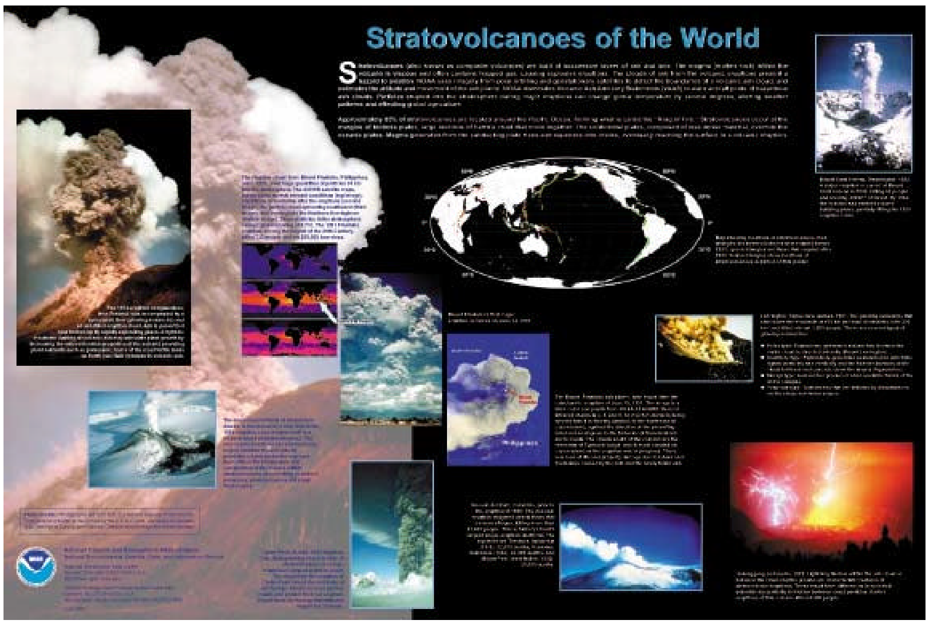
A Teachers Guide to Stratovolcanoes of the World



The purpose of this Guide is to provide additional material to educators interested in using the *Stratovolcanoes of the World* poster published by the National Geophysical Data Center in August 2000. For each volcano featured on the poster, NGDC provides a map showing the location of the volcano, a table of facts, a short fictional story to bring the volcano to life, and a section with questions to ponder, suggested activities, and additional references. Key words in **bold** throughout the text, are defined in the Glossary. Finally, we provide a more extensive list of references and resources as well as some simple activities suitable for grades 5-8.

Authors note:

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Susan McLean and Patricia Lockridge, National Geophysical Data Center, NOAA

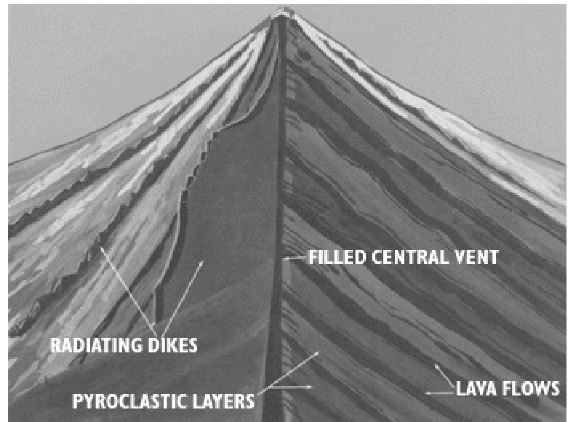
Primary web resources referenced:

- Volcano World: http://volcano.und.nodak.edu/vw.html
- USGS's Volcano Hazard Program: http://volcanoes.usgs.gov/
- NASA's Learning Project: http://learn.ivv.nasa.gov/
- New Zealand's Project Learnz http://www.learnz.org.nz/2k
- About.com Science http://home.about.com/science
- Smithsonian Institution - Global Volcanism Program at http://www.volcano.si.edu/gvp/
- Volcanoes Online at: http://library.thinkquest.org/17457/english.html
- MapQuest at http://mapquest.com

Introduction

What is a volcano?

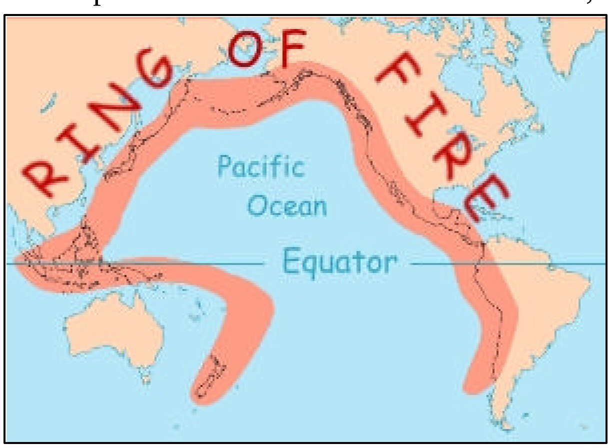
A **volcano** is simply a hole or **vent** in Earth's **crust** through which molten rock, steam and other gases come forth. Scientists group volcanoes into four main kinds--**cinder cones**, **strato**- or **composite** volcanoes, **shield volcanoes**, and **lava domes**. Volcanoes take their name from the island of Vulcano in the Mediterranean Sea. Long ago people thought this island mountain was the chimney of the blacksmith forge of the Roman God Vulcan. The steam and ash that came out of the vent was a sign that Vulcan was working at his forge making weapons for Jupiter and Mars. In Hawaii and other Polynesian islands, local people once attributed volcanic **eruptions** to the Goddess Pele. They believed Pele was moving from island to island as she sought to escape her evil sister, Na Maka O Kaha'i, the goddess of the sea. Today scientists understand that volcanic eruptions are surface reminders of Earth's still hot interior.



Schematic representation of a stratovolcano from USGS "Volcanoes."

Where do volcanoes occur?

Volcanic eruptions do not occur just anywhere. Sixty percent of all active volcanoes are found at crustal plate boundaries such as the Pacific Plate, often called the **Ring of Fire** because of the active volcanoes on its perimeter. Earth's crust, like the cracked shell of a hard-boiled egg, is broken into a number of "**plates**." These floating pieces of the crust are moving about very slowly on the hotter interior. Where the plates are moving apart or colliding with one another, volcanoes may form. Many volcanoes form oceanic islands in the Pacific Ocean or Mediterranean Sea. These volcanoes formed over "hot spots" in the crust and mantle. The Northern Hemisphere has approximately two thirds of the land-based volcanoes.



Are all volcanoes dangerous?

Not all volcanoes erupt and not all eruptions are explosive. Volcanologists label volcanoes **active**, **dormant**, and **extinct**, depending on the likelihood of an eruption occurring. Volcanoes that will never erupt again are considered extinct. Active volcanoes come in two classes -- volcanoes which are active, either erupting now or having recently erupted and dormant volcanoes, volcanoes which are currently quiet but are expected to erupt in the future. About sixty volcanoes are actively erupting each year.

Not all volcanoes erupt explosively. The style of eruption (quiet lava flows versus violent explosions of gases, ash, and debris) and frequency of eruption are related to the **viscosity** and amount of dissolved gas in the **magma**. Hot, runny magmas with little dissolved gas tend to flow smoothly out of vents and produce broad gentle volcanoes. The shield volcanoes of Hawaii are examples of this type of eruption. While such flows are not especially dangerous to humans, they can destroy buildings and agricultural land.

Somewhat cooler magma with more dissolved gas is more viscous. The magma does not run smoothly, but rather oozes out like toothpaste, clogging the vent. As the magma rises closer to Earth's surface, the pressure decreases and gases dissolved in magma separate from the liquid. If the gases cannot escape, pressure builds. When the pressure from the trapped gases exceeds the pressure of the overlying rock, an eruption occurs. This is typically a sudden violent blast sending particles as far as 20 miles high and many miles away from the volcano. The erupted material can range in size from tiny particles of **ash** to house-size boulders. Commonly there is little, if any, lava extruded. Such eruptions can be very dangerous and even deadly. It is difficult to predict when a long dormant volcano will become active. Because they erupt infrequently, unpredictably, and violently, and because they occur in populated areas, these explosive volcanoes pose the greatest danger to humans.

What are Stratovolcanoes?

Stratovolcanoes, also called composite volcanoes, are typically steep-sided, symmetrical cones built of alternating layers of lava flows, volcanic ash, and other eruptive products. Most stratovolcanoes have a **crater** at the **summit** containing a central vent or a clustered group of vents. Lavas either flow through breaks in the crater wall or issue from **fissures** on the flanks of the cone. Lava, solidified within the fissures, forms dikes that act as ribs which greatly strengthen the cone. Their stable construction allows stratovolcanoes to rise as much as 2,400 meters above their bases. The essential feature of a composite volcano is a conduit system through which magma from a reservoir deep in Earth's crust rises to the surface. The volcano is built up by the accumulation of material erupted through the conduit and increases in size as lava, cinders, ash, etc., are added to its slopes. These volcanoes are most often found at **crustal plate boundaries**. In this Guide, we will focus on eight stratovolcanoes featured on the *Stratovolcanoes of the World* poster available from NGDC. These volcanoes are located in the Pacific Ring of Fire.

Featured Volcanoes

Moving clockwise from the top of the globe:

Crater Peak, Mt. Spurr, Alaska U.S.A

Mount St. Helens, Washington U.S.A

Nevado del Ruiz, Colombia

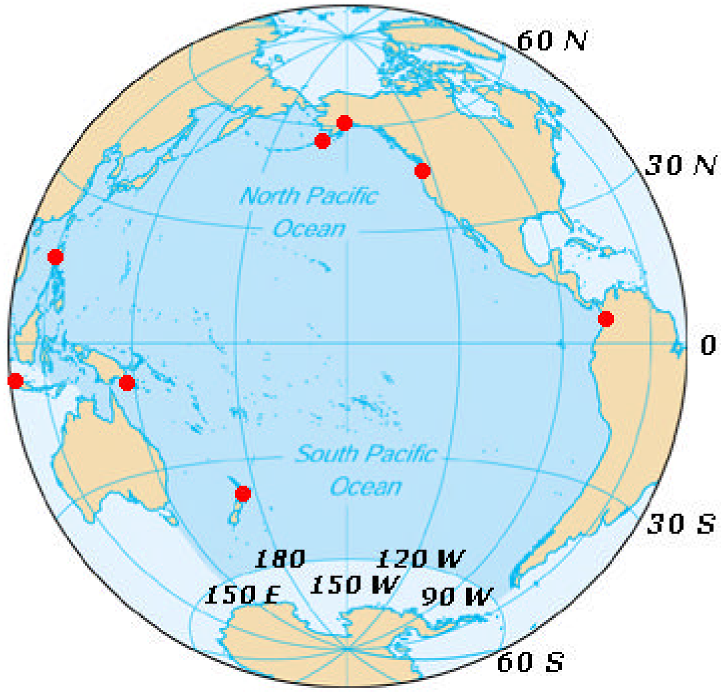
Ngauruhoe, New Zealand

Lamington, Papua New Guinea

Galunggung, Indonesia

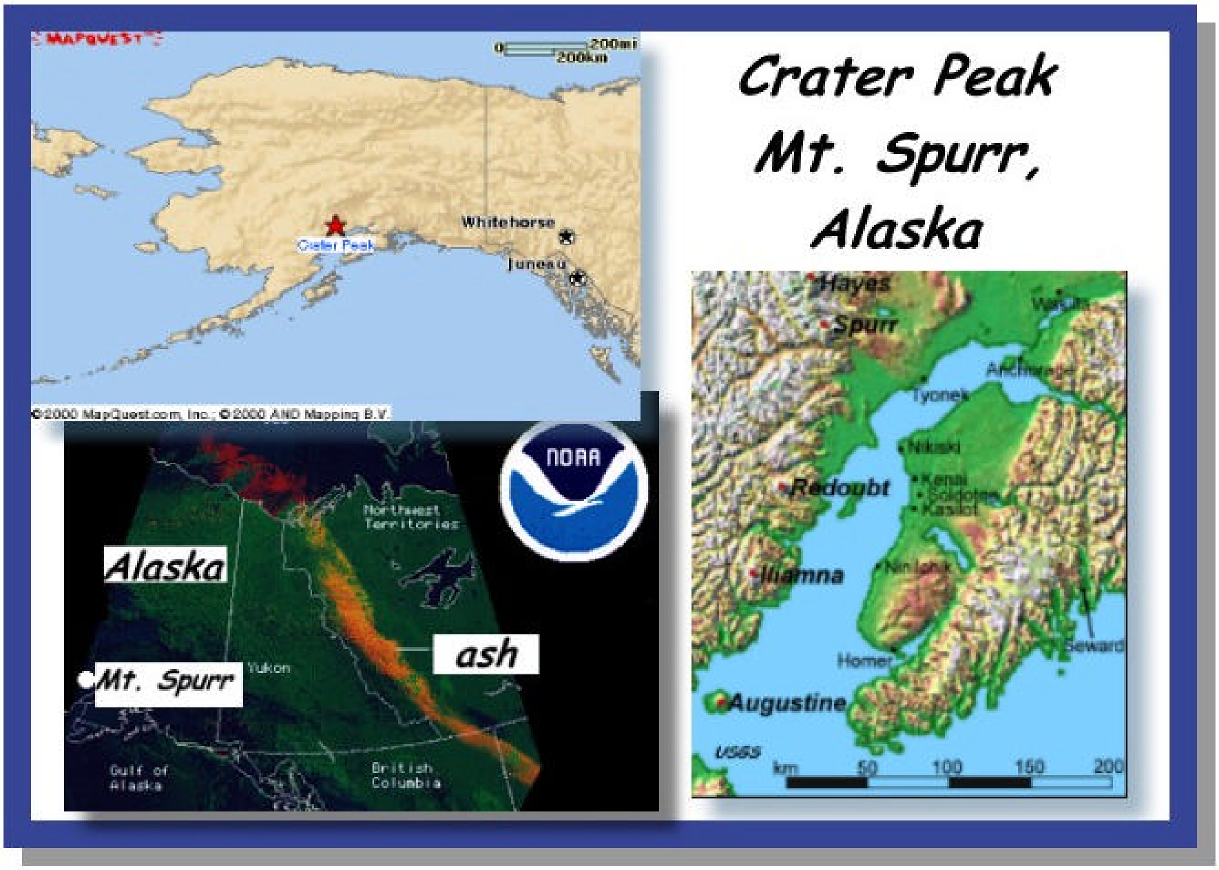
Mt. Pinatubo, Philippines

Veniaminof, Alaska U.S.A



Crater Peak, Mt. Spurr, Alaska USA

Facts and Figures



Crater Peak, Mt. Spurr, Alaska	
Location	Alaska, USA
Latitude and Longitude	61.3 ° N 152.25 ° W,
Elevation	2309 m (7576 ft)
Volcano Type	Stratovolcano
Earliest Eruption	4050 **BP**
Oldest Historic Eruption	1953 **VEI**=4
Most Recent Eruption	1992, VEI = 4
Number of Eruptions in 20th Century	3
Largest Eruption	1953, VEI = 4 1992, VEI = 4
Notable Feature(s)	In the 1992 eruption, large volcanic bombs traveled up to 4 km (2.4 mi) from the crater. The size of these blocks and bombs ranged from 10 cm (4 in) up to 2 m (6.6 ft).
Notable Statistic:	Large bombs up to 2 meters in diameter

A Fictional Story - Dante Robot

Alexa stood with her dad at the **summit** of Crater Peak, Alaska. Her long hair fluttered in the stiff breeze. It was July 28, 1994, summer in Alaska, but still cold on the mountaintop. Alexa put her hands in the pockets of her down parka to keep them warm. Her dad and some other men developed a robot named Dante II, a refurbished version of the original Dante that tried to descend into the **crater** of Mt. Erebus in Antarctica in January 1993. They were going to attempt a descent into Crater Peak with Dante II. The previous mission ended with the first Dante "dying." Its fiber optic cable communications lifeline snapped, 28 feet into the crater. The Alaskan summer was short, so it was important that today's trial work perfectly.

Crater Peak was the ideal place to test Dante II. Mt. Spurr **erupted** three times in 1992 after lying **quiescent** for 39 years. Although it had been quiet for almost two years, scientists considered the volcano too dangerous for human exploration. However, a robot could descend and bring back information that might give important clues as to the future activity of Crater Peak. During the five-day exploration, Dante II was supposed to measure temperatures and composition of gases emerging from **fissures** in the crater floor.

Alexa shuddered as she looked into the crater. "What if this volcano should suddenly wake up?" she wondered.

The crater walls of Crater Peak were nearly vertical and covered with soft **ash** deposits, loose rock, volcanic **bombs**, and ice. Dante's progress into the crater was slow. As Alexa and her father watched the slow descent, a large volcanic bomb jarred loose from the rim and tumbled toward the robot. The twisted piece of **lava** rolled right into Dante's leg, crippling the robot. Dante was able to continue its descent into the crater.

Despite the damage, Dante was able to retrieve gas and water samples. While on the crater floor, Dante took pictures and sent back video for analyses. Since it did not have lungs that could be seared by the gases, Dante could walk right through steam coming out of the cracks and withstand much higher temperatures than a human.

After several days, Dante began its return to the crater rim. Alexa held her breath. Dante had climbed more than 60 m (200 ft) when it lost its footing and fell to the crater floor. The scientists on the rim began a distress call, Alexa looked at the crumpled robot below. Nobody dared to venture down there to rescue the robot. Alexa's dad called a helicopter to airlift Dante out of the crater. The helicopter hovered over the crater while a cable tether was attached to the robot.

Finally, the helicopter began to pull up with Dante attached. The wind was coming up. A strong wind might blow the helicopter into the side of the crater. The robot began to swing wildly as the chopper struggled to maintain its course. The cable was striking the robot's crippled leg. The sharp metal on the crumpled leg was slowly cutting the cable. Alexa watched in horror as the last strand of cable let loose and the robot fell with a crash to the crater floor. After this second fall, there was little left of Dante but a crumpled mass of metal. Alexa and her dad were deeply disappointed. A radio dispatch to their base in Anchorage reported the sad news. The dispatcher was encouraging, however.

"You should see the beautiful pictures Dante sent before it crashed," they said. "Dante truly went where no man could go."

Alexa and her father are fictitious characters, but a robot named Dante II really did explore Crater Peak on Mt. Spurr in Alaska.

Eruption Feature - Volcanic bombs

Bombs are glowing clots of liquid **lava** larger than 64 mm (2.5 in) in average diameter. Because the clots are soft when **ejected** from the **vent**, their shapes can be modified during flight. The bombs may start out as long irregular strings or as discrete clots of liquid. The strings commonly break up into short segments during flight. Cylindrical or ribbon bombs are segments that fall to the ground intact. Ribbon bombs are often twisted during flight. The thicker portions of the ribbons may separate from the rest during flight be pulled into spheres, forming ball-shaped (spherical) bombs. Other bombs may be spindle-shaped or irregular in shape. Many have a crust a few centimeters thick that looks much like that of a loaf of French bread. Some are flattened on one end, apparently on impact, indicating the bomb was not completely hardened. Because volcanic bombs cool very rapidly, usually during flight, they are often glassy in texture.

In the 1992 eruption of Crater Peak on Mt. Spurr, large volcanic bombs traveled up to 4 km (2.4 mi) from the **crater**. The size of these **blocks** and bombs ranged from 10 cm (4 in) up to two m (6.6 ft). Bombs littered the crater area and sides of the **volcano**.

Questions to Ponder and Web Resources

Why is it important to study the history of a volcano?

Why are robot explorers like Dante important to the exploration of volcanoes?

Design your own robot to explore a volcano. What do you want to measure and record? What environmental factors do you need to consider in your design? Draw or build a model of your robot. Can it withstand a "bomb" rolled down the side of the "volcano"?

To learn more about Dante II visit NASA at http://img.arc.nasa.gov/dante/dante.html, Volcano World at http://volcano.und.nodak.edu/vwdocs/vw_news/dante.html, or visit the Walking Machine Catalogue at http://www.fzi.de/divisions/ipt/WMC/preface/preface.html.

Visit the USGS Volcano website http://volcanoes.usgs.gov/ for lots of information on all types of volcanoes, including Mt. Spurr and Crater Peak.

Facts and Figures

Mount St. Helens, Washington, USA	
Location	State of Washington, USA
Latitude and Longitude	46.2º N, 122.2º W,
Elevation	2,549 m (8,363 ft)
Volcano Type	Stratovolcano
Earliest Eruption	10,000 **BP**
Oldest Historic Eruption	1831
Most Recent Eruption	1990
Number of Eruptions in 20th Century	5
Largest Eruption	1855 BP **VEI** = 6; 1800 VEI = 5; 1980 VEI = 5, 57 deaths
Notable Feature(s) 1980 Eruption	"Bulge" on north face, lateral blast removed 396 m (1,306.8 ft) of the volcano.
Notable Statistic:	The blast devastated 596 square kilometers (229 square miles) and destroyed timber valued at several million dollars.

A Fictional Story - Steve and Ed's Excellent Adventure

Steve’s eyelids fluttered open.

“Those birds,” he thought. “How can they be so cheerful in the morning?”

He climbed out of his sleeping bag and out of the tent. Steve and his buddy Ed were camping on a ridge just northeast of Rifle Lake in Washington's Cascade Range. From their campsite, Steve and Ed had great views of Mt. Rainier to the north and Mount St. Helens to the southwest. They had driven down from Seattle to spend the weekend at Mount St. Helens. Unfortunately, they could not climb the mountain because of the recent volcanic activity. Ed thought this was silly, but then Ed was from California and had not seen the pictures of the **eruption** about 6 weeks earlier. Still, they could see the mountain, and with binoculars, they could pick out what looked like forest roads on the north face. It was Sunday May 18, 1980. The morning was beautiful. The air was clear and crisp and the sun was warm.

“Time to get up!” Steve called to Ed. “It's after eight! Are you going to sleep all day?"

Steve took out his binoculars to look around while Ed crawled out of his sleeping bag. Steve and Ed had been keeping an eye on Mount St. Helens during their hike the day before. The boys had hoped to catch a glimpse of the mountain erupting, but there had been no activity. Suddenly the ground beneath them began to tremble.

“Wow dude! That was a gnarly **earthquake**!” said Ed.

He was a native of L.A. and considered himself an expert on earthquakes. Steve was not paying attention to Ed. He was staring south with his binoculars.

“Look! Over there! Mount St. Helens!” Ed grabbed his binoculars.

“Looks like a **landslide**!” he exclaimed. Moments after the earthquake, there was a huge blast from the side of the mountain which seemed to flatten the surrounding forest. This was followed by another explosion sending a gray-brown cloud of ash into the sky above the volcano. While they watched, the cloud rose high into the sky and then flattened like a gigantic mushroom -- just like pictures they had seen of atomic bomb blasts. The explosions were even more frightening because there was no sound accompanying the blasts.

Steve and Ed watched the activity for the next 30 minutes. The visible area around Mount St. Helens was gray with ash and debris. The green forest from this morning was gone.

"Wow, dude! That was awesome! What happened?"

There was total destruction in an 8-mile radius around the crater. The boys could not see the trees which lay on the ground like piles of matchsticks, in some places as far as 19 miles from the crater. In other areas, the trees stood like skeletons, stripped of their branches and needles.

“Look at the mountain!" Steve exclaimed. "Something is flowing down the side!”

The boys trained their binoculars back on the mountain. Mud was flowing down the mountain--mud from the melted snow and ice at the top of the mountain. The mud followed the stream channels down the sides of the mountain and out of view. Unknown to the boys, the mudflow did not stop when it reached the bottom. Downed trees now choked it as it roared through the river channels taking bridges out as it passed.

The boys continued to watch until they realized the sun was gone, blocked by the thick cloud of ash overhead. Steve's growling stomach reminded him of breakfast and he was amazed to see it was only 10 am.

“We’d better get out of here. Our parents will be worried."

"Yeah." Ed agreed. "Dude! What an excellent adventure! I am glad that we weren’t any closer, though! Those volcanoes really mean business when they blow!”

Steve and Ed are fictitious but the description of the 1980 eruption of Mount St. Helens is accurate.

Eruption Feature - Lateral Blast:

The giant landslide at Mount St. Helens in 1980 had an effect like pulling a cork off a bottle of severely shaken soda. Once the side of the mountain was removed, the volcanic gases exploded out of the side of the volcano producing a **lateral blast**. This blast, traveling at speeds of up to 1,072 km (670 mi) per hour, quickly overtook the landslide and extended to up to 30.4 km (19 mi) from the volcano. In the areas closest to the volcano and up to about 13 km (8 mi) away the blast destroyed everything—trees, houses, wildlife, etc. and the area was left barren as the moon. In the area between approximately 13 and 30 km from the volcano, the blast toppled trees and left them lying in neat rows like tooth picks. Still further from the volcano the trees remained standing but were singed brown by the hot gasses of the blast leaving forests of “skeleton” trees with needles stripped. Most of the 57 people killed in the eruption, including volcanologist David Johnston, were killed by **asphyxiation** from the lateral blast. The hot gases scorched their lungs. The blast and the landslide (**debris avalanche**) removed the upper 396 m (1,306.8 ft) of the volcano and devastated 596 square kilometers (229 square miles) of forest. Timber loss alone was valued at several million dollars.

The photograph in the poster shows Mount St. Helens entering a new dome building phase approximately 3 years after the cataclysmic 1980 eruption. The large crater opening to the north produced in the 1980 eruption are visible in the photograph.

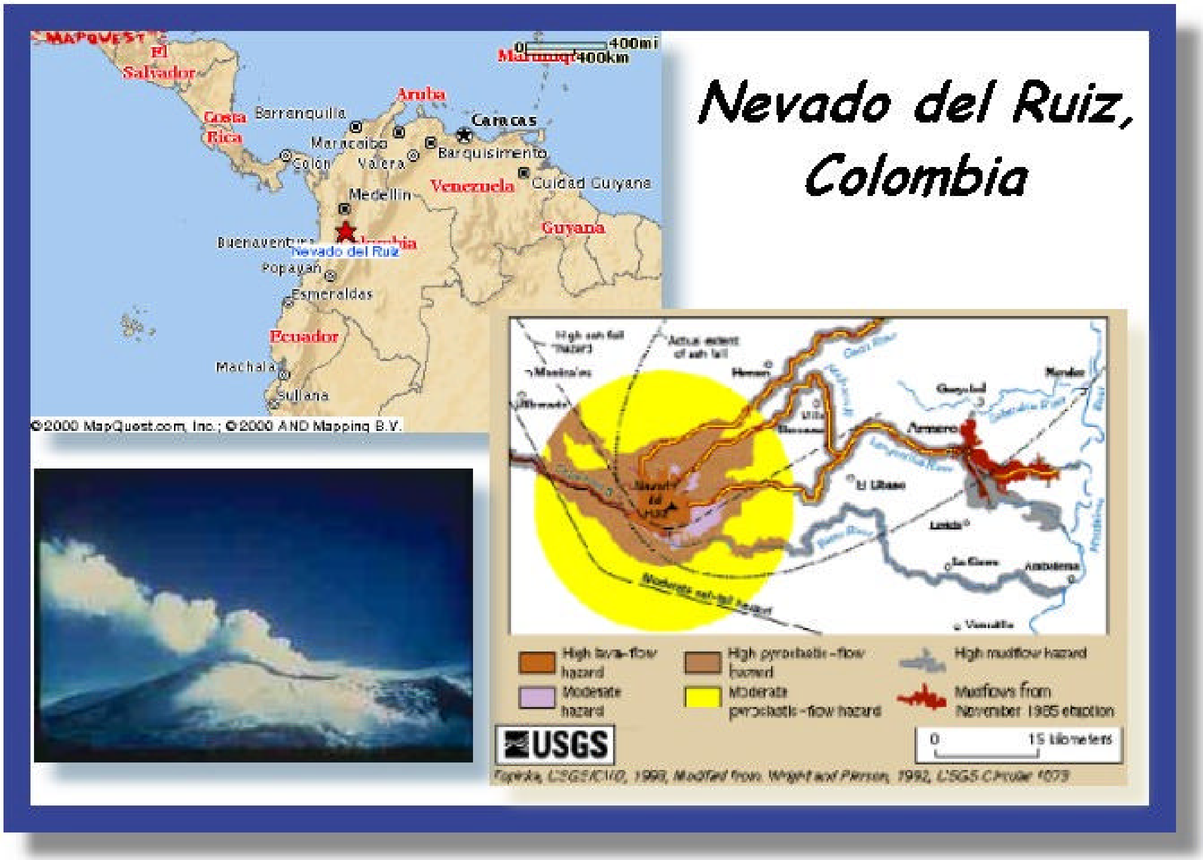
Questions to Ponder and Web Resources

Why do you think the devastation at Mount St. Helens was so severe? Compare this damage http://vulcan.wr.usgs.gov/Volcanoes/MSH/ with a typical eruption of Kilauea in Hawaii http://hvo.wr.usgs.gov/.

How do you think the area has changed in the years since the eruption? What might it look like twenty years from now? Visit the USGS Mount St. Helens Past, Present, and Future http://pubs.usgs.gov/publications/msh/, CNN's web article "Twenty years later" http://www.cnn.com/2000/NATURE/05/17/st.helens.hamann/, and the excellent Weyerhaeuser web site at http://www.weyerhaeuser.com/sthelens/mtsthelens/eruption.htm.

Nevado del Ruiz, Colombia

Facts and Figures



Nevado del Ruiz, Colombia	
Location	Colombia
Latitude and Longitude	4.88°N 75.37°W
Elevation	5,389 m, 17,784 ft
Volcano Type	Stratovolcano
Earliest Eruption	6660 **BP**
Oldest Historic Eruption	1570
Most Recent Eruption	1985; **VEI** = 3; 23,000 deaths
Number of Eruptions in 20th Century	3
Largest Eruption	1595 VEI = 4
Notable Feature(s)	**lahars** (1845, 1985 eruptions)
Notable Statistic:	second largest volcano-related disaster of 20th Century

A Fictional Story - Rosita of Armero

On November 13, 1985, twelve-year-old Rosita was awakened by the sound of clattering pottery jars on the dirt floor. As she sat up on the mat bed she shared with her sisters, she felt dizzy. The clay pots were not the only things shaking. Even the floor of Rosita's adobe home was shaking. Outside a roof tile fell to the ground. Rosita cried out.

"Hush," her mama said, "It's only the **volcano** shaking."

Rosita lived in Armero, a small town 74 km (44.5 mi) from the base of Nevado del Ruiz.

Rosita lay back down on her mat bed. The night was silent now. The clattering had stopped. Still, something did not seem right. Rosita went outside the adobe hut and looked toward the volcano. The night was unusually dark. There was a storm brewing in the mountains. Lightning flashed across the sky. Soon rain began to fall, forcing Rosita back into her home. As she sat on her mat, she thought about the volcano. Just yesterday, a white cloud of steam rose from the mountaintop. On nights when the sky was clear, she had seen a warm orange glow. Still the volcano was a long way from Amero, four hours by car over bumpy roads.

Earlier this year some scientists from the city had come to Armero. They took measurements and drew maps. Some of them dug in the ground around the village and looked closely at the soil. The scientists told Rosita's teacher that mud from the volcano reached Armero 140 years ago.

Rosita had been curious. "How do you get mud from a volcano?" she asked.

Remembering these things, Rosita was unable to sleep. She lay quietly in bed when she heard a strange swishing sound, and a sound like twigs snapping. Her curiosity drove her to the door of her hut. The storm had stopped and the moon was out. Rosita could see the bright orange glow at the volcano top. She looked for the source of the swishing. What she saw made her freeze. A wall of mud filled with trees was rushing towards the sleeping village. As Rosita watched in horror, the mud hit the first of the homes in the village. Rosita screamed, waking the household. Papa grabbed Rosita's little sister.

"Quick, up the hill," he shouted.

The family scrambled to safety just as the mud engulfed their home. In stunned silence, they looked out over the valley where the town had been. Everything was gone.

Officials from the government of Colombia and reporters from newspaper, radio, and television arrived in the morning. Rescue crews were sent to the scene but were unable to reach those trapped in **mudflows** up to 40 m (132 ft) thick. Twenty three thousand people died that night in Armero, and in villages nearby. Three quarters of the people living in the Armero were swept away or drowned in the few minutes it took for the swiftly moving mud to cover the town.

Rosita and her family are fictitious characters, but the deaths and destruction in Armero really happened.

Note: Good would come from this disaster. The U.S. Geological Survey organized a team with a **portable volcano observatory** that could be quickly sent to an awakening volcano anywhere in the world. They realized the **eruption** history of a volcano is very important. If we know when the volcano last erupted, how often eruptions occur, and what areas were affected by past eruptions we can develop better hazard maps and warnings. The impact of future disasters will be lessened because of what was learned here.

Eruption Feature - Lahars:

Lahars are debris flows and/or mud flows produced by loose soil and rock flowing down the sides of a volcano. The name comes from the Indonesian term where lahars are common volcanic hazards. Nevado del Ruiz generated killer mudflows in 1595 shortly after the arrival of Spanish colonists and again in 1845. Hundreds died in settlements located at the site of Armero. However, after the 1845 **eruption** Nevado del Ruiz was quiet for 140 years. People forgot about the destruction and devastation and Armero was built on the same site, growing to a town of 30,000 by 1980. The 1985 lahar began when twenty million cubic meters of hot **ash** and rocks erupted from the **vent** of the volcano and rained down or flowed across the ice and snow-covered **summit**. The hot ash and gases moved across the snow pack in **avalanches** of hot volcanic debris (**pyroclastic flows**) and fast-moving, hot, turbulent clouds of gas and ash (**pyroclastic surges**). The hot pyroclastic flows and surges caused rapid melting of the snow and ice. This released a lot of water and debris that swept down canyons from the summit. The **mud flows** gained volume and **density** until they were as much as 40 m (132 ft) thick, traveling at speeds of up to 50 km (30 mi) per hour.

Scientists were monitoring Nevado del Ruiz at the time of the eruption. Likely lahar pathways were identified on maps, and nearby communities were warned of the danger. The November 13, 1985 eruption took place during night. Although Armero was 74 km (44.5 mi) from the **crater** of Nevado del Ruiz, it took the lahar only two and a half hours to reach the village. A warning did not reach the people in time. The tremendous death toll at Nevado del Ruiz inspired a new respect for volcanic sites around the world where fire and ice meet in a deadly combination.

Questions to Ponder and Web Resources

What precautions could have been taken to save lives at Amero? If you were in charge of monitoring a stratovolcano with a snow-capped summit, what steps would you recommend?

Based on information presented here, how fast did the mud flow travel that engulfed Amero? Could you outrun the mudflow? If not, what is the best means of escaping a mudflow (hint: what do you do in case of flash flood or tsunami)?

Make a meter stick and measure how deep 40 meters is. How many meters high is the ceiling? Discuss the metric system and its use throughout the world.

If more than 20×10^8 m^3 of mud buried 4×10^8 m^2 of lowland around Ruiz, how deep was the mud?

Visit the U.S. Geological Survey's Volcano Observatory website and learn more about Nevado del Ruiz http://vulcan.wr.usgs.gov/Volcanoes/Colombia/Ruiz/

Ngauruhoe, New Zealand

Facts and Figures

Ngauruhoe, North Island, New Zealand	
Location	New Zealand
Latitude and Longitude	39.15º S, 175.63º E
Elevation	2,291 m (7,515 ft)
Volcano Type	Stratovolcano
Earliest Eruption	7750 **BP**
Oldest Historic Eruption	1839
Most Recent Eruption	1977
Number of Eruptions in 20th Century	45
Largest Eruption	1972 **VEI** = 3, 1975 VEI = 3
Notable Feature(s)	Pyroclastic flows: 1892, 1949, 1954, 1972, 1975, Fire fountains, **Strombolian** activity: 1954, Lava flows: 1870, 1949, 1954
Notable Statistic:	One of the most active volcanoes in the 20th Century.

A Fictional Story - Raina's Journey

As Raina packed the last of her clothing into the new suitcase, she wiped a tear from her cheek. She was leaving home for the first time to study at the University and she was leaving behind all her family and friends. Most of all, she was leaving Grandmother, who had raised her and taught her all that was most important in her life. Grandmother gave her a long hug and said,

"You grew up in the shadow of our beautiful North Island mountains Ruapehu, Tongariro, and Ngauruhoe. You know that our ***mana***, our identity, is strong. It does not matter where you go, you take our mana with you."

"Yes, I know," replied Raina. "But I will miss you Grandmother!"

"Sit down," Grandmother said, "and I will tell you the story of how the mountains came to be."

Raina sat at her grandmothers feet, like she had as a child, and listened once again to the familiar story.

"Many, many years ago, Maui Tikitiki-a-taranga and his elder brothers were fishing in this area. Maui cast his fishing line into the sea where we now live. He caught a great fish, which he drew forth from the sea. The sea frothed and boiled as the great fish broke the surface where North Island is now. Maui returned to his homeland to seek help, leaving his brothers to guard the great fish. However, his brothers were afraid and pleaded for help from Ranginui, the supreme universe. Ranginui responded by placing the great mountain Ruapehu, in the center of the fish, creating North Island. This brought peace to the land."

"Ruapehu became very lonely as the only mountain in the land. The supreme universe saw Ruapehu's loneliness and placed two teardrops at the feet of the mountain. Still Ruapehu was lonely and pleaded for company. He was given four mountains for companions. First came Tongariro, the warrior guardian, placed just north of Ruapehu. Taranaki appeared next as the custodian of the clan's ***tapu***. Ngauruhoe was third and the servant to the mountain. The last to arrive was Pihanga, a beautiful maiden, given as a bride to Tongariro to ensure the survival and future of the mountain clan."

"Ruapehu was pleased, but the tall, elegant Taranaki tempted Pihanga. As guardian of the clan's *mana*, Taranaki could not become involved with Tongariro's wife. He asked his eldest brother Ruapehu for advice. Ruapehu told Taranaki to leave the mountain clan, so he followed the winding course of the Whanganui River, to settle in the west coast. There he forever guards the place of setting sun. Ruapehu, Tangariro, his wife Pihanga, and the servant Ngauruhoe remain here, guardians still of our mana."

Grandmother paused and took Raina's hand in hers.

"Wherever you go, Granddaughter, you carry with you all that we are. Do not be saddened by the move you make. Embrace the opportunity and know that your strength of spirit comes from great mountains that have existed for many ages and will nourish you wherever you are."

Raina and her grandmother are fictitious characters.

Note: This myth was abstracted from "The Restless Land - Stories of Tongariro National Park World Heritage Area". Mountains have particular significance for the Maori people, the first inhabitants of New Zealand. Most tribes will name one mountain as having particular significance and that mountain is sacred (or *tapu*) to the tribe. It is part of the source of the tribe's sense of identity, and their *mana*, or strength of spirit. The two volcanoes of Tongariro National Park Ruapehu and Tongariro (including Mt. Ngauruhoe) hold special significance for the Whanganui people that live in the area.

Eruption Feature - Environmental Benefits of Volcanism

Although the destructive effects of volcanism are obvious, volcanoes also provide many benefits to mankind. They are the major contributors to the building of continents. All oceanic islands owe their origin directly or indirectly to volcanism. Over the billions of years of Earth’s existence, volcanoes and **hot springs** near volcanic intrusions, have released hot water from Earth's interior. This steam and hot water can be used to produce **geothermal energy**. Geothermal energy produces electricity inexpensively and with low environmental impact.

Lava flows provide fertile soil in which crops such as pineapples, sugar cane, and coffee thrive. The flows weather quickly in areas with adequate rainfall. In some cases, re-vegetation can begin in less than one year after the eruption. The lava flows are very fertile especially if covered by ash. The fine ash particles retain water within reach of plant roots and release minerals such as potassium which plants need. Vegetation destroyed by ash fall often returns in a more luxuriant form. However, in areas where there is little rainfall, the erosion and breakdown of lava flows to form fertile soils can take thousands of years.

Volcanic rocks provide an abundant local source of materials for landscaping, construction, and road building. In many parts of the world, majestic mountains produced by volcanism draw thousands of tourists each year.

Igneous processes are important in the formation of many of the world's ore deposits. Within **magma**, several processes may occur to produce an ore deposit. Liquids separate within the magma and are **crystallized**. These deposits contain minerals rich in iron, chromium, titanium, copper and sulfur. **Contact metamorphism**, which occurs when a body of magma intrudes into existing rock, also forms ores. Ores may also **precipitate** from fluids, in which case they are called hydrothermal deposits. Hot springs and **geysers** are often associated with nearby intrusive bodies.

Questions to Ponder and Web Resources

Mt. Ngaruhoe exhibits both pyroclastic flow eruptions and Strombolian eruptions. Which type of eruption do you think is more hazardous and why?

If Mt. Ngaruhoe erupted 70 times between 1850 and 1977, what was the frequency of the eruptions?

Based on the myth of North Island, how did the early Maori incorporate the geography of North Island into their life? Write your own myth describing the geography of your area.

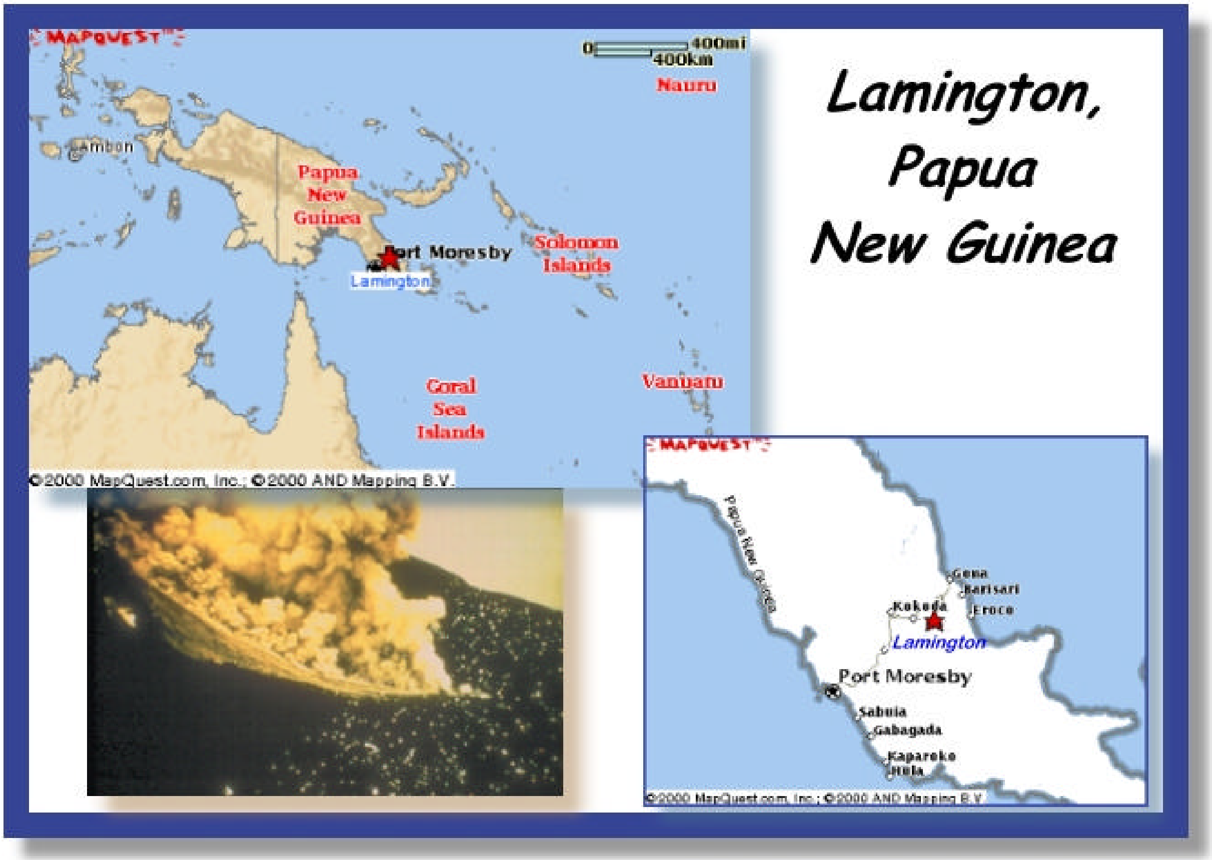
The Department of Energy estimates geothermal energy in the Earth's crust amounts to 50,000 times the energy of all oil and gas resources in the world! Discuss ways to harness and encourage use of this environmentally friendly resource.

Visit the New Zealand Learning Organization's Year 2000 site at http://www.learnz.org.nz

Learn more about Tongariro National Park at Nature & Co. http://www.natureandco.co.nz

Lamington, Papua New Guinea

Facts and Figures



Lamington, Papua New Guinea	
Location:	Papua New Guinea
Latitude and Longitude:	8.95°S, 148.15°E
Elevation:	1,680 m, 5,544 ft
Volcano Type:	Stratovolcano
Earliest Eruption:	5980 **BP**
Oldest Historic Eruption:	1951
Most Recent Eruption:	1951, - 1956, **VEI** = 4, 3,000 persons killed
Number of Eruptions in 20th Century:	1
Largest Eruption:	1951-1956
Notable Feature(s):	Dome, Pyroclastic flows
Notable Statistic:	3,000 deaths

A Fictional Story - Utopo's Mountain

It was February 15, 1989, a special day for Upoto. Today Upoto and his son Tupo were replacing the monitoring equipment at Utopo's mountain, Lamington. Lamington is a **volcano** on the southeastern tip of Papua New Guinea. Before it **erupted** in 1951, when Upoto was a boy, the people living on the mountain did not realize it was a volcano. The mountain was covered with lush vegetation. There was no recognizable **caldera**, no lava, no **geysers** or steam escaping from underground. The people had no memory of a volcanic eruption. The surprise made the 1951 eruption even more devasting.

Now the mountain was quiet again and Upoto and Tupo were taking down the most of the old **seismometers** used to measure ground motion. They would install some modern equipment for measuring ground deformation and new seismometers. The change in equipment reflected the change in threat from Lamington. While still considered an **active volcano**, Lamington's internal temperature has been dropping for many years indicating the volcano was not likely to erupt in the near future. While they would continue to monitor Lamington on a reduced scale, most of the equipment would be sent to monitor volcanic activity elsewhere. As they worked, Upoto spoke of the time years ago when Lamington awoke with a fury.

He was only ten, but Utopo would never forget the **glowing clouds** that rushed down the mountainside burning everything in their paths and killing 3,000 people. Green jungle turned to barren brown in a single day. He remembered how a **dome** grew over the volcano **vent**. Then it collapsed sending glowing, burning clouds speeding down the mountainside again. For five years, the volcano had continued this pattern. A dome would build up, then like a stack of blocks built too high, the dome collapsed blasting clouds of hot gases and **volcanic ash** down the mountainside at speeds exceeding 150 km per hour.

Because of the huge impact the volcano had on his life, it fascinated Utopo. He went to school, studied hard and got a scholarship to the university, the first in his family to do such a thing. At the university, he studied geology and math, but especially volcanoes. Finally, he graduated and returned home to study the majestic mountains that were so deadly.

As a volcanologist, Upoto had been coming to the mountain every day. It was his responsibility to check the instruments. He looked at the seismographs that recorded the **earthquakes**. He took the temperature of the water and soil and monitored the shape of the mountain. His children grew up in the shadow of the volcano. When his oldest son Tupo was five, Upoto brought him up on the mountain. The hot springs and steam coming from the surface cracks fascinated Tupo. As father and son explored the mountain, Utopo told stories of his childhood. The stories about the fire clouds from the mountain that killed so many people frightened and fascinated Tupo.

Now Tupo was a volcanologist, too. As Tupo and his father made their way up the volcano's side, they noted that the scars left by the eruptions had healed. The vegetation was thick and lush. Only a small amount of steam still escaped from waters heated deep underground. Based on the temperature and seismicity data Upoto collected over the last twenty years, scientists decided the volcano was **dormant**. It had gone back to sleep and while still a threat, did not need extensive monitoring anymore.

Upoto and Tupo took the last readings, carefully recording them in the logbook. Then they took apart the aging instruments and packed them on the back of the mule. Upoto looked proudly at his son. Tupo would leave soon to head a rapid response team monitoring active volcanoes worldwide. Lamington had given them much. The desire to learn was set aflame by its fire clouds.

Upoto and Tupo are fictitious characters, but the discription of the eruption and subsequent decline in activity at Lamington are accurate.

Note: Aerial and ground inspections of the summit at Lamington in 1991 showed a dense canopy of vegetation; with only a few scattered thermal areas. Temperatures from one of the larger thermal areas had dropped from 362°C in 1973 to 93°C by 1991. Based on the temperature decrease, the vegetation, and lack of volcanic seismicity, scientists reduced Lamington's threat status and decreased surveillance.

Eruption Feature - Domes and Pyroclastic flows

Pyroclastic flow is the term used to describe a combination of **volcanic gases** and fine **ash** particles that move down slope on the **volcano** flanks rather than rising like smoke as the **ash cloud** usually does. Pyroclastic flows can be made up of super-heated gases called **nuées ardentes** (French for "glowing cloud") and **glowing avalanches,** composed mainly of tiny ash fragments. The nuées ardentes reach temperatures between 300-800 degrees C (570-1470 degrees F) and often jump ridges, burning everything in its path. The heavier glowing avalanche typically follows canyons and drainage patterns. Together the gases and ash make up a "pyroclastic flow."

Pyroclastic flows move at speeds of 80 to 240 km per hour (50 to 150 mi per hour), although nuées ardentes may travel at twice that speed. Pyroclastic flows are extremely dangerous because of their speed of travel and very high temperatures. In 1902, Mont Pelée, a volcano on the island of Martinique in the West Indies, erupted. Within minutes of the eruption, nuées ardentes destroyed the city of St. Pierre, killing almost 30,000 inhabitants.

Nearly 3,000 persons were killed by the pyroclastic flows that accompanied the explosion of Lamington. At the end of the 1951 eruptive period, a 560-m (1848-ft) high **lava dome** partially filled the **summit crater**. A period of repeated lava dome building and collapse continued from 1951 to 1956. A dome slowly extruded from the **vent** like toothpaste. When the dome collapsed it sent pyroclastic flows speeding down the side of the volcano. The tallest dome grew 580 m (1,900 ft) above the floor of the crater before it collapsed.

Several different conditions at a volcano may result in pyroclastic flows. In the Lamington type, a lava dome grows in the vent after an eruption. When the dome reaches a certain height, part of it collapses into glowing rock particles and gases that speed down slope. Other types of pyroclastic flows include those in which the vent is open and a part of the ascending ash cloud collapses and flows down the sides of the volcano. In yet a third type of pyroclastic flow, a dome may occupy the vent but gases may escape past the dome plug and push out and down the side of the volcano.

Questions to Ponder and Web Resources

Why is it important to monitor active volcanoes? How does a scientist decide a volcano is dormant, active, or extinct? Why might scientists need to replace equipment? Learn more about monitoring volcanoes from the USGS Volcano Hazards Program website at http://volcanoes.usgs.gov/About/What/Monitor/monitor.html.

Visit Volcano World's Adventure site http://volcano.und.nodak.edu/vwdocs/adventures/ and learn more about trips to actual volcanoes.

Visit Volcano World's section on Mont Pelee at http://volcano.und.nodak.edu/vwdocs/volc_images/img_mt_pelee.html and compare this eruption with Lamington http://volcano.und.nodak.edu/vwdocs/volc_images/southeast_asia/lamington.html

What qualifications do you think a volcanologist needs? What careers interest you?

Galunggung, Indonesia

Facts and Figures

Galunggung, Java, Indonesia	
Location	Java, Indonesia
Latitude and Longitude	7.25º S, 108.05º E
Elevation	2,168 m (7,154 ft)
Volcano Type	Stratovolcano
Earliest Eruption	1822, **VEI** = 5
Oldest Historic Eruption	1822, VEI = 5
Most Recent Eruption	1984, VEI = 2
Number of Eruptions in 20th Century	3
Largest Eruption	1822, VEI = 5; 1982, VEI = 4; 35 deaths
Notable Feature(s)	**Volcanic lightning**

A Fictional Story - Chris' Flight

Chris sat with his mom in the British Airways jet. They were flying to meet Chris' dad in Singapore. Chris had talked his mom into letting him have the window seat. He did not fly very often, and he loved looking out the window.

"We will be flying a little south of our scheduled route." the pilot announced. It should take us a few minutes longer to get to Singapore, but all of you will be able to make your connecting flights!"

Chris looked out the window. He could see a big bank of clouds off to the right of the plane. They were white and glistening in the sun. Occasionally he could see the clouds light up within.

"Wow! Mom, look at those cool clouds. You can see the lightening in them!"

Chris noticed another patch of clouds. These clouds looked different. They were gray like smoke rather than white. Maybe, Chris thought, there is a big forest fire somewhere. Then he noticed these clouds were being lit up by lightning too.

Chris closed his eyes for a few minutes. A loud crash woke him. First, everything in the cabin seemed to light up. Then the cabin lights went off. A strange green light filled the cabin and pointed metal objects seemed to glow. Chris looked out the window. Suddenly, a bright flash lit up the dark cabin as lightning struck the wing of the plane. The cabin lights flickered, then came back on.

"This is the Captain speaking. We ask that you remain seated with your seat belts securely fastened. We flew through a volcanic **ash cloud** and have lost power in our engines. We are working to restart the engines, but we are losing altitude. Flight attendants, begin emergency water landing briefing."

Chris was hardly listening. What had started as an adventure, had turned very scary. He grabbed his mom's hand.

"Are we going to crash?"

His mom looked worried.

"I think we will be alright, honey. Let's listen to what the flight attendants are saying," she said.

The plane was over ocean, 180 nautical miles from the nearest suitable airport in Jakarta, Indonesia. Without power, they would land in the water in about 18 minutes, perhaps halfway to Jakarta. The plane continued to drop for eight long minutes, loosing 24,000 feet in altitude. Then the Captain's voice came on again.

"I am happy to announce that we have restarted one engine. We hope to restart our other engines, but the plane is no longer loosing altitude! For safety reasons, we are detouring to the nearest airport at Jakarta. We should have you safely on the ground in a few minutes. We will put you aboard a different plane so that you can continue your trip to Singapore."

Chris and his mother are fictitious characters, but the description of events accuately reflects what can happen when an airplane flies through a volcanic ash cloud.

Note: On June 24, a British Airways jumbo jet with 240 passengers did encounter an ash cloud from

Galunggung **volcano**. It was flying150 km (90 mi) west of Galunggung at 11 km altitude. The ash caused all four of its engines to stall. It also scratched and pitted the windshield so badly the pilots could not see to steer the plane to the terminal gate. As the jet flew through the ash cloud **St. Elmo's Fire** (ball lightning) filled the cockpit. The aircraft plunged 7,500 meters before the engines were restarted and it was able to land safely in Jakarta, Indonesia.

Eruption Feature - Volcanic Lightning

The June 24 eruption of Galunggung had a large **ash cloud** with **volcanic lightning**. Such spectacular displays occur when electrical discharges are generated by friction between particles and gases in an expanding eruption cloud. Volcanic lightning most often occurs during eruptions which have large ash clouds. A variety of types of lightning bolts are produced by such conditions including bolts of different widths traveling in different directions, **St. Elmo's Fire** (ball lightning), and small separate sparks. Volcanic lightning is primarily hazardous to airplanes and to radio transmissions. The lightning bolts are generally confined to the eruption cloud and crater area and are not a major threat to people or animals on the ground. However, volcanic lightning has been known to set forest fires in forested areas near the **volcano** crater.

Questions to Ponder and Web Resources

How often do aircraft fly through volcanically active regions? Check out some of these resources for locating aircraft (FlightTracker http://www.trip.com/) and for more information on volcano ash advisories (NOAA's Volcano Ash Advisory Center http://hpssd1en.wwb.noaa.gov/VAAC/).

If you were caught in a lightening storm on a mountainside, what measures would you take to be safe? (visit the National Lightning Safety Institute http://www.lightningsafety.com/)

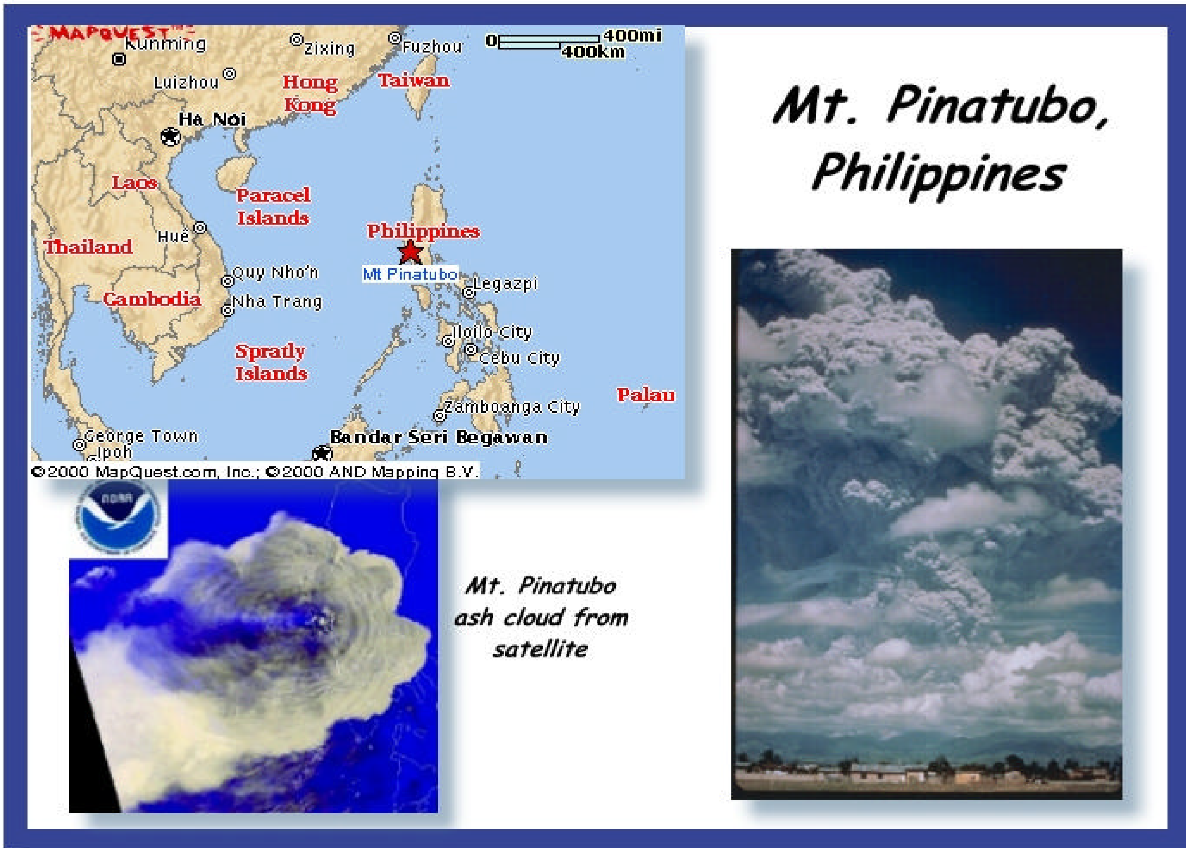
Learn more about Galunngung from the USGS Volcano Observatory web site http://vulcan.wr.usgs.gov/Volcanoes/Indonesia/Galunggung/.

Learn more about volcanoes in Java from the Smithsonian Institution http://www.volcano.si.edu/gvp/volcano/region06/java/.

Learn more about ball lightning (St. Elmo's Fire) from the Florida Sun-Sentinel at http://southflorida.digitalcity.com/DCNews/krt-ballightning.htm and from the FAA at http://www.nw.faa.gov/releases/volash.html

Mt. Pinatubo, Philippines

Facts and Figures



Mt. Pinatubo, Luzon, Philippines	
Location:	Luzon, Philippines
Latitude and Longitude:	15.13° N, 120.35° E
Elevation:	1,485 m 4,900 ft
Volcano Type:	Stratovolcano
Earliest Eruption:	6100 **BP**
Oldest Historic Eruption:	1315
Most Recent Eruption:	1992
Number of Eruptions in 20th Century:	2
Largest Eruption:	1991, **VEI** = 6
Notable Feature(s):	Ash cloud, lahars.
Notable Statistic:	Second largest eruption of the 20th Century in terms of amount of material blown out of the vent. Affect on global weather. 722 deaths.

A Fictional Story - Clark's Last Days

Brad lived with his mother and dad on Clark Air Base in the Philippines. His dad, a captain in the airforce, was stationed at Clark. Living in the Philippines was very different from Colorado, where Brad had ever lived before. The language was strange, the weather hot and humid, and the scenery totally different from anything he was familiar with. The land immediately around Clark was flat and very green, with jungle-covered mountains to the north and west. The mountain to the north, Arayat, was a beautiful **cone-shaped** mountain. A big mountain -- actually a **volcano** -- called Pinatubo was west of Clark. Lately white columns of steam could be seen rising into the sky from Pinatubo. These steam clouds did not seem threatening, just different and very far away. Brad was excited because they only had one week of school left and maybe after school his Dad could take him to get a closer look at Pinatubo.

As Brad walked to school on Monday June 3rd, he looked to the west. Steam was rising from the mountains again. It looked different today -- dirtier and thicker than before. Brad could not see the **crater** where the smoke came from, but he knew it was from Pinatubo. Suddenly the earth seemed to rock under Brad's feet. He fell to his knees and dropped his lunch. He was just getting up when a second lurch knocked him down again. Brad looked towards Pinatubo. He knew these **earthquakes** had something to do with the volcano. Ever since April, there had been several earthquakes each day, but usually they were so small Brad didn't even notice them.

On Friday morning June 7th, the last day of school for the year, Brad's teacher told the class the volcanic activity at Pinatubo was increasing and the base might be evacuated. Brad looked out the window towards the mountains and wondered

"How can that volcano do anything to us when we are so far away?"

Thoughts of volcanoes and evacuations faded as the last bell rang and school was out for summer!

Brad did not think about the volcano, until Sunday when he saw a huge gray cloud rising from the mountains. The next morning, Monday June 10th, the announcement came.

"All non-mission specific personnel must leave the base."

That meant all the families and most of the service personnel would evacuate. Brad's mother, Mary, was prepared for this. She and Brad's dad had been packing the family pictures, clothes, and important papers all weekend. They kept the most important things in their car, ready for the evacuation to Subic Bay, 50 miles south of Clark.

Brad's dad was among the mission specific personnel who had to stay behind. He kissed Brad and Mary good bye and promised to join them soon. Cars formed a long line, bumper to bumper as families left the base. As the cars moved slowly south, the sky grew darker and something like snow began to fall from the sky. Only this was not snow, it was **ash** from the volcano! Mary turned the wipers on to clear the windshield. As the line of cars crept slowly south, Brad rolled down his window to try to catch some of the ash in his hand. The terrible sulfur smell in the air surprised Brad and his mom. They started coughing and Brad quickly rolled up the window.

“Whew that stuff is really bad,” said Brad. “It hurts my throat.”

After 5 long hours, Brad and his Mom reached Subic Bay Navy Station. They joined other evacuees housed in the gymnasium, watching the sky and waiting for the OK to return to Clark.

Two days later, Brad looked to the north, towards Clark where his dad was still working. The biggest cloud of ash he had ever seen filled the sky. It seemed to stretch up forever, forming a shape like a giant mushroom. The ash, which had fallen lightly off and on for the last few days, got thicker and the sky was much darker. Orders came for families to prepare to evacuate Subic Bay and return to the United States. On Thursday, June 13th, there was another big eruption. Now Pinatubo seemed to be constantly erupting, sending clouds of ash into the air. On Saturday, the biggest eruption yet occurred, turning the sky dark with ash falling thick, even as far away as Subic Bay!

Crews at Clark and Subic Bay worked to clear the ash from roofs of buildings, hoping the roof would not collapse under the weight of the rain soaked ash. After the big eruption on Saturday, more people, including Brad's dad, evacuated Clark. Brad's dad described what he saw at Clark. He said that nearly a foot of ash covered everything - cars, houses, even the trees. The sky was so dark you needed powerful flashlights to see, even at mid-day! Now Brad, his dad and mom were all leaving the Philippines, but Brad had an amazing story to tell. He had witnessed the second largest volcanic eruption of the 20th Century and lived to tell about it!

Brad and his family are fictitious, but the 1991 eruption of Mt. Pinatubo did force the evacuation and eventual closure of Clark Air Base and Subic Bay Naval Station. Lahars continue to threaten those living around Pinatubo.

Eruption Feature - Ash Cloud:

The **eruption** of Mt. Pinatubo in 1991 stands as the second largest eruption in the 20th Century (Mt. Novarupta, Alaska 1912 claims largest eruption fame). **Ash** deposits 5 cm (2 in) thick or more covered a land area of about 4,000 square kilometers (1,544 squares miles) burning crops and other plant life around Pinatubo. A typhoon struck the area after the eruption. The weight of the rain-saturated ash, **earthquake** shaking and strong winds, caused numerous roofs to collapse in the communities around the **volcano**, including at the two large U.S. military bases Clark and Subic Bay.

The effects of the eruption were not limited to the area around Pinatubo. The eruption of Mt. Pinatubo affected weather around the globe. Huge quantities of particles from Pinatubo’s tall **ash cloud** injected into the global wind system in the **stratosphere**. These particles affected the weather in two ways. Tiny **aerosol** droplets reflected sunlight away from Earth causing cooling at the surface. Scientists observed a maximum global cooling of about 1.5°C. Sunsets and sunrises were more brilliant because of the fine ash and gases high in the air. In addition, the aerosols from the eruption had a chemical effect that reduced the density of the **ozone layer** in the stratosphere. Until the ozone reforms, it cannot shield that portion of Earth as effectively from the sun.

More than 350 people died during the eruption, most of them from collapsing roofs. Disease that broke out in evacuation camps and the continuing **mud flows** in the area caused additional deaths, bringing the total death toll to 722 people. The event left more than 200,000 people homeless. Before the eruption, more than 30,000 people lived in small villages on the volcano.

Questions to Ponder and Web Resources

How might a 1.5°C drop in temperature affect climate? Find news articles from 1991 - 1992 that show how the eruption of Mt. Pinatubo affected the global climate. Compare the 1991 eruption of Mt. Pinatubo, the 1815 eruption of Tambora, and the 1883 eruption of Krakatau. Read the "Year without Summer" at http://wchs.csc.noaa.gov/1816.htm to see how Tambora affected weather.

Visit NASA's Climate Investigation site at http://www.giss.nasa.gov/research/intro/hansen.02/. Explain why scientists often consider ash to be one of the greatest hazards posed by a volcanic eruption.

To learn more about Mt. Pinatubo, Mt. Novarupta, and Krakatau, visit the USGS Volcano Observatory website at http://vulcan.wr.usgs.gov/Volcanoes/Philippines/Pinatubo/, Territorial Days and Ashes at http://www.kodiak.org/territorial_days.html, and the Volcano Lovers web site at http://whyfiles.org/031volcano/krakatau.html.

Visit the excellent site hosted by Department of Energy ARM (atmospheric radiation measurement) scientists at http://www.arm.gov/docs/education/ to learn more about global warming.

Veniaminof, Alaska, USA

Facts and Figures

Veniaminof, Alaska, USA	
Location:	Alaska, USA
Latitude and Longitude:	56°10'N, 159°23'W
Elevation:	2,507 m, (8,273 ft)
Volcano Type:	Stratovolcano
Earliest Eruption:	3700 **BP**
Oldest Historic Eruption:	1830
Most Recent Eruption:	1993
Number of Eruptions in 20th Century:	9
Largest Eruptions:	3700 BP, **VEI** = 6 - 1750 VEI = 6
Notable Feature(s):	Caldera, lava flow in 1983 and 1993 eruptions
Notable Statistic:	The largest eruptions ever recorded include the 3,700 BP and 1750 eruptions of Veniaminof.

A Fictional Story – Little Bird and the Mountain She Could Not See

Little Bird tugged at the sleeves of her otter skin parka. She would get a new one, and this one would go to her sister. She hoped it would be soon, because the wind was strong, and her arms were always cold.

It was a beautiful autumn day at her village. Little Bird lived near the shore, which looked out toward other nearby islands. She could see many mountains far in the distance. They sparkled like ice, floating in the sea. Little Bird was one of the Unagan, living in the Aleutian Islands, 3,500 years ago.

The families of the village were busy preparing for winter. Already the first snows had come, but in between were sunny days like today. The People could work outside of their long lodges that were built partly under the surface of the ground. It was a good day for repairing the sod roofs, and mending clothing. It was also a good day to get things ready for the upcoming winter ceremonies.

Suddenly the ground began to rumble. The villagers paused, then whispered among themselves. When the mountains came alive, the earth shook. The People knew that these events could be serious. Lately, the earth was shaking more often.

Little Bird had relatives a half day away who could see a different group of mountains from their village. Messengers traveled by sea in skin covered kayaks, back and forth among the villages, to pass along the latest news about family, weather, and what they could see in the distance. The latest word was that there was smoke rising from the mountain that Little Bird could not see.

"Look, the Uncles are coming!" someone shouted.

Messengers in a two-man kayak pulled ashore. These were Little Bird's uncles, who lived at the next village. The People gathered around.

"It's getting worse," one messenger said. "Last night the sky was glowing. We think that the mountain will explode soon."

"And the villages beyond?"

"Yes, they think the same."

"Are your people staying or leaving?" Father asked the Uncles. The villagers could stay in their subterranean houses, or go out in boats some distance from shore. Either choice was a gamble.

"When we left this morning, The People had no intention of moving. They were going inside. The smoke was covering our lodges like a fog."

"And what do you think now that you've seen the mountain from the sea?"

"Sir, we think that it would be better if we *all* go out to sea."

This was the message. Little Bird felt her heart pound.

Two young men from Little Bird's village were assigned to take the kayak down the coast. The message must be passed to the next village right away. The Uncles stayed to confer with the grown-ups. Each lodge family was to assemble enough stored food and water for three days. The earth continued to shake.

Near sunset, The People gathered at the large, open skin boats with their supplies. Strong women and men were given oars. It was time to go.

"Look," said Little Bird, pointing to the ridgeline. "The sky!"

A black cloud was creeping over the ridge. The People heard an explosion from the mountain they could not see.

The People rowed their boats into the darkening twilight as quickly as possible. The women and men paddled hard to escape the rapidly descending smoke. The ash was thickening, and made a sizzling sound as it struck the water in the bay. The villagers covered their noses and mouths to keep out the choking **ash**.

When they got out far enough in the water to see the mountain, Father ordered The People to pull their boats close together. A long fiber cable was passed from boat to boat, until they were loosely connected to each other. From there, The People would wait. All was now dark except for the spectacle before them.

Little Bird could see smoke and fire coming from many **vents** around the mountain. Flames shot up from its top, and fiery clouds tumbled down its sides. Lightning flashed in the clouds over the mountain.

The mountain exploded again. Huge rafts of **pumice** fell into the water and onto the islands nearby. The whole ridgeline behind her village was on fire. A great wave rolled out from the shore, rocking the boats. Little Bird held on to Father. She watched in horror as the waves washed up on the shore where their village was located. When the waters receded, the land was flat! The trees were gone! If they had stayed, The People would have drowned.

After a night of terror, the sun shone weakly through the **ash clouds**, which seemed to melt into the sea. Little Bird could see the mountain and was amazed to see that its top was gone!

The People had survived the eruption and the **tsunami**, but now faced the challenge of surviving winter with all their preparations lost. There was nothing left except for what they had in their boats, and winter was coming quickly. They would find a new, suitable location and rebuild. And many years from that day, Little Bird would thrill her grandchildren with stories of the night the great mountain exploded.

Little Bird and her family are fictitious, but a **caldera** collapse similar to the one described here occurred at Mt. Veniaminof in the Aleutian Islands about 3,500 years ago. It was one of the greatest eruptions that occurred on Earth.

Eruption Feature - Caldera formation:

Calderas are formed by collapse of the volcano usually after much of the material in the **magma chamber** has been blown out. Calderas formed at the **summit** of **stratovolcanoes** may range in depth from a few hundred to several thousand feet. Formation of a caldera usually takes place late in the history of the **volcano** and often follows a long pause in activity during which the cone may become deeply eroded. A long quiet period preceding the eruption allows the magma mass to separate. The caldera results not from explosive decapitation of the mountain, but from subsidence of the summit along ring shaped fractures. Partial drainage of an underlying magma chamber removes support from beneath the top of the mountain, causing it to collapse.

Large calderas mark the surfaces of Mars, Venus, and Jupiter’s moon, Io. When Mt. Mazama, in southern Oregon, exploded 6,500 years ago it lost two miles of its height and formed the caldera that now holds Crater Lake. Kilauea, in Hawaii, and Katmai in Alaska's Aleutian Islands, are calderas resulting from the collapse of volcanoes. The 80 km (50 mi) Lake Balaton in Hungary is a water-filled caldera formed when a magma chamber collapsed.

Questions to Ponder and Web Resources

If calderas are formed when the underlying magma chamber of a volcano drains, what does it mean for Mars, Venus, and Io to have calderas?

Visit Volcano World http://volcano.und.nodak.edu/vwdocs/volc_models/models.html and make your own volcano!

Visit the Alaska Volcano Observatory at http://www.avo.alaska.edu and learn more about volcano hazard maps.

Find out the routes that aircraft use in flying over Alaska. Draw these on a map. Locate Mt. Veniaminof on a map. Do any of these aircraft routes fly over the volcano?

How does mythology describe volcanic activity? How did ancient people perceive volcanoes? How did people of that time know what to do? (i.e. discuss the oral tradition). http://vulcan.wr.usgs.gov/LivingWith/PopCulture/mythology.html

How are messages about natural hazards passed along to the public today? How are satellites affecting our ability to detect and predict natural hazards? (Visit the Tsunami Warning centers http://www.tsunami.gov/, Earthquake information centers http://earthquake.usgs.gov/, the Operational Significant Event Imagery web http://www.osei.noaa.gov/, and weather service reports http://iwin.nws.noaa.gov/iwin/nationalwarnings.html)

Check out images of volcanoes from the Space Shuttle at: http://volcano.und.nodak.edu/vwdocs/volc_images/

Glossary

Active: a volcano which is currently erupting or has erupted in recorded history

Aerosol: A mass of tiny solid or liquid particles suspended in air or another gas (see volcanic gas).

Aleutian Island Arc: Islands in western Alaska extending in an arc 1200 miles southwest from the Alaska peninsula.

Ash: Volcanic ash consists of tiny jagged particles of rock and natural glass blasted into the air by a volcano. Ash may be solid or molten when first erupted.

Ash Cloud: A cloud formed from tiny ash particles and gases blasted from the volcano. Wind can carry ash thousands of miles, affecting far greater areas and many more people than other volcano hazards

Avalanches: Debris avalanches (volcanic landslides) are rapid downslope movements of rock, snow, and ice. Landslides range in size from small movements of loose debris on the surface of a volcano to massive failures of the entire summit or flanks of a volcano. Volcanic avalanches and landslides can occur even when the volcano is not erupting. Excessive rainfall and/or earthquakes may start the material moving down hill.

Blast: An explosive eruption producing clouds of hot ash and/or other volcanic material.

Blocks: A solid rock fragment greater than 64 mm in diameter ejected from a volcano during an explosive eruption. Blocks commonly consist of solidified pieces of old lava flows that were part of a volcano's cone.

Bombs: Hot lava thrown out in twisted chunks that may change shape during flight from the volcano or on impact with Earth.

BP: Years (approximate) before present time.

Caldera: A large, basin-shaped depression formed by the inward collapse of a volcano after or during an eruption.

Cinder cone: A steep-sided small cone composed of cinders, ash and bombs.

Cone-shaped: Shaped like an upside down ice cream cone.

Contact metamorphism: Contact metamorphism occurs when the heat from an intruding magma changes the mineralogy and texture of the surrounding pre-existing rock. Heat, rather than pressure, is the primary cause of the metamorphism. Contact metamorphism is usually restricted to relatively shallow depths (low pressure) in Earth. This is because as depth increases, so do pressure and temperature. At depth, there will not be a large contrast in temperature between the intruding magma and the surrounding rock.

Crater: A small funnel-shaped depression in the summit of a volcano at the top of the conduit or pipe through which the magma reaches the surface.

Crust: The thin outermost layer of Earth including the continents and the ocean floors.

Earth's Interior Divisions

Layer Name	Outer Radius, km	Approximate Temperature, C	Composition
Inner Core	1229	7000	Solid Iron
Outer Core	3484	5000	Liquid Iron
Lower Mantle	5700	2000	Iron-rich Rock
Upper Mantle	6360	500	Iron-rich Rock
Crust	6371	0	Basalt, Granite

Crystallization: The process through which crystals separate from the fluid (magma) state.

Debris avalanches, debris flows: See Avalanche.

Density: A measure of how heavy or light an object is for its size.

Dome: See Lava Dome.

Dormant: An active volcano which is quiet, not presently erupting, but is expected to erupt in the future. Most of the major Cascade volcanoes are believed to be dormant rather than extinct.

Earthquake: The shaking of the ground caused by an abrupt shift of rock along a fault. Within seconds, an earthquake releases stress that has slowly accumulated within the rock, sometimes over hundreds of years.

Eject: To throw out, forcefully discharge.

Electrical Discharges: Release of electricity (a form of energy caused by the motion of electrons).

Eruption: The expelling of material including gases, ash, volcanic fragments and lava on Earth's surface due to volcanic activity. Eruptions may be explosive, or quiet lava flows.

Extinct: A volcano that is not expected to erupt again.

Fire fountain: Lava that is shot into the air like a geyser by the pressure of trapped gases within the magma.

Fissure: A fissure is an elongate fracture or crack at the surface from which lava erupts.

Geothermal energy: The word "geothermal" literally means "Earth" plus "heat". To produce electric power from geothermal resources, underground reservoirs of steam or hot water are tapped by wells and the steam rotates turbines that generate electricity.

Geysers: Most geysers are hot springs that episodically erupt fountains of hot water and steam. Such eruptions occur as a consequence of groundwater being heated to boiling temperature in a confined space (underground).

Glacier: A large mass of ice formed by compressed snow, which moves slowly under its own weight. Glaciers exist where, over a period of years, snow remains after summer's end and accumulates year after year.

Glowing avalanche: Hot ash and larger particles erupted from the volcano that flow down the sides of the volcano. Glowing avalanches are heavier than nuées ardentes and typically follow canyons and drainage patterns.

Hot spot: A hotspot is a stationary, long-lived (tens of millions of years) source of basaltic magma coming up through the mantle to the Earth's surface.

Hot spring: A spring whose water temperature is above 36.6 °C (98 °F).

Igneous: Rocks solidified from molten magma at or below the surface of Earth.

Lahars: Debris flows and/or mudflows produced by loose soil and rock flowing down the sides of the volcano.

Lateral Blast: A relatively rare explosion of hot, low-density mixture of rock debris, ash, and gases that moves at high speed out the side of the vent (laterally) rather than up from the vent (vertically).

Lava: Molten rock erupted from a volcano. Lava can occur in flows, domes, fragments and as pillows formed under water.

Lava Dome: Lava which is forced from the vent much like toothpaste from a tube, forming a half-ball shape over the vent. A lava dome forms when the lava is too viscous to flow far from the vent. It continues to grow upward until it collapses.

Lithosphere: The solid outer shell of Earth composed of the crust and the solid outermost layer of the mantle. The lithosphere lies above the asthenosphere (soft layer of the mantle) and is broken into crustal plates.

Magma: Molten rock below the surface of Earth that rises in volcanic vents. Lava is the term for magma after it erupts from a volcano.

Magma Chamber: A space beneath the surface of Earth surrounded by solid rock and containing magma.

Mana: Maori term signifying a sense of identity, pride and strength of spirit.

Mantle: The area within Earth that is below the crust and above the core of Earth.

Mudflows: The downhill movement, often rapid, of soft wet earth and debris, made fluid by rain or the rapid melting of snow.

Nuées ardentes: A French term applied to a highly heated mass of gas-charged ash which is expelled with explosive force and moves with hurricane speed down the mountainside. Nuées ardentes reach temperatures between 300 to 800 °C, are lighter than glowing avalanches, and often jump ridges when moving down the flank of a volcano.

Ozone: A form of oxygen that has a pale blue color and a strong smell. This gas is formed when an electrical discharge passes through the air. It can be poisonous in large quantities. The ozone layer high above Earth's surface blocks out some of the harmful rays of the sun.

Plinian Eruption: Plinian eruptions are one of the most explosive types of eruptions, forming enormous dark columns of tephra and gas high into the stratosphere (>11 km). They often produce nuées ardentes, lahars, and caldera collapse. Plinian eruptions are named for Pliny the Younger (Gaius Plinius Caecilius Secundus), a Roman statesman who carefully described the disastrous eruption of Vesuvius in 79 A.D. which killed his father as well as about 2,000 other people.

Plume: A long, feather-shaped cloud of steam or gases.

Portable volcano observatory: A collection of hardware and software, which is easiliy moved and installed, to monitor restless volcanoes. Key components for data gathering, storage, and analysis include (but are not limited to):

- Personal Computer (PC),
- up to 128 seismometers for measuring earthquake locations and magnitudes,
- electronic distance meters (EDMs), theodolites, reflectors, and Global Positioning System (GPS) receivers to detect surface deformation,
- correlation spectrometer (COSPEC) to measure sulfur dioxide emission rates, and
- low-data-rate, radio-telemetry system to transmit monitoring data from remote field sites to the

portable observatory.

Precipitate: A percipitate is formed when a slightly soluble substance becomes insoluble and separates from a solution due to heat or a chemical reaction. The term is used to indicate the act of forming a solid and for the substance that is precipitated out of a solution.

Pumice: Light rock froth produced by the violent separation of gas from lava. Because of the many gas bubbles, some of this froth is so light that it floats on water.

Pyroclastic flows: A high-density mass of gases, hot ash, and larger material that flows rapidly down the sides of the volcano. Flows tend to be confined to valleys. Because of the speed at which they travel and the intense heat, pyroclastic flows and surges are one of the most dangerous hazards posed by volcanoes.

Pyroclastic surge: A turbulent, low-density cloud of hot rock debris and gases that moves at extremely high speeds. Because surges are low density, they tend to spread over large areas and jump ridge crests easily.

Quiescent: A volcano that is not active, but is still registering seismic activity. When there is no more seismicity, the volcano is dormant, but still capable of erupting (see dormant, extinct).

Reservoir: A place where a large supply of magma collects.

Ring of Fire: A zone around the perimeter of the Pacific Ocean containing about two-thirds of the world's active volcanoes.

Seismograph: An instrument used to measure the shaking caused by an earthquake.

Shield Volcano: Volcanoes with broad, gentle slopes built by the eruption of fluid basalt lava.

Spreading Zone: An area of the surface of Earth where the plates are moving away from one another.

St. Elmo's Fire: An electrical discharge, like that found in a neon sign, occuring in nature on pointed objects during electrical storms. Such phenomenon occasionally occur in the ash cloud of a volcano.

Steam (Phreatic) eruption: An explosive volcanic eruption caused when water and heated volcanic rocks interact to produce a violent expulsion of steam and pulverized rocks. Magma is not involved.

Stratosphere: The layer of Earth's atmosphere that begins about 11 km (7 mi) above Earth and ends about 50 km (31 mi) above Earth. Clouds rarely form here and the air is very cold and thin.

Stratovolcano: A large, steep-sided, symmetrical cone built of alternating layers (strata) of lava, ash, cinders, blocks, and bombs. Also called composite volcanoes, these stratovolcanoes form some of Earth's grandest mountains, rising as much as 8,000 feet above their bases.

Strombolian Eruption: Derived from the volcano Stromboli, these eruptions, typically intermittent and of short duration, throw out blocks, bombs and lava flows. Stromboli is one of the Aeolian Islands north of Sicily and has been almost continuously in eruption for at least the past 2,400 years.

Summit: The top of a mountain or volcano.

Tapu: Maori word for something that is sacred.

Tectonic plates: A rigid section of Earth's crust that moves relative to other such sections on Earth's surface.

Tephra: The general term used by volcanologists for fragments of volcanic rock and lava of any size expelled from a volcano.

Tsunami: Term for large, rapidly moving water waves caused by the displacement of water, usually by earthquakes, landslides and volcanic eruptions. Tsunamis are also referred to as tidal waves, but they have no relation to tides.

VEI: Volcanic explosivity index measure of the size of eruptions. This measurement takes into account the height of the eruption cloud, amount of material erupted (ash, tephra, etc.) and distances to which objects of particular size were thrown.

Vent: Opening in Earth's crust through which volcano expels ash, other volcanic products and gases.

Viscosity: Resistance of a liquid to flow. Thick liquids have high viscosity, thin liquids have low viscosity.

Volcano: A vent in Earth's crust through which molten or hot rock, steam, and ash reach the surface, including the cone built by the eruptions.

Volcanic bombs: See bombs.

Volcanic gas: Dissolved gases contained in the magma are released into the atmosphere during volcanic eruptions. Gases may also escape continuously from volcanic vents, fumaroles, and hotsprings. The most common gas released is steam (H_2O), followed by CO_2 (carbon dioxide), SO_2 (sulfur dioxide), (HCl) hydrogen chloride and other compounds. For more information on volcanic gases, see http://volcanoes.usgs.gov/Hazards/What/VolGas/volgas.html

Volcanic lightning: Lightning fomed as a result of electrical charges in the volcano plume due to the negatively charged falling ash particles and positively charged condensed volcanic gas associated with the plume.

Volcanologists: Scientists who study volcanoes.

Vulcanian eruption: Moderate-sized explosive eruption that ejects new lava fragments that do not take on a rounded shape during their flight through the air. The name comes from Vulcano, one of the Aeolian Islands north of Sicily, believed to be the home of the Roman god of fire, Vulcan.

Volcano Feature Word Search

Find the name of the following volcano features in the table below. Names can run up, down, left, right, and diagonal—both forwards and backwards.

T	A	T	N	E	D	R	A	E	E	U	N	C
N	S	M	O	B	L	A	H	A	R	V	H	A
E	H	A	C	M	O	D	P	R	I	E	G	L
D	C	G	L	O	W	M	L	T	F	K	E	E
R	L	A	M	B	N	H	U	H	S	A	O	R
A	O	M	L	A	L	E	M	S	O	U	T	I
E	U	G	C	D	V	A	E	T	M	Q	H	F
R	D	A	O	R	E	H	R	N	L	H	E	F
O	J	M	A	E	I	R	L	E	E	T	R	O
S	E	V	U	T	N	I	A	V	T	R	M	G
O	A	O	N	A	C	L	O	V	S	A	A	N
L	K	D	O	R	M	A	N	T	H	E	L	I
V	E	N	O	C	R	E	D	N	I	C	E	R

AEROSOL
ASH CLOUD
BOMB
CALDERA
CINDER CONE
CONE
CRATER
DOME
DORMANT
EARTHQUAKE
GEOTHERMAL
LAHAR
LATERAL BLAST
LAVA
MAGMA
NUEE ARDENT
ORE
PLUME
RING OF FIRE
ST ELMOS FIRE
VEI
VENT
VOLCANO

Volcano Name Word Search

Find the name of the following volcanoes in the table below. Names can run up, down, left, right, and diagonal—both forwards and backwards.

Z	A	G	K	R	A	K	A	T	A	U	T	M
B	I	N	S	T	R	O	M	B	U	F	C	D
P	K	U	T	U	V	T	O	F	L	O	I	F
I	A	G	R	S	T	H	E	L	E	N	S	R
N	E	N	O	L	R	I	N	G	P	I	U	E
A	P	U	M	V	E	S	U	E	I	M	V	O
T	R	L	B	R	H	D	L	Z	N	A	I	H
U	E	A	O	L	R	E	O	I	A	I	S	U
B	T	G	L	C	H	U	J	D	T	N	E	R
O	A	U	I	T	A	N	P	E	A	E	N	U
K	R	M	S	U	I	V	U	S	E	V	A	A
Z	C	N	A	R	O	B	M	A	T	G	E	G
S	L	A	M	I	N	G	T	O	N	M	O	N

CRATER PEAK
GALUNGUNG
KRAKATAU
LAMINGTON
MT. SPURR
NEVADO DEL RUIZ
NGAURUHOE
PELE
PINATUBO
ST. HELENS
STROBMOLI
TAMBORA
VENIAMINOF
VESUVIUS

Word Search Teacher's Key

T	A	T	N	E	D	R	A	E	E	U	N	
	S			B	L	A	H	A	R			
	H	A	C	M			P		I	E	G	
			L	O			L		F	K	E	E
	L	A		B	N		U		S	A	O	R
A	O	M	L		L	E	M		O	U	T	I
E	U	G		D	V	A	E	T	M	Q	H	F
R	D	A	O	R	E		R	N	L	H	E	F
O		M	A	E	I	R		E	E	T	R	O
S	E	V		T			A	V	T	R	M	G
O	A	O	N	A	C	L	O	V	S	A	A	N
L		D	O		M	A	N	T		E	L	I
	E	N	O	C	R	E	D	N	I	C		R

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Z		G	K	R	A	K	A	T	A	U		
	I	N	S							F		
P	K	U	T							O		
I	A	G	R	S	T	H	E	L	E	N	S	
N	E	N	O	L					P	I		E
A	P	U	M		E			E		M		O
T	R	L	B	R		D	L			A		H
U	E	A	O		R	E	O			I		U
B	T	G	L			U		D		N		R
O	A		I				P		A	E		U
	R		S	U	I	V	U	S	E	V		A
	C		A	R	O	B	M	A	T		E	G
	L	A	M	I	N	G	T	O	N	M		N

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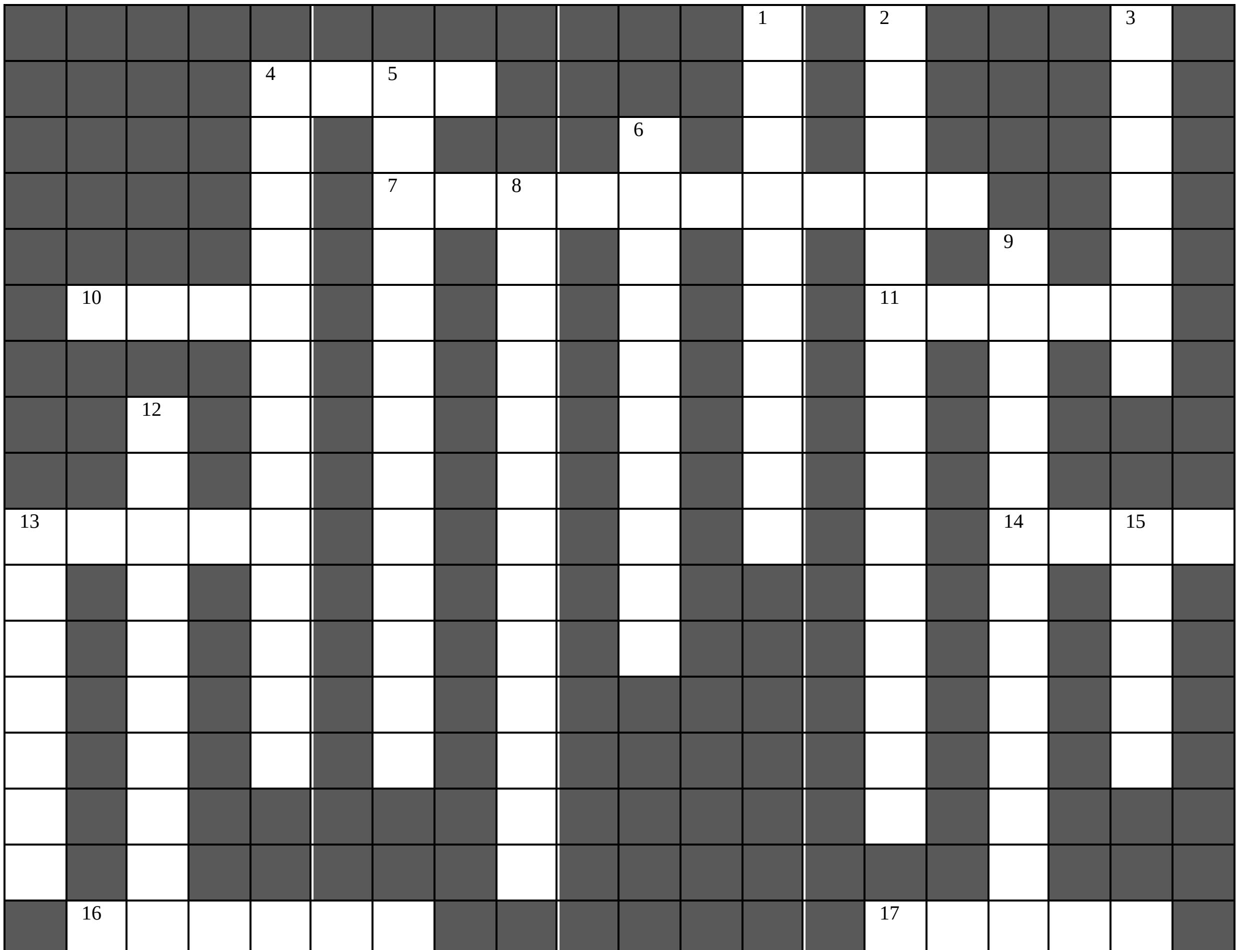
Stratovolcano Crossword Puzzle

Test your knowledge of volcanoes! The answers to the crossword clues below are found in the Stratovolcano stories, features, and glossary.



ACROSS		DOWN	
4	Maori word signifying pride, identity.	**1**	This eruption affected global weather and closed an U.S. airbase.
7	Alaskan volcano; two of the largest eruptions recorded are its 3,700 BP and 1750 eruptions.	**2**	Hazard composed of hot gas, ash, and other material, flows rapidly down sides of volcano.
10	Opening through which volcano erupts.	**3**	Depression formed by inward collapse of volcano.
11	Volcanic debris and / or mud flow.	**4**	1980 eruption devasted 596 square km of forest.
13	Name of robot used to explore Mt. Erebus.	**5**	Lahar from 1985 eruption killed 20,000+ people.
14	Term for lava, shaped like a half-ball, over a volcano vent.	**6**	Java volcano active between 1982-1985, ash cloud associated with St. Elmo's Fire.
16	Hot spring which erupt steam or water.	**8**	Light-weight, super-heated gases that speed down volcano flank.
17	Rock fragment ejected from volcano that is greater than 64 mm diameter.	**9**	Volcano type characterized by broad, gentle slopes of basalt lava.
		12	Name of area around Pacific Ocean containing two-thirds of active volcanoes.
		13	Measure of how heavy object is for its size.
		15	Molten rock below surface of Earth.

Stratovolcano Crossword Puzzle - Answer Key

Test your knowledge of volcanoes! The answers to the crossword clues below are found in the Stratovolcano stories, features, and glossary.

												1 M		2 P				3 C	
				4 M	A	5 N	A					T		Y				A	
				O		E				6 G		P		R				L	
				U		7 V	E	8 N	I	A	M	I	N	O	F			D	
				N		A		U		L		N		C		9 S		E	
	10 V	E	N	T		D		E		U		A		11 L	A	H	A	R	
				S		O		E		N		T		A		I		A	
		12 R		T		D		S		G		U		S		E			
		I		H		E		A		G		B		T		L			
13 D	A	N	T	E		L		R		U		O		I		14 D	O	15 M	E
E		G		L		R		D		N				C		V		A	
N		O		E		U		E		G				F		O		G	
S		F		N		I		N						L		L		M	
I		F		S		Z		T						O		C		A	
T		I						E						W		A			
Y		R						S								N			
	16 G	E	Y	S	E	R								17 B	L	O	C	K	

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	DOWN
1	This eruption affected global weather and closed an U.S. airbase.
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