LECTURE ELEVEN: Layered Igneous Intrusions 1

IN THIS LECTURE

- Compositional Variation in Magmas
- Crystal Fractionation
- The Phase Rule
- Binary Systems
- Congruent versus Incongruent Melting
- Crystal Liquid Separation Mechanisms
- Gravitational Settling
- Textures
- Characteristics of Layered Igneous Intrusions

COMPOSITIONAL VARIATION IN MAGMAS

Variations in the compositions of magmas may be the result of primary or secondary factors.

Primary factors
1. The composition of materials being melted in the magmatic source region
2. The degree of melting
3. The conditions under which melting took place

Secondary factors
1. Magmatic differentiation
2. Contamination
3. Zone Melting
4. Mixing of Magmas

MAGMATIC DIFFERENTIATION

Magmatic differentiation refers to the process whereby an originally homogeneous magma changes it composition or becomes heterogeneous via three main mechanisms:
Crystal Fractionation
Liquid Immiscibility
Liquid Fractionation

Crystal fractionation is likely to be the most important in controlling magmatic differentiation

CRYSTAL FRACTIONATION

Crystal fractionation refers to the process whereby crystals that were coexisting with a melt phase are removed from the system leading to a change in the composition of the remaining melt phase. Because crystals are continually forming the change in the remaining melt phase is a progressive one leading to a development of a compositional magma series.

Useful terms:
A primitive magma is one which is close to its original composition and has therefore in theory not undergone crystal fractionation.
An evolved magma is one in which crystal fractionation has taken place such the magma composition is different from the starting composition.
The liquid line of descent is the series of liquid compositions leading from the most primitive magma to the most evolved magma in a fractionation series.

In order for crystallisation differentiation to occur, a mechanism is required that will separate the crystals from the remaining magma. Several separation mechanisms have been proposed
1. Gravitational settling
2. Flow differentiation
3. Flow crystallisation
4. Filter pressing
5. Gas streaming
6. Gravitational liquid separation

Of these, gravitational settling is the most commonly invoked mechanism.

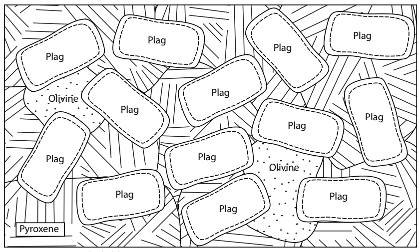
MINERAL DEVELOPMENT

Minerals crystallising out of a basaltic magma do so in the following order
Fe-Ti oxides or chromite, olivine, pyroxene, plagioclase

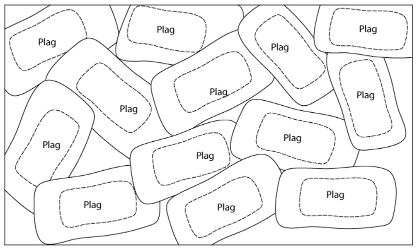
This gives rise to the typical layering seen in layered basic intrusions
Basal chromite, (dunite) pyroxenite, norite, leuconorite, anorthosite

TEXTURES

Crystal Fractionation results in the development of both crystal concentrates and evolved liquids (melts).
The rocks formed via crystal concentrates or crystal accumulation are called cumulates and are divided into two main categories:

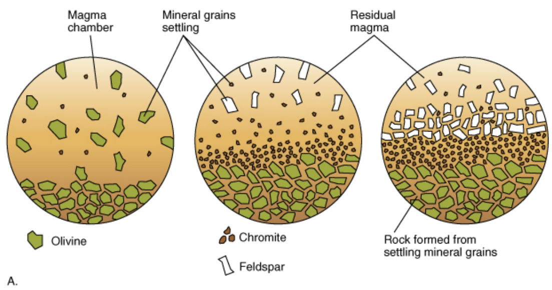


1. Orthocumulates in which the cumulus crystals are enclosed in material that has crystallised from the interstitial melt
2. Adcumulates in which the cumulus crystals continue to grow and displace the intercumulus liquid.



CHARACTERISTICS OF LAYERED IGNEOUS INTRUSIONS

The defining characteristic of layered intrusions is the layering of often ultramafic or mafic units.
The typical sequence is something like
Chromitite, dunite, pyroxenite, norite, leuconorite, anorthosite
Mixed chromitite – anorthosite layers reflect mixing as a new magma batch comes in
Layers are nearly always perpendicular to the sides of the magma chamber and may be continuous over very large distances (kms)
Layering can be either cryptic or rhythmic
Cryptic layering represents layers whose composition changes progressively in response to fractional crystallisation occuring in the parent magma
Rhythmic layering represents layers of alternating composition
All the rock types are normally fairly coarse grained, all the grain sizes are visible to the naked eye.



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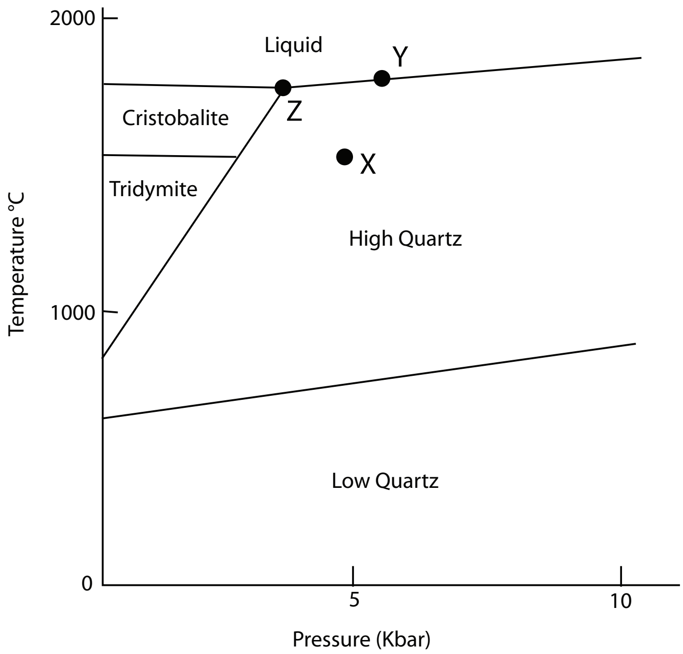
THE PHASE RULE
The phase rule tells us about how many phases can coexist at one time under certain conditions.

It is defined as: P + F = C + 2 where
P is the number of phases
C is the number of components
F is the number of degrees of freedom

The number of components is the minimum number of chemical components required to describe the composition of all phases in the system being examined.

The number of degrees of freedom refers to how many variables such as pressure and temperature that can be varied without changing the number of phases present in the system.

A binary system is one that has two components. The two examples that we will look at are Albite-Anorthite and Forsterite-Fayalite. Melting relationships in binary systems often involve phases with solid-solution.



X = Divariant Point - can change both P and T without affecting the phase present

Y = Cannot change P and T independently without changing the phases present

Z = Cannot change P or T without changing the phases present

Congruent Melting
Material changes directly from a solid to a melt of the same composition at the temperature of melting, ie melting occurs all at the one time

Incongruent Melting
Material starts to melt and the first melt formed has a different composition to the starting material. The melt only has the same composition as the starting material when it becomes completely molten. Example: Orthoclase starts to melt at around 1150°C where it forms a mixture of leucite crystals and a melt of composition intermediate between $KAlSi_3O_8$ and SiO_2. As the temperature increases leucite starts to dissolve in the melt until a temperature of 1500°C when all the leucite dissolves and the melt has an orthoclase composition.