12.001 Introduction to Geology
Spring 2008

Introduction to volcanoes

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Products: lava, rocks, gases

Magma composition and how it flows: lava flows, gas-rich pumice

Other volcanic products: pyroclastic flows and lahars

Shapes and types of volcanoes

Magma composition

SiO_2 CONTENT	MAGMA TYPE	VOLCANIC ROCK
~50%	Mafic	Basalt
~60%	Intermediate	Andesite
~65%	Felsic (low Si)	Dacite
~70%	Felsic (high Si)	Rhyolite

VISCOSITY

- Resistance to deformation
- Determined by temperature, composition, stress, pressure
- Of 10 most common elements, oxygen is the only anion and silicon is the most common cation, so naturally Si-O bonds are common.

  These Si-O bonds control viscosity through *polymerization*, the development of chains and knots of bonded atoms.

Explosive eruption

Augustine volcano in Alaska on March 27, 1986.

Photograph courtesy of the U.S. Geological Survey.

Basalt

Basalt lava (glowing rock) oozes over basalt lava flow (USGS)

Image courtesy of USGS.

Basalt has a low viscosity and can easily flow >20 km from a vent.

The low viscosity typically allows volcanic gases to escape without generating explosions. Basaltic lava fountains and fissure eruptions, however, still form explosive fountains hundreds of meters tall.

Basalt is erupted at temperatures between 1100 to 1250° C.

Pillow basalt

Pillow basalts on the south Pacific seafloor -- Courtesy of NOAA.

Cascade lava

Lava cascades over the edge of Aloi Crater generated during the 1969-71 eruption of Mauna Ulu on the east rift zone of Kilauea volcano, Hawaii.

Courtesy of Don Swanson, USGS.

A’a

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`A`a is a Hawaiian term for lava flows that have a rough rubbly surface composed of broken lava blocks called clinkers.

As pasty lava in the core travels downhill, the clinkers are carried along at the surface. At the leading edge of an `a`a flow these cooled fragments tumble down the steep front and are buried by the advancing flow. This produces a layer of lava fragments both at the bottom and top of an `a`a flow.

Andesitic flows

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Andesite flows on Lascar Volcano, Chile. Lascar is the most active stratovolcano in the central Andes. The most impressive features on the flanks of the volcano are two massive andesite flows with well-developed lava levees. Andesites erupt at temperatures between 900 and 1100°C.

Rhyolite

Image courtesy of USGS.

Flow banding in rhyolite lava from Mono-Inyo Craters volcanic chain, California (black bands composed of obsidian) (USGS)

Rhyolite is a light-colored rock with silica (SiO_2) content greater than about 68 weight percent.

Common minerals in solidified rhyolite include quartz, feldspar and biotite, often found in a glassy matrix.

Rhyolite is erupted at temperatures of 700 to 850° C.

Obsidian

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Obsidian is dense volcanic glass, usually rhyolite in composition, and typically black in color.

Compared with window glass, obsidian is rich in iron and magnesium; tiny (<0.005 mm) crystals of iron oxide within the glass cause its dark color.

Glass, unlike crystals, has no regular structure and therefore fractures in smooth conchoidal (curved) shapes. The intersections of these fractures can form edges sharper than the finest steel blades.

Obsidian flow

The Long Valley Caldera, CA, was created by crustal collapse after an explosive eruption about 650,000 years ago. Since that time, silica-rich eruptions have generated viscous rhyolitic domes and short rhyolite flows, including this 600-year-old flow called Obsidian flow.

Courtesy of S.R. Bradley, USGS.

Ash

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Ash from Mt. St. Helens.
Photograph by D.E. Wieprecht

SEM image provided by A.M. Sarna-Wojcicki
Tic marks 100 microns apart

- consists of rock, mineral, and volcanic glass fragments smaller than 2 mm in diameter.
- is extremely abrasive, similar to finely crushed window glass.
- created during explosive eruptions by shattering solid rocks and violent separation of magma into tiny pieces.

Pumice

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Photograph by W.E. Scott on 27 June 1991: Mount Pinatubo, Philippines

Pumice consists of a network of gas bubbles frozen amidst fragile volcanic glass and minerals.

Pumice is similar to the liquid foam generated when a bottle of pressurized soda is In the case of pumice, the liquid part of the froth quickly solidifies to glass around the glass bubbles.

Fumarole

Photograph by R.L. Christiansen on 27 July 1973
Close view of a fumarole on Kilauea Volcano (USGS)

- vents from which volcanic gas escapes
- may occur along tiny cracks or long fissures, in chaotic clusters or fields, and on the surfaces of lava flows and thick deposits of pyroclastic flows
- may persist for decades or centuries if they are above a constant heat source, or may disappear within weeks

The Pu`u `O`o vent on Kilauea emits 1,000 - 2,000 tons of SO_2 gas each day.

(USGS)Photograph by K.A. McGee on 19 September 1995

Gas compositions

MAIN GASES	TRACE GASES	TOXIC GASES
H_2O (70-90%)	N	HCl
CO_2	H	HF
SO_2	S	H_2SO_4
	F	H_2S
	Ar	
	CO	
	Cl	

Lahars or Debris Flows

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A small lahar on Santiaguito volcano down the Nima II River near the town of El Palmar in Guatemala.

Photograph by J.N. Marso on 14 August 1989

Lahar is an Indonesian word for a rapidly flowing mixture of rock debris and water that originates on the slopes of a volcano. Lahars are also referred to as volcanic mudflows or debris flows.

They form in a variety of ways, chiefly by the rapid melting of snow and ice by pyroclastic flows, intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, and as a consequence of debris avalanches.

Armero, Colombia, destroyed by lahar on November 13, 1985 after the Nevado del Ruiz eruption. More than 23,000 people were killed.

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Pyroclastic Flow, or Nuée Ardente

A pyroclastic flow is a ground-hugging avalanche of hot ash, pumice, rock fragments, and volcanic gas that rushes down the side of a volcano as fast as 100 km/hour. The temperature within a pyroclastic flow may be greater than 500°C.

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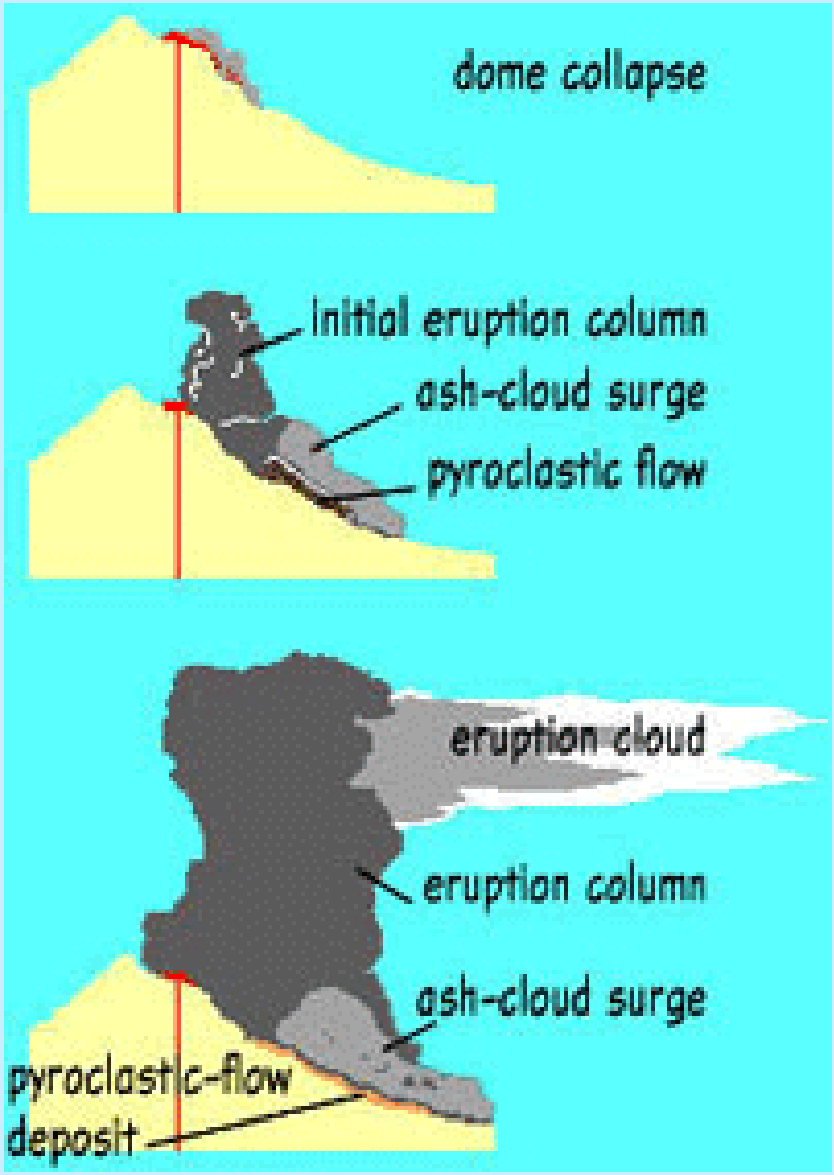
A pyroclastic flow sweeps down the side of Mayon Volcano, Philippines, in 1984.

(Photograph by C. Newhall on 15 September 1984)

Nuée Ardentes continued 2



Courtesy of B. Meyers, USGS

- the sequence of events associated with the 1991-95 nuée ardente eruptions from Mt. Unzen, Japan
- initiated by collapse of a growing lava dome generates the nuée ardente
- a faster-moving cloud of smaller ash-sized fragments (the ash-cloud surge) forms above and in front of the nuée ardente

Pyroclastic flow on Mt. Merapi

Images removed due to copyright restrictions.

As seen from the Kali Adem village, near Indonesia city of Yogyakarta May 15, 2006. REUTERS/Crack Palinggi

Ignimbrite

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Welded ignimbrite in Aso, Japan: The rock that results from a pyroclastic flow. Pumice fragments have been compacted into black glassy pancake shapes, known as fiamme.

Rhyolite and welded tuff in Marblehead MA

Stratovolcano

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Mount Mageik volcano viewed from the Valley of Ten Thousand Smokes, Katmai National Park and Preserve, Alaska.

Steep, conical volcanoes built by the eruption of viscous lava flows, tephra, and pyroclastic flows, are called stratovolcanoes.

Usually constructed over a period of tens to hundreds of thousands of years, stratovolcanoes may erupt a variety of magma types, including basalt, andesite, dacite, and rhyolite. All but basalt commonly generate highly explosive eruptions.

Shield Volcano

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View of the NNW flank of Mauna Loa Volcano from the south side of Mauna Kea Volcano, Hawai`i; both are shield volcanoes.

Built by the eruption of fluid basalt lava

Basalt can form lava tubes that enable lava to flow tens of kilometers from an erupting vent with very little cooling.

The largest volcanoes on Earth – and Mars - are shield volcanoes.

Laki, 1783-84 Iceland

Second largest flood lava eruption in historical time
Iceland's biggest natural disaster

Lava = 14.7 km^3
Tephra = 0.4 km^3

WVZ, EVZ, NVZ are Western, Eastern and Northern Volcanic Zones

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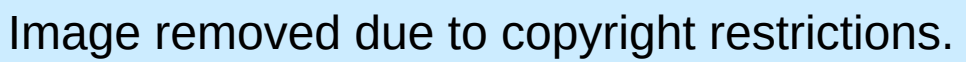
Fig. 1 from Thordarson and Self (2003)

Laki fissure, Iceland



The Laki fissure looking toward the southeast from Laki mountain. Note bus and SUVs parked at left for scale. The road across the black lava deposits. The Laki mountain did not erupt. The 1783 eruption was of the Laki fissures (Lakagígar), as shown here and in the next slide and the total length of the vent system is 27 km (Thordarson and Self, 1993). In Iceland, it is referred to as Skaftáreldar, the Skaftá Fires, because the vents poured lava into the Skaftá River gorge, turning it into a river of fire. The nearby Grímsvötn volcano, beneath the Vatnajökull glacier, also erupted at the same time, but its activity was typified by a series of minor eruptions and was not responsible for the climate change. For simplicity and consistency with recent usage, I will refer to the eruption here as the Laki eruption.

Thordarson, T., and S. Self, 1993. The Laki (Skaftár Fires) and Grímsvötn eruptions in 1783-1785. *Bulletin of Volcanology*, **55**, 233-263.

From Laki mountain toward Vatnajökull glacier, in the direction of the Grímsvötn volcano.

Image removed due to copyright restrictions.

Looking northwest from Laki Mountain. The fissure disappears under the Vatnajökull glacier, in the direction of the Grímsvötn volcano. Photo © Alan Robock, 2002.

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Franklin (1784)

During several of the summer months of the year 1783, when the effect of the sun's rays to heat the earth in these northern regions should have been greatest, there existed a constant fog over all Europe, and great part of North America. This fog was of a permanent nature; it was dry, and the rays of the sun seemed to have little effect towards dissipating it, as they easily do a moist fog, arising from water. They were indeed rendered so faint in passing through it, that when collected in the focus of a burning glass, they would scarce kindle brown paper. Of course, their summer effect in heating the earth was exceedingly diminished.

Hence the earth was early frozen,

Hence the first snows remained on it unmelted, and received continual additions.

Hence the air was more chilled, and the winds more severely cold.

Hence perhaps the winter of 1783-4, was more severe, than any that had happened for many years.

The cause of this universal fog is not yet ascertained. Whether it was adventitious to this earth, and merely a smoke, proceeding from the consumption by fire of some of those great burning balls or globes which we happen to meet within our rapid course round the sun, and which are sometimes seen to kindle and be destroyed in passing our atmosphere, and whose smoke might be attracted and retained by our earth; or whether it was the vast quantity of smoke, long continuing to issue during the summer from Hecla in Iceland, and that other volcano which arose out of the sea near that island, which smoke might be spread by various winds, over the northern part of the world, is yet uncertain.

Mt. St. Helens Today

A helicopter flies by the base of the slab or "fin" growing in the Mount St. Helens crater. The fin grows about four to five feet a day but loses some of that growth from rockfalls off its tip. The fin is about 300 feet tall from its base. Growth stopped in January, 2008.

Photo Courtesy of the U.S. Geologic Survey

Paricutin

***Paricutin 1944* -- From Foshag and Gonzales, 1956, Birth and development of Paricutin volcano, USGS Bulletin 965-D, p. 355-489.**

Photo Courtesy of the U.S. Geologic Survey

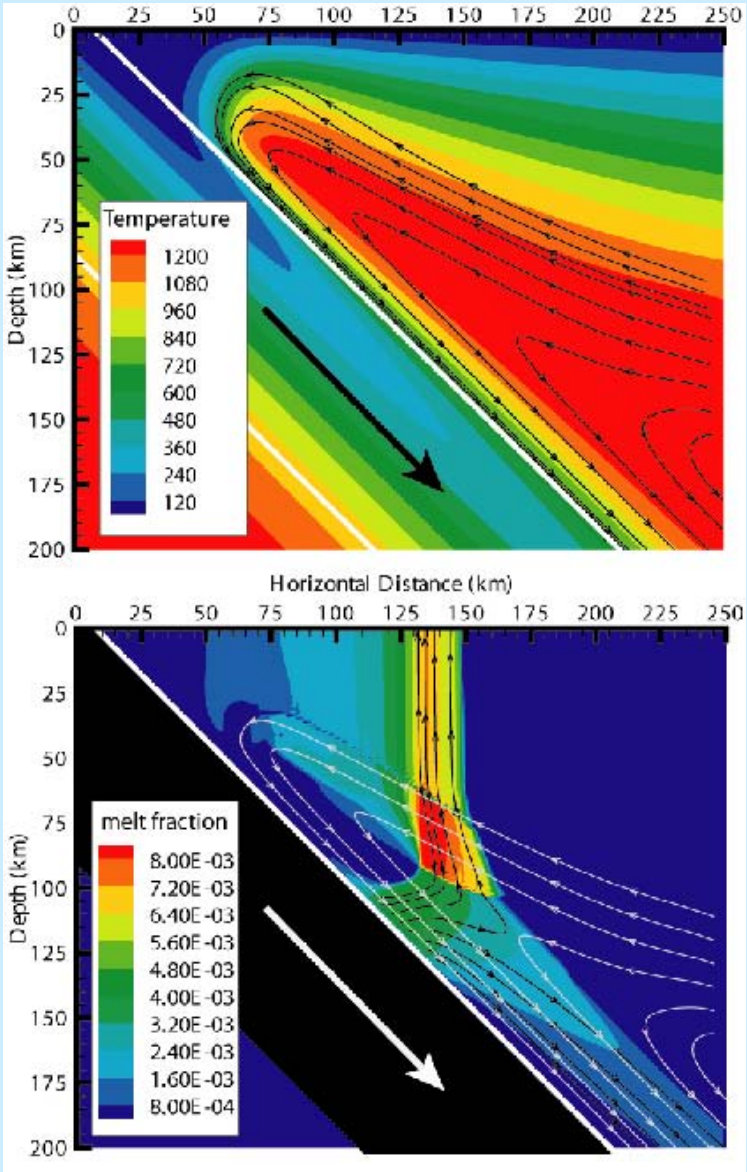
Three weeks before the Paricutin eruption occurred, the people near Paricutin village (200 miles W of Mexico City) heard the rumbling noises like thunder. On February 20, 1943 a farmer, Dionisio Pulido, and his wife were burning shrubbery in their cornfield when they observed the earth in front of them swell upward and crack to form a fissure 2-2.5 m across. They heard hissing sounds and later described the rise of "smoke" from the fissure, which had the repugnant smell of rotten eggs, a hallmark of H_2S gas.

Strombolian pyroclastic activity began at the site the following day and by the end of the day it generated a 40-m-high scoria cone. In one week it grew to a height of 100 m from the accumulation of bombs and lapilli, and it was raining down finer fragments that burned and eventually covered the village of Paricutin. There were several eruptive phases over a 9-year period. After about two years of mostly pyroclastic activity the pyroclastic phase began to wane, and the outpouring of lava from the base of the cone became the dominant mode of eruption over the next 7 years. The eruption ceased in 1952. The final height of the scoria cone was 424 m.

Mt. Etna erupting

Courtesy of NASA.

BIGGER ARC VOLCANOES



(Cagnioncle, Parmentier, Elkins-Tanton: 2007*)*

Major volcanic eruptions of the past 250 years

Volcano	Year	VEI
Lakagígar [Laki craters], Iceland	1783	4
Unknown (El Chichón?)	1809	
Tambora, Sumbawa, Indonesia	1815	7
Cosiguina, Nicaragua	1835	5
Askja, Iceland	1875	5
Krakatau, Indonesia	1883	6
Okataina [Tarawera], North Island, NZ	1886	5
Santa Maria, Guatemala	1902	6
Ksudach, Kamchatka, Russia	1907	5
Novarupta [Katmai], Alaska, US	1912	6
Agung, Bali, Indonesia	1963	4
Mt. St. Helens, Washington, US	1980	5
El Chichón, Chiapas, Mexico	1982	5
Mt. Pinatubo, Luzon, Philippines	1991	6

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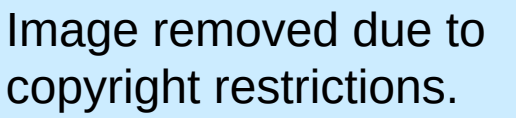
These two photos show the Earth's limb at sunset before and after the Mt. Pinatubo eruption. The first view (STS41D-32-14) shows a relatively clear atmosphere, taken August 30, 1984. Astronauts were looking at the profiles of high thunderstorms topping out at the tropopause at sunset; different atmospheric layers absorbed the last rays of light from the sun as the spacecraft moved eastward.

The same type of photograph (STS043-22-23) was taken August 8, 1991, less than two months after the Pinatubo eruption. Two dark layers of aerosols make distinct boundaries in the atmosphere. The estimated altitude of aerosol layers in this view is 20 to 25 km.

"Darkness" by Lord Byron



I had a dream, which was not all a dream.
The bright sun was extinguish'd, and the stars
Did wander darkling in the eternal space,
Rayless, and pathless, and the icy earth
Swung blind and blackening in the moonless air;
Morn came and went—and came, and brought no day,
And men forgot their passions in the dread
Of this their desolation; and all hearts
Were chill'd into a selfish prayer for light:
And they did live by watchfires—and the thrones,
The palaces of crowned kings—the huts,
The habitations of all things which dwell,
Were burnt for beacons; cities were consumed,
And men were gather'd round their blazing homes
To look once more into each other's face; . . .

Krakatau

Image removed due to copyright restrictions.

Krakatau erupting on May 27, 1883.

From *Symons, G., 1888, The*
From *Symons, G., 1888, The*
e Eruption of Krakatau and
uent phenomena: Reports of the
Krakatau Committee of the Royal
Society, Trubner, London.

Diurnal cycle effects at Batavia (Jakarta) after the August 27, 1883 Krakatau eruption

pressure

Image removed due to copyright restrictions.

temperature

— — – Aug. 26

——— Aug. 27

-------- Aug. 28

vapor pressure

Verbeek (1885)

relative humidity

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“Other ships in Lampong Bay were not as lucky. The wave lifted the steamship *Berouw* up the Koeripan River valley, depositing the ship over a mile inland, thirty feet above sealevel, killing all 28 of its crew members.

In London, the Krakatau sunsets were clearly distinct from the familiar red sunsets seen through the smoke-laden atmosphere of the city. This is demonstrated in the painting shown here of a sunset from the banks of the Thames River, created by artist William Ascroft on November 26, 1883.

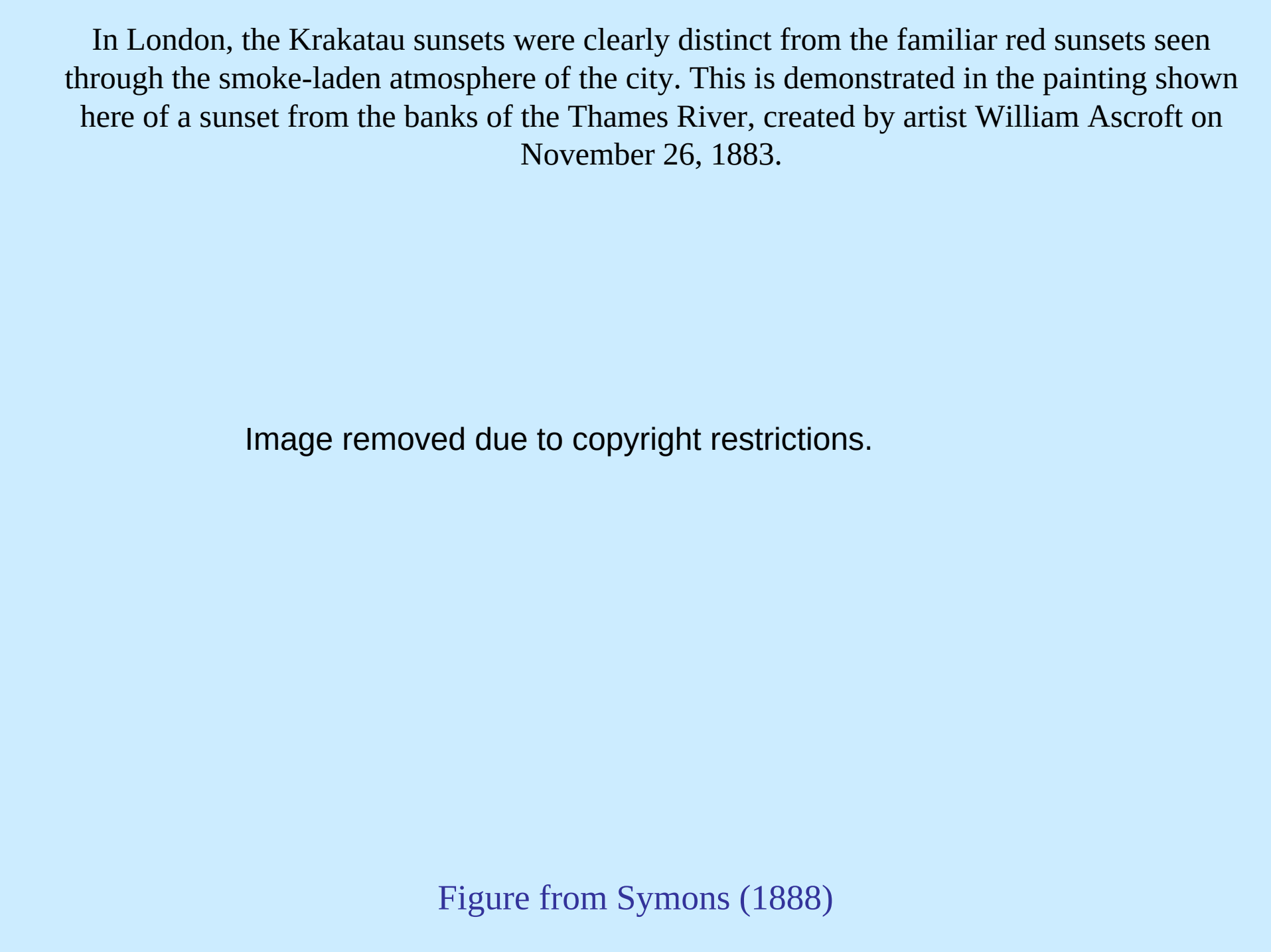
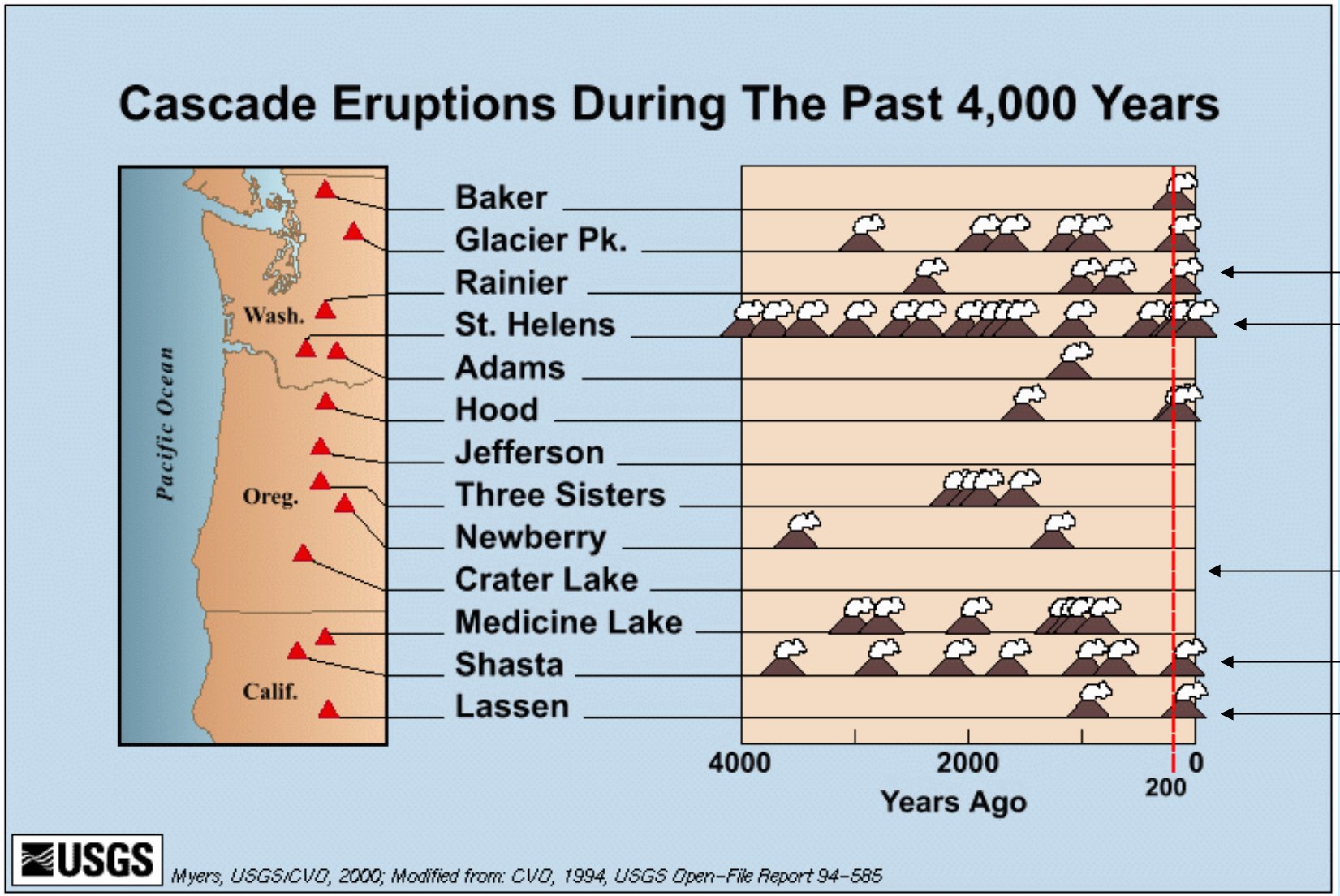


Figure from Symons (1888)

Recent Cascades eruptions



Mt. Shasta and Shastina

Tim Grove/Lindy Elkins-Tanton

7 eruptions in the last 4,000 years, and one of the largest landslides on Earth

Shastina from Mt. Shasta

Tim Grove/Lindy Elkins-Tanton

Crater Lake: The Wineglass Tuff

Image removed due to copyright restrictions.

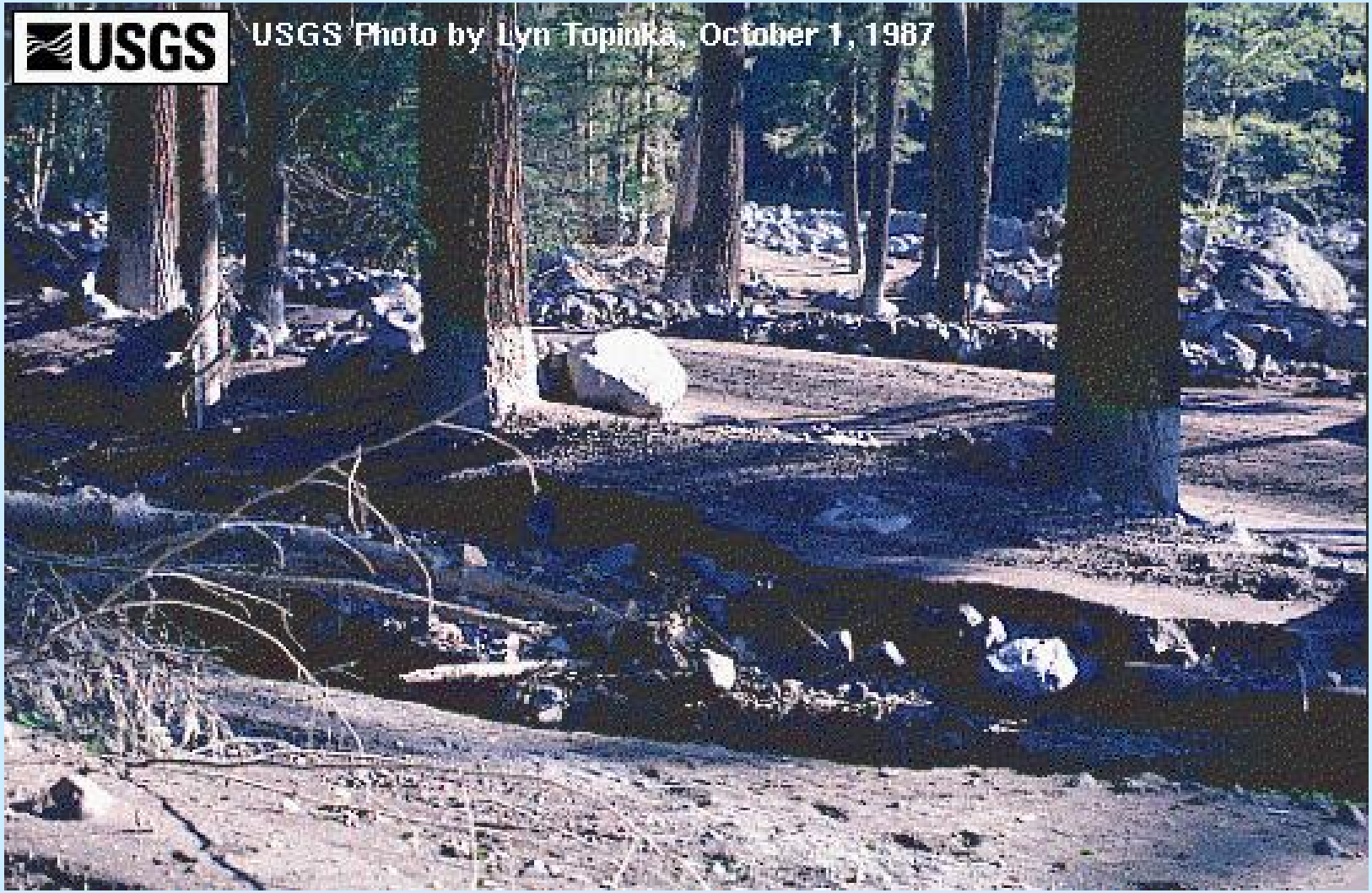
Williams and Goles (1968)

7,700 years ago the former Mt. Mazama (~12,00 feet in elevation) exploded

Mount Ranier and Takoma, Washington

4 eruptions in the last 4,000 years

Mt. Ranier debris flow



Lahars at Mt. Ranier

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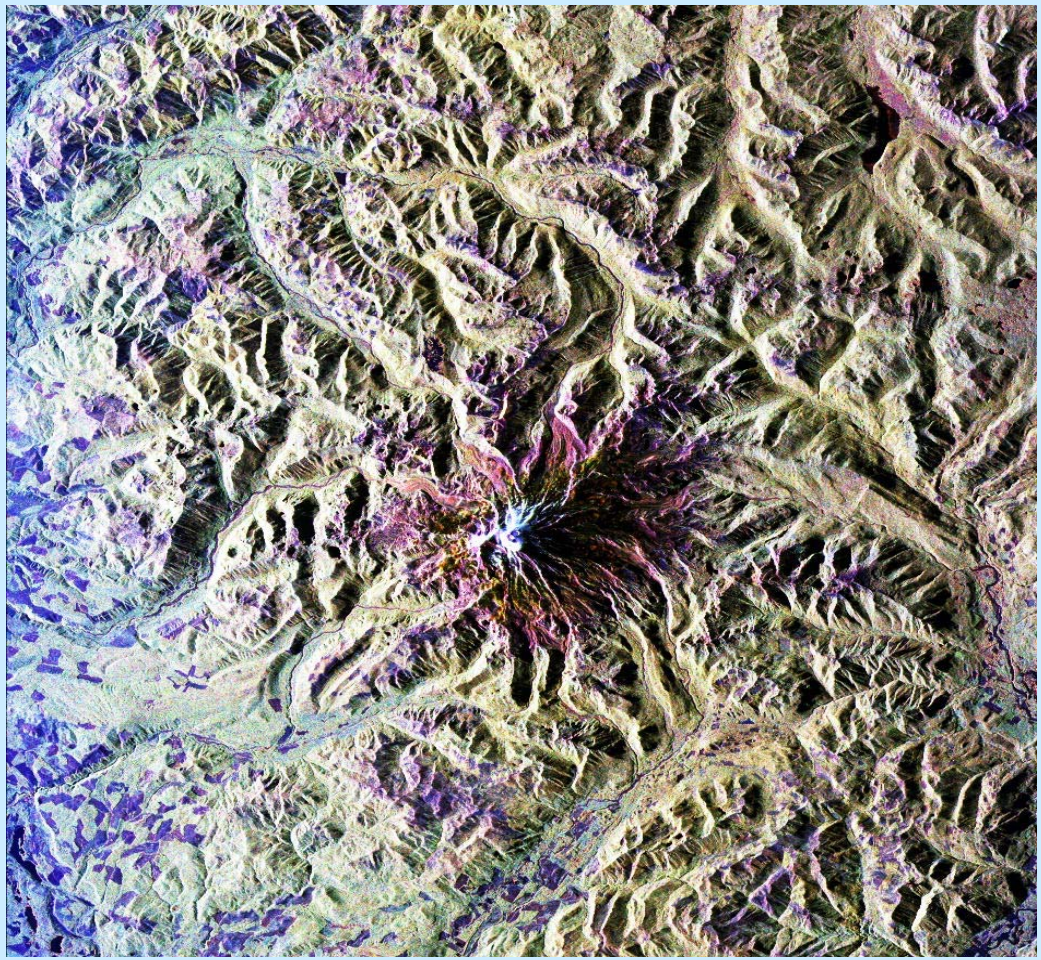
At the 4000 m summit of Mt. Rainier is the largest system of alpine glaciers in the Cascade Range.

Melting glacier ice has generated at least 50 major lahars over the past 10,000 years.

The largest was the ~5700-year-old Osceola lahar which traveled over 112 km from its source and spread to an area of over 300 square km.

More than 300,000 people now live in the area covered by these extensive lahars.

Mt. Ranier from space



NASA/International Space Station

Mammoth Lakes caldera

USGS Mammoth observatory/ D.E. Wieprecht

760,000 years ago

Mammoth dead trees

USGS Mammoth observatory/ D.E. Wieprecht

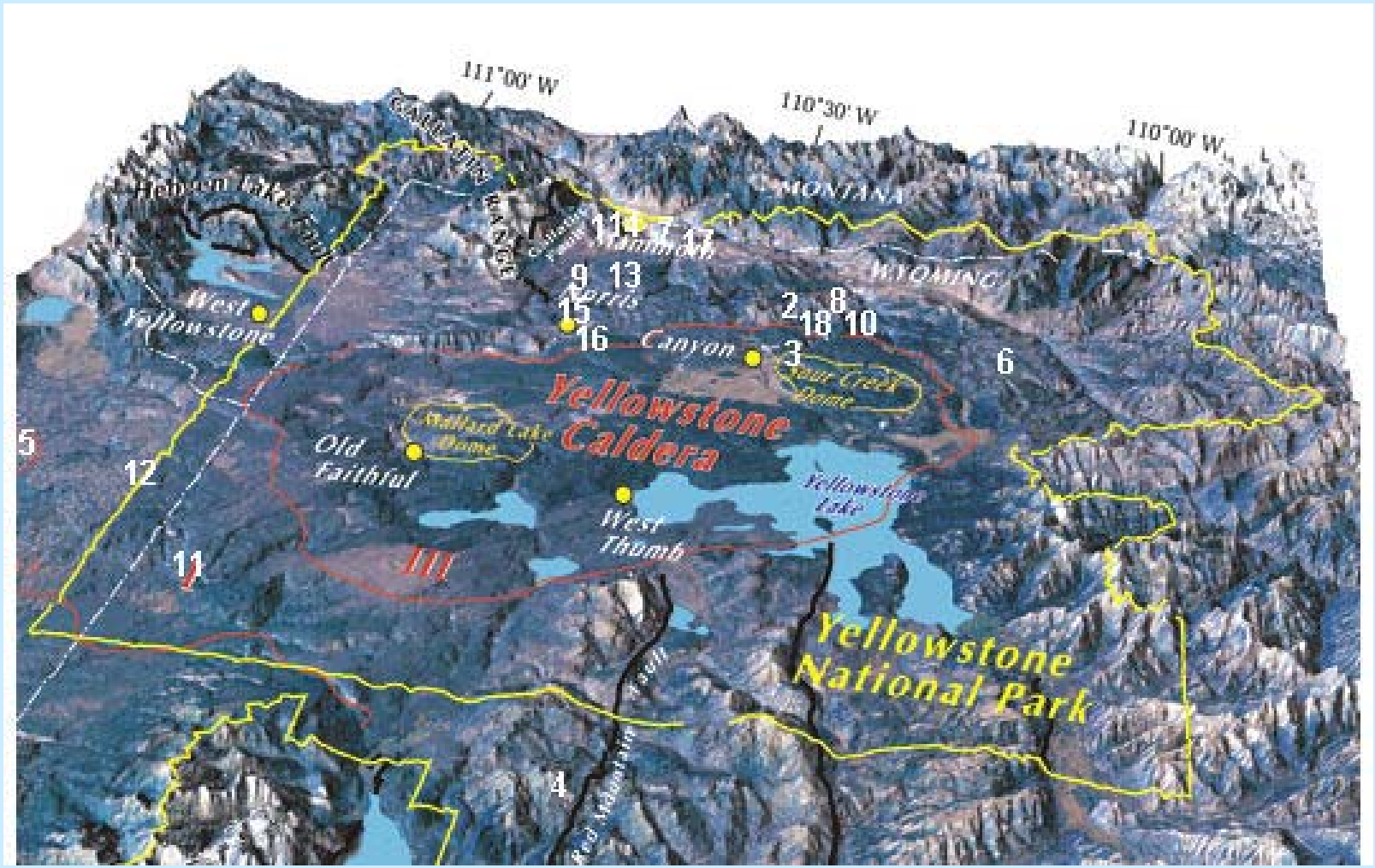
Tree death since 1990; 100 square miles are swelling

Mammoth Lakes: The Bishop Tuff

USGS Mammoth observatory

760,000 years ago; 2,000 times larger than Mt. St. Helens' eruption

Yellowstone caldera map



USGS Yellowstone volcano observatory

30 by 50 miles

Yellowstone GPS station, 1 of 60

USGS Yellowstone volcano observatory

Volume comparisons

Lava from Kilauea

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Hawaii Volcano Observatory

Has been erupting since 1983, the 55th recorded eruptive episode

Created ~600 new acres of land and covered 16,000 existing acres

Inundated 200 homes, an entire town, and the visitor center for the Hawaiian Volcanoes National Park

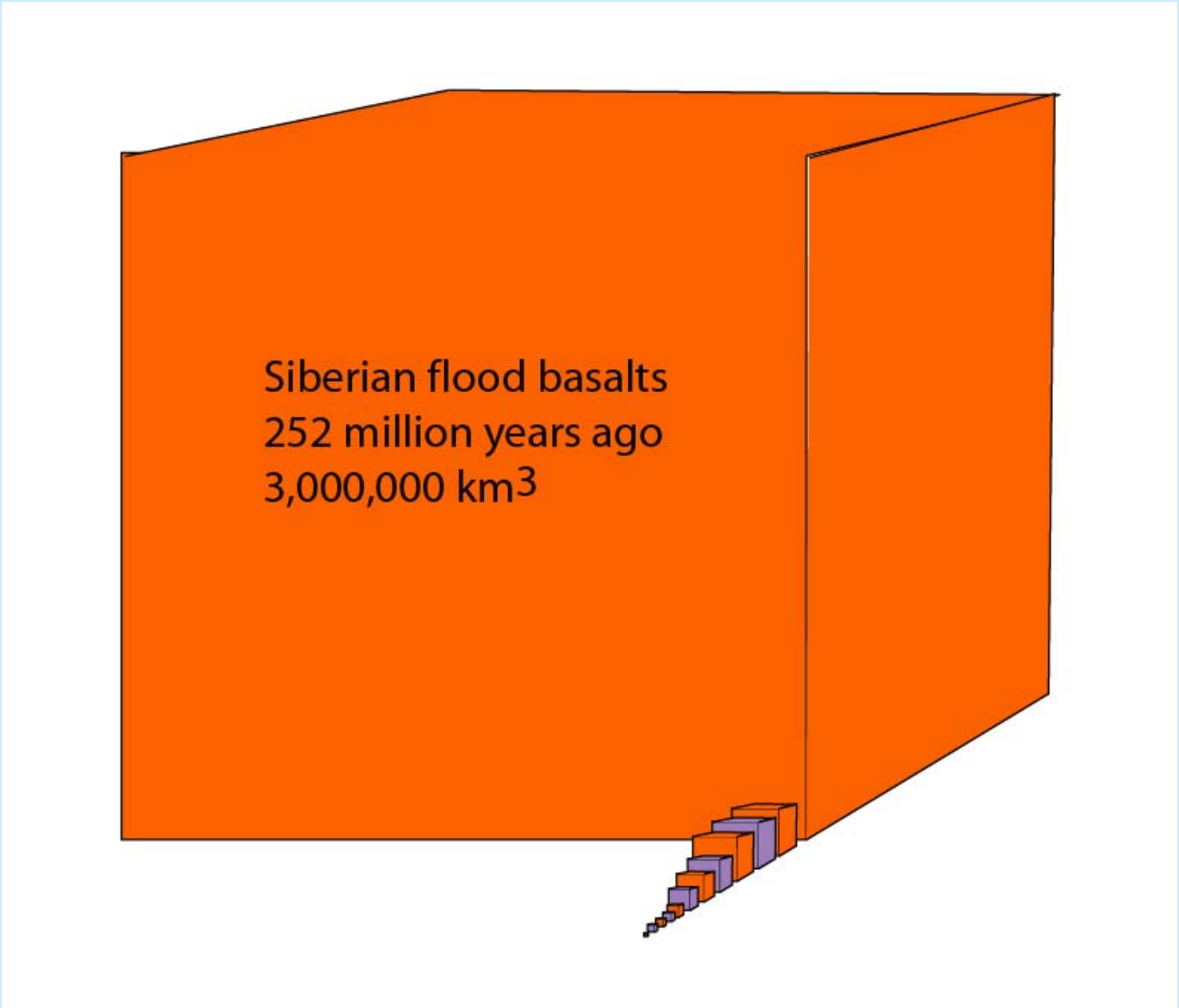
Flood basalts from the N. Atlantic Province, Mull, Scotland

Elkins-Tanton

Volume comparisons

Elkins-Tanton

Volume comparisons



Elkins-Tanton