CRATER LAKE NATIONAL PARK

GEOLOGY TRAINING MANUAL

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This manual is an overview of concepts important to understanding the geology of Crater Lake National Park. It is intended as part of the training of Volunteers and Seasonal Workers in Park Service Interpretation. The manual is written primarily for non-geologists, to give them grounding in basic geologic concepts; the concepts discussed are those that will help explain Mt. Mazama and its environs to park visitors.

Crater Lake is an exciting place to "cease the moment," to help visitors learn while they are relaxed, on vacation in one of the most beautiful places on earth. While many people have seen volcanoes from a distance, very few have actually walked on the flanks of one; far fewer have taken a boat ride inside a recently active volcano! These circumstances give interpreters a unique opportunity to stir the imagination of visitors; not only can visitors see the effects of volcanism on the flanks of Mt. Mazama, they also can examine the <u>internal architecture</u> of a large volcano.

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INTRODUCTION

Geology is the study of the earth. It incorporates more than just the identification of a bunch of rocks. Geology involves the study of processes occurring on or within the earth that make the earth come alive. Processes within the earth include those responsible for volcanism, metamorphism, earthquakes, etc.; those above the earth involve the action of wind, water or ice. A modern earth scientist observes features at Earth's surface and relates those features to Earth's processes.

Mt. Mazama, which holds Crater Lake, is the remnant of a large volcano within the Cascade Mountain Range. The Cascades form due to partial melting of a small plate of Earth's outer shell that descends beneath Washington, Oregon and northern California. Background in two areas of Geology is therefore important to the appreciation of Crater Lake National Park: <u>Tectonics</u> and <u>Volcanism</u>. *Tectonics* is the study of large features of the earth's surface and of the processes within the earth that resulted in those large features. A modern view of tectonics is that the earth's outer shell is rigid and is broken into large plates that move about relative to each other (hence the term *plate tectonics*). *Volcanism*, the melting of rocks and extrusion of magma at Earth's surface, commonly occurs along the edges of moving plates.

Presentation of the two areas of Geology begins with a discussion of the three major types of plate boundaries and of features that are formed along the boundaries. A review of volcanism then follows, including a systematic classification of igneous rocks. The remainder of the manual involves the use of plate tectonics and volcanism to appreciate the regional geology of the Pacific Northwest and the local geology of Crater Lake National Park.

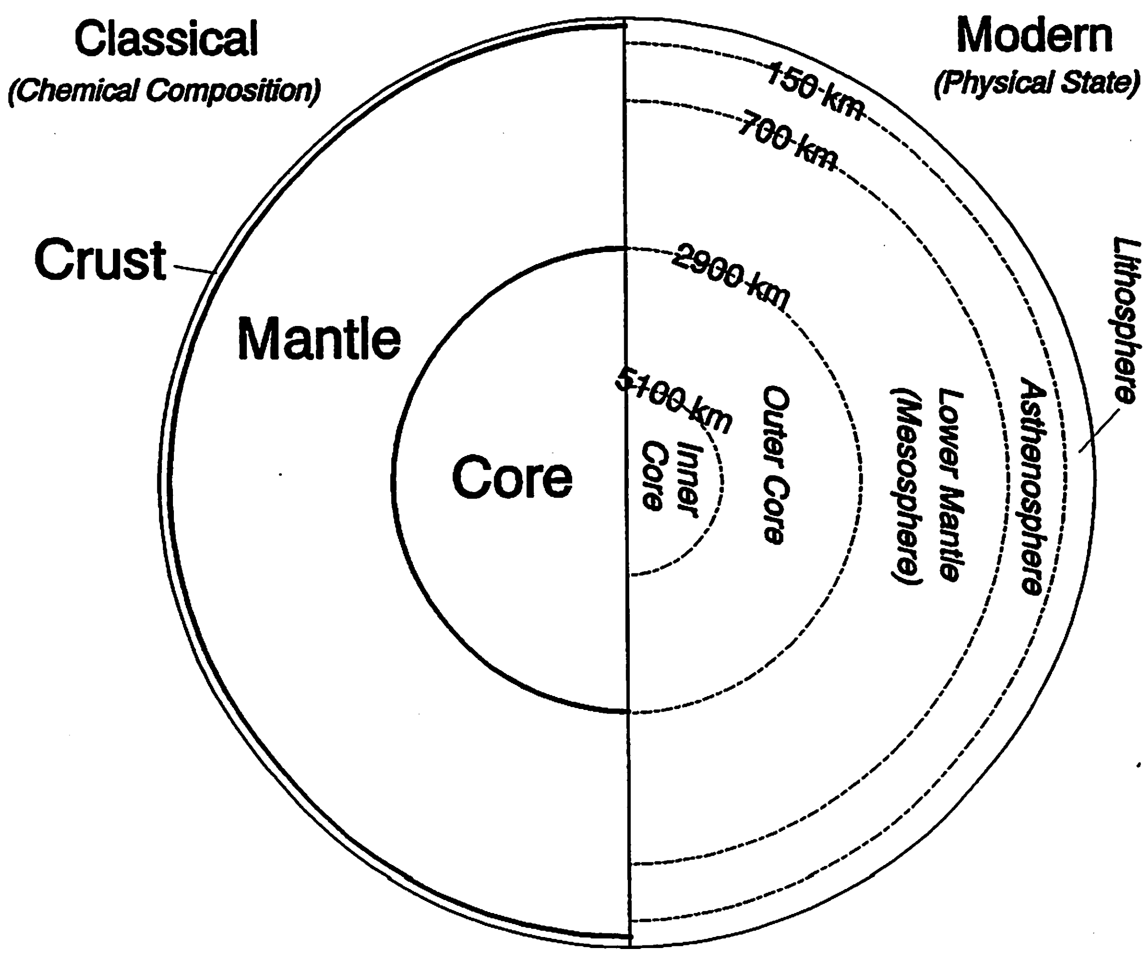
PLATE TECTONICS

"Earth scientists had just discovered something fascinating about the continent Patty Keene was standing on, incidentally. It was riding on a slab about forty miles thick, and the slab was drifting around on molten glurp. And all the other continents had slabs of their own. When one slab crashed into another one, mountains were made."

Kurt Vonnegut, Jr., Breakfast of Champions, 1973.

Gross Layers of the Earth

The earth has generally differentiated itself into layers according to density, the denser material concentrated deeper within the earth.



A) Classic divisions of the earth were generally according to chemical composition (left side of figure on previous page).

1) Core:
- From 2900 km to the center of the earth at 6300 km.
- Average density about 10.8 g/cm^3.
- About 16% of the earth's volume, 32% of its mass.
- Composed predominately of heavy minerals (iron and nickel).

2) Mantle:
- From about 30 to 2900 km depth.
- Density from 3.3 to 5.8 g/cm^3.
- 82% of earth's volume, 68% of mass.
- Silicate minerals rich in iron and magnesium.

3) Crust:
- Thickness varies from 2 to about 70 km.
- Densities generally between 2 and 3 g/cm^3.
- $<$ 2% of earth's volume, $<$ 1% of its mass.
- Of (thin) oceanic and (thick) continental types.
- Silicate minerals with far less iron and magnesium.

B) In more modern times, the gross layers of the earth have been viewed in terms of the physical state (e.g., *liquid*, *soft solid*, *rigid solid*) of the materials (right side of figure on previous page).

1) Inner Core:
- About 5100 to 6300 km depth.
- Solid.

2) Outer Core:
- 2900 to 5100 km depth.
- Liquid.

3) Lower Mantle:
- About 700 to 2900 km depth.
- Rigid Solid.

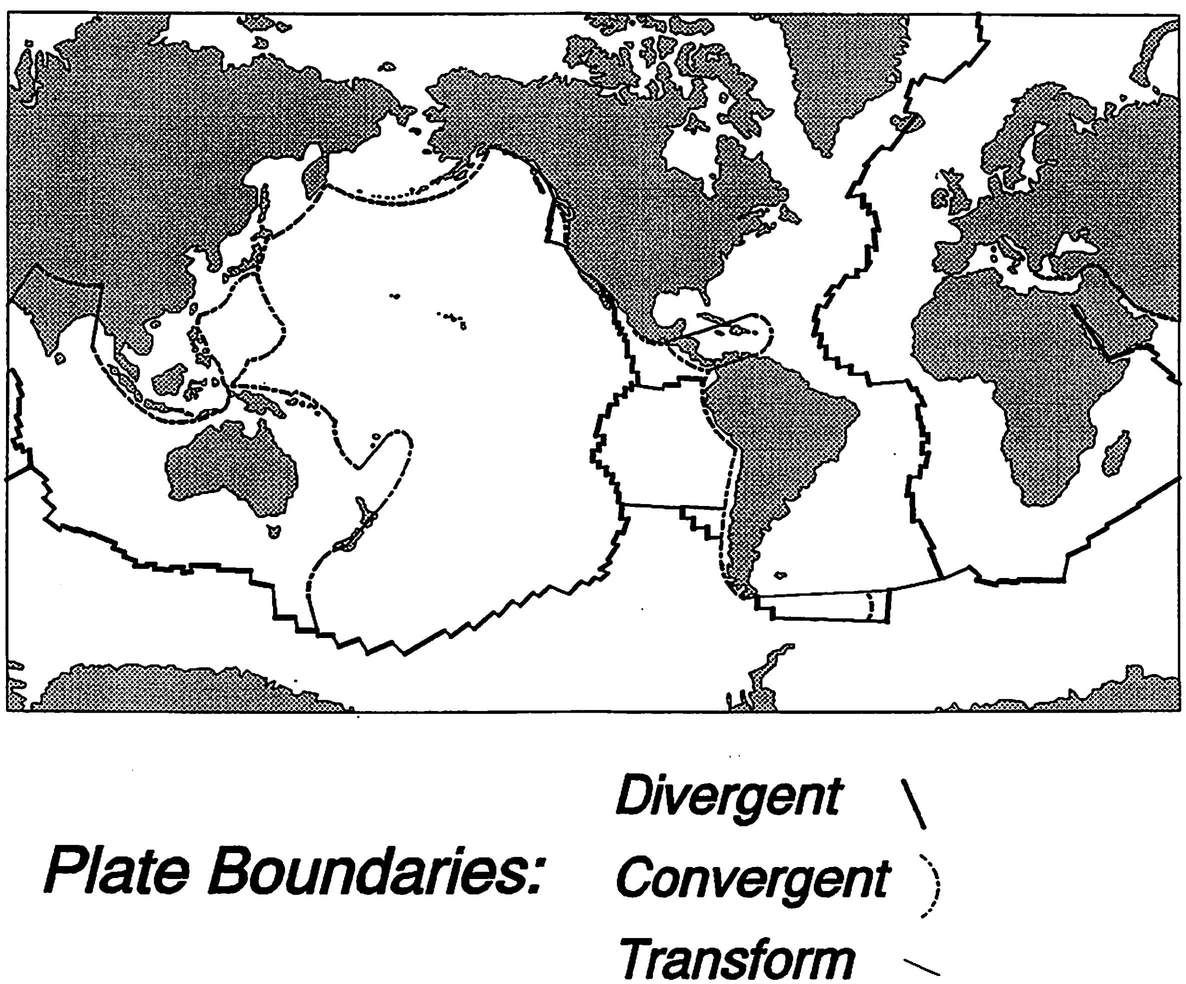
4) Asthenosphere:
- Extends from about 100 to 700 km depth (within the upper mantle).
- Material in a soft, plastic state (partially melted solid).
- Over geologic time, behaves as a slow moving fluid (like toothpaste).

5) Lithosphere:
- From the surface to about 100 or 150 km depth (includes the crust and uppermost mantle).
- Hard solid.
- Broken into rigid plates, which move over the asthenosphere (page 4).

Lithosphere and Asthenosphere

***Tectonics*:**
The study of large structures of the earth's crust and the processes that led to their development.

***Plate Tectonics*:**
- The outer, rigid layer of the earth (lithosphere) is broken into a mosaic of large plates (diagram below);
- These plates are in motion, relative to each other;
- Large-scale geologic structures result from the interaction of the plates, primarily along their edges.

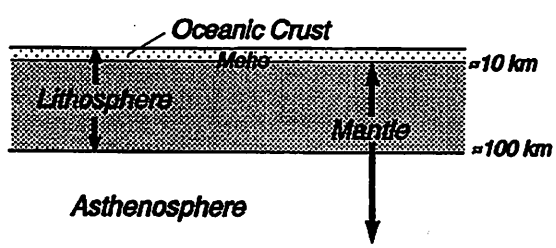


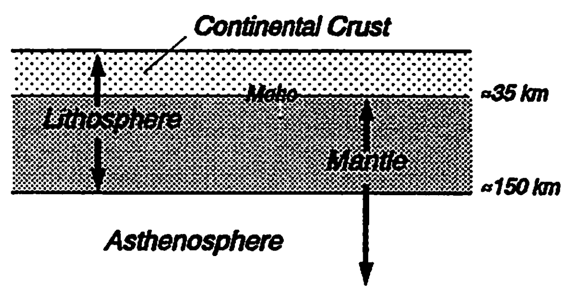
Major lithospheric plates and types of plate boundaries. (Modified from *Laboratory Manual of Physical Geology*, R. M. Busch, Editor, American Geological Institute and National Association of Geology Teachers, Macmillan Publishing Company, 3rd edition, 1993).

Earth's Outer Shell

1) Lithosphere
   a) Includes crust and part of upper mantle.
   b) About 100 to 150 km thick.
   c) Broken into a "mosaic" of several rigid plates.
   d) Plates move relative to each other over the softer asthenosphere.

2) Asthenosphere
   a) Part of upper mantle.
   b) Lies between about 100 and 700 km depth.
   c) Deforms plastically (i.e. "flows"), allowing the overlying, more rigid lithospheric plates to move relative to each other.



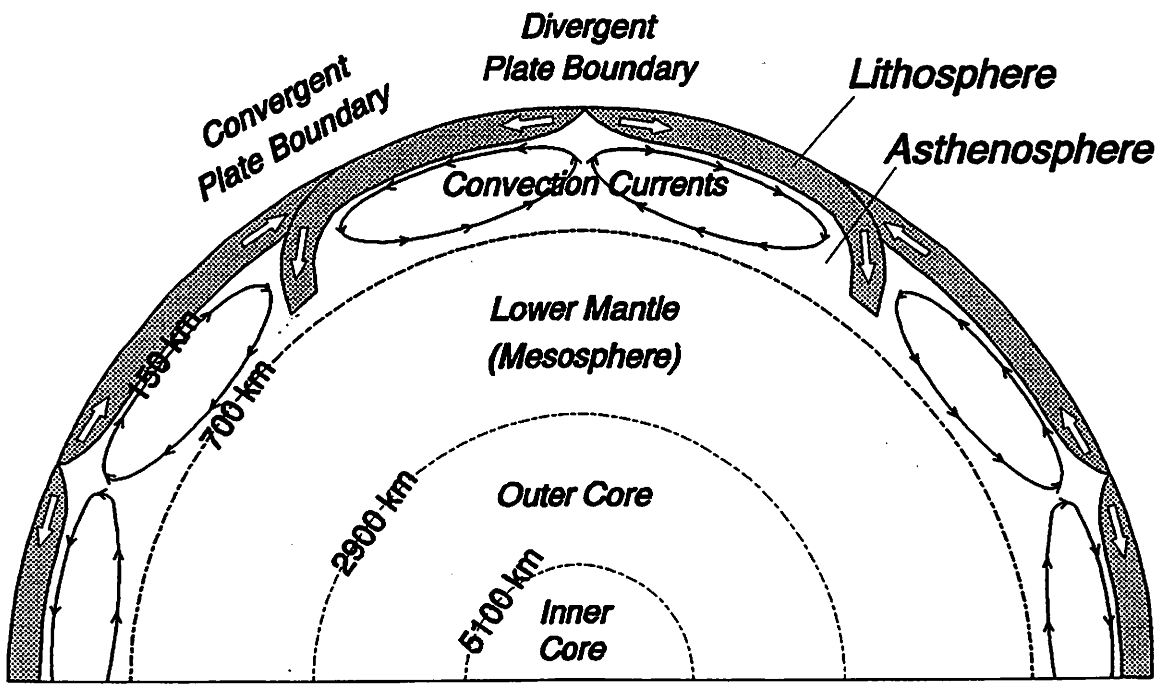


Lithospheric Plates

1) Seven major and several smaller ones (page 4).

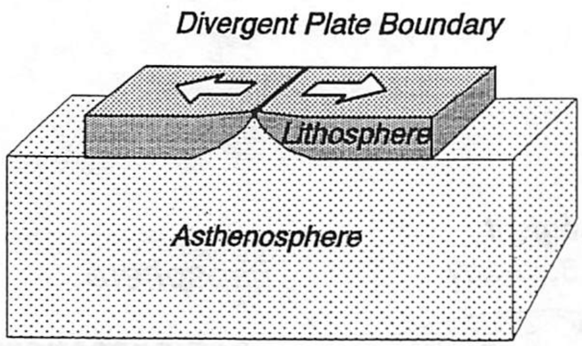
2) In constant motion:
   a) Move at a few cm/yr relative to each other.
   b) Probably driven by convection currents within the mantle.
      - Where convection currents rise, they:
         - split the plate apart;
         - bring new magma up from the mantle;
         - magma cools to form new lithosphere.
      - Where convection currents descend they:
         - drag the lithosphere down into the mantle;
         - cause melting and destruction of lithosphere.

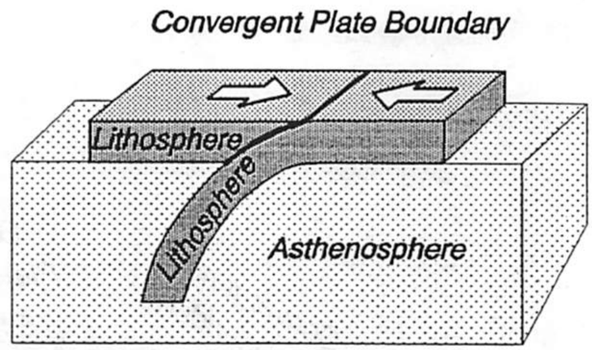
3) Constantly recycle rock materials:
   a) New lithosphere created at mid-ocean ridges.
   b) Lithosphere deformed and consumed at deep-sea trenches (subduction zones).

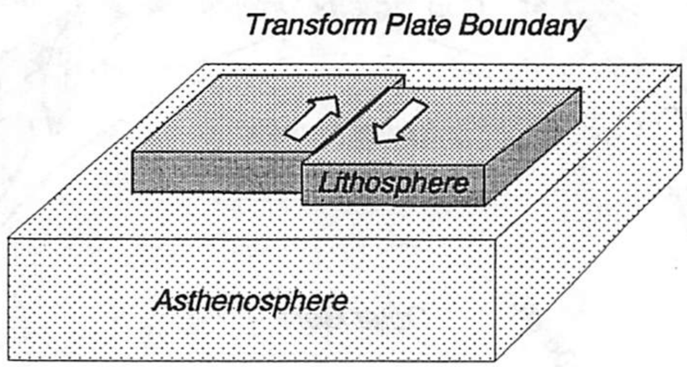

Divergent
Plate Boundary
Convergent
Plate Boundary
Lithosphere
Asthenosphere
Convection Currents
Lower Mantle
(Mesosphere)
150 km
700 km
Outer Core
2900 km
5100 km
Inner
Core

Types of Plate Boundaries

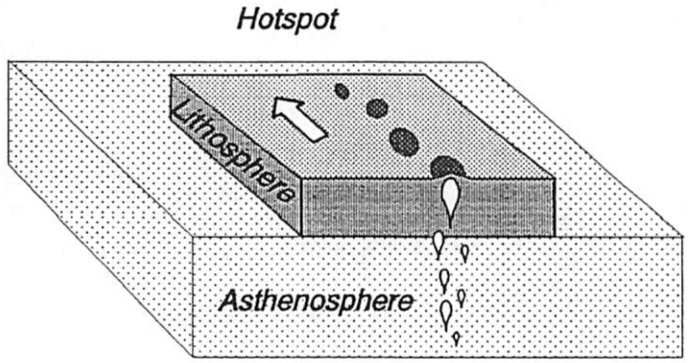
Three general types of plate boundaries are recognized:
1) Divergent.
2) Convergent.
3) Transform.







Other features, commonly not along the edges of plates but thought to relate to the motion of plates, are:
4) Hotspots.

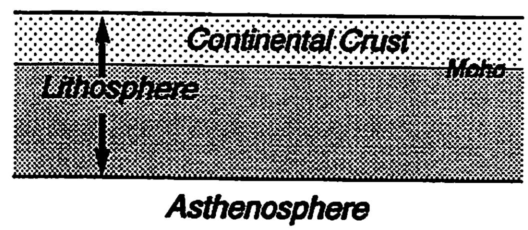


1) <u>Divergent Plate Boundaries</u>:

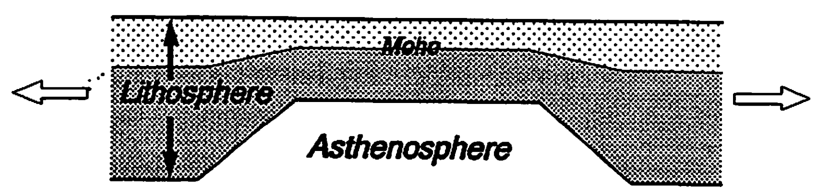
- Form where plates split and are pushing apart:

    A) <u>Continental rift zones</u>:
        - A continent is stretched apart.
        - The crust and entire lithosphere thin in the process.

Normal Continental Lithosphere

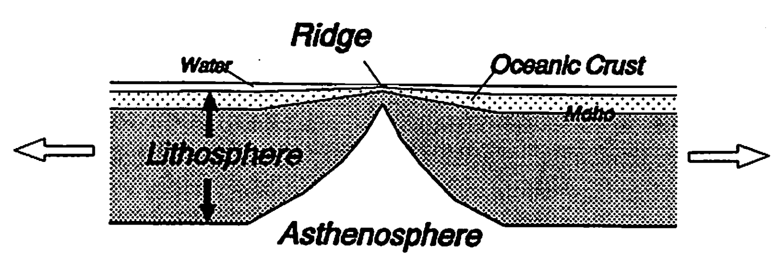


Continental Rift Zone



    B) <u>Mid-ocean ridges</u>:
        - New oceanic lithosphere created.

Mid-Ocean Ridge

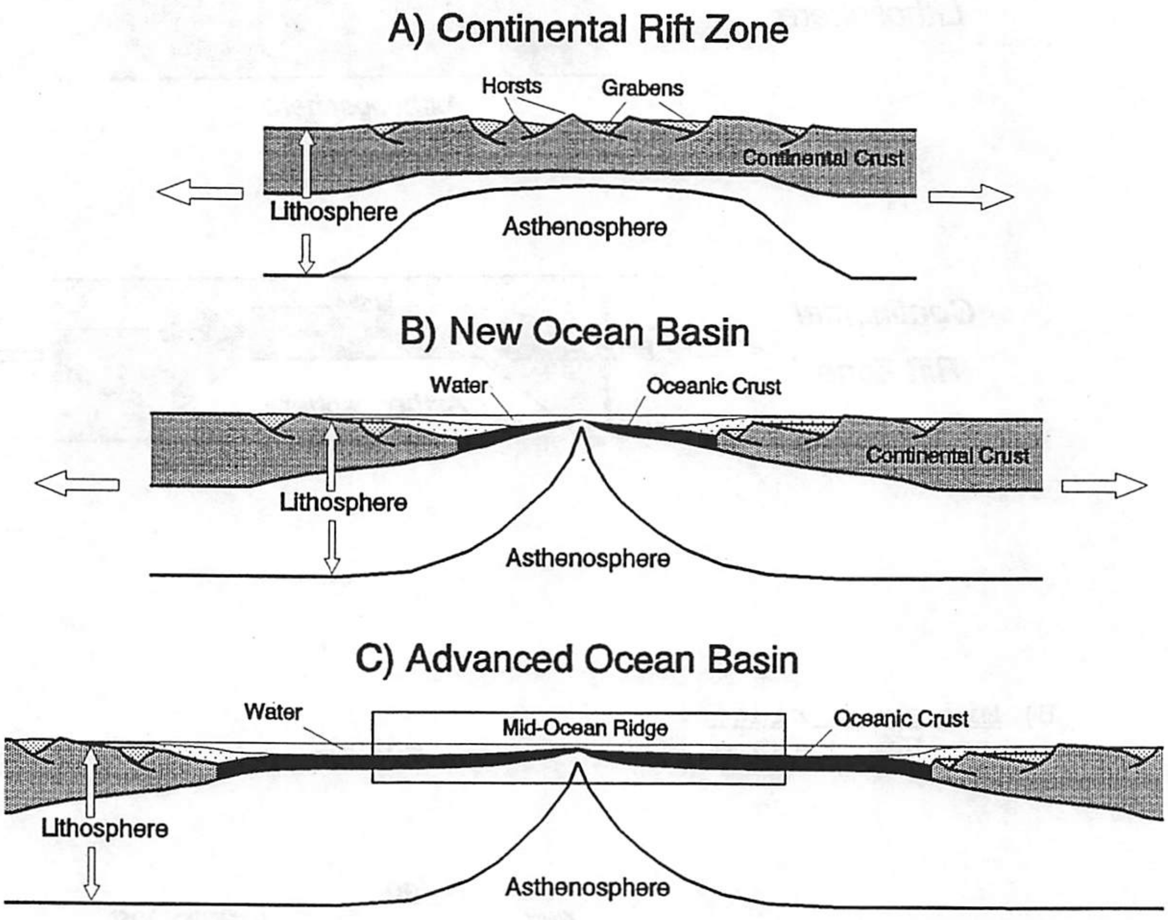


Divergent plate boundaries are characterized by:

- Tension that produces fractures, fissures and rift valleys ("grabens"), separated by fault block mountains ("horsts").

- Low-Silica (basaltic) magma from partial melting of the asthenosphere. Magma erupts from fissures at continental rifts or mid-ocean ridges, forming new crust of the diverging plates.

When continents rift apart, each fragment drifts away as part of a different lithospheric plate. If the process continues, a new ocean basin separates the continental fragments.



Examples of continental rifting - ocean basin stages:

A) Early, continental rift stage:
- East African Rifts
- **Basin and Range Province** (Nevada, Utah, **SE Oregon**, NE California.

B) New ocean basin stage:
- Red Sea.

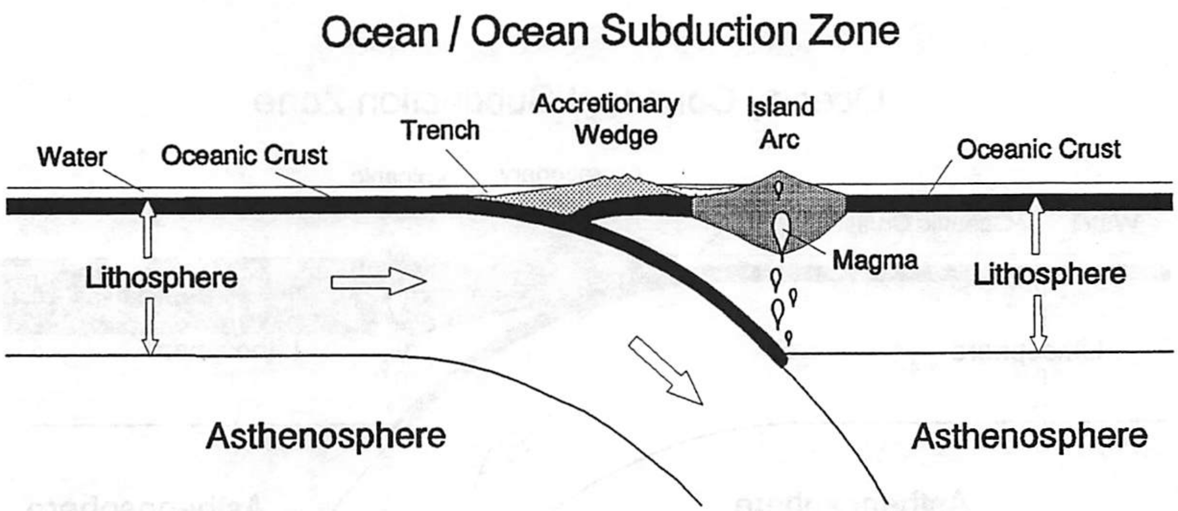
C) Advanced, old ocean basin stage:
- Atlantic Ocean.

2) Convergent Plate Boundaries:

- Develop where plates are moving toward each other:

A) Island Arc - Trench System:

- Both plates contain oceanic crust.



- One plate overrides the other.

- The other plate descends into the asthenosphere, in a process called ***subduction***:
  - The downgoing plate is heated, generating fluids that partially melt the mantle and crust of the overriding plate.
  - The rising magma thickens the crust of the upper plate, forming granitic intrusions (batholiths).
  - Magma that makes it to the surface forms the volcanic, island arc chain that may be rich in silica (andesitic volcanism).
  - The remainder of the descending plate is absorbed into the asthenosphere.

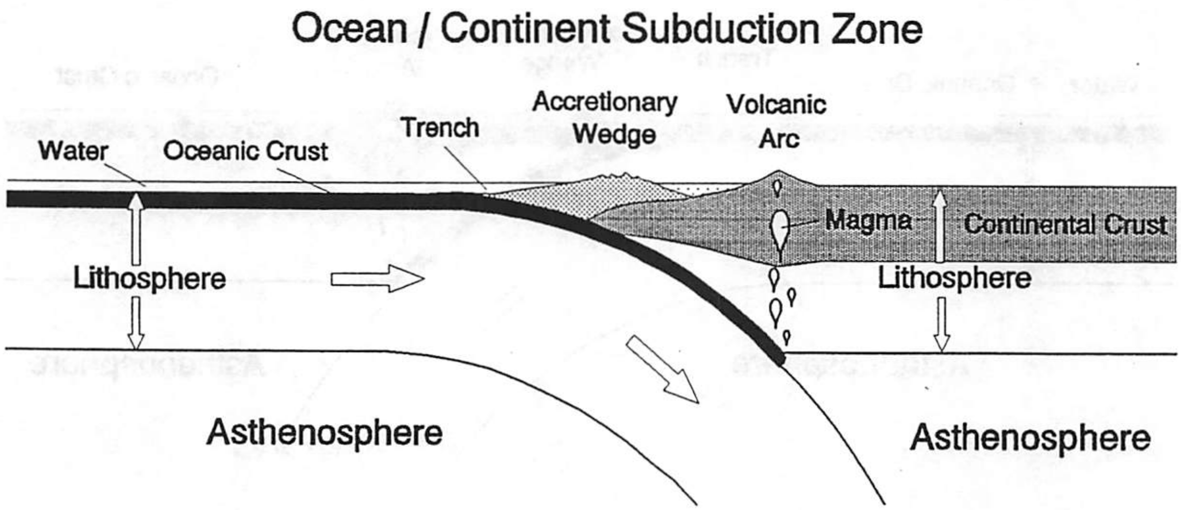
- A deep-sea trench is the surface expression of the descending plate.

- Japan and the Aleutian Islands of Alaska are examples.

B) <u>Convergent Continental Margin</u>:

- One plate contains oceanic crust (relatively thin), the other continental crust (relative thick, and therefore more buoyant).

  - The plate with oceanic crust subducts beneath the plate that has the more buoyant continental crust:



- A deep-sea trench forms where the two plate meet, just offshore from the edge of the continent.

- Two parallel mountain ranges are associated with the subduction zone:

  - A pile of sediments and ocean crust scraped off the downgoing plate and attached ("accreted") to the edge of the continent ("***accretionary wedge***").

  - A chain of volcanic mountains on the continent, above the line where the top of the plate reaches 100 to 150 km depth ("***volcanic arc***").

- <u>Western South America</u> and **<u>western Oregon-Washington</u>** are examples.

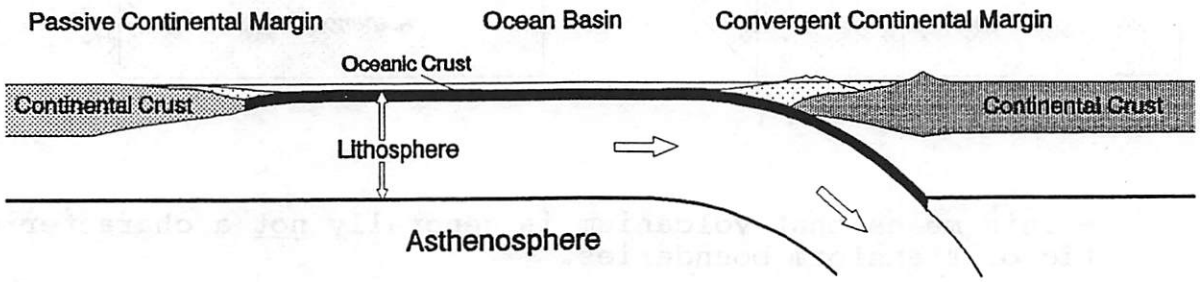
C) Continental Collision Zone:

- Both plates contain continental crust:

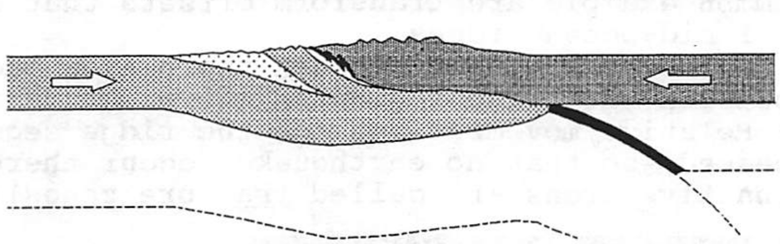
- The oceanic lithosphere that once separated the two continents was destroyed through subduction as the continents converged.

- When the continents meet, both plates are too light (i.e., too much "buoyant" continental crust) to subduct into the deeper mantle:

A) Ocean Basin Closes During Subduction



B) Collisional Mountain Range



- One plate can only override the other plate for a short distance.

- The continents are uplifted, compressed and complexly deformed, and their rocks are metamorphosed.

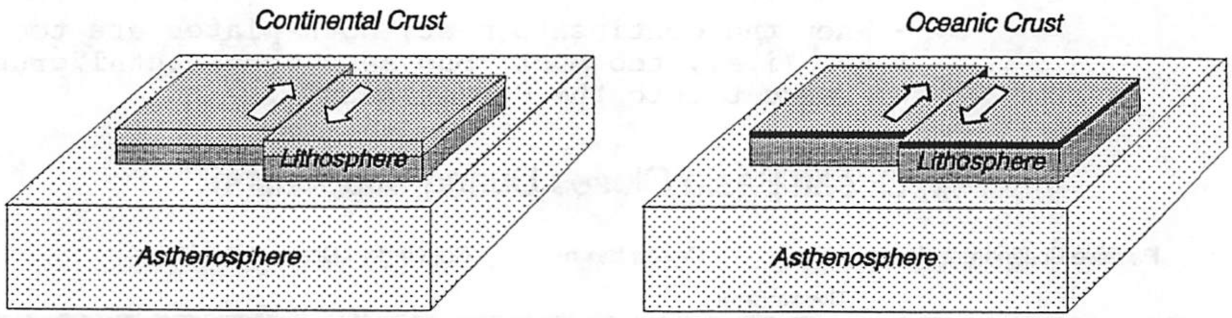
- The continents are "fused" or "welded" together, along a suture zone.

- A collisional mountain range marks the former zone of convergence:
  - An active example is the Himalayan Mountains, where the Indian subcontinent collides with Asia.
  - An ancient example is the Appalachian Mountains, where Europe and Africa collided with the eastern edge of North America about 300 million years ago.

3) Transform Plate Boundaries:

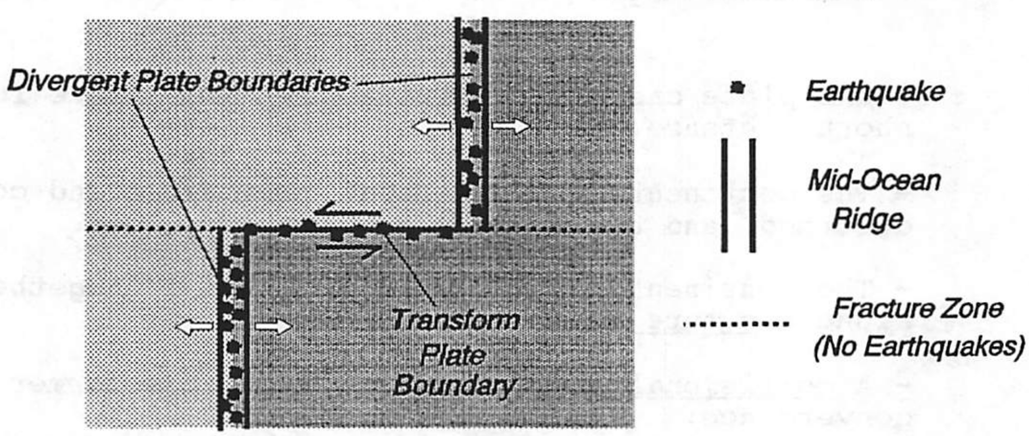
- Develop where plates slide horizontally past one another.

- Lithosphere is neither created nor destroyed:



- This means that volcanism is generally not a characteristic of transform boundaries.

- Called "transform" boundaries because they connect other plate boundaries together in various combinations:
  - A common example are transform offsets that connect segments of mid-ocean ridges.
    - Relative movement between the plates occurs only between the ridge segments, where earthquakes occur.
    - Relative movement outside the ridge segments has ceased, so that no earthquakes occur there; these inactive areas are called fracture zones):



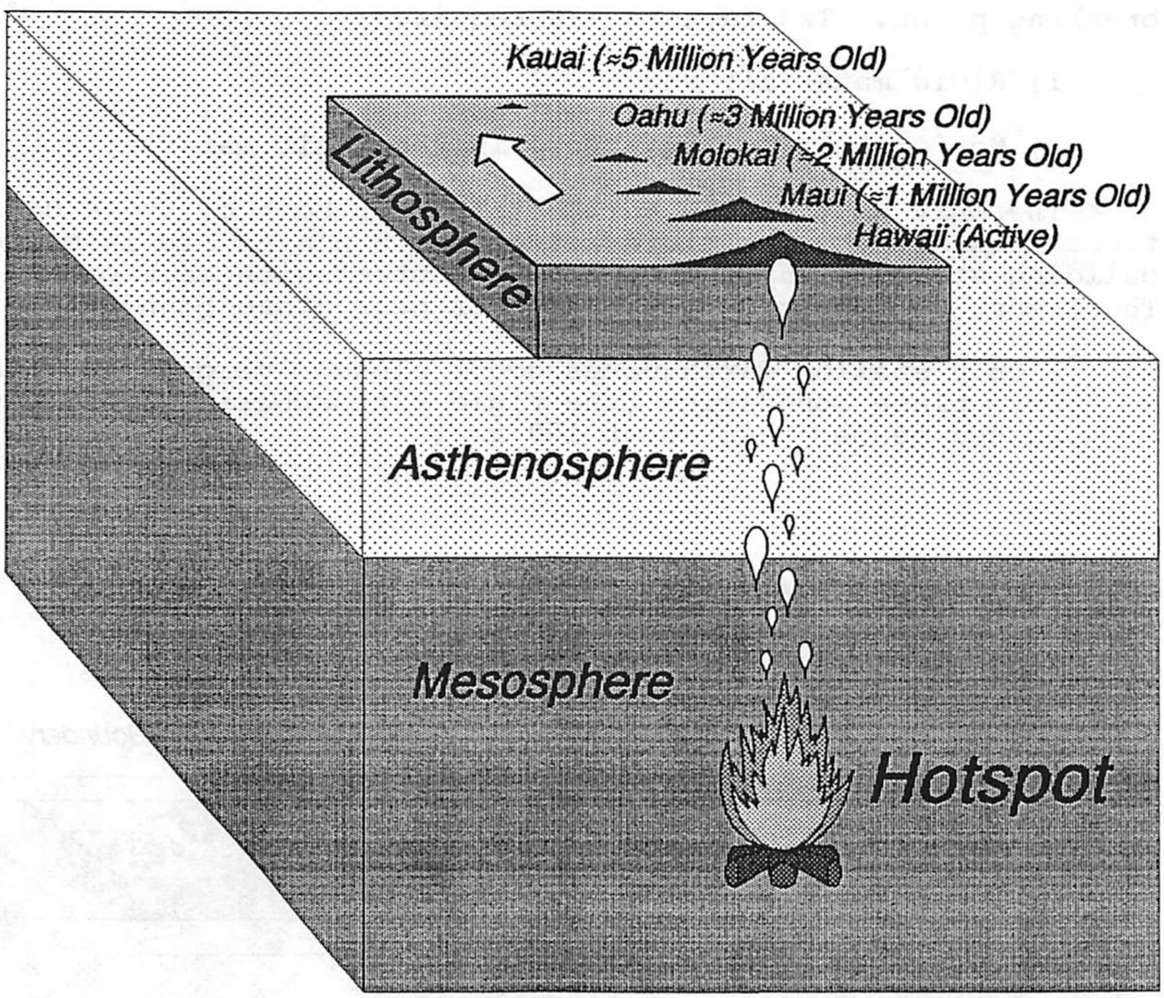
- Other examples of transform plate boundaries include New Zealand and the **San Andreas Fault** in California.

4) <u>Hotspots</u>:

- Some lines of volcanoes lie within the interior of lithospheric plates, rather that along the edges.

- The volcanoes get progressively older away from the largest and most active volcanoes.

- The volcanoes are thought to form over "plumes" of magma that originate from deep within the mantle.
  - The plates move passively over the plumes (or "hotspots"), thus forming a line of volcanoes:



- Examples of hot-spot tracks include:
  - The Hawaiian Islands within the Pacific Plate.
  - The line comprising the **Columbia Plateau**-Snake River Plain-Yellowstone area of Washington, Oregon, Idaho and Wyoming.

Manifestations along Plate Boundaries

- Most tectonic activity occurs along the boundaries of lithospheric plates:
  - Earthquakes.
  - Volcanism.
  - Metamorphism.
  - Creation and destruction of lithosphere.
  - Mountain formation.

Earthquakes:

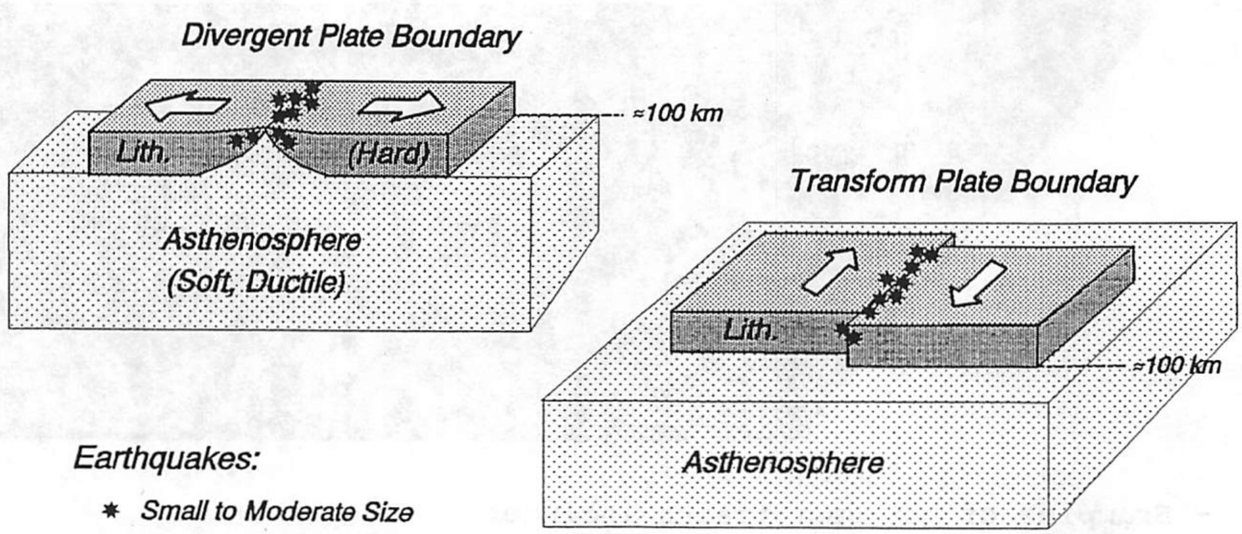
Earthquakes occur because materials are stressed to their breaking point. Two factors are required:

1) Rigid material; and

2) Motion that builds stress in the rigid material.

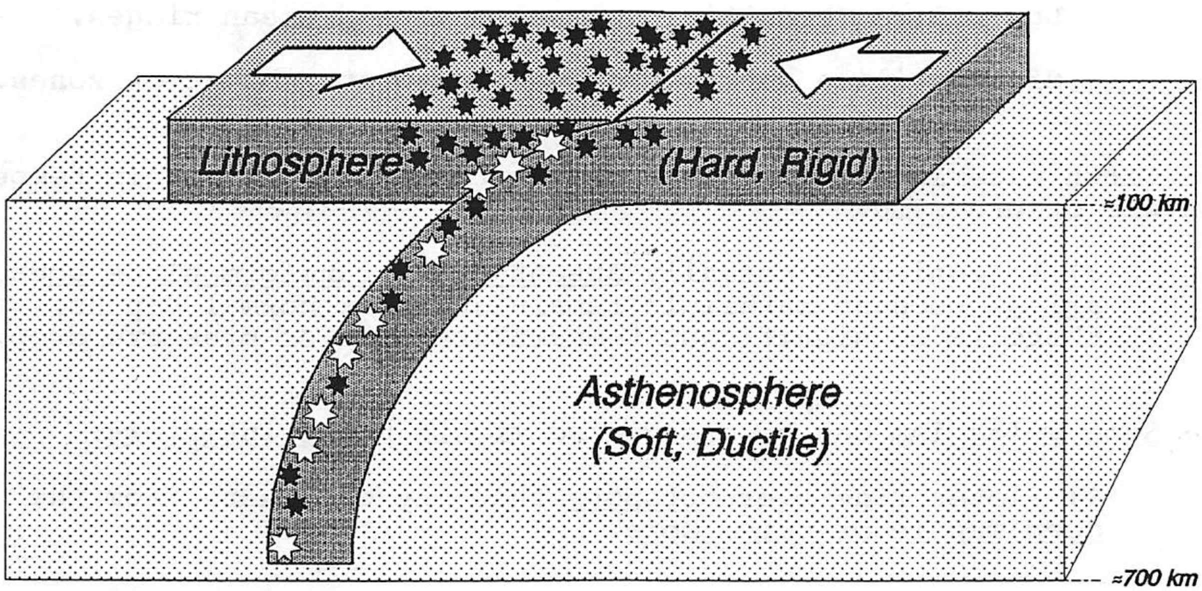
The only part of the earth that meets both of these conditions is where the the rigid lithospheric plates are in motion, building stresses where they are in contact with each other. Thus, most earthquakes occur along or near plate boundaries:

- Only shallow earthquakes occur along divergent and transform plate boundaries (the rigid lithospheric plates never extend deeper than about 100 km):



- Virtually all deep earthquakes occur along convergent plate boundaries (the rigid plates can extend downward to as deep as 700 km).

Convergent Plate Boundary



Earthquakes:

- ✱ *Small to Moderate Size*
- ✫ *Very Large*

Volcanoes:

- Earth materials commonly melt in two situations.

  1) Mantle material is quickly elevated, thus lowering the pressure while the temperature is still hot (e.g., asthenosphere shallows as plates are rifted apart at mid-ocean ridges or continental rift zones):

  2) Crustal materials are heated up, as when a lithospheric plate descends into a subduction zone:

- Most volcanic eruptions are therefore associated with divergent and convergent plate boundaries:

  - Low-silica (basaltic) volcanism at mid-ocean ridges.

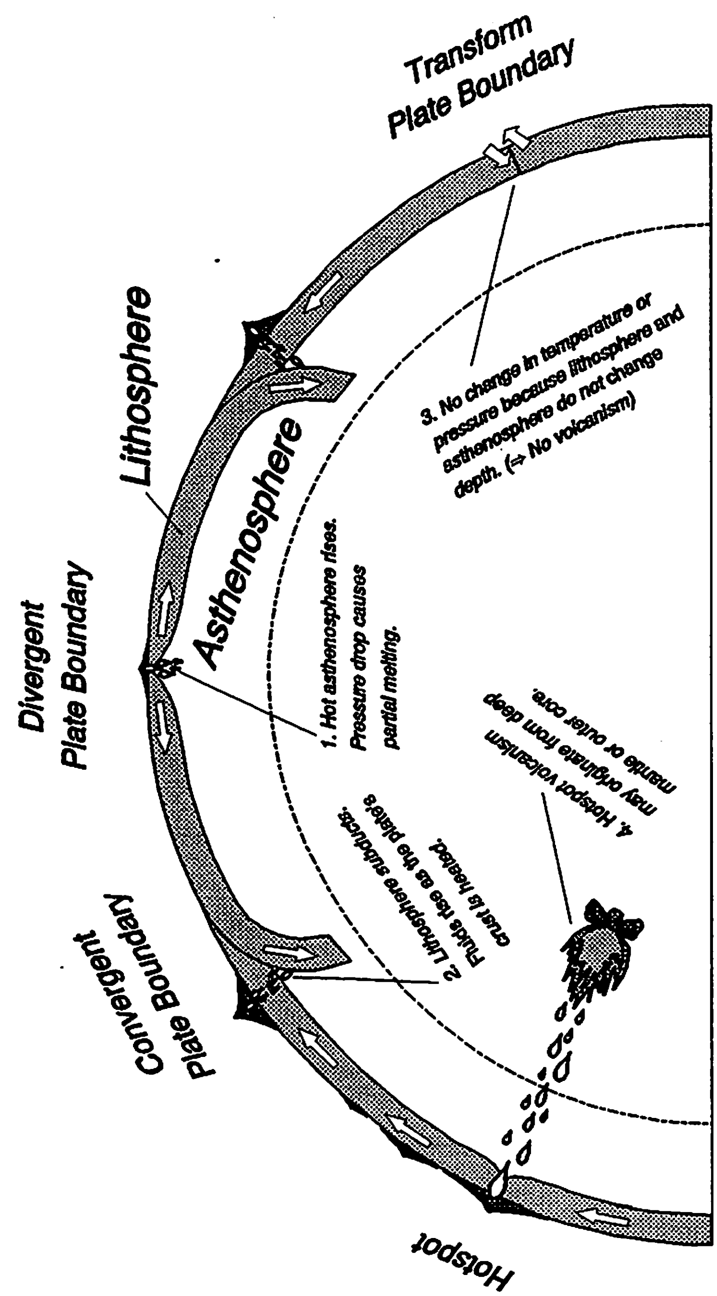
  - Higher-silica (andesitic) volcanism at subduction zones.

- Earth materials do not melt unless there are changes in temperature or pressure:

  3) Volcanism is normally absent from transform plate boundaries, because materials remain at their normal depths; there is no significant temperature rise or pressure drop.

- Some volcanism can be associated within plate interiors:

  4) Plates ride over hotspots that may originate from the deep mantle or outer core.


Transform Plate Boundary
Lithosphere
Asthenosphere
Divergent Plate Boundary
Convergent Plate Boundary
Hotspot
1. Hot asthenosphere rises. Pressure drop causes partial melting.
2. Lithosphere subducts. Fluids rise as the plates crust is heated.
3. No change in temperature or pressure because lithosphere and asthenosphere do not change depth. (⇒ No volcanism)
4. Hotspot volcanism may originate from deep mantle or outer core.

VOLCANISM

The term "volcanism" refers to the fiery action at the surface of the earth caused be the Roman god *Vulcanus*. To appreciate more modern interpretations of volcanism, some basic understanding of igneous rocks and processes is essential.

Important Definitions:

Sometimes the terms *rock* and *mineral* are confused:

***Mineral*:**
- A substance that has these properties:
    1) Naturally occurring, inorganic solid.
    2) Definite chemical composition.
        - Or specific range of compositions.
    3) Specific internal (crystalline) structure.
    4) Definite physical properties.
        - Result from the crystalline structure and chemical composition of the mineral.

***Rock*:**
- A naturally formed aggregate of minerals.
    - Generally (but not always) a rock is a mixture of more than one kind of mineral.
    - The minerals are held together as a rigid solid:
        - The mineral grains interlock, and/or
        - Particles are cemented together in some natural way.

Three Types of Rocks:

1. ***Igneous Rock*:**
    - Aggregate of interlocking minerals.
    - Formed by the cooling and solidification of molten magma.

2. ***Sedimentary Rock*:**
    - Aggregate of fragments eroded from older rocks, and/or precipitated through chemical or biological activity.
    - Generally formed through the cycle of:
        - Erosion, chemical or biological activity that forms particles (sediment).
        - Transportation of the sediment by wind or water.
        - Deposition of the sediment in lakes, oceans, etc.
        - Compaction and cementation of the particles as they are buried beneath more sediment.

3. ***Metamorphic Rock*:**
    - Aggregate of interlocking minerals.
    - Formed by recrystallization of some or all of the minerals in an existing rock. (But not by melting the rock entirely).
    - Result from high temperatures, pressures and/or chemically active fluids.

Common minerals in each rock type:

a) Igneous:
- Quartz, feldspars and micas.
- Amphiboles, pyroxenes and olivines.

b) Sedimentary:
- Quartz, feldspars and clays.
- Calcite, dolomite, halite, gypsum.

c) Metamorphic:
- Quartz, feldspars, micas.
- Amphiboles, pyroxenes, garnet, chlorites.

The terms *magma* and *lava* are often used interchangeably, but they have important differences:

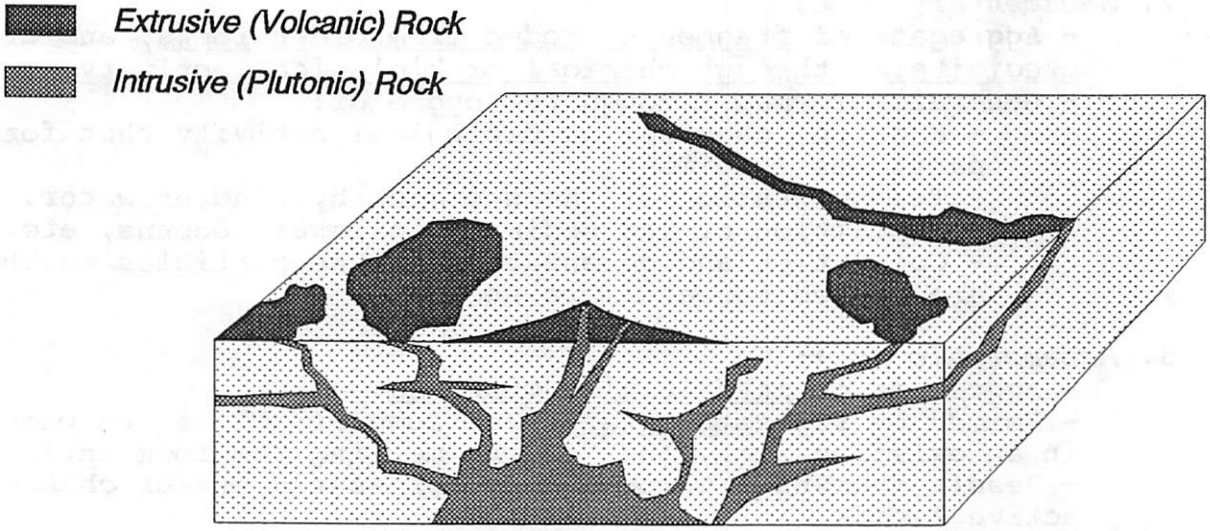
Magma: Melted earth material; in addition to liquid, magma can contain gasses and suspended solid material.

Lava: Magma that has flowed out onto the surface of the earth.

Magma can turn into rock either above or below the surface of the earth:

Intrusive Igneous Rock: The magma solidified within the earth. (*Plutonic* rock; after Pluto, Roman god of the underworld).

Extrusive Igneous Rock: The magma solidified above the surface of the earth. (*Volcanic* rock).



Classification of Igneous Rocks

- Igneous rocks are classified according to two criteria:

1) The **silica content** of the rock; and

2) the **size of the mineral grains** that comprise the rock.

1. Silica (SiO_4^{-2}) Content.

Silica is the stuff that makes common window glass. An example of a mineral that is pure silica is quartz (chemical formula SiO_2).

Common minerals found in igneous rocks that are high in silica include:

- Quartz (SiO_2)

- Feldspars:
  - Orthoclase (Potassium Feldspar; $KAlSi_3O_8$)
  - Albite (Sodium Plagioclase Feldspar; $NaAlSi_3O_8$)

- Micas:
  - Clear (Muscovite; $KAl_3Si_3O_{10}(OH)_2$)
  - Black (Biotite; $K(Mg,Fe)_3Si_3O_{10}(OH)_2$)

Common minerals in igneous rocks low in silica are:

- Amphibole (Hornblende; $NaCa(Mg,Fe)_5AlSi_7O_{22}(OH)_2$)

- Olivine ($(Mg,Fe)_2SiO_4$)

- Calcium Plagioclase Feldspar ($CaAl_2Si_2O_8$)

- Pyroxene (Ca,Fe,Mg-Silicate)

The percentage of silica is an important factor in the properties of magma. As magma cools, the silica begins to form molecules (in a tetrahedral shape) while the magma is still liquid. This early bonding of silica tends to make the magma more ***viscous*** (i.e., more sticky), like grease or molasses. Thus, magmas with high silica tend to flow sluggishly, while those with lower silica flow more freely, like fountains or rivers of water. High silica minerals also tend to have lower melting temperatures than those with low silica, so that when rocks begin to melt, magmas with high silica content will be generated before those with low silica.

When magma cools to rock, the amount of silica determines the minerals formed, hence affecting the rock's physical properties. High silica minerals tend to be light in color and weight; the rocks formed therefore have a pink to white appearance and low density (e.g. granite, rhyolite). When rocks are low in silica, they have a larger proportion of heavy, dark minerals that are high in iron and magnesium; those rocks will therefore be of high density and dark brown, dark green or black in color (e.g., basalt, gabbro, peridotite).

2. <u>Size of Mineral Grains</u>.

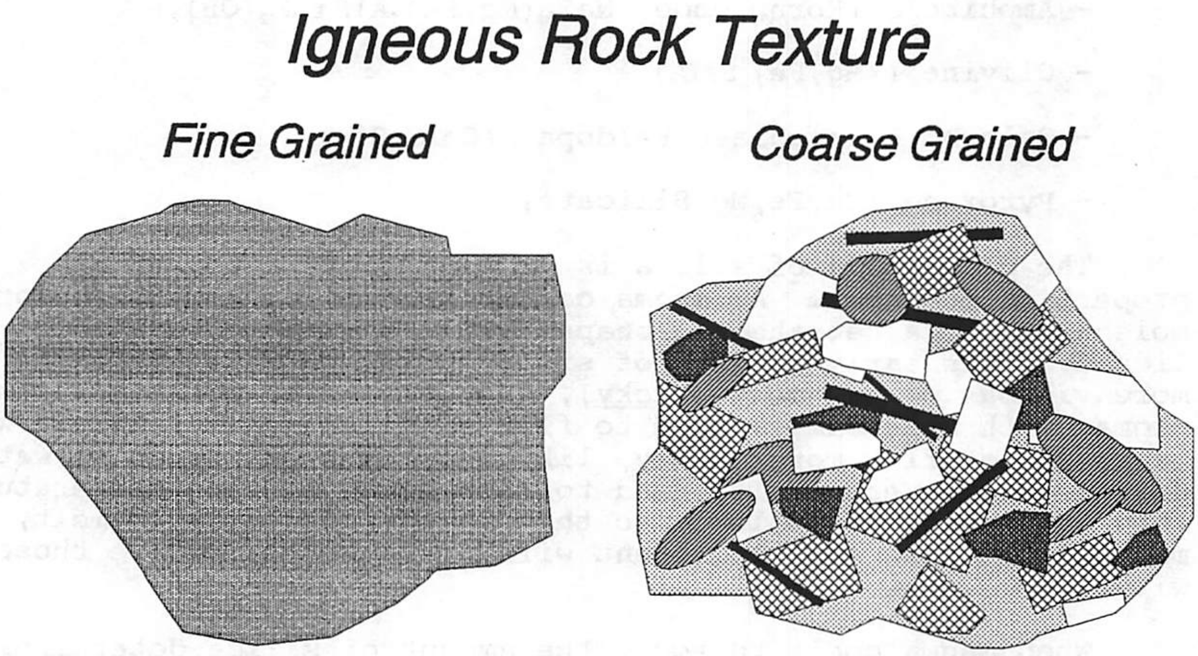
As magma cools, mineral crystals begin to form. If the rock cools quickly, the crystals will be so small that they cannot be seen with the naked eye. Slow cooling, however, gives crystals enough time to become very large. Igneous rocks can therefore be classified, and their genesis understood, by the following classification:

a) <u>Fine Grained</u> (***Aphanitic***, from Greek for "invisible"):

- The grains are small because the magma cooled at or near the earth's surface. The rocks formed are therefore <u>extrusive</u> (<u>volcanic</u>) or <u>very shallow intrusive</u>.

b) <u>Course Grained</u> (***Phaneritic***, from Greek for "visible"):

- The magma had to cool very slowly, deep within the earth, forming <u>intrusive</u> rocks.



Classification Chart

The chart on the next page illustrates classification of igneous rocks according to silica content (**chemical composition**) and texture (**grain size**). The seven names are merely a rough quide, because igneous rocks commonly have compositions falling between the exact silica and heavy mineral percentages shown. Properties of the igneous rocks and the magmas that form them also exhibit gradations between the rock types shown.

The volcanic ("extrusive") rocks found in Crater Lake National Park commonly have compositions ranging from **rhyolite** to **andesite** (shown in **bold** on the chart). A rock with a silica content intermediate between rhyolite and andesite (about 65% SiO_2) also occurs, and is called **dacite.** Volcanic projectiles coming out of the numerous cinder cones in the Park generally have compositions between that of basalt and andesite (**basaltic andesite**).

The classification scheme on the two pages following the chart relates to the chart as follows:

- Letters refer to the texture ("grain size") of the rock.
    - A) Coarsest (Phaneritic).
    - B) Finer (Aphanitic).

- Numbers correspond to the chemical composition:
    - 1) Highest silica content (Granite/Rhyolite).
    - 2) Intermediate silica content (Diorite/Andesite).
    - 3) Low silica content (Gabbro/Basalt).
    - 4) Extremely low silica content (Peridotite).

CLASSIFICATION and PROPERTIES of IGNEOUS ROCKS and MAGMAS

		CHEMICAL COMPOSITION			
GRAIN SIZE	Fine	**Rhyolite**	**Andesite**	Basalt	
	Coarse	Granite	Diorite	Gabbro	Peridotite

Cooling History		
Rate	Position	Rock Type
Fast	Above Surface	**Extrusive (Volcanic)**
Slow	Below Surface	**Intrusive (Plutonic)**

% Silica (SiO_2)	**70%**	**60%**	**50%**	**30%**
% Dark (Heavy) Minerals	30%	40%	50%	70%
Names of Common Minerals	K-Feldspar Quartz	Plag.-Feldspar Amphibole	Plag.-Feldspar Pyroxene	Olivine Pyroxene
Color	Light Colors	Intermediate	Black	Dark Green
Density (gm/cc)	2.7	2.8	2.9	3.3
Melting Temperature (Deg. C)	800	950	1100	1400
Viscosity of Magma	High	Intermediate	Low	
Extent of Lava Flows	Very Small Area	Small Area	Large Area	
% Volotiles (H_2O, CO_2)	15%	8%	1%	
Type of Eruption	Very Explosive	Explosive	Quiet	
Type of Major Volcanoes	Composite	Composite	Shield	
Cinder Cones?	No	Sometimes	Often	
Tectonic Setting: 1. Continental Rift 2. Mid-Ocean Ridge 3. Convergent Plate Boundary 4. Hot Spot 5. Continental Collision Zone	Rhyolite 1a, 3a, 4a	Andesite 3a	Basalt 1a, 2a, 3a, 4a	
Where Solidified: a. Upper Crust b. Mid-to-Lower Crust c. Mantle	Granite 3b, 5b	Diorite 3b	Gabbro 1b, 2b, 4b	Peridotite 2c

A) Phaneritic (Coarse Grained) Textures:

1) Granite:
   a) Most common minerals:
      - Potassium (K) Feldspar (Orthoclase).
      - Quartz.
      - Some Sodium (Na) Feldspar (Albite).
      - Minor amounts of Mica (Muscovite/Biotite), which stand out as clear or black flakes.
   b) Light colored (generally pink)
   c) Relatively low density (~2.6 to 2.8 g/cm^3)
   d) Common in middle and upper portions of continental crust.

2) Diorite:
   a) Most common minerals:
      - Sodium-Calcium Feldspar (Plagioclase).
      - Only minor amounts of Quartz.
      - Might have dark minerals Amphibole and Pyroxene.
   b) Grayish color (looks like "salt and pepper").
   c) Density between granite and gabbro (~2.8 g/cm^3).
   d) Common in the mid-crust beneath volcanic arcs.

3) Gabbro:
   a) Most common minerals:
      - Calcium-rich Feldspar (Plagioclase).
      - Pyroxene.
      - Minor amounts of Olivine.
   b) Dark colored (dark green to black).
   c) Relatively high density (~2.8 to 3.0 g/cm^3)
   d) Common in lower part of both continental and oceanic crust.

4) Peridotite:
   a) Mostly composed of:
      - Olivine and Pyroxene.
      - Perhaps some Calcium-rich Feldspar.
   b) Dark green color.
   c) Very high density (3.3 to 3.4 g/cm^3).
   d) Not common in the crust, but forms the mantle part of the lithosphere:
      - Generally formed from magmatic differentiation as hot asthenosphere rises at a mid-ocean ridge:
         - Low-silica magma cools first, crystallizing as the heavy minerals pyroxene and olivine (i.e., the rock peridotite).
         - The remaining silica-rich magma is lighter, so it moves upward to form the crust (gabbro and basalt).

B) Aphanitic (Fine Grained) Textures:

1) Rhyolite:

(a), (b) and (c) same as for granite on previous page.

d) Occurrence:

- Not found in ocean crust.
- Generally occurs as volcanic eruptions on continental crust that has been re-melted.

2) Andesite:

(a), (b) and (c) same as for diorite on previous page.

d) Common in volcanic rocks at convergent plate boundaries:

- The downgoing ocean crust and sediments partially melt.
- Magmas work their way to the surface, melting more crust, which further enriches the silica content.
- Named "andesite" because these rocks are common in the volcanoes of the Andes Mountains in South America.

3) Basalt:

(a), (b) and (c) same as for gabbro on previous page.

d) Originates from cooling lava flows, commonly at divergent plate boundaries:

- Upper part of ocean crust.
- Continental rift zones.

4) Fine-grained equivalents to peridotite are very rare.

- Too dense to extrude through the crust.
- Only the course-grained (peridotite) forms, because it cools slowly at depth, within the mantle.

Properties of Magma

The physical properties of magma depend, to a large degree, on the silica content of the magma (chart, p. 24):

Color. The less silica, the more dark colored minerals. Low-silica rocks are therefore dark green to black, while lighter colors (pink to white) occur as silica content increases.

Density. The less silica, the more heavy minerals (like those with iron and magnesium), so hence the more dense.

Melting (Solidification) Temperature. The more silica, the lower the melting temperature. As rock melts, the high-silica magmas generally come out first. Likewise, as magma cools, the lower silica minerals solidify first, followed progressively by those with higher and higher silica.

Viscosity (Resistance to flow; "stickiness"). Silica molecules (tetrahedra) begin to form while the magma is still liquid. High-silica magmas (rhyolite/andesite) are therefore more paste-like than low-silica magmas (basalt), which tend to erupt like fountains of water and flow like rivers.

Extent of Lava Flows. The viscosity determines how easily (and how far) lava is likely to flow. Low viscosity magmas (i.e., those with low-silica) will therefore flow much farther (and are much thinner) than those with high viscosity (high-silica).

Percent Volotiles. Volotiles (water vapor and carbon dioxide) escape easily from fluid magmas, but are trapped when magmas are sticky. Low viscosity magmas therefore have a much lower percentage of these trapped gasses than high silica magmas.

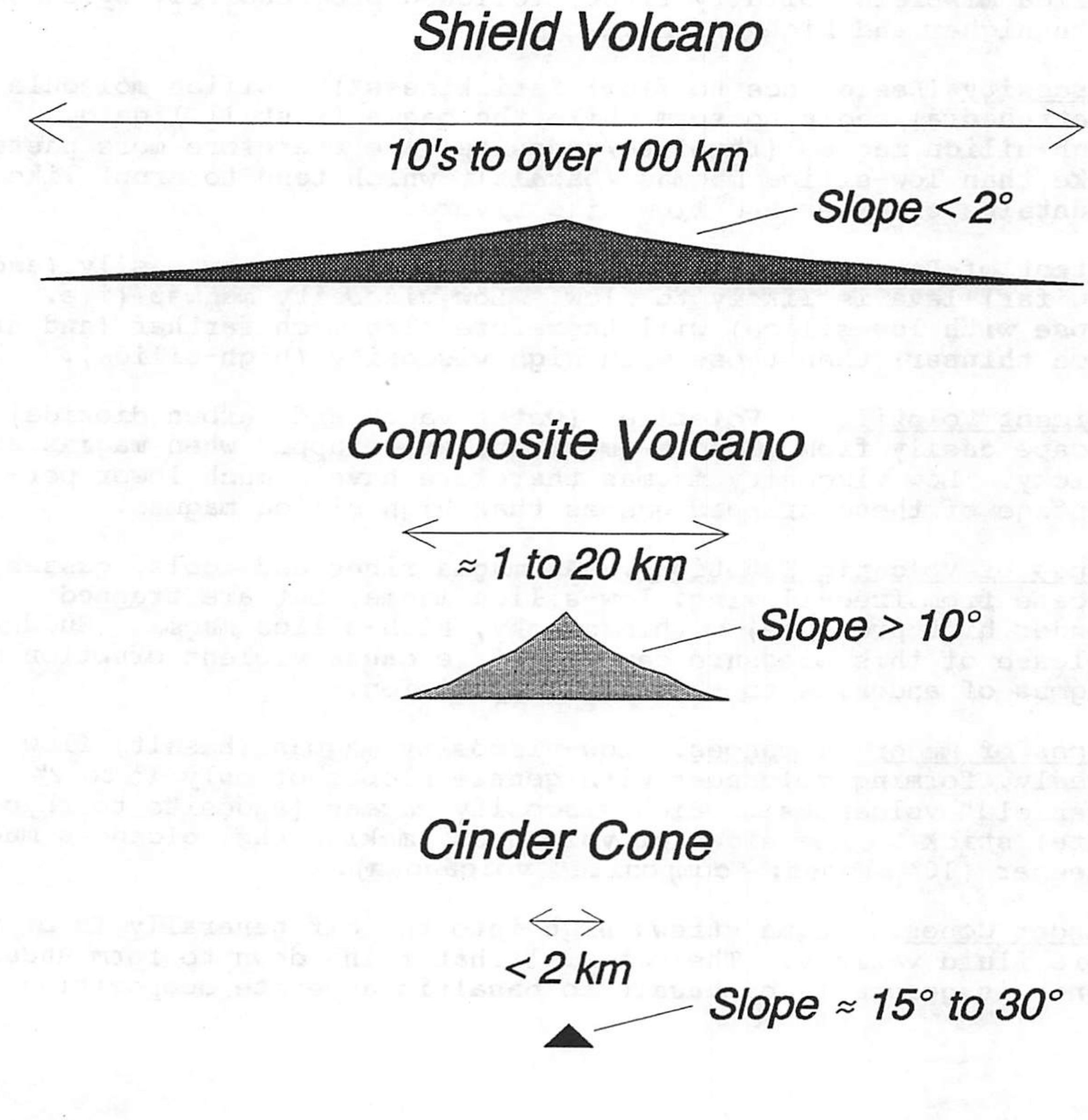
Types of Volcanic Eruptions. As magma rises and cools, gasses escape from free-flowing, low-silica magma, but are trapped (under high pressure) within sticky, high-silica magma. Sudden release of this pressure can therefore cause violent eruption of magmas of andesite to rhyolite composition.

Types of Major Volcanoes. Low-viscosity magmas (basalt) flow freely, forming volcanoes with gentle slopes of only 1° to 2° ("shield" volcanoes). High-viscosity magmas (andesite to rhyolite) stick to the sides of volcanoes, making the volcanoes much steeper (10° slopes; "composite" volcanoes).

Cinder Cones. Magma strewn high into the air generally is of the more fluid variety. The material that rains down to form under cones is generally of basalt to basaltic andesite composition.

Types of Volcanoes

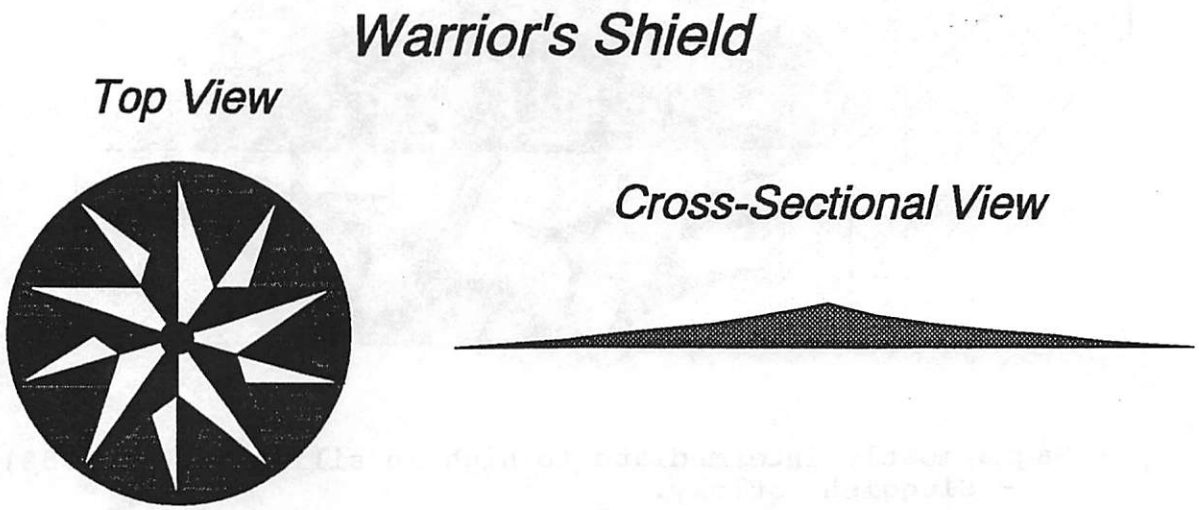
Volcanoes can be grouped into three types, as manifested by the materials that comprise the volcanoes and the overall topographic appearance of the mountains formed. The two types of large volcanoes owe their different forms to the silica content of the magmas pouring out: ***shield volcanoes*** have free flowing (basaltic) magmas, spreading out into low topographic slopes; ***composite volcanoes*** have sluggish (andesitic to rhyolitic) magmas that stick more easily to the sides of the volcano, making a steeper mountain. The third type, ***cinder cones***, are small hills of volcanic ejecta that generally occur on the flanks or summits of the two larger kinds of volcanoes.



1. Shield Volcano:

- Almost entirely of lava flows, low in silica (50% - 55%):
  - Magma is therefore free-flowing (like water):
    - Flows over long distances (10's of kilometers).
    - Volcanoes have gentle slopes (2° or less).
    - Eruptions are "quiet," generally not dangerous and explosive.
  - Lava cools to black basalt or basaltic andesite.

- Called "shield" volcanoes because, when viewed from above, they are broad and flat-lying, like the shield of a warrior.

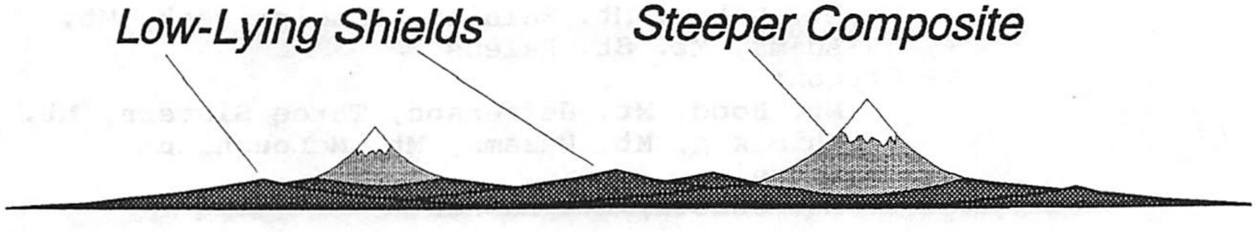


- Examples include:

  - Hawaii and Iceland volcanoes.

  - **Newberry Crater** in Oregon.

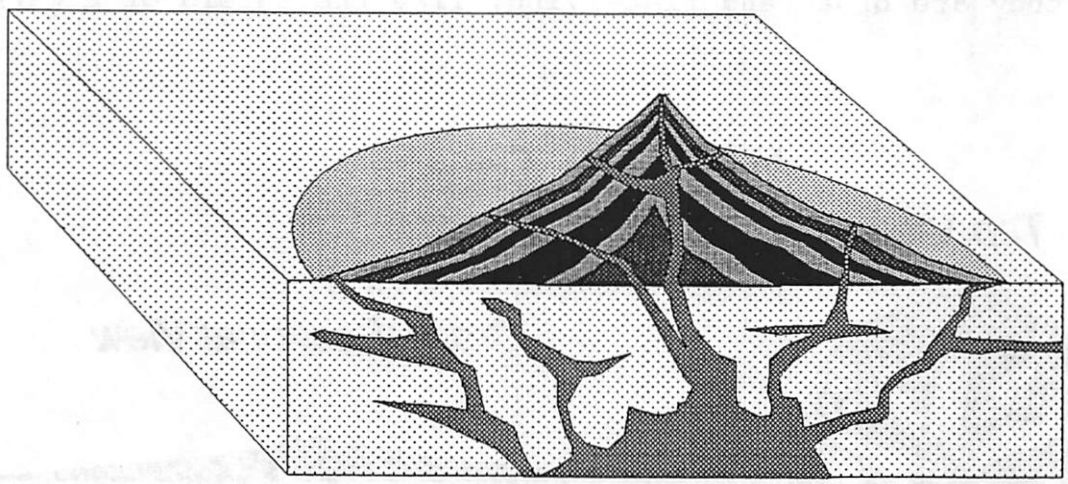
  - The high **Cascade Mountains** are a backbone of low-lying, interlocking shield volcanoes; the very high peaks are composite cones resting on the backbone.



2. <u>Composite Volcano</u>:

- Lava flows, ash, cinders, mudflows, in stratified sequence ("*strato-volcano*").

Composite (Strato) Volcano



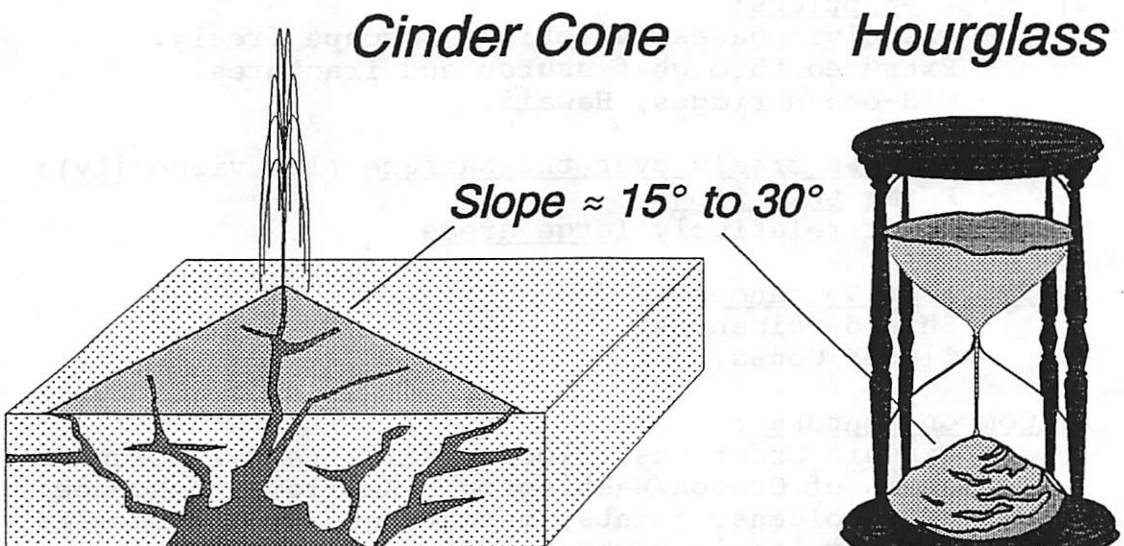
- Magma mostly intermediate to high in silica (60% to 75%).
  - Sluggish, sticky.
    - Magma flows only meters to a few kilometers.
    - Volcanoes can be steep (> 10° slopes).
    - Gasses cannot easily escape from the "sticky" magma, so that eruptions can be explosive.
  - Cools to rocks lighter colored than basalt:
    - Andesite, Dacite and Rhyolite.

- Commonly occur where one plate "subducts" under another.
  - Japan, Andes in South America.
  - The **High Cascade peaks** are composite volcanoes built on top of the backbone of shield volcanoes:
    - British Columbia:
      Mt. Garabaldi
    - Washington:
      Mt. Baker, Mt. Rainier, Glacier Peak, Mt. Adams, Mt. St. Helens
    - Oregon:
      Mt. Hood, Mt. Jefferson, Three Sisters, Mt. Thielsen, Mt. Mazama, Mt. McLoughlin
    - California:
      Mt. Shasta, Mt. Lassen

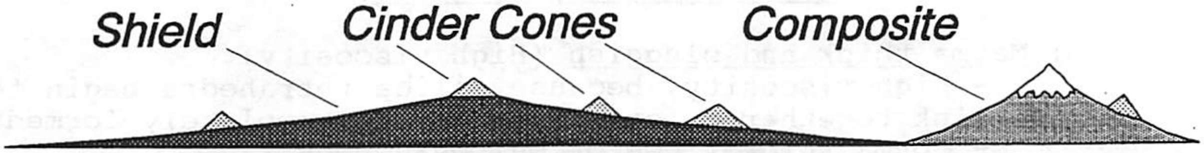
3. Cinder Cone:

- From magma thrown up into the air, solidifying, then "raining" down directly back over the vent.

- Forms sides with a constant angle of about 15 to 30 degrees, like sand in an hourglass:



- Commonly occur on the flanks, or at the very summit of, composite or shield volcanoes:



Examples from Oregon:
- Black Butte (near Sisters)
- Lava Butte (south of Bend)

Examples from Crater Lake National Park:
- **Wizard Island.**
- **Red Cone.**
- Summit of **Timber Crater.**
- **Crater Peak.**

Types of Volcanic Eruptions

The manner in which volcanoes erupt relates to the silica content the magma:

1) Silica-Poor Volcanics (Basaltic composition):

a) Quiet eruptions:
- Dissolved gases (volotiles) escape freely.
- Extruded through fissures and fractures.
- Mid-ocean ridges, Hawaii.

b) Magma flows freely over the surface (low viscosity):
- Forms thin flows.
- Cover relatively large areas.

c) Types of Volcanoes:
- Shield Volcanoes.
- Cinder Cones.

d) Common Features:
- Fissure Eruptions, flood basalts (e.g., Columbia Plateau of Oregon/Washington), Aa flows, pahoehoe flows, columnar joints, lava tubes, pillow basalts, tephra, volcanic bombs.

2) Silica-Rich Volcanics (Rhyolitic/Andesitic composition):

a) Violent eruptions:
- Gases trapped within the magma.
- The gasses expand rapidly as the magma comes to the surface, resulting in explosions.
- e.g., Mt. St. Helens, Krakatoa.

b) Magma thick and sluggish (High viscosity):
- High viscosity, because silica tetrahedra begin to link together before crystals are completely formed.
- Forms thick flows or bulbous domes.
- Cover relatively small areas.

c) Types of Volcanoes:
- Composite.

d) Common Features:
Lava domes, caldera, ash deposits, mud flows, tephra.

Distribution of Volcanism in Plate Tectonic Framework (see p. 18)

1) Divergent Plate Boundaries:

As lithospheric plates rip apart, underlying asthenosphere rises. The sudden drop in pressure on this hot material causes it to melt partially, giving low-silica (basaltic) magma that rises and cools to create new crust.

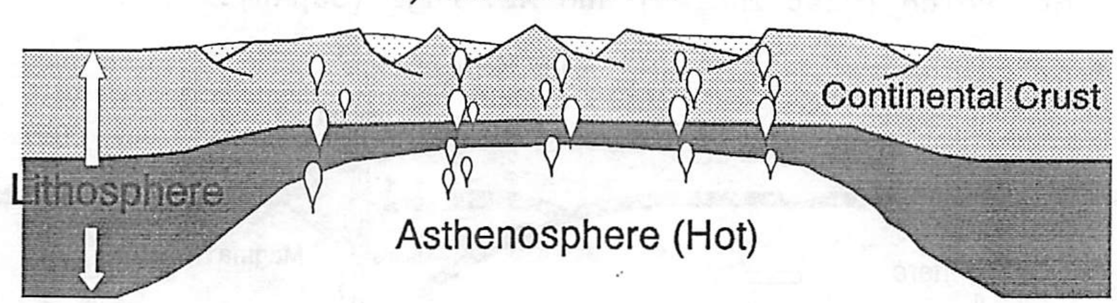
a) Continental Rift Zones:

- Commonly exhibit two-stage (bimodal) volcanism:
  - Early stage: magma must melt a lot of continental crust, producing high-silica (rhyolitic) volcanism.
  - Advanced stage: magma comes more directly from asthenosphere, producing lower-silica (basaltic) volcanism.
- Examples include Mt. Kenya and Mt. Kilamanjara in east Africa and **Newberry Volcano**, south of Bend, Oregon.

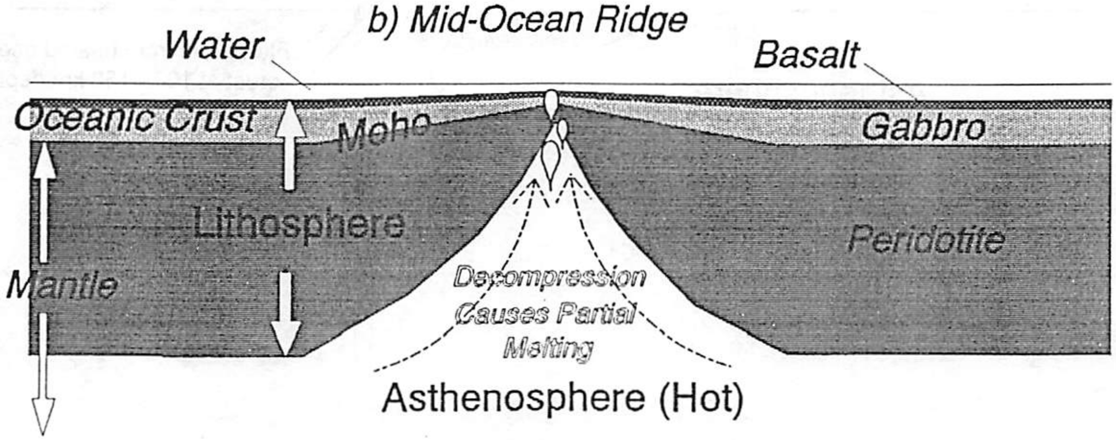
b) Mid-Ocean Ridges:

- Partially melted asthenosphere produces low-silica magma:
  - Volcanism as pillows of basalt on the seafloor;
  - Dike intrusions of gabbro comprise the lower crust.
- Remaining material is very low-silica (peridotite) of the uppermost mantle.
- Active volcanoes mostly below ocean (Mid-Atlantic Ridge, East Pacific Rise), but some break the surface (Iceland).

a) Continental Rift



b) Mid-Ocean Ridge



2) Convergent plate boundaries:

As a lithospheric plate descends into a subduction zone, it gets hot enough for fluids to be driven from the crust and sediments on top of the plate. These fluids migrate toward the surface, melting mantle and crustal materials in their path. Minerals high in silica tend to melt first, so that magmas generated in this process can range in silica content from low (basaltic) to intermediate (andesitic) to very high (rhyolitic). A chain of volcanoes ("volcanic arc") grows on the overriding plate, in the position where crust of the lower plate is at 100 to 150 km depth, thereby hot enough to generate fluids.

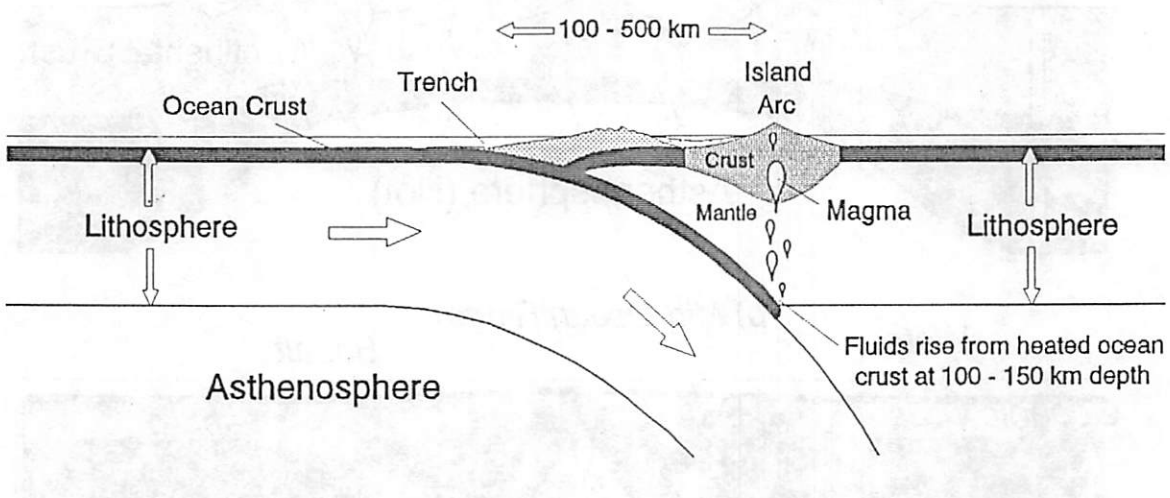
a) Ocean/Ocean:

- The volcanic (island) arc develops on one of the oceanic plates about 100 to 500 km from the plate boundary (trench).

- The rising fluids melt through mantle and thin (island arc) crust on the upper plate:
    - Magmas are therefore low-to-intermediate silica (basaltic to andesitic).

- Volcanic island arc chains include the Aleutian Islands, Philippines and Antilles.

- Examples of active volcanoes are Krakatoa (east of Java), Mt. Pelee (West Indies) and Mt. Fuji (Japan).



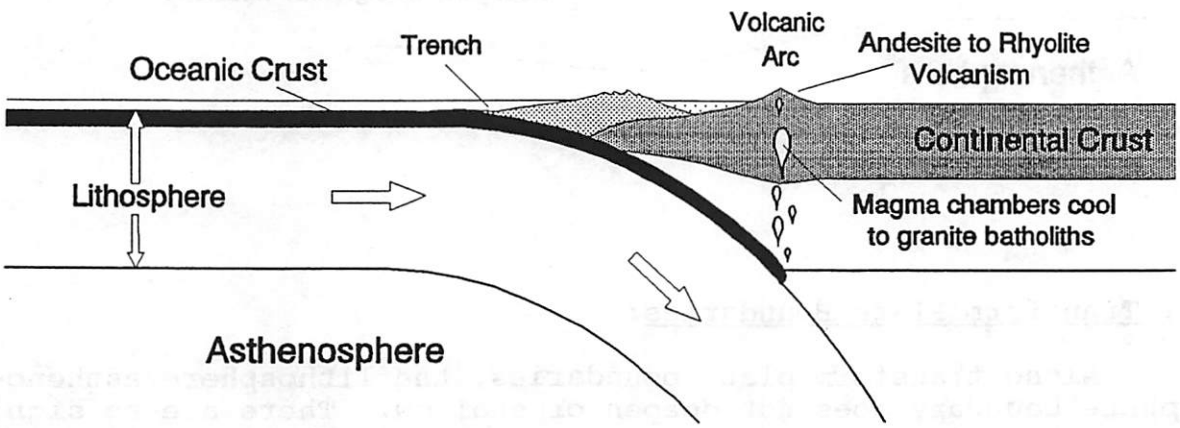
b) Ocean/Continent:

- The plate with thin (oceanic) crust descends below the (more buoyant) plate with thick (continental) crust.

- The result is volcanic mountain chains along the edges of some continents (Andes, Cascades, Kamchatka).

- The rising fluids melt continental crust in their path, producing magmas of intermediate-to-high silica content:
  - Volcanics of andesite to rhyolite;
  - Magma chambers in the deeper crust that cool to granite batholiths.

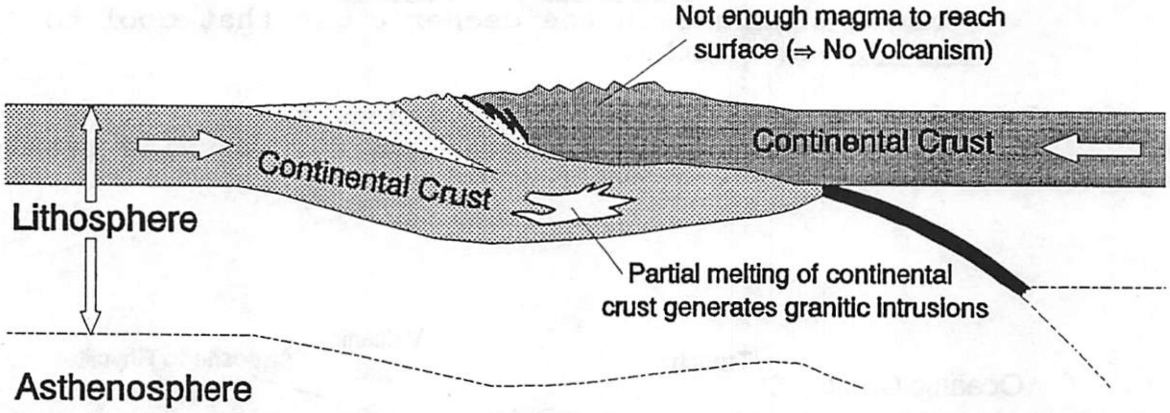
- Examples of recently active volcanoes are Mt. St. Helens (Washington), **Mt. Mazama** (Oregon) and Mt. Vesuvius (Italy).



c) <u>Continent/Continent</u>:

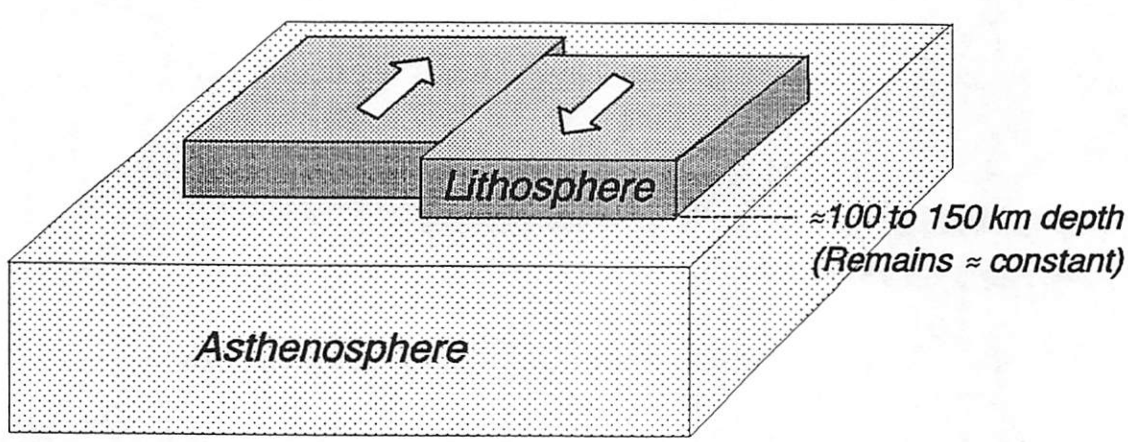
- Thick continental crusts collide when thin oceanic crust is consumed through subduction (e.g., Alps, Himalayas).

- Continental crust is too thick and buoyant to subduct:
    - The generation of fluids slows down considerably.
    - High-silica <u>granite</u> plutons form in the lower crust.
    - Volcanism ceases.



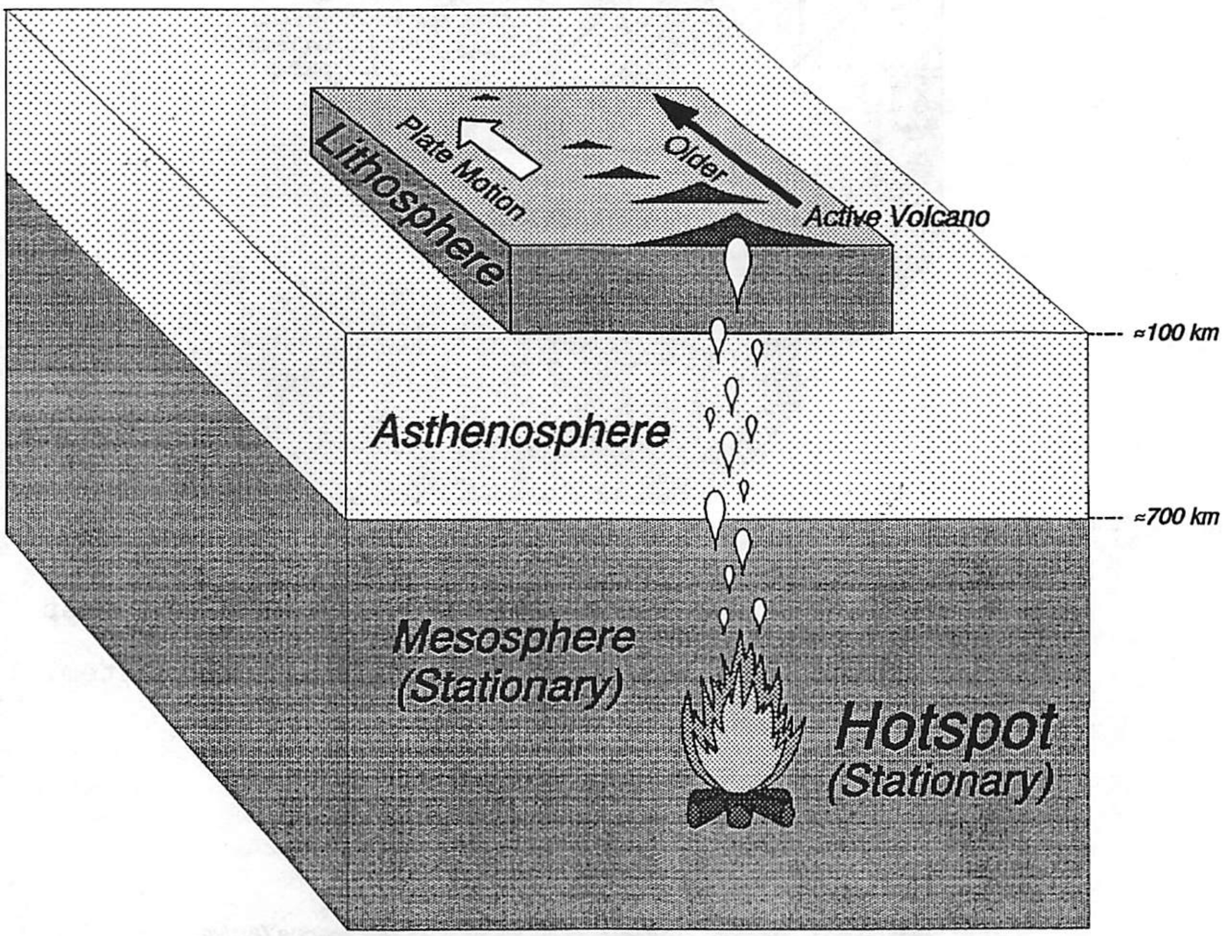
3) <u>Transform Plate Boundaries</u>:

Along transform plate boundaries, the lithosphere/asthenosphere boundary does not deepen or shallow. There are no significant changes in temperature or pressure, so that <u>no large-scale volcanism</u> occurs along transform plate boundaries.



4) <u>Volcanism Within Plates</u> ("Hotspots"):

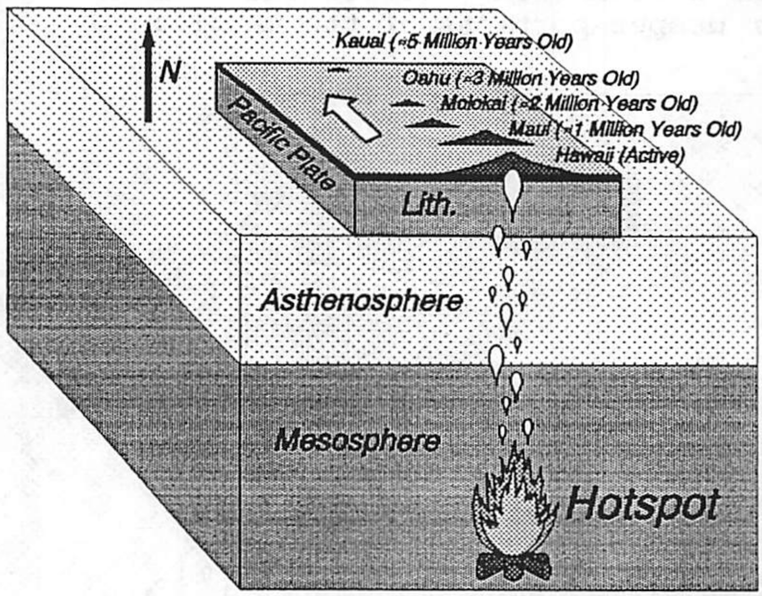
Hotspots contribute a small volume of volcanics compared with that produced along divergent or convergent plate boundaries. These regions are important, however, because the volcanoes provide a framework to track the motion of lithospheric plates over deeper portions of the mantle:



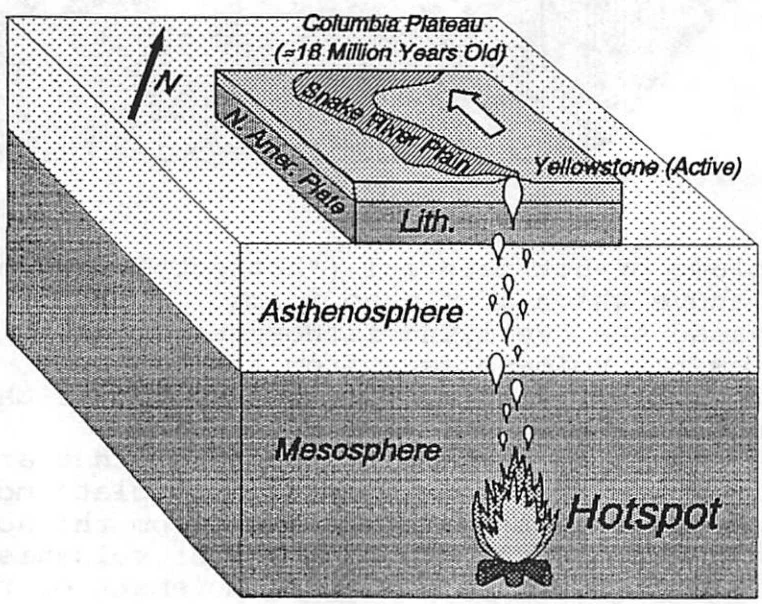
- A plume of hot material ("hotspot") develops in the mantle, above which a volcano forms.
- Because the overlying lithospheric plate is moving, it carries the volcano away from the hotspot.
- One volcano after another is built over the hotspot through this process.
- The result is a chain of volcanoes that are:
    - Parallel to the direction of plate motion.
    - Older in a direction away from the hotspot.
- After mapping the changing age of volcanism, we can calculate the rate and direction of movement of the lithospheric plate over the deeper mantle.

- Two Settings for Hotspot Volcanism:

    a) Oceanic Lithosphere:
        - Results in shield volcanoes of basaltic composition.
        - Hawaiian-Emperor seamount chain.

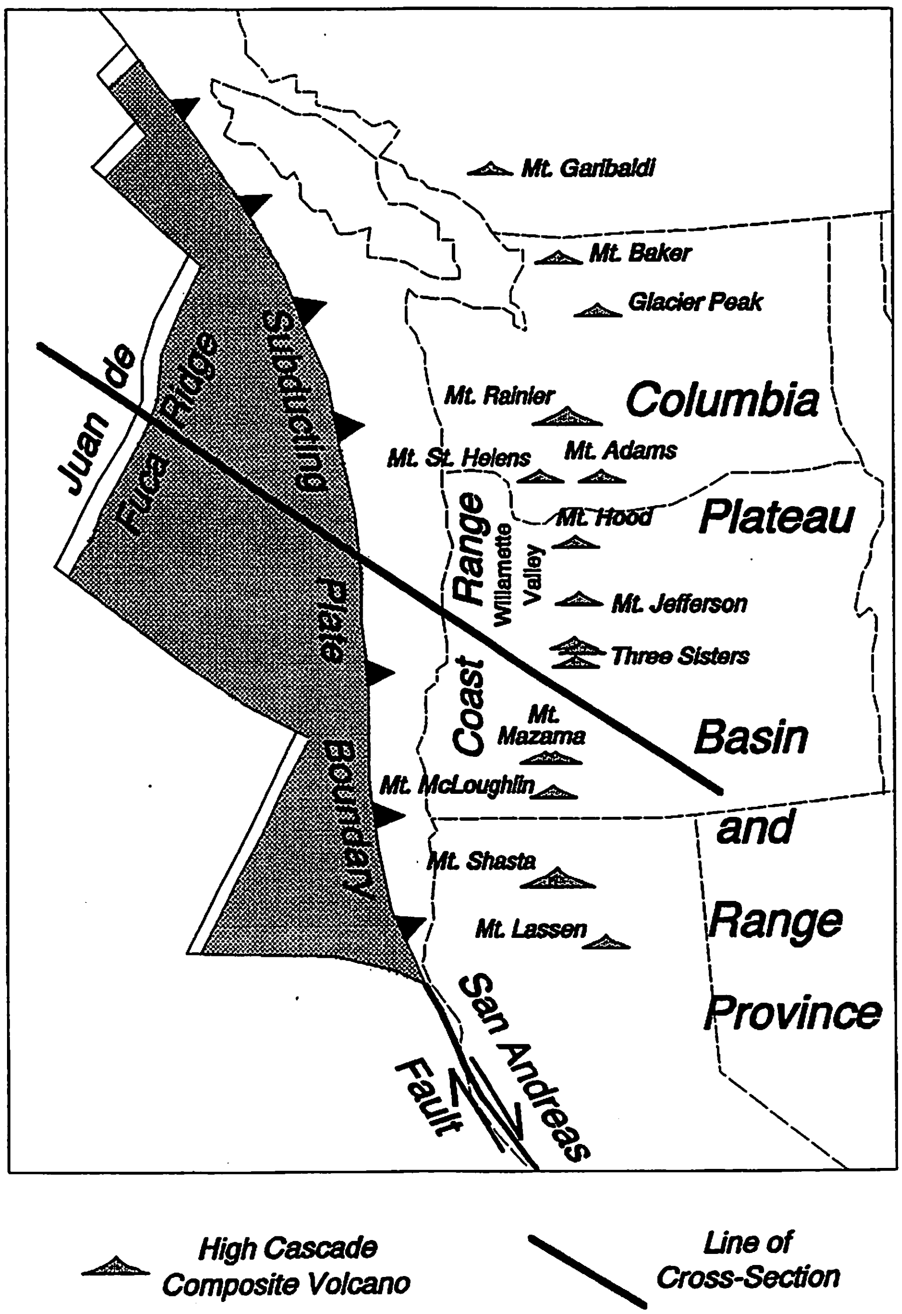


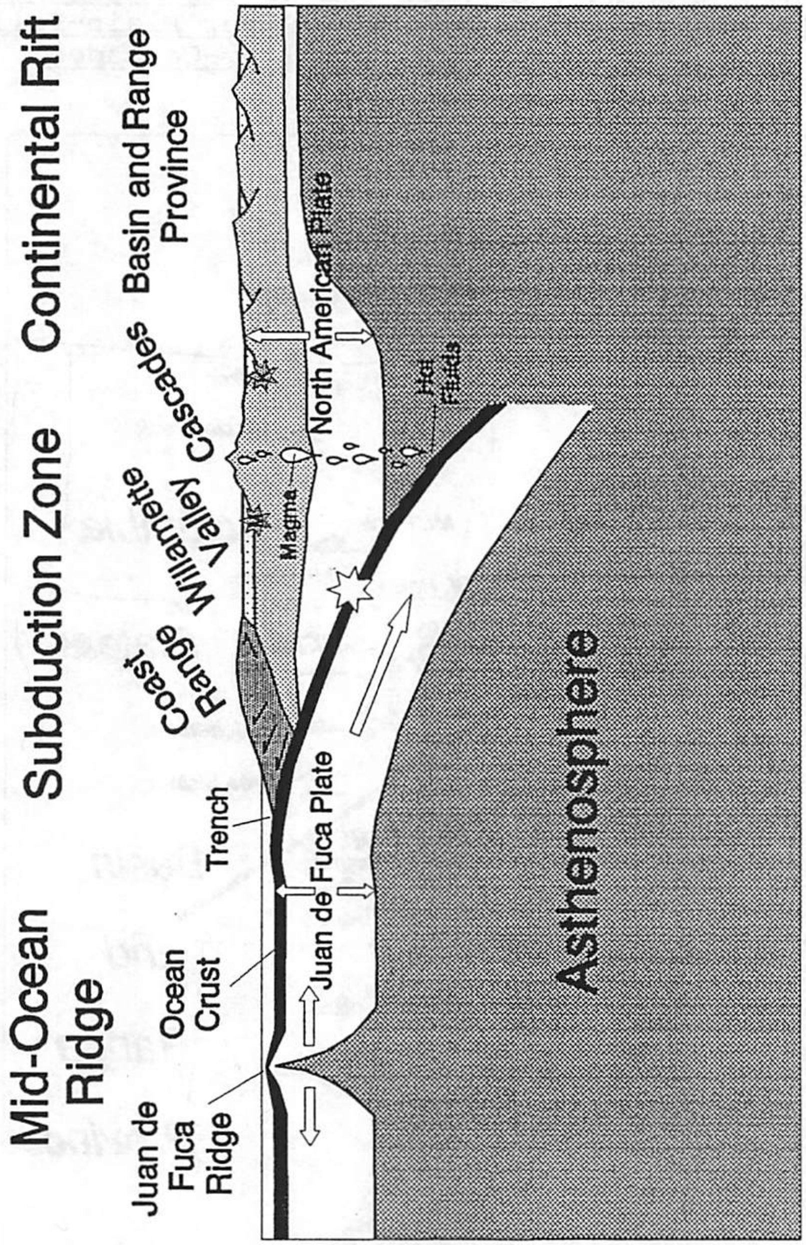
    b) Continental Lithosphere:
        - Results in flood basalts initially covering vast areas, then a more defined line.
        - Columbia Plateau-Snake River-Yellowstone system.



TECTONICS OF THE PACIFIC NORTHWEST

The Pacific Northwest offers an exciting opportunity to observe geologic features as they are forming. The region includes active examples of **continental rifting** (northeast corner of the Basin and Range Province), a **mid-ocean ridge** (Juan de Fuca Ridge), **transform faulting** (northern end of San Andreas Fault), **hotspot activity** (Columbia Plateau-Snake River Plain-Yellowstone) and **subduction** (Coast Range-Willamette Valley-Cascades).





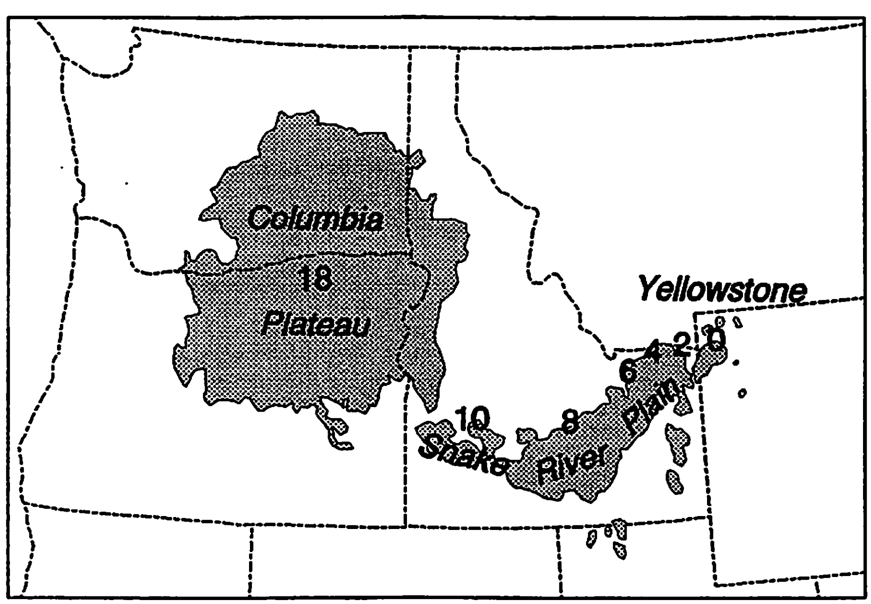
✸ Molalla (M) and Klamath Falls (K) Earthquakes, 1993 (Magnitude 5.5 to 6)

✩ "The Big One" (Magnitude > 8)

Columbia Plateau-Snake River-Yellowstone System (Hotspot)

Southeast Washington and northeast Oregon are dominated by thick layers of basalt, comprising the Columbia Plateau. This massive volume of rock resulted from lavas that poured out from the mantle 15 to 18 million years ago. Along the Snake River Plain in Idaho, lavas get progressively younger from west (at the Columbia Plateau) to east, where there is active volcanism in Yellowstone National Park. The younger lavas also tend to be more silica-rich than those that poured out initially in Oregon and Washington.

The Columbia Plateau - Snake River Plain - Yellowstone system is interpreted as the movement of the North American lithospheric plate over a hotspot that is stationary in the mantle (see page 38). Initially, the magma migrated upward from the deep mantle, in the shape of a "mushroom cloud." The broad head of the cloud struck in Oregon and Washington 18 million years ago, resulting in massive outpourings of basalt as the Columbia Plateau. As the North American plate moved over the hotspot, the thin "tail" remained. This tail resulted in far less volcanism, with a larger portion of the magma enriched in silica due to the melting of continental crust as the magma ate its way upward. The resulting lavas have poured out in a narrow, steady stream between Oregon and Yellowstone, as the plate moved westward.



Volcanic Rocks from Columbia Plateau to Yellowstone

8 Age of Volcanism, in Millions of Years (from A. Grunder, 1995)

San Andreas Fault (Transform Plate Boundary)

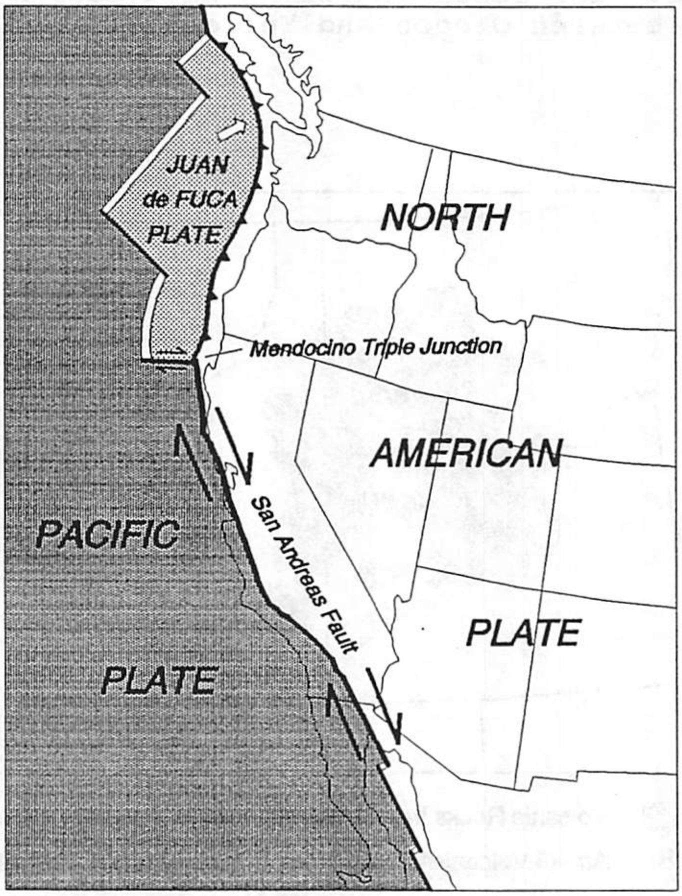
In southern California, the North American Plate is in direct contact with the Pacific Plate. The north-northwest trend of the boundary between the two plates coincides almost exactly with the relative motion of the plates. There is no significant divergent or convergent motion, so that the boundary is transform, expressed as the <u>San Andreas Fault</u>.

At Cape Mendocino, north of San Francisco, there is an intersection of the North American, Juan de Fuca and Pacific plates, known as a triple junction. Adjacent to this point the plate boundaries and relative motions are:

- <u>San Andreas Transform Fault</u>: Pacific Plate north-northwestward, relative to North American Plate.

- <u>Mendocino Transform Fault</u>: Juan de Fuca Plate eastward, relative to Pacific Plate.

- <u>Cascadia Subduction Zone</u>: Juan de Fuca Plate northwestward, relative to North American Plate.



Cascadia Subduction Zone (Convergent Plate Boundary)

The convergent boundary between the Juan de Fuca and North American plates comprises a system similar to that observed in other places where a plate with ocean crust subducts beneath one with thicker continental crust. From west to east, the major components of the Cascadia Subduction Zone are:

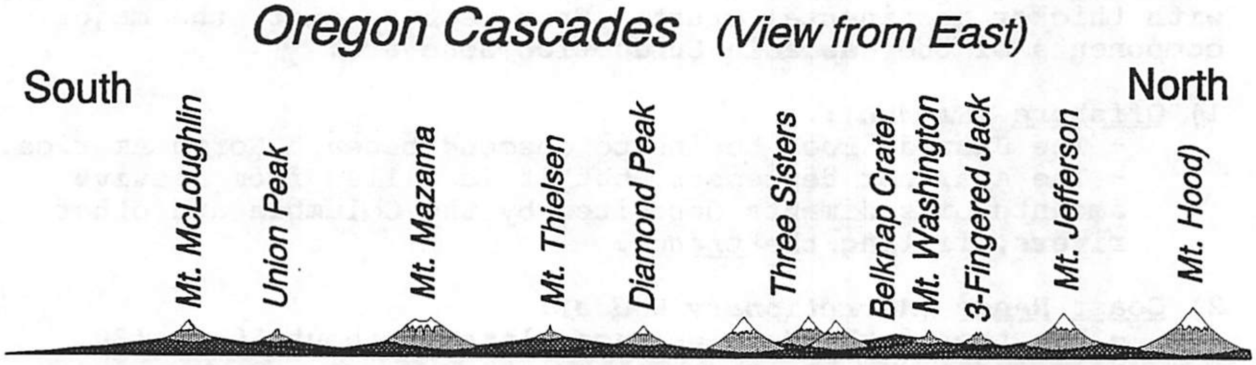
1) Offshore (***Trench***):
   - The Juan de Fuca begins to descend beneath North America.
   - The seafloor depresses, but it is filled from massive amounts of sediments deposited by the Columbia and other rivers, filling the trench.

2) Coast Range (***Accretionary Wedge***):
   - The top of the Juan de Fuca Plate is about 50 km (30 miles) deep.
   - The plate is too cold and rigid to melt.
   - Material scraped off of the top of the plate, stacking up at the surface as the Coast Range mountains.
   - This offscraped material is shape like a "wedge" and is attached ("accreated") onto the overriding plate; hence it is called an accretionary wedge.

3) Willamette Valley (OR) / Puget Sound (WA) (***Forearc Basin***):
   - These areas are a depression formed between the structural mountains (Coast Range) and volcanic mountains (Cascades).
   - The depression is in front of the volcanic arc (Cascades) and is filled with sediments; hence it is called a forearc basin.

4) Cascades (***Volcanic Arc***):
   - The top of the Juan de Fuca plate descends to about 150 km (100 miles) depth.
   - The earth at these depths is hot enough for fluids to be driven off the top of the sediments and crust of the plate.
   - These hot fluids migrate upward, remelting some of the mantle and North American crust in their path, producing magmas that may be enriched in silica.
   - The **line of Cascade volcanoes** is above the line where the **crust of the Juan de Fuca Plate begins to melt at 150 km depth.**
   - The Western Cascades (formed from 35 to 10 million years ago and comprised of andesitic volcanics) are an older version of the High Cascades.
   - Lines of volcanoes above subduction zones are often curved; hence the Cascades can be termed a volcanic arc.
   - The High Cascade region was first built up as a series of interlocking shield volcanoes (free-flowing, basaltic magma), starting about 10 million years ago.
   - The large Cascade volcanoes are **composite**, with steeper slopes because of stickier (andesitic) magma.

The High Cascade Mountains are basically interlocking, low-lying shields, with steeper, composite cones superimposed.



From north to south, prominate volcanic peaks of the High Cascades are:

<u>Southernmost British Columbia</u>:

- Mt. Garibaldi (composite)

<u>Washington</u>:

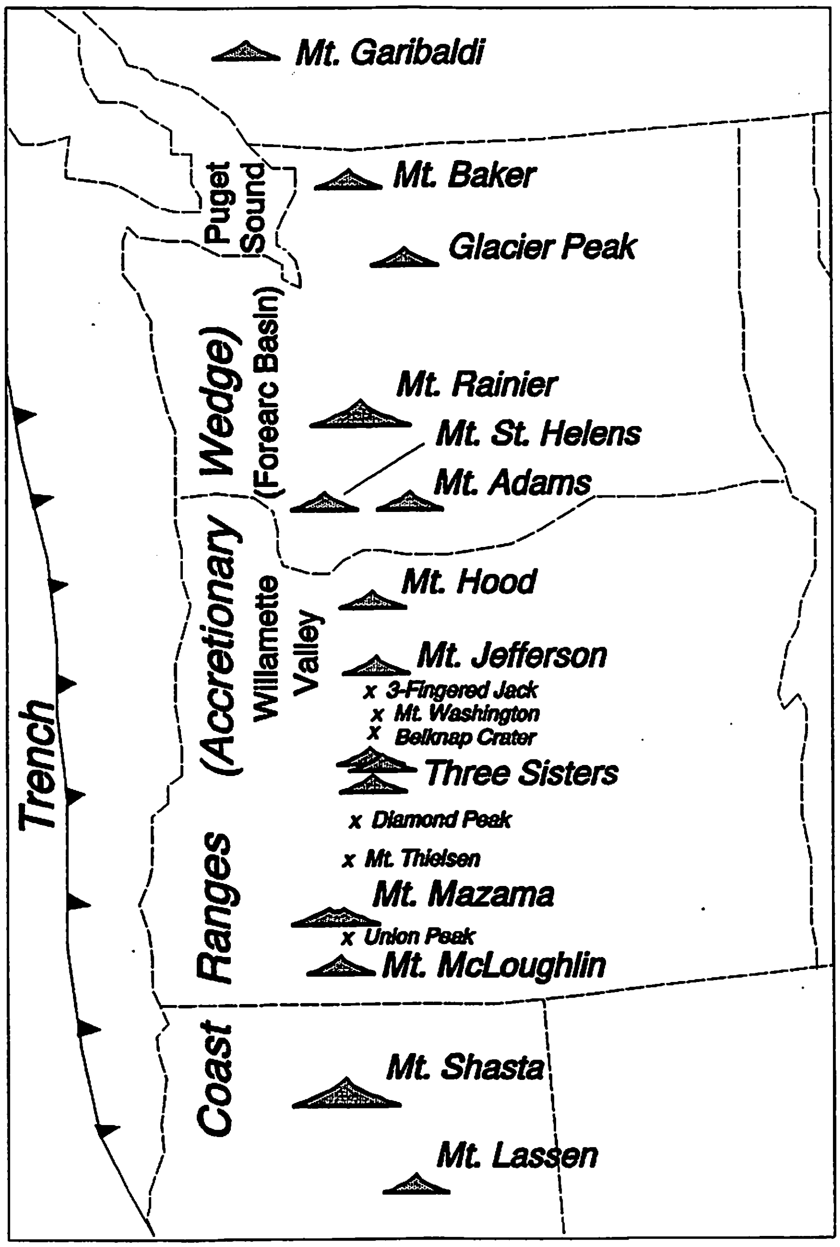
- Mt. Baker (composite)
- Glacier Peak (composite)
- Mt. Rainier (composite)
- Mt. Adams (composite)
- Mt. St. Helens (composite)

<u>Oregon</u>:

- Mt. Hood (composite).
- Mt. Jefferson (composite).
- Three Fingered Jack (eroded composite, with shield base).
- Mt. Washington (eroded composite, with shield base).
- Belknap Crater (shield).
- Three Sisters (composite).
- Diamond Peak (composite).
- Mt. Thielsen (composite).
- **Mt. Mazama (composite, containing Crater Lake).**
- Union Peak (eroded composite, with shield base).
- Mt. McLoughlin (composite).

<u>California</u>:

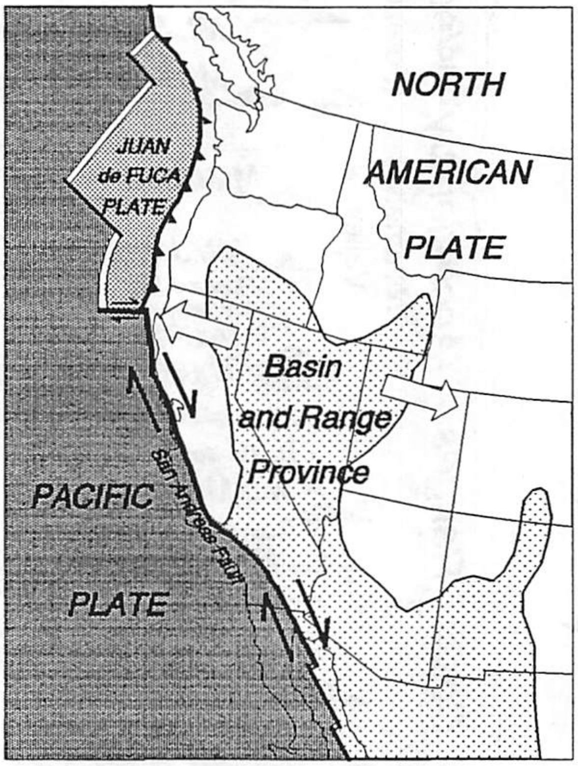
- Mt. Shasta (composite).
- Lassen Peak (composite).


Mt. Garibaldi
Mt. Baker
Puget Sound
Glacier Peak
(Forearc Basin)
Mt. Rainier
Mt. St. Helens
Mt. Adams
Mt. Hood
Willamette Valley
Mt. Jefferson
x 3-Fingered Jack
x Mt. Washington
x Belknap Crater
Three Sisters
x Diamond Peak
x Mt. Thielsen
Mt. Mazama
x Union Peak
Mt. McLoughlin
Mt. Shasta
Mt. Lassen
Trench
Coast Ranges (Accretionary Wedge)

Basin and Range Province (Continental Rift Zone)

In all of Nevada and portions of Utah, Arizona, California, Idaho and Oregon, there are long ranges of mountains separated by valleys ("basins") that fill with sediments and lava flows. This region is therefore termed the Basin and Range Province. The topography forms as the North American plate is being ripped apart; hence, this is a continental rift zone (p. 49), the beginning stages of a divergent plate boundary (p. 9 and 33):

- The "basins" are downdropped blocks in the upper part of the crust resulting from tension during the rifting.
- The "ranges" are high areas between the downdropped blocks.
- The German words "***horst***" and "***graben***" are used to signify the range and basin blocks, respectively.
- Faults dipping beneath the basins (called "normal faults") separate the horst and graben blocks.

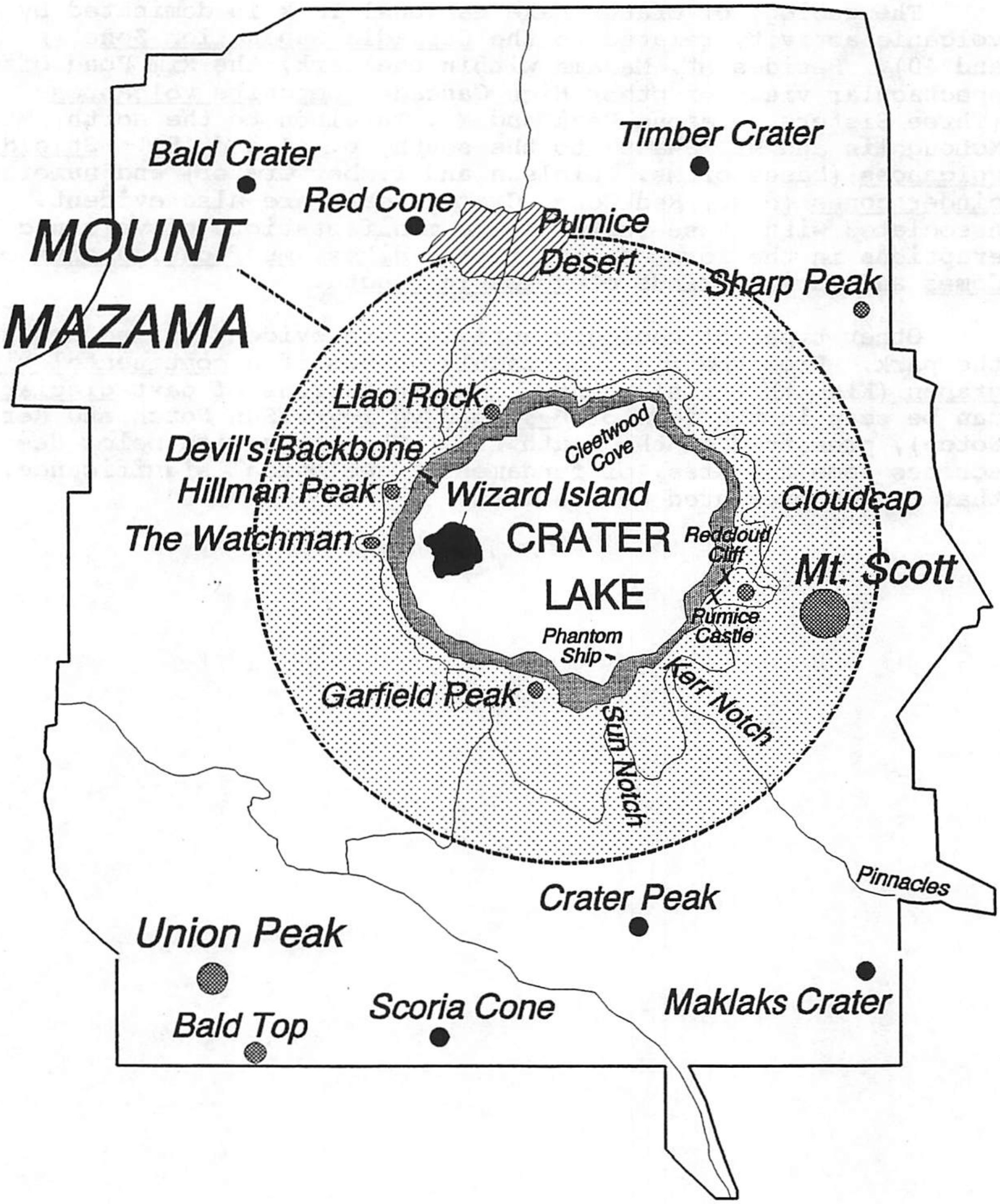


- Some of the deepest lakes in the world are within rift grabens, including Lake Baikal in Russia, lakes Tanganyika and Nyasa in East Africa and Lake Tahoe in California (part of Basin and Range Province).
- Some of the grabens in southeastern Oregon (p. 40) include those holding Klamath Lakes, Summer Lake, Lake Abert, Hart Lake and the Alford Dessert. Ranges adjacent to the basins include Winter Ridge, Abert Rim, and the Steens Mountains.

GEOLOGY IN AND AROUND CRATER LAKE NATIONAL PARK

The geology of Crater Lake National Park is dominated by volcanic activity related to the Cascadia Subduction Zone (p. 39 and 40). Besides Mt. Mazama within the park, the Rim Road offers spectacular views of other High Cascade composite volcanoes (Three Sisters, Diamond Peak and Mt. Thielson to the north; Mt. McLoughlin and Mt. Shasta to the south; p. 44 and 45). Shield volcanoes (bases of Mt. Thielson and Timber Crater) and numerous cinder cones (e.g., Red Cone, Crater Peak) are also evident. Associated with these features are manifestations of volcanic eruptions in the form of lava flows, dikes, mudflows, dacite domes and various kinds of volcanic ejecta.

Other types of geologic activity are evident in and around the park. From the rim, spectacular views of a continental rift graben (Klamath Basin) abound. Manifestations of past glaciation can be seen in the form of U-shaped valleys (Sun Notch and Kerr Notch), preserved on the south rim. The discussion below describes some features, of fundamental geological significance, that can be presented to visitors.


Timber Crater
Bald Crater
Red Cone
Pumice Desert
MOUNT MAZAMA
Sharp Peak
Llao Rock
Cleetwood Cove
Devil's Backbone
Hillman Peak
Wizard Island
Cloudcap
The Watchman
CRATER LAKE
Redcloud Cliff
Mt. Scott
Pumice Castle
Phantom Ship
Kerr Notch
Garfield Peak
Sun Notch
Pinnacles
Crater Peak
Union Peak
Scoria Cone
Maklaks Crater
Bald Top

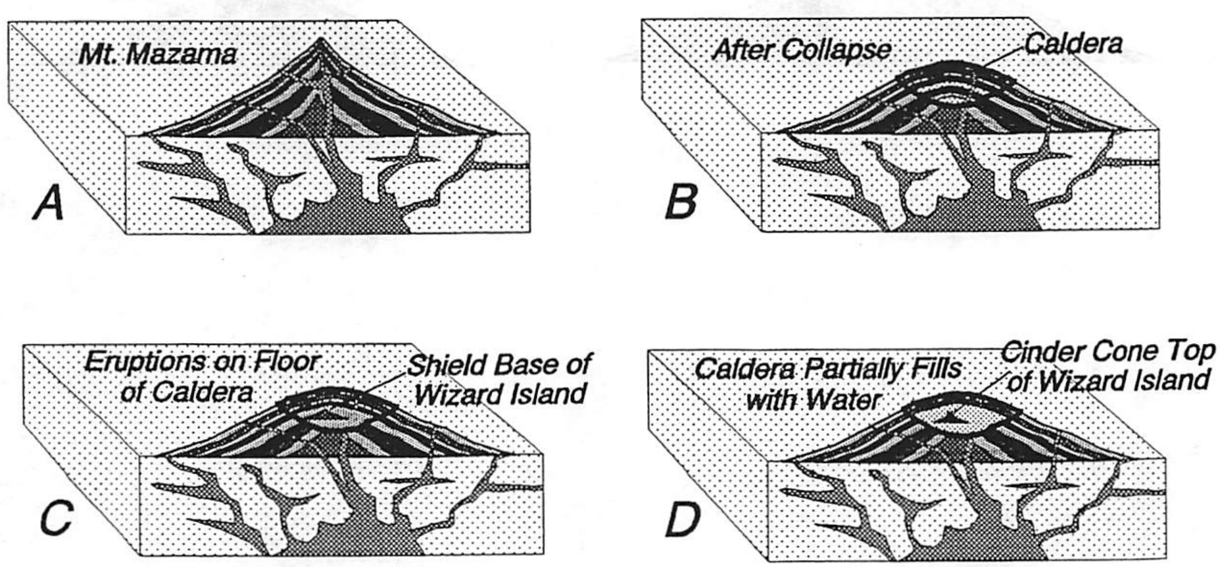
Mt. Mazama (Composite Volcano)

Crater Lake is interpreted to fill the hole (caldera) caused by the violent eruption and collapse of a large volcano, Mt. Mazama, about 7000 years ago. The mountain is more than just lava flows, it is a composite of many different materials (hence a "composite volcano"). The materials have a distinct layering, or stratification, so the term "strato-volcano" is also applicable (p. 30). Mt. Mazama began to grow as a composite volcano about 420,000 years ago. From the rim or on the tour boats, features that illustrate the external and internal architecture of the volcano can be observed.

1. Collapse Caldera

A large crater was formed as Mt. Mazama violently erupted, depleted its magma chamber, then collapsed in on itself. This giant, steep-sided hole is called a ***caldera***, from the Spanish word for "boiling pot" or "caldron." This word is especially applicable to Mt. Mazama, because, for some time after the explosion and collapse, more magma and other materials poured out onto the floor of the caldera. The original caldera depth may have been 4000 feet; the subsequent eruptions may have filled the hole with about 1000 feet of volcanic material. The activity was especially vigorous on the west side of the caldera, where large outpourings of andesite lavas formed the base of what would become Wizard Island.

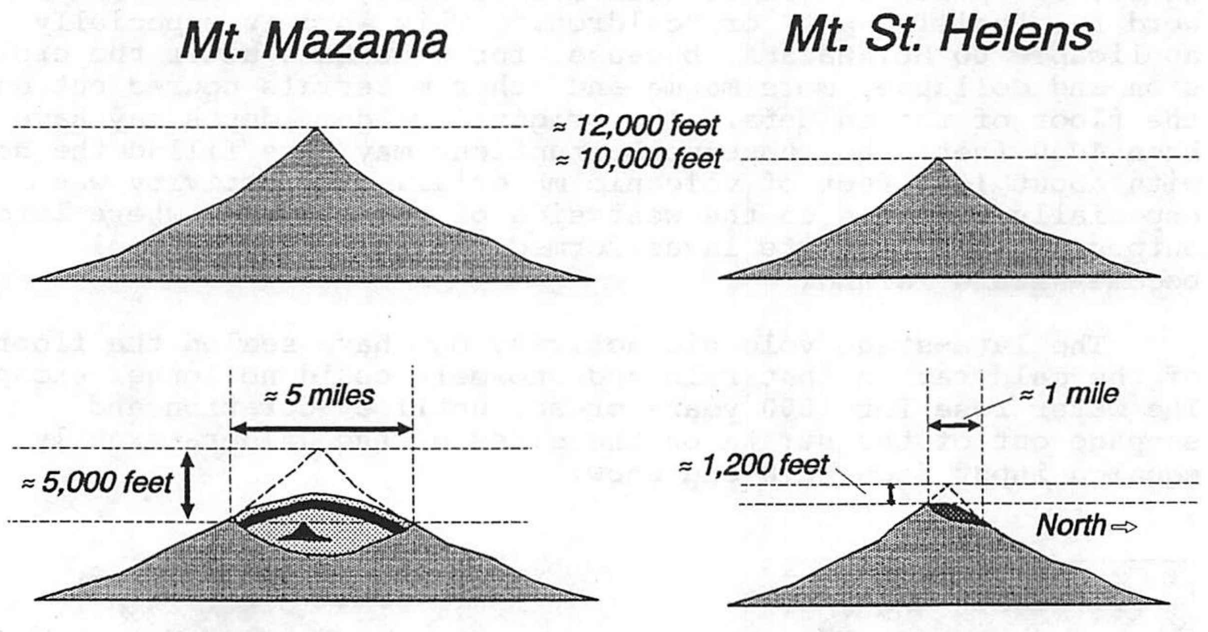
The late-stage volcanic activity may have sealed the floor of the caldera, so that rain and snowmelt could no longer excape. The water rose for 1000 years or so, until evaporation and seepage out of the strata on the sides of the caldera exactly equaled input from rain and snow.



It can be informative to compare the Mt. Mazama eruption 7000 years ago with the 1980 Mt. St. Helens eruption:

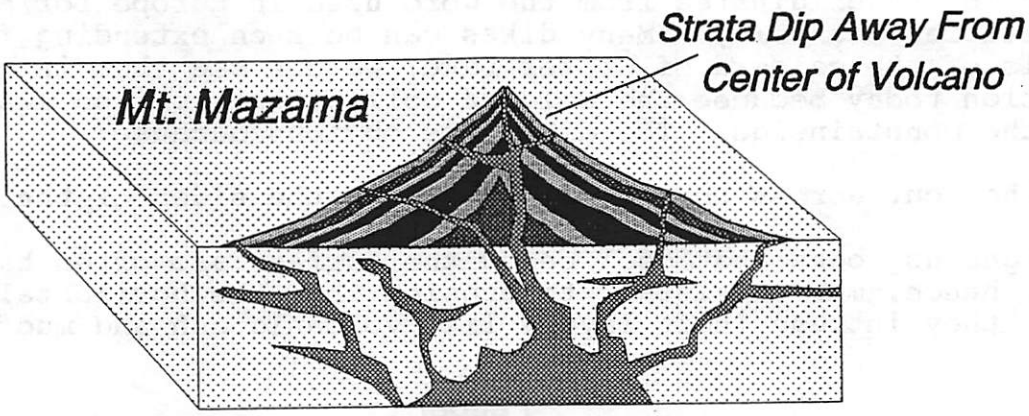
- Similarities:
  - Steep sided, composite volcanoes.
  - Magma rose to shallow position beneath mountain.
  - Trapped gasses could not escape the sticky magma.
  - An explosion occurred as the gasses rapidly expanded.

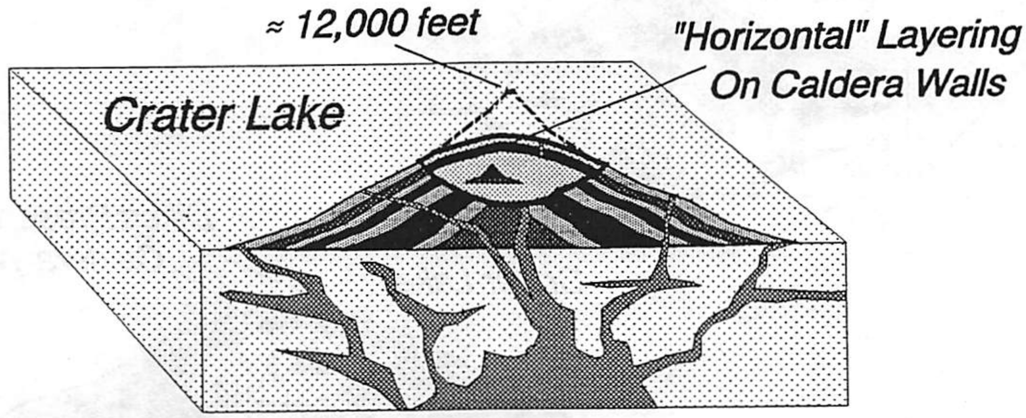
- Differences:
  - Mt. St. Helens blew out to the north, breaching the crater (no confining walls for a lake to form).
  - Mt. St. Helens' crater is about a mile across, the Mt. Mazama caldera about 5 miles.
  - Mt. St. Helens lost about 1200 feet of its former elevation, Mt. Mazama about 5000 feet.



2. Internal Layering

Layering on the caldera walls appears horizontal, but, for the most part, the layers actually dip gently outward, away from the rim. These layers are lava flows, ash, pumice, mudflows, etc., that flowed down the sides of the mountain. If you project the layers and the surface slopes upward to near the center of the lake, you can envision a mountain about 3500 meters (12,000 feet) high.



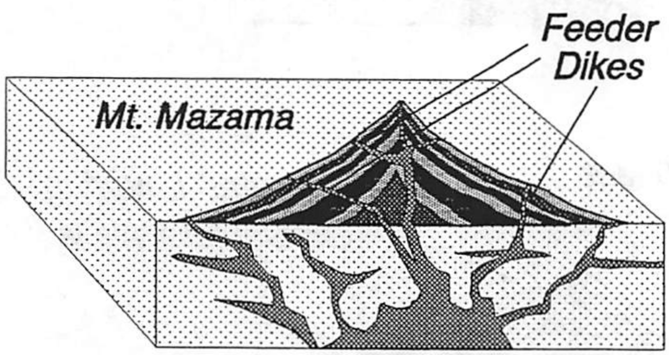


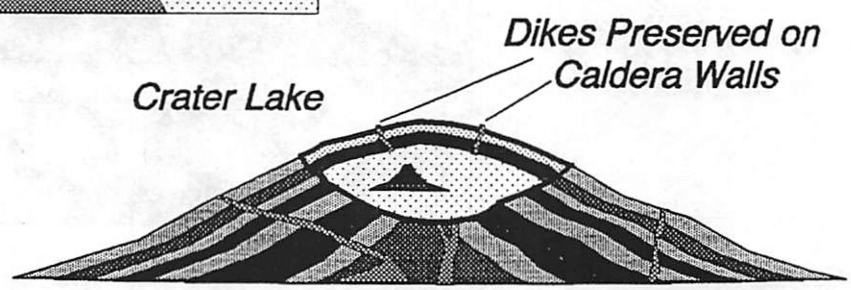
3. <u>Feeder Dikes</u>

As you look around the caldera walls, notice that there are nearly vertical features that cut across the horizontal layers. These features illustrate one of the ways that magma can work its way to the surface in a volcano. Magma doesn't just flow out of the top of a volcano, it quite often is injected out of the sides, as "sheets" of magma work their way through cracks and/or melt the existing rock. Some of the magma makes it's way up to the surface as lava flows, but some of it is left behind, cools and solidifies as an igneous intrusive form called a ***dike***. (The word "dike" originates from the word used in Europe for an artificial sea wall). Many dikes can be seen extending from the walls of the caldera of Crater Lake; we can see them in cross-section today because the Caldera collapse has sliced away much of the mountainside. The dikes are obvious because:

a) they cut across horizontal strata on the sides of the volcano;

b) igneous rocks that cool below the surface are often harder and, hence, more resistant to erosion than the horizontal strata that they intrude (soft layers like volcanic ash and mudflows).





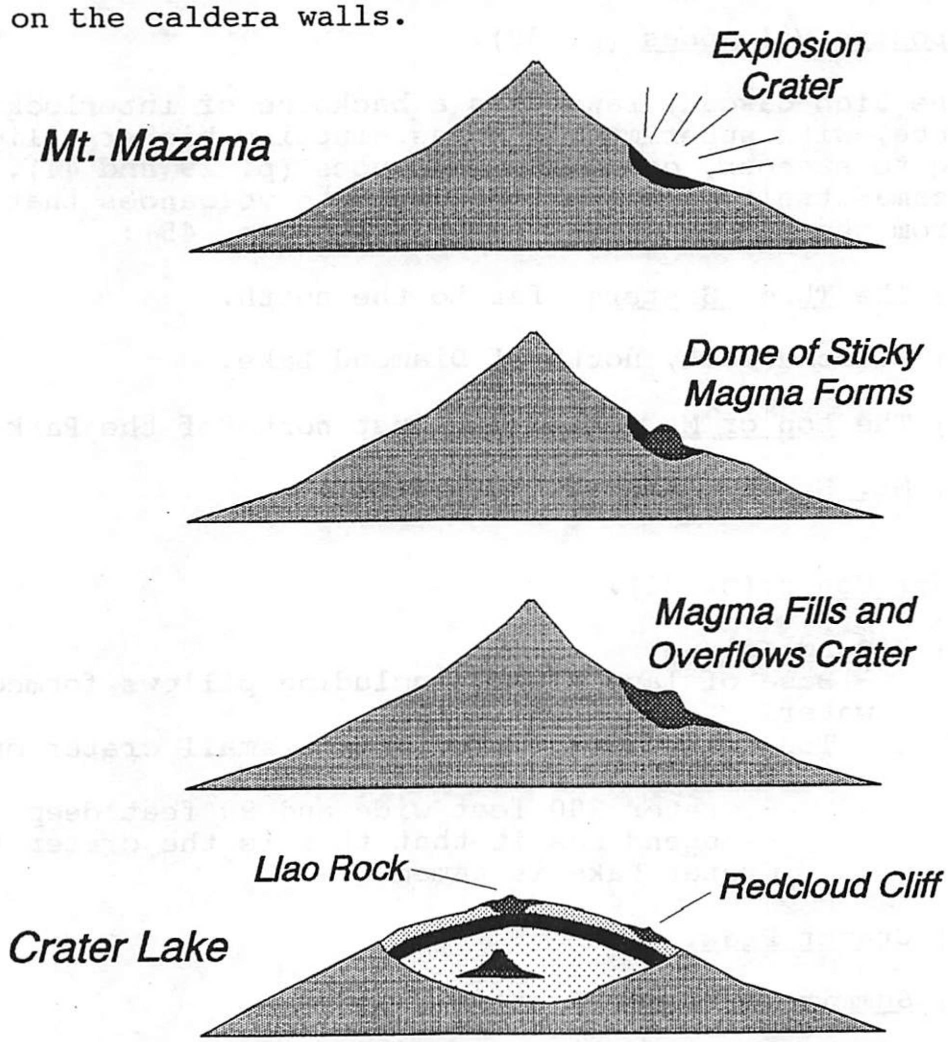
Two prominent examples of dikes are (p. 48):

- <u>Devil's Backbone</u>: The dike rocks, being so resistant to erosion, stick out like a "backbone."
    - The dike rock is about 50 feet thick in places.
- <u>Phantom Ship</u>: The dike extends from the caldera walls out to the island; the boat trip goes over the part of the dike that is breached and covered with water.
    - When the water shallows at the dike, the colors change from deep blues to greens and yellows.

4. Explosion Craters / Dacite Domes

When magma erupts violently, the explosion can leave a crater on the top or flanks of a volcano. High-silica magma, of dacite to rhyolite composition, can pour out into the crater, eventually overtopping it. This magma stays together in a domal form because it is sticky and confined by the crater. Such a dome has formed in recent years in the explosion crater on Mt. St. Helens.

At Crater Lake there are two examples of explosion craters that formed on the flanks of Mt. Mazama some time before its violent eruption (Llao Rock and Redcloud Cliff, on the south and east sides of the caldera, respectively). These craters were filled and overtopped with sticky (rhyo-dacitic) lava. The lavas remained thick and limited in areal extent because of their resistence to flow. Later, when Mt. Mazama erupted and collapsed, portions of the craters and their domes fell into the caldera, so that we now see cross-sectional views of these features on the caldera walls.



Other Volcanic Features

1. Shield Volcanoes (p. 29).

Volcanoes sometimes erupt low-silica magma during much of their activity, with occasional outpourings of higher-silica lavas or volcanic ejecta. The result can be a broad base of lavas with basalt to basaltic andesite composition, beneath a steeper, composite cone at the summit. Examples of such volcanoes in Oregon include Three Fingered Jack and Mt. Washington near Santiam Pass (p. 44 and 45). Three shield volcanoes that can be seen from the Rim of Mt. Mazama are:

a) Base of Mt. Thielson.

b) Base of Timber Crater.

c) Base of Union Peak

2. Composite Volcanoes (p. 30).

The High Cascade range has a backbone of interlocking shield volcanoes, with superimposed areas erupting higher-silica magmas, leading to steeper, composite volcanoes (p. 29 and 44). Besides Mt. Mazama itself, four of the composite volcanoes that can be seen from the rim of Crater Lake include (p. 45):

a) The Three Sisters, far to the north.

b) Diamond Peak, north of Diamond Lake.

c) The top of Mt. Thielson, just north of the Park.

d) Mt. Shasta, far to the south.

3. Cinder Cones (p. 31).

a) Wizard Island.
- Base of lava flows, including pillows formed in the water.
- Top is a cinder cone, with a small crater on top.
    - Cone 700 feet above water.
    - Crater 300 feet wide and 90 feet deep.
    - Legend has it that this is the crater for which Crater Lake is named.

b) Crater Peak.

c) Summit of Timber Crater.

4. Volcanic Ejecta

a) Mazama Ash.

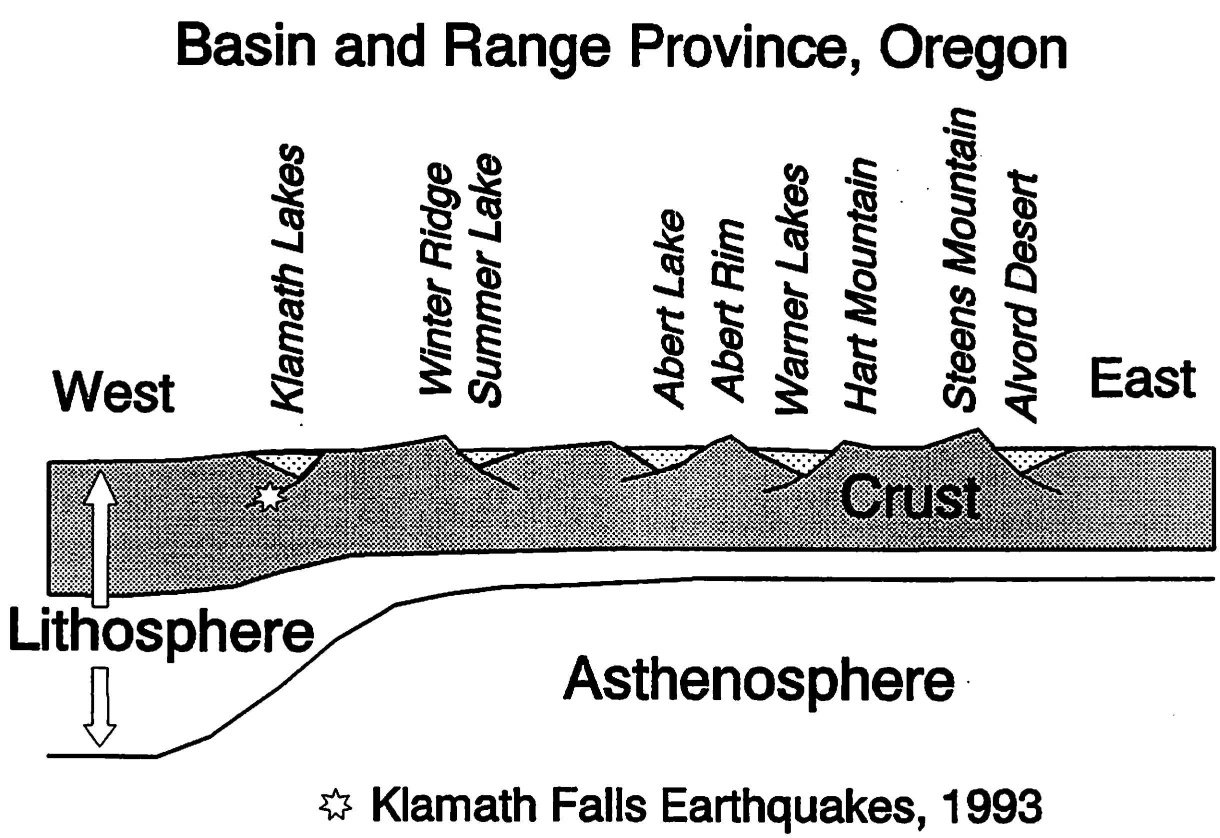
b) Pinnacles.
- Three layers, from top to bottom:
    - About 10 feet of ash
        - Gray colored; red at base
        - From ash falls
    - About 80 feet of scoria and ash
        - Gray colored
        - Andesite composition
        - From ash flows
    - About 80 feet of pumice and ash
        - Buff colored
        - Rhyodacite composition
        - From ash falls.
- The middle layer was semi-molten
    - Released water vapor and hot gasses
    - The vents ("fumeroles") hardened when the activity stopped
    - Erosion of the upper layer and softer parts of the second layer left the hardened fumeroles in tact.

c) Pumice Castle.
- About the size of Phantom Ship.
- Rock and frothy material (ash fall deposits) that have been welded together by hot gasses:
- More resistant to erosion than the surrounding ash, flows, etc.

Other Geologic Features

1. Continental Rift Graben (p. 9 and 33).

The East Rim Drive holds spectacular views of the valley holding Klamath Lakes; the valley and lakes are also visible from rooms on the south side of Crater Lake Lodge. The valley is a large rift graben, on the northeastern edge of the Basin and Range Province (p. 46, 39 and 40). The graben is mostly filled with sediments and volcanic material, probably to a depth of a few kilometers. The prominent escarpments (particularly on the east side of the basin, along highway 97) and the lakes themselves probably indicate the the faults bounding the graben are active. In fact it was one of these faults, on the east side of the valley, that was responsible for the two magnitude 6 earthquakes that occurred in September, 1993. Other prominent rift grabens (or "basins") occurr in south central and southeastern Oregon, including those holding Summer Lake, Abert Lake, Hart Lake and the Alvord Desert. Horst blocks (or "ranges") include Winter Ridge, Abert Rim, Hart Mountain and Steens Mountain.

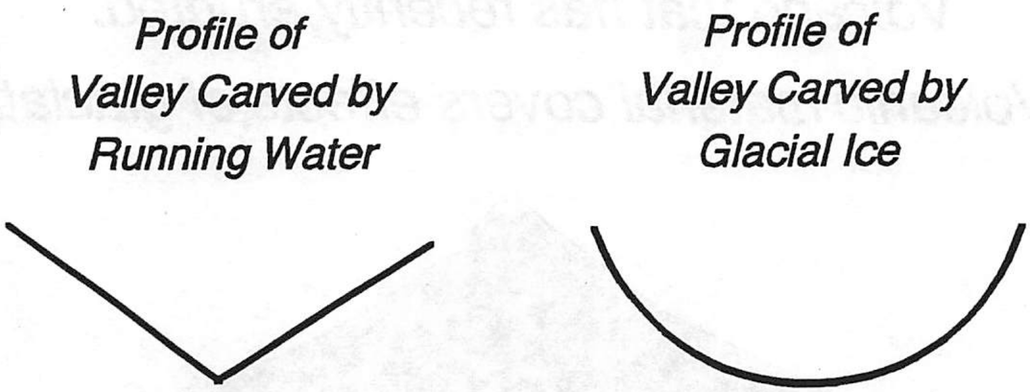


2. <u>Effects of Glaciation</u>

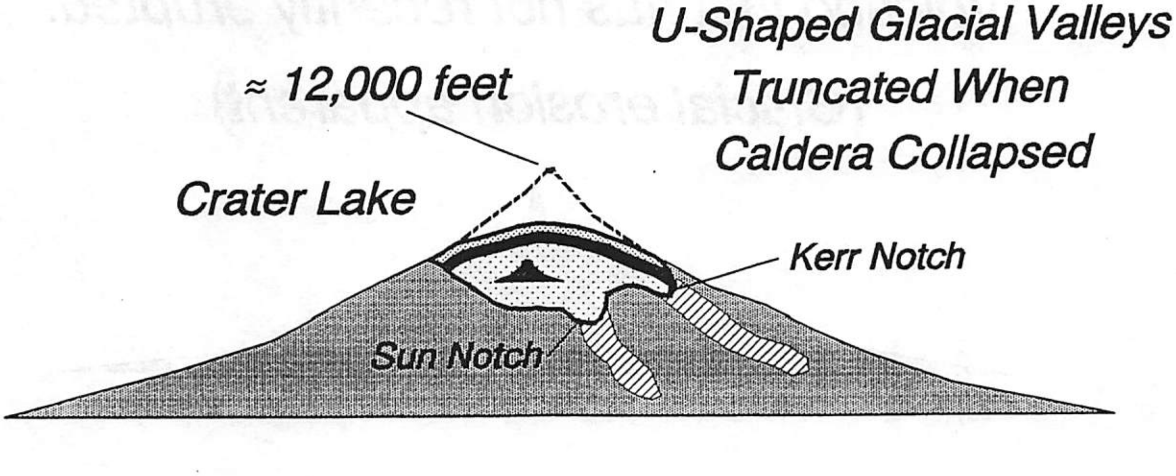
a) <u>Glacial Valleys</u>.

From the west and north rim, two prominent, u-shaped valleys can be seen on the southeast side of the caldera:
- Sun Notch.
- Kerr Notch.

Valleys that form from running water typically have equal slopes on each side, giving a "V-shaped" appearance (as on the Annie Creek trail). When glacial ice is the carving agent, however, the valleys will be gently dipping at the bottom, but increasing in slope on the sides. Thus, glacial valleys typically have a "U-shaped" appearance.



Sun Notch and Kerr Notch are evidence that Mt. Mazama was high enough, and the climate cold enough, to support glaciers. If you project the glacial valleys upward, you can get an idea of the position of the 12,000 foot summit that existed before Mt. Mazama's explosion and Collapse.

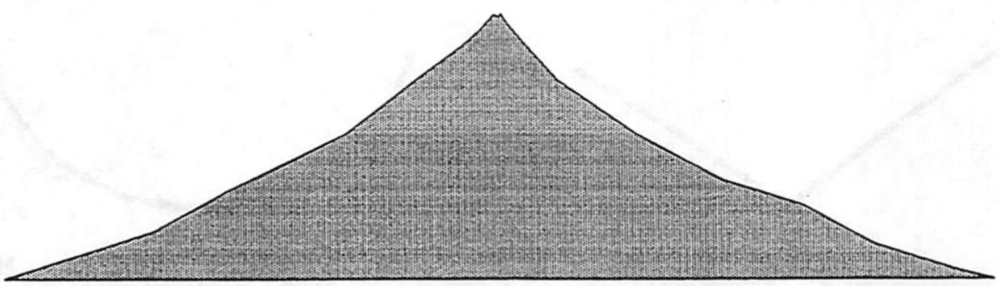


b) <u>Heavily Eroded Peaks</u>

Steep spires forming the summits of Mt. Thielson and Union Peak (p. 44 and 45), carved by glaciers, are evidence that these two volcanoes have not erupted for some time. Had they erupted since the last period of major glaciation (about 10,000 years ago), the new volcanic materials would have restored the smooth, cone shaped appearance to the volcanoes. Compare the profiles of Mt. Thielson and Union Peak with those of the Three Sisters and Mt. Shasta. The smooth, cone shapes of the later is evidence of their continued activity, covering erosion effects of the past glaciation.

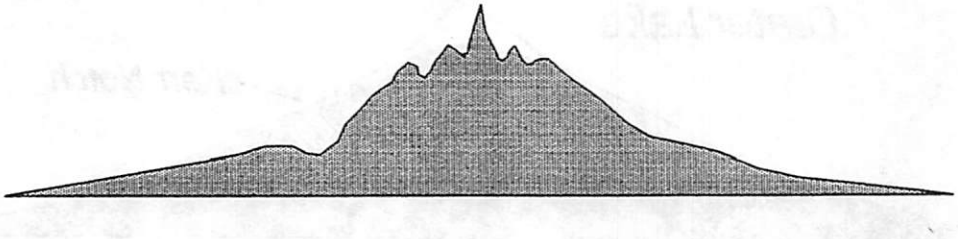
Volcano that has recently erupted.

(Volcanic material covers effects of glaciation)



Volcano that has not recently erupted.

(Glacial erosion apparent)

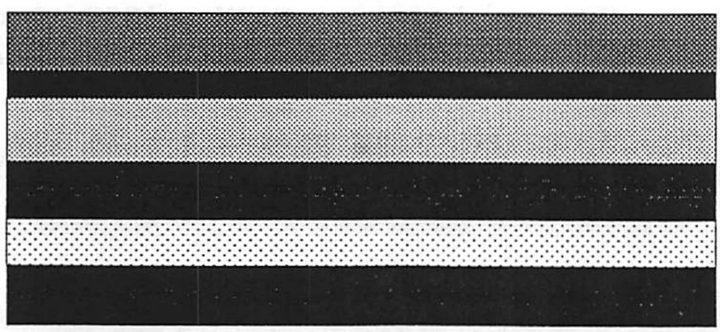


3. Landslides.

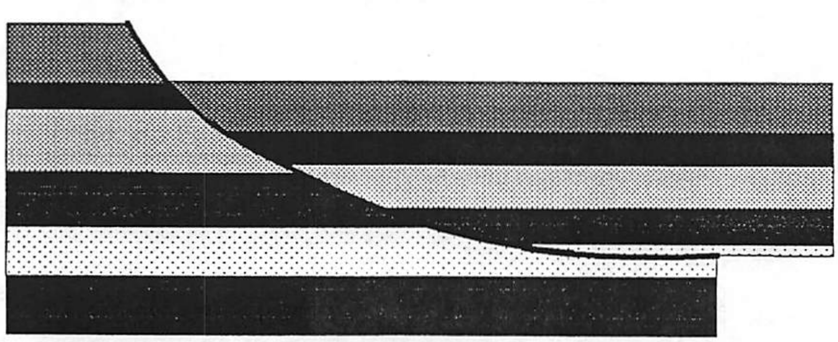
At Crater Lake, the slope of the caldera walls (about 60°) is so steep that material is unstable. Everywhere there is evidence that material has come loose and slid down the slope. The most impressive evidence of this "mass wasting" type of erosion is at Chaski Bay (between Garfield Peak and the Phantom ship, p. 48). There, layers near the lake appear to match those up on the rim, at Eagle Craggs. The offset of the layers is probably the result of a giant landslide.

If you look at the caldera wall from the boat tour, you can see a fresh scarp, along which the slide occurred. Notice that there is some flat land on the top of the slide, about half way up the slope. Nowhere else on the caldera wall is there such a wide area of flat land. (In fact, at times you can see deer grazing up there!). The flat land would erode back through time; thus, its existence probably means that the landslide is relatively young (within the last few centuries?).

Layers Before Landslide



Offset Layers Suggest Landslide



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