**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 (H₂O or CO₂)
- Vesicles = Bubbles of gas formed in magma

Physical Properties of magma depend on:
- **Temperature**
- **Density**
- **Volatile Content**
- **Viscosity**

*All depend directly or indirectly on composition.*

**TEMPERATURE**

**Basalt** @ 1 atm: 1200-1250°C liquidus, 950-1000°C solidus.

**Rhyolite:**

- Liquidus = 1050°C
- Hydrous solidus (with H₂O) = 650 ⁰C
- Anhydrous solidus (no H₂O) = 750°C

> Rhyolite solidus defined as T where viscosity >10¹³ 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$_2$O most abundant volatile in most magmas
- CO$_2$ next most abundant volatile

In general, **Basalt** magmas are DRY, i.e. H$_2$O < 0.5 wt%

- MORB = 0.25% H$_2$O
- Hawaiian Tholeiite = 0.5% H$_2$O
- Alkali Olivine Basalt = 0.9% H$_2$O

**Andesites, Rhyolites, Granites**: Higher Water Contents

- Paricutin Andesite = 2.2% H$_2$O at 1100°C
- Granites/Rhyolites wide range H$_2$O: 0.5% to 7% H$_2$O by weight.

- Water lowers viscosity: OH$^-$ ions act as Network Modifiers, 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 Modifiers”

Al$^{3+}$ = Either Modifier 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 Modifier”:

Viscosity decreases with increasing temperature and high H$_2$O, CO$_2$.

Some Natural Viscosities In Poise (= gm/cm-sec)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Viscosity @ Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O at 20°C</td>
<td>0.01 poise</td>
</tr>
<tr>
<td>glycerin</td>
<td>15 poise</td>
</tr>
<tr>
<td>Erupting Hawaiian Basalt</td>
<td>$3 \times 10^3$ poise @ 1150°C-1200°C</td>
</tr>
<tr>
<td>Rhyolite Magma</td>
<td>$10^8$ to $10^{11}$ poise @ 700-750°C</td>
</tr>
<tr>
<td>Asthenosphere</td>
<td>$10^{22}$ poise @ 1400-1600°C</td>
</tr>
</tbody>
</table>
ADIABATIC GRADIENTS AND GEOTHERMAL GRADIENTS

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

Adiabatic gradient = $0.3^\circ$C/km of ascent or $1^\circ$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:

\[ \Delta S_{\text{fusion}} = S_{\text{liquid}} - S_{\text{crystals}} = + \text{Always} \]

For DRY SYSTEMS:

\[ \frac{dP}{dT} = +\Delta S + \Delta V = \text{Positive Slope} \]

Because

\[ \Delta V_{\text{fusion}} = V_{\text{liquid}} - V_{\text{crystals}} = + \text{Always} \]

WET SYSTEMS:

Anhydrous Crystals + H2O Vapor <=> Melt with Dissolved H2O

Thus

\[ \Delta V_{\text{fusion}} = V_{\text{liquid}} - V_{\text{crystals}} + \text{vapor} = \text{Negative Always} \]

\[ \frac{dP}{dT} = +\Delta S - \Delta V = \text{Negative Slope} \]

AND
SILICATE MAGMAS (MacBirney, Appendix B)
