Lesson: Mt. Pinatubo and the Hydrosphere

Background Article

Before April 1991, when steam explosions blasted out three small craters on the north flank of Mount Pinatubo on the island of Luzon in the Philippines, the volcano had been dormant for 500 years, allowing lush tropical vegetation to cover its slopes. Eventually, the population of the region grew to nearly 1,000,000 people as towns, cities, and hundreds of villages were built on the broad gentle slopes surrounding the volcano.

The climactic explosions of June 14–16, 1991, blasted away the summit of Pinatubo, blew down surrounding forests, and rained hundreds of cubic meters of loose sand and gravel down on the mountain’s upper slopes. The eruption produced two major environmental effects. The first effect was the vast quantities of sulfur dioxide aerosols that were spewed into the stratosphere. The second major effect was the production of post-eruption mudflows, or lahars. Lahars are fast-moving mudflows of volcanic ash and debris caused by heavy rains.

The same three days of the eruption, the island of Luzon was pummeled by Typhoon Yunya, passing about 75 km (50 miles) north of the volcano. The volcanic ash cloud that normally would have been dispersed across the oceans was redistributed over Luzon by the cyclonic winds of the typhoon, greatly exacerbating the damage caused by the eruption. The water-laden ash fell over the evacuated Clark Air Base, as well as the rest of Luzon, resulting in downed power lines and the collapse of flat-roofed buildings. In some areas it was practically raining mud.

Nature and Causes of Lahars

Lahars don’t just happen during typhoons. Explosive eruptions deposit huge amounts of ash and other volcanic debris on the nearby slopes. Any source of water—intense rainfall, melting snow and ice, or the sudden failure of a natural dam—has the potential to mix with this loose volcanic material, and create mudflows that can be particularly dangerous and destructive.

Although lahars contain at least 40% (by weight) volcanic ash and rock fragments—making them dense and viscous like wet concrete—they actually flow faster than clear-water streams. These mudflows can rush down the flanks of a volcano at speeds as great as 40 miles (65 kilometers) per hour and can travel more than 50 miles (80 kilometers). Lahars that contain the most debris (as much as 90%) move the fastest and are the most destructive.

Lahars usually travel down valleys. When the largest and fastest lahars reach the lowlands surrounding Pinatubo, they have speeds of more than 20 miles per hour and travel up to 20 miles (32 kilometers), destroying everything in their path.

The village of Lourdes, built on lowlands 15 miles northeast of Mount Pinatubo, was inundated by giant, fast-moving mudflows of volcanic debris (lahars) in the months following the volcano’s cataclysmic June 1991 eruption. Since that eruption, lahars have destroyed the homes of more than 100,000 people in the area surrounding Pinatubo.

When a lahar travels down valley, the high point of the lahar is usually marked by the mudline it leaves on trees, valley walls, and buildings. This mudline marks the upper limit of how high a lahar will go. This upper limit is important because it defines how high people must go to be out of danger from the lahar.
Lahars form 1) from debris avalanches that contain water from snow and ice which, when released, mixes with loose debris to form a lahar, 2) from pyroclastic flows and surges which release water that mixes with debris, 3) from pyroclastic flows which dilute themselves with river water as they travel downslope, 4) from natural dam failure (i.e. a lava flow dam or crater lake), and 5) from rainfall on loose material such as ash. Lahars that contain 20 to 60 percent sediment are usually very turbulent. Lahars that contain greater than 80 percent sediment usually flow more smoothly (laminar flow). These smooth flowing lahars usually travel much faster than their turbulent counterparts and can float boulders, cars, buildings, and bridges.

By 1993, lahars had already caused more devastation in the lowlands than the eruption itself. Fortunately, a system to monitor and warn of lahars was rapidly established in the days following the eruption by the Philippine Institute of Volcanology and Seismology, U.S. Geological Survey, and other organizations. This system has saved hundreds of lives by enabling warnings to be sounded for most, but not all, major lahars at Pinatubo.

**Legend**
1. O’Donnell River
2. Sacobia-Bamban River
3. Pampanga River
4. Pasig-Potrero River
5. Marella River

The volume of Pinatubo’s lahars is mind-staggering. In the first few years following the cataclysmic 1991 eruption, they deposited more than 0.7 cubic miles (3 cubic kilometers; equivalent to 300 million dump-truck loads) of debris on the lowlands surrounding the volcano, burying hundreds of square miles of land. During heavy rains, lahars at Pinatubo can transport and deposit tens of millions of cubic yards of mud in a single day.

In August 1991, two months after the eruption, this house along the Sacobia-Bamban River 15 miles from the volcano was buried by a lahar. Only the tops of the roofs may be seen in the center of the photo. Inset photo shows the house before it was buried.

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Astronauts continue to photograph the changing landscape around Mt. Pinatubo. (See the photos below.) The lahars are easily identified on photographs from space: the light, even-colored river drainages radiate outward from the center of the mountain. The Pasig-Potrero River shown here drains eastern slopes of Mt. Pinatubo, just south of the former Clark Air Force Base. Some of the most destructive floods have swept down this river basin due, in part, to channeling and breakout of the mudflows through levees built to confine the lahars.

The time series of images focuses on the river and the progressively flooded regions surrounding the river basin from 1992 to 1996.

Review

1. Using what you know about Earth’s spheres, go back through this article and identify the Event-to-Sphere and Sphere-to-Sphere interactions.

2. What is a lahar? What makes it so destructive?

3. What two conditions are necessary for a lahar to occur?

4. Explain why astronauts and earth scientists are interested in studying the effect of lahars so many years after the eruption.

5. What should civil engineers do to help prevent destruction from lahars?

6. Can you think of an invention that could be designed to help warn or prevent destruction from lahars?
Activity: Save Mt. Redoubt

In 2009, Mt. Redoubt in Alaska erupted. Mt. Redoubt is capped with glaciers and prior to the eruption had an ice filled summit crater. After the eruptions began on March 22, the ice in the summit crater and much of the glaciers on the flanks of the volcano melted and mixed with ash. The lahars flowed down the valleys and threatened the Drift River Oil Terminal.

In this activity you will map out a potential path of a lahar on Mt. Redoubt in Alaska, using what you know about water flow and topography. You will compare your prediction to the paths created in the 2009 eruption.

Before you begin, you should read the article (Mt. Pinatubo and the Hydrosphere) and be able to answer the questions below. If you desire additional background on the topic, please visit

- [http://www.geo.mtu.edu/volcanoes/hazards/primer/lahar.html](http://www.geo.mtu.edu/volcanoes/hazards/primer/lahar.html) (there are 3 videos linked here which are good to watch)
- [http://www.cotf.edu/ete/modules/volcanoes/vhazards.html](http://www.cotf.edu/ete/modules/volcanoes/vhazards.html) (see page 3)
- (advanced) [http://eol.jsc.nasa.gov/EarthObservatory/Astronauts_Photograph_Mount_Pinatubo.htm](http://eol.jsc.nasa.gov/EarthObservatory/Astronauts_Photograph_Mount_Pinatubo.htm)

Self Check Questions

1. What is a lahar? What is it made of?
2. How fast can a lahar travel down a valley?
3. Why do lahars travel in valleys?
4. After the eruption of Mt. Pinatubo in 1991, what caused secondary lahars to form after the initial eruption?
5. Lahars that contain ____ to ____ percent of sediment are very turbulent (not smooth). Lahars with greater than ____ percent sediment usually flow more smoothly.

Instructions


B. Print the topographic map of the Mt. Redoubt area. Go to [http://www.challenger.org/gcce/assets/Mt_Redoubt_Topo.png](http://www.challenger.org/gcce/assets/Mt_Redoubt_Topo.png), download, and print the map (preferably in color).

C. Open the full-color image found here (from August 2000) [http://earthobservatory.nasa.gov/images/imagerecords/36000/36991/redoubt_17_20000229_lrg.jpg](http://earthobservatory.nasa.gov/images/imagerecords/36000/36991/redoubt_17_20000229_lrg.jpg) Print, if needed.

D. Google Earth can be used to gain a better perspective on the contours of the region.

If you do not have access to Google Earth, skip to step G.

If you are using Google Earth, and your teacher or technology specialist has not already done so, download and open the topo map overlay available from [http://www.gearthblog.com/kmfiles/topomaps.kmz](http://www.gearthblog.com/kmfiles/topomaps.kmz) (alternate: [http://www.gelib.com/maps/_NL/usgs-topographic-maps.kml](http://www.gelib.com/maps/_NL/usgs-topographic-maps.kml))
STUDENT WORKSHEET  |  Mt. Pinatubo and the Hydrosphere

E. Adjust your Google Earth settings (see image to the right)
   • In the SEARCH box, search for “Mt. Redoubt, AK”. Click on the magnifying glass.
   • Under PLACES, be sure the “USGS Topo Maps” layer is checked.
   • In the LAYERS menu, uncheck all the boxes except: Borders and Labels, Roads, and Water Bodies.
   • (See image below) For enhanced viewing, go to Tools > Options > 3D Viewing. Under Terrain Quality, click Show Terrain. You may try setting Elevation Exaggeration to 3. Click OK. Now you may use the joystick in the upper right to fly over the mountains at an angle and view them three-dimensionally.

F. Use Google Earth to determine the areas where you would expect to see lahars. Zoom into an altitude of about 10 miles and make your observations (your altitude may be found in the lower right corner of the screen). Now zoom out to about 25 miles elevation and make more observations. Note that blue contour lines show snow fields and glaciers.

G. On your printout of the contour map, assess and shade in the places where you predict lahars would flow. For an example, see: http://www.volcano.si.edu/volcanoes/region15/andes_c/llaima/3301lla4.jpg

H. Once you have made your assessment, go to these websites to evaluate your predictions using recent and earlier eruption images.
   • http://earthobservatory.nasa.gov (Use SEARCH to look for “redoubt lahar”)
   • http://geology.com/usgs/redoubt-volcano-photos/
   • You will also find some powerful photos here http://www.boston.com/bigpicture/2009/04/alaskas_mount_redoubt.html
Analysis: Applying Predictions

1. Did some of your lahar predictions match the real lahar patterns from 2009? How many of them were the same? If some were different, what factors could have affected lahar flow directions?

2. The eruption caused much of the snow on the volcano to melt. Looking at the map, do you think if the mountain erupted again, the lahars would be in the same places? Why or why not?

3. Consider and list two possible effects of ash and water flowing into the Drift River Oil Terminal (60.6 N, 152.1 W) storage tank area and into the greater Cook Inlet.

4. What other effects might volcanic eruptions and lahars have on the water cycle? Or hydrosphere in general?

5. How are the lahars of Mt. Redoubt different from the lahars of Mt. Pinatubo? How does the water source differ?