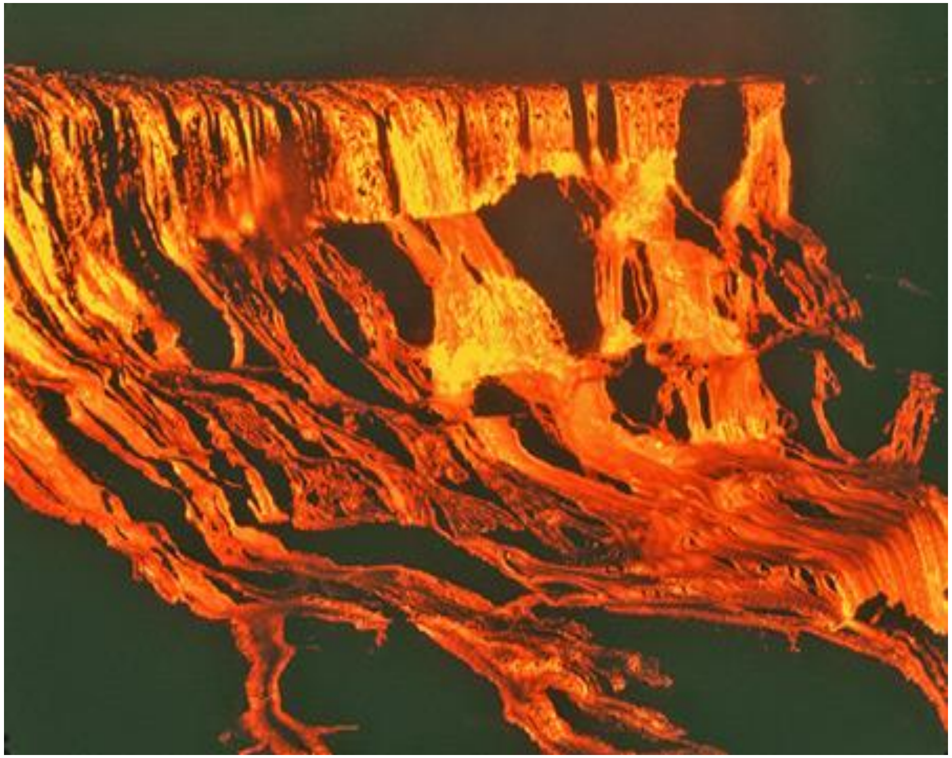
Volcanic Eruptions and Hazards

Topics

- What is a Volcano?
- Where do volcanoes occur?
- Nature of Eruptions
- Volcanoes & Plate Tectonics
  - Mid-ocean Ridge
  - Subduction Zone
  - Ocean Hotspot
- Volcanic Hazards

What is a volcano?

Volcano: hill or mountain formed by erupted lava or pyroclastic debris, or both.



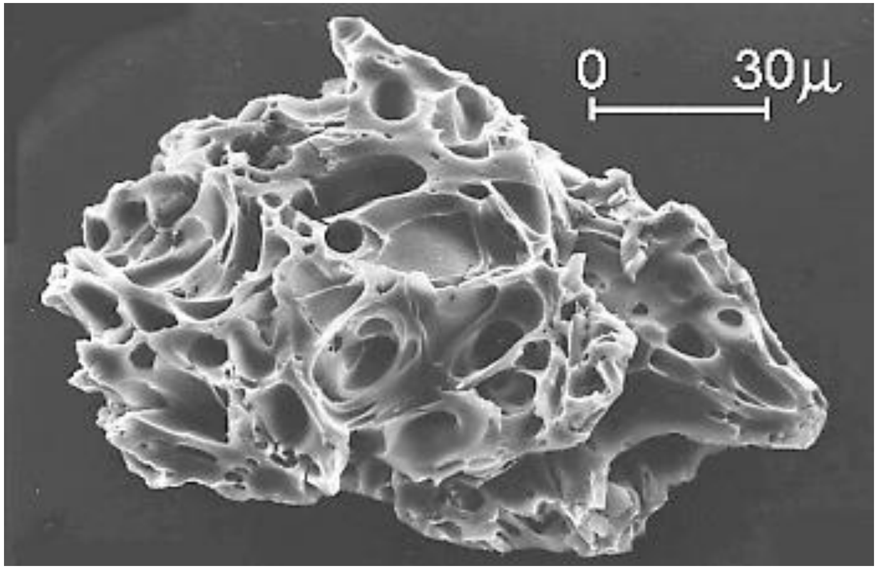
Lavas in Kilauea (USGS photo)

Pyroclastic debris from Redoubt Volcano, Alaska (USGS photo)

Volcanic bombs

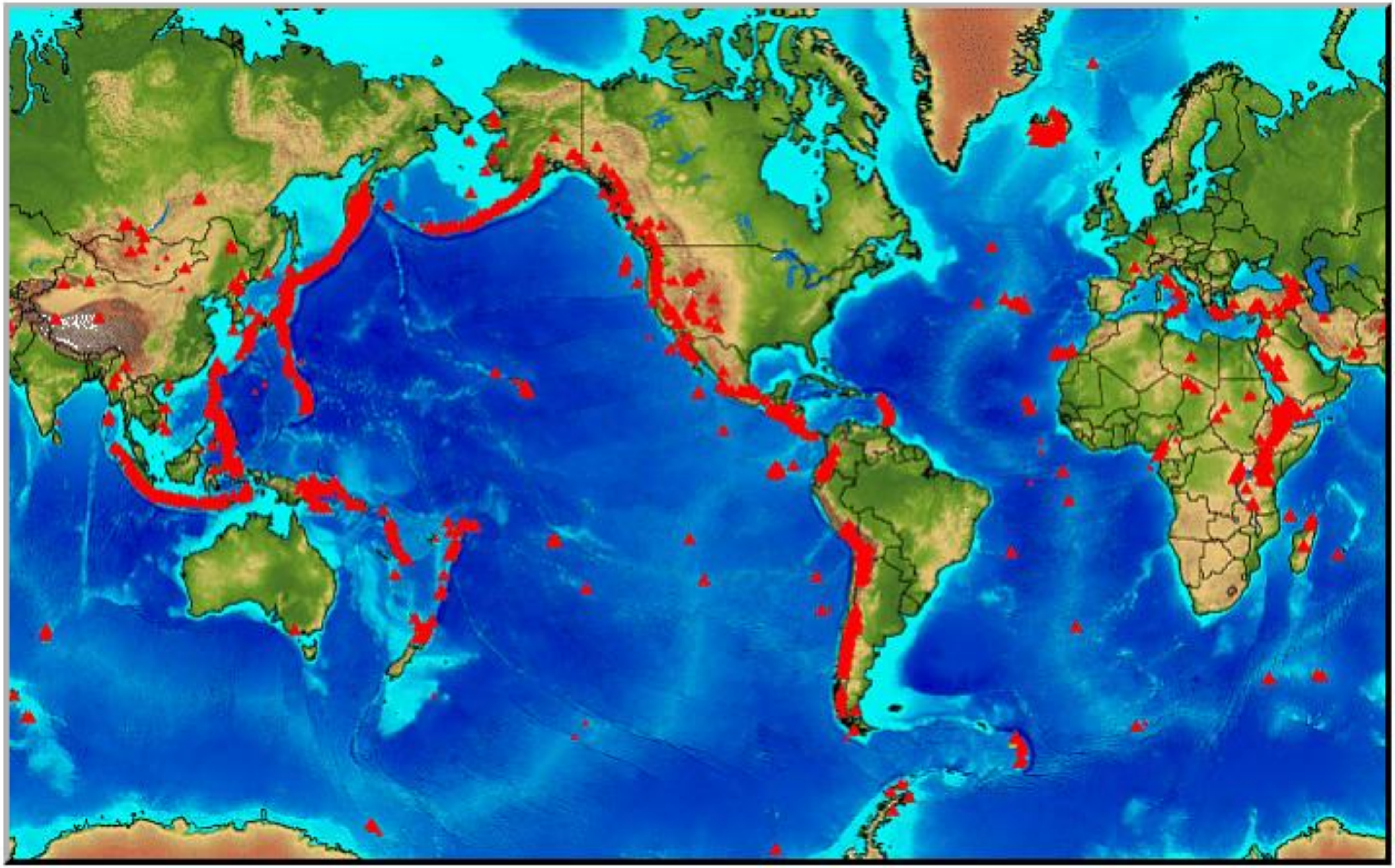
Volcanic cinders

Volcanic ash

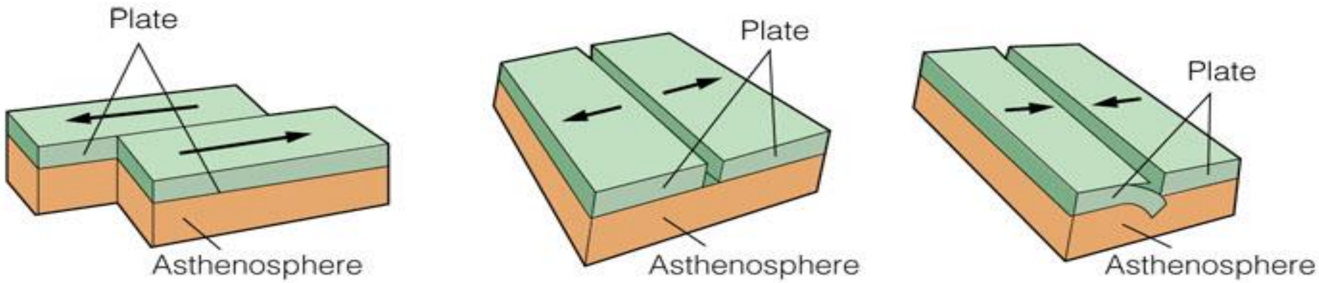


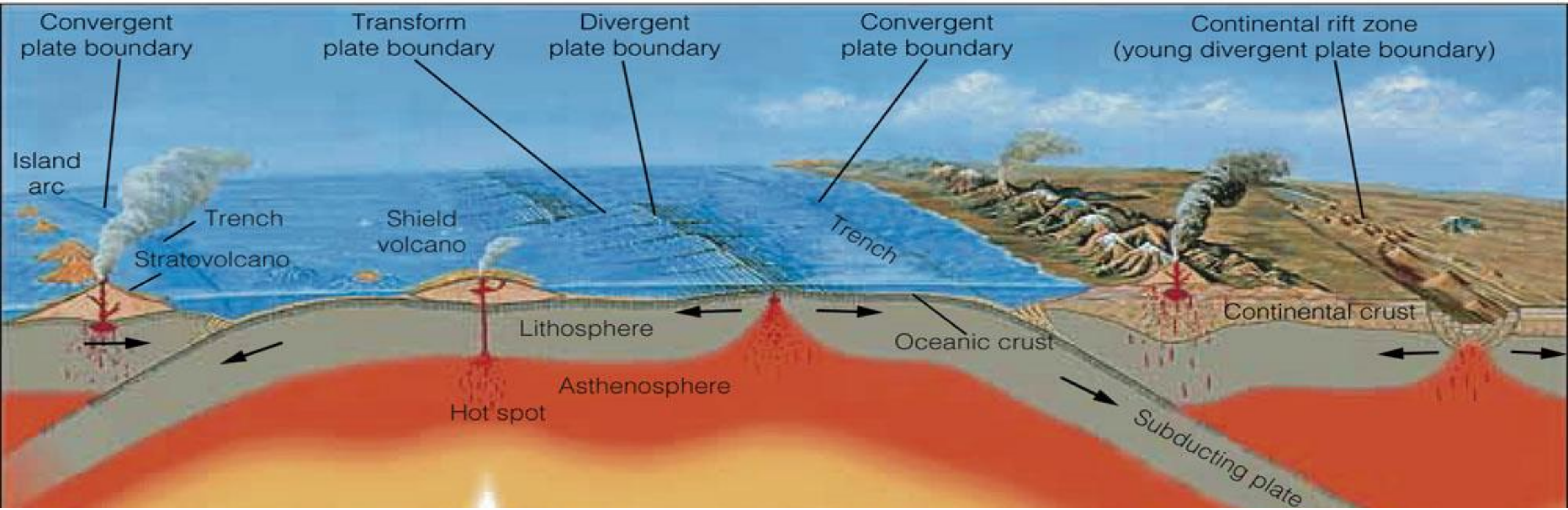
SEM image of volcanic ash

Where do volcanoes occur?



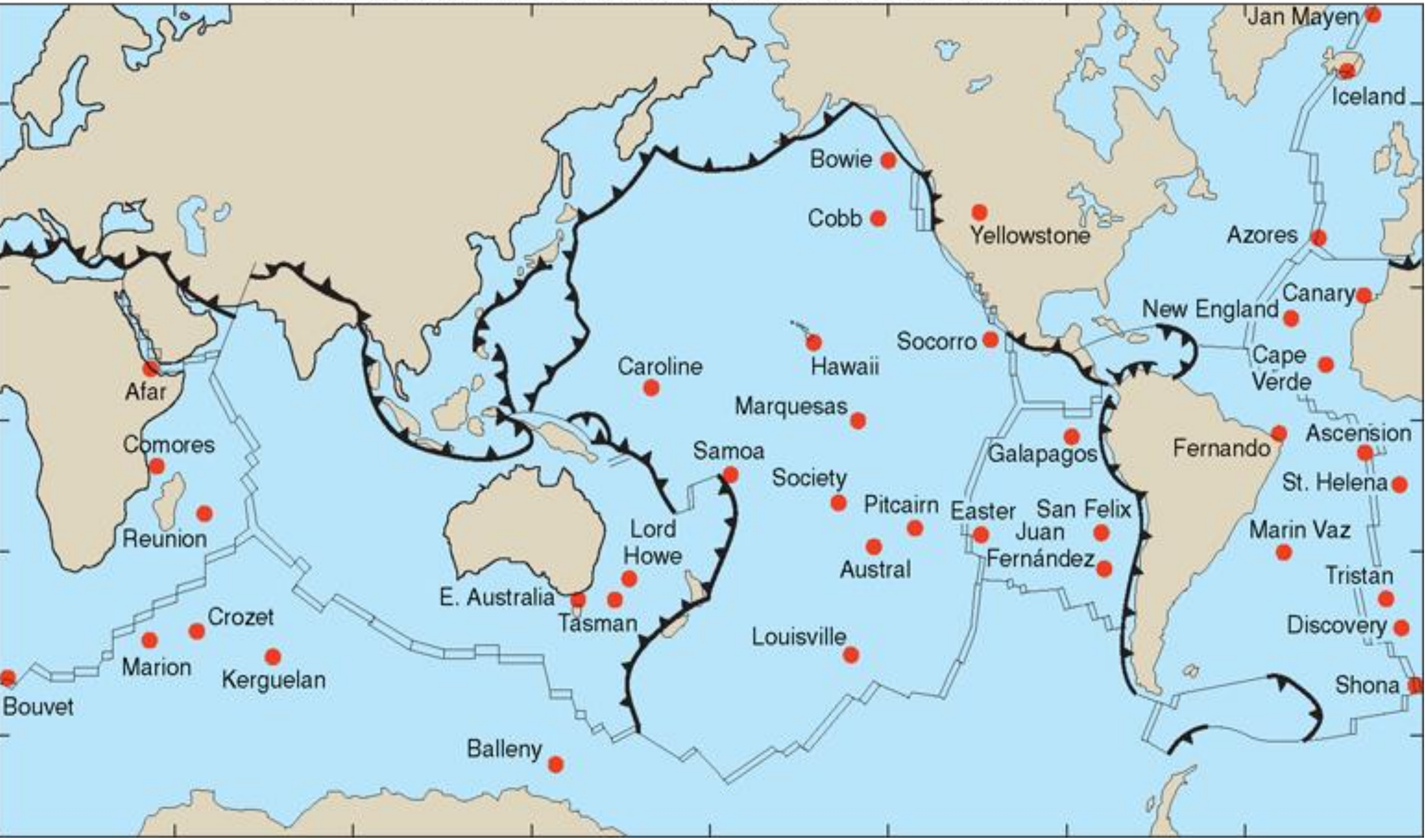
Global Map of Volcanoes (from the Global Volcanism Program)





Volcanoes are concentrated mostly at **<u>tectonic plate boundaries</u>, mainly <u>convergent</u> & <u>divergent</u>** boundaries (no eruption at transform boundaries)

Some volcanic eruptions are generated by hotspots



Nature of Eruptions

"Explosive" vs. "Quiet"
Depends on: **gas content & viscosity**

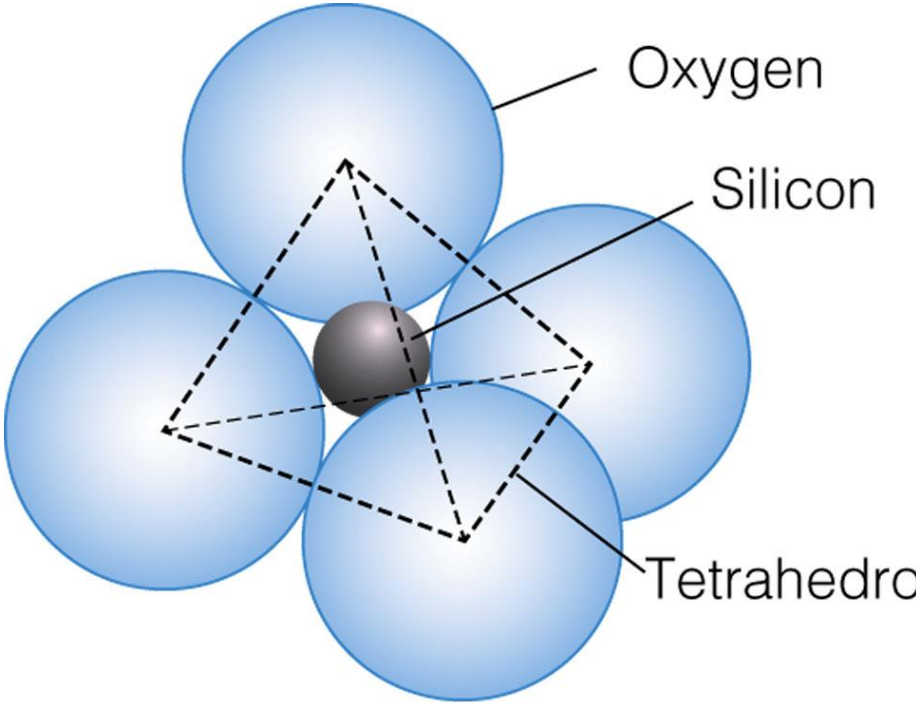
Redoubt Volcano, Alaska

Kilauea Volcano, Hawaii

Viscosity depends on temperature & SiO_2 content

Lower T : higher viscosity

Higher SiO2 : higher viscosity



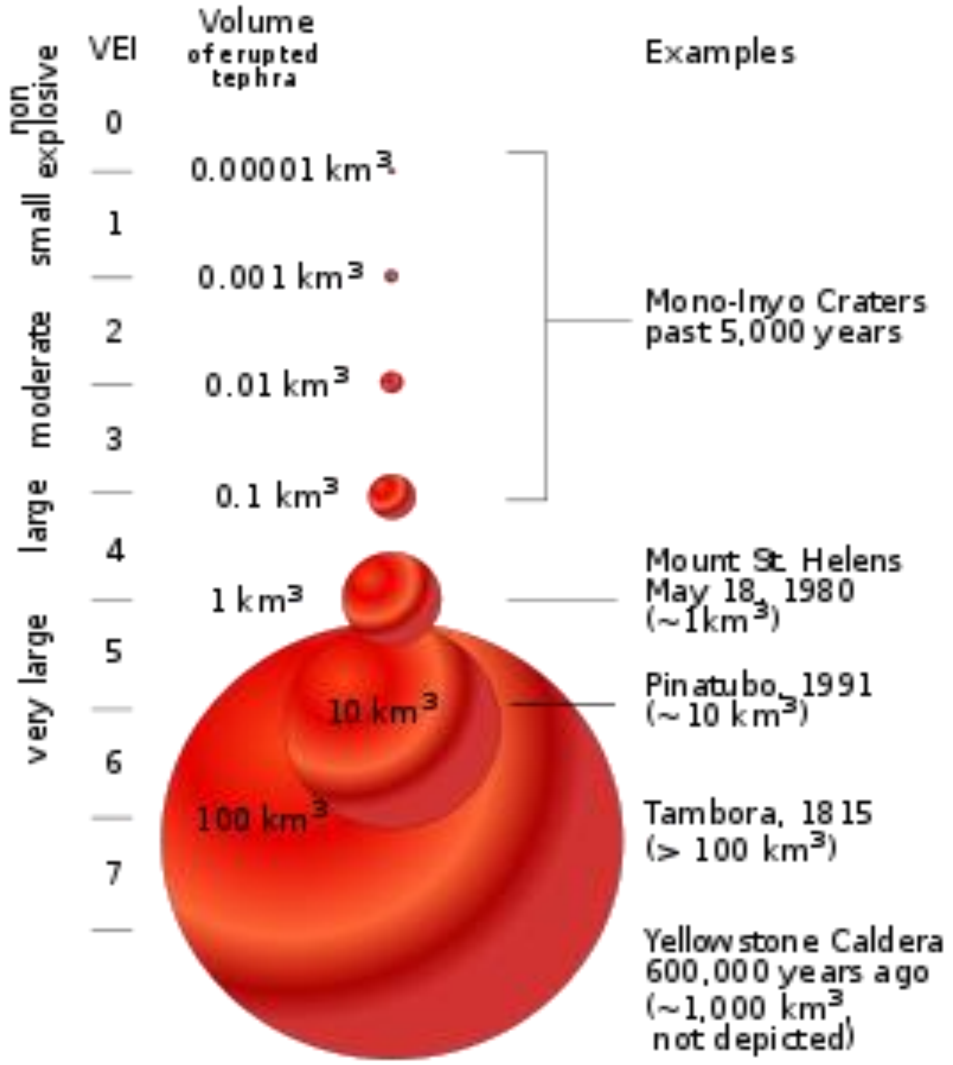
Explosive volcanism
: High gas content/high viscosity
(Water)

Scale of Eruption Explosiveness
: Volcanic Explosivity Index (VEI)

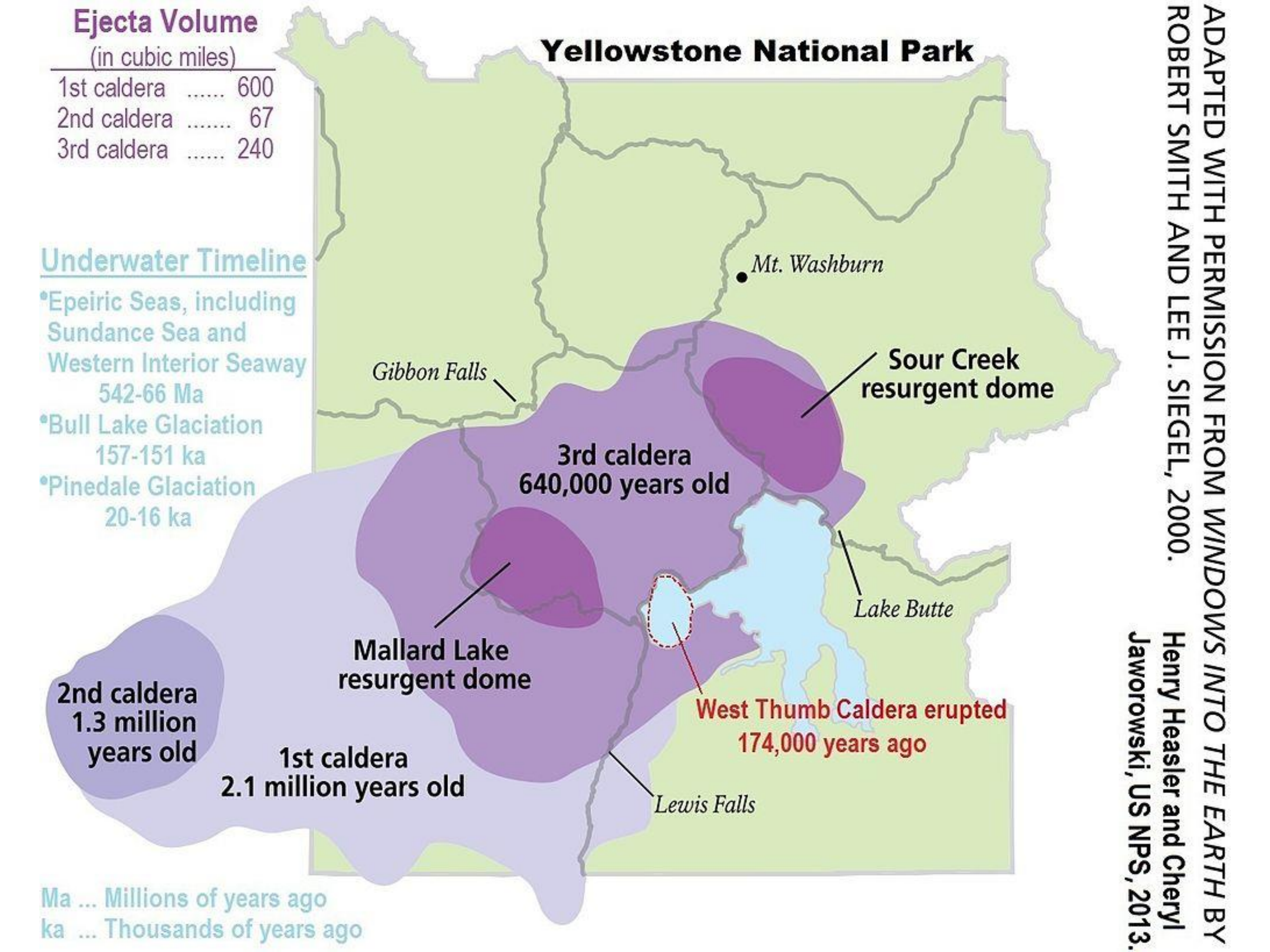
VEI values range from 0 (small lava flow) to 8 (highly explosive)

Table 7-1 Volcanic Explosivity Index (VEI) for Different Types of Individual Eruptions*

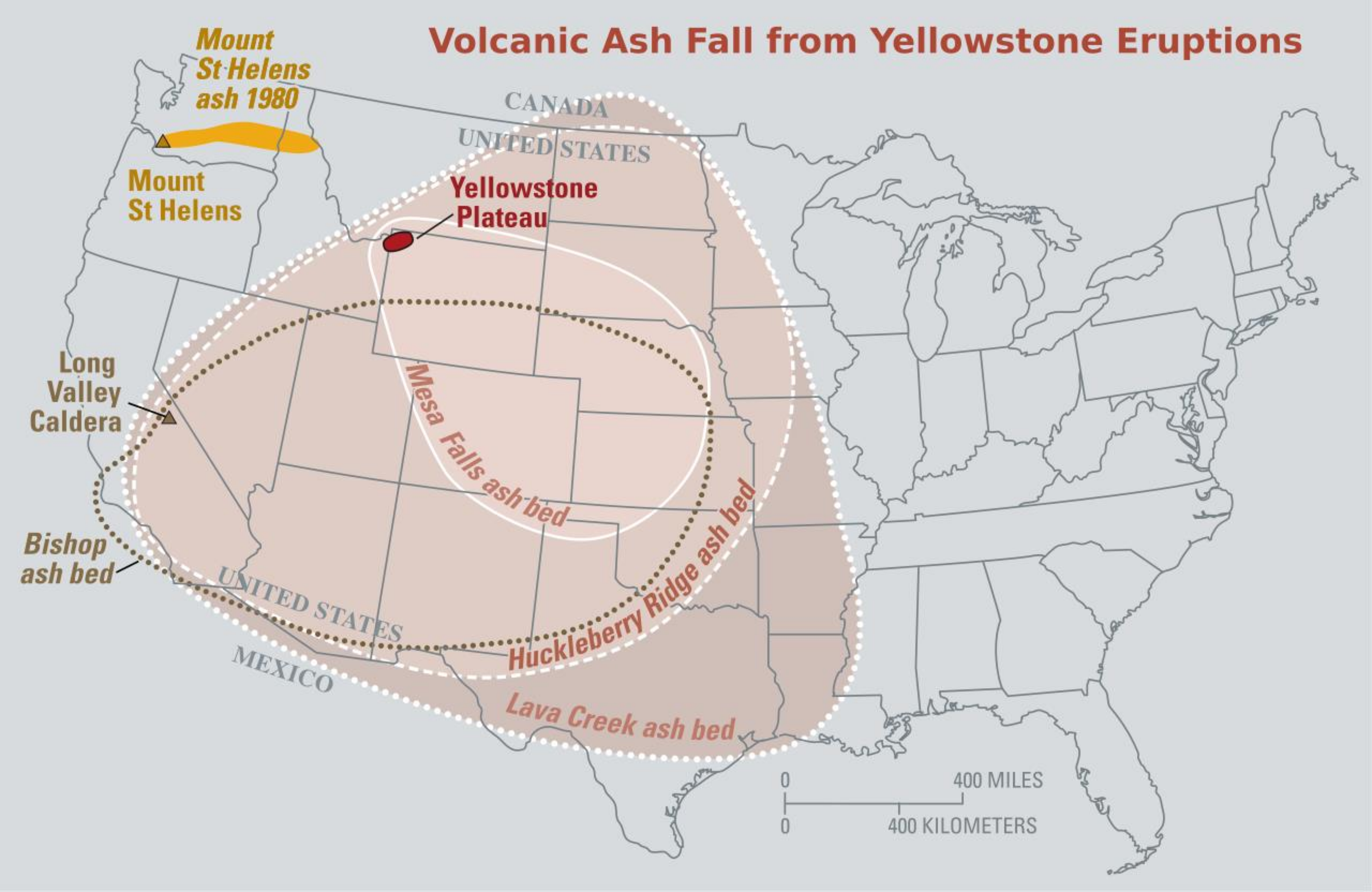
VEI	Volume of Ejecta (m^3)	Eruption Column Height (Km)	Eruption Style	Duration of Continuous Blast (Hrs.)	Eruption Frequency (Approximate)	Example Eruption
0	$<10^4$	<0.1	Hawaiian	<1		Kilauea, Hawaii
1	10^4–10^6	0.1–1	Hawaiian Strombolian	<1	100 per year	Kilauea, Hawaii Stromboli, 1996
2	10^6–10^7	1–5	Strombolian Vulcanian	<1	15 per year	Unzen, Japan, 1994
3	10^7–10^8	3–15	Vulcanian	1–6	2–3 per year	Nevado del Ruiz, Columbia, 1985
4	10^8–10^9 (0.1–1 km^3)	10–25		6–12	1/2 year	El Chichon, 1982 Papua New Guinea, 1994
5	10^9–10^{10} (1–10 km^3)	>25	Plinian	>12	1/10 years	Mount St. Helens, 1980
6	10^{10}–10^{11} (10–100 km^3)	>25	Plinian	>12	1/ 40 years	Krakatau,1883, Pinatubo, 1991 Thera (Santorini), 1600 B.C.
7	10^{11}–10^{12} (100–1,000 km^3)	>25	Plinian	>12	1/200 years	Tambora, Indonesia, 1815
8	$>10^{12}$ (1000–10,000 km^3)	>25	Yellowstone	(off scale)	1/2,000 to 1/1,000,000 years	Yellowstone, 600,000 B.C. Long Valley, California, 730,000 B Taupo, New Zealand, 186 B.C.



Volcanic Explosivity Index (VEI)

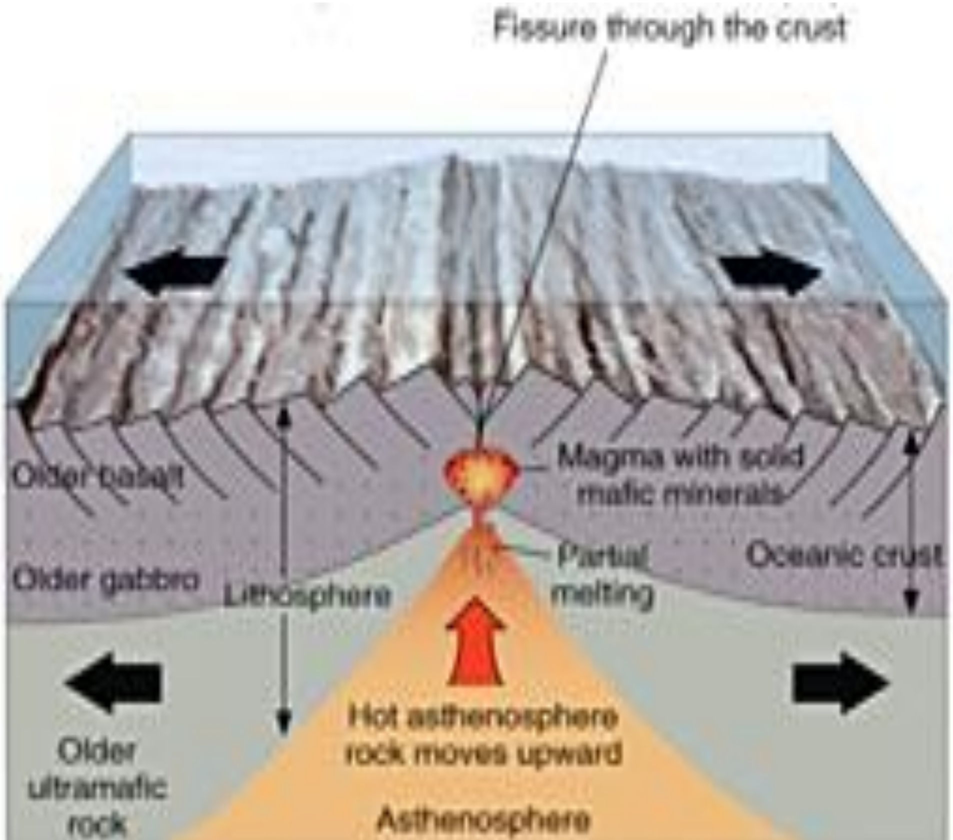


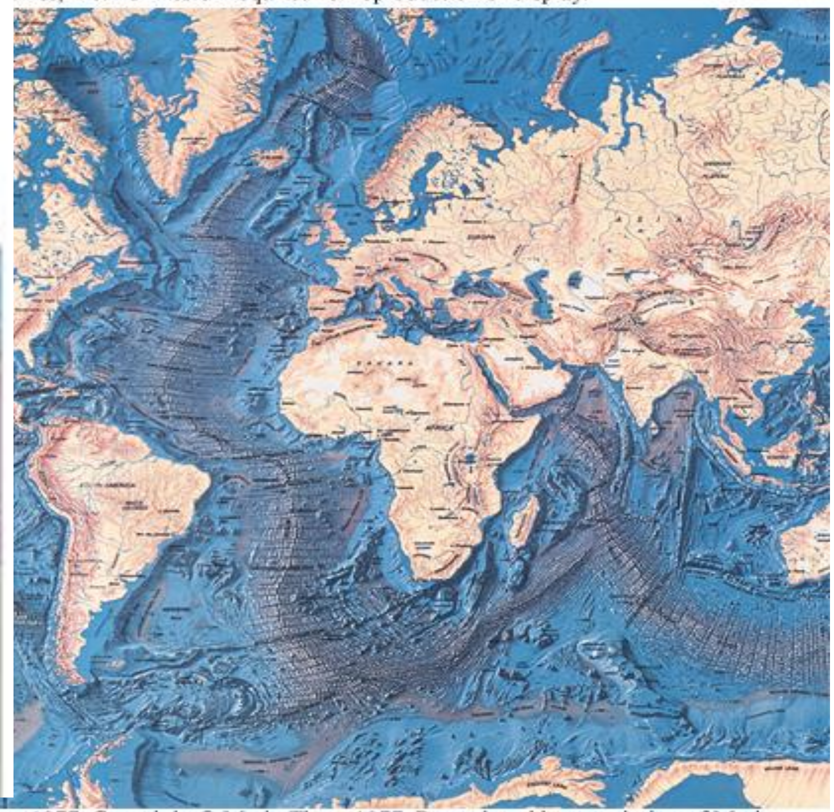
Ejecta Volume
(in cubic miles)
1st caldera 600
2nd caldera 67
3rd caldera 240
Underwater Timeline
•Epeiric Seas, including Sundance Sea and Western Interior Seaway
542-66 Ma
•Bull Lake Glaciation
157-151 ka
•Pinedale Glaciation
20-16 ka
Ma ... Millions of years ago
ka ... Thousands of years ago
Yellowstone National Park
Mt. Washburn
Gibbon Falls
Sour Creek resurgent dome
3rd caldera
640,000 years old
Mallard Lake resurgent dome
Lake Butte
2nd caldera
1.3 million years old
1st caldera
2.1 million years old
West Thumb Caldera erupted
174,000 years ago
Lewis Falls
ADAPTED WITH PERMISSION FROM WINDOWS INTO THE EARTH BY ROBERT SMITH AND LEE J. SIEGEL, 2000.
Henry Heasler and Cheryl Jaworowski, US NPS, 2013.


Volcanic Ash Fall from Yellowstone Eruptions
Mount St Helens ash 1980
Mount St Helens
CANADA
UNITED STATES
Yellowstone Plateau
Long Valley Caldera
Mesa Falls ash bed
Huckleberry Ridge ash bed
Bishop ash bed
UNITED STATES
MEXICO
Lava Creek ash bed
0
400 MILES
0
400 KILOMETERS

Volcanoes & Plate Tectonics

Divergent plate boundary- Mid-ocean Ridge

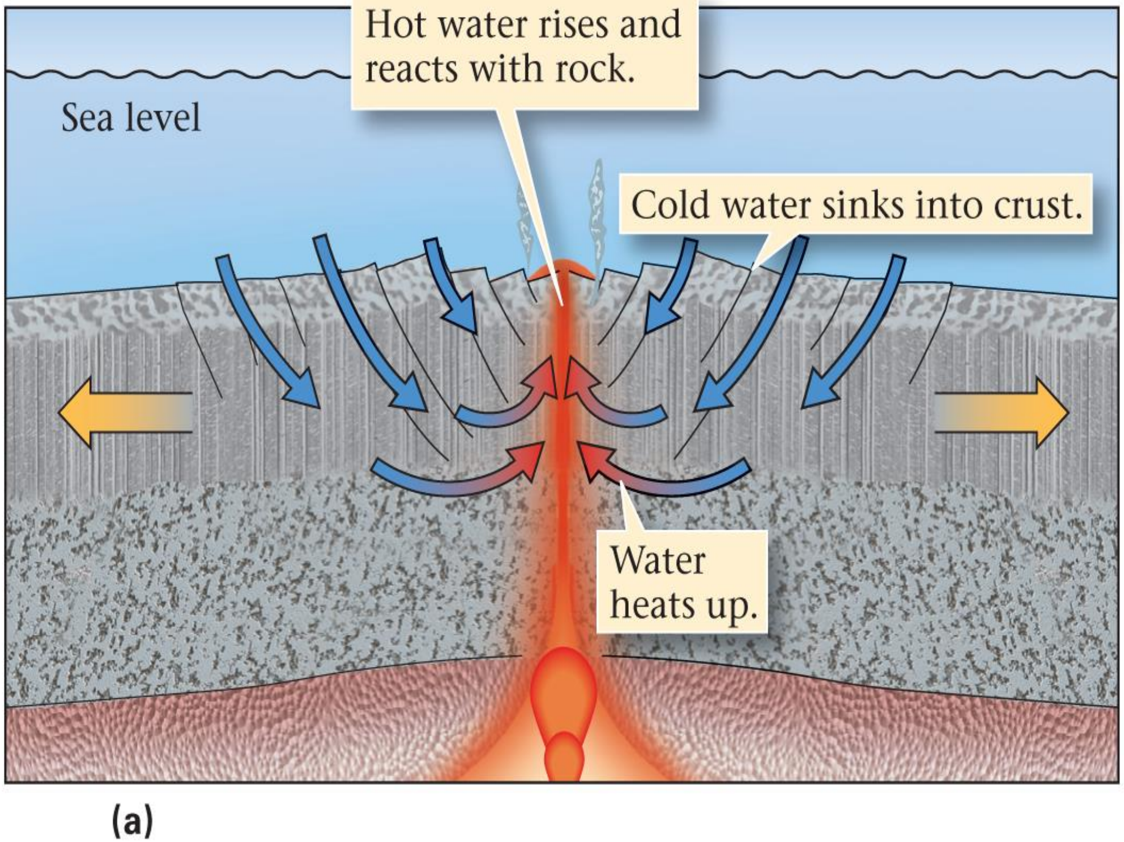




From World Ocean Floor by Bruce C. Heezen and Marie Tharp, 1977. Copyright © Marie Tharp 1977. Reproduced by permission of Marie Tharp, 1 Washington Ave., South Nyack, NY 10960

"Dry melting", high temperature, low silica, low viscosity, low volatile content → Non-explosive submarine eruptions

Divergent Boundary: Midocean Ridge



Hydrothermal circulation at mid-ocean ridge (Illustration from "Earth: Portrait of a Planet", Copyright © W. W. Norton & Company).

A black smoker at the Juan de Fuca Ridge (NOAA)

Pillow basalt

: erupted magmas get **in contact with seawater**

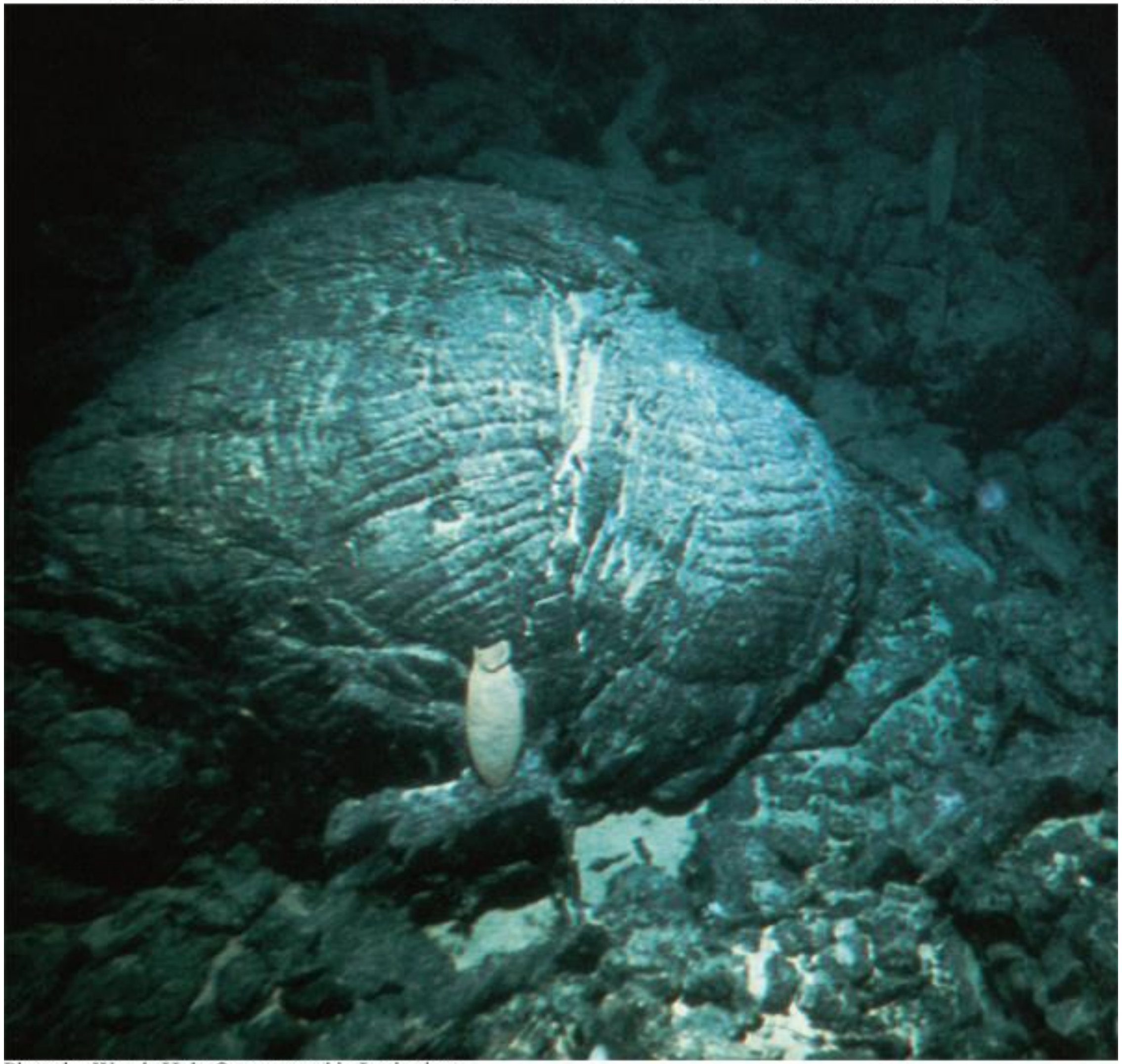


Photo by Woods Hole Oceanographic Institution

PILLOW LAVA FORMATION

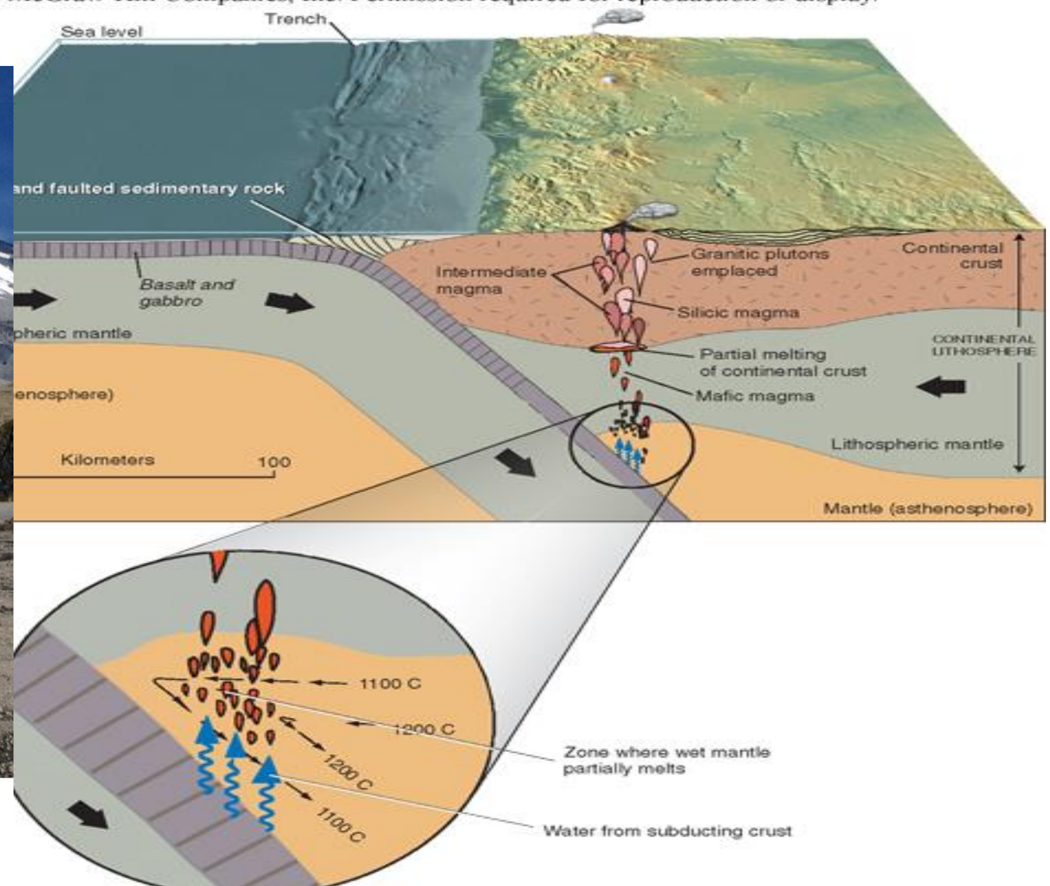
Black Smoker Hydrothermal Vents

Convergent Plate Boundary - Subduction zone

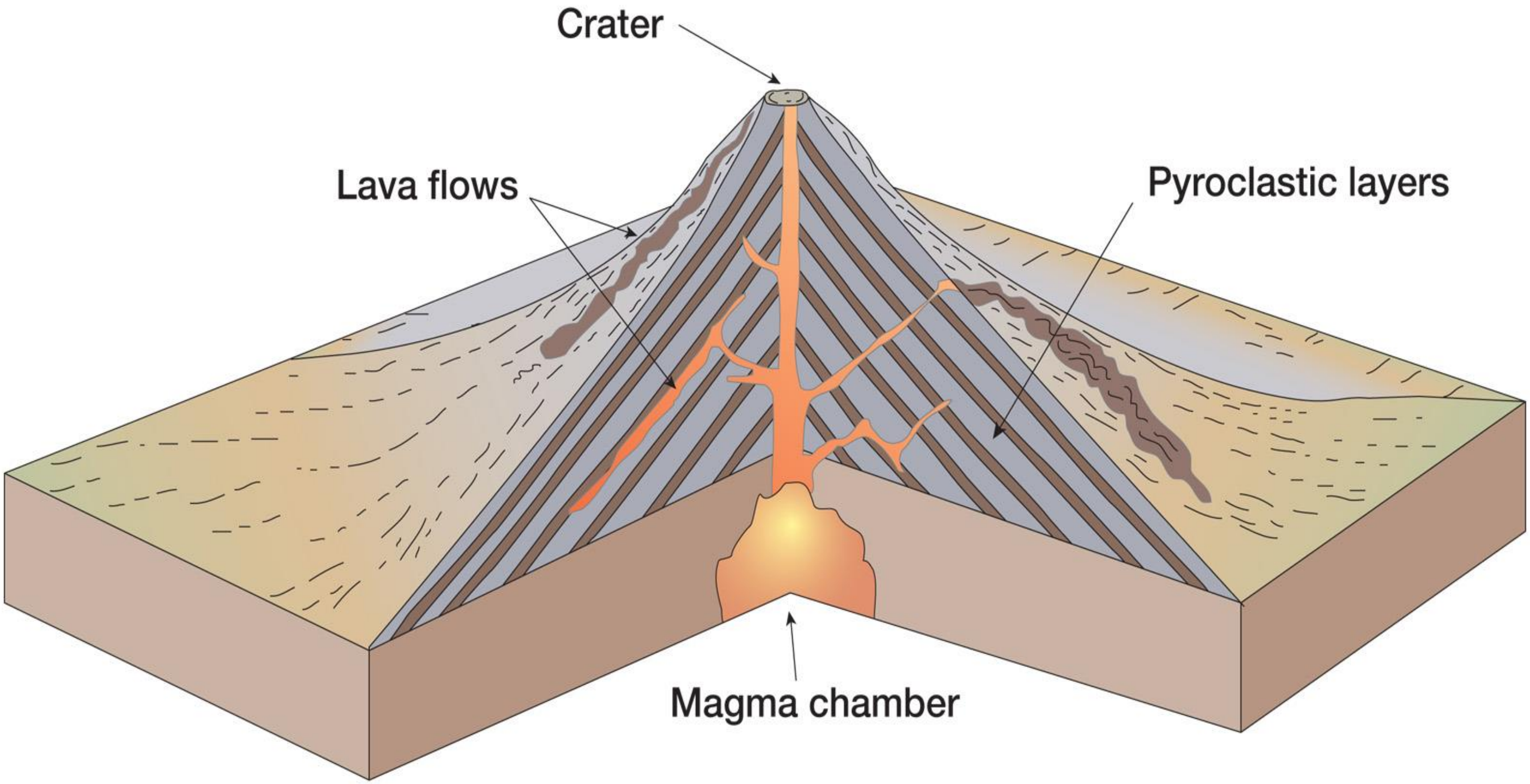
Wet melting of mantle rock → andesite

(+ secondary melting of continental crust → rhyolite)

Low temperature, high silica content, high viscosity, **high volatile** content → **explosive** volcanic eruption

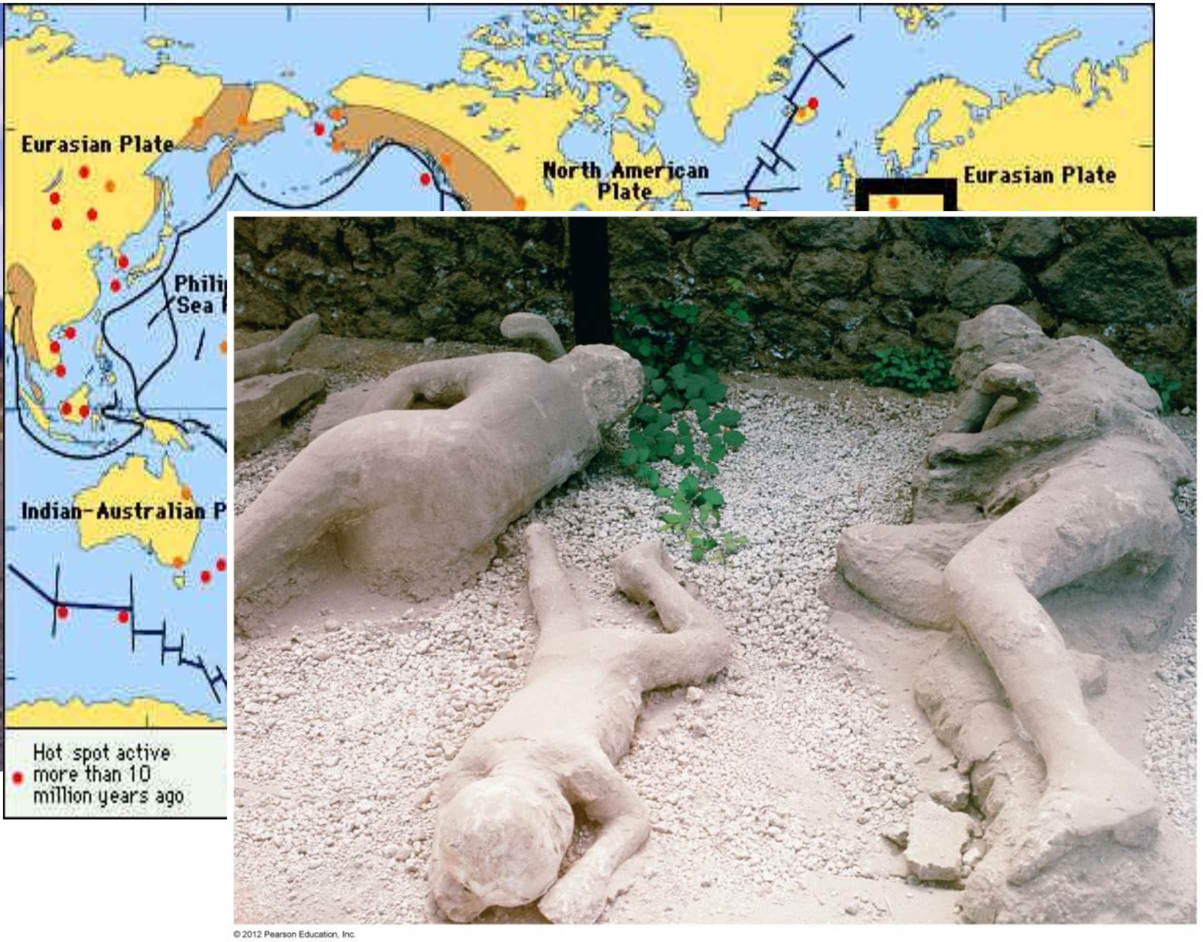


Subduction zone eruptions
: composite volcano (stratovolcano)

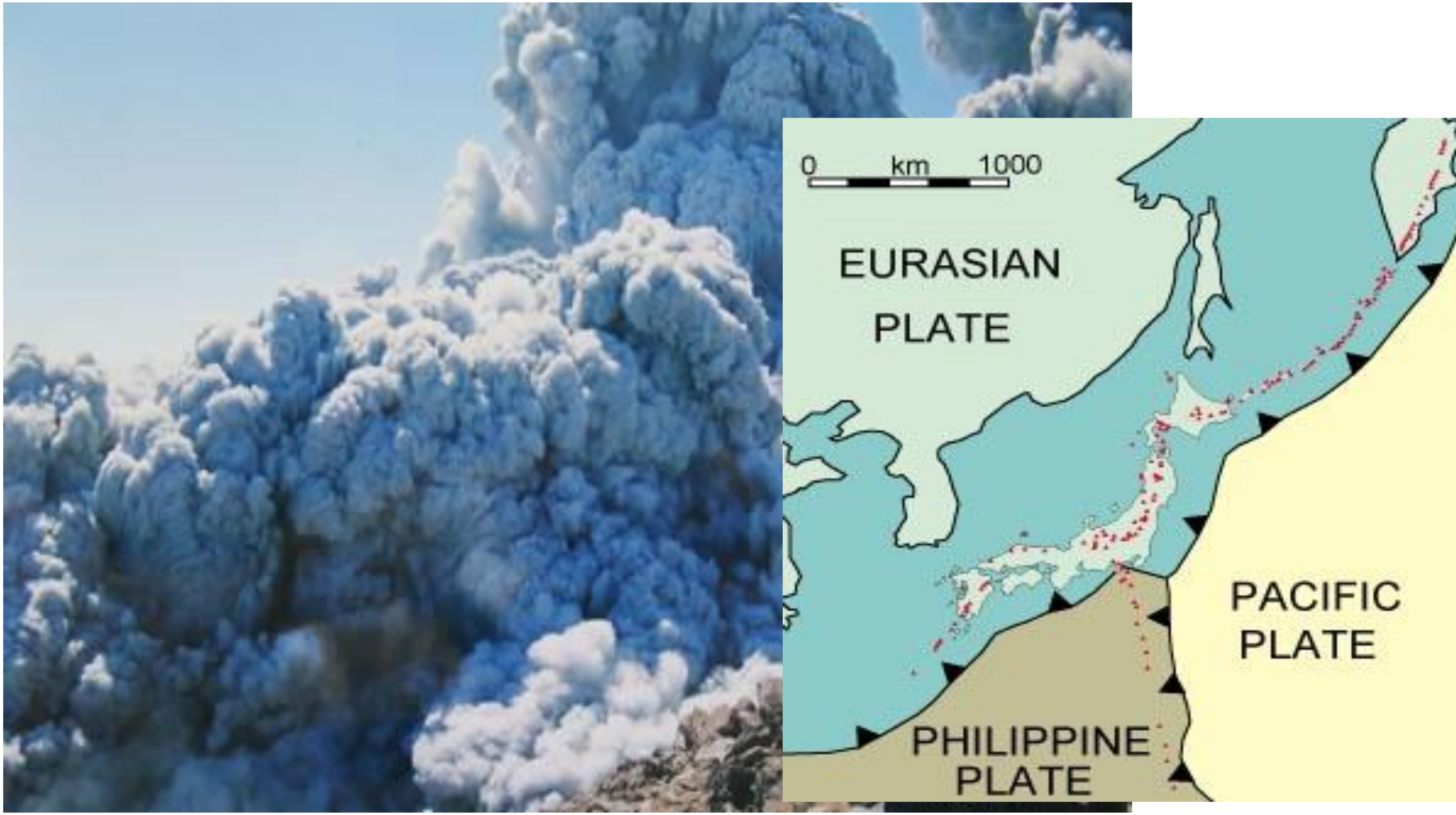


(d) Composite volcano

Subduction zone eruptions – e.g., **Mt. Vesuvius, Italy**

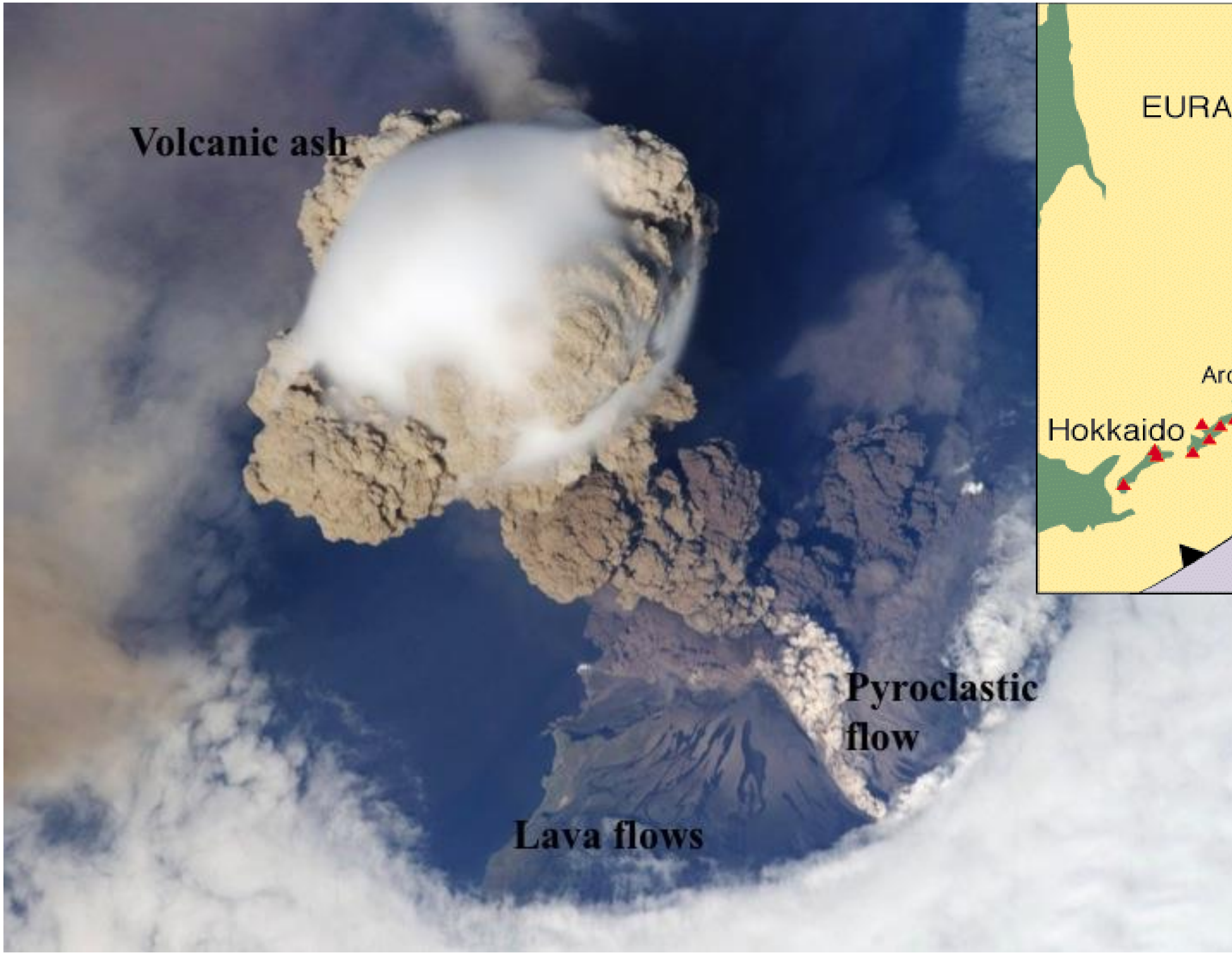


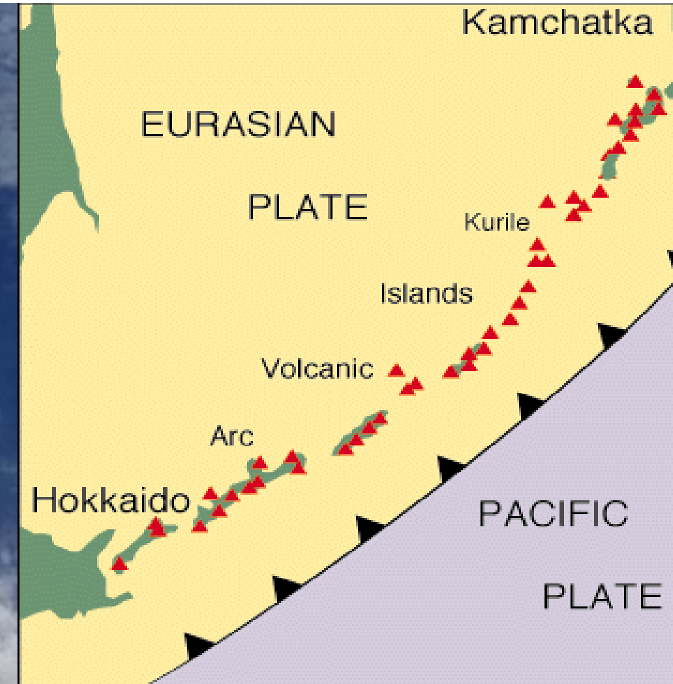
Mt. Vesuvius as seen from the ruins of Pompeii, which was destroyed in **the eruption of AD 79**.



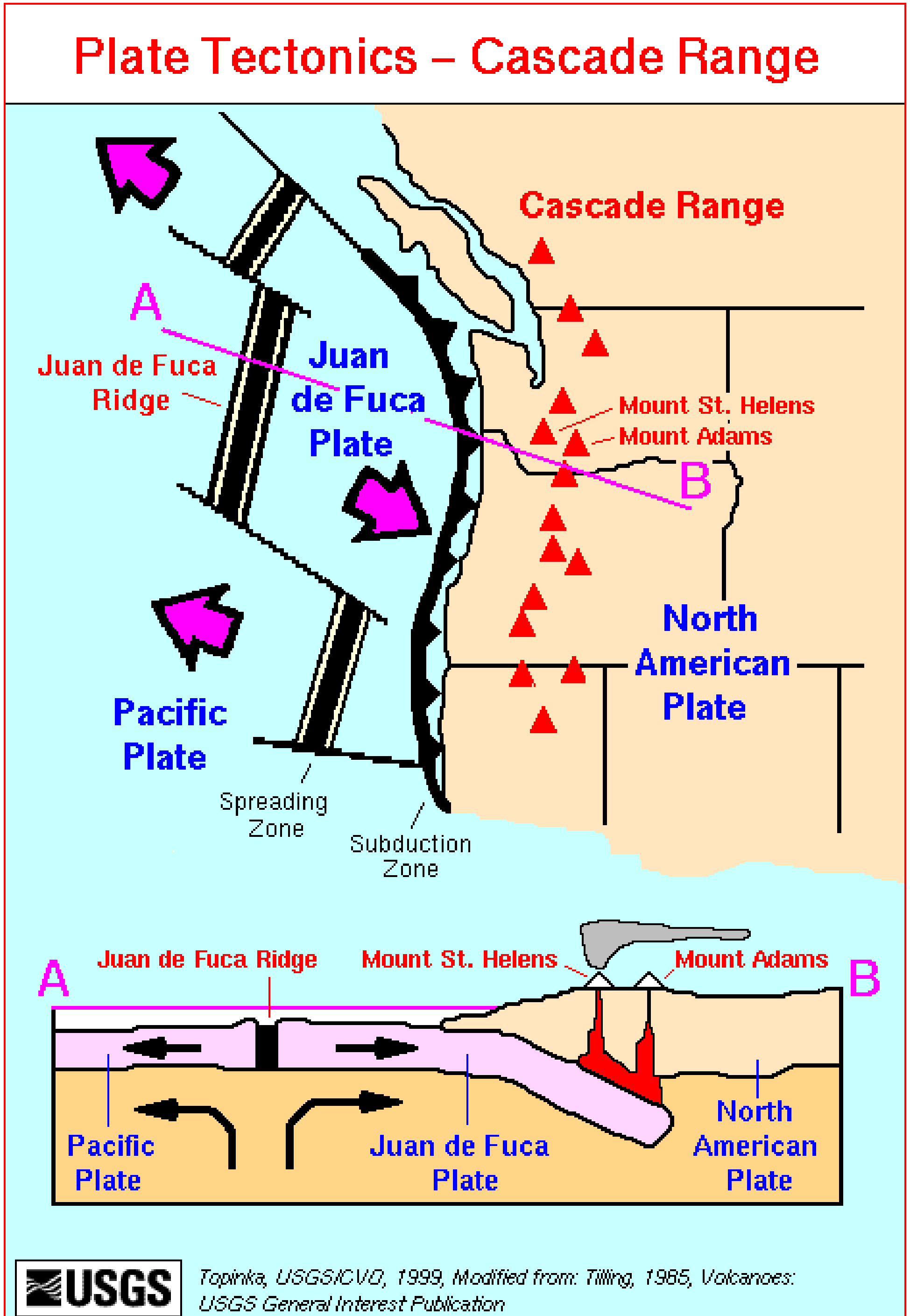
Mount Ontake eruption, Japan, 2014

Volcanic Eruptions at Subduction Zone





[Eruption at Kurile Island, 2009]



Subduction zone eruptions

e.g.,

Cascade Range

Pacific Northwest, U.S.

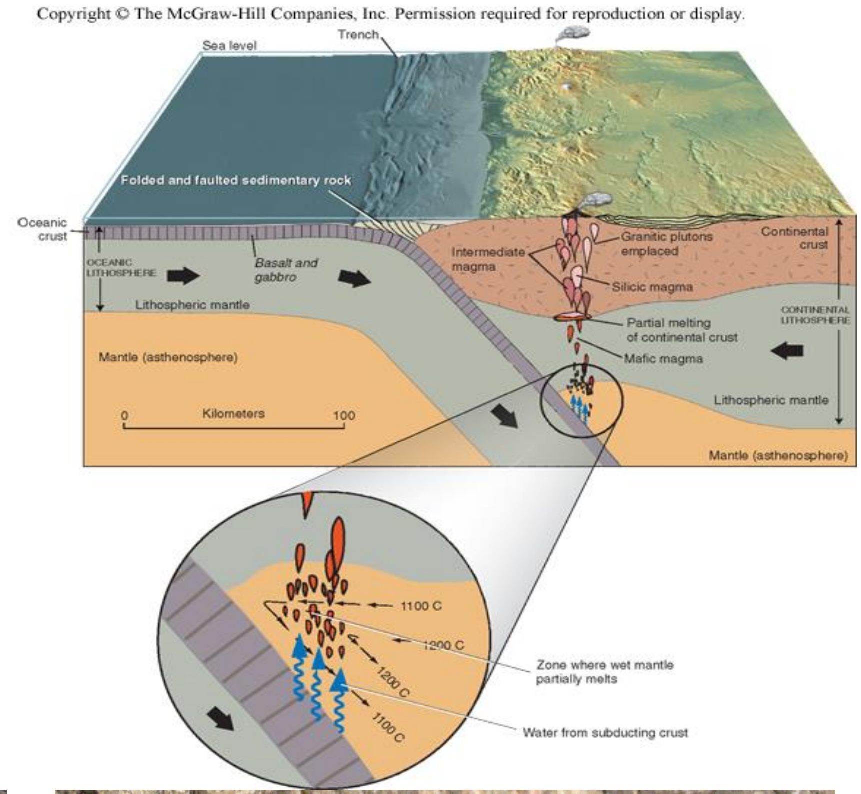
Mount St. Helens before and after the 1980 eruption

1980 Mount St. Helens Eruption

Formation of a Caldera

Crater Lake National Park in Oregon, U.S.

Hiking trail behind Jade Spring Campus



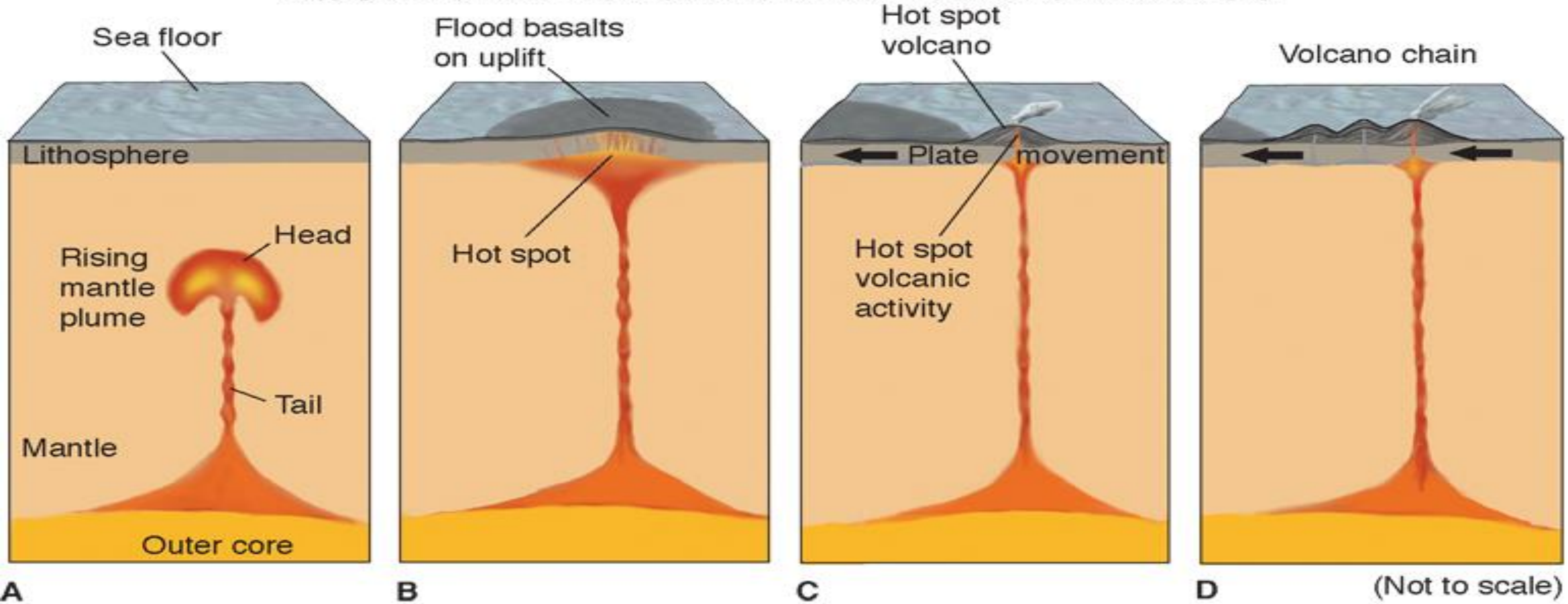
Granite

Mesozoic

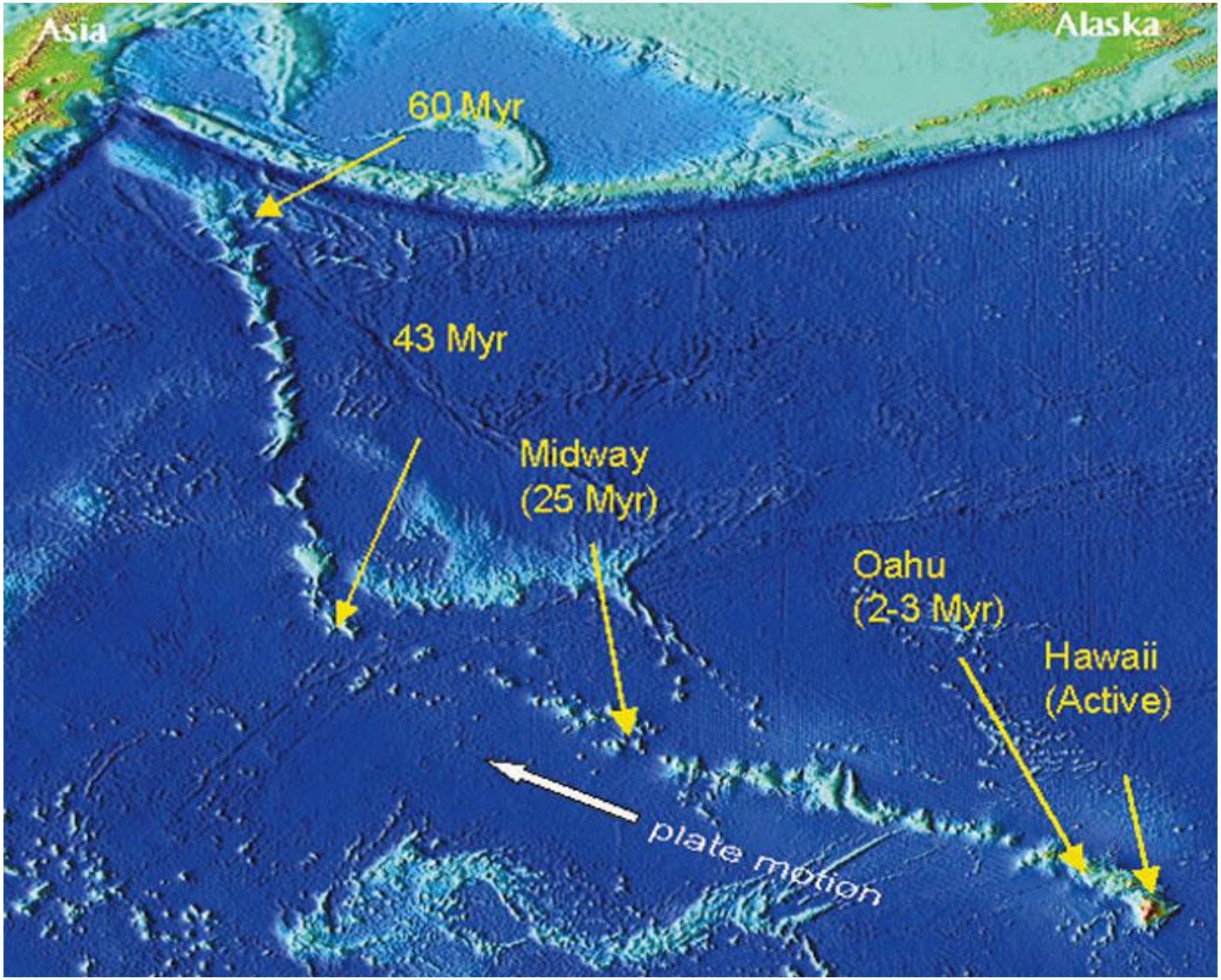
Rhyolite

Ocean hotspot volcanic eruptions

- Fixed hotspot in deep mantle, rises up as mantle plume
- Dry melting of mantle rock → basalt
- High temperature, low silica, low volatile, low viscosity
  → **non-explosive** volcanism

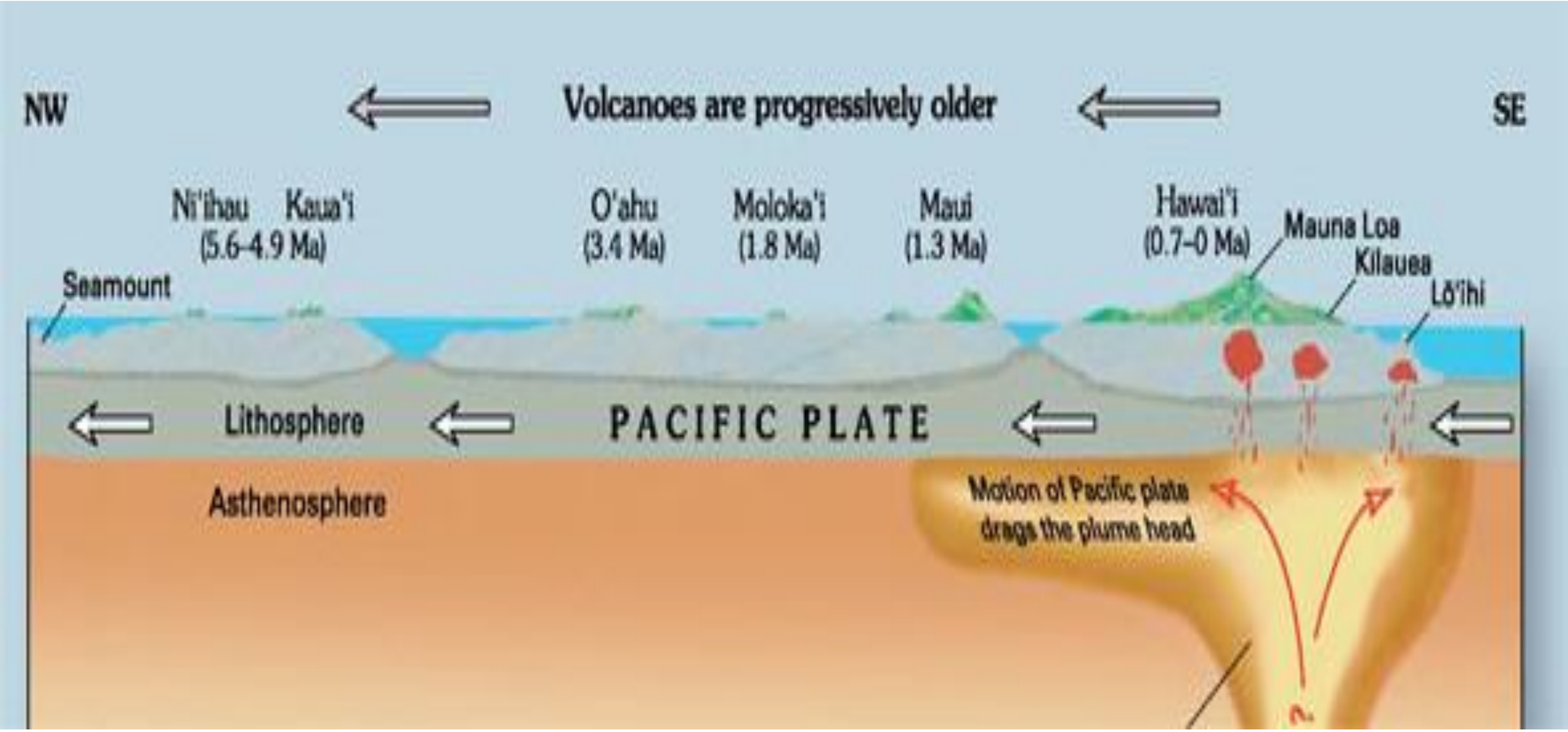


Useful in determining the rate & direction of plate movement



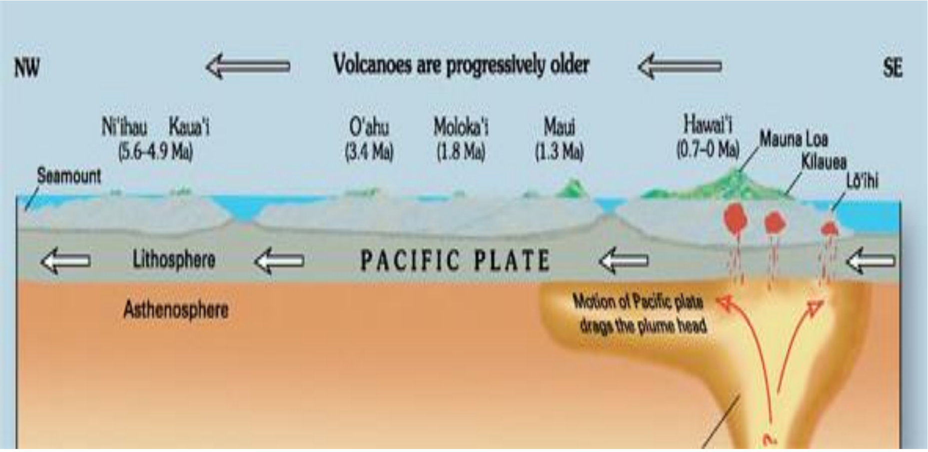
Ocean Hotspot Volcanic Eruptions

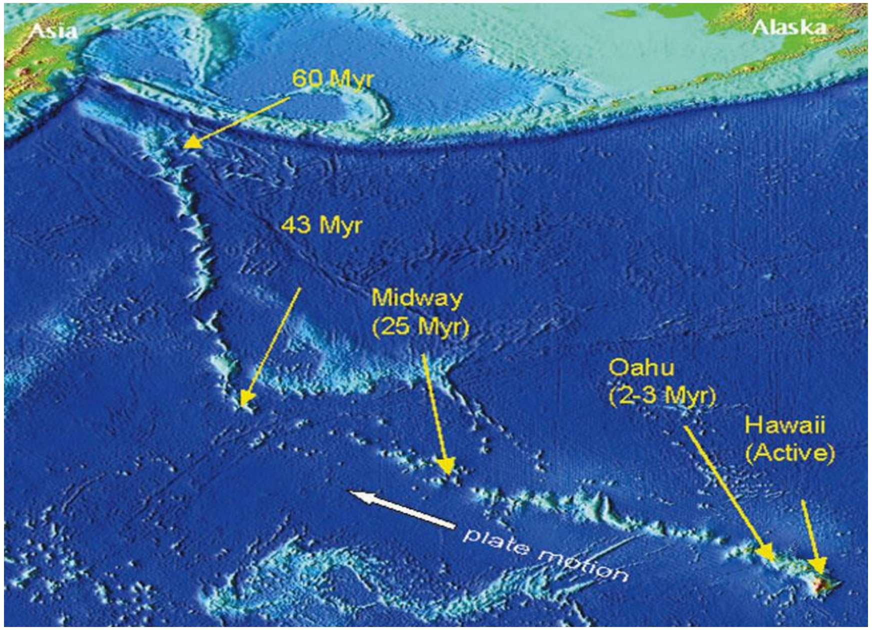
e.g., Hawaiian Islands



Volcano on moving lithosphere → **age progression** in volcanic fields

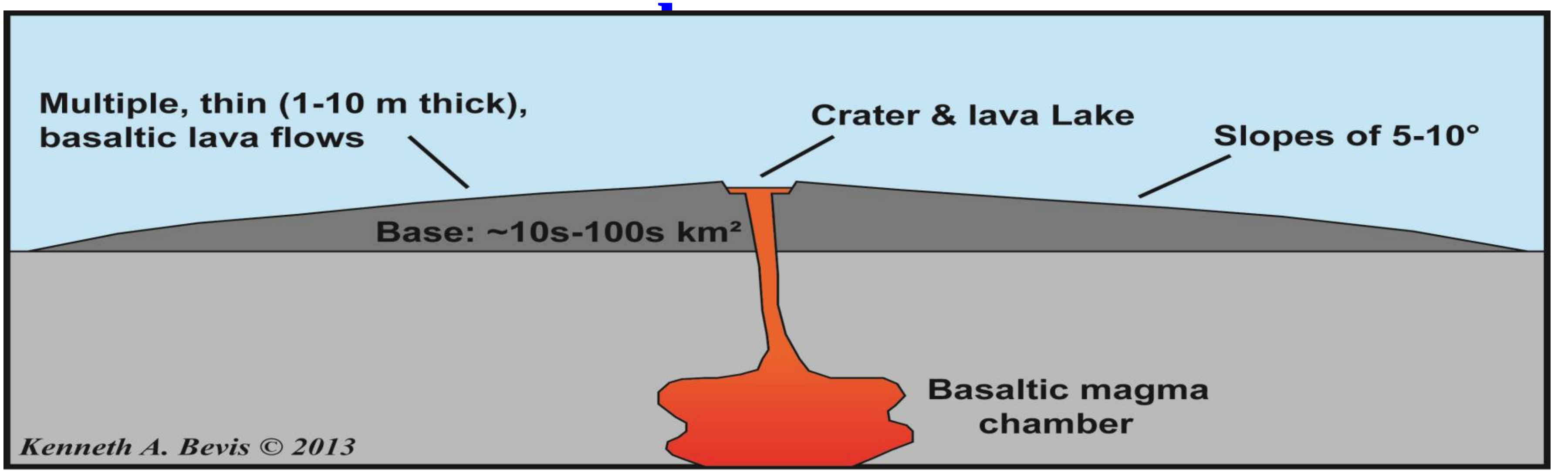
Alternative interpretation

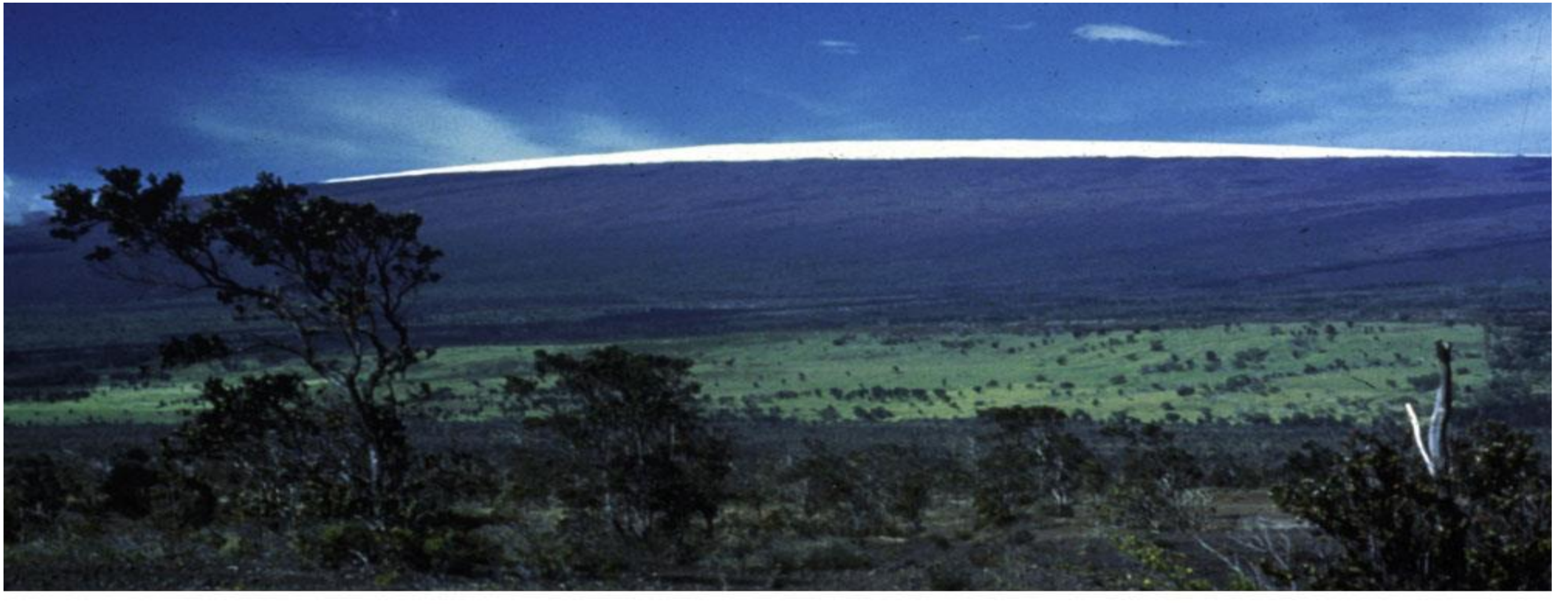




Hotspot not fixed?

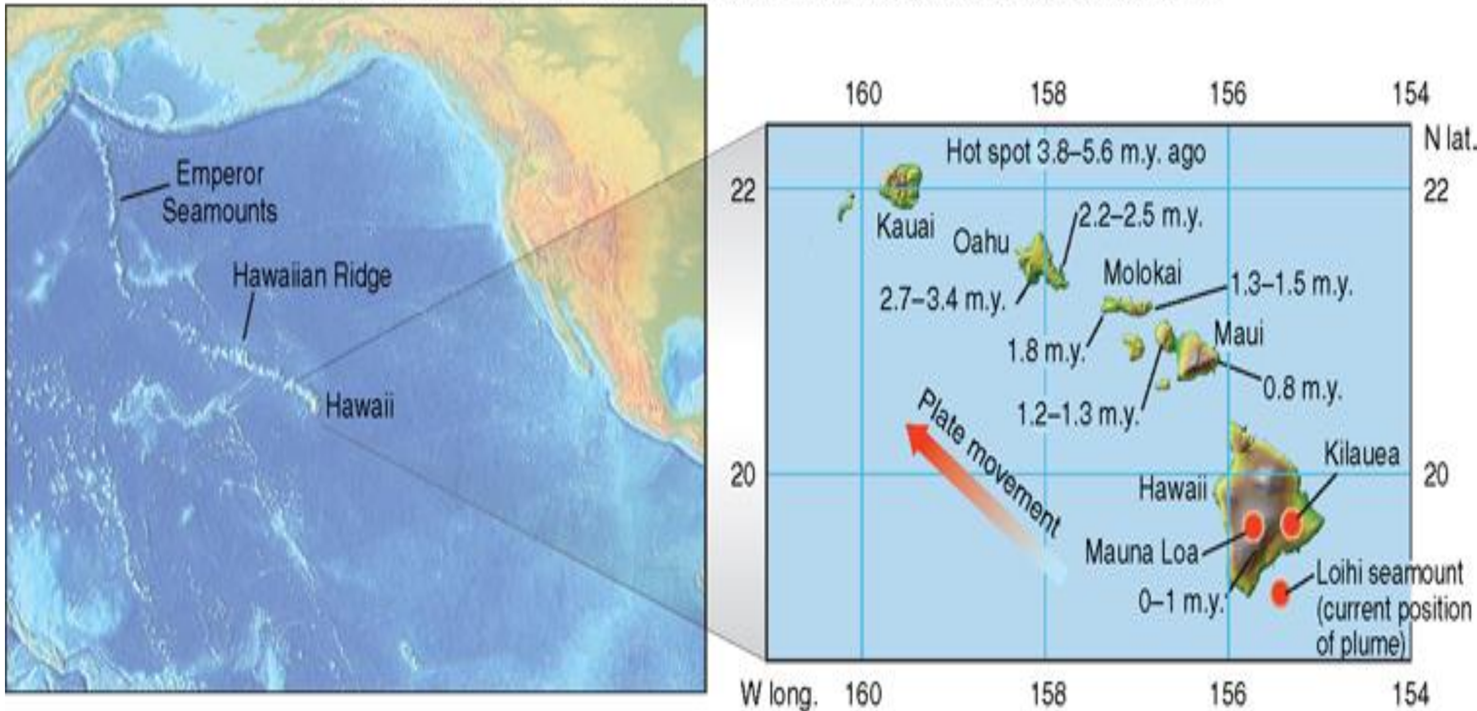
Ocean hotspot volcano: shield volcano





Shield volcanoes: Mauna Kea at the left and Mauna Loa at the right

Hawaiian volcanoes



Chain of islands that extends to Emperor islands

Night view of lavas on the east rift zone of Kilauea Volcano
(Photograph by C. Heliker, USGS, 1983)

Lava tube

Collapsed roof of a lava tube (Photo by Jeffrey B. Judd, USGS)

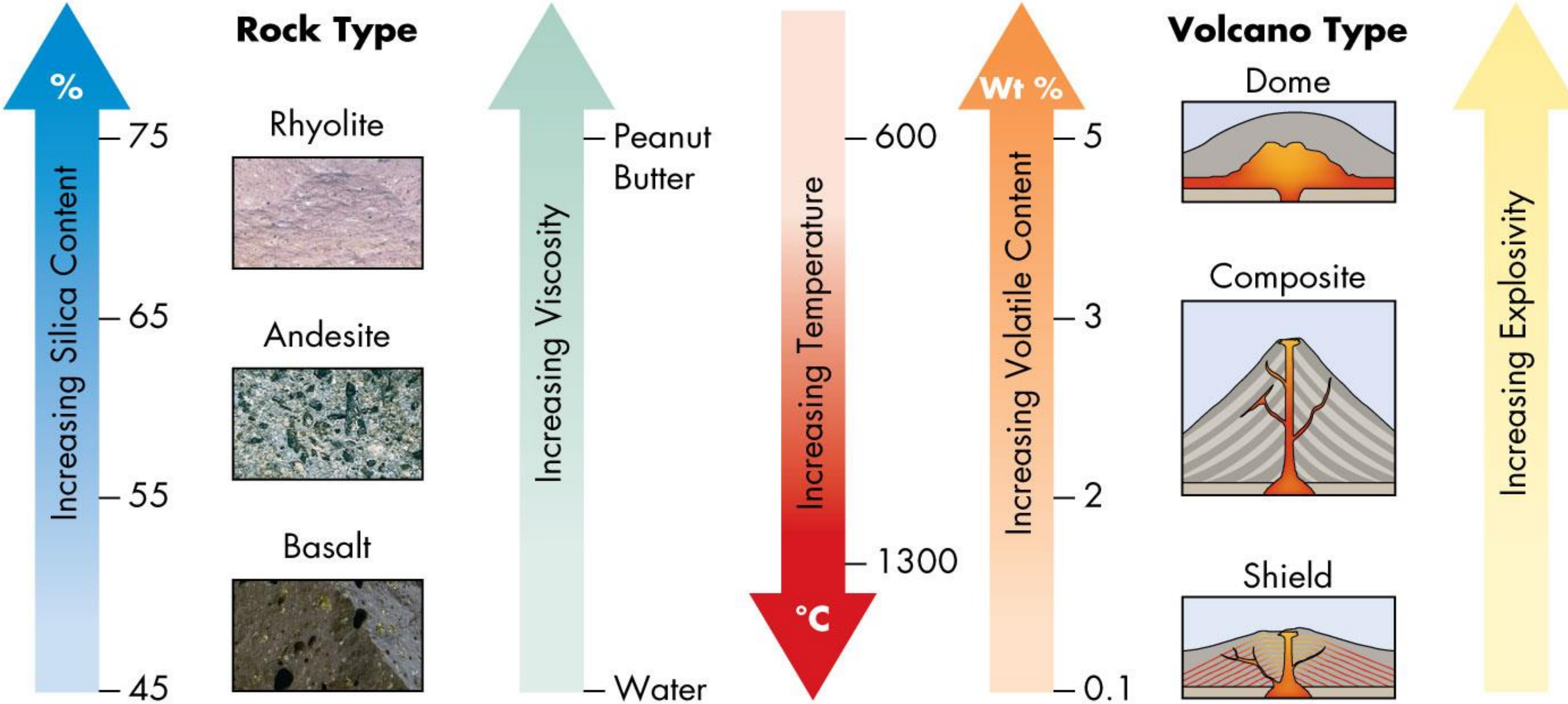
Lava fountain during a fissure eruption along the southwest rift of Kilauea (Photo from National Park Service)

Close view of ropy pahoehoe flow at Kilauea Volcano, Hawaii (Photo by T.N. Mattox, USGS, 1995)

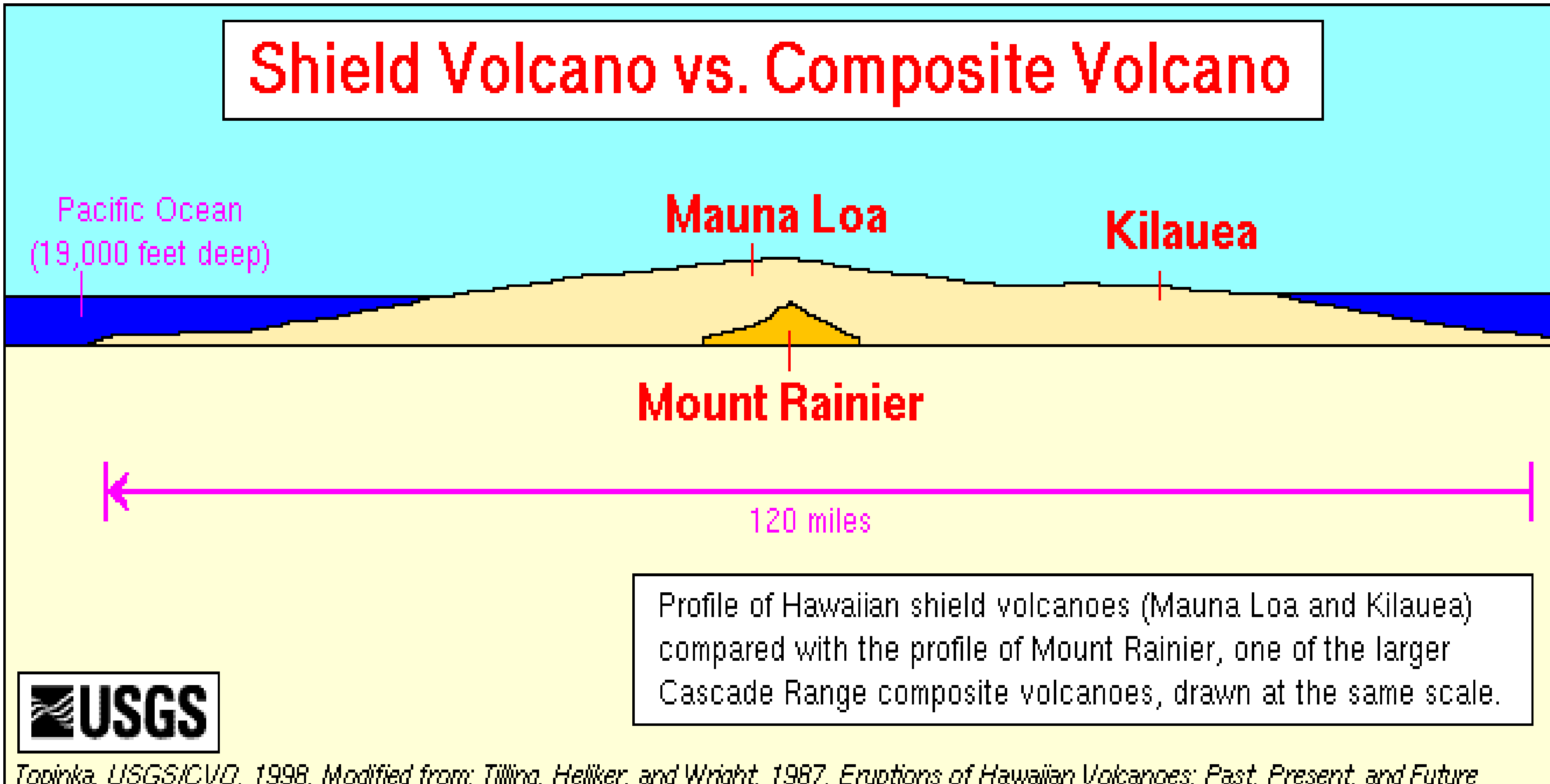
Aa flow advancing over old **pahoehoe** on the coastal plain of Kilauea Volcano, Hawaii. (Photo by T.N. Mattox, USGS, 1995)

Aa flow

Lava fountain and Pahoeoe flows

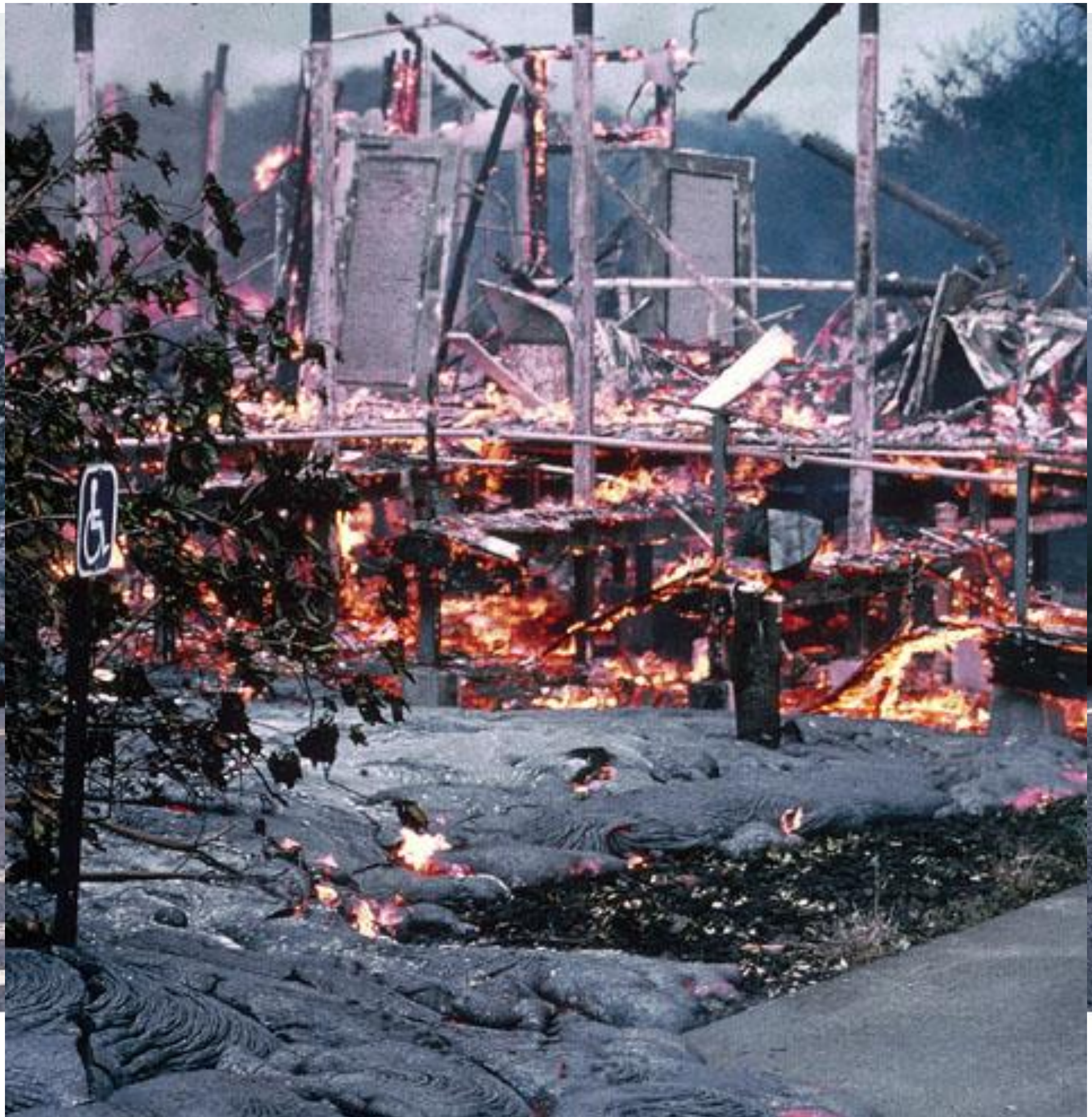


%
Increasing Silica Content
75
65
55
45
Rock Type
Rhyolite
Andesite
Basalt
Increasing Viscosity
Peanut Butter
Water
Increasing Temperature
600
1300
°C
Wt %
Increasing Volatile Content
5
3
2
0.1
Volcano Type
Dome
Composite
Shield
Increasing Explosivity


Shield Volcano vs. Composite Volcano
Pacific Ocean
(19,000 feet deep)
Mauna Loa
Kilauea
Mount Rainier
120 miles
Profile of Hawaiian shield volcanoes (Mauna Loa and Kilauea) compared with the profile of Mount Rainier, one of the larger Cascade Range composite volcanoes, drawn at the same scale.
USGS
Topinka, USGS/CVO, 1998, Modified from: Tilling, Heliker, and Wright, 1987, Eruptions of Hawaiian Volcanoes: Past, Present, and Future

Volcanic Hazards

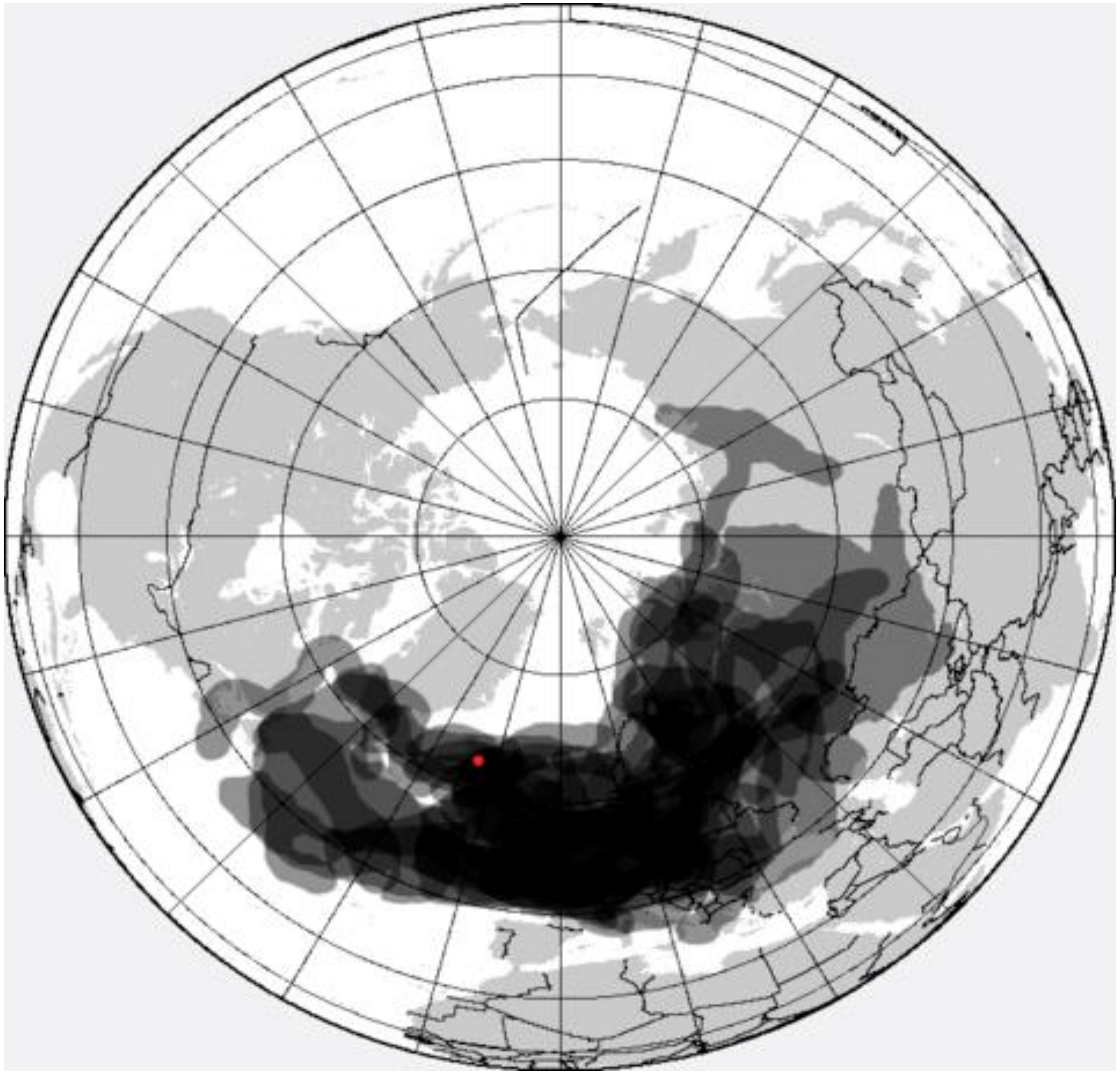
A) **Lava flows** - usually non-lethal, but can cause considerable damage



B) **Ashfall** - explosive eruption of **plume of volcanic ash** can cause structure failure, airplane engine failure, breathing problems, crop damage, livestock deaths

Redoubt Volcano, SW of Anchorage, Alaska

Ashfall from Mt. Pinatubo collapsed many roofs



A composite map of the Icelandic volcanic ash cloud that closed European air space from April 14 to April 25, 2010 (Red dot on the map shows the location of the volcano).

C) **Ashflow**

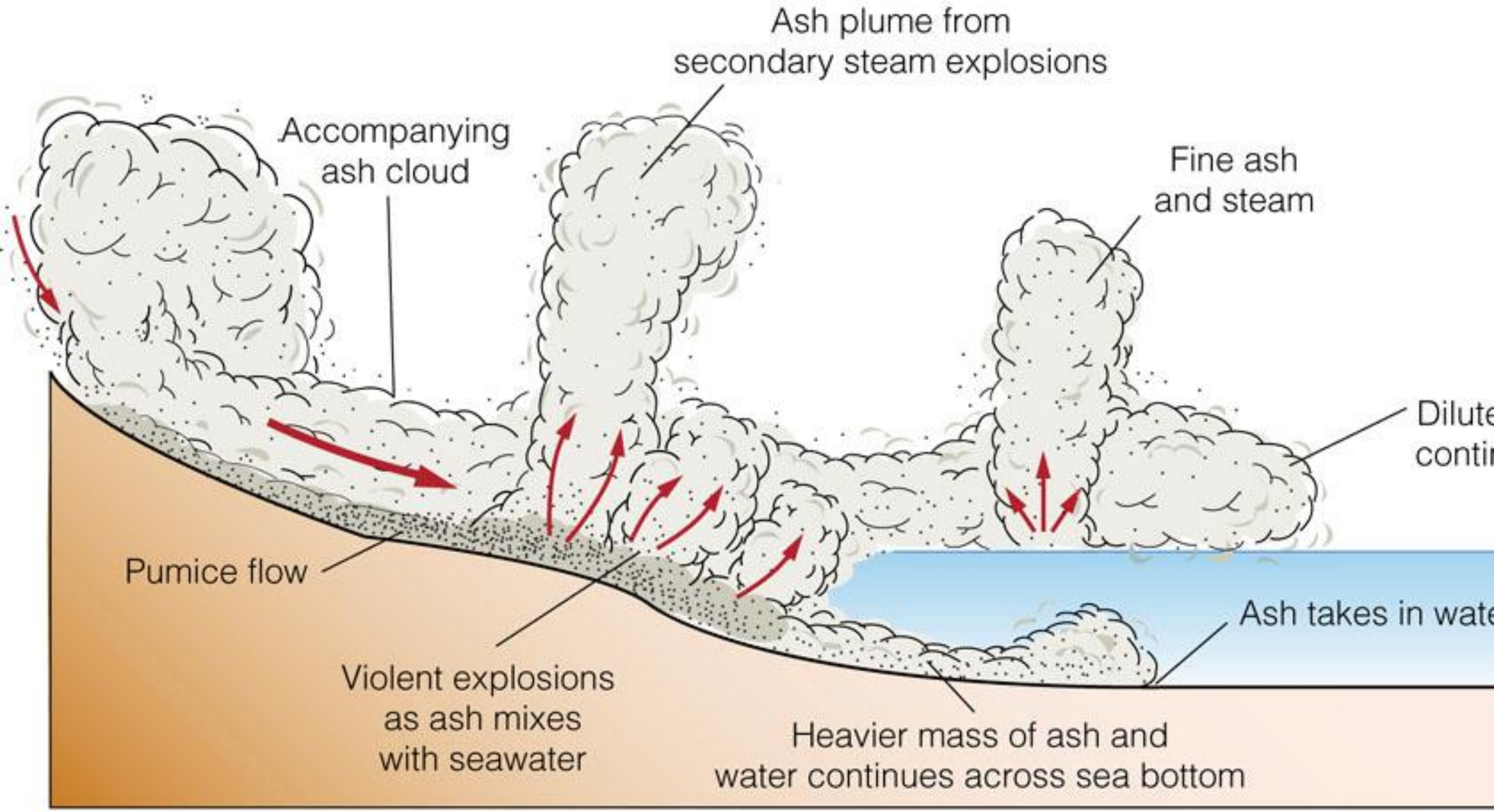
(Pyroclastic flow)

-turbulent mixture of superheated gas & pyroclastic debris

(nuee ardente - "**glowing cloud**")

that flows down slope with great speed

(up to 200 km/hr).



Hot ash flows over water

The dense part of an ash flow sinks

The lighter part continues over the water surface

Ashflows can cause enormous destruction, common during **caldera**-forming eruptions

e.g.,

Mt. Pelée eruption in 1902 on Caribbean island

Destroyed city of St. Pierre, killing ~28,000 people in ~30 seconds

D) **Lahar** (**mudflow**)- mixture of *water* & *volcanic debris that flows downslope*.

After **Mt. Pinatubo** eruption in 1991

Water is from snow + ice on mountain slope, or from rainfall.

班级成员	考勤成绩 0.0%	课堂表现成绩 0.0%	pre-test 0.0%	For those who... 0.0%	IMPORTANT: ... 5.0%	Write a detaile... 15.0%	in-class test 5.0%	Describe the ... 15.0%	in-class test 10.0%	原始成绩	最终成绩
袁晶莹 21934073	0	0		98	80	85	78	85	67	40.2	40.2
童政毅 11838006	0	0	94		60	70	70	88	71	37.3	37.3
SANGAN... 11934065	0	0	68		70	88	87	82	78	41.2	41.2
AGBAJE, ... 11934067	0	0	76		85	95	60	85	70	41.4	41.4
DEBNATH... 11934069	0	0	54	56	75	85	72	88	90	42.4	42.4
SABATA, ... 11934074	0	0		50	50	80	45	70	65	33.8	33.8
黄晟 11938029	0	0	32		75	85	70	75	65	37.9	37.9
金铨 21634031	0	0	50		90	88	81	85	73	41.9	41.9
杜昊 21934065	0	0		36	85	75	66	60	41	32	32
孙兰馨 21934075	0	0		68	40	75	82	78	82	37.3	37.3
BUTT, US... 21934204	0	0	90		80	92	75	80	55	39.1	39.1
MGBECHI... 21934207	0	0	66		70	95	90	95	95	46.1	46.1
UMAR, B... 21934209	0	0	40		82	90	47	90	67	40.2	40.2

Volcanic Hazards

(E) **Gases** - **water is major gas released** in volcanic eruptions.

Also can get other more harmful gases (e.g., CO_2, CO, SO_2, H_2S, H_2SO_4, HCl, HF)

CO_2

e.g.,1986 in Cameroon (central Africa), 1,700 died overnight due to volcano-derived **CO_2** gas that was released quickly from Lake Nyos

SO_2

Sulfur-bearing gases can oxidize to **sulfuric acid**, which is highly corrosive

SO_2

Effect on climate - large, explosive ashfall eruptions can cause ***global cooling*** of up to several degrees for 1 - 2 years after eruption

Cooling is due to SO_2 gas-coated airborne volcanic ash, which reflects sunlight

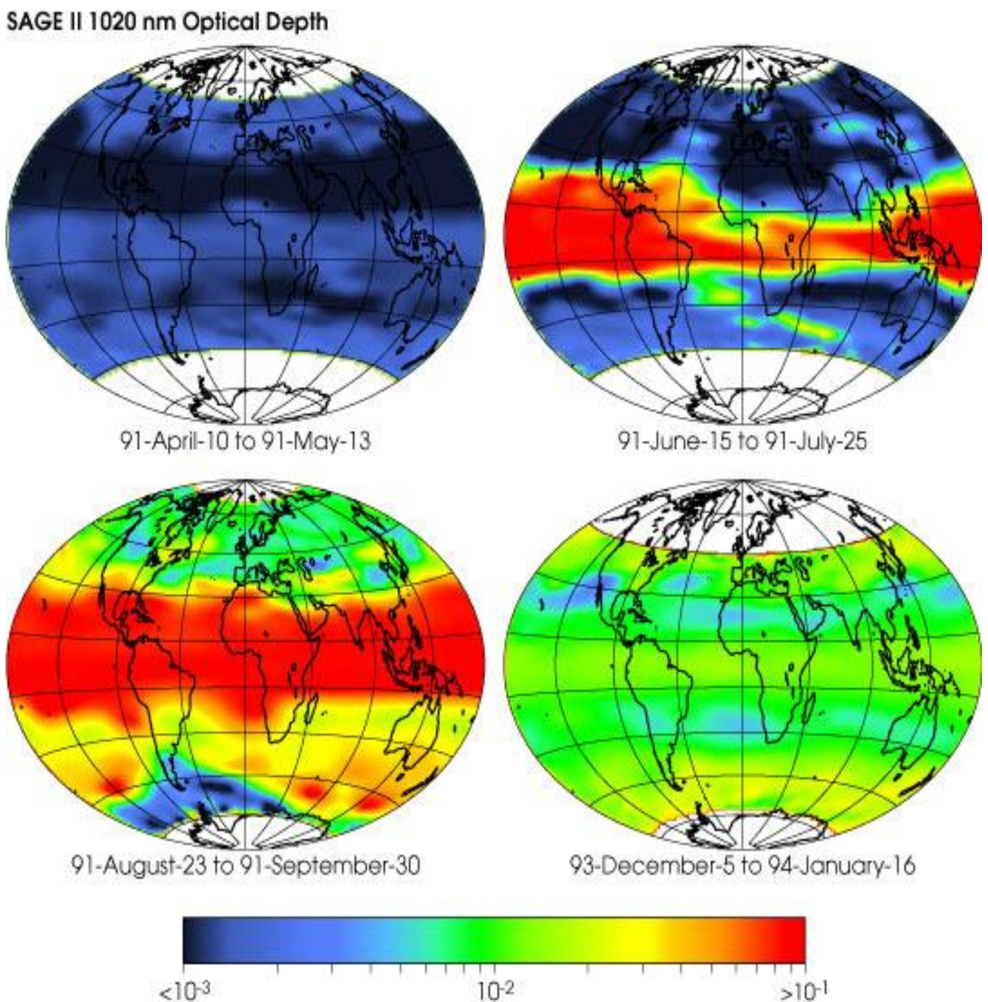
Example

[Tambora](#) (Indonesia) volcanic eruption in 1815

- 1816 - **year without summer**, summer snow in Europe & New England

Crops failed with cold temperatures; **worldwide famine resulted in ~ 90,000 deaths**)

e.g, Mt. Pinatubo, Philippines eruption in 1991 caused some global cooling

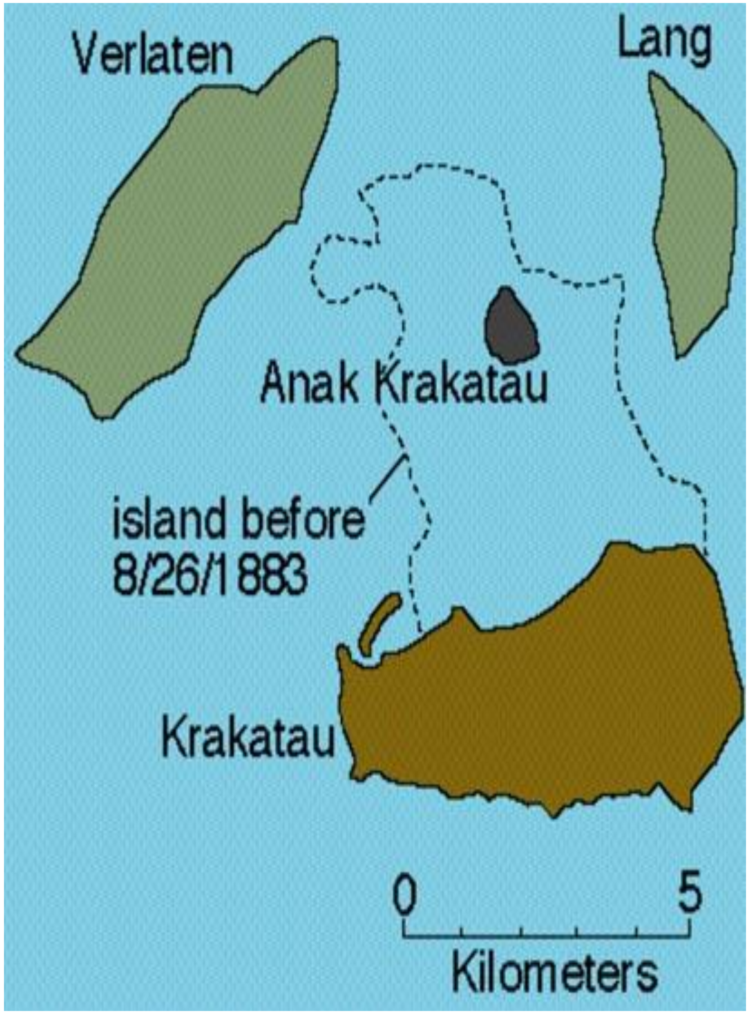


Satellite false-color images represent aerosol in the stratosphere

Volcanic Hazards

(F) <u>Tsunami</u> - volcanic eruptions rarely create tsunamis, most formed in SW Pacific

(e.g., **Krakatoa eruption)**



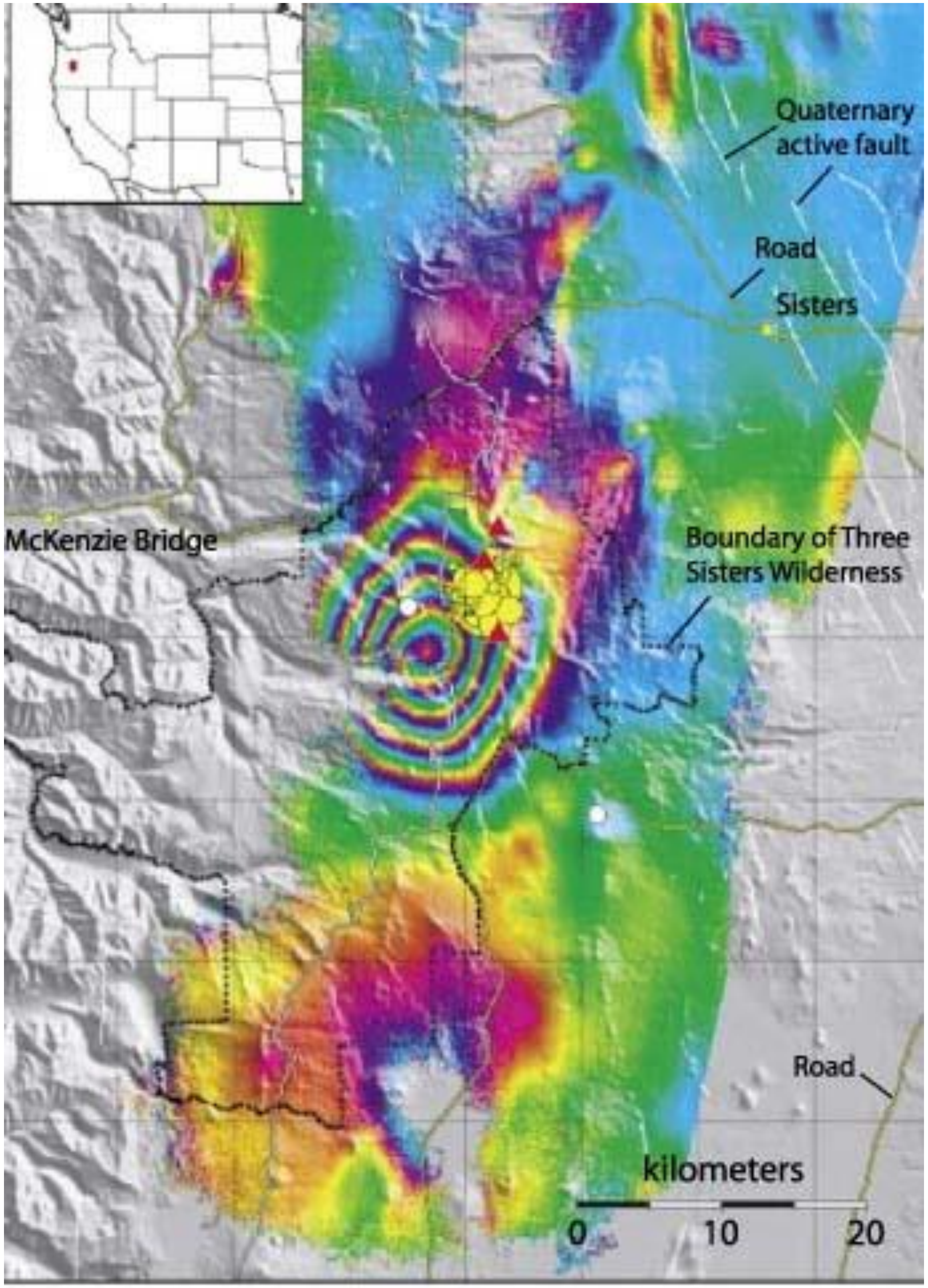
Mitigation
Monitoring Precursors

e.g., Ground deformation

A bulge developed on the north side of Mount St. Helens before the eruption (USGS Photograph taken on April 27, 1980, by Peter Lipman.)

Electronic Distance Meters (EDM): uses laser beams, reflect back, determine distance between 2 points

Electronic-distance measurement survey on the rim of Kilauea caldera in 1988, with snow-capped Mauna Loa in the background (Photo by by J.D. Griggs, U.S. Geological Survey).

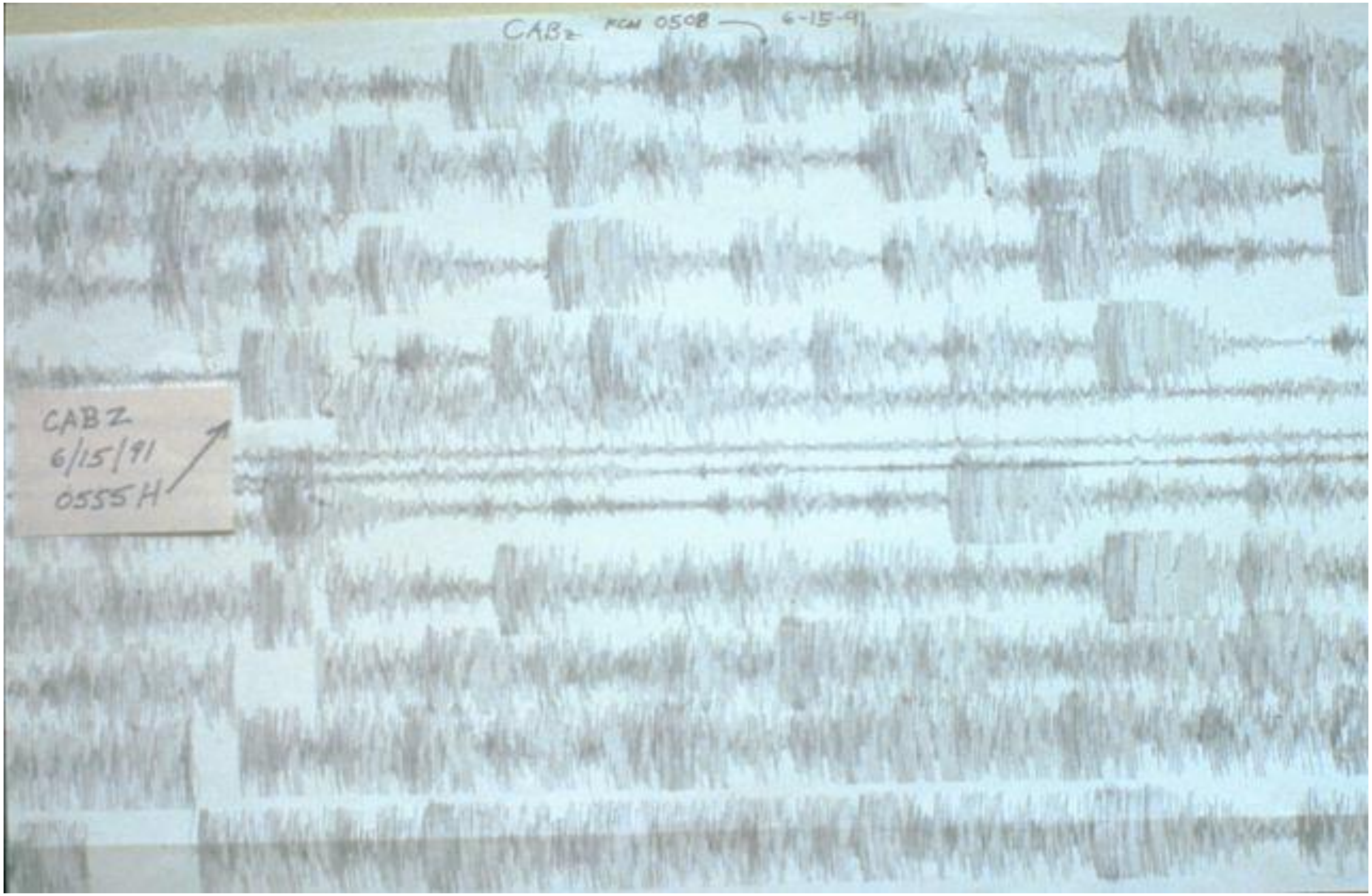


Remote Sensing Satellite imagery showing the area of uplift at the Three Sisters volcanoes (red triangles) in the Cascade Range in Oregon.

Based on images from the European Remote Sensing Satellite.

Each rainbow band on the map represents ~28 mm of uplift .

Monitoring earthquake activities



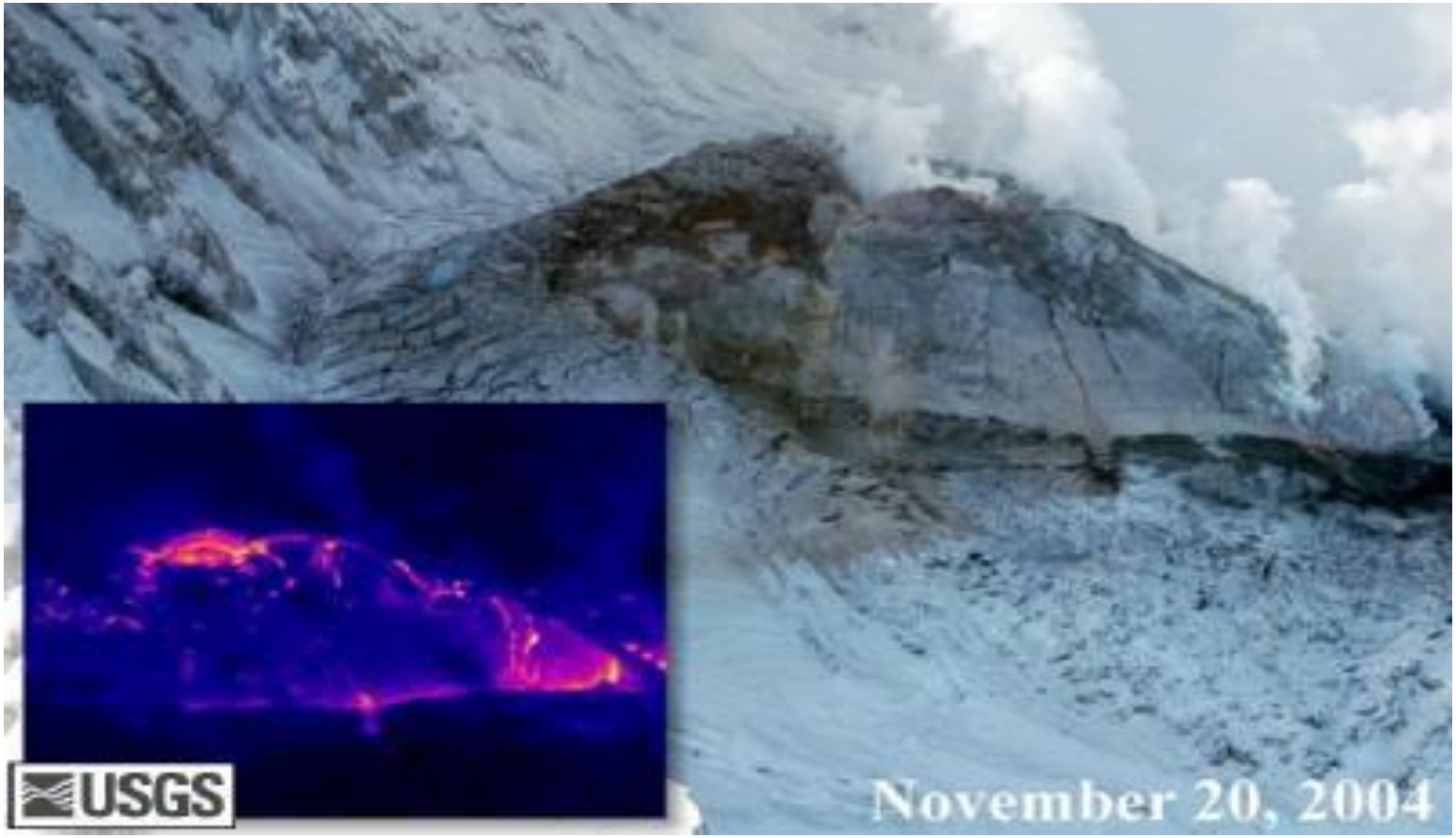
The seismogram for June 15, 1991, shows the heavy seismicity accompanying the catastrophic eruption of Mount Pinatubo in the Philippines. (Photo by Ed Wolfe, U.S. Geological Survey)

Monitoring volcanic gases

Sampling volcanic gases at Mageik Volcano in Alaska (USGS photo)

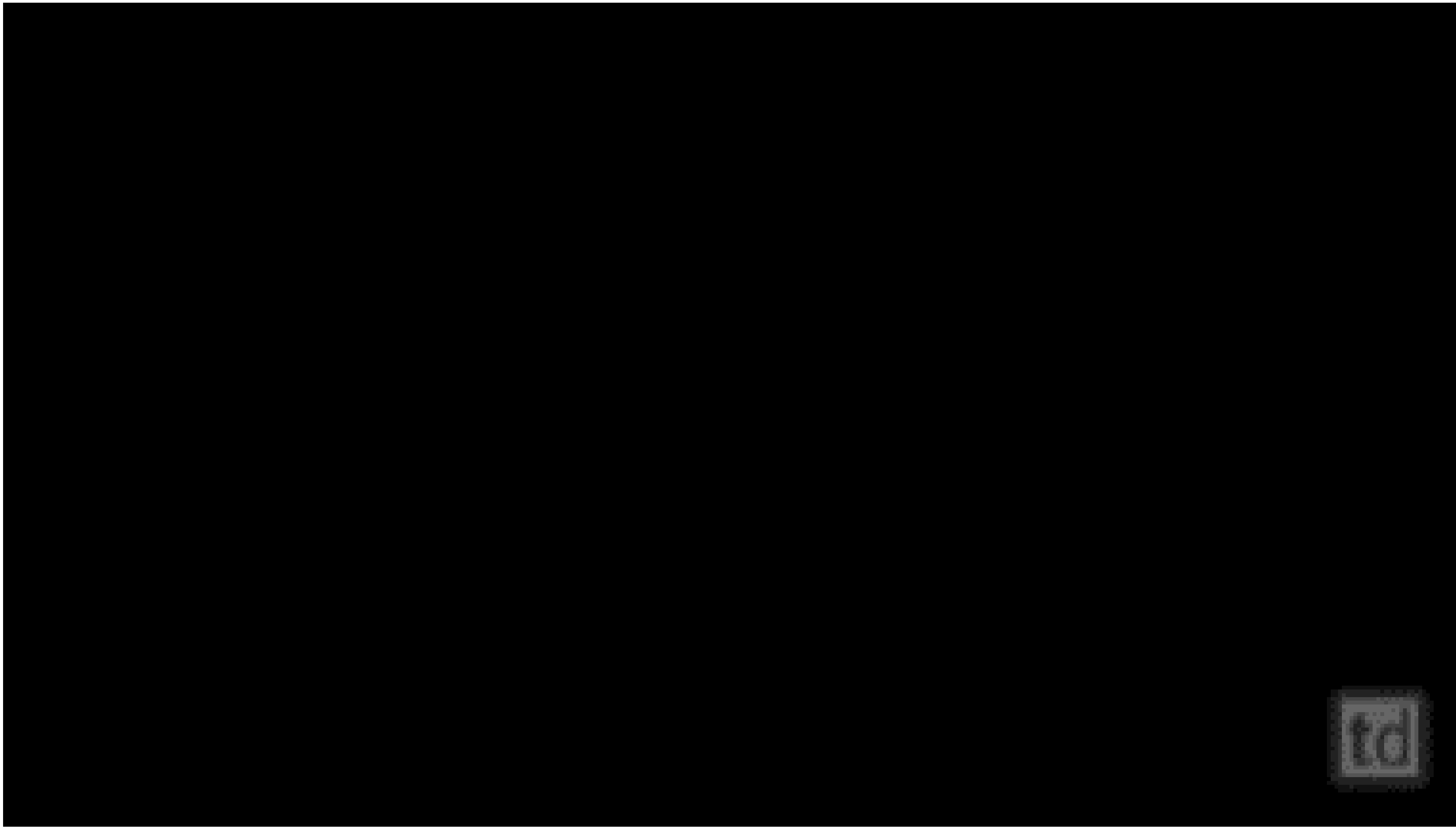
Monitoring Temperature Changes

Thermal infrared imaging



Photography compared to thermal infrared image of new growth on the Mount St. Helens' dome.

Volcanoes in the Infrared

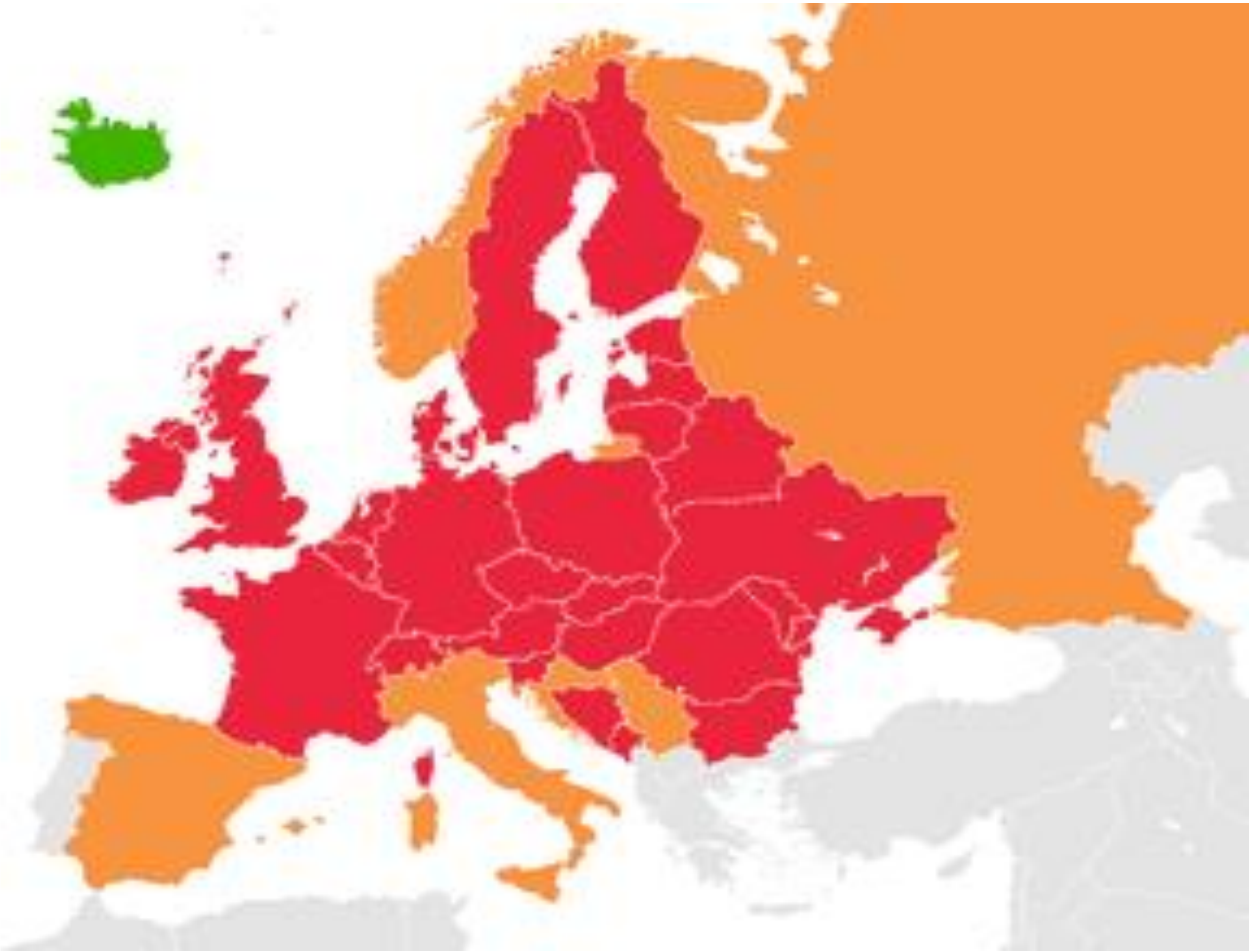


Mitigation Before/During Volcanic Eruption
e.g., Evacuation

The day before Pinatubo's cataclysmic June 15, 1991, eruption. (Photo by MSgt. Val Gempis, U.S. Air Force.)

Villagers fleeing the vicinity of Mount Pinatubo during heavy ash fall from the volcano's cataclysmic June 15, 1991, eruption. (Photo by Philippe Bourseiller/Jacques Durieux.)

Airspace Controls



European airspace completely (red) or partially (orange) closed on 18 April 2010 due to the eruption in Iceland (green**)**

Lava diversion

Firefighters pumped over 6 million cubic meters of seawater to chill and stop the lava flow in Iceland

(Photo from "Earth: Portrait of a Planet", 4th Edition, Copyright © 2012 W. W. Norton & Company)

Lava diversion

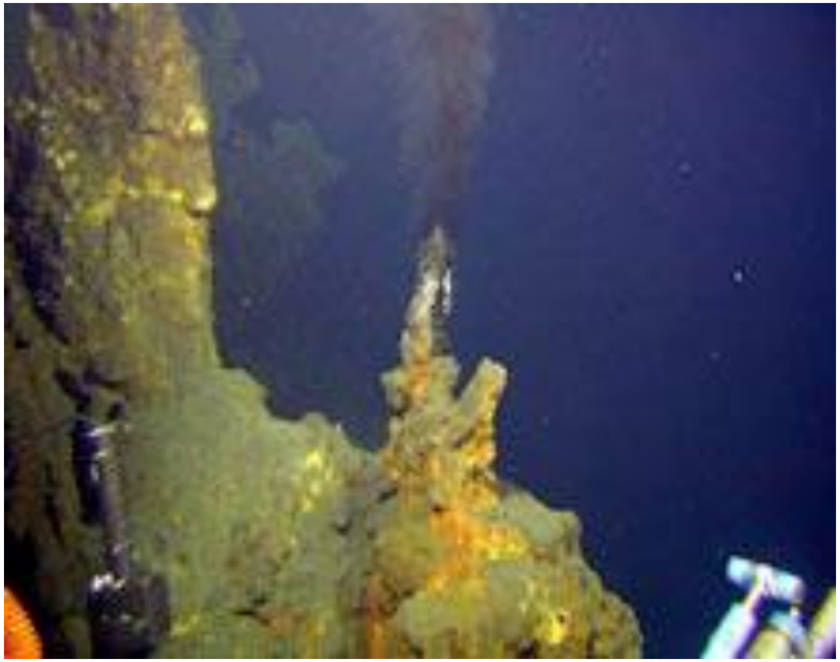
Quickly constructed embankment barrier diverted lava flows from Mt. Etna, 1983

(*Photograph by Jack Lockwood, U.S. Geological Survey)*

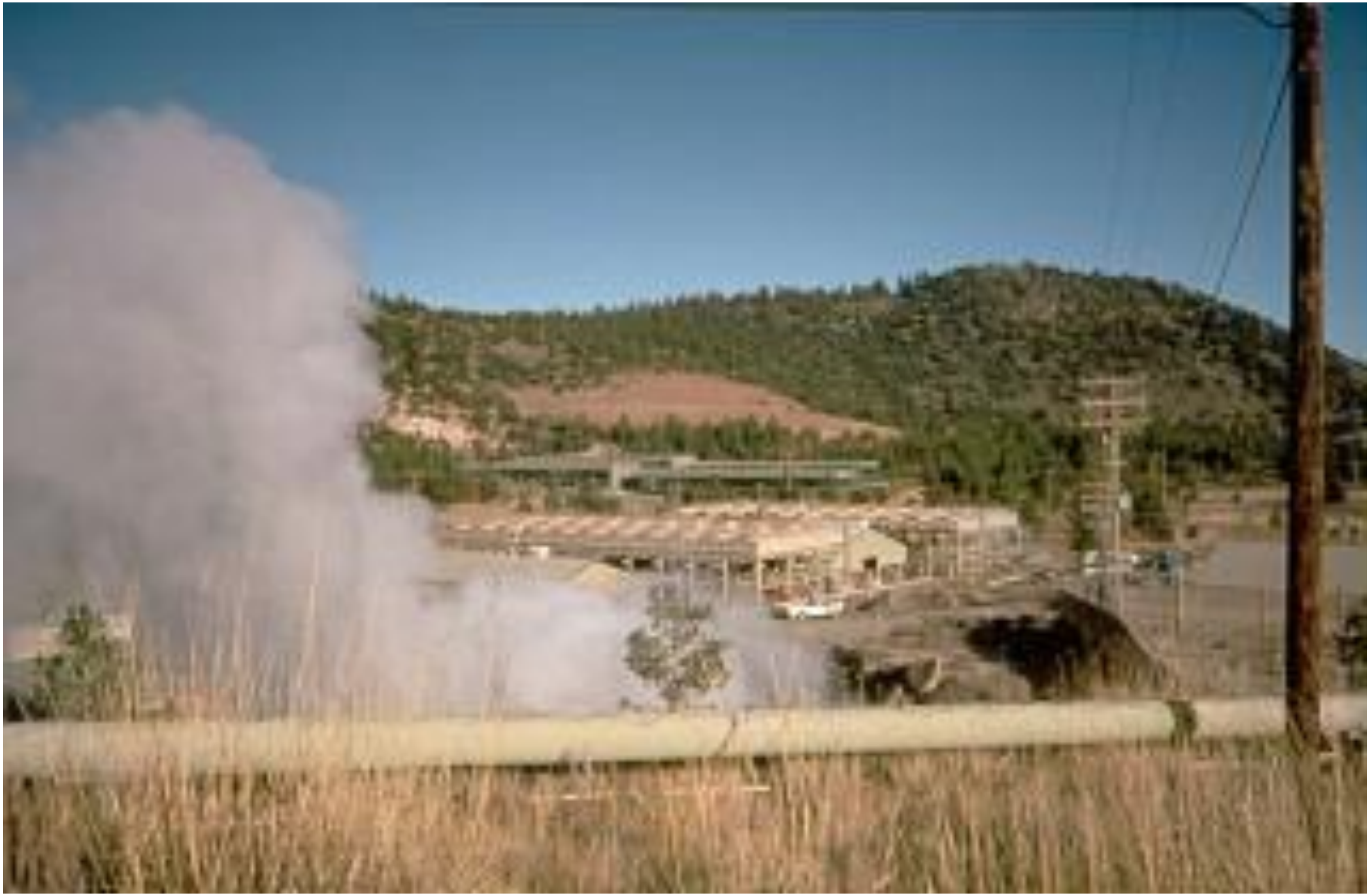
Benefits of Volcanoes & Volcanic Eruptions?

Benefits of Volcanoes & Volcanic Eruptions

Rich volcanic soils at the foot of Kaimon volcano in southern Kyushu (Photo by Lee Siebert, Smithsonian Institution).



Submarine metal deposit, Brothers Volcano in the Kermadec Arc (Photo from NOAA Ocean Explorer)



The Casa Diablo geothermal power plant in the Long Valley California. (Photo by Larry Mastin, 1991 U.S. Geological Survey).

National parks and monuments