GEOLOGY 326
PHYSICAL PROPERTIES OF MAGMAS

Magma = Molten rock material, with or w/o crystals or other suspended solids.

- May or may not contain dissolved gas phase (H_2O or CO_2)
- Vesicles = Bubbles of gas formed in magma

Physical Properties of magma depend on:

- **Temperature**
- **Density**
- **Volatile Content**
- **Viscosity**

All depend directly indirectly on composition.

TEMPERATURE

Basalt @ 1 atm: 1200-1250^{o}C liquidus, 950-1000^{o}C solidus.

Rhyolite: Liquidus = 1050^{o}C
Hydrous solidus (with H_2O) = 650 ^{o}C
Anhydrous solidus (no H_2O) = 750^{o}C

>> Rhyolite solidus defined as T where viscosity >10^{13} poise.
>> Determined experimentally.

DENSITY

Density controlled by magma composition: **FeO wt%** most important.

In general, basalts are richer in Fe, Ca, and Ti than rhyolites; rhyolites are richer in Na, Al, and Si than basalts:

Basalt magma:	2.65 to 2.80 gm/cm^3
Andesite magma:	2.45 to 2.50 gm/cm^3
Rhyolite magma:	2.18 to 2.25 gm/cm^3

Density is also controlled by *Temperature* and *Pressure*.

Higher *Temperatures* cause melts to Expand ===>> Lower Density

Higher *Pressures* cause the melts to Compress == >> Higher Density

VOLATILES

- H_2O most abundant volatile in most magmas
- CO_2 next most abundant volatile

In general, **Basalt** magmas are DRY, i.e. $H_2O < 0.5$ wt%

MORB = 0.25% H_2O
Hawaiian Tholeiite = 0.5% H_2O
Alkali Olivine Basalt = 0.9% H_2O

Andesites, Rhyolites, Granites: Higher Water Contents

- Paricutin Andesite = 2.2% H_2O at 1100^oC
- Granites/Rhyolites wide range H_2O: 0.5% to 7% H_2O by weight.

- Water lowers viscosity: OH^- ions act as Network Modifers, substitute for O_2 in tetrahedra.

- Water lowers solidus temperature: Effect greater at higher pressures

VISCOSITY

Depends on melt structure:

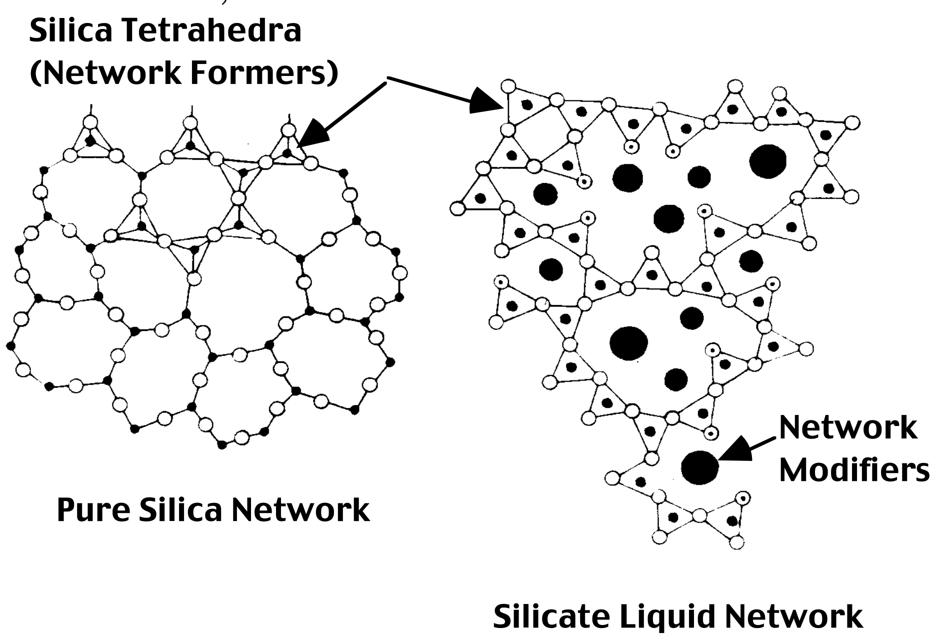
SiO_4^{-4} tetrahedra form NETWORKS, = “Network Former”

K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+} INTERRUPT network = “Network Modifers”

Al^{3+} = Either Modifer or Former; 2 coordination states: Al-6 & Al-4.

>> Al-4 tetrahedra = AlO_4^{5-}
>> Needs K^+ or Na^+ to balance extra charge on tetrahedra.

If K^+ or Na^+ not available, then Al^{VI} becomes “Network Modifer”:



Viscosity *decreases* with increasing temperature and high H_2O, CO_2.

Some Natural Viscosities In Poise {= gm/cm-sec}

H_2O at 20°C	0.01 poise
glycerin	15 poise
Erupting Hawaiian Basalt	3×10^3 poise @ 1150°-1200°C
Rhyolite Magma	10^8 to 10^{11} poise @ 700-750°C
Asthenosphere	10^{22} poise @ 1400-1600°C

ADIABATIC GRADIENTS AND GEOTHERMAL GRADIENTS

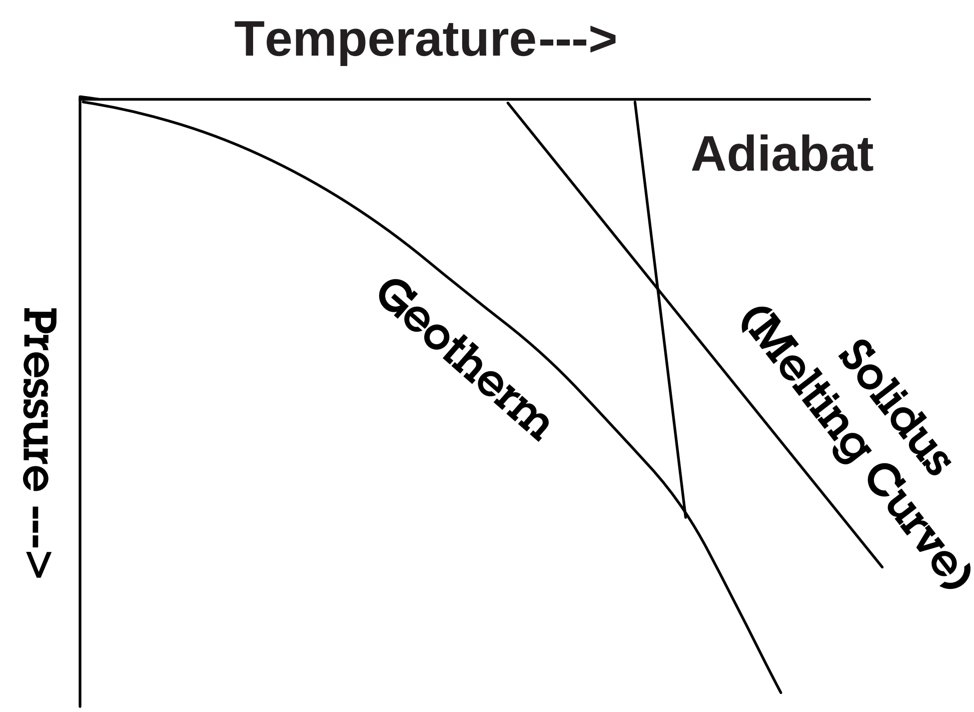
As magmas rise they cool adiabatically , i.e., constant heat content.

Adiabatic gradient = 0.3°C/km of ascent or 1°C/kb pressure.

Kbar = 1000 x atmospheric pressure, 1 Kbar = 3.3 km approximately.

Geothermal Gradient: Increase in Temperature with increasing Depth.

>> Varies with Depth (Steeper curve at Low Pressures).
>> Varies w/Location: Cratons<Mobile Belts < Rift Zones < Ocean Basins.
>> Called the "GEOTHERM".
>> MELTING occurs when Melting Curve (Solidus) intersects Geotherm.



MELTING CURVES:

Clapeyron Equation: $$\frac{dP}{dT}=\frac{\Delta H}{T\Delta V}$$

Also $$\frac{dP}{dT}=\frac{\Delta S}{\Delta V}$$ since $$\Delta S=\frac{\Delta H}{T}$$

T = Temperature P = Pressure H = Enthalpy S = Entropy

Liquids more random than solids so:

$$\Delta S_{fusion}=S_{liquid}-S_{crystals}=+Always$$

For DRY SYSTEMS: $$\frac{dP}{dT}=\frac{+\Delta S}{+\Delta V}=Positive\_Slope$$

Because $$\Delta V_{fusion}=V_{liquid}-V_{crystals}=+Always$$

WET SYSTEMS:

Anhydrous Crystals + H_2O Vapor <==> Melt with Dissolved H_2O

Thus

$$\Delta V_{fusion}=V_{liquid}-V_{crystals\ +\ vapor}=Negative\_Always$$

AND $$\frac{dP}{dT}=\frac{+\Delta S}{-\Delta V}=Negative\_Slope$$

SILICATE MAGMAS (MacBirney, Appendix B)

Bottinga Y and D F Weill 1970 Densities of liquid silicate systems calc from partial molar volumes of oxide components, *AJS* 269, 169-182.

Bottinga and Weill, 1972, Viscosity of Magmatic Silicate Liquids A model for calculation, *AJS* 272, 438-475.