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Fractionation Mechanisms

Introduction

- _______________ and _____________ are synonymous
- Fractionation mechanisms relate the ______ ______________ observed in a suite of igneous rocks to the ________, _________ composition of the __________, from which it was derived
- For fractionation an ____________ link is implied, yet no specific mechanism is suggested
- **Definition**
  –

Introduction

- Any mechanism which accomplishes this is a fractionation or differentiation mechanism
- Each fractionation mechanism involves the migration or transport of particular atoms of one element relative to other elements resulting in different bulk compositions formed from a single homogeneous parent composition
- The obvious manifestation of fractionation is the variation observed in the chemical composition of a single volcanic flow or a pluton

For large datasets, graphical methods are preferred.

Harker diagram for Crater Lake

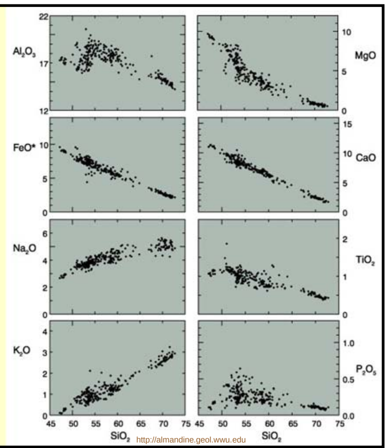

Figure 8-2. Harker variation diagram for 310 analyzed volcanic rocks from Crater Lake (Mt. Mazama), Oregon Cascades. Data compiled by Rick Conrey (personal communication).

Introduction

- Examine three fractionation mechanisms
-
-
-

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Liquid Immiscibility

- Immiscible – __________________
- Immiscibility has been proposed to explain the juxtaposition of two ______________ __________________, with no intermediate compostion, in a single rock
  - e.g.
  - varioles, sperules ➔ variolitic, spherulitic
- First suggested _______________

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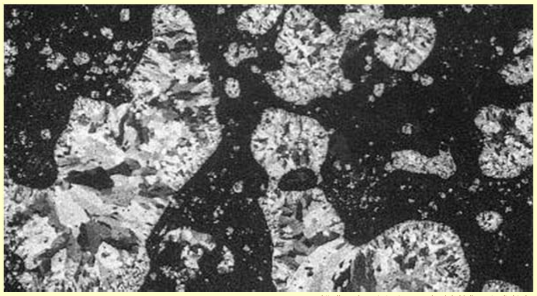
Liquid Immiscibility



http://www.impact-structures.com/spain/rubie/Impactmelts.html

Carbonate-silicate liquid immiscibility in the Ries crater suevite (Graup 1999). Photomicrograph, crossed polarizers. The field is 5 mm wide.

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Liquid Immiscibility

- Proposed to have played a role in the generation, by fractionation, of:
  - Archean volcanic rocks for the Abitibi Subprovince of NE Ontario and NW Quebec
  - Lunar Mare Basalts
    - All basalt samples collected by Apollo missions exhibit evidence of liquid immiscibility
  - Cretaceous Deep Sea Basalts

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Liquid Immiscibility

- In all of the above examples the immiscibility consists of a ______ host with '_________' globules or varioles
- Immiscibility has been proposed and or observed in:
  –
    - which may have coexisting silicate liquids or a silicate and carbonate liquid
  –
    - may have silicate and sulphide liquids

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Hydridization and Assimilation

- Magma rising through the crust may ____________ (absorb and digest) fragments of country rock
- The assimilated material will change (______________) the magma, resulting in a 'new' liquid, with a distinctly different composition than the original liquid, and will solidify to a different rock that the ______________________ liquid

Hydridization and Assimilation

- Xenoliths and/or inclusions in a plutonic or volcanic rock provide evidence in support of assimilation
- Assimilation is a ______________ process

Heat of solution = heat of melting + heat of mixing

Ability of a magma to ____________ an inclusion

Heat capacity + heat of crystallization of the __________ involved

Heat required to _________ the two the liquids

Hydridization and Assimilation

Consider a basaltic liquid assimilating chunks of granite (Q,A,P)

- Q, A and P will be melted
- The heat to melt these minerals comes from the heat generated by the crystallization of olivine and pyroxene from the liquid
- Not from the temperature of the basaltic liquid
- Granitic chunks will not be completely melted (partial melting)
- End result is a basaltic andesite with inclusion of chewed up, partially melted granitic xenoliths

Hydridization and Assimilation

For the reverse process, where a granitic liquid incorporates basalt
- The basalt is composed of ol, px and pl
- The first change involves the hydration of these minerals to serpentine,micas, amphiboles and epidote, through the addition of water from the granitic magma
- The heats of crystallization of Q, F and bio from the granitic liquid are not large enough to melt the basalt inclusion, resulting in very minor changes in the original liquid composition
- Result is a granite with amphibolite inclusions

- Any changes caused by assimilation and hybridization are dependant on the nature of the inclusions

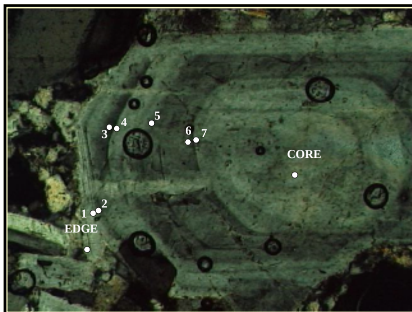
Fractional Crystallization

- Charles Darwin, in 1844, first suggested that fractional crystallization played a role in the development of igneous rocks
- This is the process by which _______, _________ _________, which form from the liquid, are prevented from ________ with the liquid

Fractional Crystallization

Evidence for fractional crystallization:

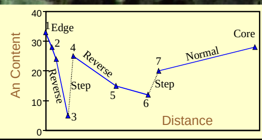
1. Observed changes in bulk chemical _______________ of a liquid, eg. a single volcanic flow within a single volcano
2. __________ in minerals
   - Most silicate minerals crystallized in igneous systems exhibit evidence of zonation, which directly reflects changes in the liquid compostion from which the mineral formed.



Zoning in plagioclase – evidence for changing liquid compositions

Progressive zoning indicates subtle changes in liquid composition

Step indicates drastic changes



Plot of An content vs distance from core to edge

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Fractional Crystallization

3. Reaction Rims

- Result from the reaction between _____ ________ and ______ in response to changes in ________ composition and/or changes in T and P
  - eg. pyroxene rims on olivine result when the liquid containing the olivine becomes saturated with respect to silica as a result of the formation of the olivine

$$Mg_2SiO_4 + SiO_2 ===> 2MgSiO_3$$

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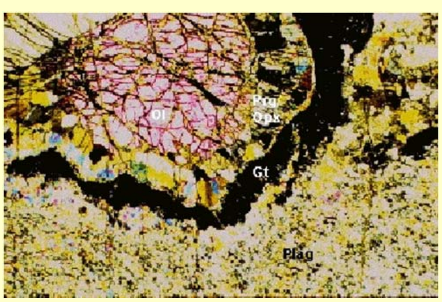

Corona texture in c. 2.45 Ga troctolite within metagabbro-anorthosite Kolvitsa Massif of the footwall. Igneous olivine (Ol) and plagioclase (Plag, recrystallised) react to inner "palisade" rim of orthopyroxene ± pargastic amphibole (Opx/Prg, against Ol) and outer rim of garnet (Gt, against Plag). Often clinopyroxene occurs instead of Opx/Prg; green spinel is locally intergrown with Prg. This reaction is suspected to have occurred as a result of tectonic burial during the 1.90 Ga Lapland-Kola orogeny.

http://www.geo.uni-potsdam.de/Personal/Timmerman/KolaResearch/gallerykolaMicro.html

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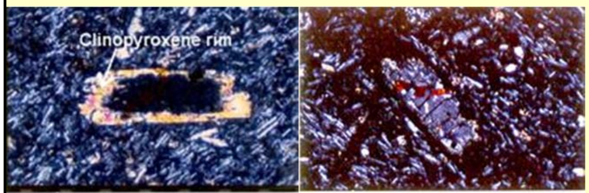

http://www.metu.edu.tr/home/www64/geoweb/igneous-overgrowth.htm

Basalt sample containing composite pyroxene. Subhedral orthopyroxene phenocryst with rounded margins (inner part), is surrounded by clinopyroxene rim (red-yellow colored) due to reaction with the melt.

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Fractional Crystallization

- In fractional crystallization, the _______ are removed or isolated from the _____, resulting in a the liquid having a ‘new’ _____________
  - eg.
    - a basaltic liquid crystallizing olivine (Mg_2SiO_4) will become __________ in Mg
    - ol is undersaturated wrt SiO_2, resulting in ____ Mg and ____ Si in the liquid
    - Remove the ol, the ________ liquid is now ______ in Mg and _________ in Si, in comparison to the ______ _______ liquid

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Gravitational Effects

- Effects due to ________ are the most often suggested mechanism for fractional crystallization
- Dependant on the _______ of the _____ and the _______ forming from the liquid
- Fractionation results from the crystals _________ or ________ in the magmatic liquid

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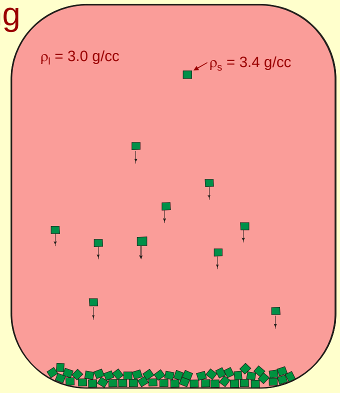
Crystal Settling

- Most often cited gravitational effect
- Results from _______ difference between liquid and solid
- Evidence for settling has been observed in a ________________ ________________ ________________ ________________ ________________



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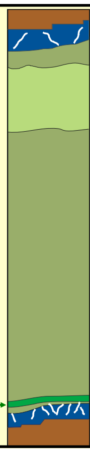
Palisades Sill

George Washington Bridge Section

- Olivine-rich layer
- Cg Diabase
- 'Normal' Diabase
- Chilled Contact
- Triassic sediments
- White Veins



Data from Walker (1940)

- Triassic age
- Outcrops along the west bank of the Hudson River in New Jersey
- Total thickness varies from 230-365 m
- At or near the base is an olivine-rich layer inferred to have accumulated by crystal settling
- Estimated that it took ~7,000 hours (279 days) for this layer to accumulate

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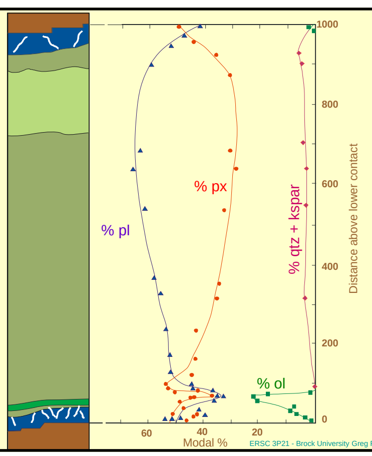

Data from Walker (1940)

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Photos of striking graded beds between homogeneous layers, within Trough B. Again, my impression is that the graded bed average mineralogy is the same as the adjacent homogeneous rock.

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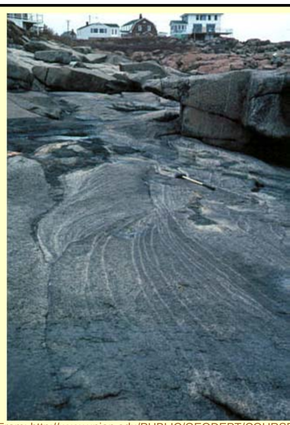

Nubble Point Gabbro, Maine

Overlapping troughs and cross bed structures, layering is essentially vertical.

From: http://www.union.edu/PUBLIC/GEODEPT/COURSES/petrology/labs/wmms/wmms.htm

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Crystal Floatation

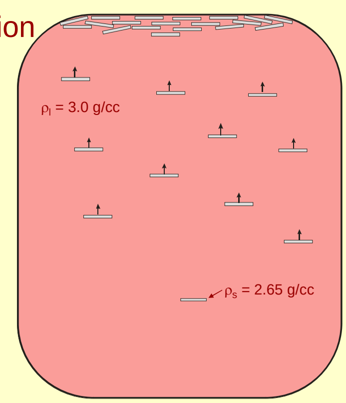
- Demonstrated experimentally
- Results from ______ difference between liquid and solid
- Observed in

____

____

____

____



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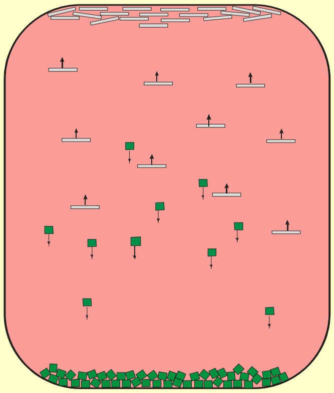
Combination

- _______ and _______ may occur simultaneously within a magma



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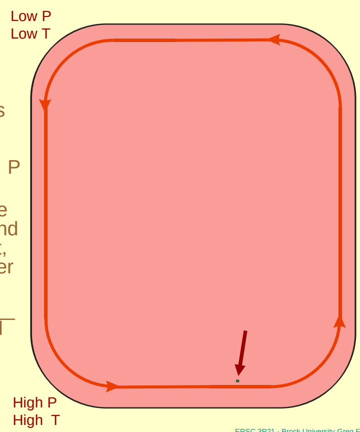
Convection Effects

- Convection occurs in the magma chamber due to a _______ in T and P
- Convection cell ____________ the magmatic liquid and any solids present, within the chamber
- Crystallization occurs in the _____ portions of the cell



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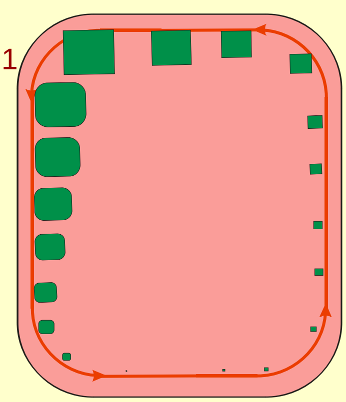
Convection Effects - Case 1

- Once the grain is formed it is carried in the convection cell around the chamber
- As it migrates to cooler portions, it continues to grow
- As the grain is returned to hotter portions it is _______ (melted) back into the liquid
- Melting is complete and the process begins again



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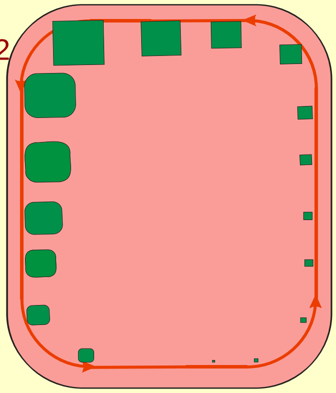
Convection Effects – Case 2

- If resorbtion of the grain is incomplete, the core of the grain remains and can now be carried around the cell, and form the nucleus onto which new growth, of a different composition, can occur



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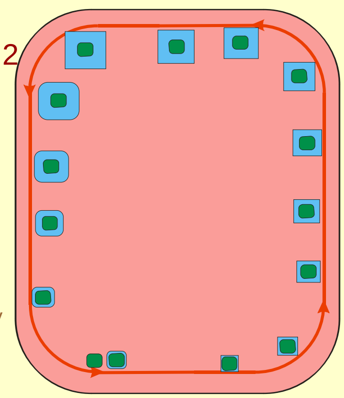
Convection Effects – Case 2

- The new growth will have a different composition than the previous layer, due to changes in the liquid composition
- This 'new' grain is carried in the cell and continues to grow and eventually begins to sink and be resorbed



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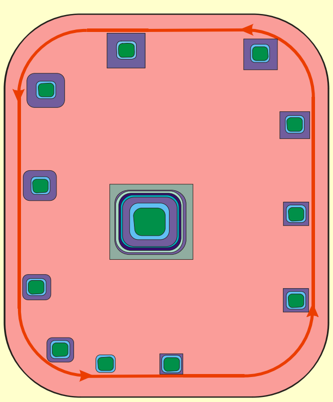
Convection Effects

- If the resorbtion is incomplete with each cycle around the chamber, then the resulting grains will exhibit zoning, reflecting the change in liquid composition with each pass



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Trough structures in the Western syenite of the Kungnat, S. Greenland

From: Hodson and Finch, 1997, CMP 127: 46-56

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Convection Effects

- For convection to be effective, the ______ of liquid must be much ________ than the ________ of solid in the system
- Any combination of fractionation mechanisms can occur within a magma chamber

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