Geology and Art, Fall 2004
Igneous Rocks, Lecture 3
Dynamic Earth, Chapter 4

Skinner, B. J., Porter, S. C., and Park, J., 2004, *Dynamic Earth, An Introduction to Physical Geology*: John Wiley & Sons. (ISBN 0-471-15228-5)

Igneous rocks are crystallize or glassy rocks formed by the cooling and solidification of magma
magma: molten rock within the Earth (liquid, vapor solid phases)
lava: molten rock that flows above the Earth's surface (flows, tephra)

Formation of Magma: heat causes bond to break (vibration), when all bonds in a solid have broken, a liquid (magma) results. The melting point of minerals vary dependent on the characteristics of their bonds. As additional heat increases the temperature of the melt minerals with progressively higher melting points melt and contribute to the composition of the magma.

Formation of an Igneous rock: as the magma cools and the temperature drops minerals crystallize from the magma in order of their melting points (bonds form) and this alters the composition of the remaining melt. Crystals grow until the faces or edges are restricted by adjacent crystals. Eventually the entire igneous body expels its volatiles (incompatibles) and solidifies.

As magma cools the chemical constituents are reorganized into a variety of minerals. The characteristics of these minerals depend on:

1. composition of the original magma
2. cooling history (temperature)
3. depth of crystallization (pressure)

Intrusive: igneous rocks formed when magma cools (slowly) within the crust
Extrusive: igneous rocks formed when magma cools (quickly) on the Earth’s surface.

Texture: the size, shape and arrangement of the mineral component of the rock.

Cooling history (rate) is principally responsible for determining the texture. Slow cooling rates (subsurface) allow minerals to crystallize over thousands of years, creating **phaneritic** texture and intrusive (plutonic) rocks. Rapid cooling rates (surface) do not allow crystals to grow to macroscopic size, creating **aphanitic** texture and extrusive rocks

Porphyry is an igneous rock in which 50% or more of the rock is coarse mineral grains in a fine-grained matrix. The large grains are called **pheocrysts**. These rocks were derived from magmas that initially cooled within the crust and then were extruded, cooling quickly.

Glassy rocks are created when magma cools so quickly that the atoms don’t have time to organize themselves into crystal structures. Pumice, obsidian, and ash are glassy rocks.

The arrangement of the crystals are almost always interlocking in igneous rocks.

Mineral Assemblages in Igneous Rocks

Rocks are classified based on texture and mineral assemblage

Figure 4.6 shows this classification (quartz, feldspar, amphibole, pyroxene, olivine)

Intrusive Rocks:

Granite and **Granodiorite**: predominantly quartz and (postassium) feldspar with mica (muscovite or biotite) and amphibole (hornblende)

Diorite: predominantly plagioclase feldspar with amphibole and/or pyroxene.

Gabbro and **Peridotite**: pyroxene and amphibole account for over 50% of a gabbro. Peridotite is dominated by olivine.

Extrusive Rocks:

Rhyolite and **Dacite**: rhyolite is similar in composition (and mineralogy) as granite and dacite is an aphanitic granodiorite. These often have porphyritic textures (porphyritic rhyolite)

Andesite: has the same minerals as diorite. Many are porphyritic with phenocrysts of pyroxene, amphibole, plagioclase feldspar, or quartz.

Basalt: a dark gray or black rock that is compositionally similar to gabbro. Phenocrysts can be plagioclase, pyroxene, or olivine.

Pyroclastic Rocks:

A fragment of rock ejected during a volcanic eruption is called a **pyroclast**. Rocks formed from pyroclasts are called pyroclastic rocks.

Tephra: a term for all airborne pyroclasts

Bombs	>64mm
Lapilli	2–64 mm
Ash	<2 mm

"tephra is igneous when it goes up, but sedimentary when it comes down" – transitional between igneous and sedimentary

Intrusive Structures

Magma is generally more buoyant than the surrounding country rock and so it tends to migrate up.

Space problem: how does an intrusion make space for itself?

Assimilation (xenoliths) also called stoping.

Pushing aside rocks (doming, diapir)

Pluton: intrusive igneous body (named after Pluto, the Greek god of the underworld)

Concordant plutons: trend parallel with the structure of the country rock

Sills: tabular bodies that are concordant with the bedding or foliation (layering) in which they are emplaced.

- low pressure (shallow)
- intrude relatively unfolded country rock
- low viscosity
- differentiated or homogenous
- thickness ranges from less than a meter to several hundred

Laccoliths: mushroom-shaped bodies that are concordant with the bedding or foliation. They form by diapiric rising until they encounter a resistant layer which is blistered.

- diameter ranges from 1 to 8 km
- maximum thickness of 1 km
- intrude relatively unfolded country rock
- low pressure (shallow)
- tend to be silica-rich magmas (viscous), chilling on margins enhances the blistering

Discordant plutons: cuts across the structure (layering)of the country rock

Dikes and Veins: thin, tabular, discordant bodies (thin but laterally extensive)

- a dike forms when magma squeezes into a fracture
- thickness ranges from cm to 100's of meters
- may occur individually or in swarms
- veins form by mineral precipitation from fluids

Volcanic neck (pipe): conduit that once fed magma to a volcanic vent.

Batholiths and Stocks: large plutons which are concordant to discordant composed of silica-rich igneous rocks (granitic)

- large bodies (Coast Range Batholith of BC and SW Alaska is 1500 km long)
- batholiths: 100-1000's km^2
- stocks: <100 km^2
- composite: multiple phases of intrusion
- contacts can be sharp or gradational
- depth of emplacement varies:
  catazonal: surrounded by high-grade met. (migmatites)
  mesozonal: low to medium-grade met., sharp contacts
  epizonal: discordant, sharp contacts, angular xenoliths, emplacement, chilled margins

Occurrence of Igneous Rocks

Basalts and Gabbros: basaltic magmas occur on both continental and oceanic lithosphere. The source of the basaltic magma is the mantle, beneath the crust. A partial melt of the mantle will produce basaltic magmas.

The ultramafic mantle is the source of the basalt/gabbro
The mantle is heterogeneous, so basalts/gabbros also vary in composition
Oceanic basalts

Mid-Ocean Ridge Basalts (MORBs) are produced at divergent plate boundaries (rifts)

Ocean Island Basalts (OIBs) are associated with **hot spots** such as Hawaii

Continental basalts occur in regions experiencing extension

Andesites and Diorites: andesitic magmas occur on both oceanic and continental lithosphere (crust), due to the partial melting of basaltic rock.

Rhyolites and Granites: rhyolitic magmas are restricted to continental crust and are due to the partial melt of andesitic rock.

Partial Melt and the Generation of Magma

Creation of magma or melting of a parent rock

Heat
Pressure
Water content

Sources of heat include

- Primordial heart, produced during the Earth's formation
- Heat created by the decay of radioactive isotopes
- Frictional heat produced at plate boundaries (lithospheric and asthenospheric)

Geothermal gradient: the temperature of the Earth increases with depth (approx. 25°C/km)

An increase in temperature (heat) can initiate melting of a parent rock

Pressure: the pressure (lithostatic) of the Earth increases with depth. As opposed to heat, pressure tends to hold the atoms in a solid and more heat energy (vibrational) is required to break the bonds. As pressure increases melting points of minerals increases as well

Albite (feldspar)	$NaAlSi_3O_8$
Pressure	Melting temperature
Surface pressure	1118 °C
100 km	1440 °C

A decrease in pressure can initiate melting (rifting, rising magma)

Water content: water acts as a catalyst in the melting process

The higher the water content, the lower the melting point of a rock. At high pressures, water plays more of a role in enhancing melt.

Minerals crystallize at the same temperature that they melt (if pressure and water content is constant) – minerals that melt last are the first to crystallize.

Chemical differentiation by partial melt: the process of forming magma through the incomplete melt of a parent rock. Lower temperature minerals melt first and so as melting progresses the magma becomes progressively more mafic (iron and magnesium rich).

Chemical differentiation by fractional crystallization: the composition of a magma and rock can be changed by the separation during solidification. This removal of crystals changes the bulk composition of the remaining system, making the remaining melt increasingly felsic (aluminum and silica rich)

In natural systems equilibrium between the crystals and the melt is rarely maintained (kinetics and migration of phases)

Gravity settling:

material	density
olivine/pyroxene	3.0 g/cm^3
basaltic magma	2.7 g/cm^3
plagioclase	2.6 g/cm^3

Fractional crystallization decreases the volume of the final magma. If granite was derived only from fractional crystallization of basaltic magma, it would require nine to ten times as much basalt than the final volume of granitic magma

Basaltic Magma

Studies have found the a 5-10% dry partial melt of a garnet peridotite (upper mantle material) will produce a basaltic magma

Andesitic Magma

Andesite is the same bulk composition as the crust and so it can be produced by the complete melt of the crust and wet partial melt of basalt and upper mantle at high pressures (subduction zones).

Rhyolitic Magma

Rhyolitic magmas are produced by the wet partial melt of andesitic rock. As the magma rises and the pressure drops, the effectiveness of water reducing melting temperatures diminishes and most rhyolitic magma solidifies in the subsurface.

.