The Volcano-Magma System of the Canary Islands: Origin evolution, and the balance between hazards and resources

Prof. Valentin R. Troll

Volcanic Hazards, Eruption products, and Volcanic Resources

GEOCHEMISTRY PETROLOGY VOLCANOLOGY
UPPSALA UNIVERSITY

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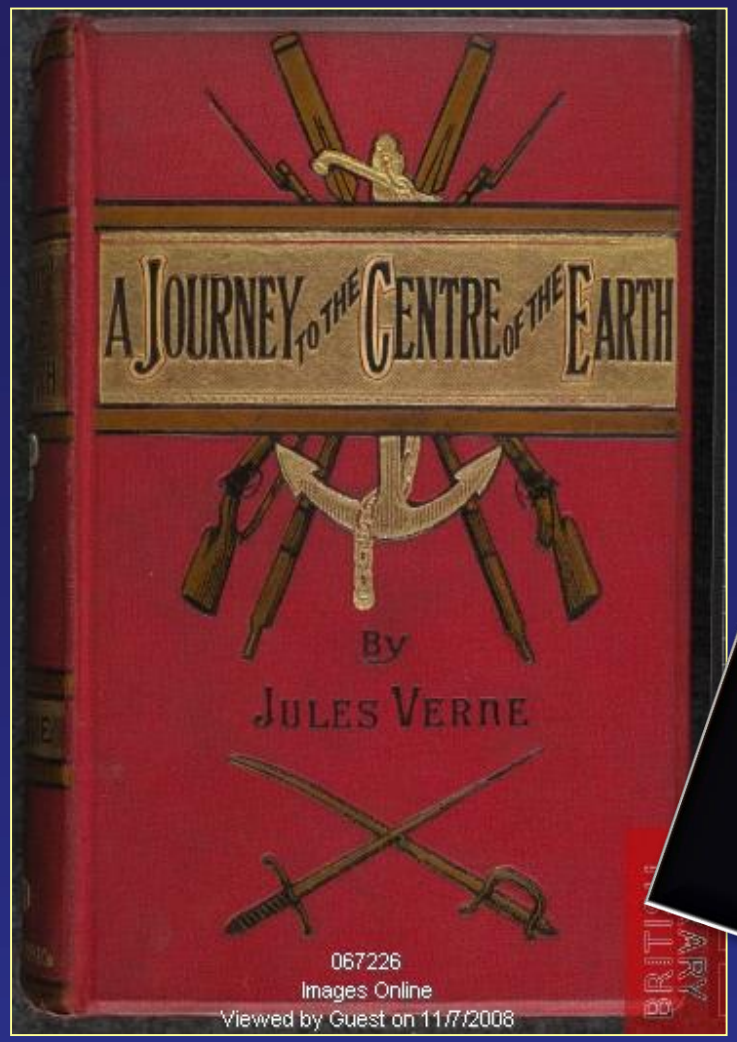
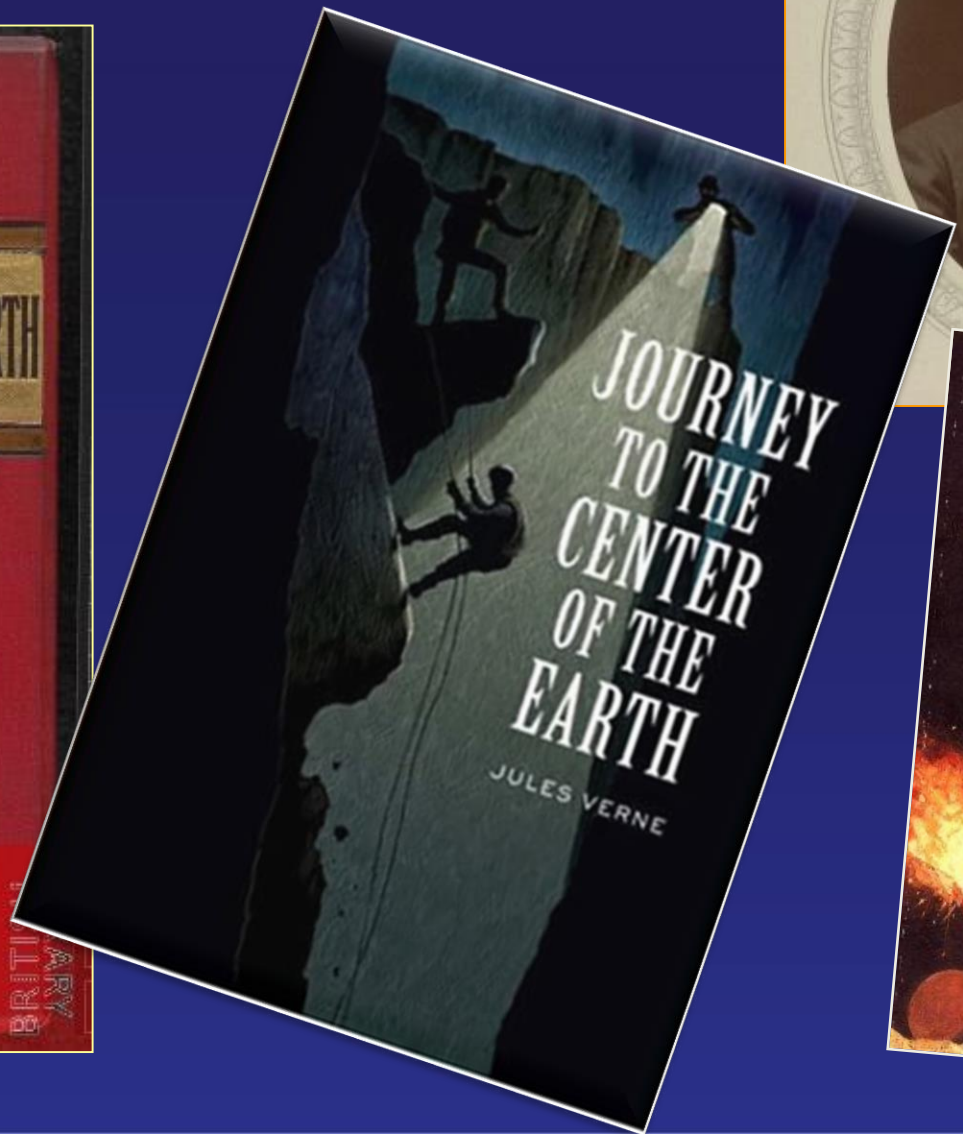
ULPGC · UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

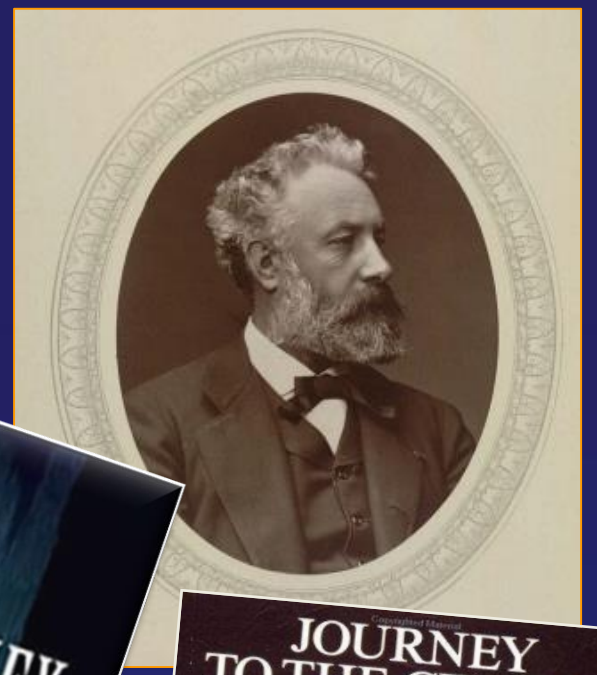
CNDS
Centrum för naturkatastrofslära

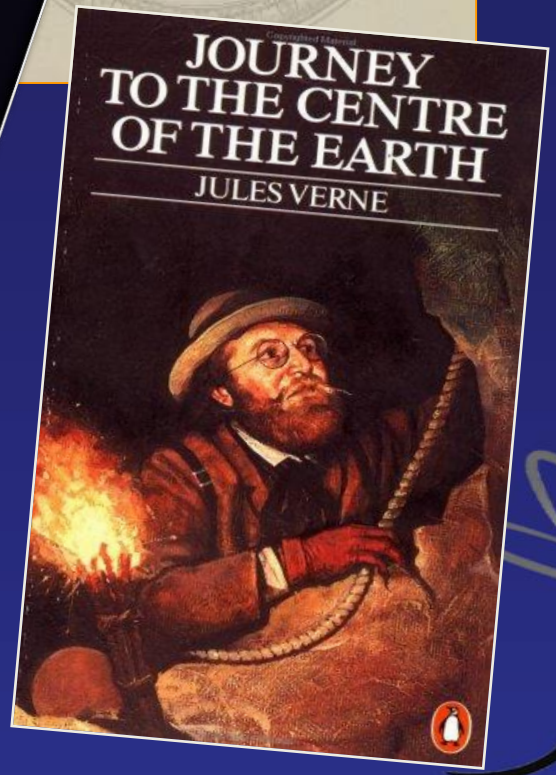
Journey to the Centre of the Earth

Jules Verne









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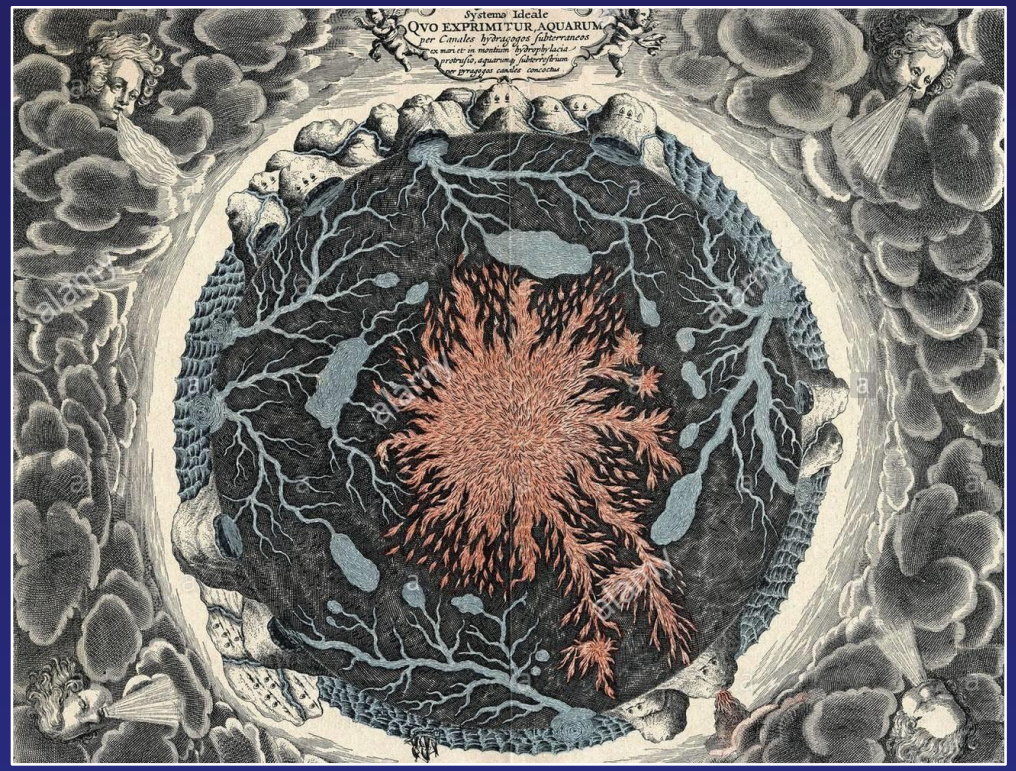
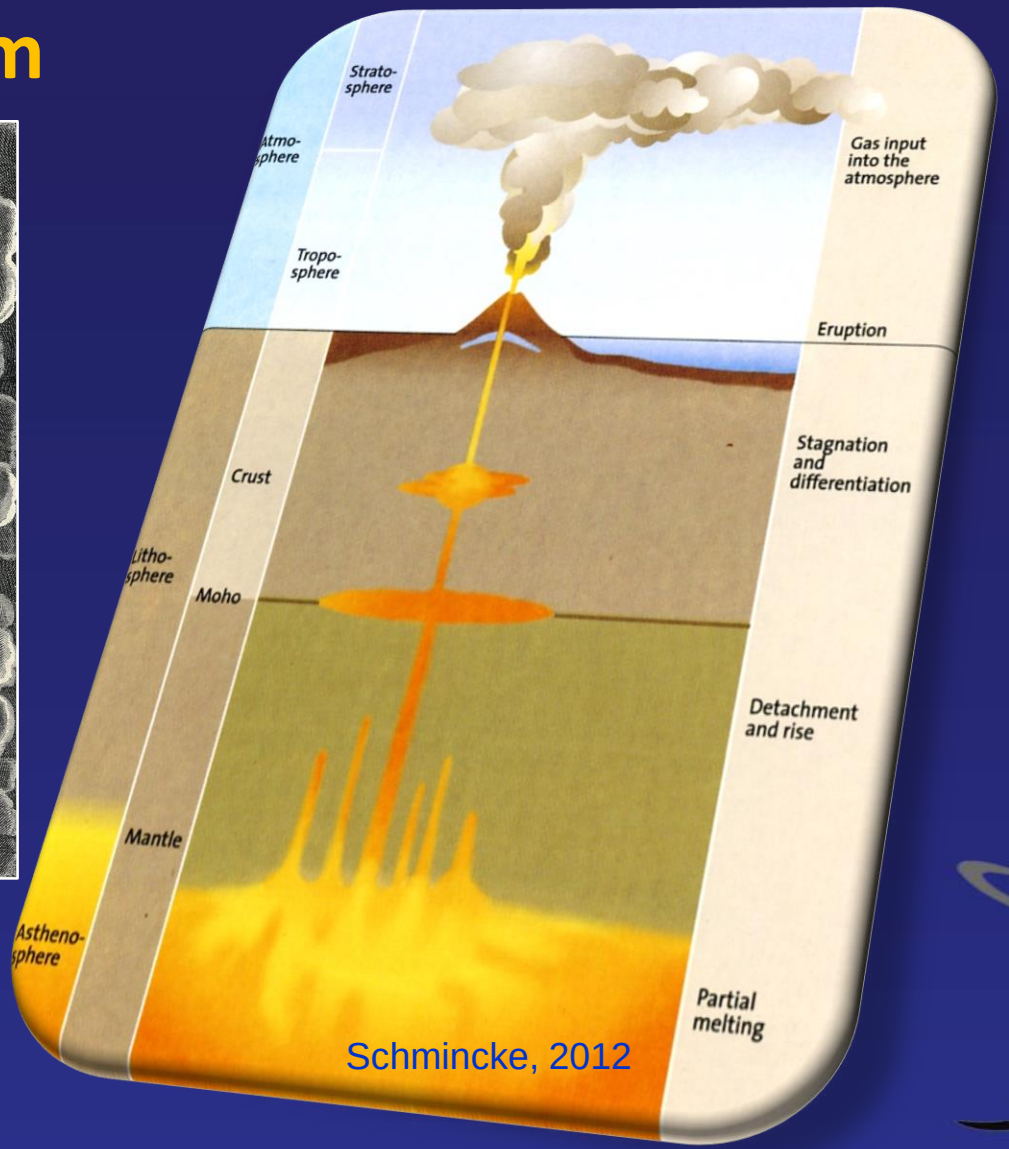
Rather than us going into the bowls of the Earth, we can be Probing the Depth of the Earth:

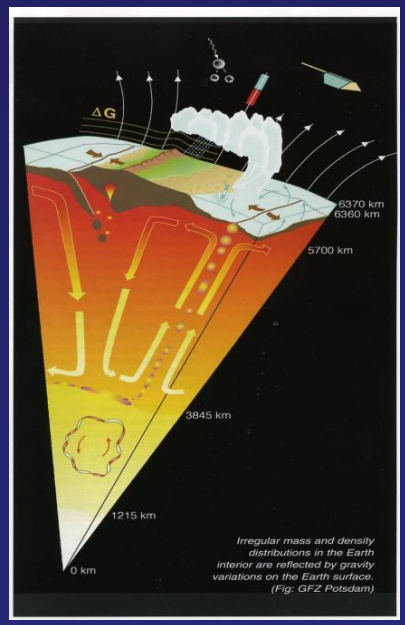
The Volcano-Magma System



A. Kircher, 1664



Schmincke, 2012



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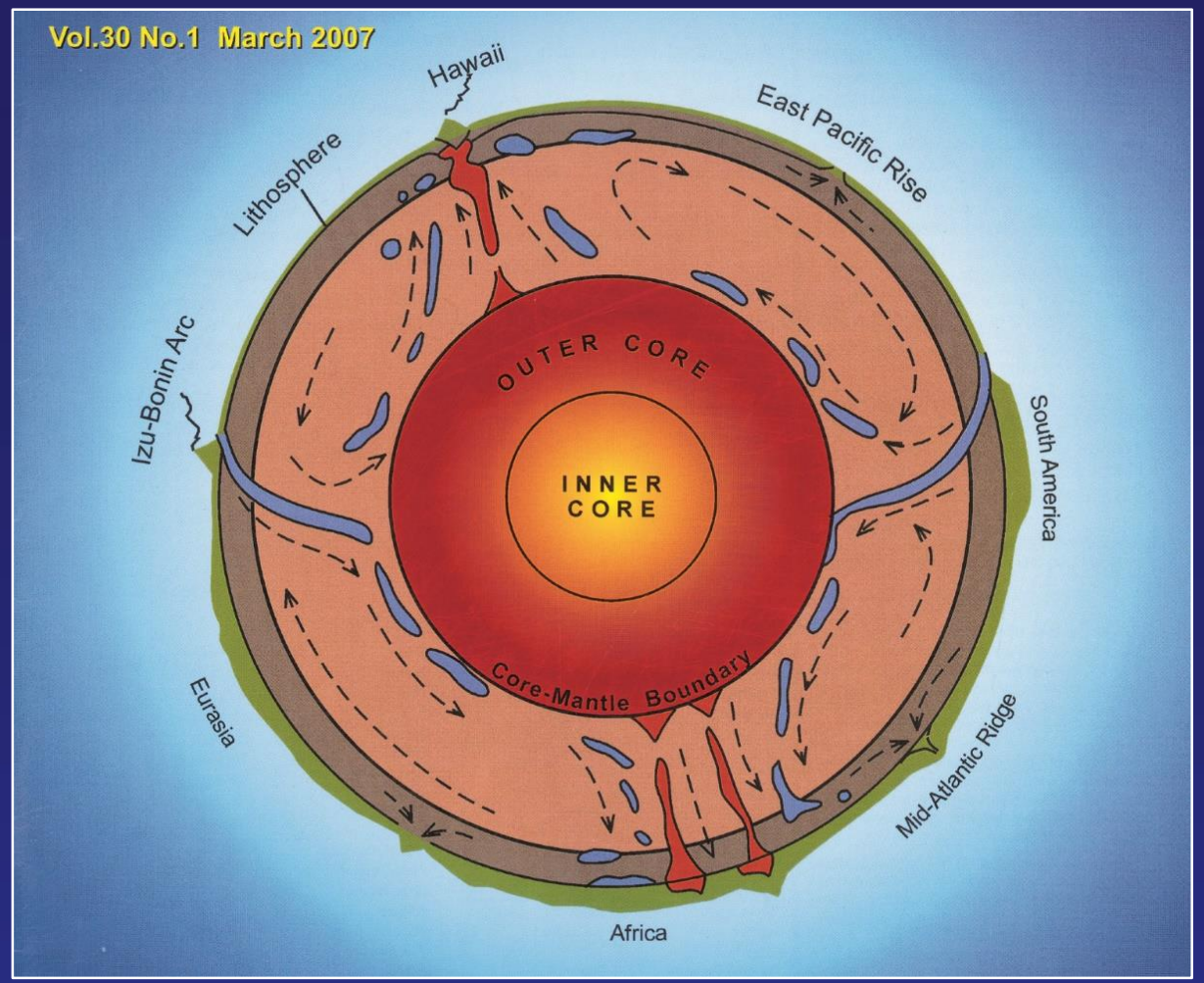
The Volcano-Magma System and the Origin of Magmatic Diversity



- Magma is one of the most important probes into the Earth's interior.
- Magma erupted from a volcano gives us clues on the magma source region, the processes on ascent and the rocks it passed during this journey.
- Lava erupted at volcanoes is compositionally very diverse, making it a real challenge for the petrologist ...

Content

1. . Volcano Science; an Introduction

2. Background on Prof. Troll

3. Origin of the Canary Islands

4. Landslides, Rift zones, and Magma evolution

5. Volcano Resources & Society

Troll's background

- Born in Würzburg (Bavaria, Germany)
- BSc Geology (St Andrews, Scotland, UK)
- PhD (GEOMARine Research Center, Kiel, Germany)
- Lecturer, then Assoc. Prof at Trinity College Dublin (TCD), Ireland
- Habilitation (Blaise Pascal Univ, Clermont- Ferrand, France)
- Fellow of Mineralogical Society (UK), Fellow of the Royal Society of Arts (UK), and Fellow Trinity College Dublin (FTCD)
- Since 2008, Chair of Petrology at Uppsla University, Sweden

Uppsala University, Sweden, est. 1477

Since 2008; Chair of Petrology at Uppsala University, Sweden

Head of Natural Resources and Sustainable Development (57 Employees)

UPPSALA UNIVERSITET

Director of Postgraduate Studies

Completed > 20 PhD student and > 25 MSc students

Research Mission

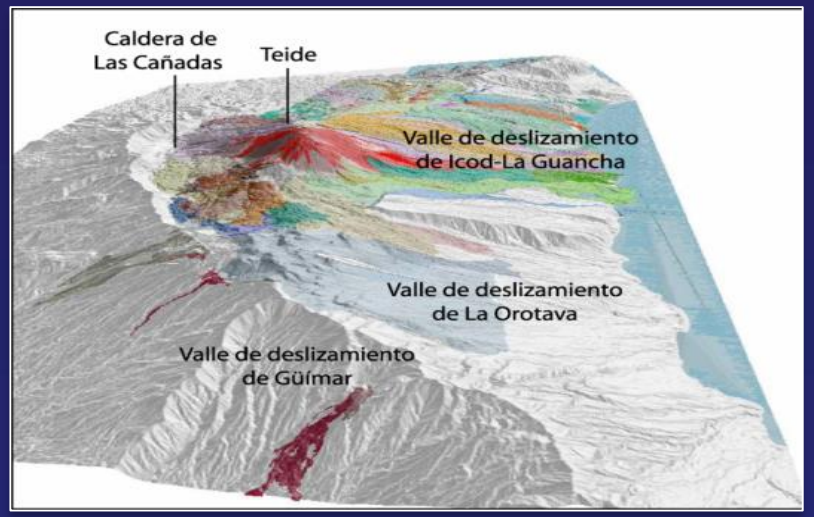
To understand the Dynamic Interplay of Magma Generation, Magma Chamber Processes, Magma Transport, and Eruptive Behaviour and what information it reveals for large-scale Geodynamic Processes and their Relevance for Society:

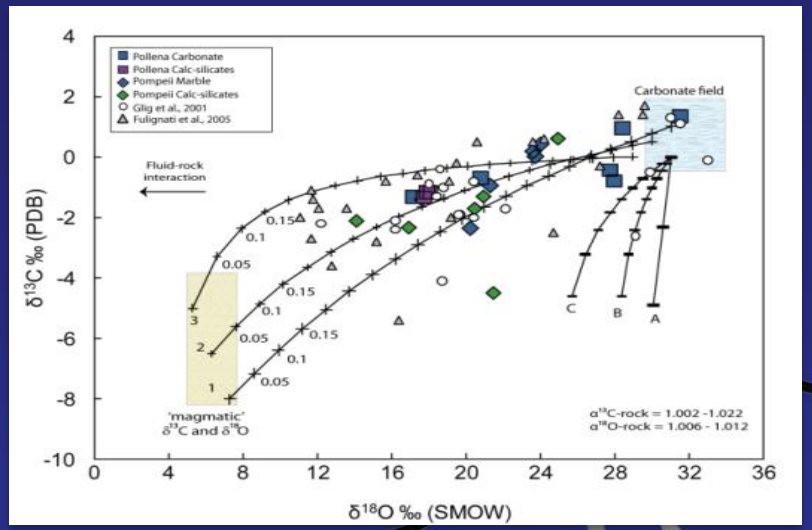
Magmatic Processes, Volcanic Hazards & Natural Resources




Approaches

- I use a wide variety of approaches to investigate the various aspects that influence magmas from source to surface.
- Field-work, experimental and numerical simulations and petrological, geochemical and isotope studies !
- Targets ranges from a 100s of kilometre scale in regional geochemical approaches to micrometer-scale in crystal analysis and imaging.





Impact of Large Igneous Provinces (LIPs) on climate in the High Arctic LIP

Magma genesis and evolution in Iceland, Greenland, and the Faroes

Fe-apatite ore genesis and genesis of Alnö carbonatites

Magma genesis and evolution in the British-Irish Paleogene Igneous Province

Magma genesis in Central European Volcanic Systems and Aegean arc

CO_2 mobilisation in magma from carbonate at Popocatépetl volcano

Mantle sources and magma evolution in the Central Atlantic Canary and Cape Verde Volcanic Provinces

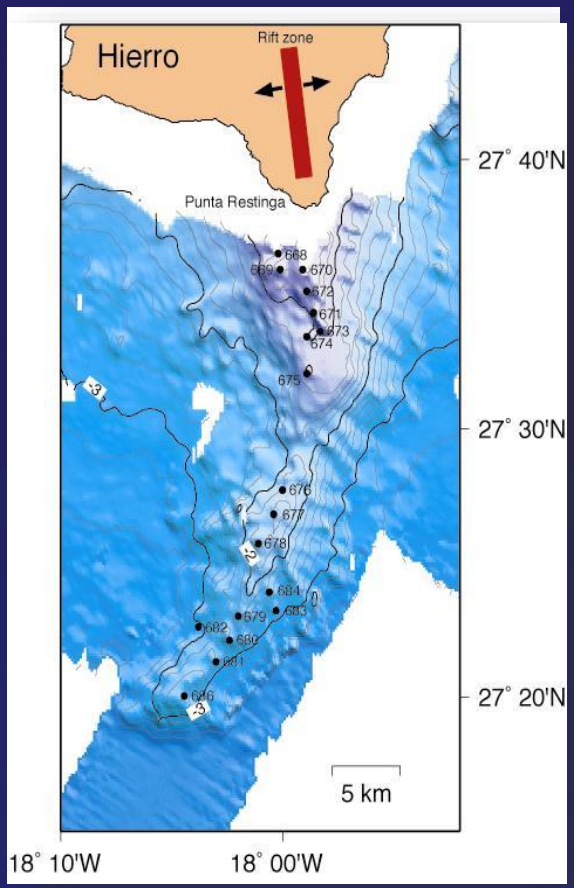
Arc petrogenesis in the Izu-Bonin-Mariana arc

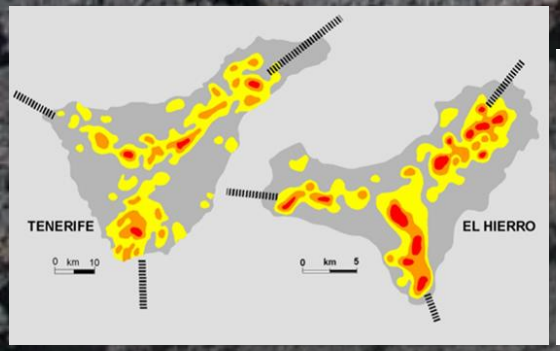
Arc magma petrogenesis in the Sunda arc subduction zone, Indonesia

Mantle and crustal processes in the Taupo volcanic zone

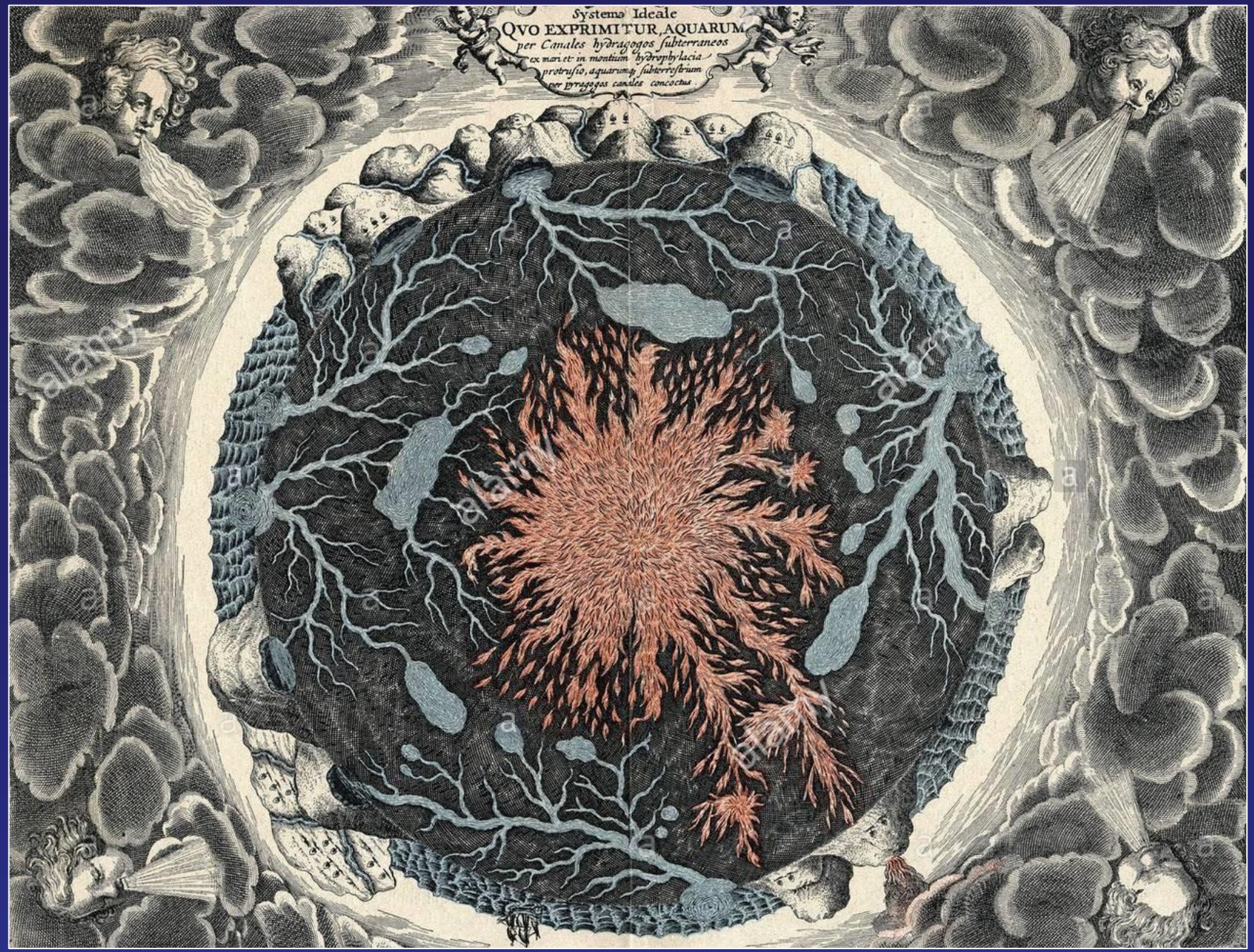
Mantle room project

Central Atlantic; Canary Islands, Cape Verdes





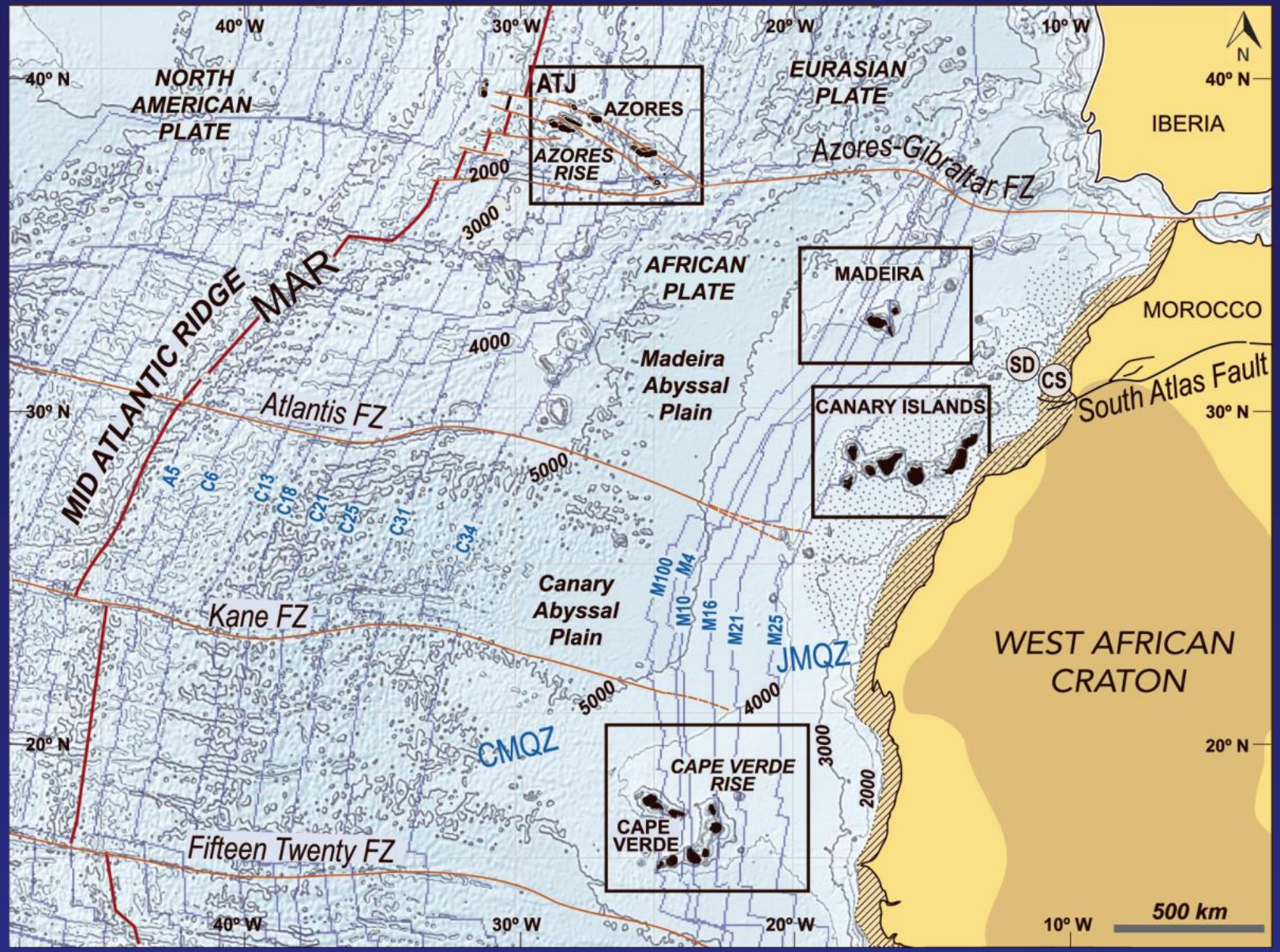
Islas Canarias
volcanic
experience



Atanasius Kircher, 1664

How do Volcanoes like the Canaries form ?

Contributions to our understanding of the origin and evolution of the Canary Islands



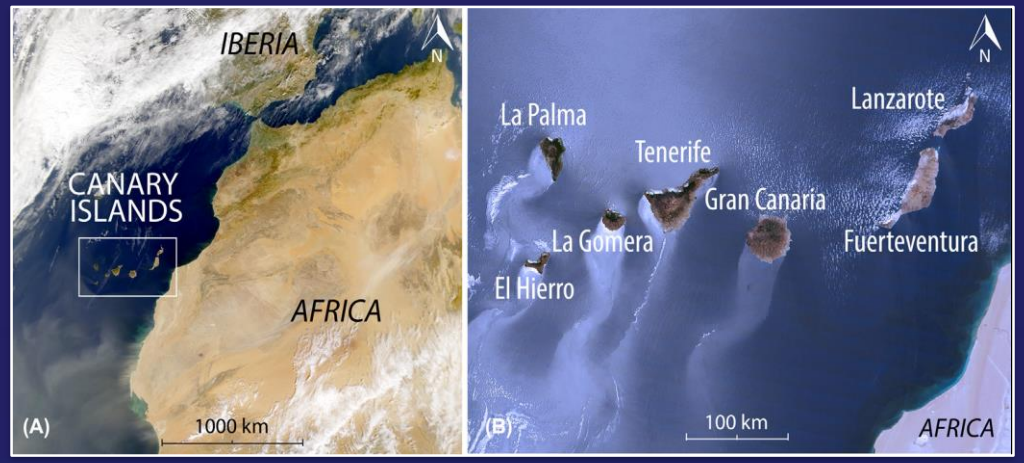
The geological and geodynamic features of the Central-East Atlantic region **(from Carracedo and Troll 2021).**

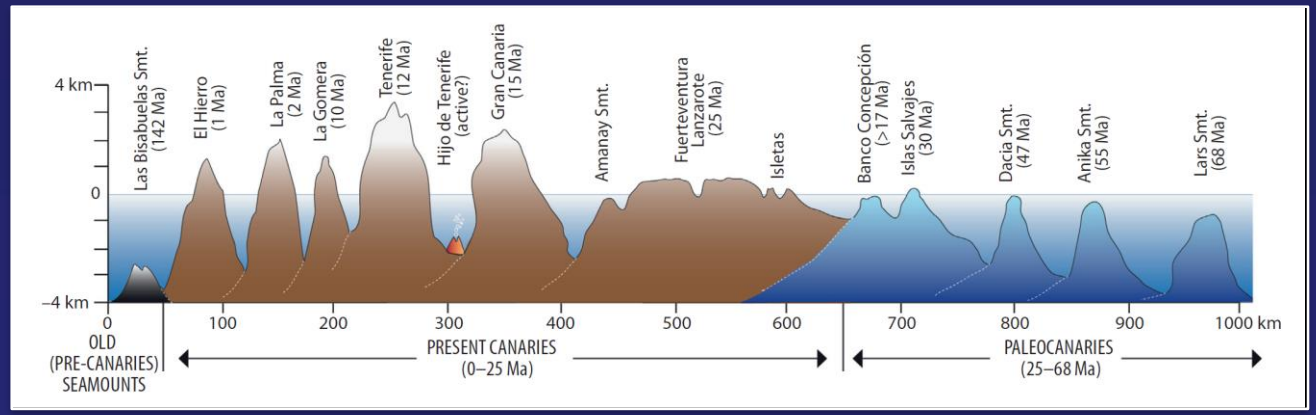
How do Volcanoes like the Canaries form ?

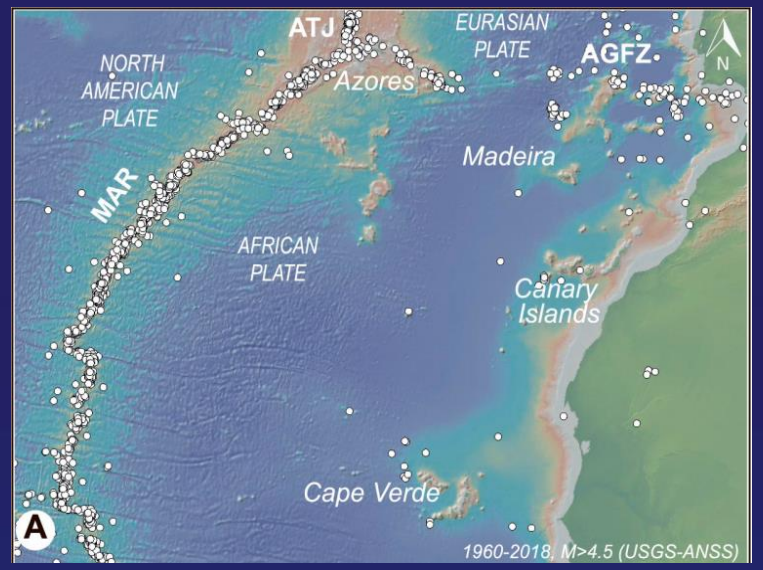
Contributions to our understanding of the origin and evolution of the Canary Islands

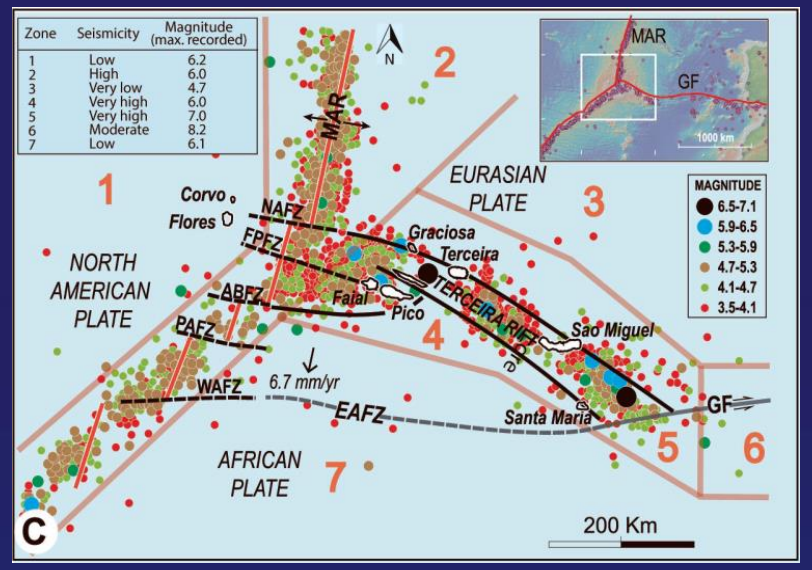
The Canary Islands

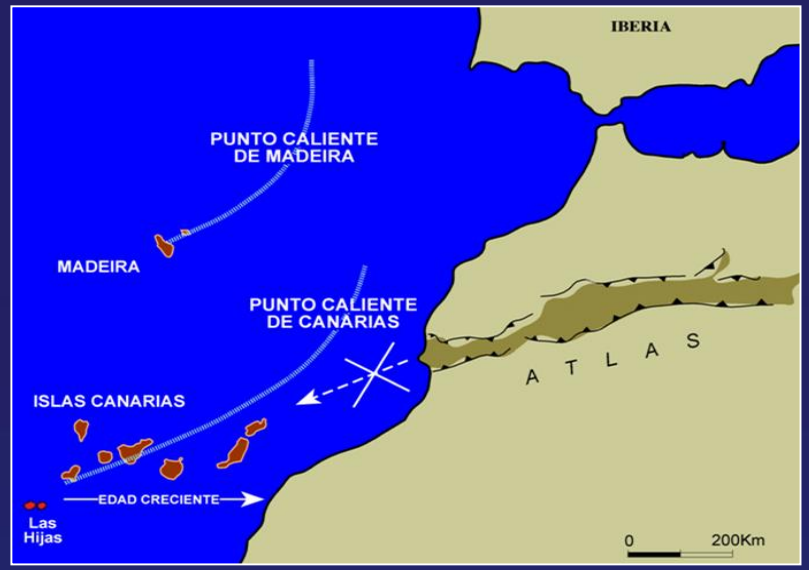
- Archipelago of volcanic origin, seven main islands: Fuerteventura, Lanzarote, Gran Canaria, Tenerife, La Gomera, La Palma, and El Hierro
- Stretches from ~100 km from the African coast to over ~500 km
- All islands are volcanically active (Holocene volcanism) apart from La Gomera

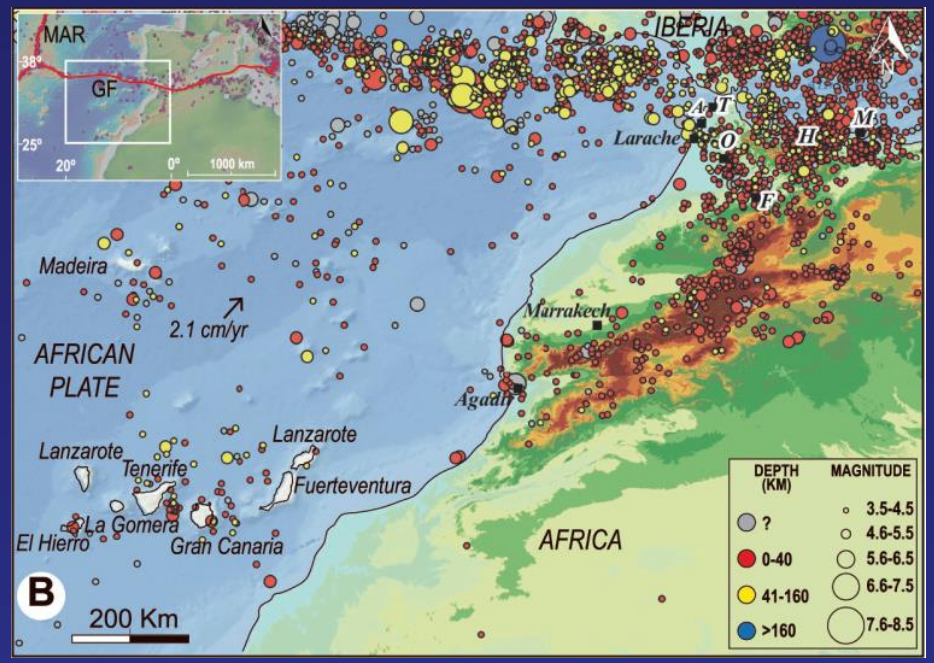


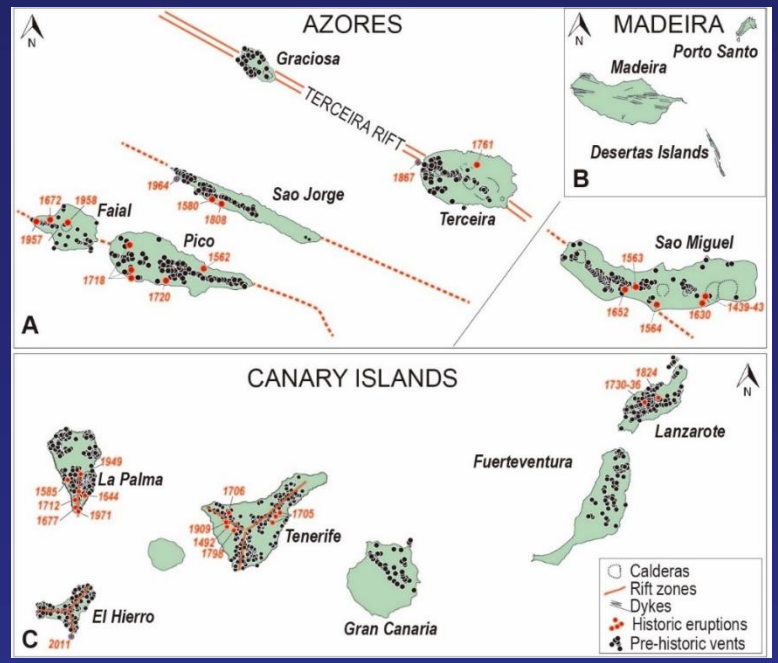








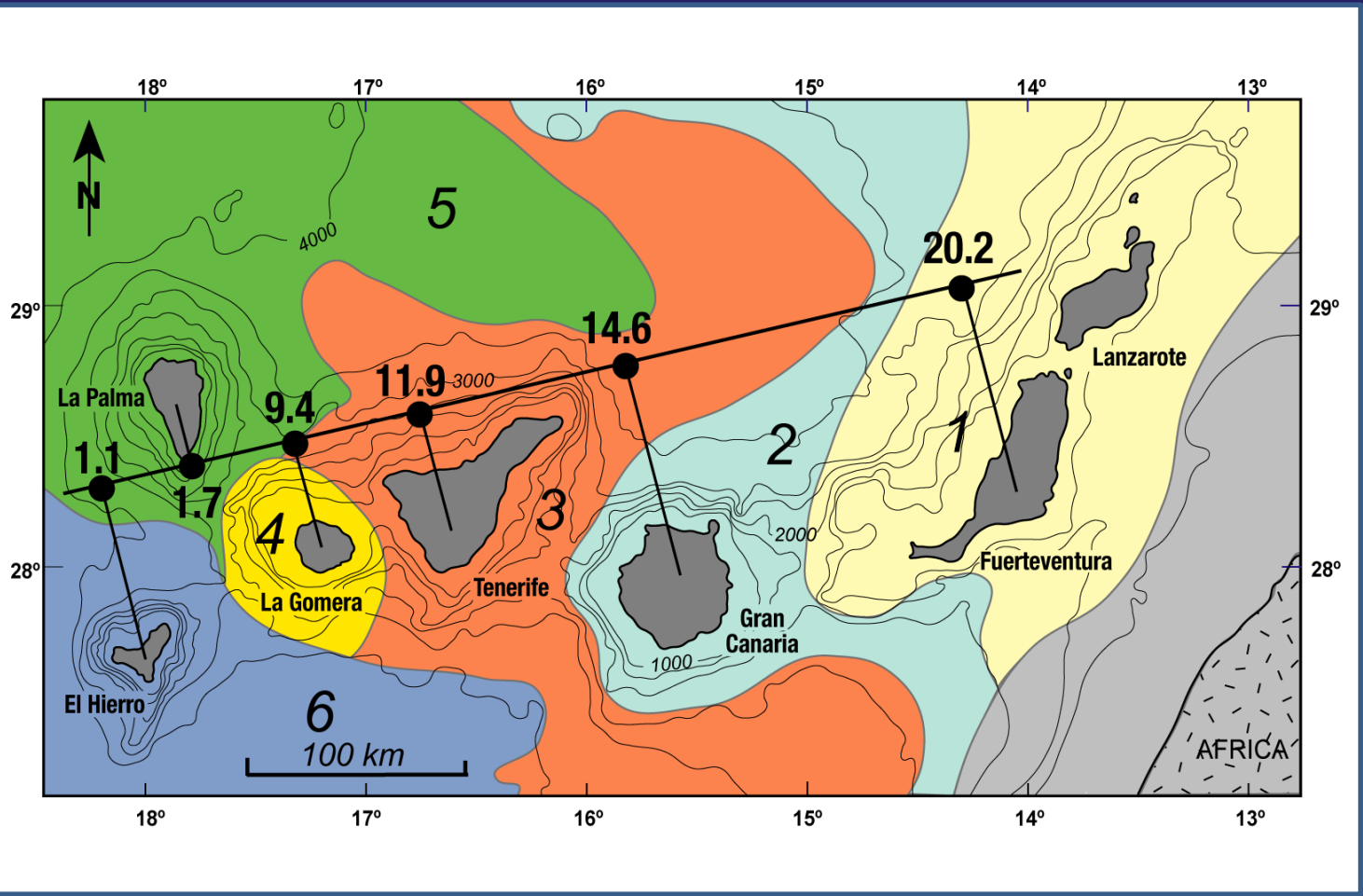


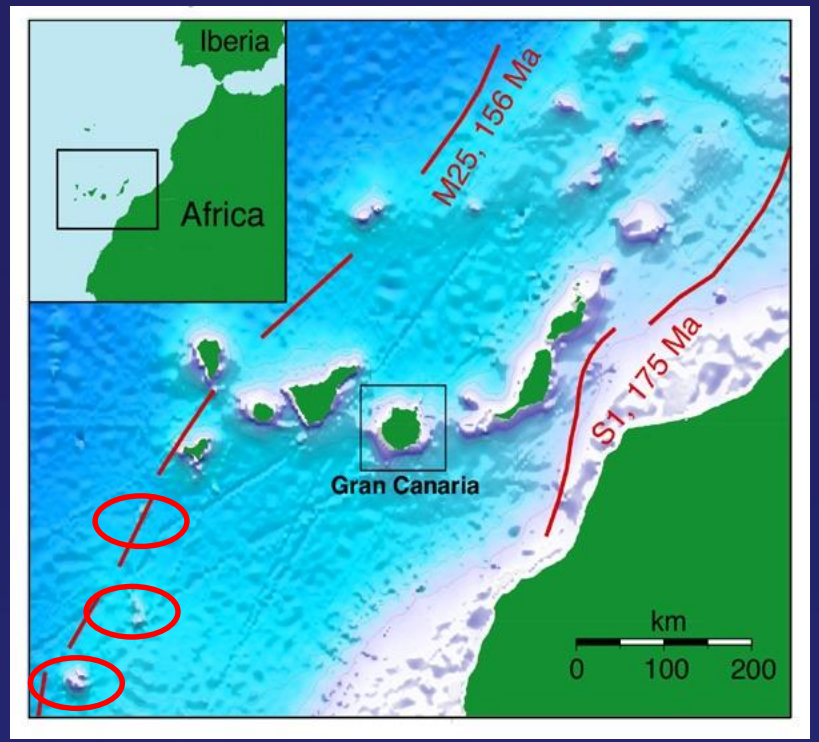


Troll et al., 2015;
Carracedo & Troll 2021

Fracture or chain ?

- Cluster: no age progression expected
- Chain: age progression expected

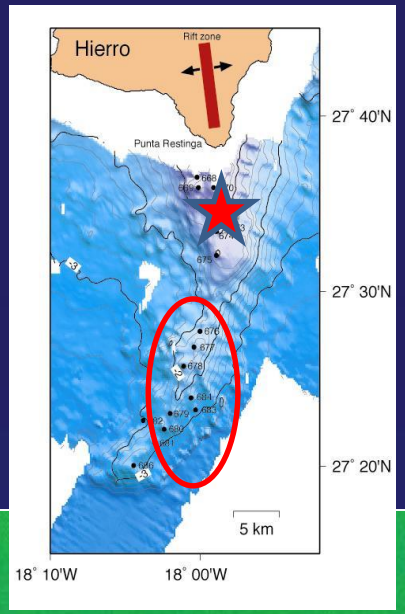


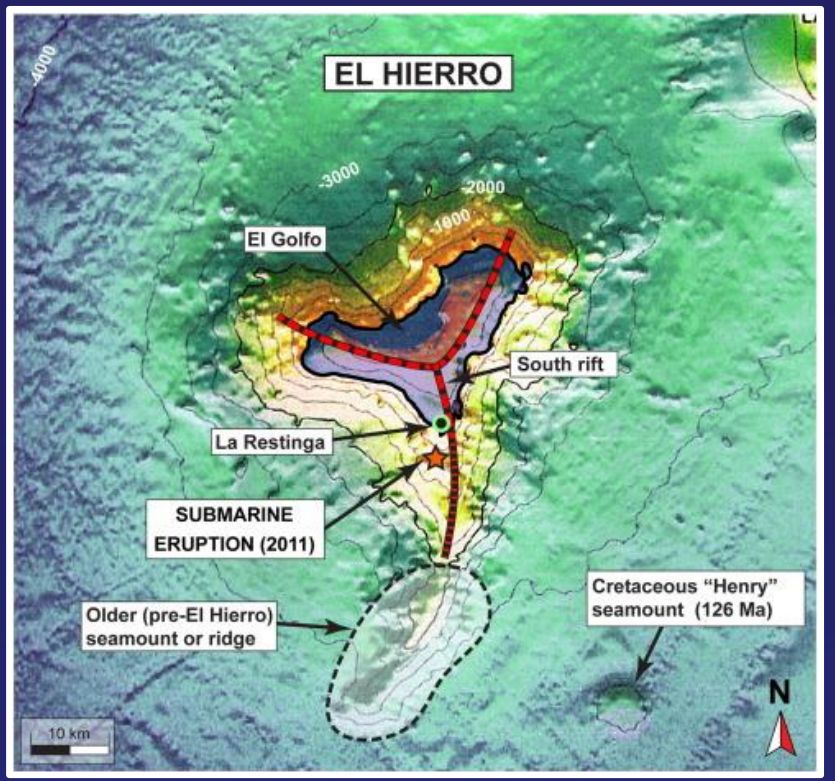


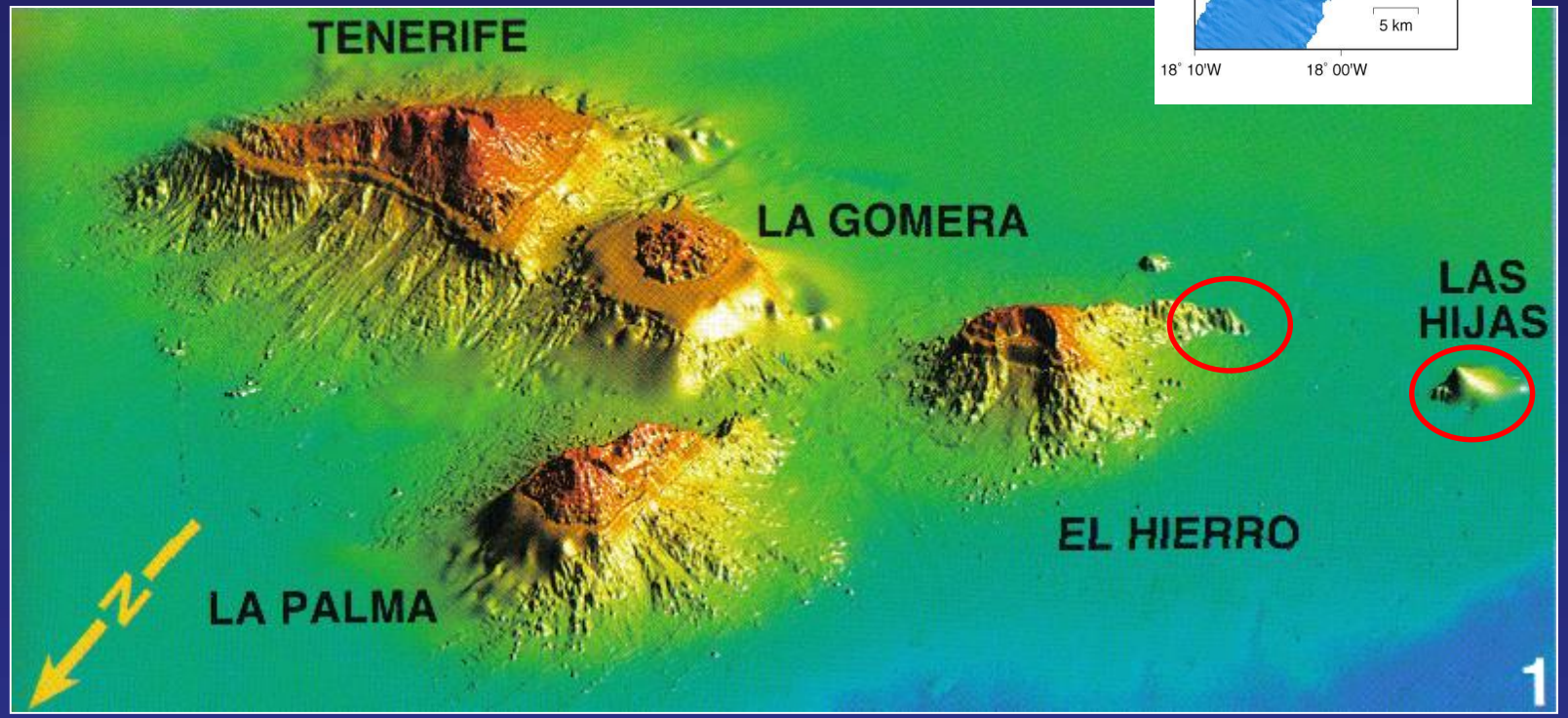
- Van den Boogard 2013 dates seamounts SW of Canaries as Cretaceous in age

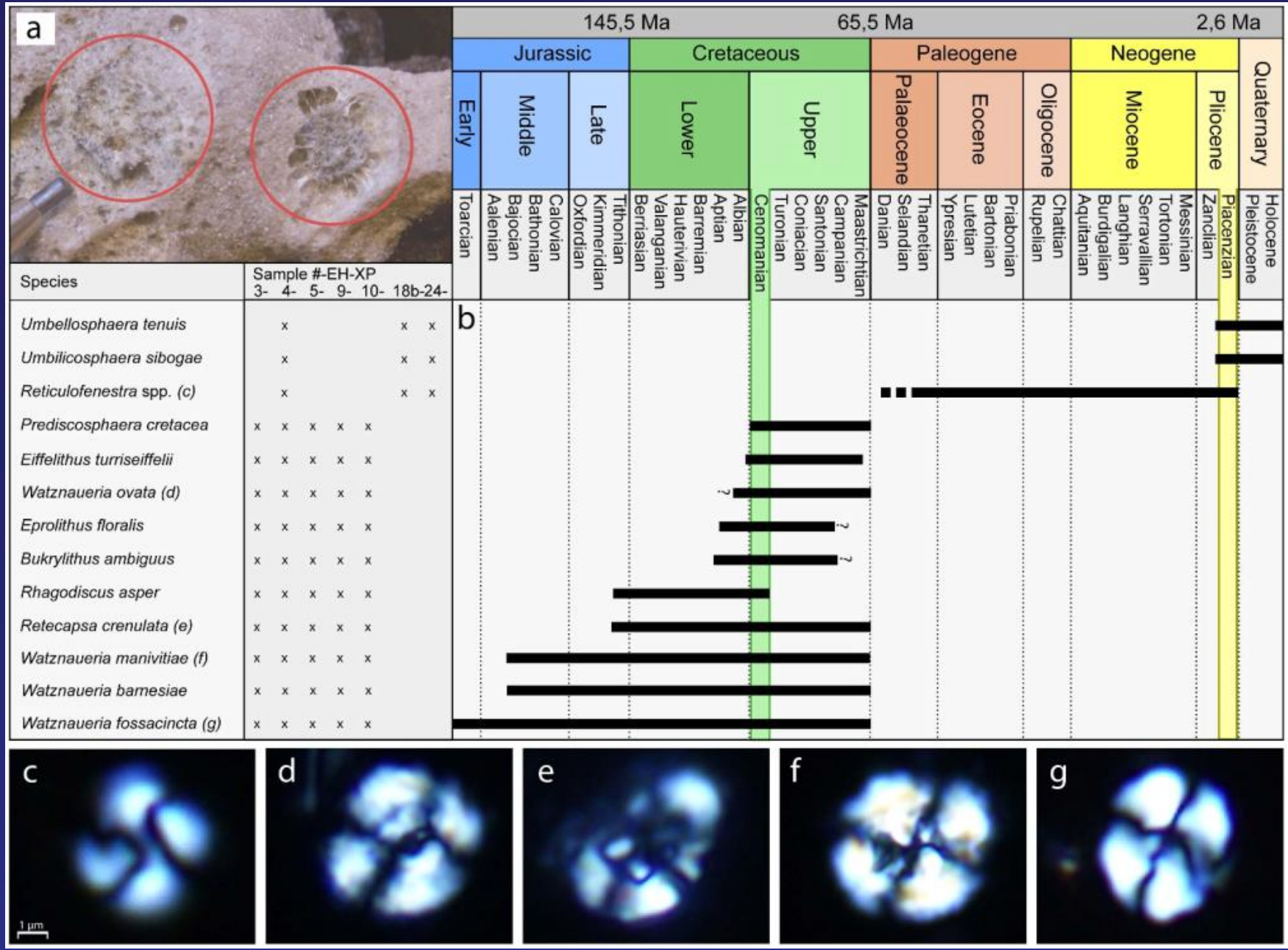
Fracture or chain ?

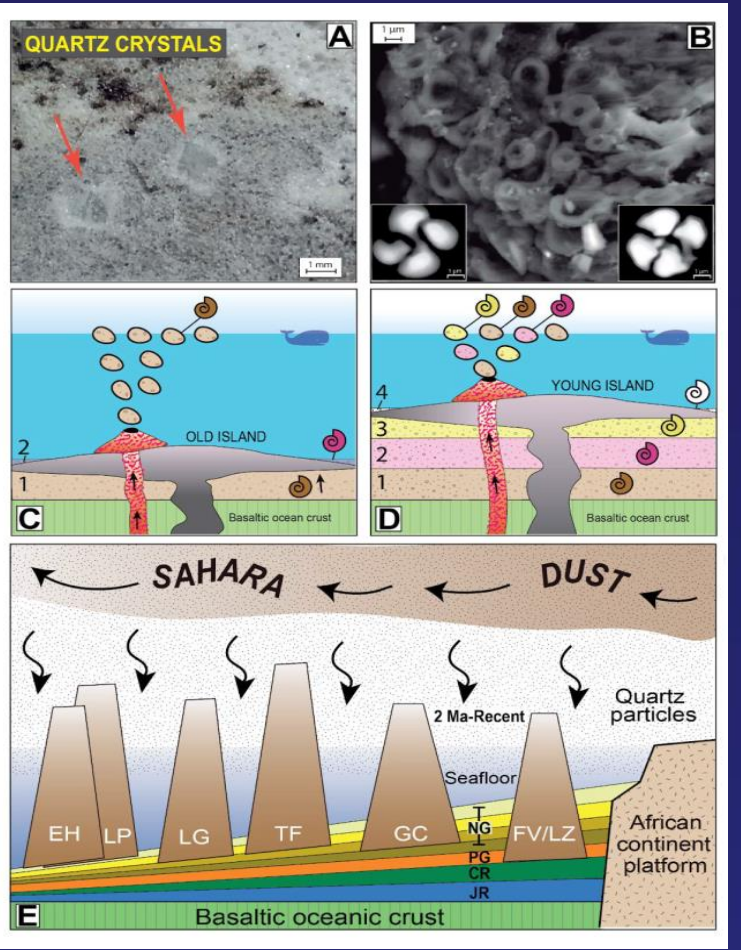
- Van den Boogard 2013 dates seamounts SW of Canaries as Cretaceous in age.
- **Las Hijas and south El Hiierro Ridge are very old!**
- **Onsore and offshore ages in conflict !**



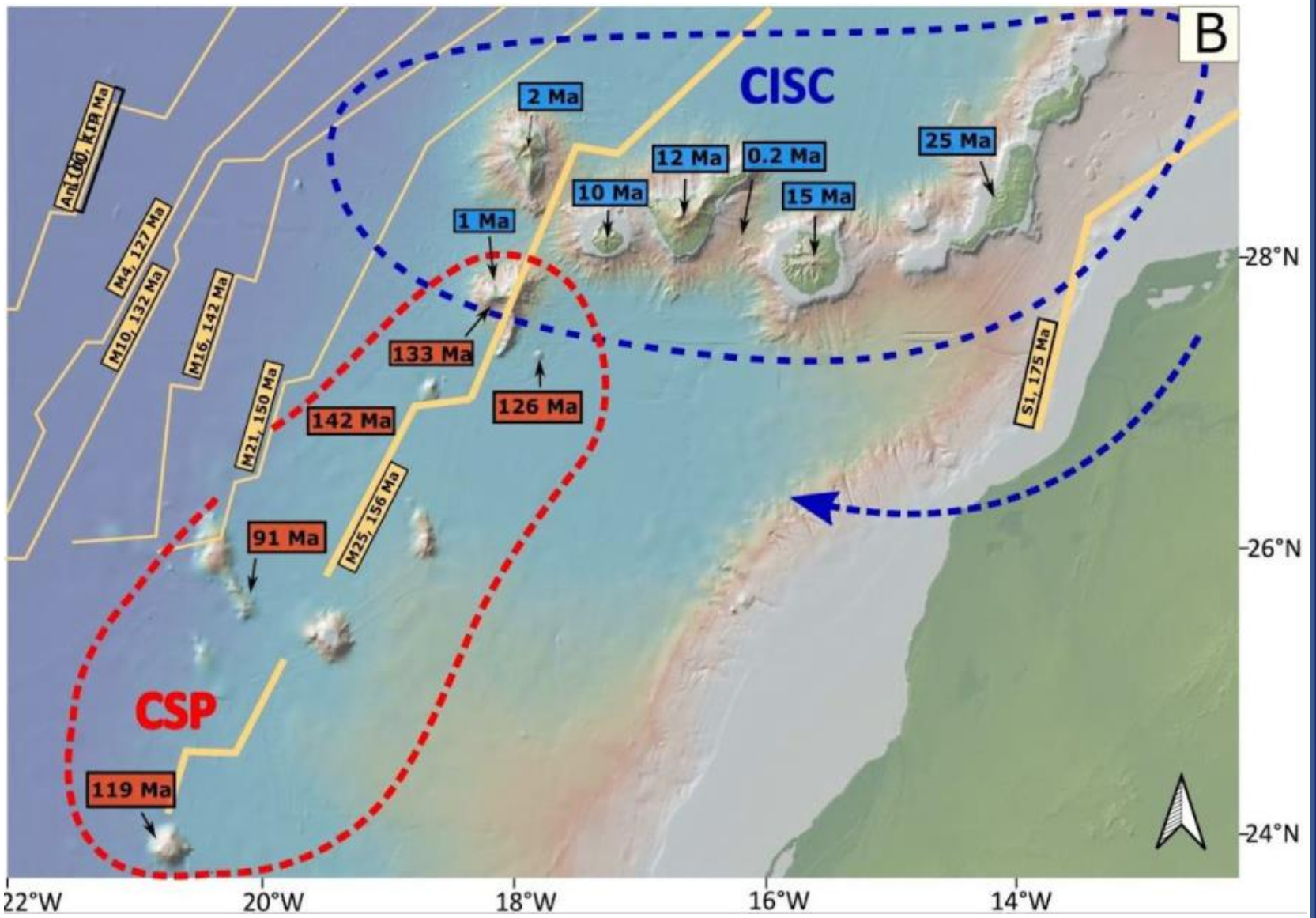





a
145,5 Ma
65,5 Ma
2,6 Ma
Jurassic
Cretaceous
Paleogene
Neogene
Quaternary
Early
Middle
Late
Lower
Upper
Paleaocene
Eocene
Oligocene
Miocene
Pliocene
Holocene
Pleistocene
Toarcian
Aalenian
Bajocian
Bathonian
Calovian
Oxfordian
Kimmeridian
Tithonian
Berriasian
Valanginian
Hauterivian
Barremian
Aptian
Albian
Cenomanian
Turonian
Coniacian
Santonian
Campanian
Maastrichtian
Danian
Selandian
Thanetian
Ypresian
Lutetian
Bartonian
Priabonian
Rupelian
Chattian
Aquitanian
Burdigalian
Langhian
Serravallian
Tortonian
Messinian
Zanclian
Piacenzian
Species
Sample #-EH-XP
3- 4- 5- 9- 10- 18b- 24-
Umbellosphaera tenuis
Umbilicosphaera sibogae
Reticulofenestra spp. (c)
Prediscosphaera cretacea
Eiffelithus turriseiffelii
Watznaueria ovata (d)
Eprolithus floralis
Bukrylithus ambiguus
Rhagodiscus asper
Retecapsa crenulata (e)
Watznaueria manivitiae (f)
Watznaueria barnesiae
Watznaueria fossacincta (g)
b
c
d
e
f
g
1 µm


QUARTZ CRYSTALS
A
B
1 µm
1 mm
OLD ISLAND
YOUNG ISLAND
Basaltic ocean crust
C
D
SAHARA
DUST
2 Ma-Recent
Quartz particles
Seafloor
EH
LP
LG
TF
GC
NG
FV/LZ
PG
CR
JR
African continent platform
E
Basaltic oceanic crust


A
B

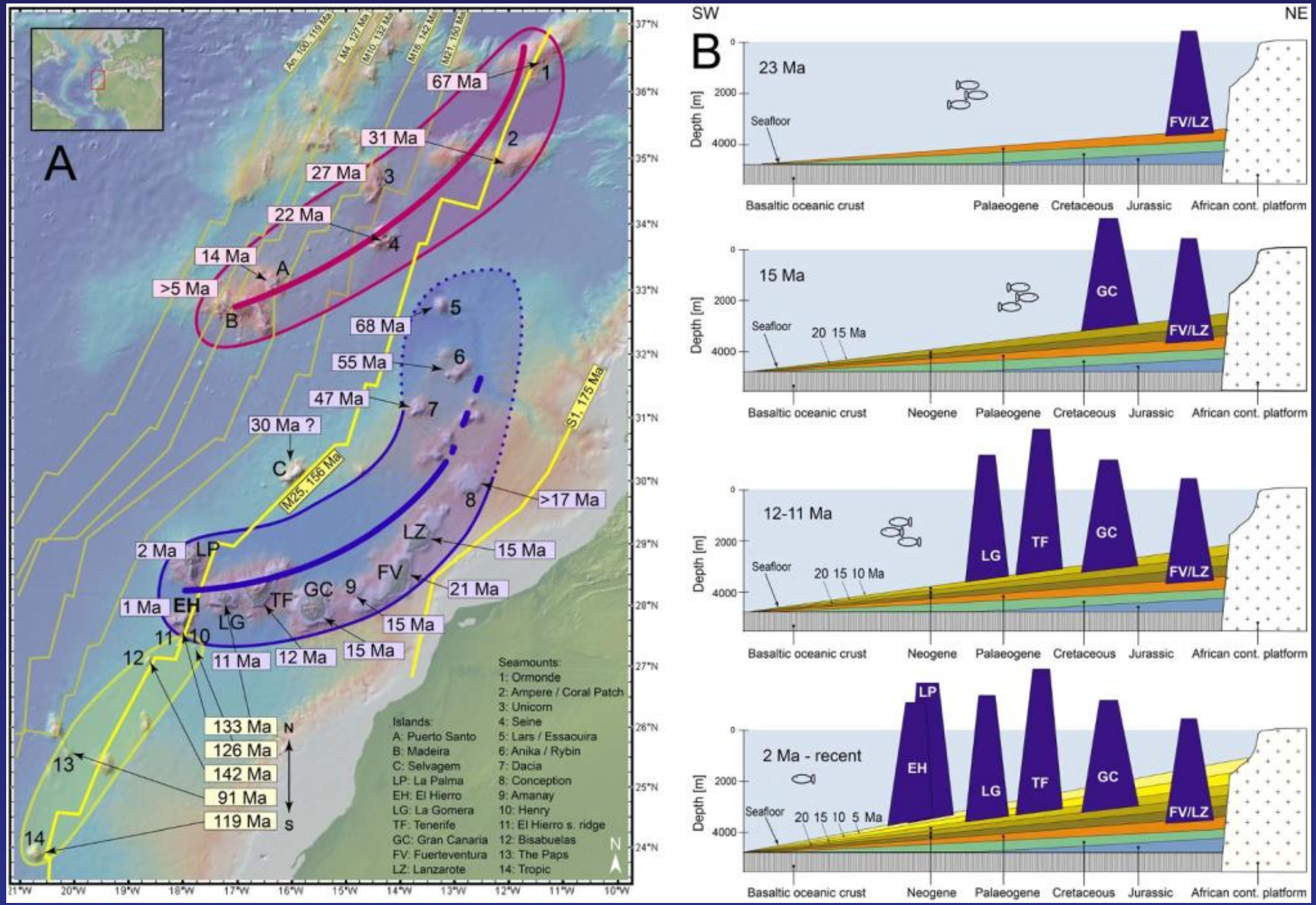


After Troll et al., (2015); Carracedo and Troll (2016; 2021)

The Canary Islands display an age progression from oldest in the east to youngest in the West

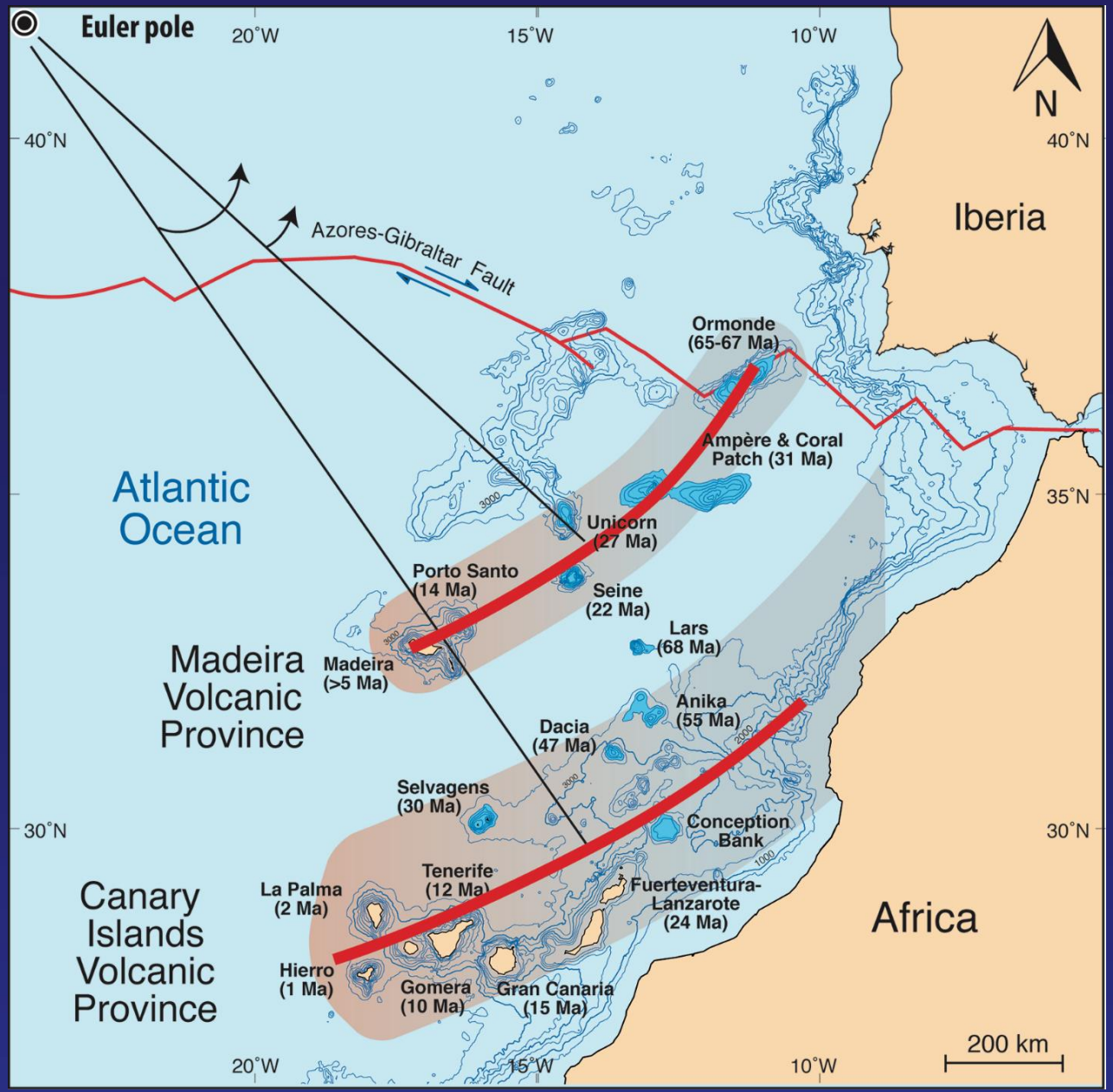
A group of submerged Cretaceous seamounts intersects the Canary Island trend, but aligns with ocean fractures and ocean floor magnetic anomalies

The Cretaceous seamounts do not follow a clear age progression, implying they are fracture related, and unrelated to the Canary archipelago



Similar to Madeira trend!

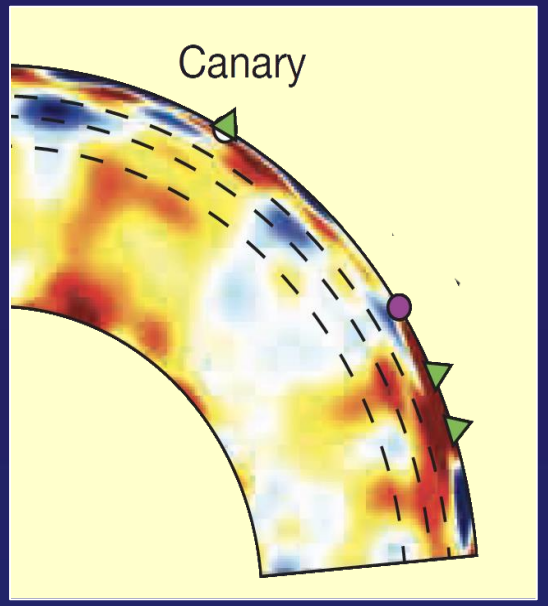
Troll et al., 2015; Carracedo et al., 2015; Zaczek et al., 2015;
Troll et al., 2022

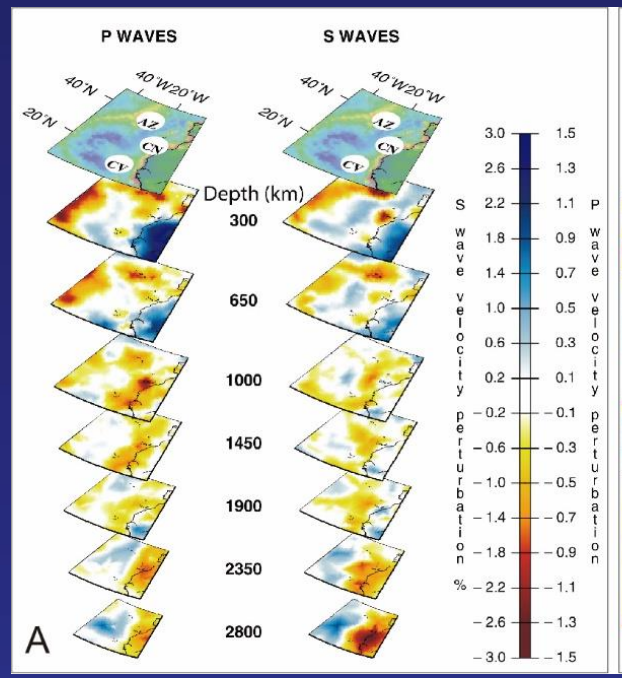


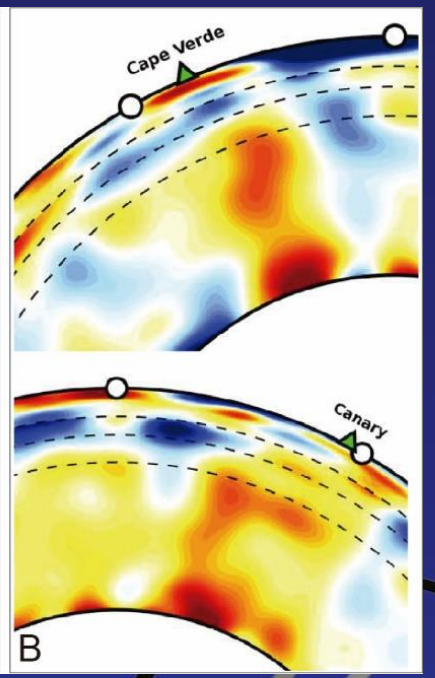
Troll et al., 2015; Carracedo and Troll 2021

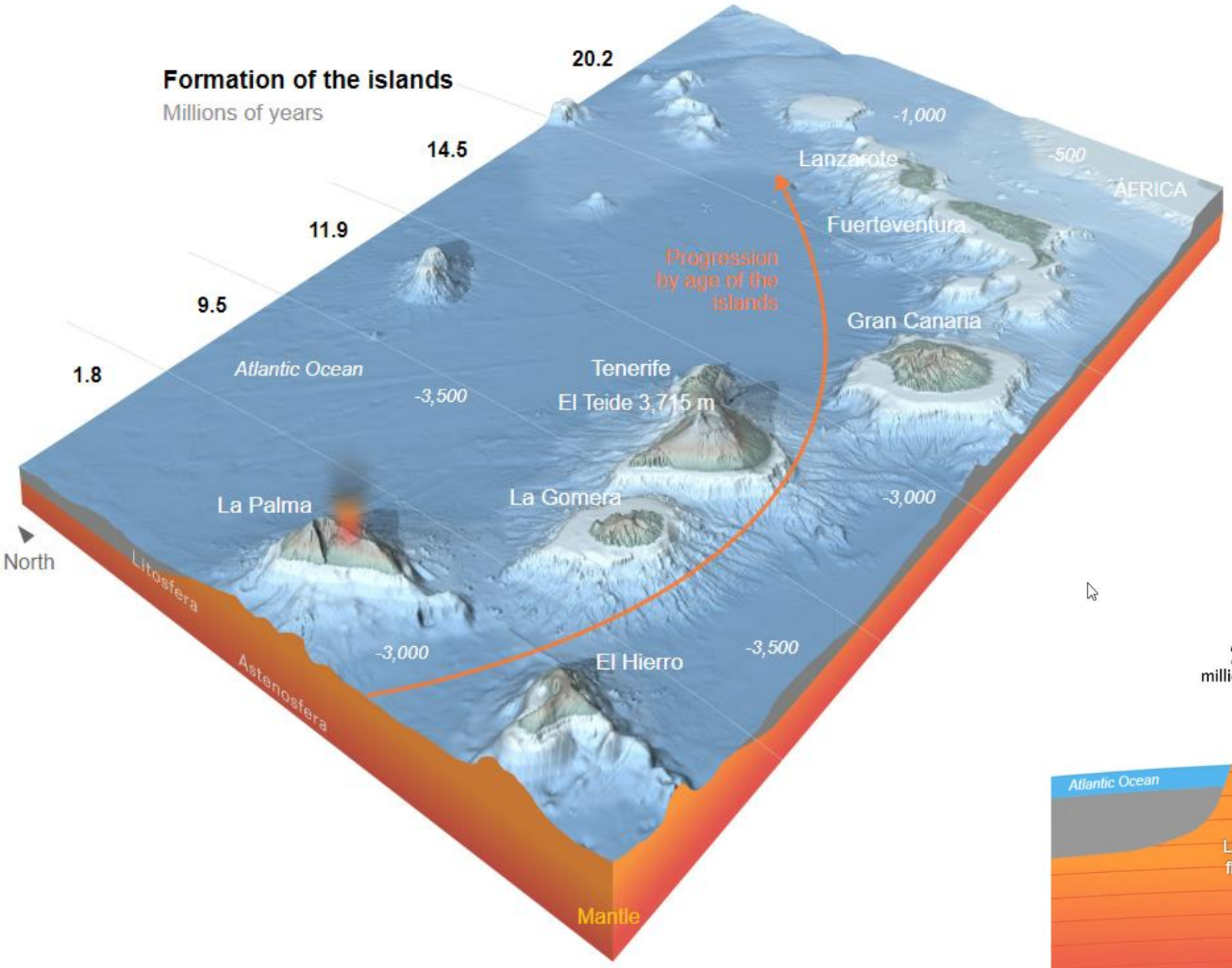
Troll et al., 2015 & Carracedo and Troll 2016; 2021 describe Euler pole and link this with deep seismic roots.

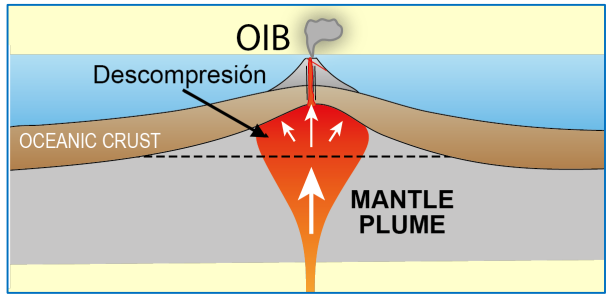
Thus no link to Atlas fault is apparent

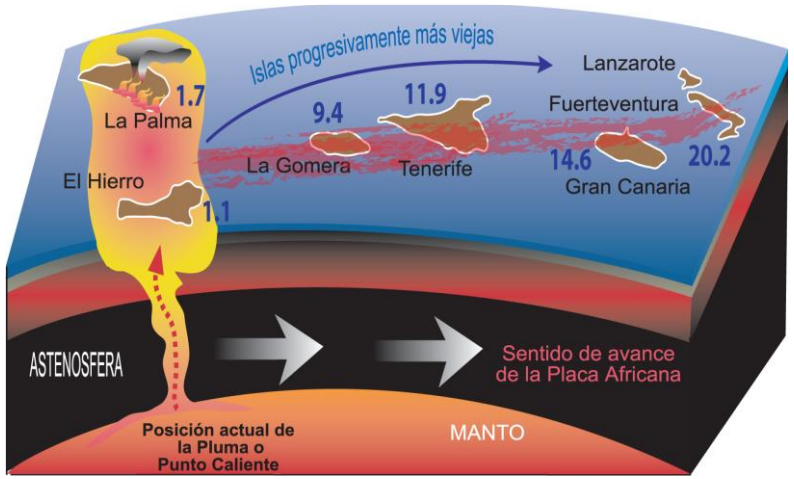




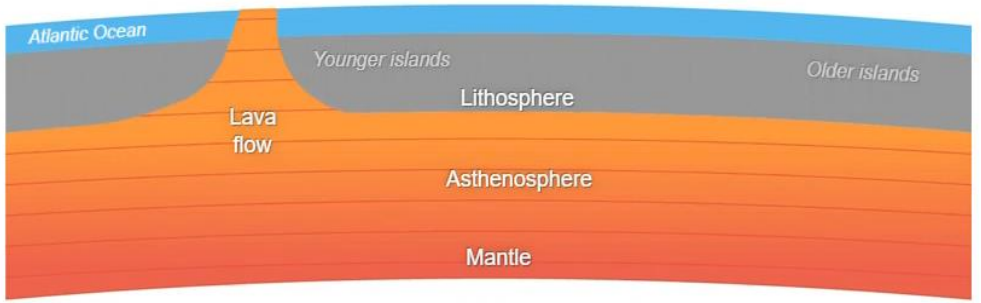






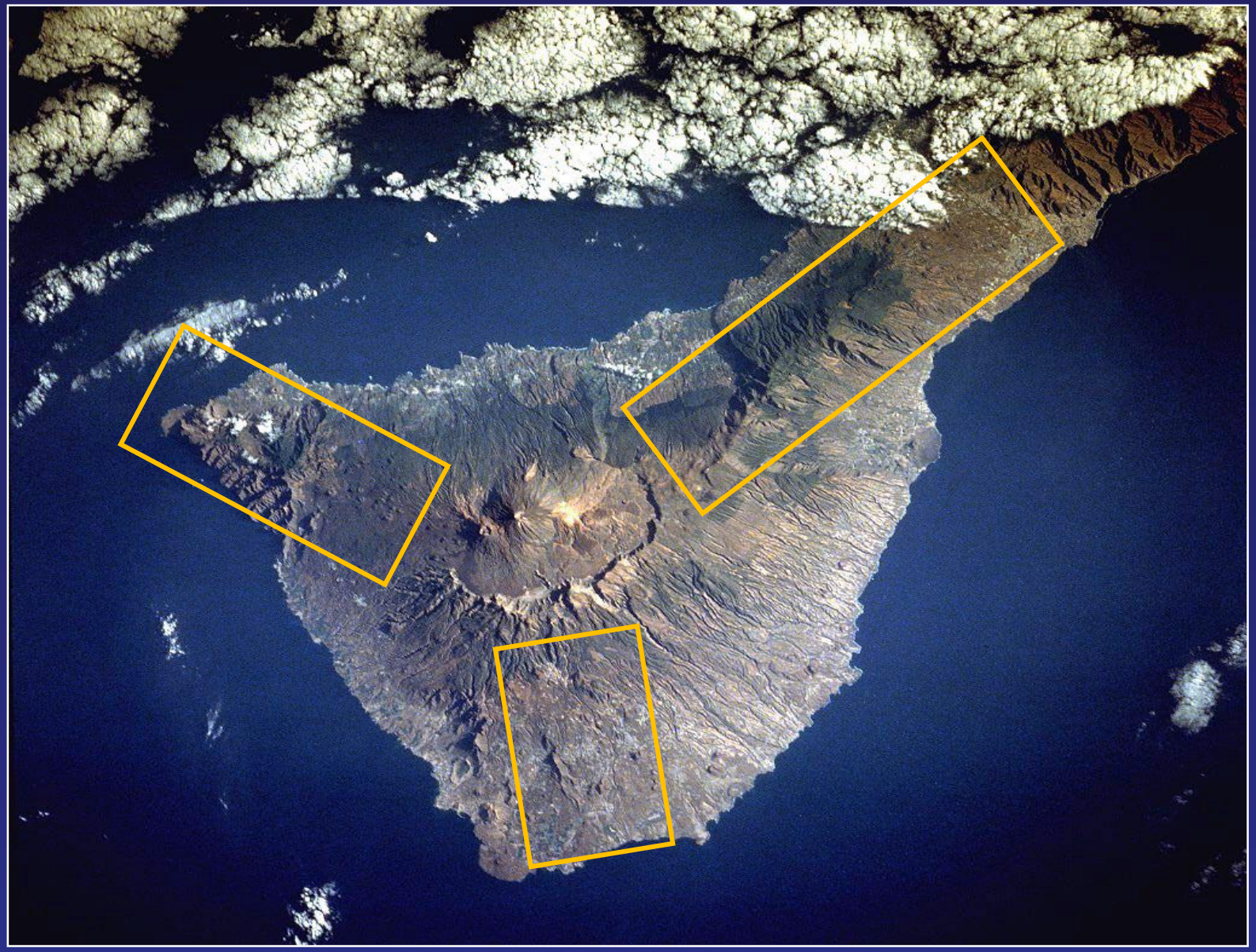


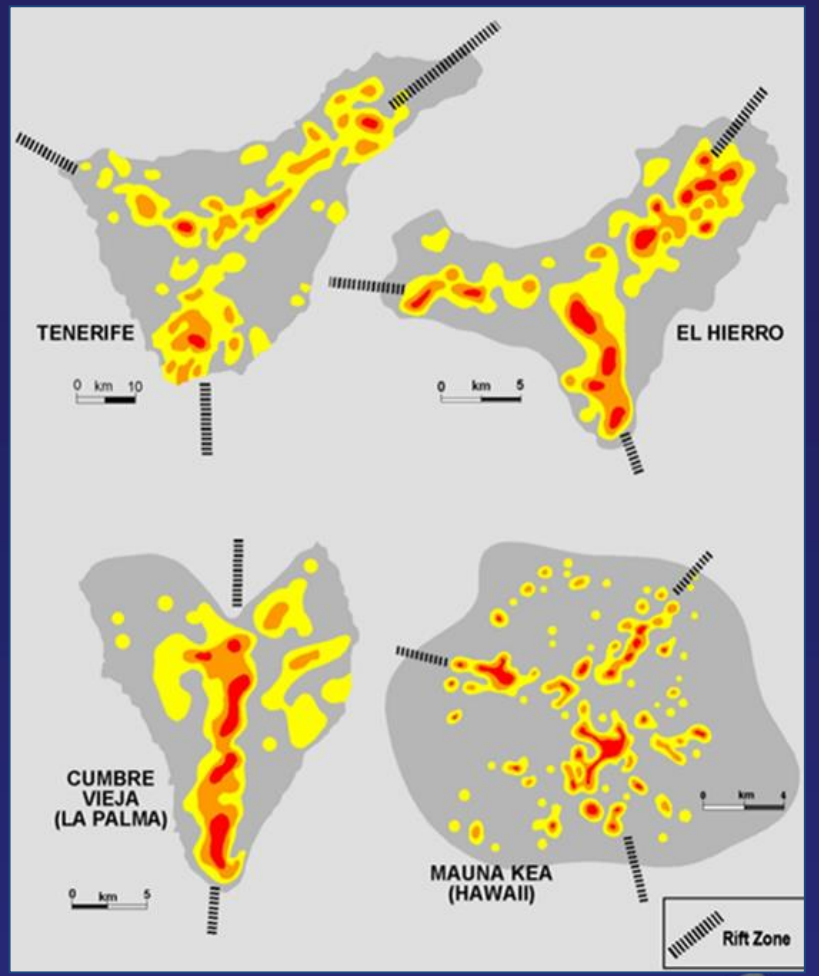
20
million years



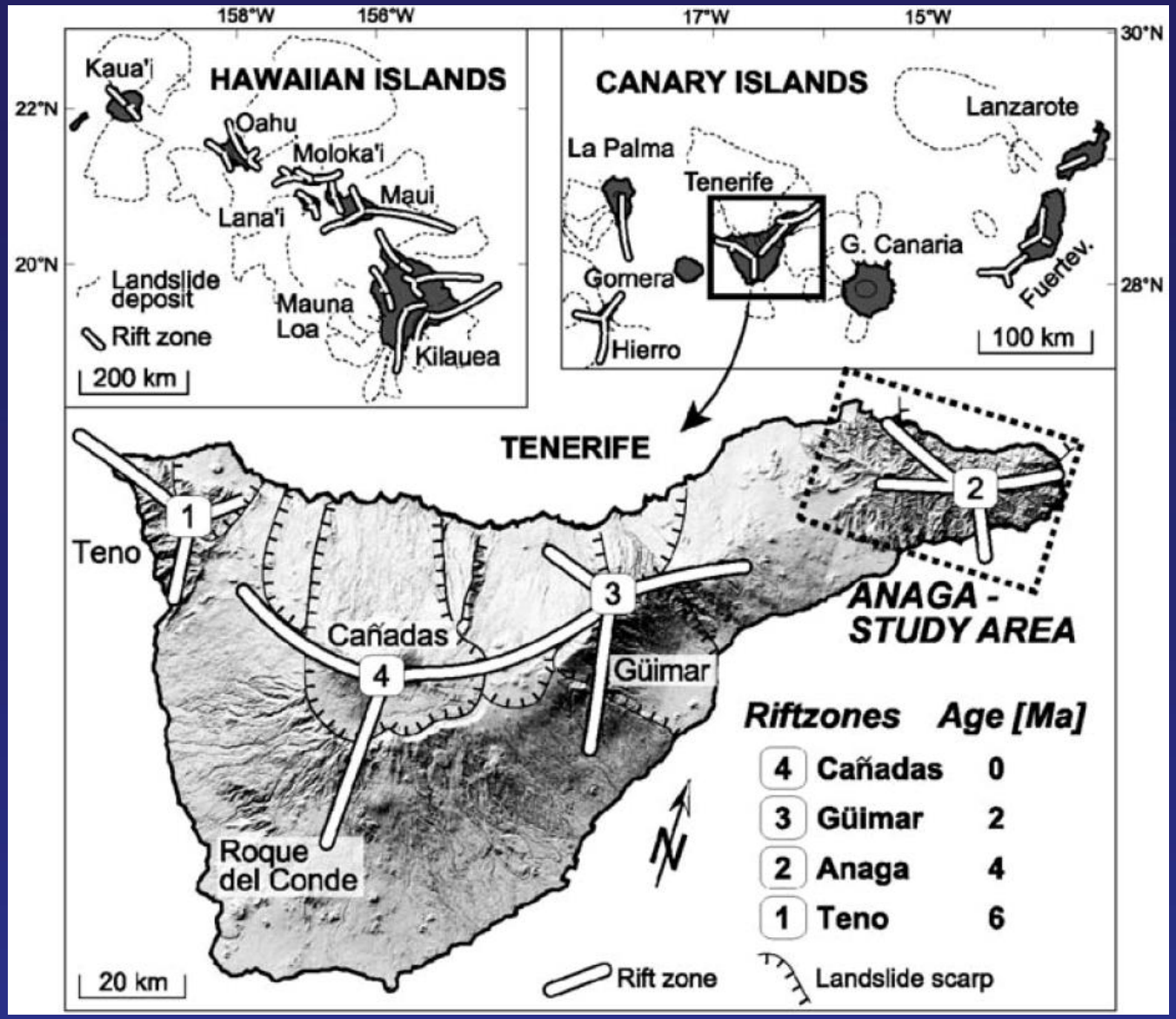
Simplified outline of the geological evolution of the Canary Islands over 20 million years.

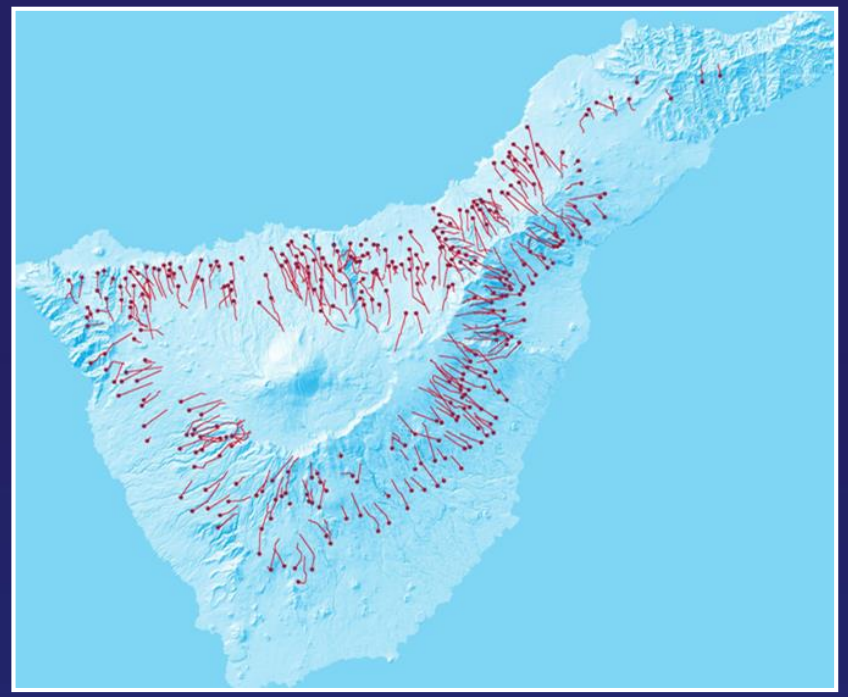
Understanding large structures in the Canary Islands: RIFTS

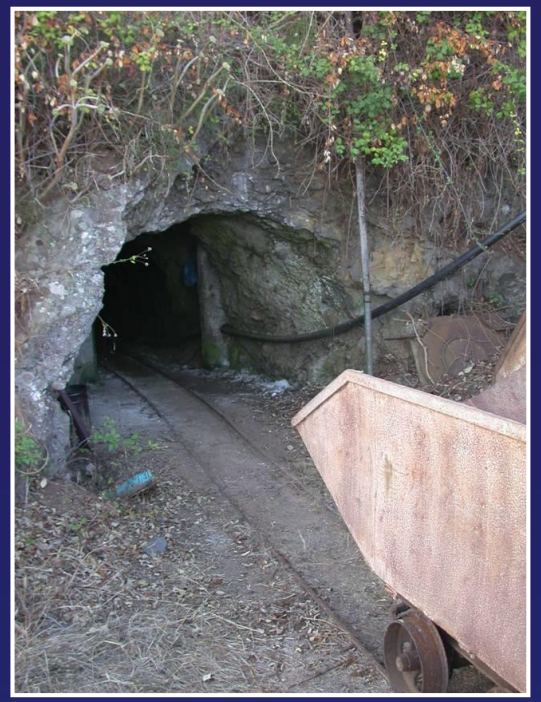




Rift Zones and giant landslides: How do tripe rifts form?



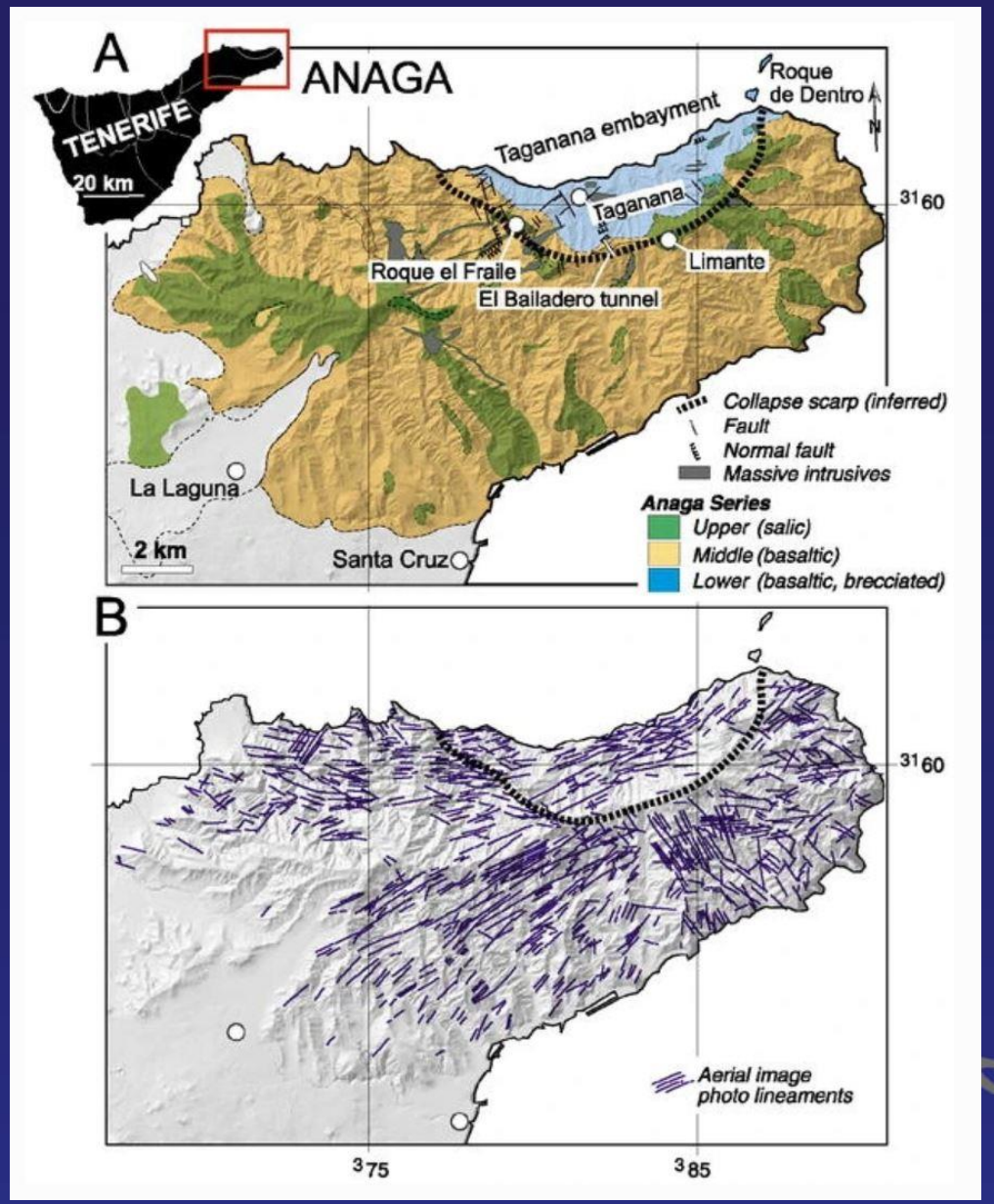


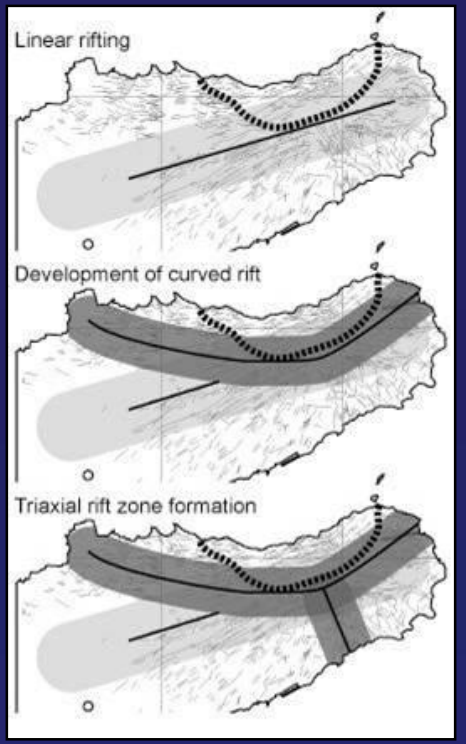



Carracedo et al., 2011;
Deegan et al., 2012;
Delcamp et al., 2012; Troll
et al., 2013

Anaga shield

- One of TF's three shield massifs, > 5Ma old
- Displays major landslide and dyke swarms (rifts)
- Landdslide at 4.1 Myrs BP





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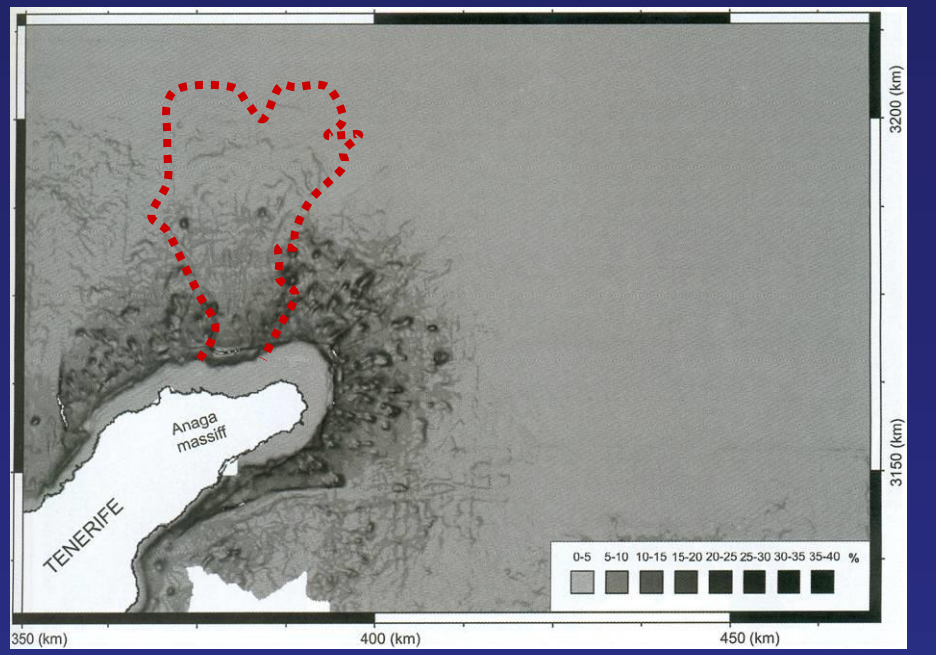
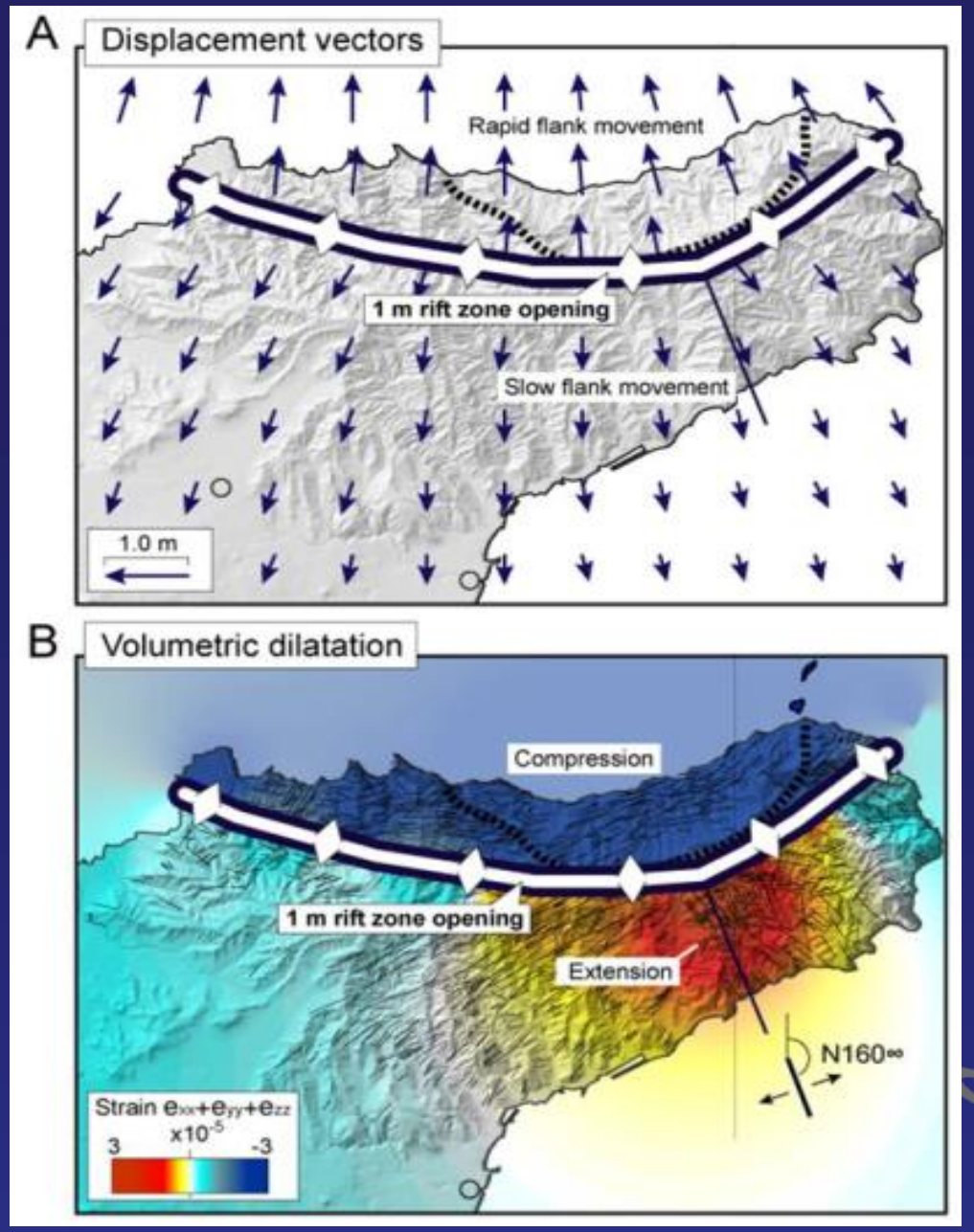
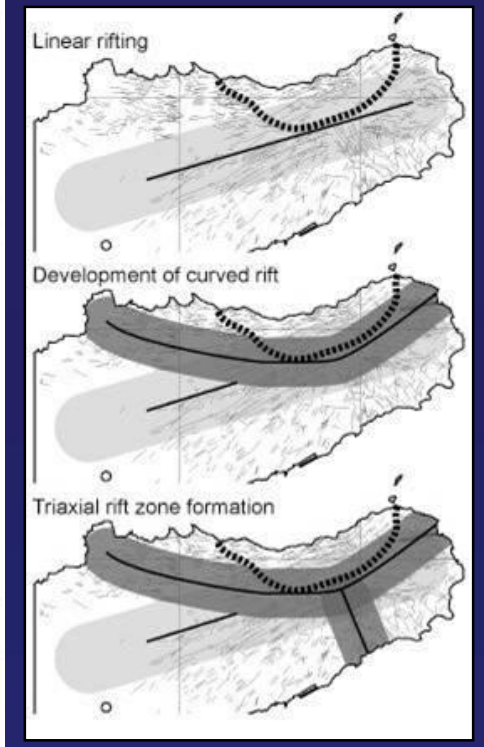
- Displays major landslide and dyke swarms (rifts)
- Landdslide at 4.1 Myrs BP

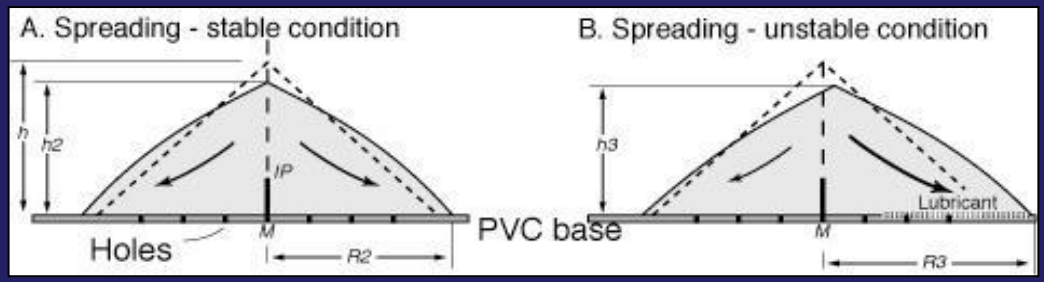


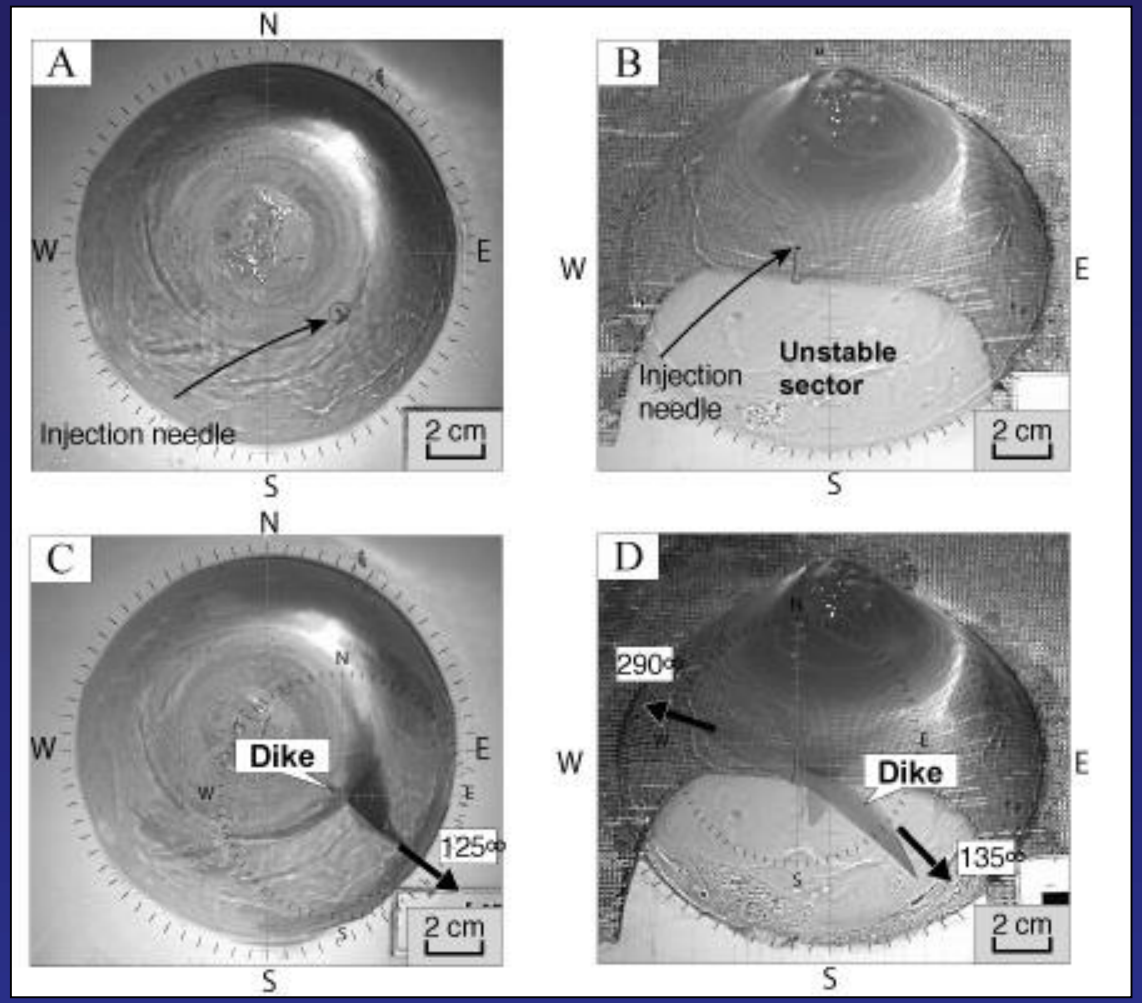


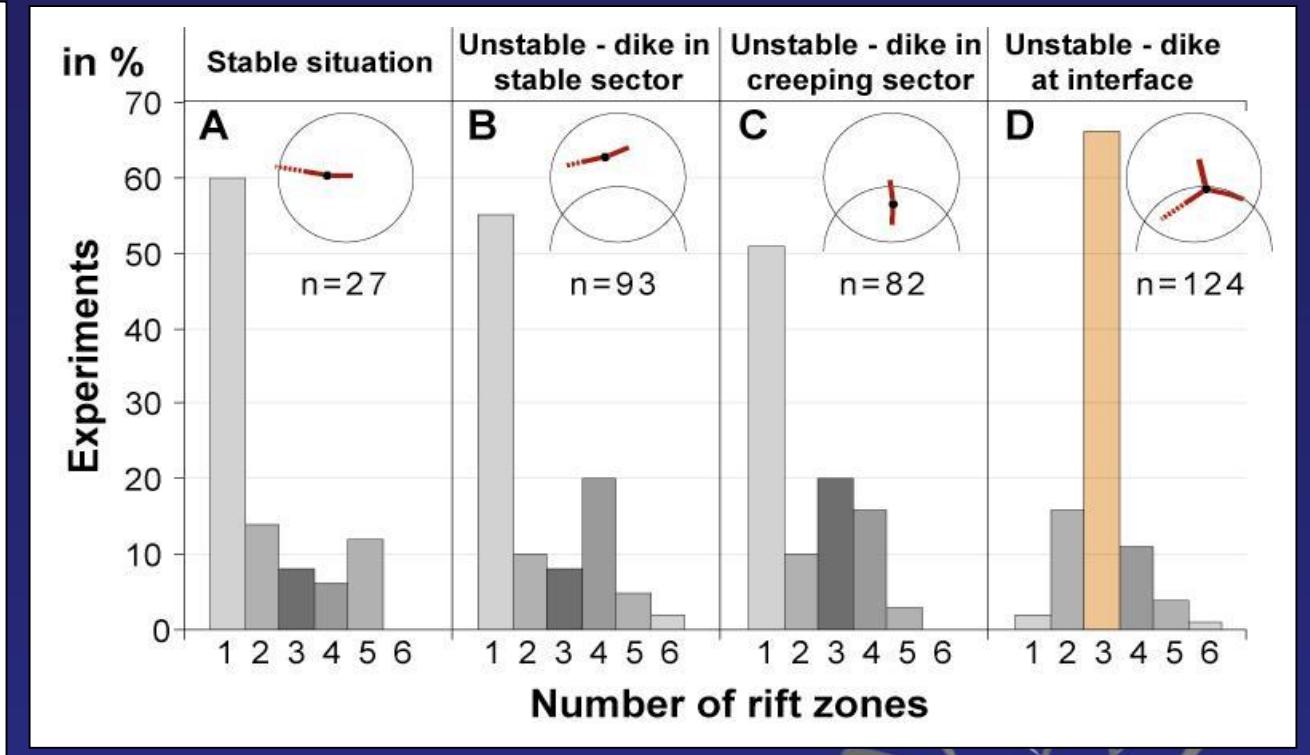


Gelatine Experiments

Injecting fluid into gelatine cones with differential stress



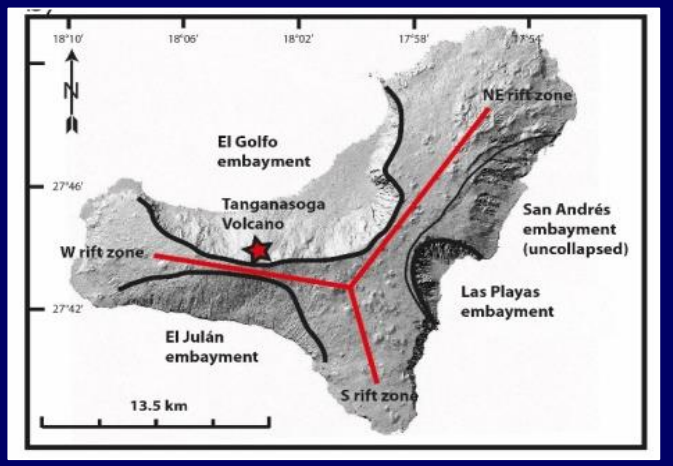


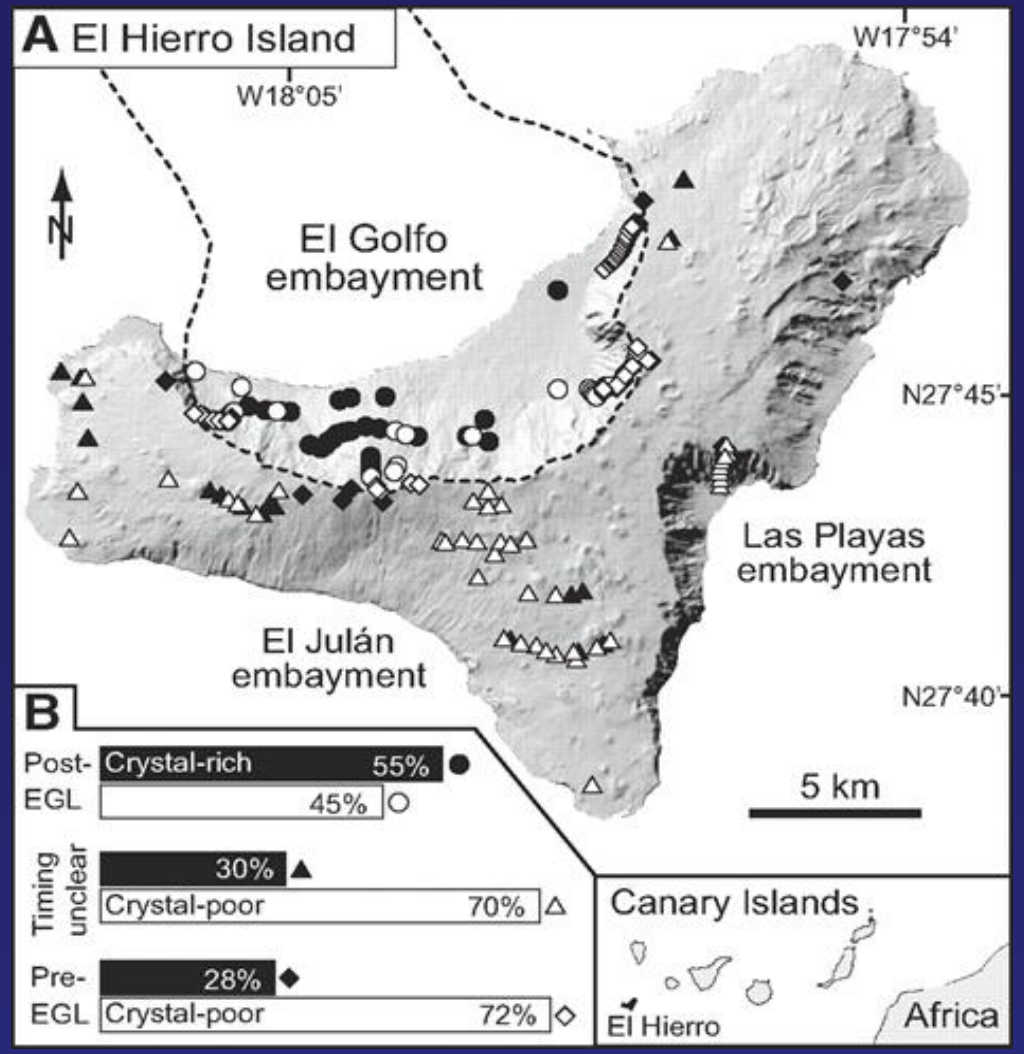


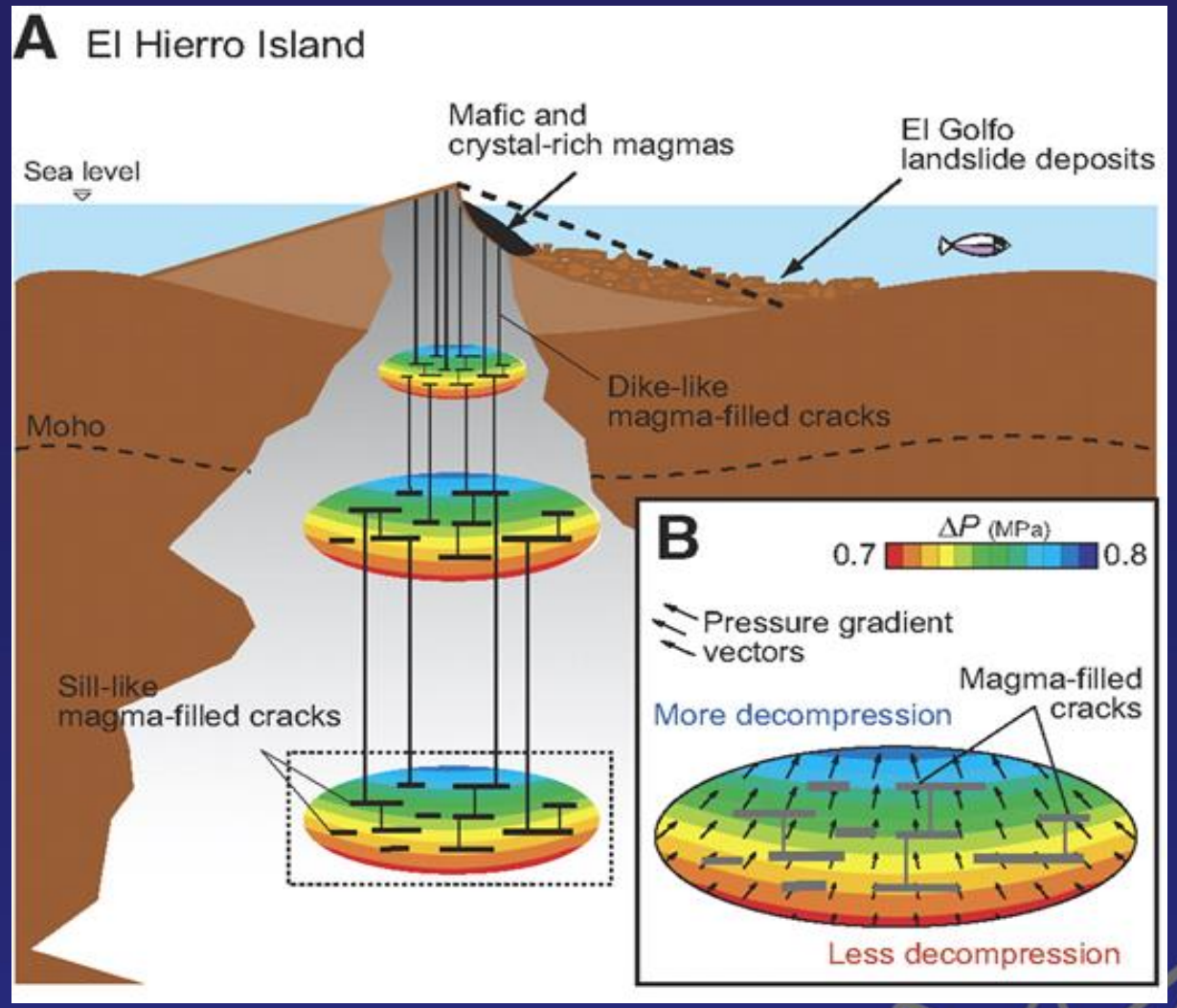
Walter & Troll 2003; Walter et al., 2005; Troll et al., 2013

What about the deepr regions?

Giant landslides and deep mantle processes







From Manconi et al., 2009: Ankaramite, "crystal-rich" volcanics (black bars) have out-proportioned eruptions compared to all other lava types (white bars) in rcent, post-EGL volcanic phase of El Hierro

El Golfo magma storage zone located at ~20 km depth. Decompression induces magma degassing that favours remobilization, ascent, and mixing of different magma batches

Caldera Volcanoes: The Tejeda Volcano, Gran Canaria

Miocene phase

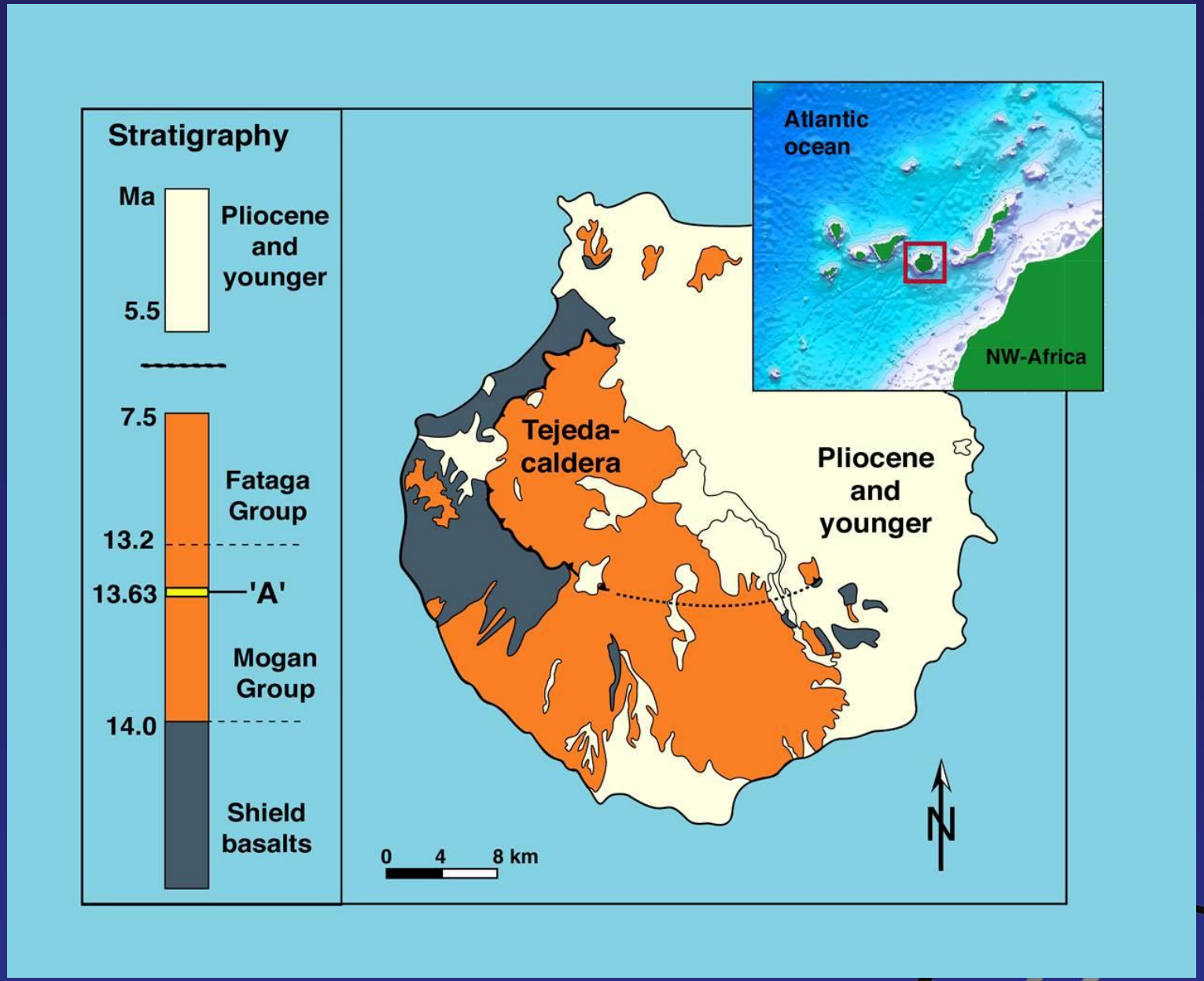
> 14 Ma shield basalts.

14-7 Ma subalkaline to alkaline felsicpyroclastics fed from central caldera.

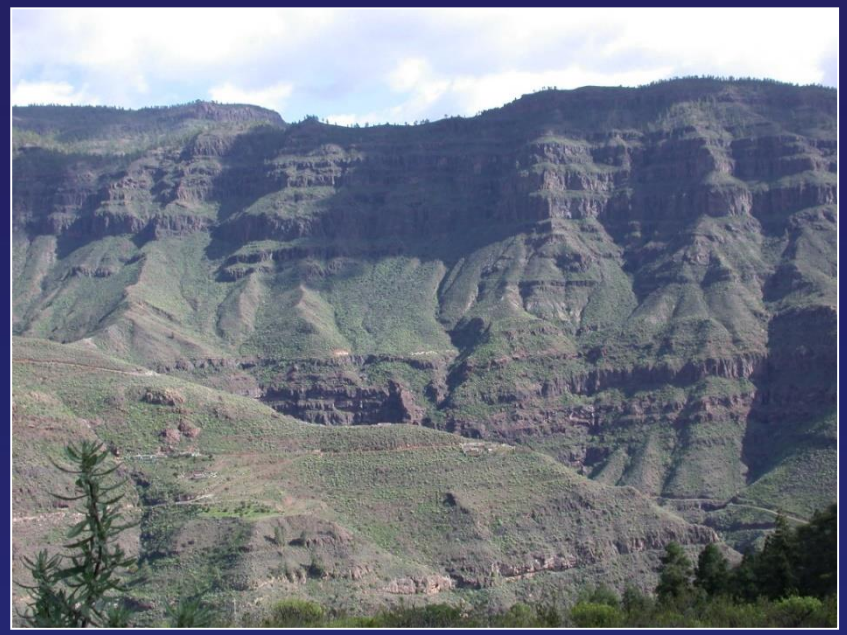
Hiatus after Miocene

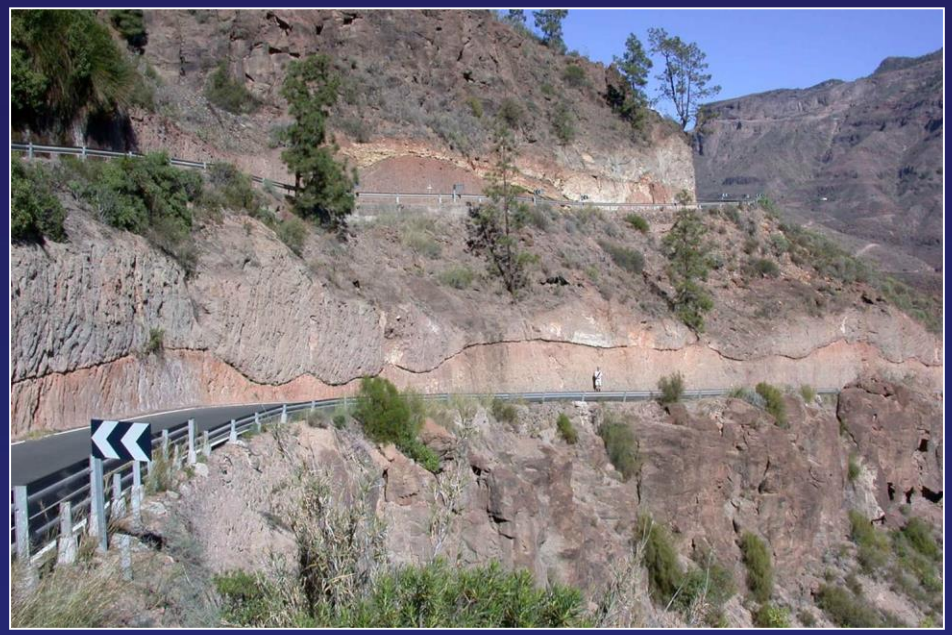
Post-Miocene phase

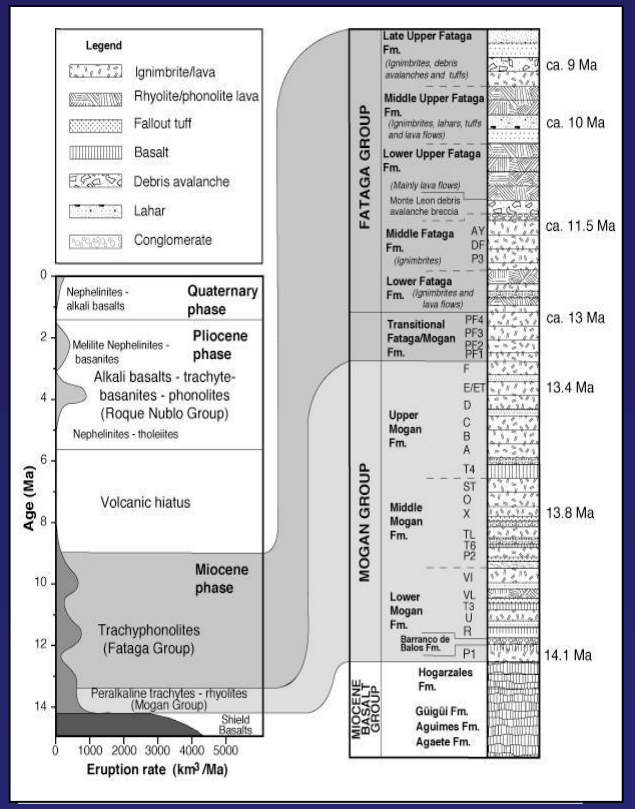
Pliocene and Holocene eruptive phases: mafic alkaline rocks).

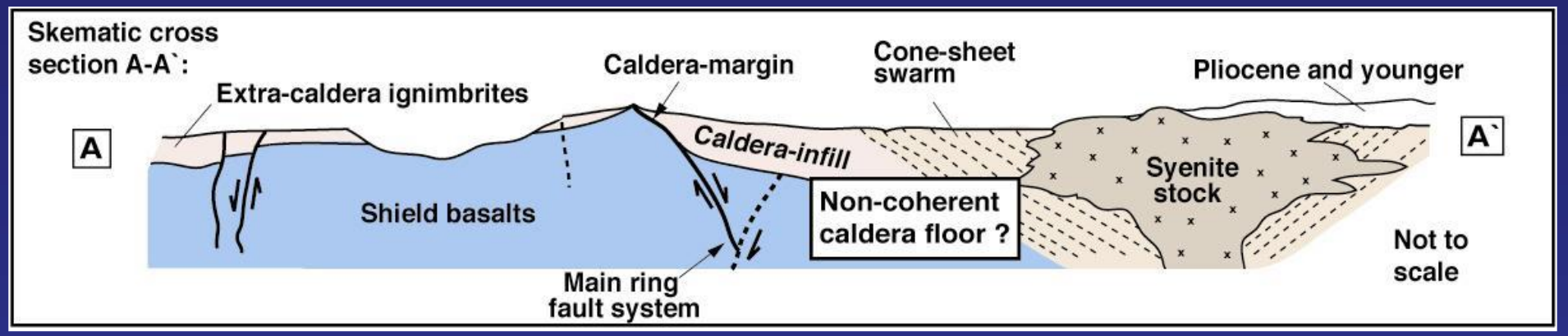


Extra-caldera ignimbrites







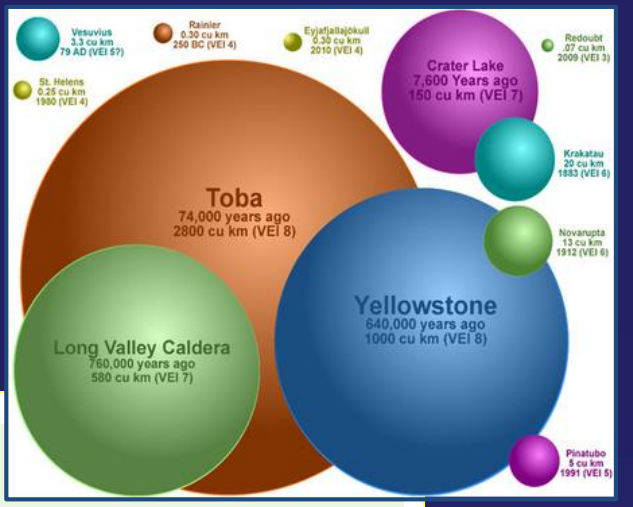


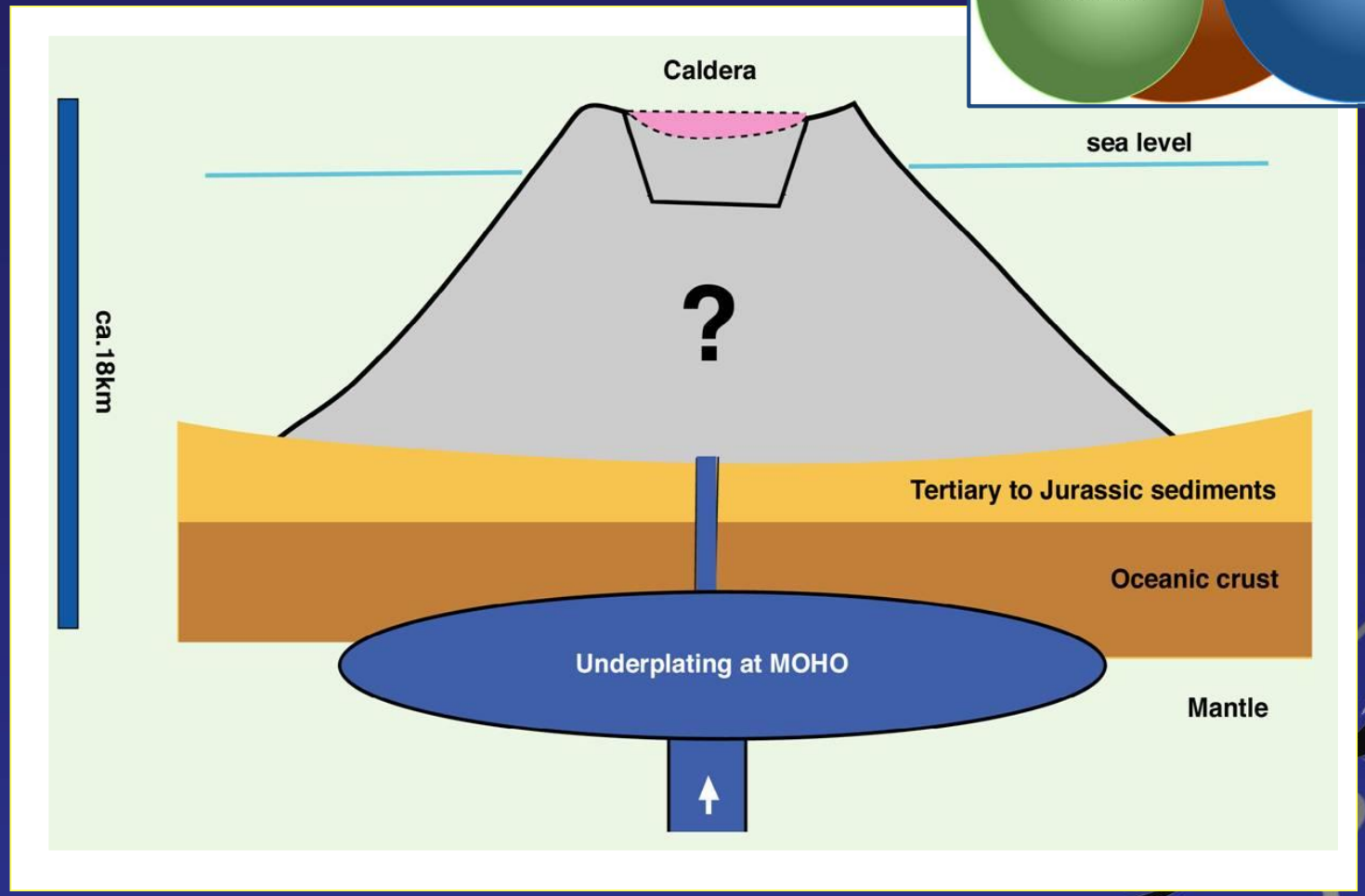
How do we make large-volume rhyolites ?

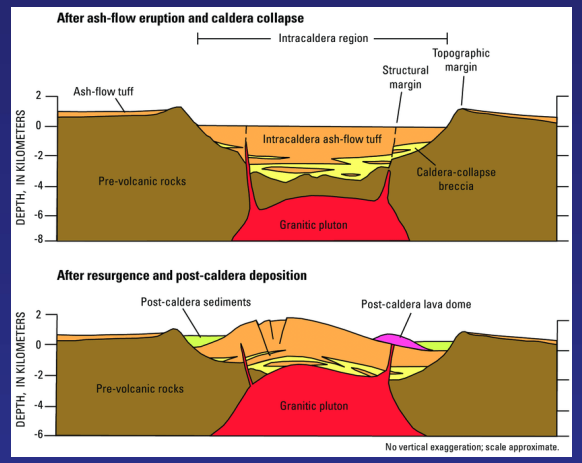
- **Basalt underplating has been documented through seismics and mineral barometry.**

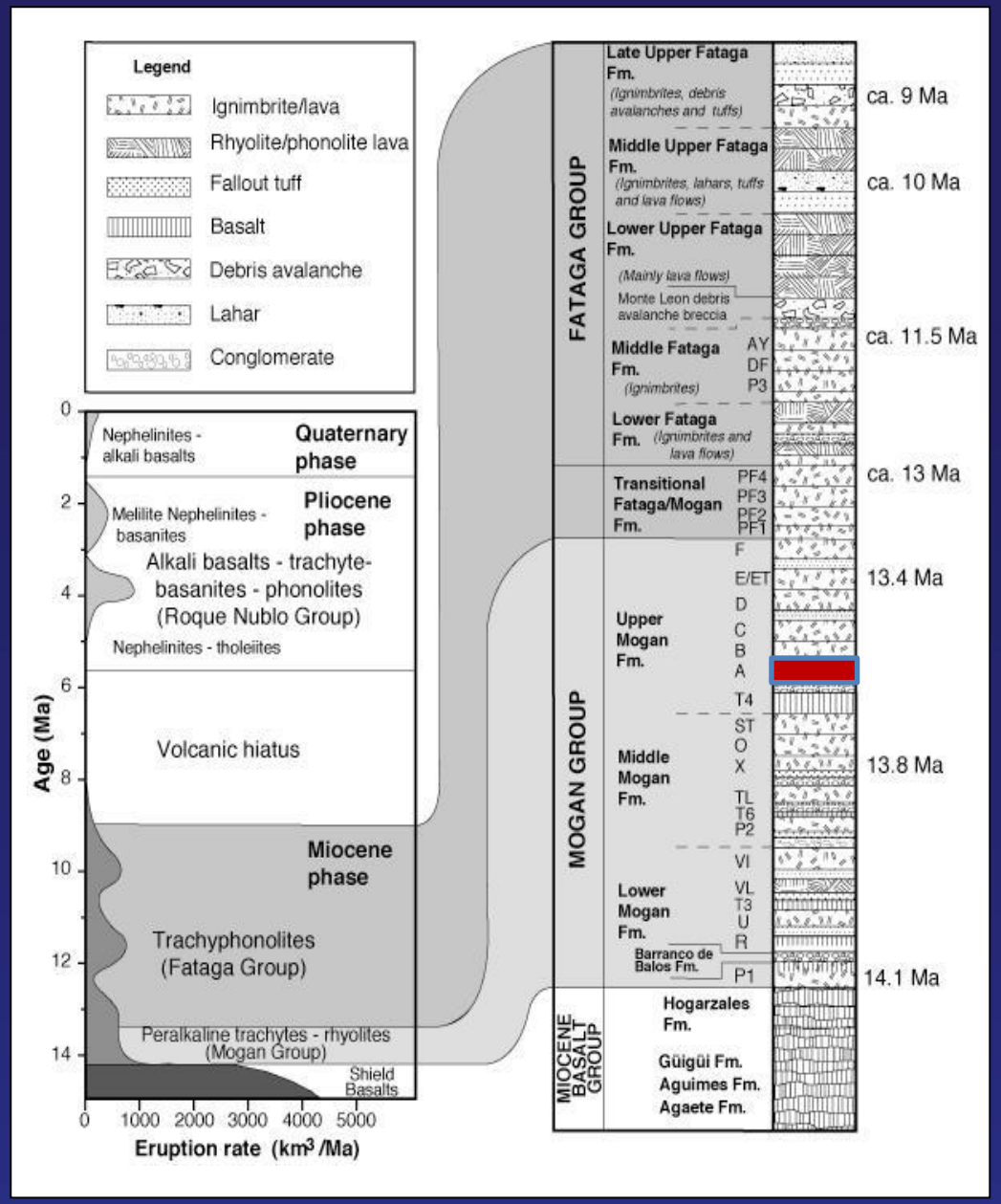
- Yet, substantial silicic volcanism occurred at the (> 1800 km3).

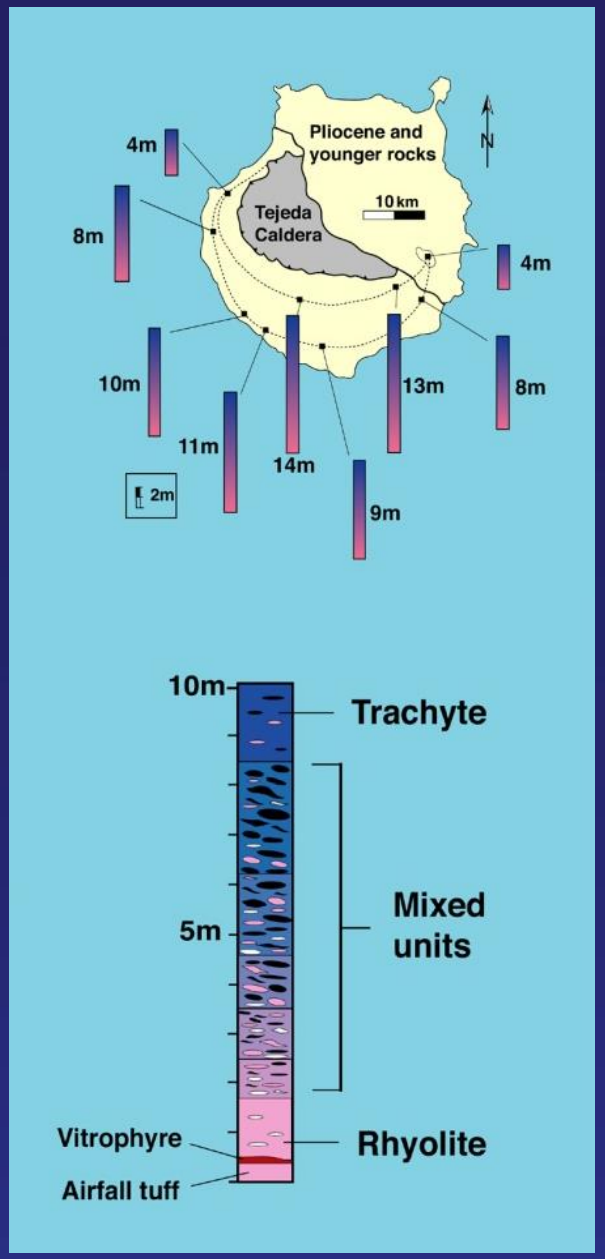
- So, what happens in the island's interior ?



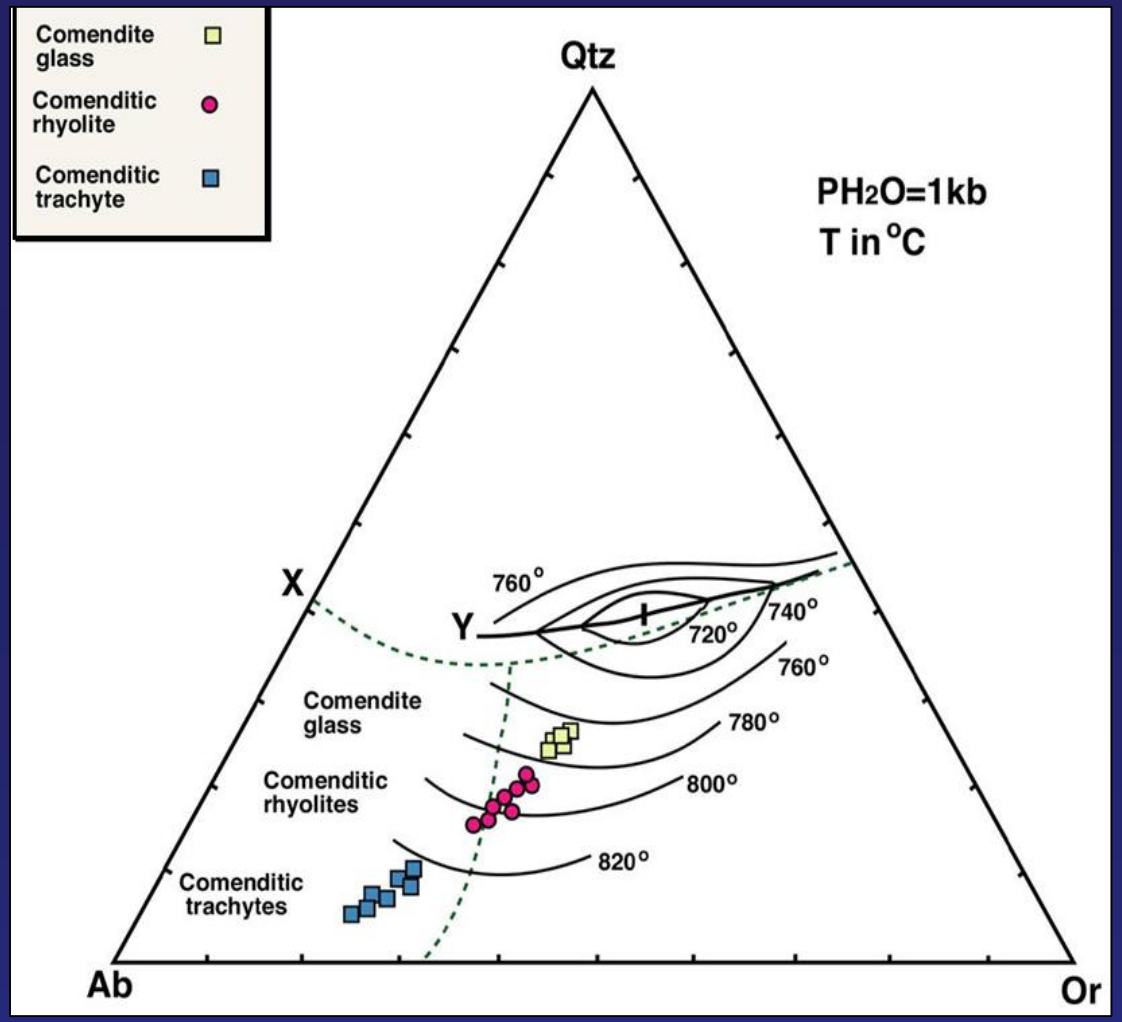


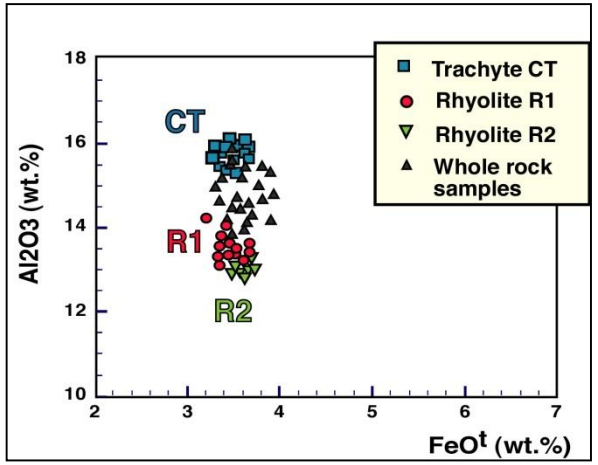


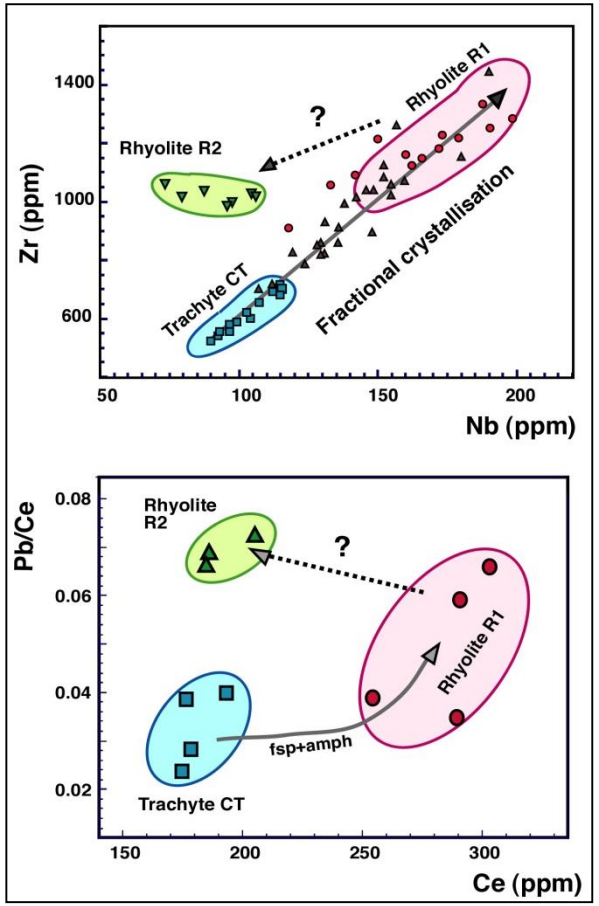




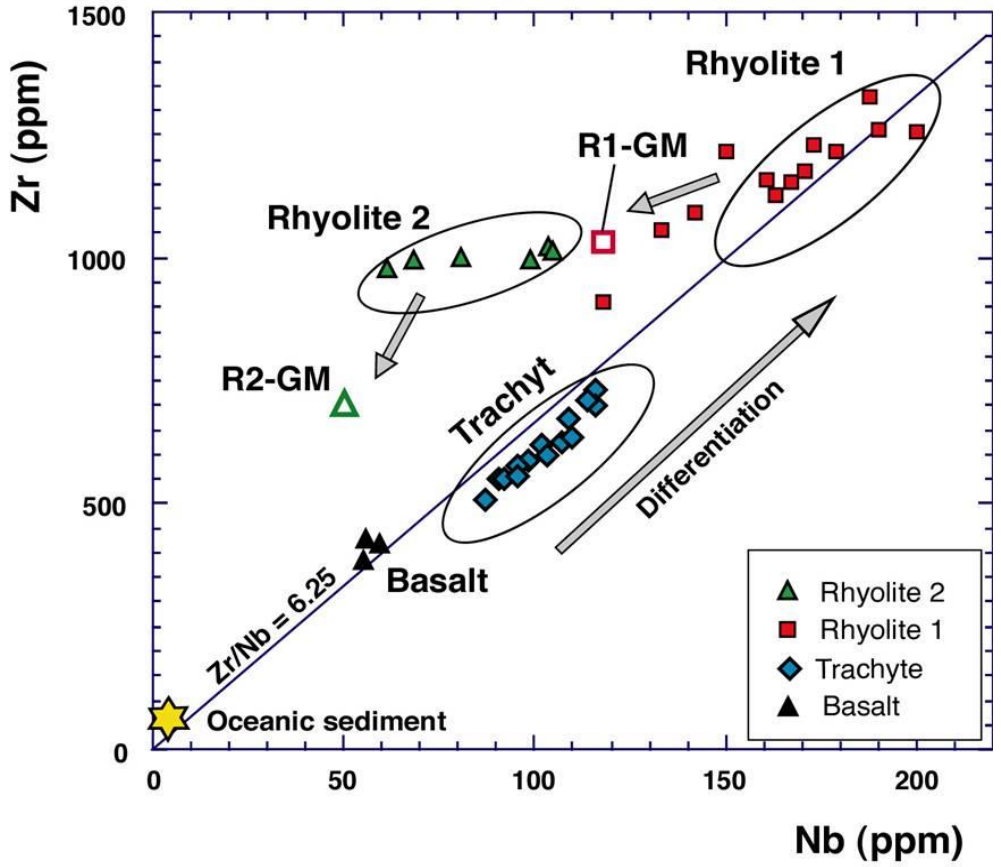
Schmincke & Sumita 1998; Troll & Schmincke, 2002; Troll et al., 2003

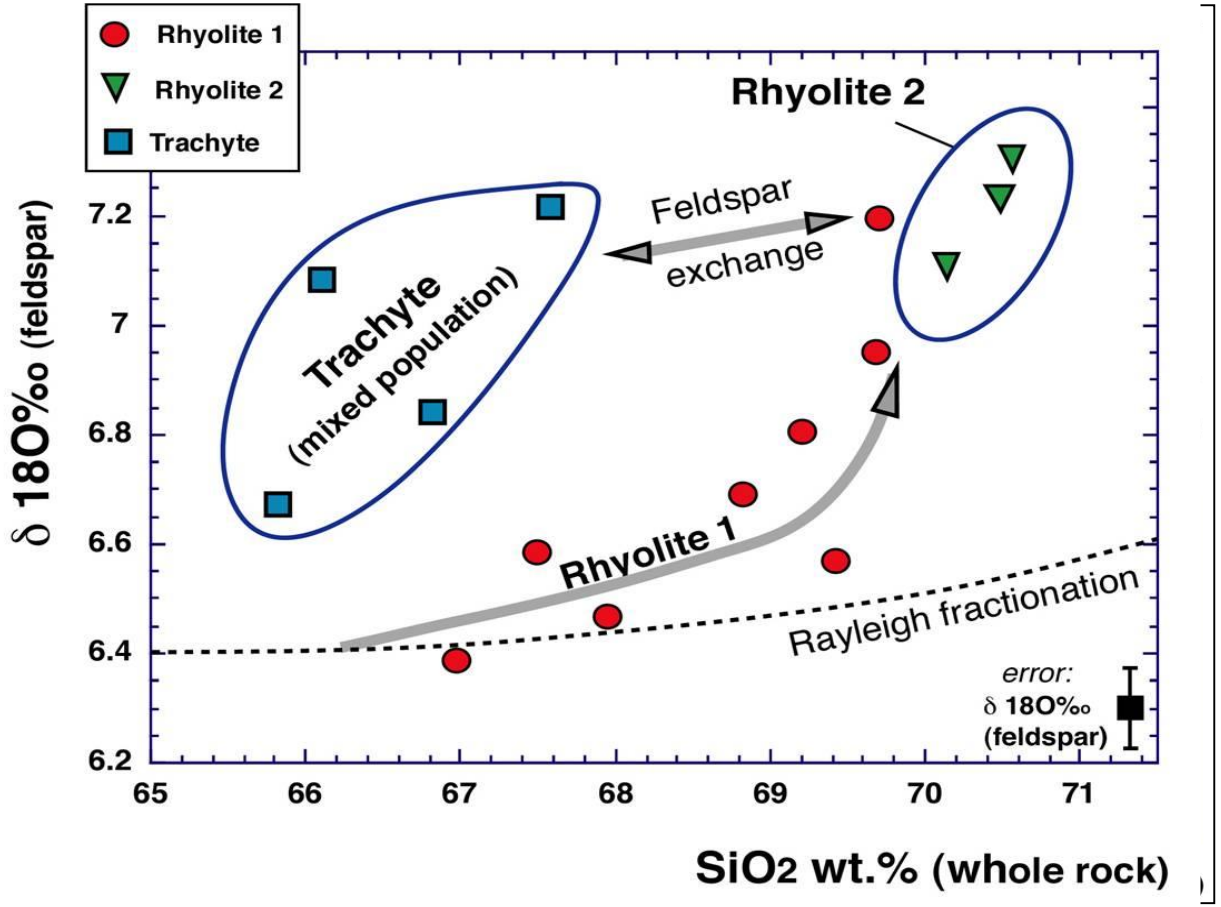






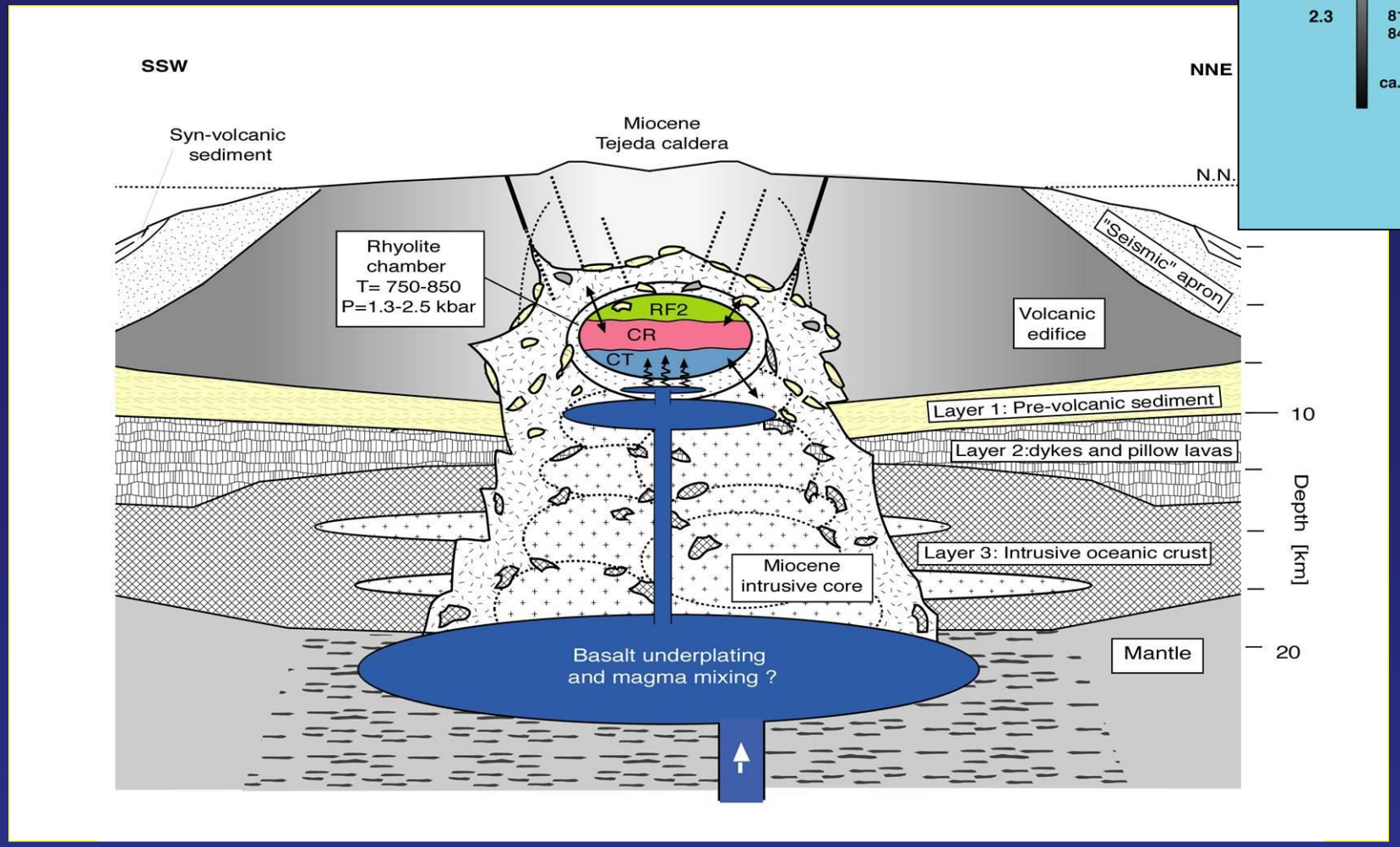
Troll and Schmincke (2002); Hansteen and Troll 2003; Different coloured components have different chemical signatures

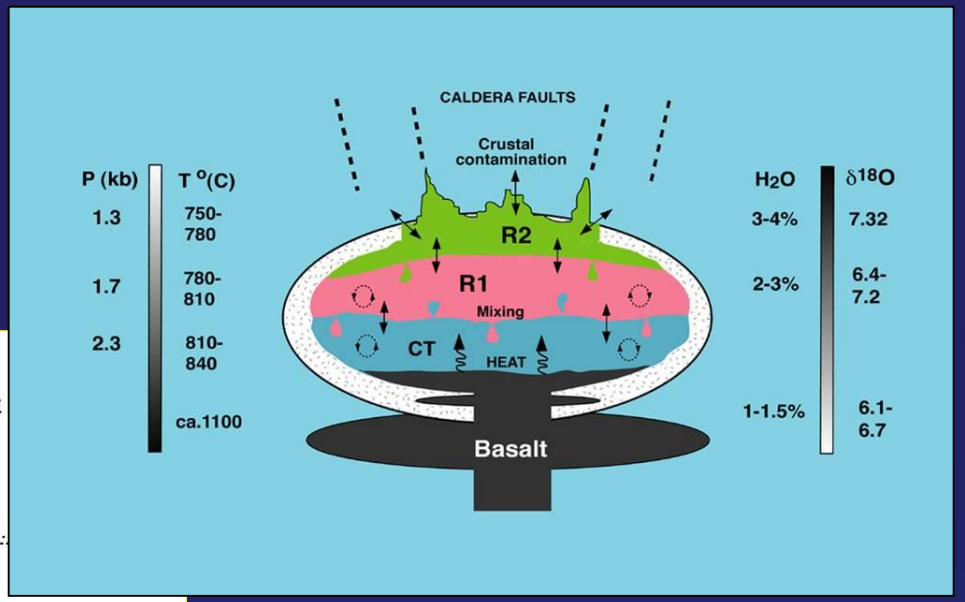




Troll and Schmincke (2002); Hansteen and Troll 2003; Different coloured components have different chemical signatures

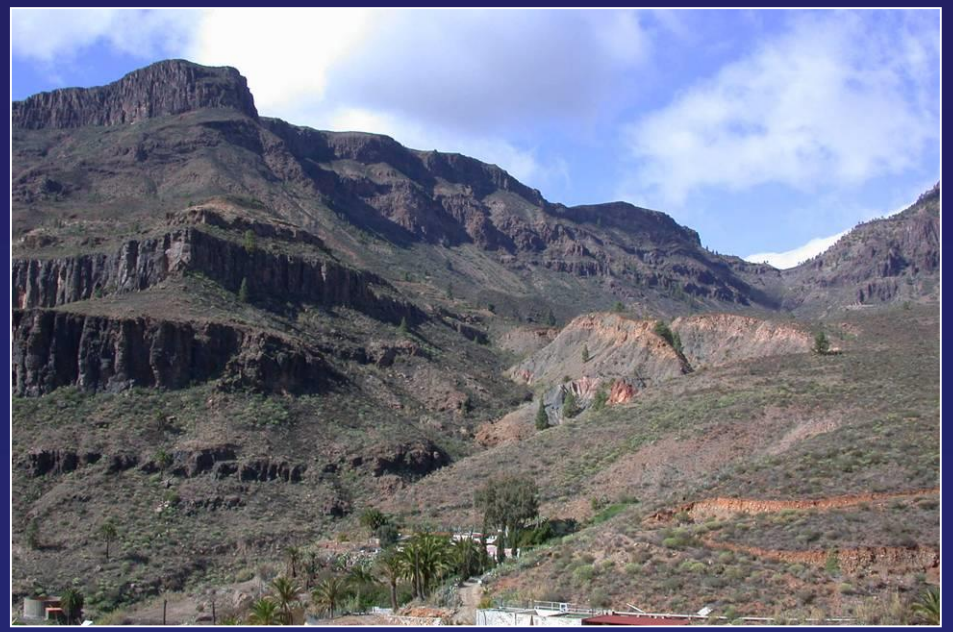
Reconstruction of the Magma Reservoir

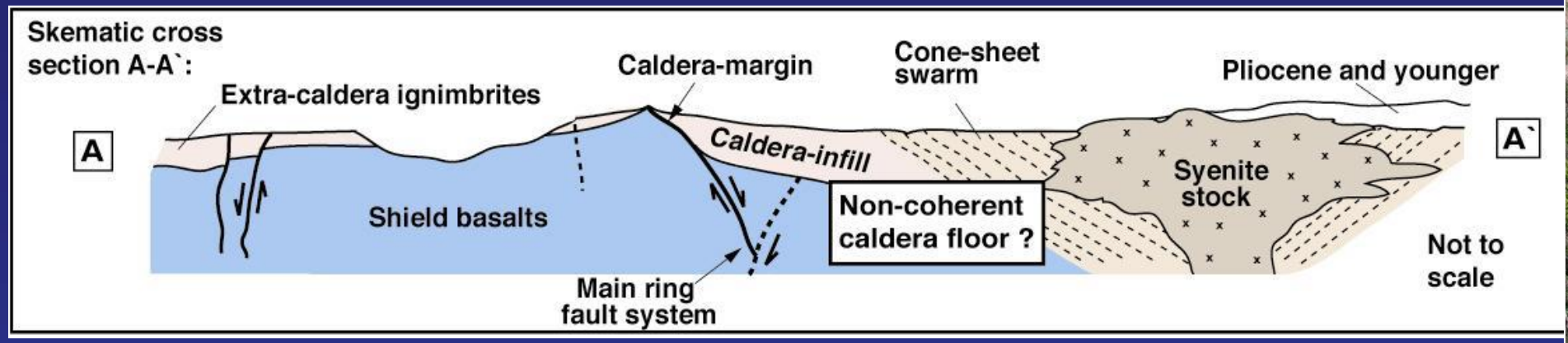


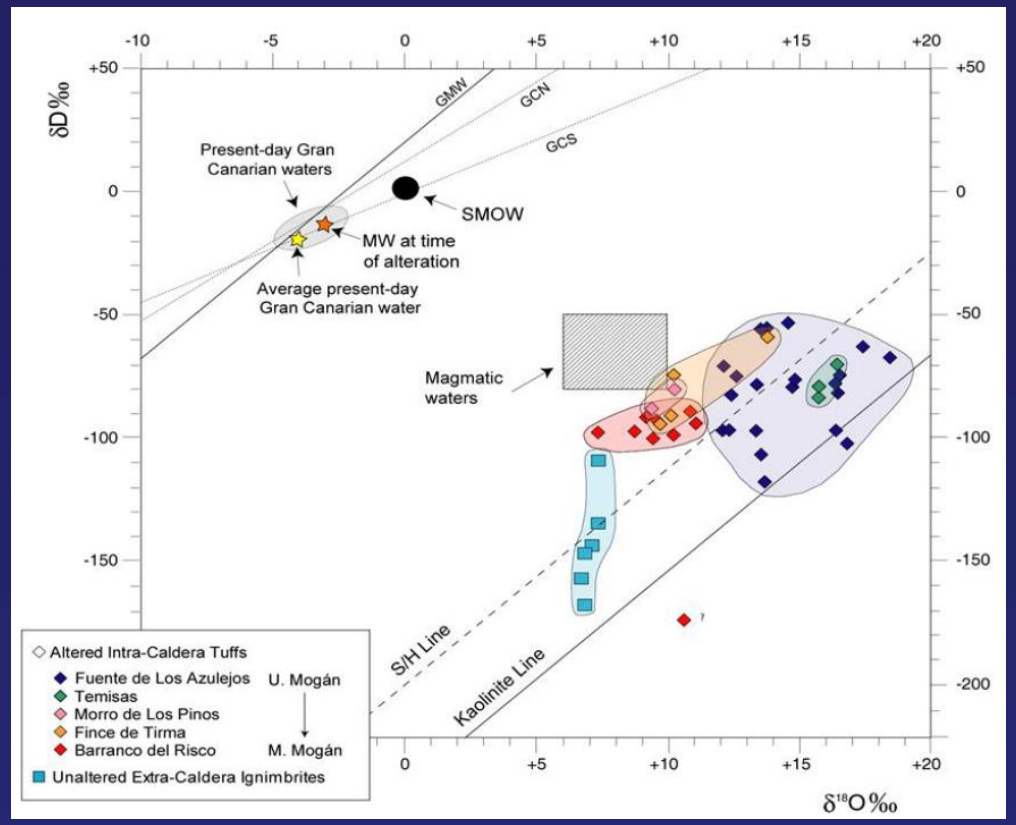


Troll and Schmincke (2002); Hansteen and Troll 2003

Caldera margin



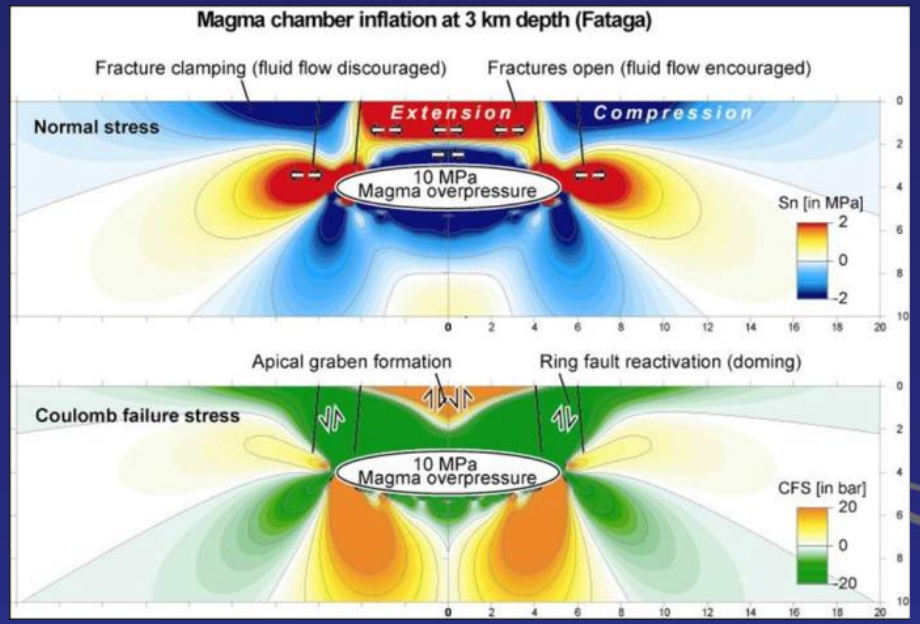




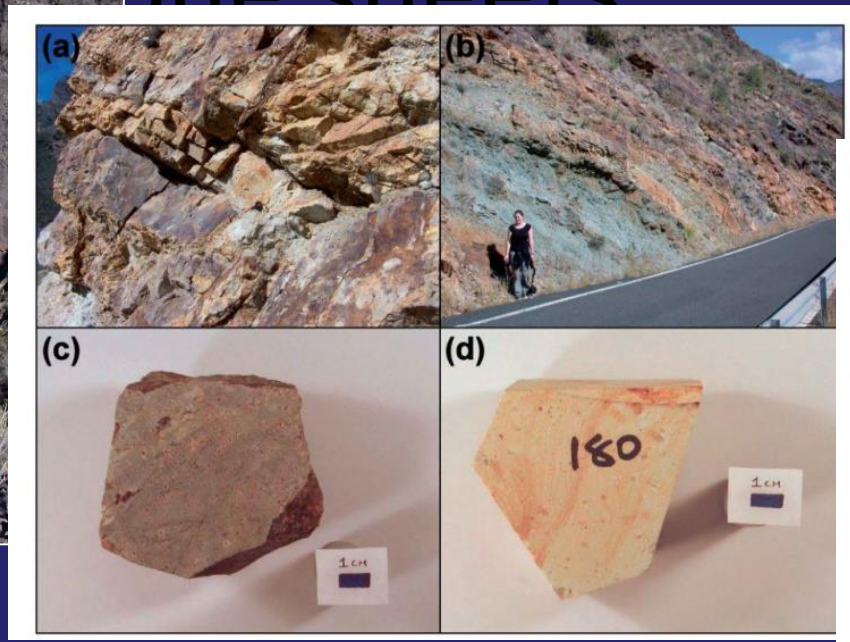
Plot of whole-rock δD versus whole-rock $\delta^{18}O$ isotope composition for altered intra-caldera tuffs, and unaltered extra-caldera ignimbrites from Gran Canaria. **Donoghue et al., (2008)**

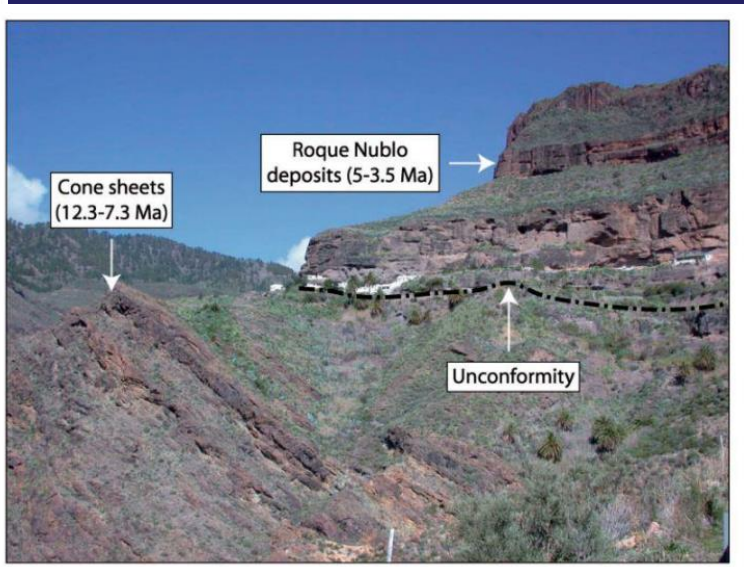
Low-Temperature fault controlled fluid flow

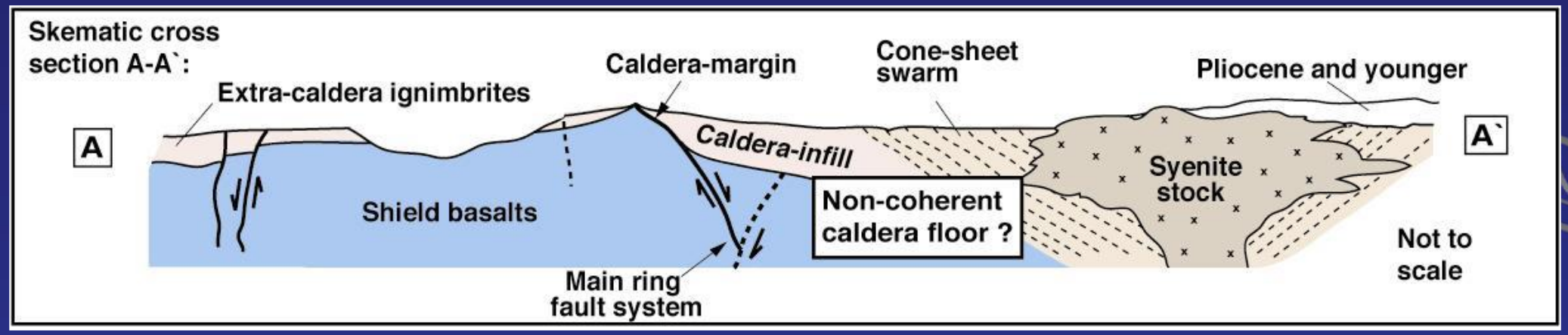
Donoghue et al. (2008): Numerical models of magma reservoir inflation as cross-section through a shallow magma reservoir show the distribution of the maximum principal tensile stress.

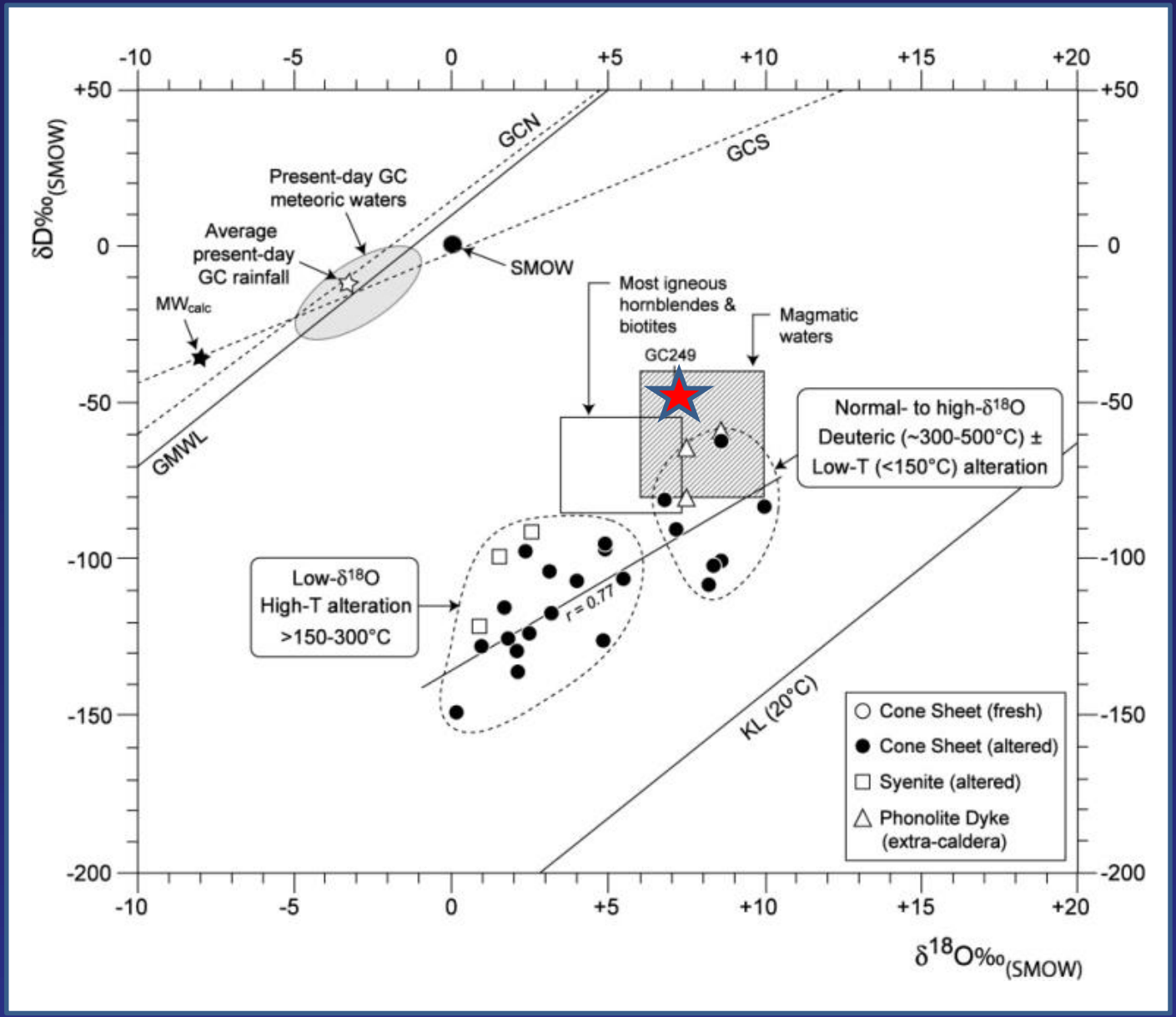


Intra-Caldera cone sheets





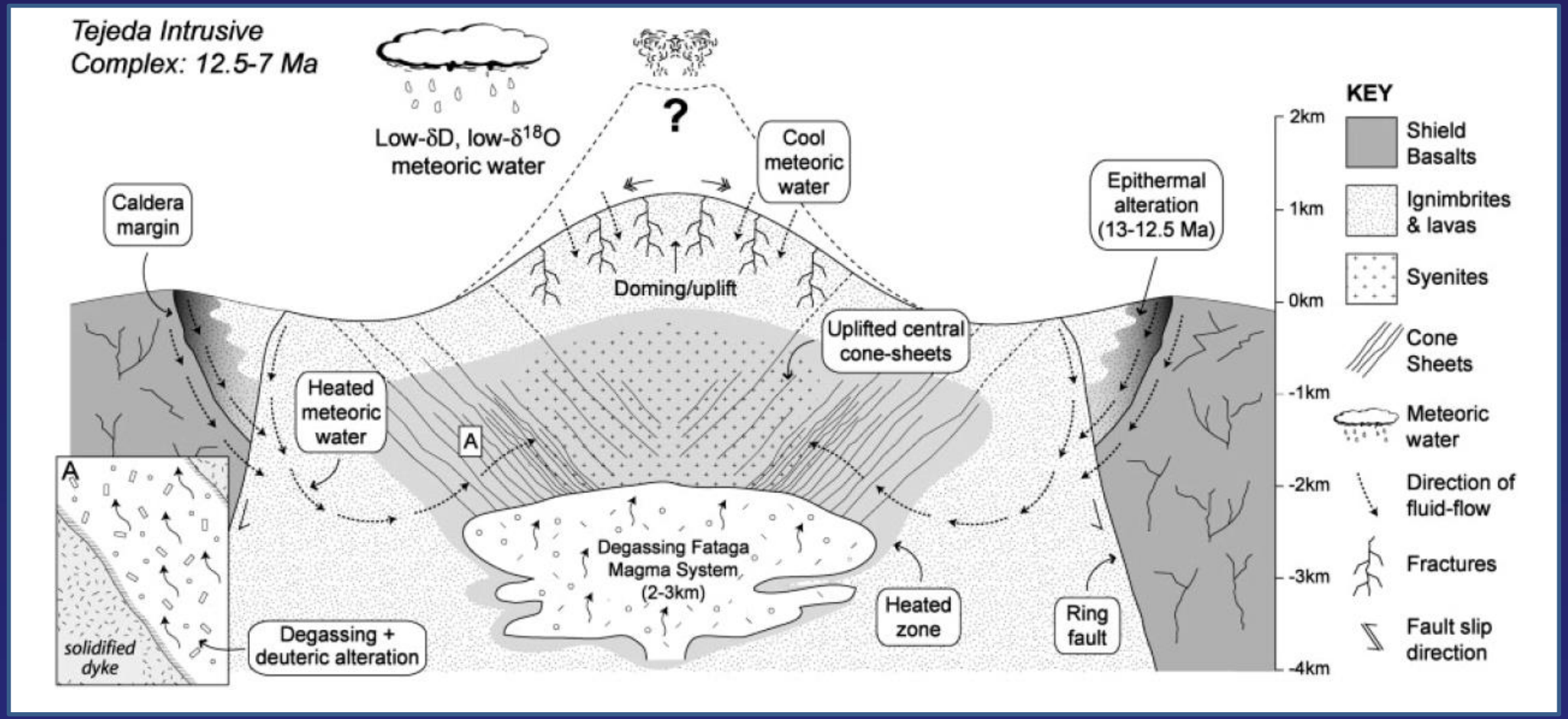




Whole-rock δD vs δ18O for the altered cone sheets and syenites, unaltered cone sheet, and apparently unaltered extra-caldera phonolite dykes (from Donoghue et al., 2010)

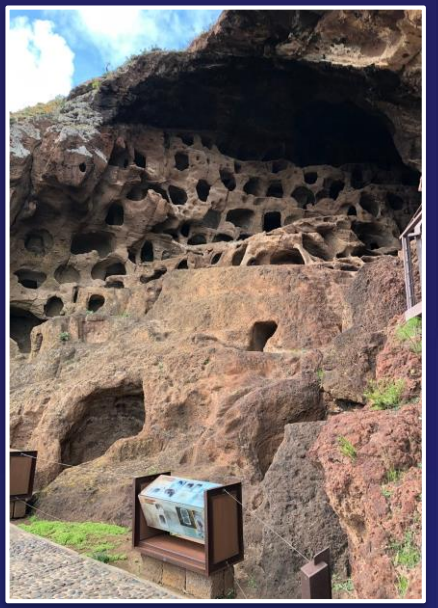
The majority of samples have low $\delta^{18}O$ values relative to the unaltered cone sheet, reflecting the effects of high-temperature, meteoric–hydrothermal alteration

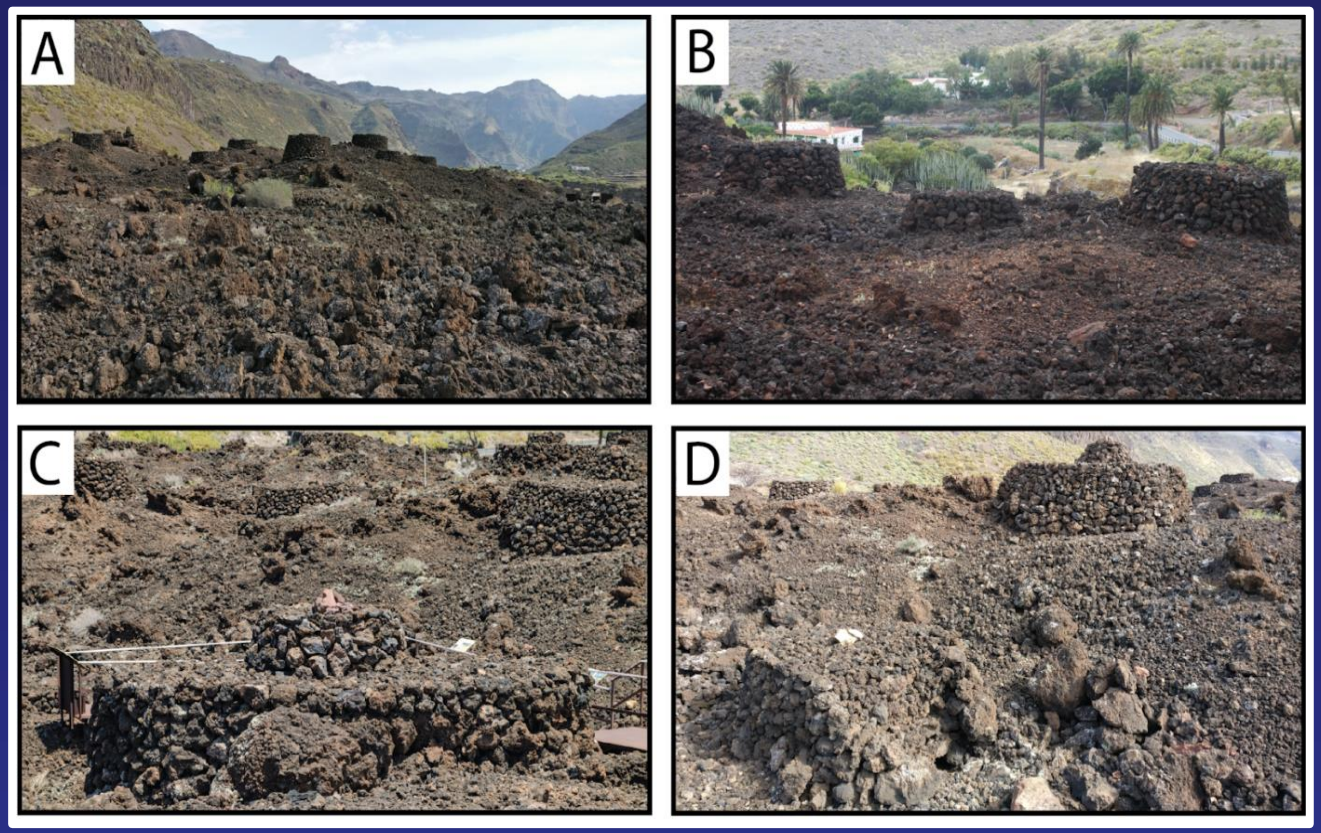
The decrease in the $\delta^{18}O$ and δD values of local meteoric water implies an increased recharge altitude and thus a corresponding large volcanic edifice may have existed above the Tejeda Intrusive Complex during the late Miocene



A large volcanic edifice may have existed above the Tejeda Intrusive Complex during the late Miocene, but was already eroded before the Roque Nublo volcanic episode in the Pliocene…**thus represnting a 'lost volcano' prior to the Pliocene Volcanic cycle** (from Donoghue et al., 2010)

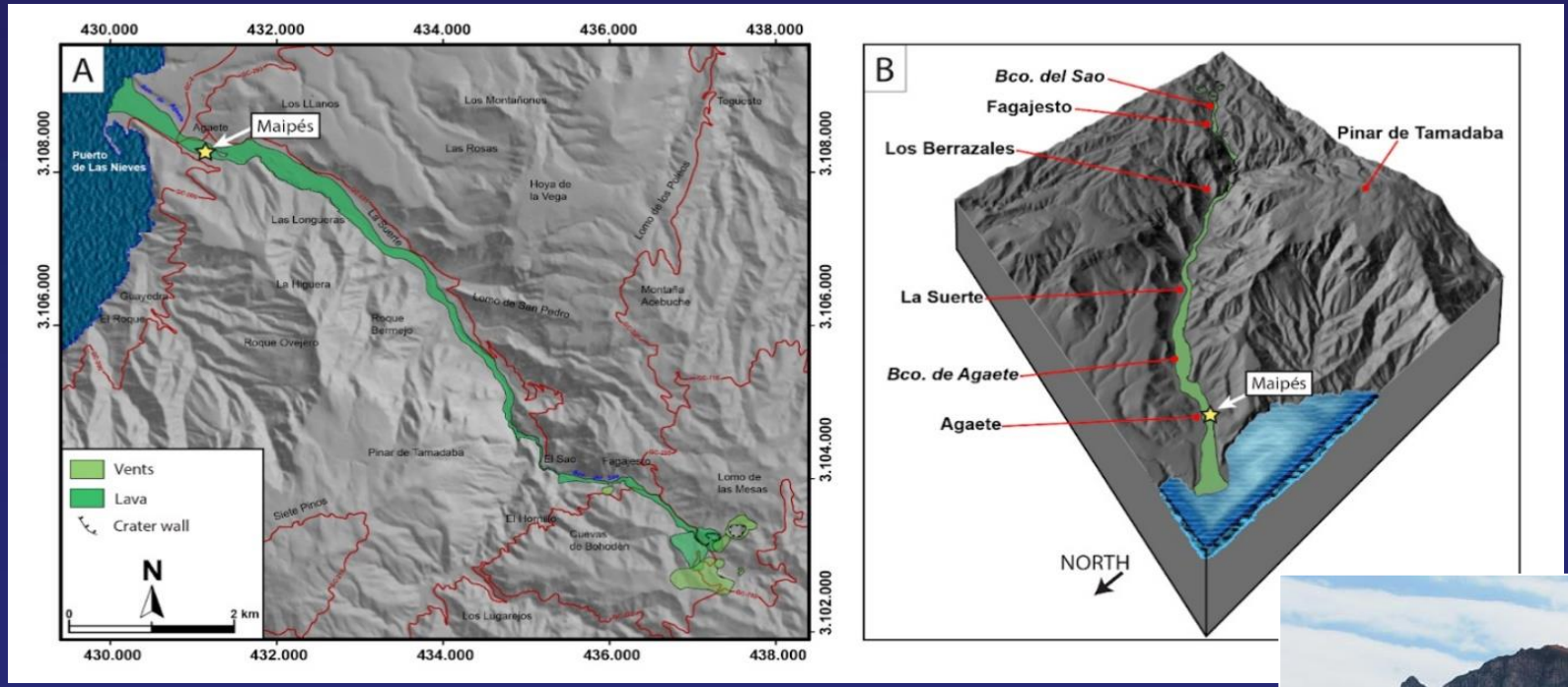
VOLCANIC RESOURCES: Aboriginal settlements and graveyards exploited volcanic rock (Troll et al., 2019)





Volcanic Resources of the Canary Islands

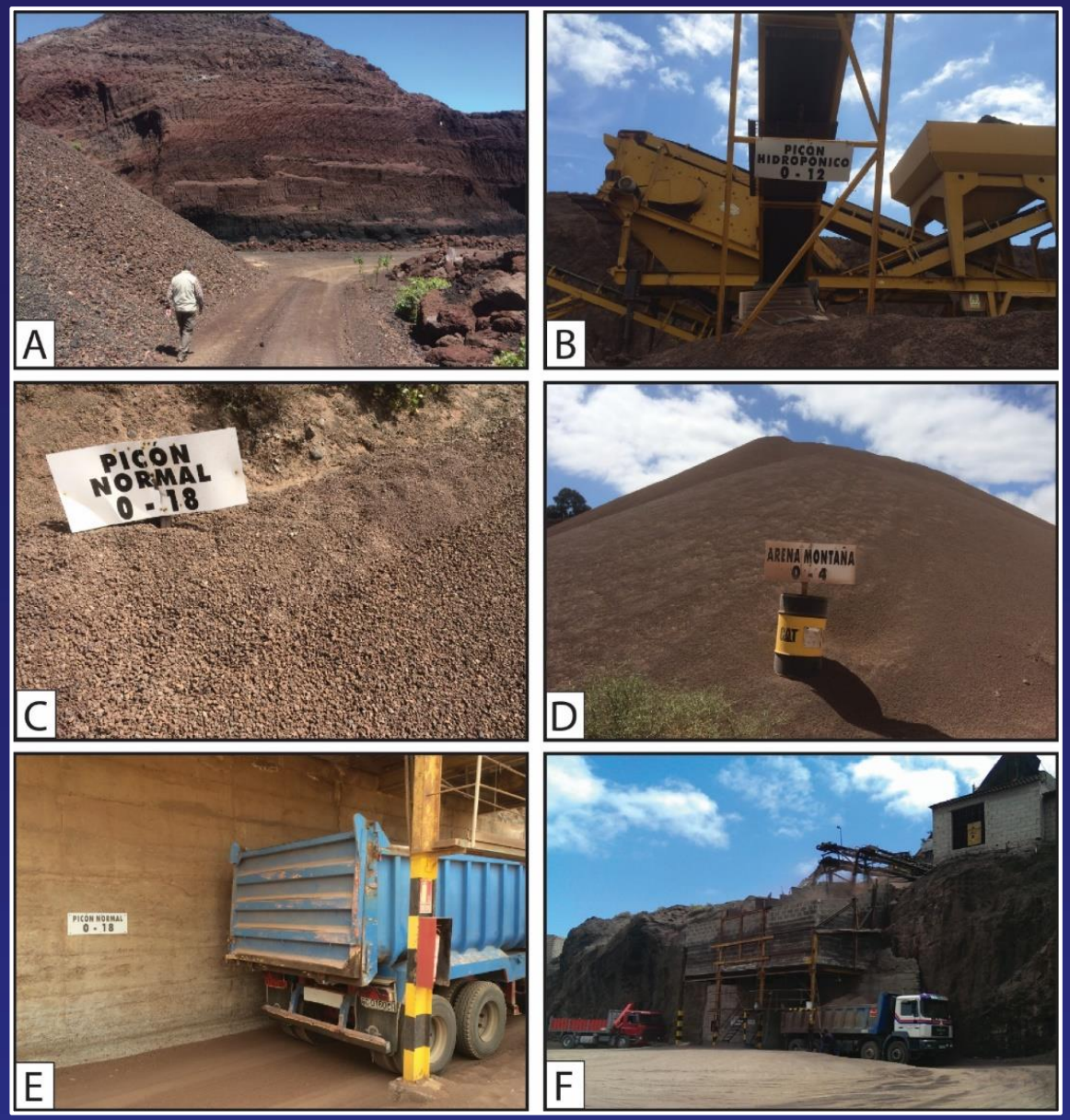
Use of ‘malpais’ as ceremonial site



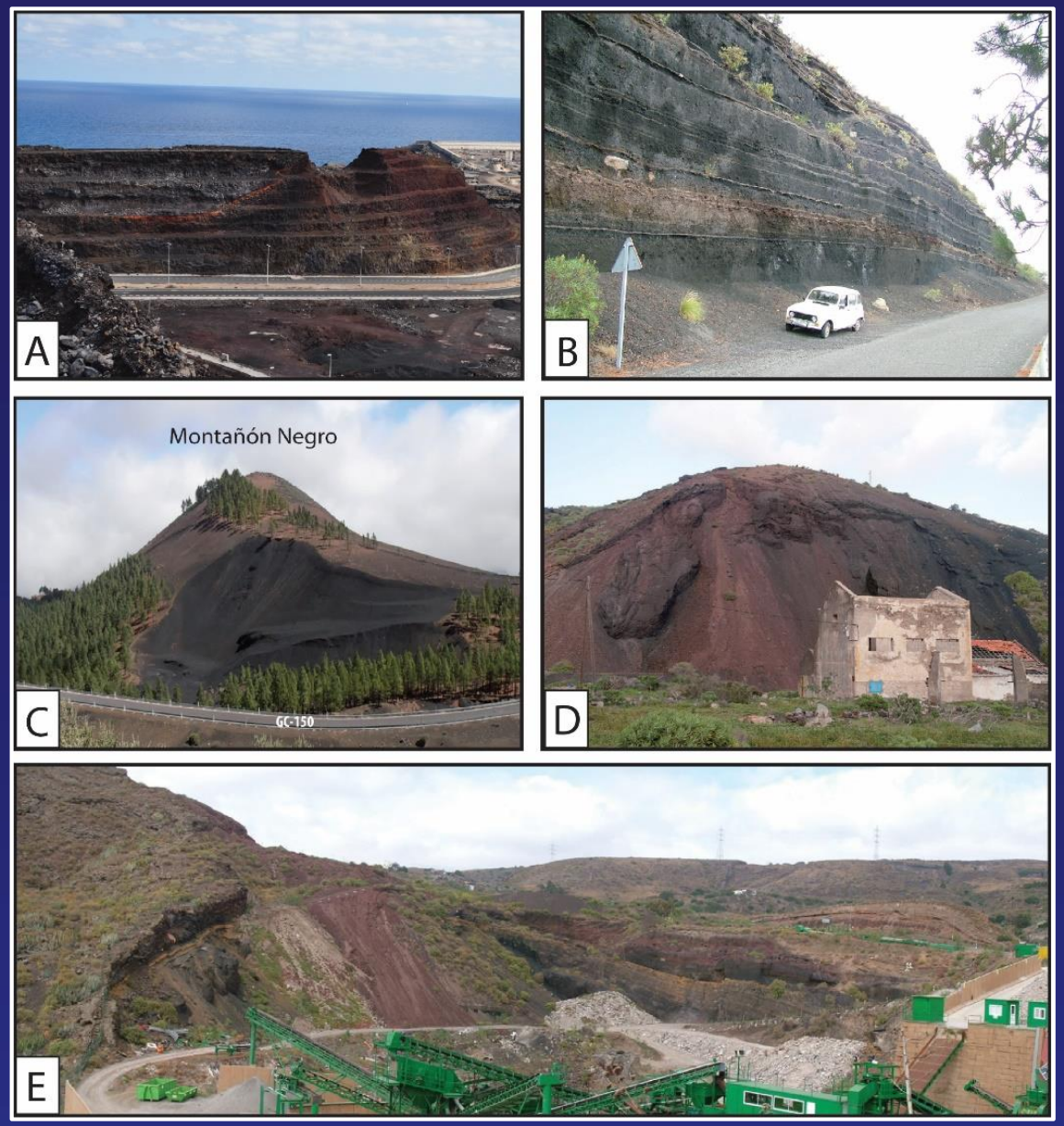
From Troll et al., 2019: Map and reconstructed topographic projection showing the valley filling nature of the Agaete lava flow

The lava erupted from vents some ~ 11 km inland and progressed to the coast. Maipés is located at the widening of the Barranco Agaete just when it opens up towards the sea

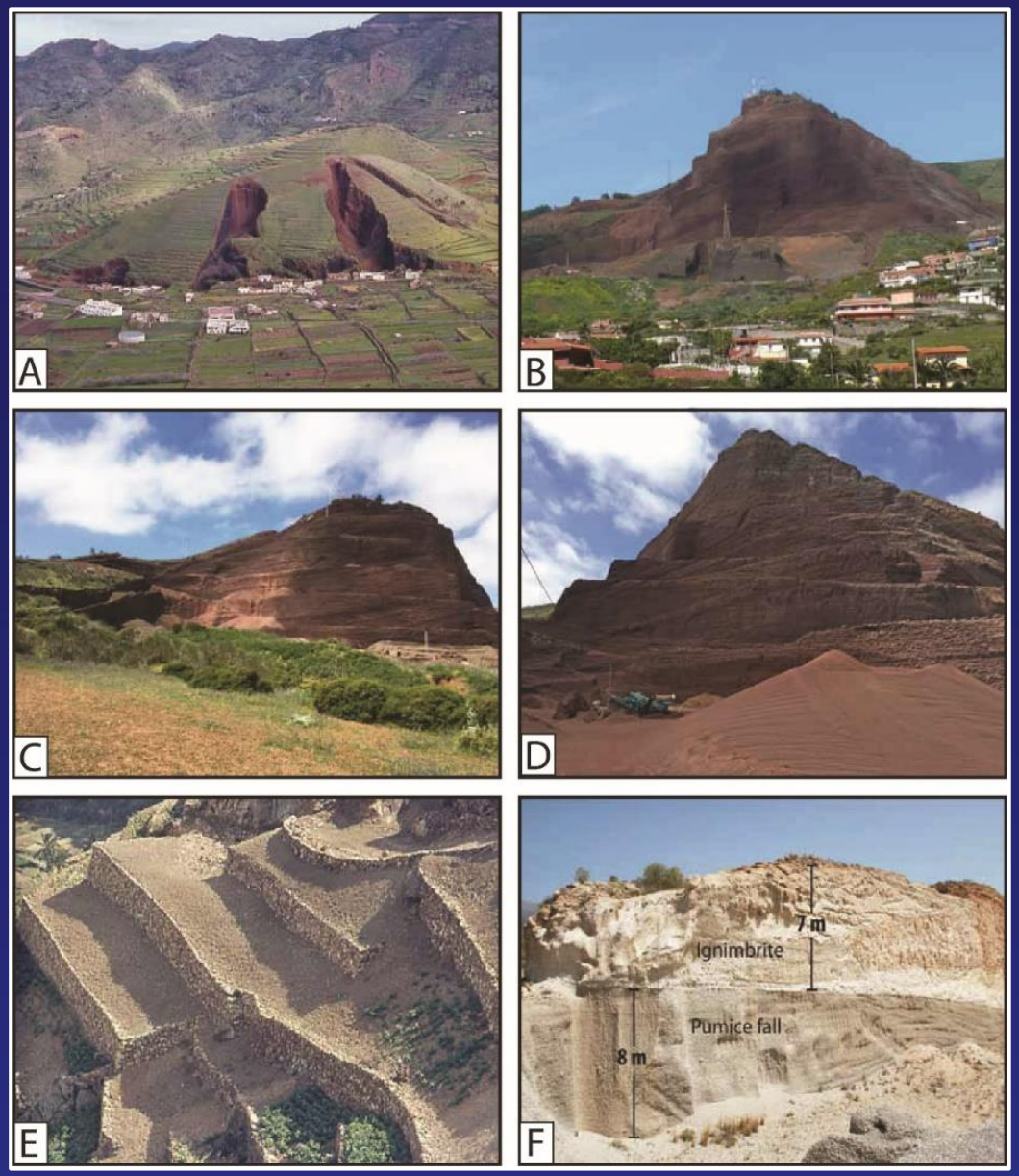
Arico church on Tenerife, Canary Islands



Montaña Santidad and Montaña Pelada

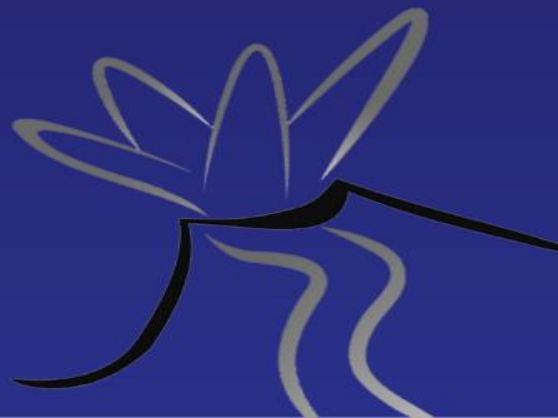


La Isleta, Pico de Bandama, Montañón Negro, Montaña Negra de Jinámar, Sima de Jinámar



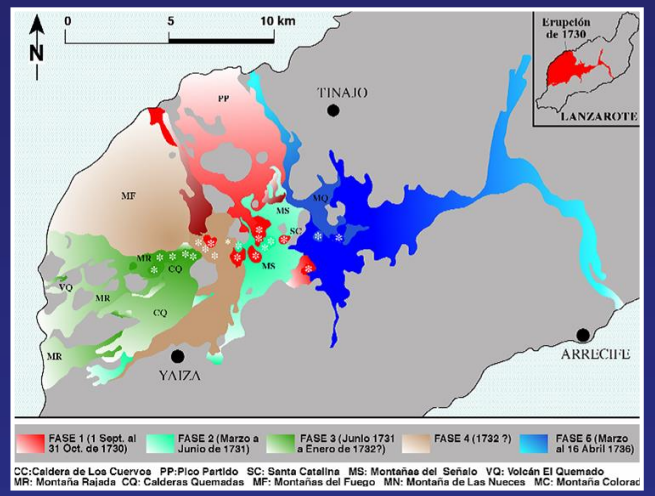
Mña. de El Palmar, Montaña Birmagen, Chimique

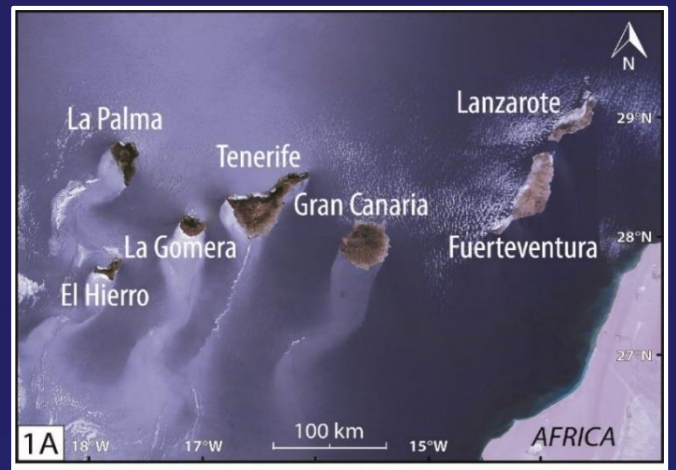
Volcanic particles are creating fertile soils for agriculture (Troll et al., 2017)



The Lanzarote 1730-1736 eruption (Troll et al., 2017)

- Intense Earthquakes and eruption commenced in mid-1730. Eruption started in early 1731. 23% of island covered
- Bishop Dávila y Cardenas sent in mid 1731 to observe the events
- He notes: Areas covered by lapilli with thick cover: no vegetation, but with thin cover, they are blooming
- Lapilli then used widely in agriculture on Lanzarote



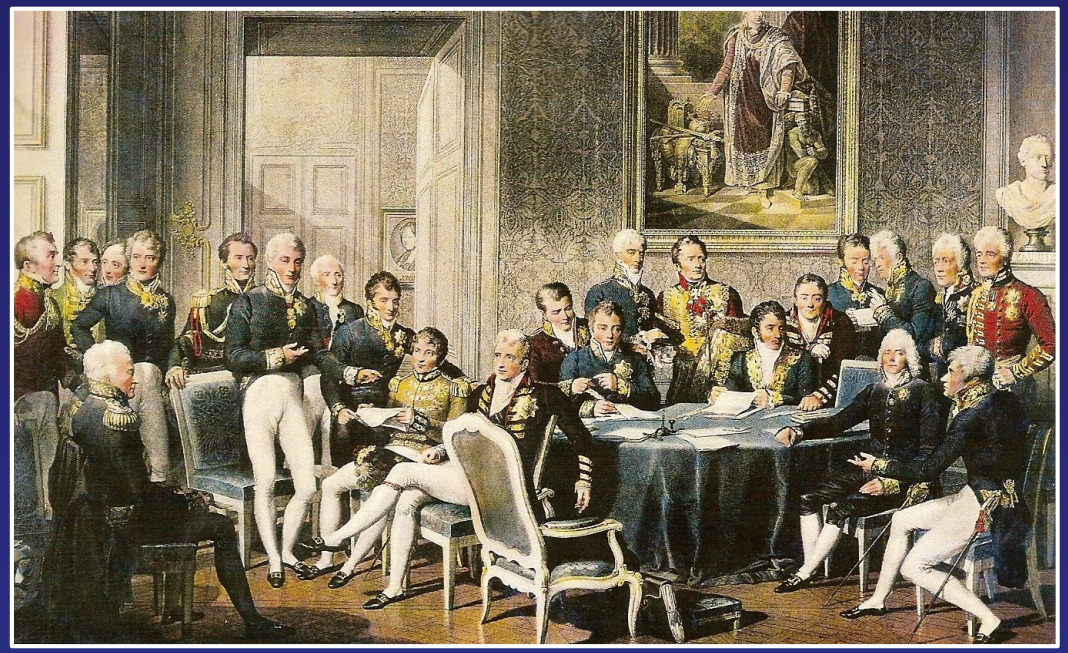


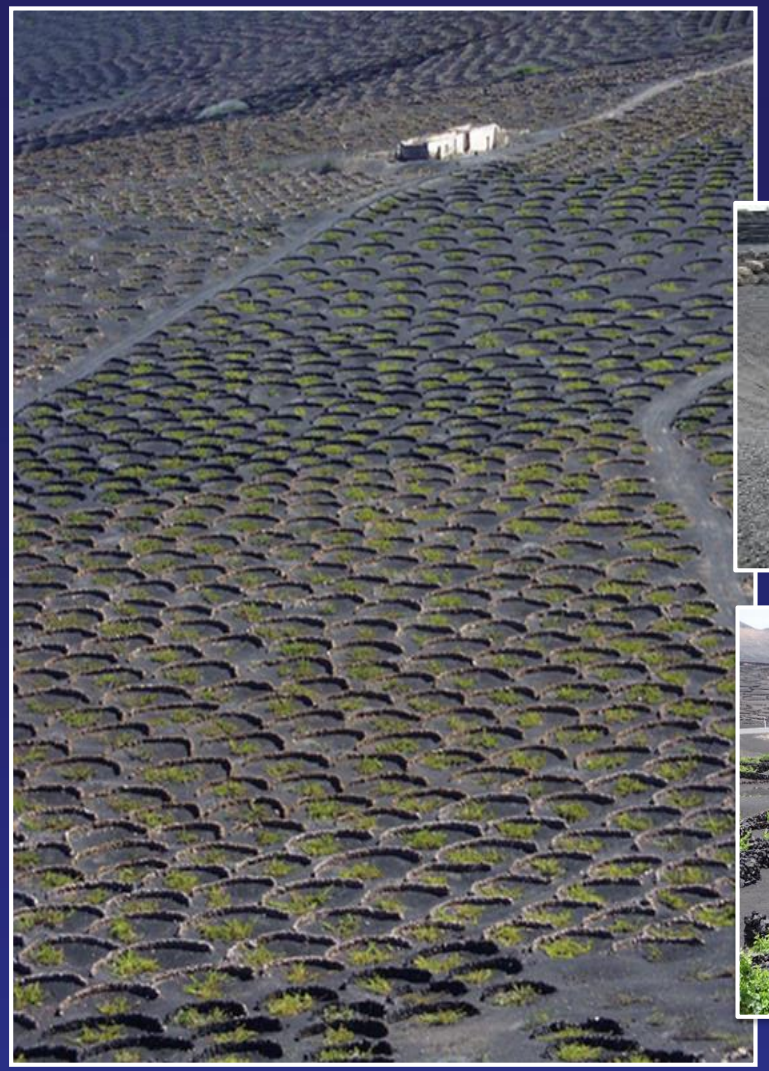

malvasía volcánica
semidulce


la geria

The secret of picon

- The Population of Lanzarote doubles in the next 50 years
- Famous malvasia wine, drank at “Vienna congress“ in 1814!



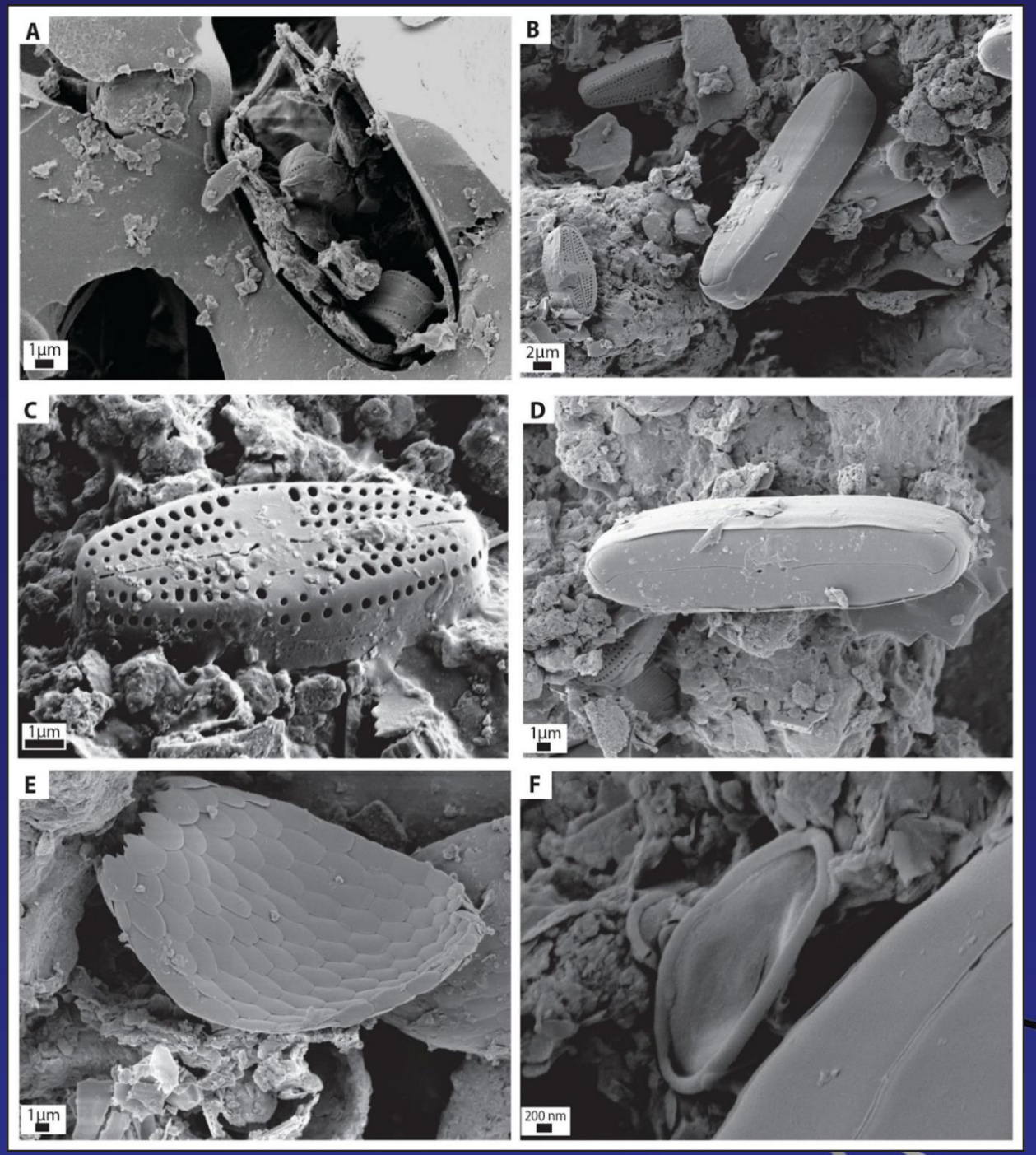


What is the secret of picon: From Troll et al., 2017; SEM images of micro-organisms found in vesiculated lapilli from Gran Canaria.

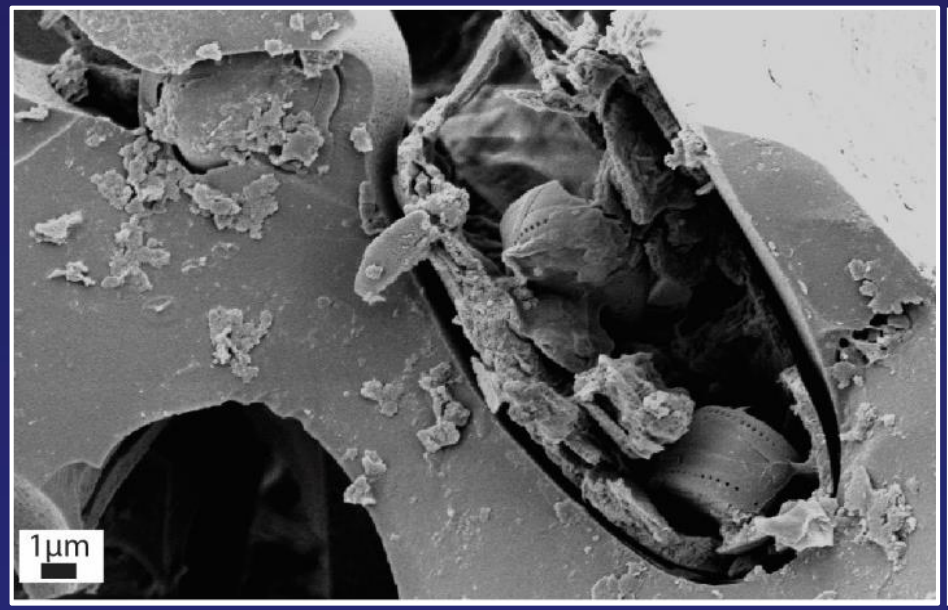
A. Several frustules (= silicate tests of diatoms) in a vesicle. **B.** Frustules of Pinnularia sp. and Luticola sp. next to each other. **C.** Luticola sp. **D.** Pinnularia sp.; note that the organic casing is still present, obscuring pores and slits of the frustule. **E.** Test of the thecamoeba Euglyphia sp. **F.** Remains of an as yet unidentified micro-organism.

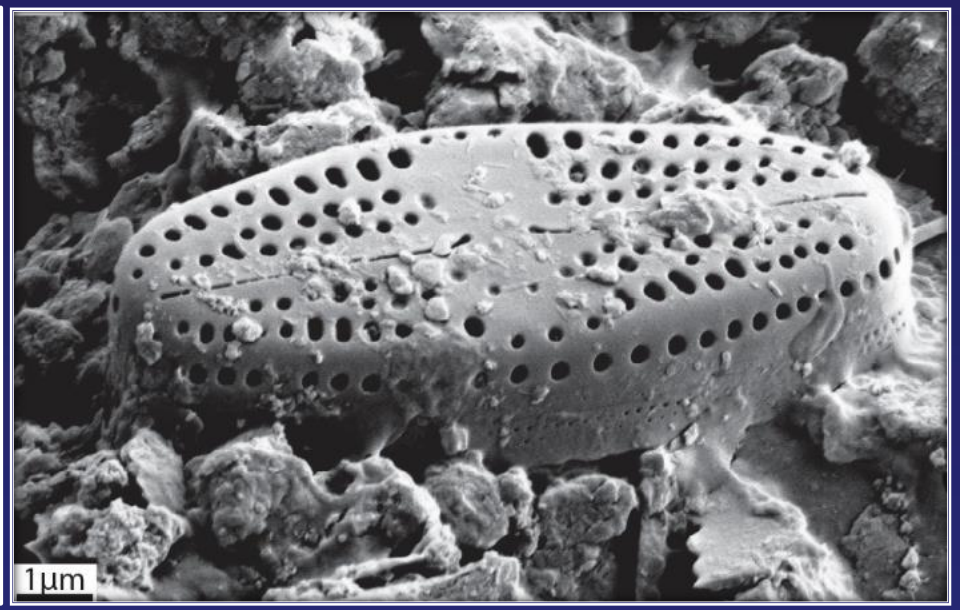
These micro-organisms underline the importance of biological processes inside the volcanic particles to help release nutrients to the growing plans and will sequester CO_2 into the soil,

This creates what is known as a 'living soil. This concept could be exploited to help combat global hunger and also global climate change.

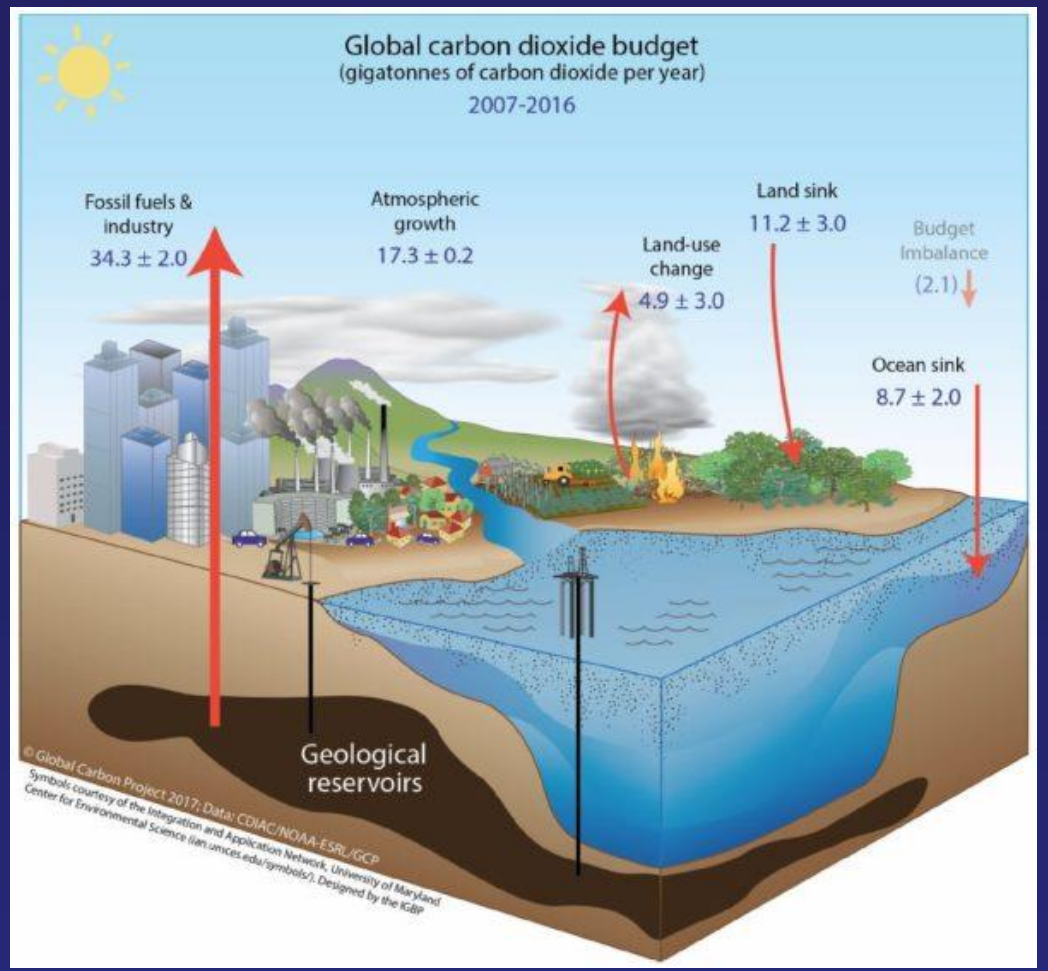


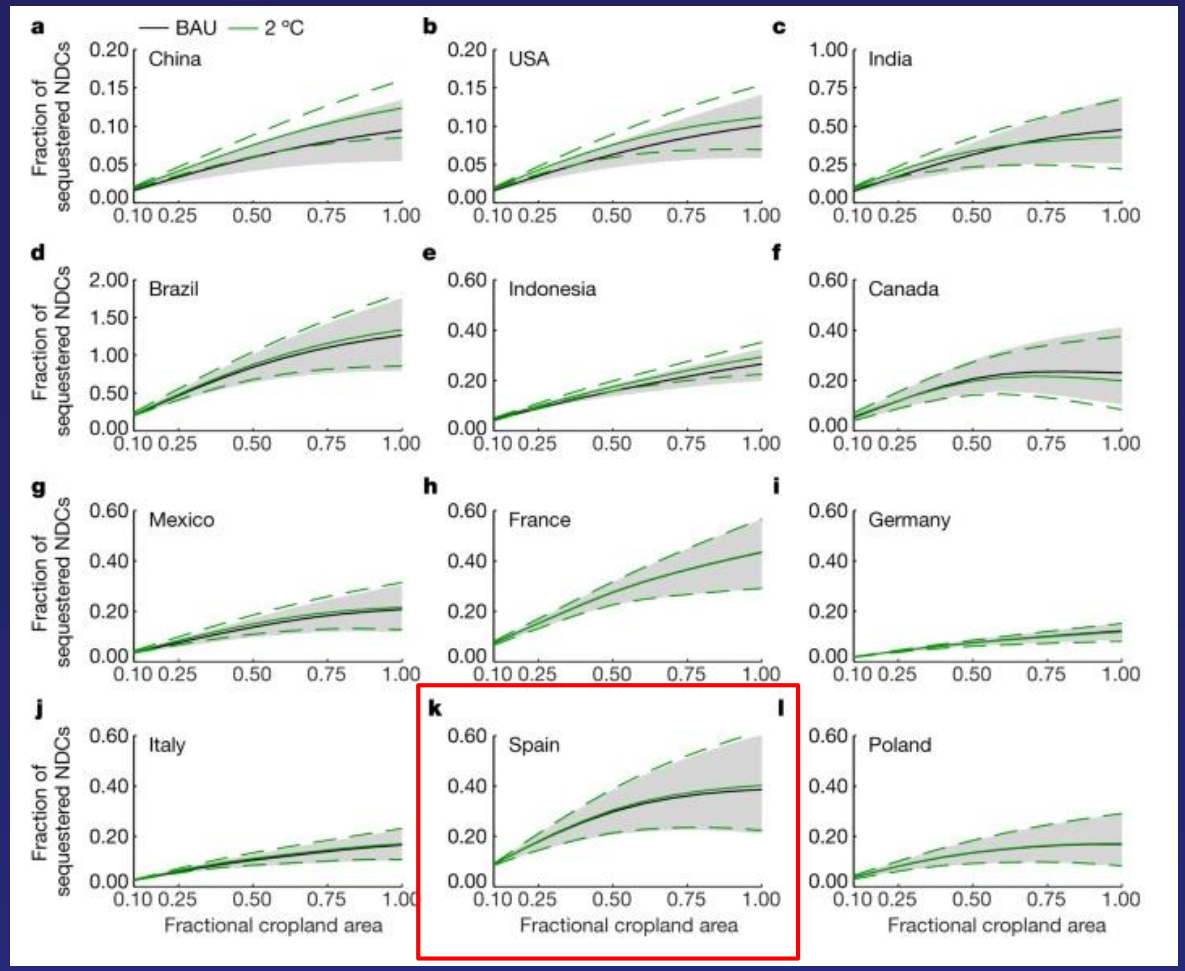
Microscopic life inside picon





- Lapilli from N-Gran Canaria were sampled and analyzed
- Variety of micro-organisms identified inside the vesiclesLiving soil has higher yield and locks up CO2





Beerling et al., 2020, Nature

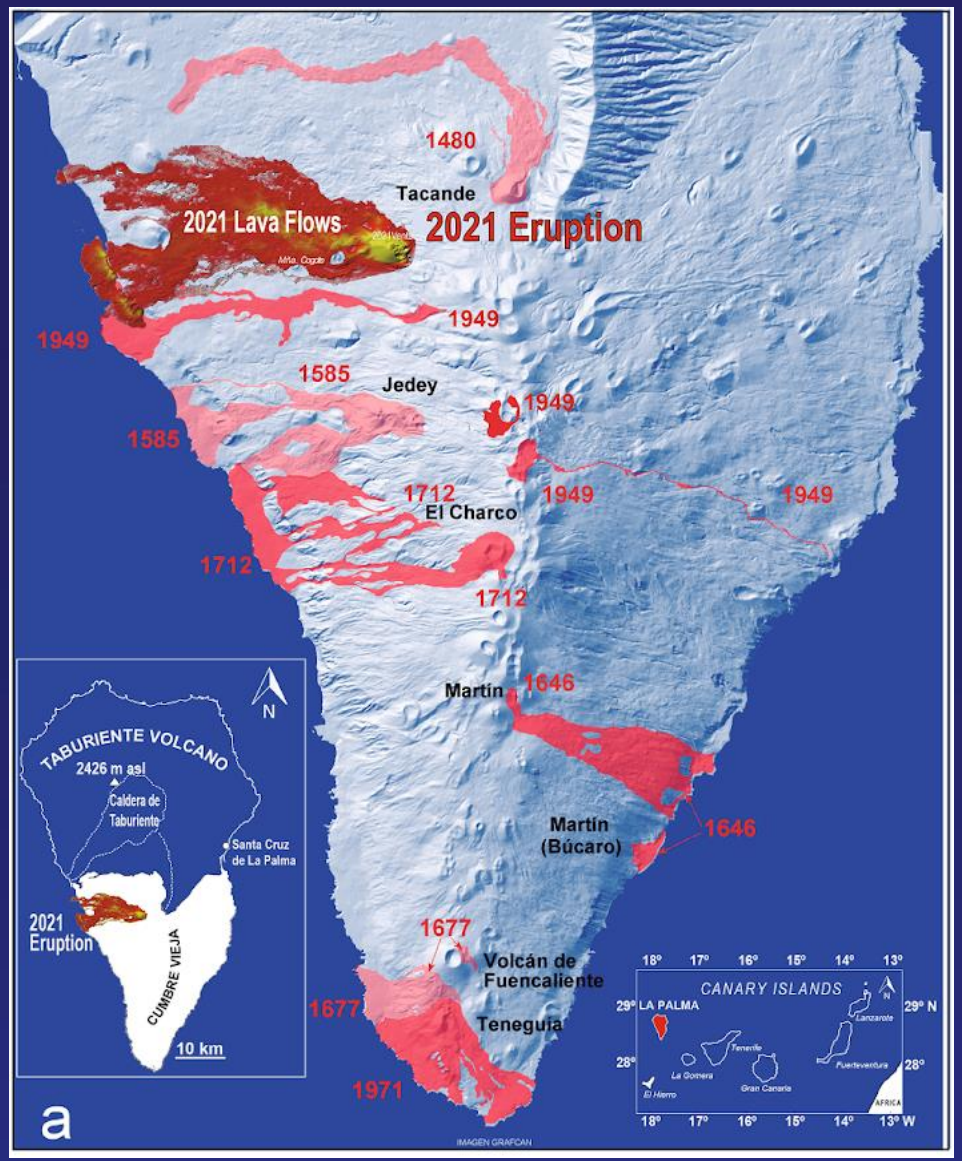
Enhanced Rock Weathering (ERW)

National Determined Contribution (NDC)

Plants circulate CO_2 from the air to soils, and consume about one-third of the CO_2 that humans produce. Of that, about 10–15% ends up in the soil. Higher soil CO_2 will cause higher crop production (up to 20%)....So this could be several Gt ending up in soil through extra plant growth.

Beerling et al. (2020) argue that this inorganic CDR (through ERW) would enable an extra 0.5 to 2 Gt of CO_2 to be removed from the atmosphere each year.

La Palma, Canary Islands 2021



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Cumbre Vieja rift zone forms the southern half of the island of La Palma (see inset) produced more than half of all the archipelago's historical; **Carracedo et al., 2022).**

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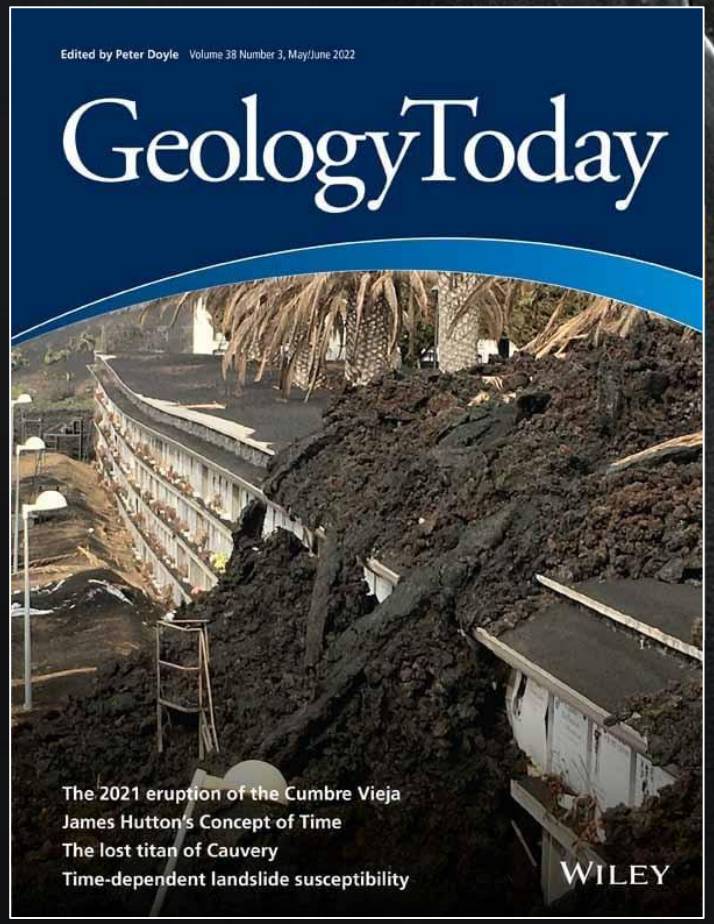
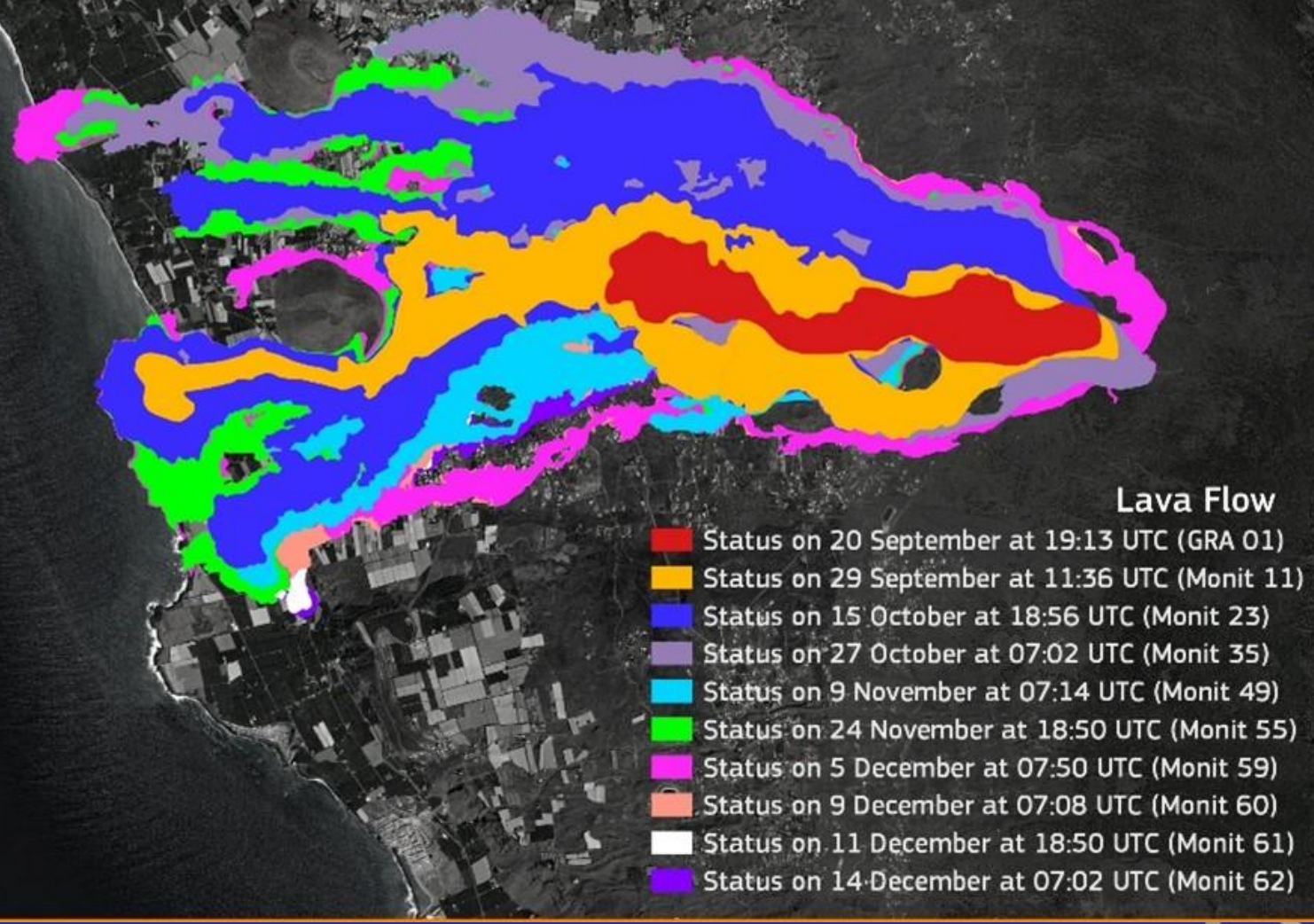
Volcanic eruption in La Palma, Spain





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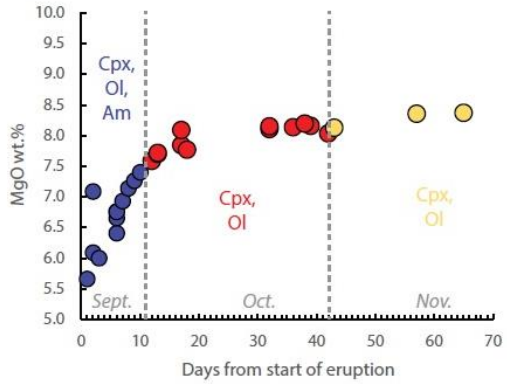

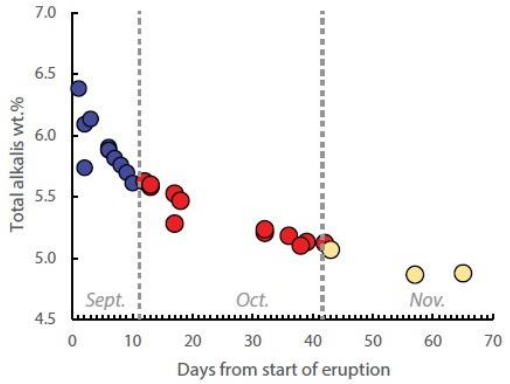

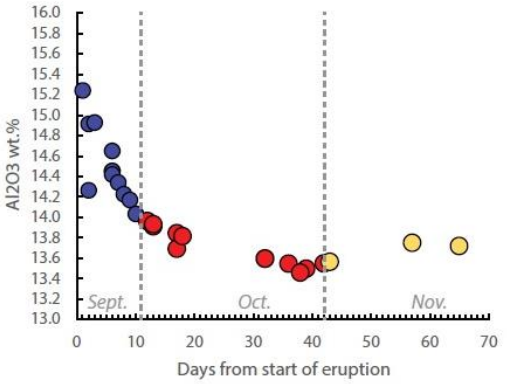

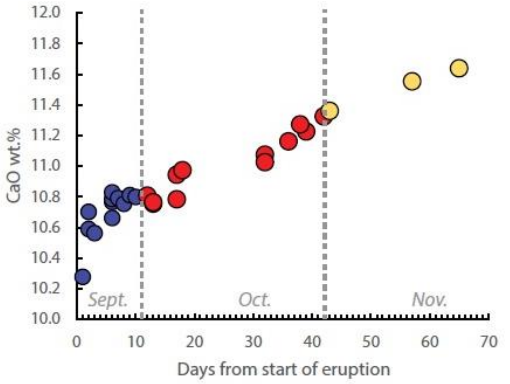

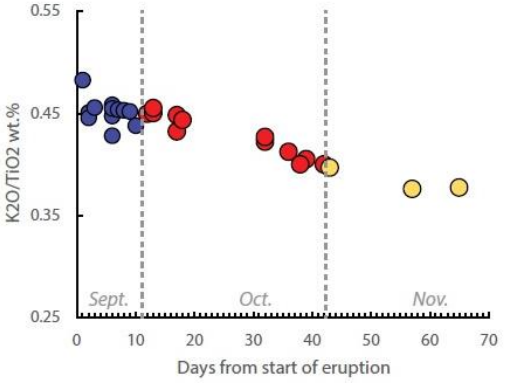

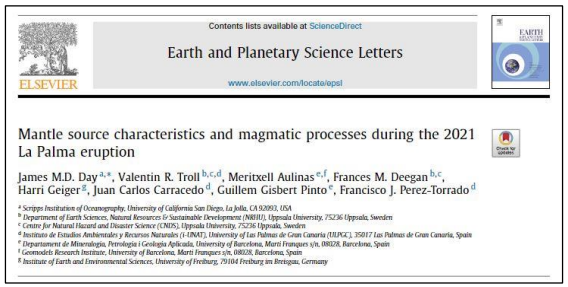

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Mantle source characteristics and magmatic processes during the 2021 La Palma eruption

James M.D. Day [a,*], Valentin R. Troll [b,c,d], Meritxell Aulinas [e,f], Frances M. Deegan [b,c], Harri Geiger [g], Juan Carlos Carracedo [d], Guillem Gisbert Pinto [e], Francisco J. Perez-Torrado [d]

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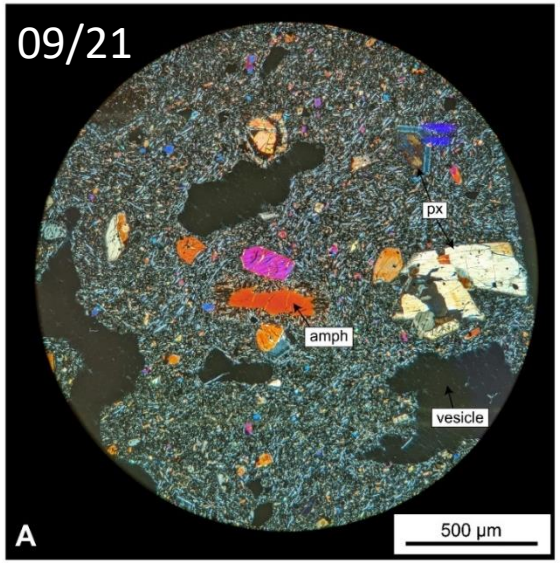
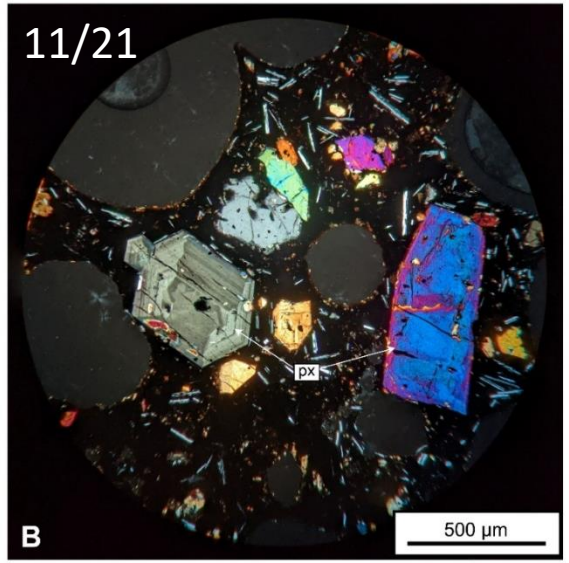
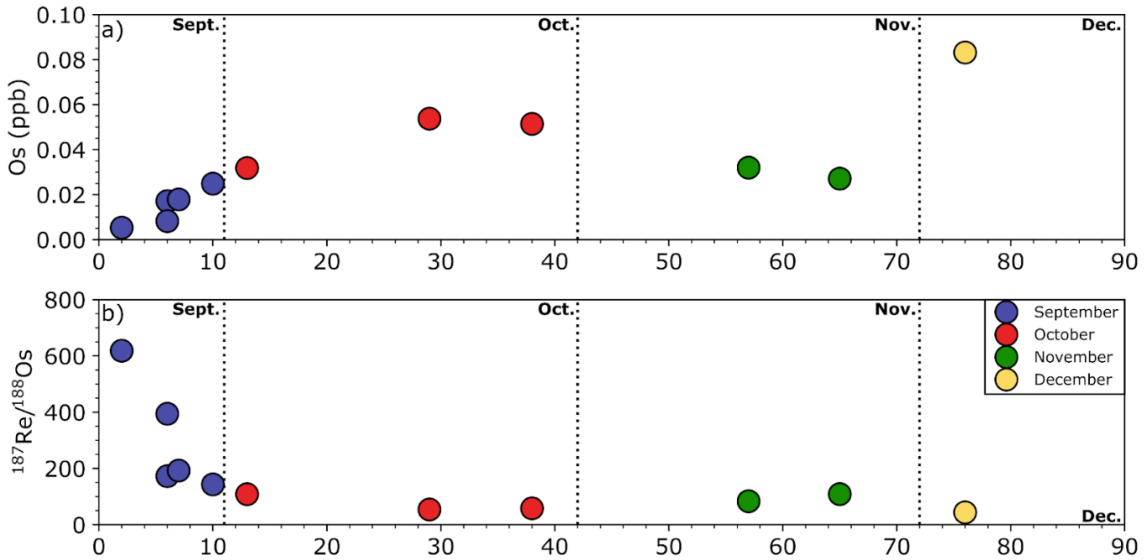
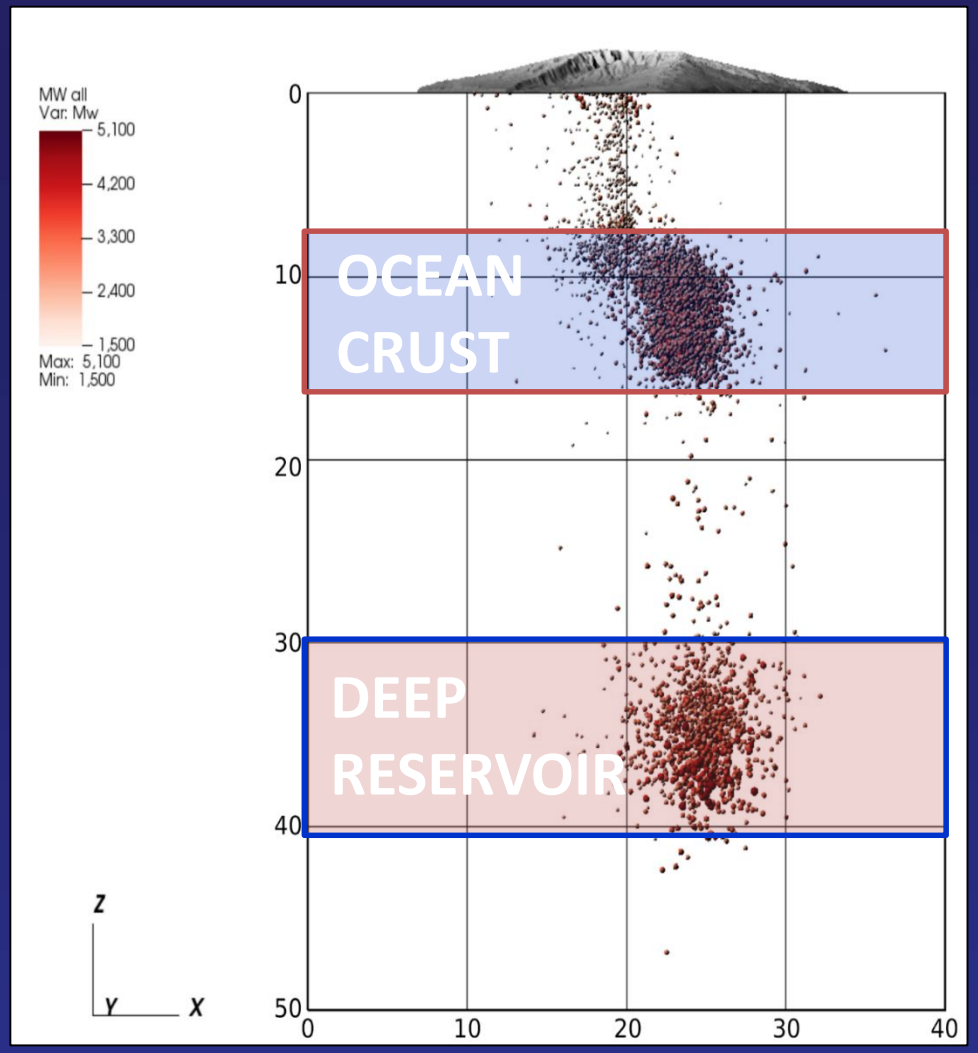
[g] Institute of Earth and Environmental Sciences, University of Freiburg, 79104 Freiburg im Breisgau, Germany



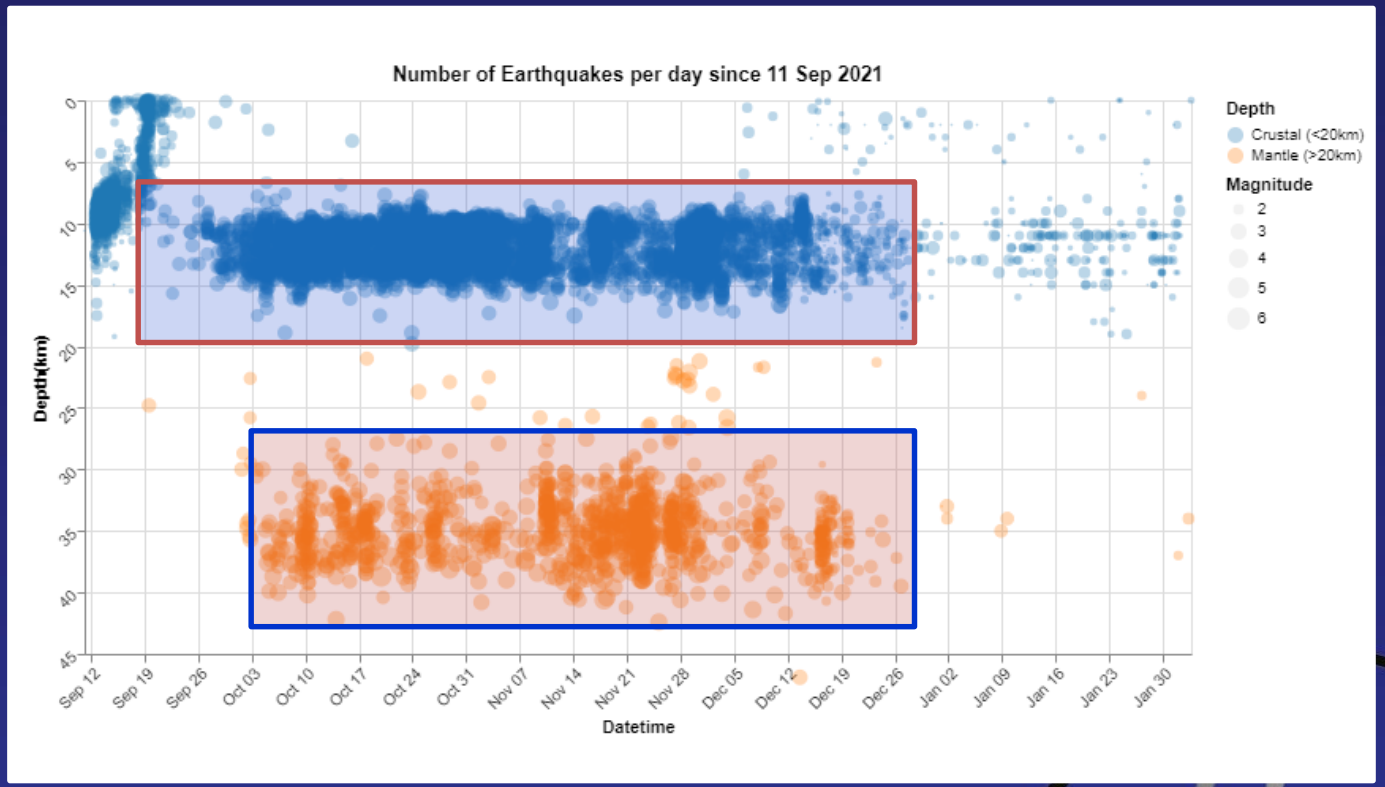




Unraveling Magma Storage and Supply



Carracedo et al., 2022; Day et al., 2022; Dayton et al., 2023



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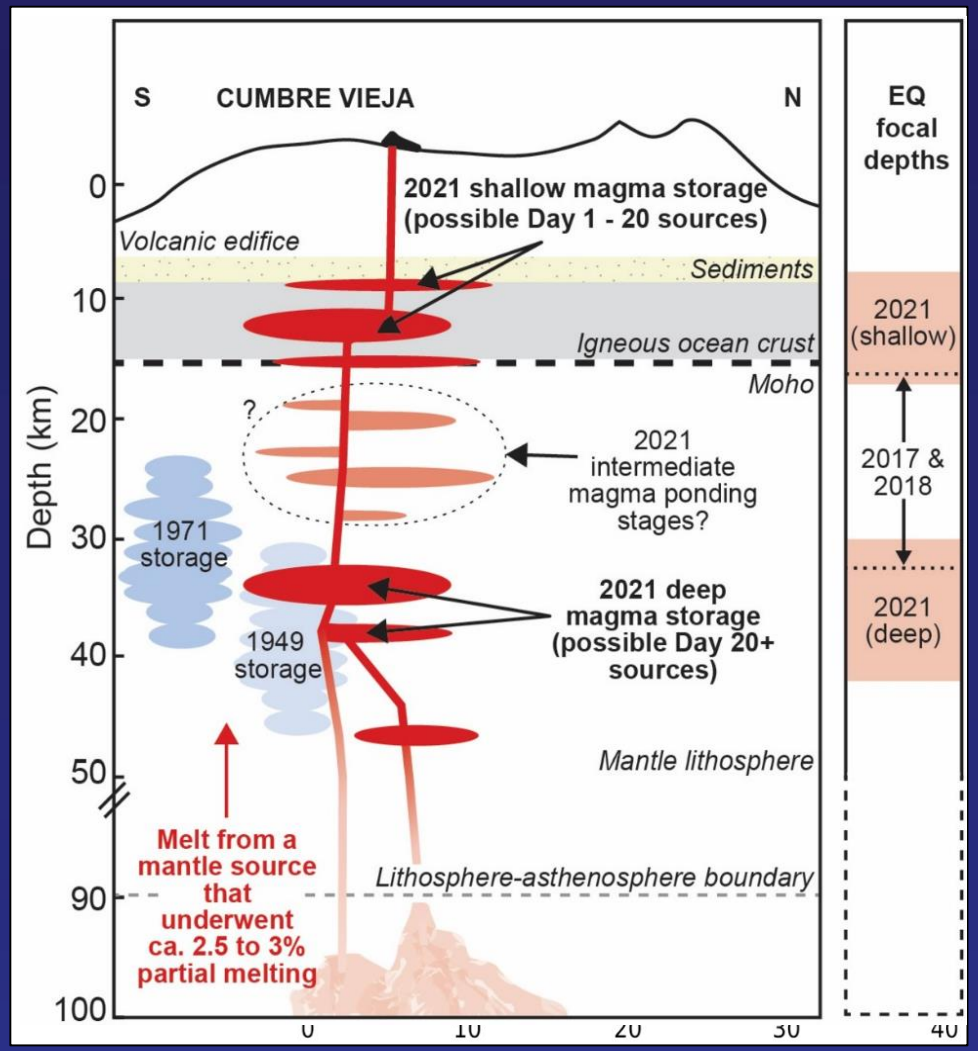

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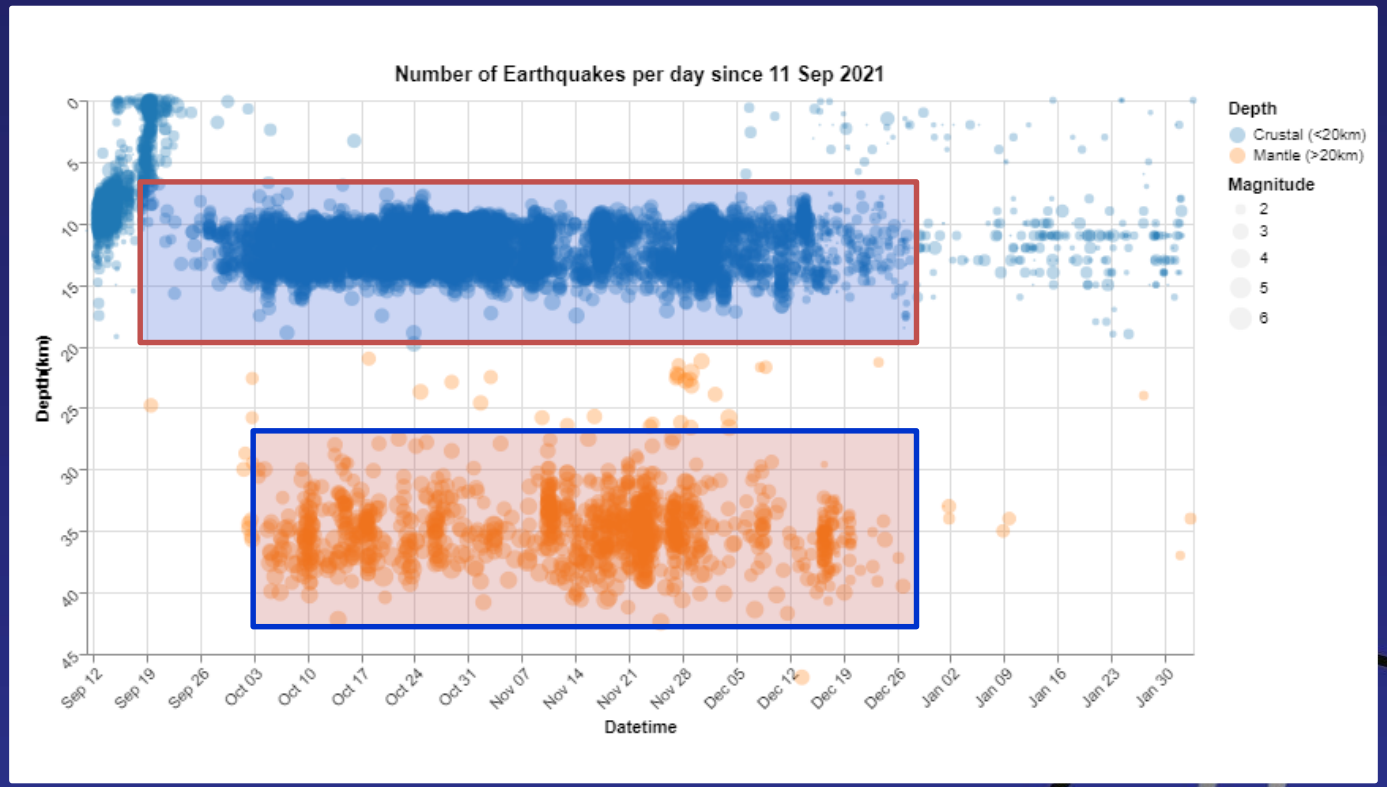


b)


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October 27th 2021


December 2nd 2021
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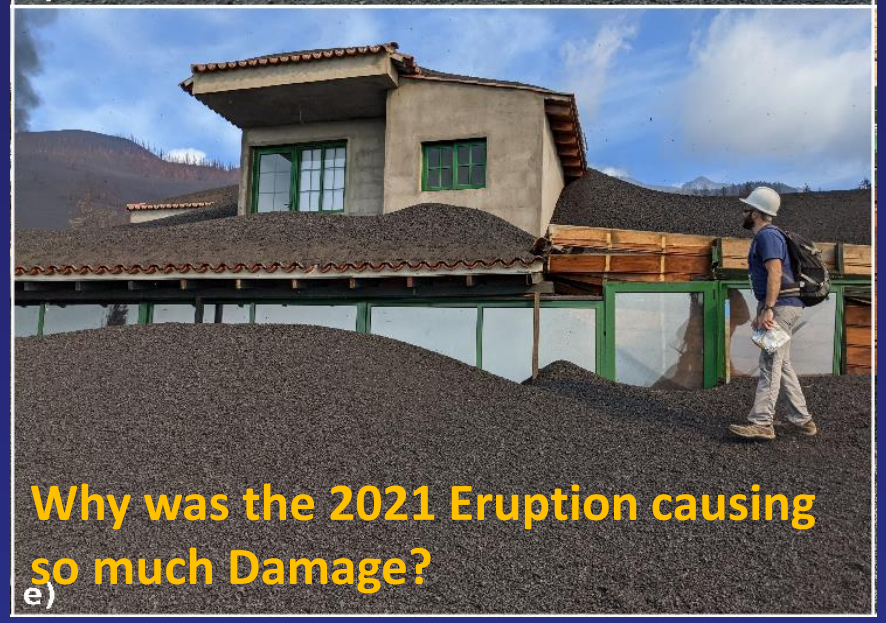
@harrigeiger


Why was the 2021 Eruption causing so much Damage?
e)

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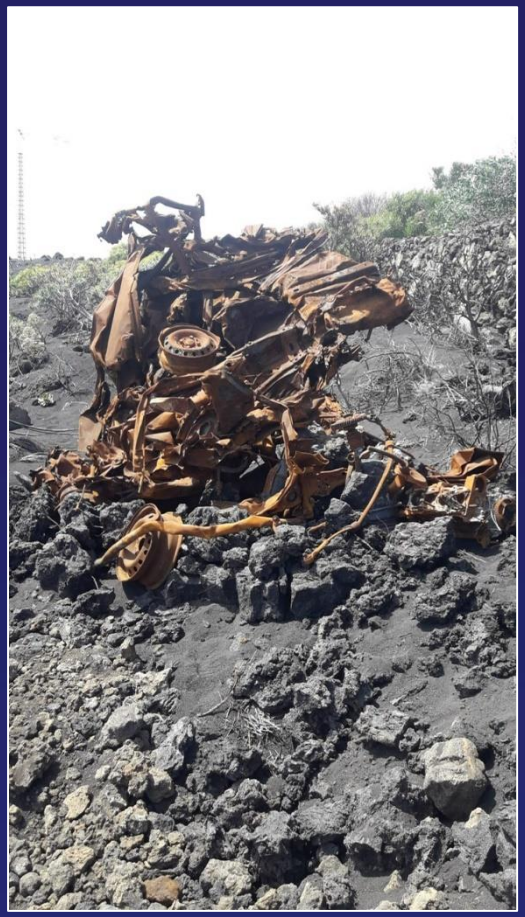
Why was the damage so much more severe than in 1971 and 1949?

Tajogaite lavas that covered some 350 hectares of land and destroyed close to 3000 man-made structures, public services facilities, and crops, as well as truncated over 70 km of roads.


Harri Geiger
@harrigeiger

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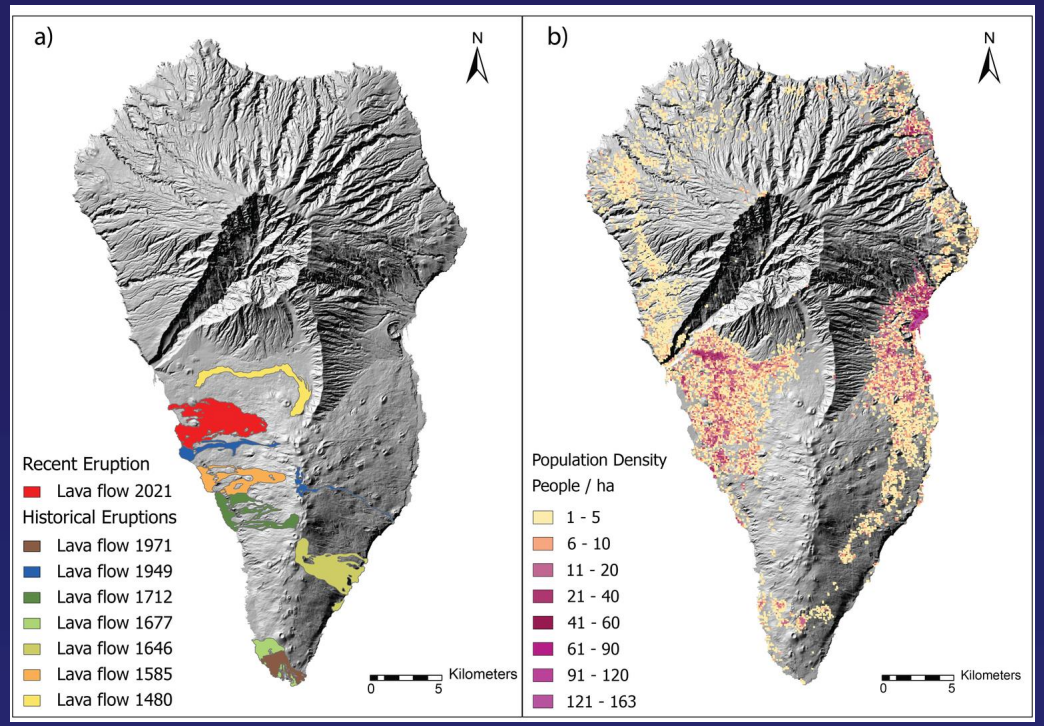
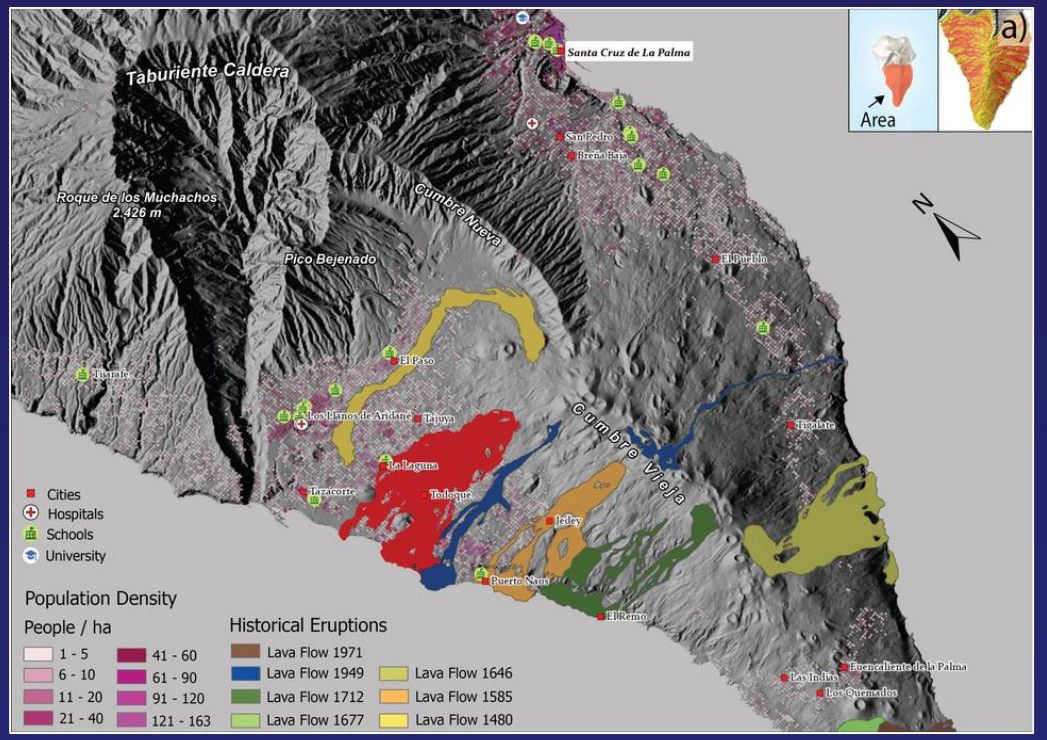
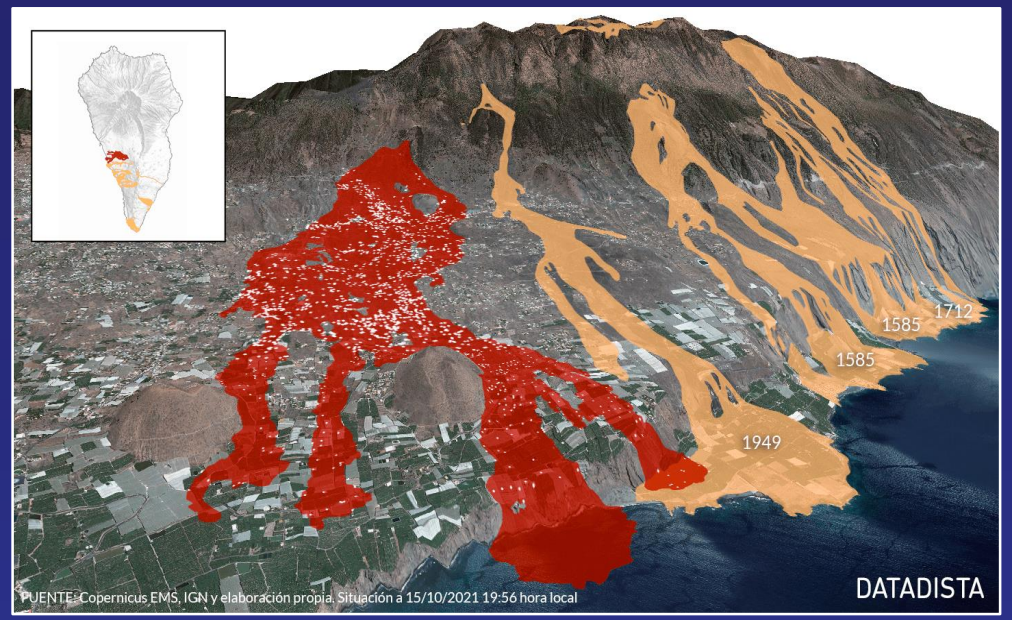
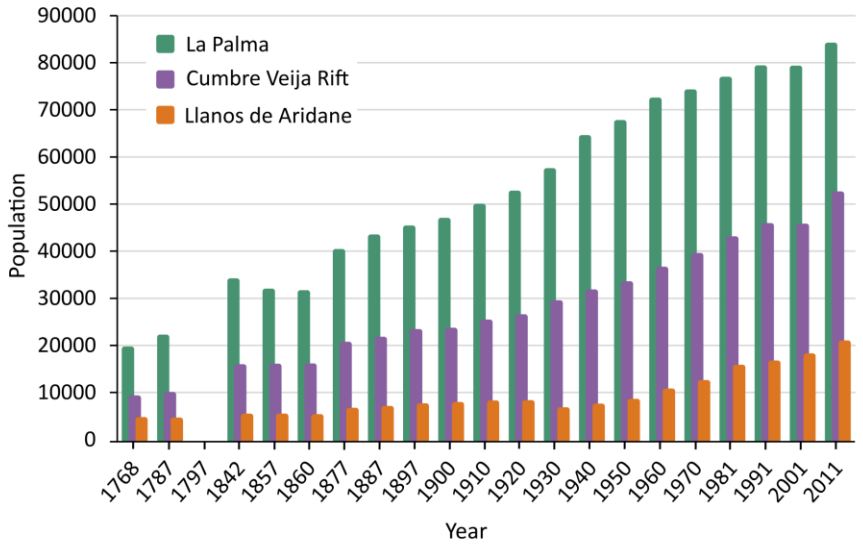
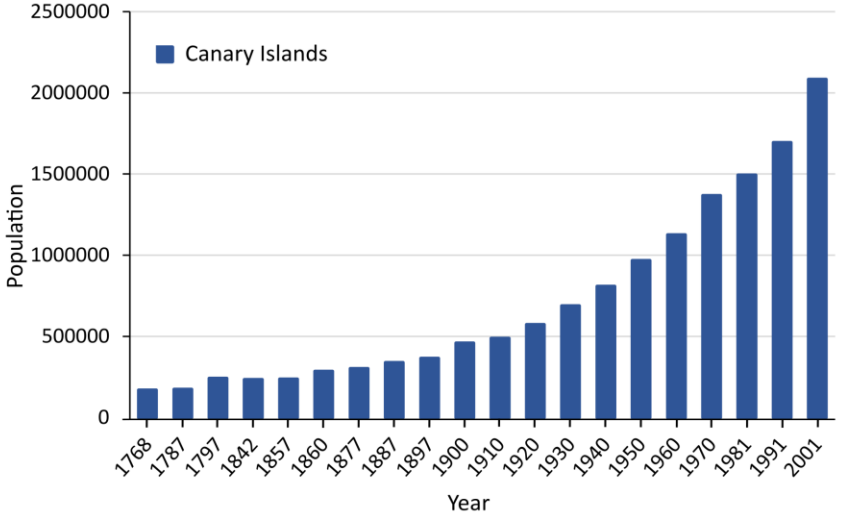
The Cumbre Vieja

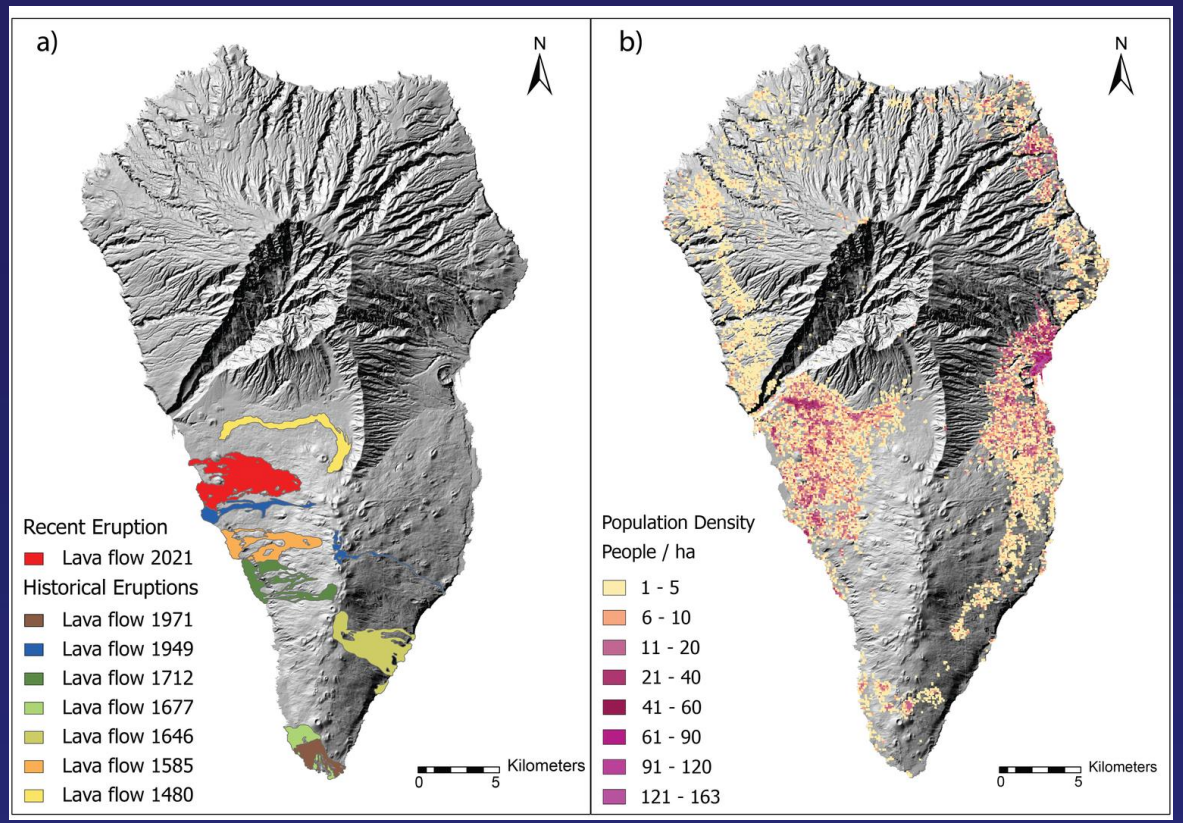












Population growth in the Canary Islands, La Palma, the Cumbre Vieja Ridge (CVR) and in Los Llanos de Aridane (data: Instituto Canario de Estadística , ISTAC, 2022)

Population growth on the CVR since the last eruption in 1971 is stronger than on La Palma overall, adding to rapidly increasing vulnerabilities in this region (from Troll et al., 2023)

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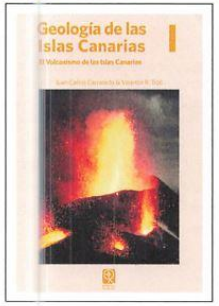

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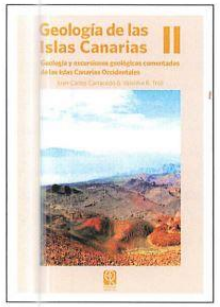

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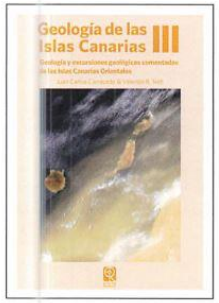

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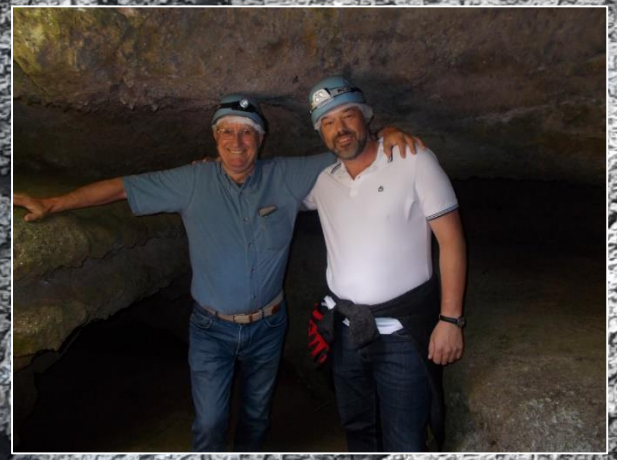
The CONVERSE Center is organizing its second webinar series for the fall of 2023. Presentations will focus on science resulting from volcanic eruptions.

Date	Time	Presentation	Video
September 19	1:00 pm MDT	Dr. Thor Thordarson, University of Iceland: Observing, Monitoring and Documenting the Three Eruptions of the 2021-23 Fagradalsfjall Fires and Its consequences.	View
October 17	1:00 pm MDT	Dr. Michelle Coombs, Alaska Volcano Observatory: Responding to Alaska's Numerous Eruptions.	View
November 14	1:00 pm MDT	Dr. Valentin Troll, Uppsala University, Sweden: The 2021 La Palma eruption, Canary Islands; eruptive phenomena, magma plumbing, and societal consequences	

Webinar on November 14th for a webinar on the 2021 La Palma eruption. Register here: https://conversecenter.org/fall-2023-webinar/

Thank you !



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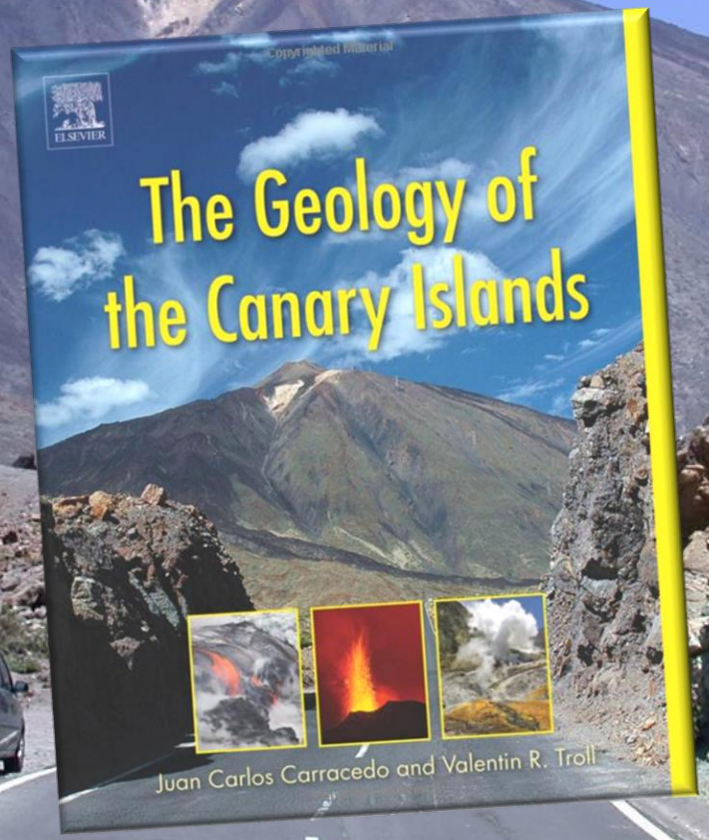
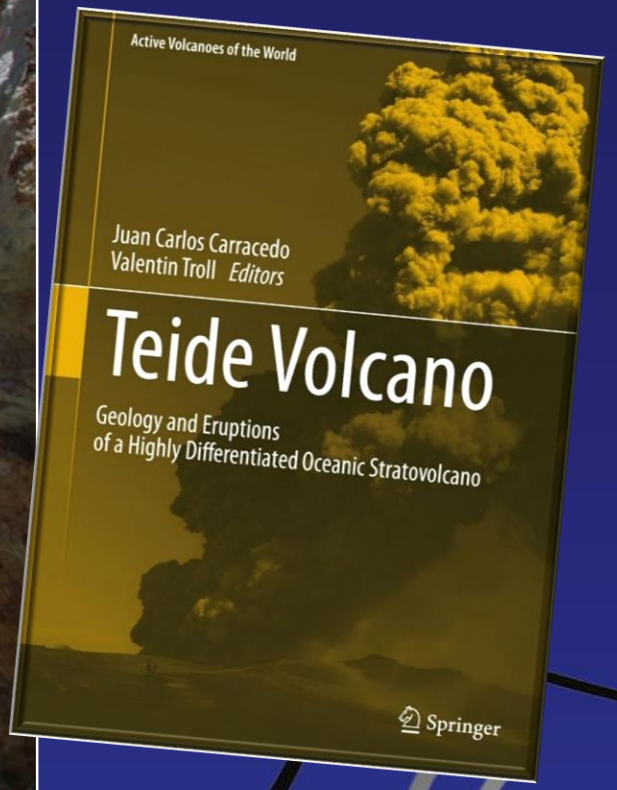


Islas Canarias
volcanic
experience



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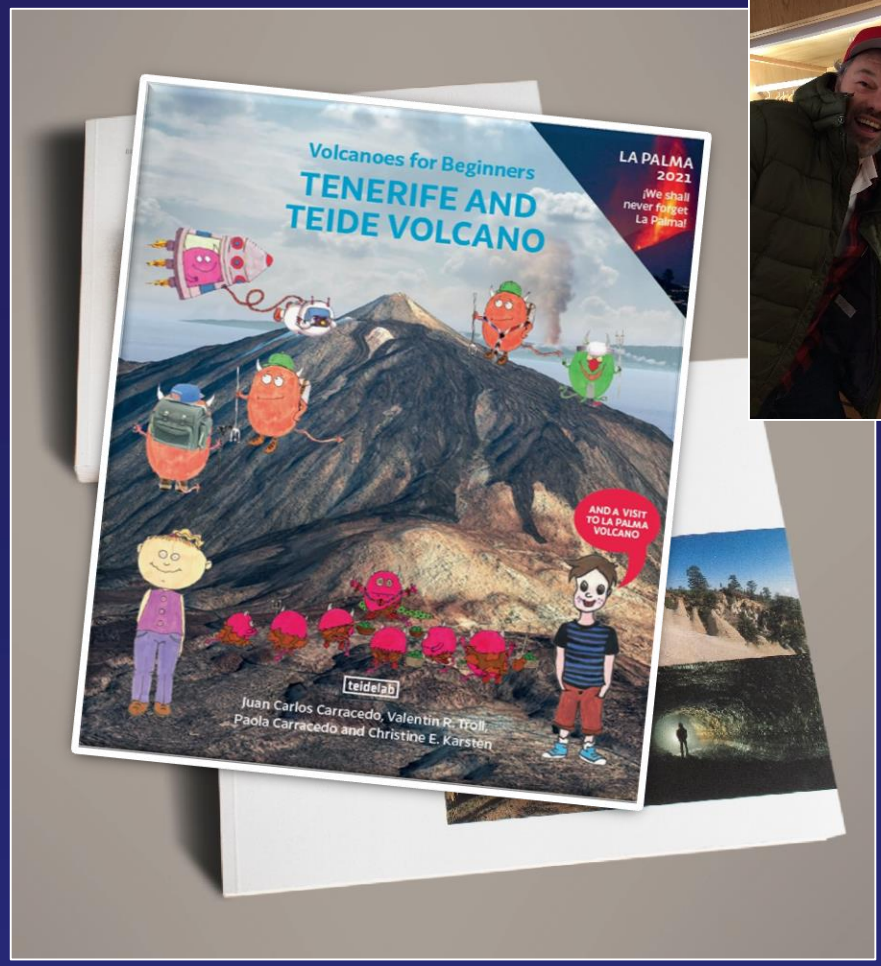

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