EARTH 270 – DISASTERS AND NATURAL HAZARDS (v. 2018)

Kensennuma City, Miyagi Prefecture , Japan, March 2011

PROFESSOR S.G. EVANS, PhD, PEng (Room 303, Earth Science and Chemistry (ESC) Building)

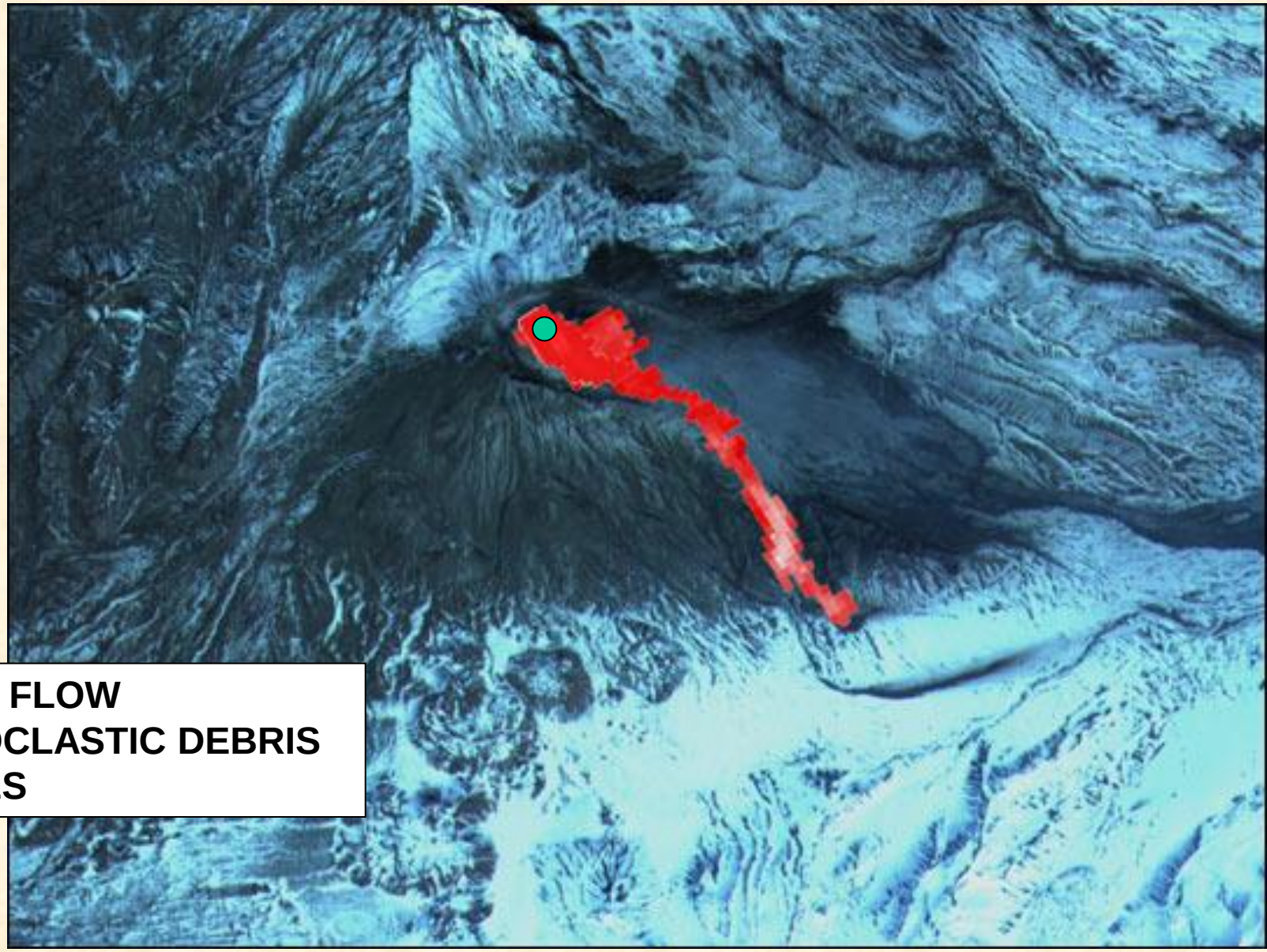
UNIVERSITY OF WATERLOO

VOLCANOES, VULCANISM AND VOLCANIC HAZARDS 2

VOLCANOES II

Chaiten volcano, Chile, 2008

NATURE OF VOLCANIC ERUPTIONS: ERUPTIVE PRODUCTS



1. LAVA FLOW
2. PYROCLASTIC DEBRIS
3. GASES

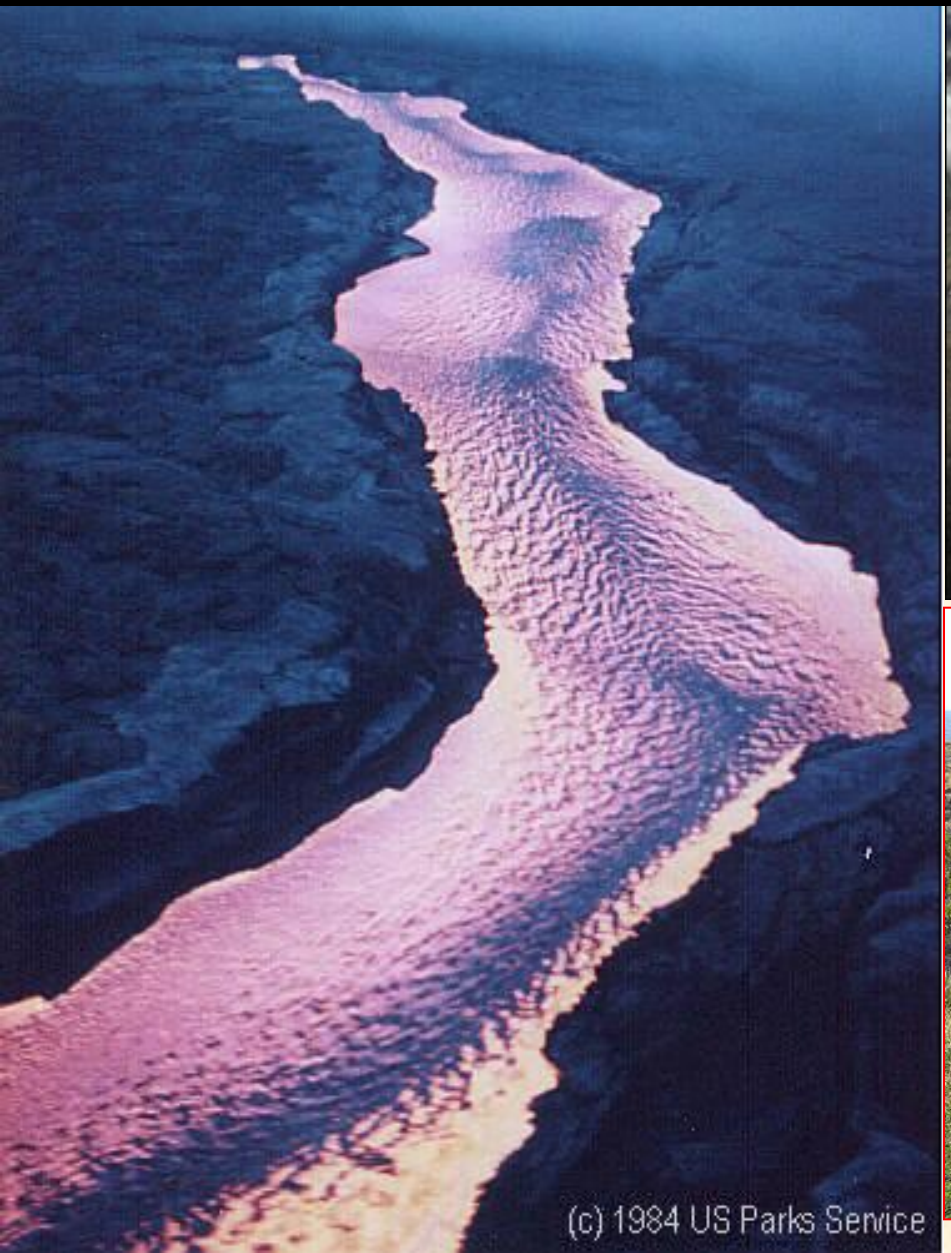
1. LAVA FLOWS

- Path is generally *predictable*, as lava flows generally move *fairly slowly* and flow within existing low areas.
- Geometry varies considerably, depending on viscosity: fluid flows are thin & widespread (*mafic magma*), whereas more viscous flows (with higher % silicates) tend to be *lobate* and to have distinct margins.

Basaltic aa (ah-ah) flow with surface of rough, jagged blocks

Pahoehoe (pa-hoy-hoy) lava flow (ropy); less viscous basaltic lava with smooth skin that wrinkles

LAVA FLOWS – FLOW CHARACTERISTICS AND SURFACE MORPHOLOGY REFLECT THEIR GEOCHEMISTRY



KLYUCHEVSKAYA VOLCANO, KAMCHATKA, RUSSIA

LAVA FLOW CHARACTERISTICS AND ERUPTION STYLES

VISCOSITY →

← VELOCITY

SILICATE CONTENT (FELSIC MINERALS) →

← MAFIC MINERALS

VOLATILES →

(a)

FIGURE 9.3

Earth: Portrait of a Planet, 2nd Edition
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EXPLOSIVITY OF ERUPTION →

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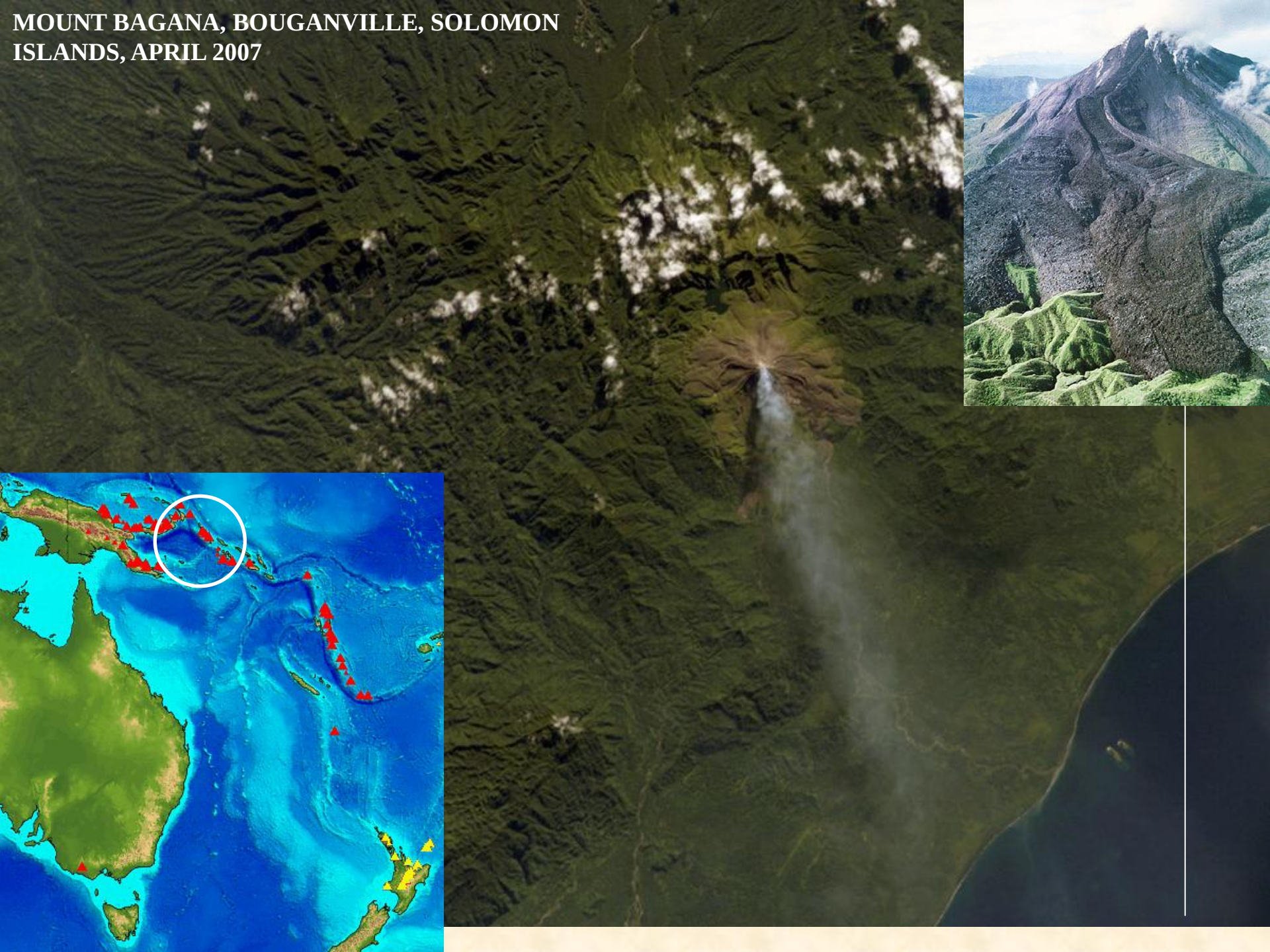
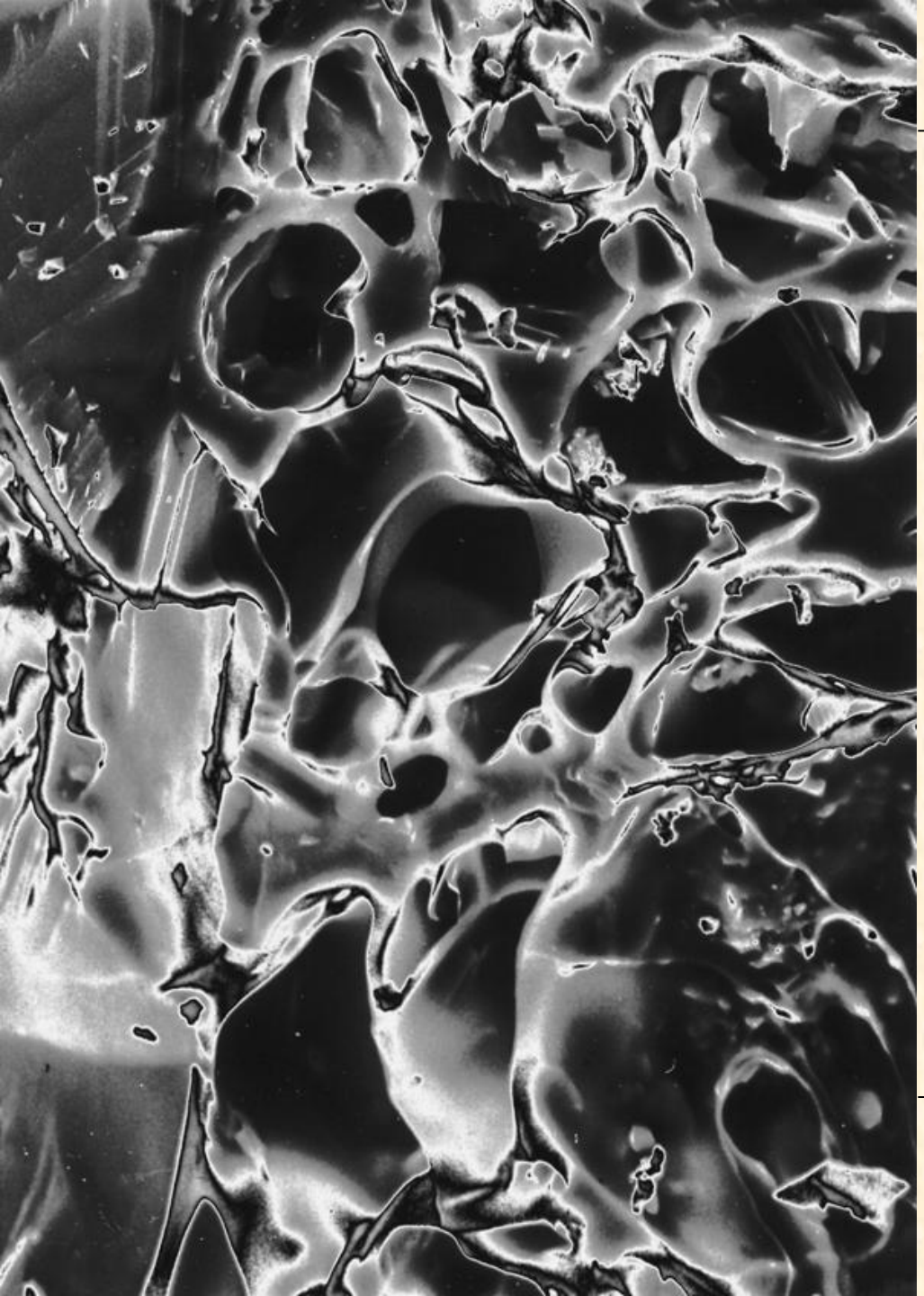
TABLE 8.5

Comparison of Three Types of Magma

	Volcanic Rock Types		
	Basalt	**Andesite**	**Rhyolite**
Rock description	Black to dark gray; contains Ca-plagioclase, pyroxene, olivine	Medium to dark gray; contains amphibole, pyroxene, intermediate Ca-Na-plagioclase	Light-colored; contains quartz, K-feldspar, biotite, Na-plagioclase
Volume at Earth's surface	80%	10%	10%
SiO_2 content	45–55%	55–65%	65–75%
	← increasing SiO_2 →		
Temperature of magma	1,000–1,300°C	800–1,000°C	600–900°C
	← decreasing temperature →		
Viscosity	Low (melted ice cream)		High (toothpaste)
	← increasing viscosity →		
Water dissolved in magma	~0.1–1 wt. %	~2–3 wt. %	~4–6 wt. %
	← increasing water →		
Gas escape from magma	Easy		Difficult
	← increasing difficulty →		
Eruptive style	Peaceful		Explosive
	← increasing explosiveness →		

MOUNT BAGANA, BOUGANVILLE, SOLOMON ISLANDS, APRIL 2007





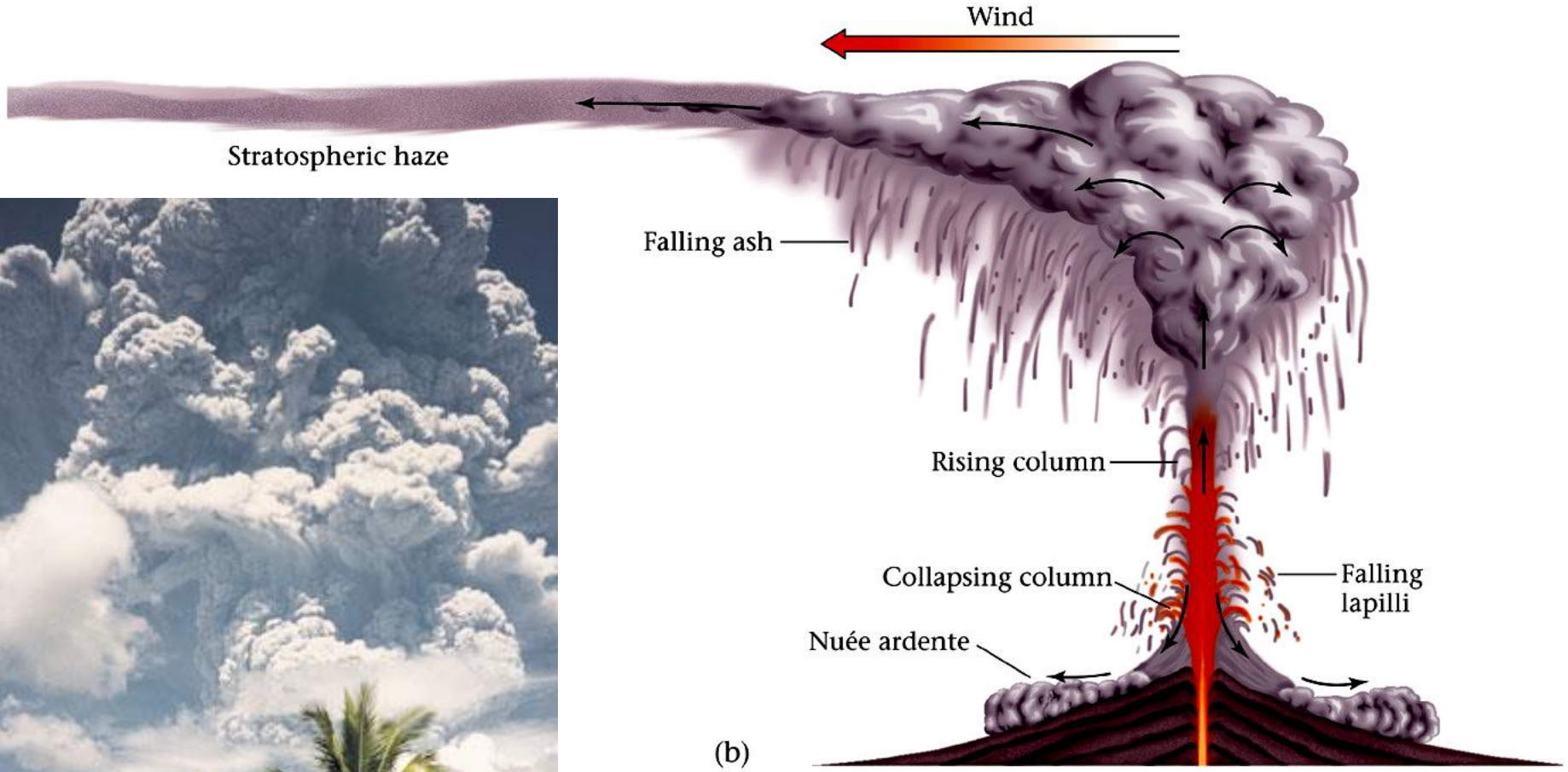
2. PYROCLASTIC DEBRIS

1. **VOLCANIC ASH**
2. **LAPILLI** [PEA TO PLUM-SIZED FRAGMENTS]
3. **BLOCKS AND BOMBS**

Unconsolidated deposits of these debris are called TEPHRA

Photomicrograph of felsic ash erupted in 1980 at Mt St Helens (SGE photo)

ERUPTION OF FELSIC (SILICA RICH) VOLCANOES



PYROCLASTIC FLOWS (*NUÉE ARDENTE* – GLOWING CLOUD)

VERY FAST MOVING HOT TURBULENT AVALANCHES OF ASH, LAPILLI, AND GAS (e.g., DESTROYED POMPEII (A.D. 79) AND ST. PIERRE (MARTINIQUE – 1902)}

1. **ERUPTION OF HOT MAGMA AND ASH**
2. **COLLAPSE OF ERUPTIVE COLUMN**
3. **COLLAPSE OF HOT LAVA DOME**

[VELOCITY IN EXCESS OF 40 m/s]

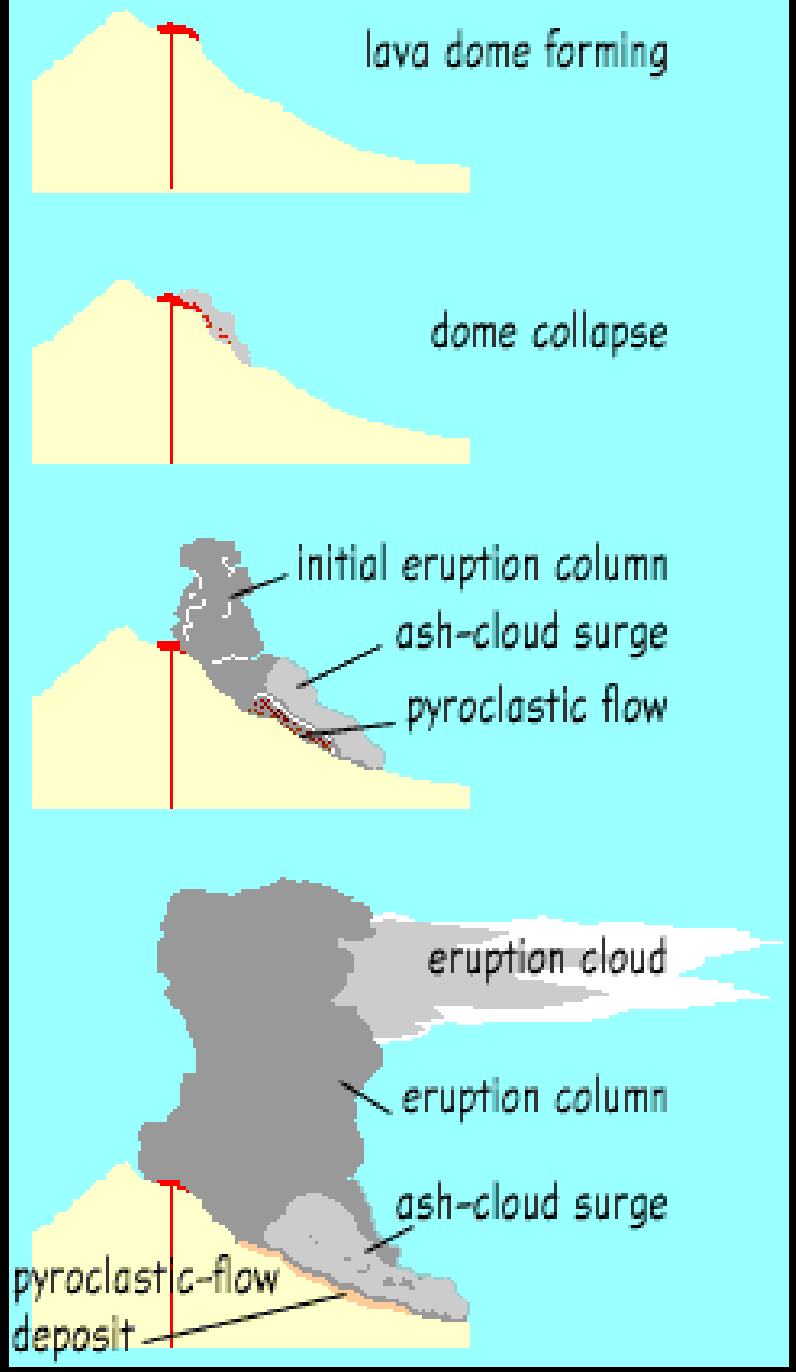
LAVA DOMES

- When magma, high in silica and therefore extremely viscous, is erupted sometimes it does not spread out at the outlet of the eruptive mouth. Instead the magma rises above the magma conduit to build up an external dome within the crater or on the flank summit.
- They may (in whole or in part) become unstable and fail in a large-scale hot rockslide which is quickly transformed into a hot pyroclastic flow; a dome collapse may also trigger an eruption

LAVA DOME AT MT. UNZEN, JAPAN

Montserrat , January 2010

Montserrat – October 2009



DOME COLLAPSE ON MONTSERRAT

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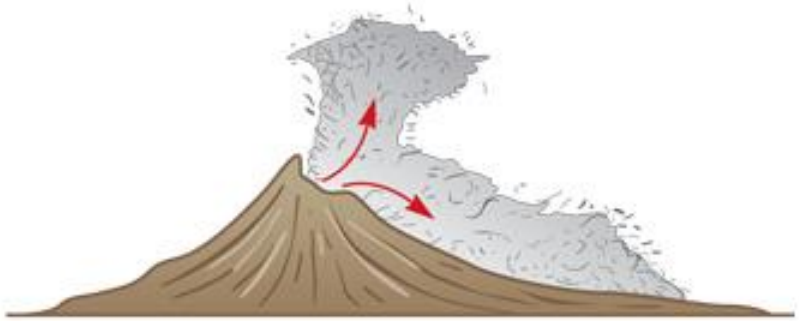
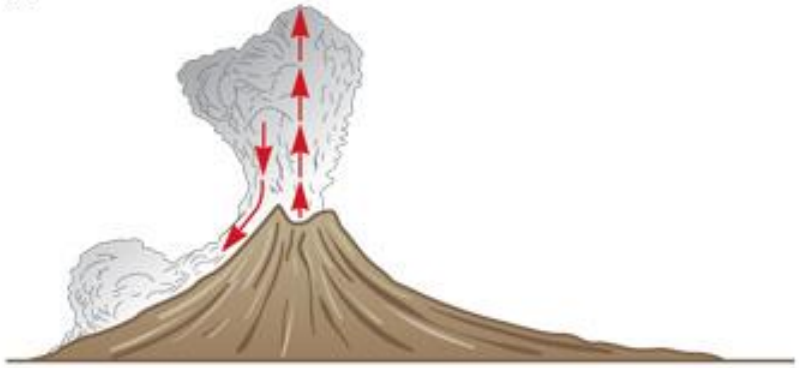
(a) Dome collapse

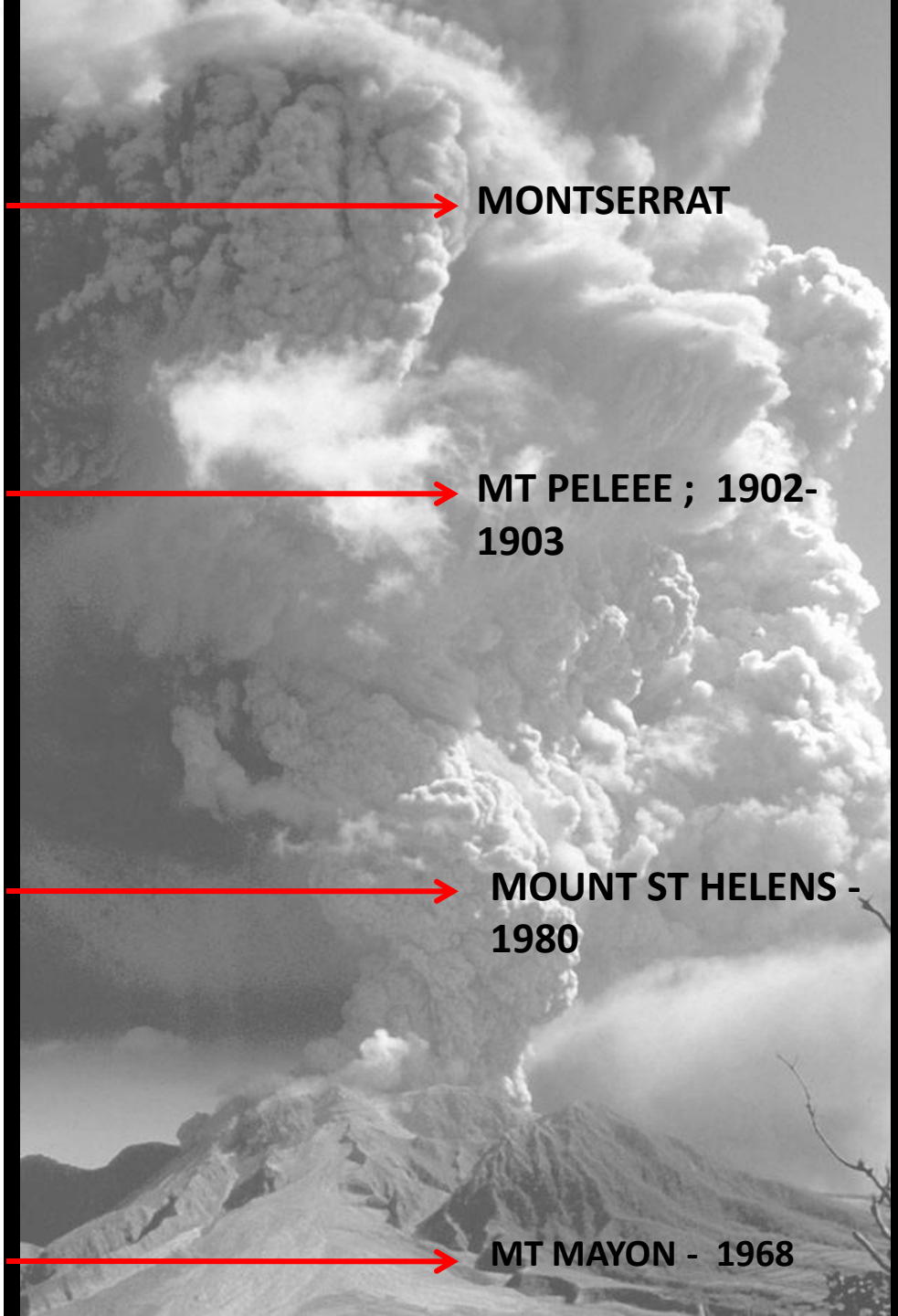
(b) Overspilling crater rim



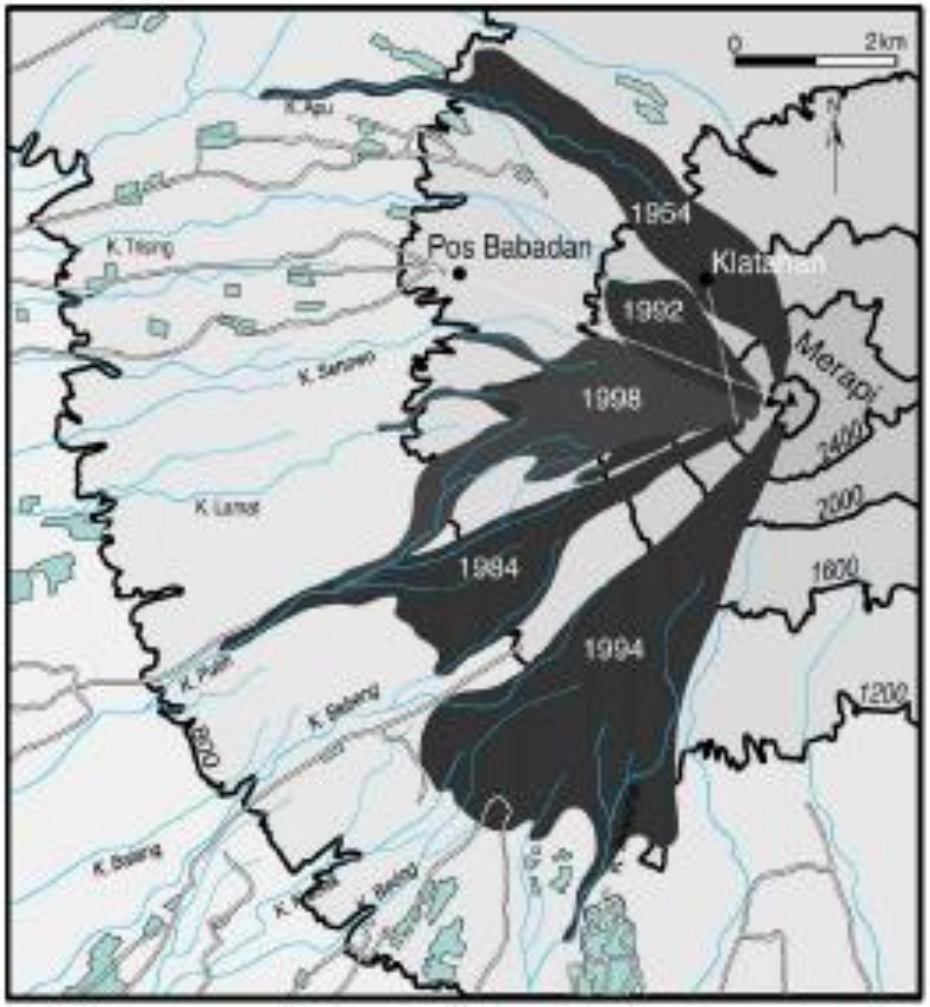
(c) Direct blast



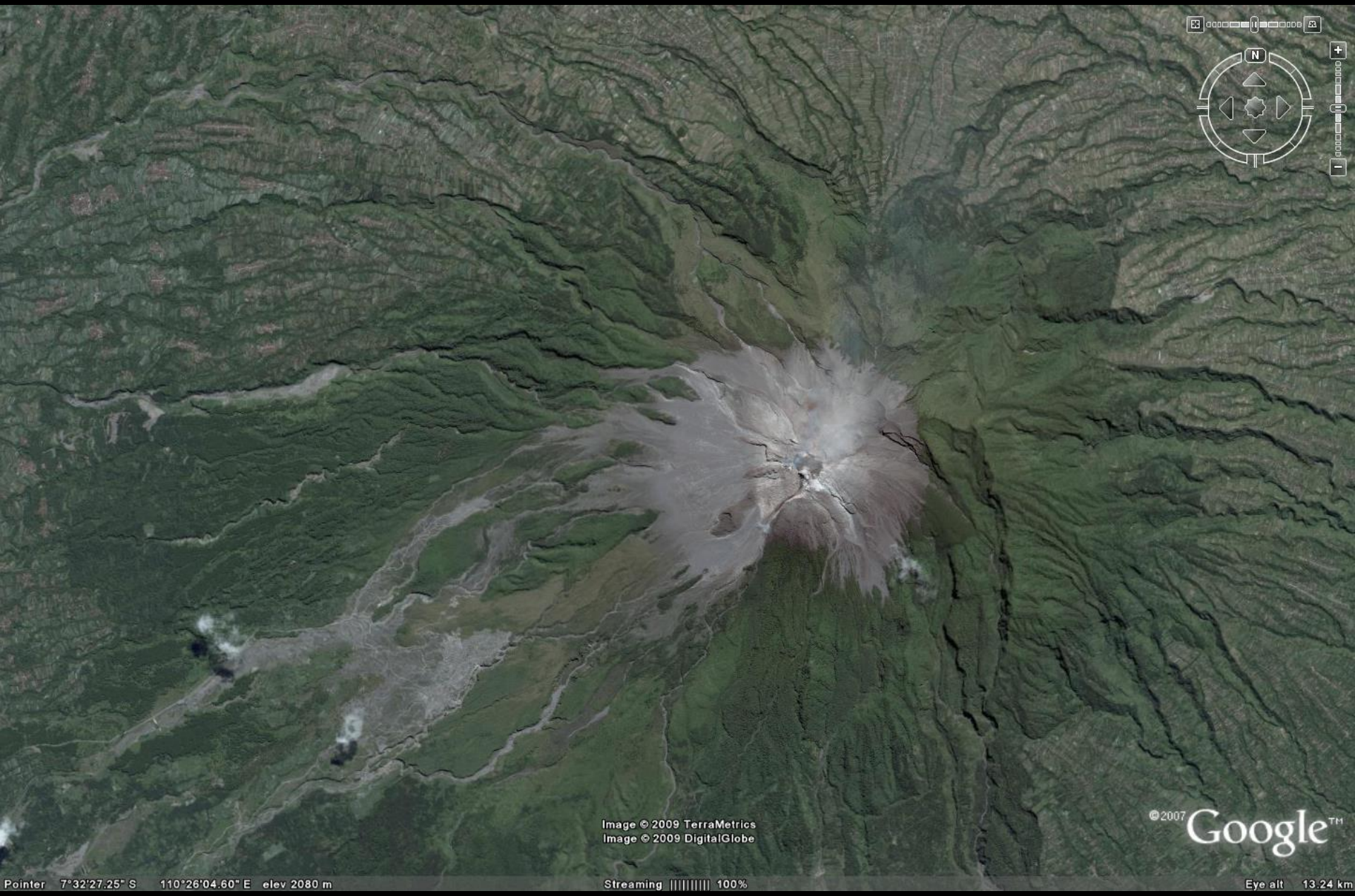
(d) Eruption column collapse



Pyroclastic flows on Mt Mayon, Philippines, during 1984 eruption ; 73,000 people evacuated



PYROCLASTIC FLOWS ON MERAPI VOLCANO, INDONESIA



Merapi volcano, Indonesia

VILLARRICA VOLCANO, CHILE

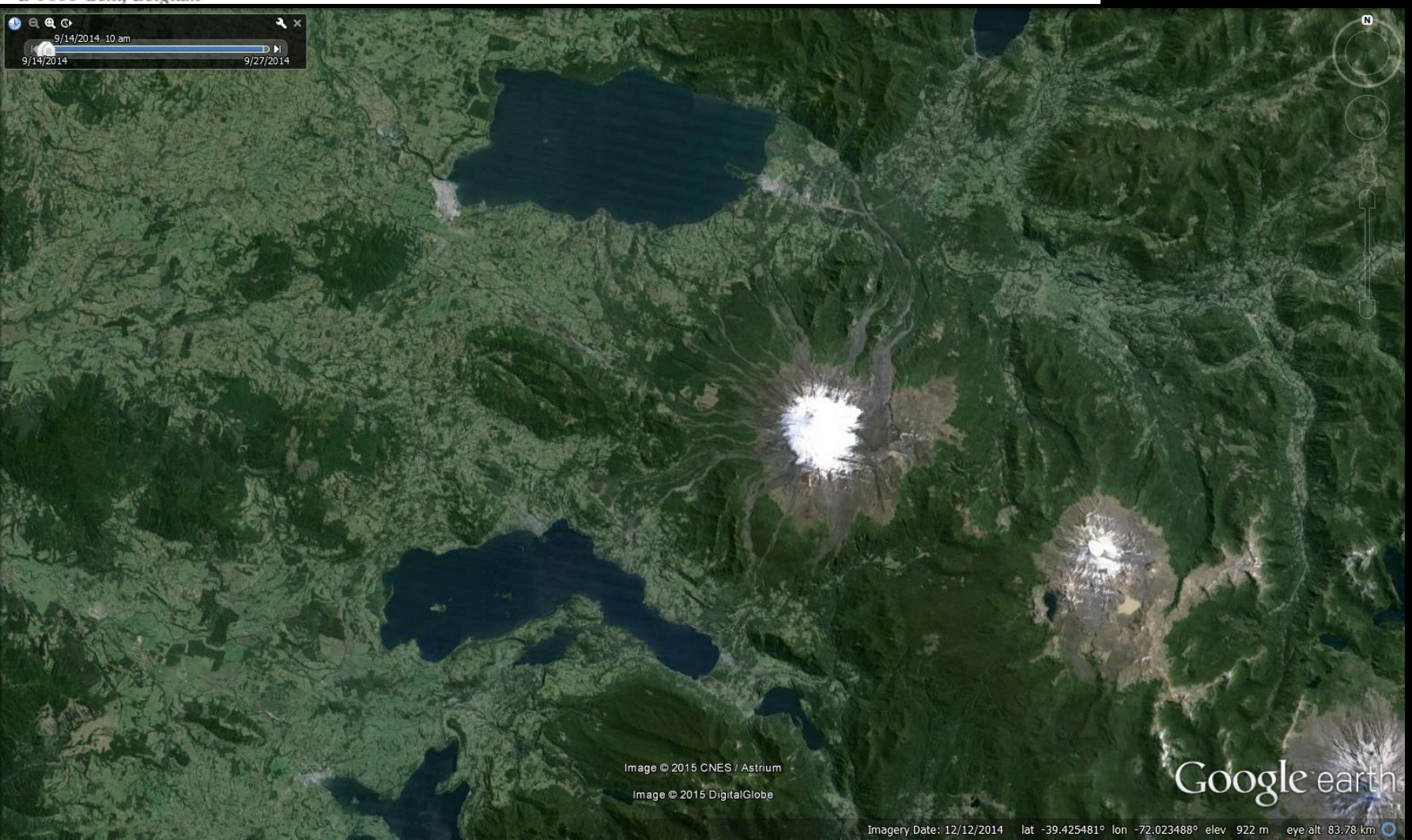
VILLARRICA VOLCANO ERUPTING, March 2015 (CHILE)

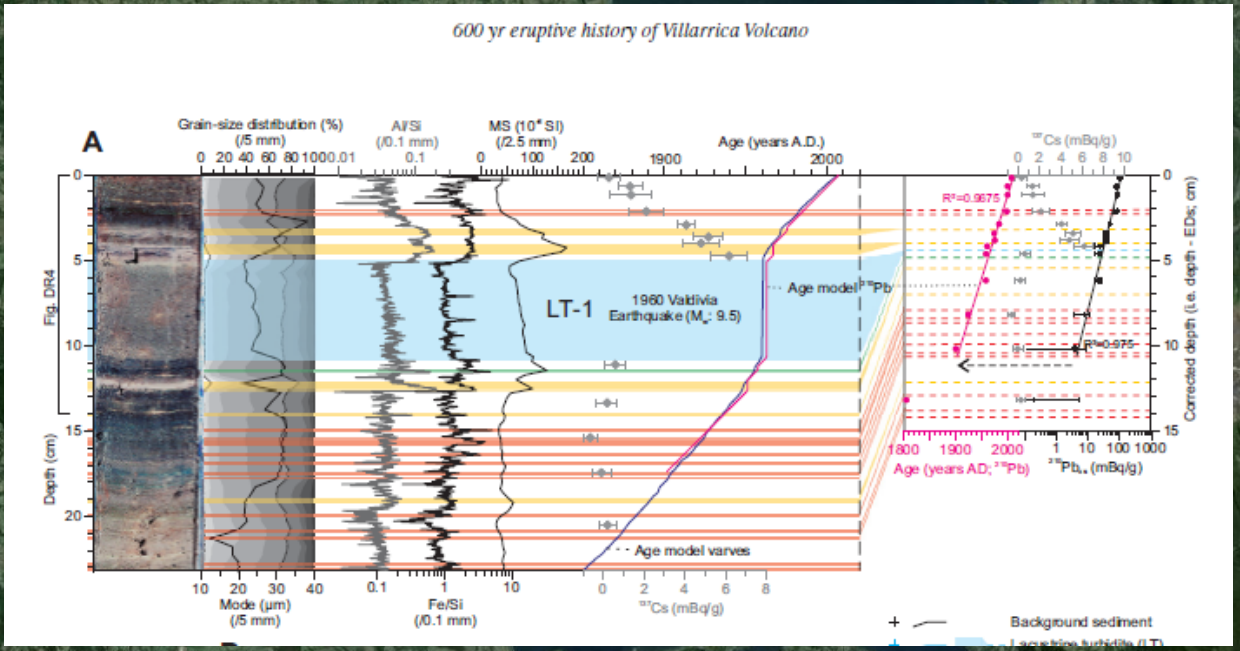
VILLARRICA VOLCANO ERUPTING, March 2015 (CHILE)

The 600 yr eruptive history of Villarrica Volcano (Chile) revealed by annually laminated lake sediments

M. Van Daele[1,†], J. Moernaut[1,2], G. Silversmit[3], S. Schmidt[4], K. Fontijn[5], K. Heirman[1], W. Vandoorne[1], M. De Clercq[1], J. Van Acker[6], C. Wolff[7], M. Pino[8], R. Urrutia[9], S.J. Roberts[10], L. Vincze[3], and M. De Batist[1]

[1]*Renard Centre of Marine Geology (RCMG), Department of Geology and Soil Science, Ghent University, Krijgslaan 281/S8, B-9000 Gent, Belgium*





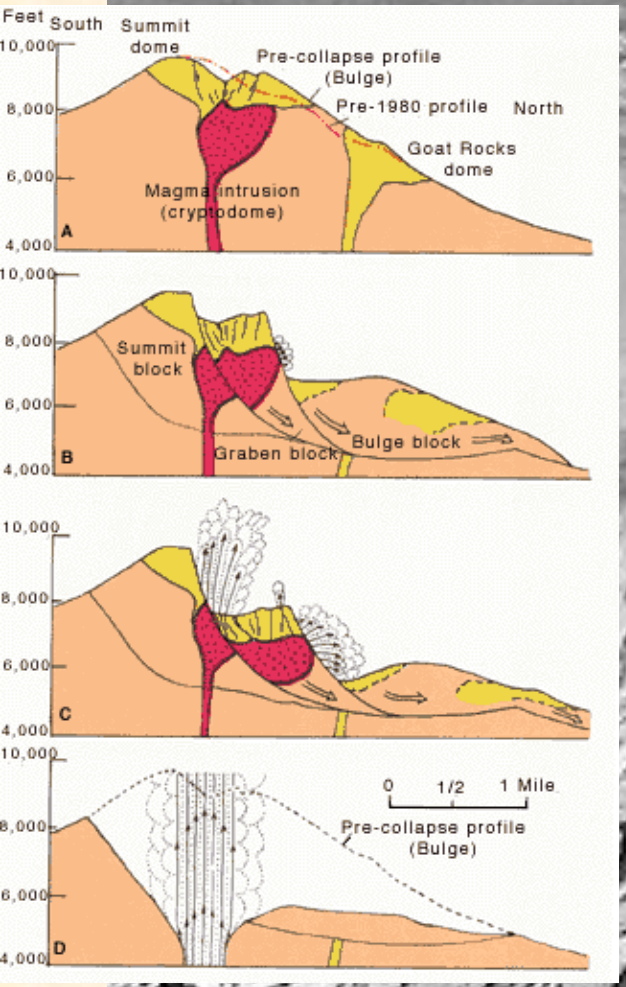
sediments. Time-series analysis shows 112 eruptions with a volcanic explosivity index (VEI) ≥2 from Villarrica Volcano in the last ~600 yr, of which at least 22 also produced lahars. This significantly expands our knowledge of the eruptive frequency of the volcano in this time window, compared to the previously known eruptive history from historical records. The last VEI ≥2 eruption of Villarrica Volcano occurred in 1991. Based on the last ~500 yr, for which we have a complete record from both lakes, we estimate the probability of the occurrence of future eruptions from Villarrica Volcano and statistically demonstrate that the probability of a 22 yr repose period (anno 2013) without VEI ≥2 eruptions is ≤1.7%. This new perspective on the recurrence interval of eruptions and historical lahar activity will help improve volcanic hazard assessments for this rapidly expanding tourist region, and it highlights how lake records can be used to significantly improve historical eruption records in areas that were previously uninhabited.

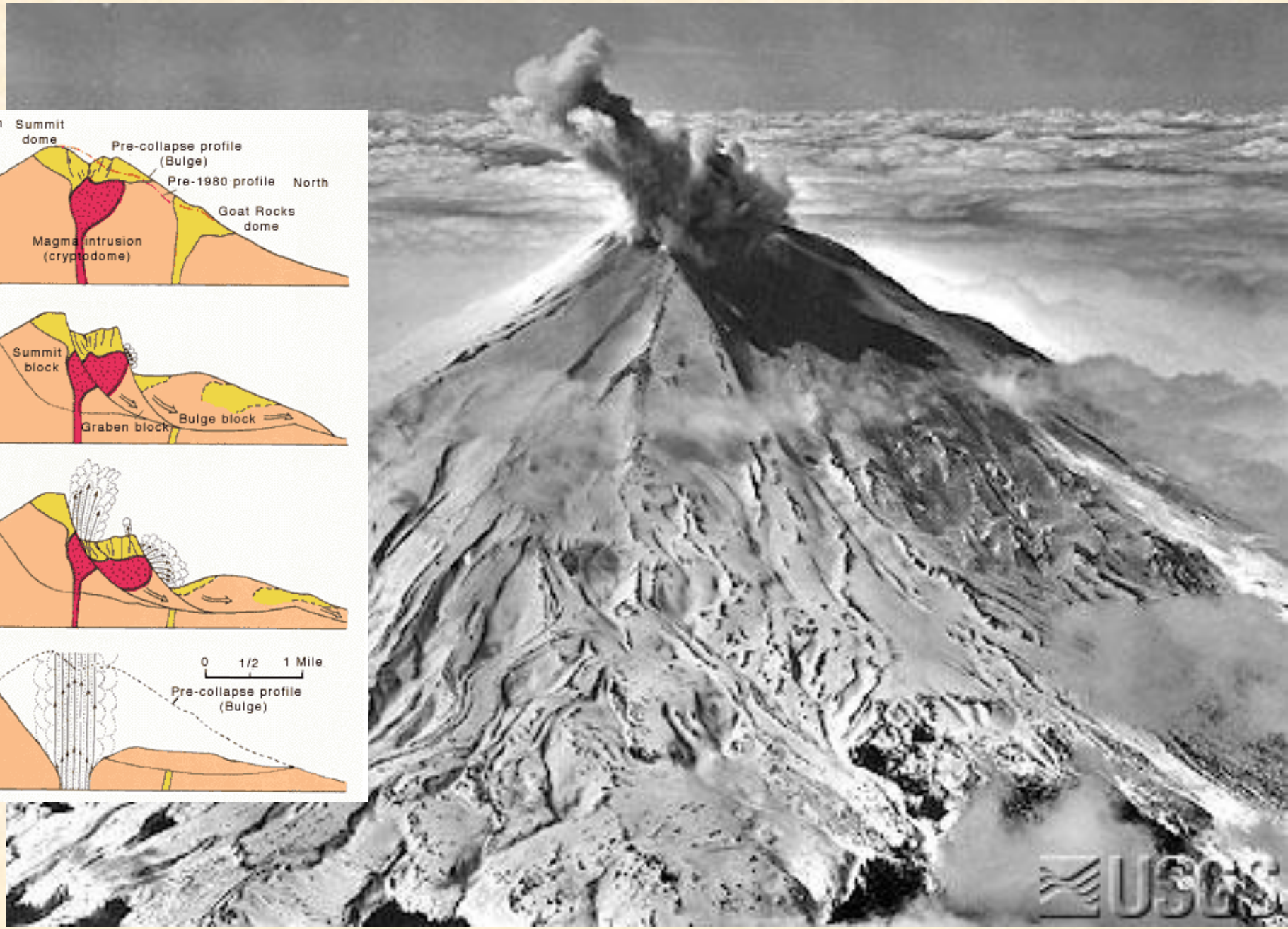
3. VOLCANIC GASES

- **Volcanic gases are the driving force of eruptions**
- Samples indicate that volcanic gases are:
  - **50 to 80% water vapor (H_2O)**
  - Followed by carbon dioxide (CO_2) sulphur dioxide gases
  - very small amounts of carbon monoxide, hydrogen and chlorine
- **Gases expand as pressure decreases as magma rises towards the surface**
- In highly viscous silica-rich magma, expansion is inhibited and gas pressure rises: pressure may become great enough to cause an explosion and produce pyroclastic materials such as ash.

MT ST HELENS – BEFORE (HAD BEEN DORMANT FOR 123 YEARS)

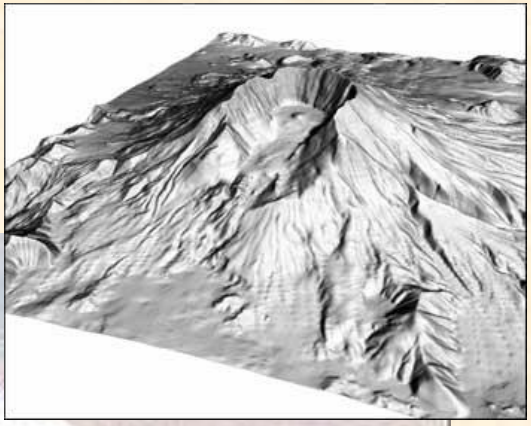
MT ST HELENS – 1980; JUST AT THE POINT OF FLANK COLLAPSE AND ERUPTION

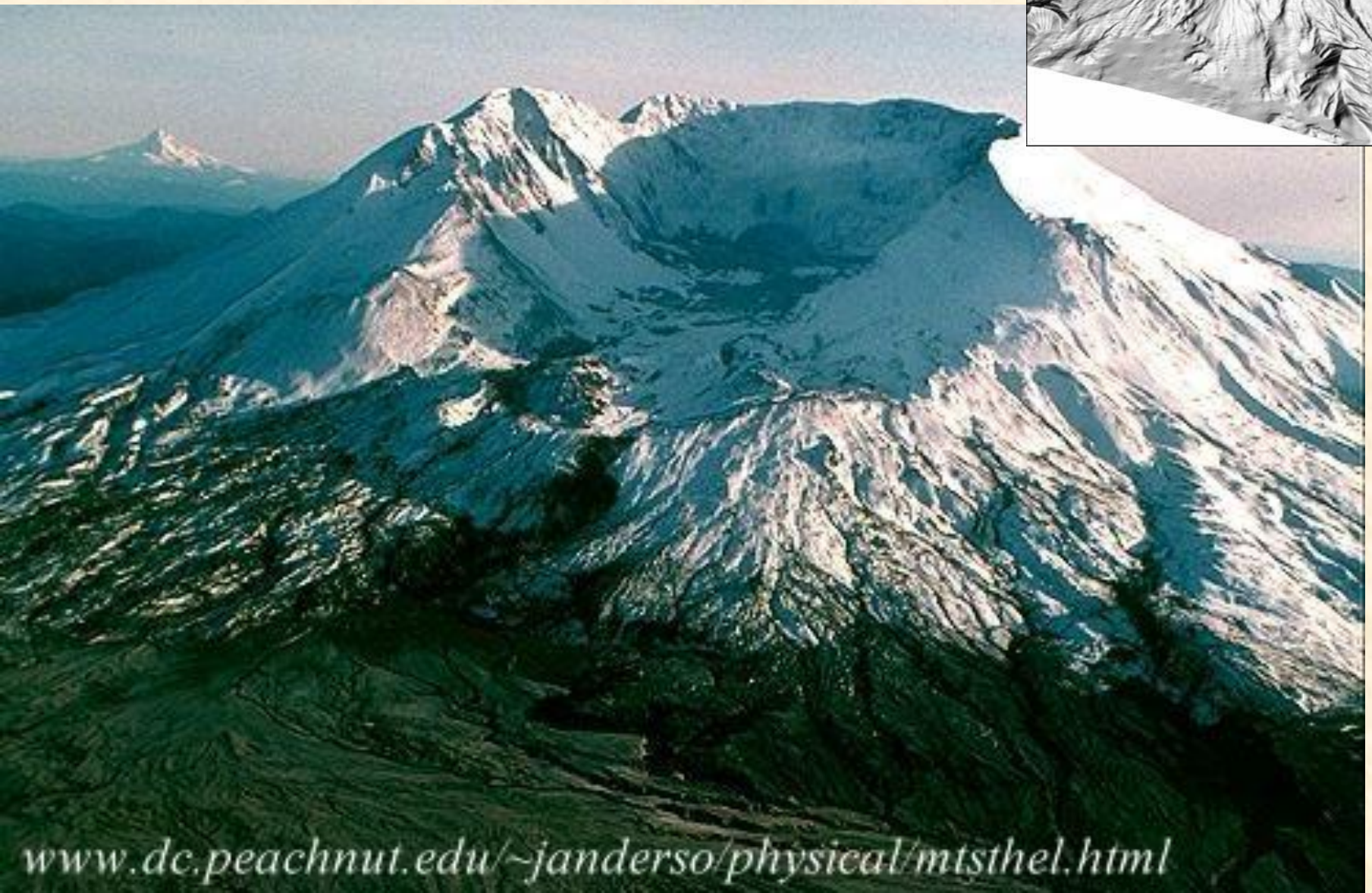


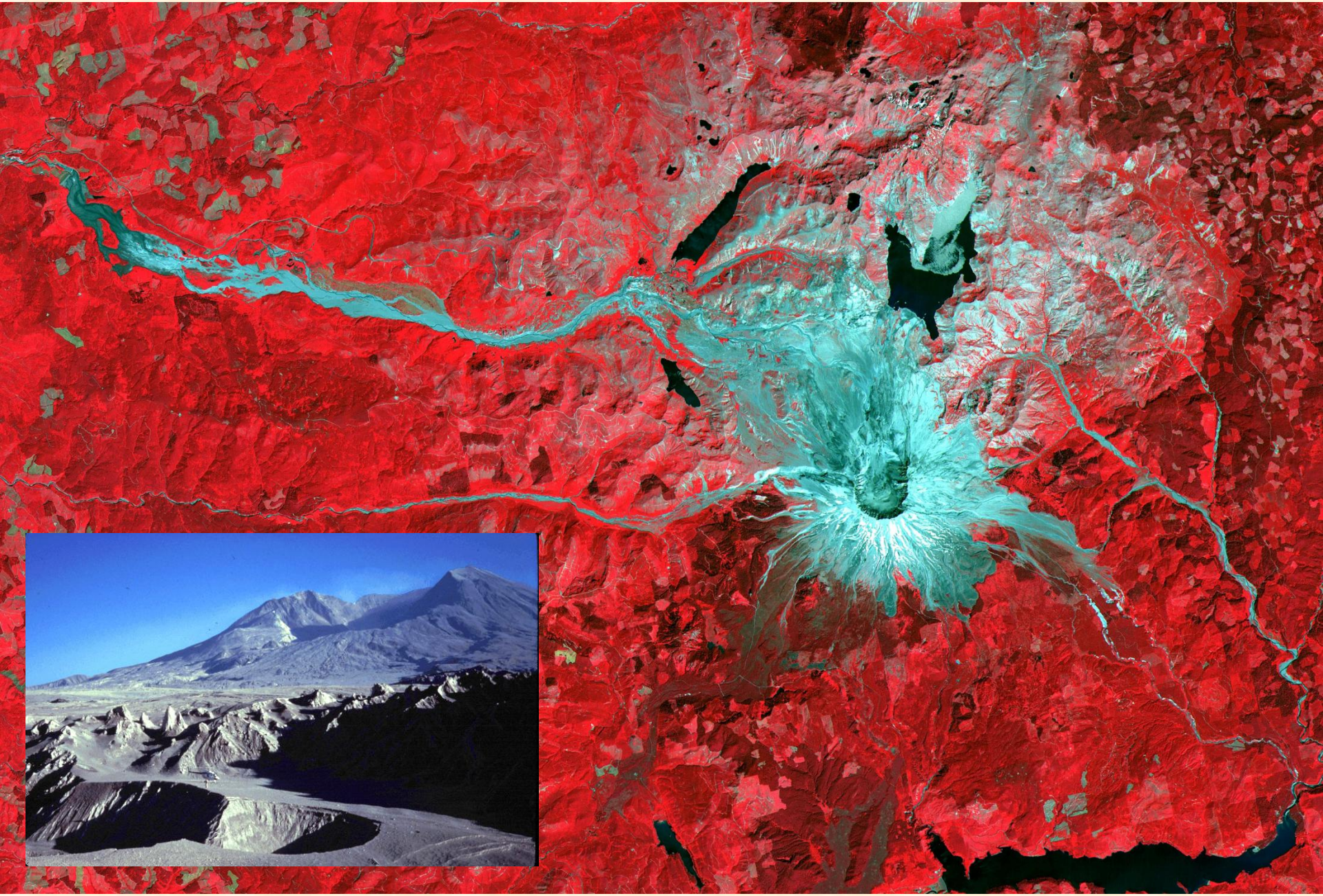


MT ST HELENS – DURING ERUPTION MAY 1980

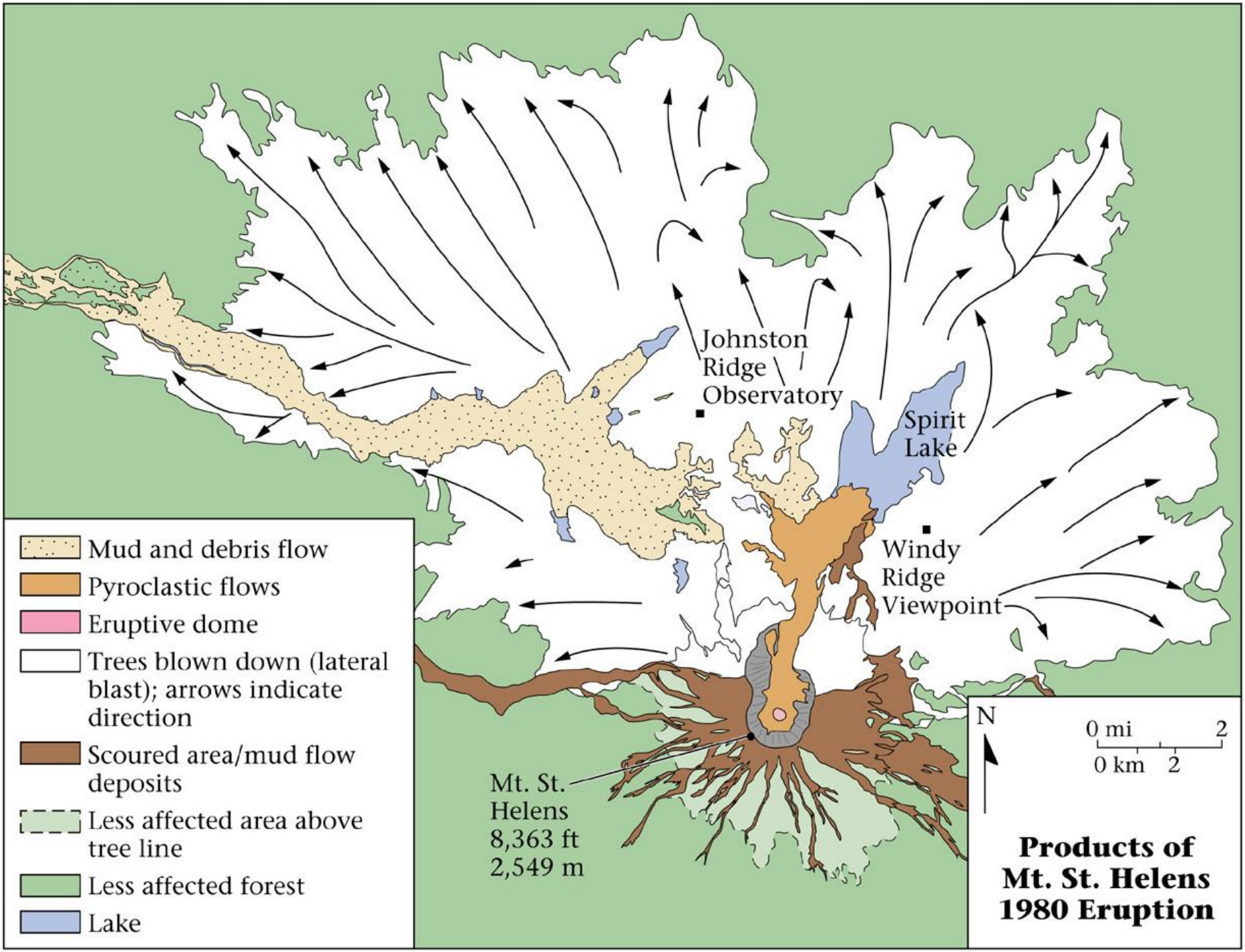
MT ST HELENS: AFTER







MT ST HELENS : AFTERMATH OF 1980 ERUPTION


Johnston Ridge Observatory
Spirit Lake
Windy Ridge Viewpoint
Mt. St. Helens 8,363 ft 2,549 m
Mud and debris flow
Pyroclastic flows
Eruptive dome
Trees blown down (lateral blast); arrows indicate direction
Scoured area/mud flow deposits
Less affected area above tree line
Less affected forest
Lake
N
0 mi 2
0 km 2
Products of Mt. St. Helens 1980 Eruption

1980 ERUPTION OF MT ST HELENS

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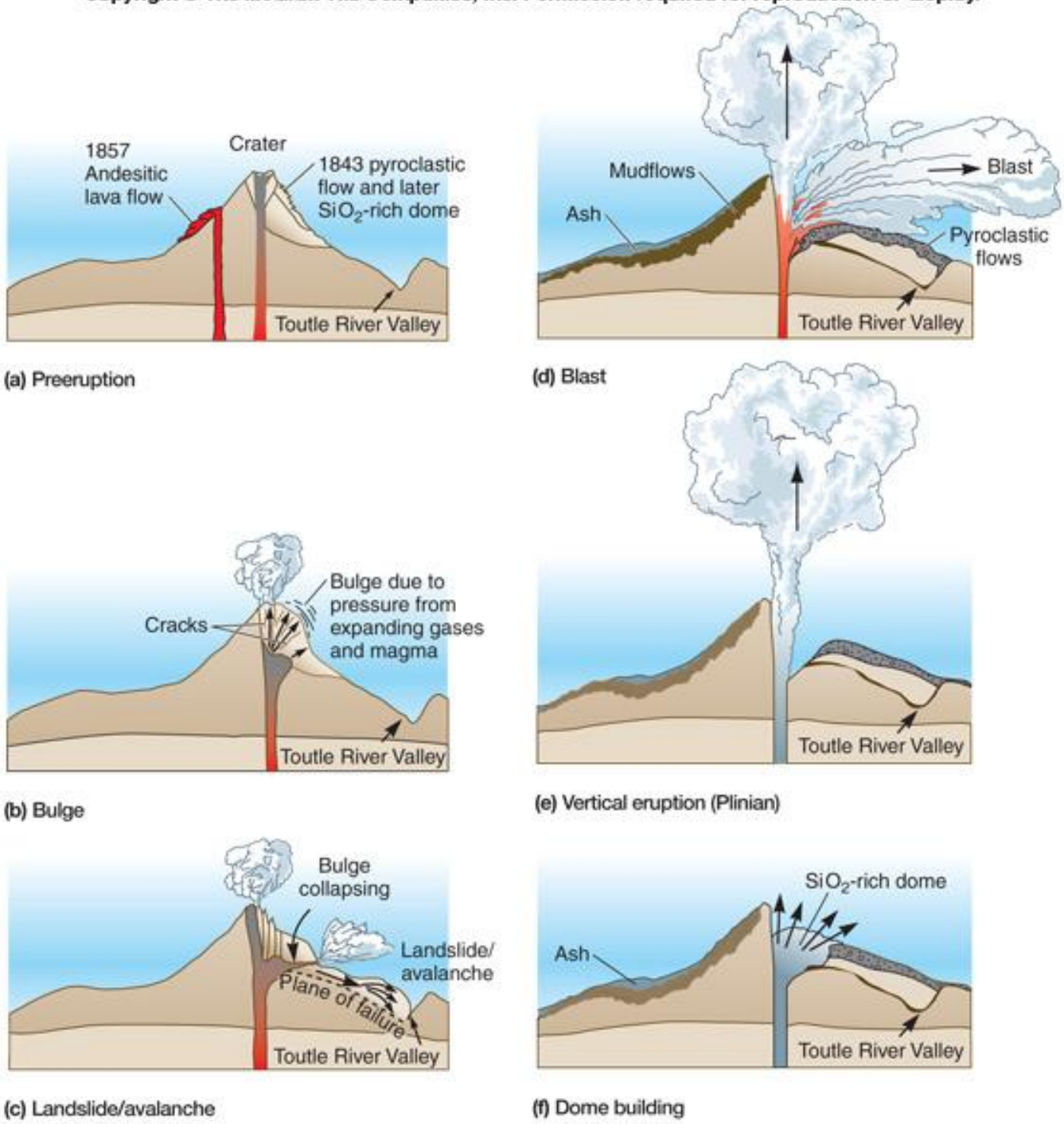


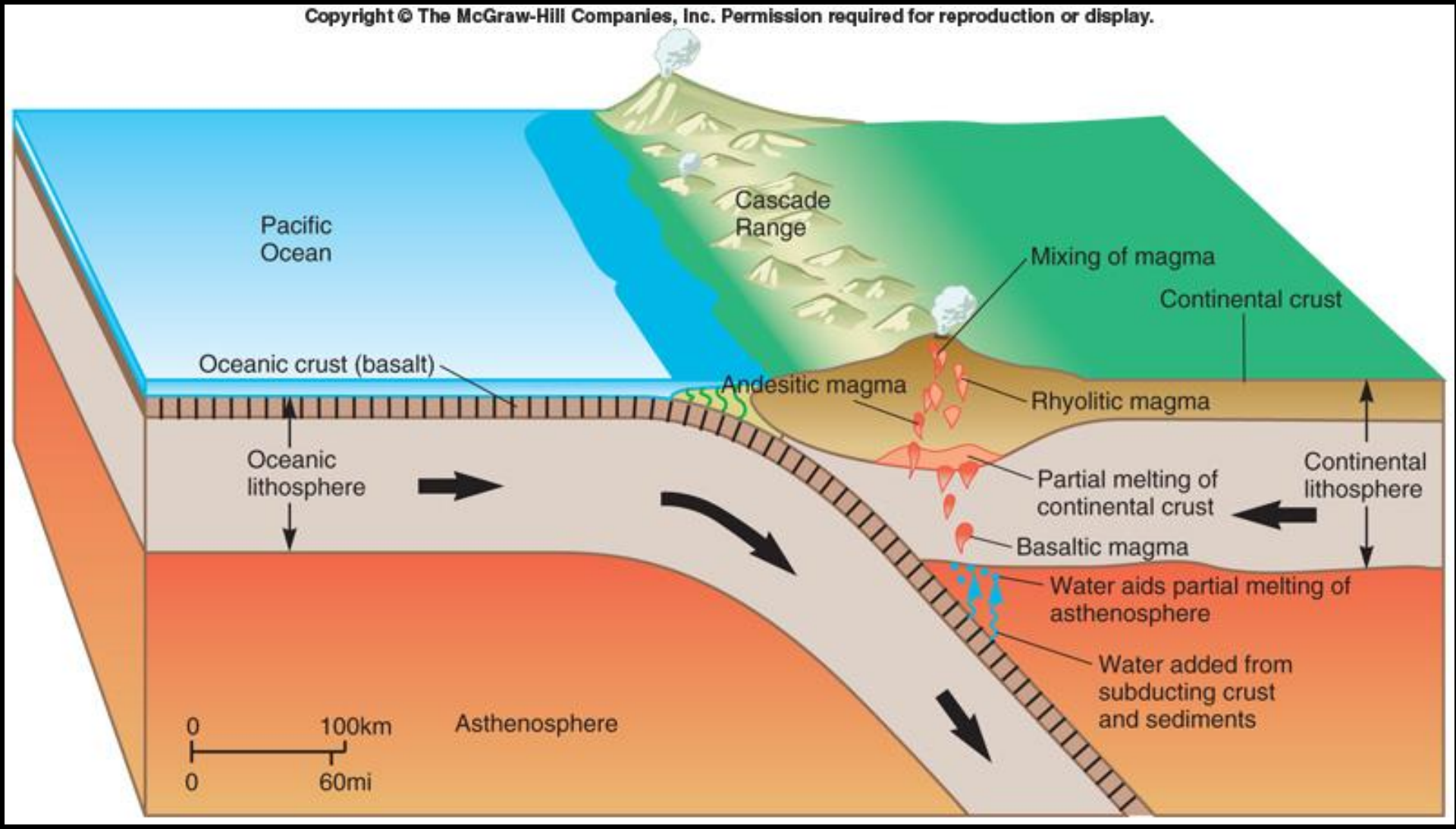
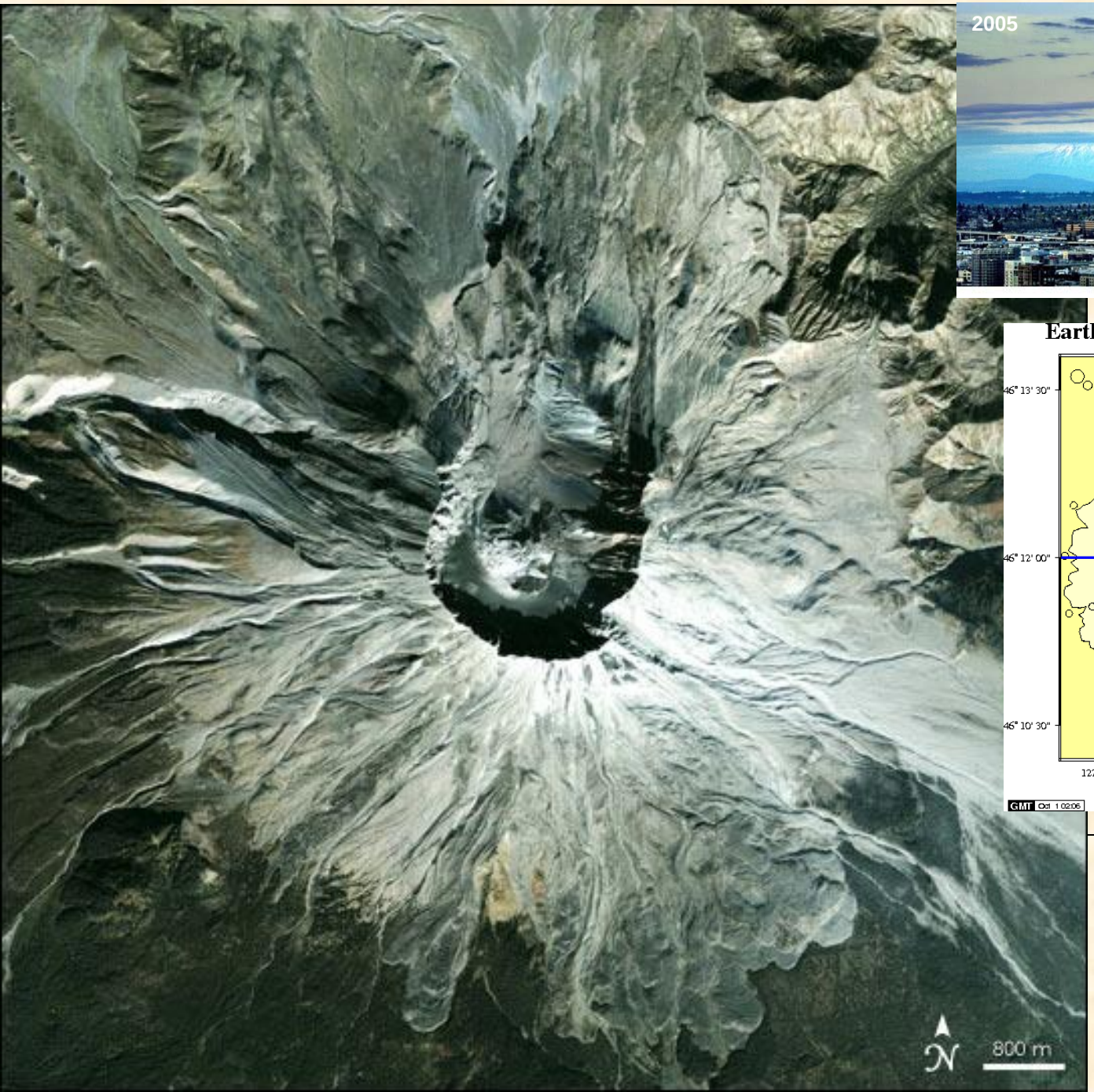
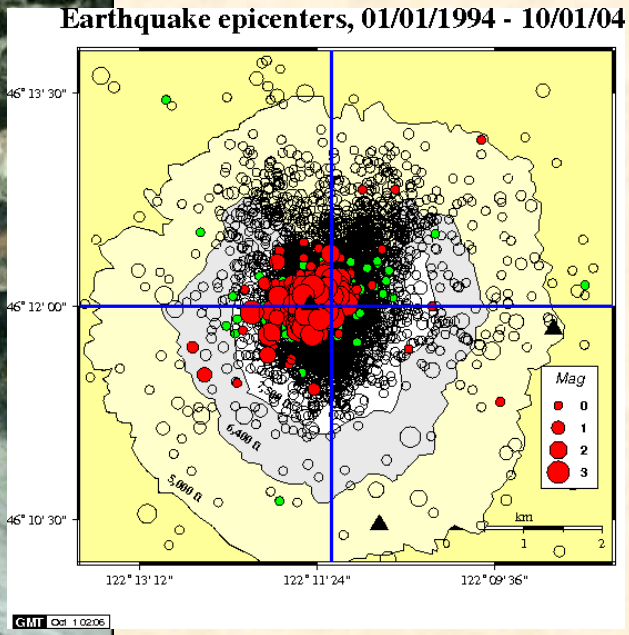
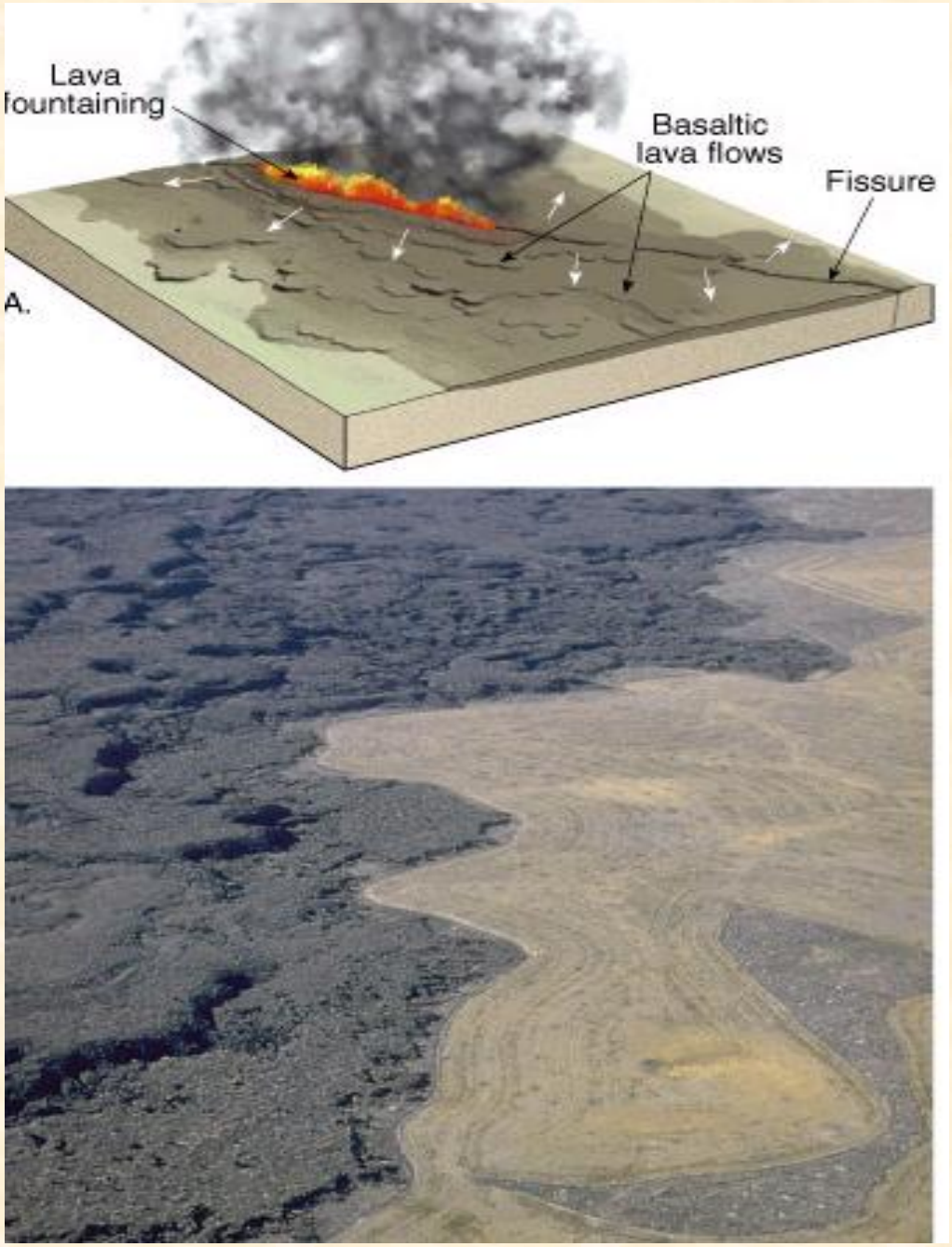


PLATE TECTONIC SETTING OF CASCADE VOLCANC BELT





RECENT BEHAVIOUR OF MT ST HELENS INDICATES MAGMA CHAMBER STILL ACTIVE



FISSURE ERUPTIONS

- Basaltic lavas erupted from long fissures that are so fluid that volcanic cones fail to develop. Lava spreads widely to form lava plateaux (Plateau Lavas/Plateau Basalts)
- Columbia River Plateau, NW USA; Parana Plateau, Brasil, Deccan Traps, 500,000 km^2 west central India

ARCHITECTURE OF PLATEAU LAVAS

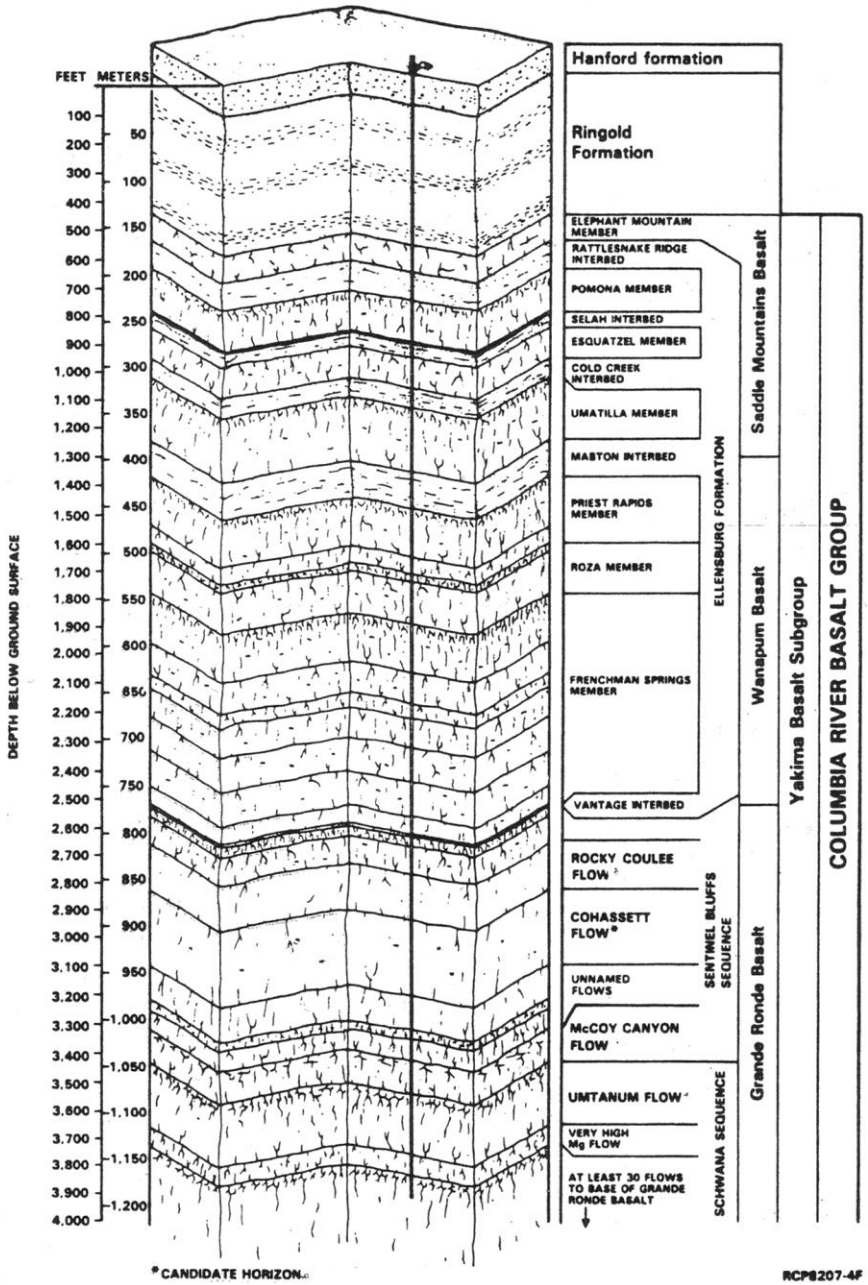
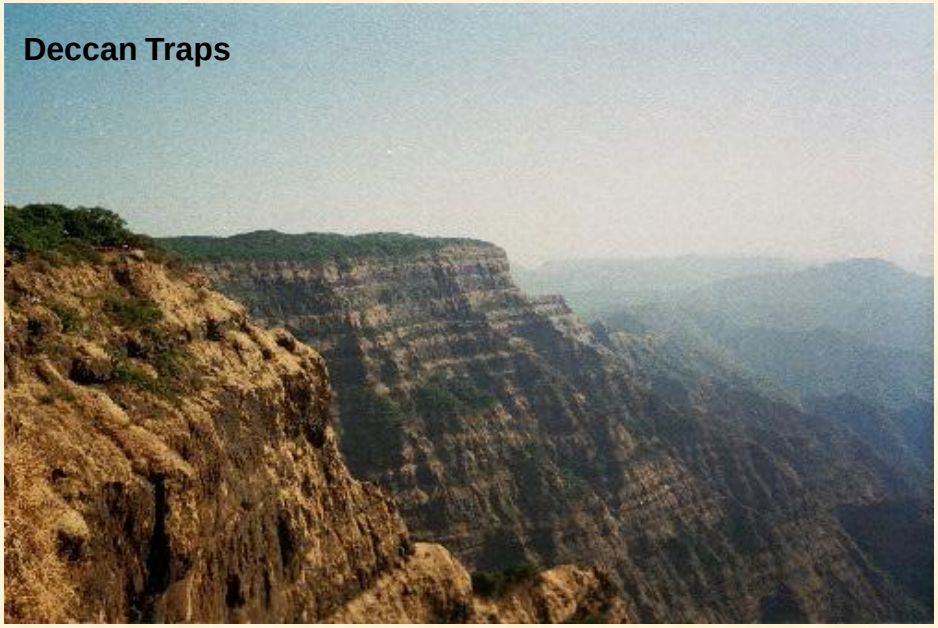


Figure 2. Generalized Stratigraphy (DOE, 1985)



IGUAZU FALLS – PARANA PLATEAU BASALTS

ON THE BORDER OF BRAZIL AND ARGENTINA

ENTRY TO HAZARD ASSESSMENT-HOW CAN WE QUANTIFY AN ERUPTION ?

MT ETNA ERUPTING IN 2002

SIZE OF VOLCANIC ERUPTIONS

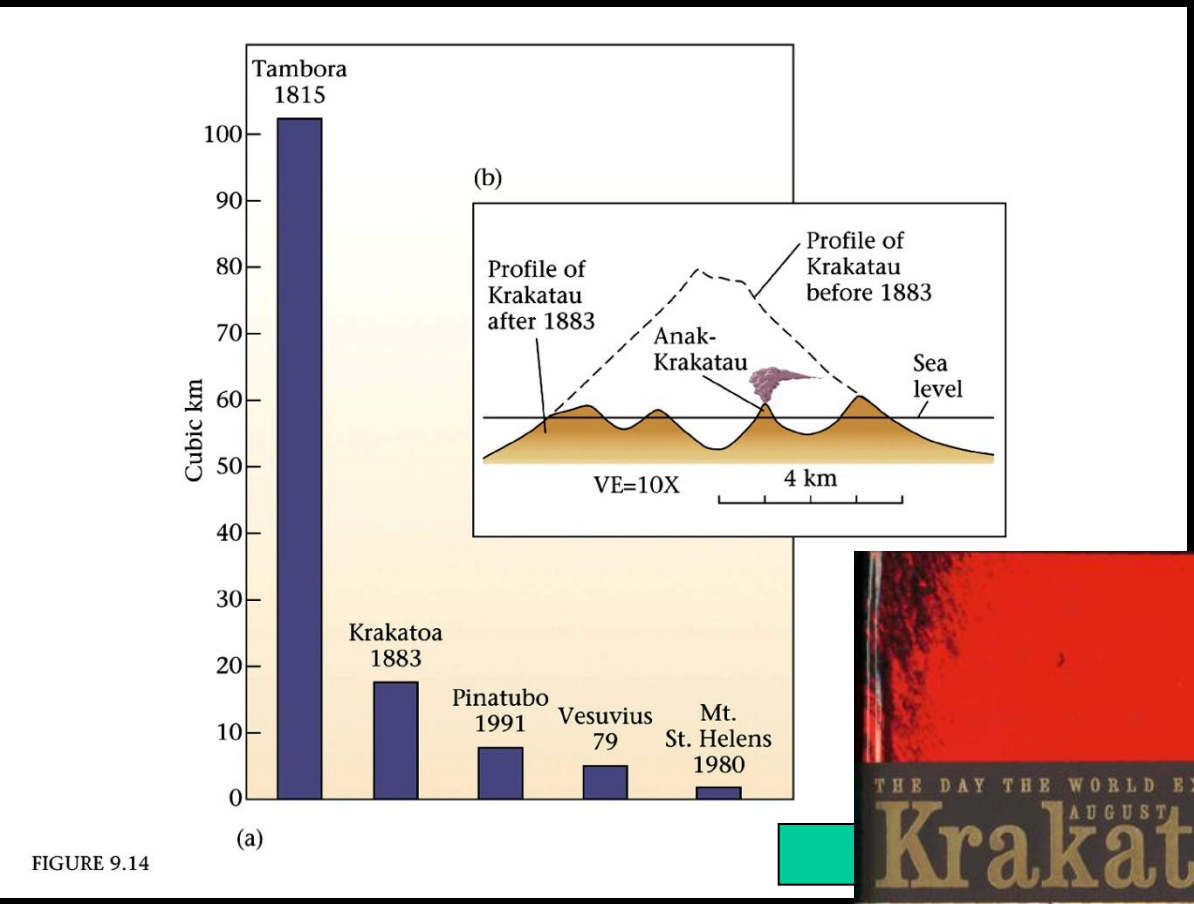
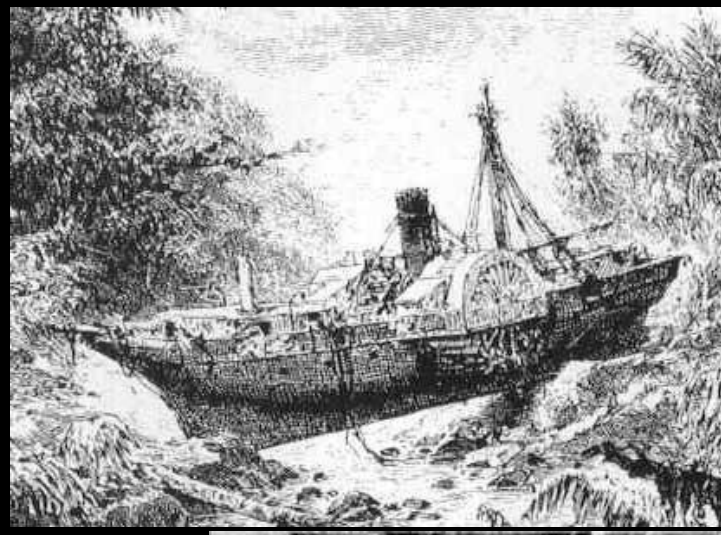
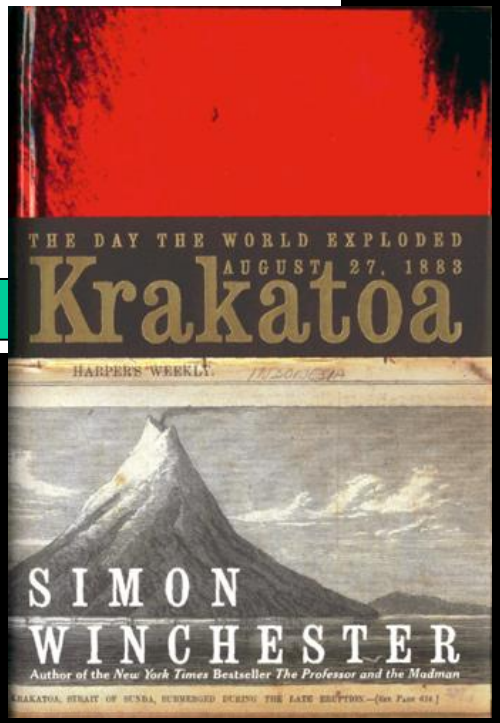
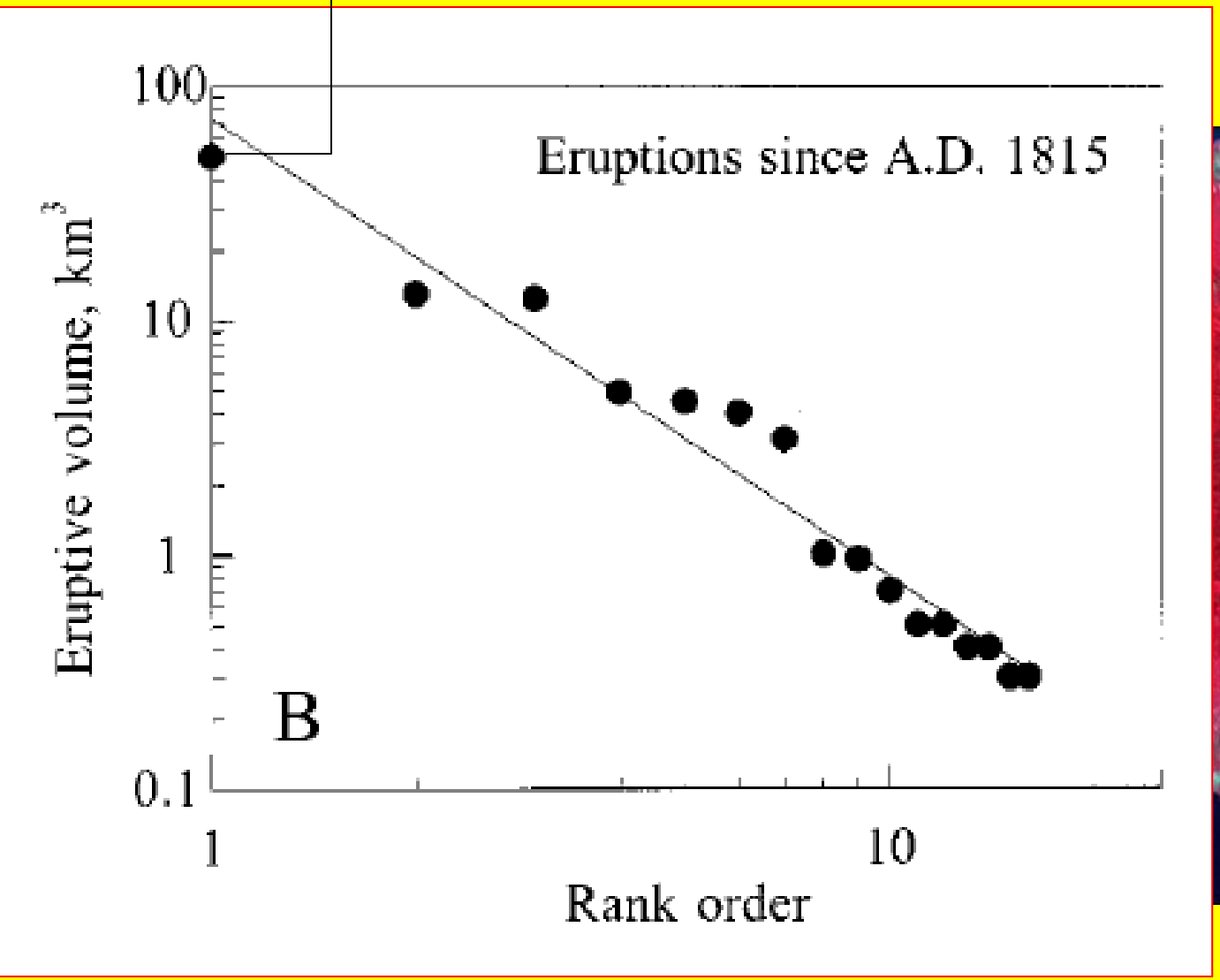


FIGURE 9.14

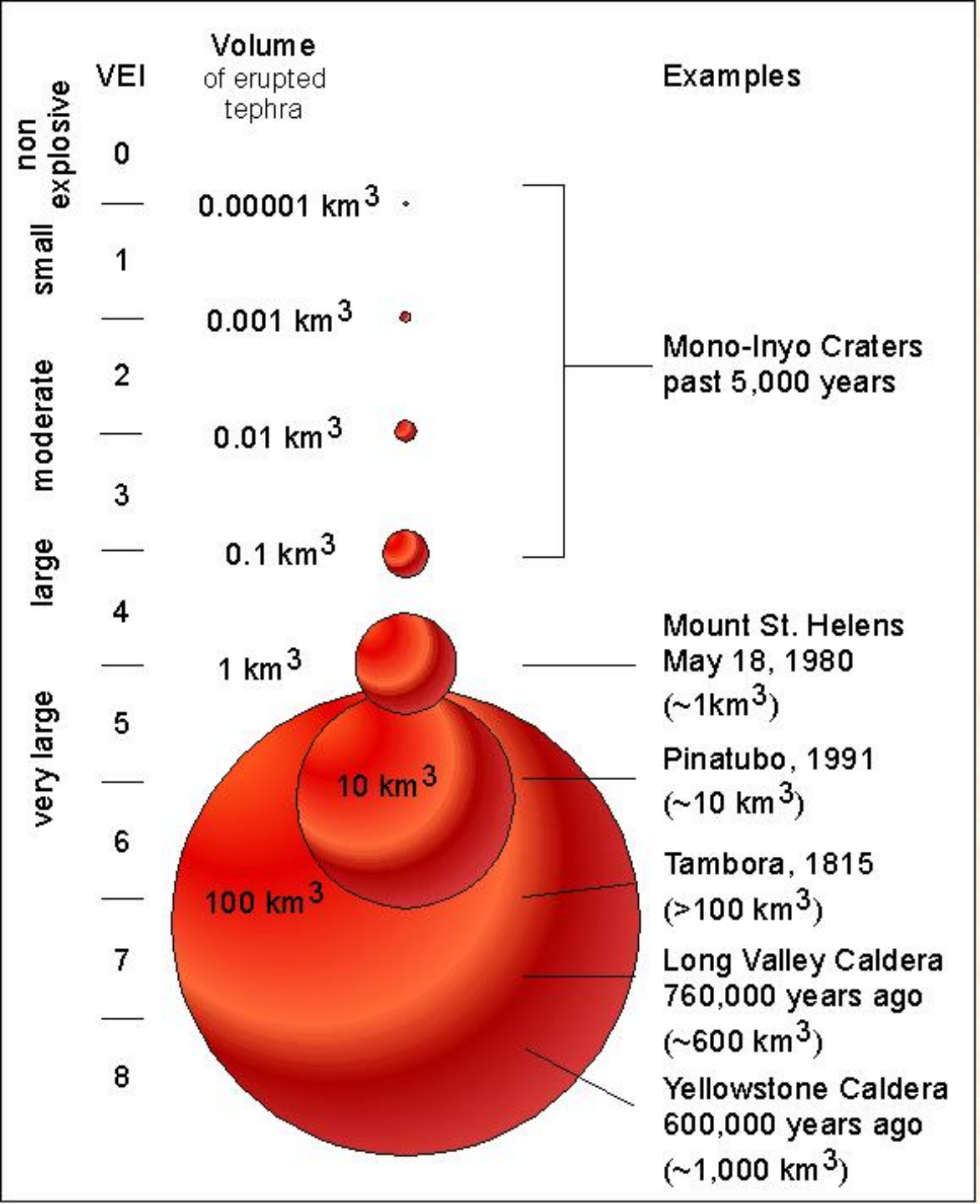




1883 ERUPTION OF KRAKATOA



RANK ORDER OF ERUPTIVE VOLUME (km^3)DURING 16 MAJOR ERUPTIONS SINCE 1815



VOLCANIC ERUPTION – VOLCANIC EXPLOSIVITY INDEX (VEI)

The **Volcanic Explosivity Index**, or VEI, was proposed in 1982 as a way to describe the relative size or magnitude of explosive volcanic eruptions. It is a 0-to-8 index of increasing explosivity. Each increase in number represents an increase around a factor of ten. The VEI uses several factors to assign number, including **volume of erupted pyroclastic material** (for example, ashfall, pyroclastic flows, and other ejecta), **height of eruption column**, **duration in hours**, and qualitative descriptive terms.

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TABLE 8.9

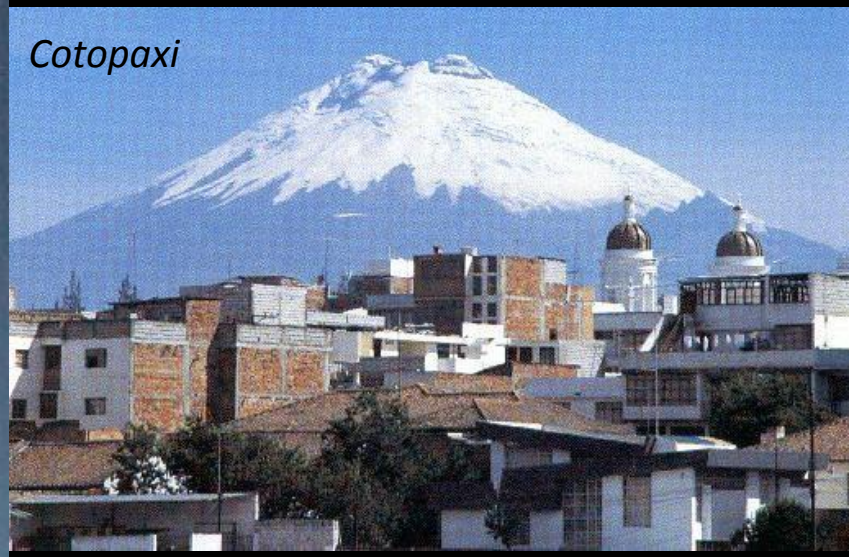
Volcanic Explosivity Index (VEI)

	VEI								
	0	1	2	3	4	5	6	7	8
Volume of ejecta (m^3)	$<10^4$	10^4–10^6	10^6–10^7	10^7–10^8	10^8–10^9	10^9–10^{10}	10^{10}–10^{11}	10^{11}–10^{12}	$>10^{12}$
Eruption column height (km)	<0.1	0.1–1	1–5	3–15	10–25	>25			
Eruptive style	<-----Hawaiian----->		<-----Vulcanian----->						
		<-----Strombolian----->				<----------Plinian---------->			
Duration of continuous		<-----<1----->		<-----1–6----->			<--------->12-------->		
blast (hours)					<-----6–12----->				

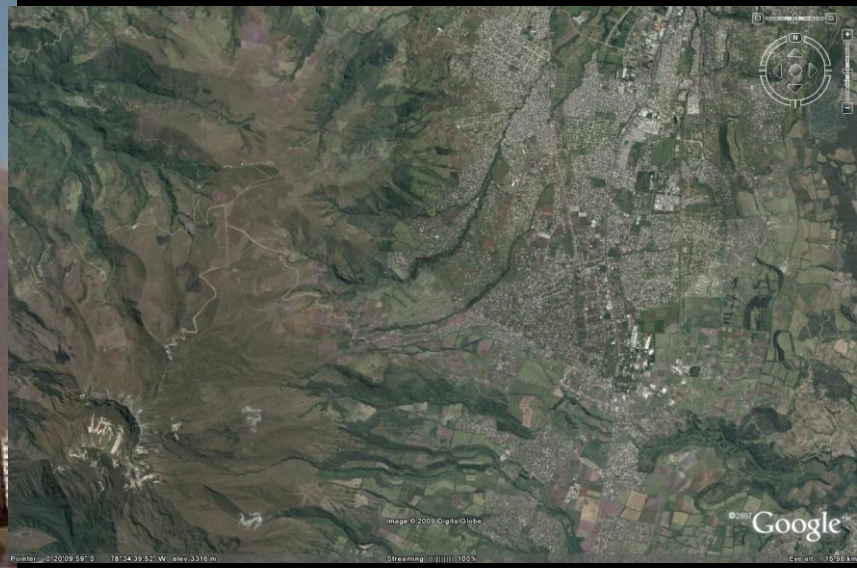
Source: After Newhall and Self (1982).

VOLCANIC HAZARDS : WHAT HAPPENS WHEN PEOPLE LIVE IN CLOSE PROXIMITY TO ACTIVE VOLCANOES ?

Galeras volcano and the city of Pasto, Colombia

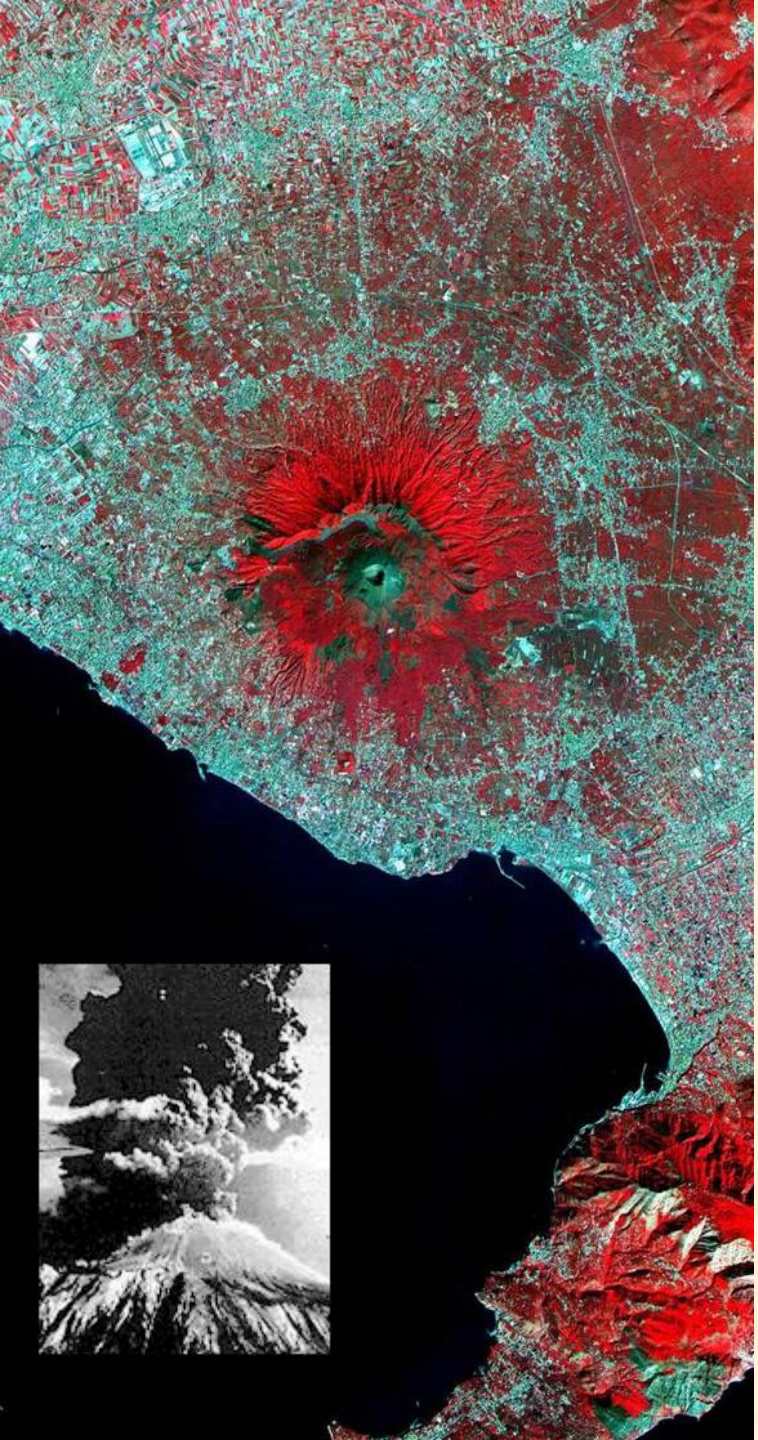


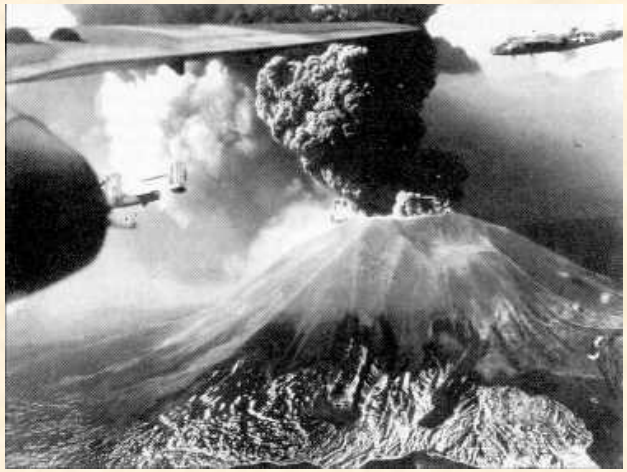
QUITO, ECUADOR



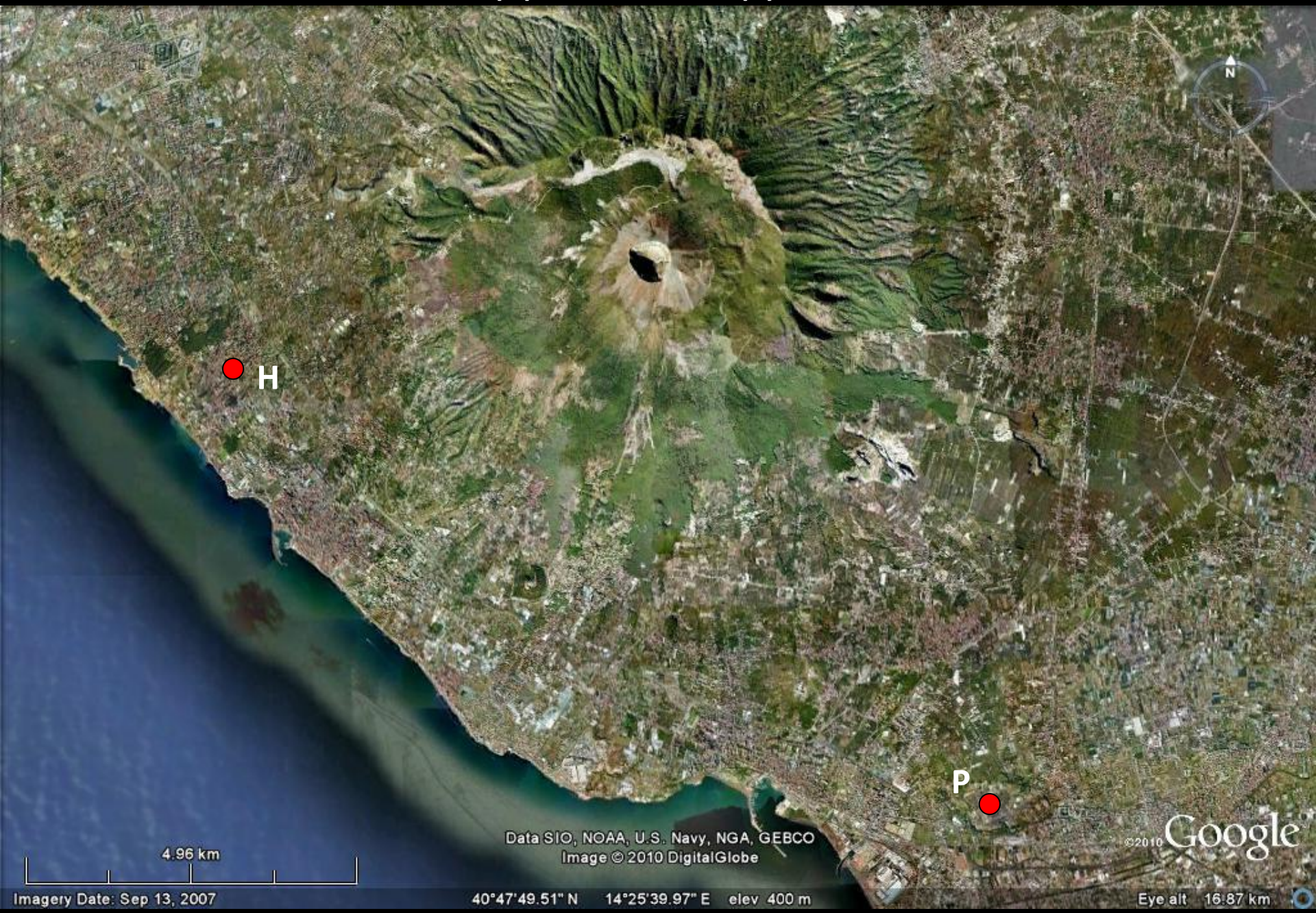
Vesuvius erupting in 1944

MT VESUVIUS – ERUPTION OF 1944





LOCATION OF HERCULANEUM (H) AND POMPEII (P) ENTOMBED IN A.D. 79 ERUPTION



79 AD ERUPTION

Chaiten volcano, Chile, May 2008

CUMULATIVE FATALITIES IN VOLCANIC ERUPTIONS 1500 – PRESENT

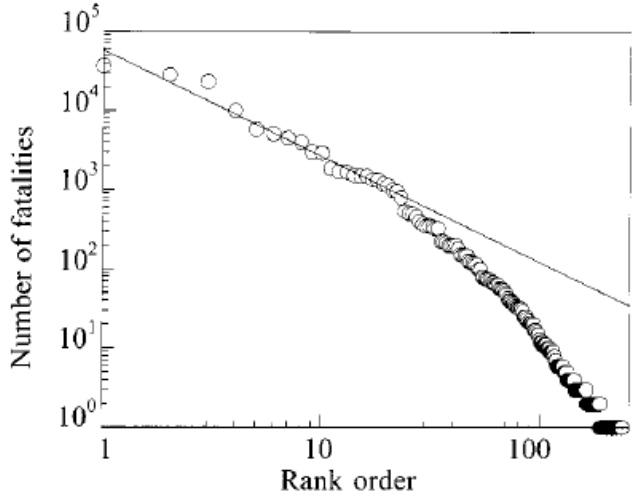
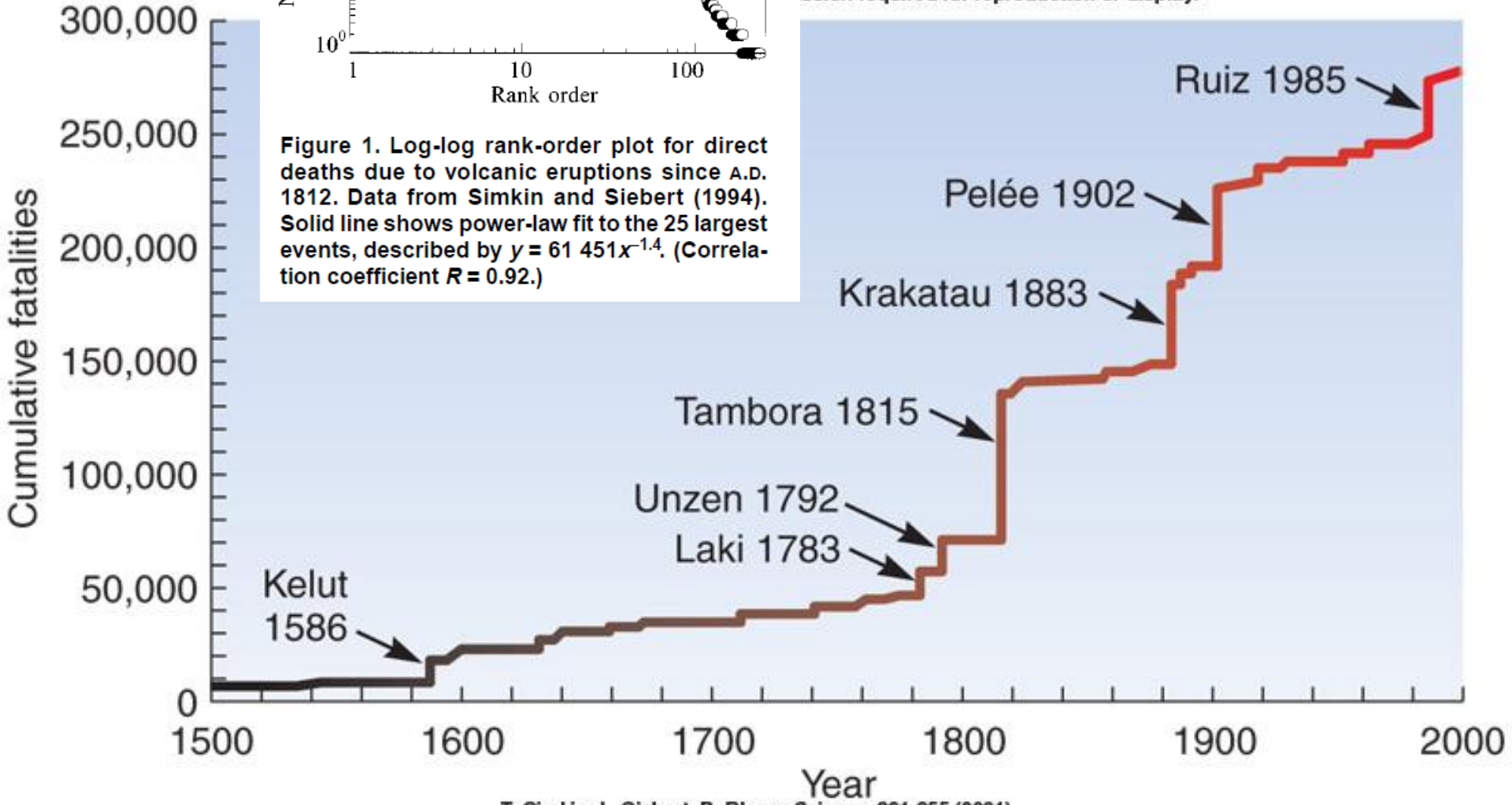


Figure 1. Log-log rank-order plot for direct deaths due to volcanic eruptions since A.D. 1812. Data from Simkin and Siebert (1994). Solid line shows power-law fit to the 25 largest events, described by $y = 61\,451x^{-1.4}$. (Correlation coefficient $R = 0.92$.)

ission required for reproduction or display.



T. Simkin, L. Siebert, R. Blong, *Science*, 291:255 (2001)

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TABLE 9.1

Volcanic Causes of Deaths

	275,000 Deaths	530 Volcanic Events
Pyroclastic flow	29%	15%
Tsunami	21%	5%
Lahar	15%	17%
Indirect (famine)	23%	5%
Gas	1%	4%
Lava flow	< 1%	4%
Pyroclastic fall (bombs)	2%	21%
Debris avalanche	2%	3%
Flood	1%	2%
Earthquake	< 1%	2%
Lightning	< 1%	1%
Unknown	7%	20%

Data source: *Simkin, T., Siebert, L., and Blong, R., "Volcano fatalities" in* Science, *291:255, 2001.*

Volcano Hazards

prevailing wind

eruption cloud

eruption column

tephra (ash) fall

acid rain

bombs

debris avalanche (landslide)

pyroclastic flow

dome

dome collapse

pyroclastic flow

fumaroles

magma

conduit

ground water

lava flow

lahar (debris flow)

crack

magma reservoir

magma

U.S. Geological Survey

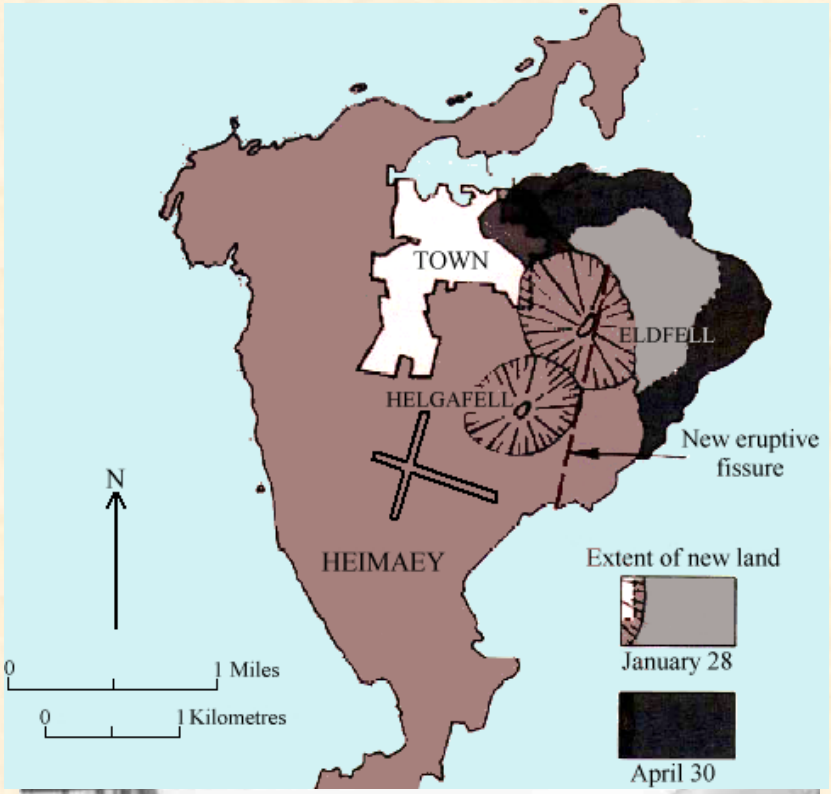
Eruption of Mt Sinabung, Sumatra, February 2014

VOLCANIC HAZARDS

1. LAVA FLOWS
2. PYROCLASTIC FLOWS
3. LAHARS (VOLCANIC DEBRIS FLOWS)
4. ESCAPE OF GASES
5. VOLCANIC ASH
6. FLANK COLLAPSE

LAVA FLOWS IMPACT ON COMMUNITIES AND INFRASTRUCTURE

VOLCANIC HAZARDS 1 – LAVA FLOW; THE CASE OF ELDFELL, HEIMAEY, ICELAND (1973)

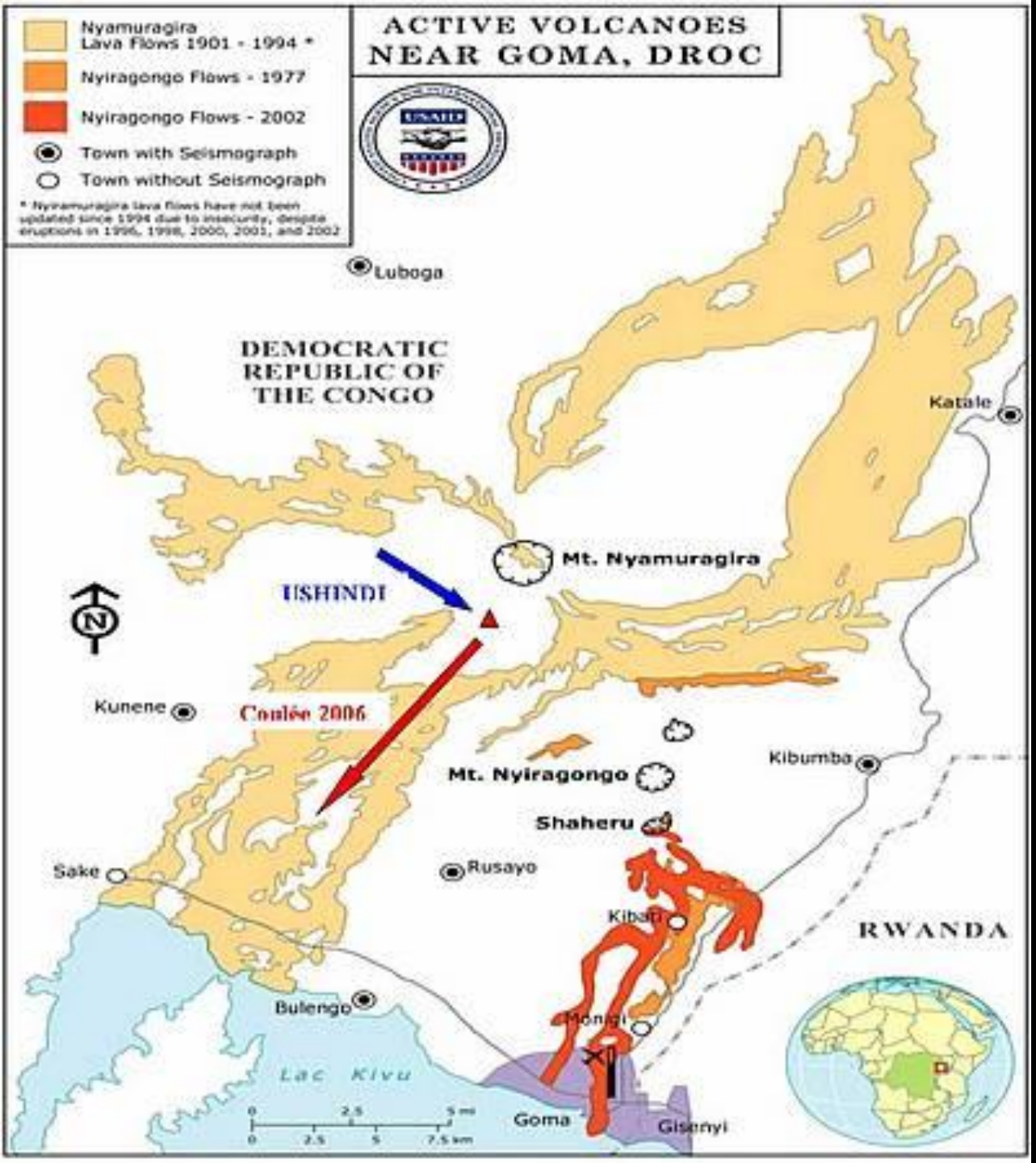


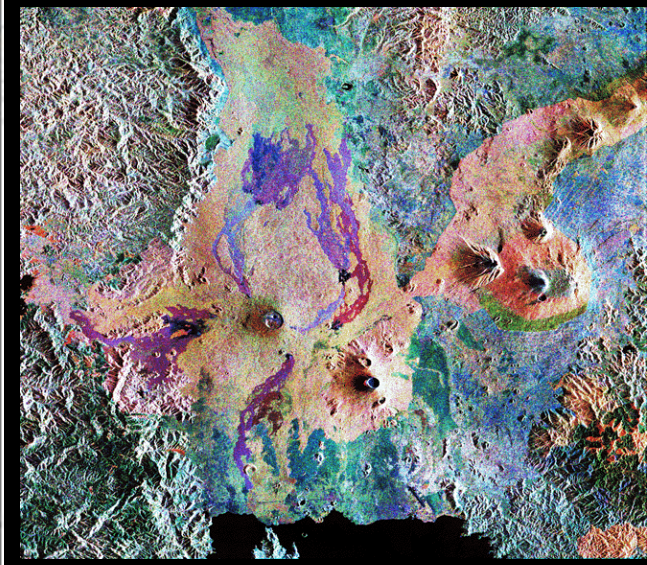
Heimay, Iceland

Heimay, Iceland

Heimay, Iceland

VOLCANIC HAZARDS IN EAST AFRICA

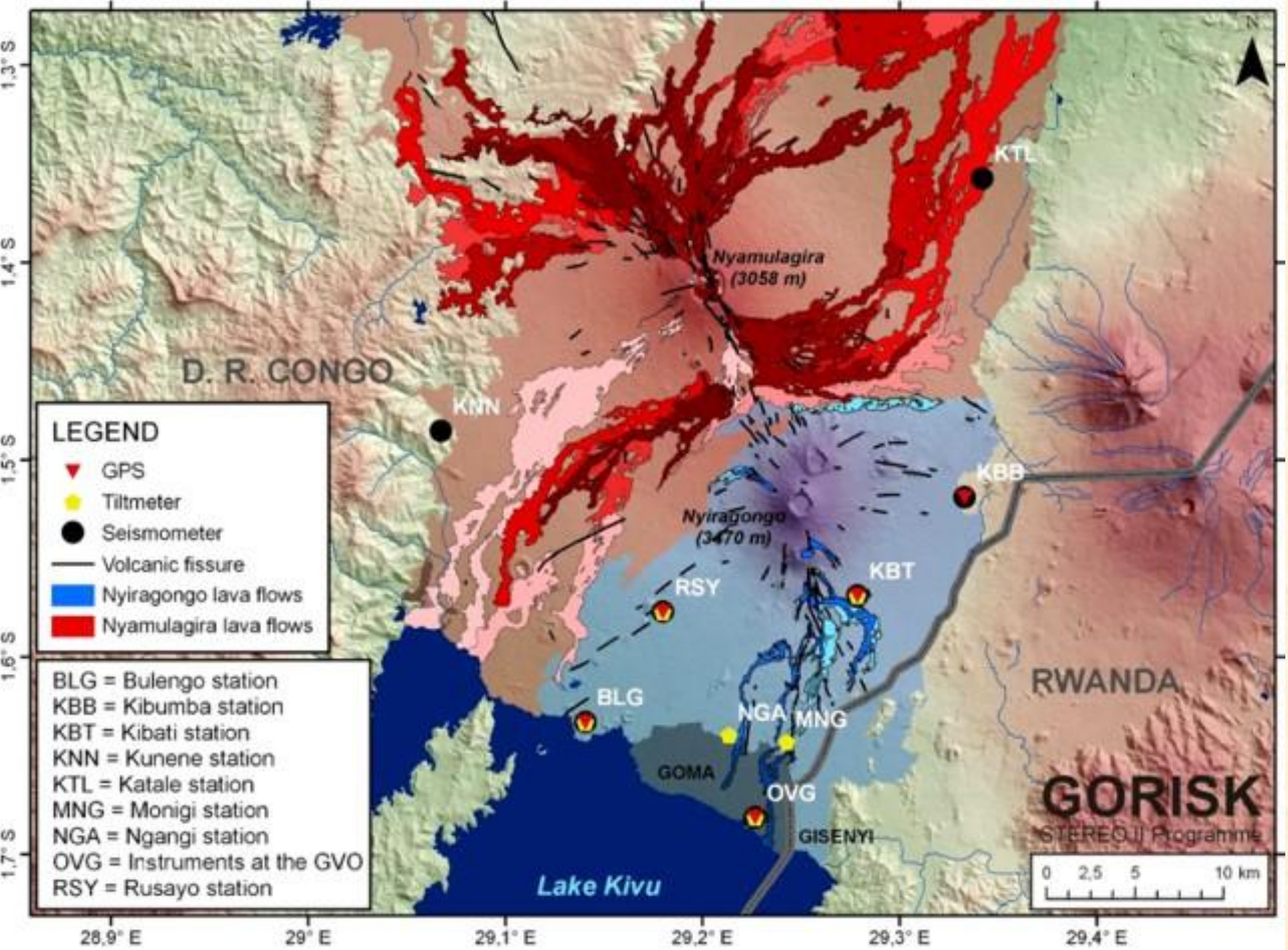




VOLCANIC HAZARDS 1; LAVA FLOWS – THE CASE OF GOMA 2002 [CONTINENTAL RIFT]

VOLCANIC HAZARDS 1; LAVA FLOWS – THE CASE OF GOMA

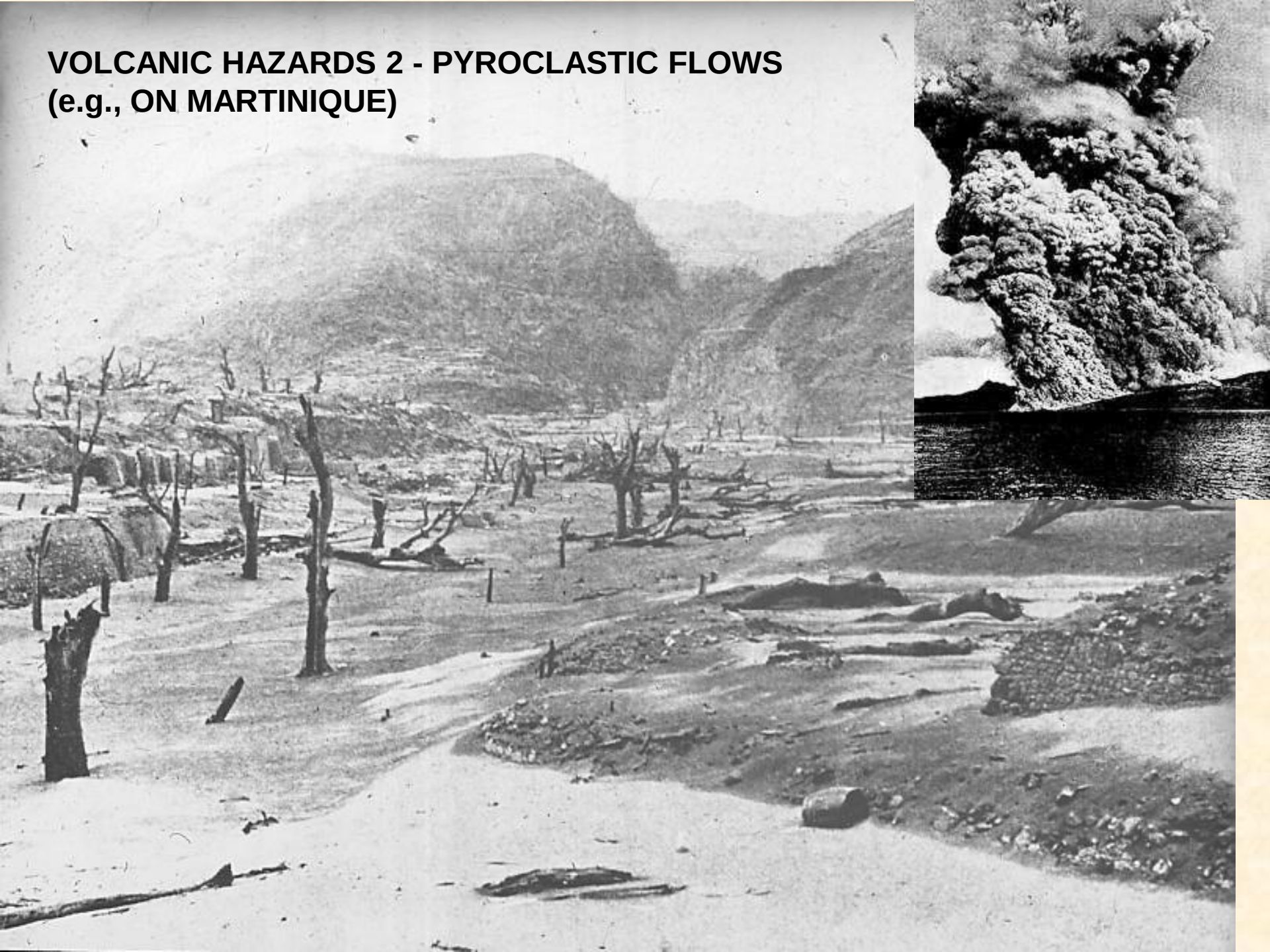
Nyiragongo volcano and the city of Goma (DR Congo)


LEGEND
GPS
Tiltmeter
Seismometer
Volcanic fissure
Nyiragongo lava flows
Nyamulagira lava flows
BLG = Bulengo station
KBB = Kibumba station
KBT = Kibati station
KNN = Kunene station
KTL = Katale station
MNG = Monigi station
NGA = Ngangi station
OVG = Instruments at the GVO
RSY = Rusayo station
D. R. CONGO
RWANDA
Nyamulagira (3058 m)
Nyiragongo (3470 m)
KTL
KNN
KBB
KBT
RSY
BLG
NGA
MNG
OVG
GOMA
GISENYI
Lake Kivu
GORISK
STEREO II Programme
0 2,5 5 10 km
1,3° S
1,4° S
1,5° S
1,6° S
1,7° S
28,9° E
29° E
29,1° E
29,2° E
29,3° E
29,4° E

LAVA FLOW AT GOMA AND GOMA AIRPORT

COMPLEX EMERGENCIES – backdropped by Nyiragongo, displaced Congolese gather near Goma to escape civil war conflict and cholera outbreak. (August 2012)

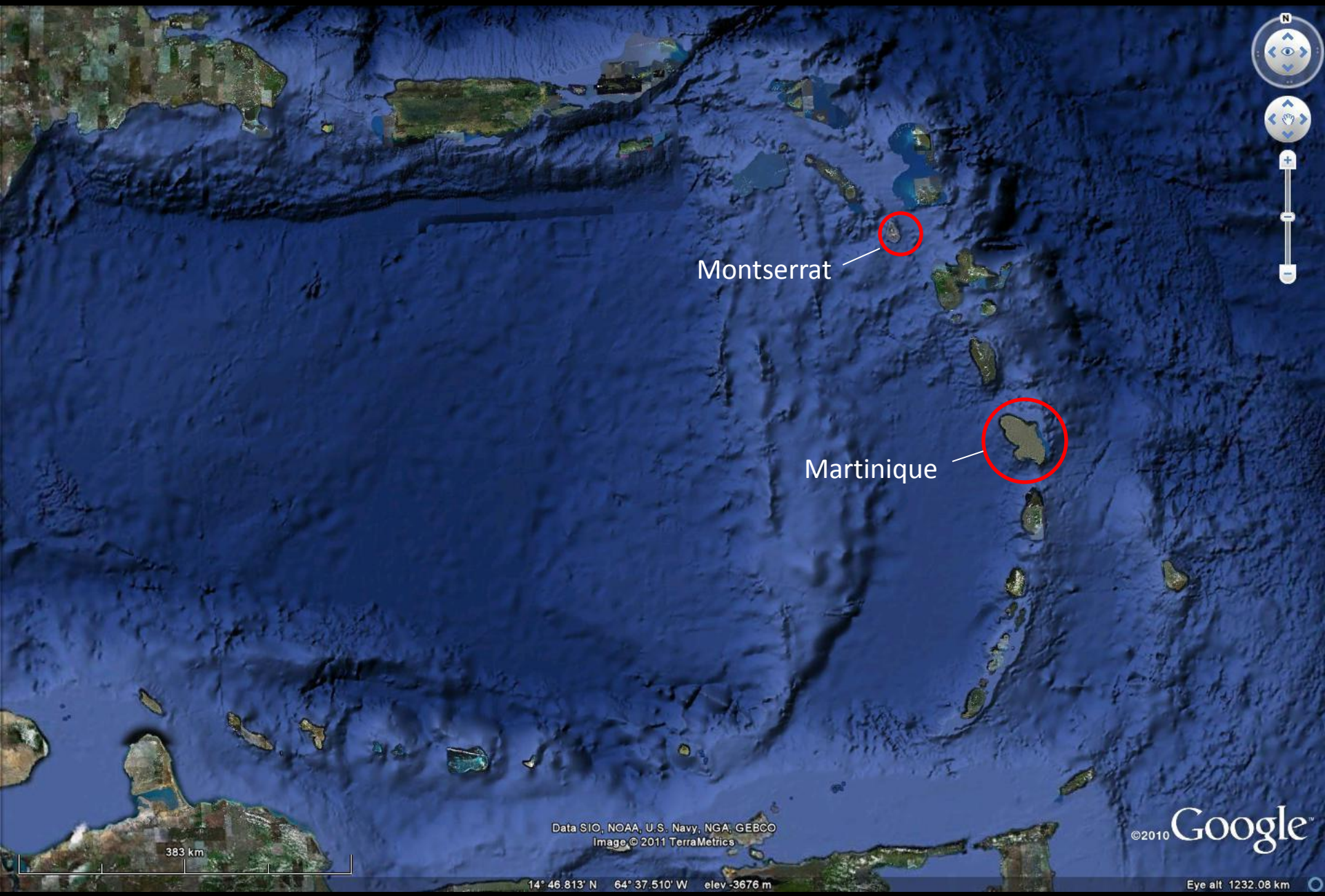
VOLCANIC HAZARDS 2 - PYROCLASTIC FLOWS (e.g., ON MARTINIQUE)

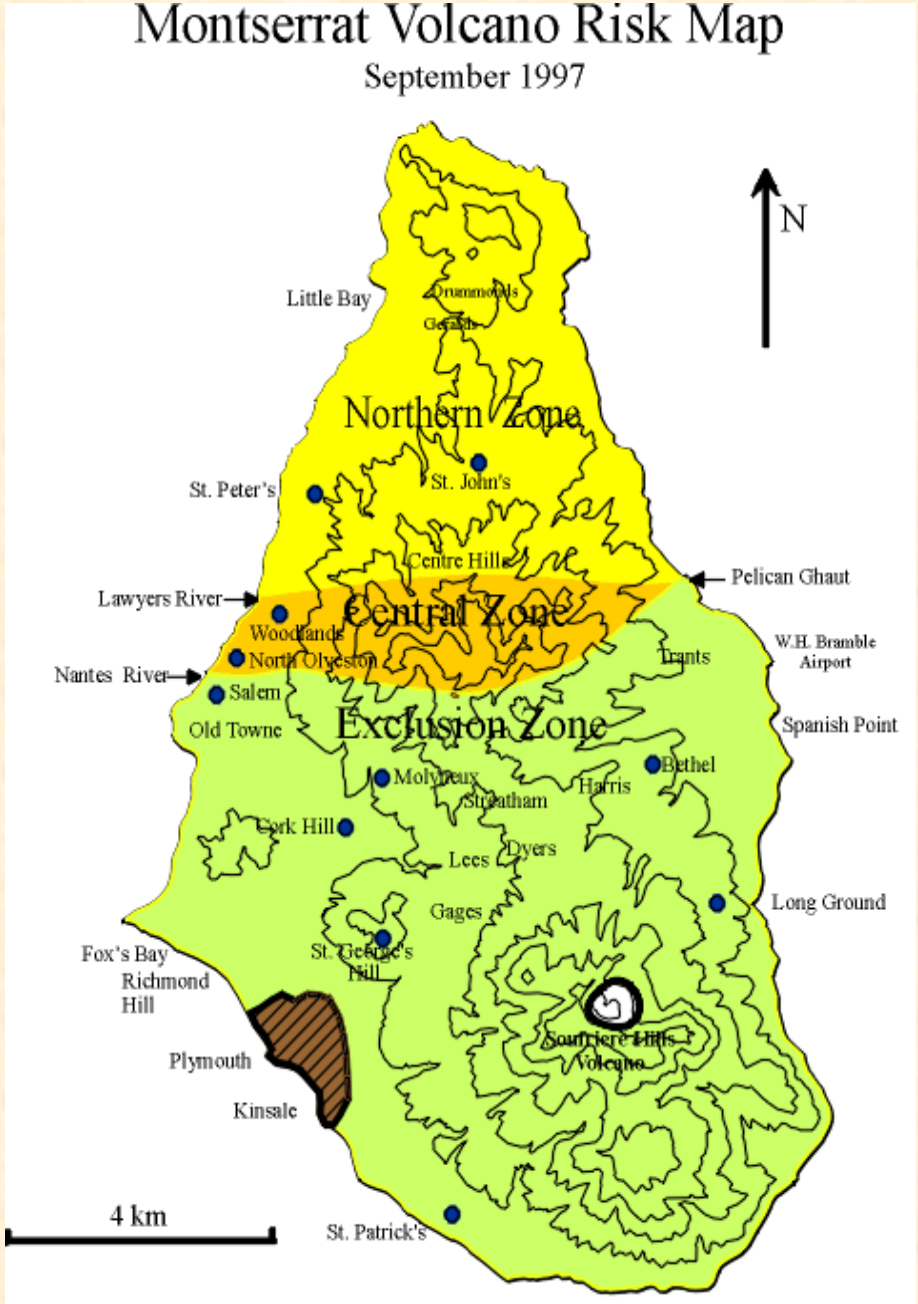


Montserrat, February 21, 2010

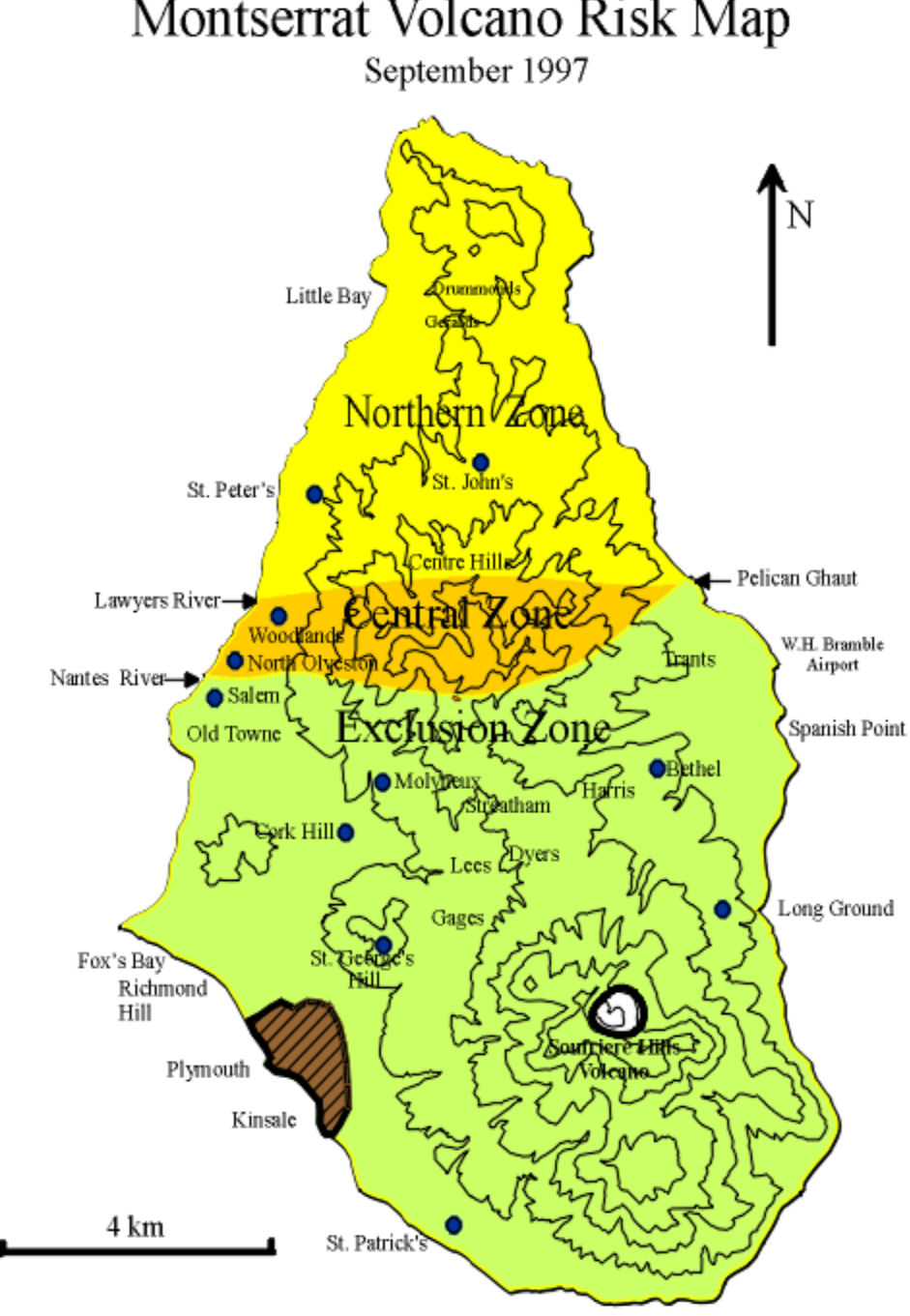
A massive eruption of Montserrat's Soufrière Hills Volcano covered large portions of the island in debris. The eruption was triggered by a collapse of Soufrière Hills' summit lava dome on February 11, 2010.

Pyroclastic flows raced down the northern flank of the volcano, leveling trees and destroying buildings in the village of Harris, which was abandoned after Soufrière Hills became active in 1995. The Montserrat Volcano Observatory reported that some flows, about 15 meters thick, reached the sea at Trant's Bay. These flows extended the island's coastline up to 650 meters .


Montserrat
Martinique
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2011 TerraMetrics
©2010 Google
383 km
14° 46.813' N 64° 37.510' W elev -3676 m
Eye alt 1232.08 km



DOME COLLAPSE AT SOUFRIERE HILLS VOLCANO, 1997

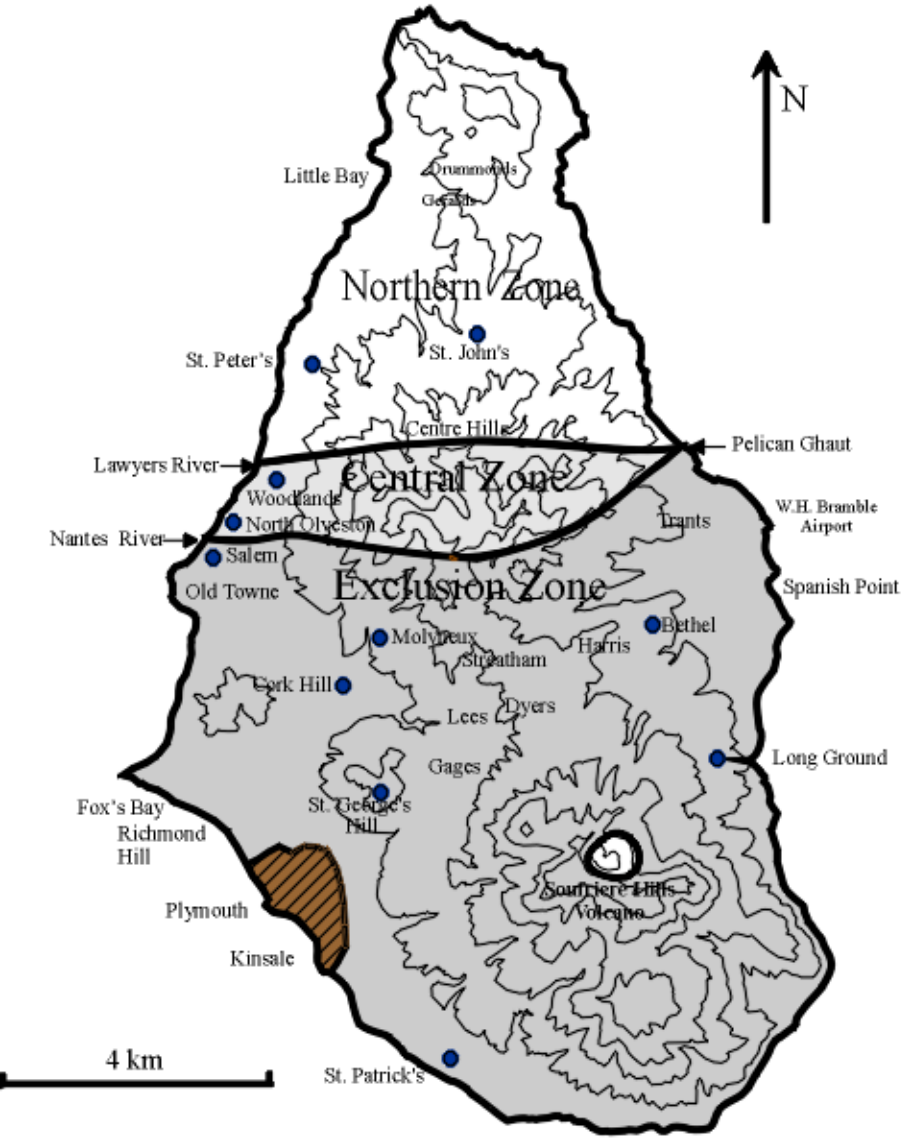


Montserrat Volcanic Hazard Zoning

The town of Plymouth, Montserrat, after lahars triggered by heavy rains in 1997

Montserrat Volcano Risk Map

September 1997



Exclusion Zone	No admittance except for scientific monitoring and National Security Matters
Central Zone	Residential area only, all resident on heightened state of alert. All resident to have rapid means of exit 24 hours per day Hard hat area all residents to have hard hats and dust masks.
Northern Zone	Area with significantly lower risk, suitable for residential and commercial occupation

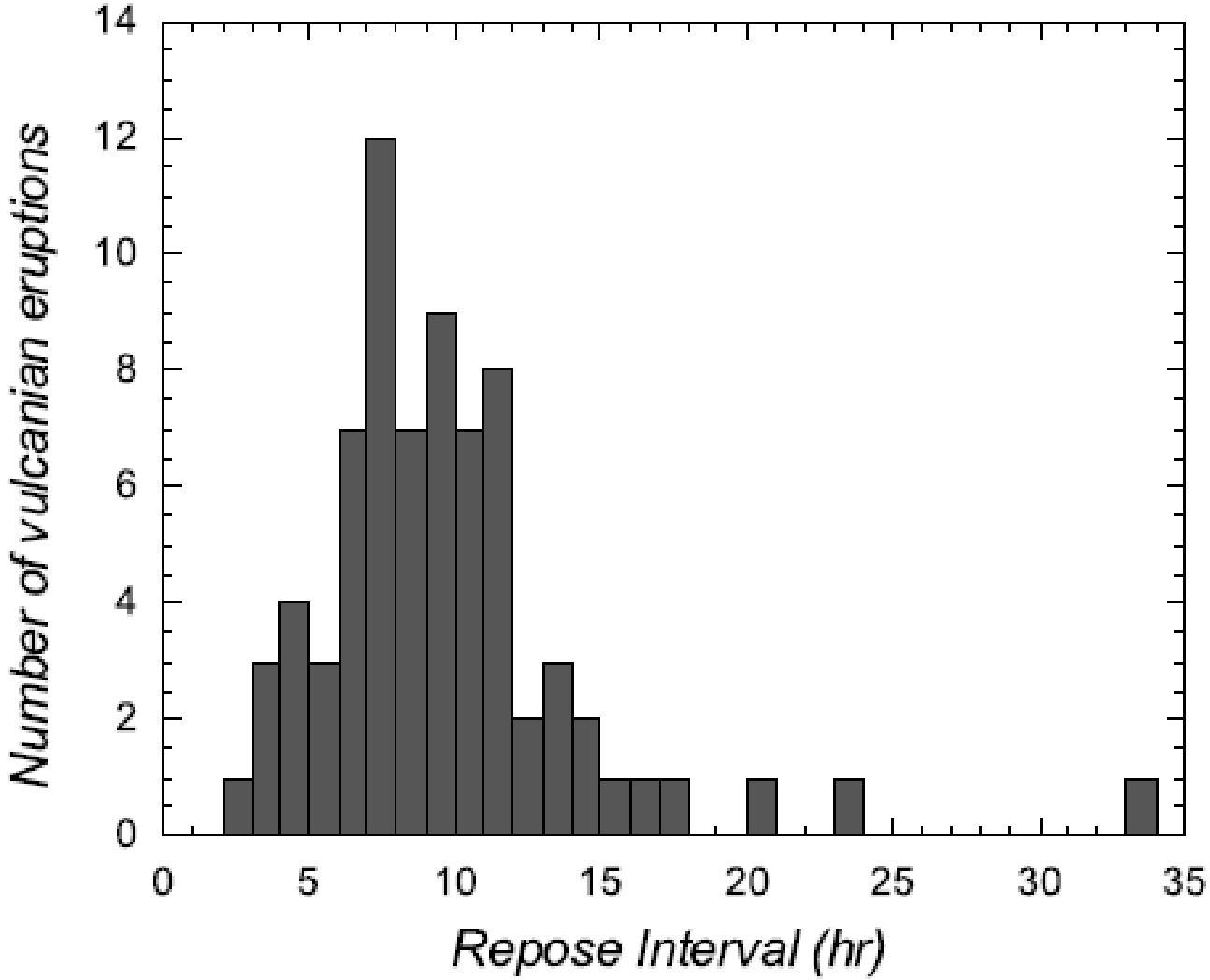
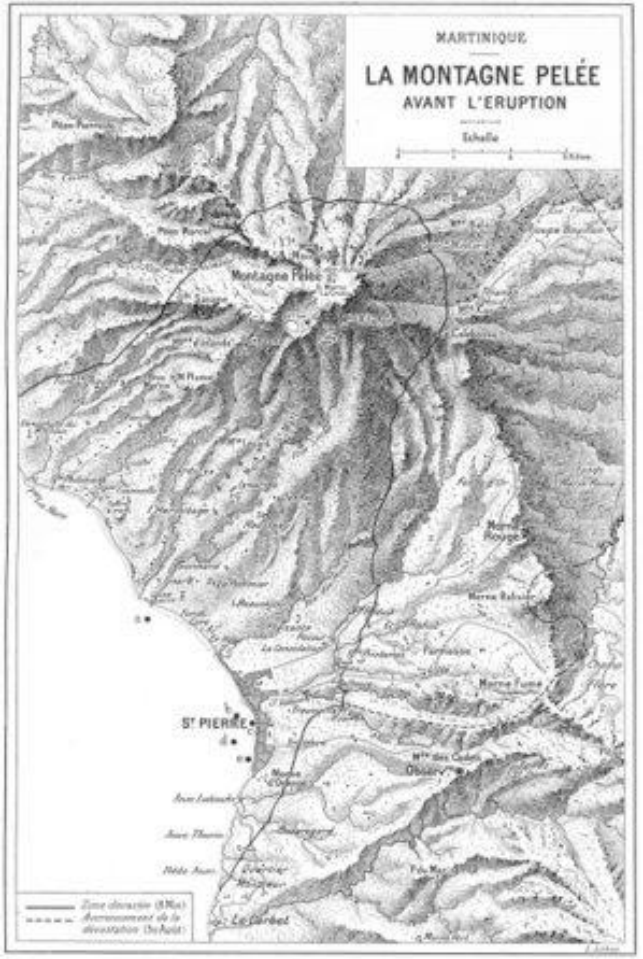


Figure 1. Histogram of 74 repose intervals between vulcanian explosions at Soufrière Hills volcano between September–October, 1997. Data from *Young et al.* [1999].

PYROCLASTIC FLOWS AT MT MAYON VOLCANO, PHILIPPINES

PYROCLASTIC FLOWS AT MT PINATUBO 1990

PYROCLASTIC FLOWS ON PHILIPPINE VOLCANOES

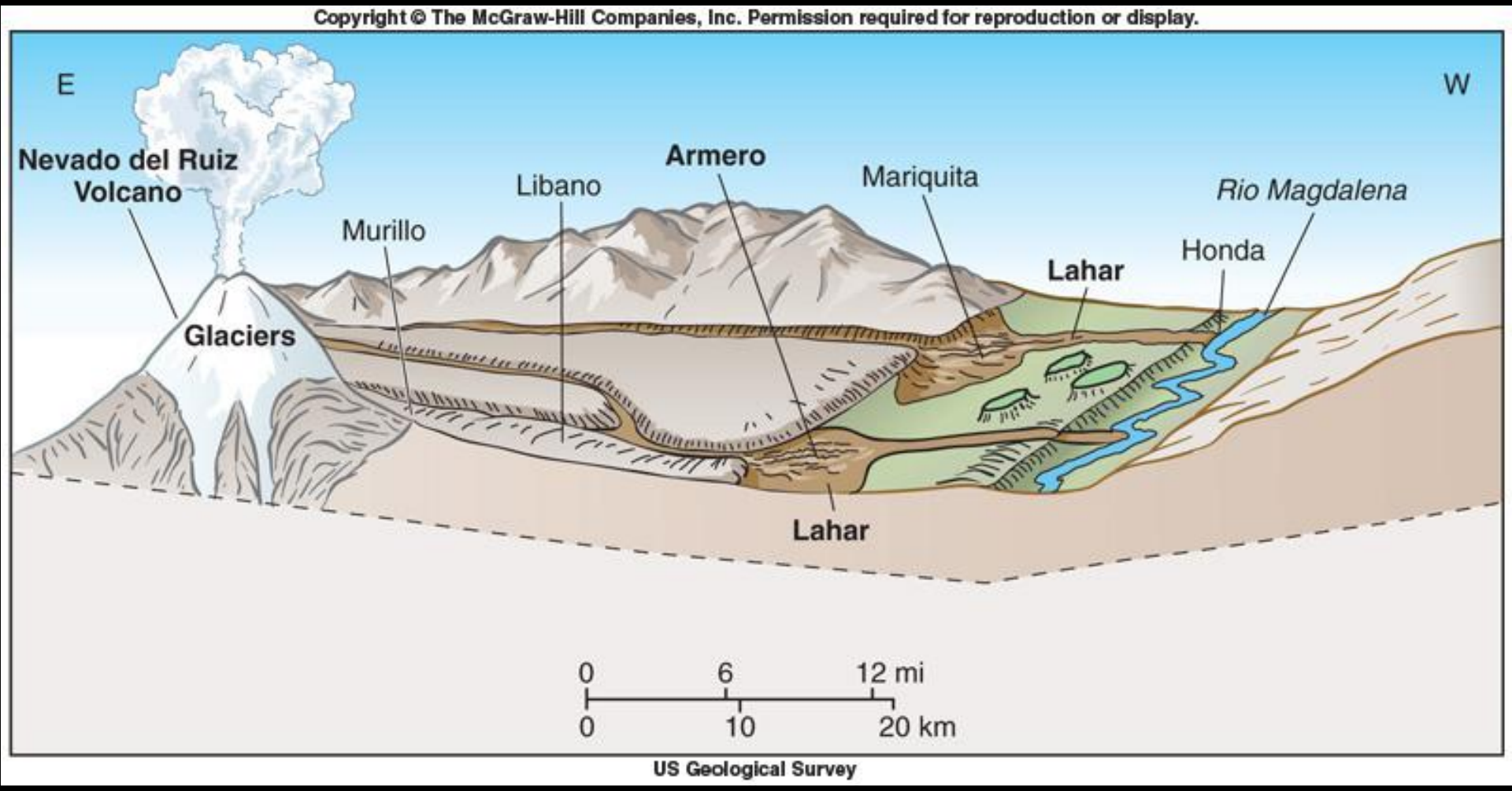


DESTRUCTION OF ST PIERRE (MARTINIQUE) IN 1902 BY PYROCLASTIC FLOW FROM MT PELEE VOLCANO (28,000 deaths)

MT. PELEE VOLCANO (MARTINIQUE) AND LOCATION OF ST. PIERRE (CIRCLED)

VOLCANIC HAZARDS 3 – LAHARS (VOLCANIC MUDFLOW/DEBRIS FLOW)

Armero, Colombia after destruction by volcanic mudflow (lahar) from Nevado del Ruiz in 1985 – 25,000 deaths



SETTING OF 1985 ARMERO DISASTER, NEVADO DEL RUIZ, COLOMBIA

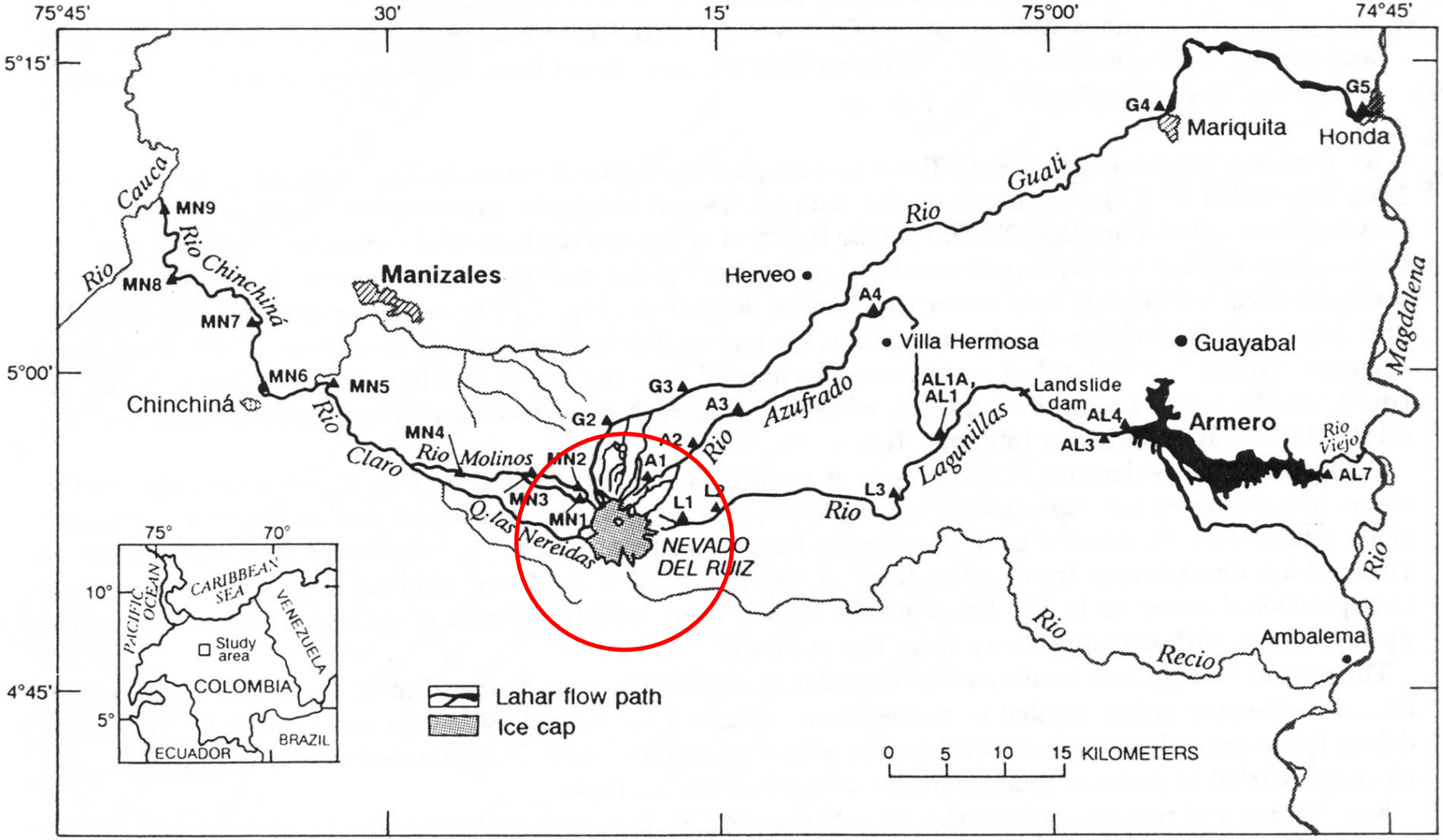


Fig. 1. Location of Nevado del Ruiz volcano in the Cordillera Central of Colombia, and channels that conveyed major lahars. Principal lahar deposition is shown near town of Armero. Sample/measurement locations on channels are indicated.

VOLCANIC MUDFLOWS TRIGGERED BY ERUPTION OF NEVADO DEL RUIZ, COLOMBIA, 1985

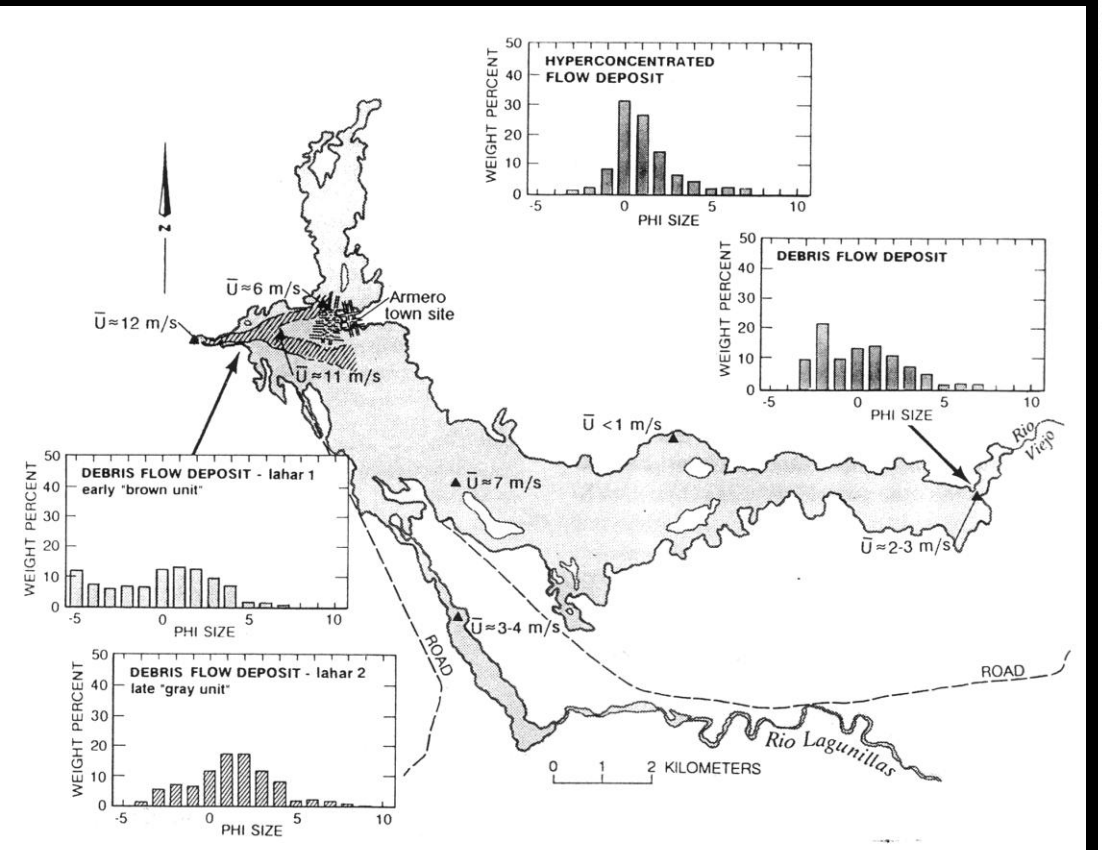
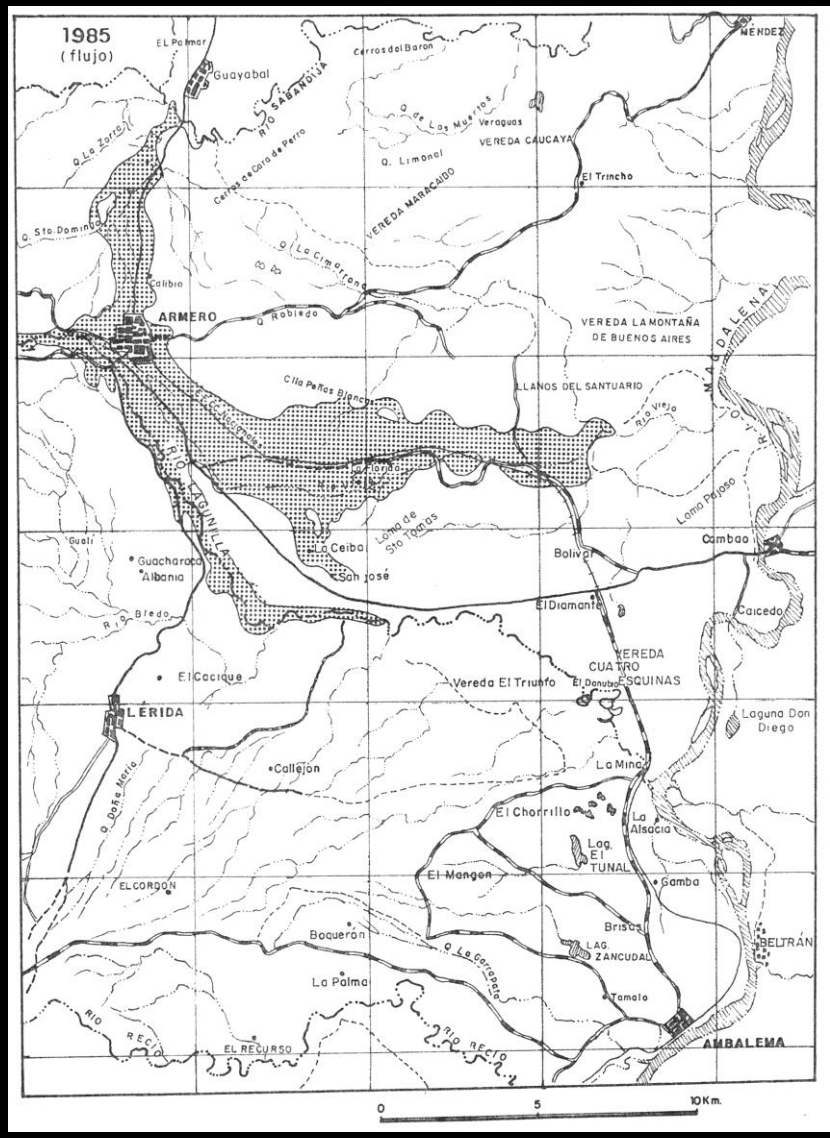
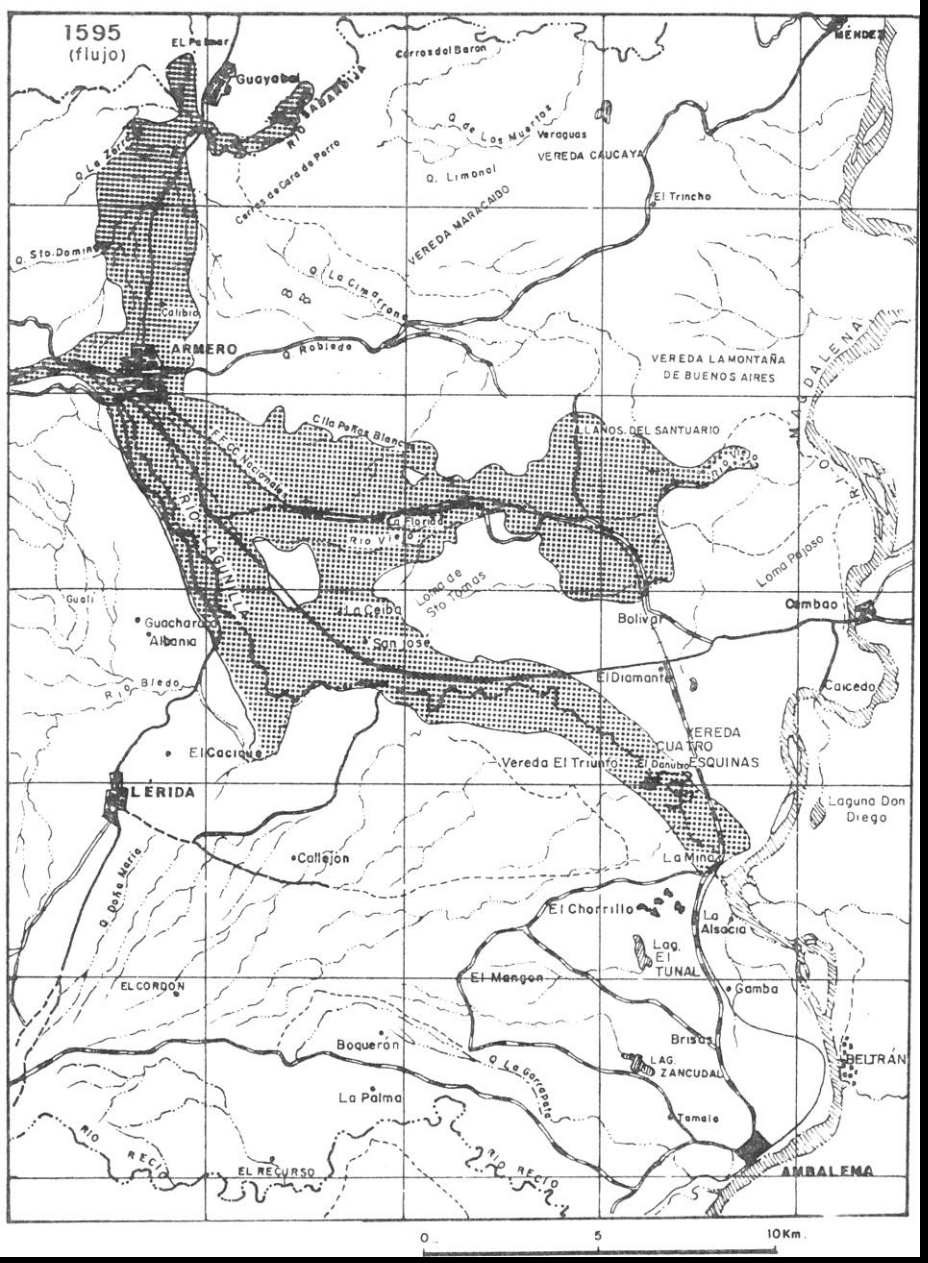


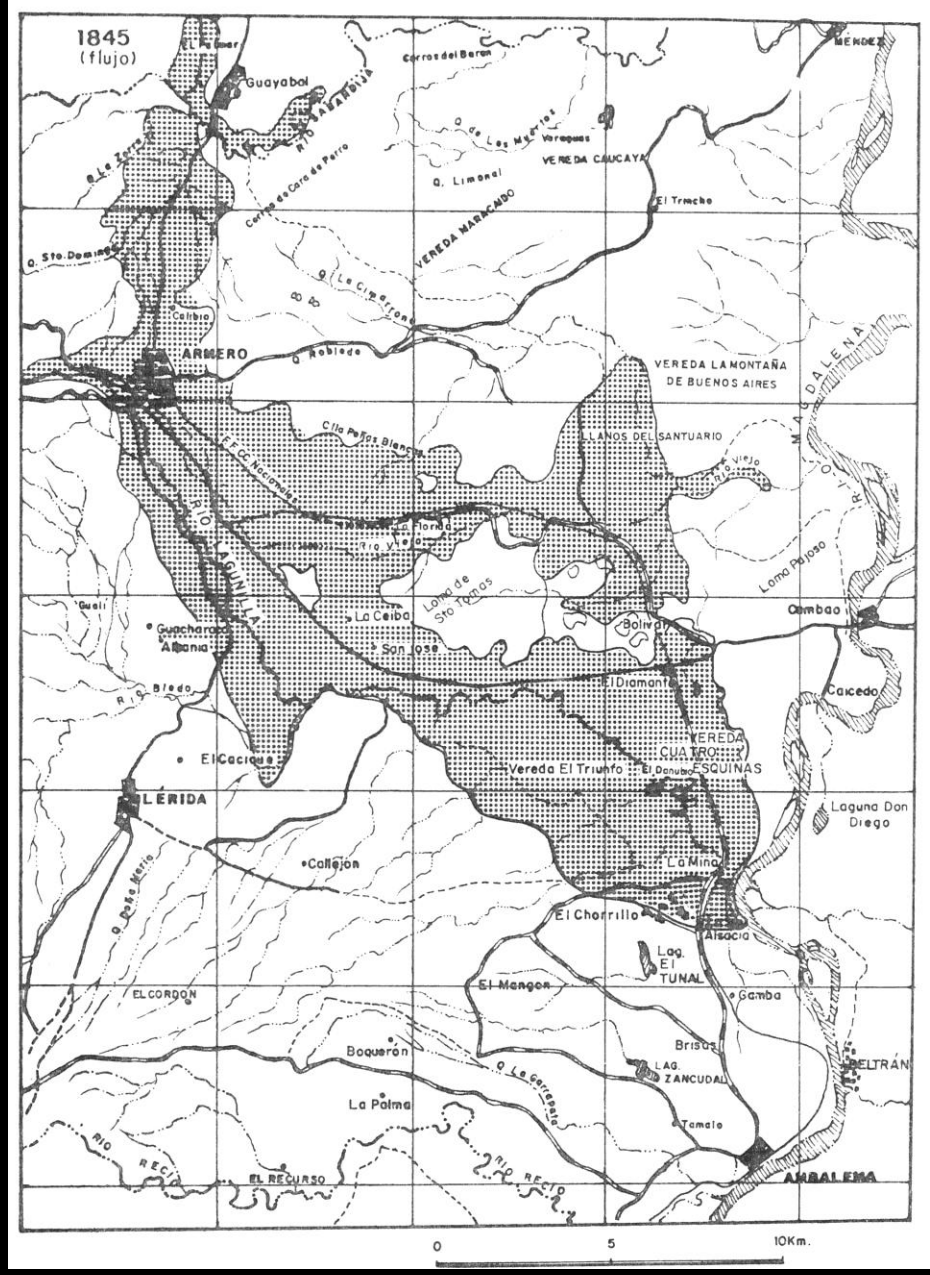
Fig. 30. Extent of lahar deposition, average peak-flow velocities, and proximal and distal deposit textures on the Armero debris fan. Gray unit (patterned area) could not be traced beyond Armero town site. Map drawn from uncorrected photomosaic (1:50,000) compiled by Instituto Geografico "Agustin Codazzi", Bogota.



EXTENT OF 1985 FLOW IN VICINITY OF ARMERO

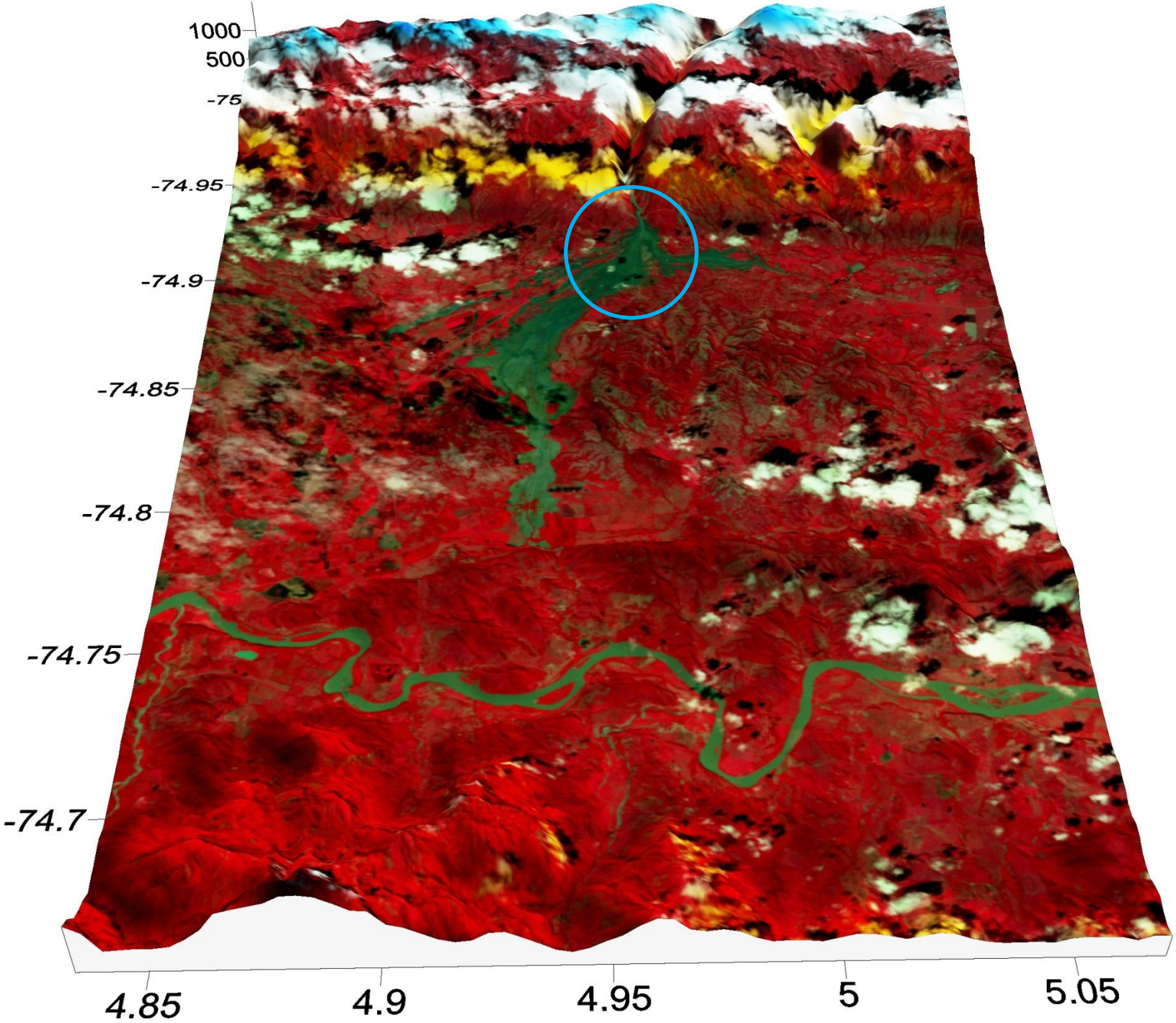

1595
(flujo)
El Palmar
Guayabal
Cerros del Baron
MENDEZ
RIO LAGUNILLA
Q. Le Zarra
Q. de Los Muertos
Veraguas
VEREDA CAUCAYA
Q. Limonal
Cerros de Cara de Perro
El Trincho
VEREDA MARACAIBO
Q. Sto. Domingo
Q. La Cimarrona
Calibio
ARMERO
Q. Robledo
VEREDA LA MONTAÑA DE BUENOS AIRES
MAGDALENA
Cilla Peñas Blancas
LLANOS DEL SANTUARIO
F.C. Nacional
La Florida
Rio Viejo
Loma de Sto Tomas
Loma Pajoso
Guali
Guacharaca
Albania
La Ceiba
San Jose
Bolivar
Ombao
Rio Bledo
El Diamante
Caicedo
VEREDA CUATRO ESQUINAS
El Cacique
Vereda El Triunfo
El Danubio
LÉRIDA
Laguna Don Diego
Callejon
La Mina
Q. Doña Maria
El Chorrillo
La Alsacia
Lag. El TUNAL
EL CORDON
El Mengon
Gamba
Brisas
Boqueron
LAG. ZANCUDAL
BELTRÁN
Q. La Corrapata
La Palma
Tamalo
RIO RECIO
EL RECURSO
AMBALEMA
0
5
10Km.

1595

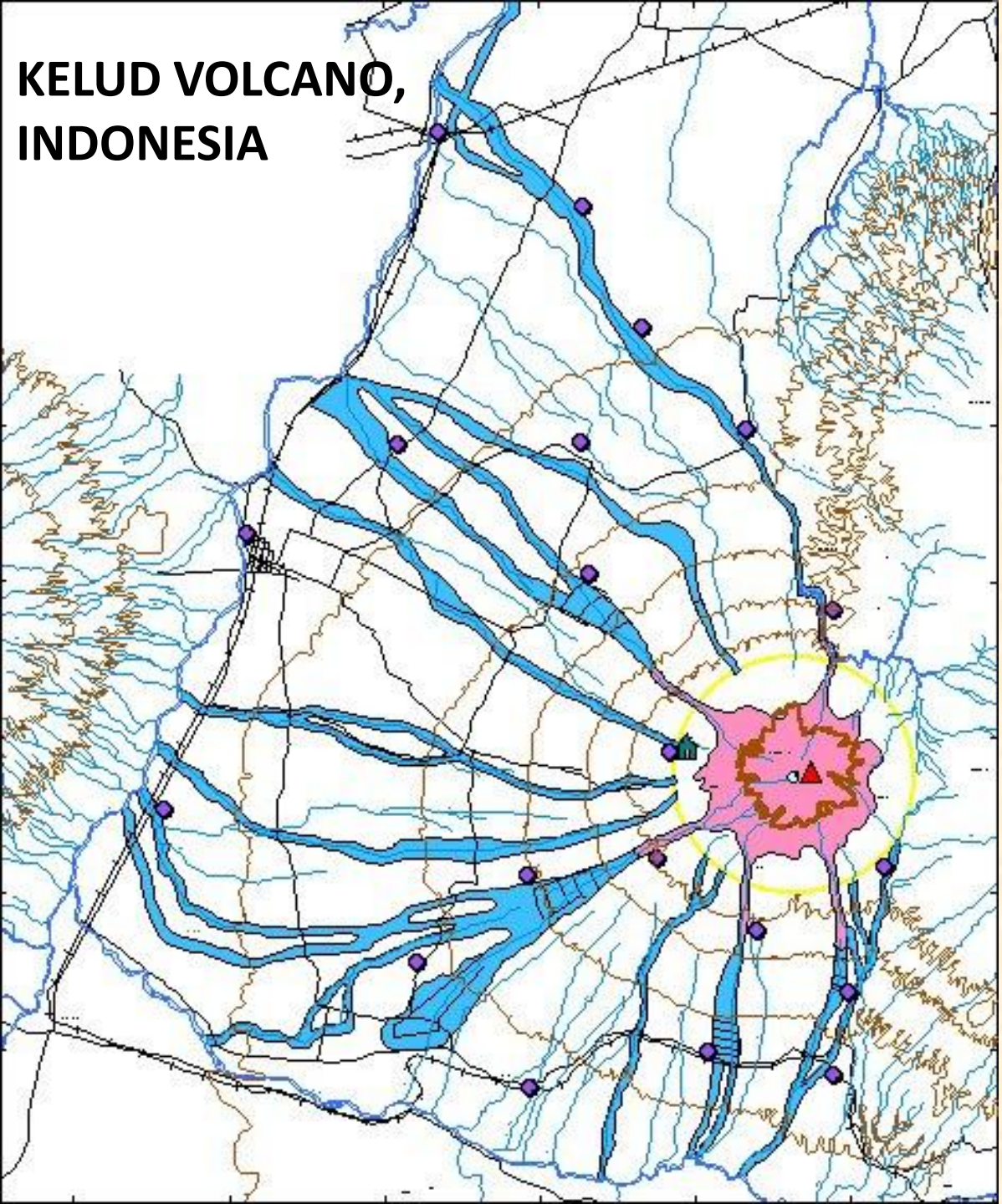

1845
(flujo)
El Palmar
Guayabal
Cerros del Baron
MENDEZ
RIO LAGUNILLA
Q. Le Zarra
Q. de Los Muertos
Veraguas
VEREDA CAUCAYA
Q. Limonal
Cerros de Cara de Perro
El Trincho
VEREDA MARACAIBO
Q. Sto. Domingo
Q. La Cimarrona
Calibio
ARMERO
Q. Robledo
VEREDA LA MONTAÑA DE BUENOS AIRES
MAGDALENA
Cilla Peñas Blancas
LLANOS DEL SANTUARIO
F.C. Nacional
La Florida
Rio Viejo
Loma de Sto Tomas
Loma Pajoso
Guali
Guacharaca
Albania
La Ceiba
San Jose
Bolivar
Ombao
Rio Bledo
El Diamante
Caicedo
VEREDA CUATRO ESQUINAS
El Cacique
Vereda El Triunfo
El Danubio
LÉRIDA
Laguna Don Diego
Callejon
La Mina
Q. Doña Maria
El Chorrillo
La Alsacia
Lag. El TUNAL
EL CORDON
El Mengon
Gamba
Brisas
Boqueron
LAG. ZANCUDAL
BELTRÁN
Q. La Corrapata
La Palma
Tamalo
RIO RECIO
EL RECURSO
AMBALEMA
0
5
10Km.

1845

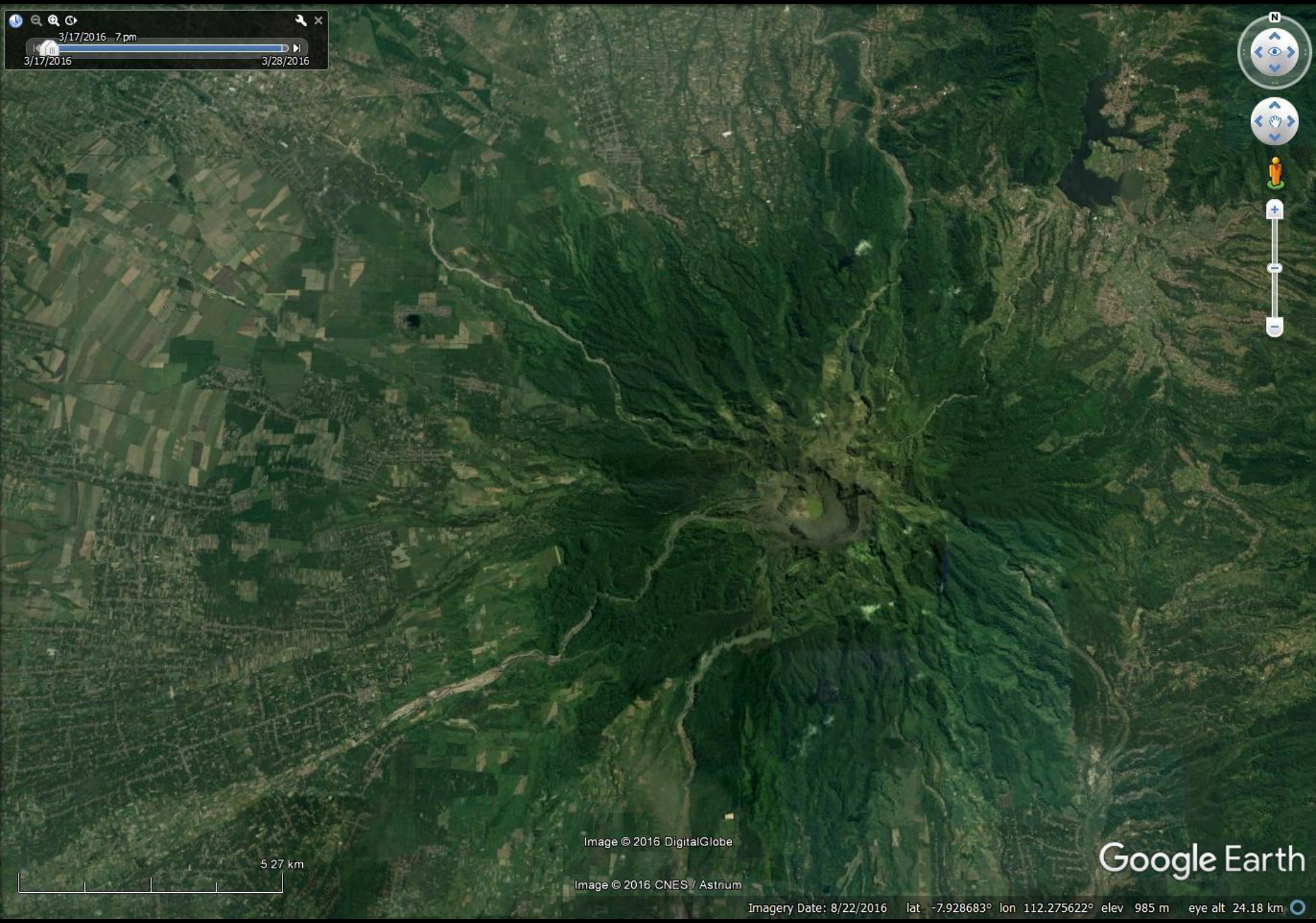
AERIAL VIEW OF ARMERO FAN, 1985


1000
500
-75
-74.95
-74.9
-74.85
-74.8
-74.75
-74.7
4.85
4.9
4.95
5
5.05

KELUD VOLCANO, INDONESIA

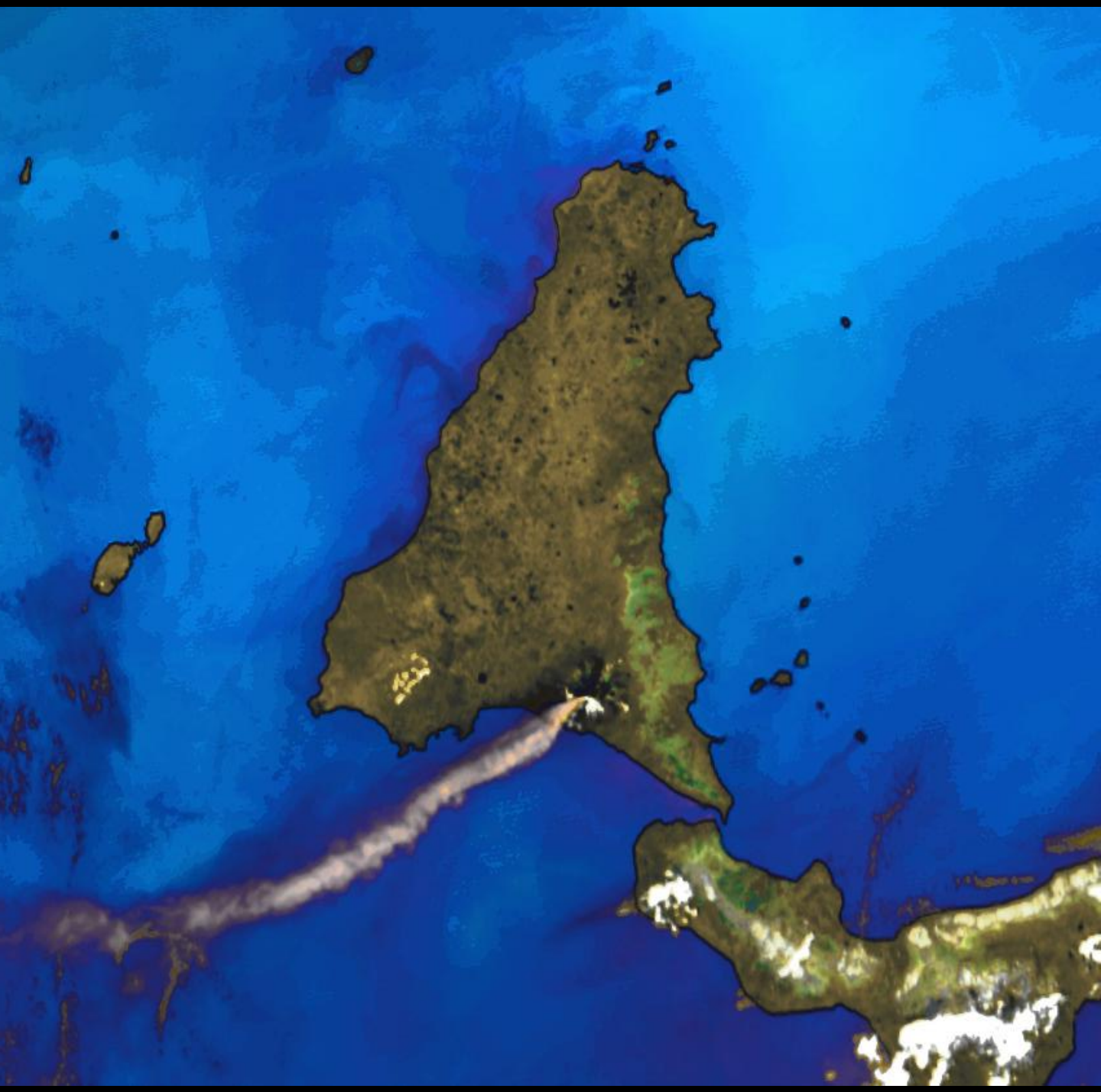


1921 ; Volcanic eruption ejected crater lake (est. vol. ~ 38 M m^3) forming lahars which moved downslope up to 37 km from crater at about 17 m/s; 104 villages partially or totally destroyed; lahars covered 131.2 km^2 of agricultural land (5,110 deaths); Similar event took place in 1586 (10,000 deaths)

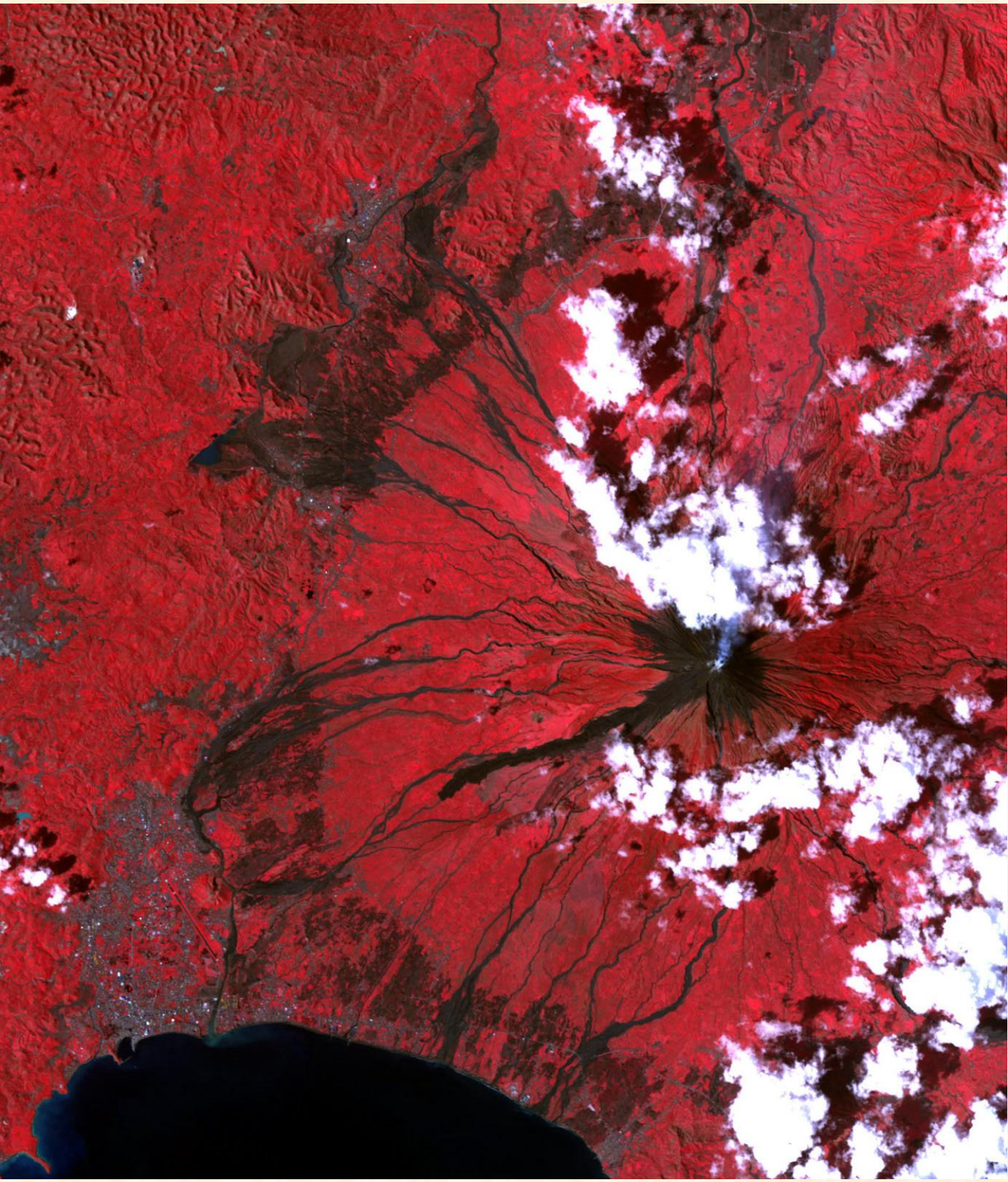

3/17/2016 7 pm
3/17/2016
3/28/2016
N
Image © 2016 DigitalGlobe
5.27 km
Image © 2016 CNES / Astrium
Google Earth
Imagery Date: 8/22/2016 lat -7.928683° lon 112.275622° elev 985 m eye alt 24.18 km

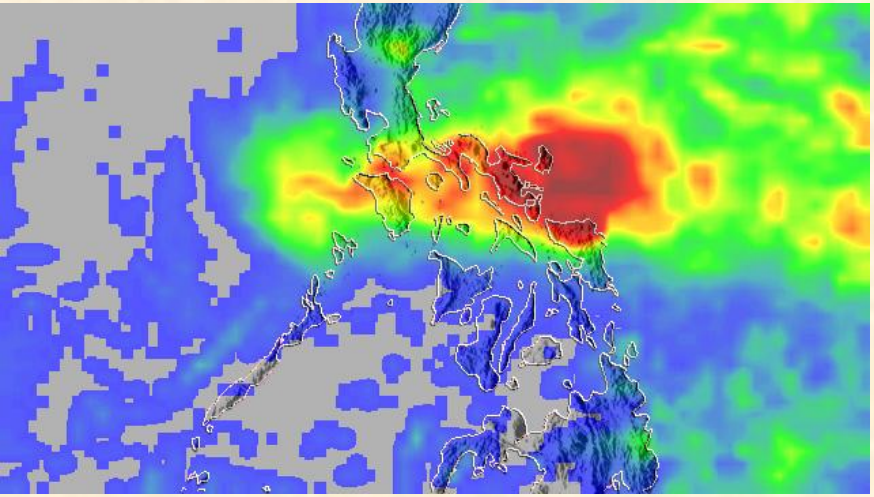
MOUNT ETNA – May 26, 2016

MOUNT ETNA ERUPTING



SATELLITE IMAGE OF DECEMBER 2006 LAHARS, MAYON VOLCANO, PHILIPPINES

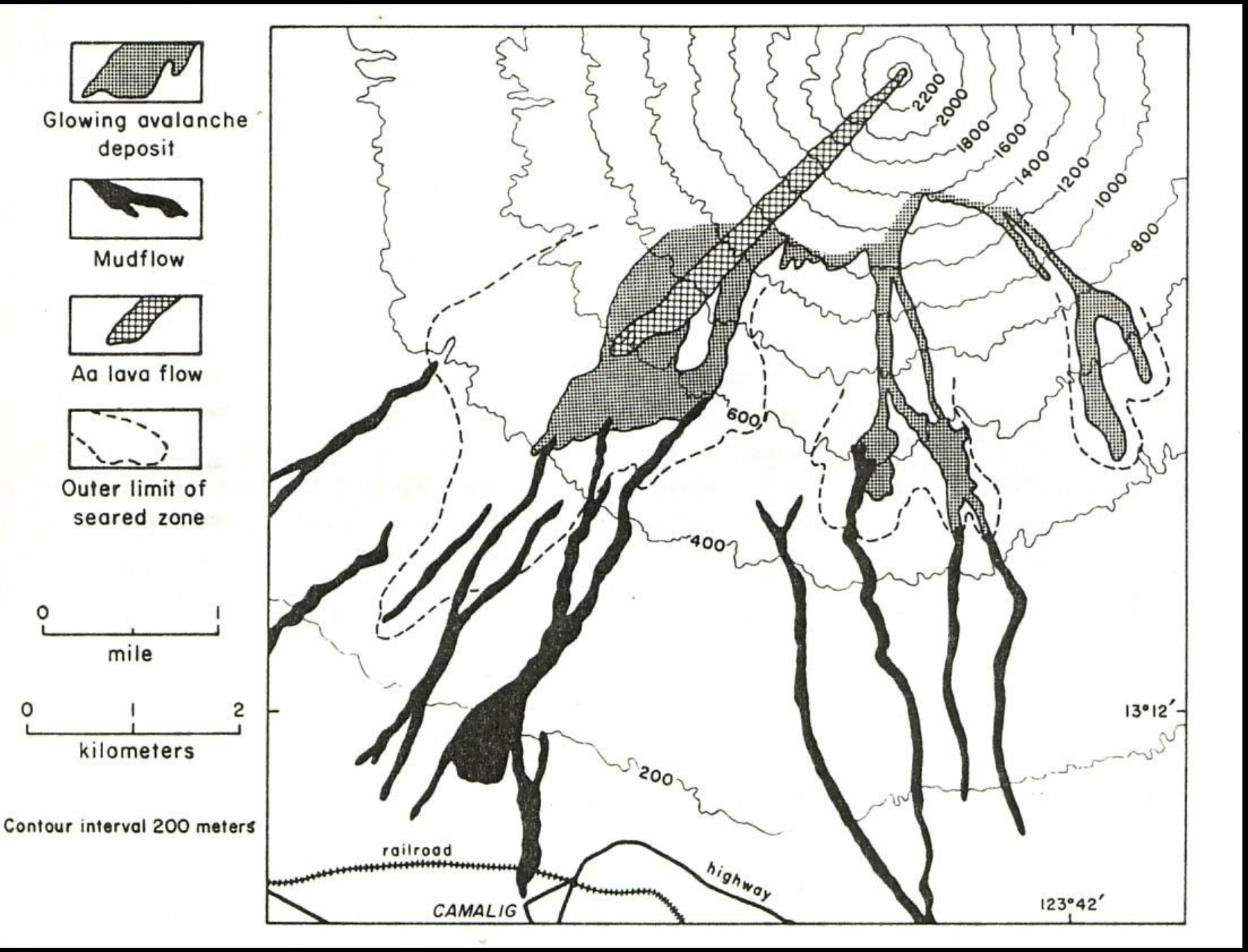




RAINFALL - INDUCED (TYPHOON) LAHARS AT MAYON VOLCANO, PHILIPPINES, DECEMBER 2006

> 1,049 Deaths

HOT AND COLD LAHARS AT MAYON VOLCANO, PHILIPPINES



RUAPEHU VOLCANO, NEW ZEALAND – LAHAR SEEN ON SATELLITE IMAGE

VOLCANIC HAZARDS 4 : ESCAPE OF GAS FROM VOLCANIC LAKES

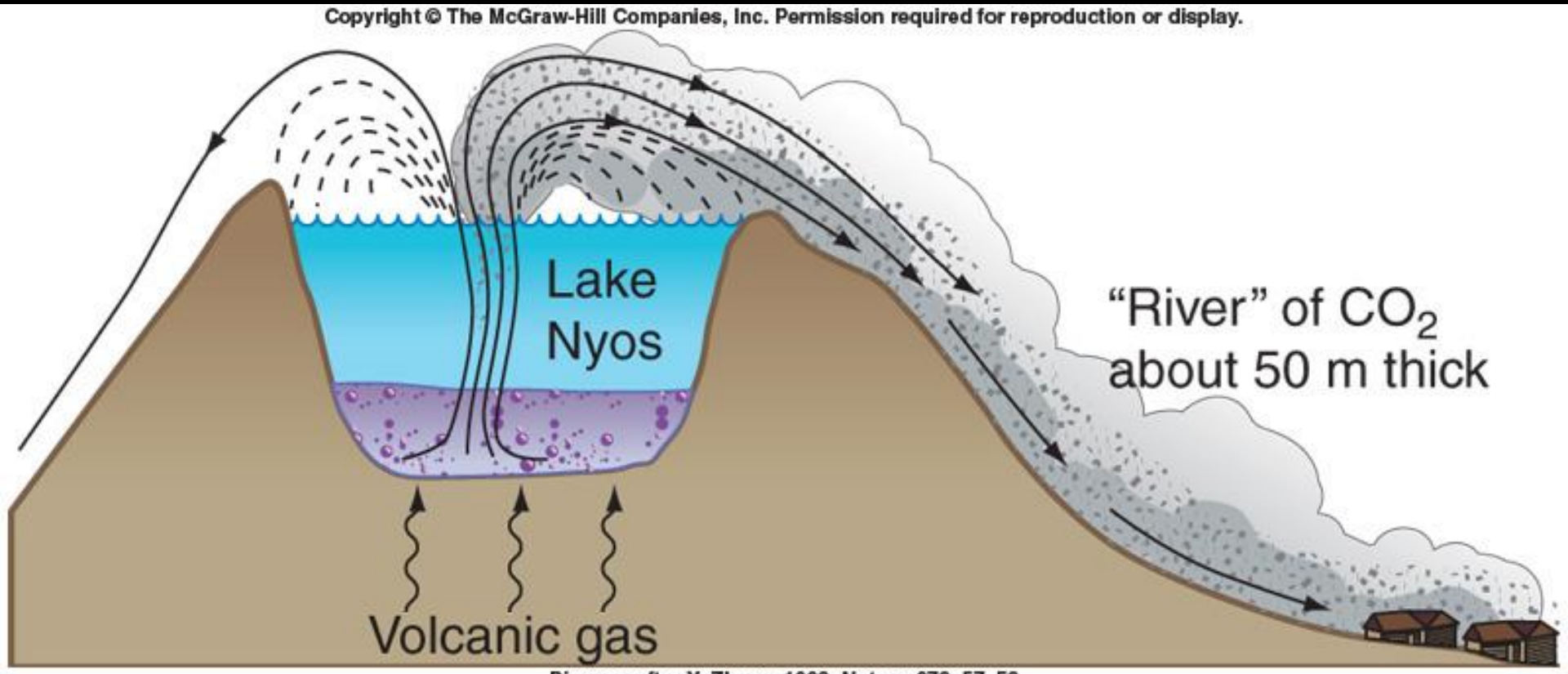


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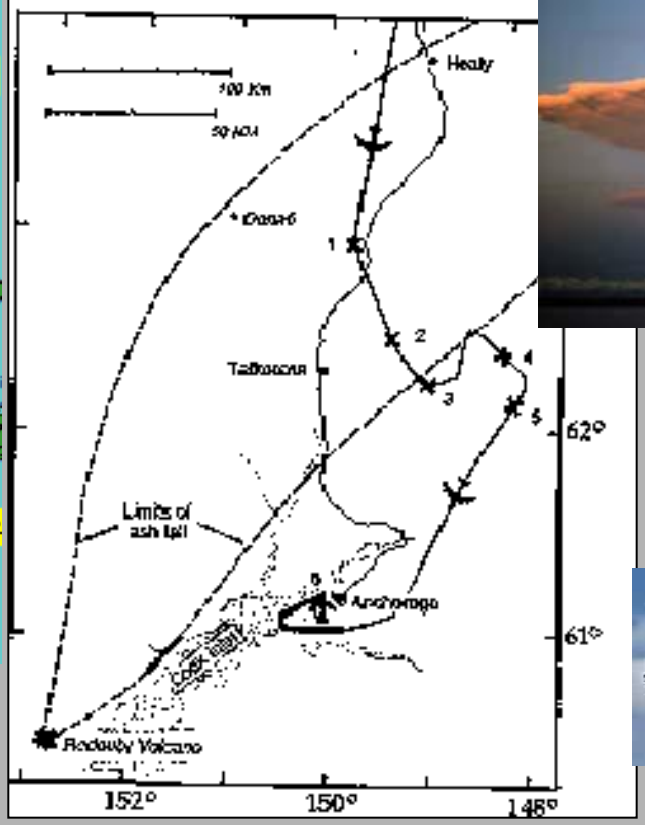
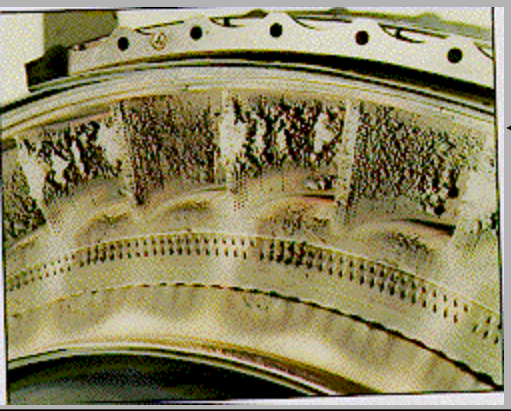
Diagram after Y. Zhang, 1996, *Nature*, 379, 57–59

THE CASE OF LAKE NYOS, CAMEROON – 1986; 1,700 DEATHS BY ASPHYXIATION

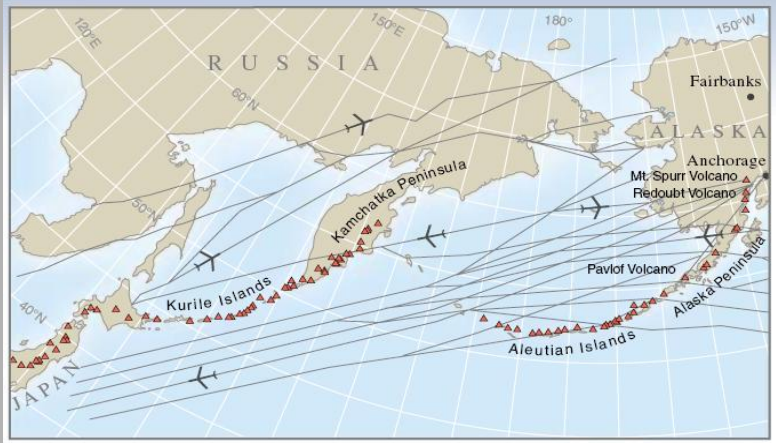
VOLCANIC ASH CLOUD FROM 1992 ERUPTION OF MT. SPURR, ALASKA – DISRUPTED NORTH AMERICAN AIR TRAFFIC



REDOUBT VOLCANO AND KLM 747



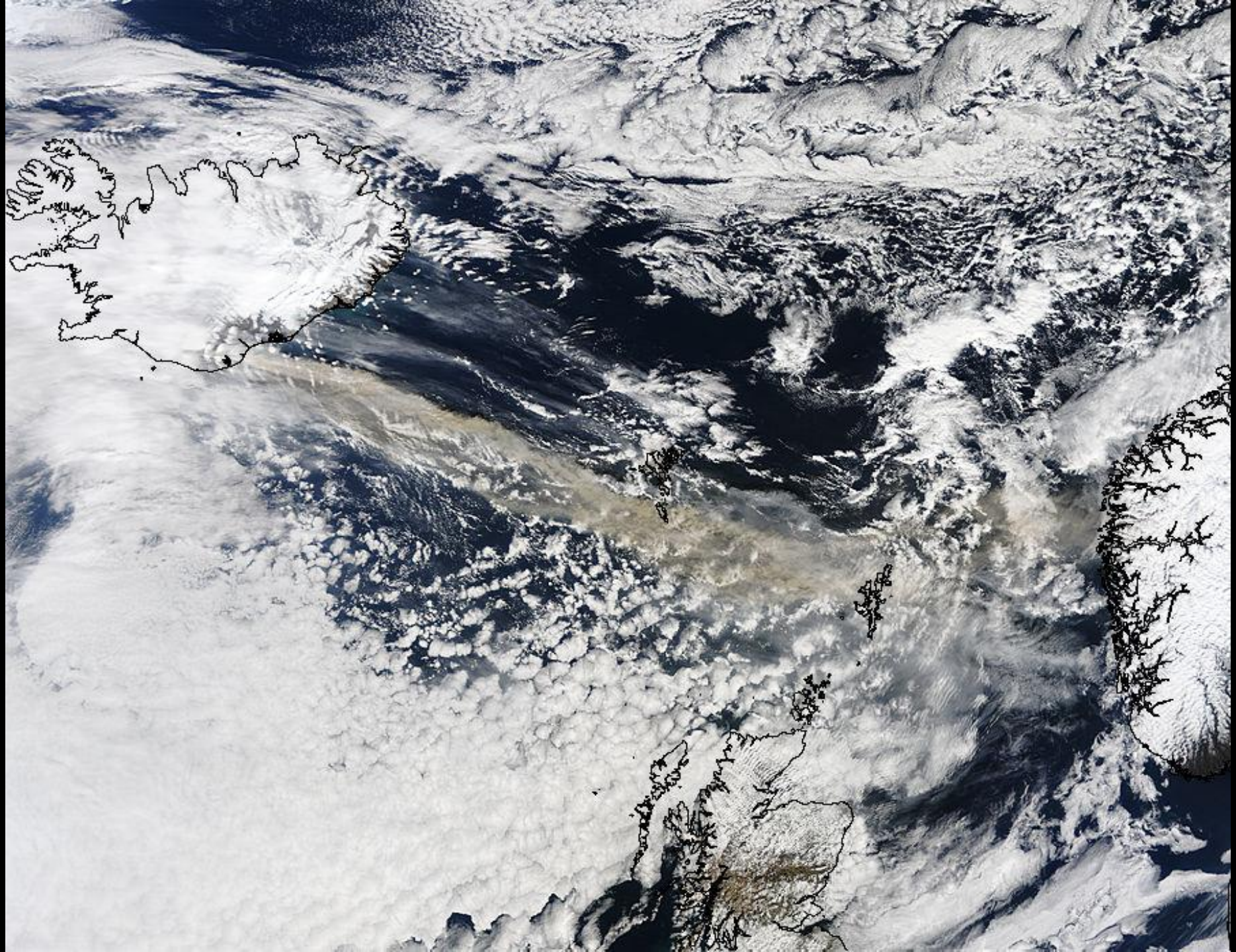
BA 747 ENGINE AFTER FLYING THROUGH ASH CLOUD OVER INDONESIA

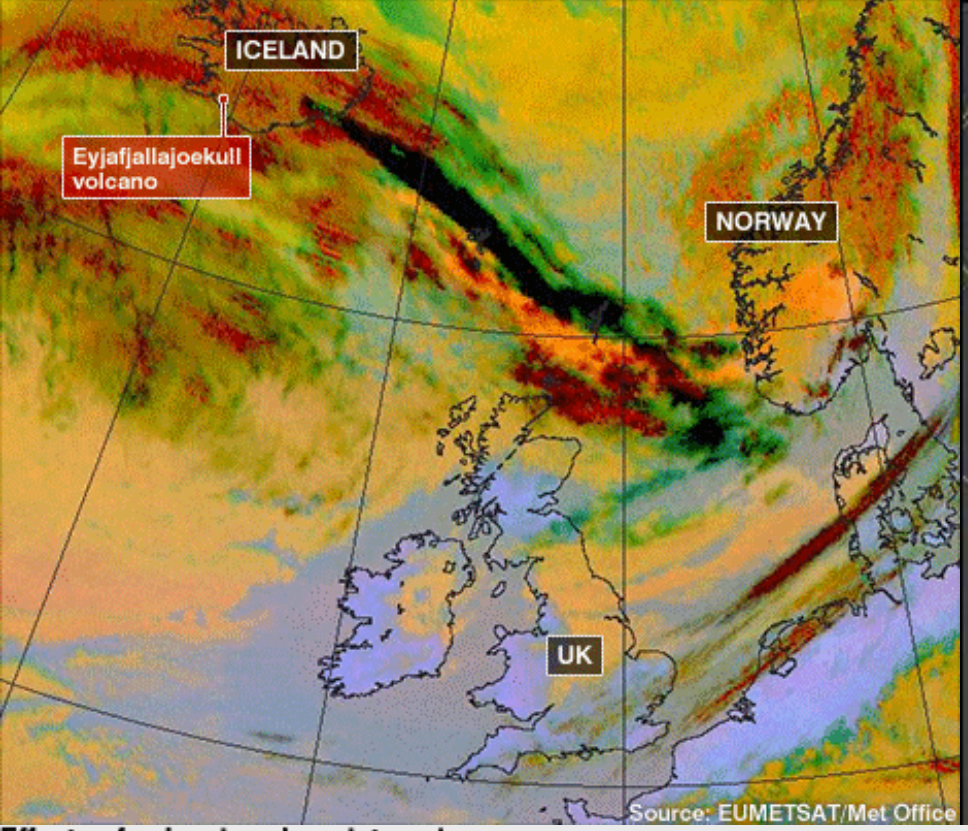


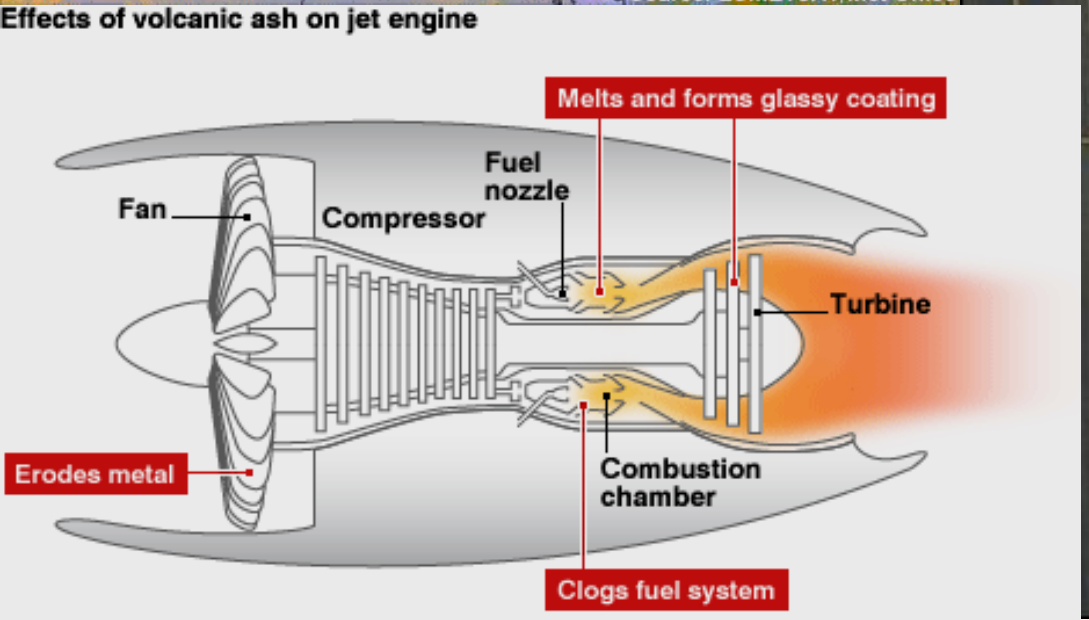
North Pacific and Russian Far East air routes (gray lines) pass over or near more than a hundred potentially active volcanoes (red triangles). Aircraft flying along these routes, some of the busiest in the world, carry more than 10,000 passengers and millions of dollars of cargo each day to and from Asia, North America, and Europe. In the North Pacific region, several explosive eruptions occur every year. Ash from these eruptions, which has caused jet engines to fail, is usually blown to the east and northeast, directly across the air routes.

VOLCANIC HAZARDS 5 : VOLCANIC ASH AND HAZARDS TO AVIATION

EYJAFJALLAJOKULL GLACIER ERUPTION, ICELAND, APRIL 2010

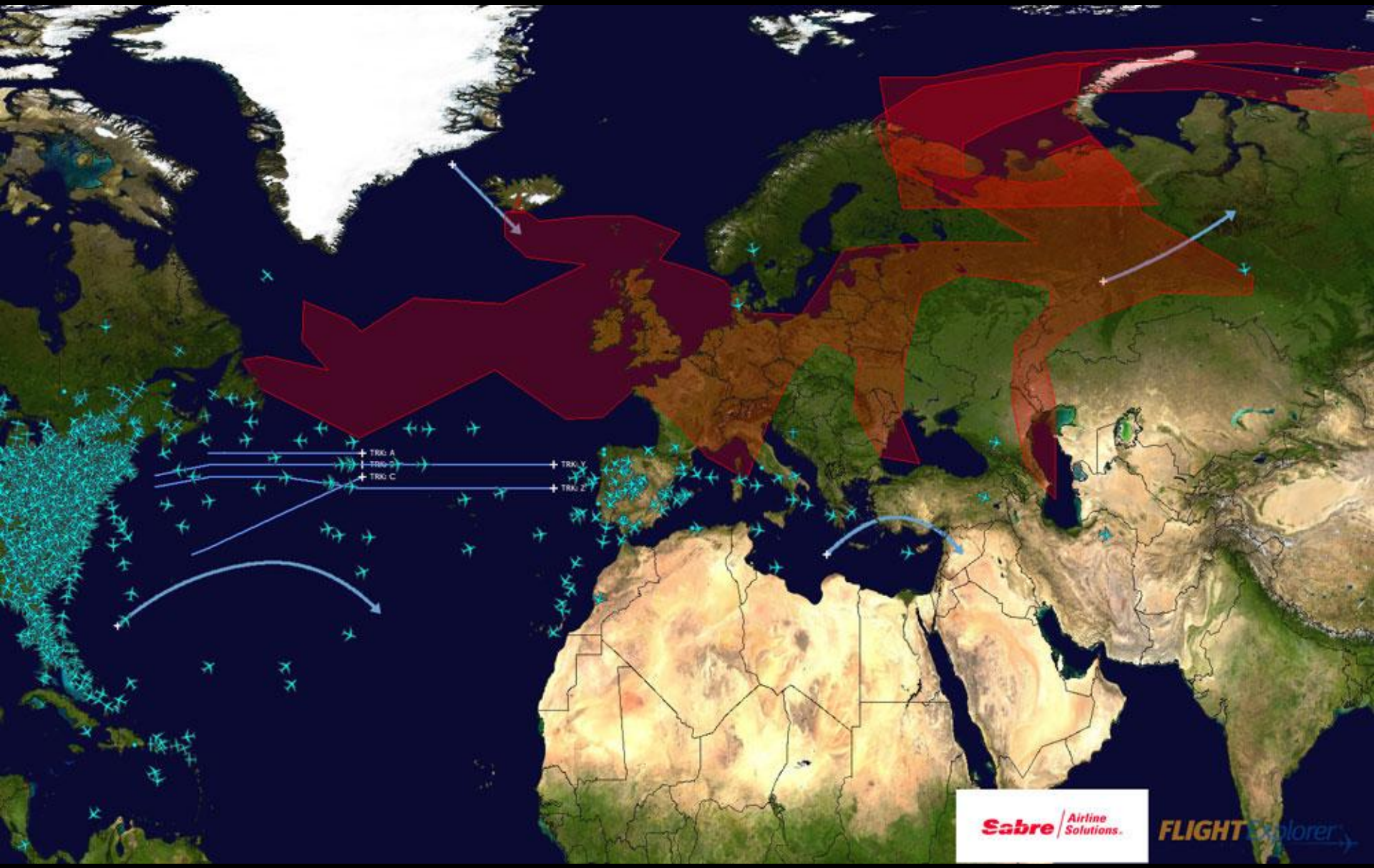


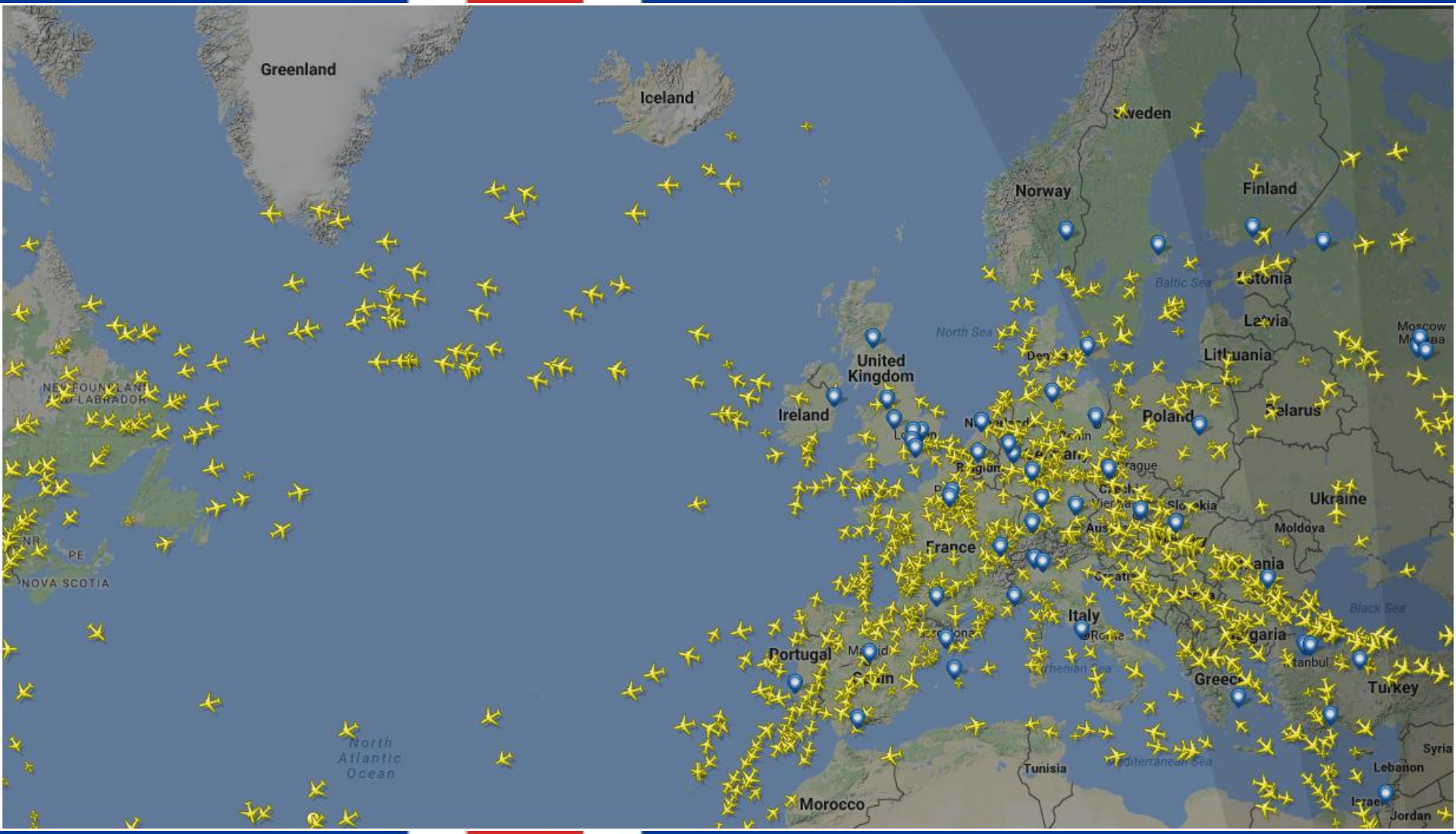

ICELAND
Eyjafjallajoekull volcano
NORWAY
UK
Source: EUMETSAT/Met Office


Effects of volcanic ash on jet engine
Melts and forms glassy coating
Fuel nozzle
Fan
Compressor
Turbine
Erodes metal
Combustion chamber
Clogs fuel system

AFP

AIR TRAFFIC IN THE NORTHERN HEMISPHERE APRIL 19, 2010





AIR TRAFFIC IN NW EUROPE - FEBRUARY 16, 2017

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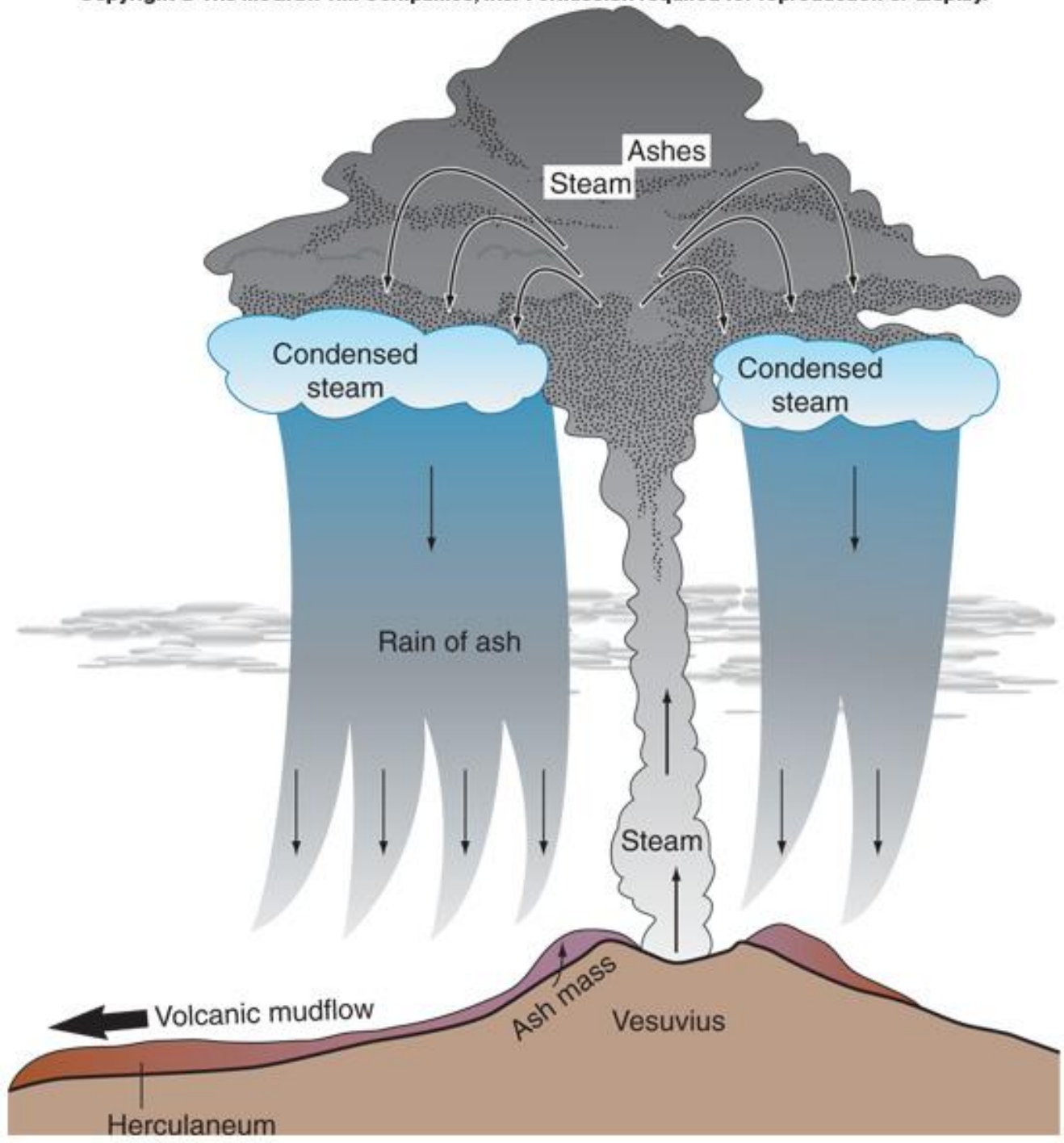
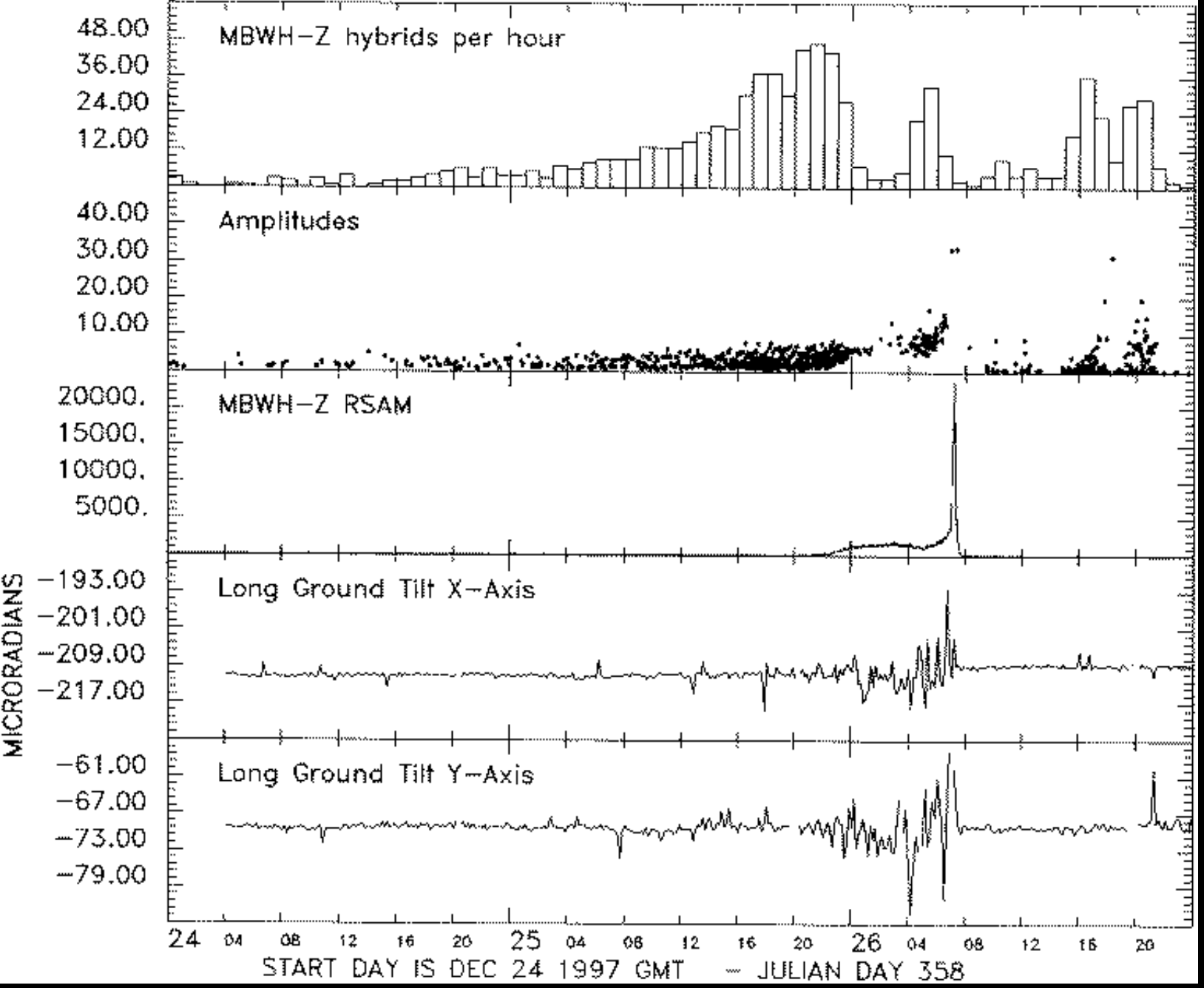


ASHFALL HAZARD

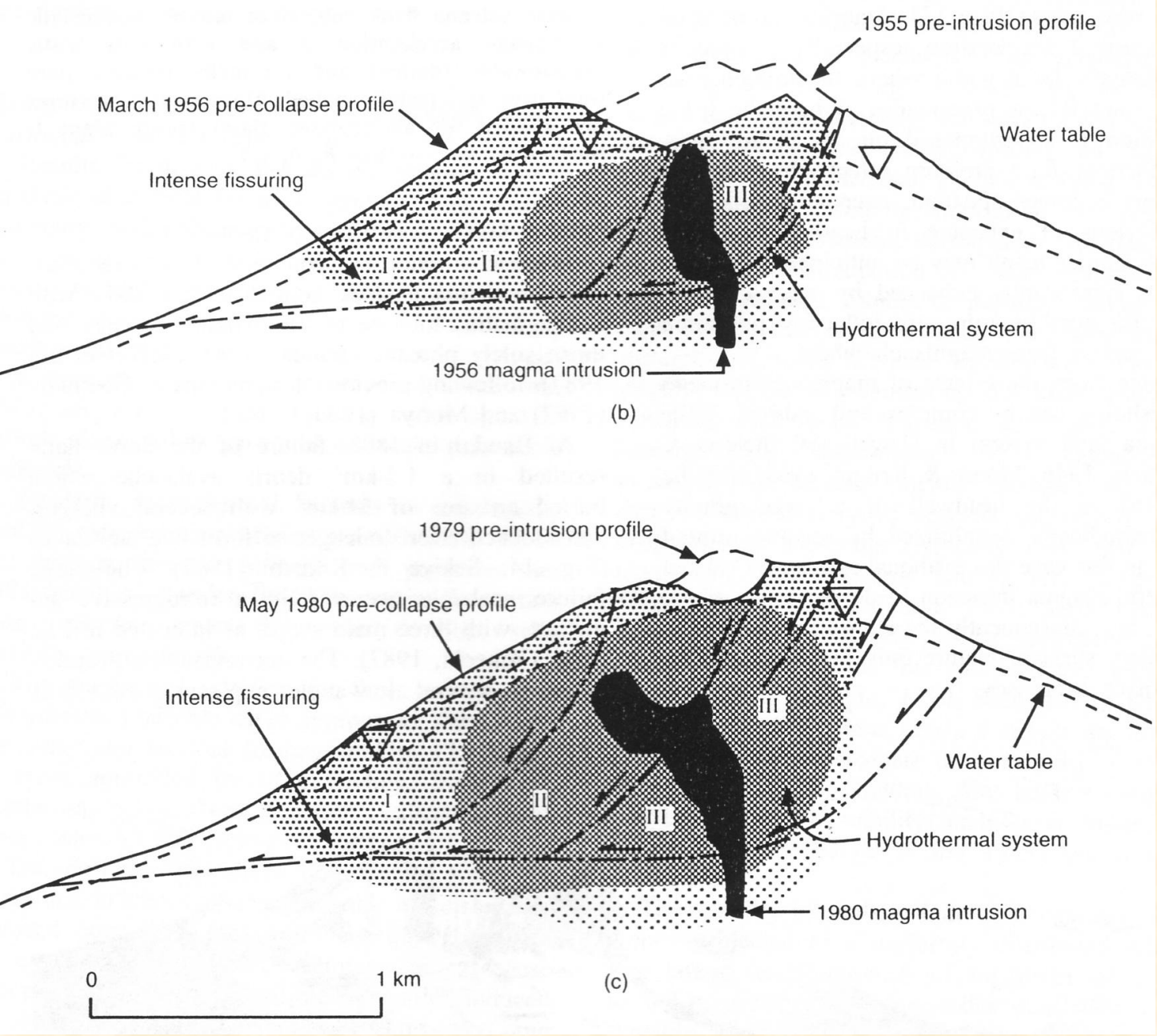
Chaiten, Chile, June 2008

VOLCANIC HAZARDS 6 – MAJOR STRUCTURAL INSTABILITY

MONTSERRAT VOLCANO, WEST INDIES – BOXING DAY COLLAPSE 1997



SESIMIC AND DEFORMATION PRECURSORS TO COLLAPSE – EVACUATION

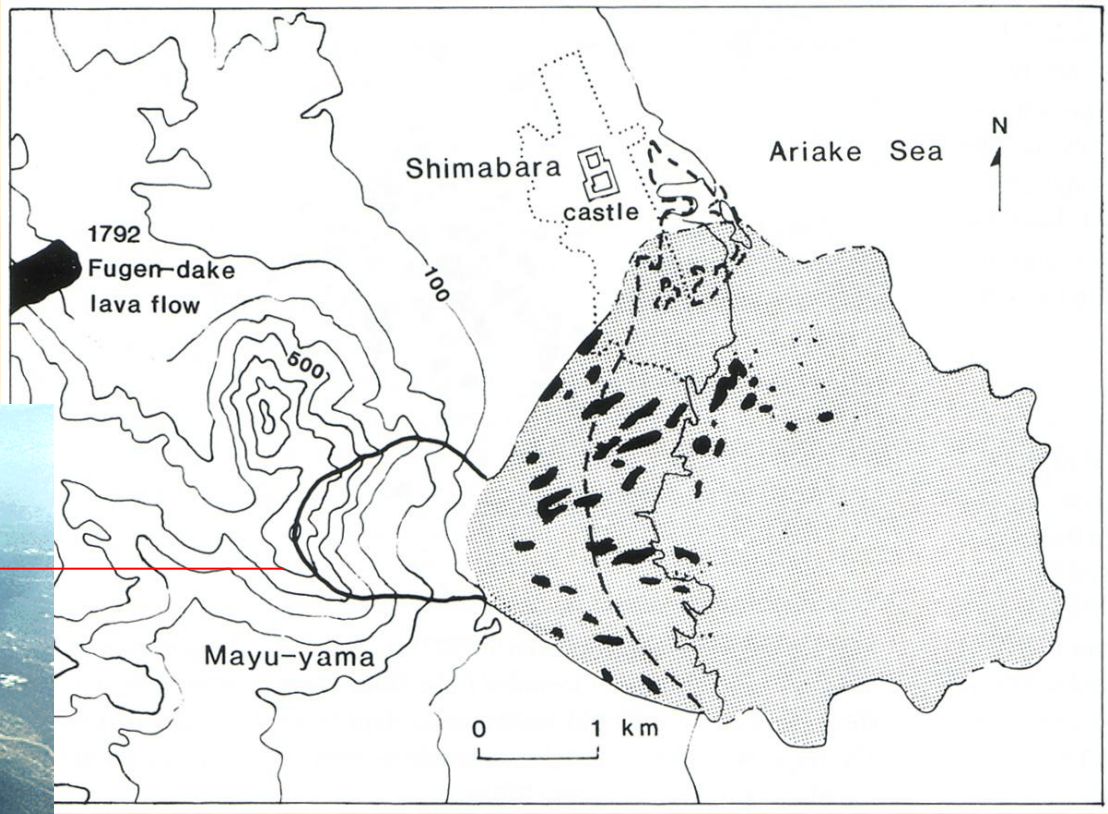


BEZYMIANNY

MT. ST HELENS

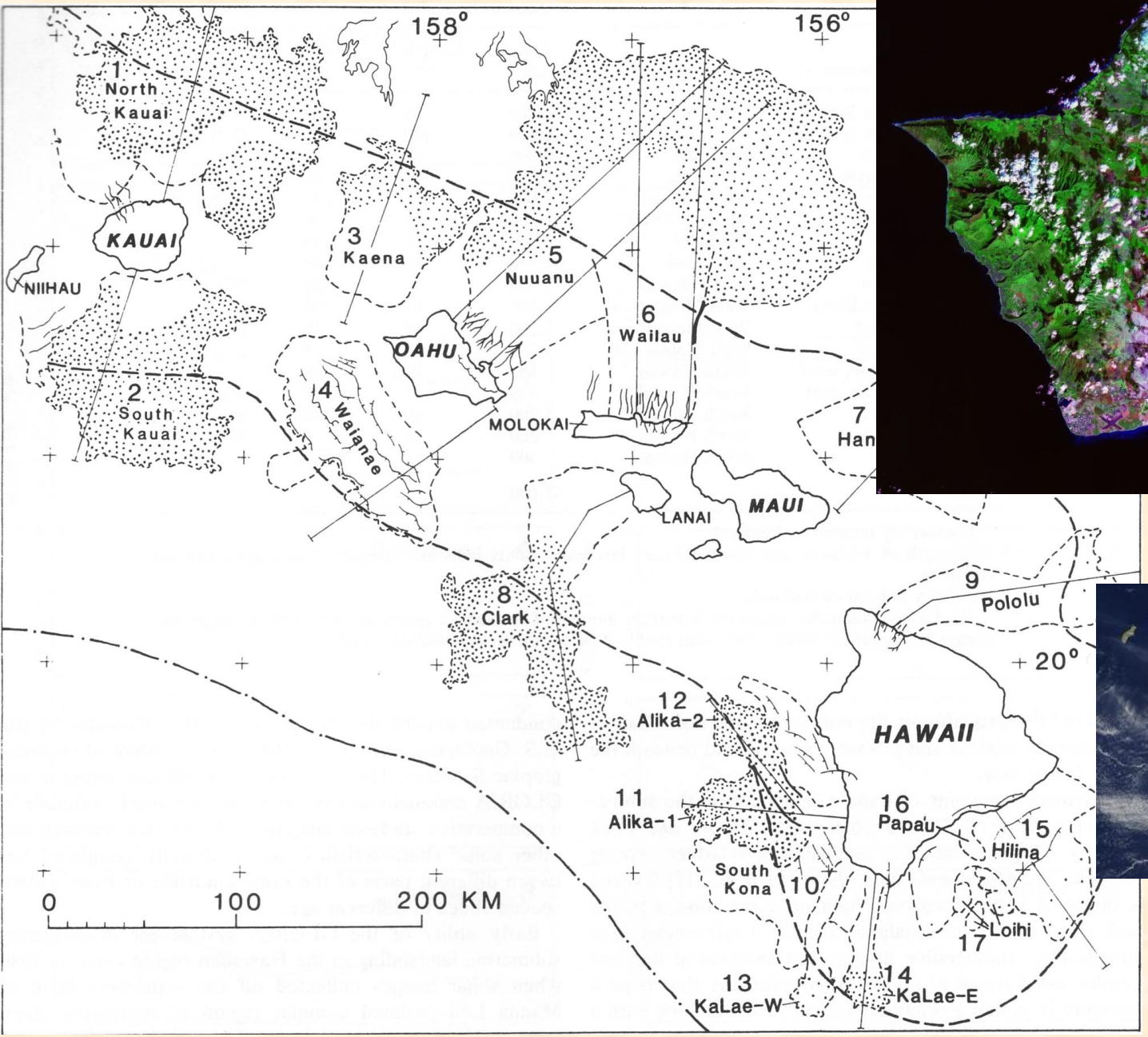
LARGE-SCALE DEFORMATION AND FLANK STEEPENING CAUSED BY MAGMA INTRUSION

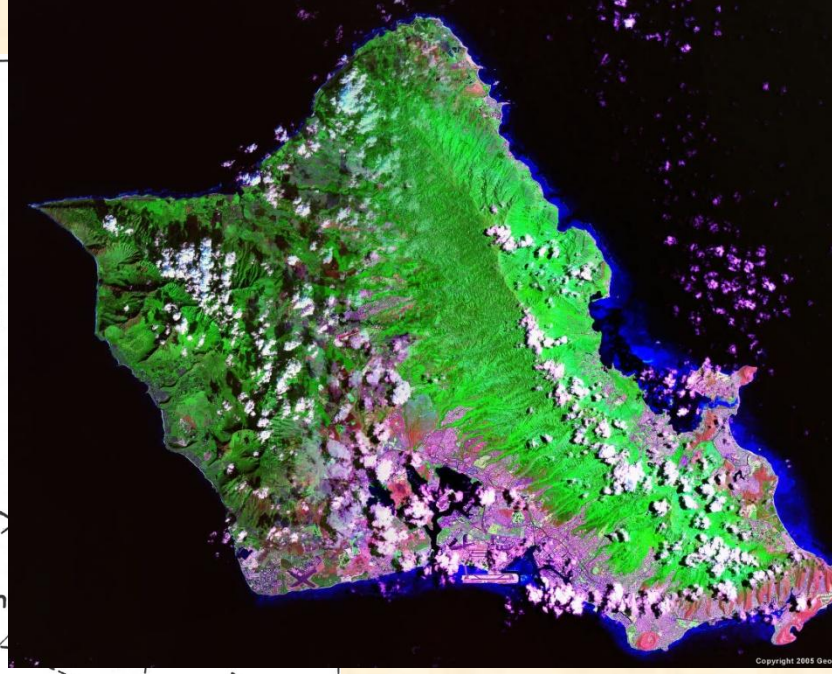
MT. UNZEN VOLCANIC COMPLEX, JAPAN



1792 COLLAPSE OF MAYUYAMA

1. Collapse during eruption of Fugen-dake
2. Volume ~ 10 km^3
3. Tsunami in Ariake Sea killed ca. 15,000 people





PRODIGIOUS SUBMARINE LANDSLIDES ON THE HAWAIIAN RIDGE

TABLE 1. Hawaiian Submarine Slides

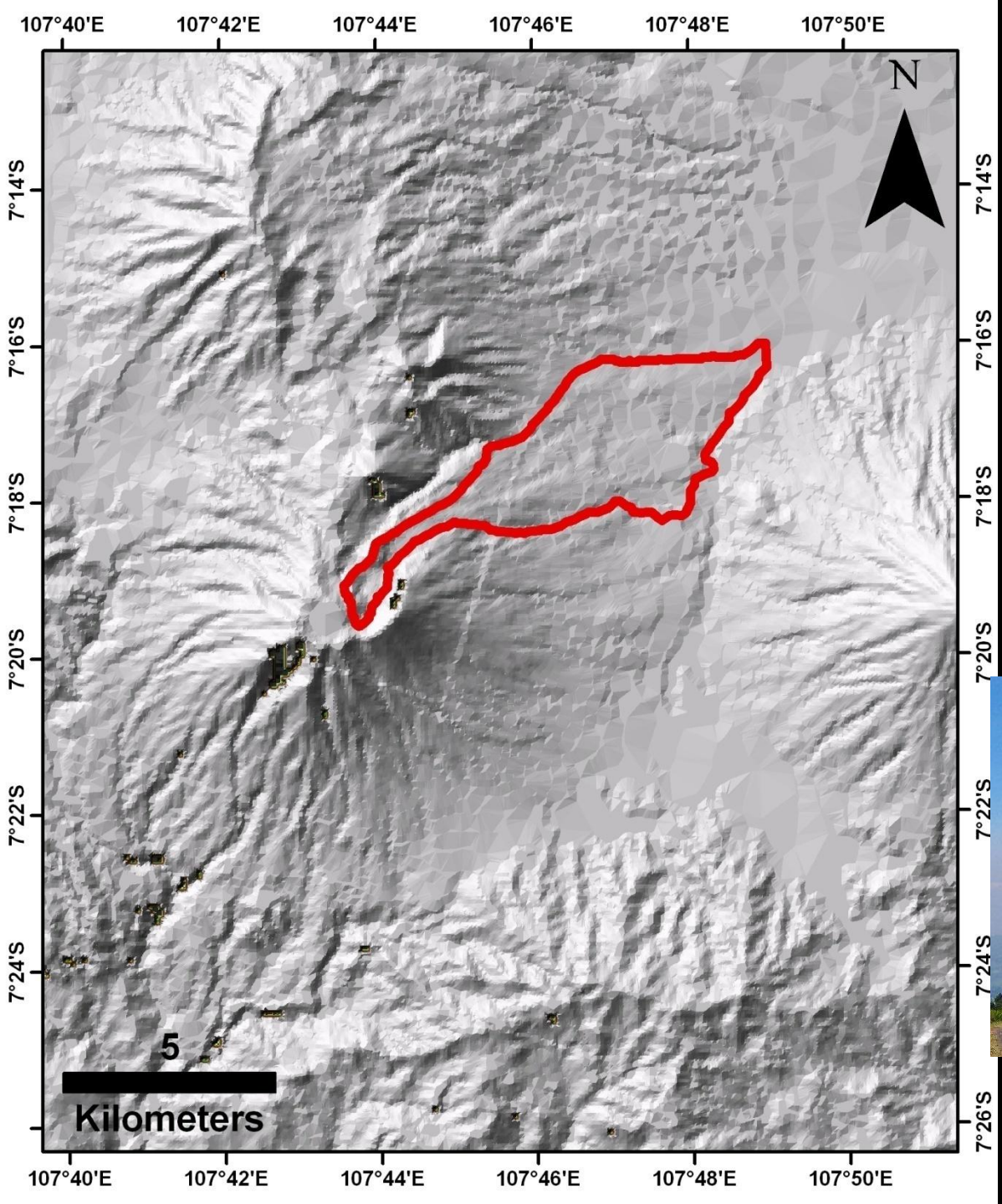
No.	Name	Location	Area, km^2	Length,[a] km	Width,[b] km	Type[c]
1	North Kauai	North Kauai	14,000	140	100	D (0.6–0.9)
2	South Kauai	South Kauai	6,800	100	50	D (0.6–1.2)
3	Kaena	NE Oahu	3,900	80	45	D
4	Waianae	SW Oahu	6,100	50	80	S (1.0)
5	Nuuanu	NE Oahu	23,000	235	35	D (0.8–1)
6	Wailau	North Molokai	13,000?	<195	40	D (0.7)
7	Hana	NE Maui	4,900	85	110	S
8	Clark	SW Lanai	6,100	150	30	D (0.5–1)
9	Pololu	North Hawaii	3,500	130	20	D
10	South Kona	West Mauna Loa	4,600	80	80	S
11	Alika-1	West Mauna Loa	2,300	88	15	D (0.9–1)
12	Alika-2	West Mauna Loa	1,700	95	15	D (2–5)
13	Ka Lae, west	South Hawaii	850	85	10	D
14	Ka Lae, east	South Hawaii	950	75	10	D (2)
15	Hilina	South Hawaii	5,200	40	100	S
16	Papa'u	South Hawaii	200	20	6	SF
17	Loihi	South Hawaii	500	15	10–30	L
Total			97,600			

Located by number in Figure 2.

[a]Length of Waianae and South Kilauea landslides omits indistinct irregular topography beyond steep toe.

[b]Width at head of landslide.

[c]D, Debris avalanche; (number) is average number of hummocks appearing in GLORIA images per square kilometer; S, Slump; SF, sand rubble flow; L, three unclassifeid landslides.

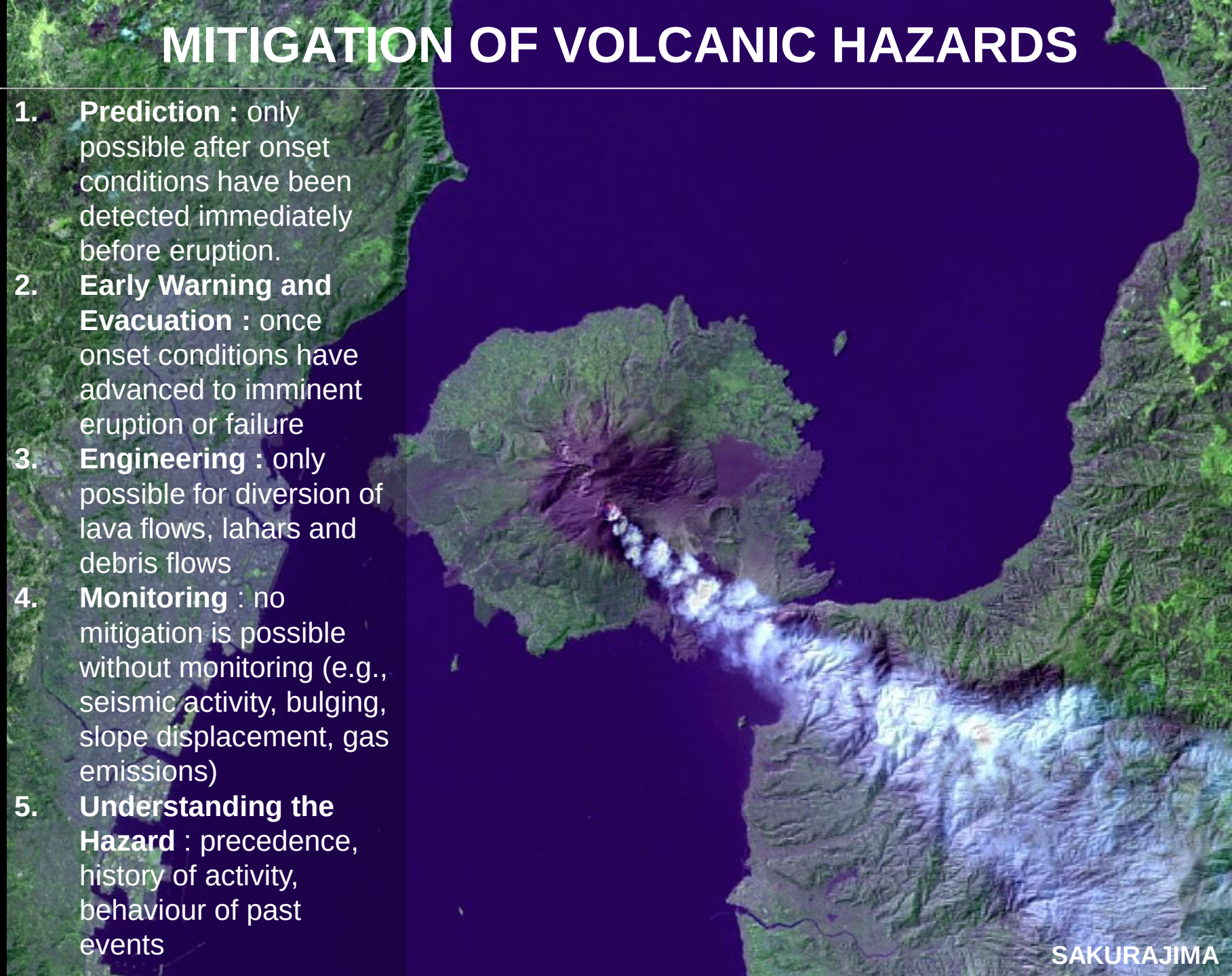


FLANK COLLAPSE OF PAPANDAYAN, JAVA, INDONESIA IN 1772

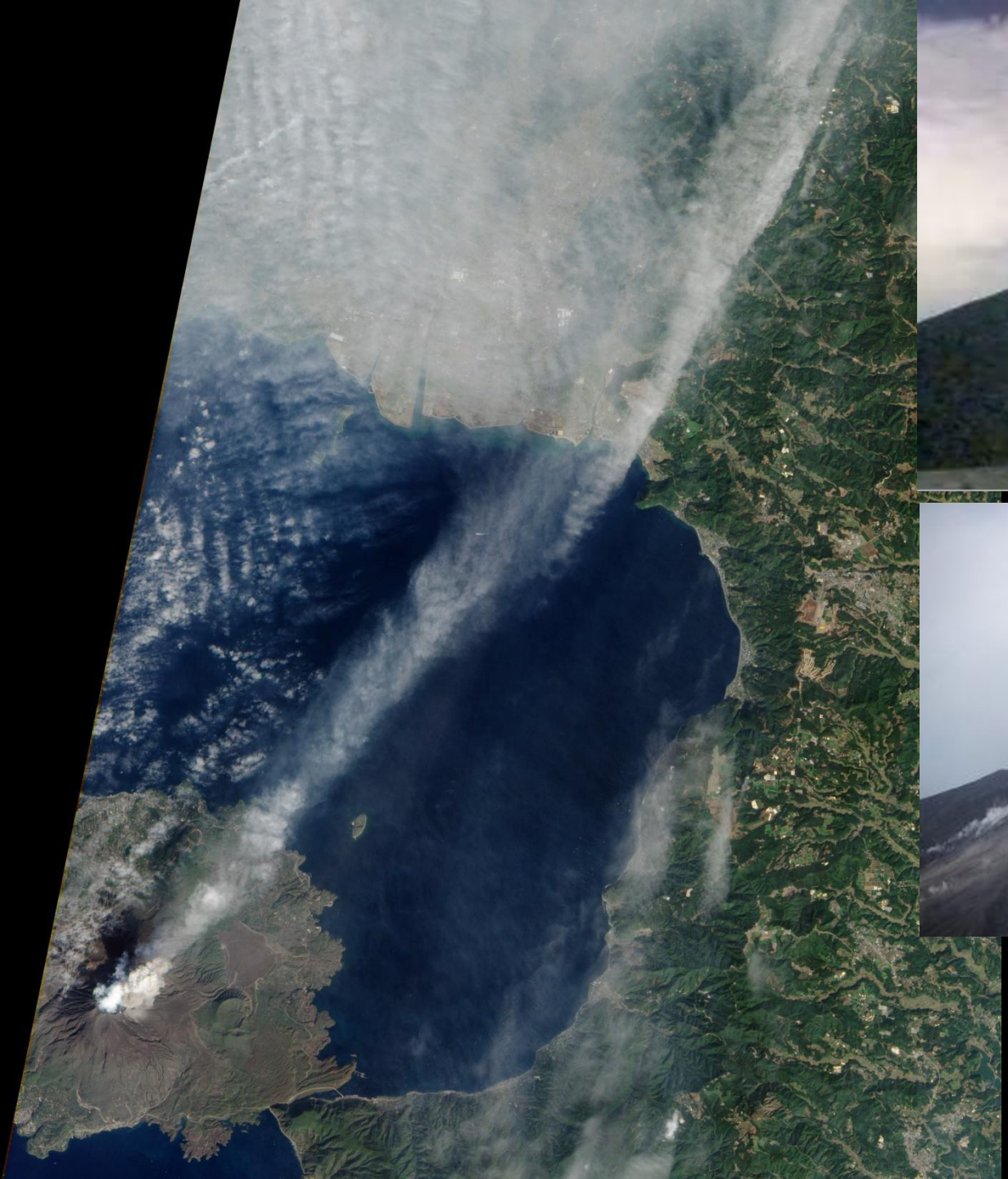
- 40 villages buried
- 2,957 deaths

MITIGATION OF VOLCANIC HAZARDS

1. **Prediction :** only possible after onset conditions have been detected immediately before eruption.
2. **Early Warning and Evacuation :** once onset conditions have advanced to imminent eruption or failure
3. **Engineering :** only possible for diversion of lava flows, lahars and debris flows
4. **Monitoring** : no mitigation is possible without monitoring (e.g., seismic activity, bulging, slope displacement, gas emissions)
5. **Understanding the Hazard** : precedence, history of activity, behaviour of past events



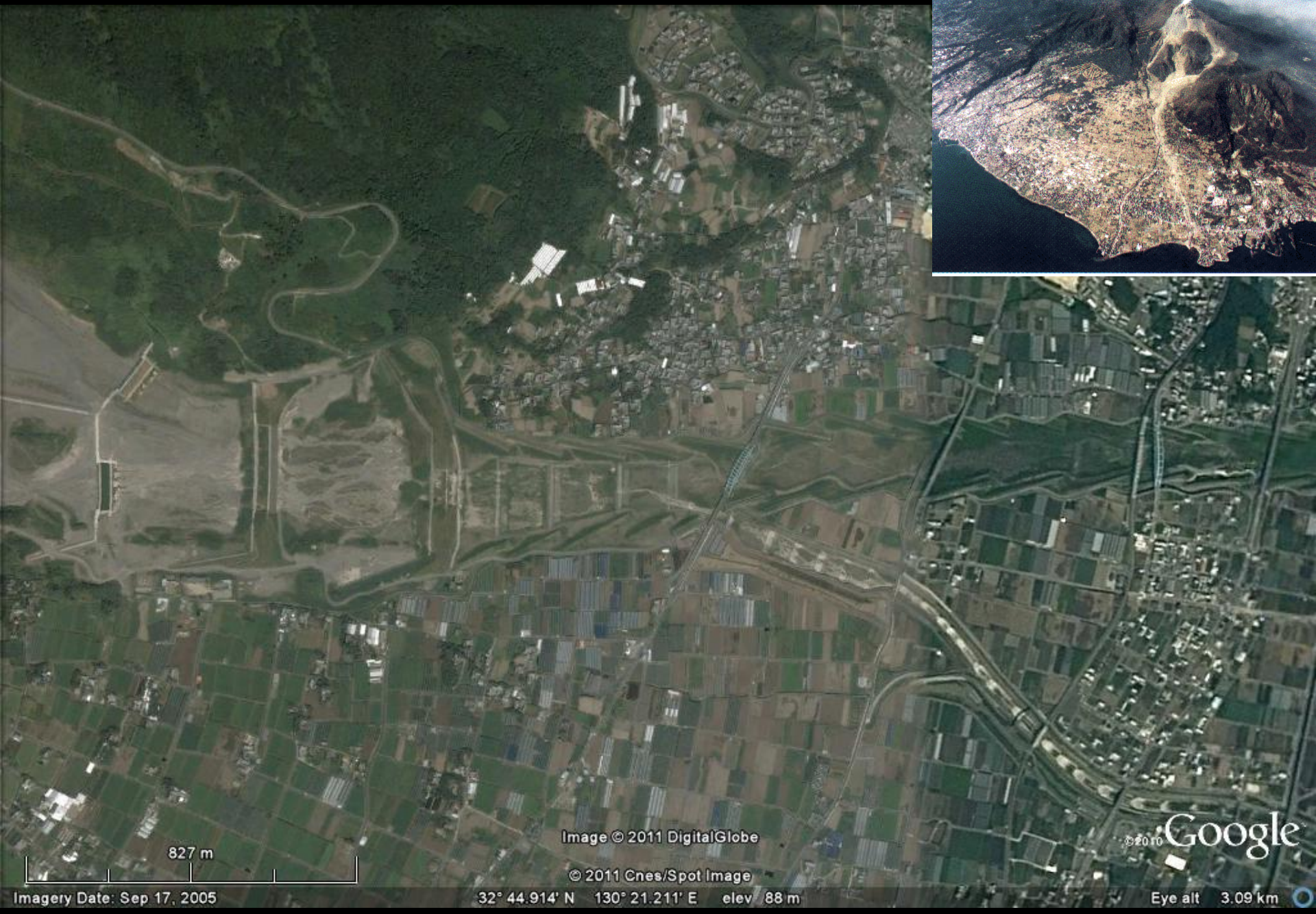
N
© 2011 Cnes/Spot Image
Image © 2011 DigitalGlobe
Image © 2011 TerraMetrics
Data © 2011 MIRC/JHA
3.94 km
©2010 Google
Imagery Dates: Feb 23, 2005 - Apr 13, 2005
31° 35.176' N 130° 40.074' E elev 666 m
Eye alt 13.57 km

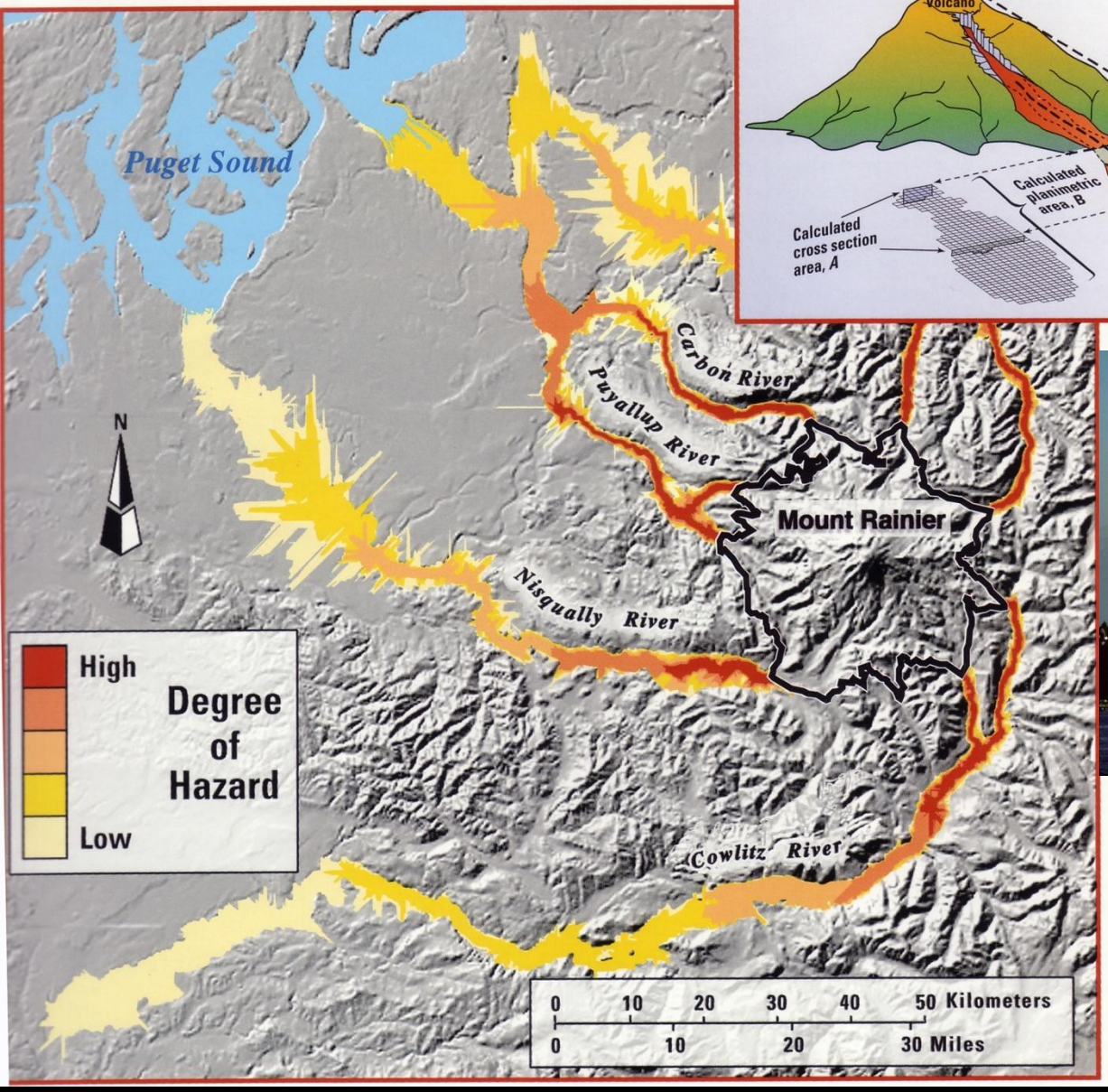


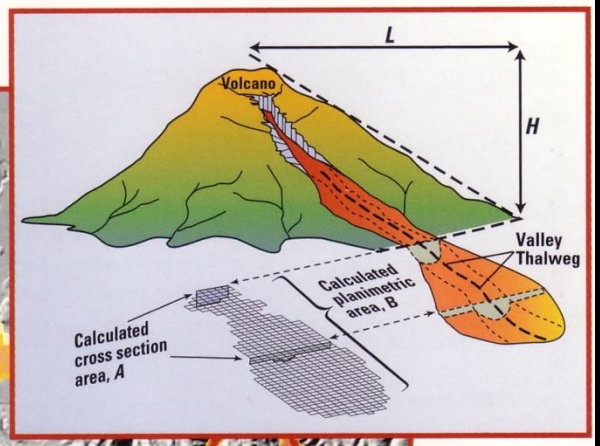
2010 ERUPTIONS OF SAKURAJIMA

Kagoshima city and erupting Sakurajima, Japan [March 2009]

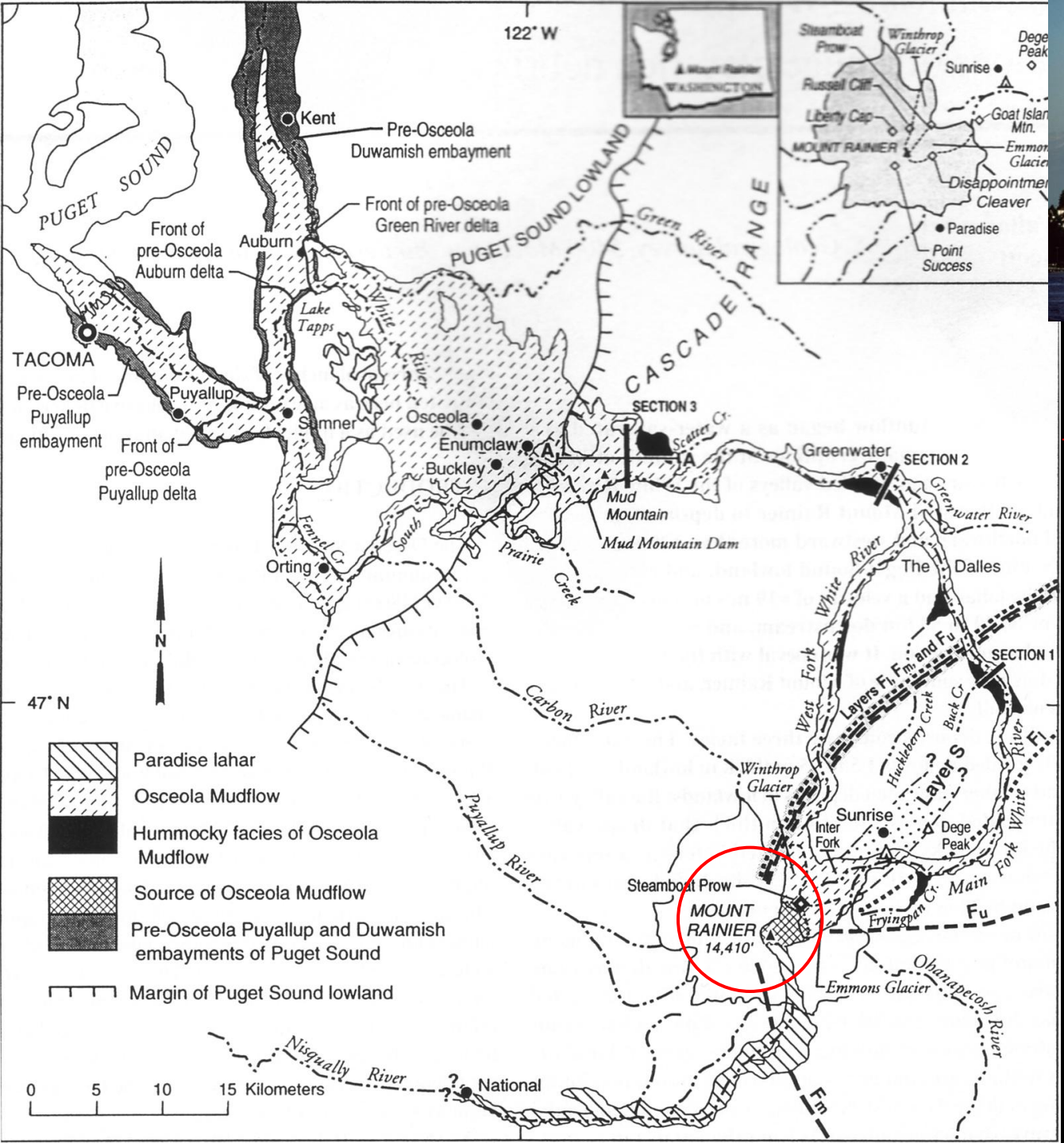
DEFENCES FOR LAHARS AND PYROCLASTIC FLOWS AT MT. UNZEN, JAPAN







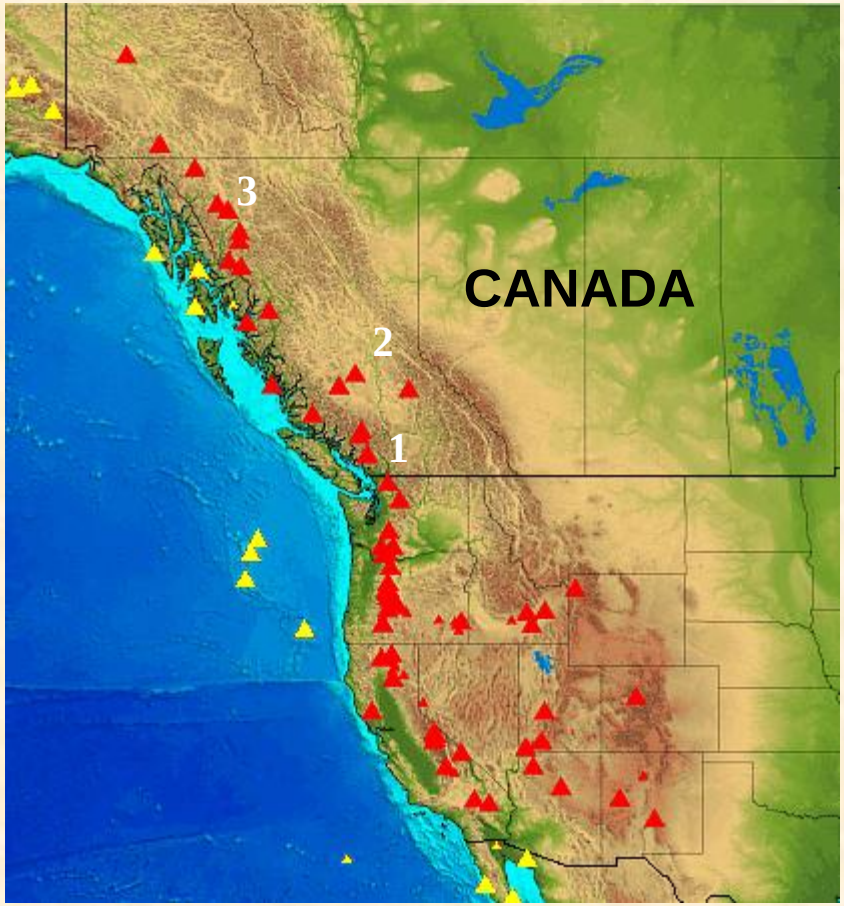
LAHAR HAZARD MAPPING FOR MOUNT RAINIER, WASHINGTON STATE



OSCEOLA MUDFLOW

1. VOLUME ~ 3.8 km^3
2. 5,600 y BP
3. TRANSFORMED FROM DEBRIS AVALANCHE TO MUDFLOW WITHIN 2 km OF ITS SOURCE
4. RUN-OUT 120 km

VOLCANISM AND VOLCANOES IN CANADA



3 MAJOR BELTS

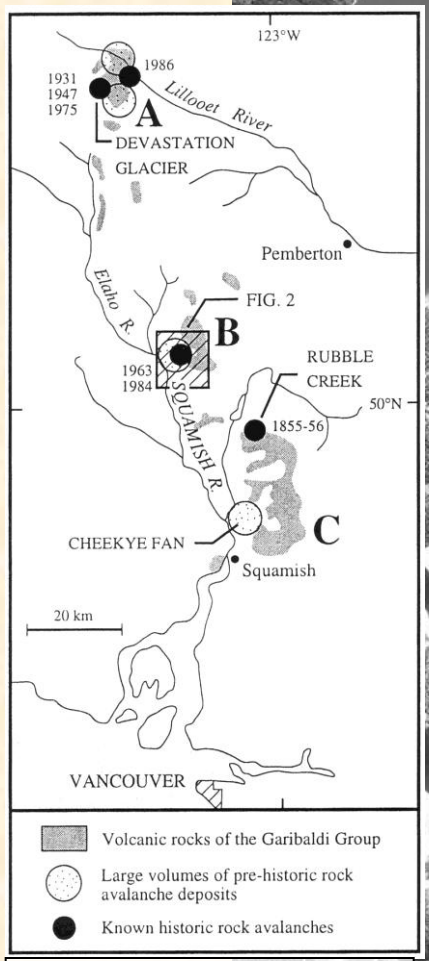
1. GARIBALDI VOLCANIC BELT
2. ANAHIM - WELLS GRAY VOLCANIC BELT
3. STIKINE VOLCANIC BELT

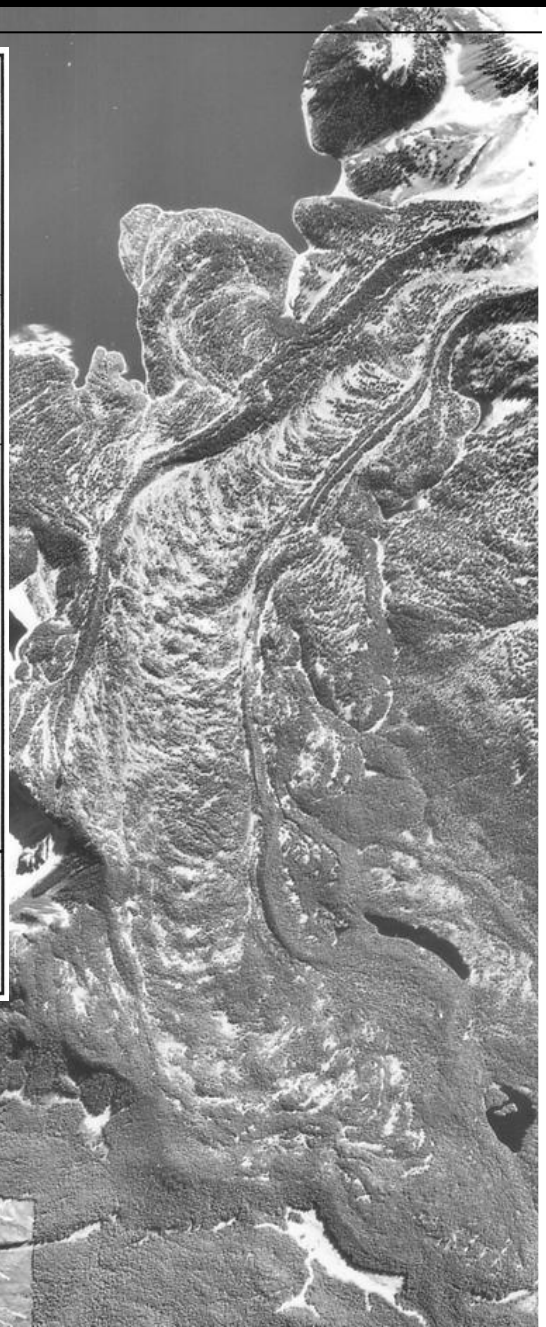
•MOST RECENT LARGE SCALE ERUPTION (MOUNT MEAGER – PLINTH PEAK ca. 650 BC, GARIBALDI VOLCANIC BELT)

•MOST RECENT ERUPTIVE EPISODE (AIYANSH LAVA FLOW ca. 1750 AD, STIKINE VOLCANIC BELT)

ISSUES : 1) GEOTHERMAL ENERGY ? 2) LANDSLIDE HAZARDS 3) TOURISM AND RECREATION (HOT SPRINGS DEVELOPMENT)

GARIBALDI VOLCANIC BELT





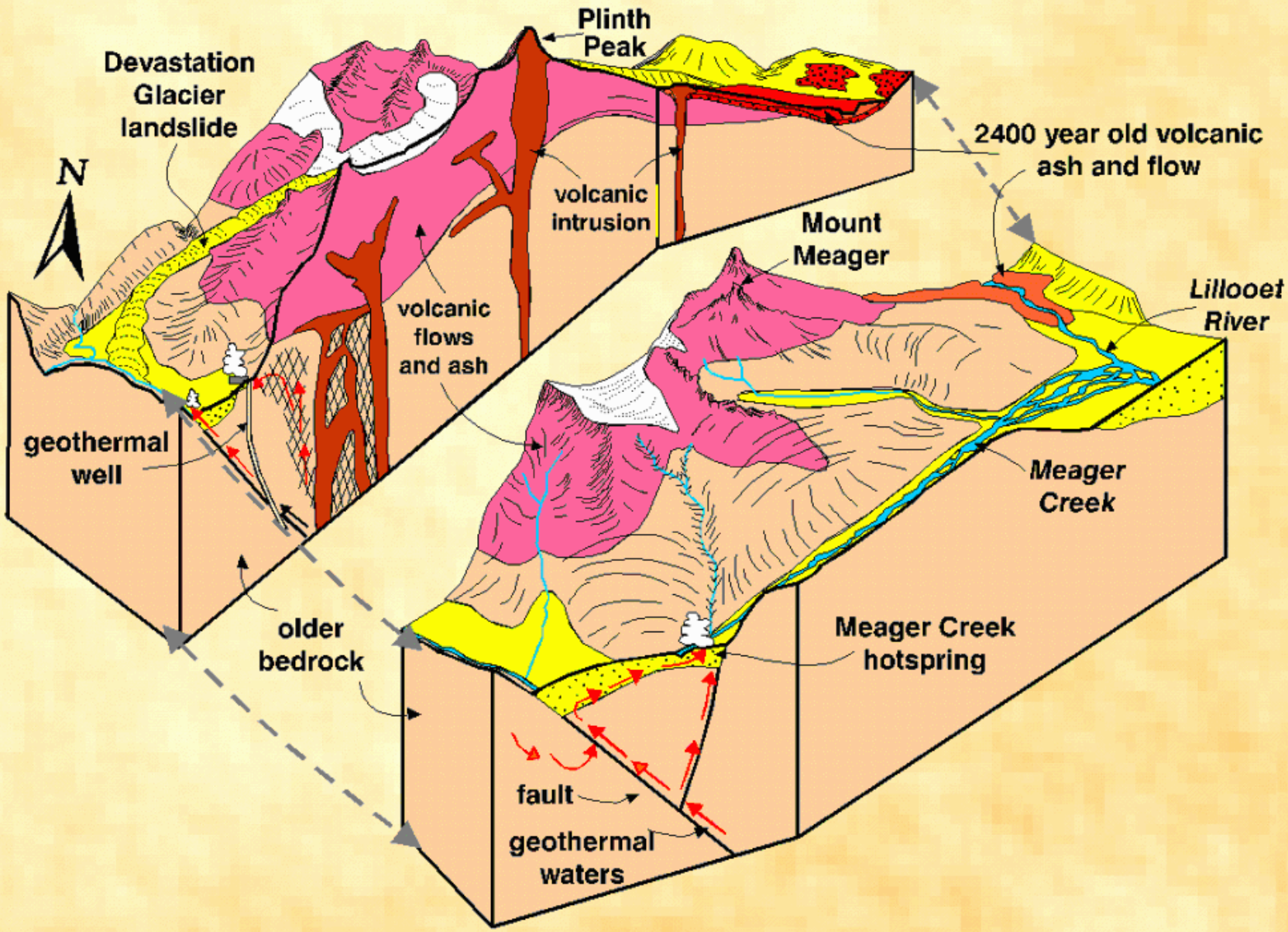
A – Mount Meager Volcanic Complex

B – Mount Cayley Volcanic Complex

C – Mt. Garibaldi Volcanic Complex

PLINTH PEAK, MOUNT MEAGER VOLCANIC COMPLEX : SOURCE OF 650 B.C EXPLOSIVE ERUPTION THAT SPEWED ASH EASTWARD INTO BRITISH COLUMBIA AND ALBERTA

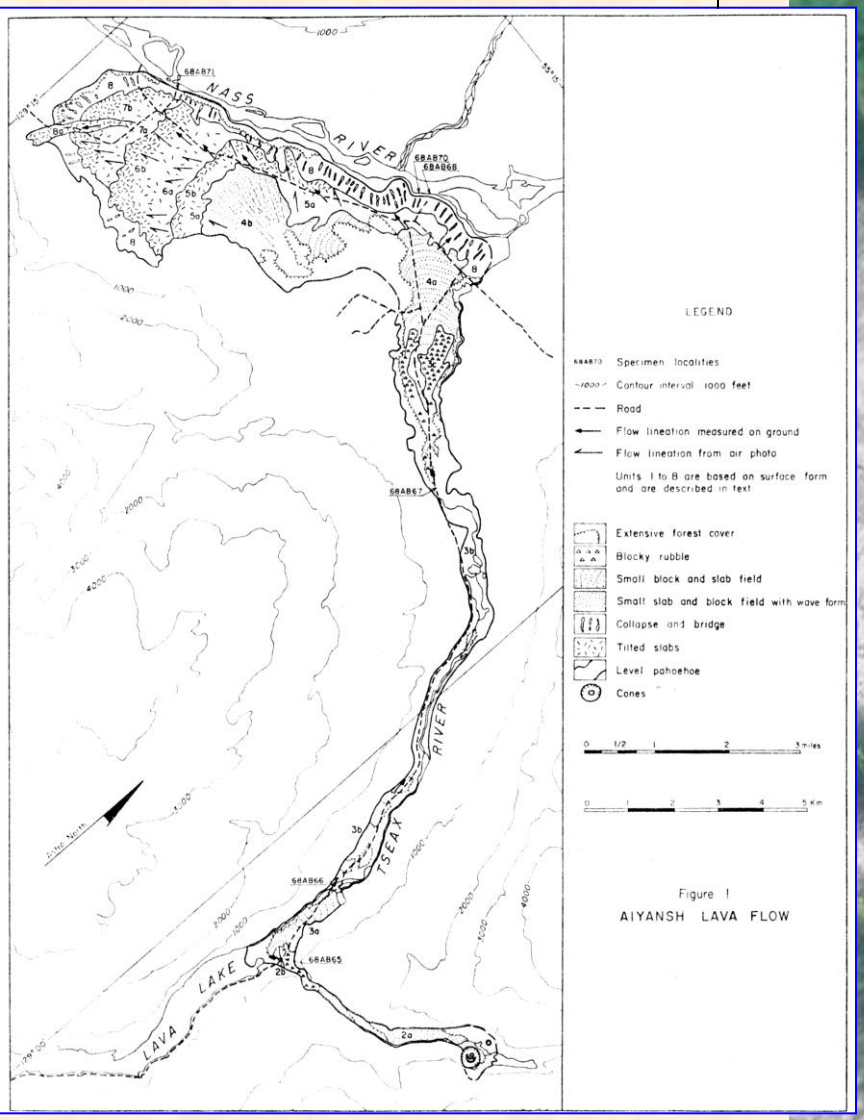
(after Geological Survey of Canada)



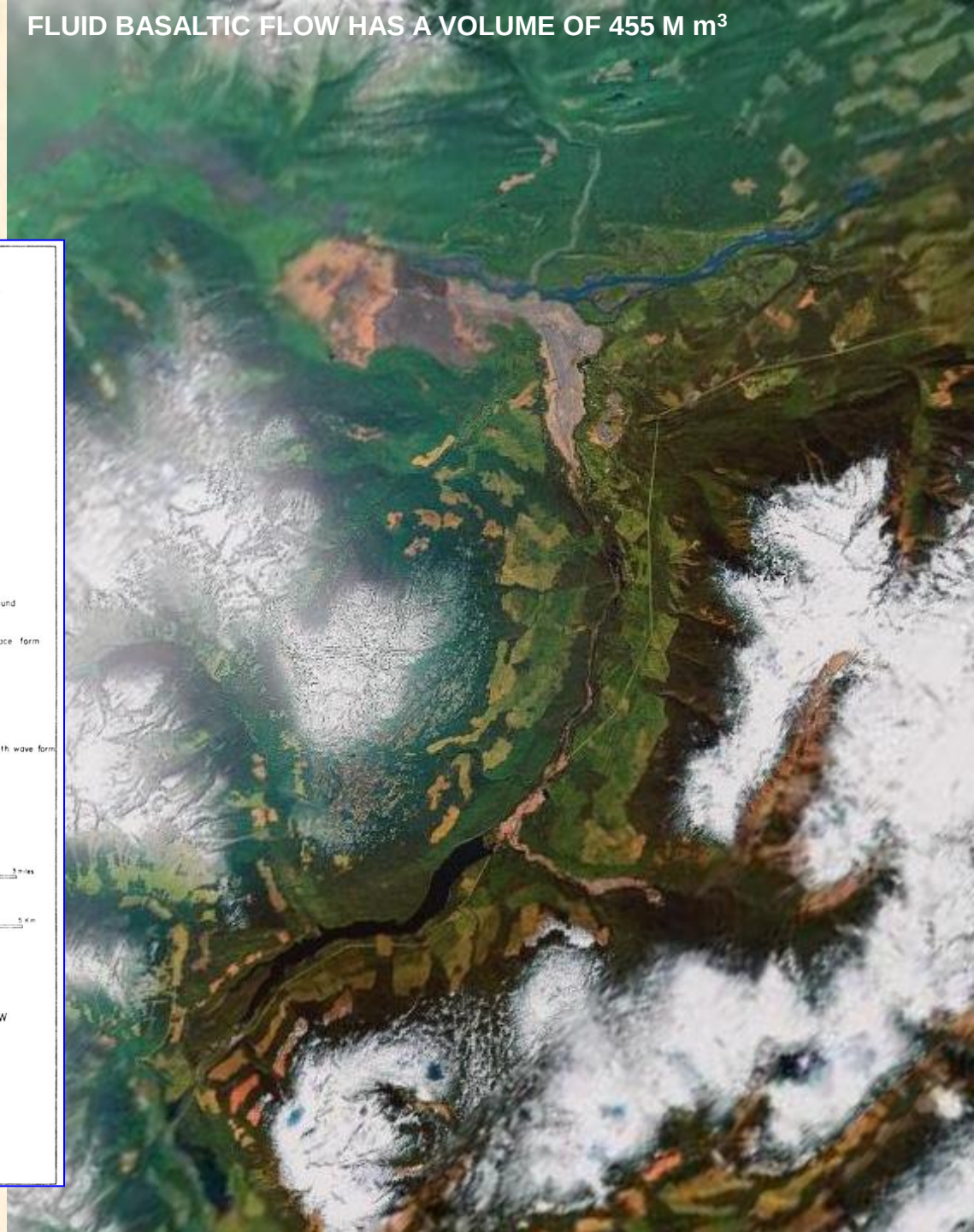
MOUNT MEAGER VOLCANIC COMPLEX, GARIBALDI VOLCANIC BELT, BRITISH COLUMBIA

MOUNT MEAGER ROCK AVALANCHE, AUGUST 6, 2010

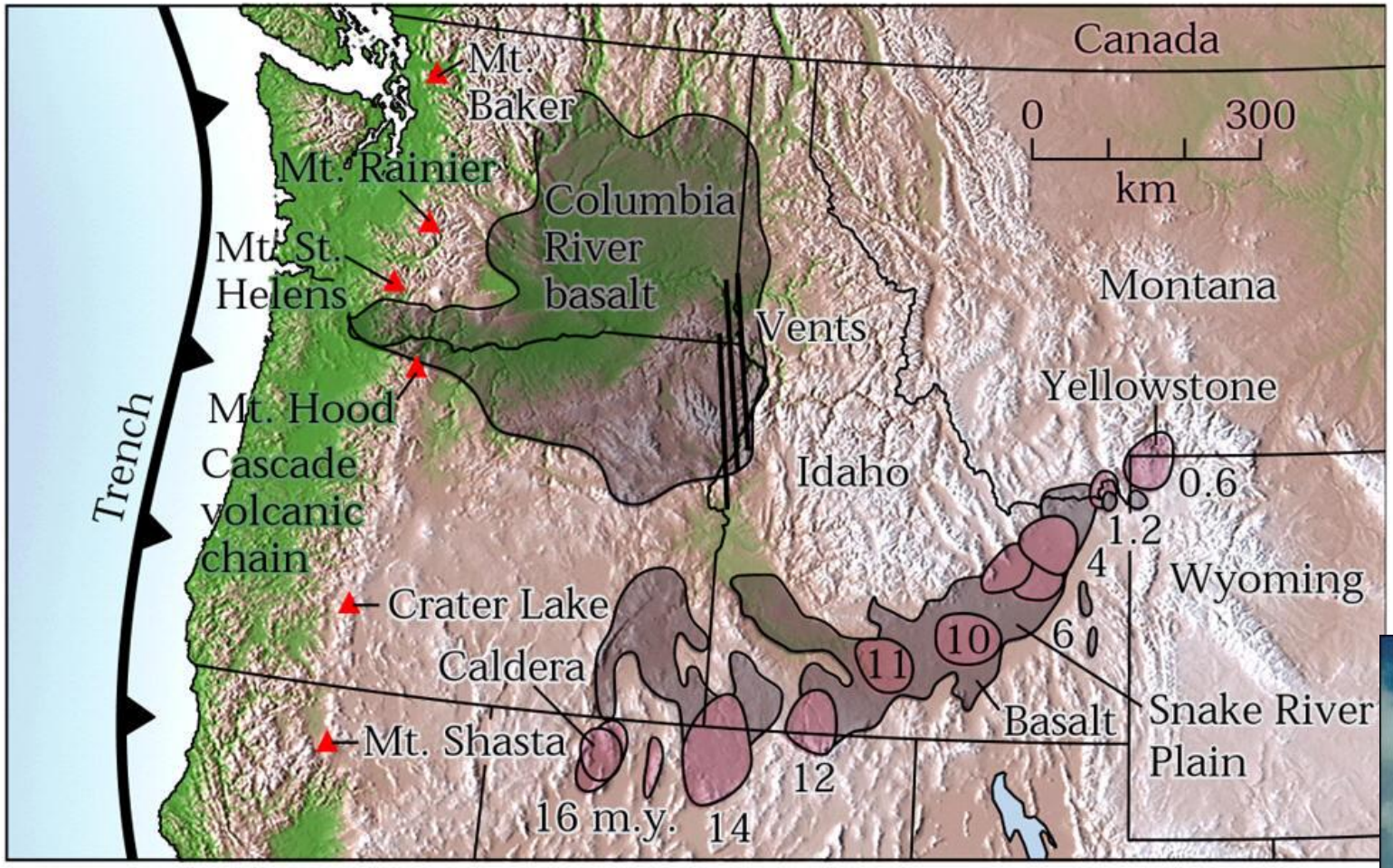
AIYANSH LAVA FLOW – THE MOST RECENT VOLCANIC ERUPTION IN CANADA (ca 1750 A.D.)



(after Sutherland-Brown, 1969)



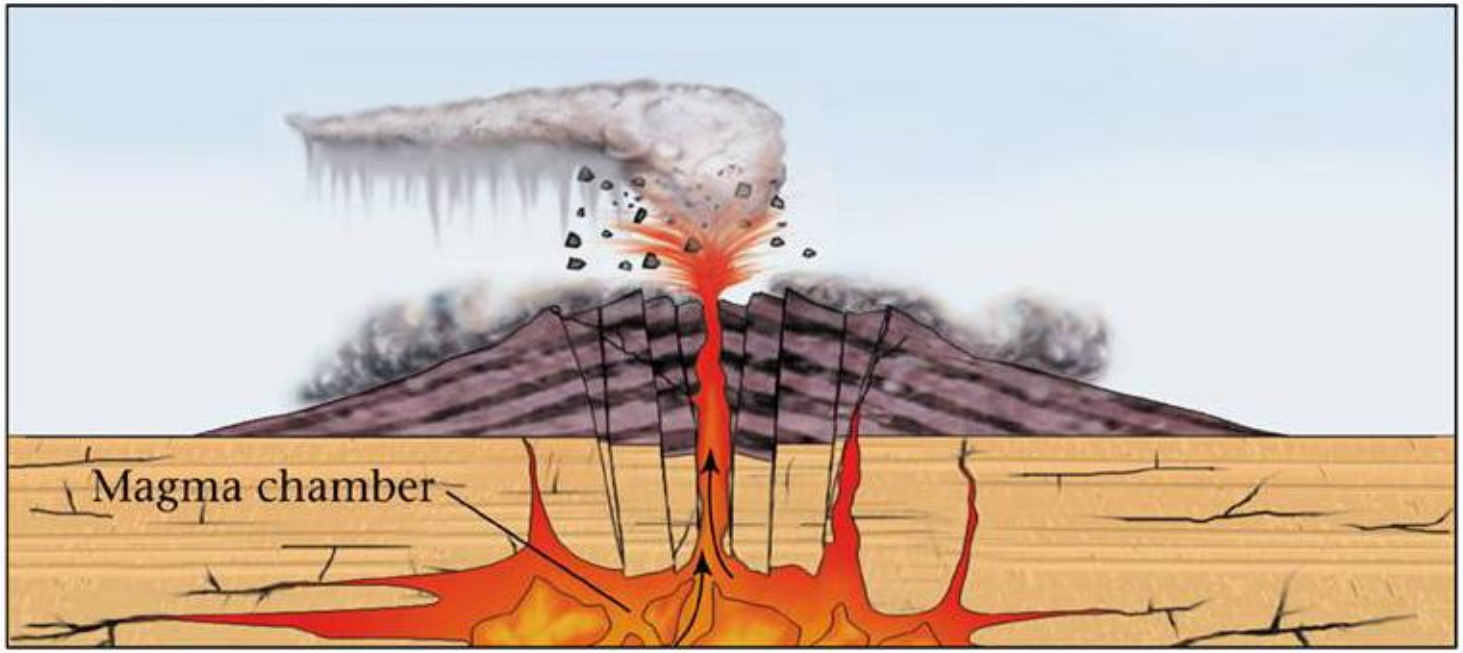
YELLOWSTONE HOTSPOT AND SUPER VOLCANO (?) – POSSIBLE ERUPTION PRECURSORS



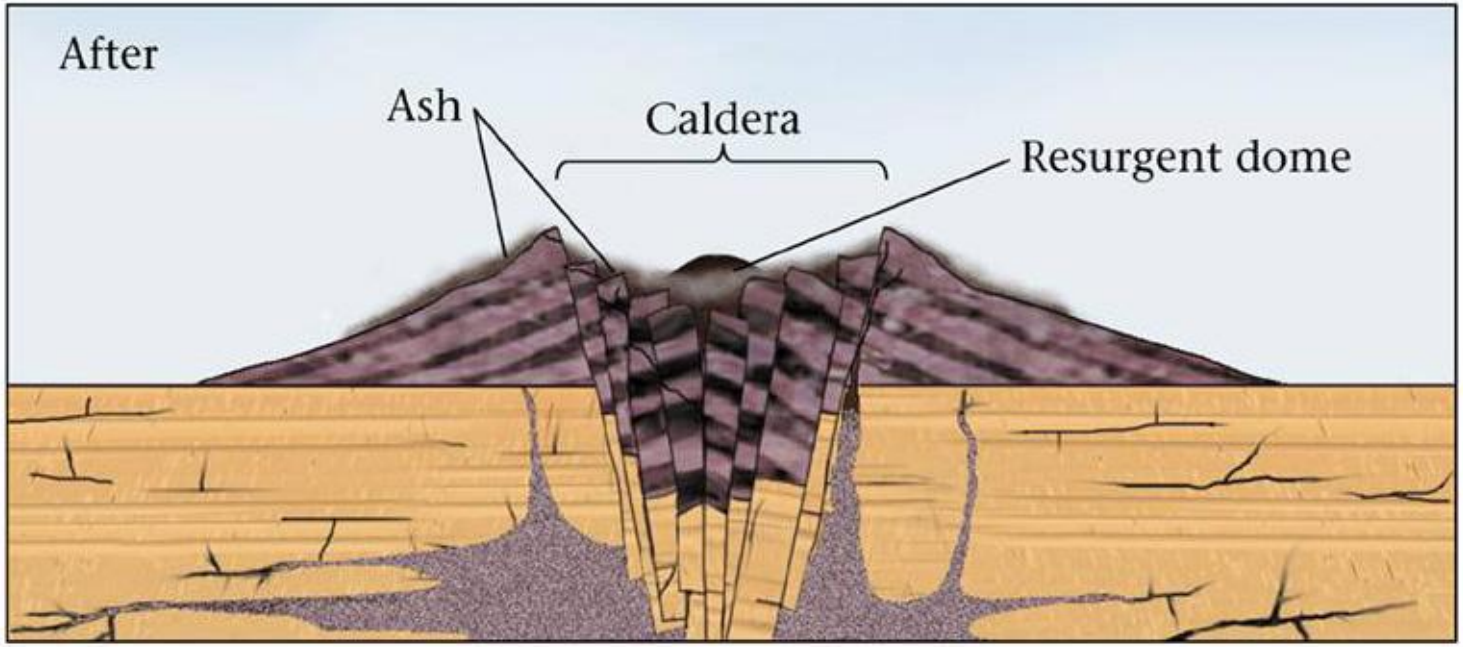
MIGRATION OF YELLOWSTONE CALDERA

Yellowstone Geyser

CALDERA FORMATION – COLLAPSE OF ERUPTION CENTRE INTO EMPTIED MAGMA CHAMBER



(b)



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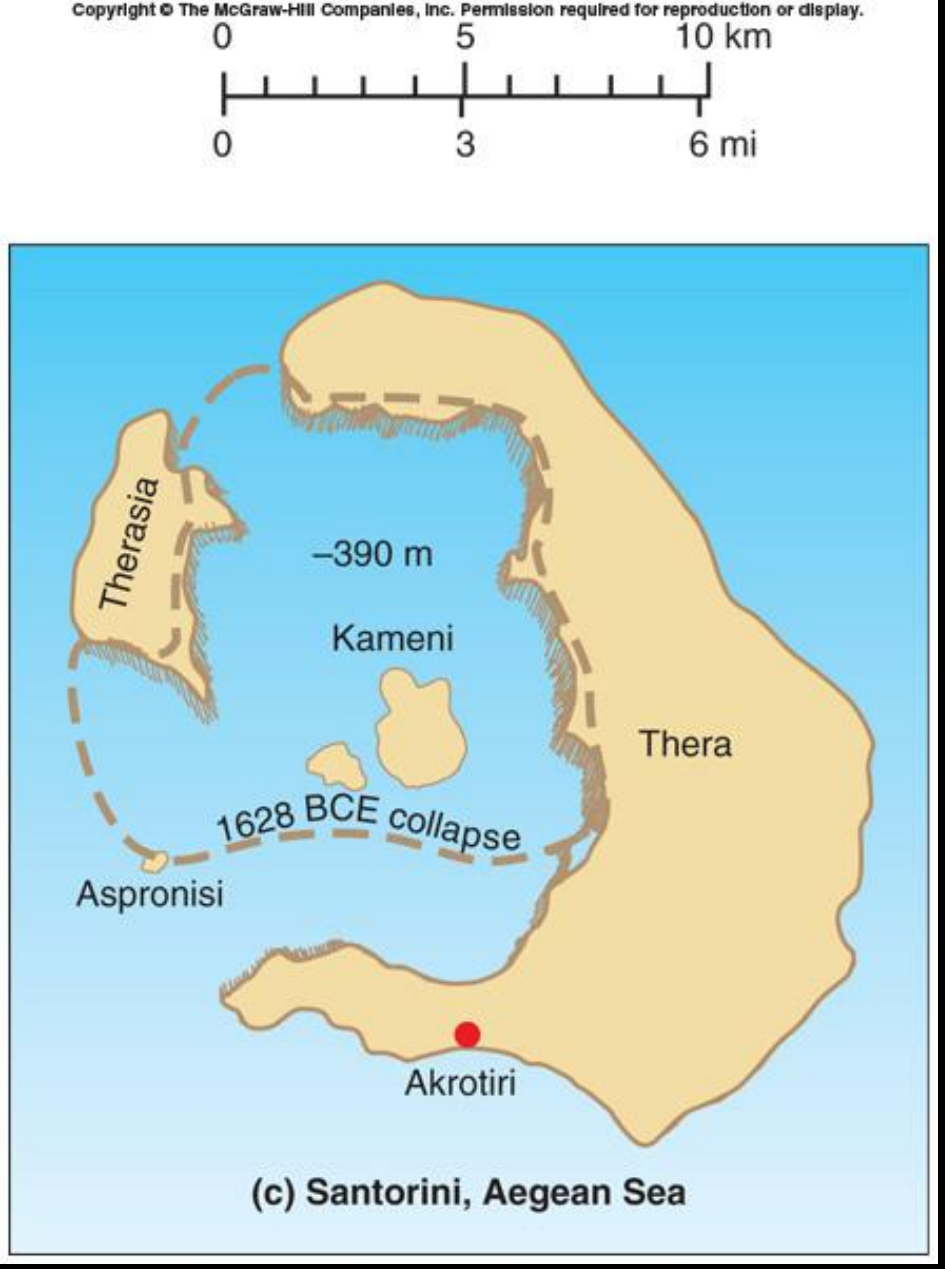
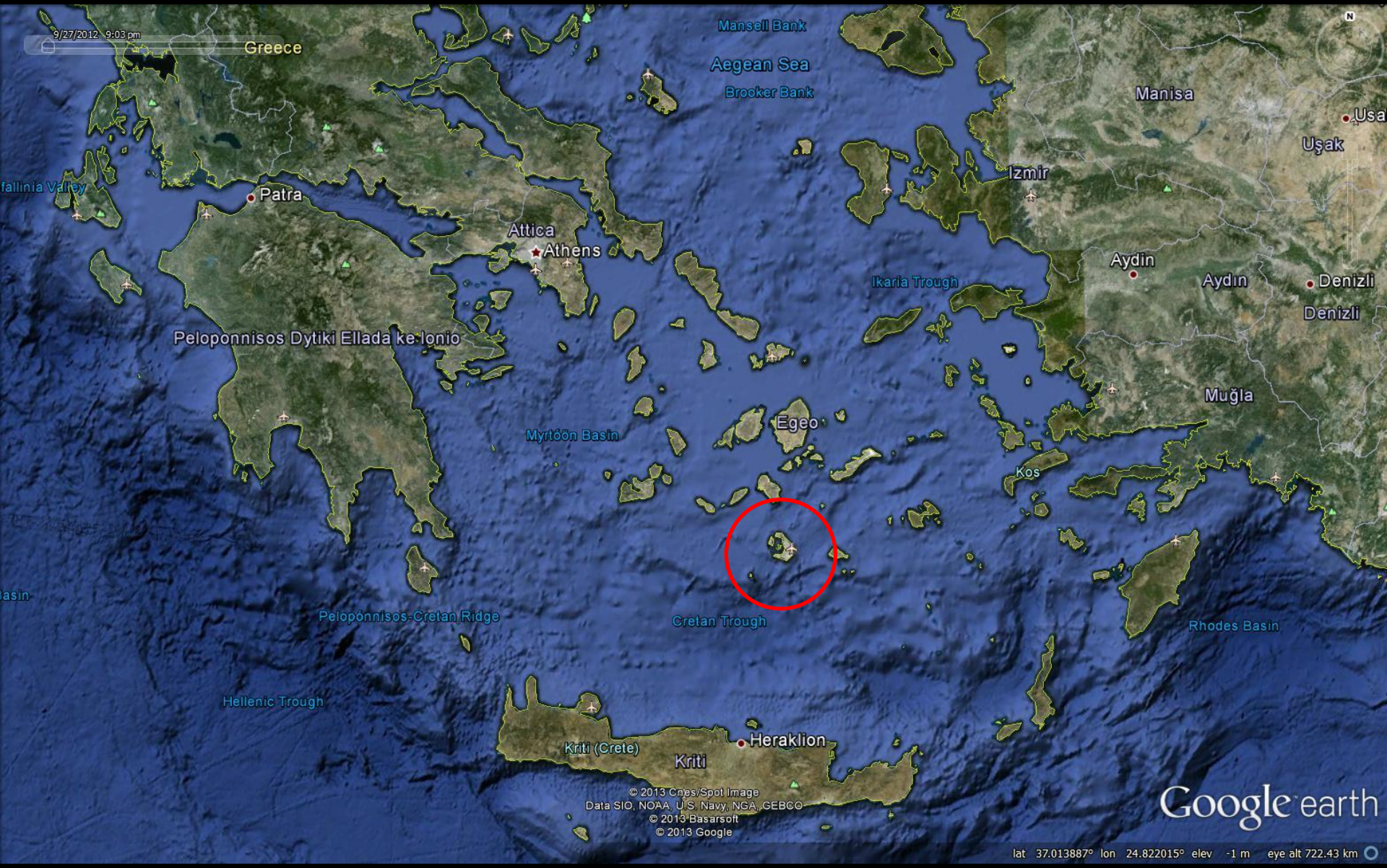


SANTORINI CALDERA EXPLOSION 1628 BC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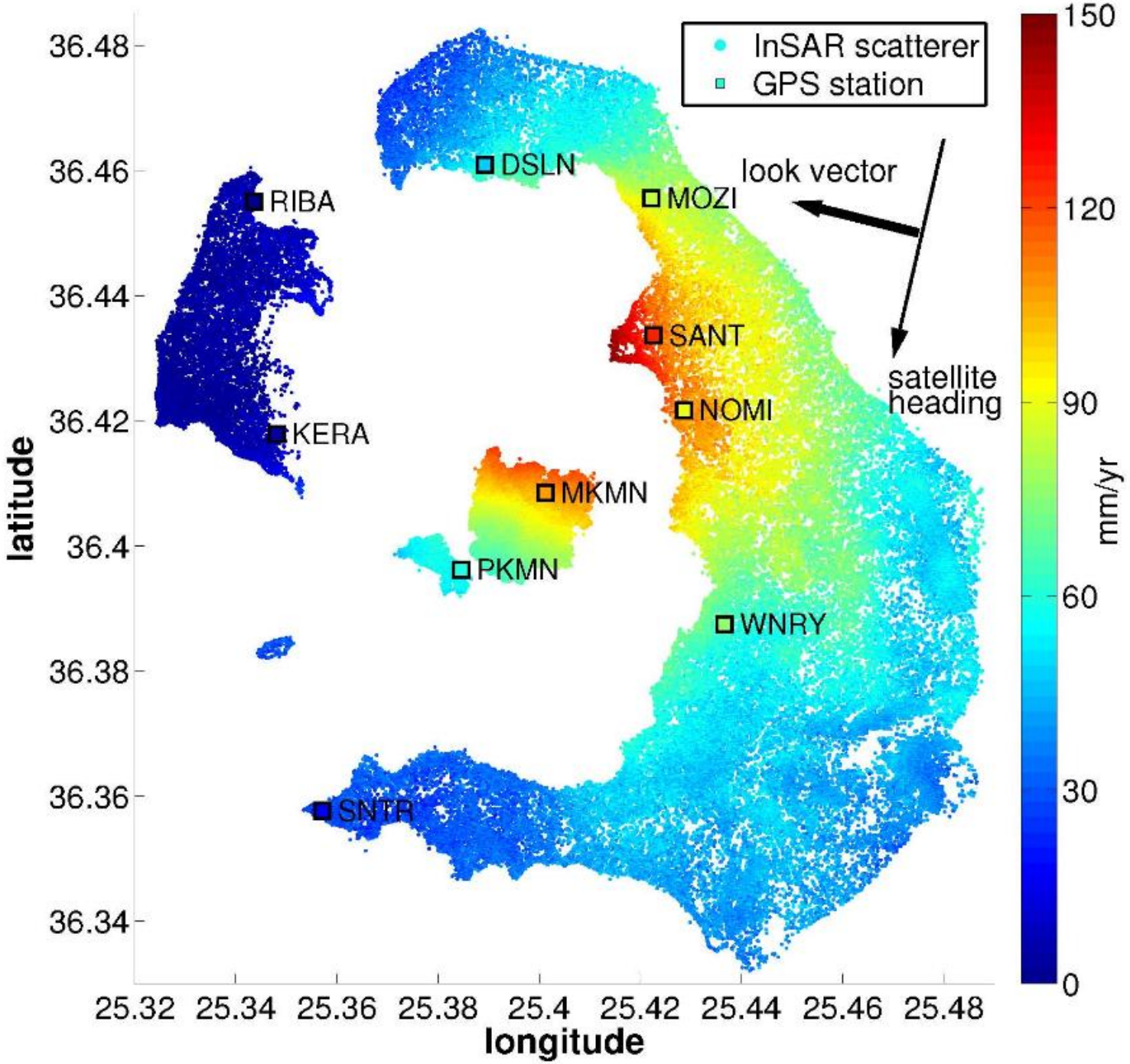
Greece
Mansell Bank
Aegean Sea
Brooker Bank
Manisa
Usa
Uşak
İzmir
fallinia Valley
Patra
Attica
Athens
Aydin
Aydın
Denizli
Denizli
Ikaria Trough
Peloponnisos Dytiki Ellada ke Ionio
Muğla
Egeo
Myrtoön Basin
Kos
Pelopónnisos-Cretan Ridge
Cretan Trough
Rhodes Basin
Hellenic Trough
Kriti (Crete)
Kriti
Heraklion
© 2013 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Basarsoft
© 2013 Google
Google earth
lat 37.013887° lon 24.822015° elev -1 m eye alt 722.43 km


InSAR scatterer
GPS station
look vector
satellite heading
DSLN
MOZI
RIBA
SANT
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KERA
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SNTR
latitude
longitude
mm/yr
36.48
36.46
36.44
36.42
36.4
36.38
36.36
36.34
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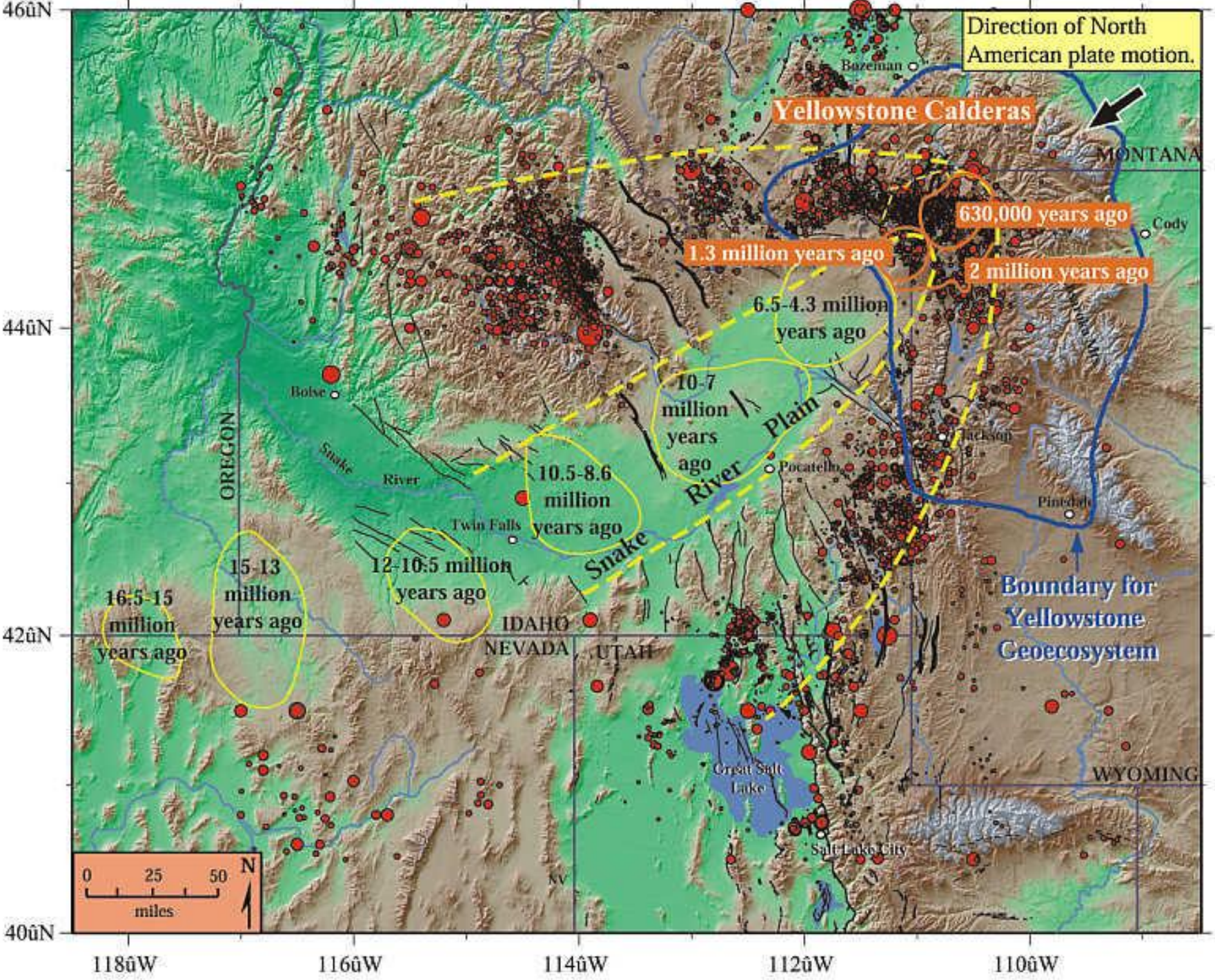
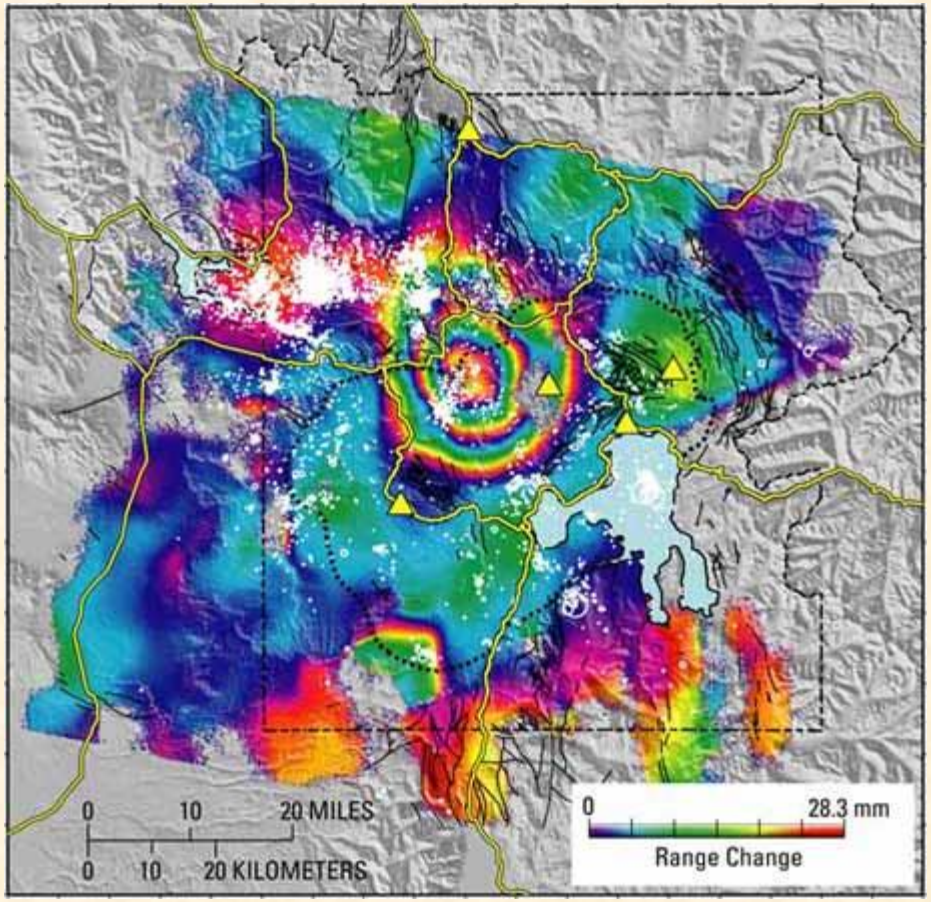
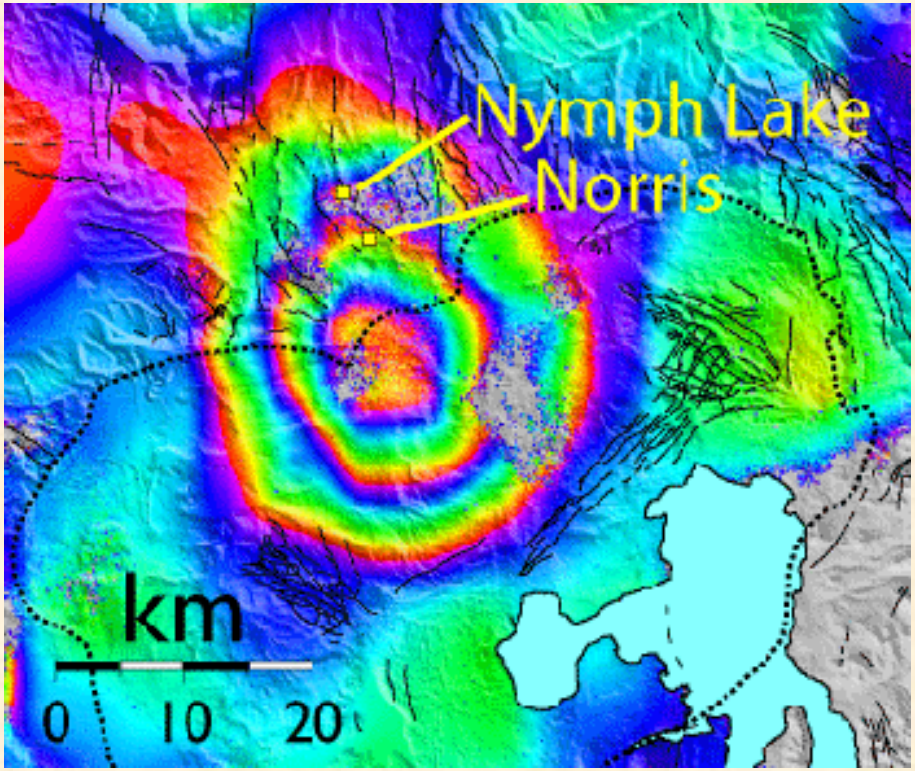
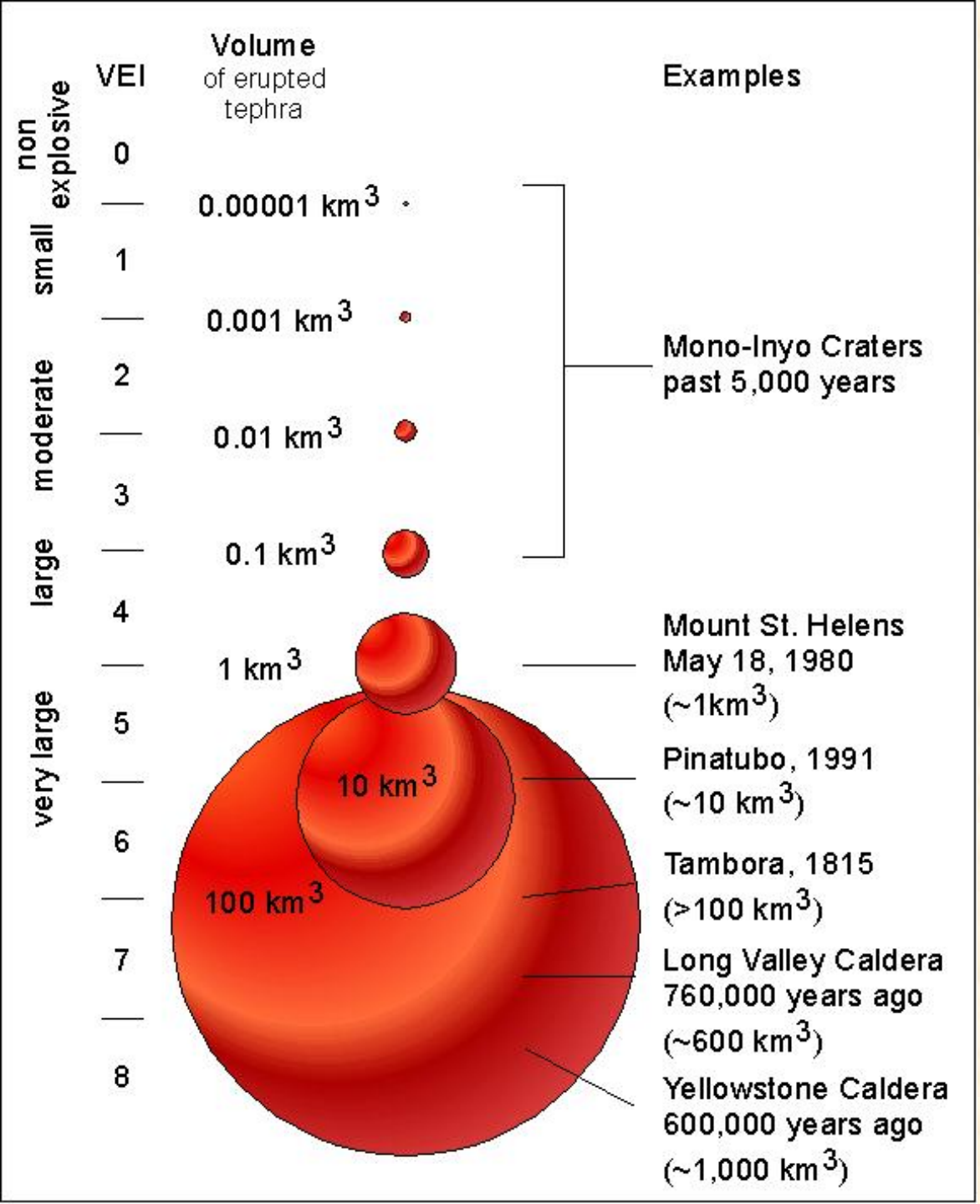

Direction of North American plate motion.
Yellowstone Calderas
MONTANA
630,000 years ago
1.3 million years ago
2 million years ago
Cody
Bozeman
6.5-4.3 million years ago
10-7 million years ago
Snake River Plain
Boise
OREGON
Snake River
Pocatello
Jackson
Pinedale
10.5-8.6 million years ago
Twin Falls
12-10.5 million years ago
15-13 million years ago
16.5-15 million years ago
IDAHO
NEVADA
UTAH
Boundary for Yellowstone Geoecosystem
Great Salt Lake
Salt Lake City
WYOMING
0 25 50
miles
N
46ûN
44ûN
42ûN
40ûN
118ûW
116ûW
114ûW
112ûW
110ûW

YELLOWSTONE SUPERVOLCANO (?) – BULGING HOTSPOT MEASURED BY HIGH RESOLUTION GPS





IS IT GOING TO BLOW ??



VOLCANIC ERUPTION – VOLCANIC EXPLOSIVITY INDEX (VEI)

The **Volcanic Explosivity Index**, or VEI, was proposed in 1982 as a way to describe the relative size or magnitude of explosive volcanic eruptions. It is a 0-to-8 index of increasing explosivity. Each increase in number represents an increase around a factor of ten. The VEI uses several factors to assign number, including **volume of erupted pyroclastic material** (for example, ashfall, pyroclastic flows, and other ejecta), **height of eruption column**, **duration in hours**, and qualitative descriptive terms.

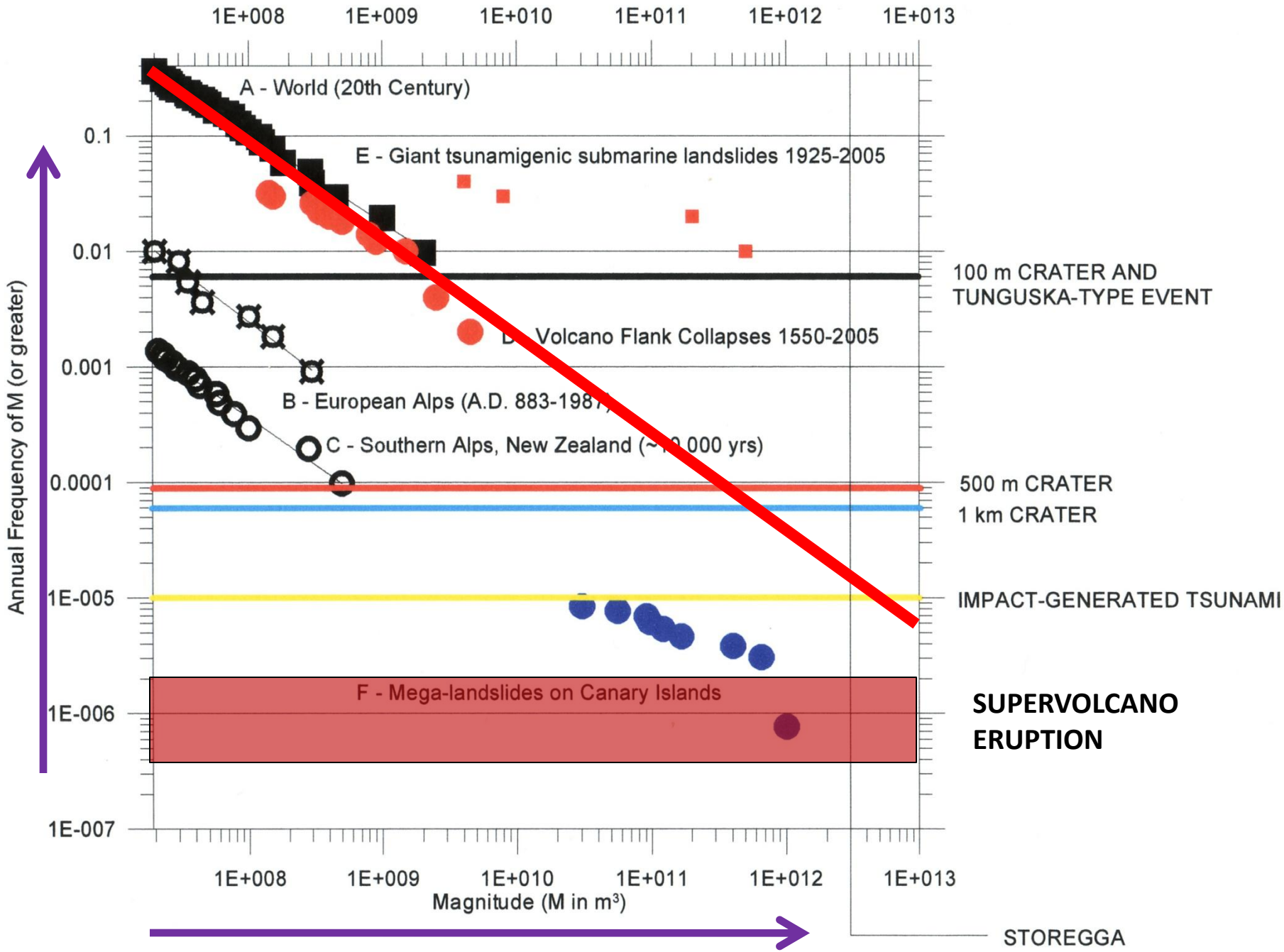
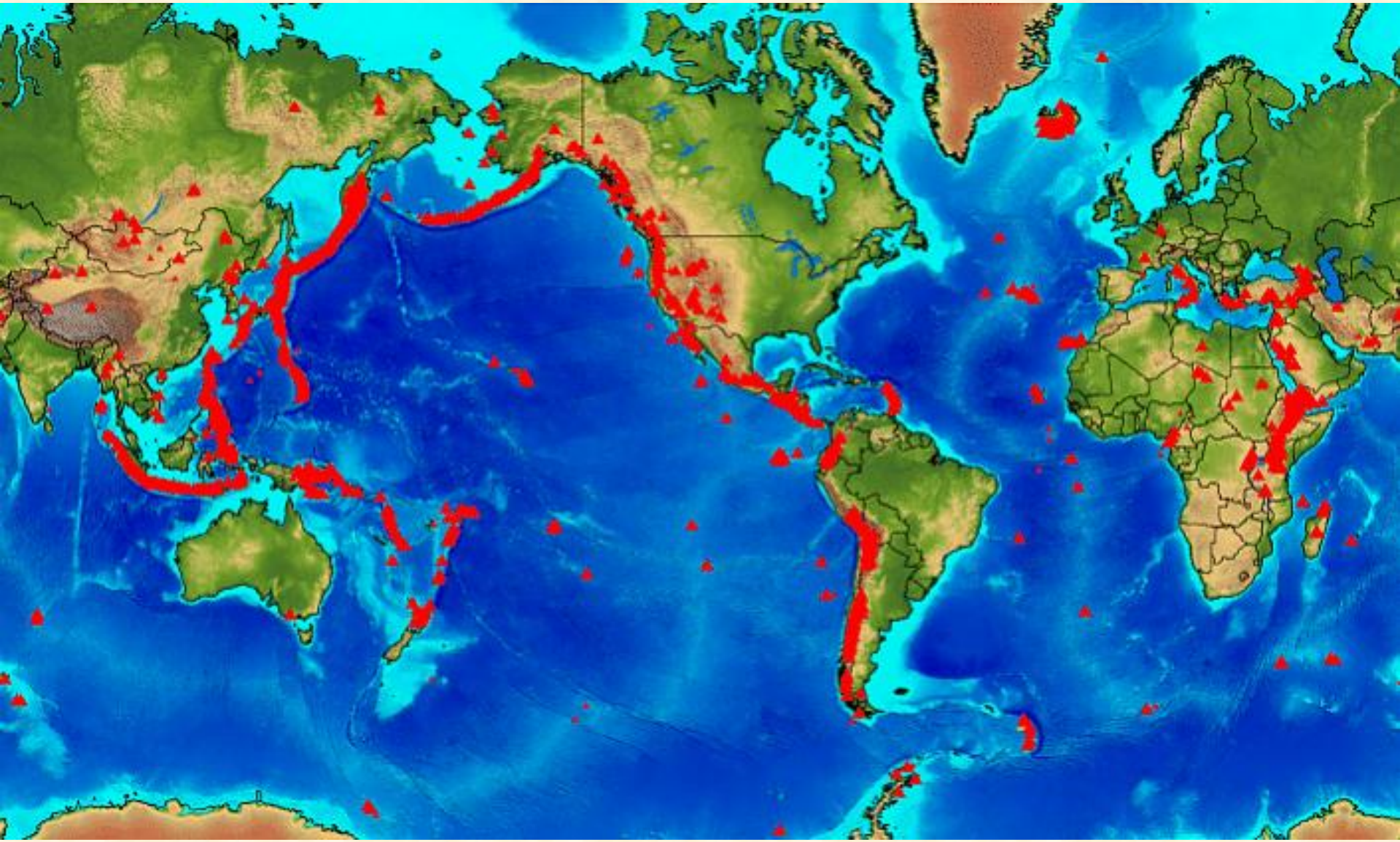

1E+008
1E+009
1E+010
1E+011
1E+012
1E+013
A - World (20th Century)
E - Giant tsunamigenic submarine landslides 1925-2005
100 m CRATER AND
TUNGUSKA-TYPE EVENT
Volcano Flank Collapses 1550-2005
B - European Alps (A.D. 883-198
C - Southern Alps, New Zealand (~
000 yrs)
500 m CRATER
1 km CRATER
IMPACT-GENERATED TSUNAMI
F - Mega-landslides on Canary Islands
SUPERVOLCANO
ERUPTION
STOREGGA
0.1
0.01
0.001
0.0001
1E-005
1E-006
1E-007
Annual Frequency of M (or greater)
Magnitude (M in m³)

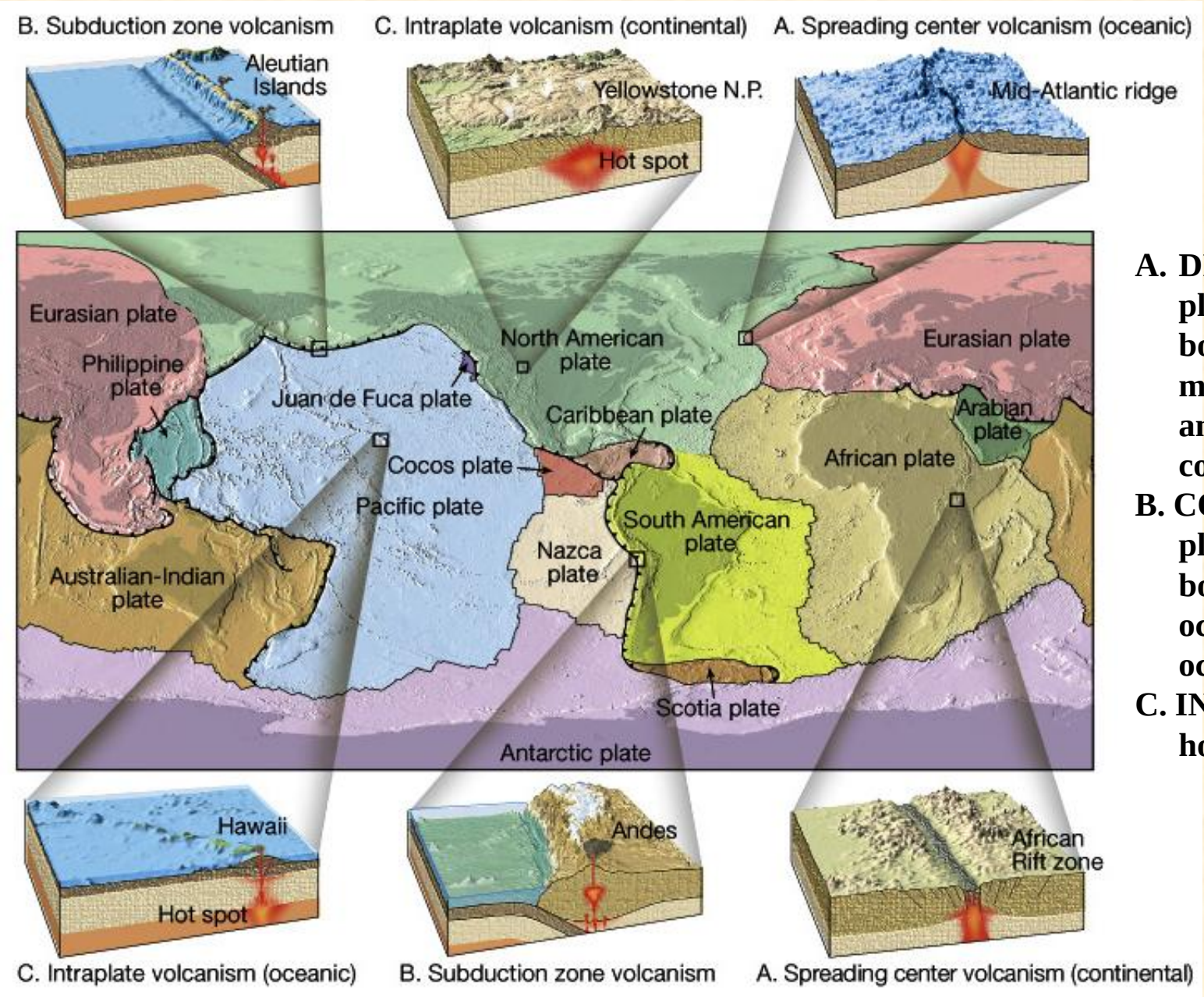
PLATE TECTONICS AND ACTIVE VOLCANISM

ARENAL

DISTRIBUTION OF ACTIVE VOLCANOES I



THREE ZONES OF VOLCANISM



A. DIVERGENT plate boundaries mid-ocean ridge and continental rift

B. CONVERGENT plate boundaries: ocean-ocean ocean-continent

C. INTRAPLATE hot-spot

Augustine Volcano, Alaska

Montserrat

Eruption of Pichincha, Quito, Ecuador, 1999

Asama Volcano, Japan ; February 7, 2009