This lava flow has destroyed a portion of a road in Hawaii. Slow-moving lava like this causes damage but rarely fatalities. Other types of volcanic eruptions are far more dangerous. In this lesson we review types of volcanoes, the hazards they create, and efforts at prediction and mitigation.
Summary of Important Concepts

• Volcanoes form from sources of magma inside the earth. The main sources of magma are:
  - Subduction at convergent plate boundaries.
  - Sea floor spreading at divergent plate boundaries.
  - Hot spots.

• The violence and explosiveness of a volcanic eruption depends on the amount of time since the last eruption, and the magma’s viscosity and gas content. The more viscous (thick) and more gaseous the magma, the more explosive the eruption. The Volcanic Explosivity Index ranks eruptions by size from 0 to 8.

• The main types of volcanic features on earth are:
  - shield volcanoes
  - stratovolcanoes and calderas
  - lava domes
  - cinder cones
Summary of Important Concepts, continued

• The main **HAZARDS** associated with volcanic eruptions are:

  - **Pyroclastic flows**: hot, fluid mixtures of rock particles and gas that travel at great speed down the flanks of a volcano; have caused thousands of fatalities.
  - **Lahars**: fast-moving mud flows caused by mixing volcanic ash with water (from rain or from eruptions melting snow and ice on the volcano); responsible for more death and destruction than any other volcanic hazard.
  - **Lava flows** that burn and destroy what they overrun.
  - **Ash falls** that cover vast areas of landscape, creating respiratory problems, messy conditions, and potential landslides.
  - **Gases** emitted during eruptions that may be toxic and/or corrosive; the most common is CO2 gas - when present in large enough quantities it causes suffocation.
  - **Tsunamis** generated by undersea eruptions.
Summary of Important Concepts, continued

• Volcanic activity has some benefits, chiefly:
  - **Geothermal energy**: magma close to the earth’s surface is used to make steam for electrical generation.
  - **Construction**: volcanic rock is used for some building materials.

• There is no effective way to **mitigate** most volcanic hazards after an eruption has occurred. One exception is lava flows, which have been mitigated by diverting the moving flows and/or by chilling the lava with sea water. Volcanic **hazard zone maps** are useful for delineating areas at risk from various volcanic hazards.

• Fortunately many volcanic eruptions can be **predicted** quite accurately. The main precursors that signal an impending eruption:
  - **increased seismic activity** ("earthquake swarms") caused by magma rising below the volcano
  - **tilting and swelling** of the volcano’s sides
  - **increased gas emissions**
Locations of Volcanic Activity and Volcanic Hazards

Volcanoes and the hazards they produce are not located randomly on the earth’s surface. Volcanic activity is very clearly controlled by plate tectonics, because plate movements relate to where sources of magma originate inside the earth. Nearly all active volcanoes are located in one of three plate tectonic settings:

1. **Subduction zones at convergent plate boundaries**, where the plate sinking into the mantle melts and creates magma.
   
   *Example: Volcanoes lining the trenches of the Pacific Ocean, forming the Pacific “Ring of Fire”.*

2. **Rifting and sea floor spreading at divergent plate boundaries**, where the separation of the plates corresponds to magma rising up from the mantle.
   
   *Example: Volcanic eruptions at mid-ocean ridges, and in some rift zones on the continents, like the East African Rift Valley.*
3. **Hot spots**: places where tectonic plates move over stationary point sources of magma from the mantle.

   *Example: The volcanoes that form the Hawaiian Islands and the Galapagos Islands.*

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Of these three plate tectonic settings, by far the most important is #1: **Subduction zones at convergent plate boundaries**.

The map on the next slide shows the location of the world’s active volcanoes. Notice that most active volcanoes occur around the rim of the Pacific Ocean. The reason is that most of the edge Pacific has oceanic trenches, meaning subduction is occurring around nearly the entire Pacific Ocean.

This ring of active volcanoes is known as the **Pacific “Ring of Fire”**.
Map of the world’s active volcanoes, showing that the majority of active volcanoes (about 66%) occur in the Pacific Ring of Fire.
Because the western U.S.A. borders the Pacific Ring of Fire, volcanic hazards exist primarily in the western states. On the map, regions with the greatest risk of volcanic hazards are shown in red, and those with the lowest risk are shown in blue. Areas that are uncolored are considered “risk free”.
Zooming in for a closer look at the western U.S., we see in this figure that the volcanoes of the **Cascade Range**, which extends from northern California north into Oregon and Washington, are related to the presence of the **Cascadia Subduction Zone** offshore.

The most recent major eruption in the Cascade Range was that of **Mount Saint Helens** in 1980. The Cascade Range is part of the Pacific Ring of Fire.
Volcanic Explosivity

The violence and size of a volcano’s eruption is expressed by the 
Volcanic Explosivity Index (VEI). Values for the VEI range from 0 to 8, and are based on three criteria:

• the volume of material (lava and particles) erupted
• the height of the eruption column
• how long the eruption lasts

**The larger the VEI value, the larger the eruption.**

Two main factors determine the size and explosivity of a volcano’s eruption:
1. The **amount of time** that has passed since the last eruption.
2. The **viscosity (thickness) and gas content** of the magma.

These concepts are explained on the following slides……
This figure plots VEI values (vertical axis) versus the eruption cloud height and the number of known eruptions of that size (horizontal axis).
This figure shows that individual eruptions become more violent as the time gap between eruptions increases. In other words, the longer a volcano has been dormant, the more violently it may erupt in future.
As mentioned, the size and explosivity of a volcano’s eruption is determined by two factors:
• the amount of time that has passed since the last eruption
• the viscosity and gas content of the magma

**Viscosity** is a measure of a fluid’s resistance to flow. For example, honey has higher viscosity than water. Think of viscosity as the “thickness” of a fluid. The main factor that determines the viscosity of magma is its silica (SiO2) content. The more silica in the magma, the more viscous it is. The more viscous (silica-rich) the magma, the more violent the eruption.

The gas content of a magma also relates to its behavior. A magma with low gas content will tend to flow out of a volcano as relatively quite lava. A magma with high gas content will tend to blow apart violently upon erupting. The higher the gas content, the more violent the eruption.
It turns out that viscosity and gas content of magma both relate to plate tectonic setting:

**Divergent boundaries** (mid-ocean ridges) and **hot spots** both draw their magmas from the **upper mantle**. This magma is called **MAFIC MAGMA**, and is characterized by **relatively low silica** and **low gas content**. Mafic magma does not generally erupt violently (the eruptions have low **VEI**).

In contrast, the magma at **convergent boundaries** comes from melting of **subducted oceanic plates**. This magma is called **FELSIC MAGMA**, and is characterized by **relatively high silica** and **high gas content**. Felsic magma often erupts with great violence (the eruptions have high **VEI**).

**Bottom line:** *The world’s most dangerous volcanoes are those at convergent plate boundaries!***
Types of Eruptions and Volcanic Features

Volcanoes take several different forms, or shapes. The five most common are:

- shield volcanoes
- stratovolcanoes
- calderas
- lava domes
- cinder cones

Notice the differences in shapes and sizes of these examples of volcanic forms.
Shield volcanoes are very large, with gently sloping sides and a convex shape. They form from relatively quiet eruptions of mafic magma. You will find shield volcanoes at oceanic hot spots (like the Hawaiian Islands and Galapagos Islands) and places where mid-ocean ridges stick up above sea level (the country of Iceland). The photo shows a shield volcano in the Galapagos Islands.
The big island of Hawaii, the largest volcano on earth, is an active shield volcano.
The mafic magma erupting in Hawaii doesn’t obey road signs, but these eruptions are fairly gentle and quite. They may cause property damage, but rarely fatalities. (Unless someone is dumb enough to fall into the moving lava!)
Stratovolcanoes are high and steep-sided. Unlike shield volcanoes, they form from violent eruptions of felsic magma. You will find stratovolcanoes at almost all convergent plate boundaries, where subduction makes viscous (silica-rich) and gas-rich magma.

The photo shows Mount Rainier in Washington state. Due to its location near the heavily populated Seattle area, this stratovolcano is considered by many geologists to be the most dangerous volcano in the U.S.!
Some eruptions of stratovolcanoes are so violent that after the eruption ends the volcano collapses into the empty magma chamber beneath, leaving a large crater behind called a caldera. The photo shows Crater Lake in Oregon, an example of a volcanic caldera.
Lava domes form when viscous lava piles up in and around a volcanic vent. Some domes appear to form in the last stages of an eruption, when the final masses of felsic magma squeeze out of a vent and plug it up. The photo shows the Mono Craters, lava domes east of the Sierra Nevada Mountains, California.
**Cinder cones** are smaller volcanic cones that occur worldwide. They appear to be largely “one-shot” events where a source of magma erupts once and then becomes inactive. Cinder cones form as erupted rock particles pile up around a vent, building up a cone-shaped hill. The photo shows the eruption of Paricutin Volcano, Mexico, a classic example of a cinder cone.
VOLCANIC HAZARDS

Be careful where you park your car in Hawaii!
VOLCANIC HAZARDS

We will now review the main HAZARDS associated with volcanic eruptions.

Most significant volcanic hazards are associated with the explosive eruptions of stratovolcanoes. Remember that stratovolcanoes form from highly viscous, silica-rich and gas-rich felsic magma. This magma does not flow easily, and so tends to blow apart violently upon erupting.

The only significant hazard associated with shield volcanoes is destruction by flowing lava, and occasionally gas emissions. Lava domes and cinder cones may also produce hazards from flowing lava, but the hazards associated with these smaller volcanic features pales in comparison to the hazards of stratovolcano eruptions.
This figure shows a composite of the main hazards associated with a typical stratovolcano.

The main hazards are:
- pyroclastic flows
- lahars
- lava flows
- ash falls
- gas emissions
By far the two most *dangerous* hazards in terms of loss of life are *pyroclastic flows* and *lahars*.

**Pyroclastic flows** are fluid mixtures of hot rock particles and hot gas that are denser than air. They boil out from the top of the volcano and travel at great speed down the flanks. The other common term for pyroclastic flow is *nuée ardente*, which means “glowing cloud” in French.

Pyroclastic flows can attain speeds of over 100 miles per hour, and can travel for 10’s of miles across the countryside, burning, burying and suffocating everything in their path. Such flows have buried entire cities and their inhabitants. Perhaps the most famous examples are Pompeii and Herculaneum, which were buried in A.D. 79 by the eruption of Mount Vesuvius.
Examples of pyroclastic flows cruising down the flanks of their parent volcanoes.

*Above:* 1997 eruption on island of Montserrat in the West Indies.

The eruption of Mount Saint Helens in 1980 produced a devastating pyroclastic flow, seen here blasting out to the right (north). The eruption was so violent that the entire top of the mountain was blown off. This flow killed people within several miles of the mountain.
The Mount Saint Helens pyroclastic flow knocked down vast acres of forest, stripping the bark entirely off trees. Many of the trees you see here were 2 or more feet in diameter. They were broken like you would break a toothpick.
Just to put the size of the Mount Saint Helens eruption in perspective, this figure compares the size of that eruption (as measured by the volume of ejected material) to some bigger ones in the past. Notice how small Mt. St. Helens was compared to the others!! The eruption of Taupo (New Zealand) is discussed in your book as Case Study 5.1.
One of the greatest volcanic disasters in history was the destruction of the city of Saint Pierre, Martinique, by a pyroclastic flow from Mount Pelee in 1902. This photo shows the city in the foreground and Mount Pelee in the background before the eruption......
....and after the eruption. The entire city was utterly destroyed, and an estimated 30,000 people died gruesomely by burning, burial, and suffocation.
Pyroclastic flows are probably the most dramatic volcanic hazard. But in terms of **numbers of fatalities** caused in human history the most dangerous volcanic hazard is a **lahar**.

**Lahars** are fast-moving **mud flows** caused by mixing water with loose volcanic ash and debris on the flanks of a volcano. Two things combine to make a lahar: Thick, loose deposits of volcanic ash, and abundant water. Any active volcano has lots of loose ash on its flanks. The water can come in several ways:
- A major rainstorm dumps water on the volcano.
- An eruption melts large amounts of snow and ice on the flanks of the volcano.

Lahars are more dangerous than pyroclastic flows because they are more common, and they can occur at any time (not just during an eruption).
This valley (north fork of the Toutle River) was filled by a muddy lahar several 10’s of feet thick during the eruption of Mt. St. Helens.
Lahar hazards make **Mount Rainier**, near Seattle, Washington, the most dangerous volcano in the U.S. according to many geologists.

The black areas on this map show the location of places threatened by potential lahars. Most of this area is densely populated.
The remaining volcanic hazards to consider are lava flows, ash falls, and gas emissions.

Lava flows burn and destroy whatever they overrun. This hazard relates mostly to property damage, not fatalities. As the photo shows, people in Hawaii have to deal with troublesome lava flows, but the flow is not life-threatening if you keep your distance!
Ash falls can cover vast areas of landscape. The ash is like a very fine power. It causes problems for breathing and operation of engines. When wetted by rain the ash creates messy, muddy conditions and potential landslides.

The photo shows an interesting problem caused by the weight of ash on the tail of a DC-10. This was during the 1991 eruption of Mount Pinatubo.
Gases emitted during volcanic eruptions may be toxic and/or corrosive. However the most common hazardous gas is CO2, which is neither toxic nor corrosive. However when present in large quantities, CO2 can cause suffocation by driving away oxygen!

In the center of the photograph is a stand of dead trees killed by excess CO2 seeping from the ground. The area, near Mammoth Lakes, CA, is the sight of an ancient caldera. The region has magma close to the surface, and in the past several years volcanogenic CO2 has caused tree kills like this one in several places.
These cattle, and about 1700 people, were victims of a massive CO2 discharge from Lake Nyos (Cameroon, West Africa) in 1986. Lake Nyos lies within a volcanic crater. It is not certain what events caused the sudden discharge of an estimated 100 million cubic yards of CO2 gas.
Mitigation and Prediction of Volcanic Hazards

There is no effective way to mitigate most volcanic hazards after an eruption has occurred. One exception is lava flows, which have been mitigated by diverting the moving lava and/or by chilling the lava with sea water. Chilling with water was done successfully on Iceland in 1973 to save a town from being overrun by lava.

Mitigation before an eruption can be done by assessing a region for its potential volcanic hazards and creating a hazard-zone map, which indicates the type and degree of risk in particular areas.

Prediction of volcanic eruptions has become quite accurate, due to various precursors which generally signal an impending eruption.
An example of diversion of a lava flow. The bulldozer is making a barrier to force a moving lava flow away from its path toward a village in Hawaii.
An example of a **volcanic hazard zone map**, showing lava flow hazard zones for the big island of Hawaii.

The bluest areas are at highest risk of being overrun by lava.

Such maps are useful for urban planning and development (if anybody actually pays attention to them, that is!)
There is little that can be done to mitigate against most volcanic hazards once they have begun, but fortunately many volcanic eruptions can be predicted quite accurately. However present methods allow us only to predict approximately when an eruption may occur; not how large that eruption may be.

To predict an eruption, geologists depend on various precursors: events that occur prior to an eruption. The main precursors that signal an impending volcanic eruption are:

1. **Increased seismic activity** below the volcano. Many small earthquakes -- called *earthquake swarms* -- often precede a major eruption. Earthquakes swarms are thought to be caused by fresh magma rising below the volcano.
2. **Tilting and swelling** of the volcano’s sides. As magma rises below a volcano, it forces the earth’s surface upward and outward, somewhat like a balloon being inflated.
3. **Increased gas emissions**, probably caused by rising magma emitting gas as it approaches the surface.
This figure illustrates the events that allow us to predict a volcanic eruption.

As magma rises, it causes earthquake swarms, and swells the volcano’s sides.