in the framework
- Formula changes from $(Si_4O_8)^0$ to $(AlSi_3O_8)^{1-}$
- Alkali Feldspars $(K^+, Na^+)AlSi_3O_8$
- Orthoclase, $KAlSi_3O_8$, and Albite, $NaAlSi_3O_8$
- If Al^{3+} substitutes for $^1/_2$ of the Si^{4+} in the framework
- Formula changes from $(Si_4O_8)^0$ to $(Al_2Si_2O_8)^{2-}$
- Anorthite $Ca^{2+}Al_2Si_2O_8$

Feldspars all have similar 3D Frameworks that contain linked Double Crankshafts

View Crystal Structure Movies

K-feldspar (Sanidine) - http://socrates.berkeley.edu/~eps2/wisc/geo360/Sanidine.mov

Albite - http://socrates.berkeley.edu/~eps2/wisc/geo360/Albitem.mov

first frame of Albite Movie shows the Feldspar Structure best

Anorthite - http://socrates.berkeley.edu/~eps2/wisc/geo360/Anorthite.mov

Three Feldspar End-members - plot on a triangle

- Albite (Ab) $NaAlSi_3O_8$
- Anorthite (An) $CaAl_2Si_2O_8$
- Orthoclase (Or) $KAlSi_3O_8$

Suppose we have a Feldspar with the formula: $Ca_{.05}Na_{.25}K_{.70}Al_{1.05}Si_{2.95}O_8$

- To plot that feldspar on a triangular diagram, we need % of each of the three feldspar end members

- Easiest way is to calculate the mole % of Ca, Na, and K:
- Ca/(Ca+Na+K)*100 = (.05/1.00)*100 = 5 % An
- Na/(Ca+Na+K) * 100 = (.25/1.00)*100 = 25 % Ab
- K/(Ca+Na+K) * 100 = (.70/1.00)*100 = 70 % Or

How do Triangular Diagrams Work? - see handout

The Feldspar Ternary - see handout

Alkali Feldspar (esp. Orthoclase) Properties

- H=6, G=2.56
- Generally turbid (cloudy); color white, pink or flesh-colored
- 2 Perfect to good perpendicular cleavages
- Habit: stubby prisms, simple twins common
- Optical: low relief and low birefringence
- Commonly **Perthitic** (micro and macro)

Typical Orthoclase (alkali feldspar)

Alkali Feldspars have Perthites

What causes Perthites?

- Caused by **un-mixing** or **exsolution** of Na^+ (~1.1A) and K^+ (~1.6A) as the feldspar cools
- At low temperatures, there is a **miscibility gap** between $NaAlSi_3O_8$ and $KAlSi_3O_8$

What's a miscibility gap? - see handout

Microcline (a polymorph of $KAlSi_3O_8$ different from orthoclase) is sometimes bluish green

Microcline also has plaid twinning

Plagioclase Properties

- H=6-6.5, G=2.62-2.76
- Luster pearly, vitreous/translucent
- Color white to gray
- One perfect, one good cleavage
- Optical: low relief and low birefringence
- Polysynthetic **albite twinning** usually present
- **Not Perthitic!** Commonly **zoned**

Plagioclase hand specimen - note polysynthetic twinning

Plagioclase Feldspars have (polysynthetic, lamellar) Albite Twins

Plagioclase Feldspars are commonly zoned

Plagioclase Feldspars DO NOT have perthites. Why?

- In some parts of the plagioclase, Al^{3+} substitutes for half of the Si^{4+}; formula $(Al_2Si_2O_8)^{2-}$
- **Ca^{2+} must balance charge!**

- In some parts of the plagioclase structure, Al^{3+} substitutes for $^{1}/_{4}$ of the Si^{4+}; formula $(AlSi_3O_8)^{1-}$
- **Na^{1+} must balance charge!**
- Al^{3+} is locked tightly in feldspar framework
- Therefore, Al^{3+} can't move
- Na^{+} and Ca^{2+} can't move without Al^{3+} (That would destroy charge balance!)
- Therefore, exsolution or **perthites can't happen in Plagioclase Feldspar**
- And orthoclase doesn't have albite twins!

Review Feldspars – see handout