

Natural Disasters

Lecture 19

Ch 6 – Volcanic Eruptions: Plate Tectonics and Magmas

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Chapter 6 (p. 144-156)

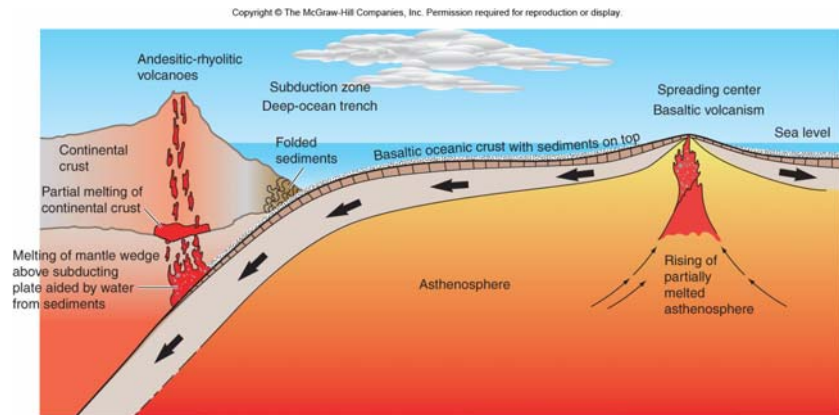
6.1: Ch. 6 – Volcanic Eruptions: Plate Tectonics and Magmas

● Plate Tectonic Setting of Volcanoes:

(Fig. 6.2)

◆ Over **90%** of volcanism is associated with the **edges of tectonic plates**

● Most other volcanism occurs **above hot spots**



● Over **80%** of Earth's magma extruded through volcanism takes place at the **oceanic spreading centers, as pure basalt** magma (below sea level), and creates 20 km^3 (5 mi^3) of new oceanic crust each year

● **Subduction zones** account for 7-13% of all magma, which is more of a **composite mixture**, as the presence of water lowers the melting point of the continental crust; this adds new melt of **different compositions** to rising plumes of magma

● Transform faults and continent-continent collisions have **little or no** associated volcanism

◆◆ **Spreading center** volcanoes are relatively **peaceful**, but **subduction-zone** volcanoes are **explosive and dangerous!**

• Chemical Composition of Magmas

• Of the 92 naturally occurring elements, only **eight (8)** make up more than **98%** of Earth's crust, with the next four (4) raising the total to 99.23%

♦ The most abundant element in the Earth's crust is **oxygen (O_2) at ~45%**, while the second most abundant element is **silicon (Si) at ~27%**

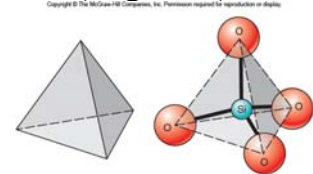
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TABLE 6.2
Common Elements of the Earth's Crust (weight %)

Eight Most Common	
Oxygen (O^{2-})	45.20%
Silicon (Si^{+4})	27.20
Aluminum (Al^{+3})	8.00
Iron ($Fe^{+2,+3}$)	5.80
Calcium (Ca^{+2})	5.06
Magnesium (Mg^{+2})	2.77
Sodium (Na^{+1})	2.32
Potassium (K^{+1})	1.68
Total	98.03%
Next Four Most Common	
Titanium ($Ti^{+3,+4}$)	0.86%
Hydrogen (H^{+1})	0.14
Phosphorus (P^{+5})	0.10
Manganese ($Mn^{+2,+3,+4}$)	0.10
Total	99.23%

• As magma begins cooling, some silicon and oxygen atoms will form a **silicon-oxygen tetrahedron (SiO_4) covalent bond**. The central **Si** atom (+4 charge) shares its electrons with four surrounding **O_2** atoms (each -2 charge); the resulting **-4** charge of **SiO_4** attracts and ties up **positively** charged atoms. (**SiO_4** is also called **silica, sand and quartz.**)

(Fig. 6.8)



• After the **negatively** charged **oxygen**, the other 11 elements of greatest abundance are all **positively** charged and as a result, are attracted to and bound up by, **oxygen**. This further results in combinations called: **oxides**.

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TABLE 6.3
Crustal Elements in Weight-Percent Oxides

Continental Crust		Oceanic Crust	
SiO_2	60.2%	SiO_2	48.7%
Al_2O_3	15.2	Al_2O_3	16.5
Fe_2O_3	2.5	Fe_2O_3	2.3
FeO	3.8	FeO	6.2
CaO	5.5	CaO	12.3
MgO	3.1	MgO	6.8
Na_2O	3.0	Na_2O	2.6
K_2O	2.9	K_2O	0.4

• It is the marked differences in **silicon dioxide (SiO_2) percentages** that produce magmas of **variable eruptive behavior**.

● Viscosity, Temperature and Water Content of Magmas

◆ The **viscosity** (the “stickiness” of a liquid) of magma is changed by:

(1) **higher temperature lowers** viscosity (more fluid); at 600° C, magma viscosity is 100,000 times more viscous (“stickier”) than at 900° C

(2) **SiO₂ increases** the viscosity of magma, as they form abundant **SiO₄** tetrahedra that create more joins and bonds between atoms and make flow difficult

(3) Increasing content of **mineral crystals increases** viscosity

◆ Magma contains **dissolved gases (H₂O, CO₂, SO₂)** held as **volatiles**; their solubility increases as pressure increases and temperature decreases (e.g., **CO₂** in canned soda); **dissolved water (H₂O)** is the most abundant dissolved gas

◆ The table above shows three primary types of magma: **basaltic, andesitic (composite) and rhyolitic**.

◆ **Basaltic** magma at spreading centers and hot spots is of lower **SiO₂** content, high temperature, low viscosity (gas escape easy), low in dissolved **H₂O**, leading to **peaceful eruptions**.

◆ **Rhyolite** magma at subduction zones is of higher **SiO₂** content, lower temperature, high viscosity (gas escape difficult), high in dissolved **H₂O**, leading to **explosive eruptions**.

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TABLE 6.5

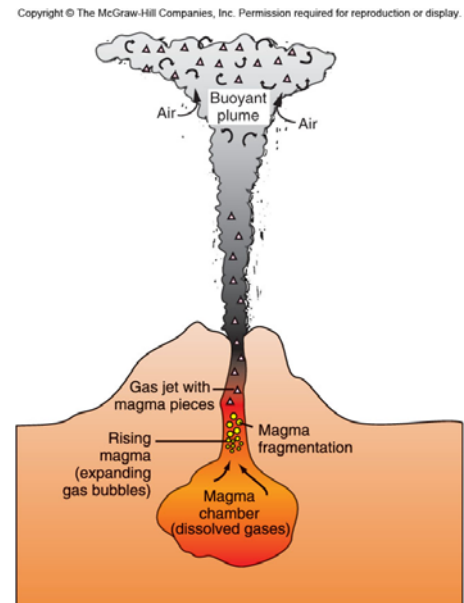
Comparison of Three Types of Magma

	Basaltic	Andesitic	Rhyolitic
Volume at Earth's Surface	80%	10%	10%
SiO ₂ Content	45–55%	55–65%	65–75%
	Increasing SiO ₂ →		
Temperature of Magma	1,000–1,300°C	800–1,000°C	600–900°C
	Decreasing temperature →		
Viscosity	Low (melted ice cream)		High (toothpaste)
	Increasing viscosity →		
Water Dissolved in Magma	~0.1–1 weight %	~2–3 weight %	~4–6 weight %
	Increasing water →		
Gas Escape from Magma	Easy		Difficult
	Increasing difficulty →		
Eruptive Style	Peaceful		Explosive
	Increasing explosiveness →		
Rock Description	Black to dark gray; contains Ca-plagioclase, pyroxene, olivine	Medium to dark gray; contains amphibole, pyroxene, intermediate Ca-Na-plagioclase	Light-colored; contains quartz, K-feldspar, biotite, Na-plagioclase

- **How a Volcano Erupts:** a rapid means for the Earth to expel some of its internal heat (Fig. 6.14)

- Superheated rock rises to levels with **lower pressure**, and some solid rock may change phase to **liquid magma**, resulting in **volume expansion**, leading step-by-step to eruption:

- **Magma** is generated by **melting rock**: (1) lowering the **pressure** on it; (2) raising its **temperature**; or, (3) increasing its **water (volatile)** content; points (1) & (3) most relevant



- ◆ Melting by decreasing **pressure** is called **decompression melting**; most rock that melts to form magma is because of **decreasing pressure on it, not by adding more heat**

- As the magma **expands in volume, it fractures** the overlying rocks, allowing it to rise to even **lower pressure** levels, causing more superheated rock to **liquefy** and become magma, and collect in a **magma chamber**.

- At high pressure, the **volatiles (gases)** remain dissolved in solution, but as the magma rises toward the surface, the **gases** begin to come out, forming **bubbles that expand** with decreasing pressure, **fragmenting and propelling** the magma upwards and out through **fractures, or pipes (underground water conduits)**, by a powerful **gas jet**!

◆◆◆◆◆ BOOM! ◆◆◆◆◆

- Upon escape from the volcano, the **gas jet draws in air**, which adds to **buoyancy** in the turbulent, rising plume.

♦ Eruption Styles and the Role of H_2O Content:

whether a volcanic eruption is peaceful or explosive depends significantly on the **concentration of H_2O** in the magma.

- If all magmas contained **low** concentrations of H_2O , then there would be **no** explosive eruptions.
- Even a high-viscosity **rhyolite** magma, with a **low H_2O** concentration will lead to slow flows, or no flow as the magma oozes upward and builds a **dome**
- Even a **basalt** magma can erupt explosively if it is **high** in **volatiles (mainly H_2O)**

♦♦ Non-Explosive: **Icelandic and Hawaiian**

♦♦ Somewhat Explosive: **Strombolian**

♦♦ Explosive: **Vulcanian and Plinian**

• Volcanic Materials:

♦ **Non-Explosive Eruptions:** highly liquid basaltic magma may cool as a **pahoehoe lava**; slower-flowing, more viscous lava is called **aa lava**; lava underwater forms **pillow lava**

♦ **Explosive Eruptions:** explosions tear apart magma and older rock into **pyroclastic debris**, from dust to huge blocks and **bombs**; the **high-speed (>100 mph), very hot, gas-charged pyroclastic flows** are especially deadly!

- **Obsidian:** fast-cooling magma; a non-porous volcanic glass
- **Pumice:** escaping gases leave holes; a porous volcanic glass

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TABLE 6.6

Volcanic Materials

Lava	Pahoehoe	Smooth, ropy surface
	Aa	Rough, blocky surface
	Pillow	Ellipsoidal masses formed in water
Pyroclastic Air-fall Fragments		
	Fine ash (dust)	Flour-size material
	Coarse ash	Sand size
	Cinders	Marble to baseball size
	Blocks	Big fragments, solid while airborne
	Bombs	Big fragments, liquid while airborne
	Volcanic tuff	Rock made of smaller fragments (e.g., deposit of a hot, gas-charged flow)
	Volcanic breccia	Rock made of coarse, angular fragments (e.g., deposit of a water-charged debris flow)
Glass	Obsidian	Nonporous glass
	Pumice	Porous glass (froth)