

EASC 421 - Volcanology

???

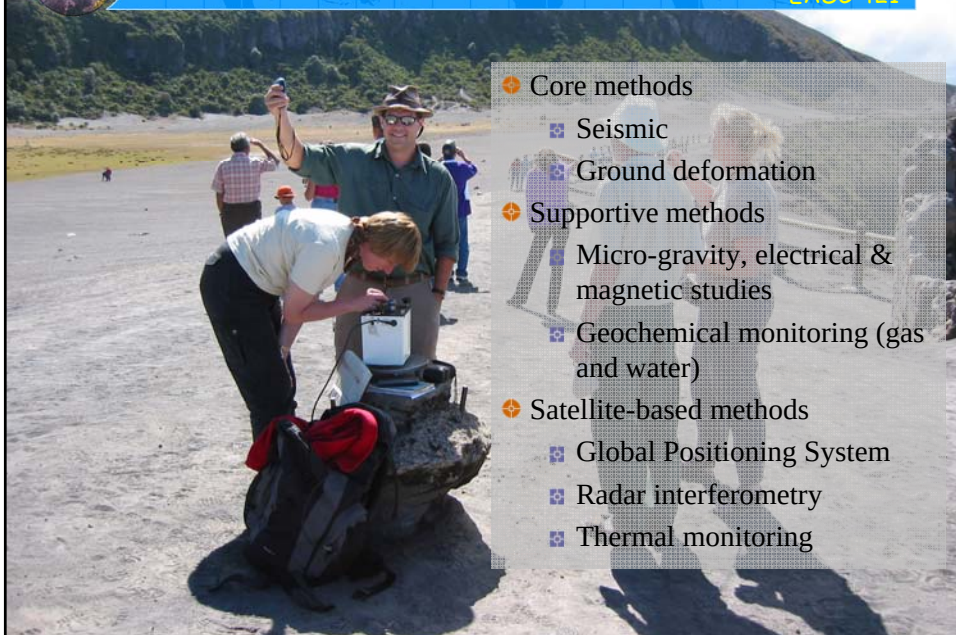


Volcano monitoring & mitigation



Volcano monitoring methods

EASC 421



Core methods

- Seismic
- Ground deformation

Supportive methods

- Micro-gravity, electrical & magnetic studies
- Geochemical monitoring (gas and water)

Satellite-based methods

- Global Positioning System
- Radar interferometry
- Thermal monitoring



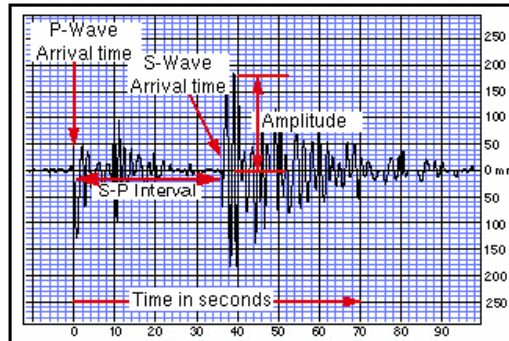
Seismogram interpretation

EASC 421

- ✦ Can determine
 - ✦ hypocentre location
 - ✦ Magnitude & frequency
 - ✦ source properties
- ✦ Record P, S & surface waves

Waves

- ✦ **Amplitude**
 - ✦ height of a wave above its zero position
- ✦ **Period**
 - ✦ time taken to complete one cycle of motion
- ✦ **Frequency**
 - ✦ number of cycles per second (Hertz)
 - ✦ felt shaking during quake has freq. from 20 Hz down to 1Hz



Human ear can detect frequencies down to 15 Hz



Seismic monitoring

EASC 421



- ✦ Earliest volcano observations using seismometers

- ✦ Vesuvius 1856
- ✦ Usu 1910
- ✦ Kilauea 1912
- ✦ Sakurajima 1914
- ✦ Aso 1930
- ✦ Merapi 1924



- ✦ Vital tool for monitoring and forecasting
- ✦ Baseline monitoring essential
- ✦ Ideal seismic networks
 - ✦ 6 or more local seismic stations (within 15 km)
 - ✦ several regional stations (>15 km)
 - ✦ capable of detecting volcanic quakes of $M \geq 0$ beneath volcano



Volcano seismicity

EASC 421

Five main types of seismic event:

- ❑ high frequency (tectonic)
 - Rock fracture (brittle strain at 0-3 km)
 - Small mag., high freq.
- ❑ low frequency
- ❑ Tremor
 - Magma/gas movement
 - Long period signals
 - Shallower level
- ❑ explosion
- ❑ surface (rock falls, lahars)

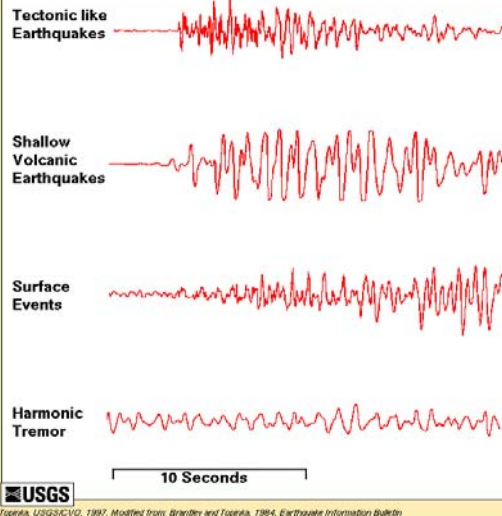
Pre-eruption quakes

- ❑ typically swarms, $M < 5$
- ❑ increase in number
- ❑ occur close to eruption location

Aseismic zones!

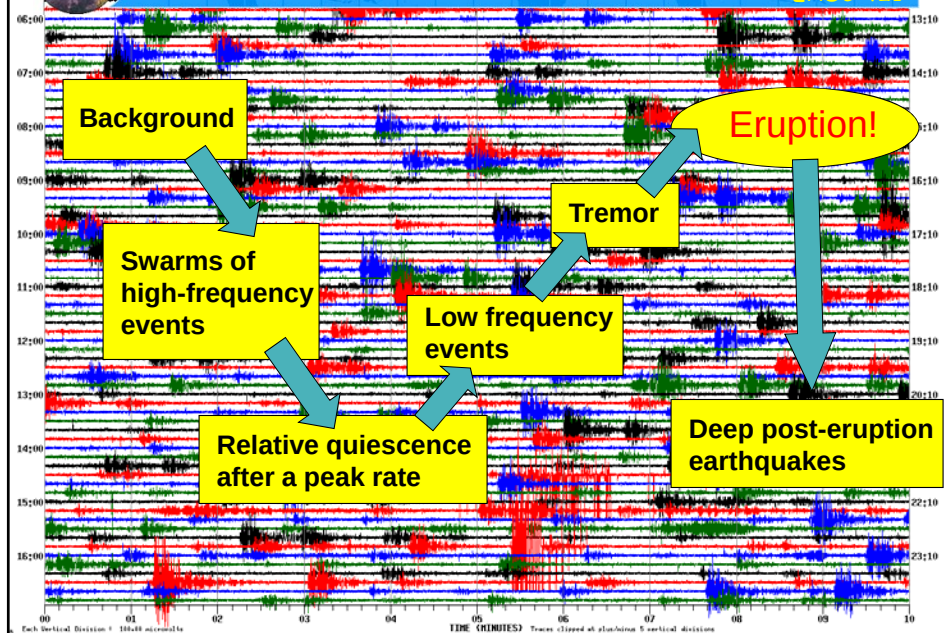
- ❑ potential magma (liquid) storage area

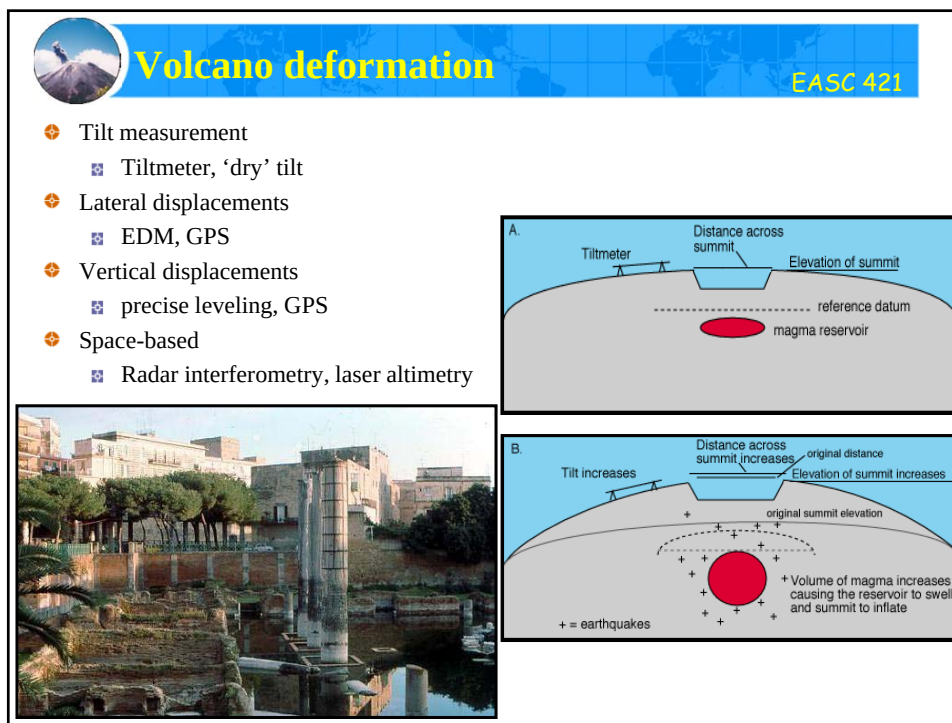
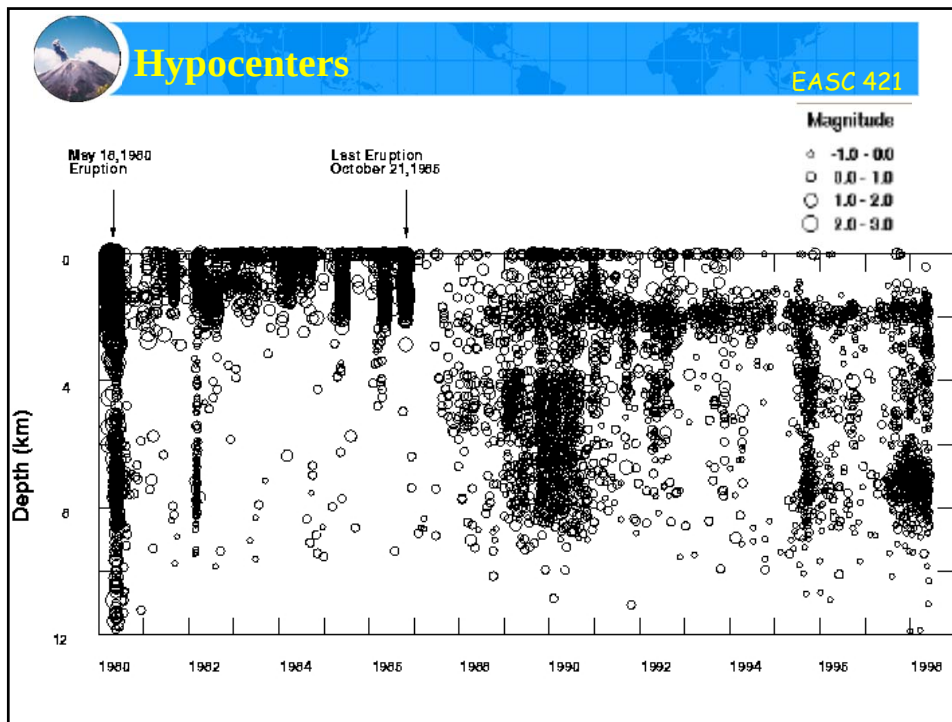
Four Major Types of Seismograms



Pre-eruption swarm sequence

EASC 421

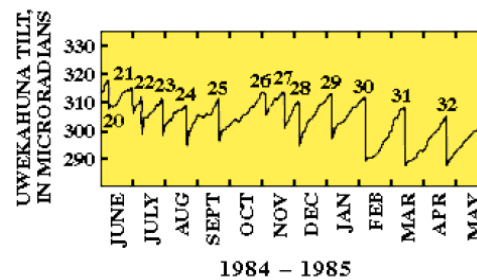
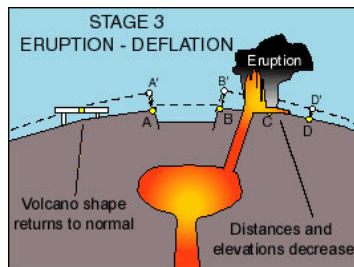
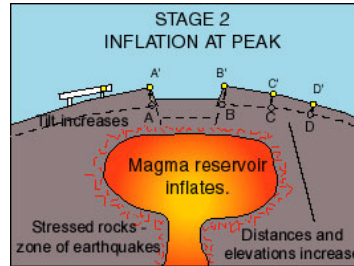
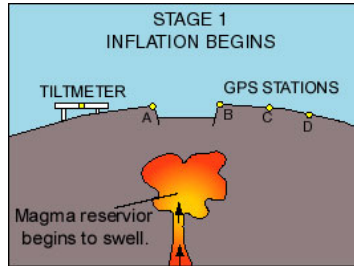






Deformation at Kilauea & Mauna Loa

EASC 421



Problem: how to determine point of maximum inflation and eruption ?



Tilt measurement

EASC 421

- ✦ Early versions - one of the oldest techniques
 - ❑ water-tube tilt-meters
- ✦ 'Dry' tilt leveling
- ✦ Borehole tiltmeters
 - ❑ provide continuous record
- ✦ can detect changes in slope as small as 1 mm over 1km distance
- ✦ **Problems**
 - ❑ site specific
 - ❑ no measure of absolute altitude change or horizontal movements





Precise leveling & Elec. Dist. Measurements EASC 421

- ✦ Most accurate way for relative height changes
- ✦ accuracies of **0.8 mm** over 1 km possible
- ✦ First used to investigate 1910 Usu eruption
- ✦ Uses a level & graduated measuring staff!
- ✦ **time consuming** and **labour intensive!**



- ✦ Measures horizontal distance changes in a network of benchmarks
- ✦ Uses laser or IR Total Stations (electronic theodolite)
- ✦ Corrections for T and P made to give final distance
- ✦ accuracies of a **few cm** over a **few km**

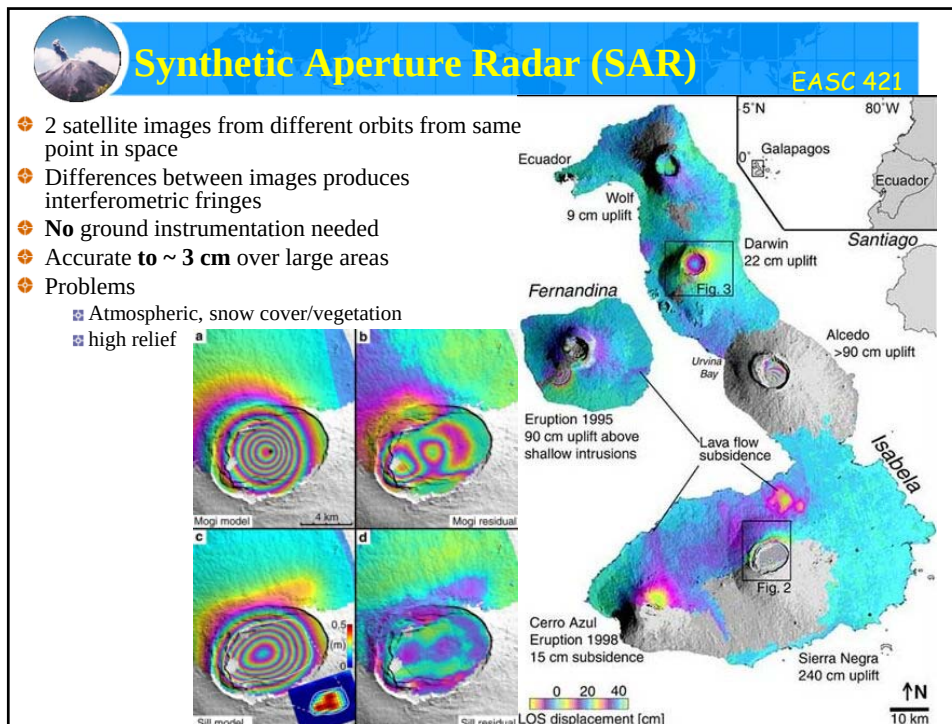


Global Position System - GPS EASC 421



- ✦ Most accurate measurement of horizontal position over large distances
- ✦ Uses 'constellation' of ~ 24 satellites that beam radio signals to Earth – need **at least 4!**
- ✦ Accuracies of a **few mm over 10s km** using dual receiver differential GPS
- ✦ **drawbacks:** line of sight; weather; \$\$\$





Thermal monitoring – Direct measurements EASC 421

The moment all great volcanoes fear

- ✦ volcanoes can begin to heat up weeks to days before an eruption
- ✦ soil & water (groundwater and surface water) temperatures can be monitored
- ✦ Direct measurement
 - ▣ using probes
 - ▣ can be dangerous for volcanologist



Thermal monitoring – Indirect measurements

✦ Indirect measurement

- ✦ radiant heat can be measured from a distance using a more sensitive device flown in aircraft/satellite

Etna: 22 Jul 2001



Erta Ale: 12 Apr 2001



Thermal monitoring – Indirect measurements

- ✦ well developed channels well developed with tube formation high on the shield

- ✦ using a hand-held device for small distances (< 2 km)





Gas monitoring – direct sampling

EASC 421

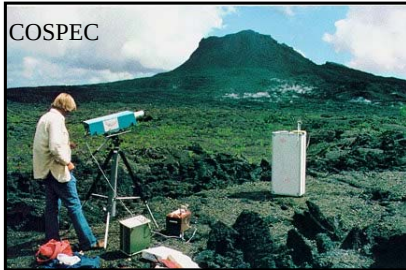
- ✦ chemistry of emitted volcanic gas can be used to determine the composition of magma & likelihood of an eruption
- ✦ capture gases emitted from vents, fumaroles, lakes & soil
- ✦ SO₂, CO₂, acids...
- ✦ Need to be close so **dangerous!** No real time **networks** yet.



Gas monitoring – indirect sampling

EASC 421

COSPEC



- ✦ Satellite, plane & ground measurements
 - ✦ certain gases are easily detectable (SO₂, H₂, HF)
 - ✦ others are not (H₂O, CO₂, CO)

FLYSPEC



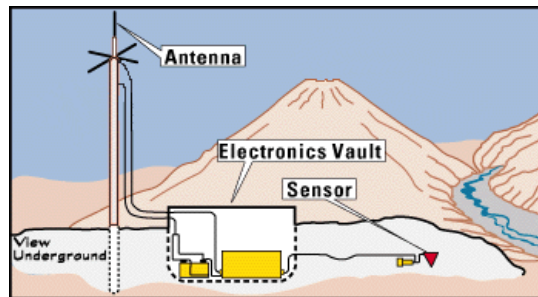
FTIR



Hydrologic Monitoring

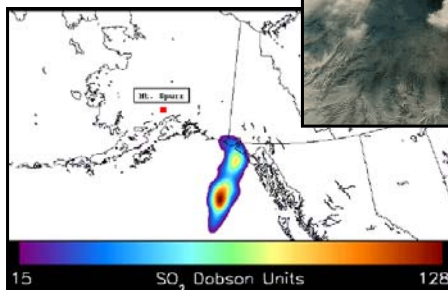
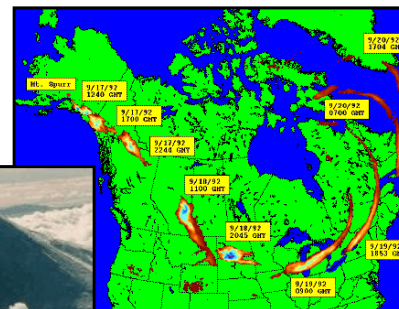
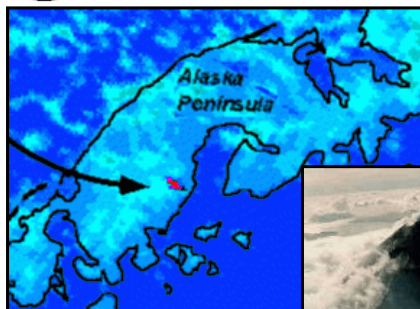
EASC 421

- ✦ lahar hazards (*days - months*)
- ✦ long-term threat of sediment transport/erosion and increased flooding (*months - years*)
 - ❑ direct sampling
 - stream gauges
 - Mapping
 - ❑ indirect sampling
 - ❑ acoustic-flow monitor (AFM) stations
 - ❑ rainfall meters
- ✦ AFM measure ground vibrations from lahars
- ✦ Insensitive to ground motion from EQ, which occur at lower frequency



Satellite monitoring

EASC 421



- ✦ SO₂, heat, ash...
- ✦ Global coverage
- ✦ Can have rapid repeat measurements (~15 min.)
- ✦ Ideal for early warning, especially in remote areas
- ✦ Volcanic ash eruptions!!



Monitoring vs Mitigation

EASC 421

✦ Mitigation

- ✦ activities, processes or procedures designed to reduce and/or eliminate the threats of volcanic hazards
- ✦ **important** to remember that mitigation is different from monitoring
- ✦ BUT monitoring is necessary for eventual mitigation

✦ Different Categories

- ✦ physical structures/effort
- ✦ public education
- ✦ use of new technologies



Lava diversion

EASC 421

- ✦ use of permanent or temporary structures to keep lava from town or structure
- ✦ works because of the slow flow rates of most lavas
- ✦ only effective sometimes & on a small scale
- ✦ large, fast flows quickly overtop any man-made structure



Etna - berm



- ✦ used successfully in '83 eruption of Etna
 - ✦ within a month flow was 6.5 km long threatening 3 towns
 - ✦ rubble barrier ~10 m high, 30 m wide & 400 m long
 - ✦ total cost = \$3 million (potentially saved ~\$5-25 million)



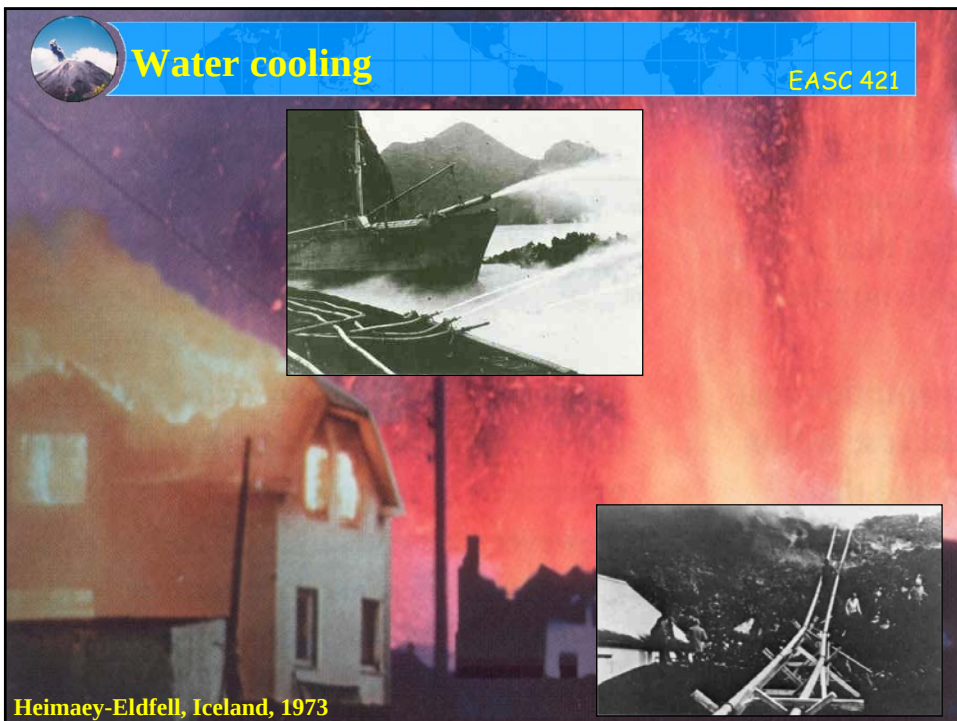
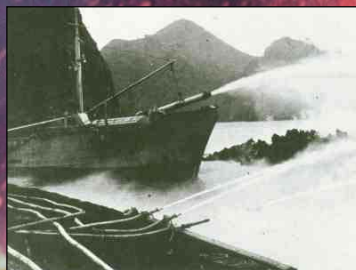
Etna

EASC 421



Water cooling

EASC 421



Heimaey-Eldfell, Iceland, 1973



Lahar diversion

EASC 421



Mayon - dam

- ✦ Sabo Dams: constructed in river valleys & designed to:
 - ✦ strain out large debris
 - ✦ divert lahar away from people/property
 - ✦ minimize erosion



Unzen - sabo works

- ✦ common in Japan & Indonesia
 - ✦ where large populations live & work near/in threatened river valleys



Unzen

EASC 421





Mitigation & Education

EASC 421

- ✦ Overcoming the '**not in my lifetime**' problem
- ✦ Coherent public education program critical
 - ✦ multiple messages, channels & agencies
 - ✦ **consistent message**
- ✦ **Schools** play a vital role
- ✦ People respond to
 - ✦ personalized information
 - ✦ facts about likelihood & severity
 - ✦ practical precautionary measures
- ✦ Involvement (Philippines)

SHOULDN'T WE START BUILDING THE VOLCANO SHELTER?

IN A MINUTE, WE'VE GOT ANOTHER 25,000 YEARS

Wearing a breathing mask?
For security reasons, please remove your mask while in the bank.
Thank you for your cooperation.
St Helens, USA

Sakurajima, Japan



New Technologies

EASC 421

- ✦ remote sensing/detection: newer satellite instruments are providing better detection
 - ✦ increased resolution & quicker coverage, which are all important for hazard mitigation
- ✦ robotics & ground-based sensors are providing needed data without endangering lives of volcanologists
- ✦ warning systems are being established
 - ✦ lahar “detectors”
 - ✦ tsunami systems
 - ✦ seismic stations



Emergency response

EASC 421

- ✦ Effective emergency response depends upon
 - ✦ pre-crisis education and training
 - ✦ an established information and warning system
 - ✦ a simple & understandable ALERT SYSTEM
- ✦ Successes
 - ✦ Pinatubo (1991), Rabaul (1994)
- ✦ Failures
 - ✦ Ruiz (1985)

GREEN:	No eruption anticipated. Volcano is in quiet, “dormant” state
YELLOW:	An eruption is possible in the next few weeks and may occur with little or no additional warning. Small earthquakes detected locally and (or) increased levels of volcanic gas emissions.
ORANGE:	Explosive eruption is possible within a few days and may occur with little or no warning. Ash plume(s) not expected to reach 25,000 feet above sea level. Increased numbers of local earthquakes. Extrusion of a lava dome or lava flows (non-explosive eruption) may be occurring.
RED:	Major explosive eruption expected within 24 hours. Large ash plume(s) expected to reach at least 25,000 feet above sea level. Strong earthquake activity detected even at distant monitoring stations. Explosive eruption may be in progress.