**Magma is formed by melting pre-existing rock in Earth's interior.** The resulting material is comprised of melt, crystals of minerals, and gas bubbles. Magma is less dense than solid rock, so it will rise towards the surface of the Earth. Some magmas are trapped in the crust, whereas other magmas travel through fractures in the crust and eventually extrude onto Earth's surface.

Magma that has erupted and cools to form solid rock is called **lava**.

Most magmas are composed of varying proportions of 8 elements: oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), with O and Si being present in the greatest amounts. Lesser amounts of titanium (Ti), manganese (Mn), phosphorus (P), and hydrogen (H) are present.

The sizes of the crystals that form in a solidified magma are dependent on how long it takes the magma to cool. Magmas that cool slowly underground, in crustal magma chambers, are called **intrusive rocks**. In contrast, magma that extrudes at Earth's surface cools quite quickly in terms of geologic time, commonly solidifying over days to weeks. These erupted magmas, called lavas, typically have very small sizes of crystals, most of which are too small to be seen with your eye. The resulting texture is called **extrusive** or fine-grained.

1. **Mafic magmas** (those with the lowest SiO2 content) exist at high temperatures, have the lowest viscosity, have low gas contents, and tend to erupt effusively (non-explosively). They form dark colored *mafic* rocks called **basalts**.
2. **Felsic magmas** form at lower temperatures, have high viscosity, and tend to erupt explosively. They form lighter-colored *felsic* rocks called **rhyolites**. Felsic magmas also tend to have higher gas contents than mafic magmas, and it is this combination of high viscosity and high gas content that leads to explosive eruptions.
3. **Explain what magma density and magma viscosity are and how they control volcanic behaviour.**

For magma to rise through the crust it must be: (1) Less dense than the crust ; (2) Runny enough to flow (i.e., it must have low viscosity); and (3) Hot enough to stay liquid. All these properties depend on the magma's composition and temperature.

1. **List the different categories of volcanic rocks and explain the differences between the magmas they came from.**

**1. Lava flows.** When magma erupts at Earth's surface, it can form an array of eruptive products, depending on its chemical composition. Lava flows result when magma that is relatively low in gas content (less than a few percent) erupts effusively at Earth's surface.

**2. Volcanic glass.** In some cases magma erupts and cools so quickly that crystallization does not occur. This glass is called **obsidian** if it is massive, or **pumice** if it contained many bubbles (called **vesicles**). The bubbles form from gas that escaped from the magma during eruption.

**3. Pyroclastic material.** Pyroclastic material refers to fragments of all sizes that are erupted explosively out of a volcano. These range from the finest material, **ash** (< 2 mm diameter) through **lapilli** (2 - 64 mm) to larger **blocks** and **bombs** (> 64 mm). Many pieces of pumice are actually pumice lapilli. These explosive fragments cause the most hazards during volcanic eruptions. Pyroclasts can erupt as ballistic fragments (bombs or blocks), flows (pyroclastic flows), or fall deposits (air fall deposits).

**4. Gaseous products.** Gaseous compounds bubble out of magma during eruptions and form vesicles in the solid rock. H2O (steam) is by far the most common volcanic gas, but CO2 (carbon dioxide), SO2 (sulfur dioxide), H2S (hydrogen sulfide), and HCl (hydrogen chloride) are other important volcanic gases. H2S gives volcanic gas its rotten egg smell. CO2, is a colorless, odorless gas, and is denser than air and thus may accumulate in low areas.

1. **Explain why some magmas erupt explosively (as pyroclastic material) and some magmas erupt effusively (as lava). Explain what controls volcanic explosivity.**

The **gas content** of magma contributes to the explosivity of an eruption. As magmas rise towards Earth's surface, dissolved gases, which are compressed at depth, expand and try to escape the magma. Gas bubbles are formed, grow larger, and eventually explode. Magmas with higher gas contents have more explosive, and thus more hazardous, eruptions.

**Viscosity** is defined as resistance to flow. The more easily magma flows, the more likely it is that gas bubbles in it will dissipate and the magma will erupt effusively rather than explosively.

**It is the combination of high gas content and high viscosity that leads to the most explosive volcanic eruptions.**

What factors influence viscosity?

First, the **chemical composition** of the magma exerts a profound control on its viscosity. Magmas have varying amount of SiO2: the more SiO2, the higher the viscosity. Remember that the Si-O bond is quite strong, so the more Si and O that are in a magma, the more will it resist flow.

Second, **temperature** has an effect on viscosity. As magma cools, more Si-O bonds form, and the magma is said to polymerize. This makes the magma stickier and thicker as it cools, or in other words, more viscous.

To summarize,

* viscosity is proportional to the weight percent of SiO2 in a magma; and
* viscosity is proportional to 1 / T of a magma, where T = temperature

1. **Explain the differences between pahoehoe and a'a lavas.**

Pahoehoe lavas have a ropy-textured surface while a’a lavas have a rubble-y textured surface.

1. **Describe the different types of volcanic eruptions and how they are related to magma properties.**
2. High silica magma forms in the crust by melting of pre-existing rock. Gas is dissolved in this magma due to the high pressure underground.
3. The magma rises towards Earth's surface because it is less dense than the surrounding solid rock.
4. As the magma rises, the dissolved gas expands and forms bubbles in the magma. This process is called **vesiculation**.
5. Because the magma is also cooling at it rises, its viscosity is increasing (Si-O bonds are forming). The gas bubbles are trapped in the viscous magma and gas pressure builds within the bubbles as they get closer to the surface.
6. When the percentage of the bubbles in the magma is about 75%, they are close enough that they touch. The walls between adjacent bubbles are so thin that the gas pressure overcomes the viscosity of the magma.
7. **BOOM!** An explosive eruption takes place, and fragments of magma are erupted as pyroclasts.  
   If the magma was mafic (low in silica content), the included gas bubbles would be able to escape from the rising magma and pop easily upon eruption, resulting in less explosive eruptions.
8. **Describe the morphology, dominant rock type and typical eruption style of the different types of volcanoes**

A **volcano** is a mass of material that forms at Earth's surface in response to one or more eruptions of magma.

**1. Mafic volcanic landforms: Shield Volcanoes and Cinder Cones**

**Mafic** lavas are very fluid (low viscosity) and can travel long distances from a vent. They may flow downhill at speeds of up to 30 km/hr, and travel tens to over one hundred kilometers from their vent.

* 1. **Shield Volcano**. It is tens of kilometers high and may be over 100 km across. Repeated eruption of basaltic lava flows forms most of a shield volcano, although small eruptive centers called cinder cones (see below) are present on the flanks.
  2. **Cinder Cone**. A cinder cone is a conical hill formed from the accumulation of pyroclastic material (cinders are 4 - 32 mm in size) around a volcanic vent. The cones are commonly 10's to 100's of meters high and 100's of meters across. One or more lava flows may issue from the vent after the cone forms. In general, cinder cones are composed of mafic magma, although andesitic cinder cones are not unknown.

2. **Intermediate to felsic volcanic landforms: Stratovolcanoes**

When **intermediate to felsic magma** erupts explosively, it can produce ash columns that penetrate to higher than 40 km into the atmosphere. Ash is the finest grained pyroclastic material, and if it gets into the stratosphere, it can travel around the world in upper level winds. When the winds die, ash falls out of the atmosphere due to gravity and it forms layers that blanket the landscape. Air-fall ash eruptions typically take place at composite volcanoes and calderas.

* 1. **Stratovolcano/Composite Volcano**. Composed of alternating layers of lava flows and pyroclastic layers, along with volcanic domes and tabular intrusions known as **dykes** and **sills**. These volcanoes are tall, conical, and have steep slopes. They can be several kilometers high and over 10 km across. Composite volcanoes get their name because they erupt magmas of a full range of silica contents. The mafic and some intermediate eruptions tend to form flows, whereas magmas with higher silica contents commonly erupt explosively as pyroclastic material, either in the form of bombs, flows, or falls.
  2. **Lava Dome**. Another type of intermediate to felsic landform is a **lava dome**. A dome is a pile of viscous lava that forms over a vent. It commonly has a mushroom-like shape because the lava is viscous and does not travel far from the vent. Domes may stand alone, or be erupted in the center or on the flank of an existing volcano.

3. **Felsic volcanic landform: Calderas**

* 1. **Caldera**. Calderas are very large depressions in Earth's crust, caused by voluminous eruption of explosive, felsic pyroclastic material. They are typically 10's to over 100 km across and kilometers deep. Calderas form because so much magma is erupted that the existing crust founders into the void left by the evacuated magma chamber.  
       
     Do not confuse a crater with a caldera! A crater is a depression on top of a volcanic vent, and it typically is only 10's to 100's of meters across, although craters on some of the Hawaiian shield volcanoes are kilometers across. A crater normally does not form because a block of crust is downdropped. Rather, it forms by default as piles of erupted material surround a volcanic vent.  
       
     The sequence of events that forms a caldera is as follows:

1. Formation and accumulation of a very large body of felsic magma in a near-surface magma chamber. This magma is buoyant and it domes the overlying crust, creating both radial and ring fractures.
2. Gas pressure in the felsic magma chamber increases to the point that explosive fragmentation occurs. Pyroclastic material erupts through fractures in the overlying crust in the form of pyroclastic flows, and produces a deposit known as an ash flow tuff sheet. This tuff sheet blankets the countryside for many kilometers out from the caldera, and some of the tuff sheet is deposited in the center of the caldera.
3. So much magma erupts that the roof of the caldera collapses back into the void left by the evacuated magma, producing a very large closed depression in the surface.

Calderas are the most explosive volcanoes, expending tremendous amount of energy on the landscape. Luckily for us, they erupt infrequently in terms of our lifetimes.

1. **Explain what lava flows, fire fountains, lava bombs, and volcanic ash are and how they form.**
2. **Describe the particular hazards associated with lava flows, fire fountaining, lava bombs, and ash fall.**

Volcanoes can have multiple types of eruptions and thus the hazards due to these will vary with time.

1. **Lava Flows**. Low viscosity **mafic lava flows** can flow and spread laterally out of a stream canyon onto a valley floor. They erupt at 1200 - 1400 °C. However, they are NOT explosive. Most people are able to run out of the way or avoid a particular valley through which a flow is progressing. Thus, the main hazard associated with mafic flows is infrastructure damage. Road and buildings are easily overrun and incinerated.

2. Sometimes, basaltic lava can contain lots of gas which create **small** explosive eruptions called **fire fountains**. As partially liquid drops fall back to the ground, they may coalesce to re-form a lava flow.

3. **Pyroclastic Material**. Most pyroclastic material or **tephra** form from high-silica magma, although mafic and intermediate-composition pyroclasts are not unheard of. Mafic pyroclasts are called **scoria**.

1. **Ash particles** are the smallest pyroclasts (< 2 mm diameter). These form from fragmentation of a frothy magma, when the pressure within the gas bubbles exceeds the strength of the viscous magma.

A description of the process shown in the diagram above follows:

* + 1. Gas bubbles form in a high-silica magma but do not pop because of the high viscosity. Therefore, the pressure in each bubble increases as the magma makes it way towards the surface.
    2. The bubbles expand until they are almost touching. At this point the magma is frothy, as only thin walls of silicate melt are present in between adjacent bubbles.
    3. BOOM! The gas pressure in the bubbles exceeds the strength of the thin walls of silicate melt, causing explosive fragmentation, and triangular glass shards called ash rise into the atmosphere in an eruption column. Some larger fragments (see definitions below) are left from incomplete fragmentation of the gas-rich magma.

During explosive volanic eruptions, ash falls downwind of the volcano. In the case of very large eruptions, **ash columns** may rise to altitudes of > 40 km, where the fine ash particles are picked up by global winds and circulated around the world. This allows for ash to be deposited over a vast area. Ash injected into the stratosphere can contribute to a lower amount of solar radiation reaching Earth's surface, and therefore to global cooling.

Ash can choke vehicle and airplane engines, aggravate respiratory ailments, bury homes and other structures and/or cause their collapse, and cover valuable agricultural land, thereby decreasing the food supply and leading to famine.

* 1. Lapilli are pyroclasts in the 2 - 64 mm range. These are associated with large eruption columns and are mostly fragments of vesicular felsic rock called pumice. Lapilli-sized pumice fragments fall out of an eruption column and blanket surrounding areas, forming a pumice fall deposit.
  2. **Bombs and blocks** (> 64 mm in diameter) are the largest pyroclasts. These are explosively ejected during an eruption as ballistic projectiles, most of which land near the volcanic vent.

1. **Explain what pyroclastic flows, lahars, volcanic domes, sector collapses, lateral blasts, and toxic gases are and how they form.**
2. **Describe the particular hazards associated with pyroclastic flows, lahars, dome collapses, sector collapses, lateral blasts, and toxic gases.**

1. **Pyroclastic Flows**. Pyroclastic flows are turbulent mixtures of hot gas and pyroclastic fragments that are emplaced laterally from a volcanic vent. They consist of ash, lapilli, crystals, and other rock fragments called **lithic fragments**. These flows are density currents that move at speeds of 300 - 400 km/hr. The largest pyroclastic flows can travel 10's of kilometers from their source. The temperature of a pyroclastic flow is generally in the 500 - 700 °C range.

Pyroclastic flows tend to be confined to low areas in the topography such as stream valleys radiating from a volcanic cone.

Pyroclastic flows **originate in several ways**. The most common way is by collapse of an eruption column. Another method is by sudden collapse of part of an erupting **volcanic dome**. Thirdly, is when a small pyroclastic eruption builds up and overspills the crater rim resulting in a high-speed flow of pyroclastic materials. Lastly, failure of one side of a volcanic edifice may lead to a **lateral blast** of pyroclastic material which then flows down slope.

Pyroclastic flows are the most lethal of the eruptive products. These flow mostly along channels, ridges, and valleys, but can also jump the banks as it travels at high speed over tens of kilometres. Effects from pyroclastic flows are mostly limited to the immediate vicinity of the source volcano, but all life and structures in its path are destroyed.

2. **Lahar**. There are additional hazards associated with volcanoes that do not necessarily occur when a volcano is actively erupting. Lahars or volcanic mud or debris flows are extremely destructive mixtures of water, ash, rock fragments of all sizes, and debris that travel swiftly down slope from a volcano, at speeds up to 50 km/hr. They follow stream valleys. Some lahars are hot when they are emplaced because they are associated with pyroclastic eruptions, but other lahars may occur long after volcanic activity has ceased.

//They do a lot of damage because they travel long distances away from a volcano so their presence may not be associated with it, and they can occur in between times of volcanic activity.

//Some volcanic eruptions can cause their own micro-weather system which can result in lahars. Water, a common gaseous product of eruption, can be blown high into the atmosphere as steam, eventually to fall as heavy rain. Rain falling on thick accumulations of pyroclastic material on steep slopes set off lahars.

Summary: formation of a lahar requires the following: pyroclastic material and water. Lots of water! The water may come from melted snow and ice high on the flanks of a volcano.

3. **Toxic Gases**. Toxic gases may be released by a volcano during or between active eruptions. Many types of gas are emitted from volcanoes, but water (H2O) and carbon dioxide (CO2) are the most common components. Other gases include sulfur dioxide (SO2), hydrogen sulfide (H2S), and hydrogen chloride (HCl). About 1 - 10% of a magma consists of gas.

There are many hazards associated with volcanic gases. SO2 may combine with H2O to form dilute sulfuric acid (H2SO4). This in turn forms "acid rain" which can destroy crops, leach heavy metals from steel structures, nails, and paint, and contaminate cisterns full of drinking water.

//CO2 is dangerous because it is denser than air and can accumulate in low areas. Lake Nyos in Cameroon, western Africa, is a crater lake in the middle of a dormant volcano. In 1986, the sudden release of 109 m3 of CO2 that was previously trapped in sediments on the floor of the lake asphyxiated 1,700 people and all livestock in the area, with no warning.

4. **Volcanic Landslide/Sector Collapse**. A volcanic landslide is a down slope failure of a portion of a volcanic edifice. Eruptive products that compose the volcano are altered to clay minerals by hydrothermal fluids. Clays have low shear strength. The combination of water percolating into the volcano (either from rain, melted snow, or hot springs) combined with clay can lead to failure under the influence of gravity with no warning or precursor activity. Volcanic landslides may turn into mudflows or debris flows down slope.

You should recognize from the description of the materials involved in a sector collapse, that the landslide that ensues can be classified as a **debris avalanche**.

//Volcanic landslides can be triggered by volcanic activity, earthquakes, rapid melting of snow and ice, or heavy rainfall events. On May 18, 1980, at 8:32 am Pacific Daylight Time, a magnitude 5.1 earthquake triggered a landslide off of the north flank of Mount St. Helens. The landslide in turn depressurized a near-surface magma body and precipitated a catastrophic eruption that included a lateral blast, a vertical ash column, and pyroclastic flows.

1. **Use the VEI to rank the size of a volcanic eruption.**

The classification considers:

* **volume** of eruption products;
* eruption **plume or cloud height**;
* **duration** of eruption; and
* **qualitative observations** (with terms that range from non-explosive, gentle, cataclysmic, to mega-colossal)

1. **List the different volcano monitoring techniques and the instruments that are used.**

1. **Increased seismic activity**

1. **Seismic monitoring -> Seismometer**. Increased seismic activity is associated with eruptions or precursor activity before eruptions. As buoyant magma rises through the crust, it fractures the overlying rock to make room for itself. This causes concentrations of earthquakes in space and time.
2. **Acoustic flow monitors (AFM) -> Seismometer.** A specialized type of seismometer that are optimized to detect and record high frequency (10 - 250 Hz) vibrations caused by lahars, rather than lower frequency vibrations in the 0.5 - 10 Hz range that are typical of earthquakes. These units are generally solar-powered and are buried in the ground adjacent to stream valleys radiating out from a volcano. When an AFM senses vibrations typical of a lahar, it sends a signal from an antenna to a receiving station where an alarm can be sounded to alert people downstream to get to higher ground.

2. **Ground deformation**.

1. **Direct Measurements of Horizontal Displacement -> Physical Tape.** Physically taping the distance between two metal stakes, or by measuring an increase in the width of cracks growing on a volcano, and keeping track of the change in distance over time.
2. **Tilt of Volcano Edifice -> Tiltmeters.** Sensitive instruments that record changes in the tilt of a surface. These instruments are placed around the flanks of a volcano and the change in tilt is measured over time. Individual tiltmeters record tilting outward from the central crater as the volcano inflates with magma in its interior. After an eruption, the tiltmeters record decreasing tilt as the volcano deflates.
3. **Global Positioning System -> GPS Receivers.** Pinpoint horizontal and vertical movement of targets on a volcano through repeated measurements over time. This technique may involve placing automated GPS receivers at known locations around a volcano, or geoscientists may make the measurements directly at each site using portable GPS receivers. EXPENSVE EQUIP.
4. **InSAR (satellite radar interferometry) -> Satellites.** This technique involves satellites using radar waves to measure the elevation of large areas of the crust in the vicinity of active volcanoes over an interval of time. These remotely sensed images can be superimposed over each other using digital techniques and areas of uplift can be identified by the presence of deformation fringes, which show up as colored irregularly shaped rings on an InSAR image.

3. **Increased gas emissions**. Increased gas emissions may reflect a change in magma supply rate, a change in the type of magma that is erupting, or a change in the underground fracture system that is routing gas towards the surface.

1. **Direct collection of gases** emitted at fumaroles is possible, but in an active volcanic setting this may be getting too close for comfort for most people!
2. **Correlation Spectrometer (COSPEC) -> Spectrometer.** Estimate SO2 emissions in an eruption plume from afar and thus with little danger. A COSPEC **measures** the amount of solar ultraviolet light absorbed by sulfur dioxide and compares it to a standard. The amount of absorption is proportional to the concentration of sulfur dioxide. Measurements are made over a period of time and the data are used to calculate the sulfur dioxide daily emission rate.
3. **Fourier transform infrared spectrometer (FTIR) -> Spectrometer.** Third technique commonly used in sampling and measuring gas emissions from volcanoes. The FTIR analyzes several gases simultaneously and uses a mathematical process (the Fourier transform) to convert the raw data into the desired format, the amount of light absorbed at each wavelength. As in COSPEC, the amount of light absorbed at specific wavelengths indicates the concentration of specific gases in the volcanic plume.

4. **Visible signs of volcanic activity: new eruptive material**.

1. **Still photography** and **video footage** are used extensively to document changes to active volcanoes.
2. **LIDAR (light detection and ranging)** images can be used to calculate the volume of new material added over time.

5. **Increased heat flow**. Increased heat flow from a volcano may indicate the presence of new magma at the surface, fracturing of the crust due to magma upwelling, or increased activity at hot springs and/or fumaroles. There are a number of techniques used to measure heat flow.

1. **Direct observations** of glowing magma or glowing cracks in a volcano are certainly possible. An **optical pyrometer**, a hand-held device, may be used to determine the temperature of glowing lava.
2. **Aerial remote sensing of infrared spectra** can record anomalously hot areas.
3. **Forward looking infrared (FLIR)** images, taken by airplanes or satellites, are also being used extensively to monitor dome growth.

**Remote Sensing (Satellite) Monitoring Strategies**: GPS, InSAR, LIDAR, and FLIR.

1. **Explain what a volcanic hazard map is and why they are useful.**

Spatial data for a volcano, such as the distribution of eruptive units, are plotted on a geologic map. The map is then used to identify hazards, based on past history, and to produce a **volcanic hazards map** showing zones of likely eruptive activity, and specific hazards.

1. **Use your knowledge of volcanic processes to map major hazards around different volcanoes.**

**ok**

1. **Evaluate volcanic hazards and their risks that may affect Vancouver.**

Within the Garibaldi-Cascades arc, eruptions are frequent enough that, based on historical activity, we will likely witness another eruption during our lifetime. Based on the longer recurrence interval of catastrophic events from caldera eruptions, it is harder to predict whether we will experience one from any of the three youngest calderas in western North America (Yellowstone, Long Valley, and Jemez calderas) during our lifetime. We now know, however that it is not impossible.

1. **Describe the distribution of the world's active volcanoes.**

**Sub-aerial active volcanoes.** What you will note is that about 80% of active **sub-aerial** volcanoes (those located above ground level) are associated with convergent plate margins. Many active volcanoes are found along the **margins of the Pacific Ocean basin**, where their presence is due to the convergent margin setting. This has lead to the term "**Pacific Ring of Fire**" to describe this concentration of volcanoes.

Divergent plate boundaries are host to about 15% of Earth's active sub-aerial volcanoes, but many more **submarine** volcanoes are found at the mid-ocean ridge (MOR). In fact most volcanic activity on Earth is probably taking place at the MOR, but the majority of these volcanic vents are under water and therefore not so dangerous to us.

Additional active sub-aerial volcanoes are found **within** oceanic and continental plates, and not located along a plate boundary. These are called **hotspot** volcanoes.

1. **List the three types of plate boundaries and the different types of volcanoes that occur at these plate boundaries.**

At **divergent margins**, two plates spread apart due to upwelling of the upper mantle and the injection of magma. Most divergent margins are located in the ocean basins and are called **mid-ocean ridges** (MOR), as they form **undersea mountain ranges**. The on-land equivalent of a MOR is known as a **continental rift zone**. An example would be the East African Rift.

Where two plates collide, one plate will subduct into the mantle beneath the other plate to form a **convergent margin**. This holds true for ocean-ocean collisions and ocean-continent collisions, and **volcanic arcs** form in the overlying plate in these settings. Where two continental plates collide, however, neither will subduct, as both are too buoyant to descend into the dense mantle. Rather, they suture together in a massive collisional zone to form a large mountain chain. This is what happened when India collided with Asia to form the Himalayan Mountains. **Magmatism is rare** in continent-continent collision zones.

A third type of plate boundary is a **transform fault**, where two plates slide laterally past one another. **Magmatism is also rare** along this type of plate boundary.

**1. Ocean-ocean convergent margins**.

At depth, the lithosphere dehydrates and water is introduced into the overlying asthenosphere (upper mantle). This water induces **melting of the mantle** (by lowering the melting temperature), which leads to the formation of mafic magma. Being less dense than the surrounding mantle, mafic magma rises into the crust and towards the surface.

If the plate overlying the rising magma is oceanic, the mafic magma will have limited interaction with it. Intermediate magmas may form from differentiation processes that change the composition of the mafic magma and slightly raise the SiO2 content. Thus, magmas produced in oceanic arcs are mostly mafic, with some intermediate magmas. By-and-large, volcanoes in **oceanic arcs are composite volcanoes**, and the rocks that form from them are **basalts** and **andesites**.

2. **Ocean-continent convergent margins**.

At ocean-continent convergence zones, mafic magma forms in the mantle through the same mechanism described in the previous section; that is, water introduced by the subducted slab **lowers the melting temperature of the mantle**. However, as the resulting mafic magmas rise through continental crust, they interact with it to produce intermediate and felsic magmas. These interactions include melting of the continental crust (to produce felsic magma) and/or changing (or **differentiating**) the composition of mafic magma to a more SiO2-rich composition (to form intermediate and/or felsic magmas).

Volcanoes that result from eruption of magmas with a wide range of silica contents are called **composite volcanoes**, and they consist of rocks that range from **basalt**, to **andesite**, and **rhyolite**. The higher silica magmas produce the most explosive and therefore most hazardous eruptions at these volcanoes.

1. **Describe the type of volcanoes that occur at oceanic and continental hot spots.**

**1. Oceanic hotspots**.

When a mantle plume induces melting in the mantle near the base of an oceanic plate, mafic magma is produced. This mafic magma rises to the surface through mafic crust with little interaction because the melting temperatures of the magma and crust are similar. Volcanoes formed in these oceanic hotspot settings are typically **shield volcanoes** (along with some small cinder cones) that erupt mafic magma. The resulting volcanic rocks are dark-colored, low in viscosity, and low in SiO2. They are called **basalts**.

2. **Continental hotspots**.

Mantle plumes found beneath continental plates are no different than mantle plumes found beneath oceanic plates. However, continental hotspot volcanoes are very different from the shield volcanoes found in oceanic hotspot settings. This is because of the higher silica content of the continental crust and the resulting interactions of mantle-derived magmas with that of continental crust.

A rising mantle plume will induce melting in the upper mantle or the lithosphere near the base of a continental plate. The resulting melts are mafic. As mafic magma rise through the continental crust, the crust melts. This is because continental crust has, on average, a higher silica content and hence a lower melting temperature than mafic crust. Thus in this manner, mafic magmas can produce large volumes of felsic melt.

The production of large volumes of high silica, high viscosity magma in continental hotspot settings leads to the formation of **giant calderas**. Calderas are the most explosive type of volcano, but luckily for us, they have the longest recurrence interval between eruptions. The light-colored, high silica magmas produced by eruption of SiO2-rich magmas are called **rhyolites**. Because of their high viscosity and high gas content, these felsic magmas typically erupt as large volumes of ash flow tuff.

1. **Describe the tectonic setting of British Columbia and determine the dominant type of volcano that occurs here.**

The Garibaldi-Cascade arc (the Cascade Range volcanoes) formed from subduction of the Juan de Fuca plate beneath the North American Plate. This array of volcanoes stretches from Mount Meager in southern B.C. to Mount Lassen in northern California.

Within the Garibaldi-Cascades arc, eruptions are frequent enough that, based on historical activity, we will likely witness another eruption during our lifetime. Based on the longer recurrence interval of catastrophic events from caldera eruptions, it is harder to predict whether we will experience one from any of the three youngest calderas in western North America (Yellowstone, Long Valley, and Jemez calderas) during our lifetime. We now know, however that it is not impossible.