Volcanoes Hazards: Assessment & Mitigation

EAS 458
Volcanology

Introduction

- 1,300 known volcanic eruptions in past 10,000 yrs. 300,000 killed since 1000 AD.
- About 360 million people live near potentially dangerous volcanoes
  - total abandonment of areas not reasonable, need to cope with the problem of living near them.
- Risk is increasing because of increasing population, in particular in volcanic areas, Japan, Indonesia, South America.
- Volcanoes are, however, not the worst natural disasters.
  - Largest known loss of life was Tambora, 1815, with 92,000 killed, most in resulting famine.
  - 1556 Huahsien earthquake killed 800,000.
  - Hurricane in Bangladesh killed 500,000 in 1970.
Definitions

- **Volcanic Hazard**
  - The probability of a given area affected by potentially destructive volcanic processes or products within a given amount of time.
  - For example, one might say the hazard is 10% in the next 25 years.
- **Vulnerability**
  - the proportion (0-100%) of the value (or lives) likely to be lost in a given hazardous event.
- **Volcanic Risk**
  - The possibility of a loss — such as life, property, productive capacity — within the area subject to the hazard. Assessment of risk involves the consideration of the relation:
    - Risk = Value \times \text{Vulnerability} \times \text{Hazard}
  - where value may include the number of lives, property, infrastructure, production capacity, etc. threatened.
  - Thus risk could have units of lives or monetary units.

Volcanic Hazard Assessment

- Volcanologists are responsible for assessing volcanic hazards. The process of hazard assessment begins with determining the past behavior of a volcano. One of the main products of the volcanic hazard assessment process is the Hazard Zonation Map, which assigns hazard rating to geographic areas in the vicinity of volcanoes.
Reconstructing Past Behavior

- Complete records of historical eruptions.
- Prehistoric activity deduced from geologic record.
- Geologic data on nature and distribution of eruptive products.
- Dating volcanic products (and events producing them).

Pumice-producing eruptions of Mt. Rainer over the past 10,000 years
Uses of Hazard Zonation Maps

- Provide guidelines for long-range land-use planning.
- Determine which areas should be evacuated and avoided during eruptions.
  - Emergency Services Planning
  - Evacuation Route Planning
- Caveat: volcanoes do not always follow previous history.
Hazards Associated with Volcanic Events

- Volcanoes pose a variety of hazards, a complete hazard assessment must consider all relevant ones and consider and predict the distribution of each.
  - This can involve producing several hazard zonation maps

Hazards to Consider
- Lava Flows and Domes
- Pyroclastic Flows and Surges
- Structural Collapse
- Lahars
- Tephra Falls and Ballistics
- Volcanic Gases
- Volcanic Earthquakes
- Atmospheric Shock Waves
- Tsunamis

Lava Flows and Domes

- With rare exceptions, flows advance slowly and present little hazard to life.
- Threat to property is serious
- Flow paths can be predicted
  - Extent is more difficult and depends on effusion rate and physical properties
- Some successful interventions have been achieved
  - Heimaey, Iceland - cooling with water
  - Etna - explosives, barriers
**Pyroclastic Flows and Surges**

- Most hazardous of volcanic events, grave threat to life.
- Associated with andesitic and dacitic volcanoes and silicic calderas.
- Can travel at >100 km/hr and, in cases of large ignimbrites, cover tens of thousands of km².
- Very effective at melting ice, so floods and lahars are secondary hazard.
- Flows are topographically controlled, so path can be predicted.
- Surges not topographically controlled - more difficult to predict.

**Flow and Surge Hazard**

- Fatalities
  - >2000 in Vesuvius in 79 AD
  - >28,000 in Mt. Pelee, 1902
  - >1500, Soufriere, 1902
  - Mt. Lamington, 1951 ~ 3000
  - El Chichon, 1982 ~ 2000
- Very considerable property damage also occurs.
- Escape is essentially impossible once flow has begun; prior evacuation is only effective method of mitigation.

Ruins of a rum distillery, St. Pierre
Recent measurements by \textit{in situ} sensors

- Pressure of associated surge (<0.5 bar; 0.1 bar pressure corresponds to wind of 450 km/hr).
- Velocities of ash particles as high as 160 m/s (575 km/hr).
- Flow front velocities: 20-80 km/hr
- Flow interior $T = 600^\circ$C
- Ash cloud $T = 350^\circ$C

Damage to boiler tank made of 1/4” iron

Structural Collapse & Debris Avalanches

- Due to their unstable nature, volcanoes are particularly subject to collapse.
- These collapses may or may not be associated with eruptions.
- Non-eruption-related collapses generate debris avalanches that are a serious hazard and can generate lahars and tsunamis.
Mt. Rainier Debris Avalanche: A Quick Case History

- Mt. Rainier suffered a major ‘sector’ collapse 5600 years ago, transforming into a 50 km lahar that produced a deposit known as the Osceola landslide.
  - Intruding magma caused hydrothermally weakened summit rocks to fail.
- A smaller collapse about 500 years ago produced the Electron Mudflow.
- Distal ends of these flows reached areas that are now the highly populated suburbs of Tacoma and Seattle.

Generations of the Osceola Flow
Lahars & Floods

- Affect both life and property (23,000 killed by Nevado del Ruiz in 1985). Threat to navigation and bridges. Long lasting effects can include reducing the carrying capacity of rivers, making them more prone to flooding.
- Lahars generation
  - Catastrophic release of water in crater lake by eruption
  - Water-saturated avalanches or avalanches that overrun rivers
  - Pyroclastic flows that overrun water
  - Meltwater from mixing of pyroclastic flows with snow and ice

Lahar Mitigation Strategies

- Lahars have well-defined topographic limits.
- With early warning, lives can be saved by moving people out of valley (typically only a short distance).
USGS Experimental Lahar Detection System

- USGS has installed experimental Acoustic Flow Monitors (AFM) in Puyallup and Carbon River valleys draining Mt. Rainier.
- Lahars are detected by their acoustic signal (rumbling) and warning radioed to county and city 911 centers.
- In addition, 2 AFM stations in each valley located within the expected lahar inundation zone. Those stations serve as "deadman" devices whose destruction would be noted by the system and warn of a dangerous event.

Tephra Fall and Ballistic Projectiles

- Tephra falls are widest-ranging hazard.
- Bombs can travel great distances: 1 m bombs fell 4.5 km from source in Asama (Japan), 1938; pumice bombs up to 100 mm can travel 20-80 km.
- Tephra and Bombs endanger life by:
  - Force of impact
  - Burial
  - Suspension of fine-grained particles in air and water (suffocation)
  - Carrying noxious gases and heat
- Threats to property:
  - Collapse of structures due to weight
  - Impact damage
  - Disruption of transportation
  - Damage to utilities including electrical generation, sewers, surface drainage, communications facilities
  - Agricultural damage, loss of land use
Volcanic Gases

- Toxic gases: carbon monoxide, sulfur oxides, hydrogen sulfide, chlorine, fluorine. Often transported as acid aerosols. Carbon dioxide is not toxic but is denser than air and can kill by asphyxiation.

Limnic Eruptions: Maars of the Oku Field, Cameroon
Lake Nyos 1986 Limnic Eruption

- Lake Nyos and Lake Monoun occupy maars located in the Cameroon Line volcanic chain (exactly how they formed is a bit unclear).
- In 1984, 37 people and some livestock in the vicinity of Lake Monoun died mysteriously.
- On August 21, 1986, a large number of livestock and 1700 people died of CO$_2$ asphyxiation in a 25 km radius from Lake Nyos. Another 845 were hospitalized. In addition, vegetation was flattened and trees knocked down.
- Exactly what had happened was at first not understood.

Limnic Eruptions

- A UNESCO team of volcanologists eventually decided the cause was a previously unknown phenomenon: a limnic eruption.
- CO$_2$ is seeping slowly into both lakes from below and dissolving. (Lakes in this equatorial region are permanently stratified.)
- The deep water eventually saturated in CO$_2$, which then exsolved in bubbles.
- As the bubbles rose, they entrained deep water, pulling it up lower pressure, so more CO$_2$ exsolved.
- This eventually resulted in catastrophic exsolution and eruption of CO$_2$ from the lake.
Mitigating the Limnic Eruption Problem

- Attempting to mitigate the threats in Cameroon is complicated by the extreme poverty of the country. Any solution had to be cheap.

The Soda Straw Solution

- Deep water in both lakes is oversaturated with CO$_2$ at the surface.
- Thus if the water can pulled to shallow depth, CO$_2$ will exsolve, and the bubble-water mix will rise the rest of the way on its own.
- The solution was to place a PVC pipe in the lake that went from near bottom to the surface.
- Initial pumping on the straw “primes” it, and subsequently a self-sustained rise of water occurs.
- Enough CO$_2$ can be degassed this way to match the volcanic input, thus preventing a future limnic eruption.
Other Volcanic Hazards

- **Volcanic Earthquakes**
  - With some exceptions, these do not cause damage far from source. But can come in series lasting years.

- **Atmospheric Shock Waves**
  - Shock wave from Tambora, 1815 broke windows 400 km away. Shock wave from caldera collapse of Fernandina (Galapagos), 1968 damaged buildings 100 km away.

- **Tsunamis**
  - One of most severe hazards associated with volcanoes. Krakatau, 1883 tsunami killed 30,000.
Medical Effects: Why do people die?

- *Nuées Ardentes* (pyroclastic flows and surges) are primary killers: 70% of direct deaths
- Main indirect killers are tsunamis, lahars, and famine (atmospheric/climatic effect).

Potential Causes of injury & Death

- Thermal injury
  - apparently prime cause of injury
  - Thermal energy transferred primarily by particles rather than air or gas.
- Asphyxia
  - suffocation through inhalation of volcanic ash or gases. *Nuées* contain a few percent particles less than 7 µ, which are capable of being inhaled.
- Trauma from missiles or body displacement
- True 'blasts' are rare, so typical medical effects of blasts, e.g., rupture of eardrum, contusion of lungs are not likely to be associated with *nuées*. Nevertheless various impact injuries can be important.
- toxic gases
- crush injury
- lightning
- sandblasting of skin
- in lahars: infected wound
Medical Case History: Mt. St. Helens

- Three zones from a damage perspective
  - 1. mudslides, avalanches
  - 2. downed timber:
    - 2a: direct flow
    - 2b: topography influenced flow
  - 3. damaged, but not downed, timber
- Temperature of the flow ranged from over 350° C at source to 50-200°C where timber was singed. Temperature peak lasted 1-10 minutes, flow at any location last only 2 minutes. Velocity ranged from 160 m/s to 28m/s.
- Overall dead to injured ratio was 16:1. Overall survival rate 47%.

Mt. St. Helens Injury Types

- Zone 1, 2a:
  - no survivors, no bodies recovered. At margin, 4 survivors found, 3 died of thermal injury, 1 of asphyxia by inhalation of volcanic ash (was inside vehicle). All had bone fractures, one was dismembered.
- Zone 2b:
  - 17 bodies examined, 14 died immediately of asphyxia by inhalation of ash, 1 killed by a rock, 2 died in hospital from effects of inhaling ash and severe burns, 9 survived, generally finding a protected location. Clothing provided little protection: severe burns beneath unburned clothing was noted.
- Zone 3:
  - 2 fatalities due to asphyxiation, 2 killed by falling tree.
Mt. Pelée, 1902

- Most corpses in open lay parallel to direction of flow, many in pugilistic attitude, limbs flexed, spine extended. This attitude is associated with extreme heat (200-250° C). Many corpses mummified, also indicative of extreme, dry heat. Injured in harbor spoke of momentary blast of heat, followed by sensation of suffocating. Many had burns on skin and to respiratory tract.
- Dead to injured: 230:1

Louis-Auguste Cyparis

- 25-year-old Louis-Auguste Cyparis was only of only two survivors in St. Pierre.
- In jail for his involvement in a brawl when the volcano erupted the morning of May 8, 1902 in solitary confinement in an underground cell.
- Cyparis was severely burned by hot air and ash. He managed to survive trapped in the cell for four days until rescued.
Soufrière, 1902

- Most survivors were in houses. For those in houses, clothing provided protection against burns, but most hospitalized survivors had burns to exposed skin. 90% died from thermal effects and asphyxiation, remainder by collapsing roofs, falling stones, and lightning. Dead to injured: 11:1

NVEWS: Proposed National Volcanic Early Warning System

- 169 active volcanoes within the territory of the U.S.
- In the last 25 years, there have been eruptions or signs of unrest at 33 of these.
  - Most eruptions in Alaska, but unrest has occurred at Mt. Hood, Three Sisters (OR), Long Valley (CA), and Medicine Lake (CA).
  - “At present, about half of the most threatening U.S. volcanoes are monitored at a basic level with real-time sensors (primarily seismic arrays), and a few are well monitored with a suite of modern instrument types and methods.”
Volcanoes in the US

Elements of NVEWS

- National 24x7 Volcanic Watch Office
  - Increase inter-operability among the 5 USGS volcano observatories and permit all data streams from monitored volcanoes to be accessed in real time at multiple locations.
  - One goal: warning issued to FAA within 5 minutes of explosive eruption.
  - Improvements in monitoring based on “threat score” - the product of hazard and risk.

- Highest priorities:
  - 5 currently erupting volcanoes or exhibiting precursory unrest.
  - 13 very-high-threat volcanoes with inadequate monitoring (9 in the Cascade Range and 4 in Alaska).
  - 19 volcanoes in Alaska and the Mariana Islands that have high aviation-threat scores and no real-time ground-based monitoring to detect precursory unrest or eruption onset.

- Next priority:
  - An additional 21 under-monitored volcanoes in Washington, Oregon, California, Hawaii, Alaska, the CNMI, and Wyoming also are priority NVEWS targets.
### New USGS Alert Levels

#### Table 1. SUMMARY OF VOLCANIC-ALERT LEVELS

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
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<tbody>
<tr>
<td>NORMAL</td>
<td>Typical background activity of a volcano in a non-eruptive state. After a change from a higher level: Volcanic activity considered to have ceased, and volcano reverted to its normal, non-eruptive state.</td>
</tr>
<tr>
<td>ADVISORY</td>
<td>Elevated unrest above known background activity. After a change from a higher level: Volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.</td>
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<tr>
<td>WATCH</td>
<td>Heightened/escalating unrest with increased potential for eruptive activity (timeframe variable) OR a minor eruption underway that poses limited hazards.</td>
</tr>
<tr>
<td>WARNING</td>
<td>Highly hazardous eruption underway or imminent.</td>
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5 volcanoes currently Advisory level, 2 at Watch level