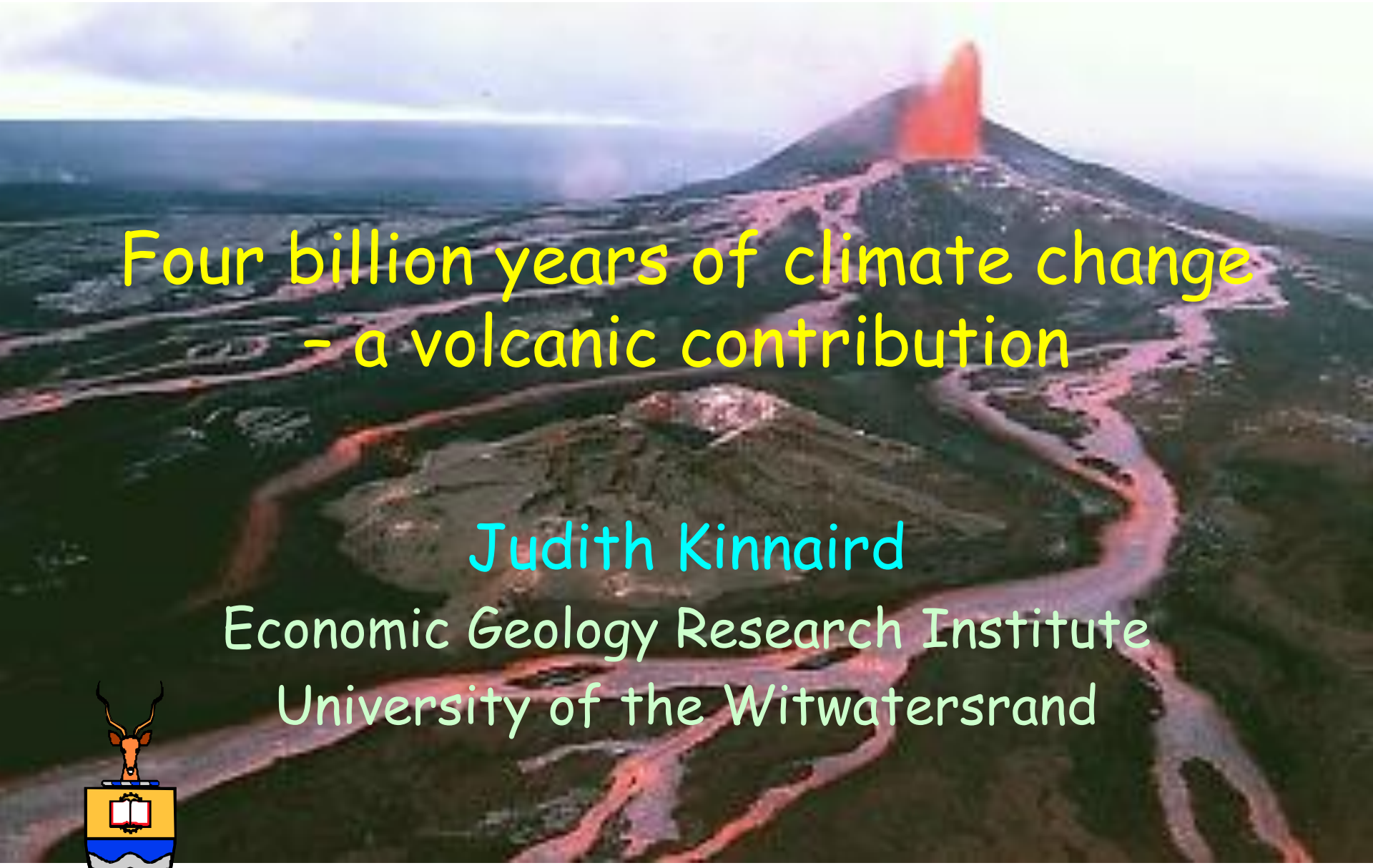
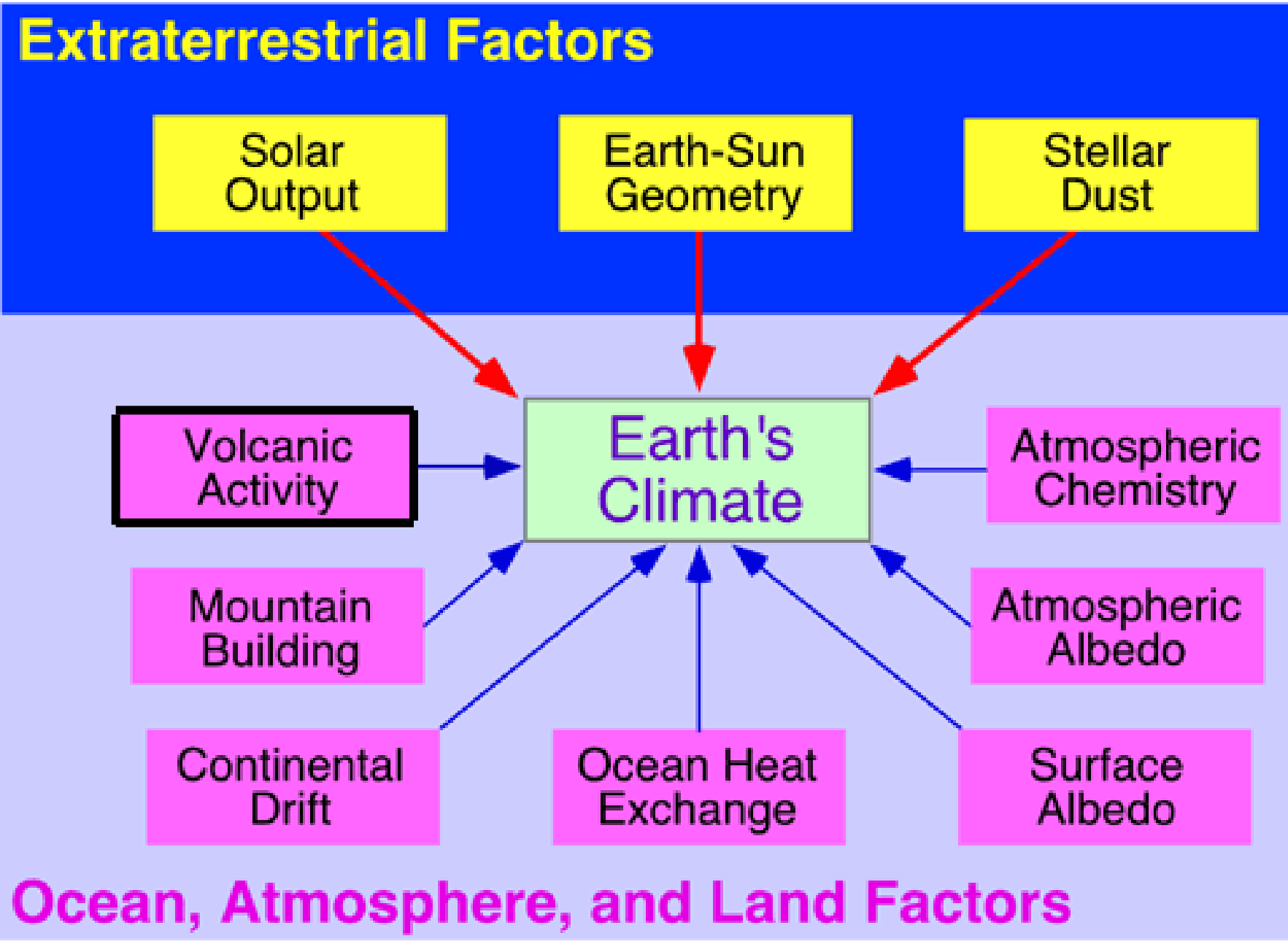
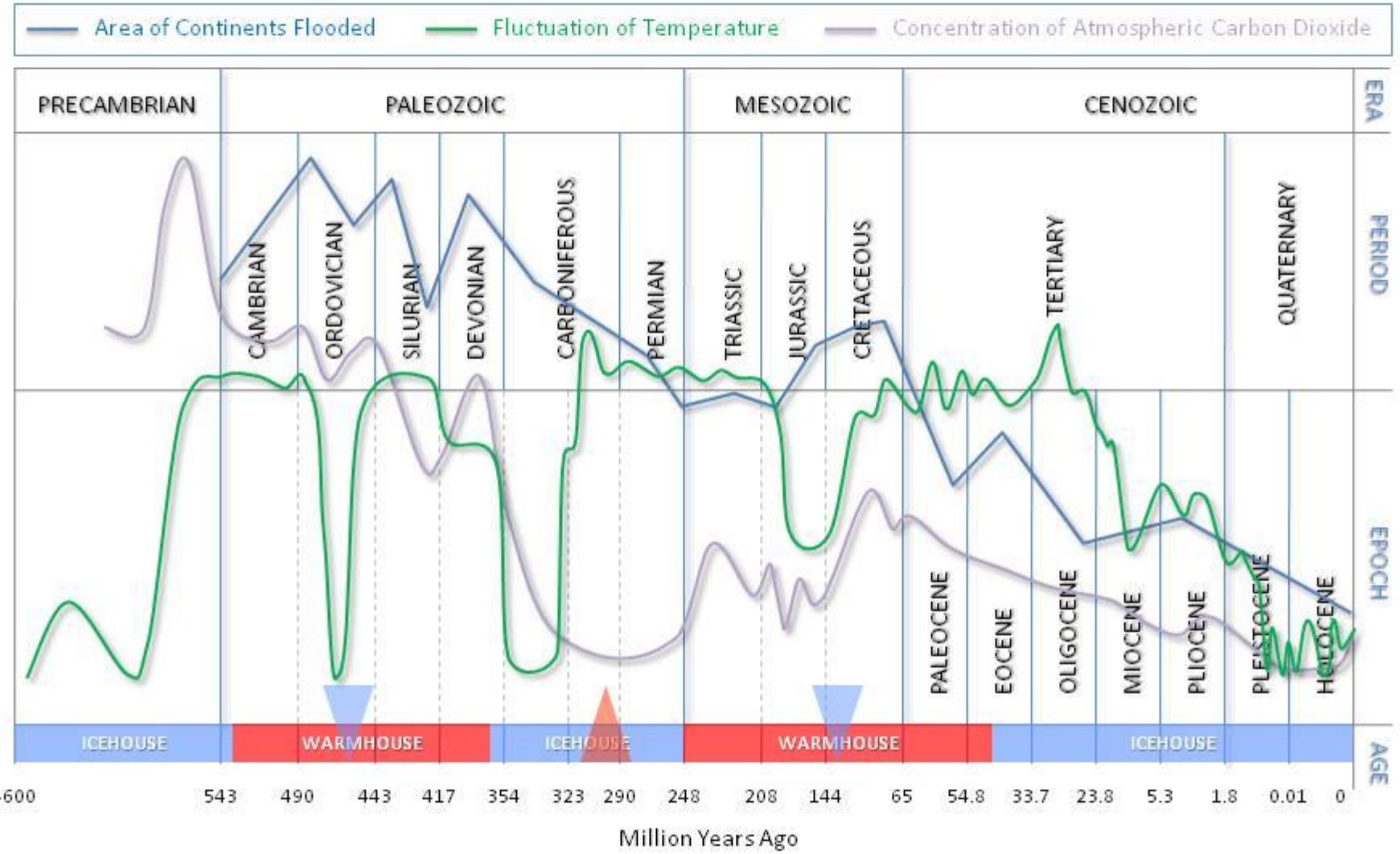


# Four billion years of climate change – a volcanic contribution

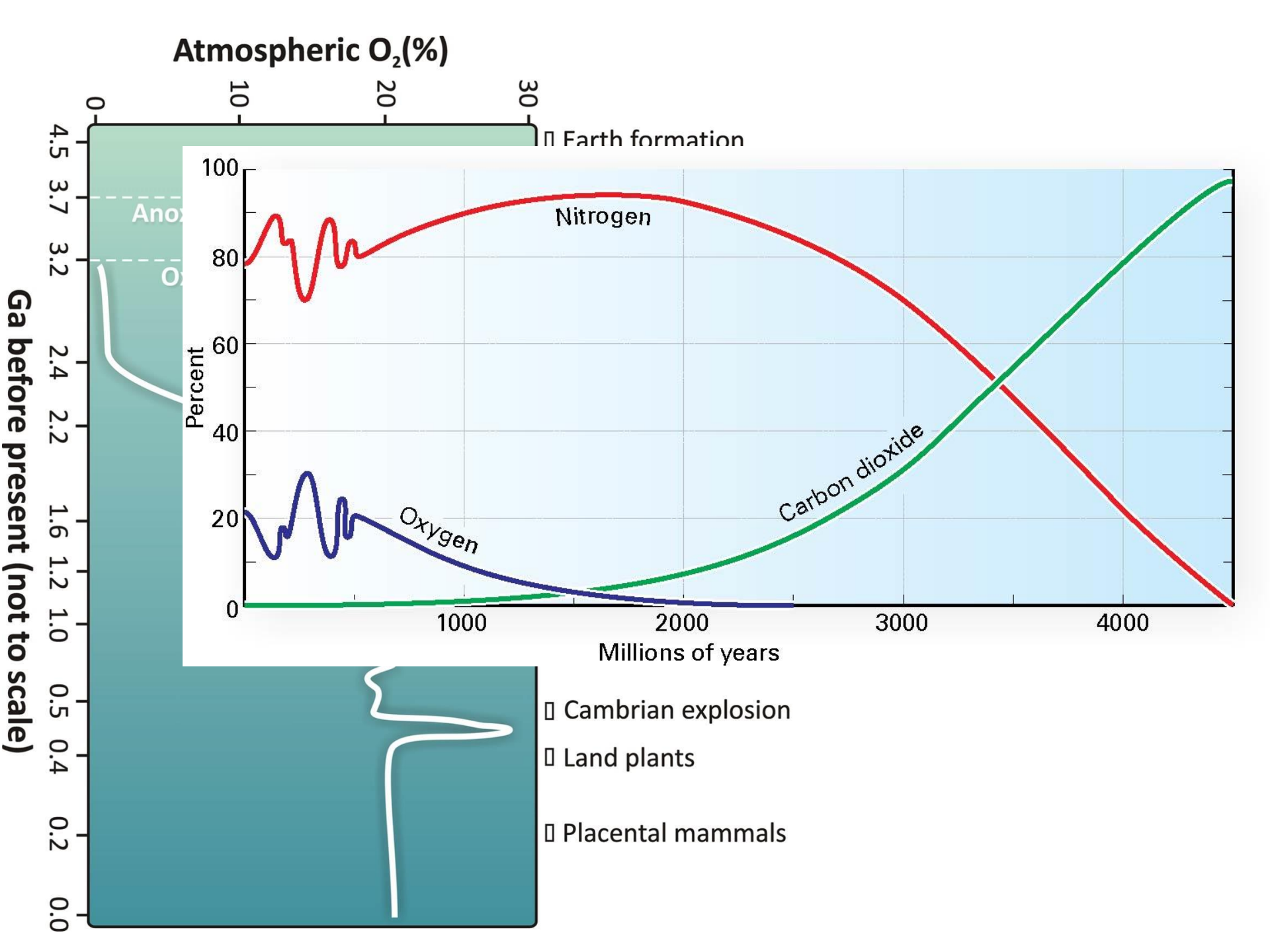
Judith Kinnaird
Economic Geology Research Institute
University of the Witwatersrand


Extraterrestrial Factors
Solar Output
Earth-Sun Geometry
Stellar Dust
Volcanic Activity
Earth's Climate
Atmospheric Chemistry
Mountain Building
Atmospheric Albedo
Continental Drift
Ocean Heat Exchange
Surface Albedo
Ocean, Atmosphere, and Land Factors

# Geologic Timescale: Area of Continents Flooded, Concentration of $CO_2$ and Temperature fluctuations



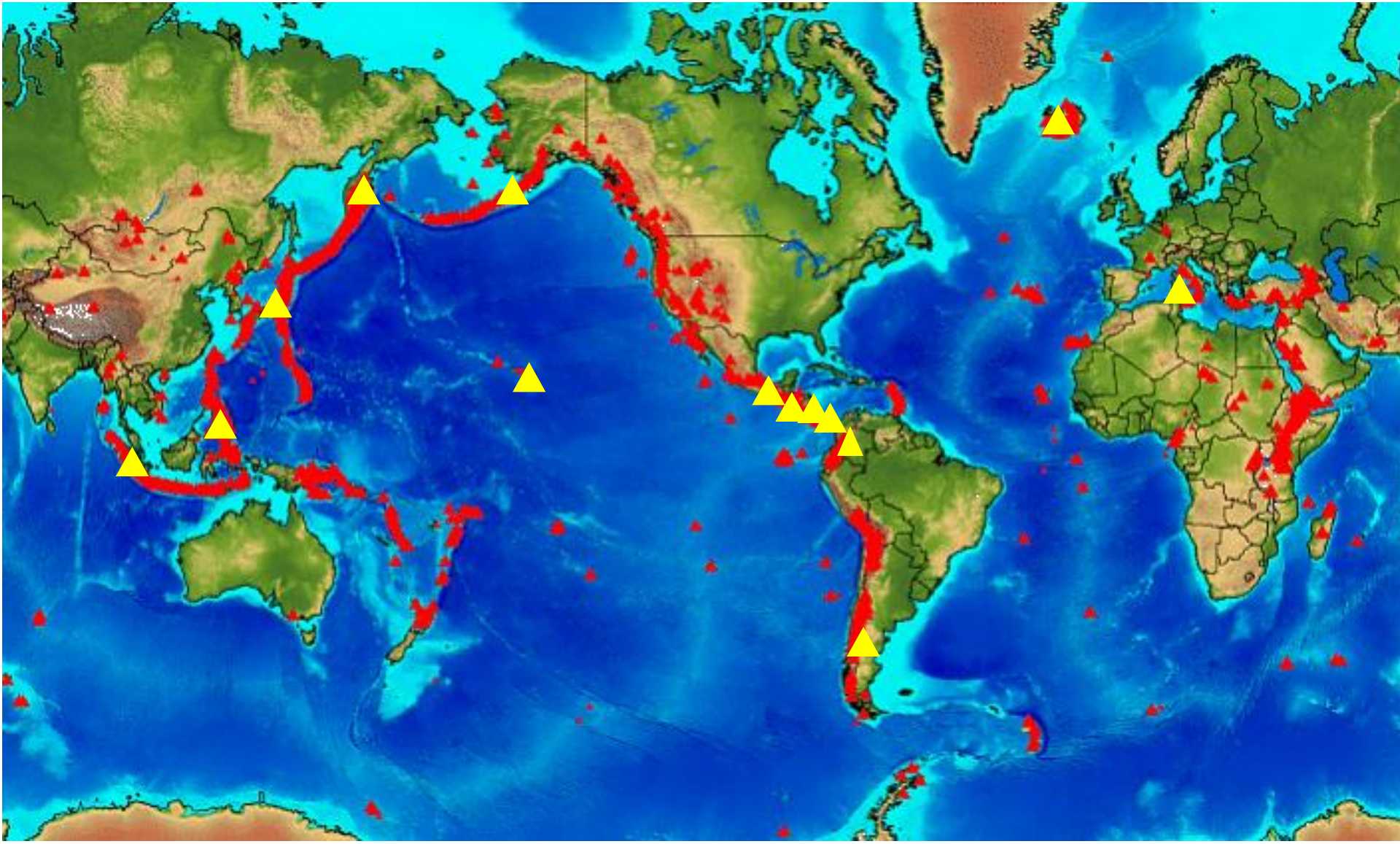

1- *Analysis of the Temperature Oscillations in Geological Eras* by Dr. C. R. Scotese © *2002*. 2- Ruddiman, W. F. 2001. *Earth's Climate: past and future*. W. H. Freeman & Sons. New York, NY. 3- Mark Pagani *et all*. *Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleocene*. Science; Vol. 309, No. 5734; pp. 600-603. 22 July 2005. 4- Ronov, A. B. 1994. *Phanerozoic Transgressions and Regressions on the Continents: A Quantitative Approach Based on Areas Flooded by the Sea and Areas of Marine and Continental Deposition*. American Journal of Science 294:777–801. 5- *Source for Nomenclature and Ages*: © 1999, The Geological Society of America. *Product Code CTS004*. Compilers: A. R. Palmer and John Geissman. *Conclusion and Interpretation*: Nasif Nahle ©2005, 2007, 2009. *Corrected on 07 July 2008 (CO2: Ordovician Period).*


Atmospheric $O_2$(%)
0
10
20
30
Ga before present (not to scale)
4.5
3.7
3.2
2.4
2.2
1.6
1.2
1.0
0.5
0.4
0.2
0.0
Earth formation
Cambrian explosion
Land plants
Placental mammals
Percent
100
80
60
40
20
0
Nitrogen
Oxygen
Carbon dioxide
1000
2000
3000
4000
Millions of years

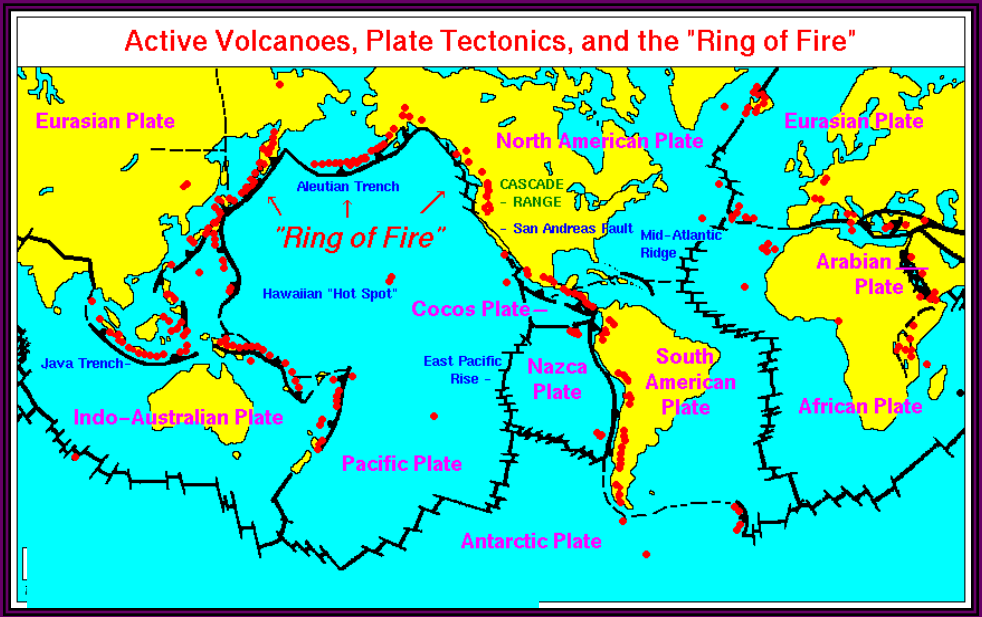
- Volcanoes have erupted throughout the 4 billion years of Earth's history. Around 1500 volcanoes have erupted in the last 10,000 years

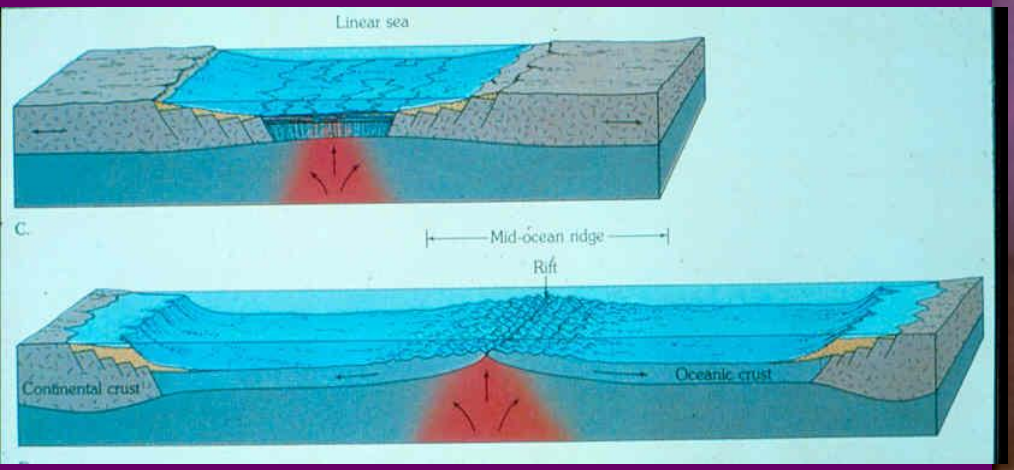
# Active Volcanoes, Plate Tectonics, and the "Ring of Fire"

# current eruptions

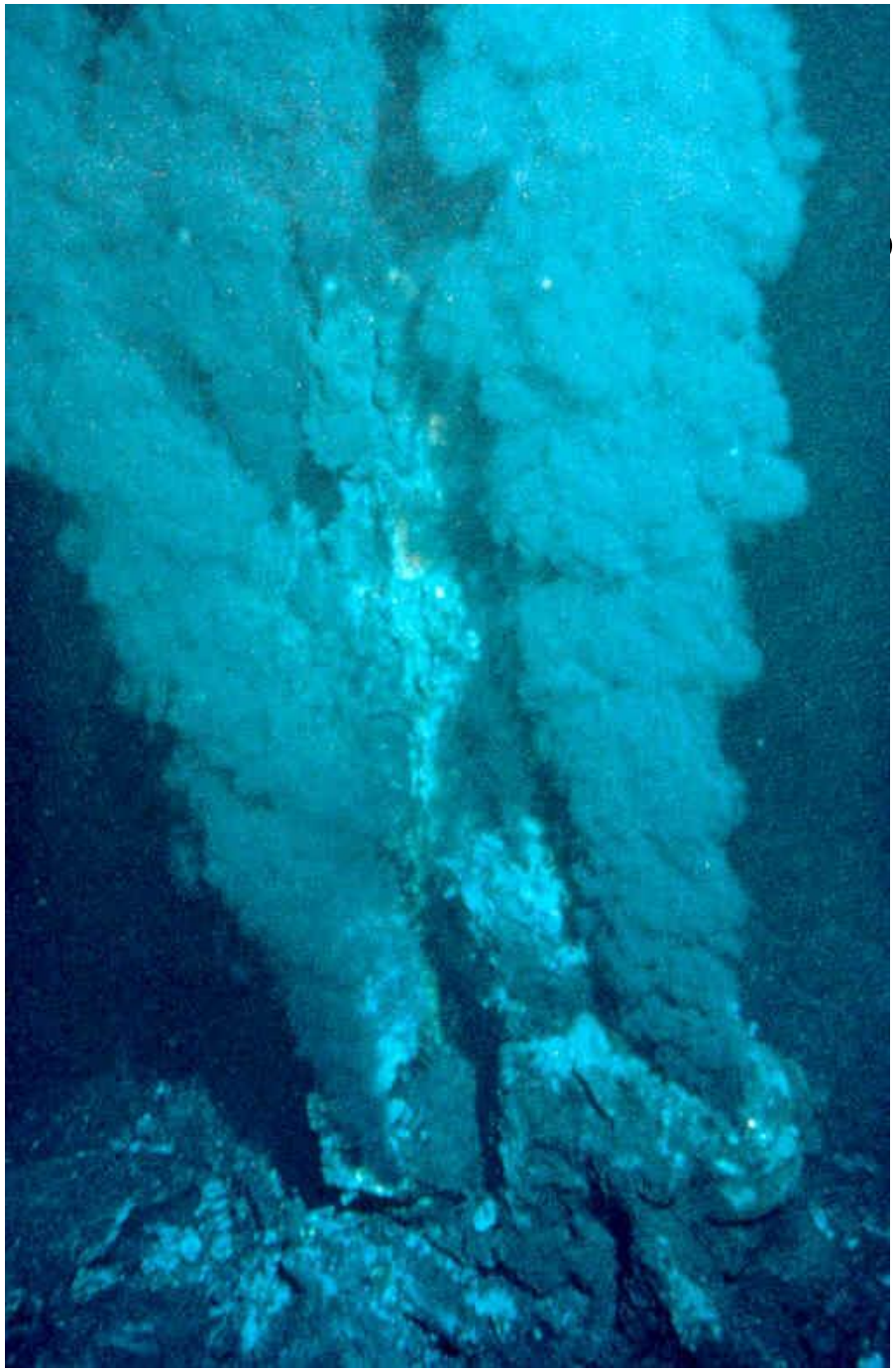


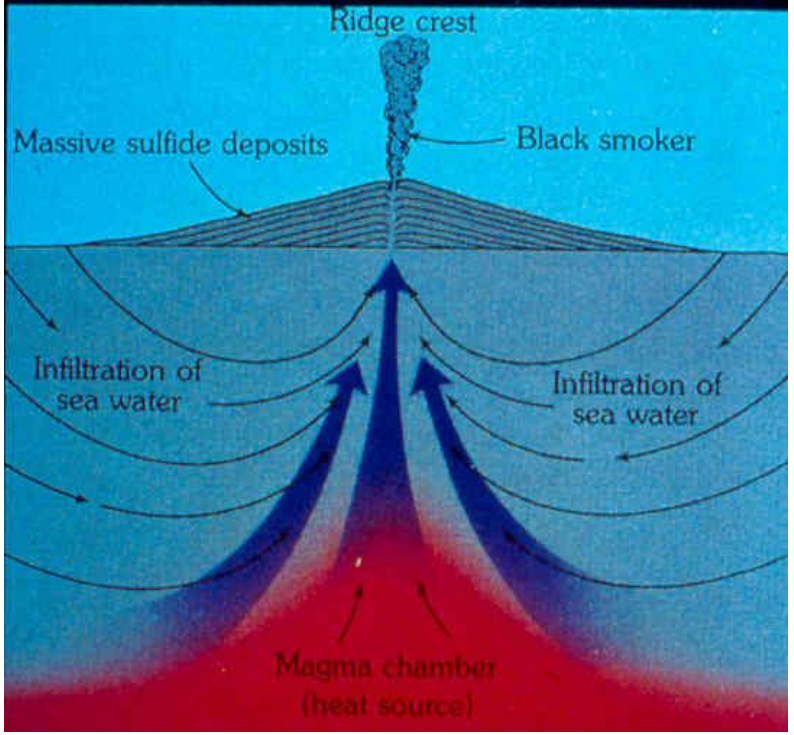
# Constructive plate margin



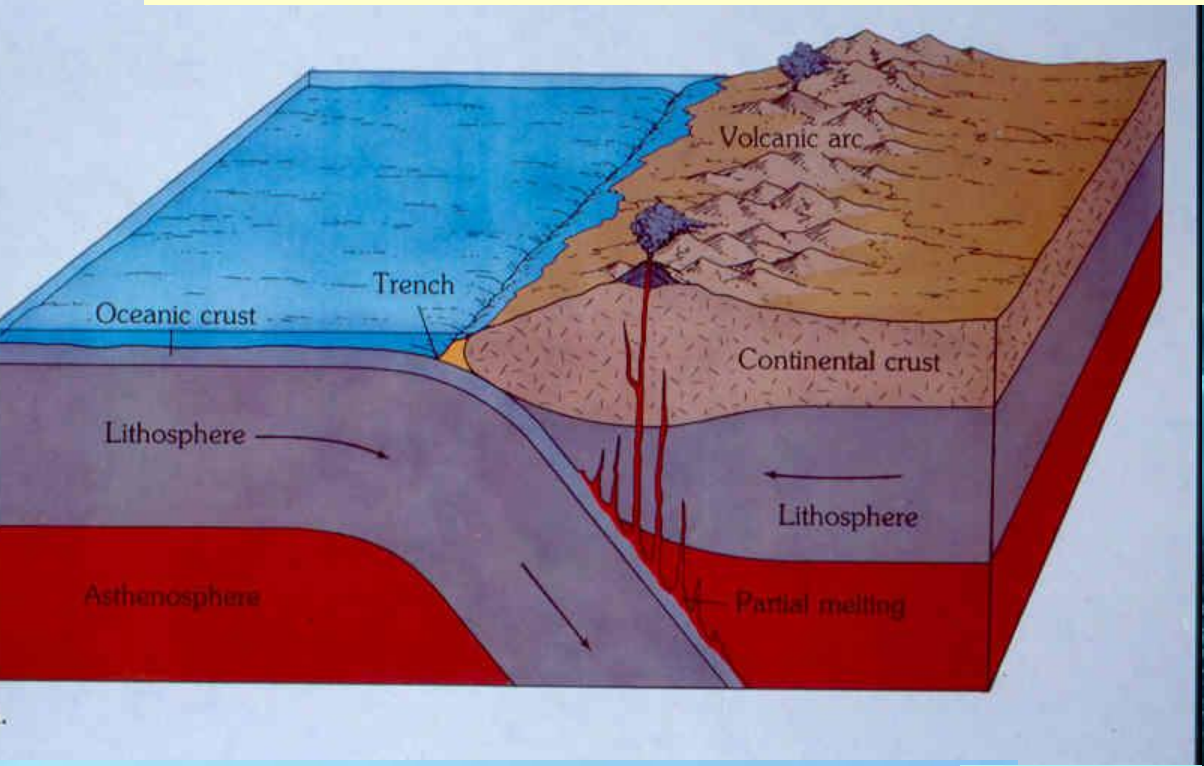

Surtsey 1963



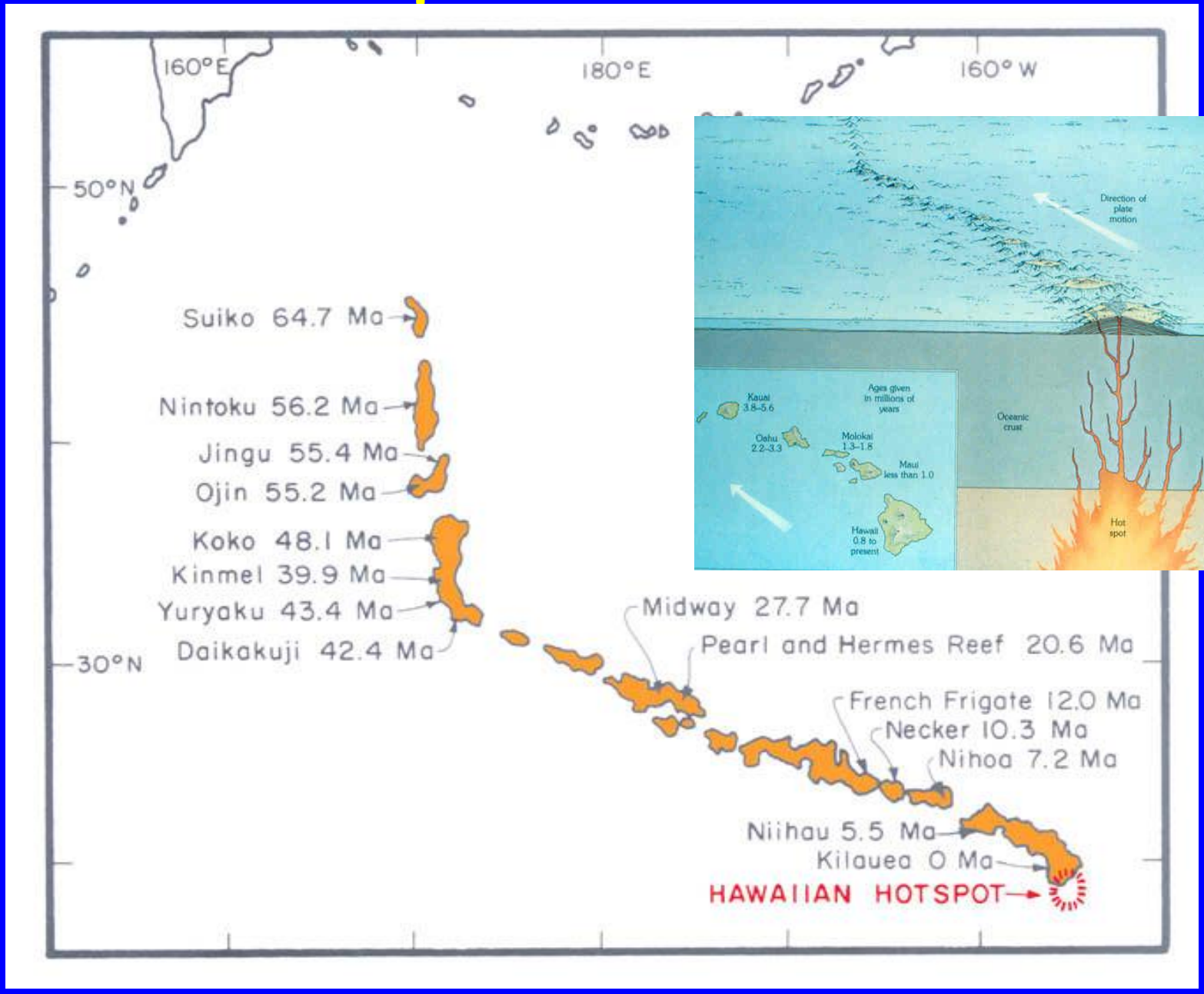

Ridge crest
Massive sulfide deposits
Black smoker
Infiltration of sea water
Infiltration of sea water
Magma chamber (heat source)

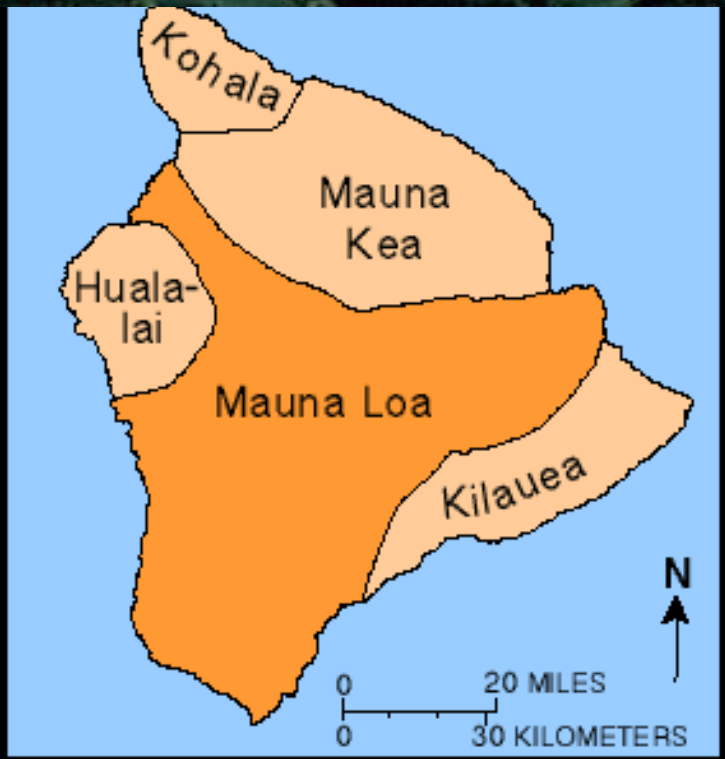
# Pillow basalts

# Destructive plate margins




# hot spot volcanism




Kohala
Mauna Kea
Hualalai
Mauna Loa
Kilauea
N
0
20 MILES
0
30 KILOMETERS

# As well as lava volcanoes produce enormous quantities of gas


- Eyjafjallajökull spewed tons of ash into the air in 2010
- Bardarbunga began erupting on 31st August 2014
- By October 1, it had already spewed out more sulphur dioxide than any other Icelandic volcano in the past several hundred years

| **Volcano**<br>Tectonic Style<br>Temperature | **Kilauea**<br>Hot Spot<br>1170°C | **Erta` Ale**<br>Divergent<br>1130°C | **Momotombo**<br>Convergent<br>820°C |
|---|---|---|---|
| **$H_20$** | **37.1** | **77.2** | **97.1** |
| **$C0_2$** | **48.9** | **11.3** | **1.44** |
| **$S0_2$** | **11.8** | **8.34** | **0.50** |
| **$H_2$** | **0.49** | **1.39** | **0.70** |
| **CO** | **1.51** | **0.44** | **0.01** |
| **$H_2S$** | **0.04** | **0.68** | **0.23** |
| **HCl** | **0.08** | **0.42** | **2.89** |
| **HF** | **---** | **---** | **0.26** |

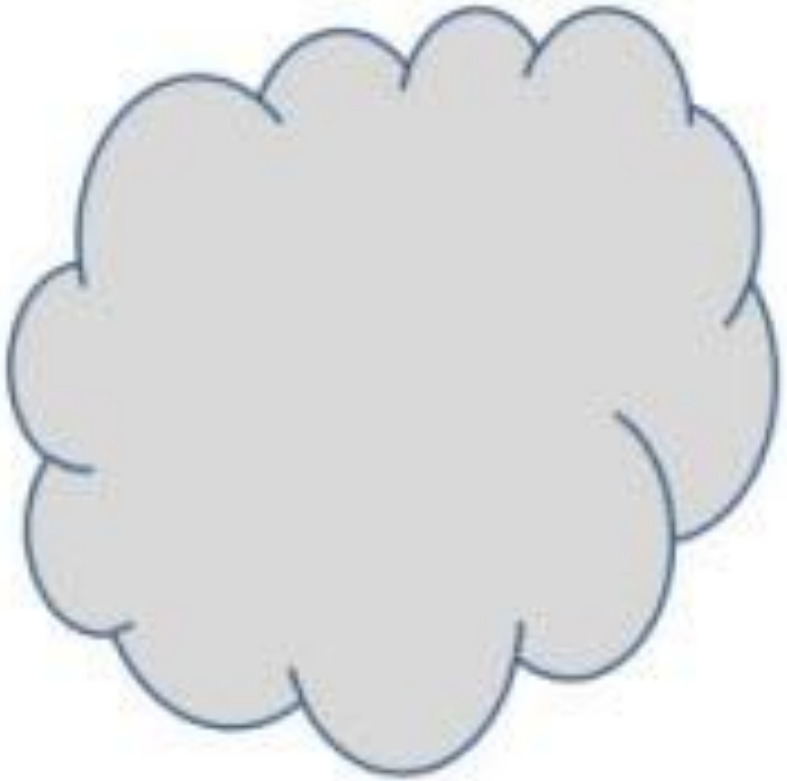
| | Volcanoes per year | Man |
|---|---|---|
| $CO_2$ | 65-319 million tonnes | 29 billion tonnes |


Man is releasing more than 100 times the amount of $CO_2$ emitted by volcanoes each year

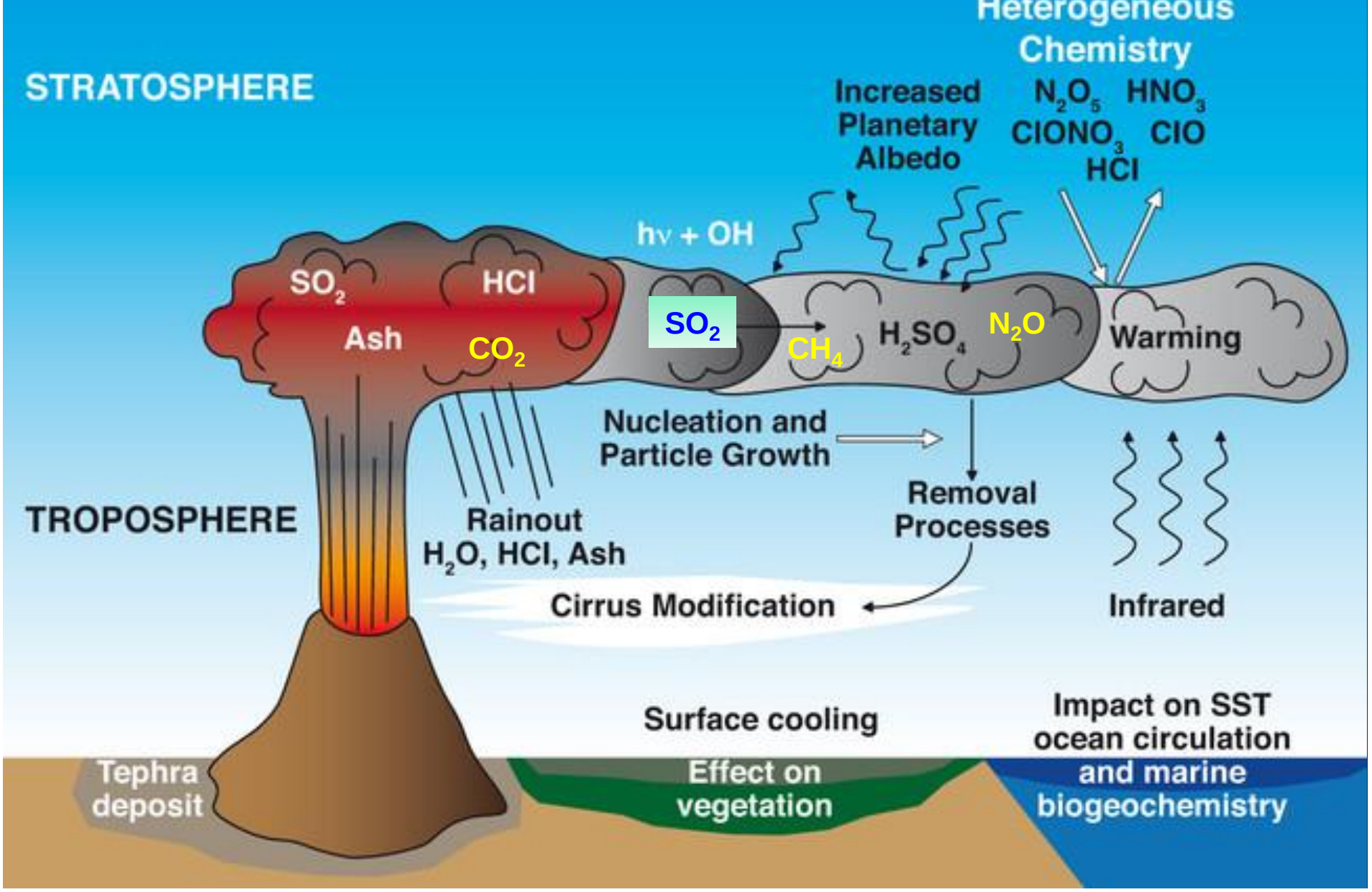
Carbon dioxide has increased in the Earth's atmosphere from 280 ppm in 1700 to 360 ppm in 1990.

Carbon dioxide and methane cause the greenhouse effect

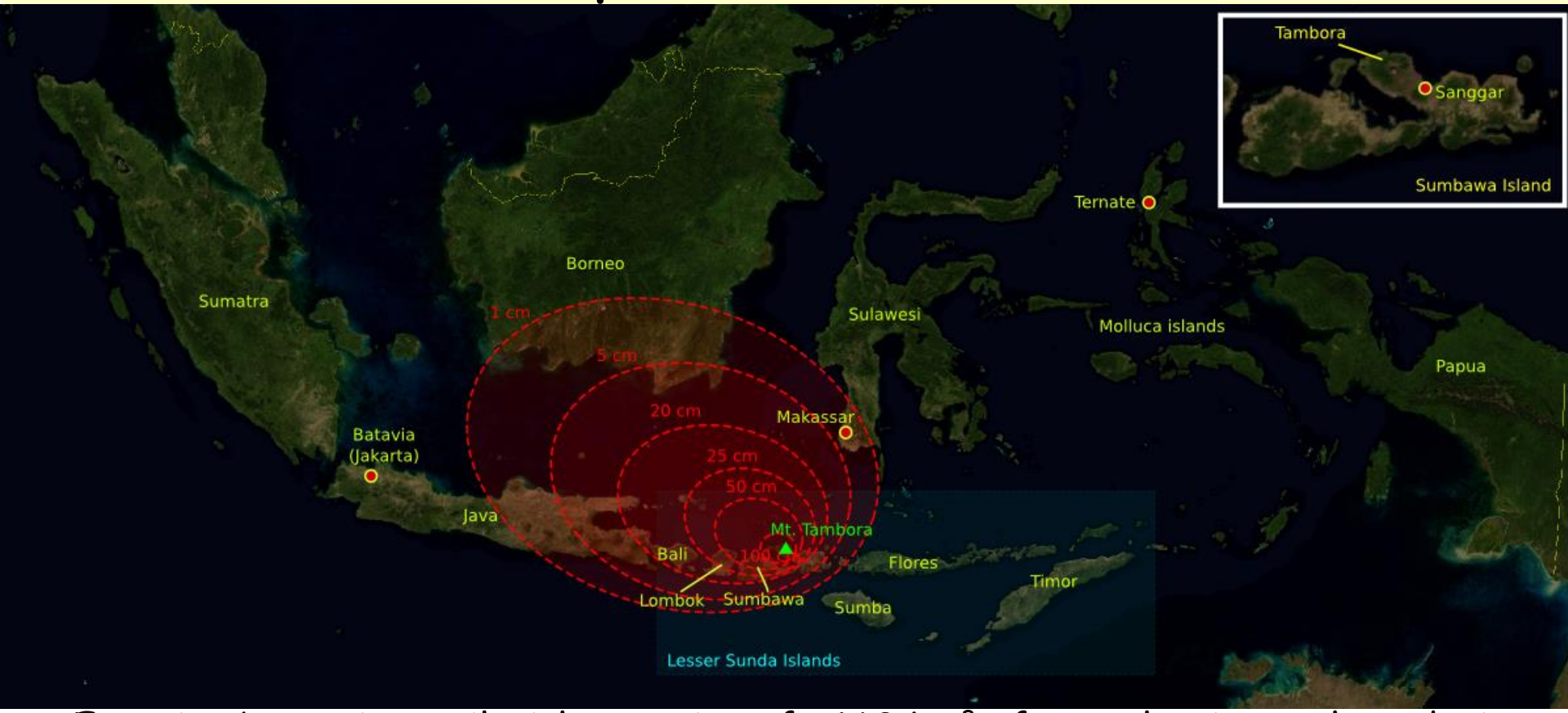
Total volcanic $CO_2$ emissions
65-319 million tonnes/year
(min-max estimates)



World $CO_2$ emissions from fossil fuel use
29 billion tonnes/year
EIA 2007


Heterogeneous Chemistry
STRATOSPHERE
Increased Planetary Albedo
$N_2O_5$ $HNO_3$
$ClONO_3$ ClO
HCl
hν + OH
$SO_2$
HCl
Ash
$CO_2$
$SO_2$
$CH_4$
$H_2SO_4$
$N_2O$
Warming
Nucleation and Particle Growth
Removal Processes
TROPOSPHERE
Rainout
$H_2O$, HCl, Ash
Cirrus Modification
Infrared
Surface cooling
Impact on SST ocean circulation and marine biogeochemistry
Tephra deposit
Effect on vegetation

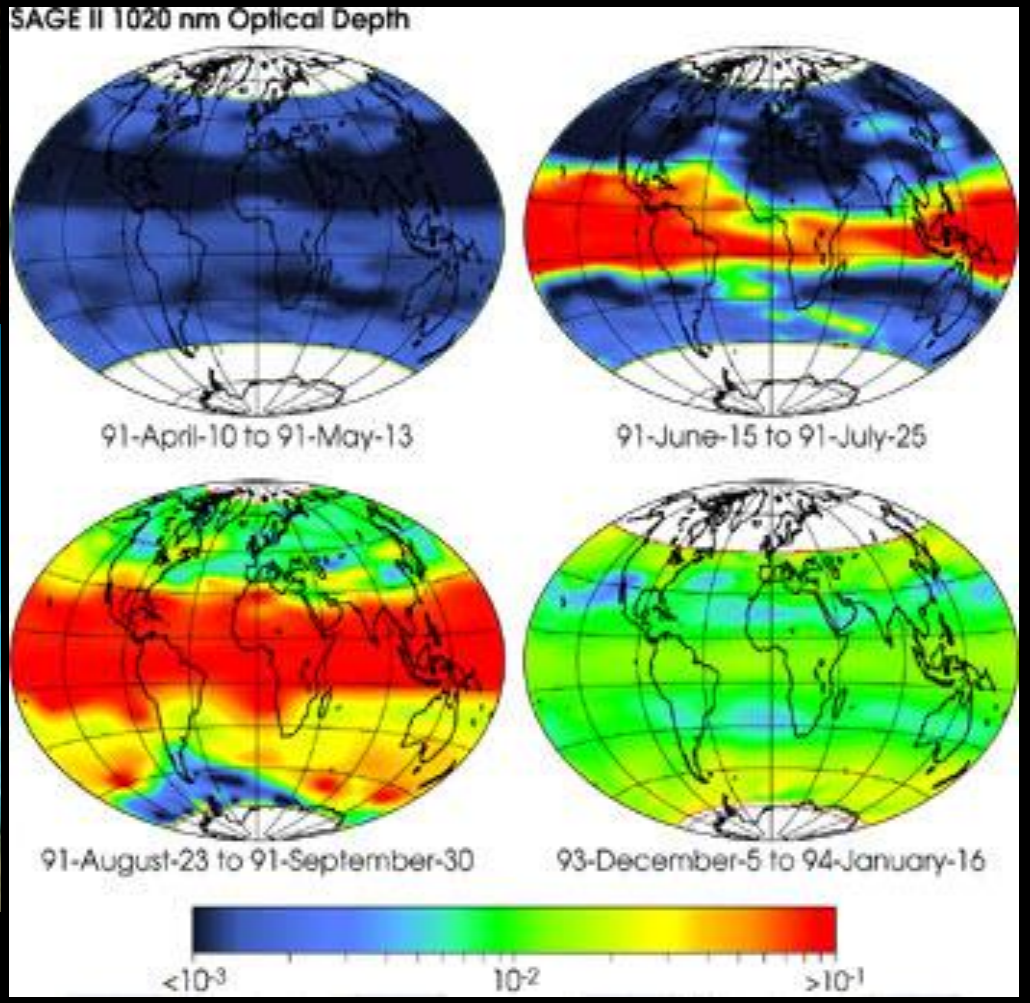
# Tambora eruption of Sumatra in 1815

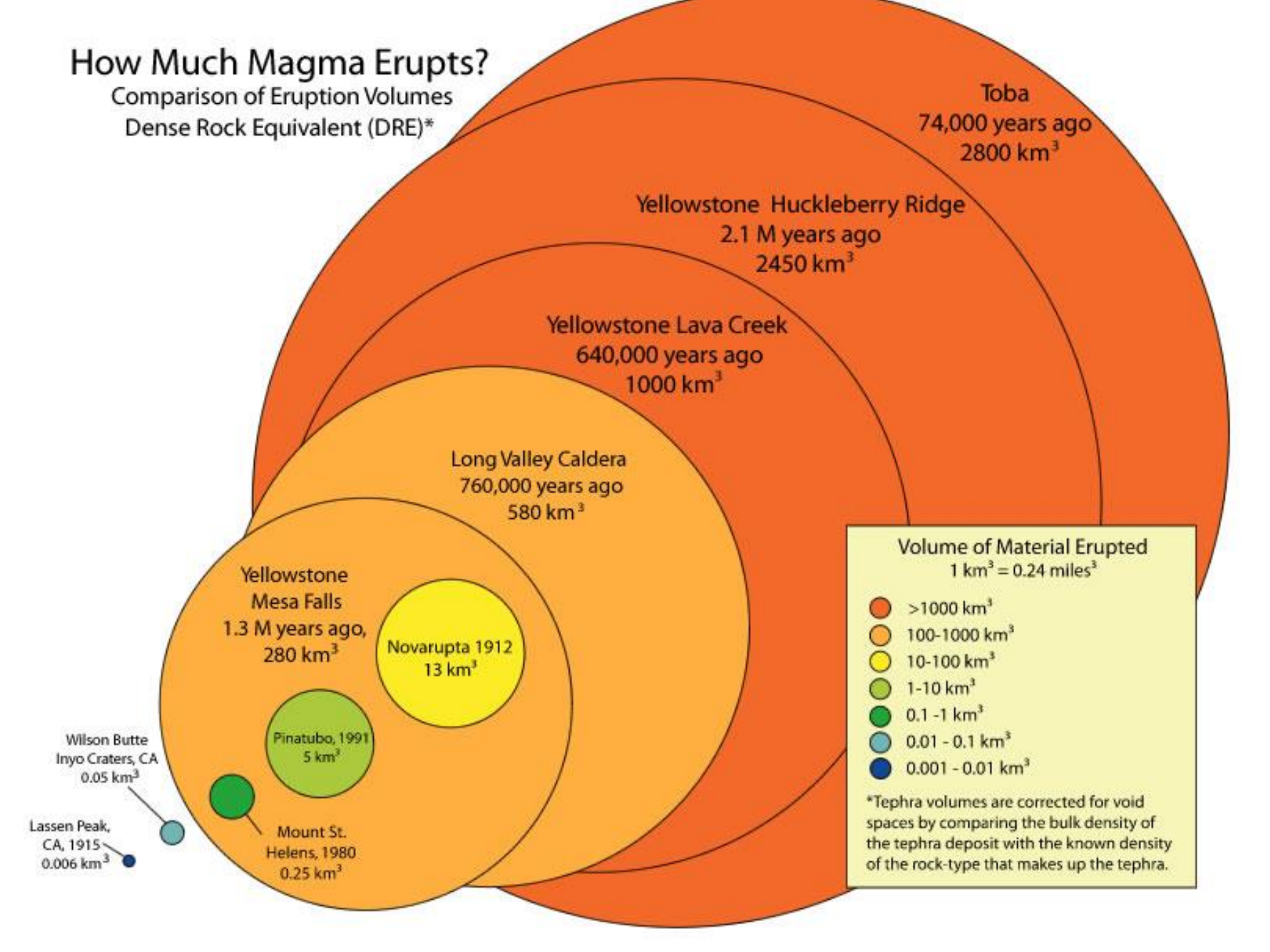



- Eruption began in April with eruption of ~160 $km^3$ of pyroclastic trachyandesite, leaving a caldera 6–7 km across and 600–700 m deep.
- Before the explosion, Mount Tambora was about 4,300 m high. After the explosion, it measured only 2,851 m (about two thirds of its previous height).
- One of the coldest years in the last two centuries occurred after the Tambora eruption which killed 92,000 people 70,000 of which died from starvation following crop failure as a result of the eruption-induced climate change.

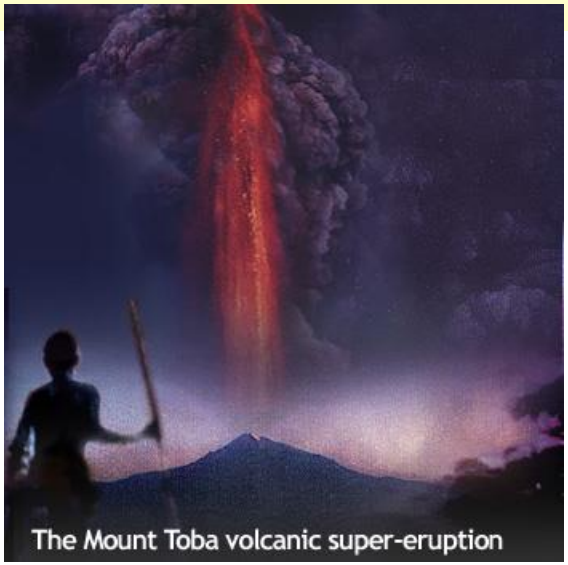
# El Chichon, 1982
# Pinatubo, June 1991

Pinatubo 20 MT $SO_2$ 20 km into air

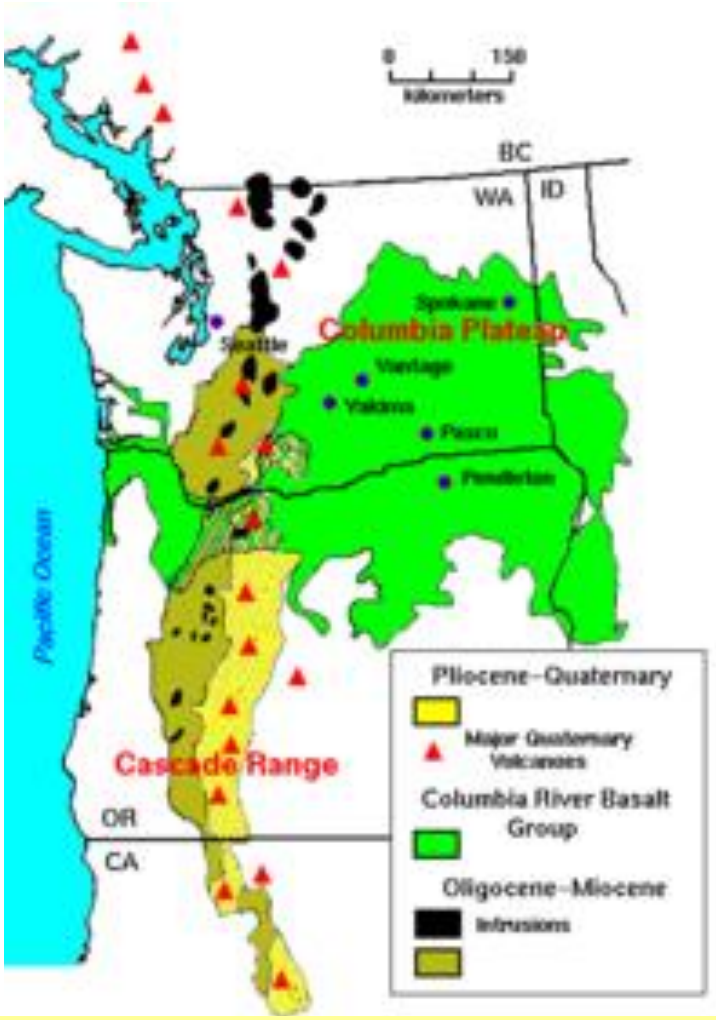



How Much Magma Erupts?
Comparison of Eruption Volumes
Dense Rock Equivalent (DRE)*
Toba
74,000 years ago
2800 km3
Yellowstone Huckleberry Ridge
2.1 M years ago
2450 km3
Yellowstone Lava Creek
640,000 years ago
1000 km3
Long Valley Caldera
760,000 years ago
580 km3
Yellowstone
Mesa Falls
1.3 M years ago,
280 km3
Novarupta 1912
13 km3
Pinatubo, 1991
5 km3
Mount St.
Helens, 1980
0.25 km3
Wilson Butte
Inyo Craters, CA
0.05 km3
Lassen Peak,
CA, 1915
0.006 km3
Volume of Material Erupted
1 km3 = 0.24 miles3
>1000 km3
100-1000 km3
10-100 km3
1-10 km3
0.1 -1 km3
0.01 - 0.1 km3
0.001 - 0.01 km3
*Tephra volumes are corrected for void spaces by comparing the bulk density of the tephra deposit with the known density of the rock-type that makes up the tephra.

# Toba eruption, Sumatra 67,500 - 75,500 years ago





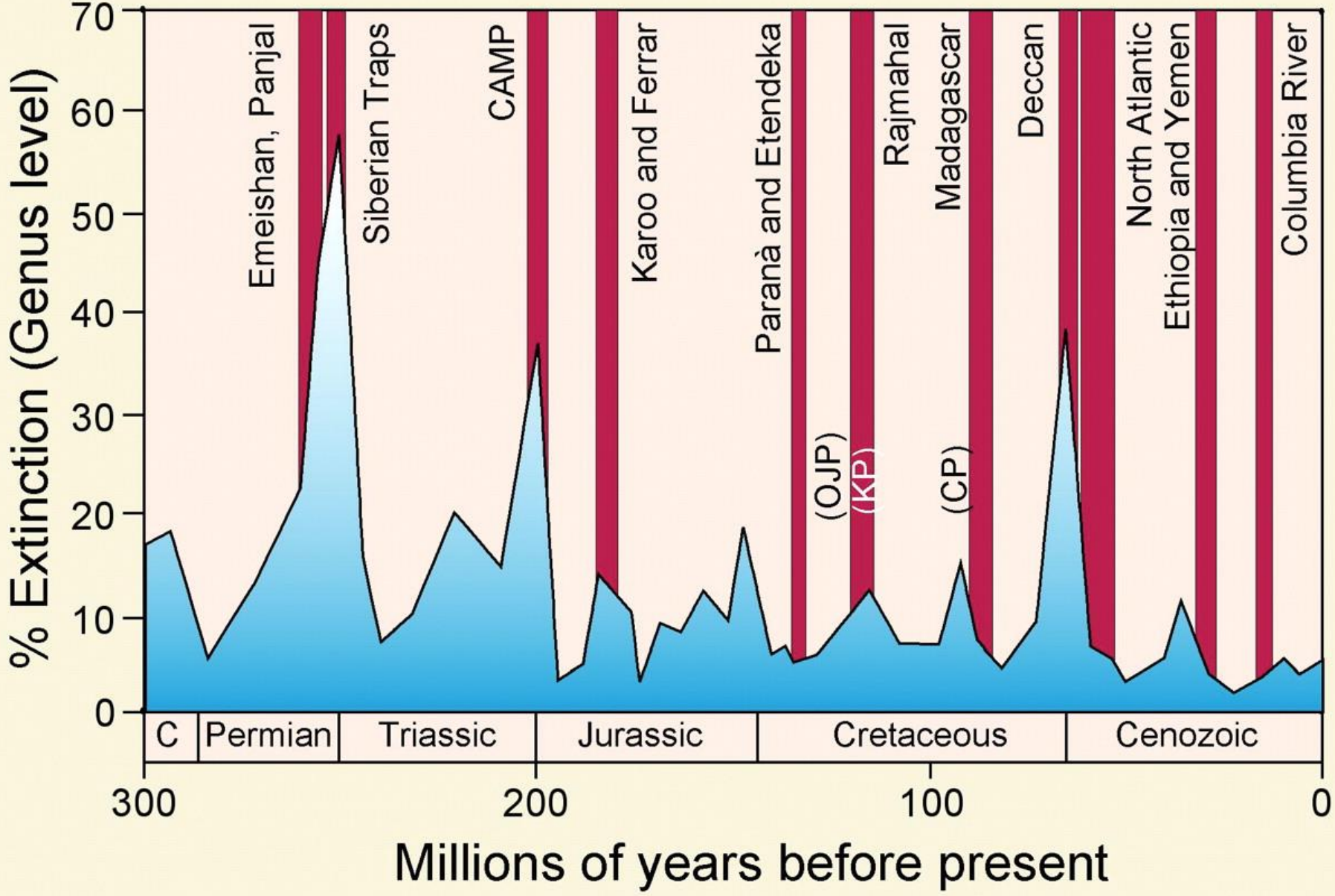


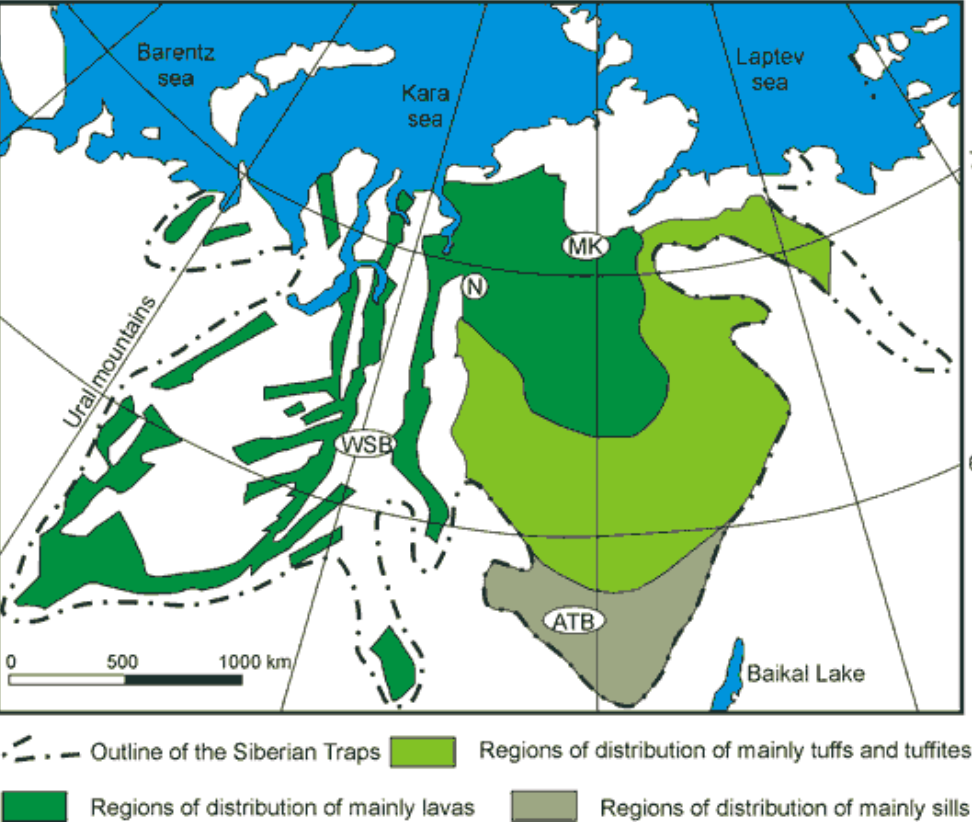
In the past flood basalts have occurred every ~30 Ma e.g. Karoo

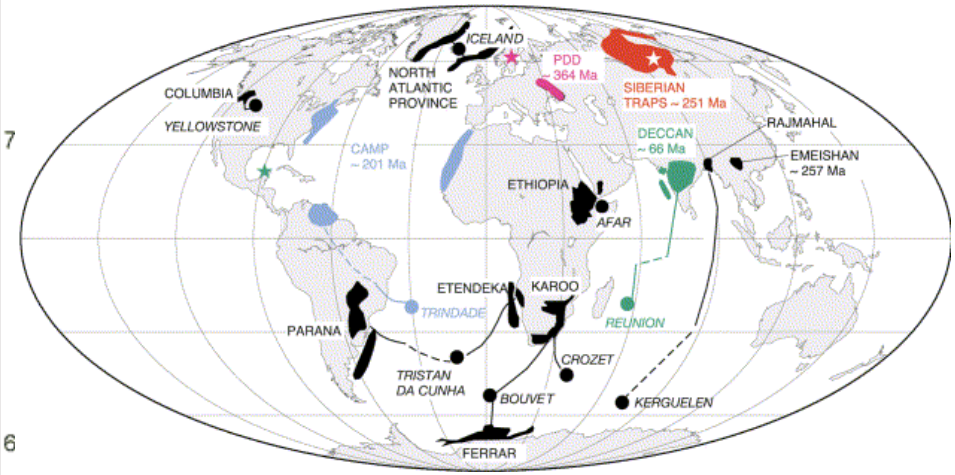
Most vigorous eruptions in Yellowstone area were from 14 to 17 Ma; 180,000 $km^3$ to form the Columbia River basalts

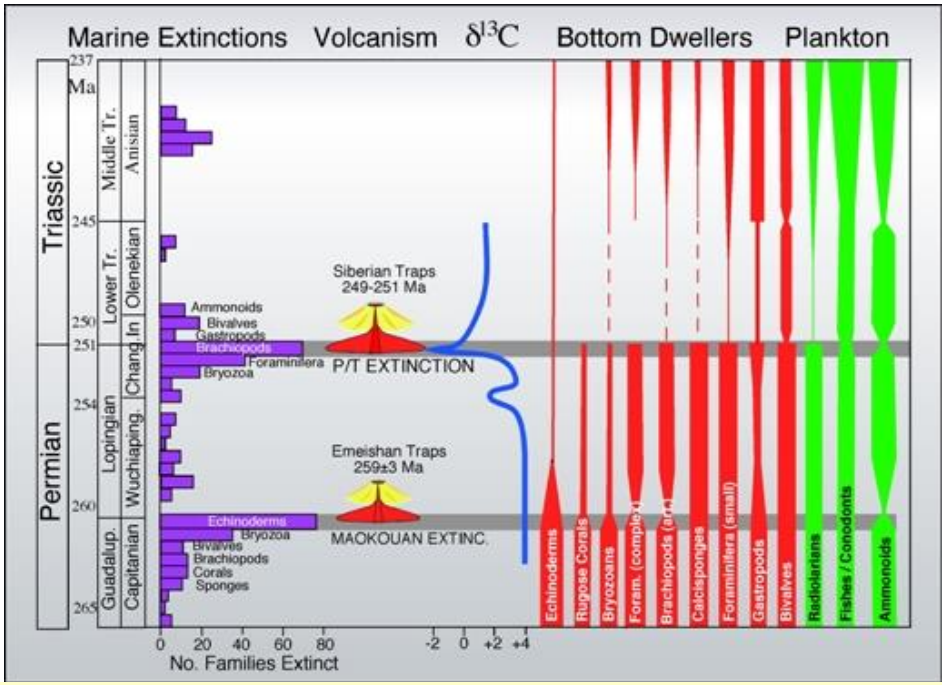
The extent of the flood basalts in India today. More than 1 million $km^3$ of lava was erupted onto the surface in less than 500 000 years

# Volcanoes and extinction





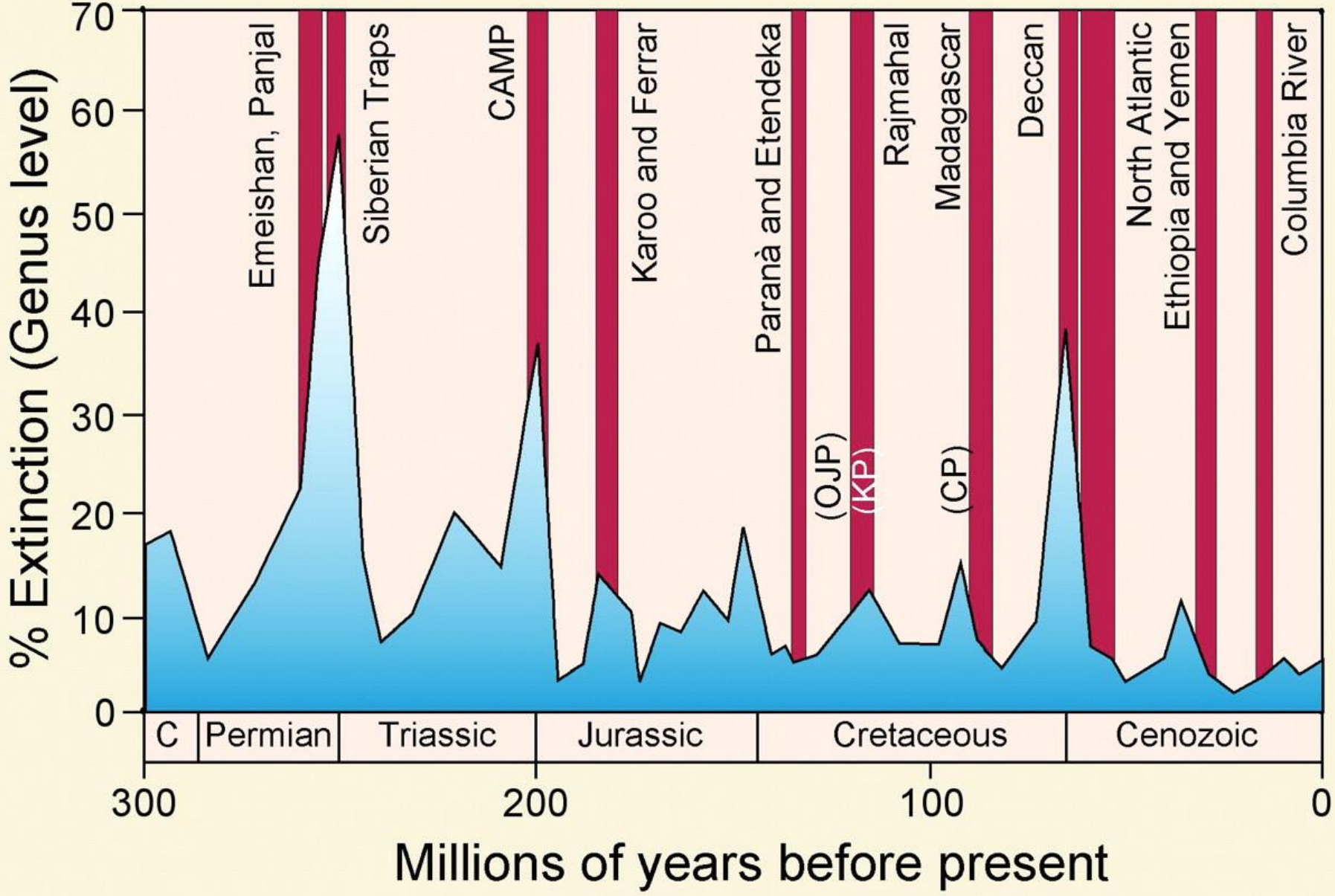



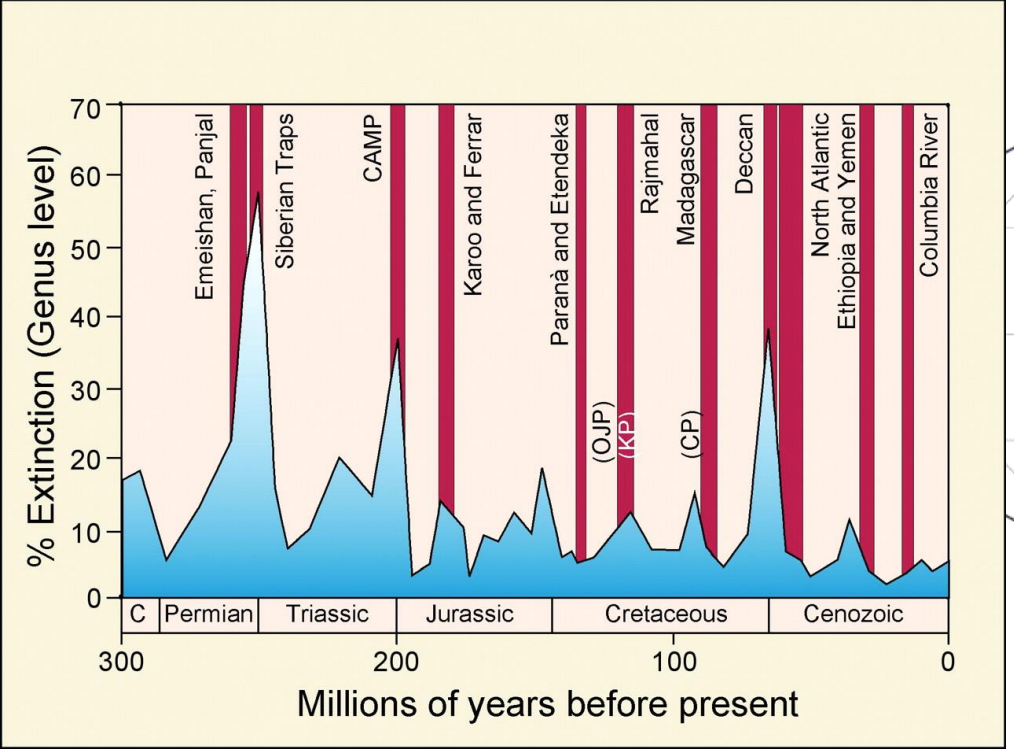



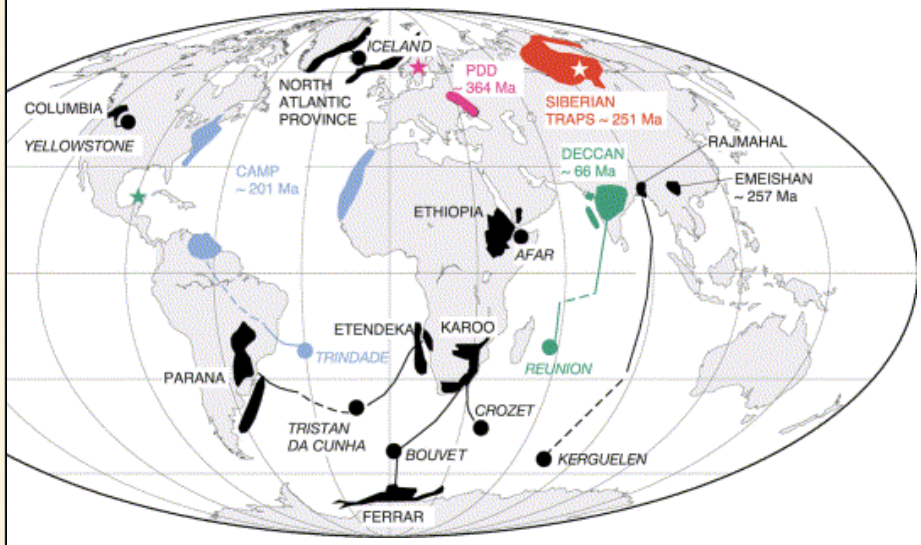

- Vincent Courtillot is a French geophysicist, critical of the hypothesis that impact events are a primary cause of mass extinction on the Earth.
- Courtillot favours the idea that major mass extictions are caused by major volcanic eruptions

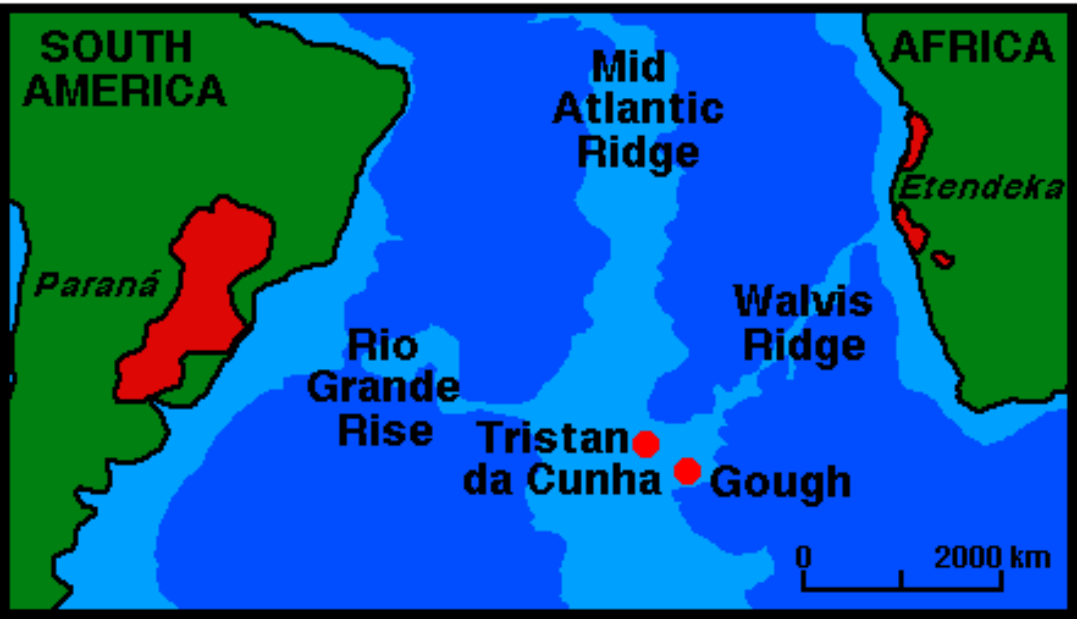
P/T extinctions at the end of the Paleozoic were caused by the Emeishan and Siberian Traps eruption

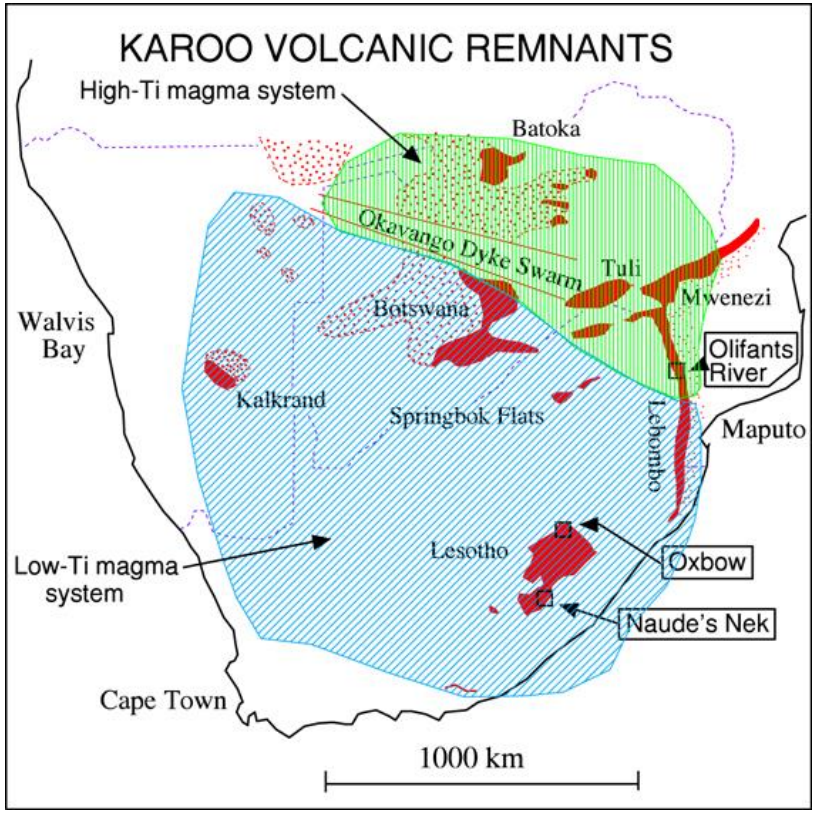
# Volcanoes and extinction



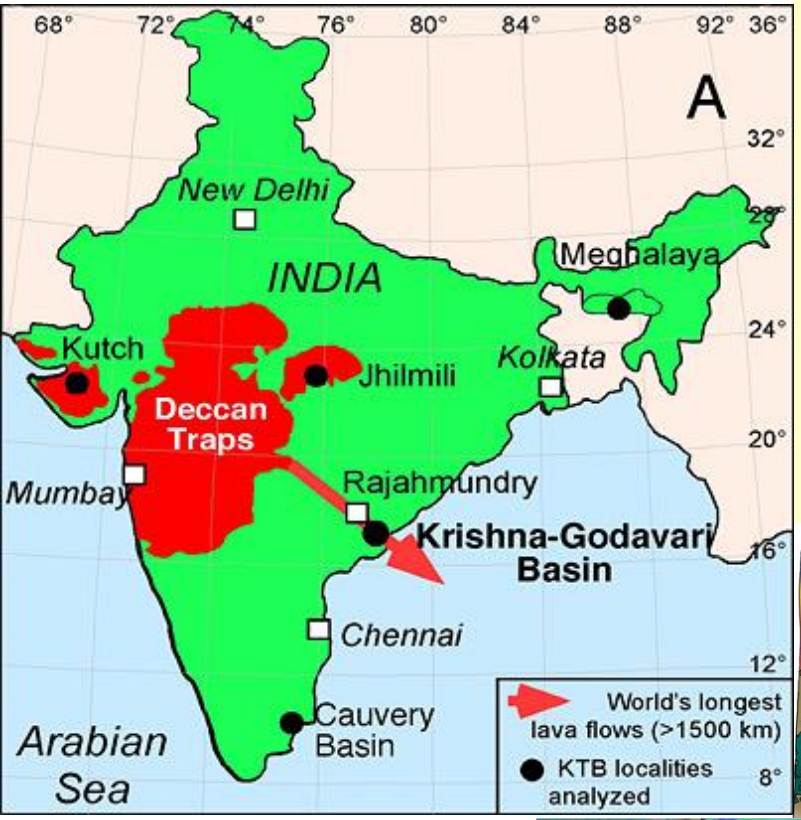

% Extinction (Genus level)
70
60
50
40
30
20
10
0
Emeishan, Panjal
Siberian Traps
CAMP
Karoo and Ferrar
Paranà and Etendeka
(OJP)
(KP)
Rajmahal
Madagascar
(CP)
Deccan
North Atlantic
Ethiopia and Yemen
Columbia River
C
Permian
Triassic
Jurassic
Cretaceous
Cenozoic
300
200
100
0
Millions of years before present


ICELAND
NORTH ATLANTIC PROVINCE
PDD ~ 364 Ma
SIBERIAN TRAPS ~ 251 Ma
COLUMBIA
YELLOWSTONE
CAMP ~ 201 Ma
DECCAN ~ 66 Ma
RAJMAHAL
EMEISHAN ~ 257 Ma
ETHIOPIA
AFAR
ETENDEKA
KAROO
TRINDADE
REUNION
PARANA
CROZET
TRISTAN DA CUNHA
BOUVET
KERGUELEN
FERRAR

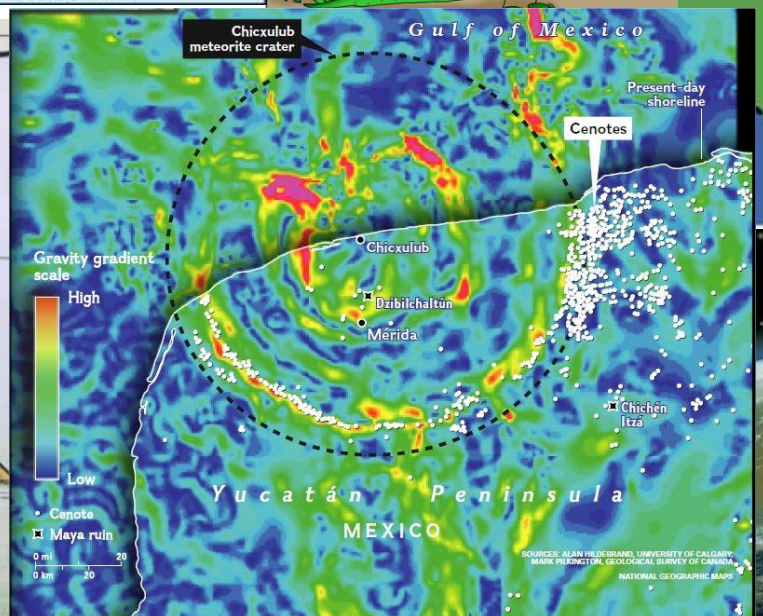

SOUTH AMERICA
Mid Atlantic Ridge
AFRICA
Etendeka
Paraná
Walvis Ridge
Rio Grande Rise
Tristan da Cunha
Gough
0
2000 km


KAROO VOLCANIC REMNANTS
High-Ti magma system
Batoka
Okavango Dyke Swarm
Tuli
Mwenezi
Botswana
Walvis Bay
Olifants River
Kalkrand
Springbok Flats
Lebombo
Maputo
Low-Ti magma system
Lesotho
Oxbow
Naude's Nek
Cape Town
1000 km

- Cretaceous–Paleogene extinction event that ended the Mesozoic Era was caused by the Deccan Traps vulcanism in India
- His position is generally opposed to the hypothesis championed by Luis and Walter Alvarez, that the K/T extinction that saw the end of the dinosaurs was primarily due to the asteroid impact at Chicxulub on the Yucatan Peninsula

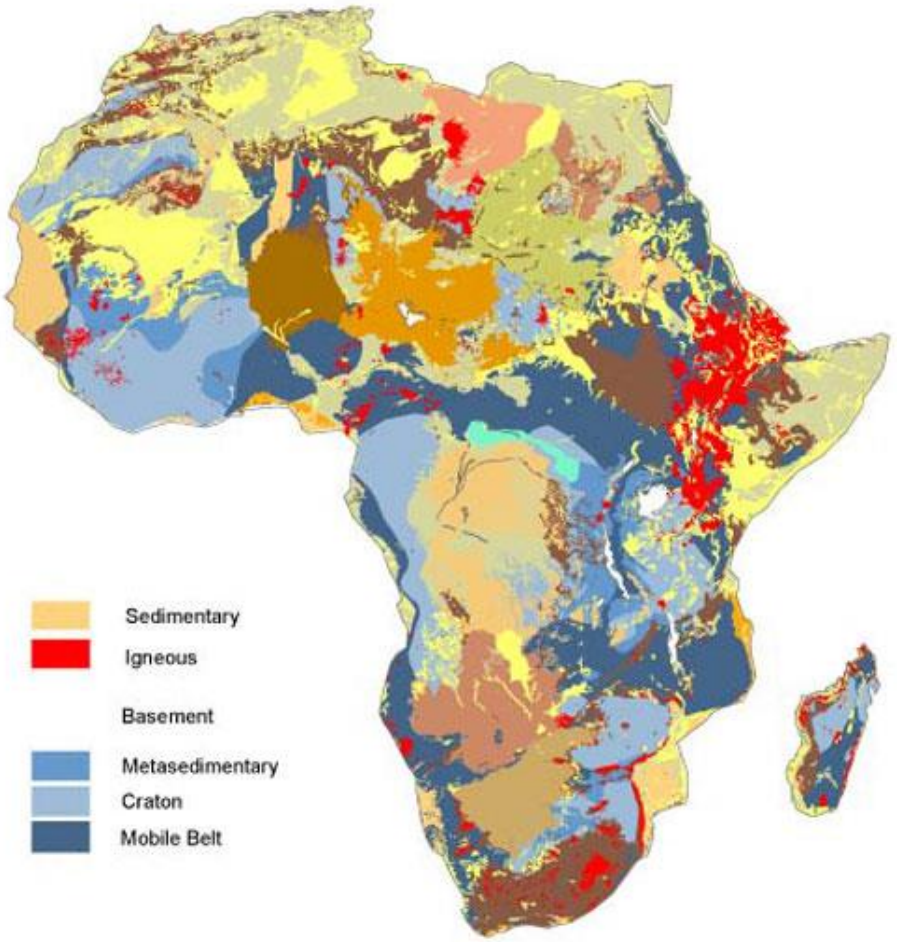




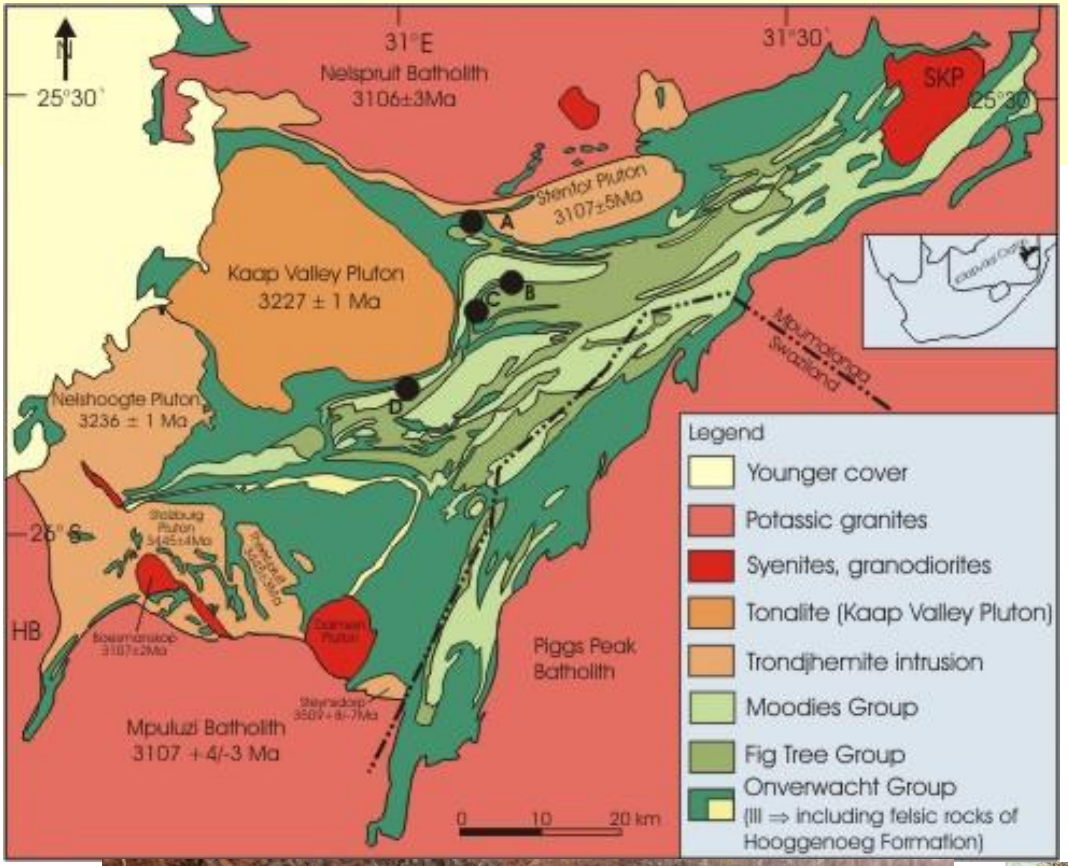




# So what about Africa

- Barberton, South Africa 3.1-3.5 Ga
- Archaen granite-green stone terranes in Africa
- Ventersdorp event 2.6 Ga, South Africa
- Great Dyke, Zimbabwe
- Bushveld Complex 2.05 Ga
- Damaran-Lufilian magmatism, Namibia, Zambia 570-510 Ma
- Karoo
- Nigerian Ring Complexes 190-140 Ma
- Sudan Complexes  175-130 Ma
- Rift valley volcanoes -Recent

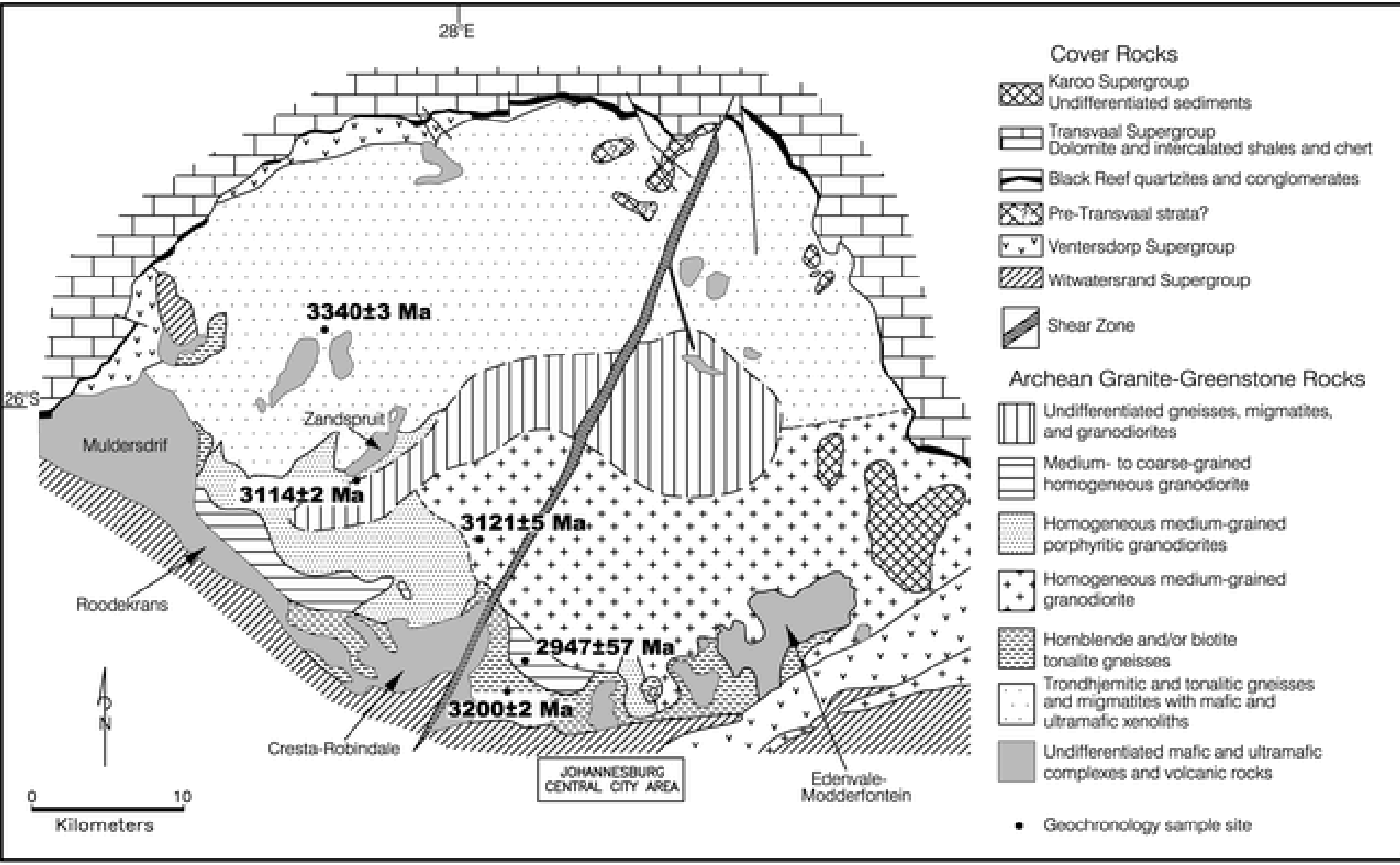


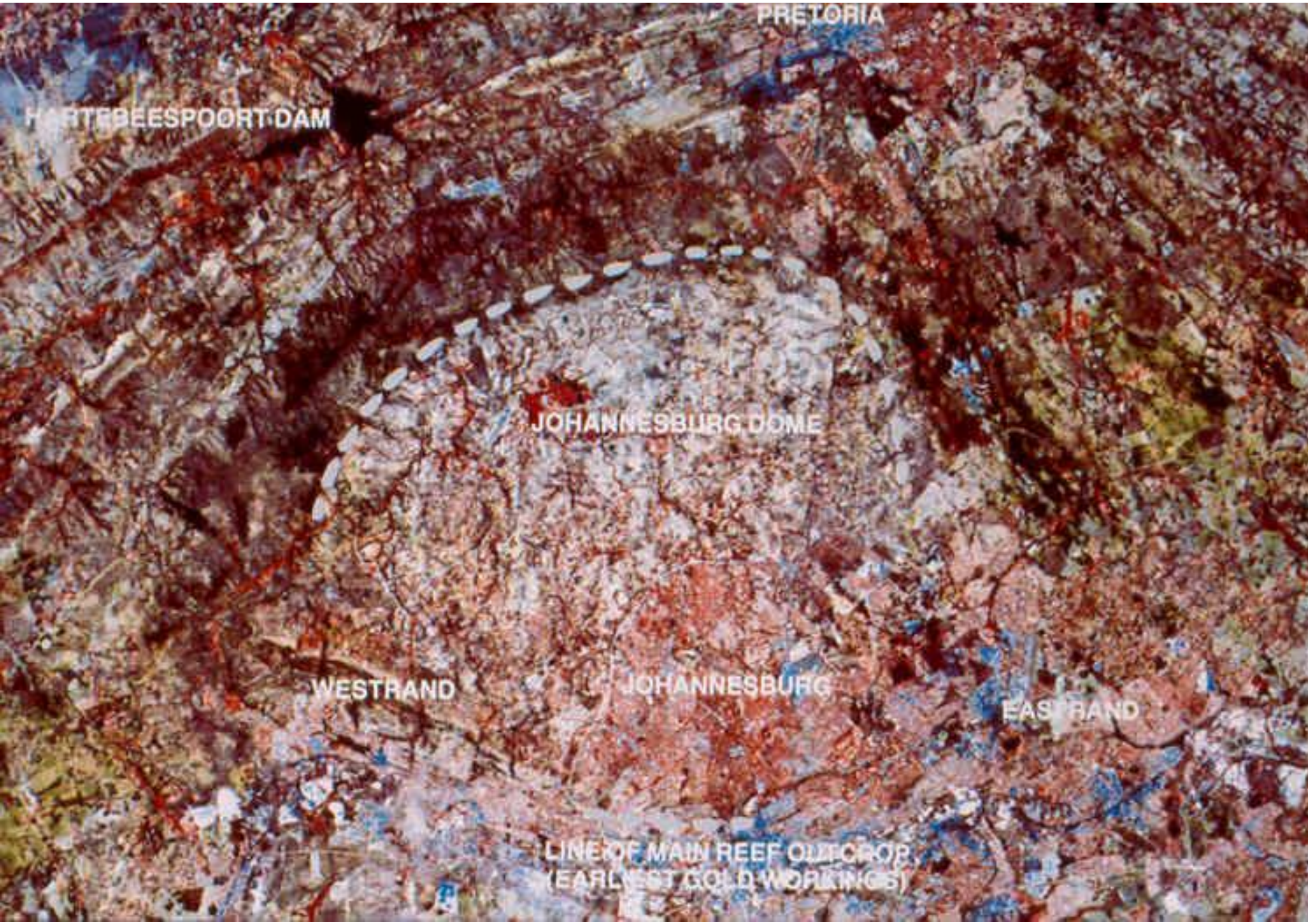
# Barberton



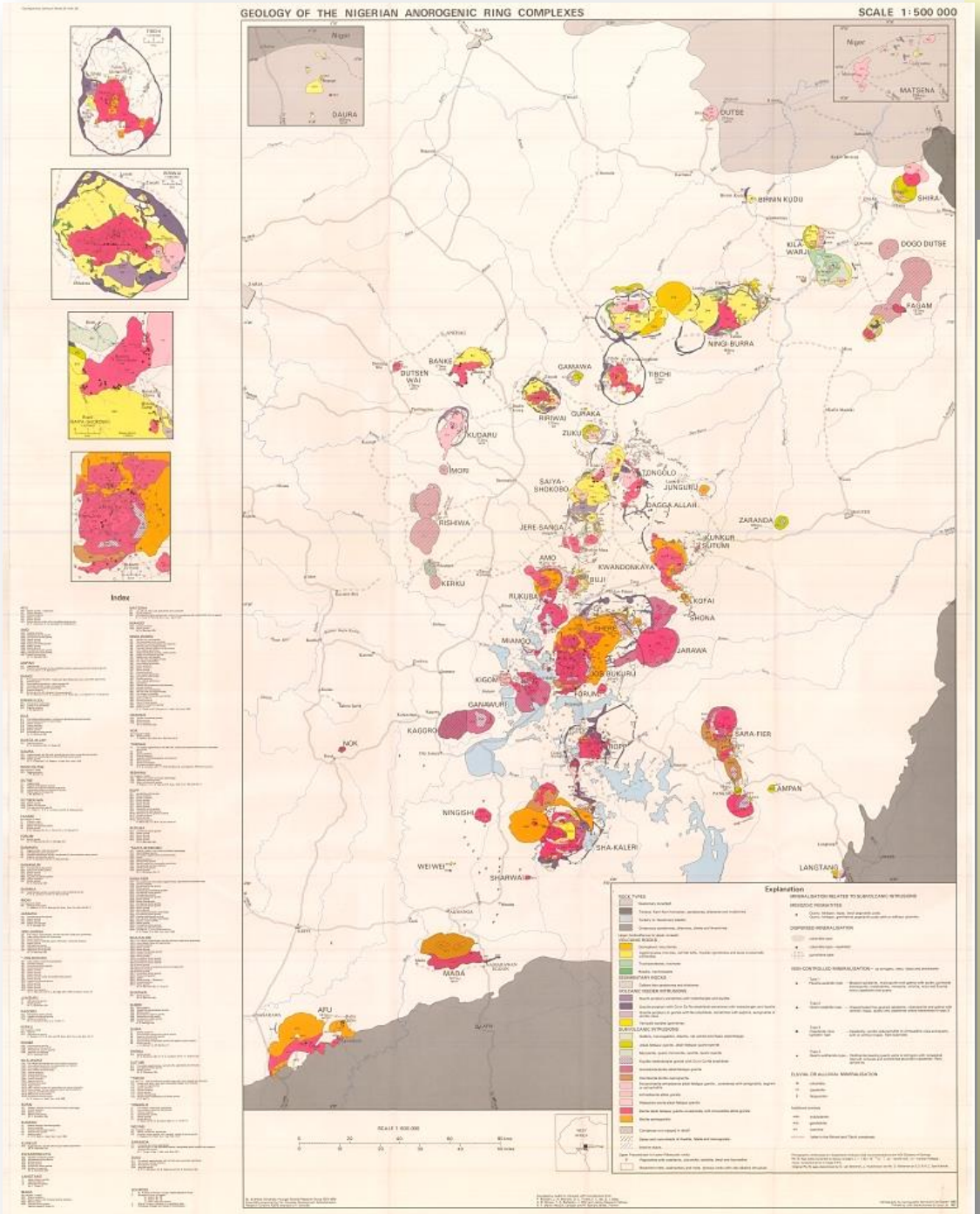

- The Barberton greenstone belt, is one of the oldest and best exposed Archaean greenstone belts on Earth
- Comprises volcanic and sedimentary rocks formed 3.5-3.1 billion years ago.
- Major episodes of tectono-magmatic activity occurred at ca. 3.45, 3.23 and 3.1 Ga, the earliest of which is a result of subduction-related crustal shortening.

# Johannesburg Dome




PRETORIA
HARTEBEESPOORT DAM
JOHANNESBURG DOME
WESTRAND
JOHANNESBURG
EAST RAND
LINE OF MAIN REEF OUTCROP

# Nigeria

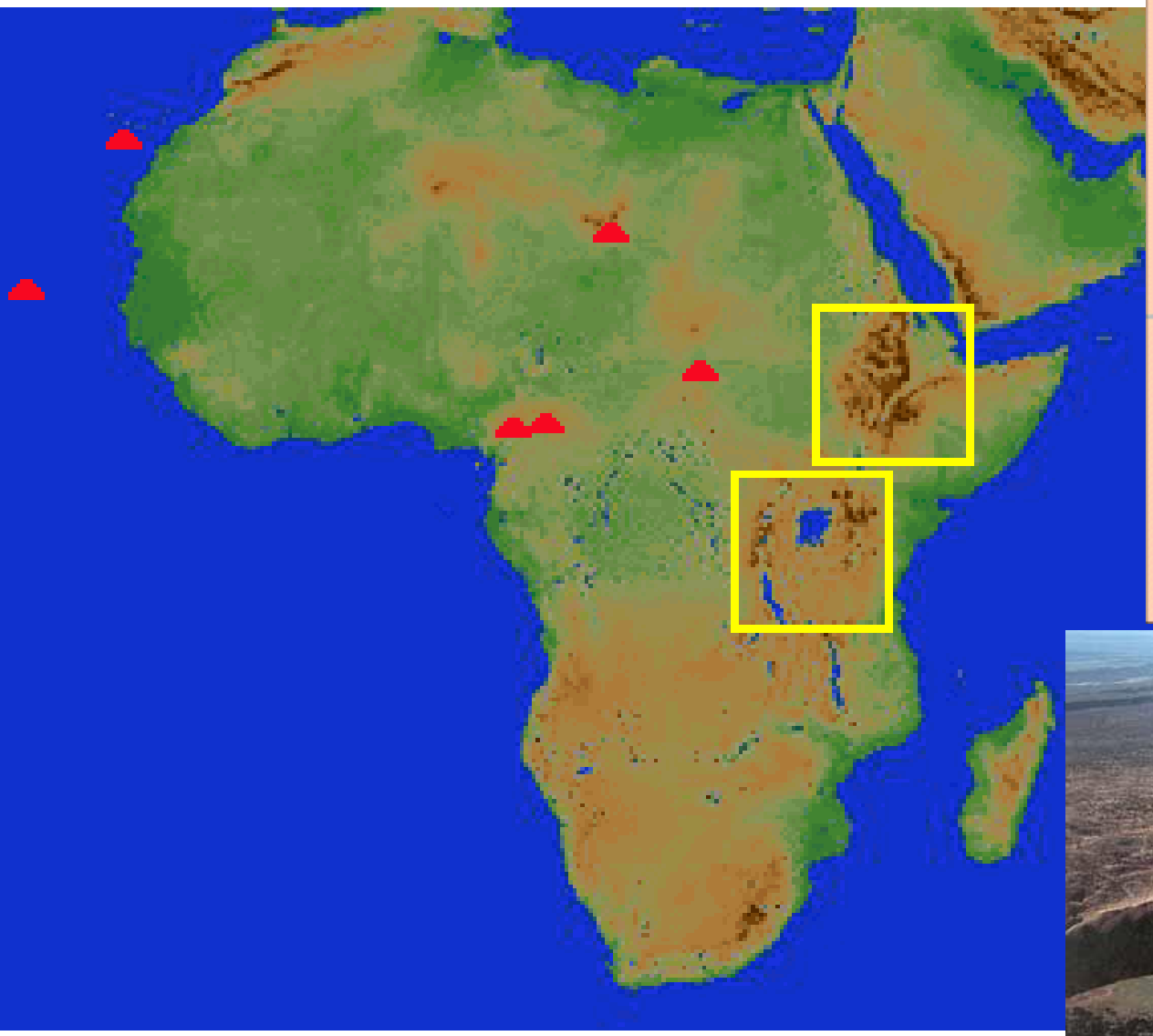


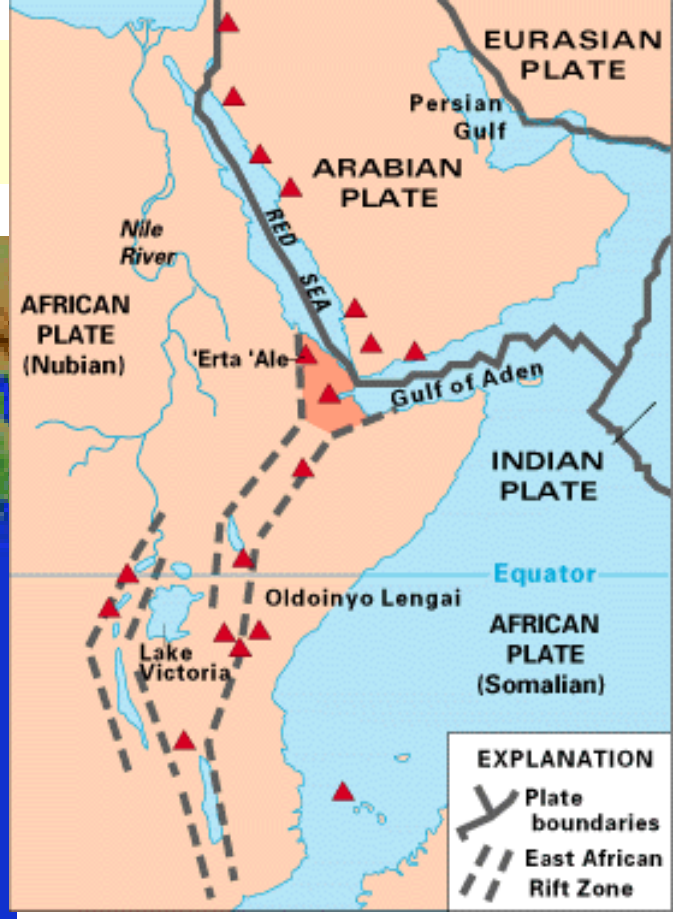

- Ring complexes show granite intruded into high crustal levels to intrude their own volcanic pile
- Magmatism migrated from the northern border at 190 Ma southwards
- The youngest complex is 144 Ma
- Volcanics are mainly preserved in the north

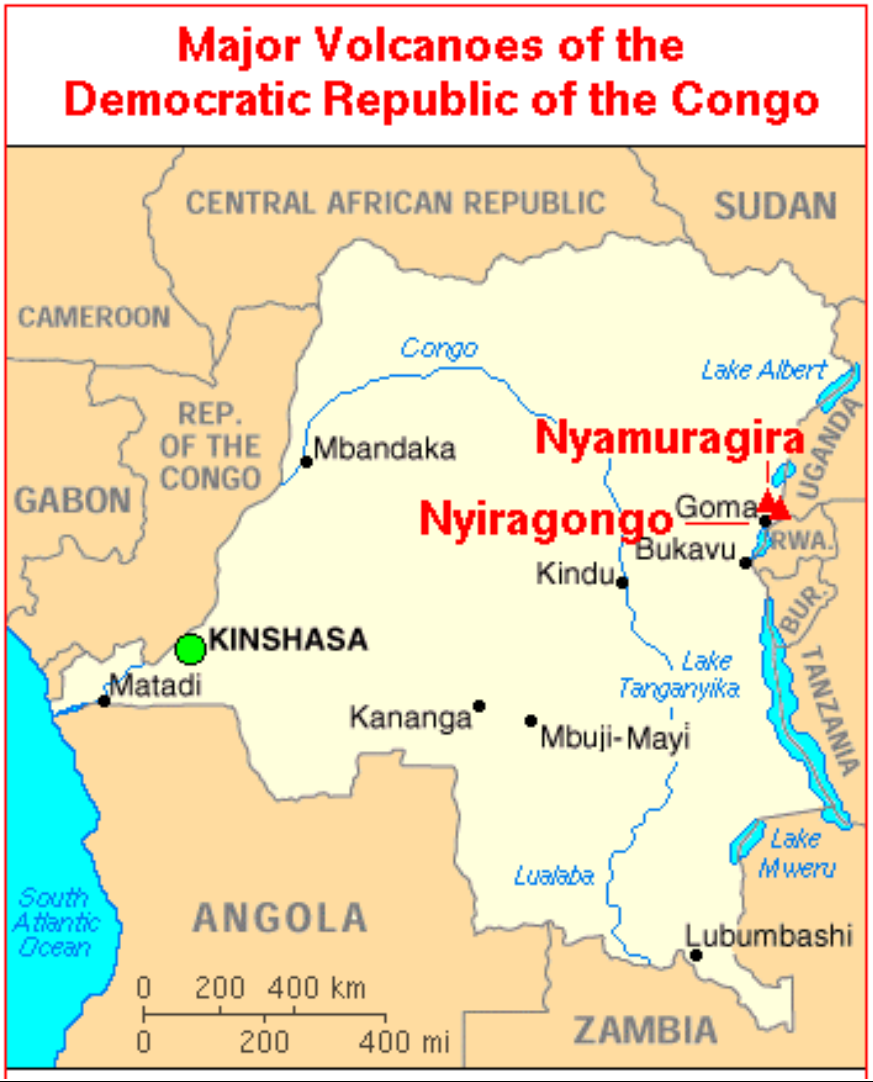
# Volcano eruptions

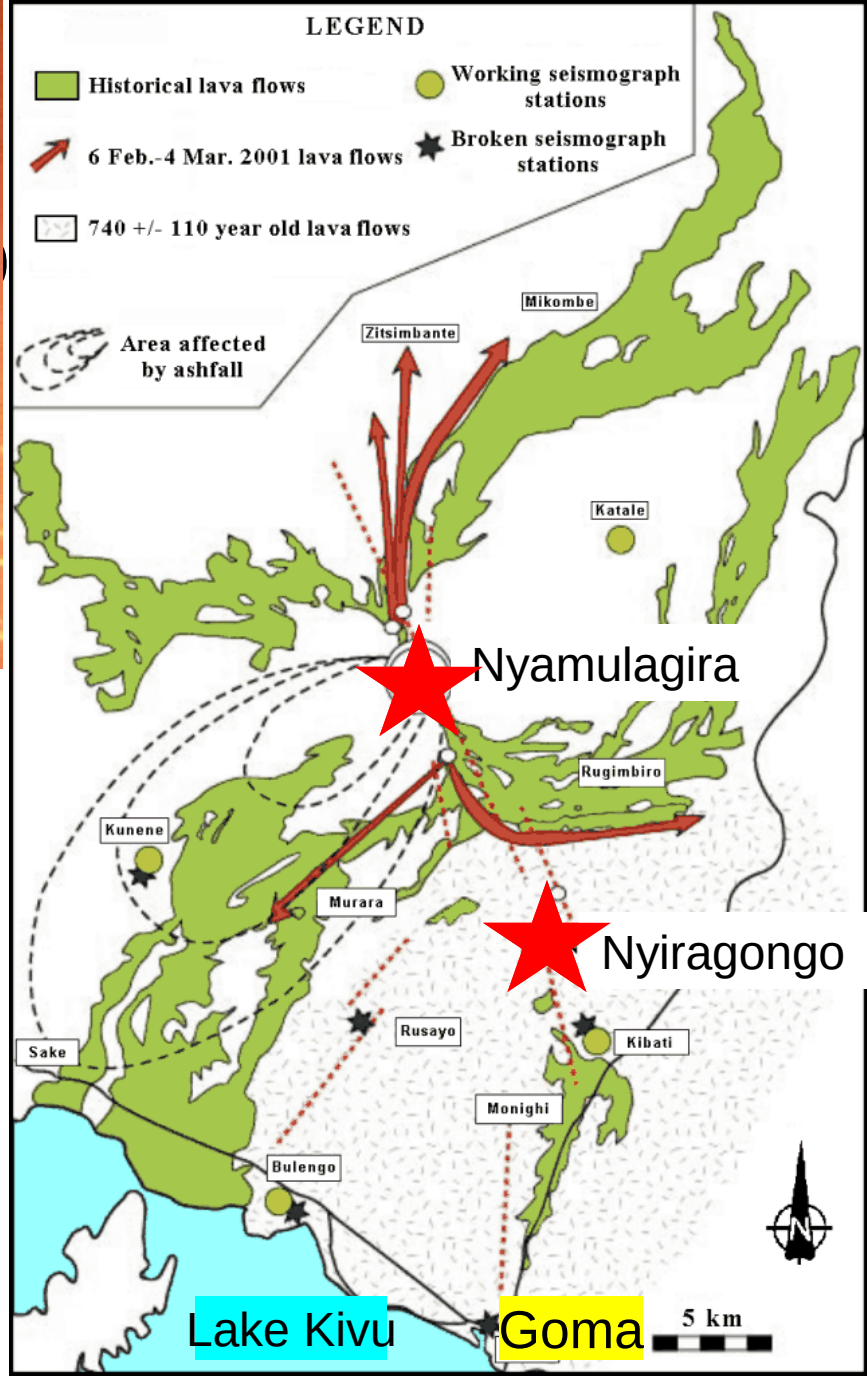
Challenges to Africa

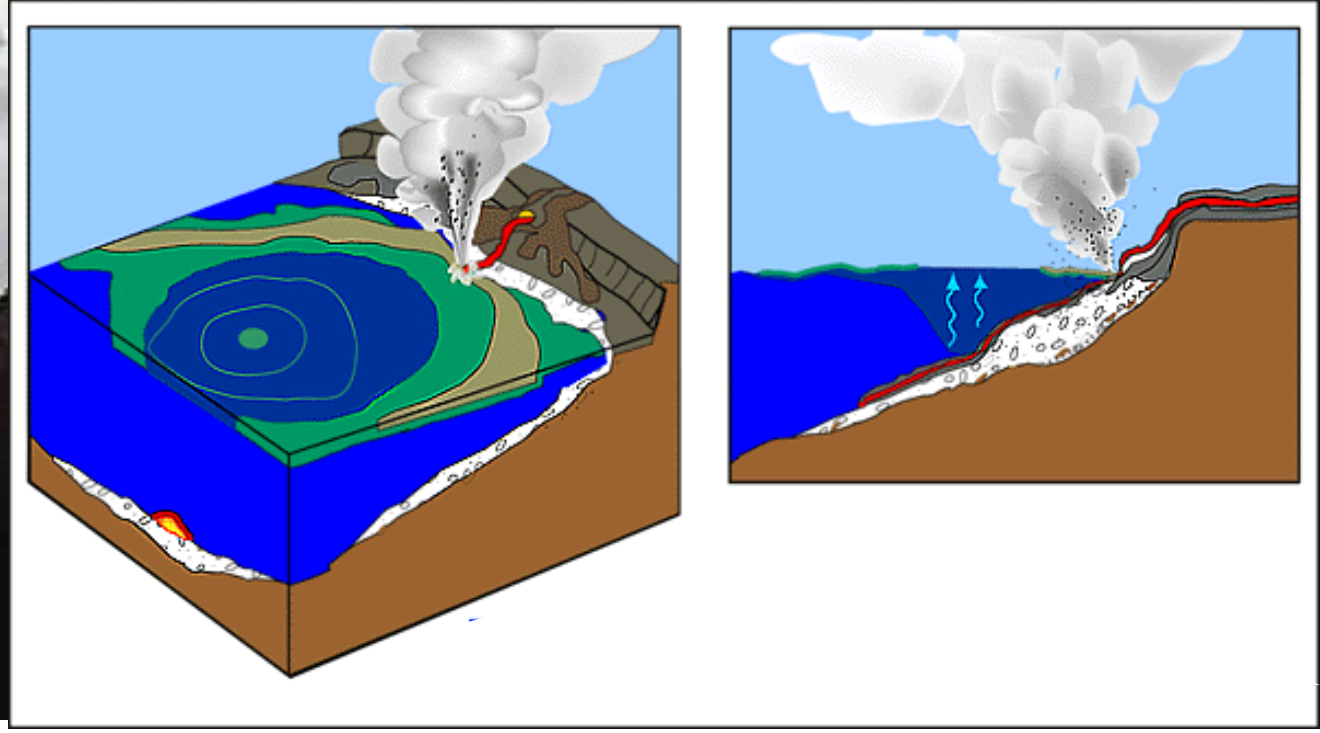
# Active volcanoes



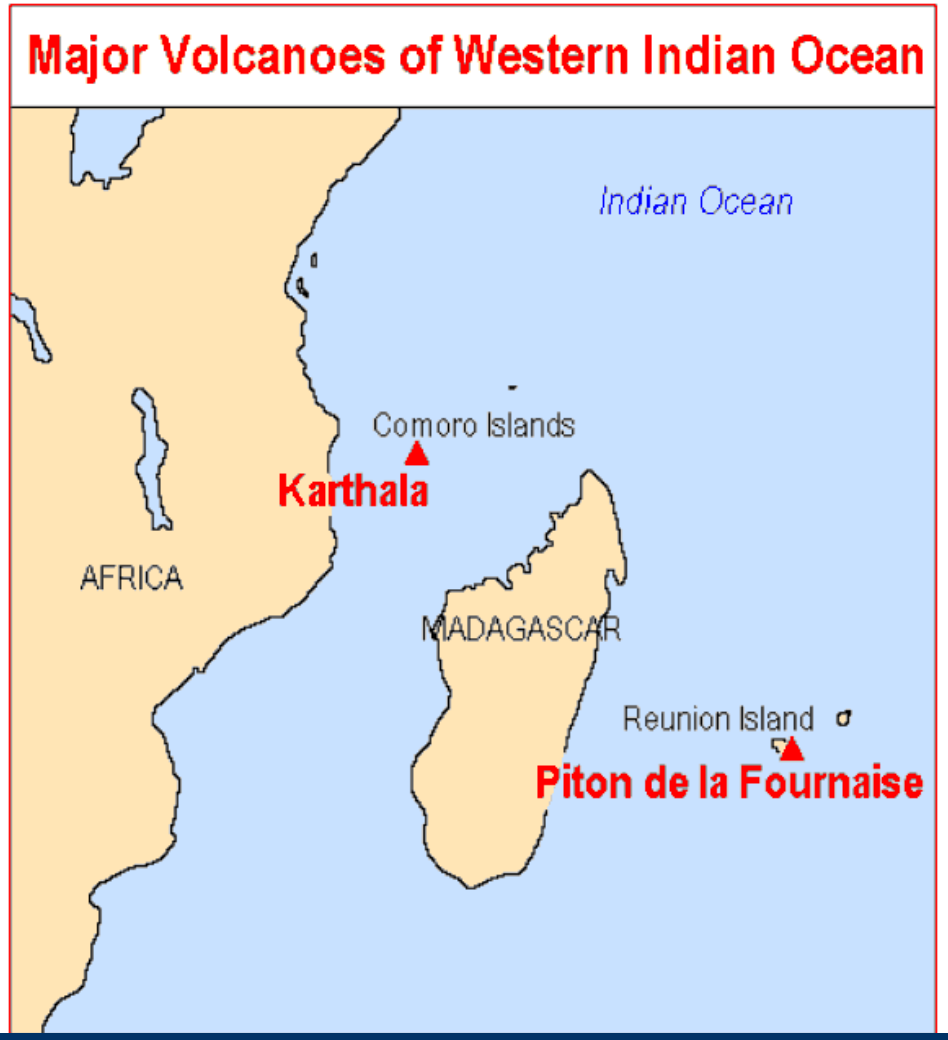


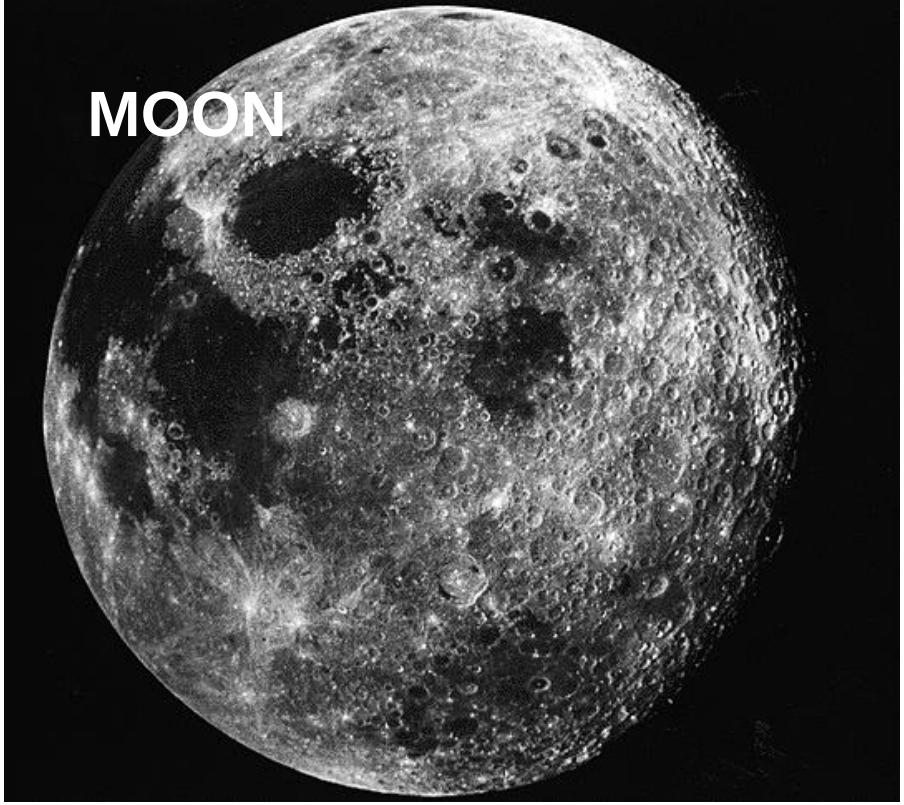


Major Volcanoes of the
Democratic Republic of the Congo
CENTRAL AFRICAN REPUBLIC
SUDAN
CAMEROON
Congo
Lake Albert
REP.
OF THE
CONGO
Mbandaka
Nyamuragira
UGANDA
GABON
Nyiragongo
Goma
RWA.
Bukavu
Kindu
BUR.
KINSHASA
Lake
Tanganyika
TANZANIA
Matadi
Kananga
Mbuji-Mayi
Lake
Mweru
Lualaba
South
Atlantic
Ocean
ANGOLA
Lubumbashi
0 200 400 km
0 200 400 mi
ZAMBIA

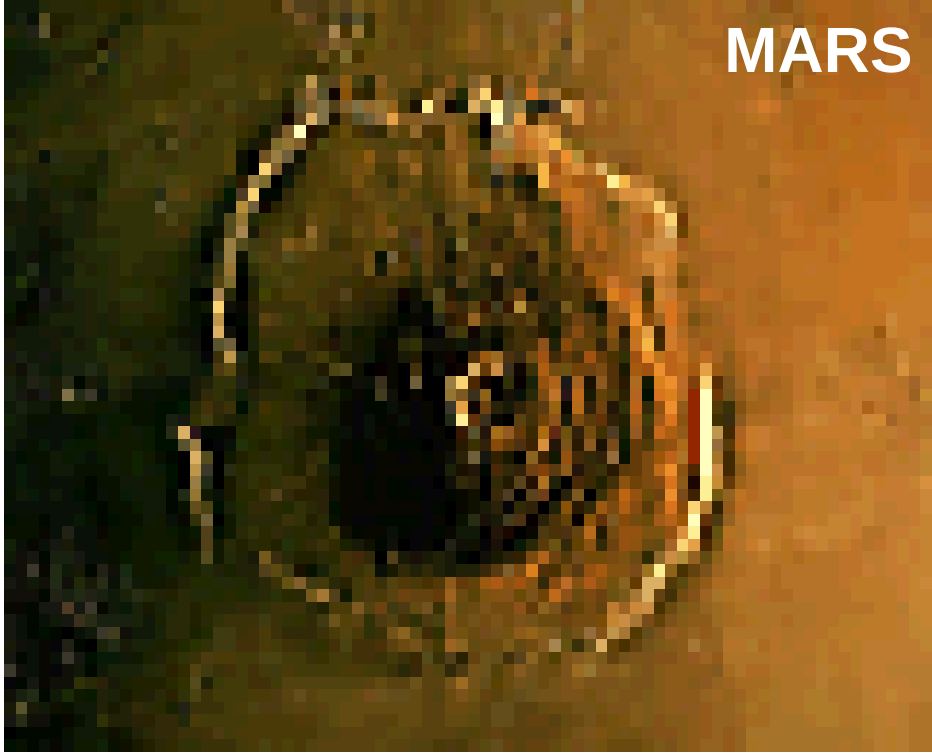

LEGEND
Historical lava flows
Working seismograph stations
6 Feb.-4 Mar. 2001 lava flows
Broken seismograph stations
740 +/- 110 year old lava flows
Area affected by ashfall
Mikombe
Zitsimbante
Katale
Nyamulagira
Rugimbiro
Kunene
Murara
Nyiragongo
Rusayo
Kibati
Sake
Monighi
Bulengo
Lake Kivu
Goma
5 km

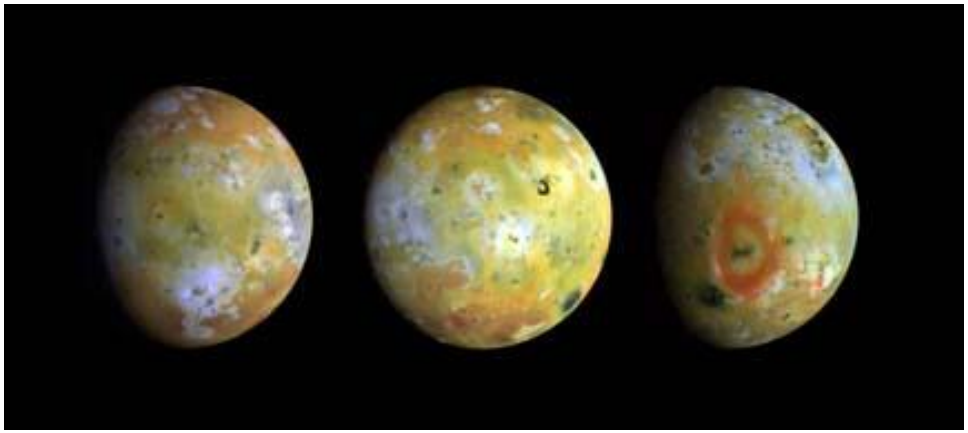



250 km
LAKE
VICTORIA
Nairobi
Lengai
Meru
Kilimanjaro
Ngorongoro
Arusha
ZANZIBAR
LAKE
TANGANJIKA
Dar Es Salaam
LAKE
MALAWI

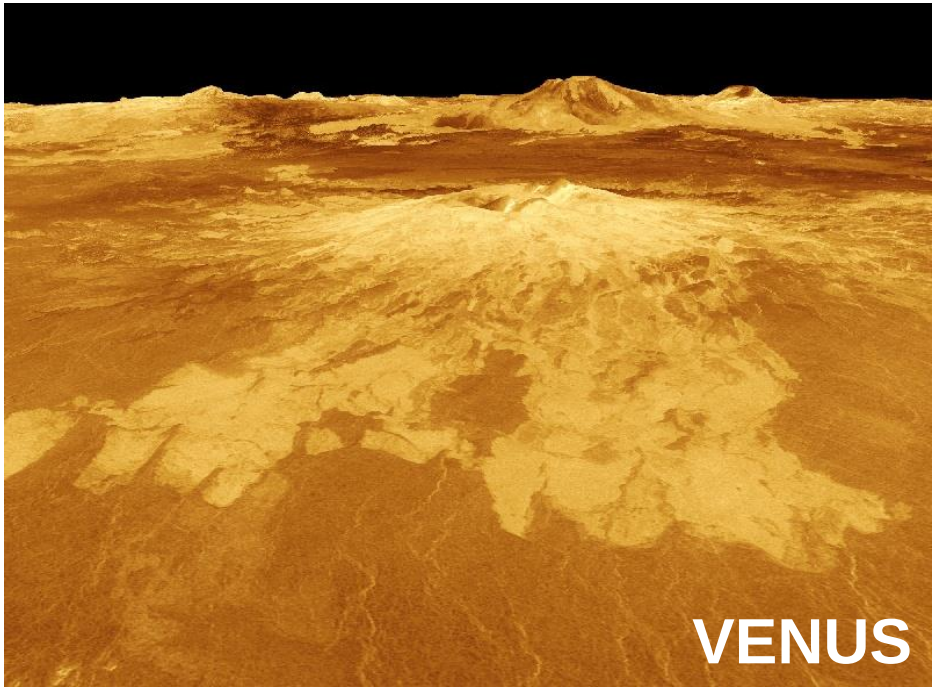

Major Volcanoes of Western Indian Ocean
Indian Ocean
Comoro Islands
Karthala
AFRICA
MADAGASCAR
Reunion Island
Piton de la Fournaise

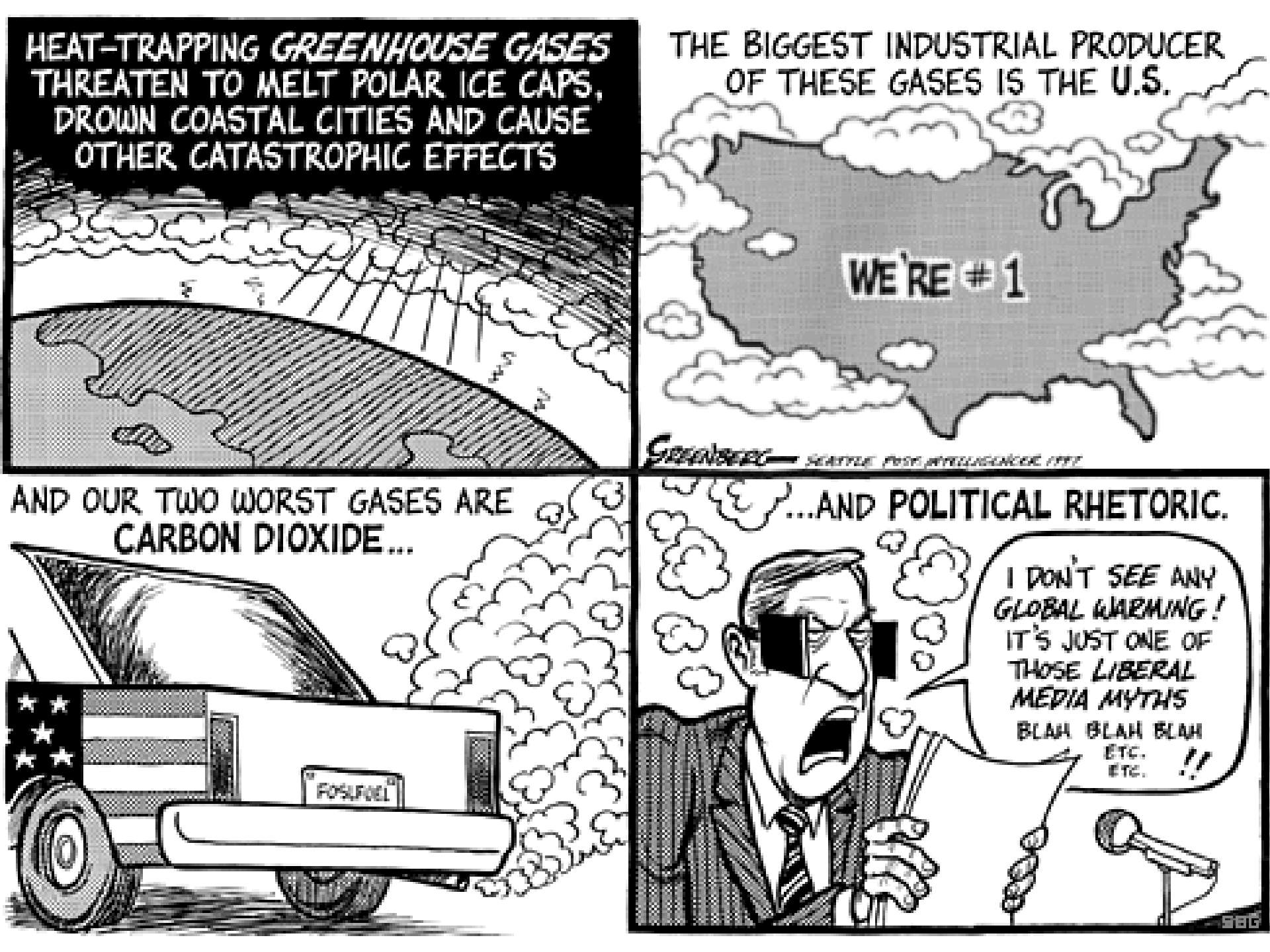


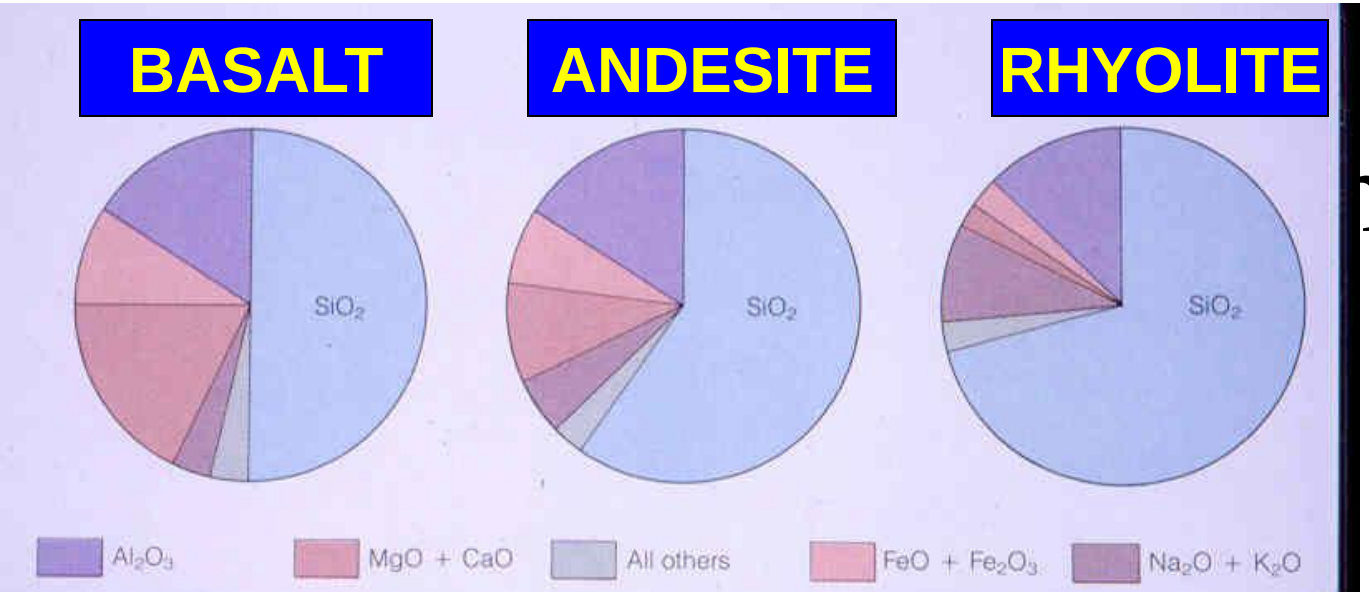



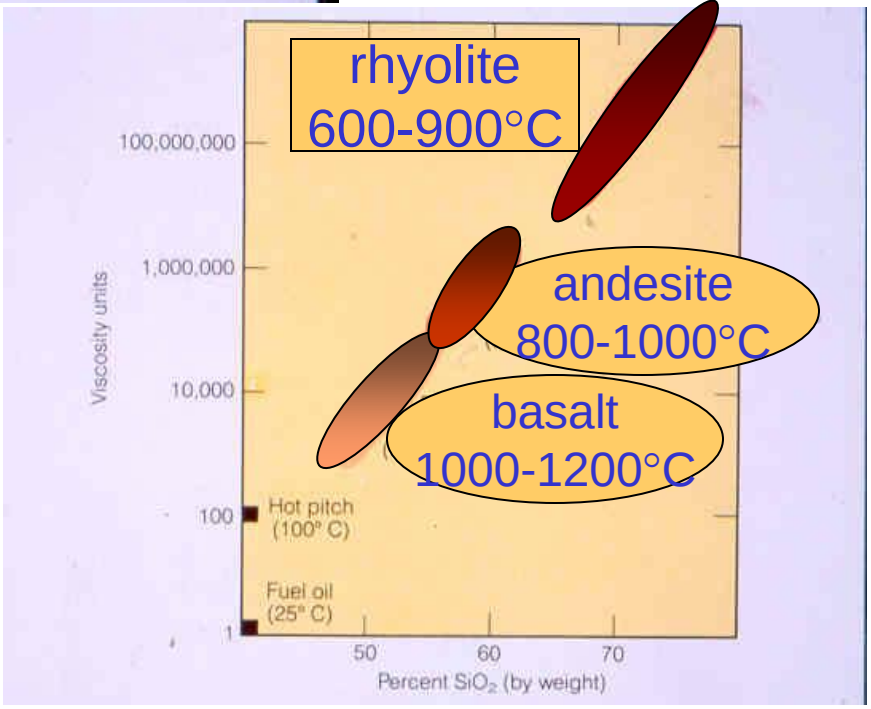



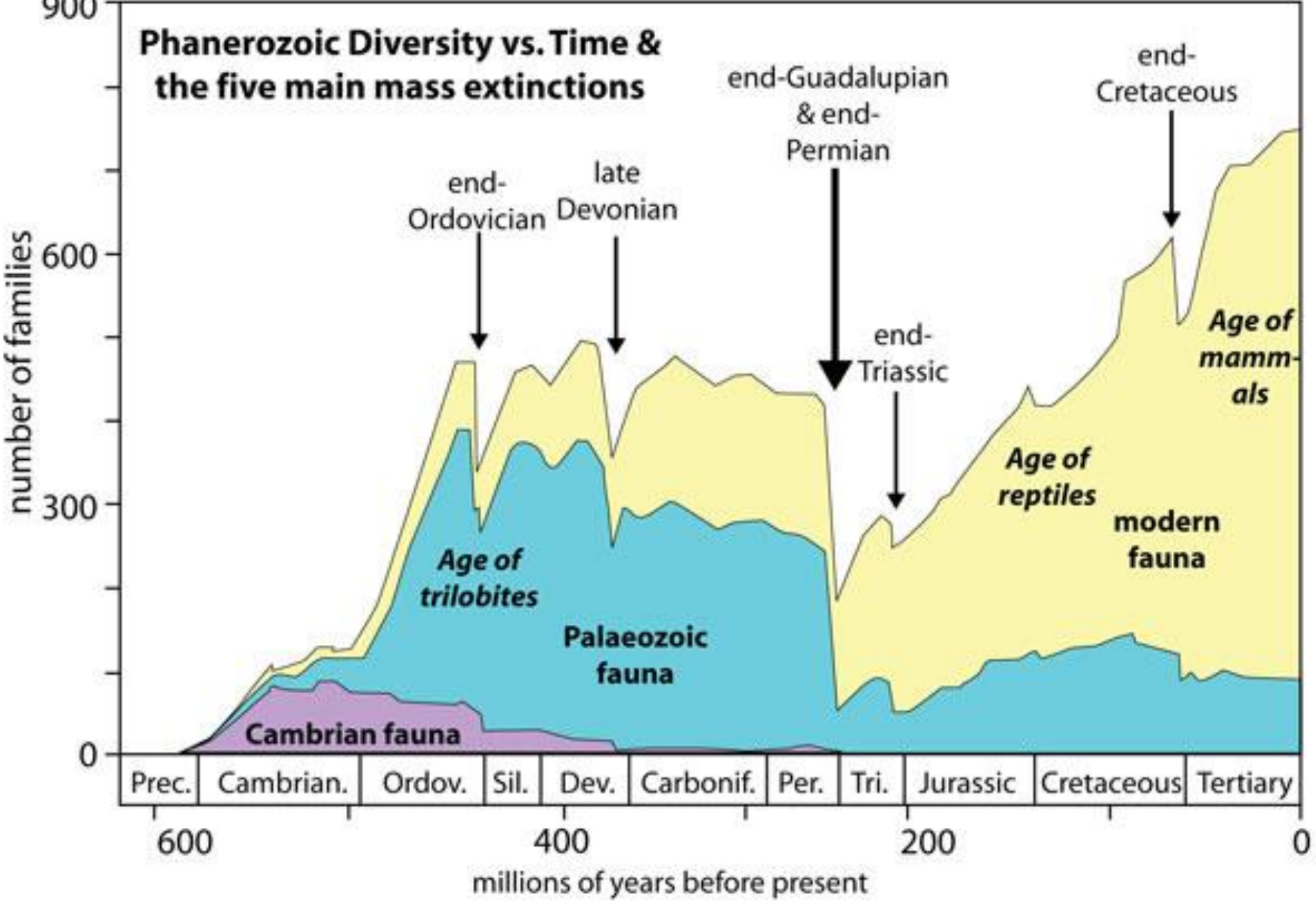
Io - one of the moons of Jupiter




HEAT-TRAPPING GREENHOUSE GASES THREATEN TO MELT POLAR ICE CAPS, DROWN COASTAL CITIES AND CAUSE OTHER CATASTROPHIC EFFECTS
THE BIGGEST INDUSTRIAL PRODUCER OF THESE GASES IS THE U.S.
WE'RE #1
GREENBERG— SEATTLE POST-INTELLIGENCER 1997
AND OUR TWO WORST GASES ARE CARBON DIOXIDE...
FOSUFUEL
...AND POLITICAL RHETORIC.
I DON'T SEE ANY GLOBAL WARMING! IT'S JUST ONE OF THOSE LIBERAL MEDIA MYTHS BLAH BLAH BLAH ETC. ETC. !!


BASALT
ANDESITE
RHYOLITE
SiO2
SiO2
SiO2
Al2O3
MgO + CaO
All others
FeO + Fe2O3
Na2O + K2O


rhyolite
600-900°C
andesite
800-1000°C
basalt
1000-1200°C
100,000,000
1,000,000
10,000
100
1
Viscosity units
Hot pitch
(100° C)
Fuel oil
(25° C)
50
60
70
Percent SiO2 (by weight)


Phanerozoic Diversity vs. Time &
the five main mass extinctions
number of families
900
600
300
0
end-
Ordovician
late
Devonian
end-Guadalupian
& end-
Permian
end-
Triassic
end-
Cretaceous
Age of
trilobites
Palaeozoic
fauna
Cambrian fauna
Age of
reptiles
modern
fauna
Age of
mamm-
als
Prec.
Cambrian.
Ordov.
Sil.
Dev.
Carbonif.
Per.
Tri.
Jurassic
Cretaceous
Tertiary
600
400
200
0
millions of years before present