A sea of volcanoes I
Origin of the Canary Islands

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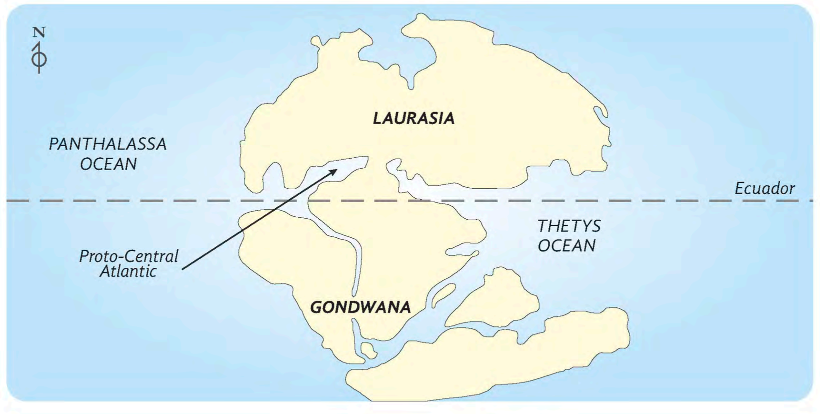
The first Canary island was born about 20 million years ago

Although 20 million years may seem like an eternity, it is nothing compared to the age of the Earth. If we concentrate the entire age of the planet in 1 year, the Canary Islands, including the Atlantic Ocean in which they arise, were formed during December, the last month. El Hierro would have 2 hours of life and La Palma 3 hours.

Where do we come from?

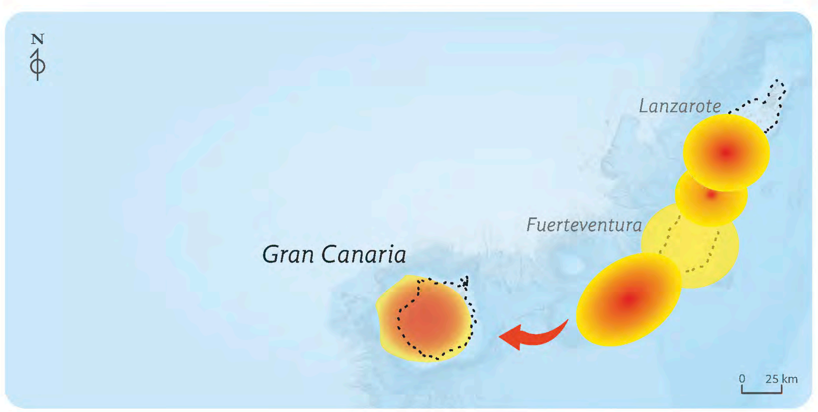
As other volcanic islands that are born inside a tectonic plate, the Canary Islands arise from the bottom of the ocean when a thermal anomaly in the Earth's mantle (known as a mantle plume) achieves to melt a part of it, and the melt reaches the surface, giving rise to what is known as a hot spot.

Geological age Ma (million of years)		Natural year
~ 4600	Earth formation	01 January 00 h
~ 180 ~ 160	Proto-Central Atlantic opening Creation of the oceanic crust of the Canary Islands area	17 December 18 December

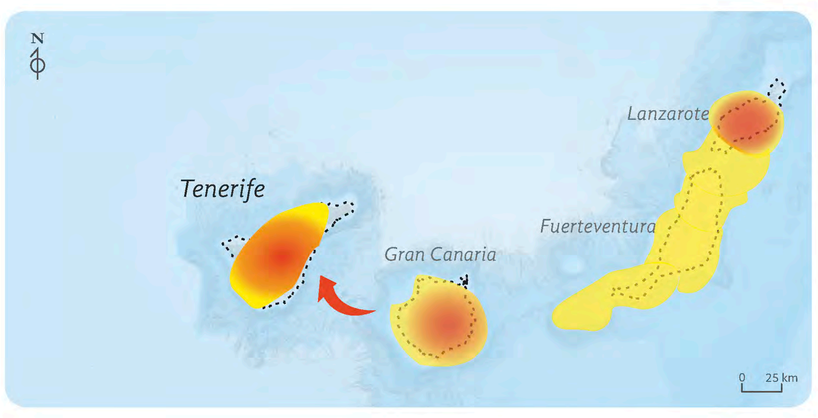


Geological age Ma (million of years)		Natural year
~ 68 ~ 30	Formation of Paleo-Canaries Lars, Anika, Dacia, Conception and Salvagem seamounts	26 December 29 December
~ 20.2 ~ 15.6	Birth of joint volcanic megastructure Fuerteventura and Lanzarote	30 December 06 h 30 December 18 h

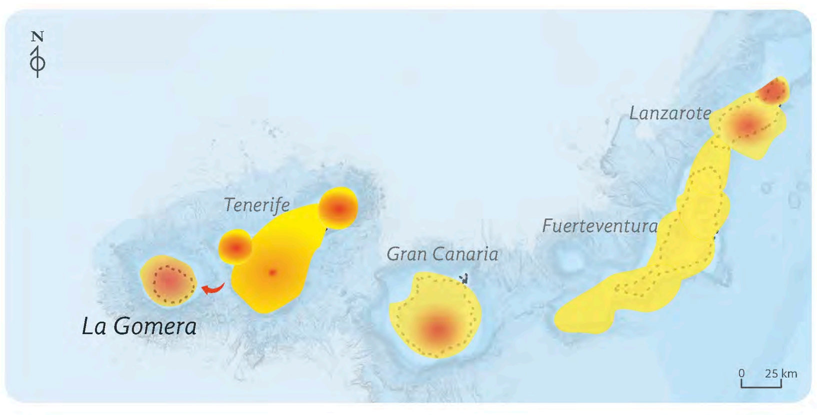
Geological age Ma (million of years)		Natural year
~ 14.5	Birth of Gran Canaria	30 December 20 h



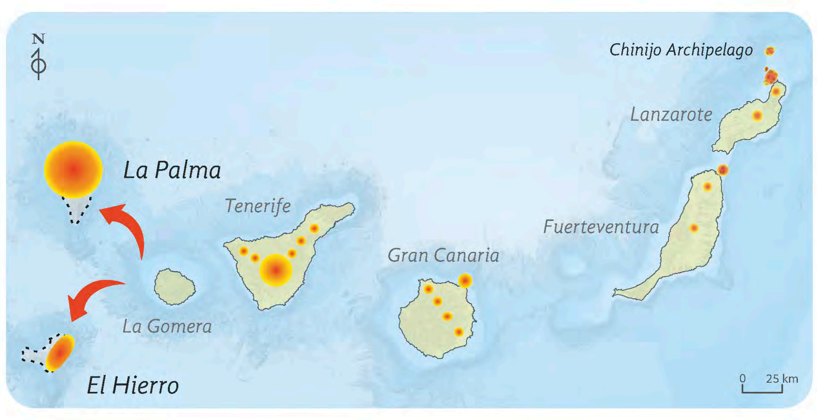
Geological age Ma (million of years)		Natural year
~ 11.9	Birth of Tenerife	31 December 01 h



Geological age Ma (million of years)		Natural year
~ 9.5	Birth of La Gomera	31 December 06 h

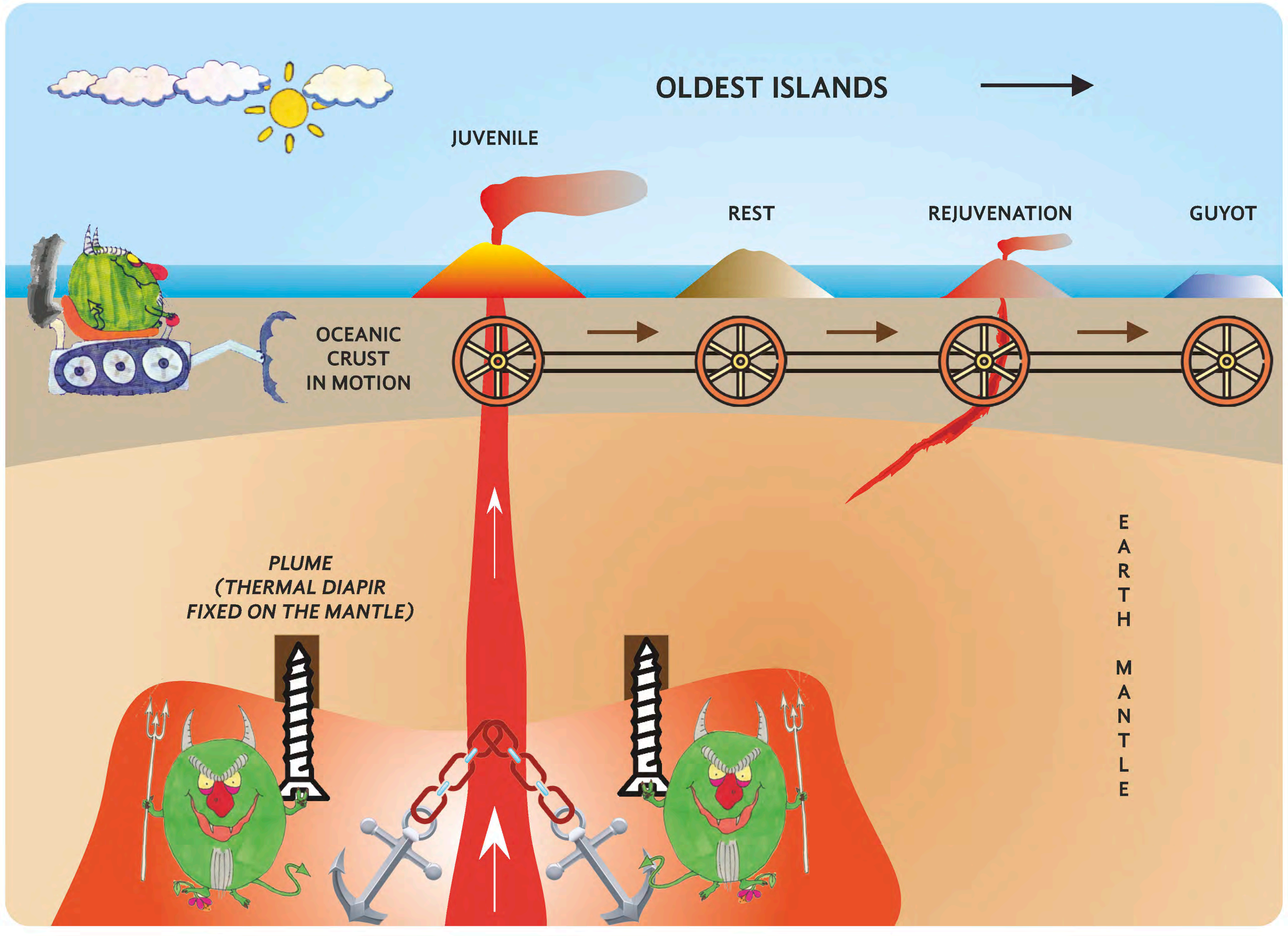


Geological age Ma (million of years)		Natural year
~ 1.8 ~ 1.1	Birth of La Palma (first) and El Hierro Change from single to double alignment Birth of Chinijo Archipelago	31 December 21 h 31 December 22 h



How do intraplate islands evolve?

These islands evolve through a competition between constructive processes (mainly volcanic activity) and destructive processes (giant landslides and erosion). Throughout its life, an intraplate volcanic island will go through different stages, known as the juvenile stage (in which volcanic growth predominates), rest (there is no volcanic activity, only erosion), and rejuvenation (erosional dismantling continues to predominate, but volcanic activity resurfaces). Finally, when all volcanic activity ceases (the island is far from the vertical of the hot spot that created it), it will be engulfed by the sea, giving rise to a more or less flat-topped seamount known as a guyot.

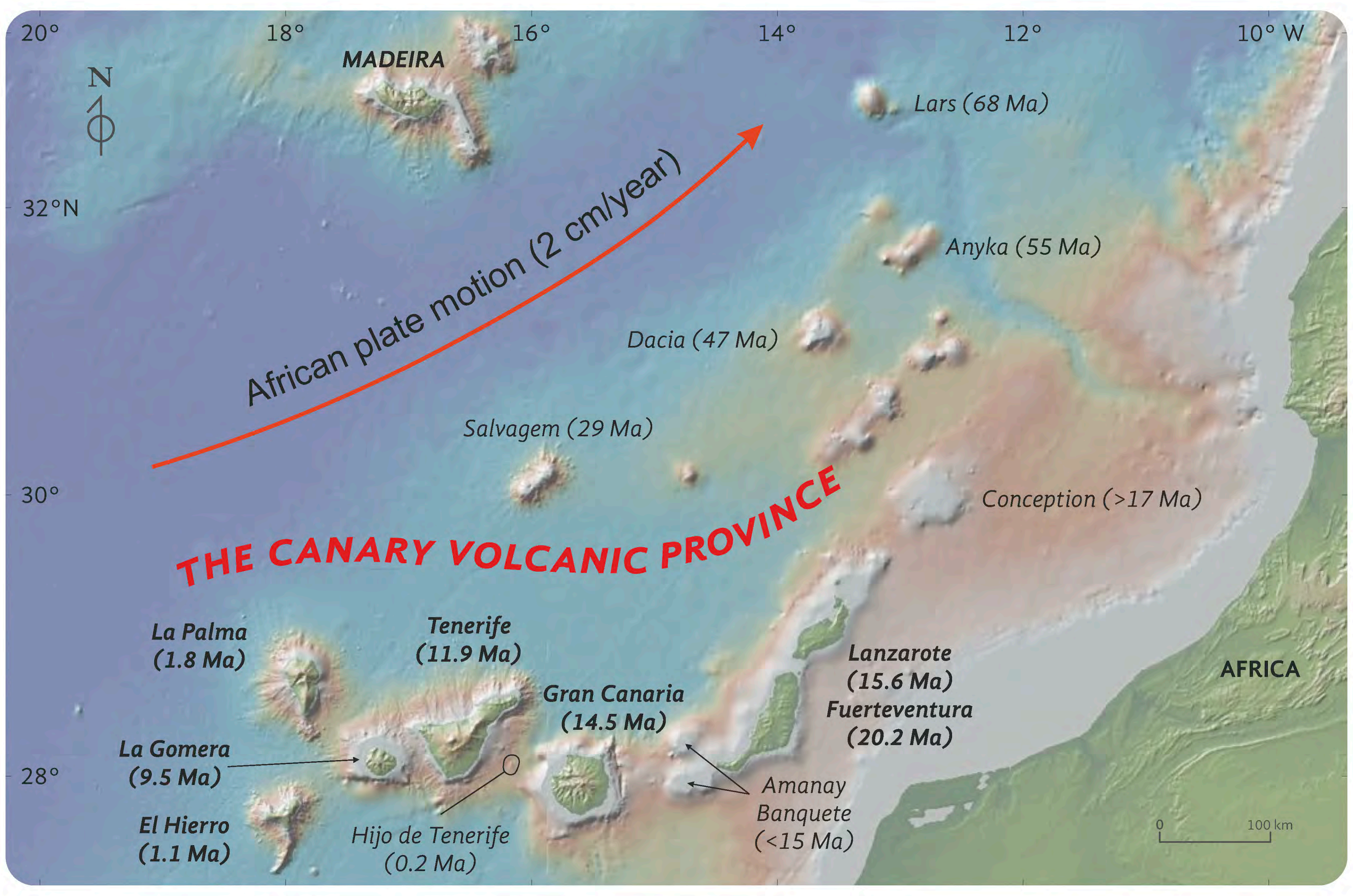


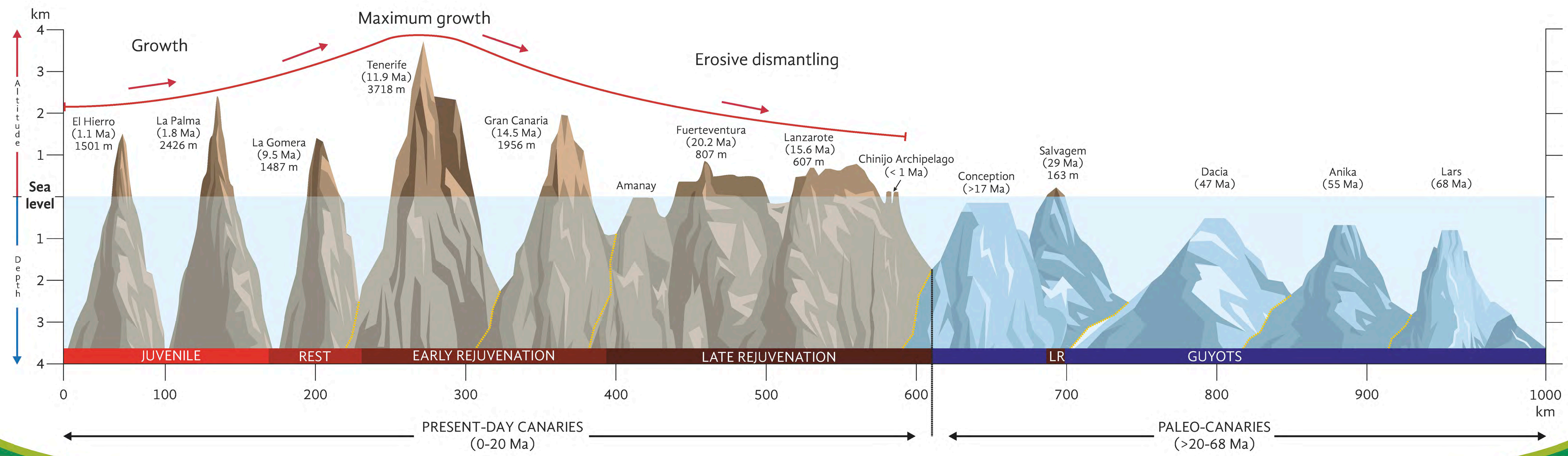
What is the engine of that evolution?

We need the hot spot that feeds magmas for the volcano's growth and the movement of the tectonic plates as a conveyor belt. The islands in the vertical to the hot spot will be in the juvenile stage, and as the oceanic crust on which they sit moves, they will go through the other evolutionary stages until they disappear under the sea.

The Canary Volcanic Province

From a geological point of view, in addition to the current Canary Islands that we can see above the sea, this Volcanic Province is made up of seamounts (guyots) that were once islands (Concepción, Salvajes, Dacia, Anika, and Lars) and seamounts that in the future they will be new islands.





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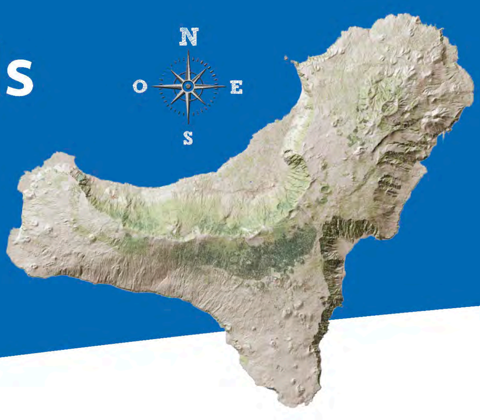
A sea of volcanoes II
And El Hierro was born



El Hierro emerged from the Atlantic 1.12 million years ago

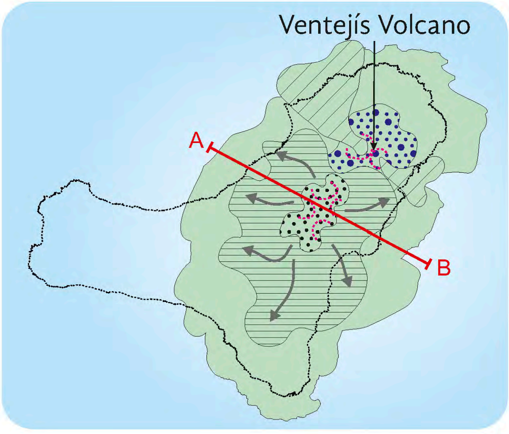
During his short life, El Hierro has seen two large volcanic edifices grow and be destroyed: Tiñor and El Golfo. Its landscape reflects the constant struggle of nature: volcanic growth versus erosive dismantling and giant landslides. In its last 158,000 years, volcanism has concentrated in structures known as rifts, called in the Canary Islands *dorsal*. The current shape of the island, triangular and lobed, is the result of these rifts and its three prominent giant landslides: El Golfo, Las Playas, and El Julan.

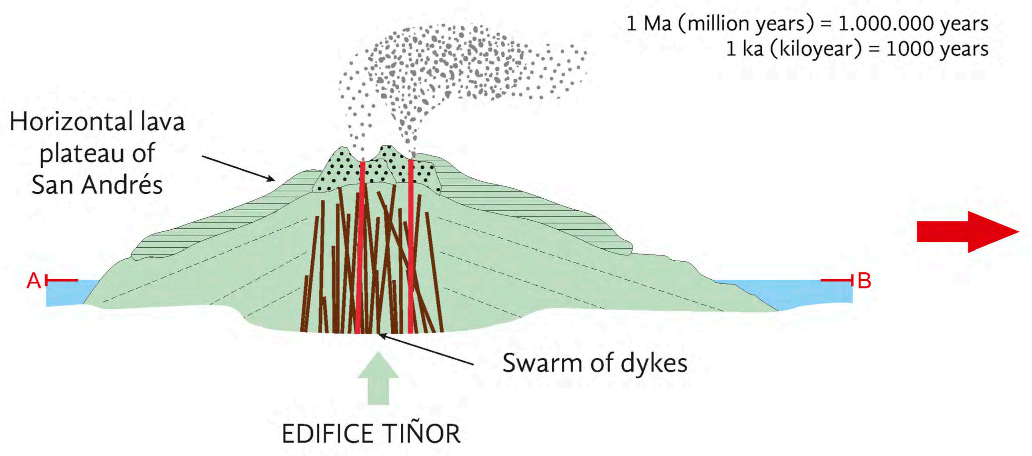
Let us see below its geological growth

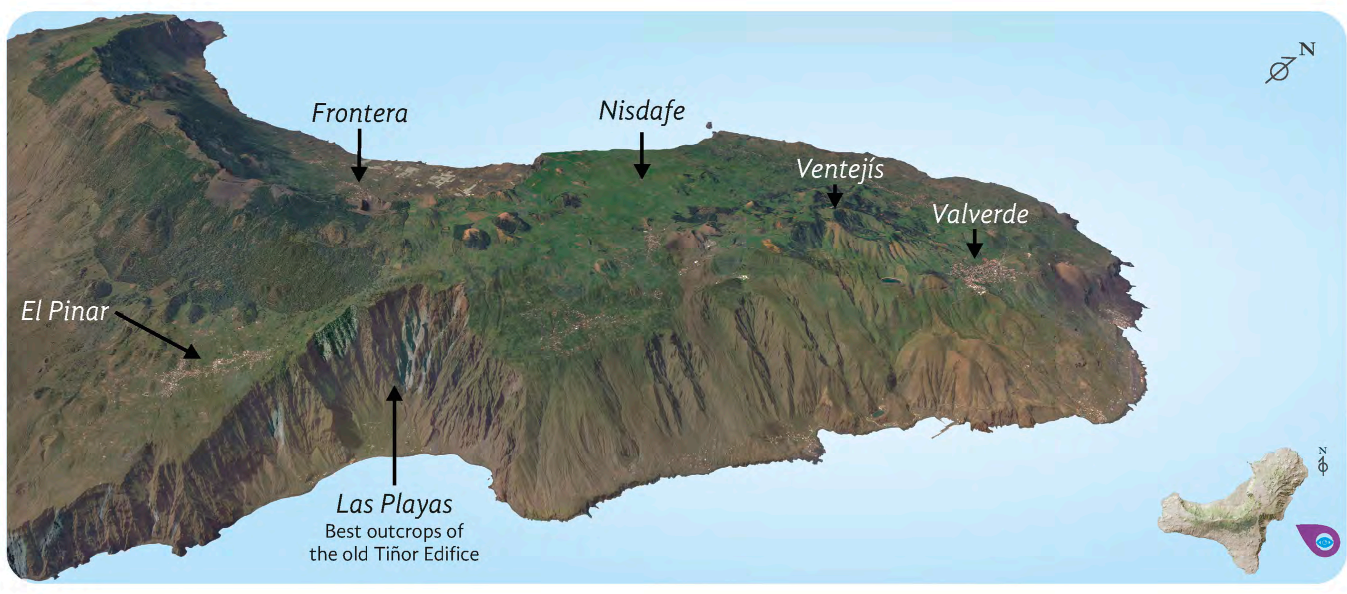
1 Volcanic edifice Tiñor. Final phases: plateau of San Andrés and Ventejís Volcano

Between 1.12 and 0.88 Ma

1 Ma (million years) = 1.000.000 years
1 ka (kiloyear) = 1000 years

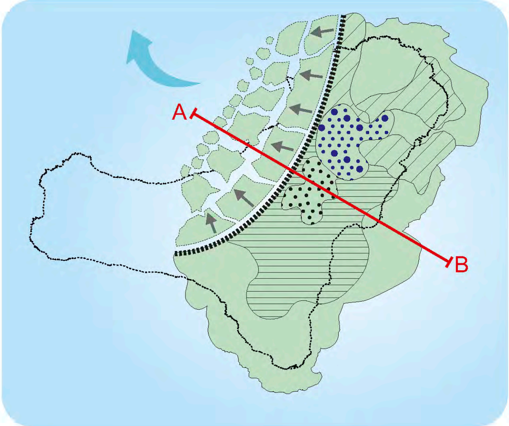


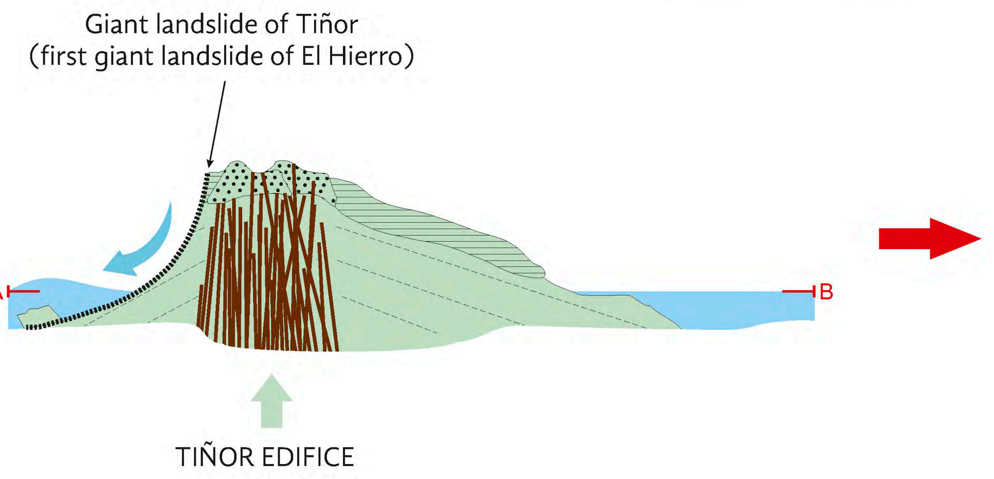


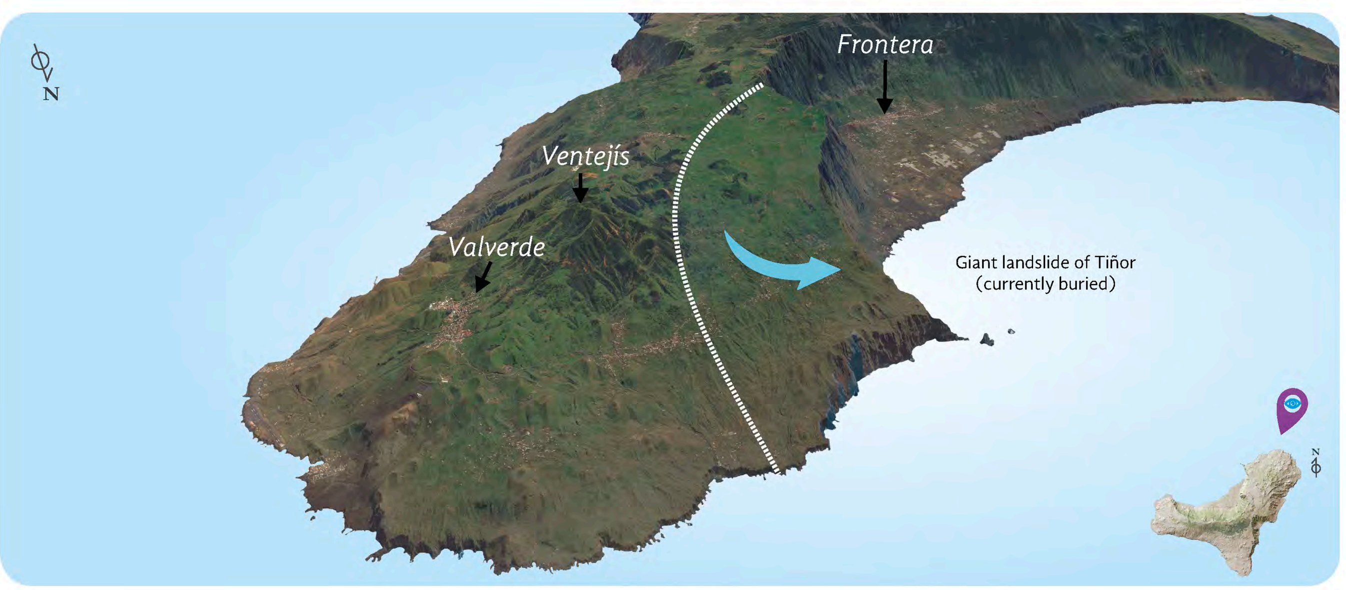


2 Giant landslide of Tiñor Edifice

Between 0.88 and 0.54 Ma

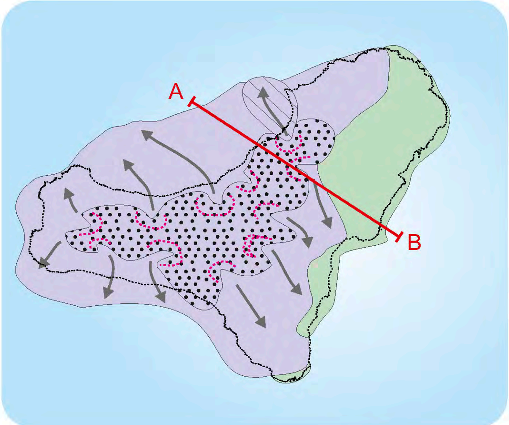


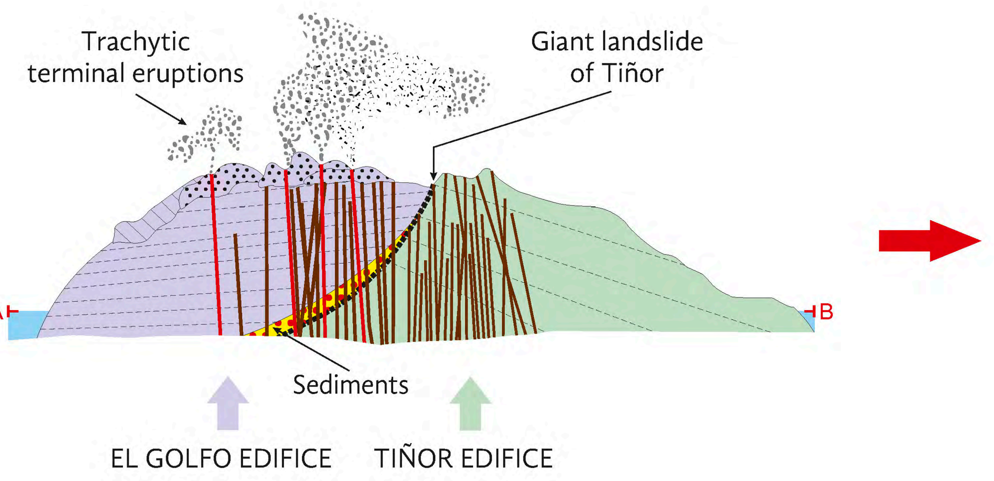


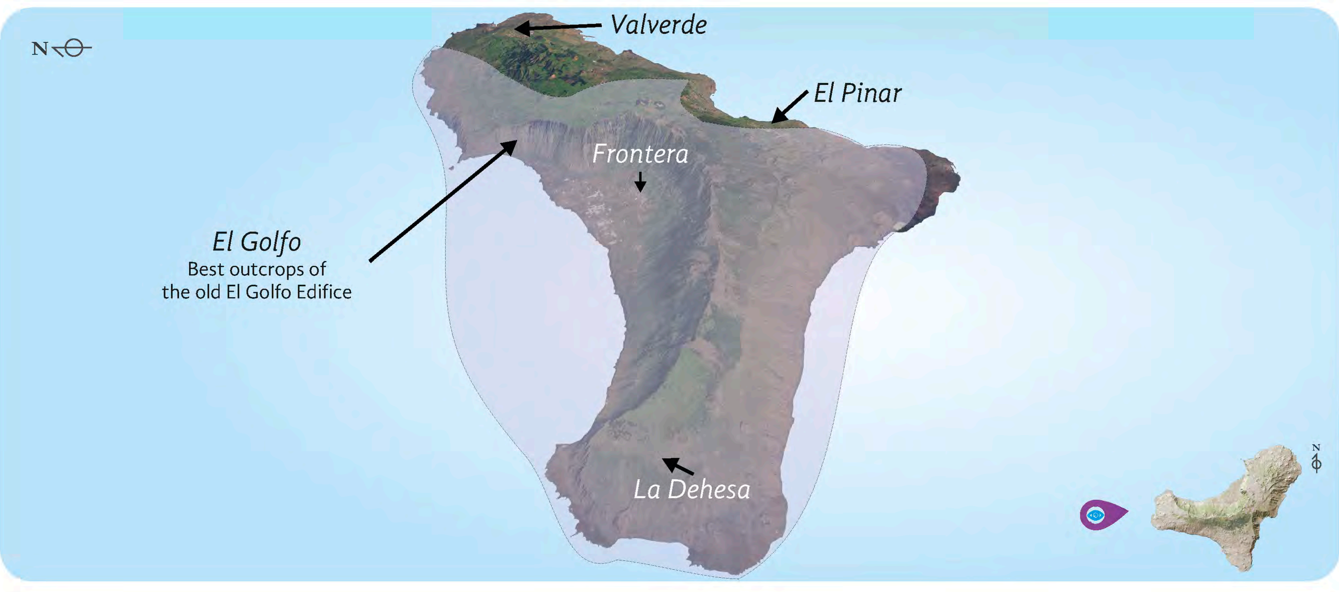


3 Volcanic Edifice El Golfo, partially covers the Volcanic Edifice Tiñor

Between 545 and 176 ka

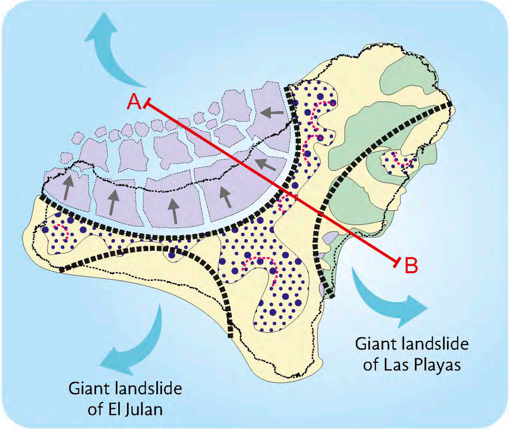


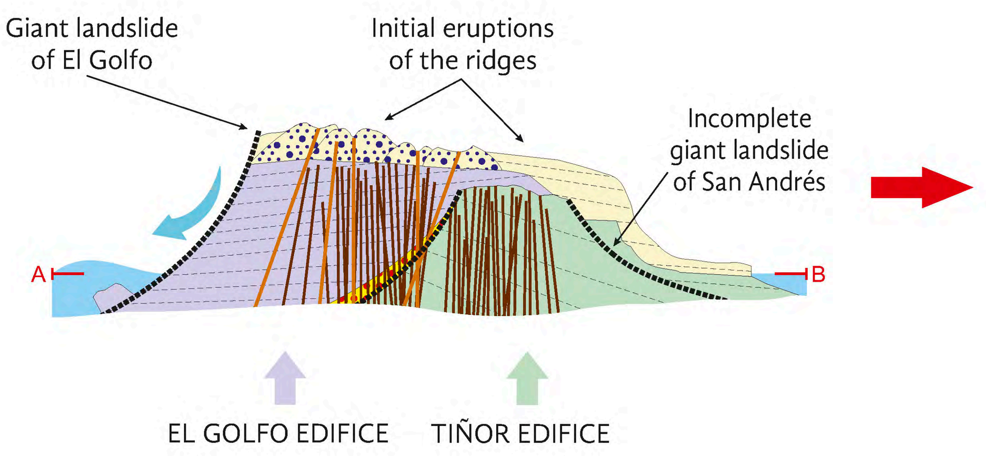


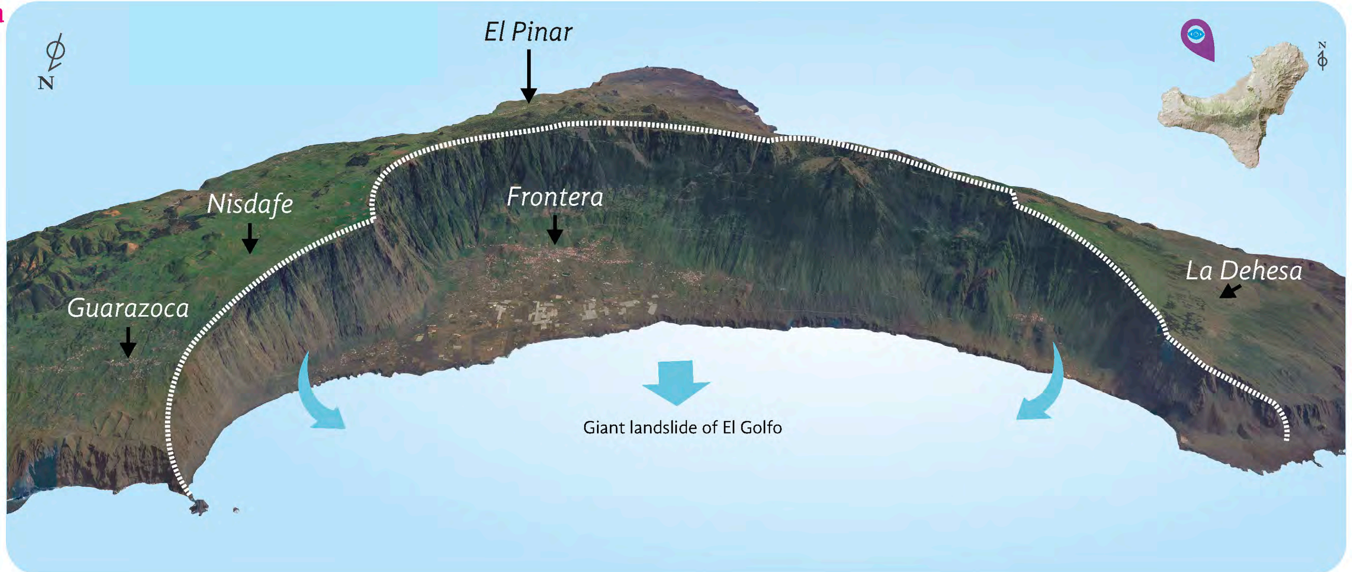


4 Giant landslides of Las Playas and El Julan, beginning of the volcanism of the ridges (cliff lavas) around 158 ka, El Golfo giant landslide

Between 176 and 20 ka

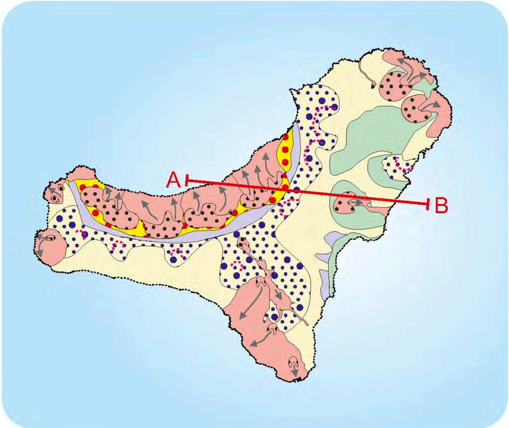


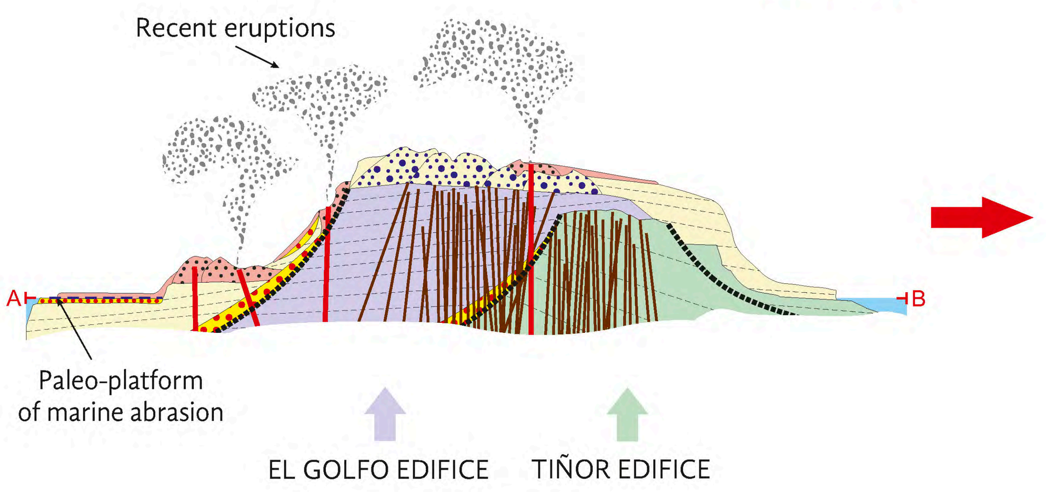




5 Recent ridge volcanism (platform lavas), *islas bajas*

Between 20 ka and present-day





What am I stepping on?

El Hierro has a surface area of 269 km² and is an open book where you can learn how oceanic volcanic islands are built. A landscape was built little by little on two large buildings, Tiñor and El Golfo, which have grown and fallen, leaving deep traces throughout the territory. El Hierro grows to the rhythm of the giant landslides. Walking on the island is a trek between volcanoes and badlands, cliffs and leaks. Moreover, the island is still alive with the volcanic activity of the ridges, which in the last 20 thousand years, with the sea level similar to the current one, has given rise to lava platforms that in Geology are known as lava deltas and in the Canary Islands we call *islas bajas* (low islands).

- Sediments (alluvial and pedemont)
- Most recent eruptions (BP = before present)
- Platform lavas (lava deltas) — Ridges (Rifts) (<158 ka)
- 3 El Golfo giant landslide scar
- Cliffs lavas
- 2 Scars of the giant landslides of Las Playas, El Julan and San Andrés (incomplete)
- Edifice El Golfo (545 - 176 ka)
- 1 Tiñor giant landslide scar (buried)
- Edifice Tiñor (1.12 - 0.88 Ma)

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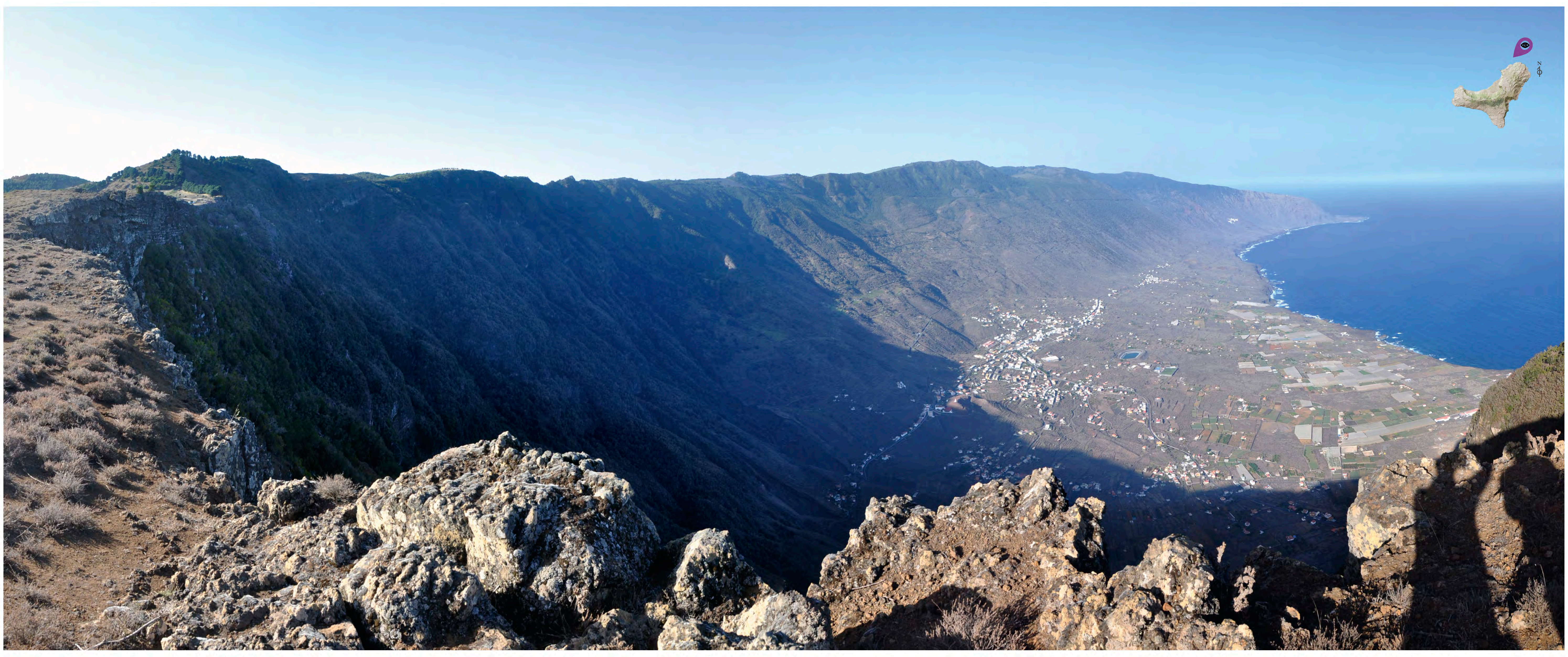
Volcanic landscapes I
Megastructures

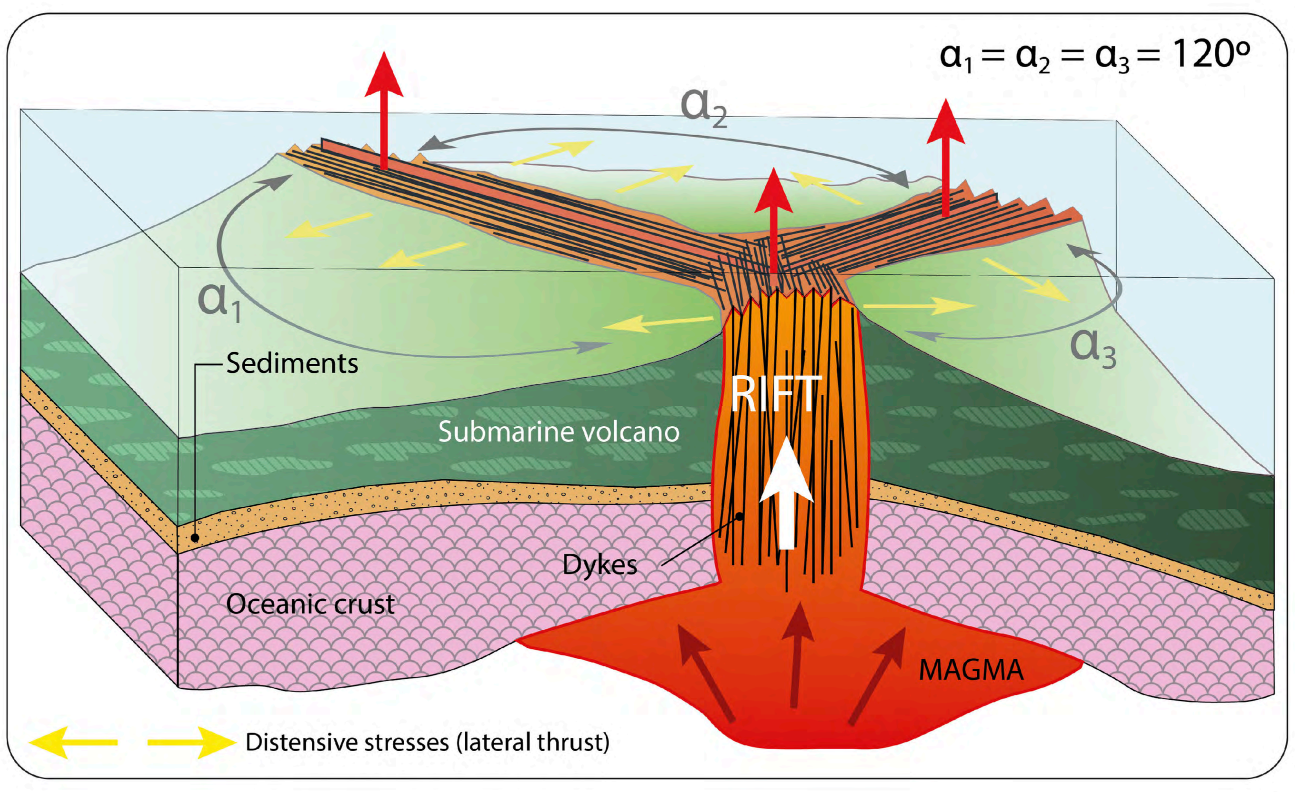
El Hierro continues to grow...

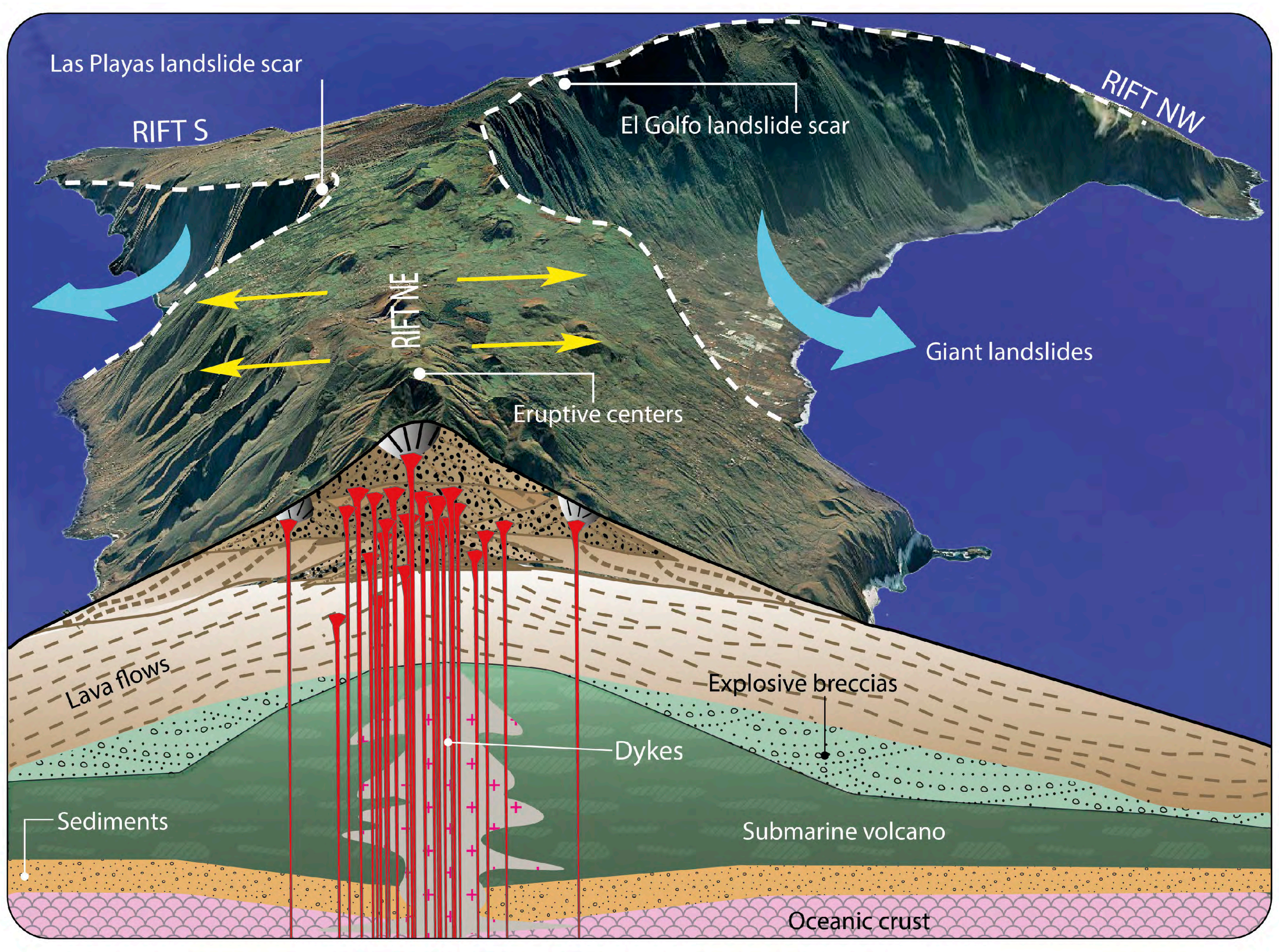
The ridges (rifts) and giant slides are the island's architects. El Hierro stands out, from sea and air, for the breadth of its large concave and convex shapes and its almost impossible slopes. Most of its territory is a splendid watchtower. As Viera y Clavijo wrote, “there is no tower or any fortress in El Hierro because nature has been the engineer who has worked to defend it with its high and rough cliffs, its waves and its currents...”. The island's youth is synonymous with growth.



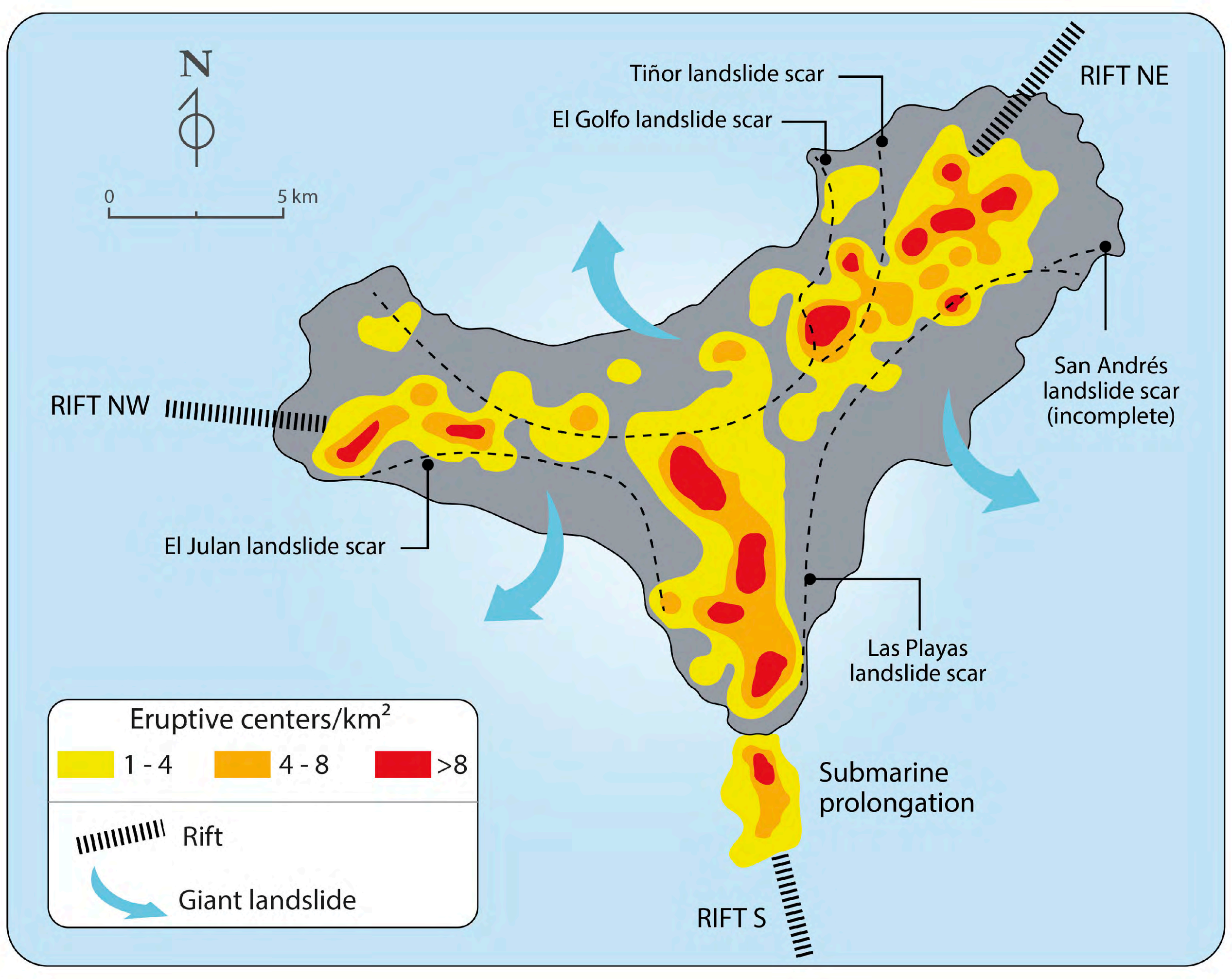
Relationship between ridges (rifts) and giant landslides

It has been possible to develop a geological model that relates the ridges or *dorsales* (rifts) with the giant landslides in the Canary Islands. The successive injections of magma that feed the volcanoes are concentrated in three arms distributed in the shape of a “Mercedes Benz” star, at 120° between them. These injections cause a lateral push effect (distensive stresses) as if we were sticking knives between the pages of a closed book, which, over time, cause giant landslides between two ridges.





The ridges entrails (the feeder magmatic dykes) have been observed in the Canary Islands thanks to the excavation of galleries to search for groundwater. The location and distribution of the feeder dykes coincided on the surface with those of the eruptive centers.

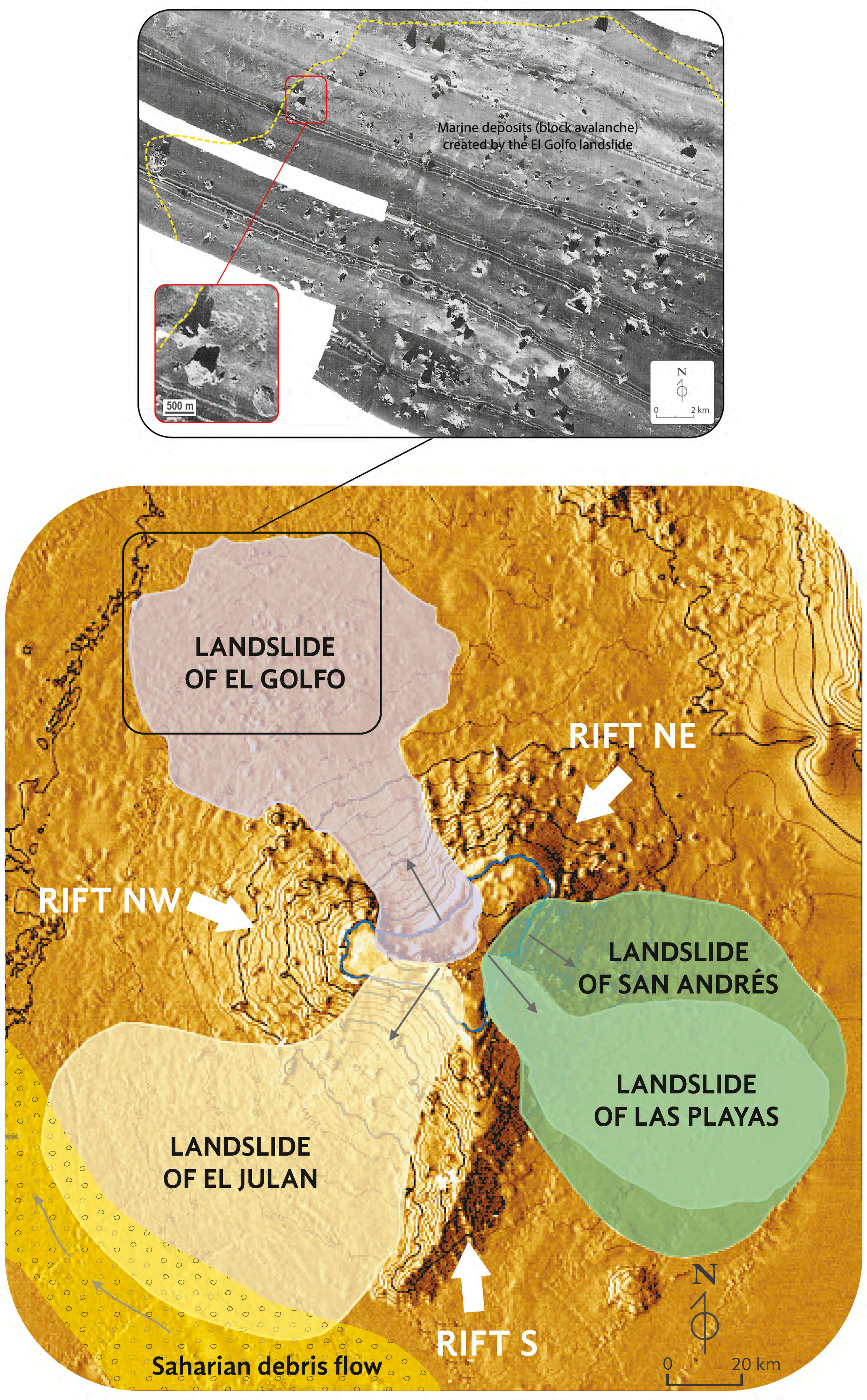


Mirror of the San Andrés Fault

The San Andrés Fault represents a unique case of an incomplete giant slide in the Canary Islands. The terrain to the right of the fault mirror surface in the photo corresponds to the slipped block but did not end up falling into the sea.

Where are the deposits of the giant landslides?

The marine deposits created by the giant landslides are the missing pieces of the puzzle on the current island. The oceanographic ships “photograph” them up to 5,000 m deep, where there are still blocks (fragments of the island) of more than 500 m in size.



Seafloor figures modified from:
D.G. Masson y A.B. Watts (2003): *Debris avalanche deposits on the flanks of the Canary Islands: Contrast between El Hierro and Tenerife.* In “European Margin Sediment Dynamics” (J. Mienert y P. Weaver, editors). Springer, 271-278

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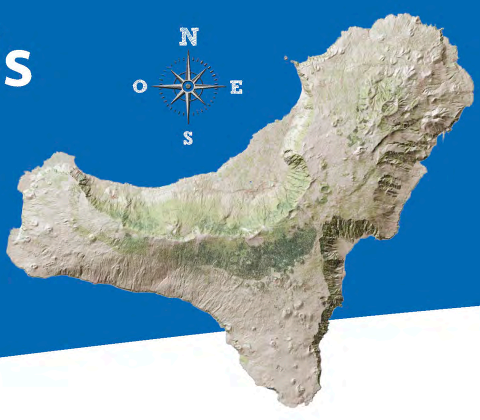
Volcanic landscapes II
Structures on the ground



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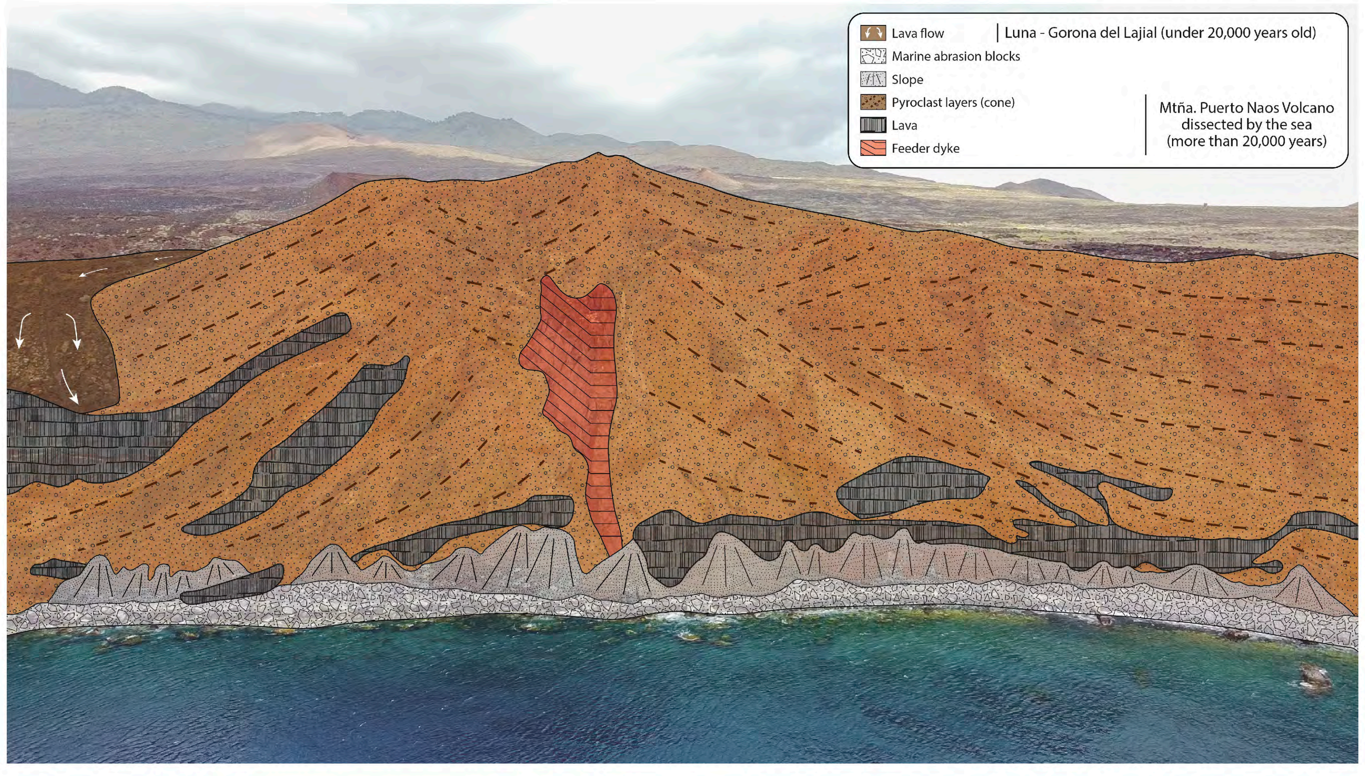
Looking at the ground, discovering the details

On the island of El Hierro, the geological details are found in its different types of volcanoes and the variety of shapes of the associated lava fields.

Eruptive centers or foci: Volcanoes

Volcanoes are usually classified into polygenetic (formed by numerous eruptive events over thousands of years) and monogenetic (formed in a single eruptive event lasting from days to tens of years). In El Hierro, monogenetic cones predominate by the accumulation of pyroclasts around an eruptive mouth fed by a magmatic conduit that, when petrified, is called a dyke. Pyroclasts are solidified fragments of magma of different sizes, from bombs, blocks, and slag (more than 64 mm in size), passing through lapilli (64 to 2 mm), to ashes (less than 2 mm), which in the Canary Islands receive different names such as *picón*, *rofe*, and *jable*. Other common monogenetic volcanoes on the island are hornitos (such as Roque Grande in Gorona del Lajial) and sinking craters (such as Luna, Hoya del Roque and Cueva la Paja in Gorona del Lajial).

with geological eyes



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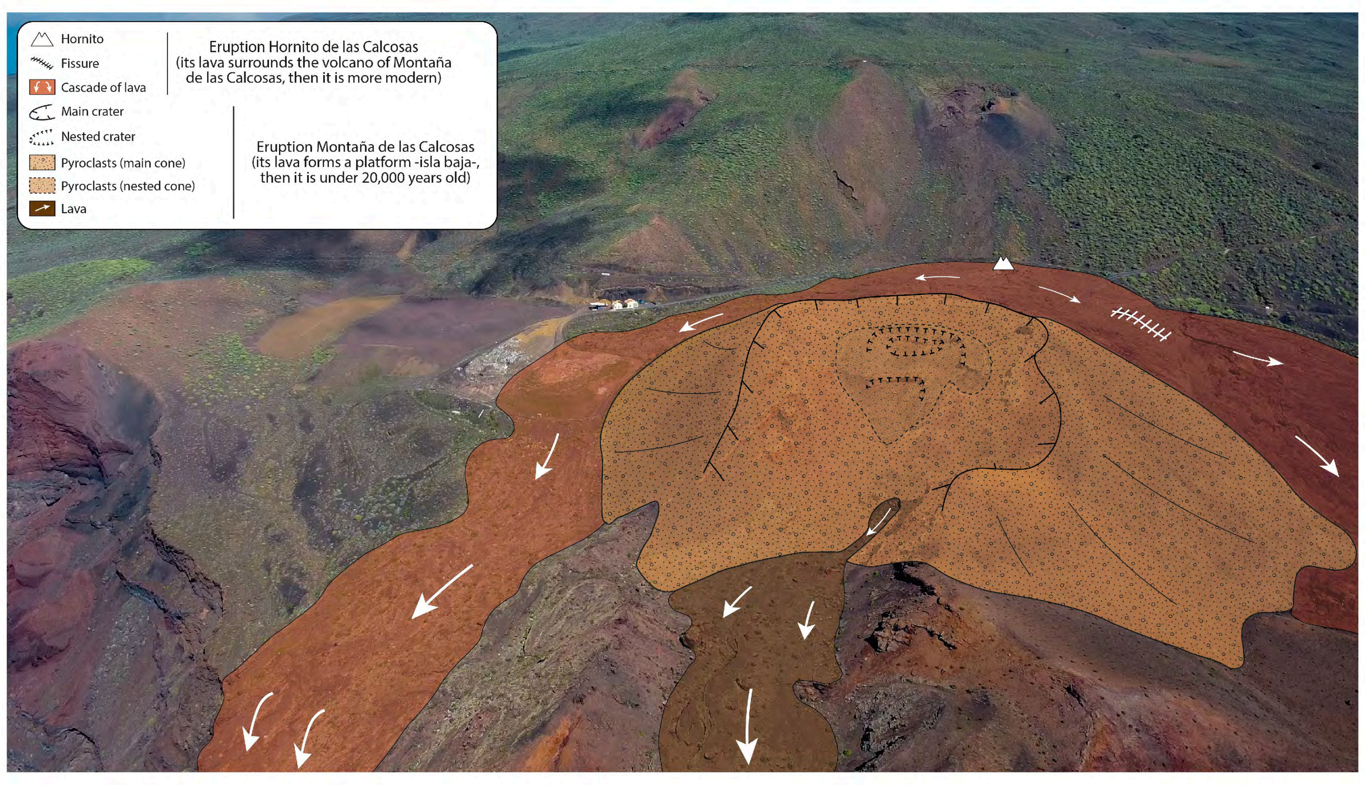
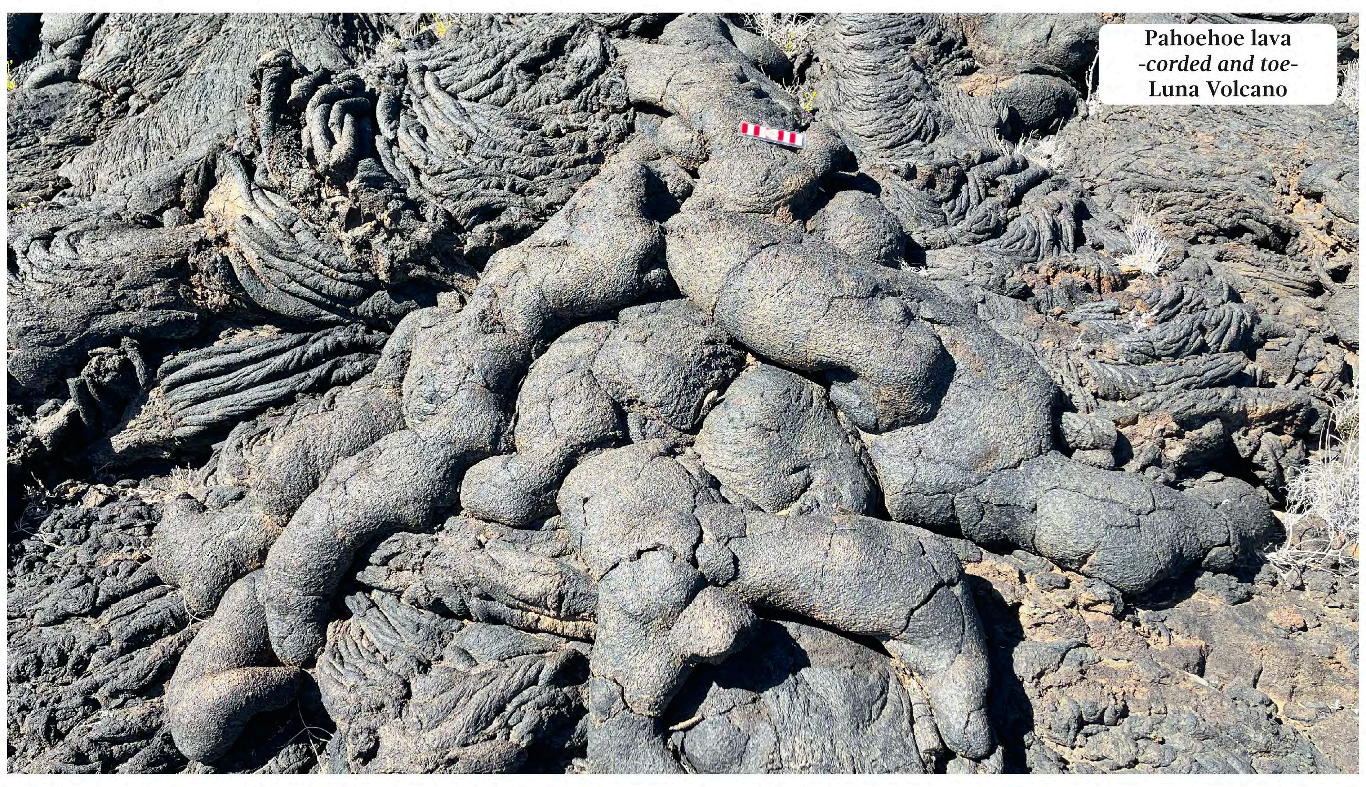


Lava fields

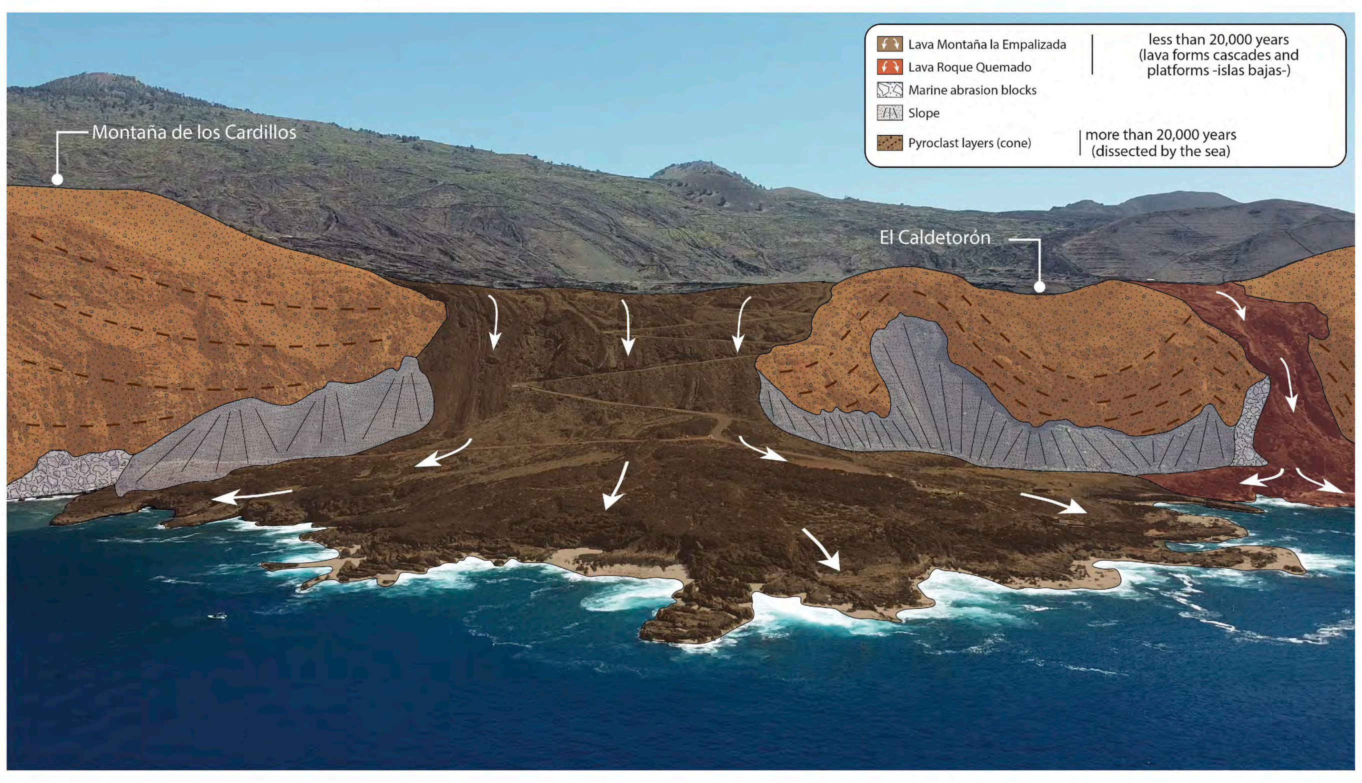
Lavas are classified according to their morphology, which depends on several factors, including the chemical composition of the magma (which classifies them as mafic, intermediate, and felsic, from lowest to highest silicon content) and the cooling environment (marine or terrestrial). On the island of El Hierro, predominate lava fields derived from mafic magmas (hence their dark colors, since these magmas are rich in iron and magnesium) and cooled in the terrestrial environment. Under these conditions, lavas a'a (*malpaís* in the Canary Islands) and pahoehoe (*lavas cordadas*, *en tripas*, *dedos*, *lisas*, etc. in the Canary Islands) are formed.



Lavas forming marine platforms (lava deltas): *islas bajas*

The geomorphological position of the lavas allows an estimate of the eruptive event age. The lavas forming marine platforms at the current sea level, that in Geology are known as lava deltas and in the Canary Islands we call *islas bajas* (low islands), must have been formed in the current interglacial period that began about 20,000 years ago. On the contrary, the lavas (and the volcanic cones) that are dissected by the sea, forming the cliffs, have formed with a sea level very different from the current one (in previous glacial or interglacial epochs). Therefore, they must be older than 20,000 years.

with geological eyes



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Volcanoes in motion: El Hierro & La Palma islands

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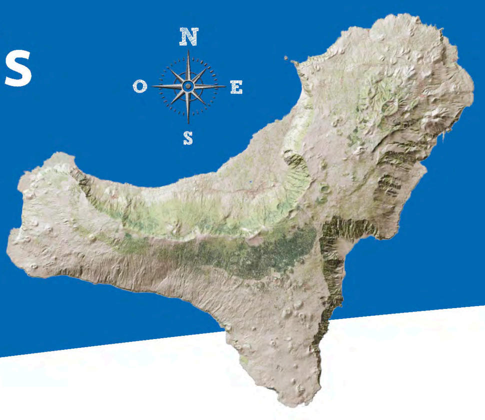
Explore the volcanic paradise I

Walking among volcanoes



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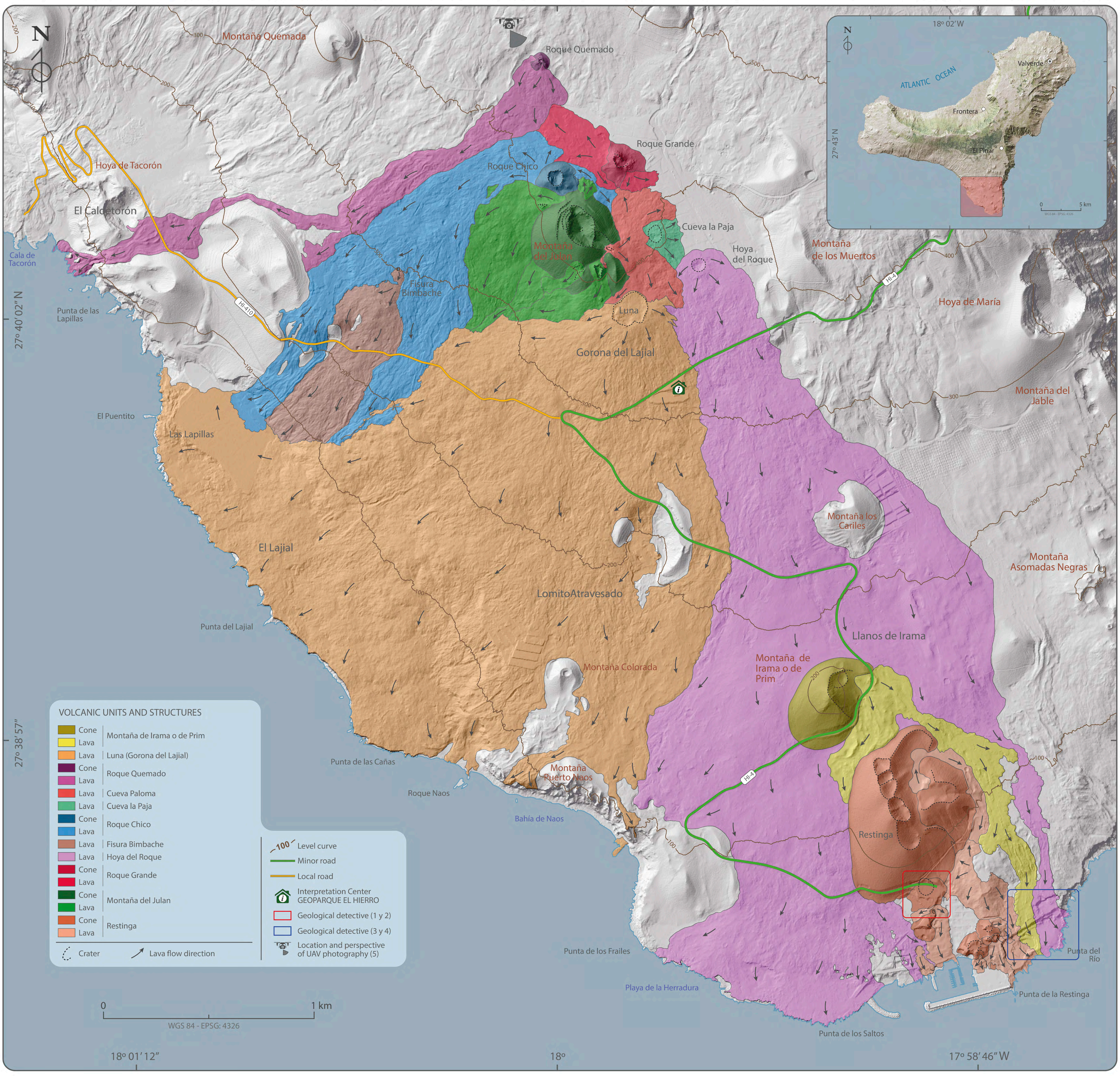
Map 'Gorona del Lajial': a geological puzzle

One of the main results of the LAJIAL research project is the accurate geological map of the entire Gorona del Lajial volcanic field. This map results from many hours of work on the field, identifying and distinguishing all the eruptive sources (more than 25) with their corresponding lava fields. This work has temporarily ordered the different eruptive events, solving previous map errors. With an area of 9.85 km², all types of pahoehoe lavas can be found. This volcanic field is one of the largest and best-preserved globally with these characteristics.



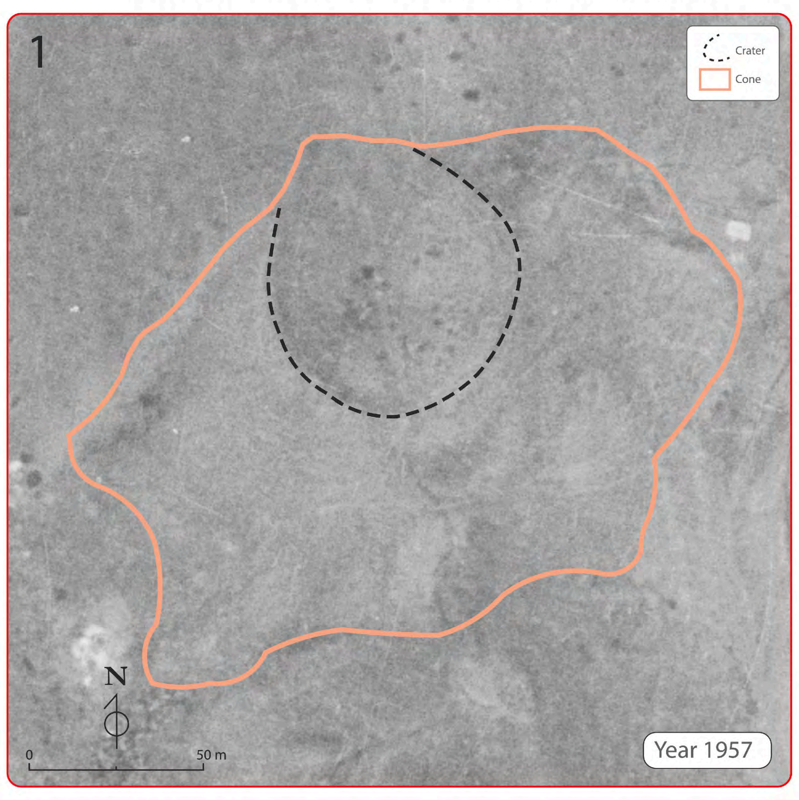
Geological detective

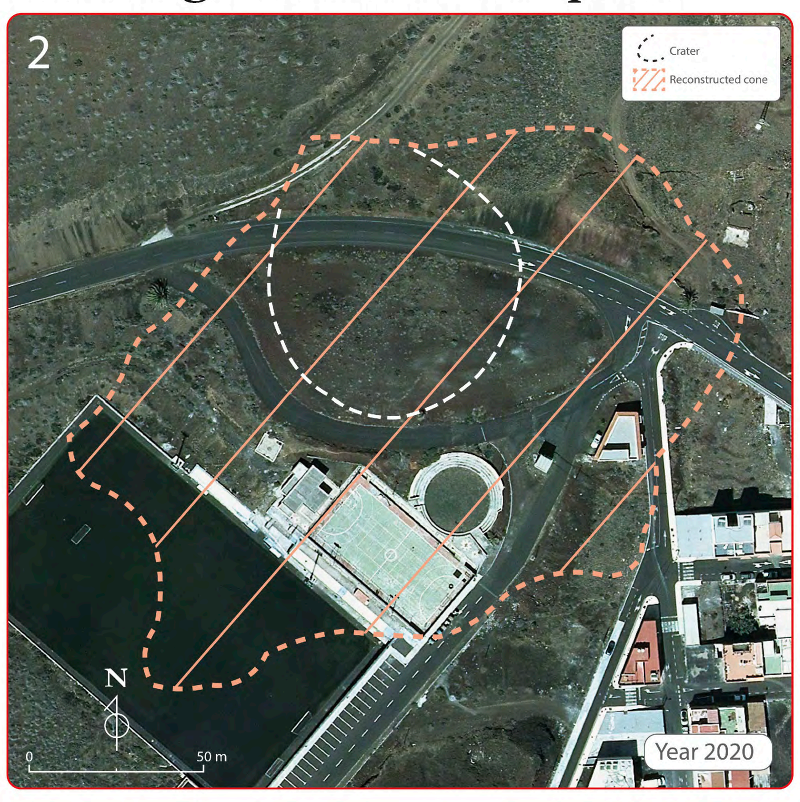
Thanks to the old aerial photos generated from the photogrammetric flights carried out by the Cartographic and Photographic Center (CECAF) between 1951 and 1957, it is possible to observe the land use and cover changes. After more than 60 years, these images are one of the few historical aerial resources available to reconstruct volcanoes and lava fields that have disappeared today due to human action. To appreciate these changes, we compare aerial images of 2020 against those of the 1957 flight.

Images 1 and 2 show the change in one of the cones of the Restinga volcanic complex, now almost completely disappeared.

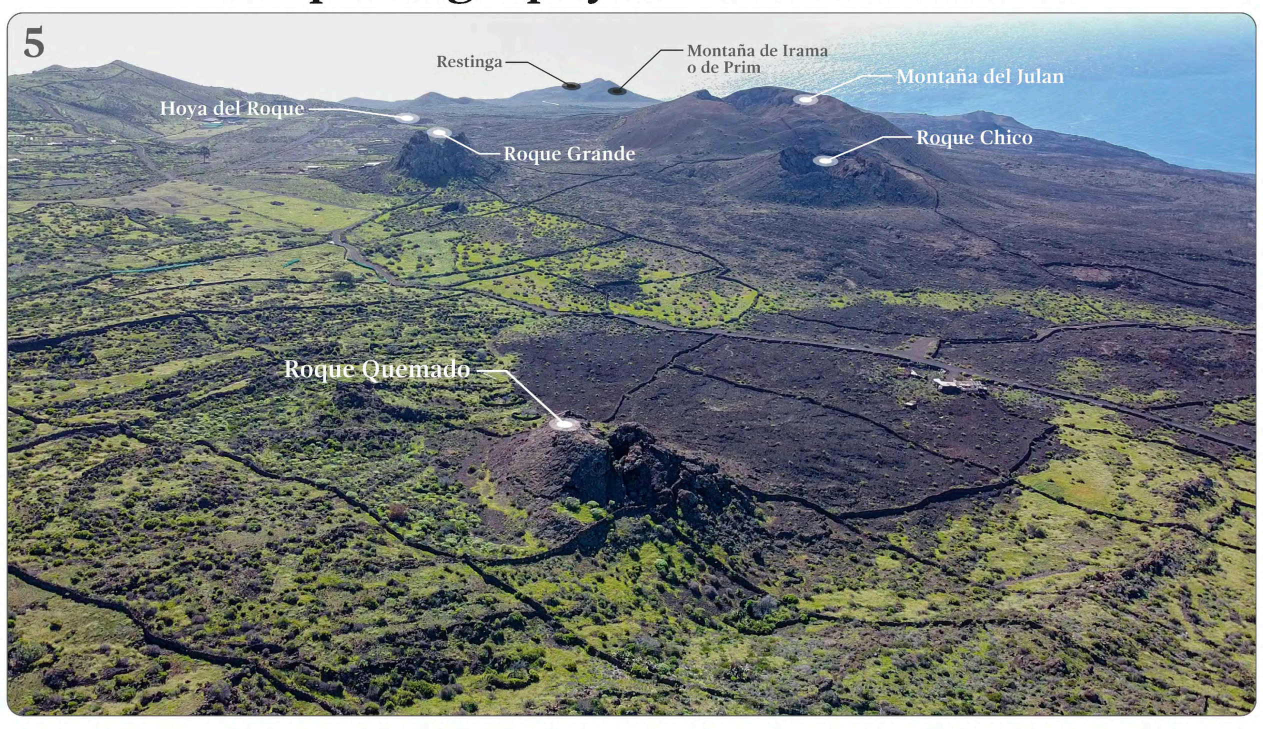
Images 3 and 4 represent the changes undergone in the lava fronts of the eruptions of Montaña de Prim and Hoya del Roque upon reaching the sea, today removed by extraction quarries.

Reconstruction of a cone of the Restinga volcanic complex

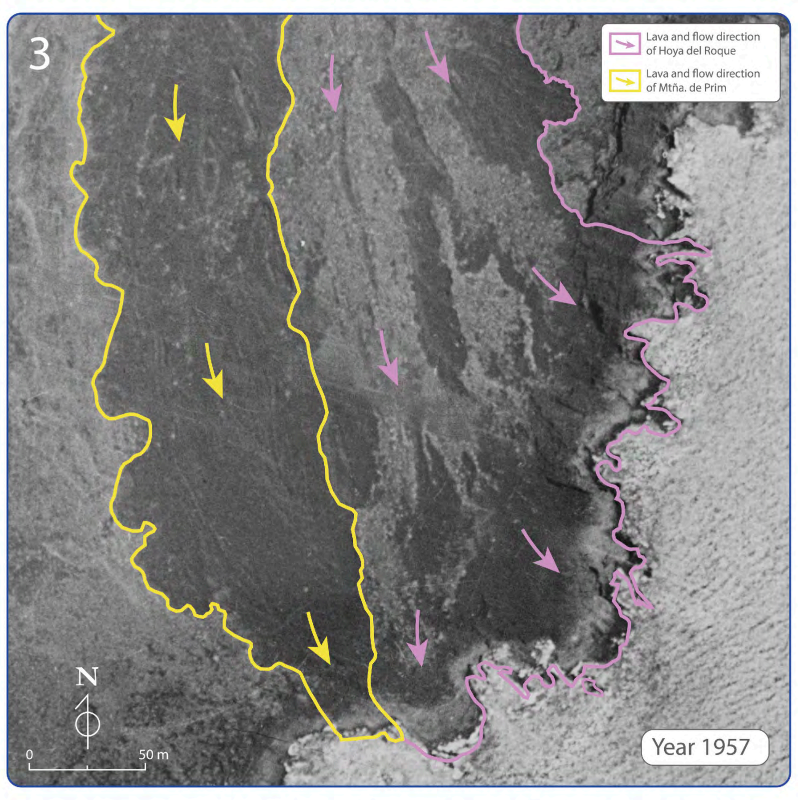


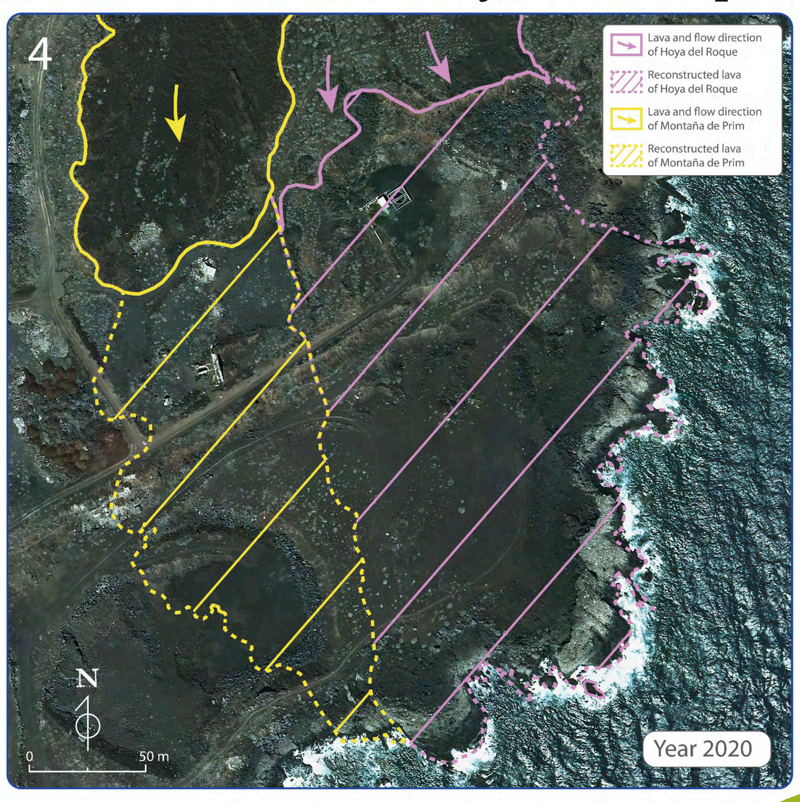


UAV photography of volcanic centers



Reconstruction of the lavas of Montaña de Prim and Hoya del Roque





Sources:
- LIDAR location map: Cartográfica de Canarias, S.A. (GRAFCAN)
- Ortophoto year 2020: Cartográfica de Canarias, S.A. (GRAFCAN)
- Ortophotos years 1951-1957: Centro Cartográfico y Fotográfico (CECAF)

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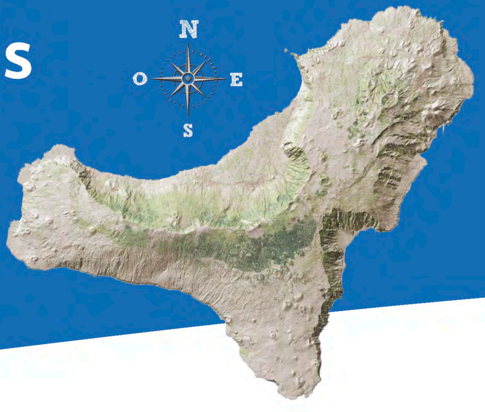


Explore the volcanic paradise II
The last volcano of El Hierro

To download:

The Tagoro volcano erupted where appropriate

The last eruption in El Hierro, the Tagoro volcano, occurred in the submarine extension of the southern rift of the island. It is not a coincidence. The volcano was born in a place with high probabilities: a rift or ridge. Geological knowledge helps to understand better the evolution of the island and anticipate where it will speak again.

The island under the sea

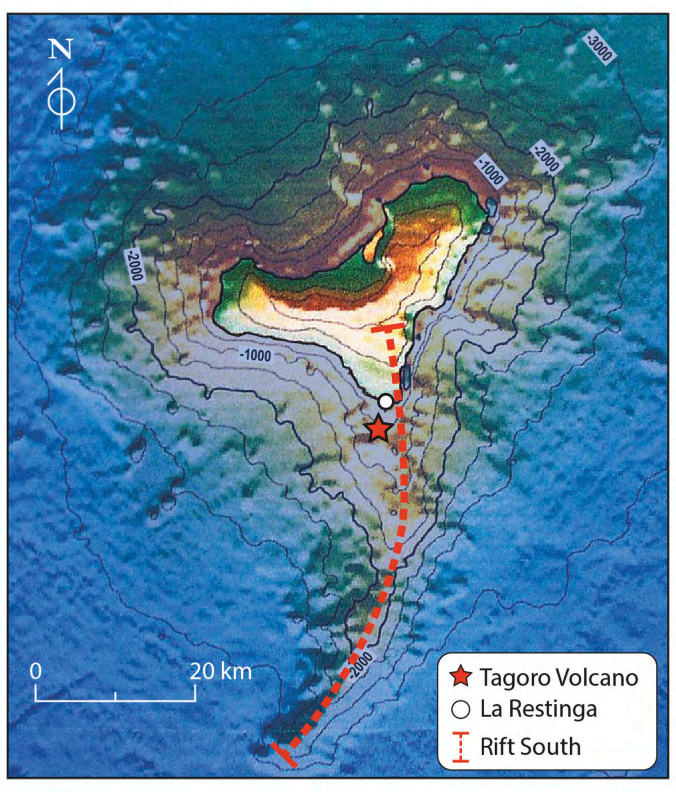
Despite El Hierro is the youngest volcanic island in the archipelago, the absence of historical eruptions was striking. The submarine eruption of the Tagoro volcano (between October 2011 and March 2012), located about 2 km south of La Restinga and about 350 m deep, has revealed this youth. Probably, it was one of many submarine eruptions in recent times, but they have been able to go unnoticed due to the lack of modern scientific equipment for their observation, such as that used in this Tagoro eruption. Also, if they were born at a greater depth, they might not have had almost any volcanic manifestation on the sea surface.

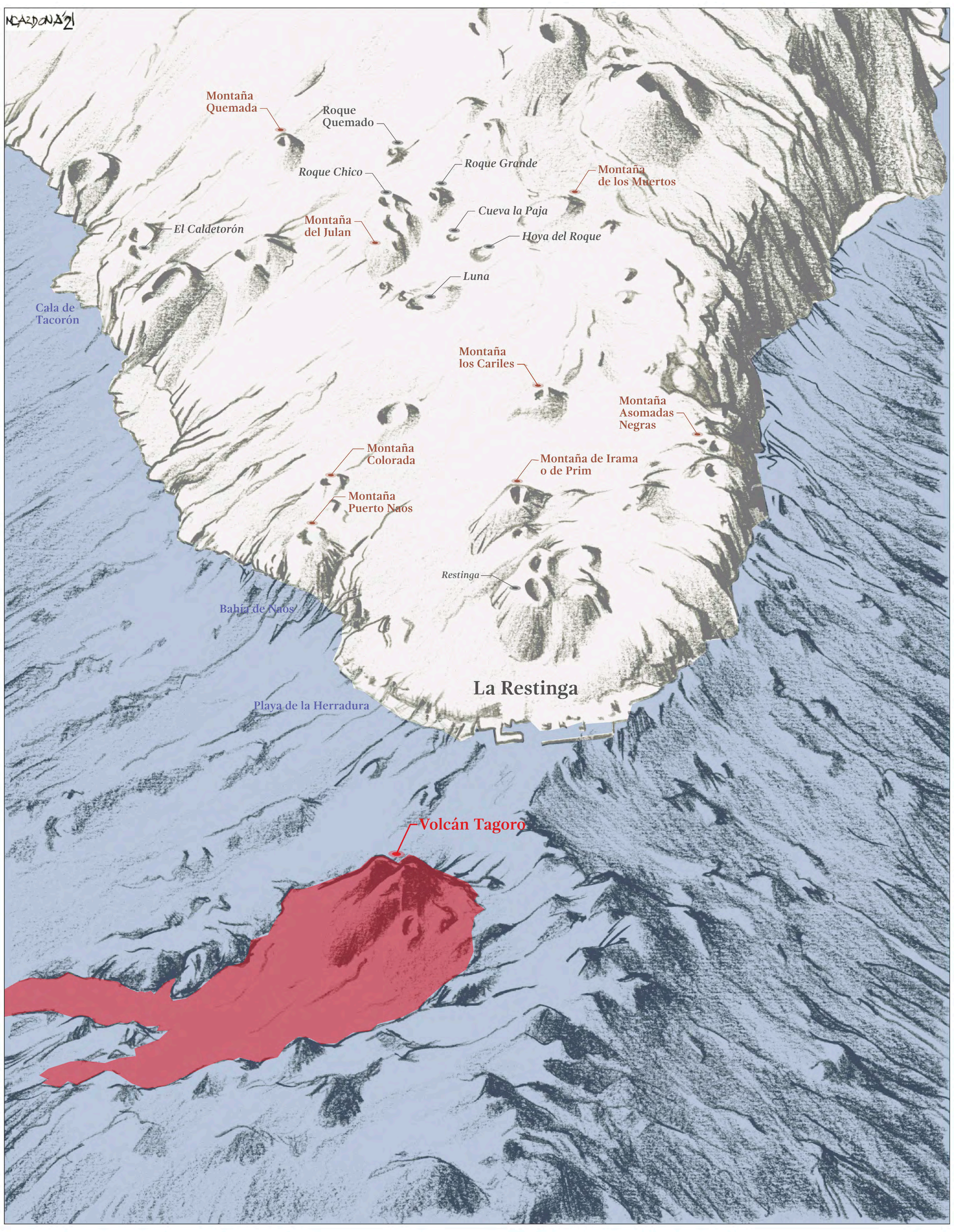
Thus, the birth of the Tagoro volcano has corroborated the previous geological knowledge of El Hierro and, in general, of the Canary Islands, highlighting three key aspects:

1) It occurs on the geologically youngest islands, vertical to the hot spot that generated the Canary Archipelago.

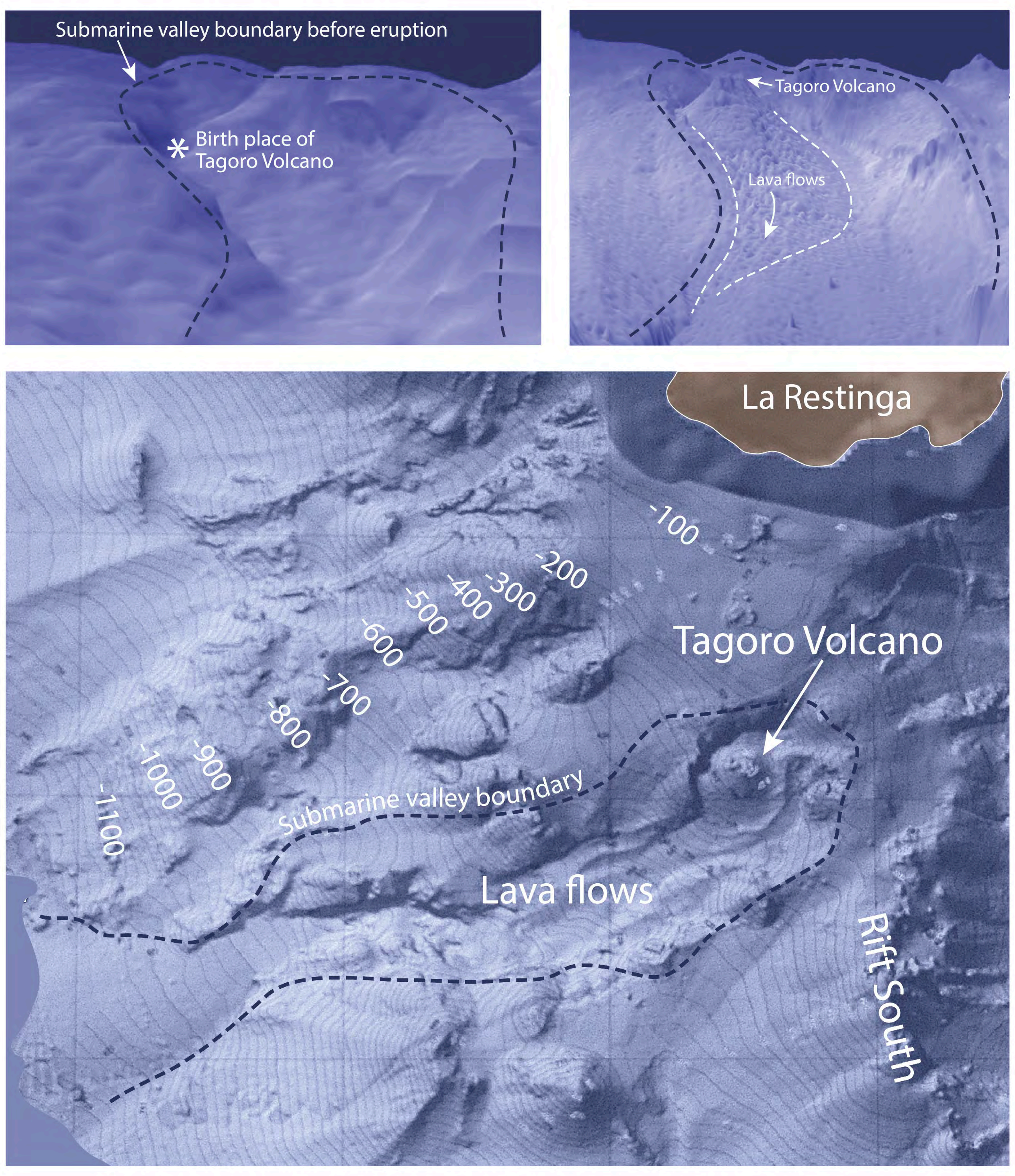
2) It is submarine, which is consistent with the fact that the largest volume of each island is submerged. In the case of El Hierro, more than 90% of its volume is located under the sea. In other words, volcanic islands are like icebergs.

3) It has been located in the submarine extension of the southern ridge or rift, where the largest number of the island's most recent eruptions is concentrated.

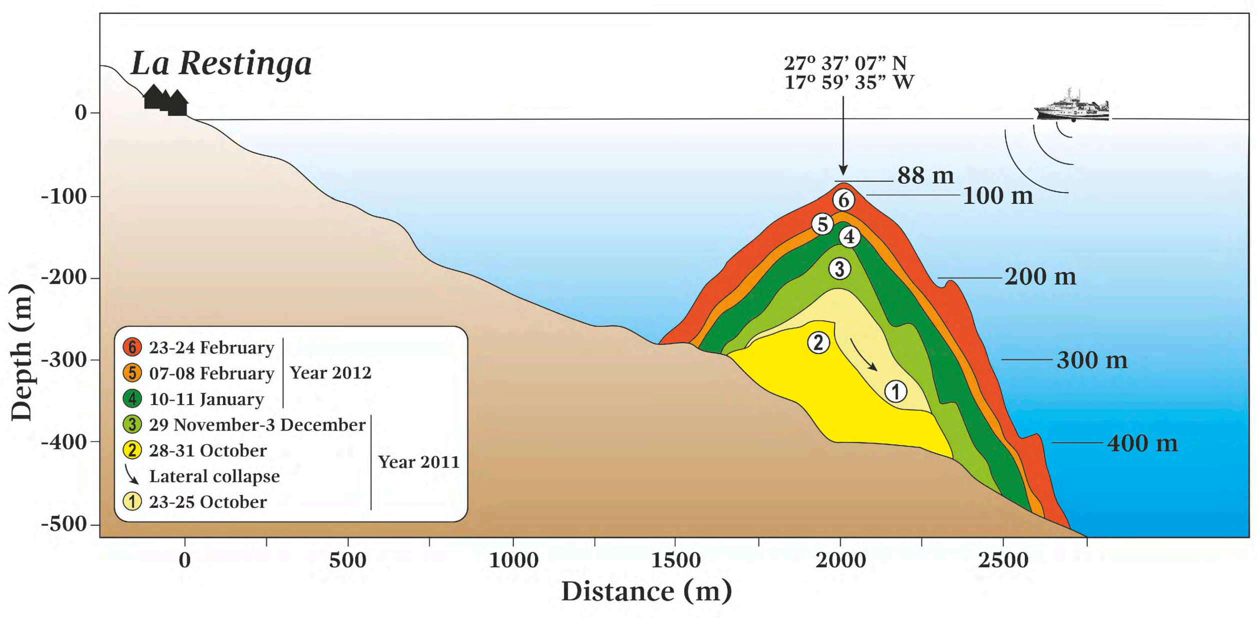




The birth of a volcano



Source of submarine relief images: Instituto Español de Oceanografía (IEO)

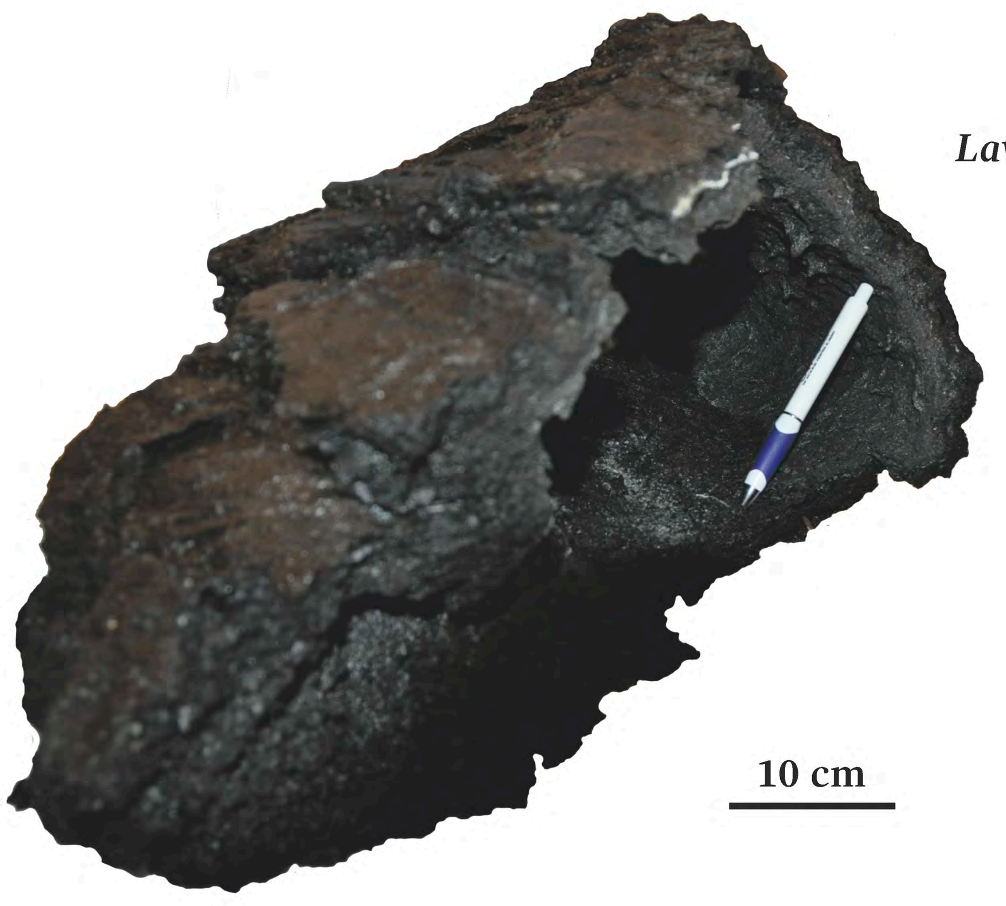


And left us the restingolite

The record of an underwater volcanic eruption in El Hierro came on October 15, 2011, with the arrival at the sea surface of volcanic bombs of 10 to 40 cm in diameter that had the particularity of having a thin outer layer of black color enveloping a very porous white pumice-like material (scientifically, xeno-pumice). These floating bombs were quickly named restingolites, becoming very popular and the subject of passionate scientific debate. Over time, the restingolites were replaced by other larger volcanic bombs with hollow interiors, previously observed in other submarine eruptions in different volcanic archipelagos and named "lava balloons". Upon reaching the sea's surface and losing the gas inside, they filled with water and sank.

Restingolite

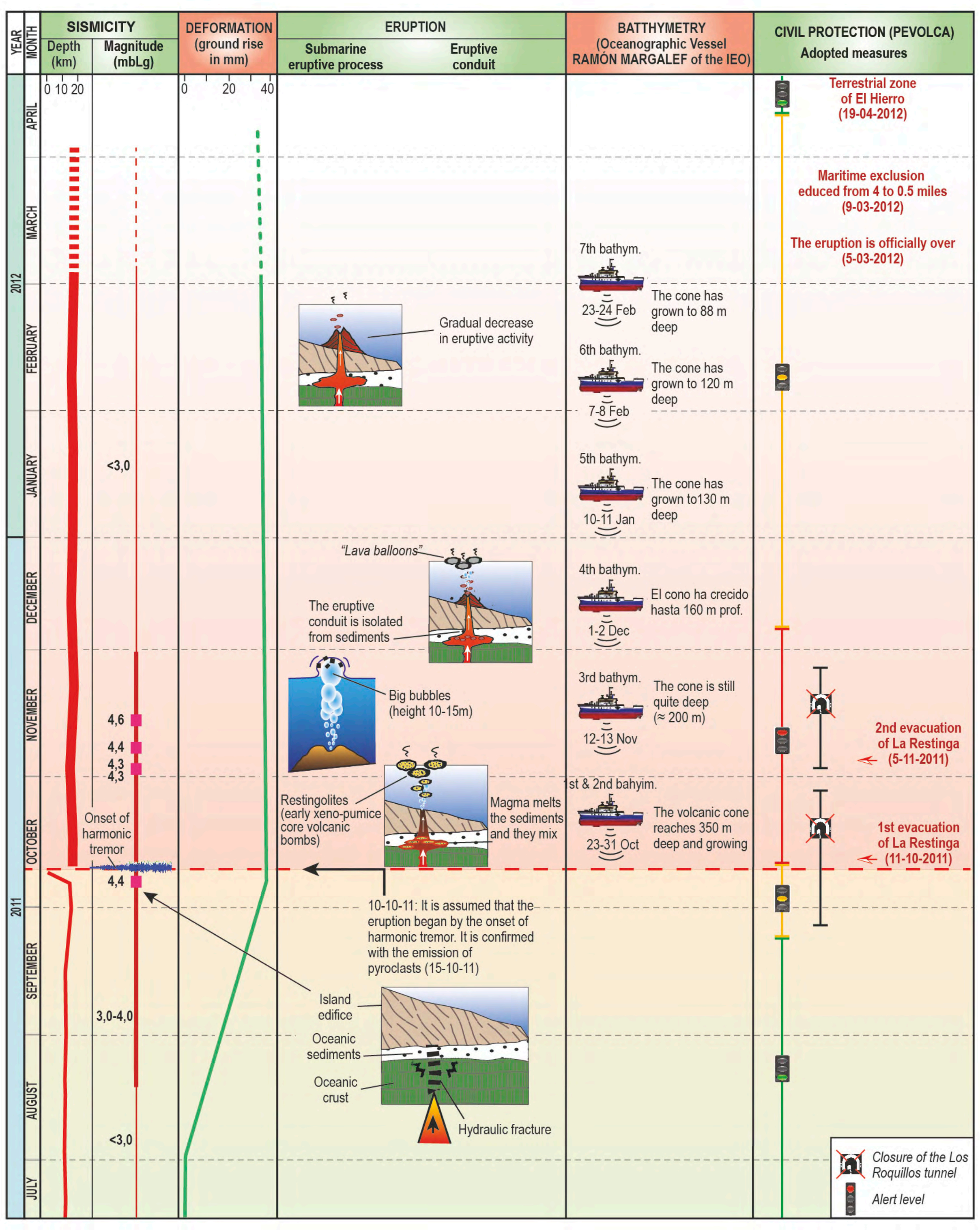
5 cm



Lava balloon

10 cm

Eruption diary



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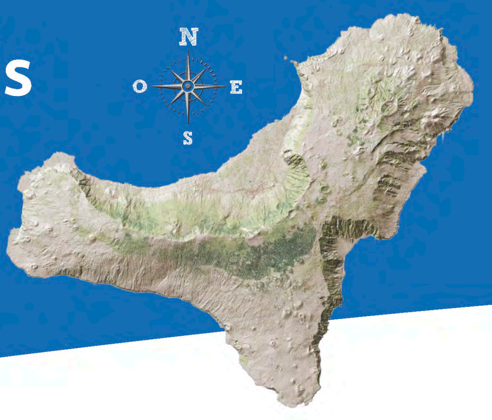

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The geological Garoé: groundwater in El Hierro

The volcanism of the island of El Hierro is very young, so its materials are very porous and permeable. This permeability determines that there are no well-developed ravines. The water infiltrates and goes out to the sea if it does not meet impermeable levels that retain it as groundwater.

What is an aquifer?

An aquifer is a geological formation that contains water in its pores, allowing it to flow, being its exploitation economically profitable. Groundwater circulation is slow in volcanic aquifers and flows through very different materials.

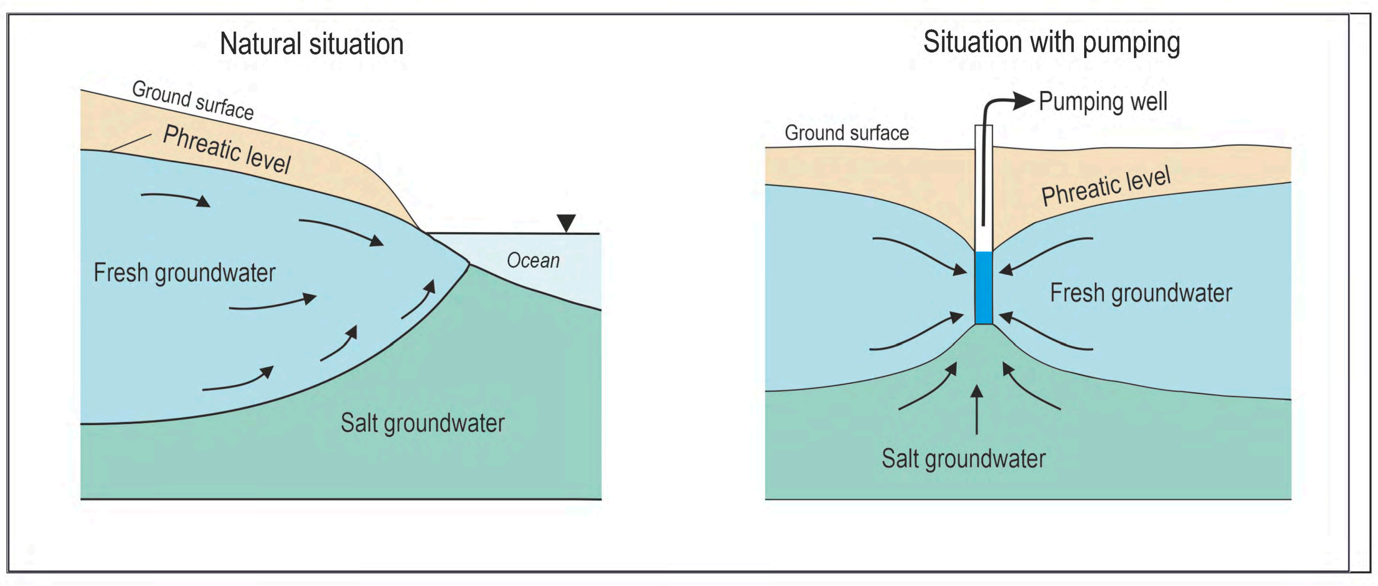
The Garoé tree

The bimbaches or bimbapes suffered from a significant shortage of fresh water and took advantage of the water condensed in the vegetation from the clouds. Viera y Clavijo described "*...the holy tree, which they say is called Garoé in their language, which for so many years has been kept healthy, whole and fresh; whose leaves distill so much and continuous water, that it gives the entire island to drink, nature having provided this miraculous source to dryness*".

What is a marine intrusion?

There is a fragile balance between freshwater and the denser saltwater, located below, in the coastal aquifers.

Pumping in wells or boreholes breaks that freshwater-saltwater balance in the aquifer, and the pumped water undergoes progressive salinization. This process is known as a marine intrusion.



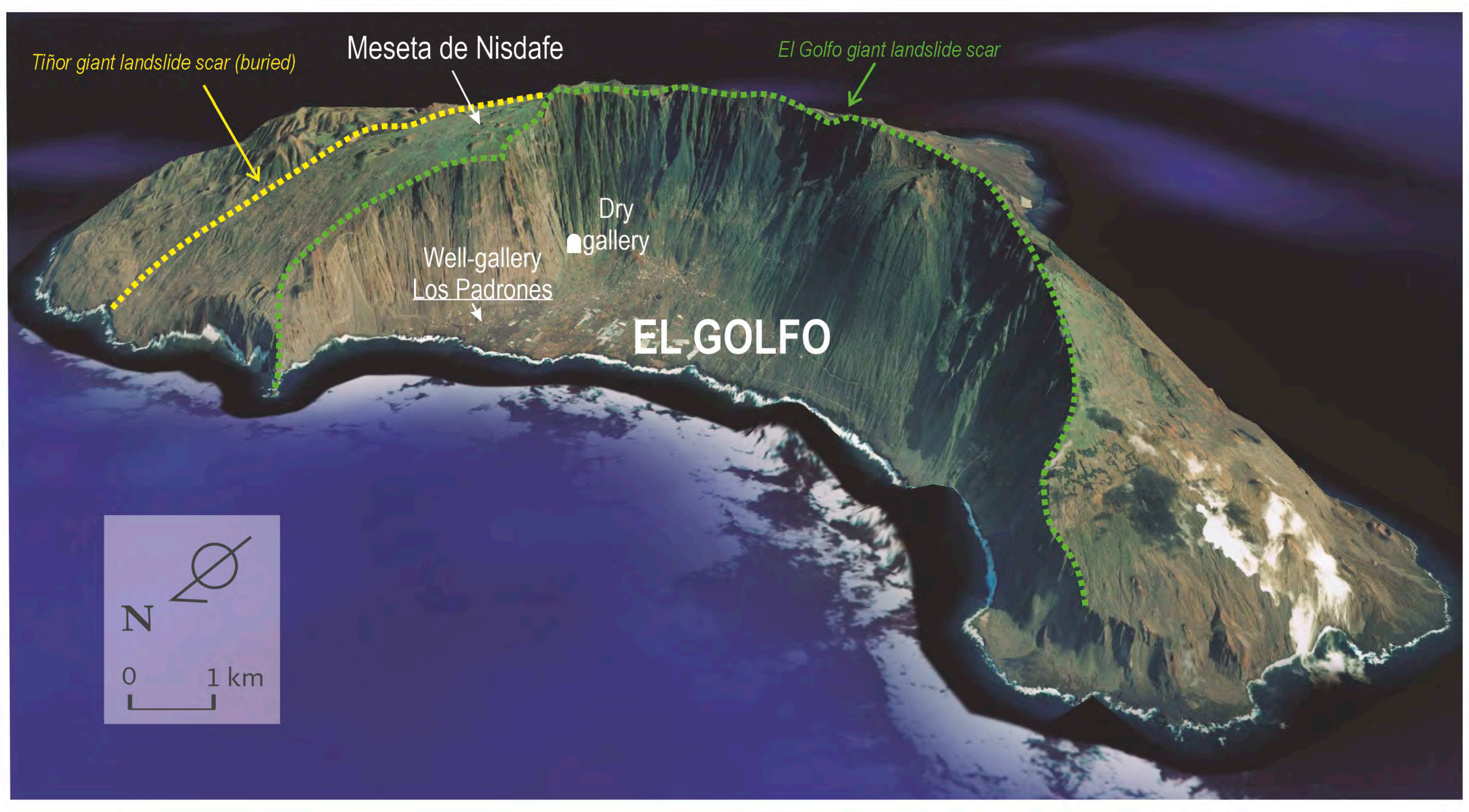
The water occupies pores and fractures of rocks in the aquifers, while in the above-unsaturated zone, these pores and fractures are occupied by water and air. The surface that separates the unsaturated zone from the saturated zone or aquifer is called the water table.

The Nisdafe Aquifer

The drilling of the gallery in the Los Padrones well made it possible to identify an aquifer differentiated from the coastal aquifer of El Golfo. This aquifer is made up of the materials that filled the giant landslide of the Tiñor volcanic edifice and cut by the subsequent giant landslide of the El Golfo volcanic edifice. The aquifer receives the recharge of the water that infiltrates the Nisdafe Plateau. For this reason, it has been named as "Nisdafe Aquifer".

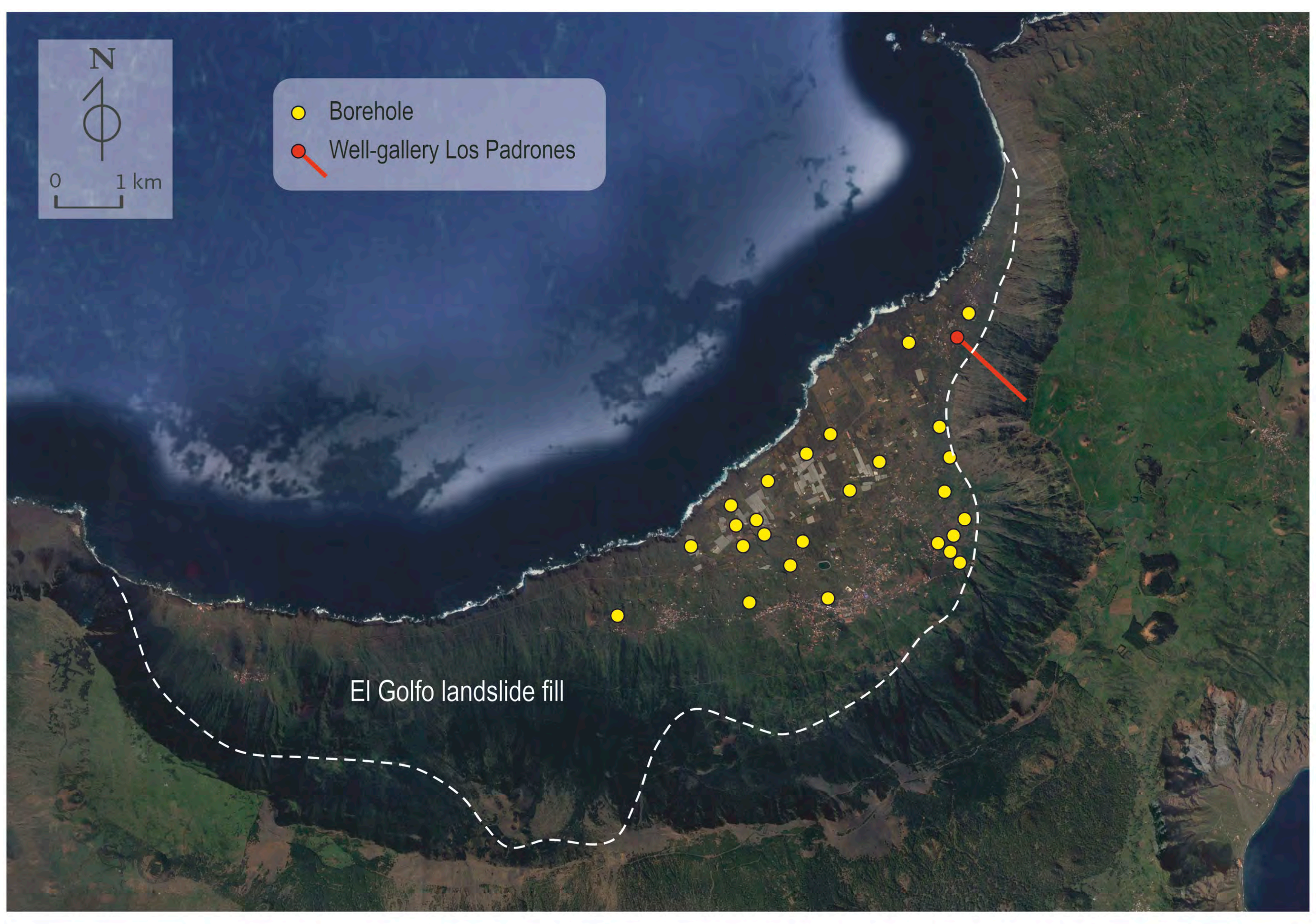
The lower limit of the aquifer is made up of landslide breccias that behave as an impermeable layer. For this reason, the Nisdafe aquifer is only found on the northeast margin of El Golfo, where the two scars of the giant Tiñor and El Golfo landslides converge.

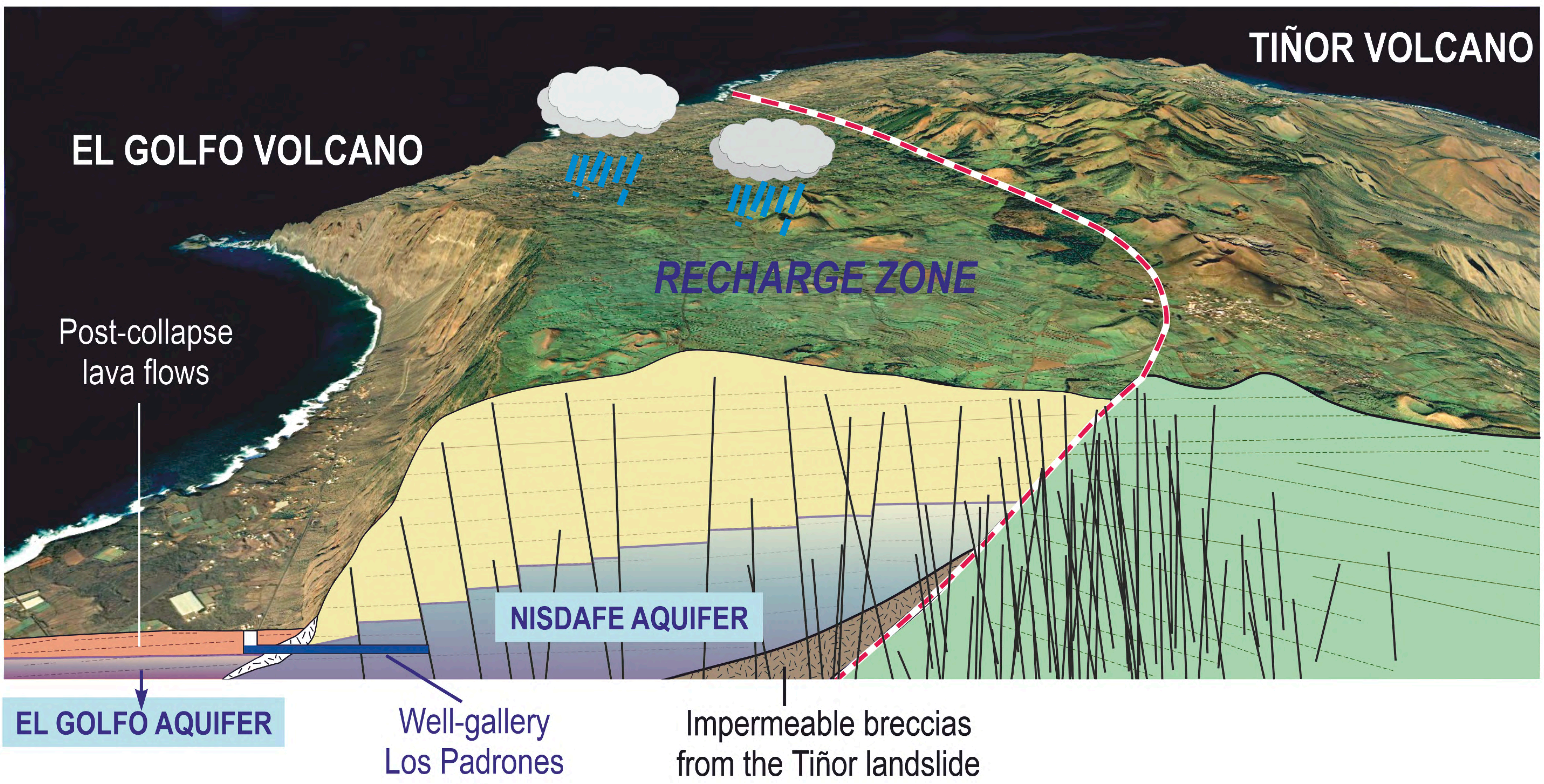
The Nisdafe aquifer constitutes the true geological Garoé of the island, and its reserves must be evaluated for rational exploitation, guaranteeing the conservation of the resource.

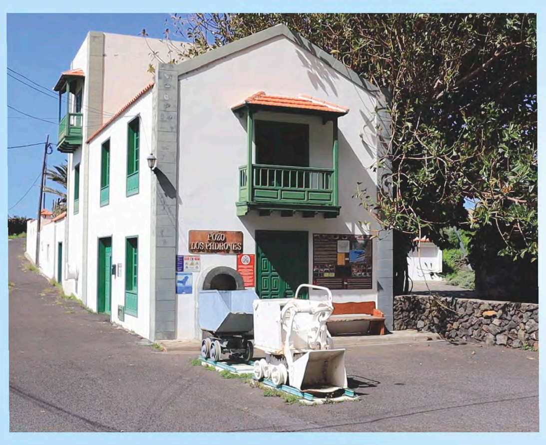


The El Golfo Aquifer

The platform lavas that filled the hole left by the landslide of El Golfo volcanic edifice are the most recent on the island and are emplaced in the lower parts of El Golfo. Their high porosity and permeability make them prone to marine intrusion when water is extracted from wells or boreholes. The data collected in the research boreholes drilled in this aquifer provide regular information on the mixing zone between fresh water and saltwater, called the interface.







Outside view

View of the gallery

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© Google Earth: 3D images of the El Hierro island

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Living among volcanoes II
What the land tell us

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Living today among volcanoes is an opportunity for the future

The geographical identity of El Hierro is marked by its geological status as a young volcanic island. The land tells us about the intimate historical relationship between the volcanoes and the people of El Hierro. Women and men who fought against an adverse nature, adapting their land to adequate agricultural and livestock exploitation, made these volcanic landscapes orchards or fertile pastures to feed the family. They constitute the best example of rational use of natural resources. This is achieved through a wise popular culture, which makes the occupation and balanced use of the territory spatially coincide with the ecological potential of the island. The challenge is integrating these values into the island's economic, social and environmental sustainability strategies.

The language of the volcanic territory

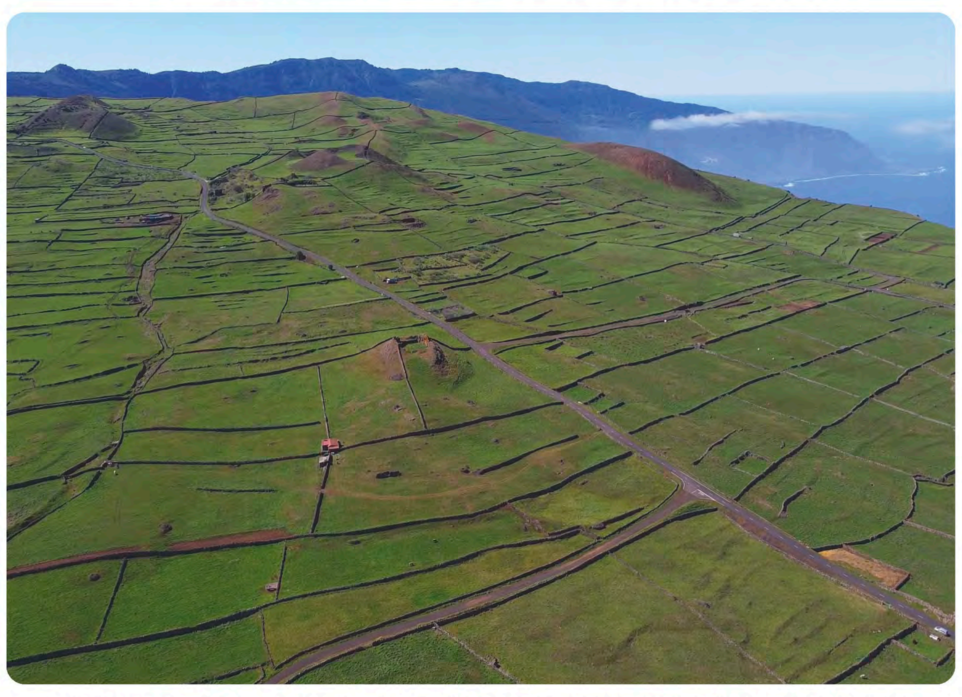

The bimbapes or bimbaches, the first settlers of the island, spoke to us from the lava


Hermitage "Nuestra Señora de Los Reyes" and the shepherds took shelter between volcanoes


Vineyards take advantage of the crater soils of the Montaña del Juramento


Between levees (the walls of the lava channels), they farmed and herded their cattle

The La Caldereta crater water reservoir helps provide clean, renewable energy to the island


Nisdafe is a unique landscape where volcanoes dominate the puzzle of green pastures

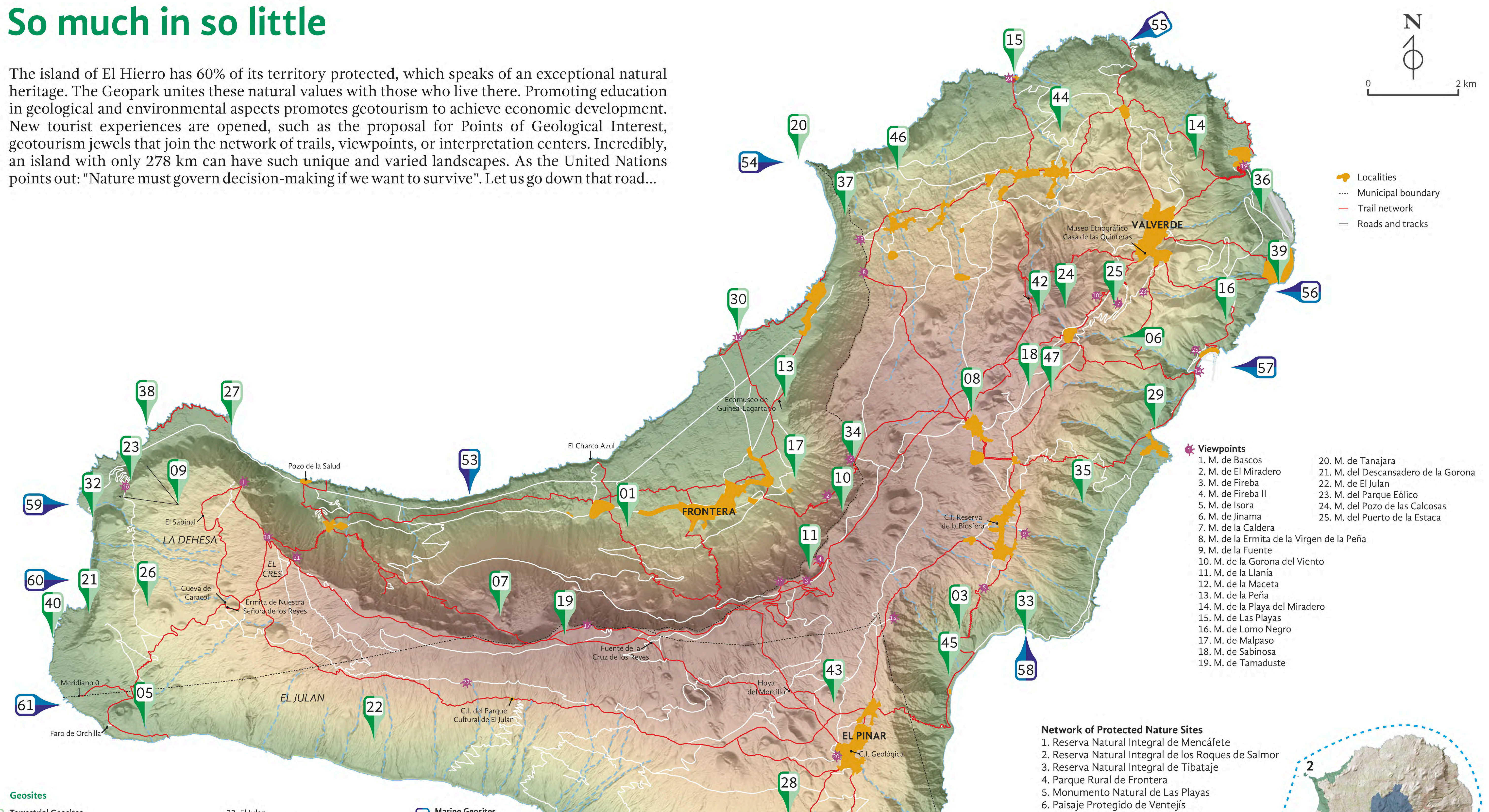
César Manrique defied the void by building the Mirador de la Peña in harmony with the lava


The Pozo de las Calcosas is on the *isla baja* built by the Aguarijo Mountain lava flow


All possible forms are drawn in the Valle de El Golfo when the scenery is the best canvas

So much in so little

The island of El Hierro has 60% of its territory protected, which speaks of an exceptional natural heritage. The Geopark unites these natural values with those who live there. Promoting education in geological and environmental aspects promotes geotourism to achieve economic development. New tourist experiences are opened, such as the proposal for Points of Geological Interest, geotourism jewels that join the network of trails, viewpoints, or interpretation centers. Incredibly, an island with only 278 km can have such unique and varied landscapes. As the United Nations points out: "Nature must govern decision-making if we want to survive". Let us go down that road...



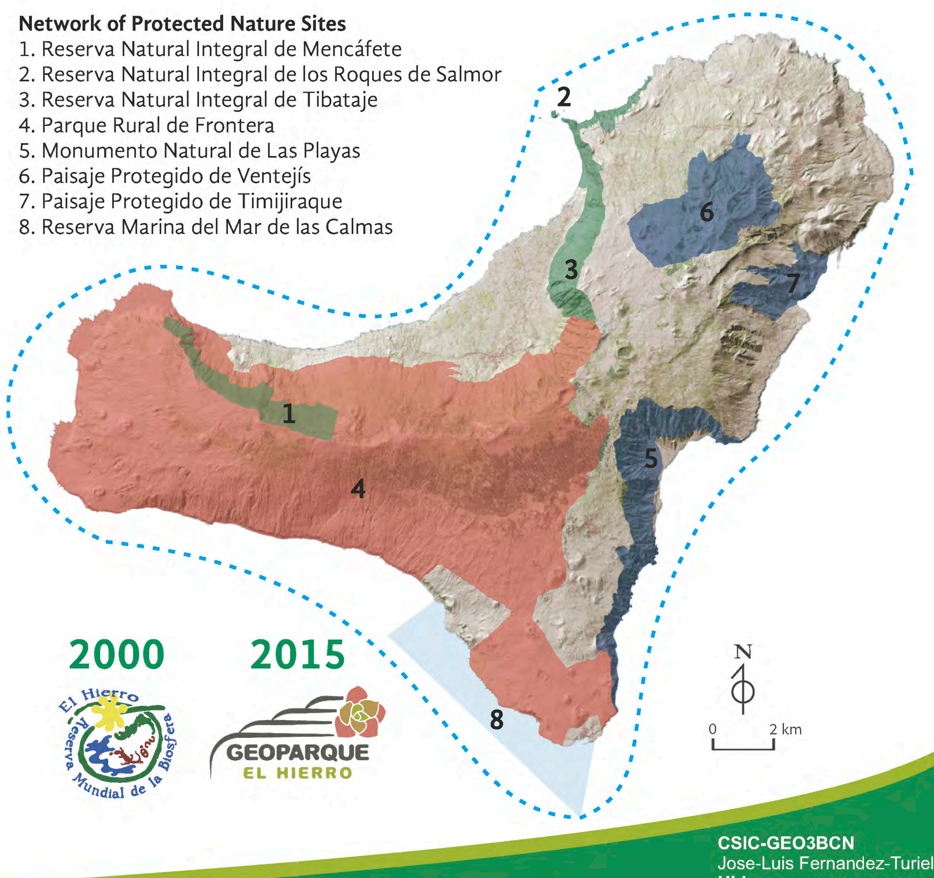
Geosites

Terrestrial Geosites
01. El Valle de El Golfo
02. El Lajial
03. El Valle de Las Playas
04. Cueva de Don Justo
05. Conjunto volcánico de Orchilla-fisuras eruptivas y acantilados
06. La falla de San Andrés (en el Barranco de Tiñor)
07. Volcán Tanganasoga
08. Los moldes de troncos de la colada de Montaña Chamuscada
09. Restos del anillo de tobas de la Hoya del Verodal
10. El Jorado
11. Lo Hoya de Fireba
12. Volcán submarino Tagoro
13. Fuga de Gorreta
14. La Montaña del Tesoro, sus coladas y la plataforma lávica de Tamaduste
15. Pozo de las Calcosas
16. La Falla de San Andrés (en la carretera al Puerto de La Estaca, en Morro de Jayo)
17. Depósitos de avalancha rocosa del 2º deslizamiento gravitacional de El Valle de El Golfo
18. Jondana
19. Depósitos félsicos de Malpaso
20. Roques de Salmor
21. Los conos de piroclastos disectados de los acantilados (La Punta de los Reyes)
22. El Julan
23. El volcán de Lomo Negro
24. Volcán Ventejís
25. La Caldereta
26. Juaclo de las Moleras
27. Playa levantada de Arenas Blancas
28. Campo de volcanes de la dorsal Meridional
29. Pillow-lavas y brechas hialoclastíticas en la base del Edificio Tiñor en Timijiraque
30. La Maceta
31. Cala de Tacorón
32. Playa el Verodal
33. Roque de la Bonanza
34. El dique del Mirador de Jinama
35. Fallas antitéticas del Barranco de las Playecitas
36. Coladas cargadas de xenolitos de La Caleta
37. La colada traquítica del Edificio El Golfo
38. Arcos de piedras costeros (Puntas de Gutiérrez)
39. Playa levantada de La Caleta
40. Disyunción columnar costera en la zona del Cachopo
41. La Montaña de Puerto Naos
42. El Garoé
43. Sima del Pico de la Mata
44. Cueva del Curascán
45. Coluviones del Barranco de las Arenas
46. Los Jables
47. La fosa tectónica entre la carretera de San Andrés y La Cumbrecita

Marine Geosites
48. El Salto
49. El Diablo Cave
50. El Bajón
51. Baja Bocarones
52. El Arco
53. La Hoya
54. Bajo de la Palometa
55. Charco Manso
56. La Caleta
57. Bajón del Puerto
58. Roque de la Bonanza
59. Baja de Anacón
60. Los Negros
61. El Barbudo

Viewpoints
1. M. de Bascos
2. M. de El Miradero
3. M. de Fireba
4. M. de Fireba II
5. M. de Isora
6. M. de Jinama
7. M. de la Caldera
8. M. de la Ermita de la Virgen de la Peña
9. M. de la Fuente
10. M. de la Gorona del Viento
11. M. de la Llanía
12. M. de la Maceta
13. M. de la Peña
14. M. de la Playa del Miradero
15. M. de Las Playas
16. M. de Lomo Negro
17. M. de Malpaso
18. M. de Sabinosa
19. M. de Tamaduste
20. M. de Tanajara
21. M. del Descansadero de la Gorona
22. M. de El Julan
23. M. del Parque Eólico
24. M. del Pozo de las Calcosas
25. M. del Puerto de la Estaca

Network of Protected Nature Sites
1. Reserva Natural Integral de Mencáfete
2. Reserva Natural Integral de los Roques de Salmor
3. Reserva Natural Integral de Tibataje
4. Parque Rural de Frontera
5. Monumento Natural de Las Playas
6. Paisaje Protegido de Ventejís
7. Paisaje Protegido de Timijiraque
8. Reserva Marina del Mar de las Calmas



2000
El Hierro Reserva Mundial de la Biosfera
2015
GEOPARQUE EL HIERRO

Sources:
- Hypsometric Base: Cabildo de El Hierro
- LIDAR Base: GRAFCAN

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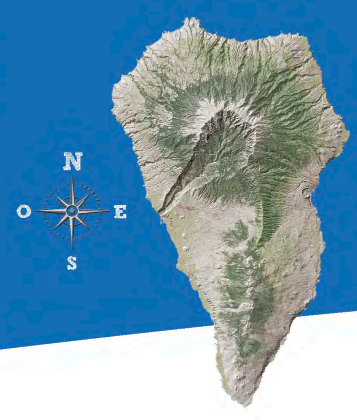
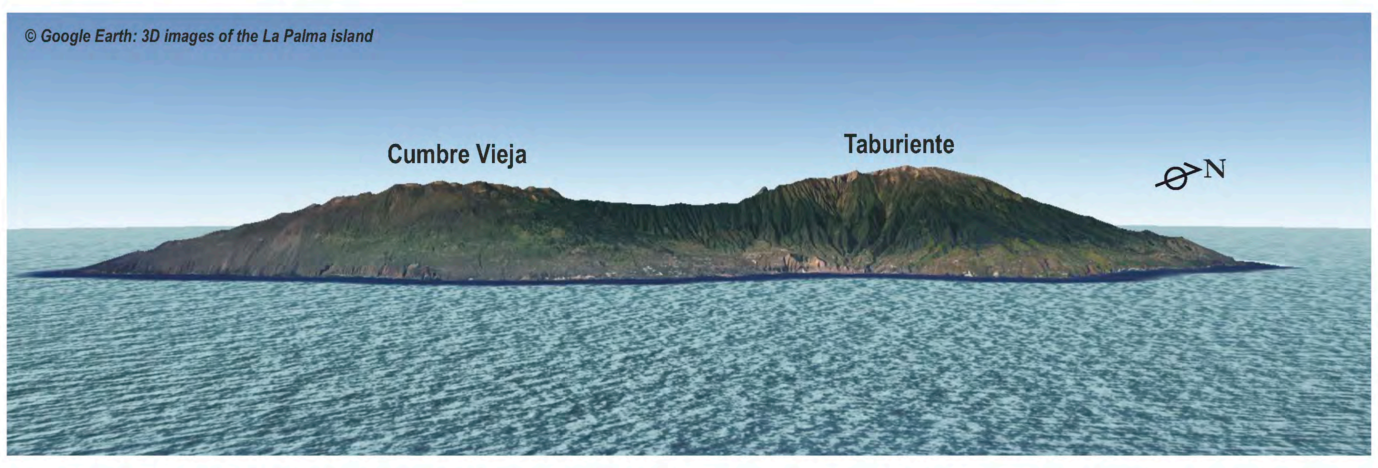
La Palma: the pretty island I

And La Palma was born



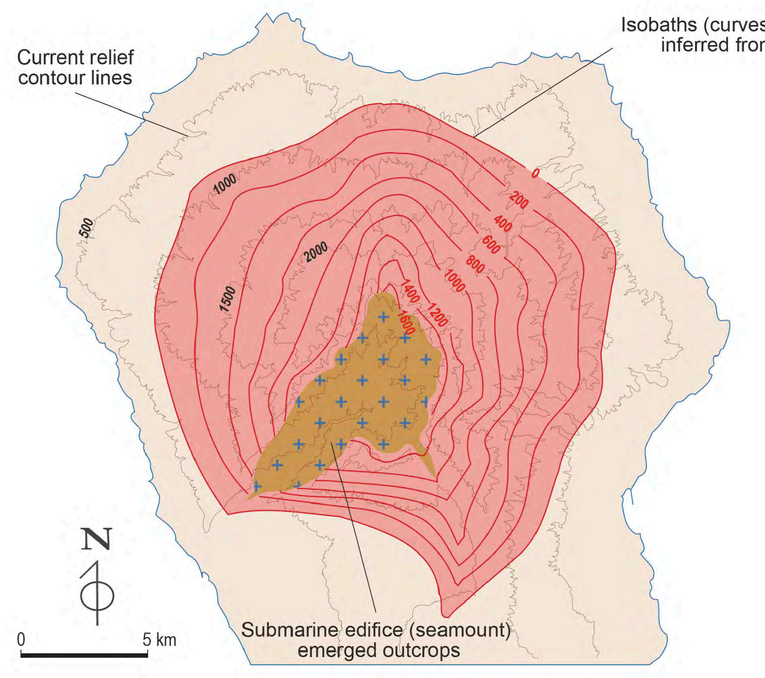
1.77 million years ago, La Palma emerged from the Atlantic

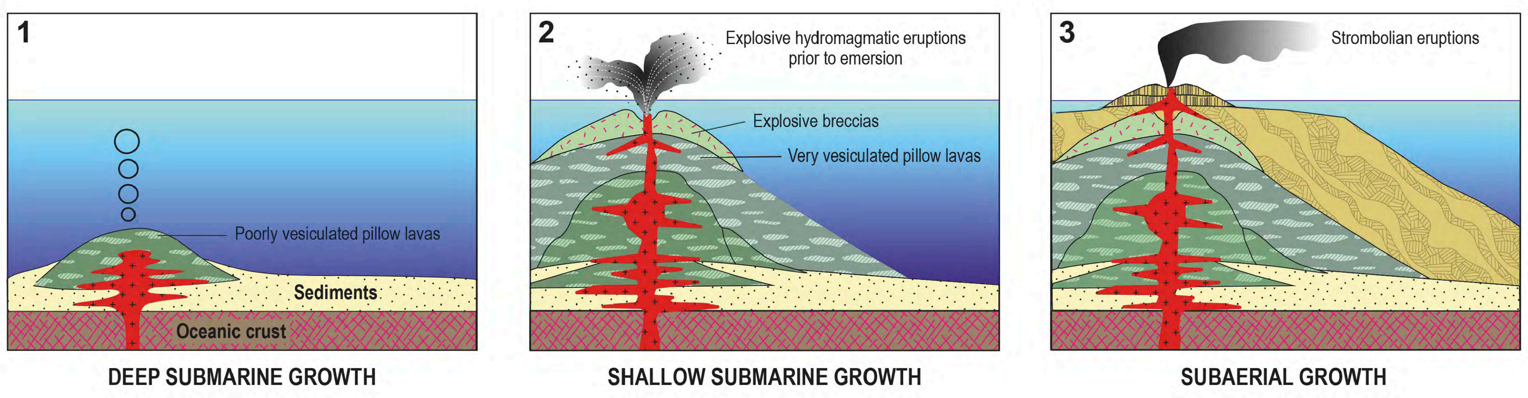
La Palma is the island of the "two humps" due to its relief: the old Taburiente volcano to the north, with a radial network of deep ravines, and the most recent one of Cumbre Vieja to the south, with hardly any erosive incision and dotted with hundreds of volcanic cones and lava flow badlands. Between them is the majestic Caldera de Taburiente.

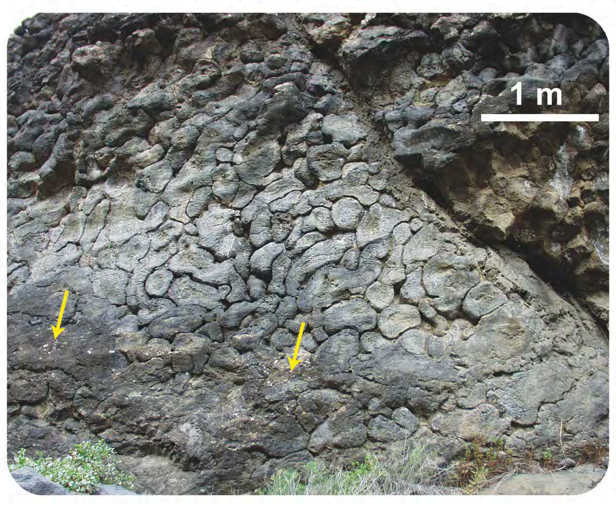


The submarine growth

The submarine edifice (seamount) was generated 4 to 3 million years ago (Pliocene). Thanks to a combination of volcano-tectonic and erosive processes, a part of this submarine edifice emerged and tilted inside the Caldera de Taburiente, so that as you go up the Barranco de las Angustias (Ravine of Anguish), you penetrate the materials formed deeper and deeper.



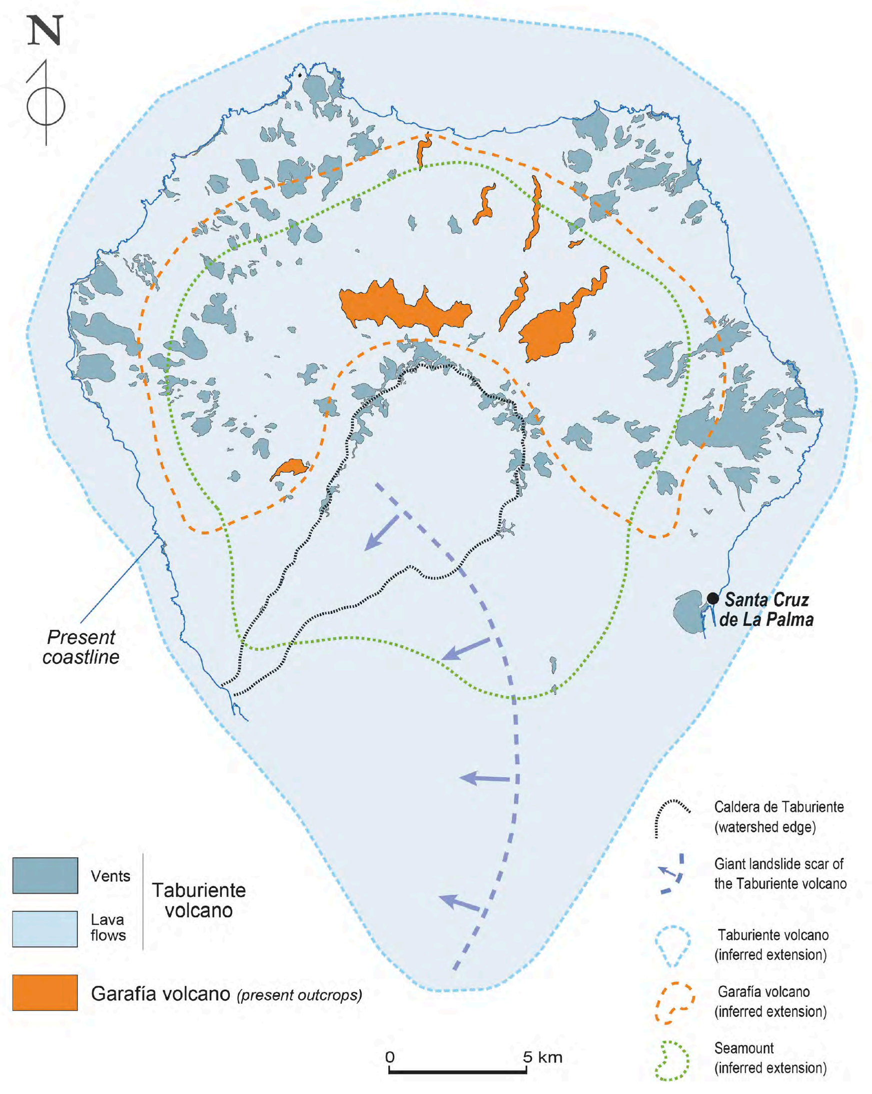


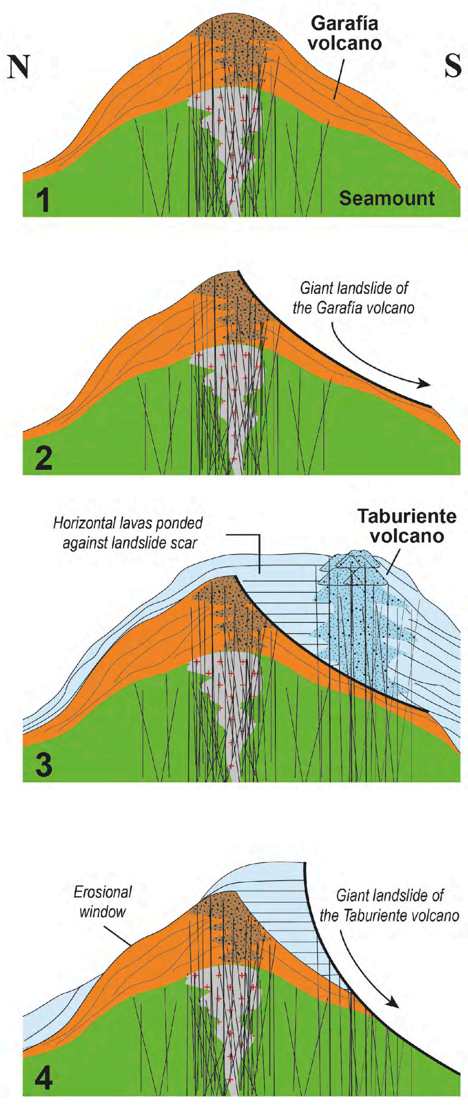


Shallow pillow lavas, with high vesicularity and fossil coral fragments (yellow arrows) between them.

The subaerial growth

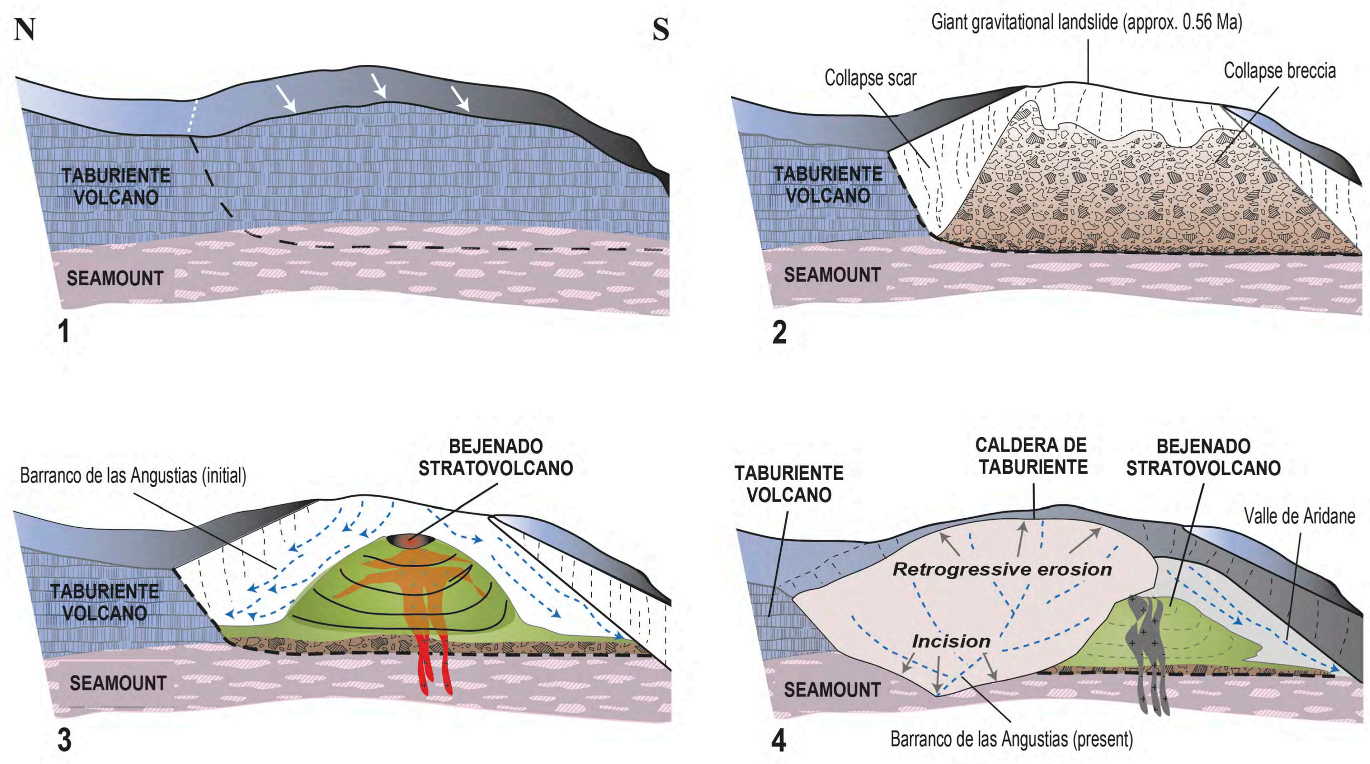
The subaerial growth of the island began about 1.77 million years ago (Pleistocene). Along it, there have been two shield volcanoes (Garafía and Taburiente volcanoes), a stratovolcano (Bejenado) and a rift-type volcanic edifice (Cumbre Vieja), named in the Canaries as Dorsal de Cumbre Vieja. This last volcanic edifice concentrates all the volcanic activity of the island in its last 150,000 years. At the end of the evolution of the Garafía and Taburiente shield volcanoes, two giant landslides took place, the last of which largely conditioned the formation of the Caldera de Taburiente.



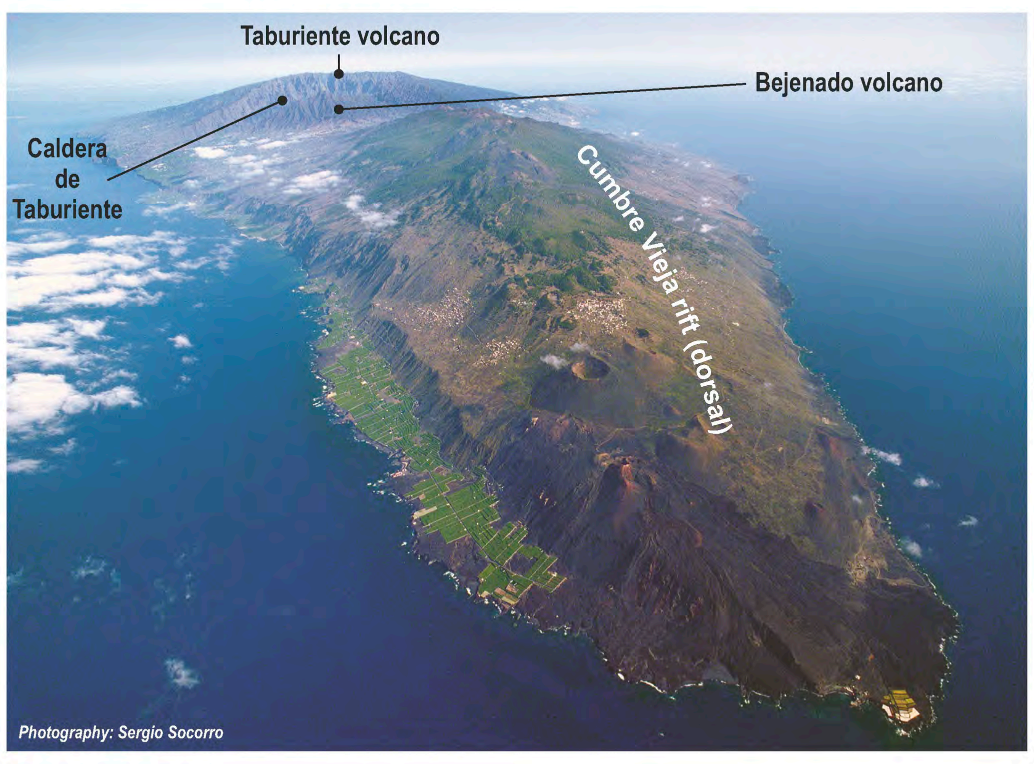


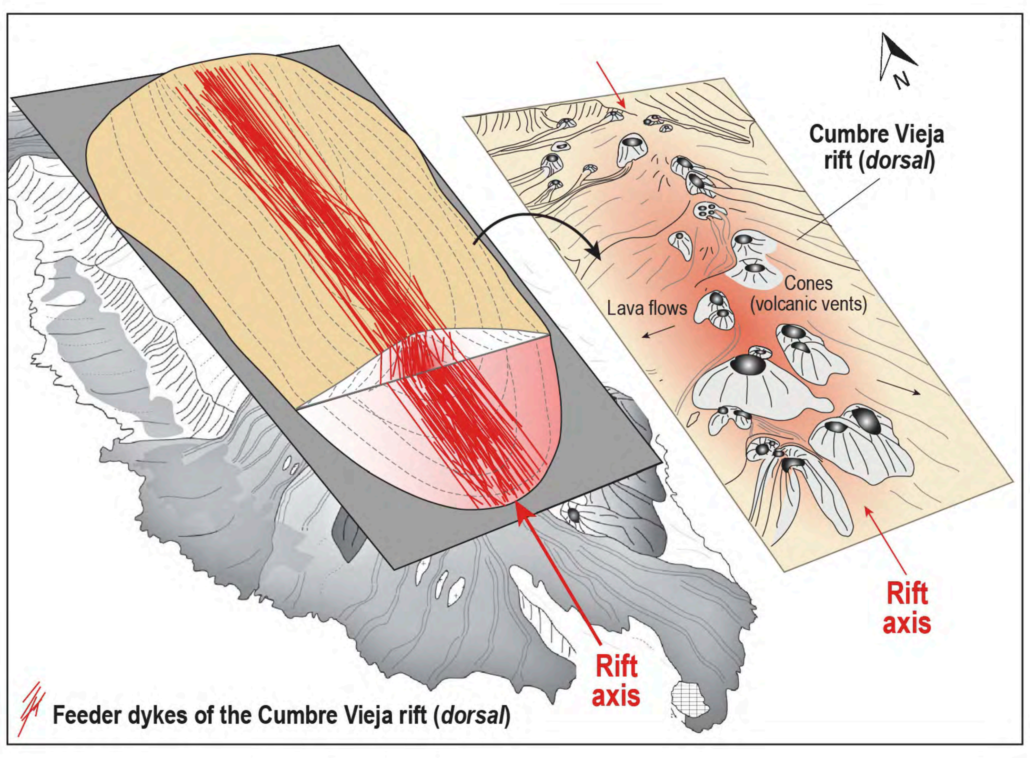
The Caldera de Taburiente

The German geologist Leopold von Buch first coined the term "caldera" for the scientific literature in 1825, using the Caldera de Taburiente as an example. With current scientific criteria, it cannot be considered a "volcanic caldera" since its formation is not linked to eruptive processes but rather to the succession of the following events: a) giant landslide of Taburiente edifice (about 0.56 million years ago); b) nested growth inside the scar of the Bejenado stratovolcano (between 0.56 and 0.49 million years); c) formation of the Barranco de las Angustias fitting between the escarpment of the giant landslide and the Bejenado stratovolcano; d) erosive retreat of its head and slopes, at the same time that an incision is produced in its channel. Therefore, in geological terms, the Caldera de Taburiente must be considered the hydrographic basin of the Barranco de las Angustias.



The Cumbre Vieja rift (*dorsal*)





Cumbre Vieja is a polygenic (i.e., formed during numerous eruptions across time) rift-type volcanic edifice (*dorsal* in the Canaries) with a morphology as a "gabled roof". Most monogenetic (i.e., formed in a single eruption) volcanic cones are concentrated in its central axis and aligned in a North-South direction, from where the different lava flows emerge downward by both sides of the ridge. Thanks to the existence of galleries for collecting groundwater (for example in the Tenerife island), it has been possible to observe in the subsoil that the axis area is where most feeder dykes are injected following the same direction of the volcanic cones, in the case of the Cumbre Vieja rift it must be North-South.

The Cumbre Vieja rift (*dorsal*) began to grow about 150,000 years ago, attached to the old Taburiente volcano on its southern slope, which has conditioned its development in one main direction (North-South). It is home to all the historical eruptions on La Palma, including the most recent one of the Tajogaite volcano in 2021.

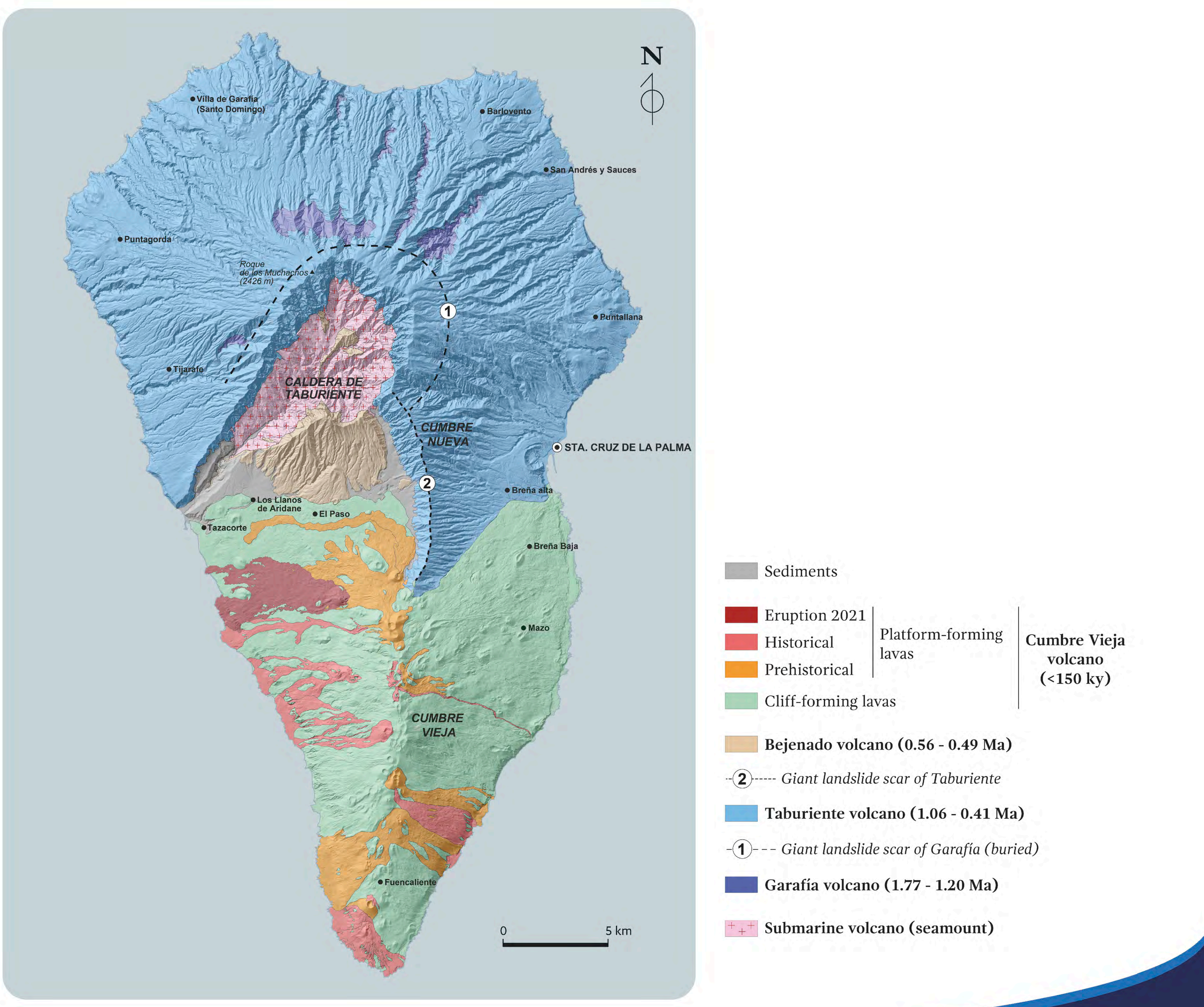
What am I stepping on?

Throughout the more than 708 km² of the island of La Palma, an incredible variety of volcanic forms and materials and erosive modelling are displayed. It is the island with the highest number of historical eruptions in the entire archipelago, 7 with the one in 2021, which gives an idea of its geological youth.

To all of the above, we must add the geological treasure that is the Caldera de Taburiente, which houses the best outcrops for observing and studying the submarine growth (seamount) that all intraplate volcanic islands have in common, but that in the vast majority of they are hidden under the sea.

Finally, in the Cumbre Vieja volcano, numerous lava deltas form fan-shaped platforms that go into the sea, conquering new terrain for the island. These lava deltas (known as *islas bajas* on La Palma) have to be built with a sea level similar to the current one, so their ages must be between 20 thousand years (approximate age of completion of the last glacial period undergone on the planet) and the present. In contrast, the lavas that form the cliffs must have formed before those 20 thousand years, with a position of sea level different from the current one and enough time to erode them.

All this geological wealth makes La Palma a unique natural laboratory for Volcanology studies, as evidenced by the eruption of the Tajogaite volcano in 2021, which attracted the attention of scientists from all over the world.



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La Palma: the pretty island II
The 2021 eruption

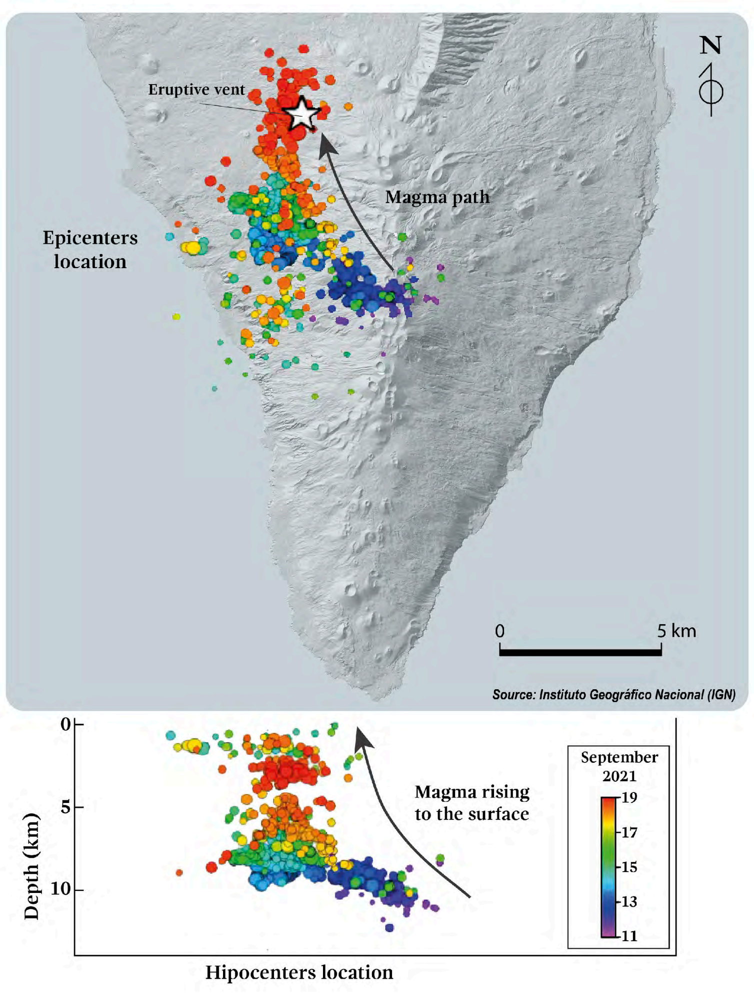
To download:

Where and how? predicted, when? anticipated

Detailed geological knowledge of the terrain is the key to determining its future behaviour. In the case of volcanic areas, it should focus on the most recent eruptions and, especially, on historical ones based on documents. The geological cartography of the different materials and volcanic structures constitutes the basis of this knowledge. From it and with the support of stratigraphic, petrological, tectonic studies, etc., it is possible to predict the area most likely to host an eruption (where?) and the main eruptive mechanism that will be involved (how?). In the case of the eruption of the Tajogaite volcano in 2021 on the island of La Palma, the most likely area was the Cumbre Vieja rift, and the main eruptive mechanism expected was Strombolian: the predictions came true.

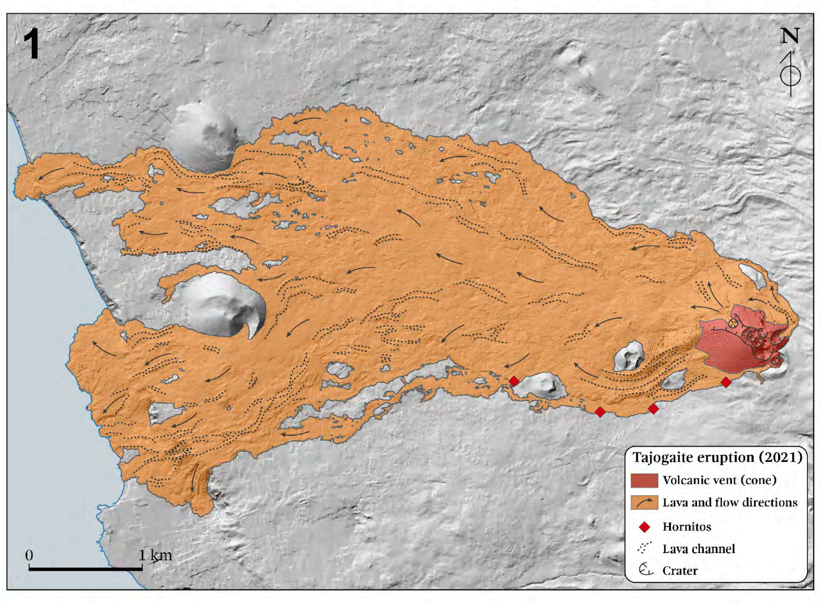
Surveillance network

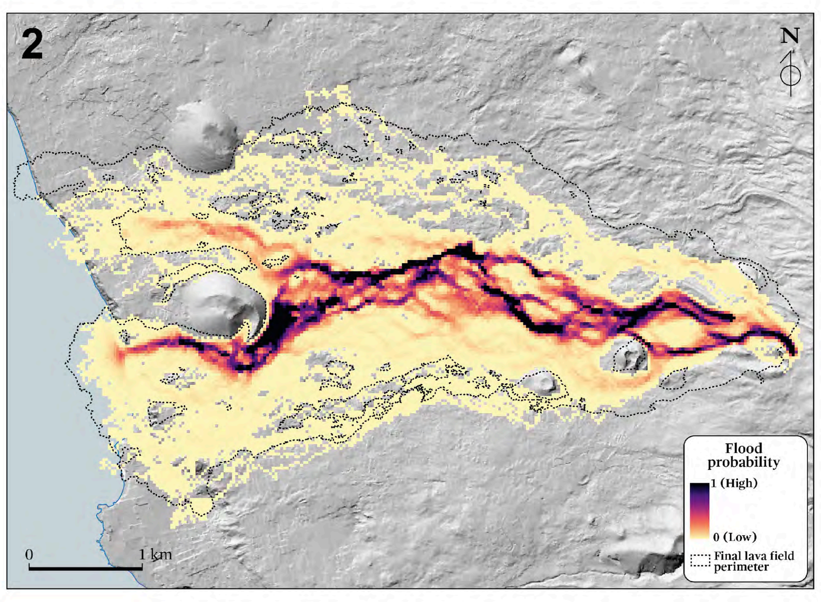
Since October 2017, up to 9 seismic swarms have been located under La Palma, announcing magma accumulation in the Earth's mantle below the island. On September 11th, 2021, a new seismic swarm began pointing out the final path of the magma. With increasingly superficial hypocenters, the epicentres migrated towards the area where the eruption finally occurred, and the uplift of the terrain in that area was about 15 cm. They were unequivocal signs that the probability of a volcanic eruption was very high, which allowed the authorities to prepare the population in those previous days.

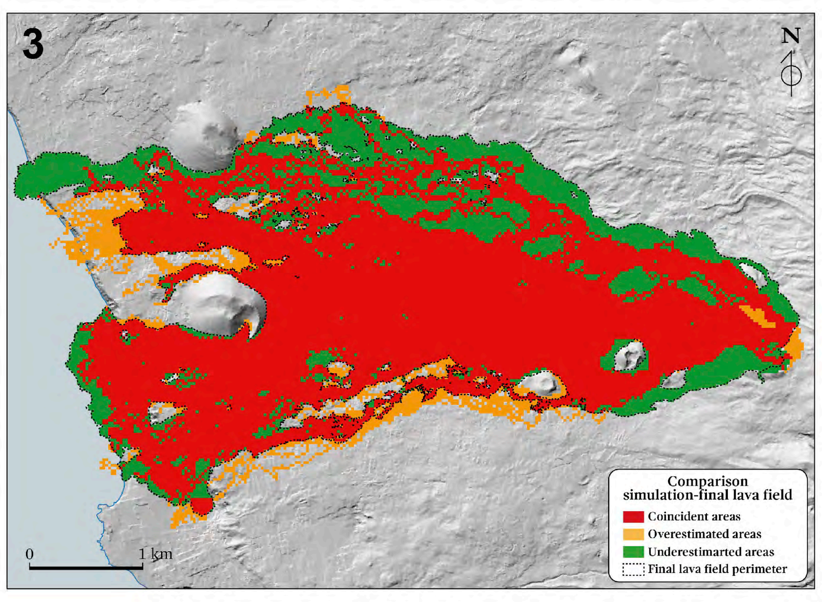


Lava flow simulation maps

Knowing previous volcanic eruptions also allowed us to anticipate the paths that the different lava flows would take once the coordinates of the eruptive vent were determined. Here the final geological map (1) is presented, compared with the lava flow simulation map (2). This simulation was performed on the eruption's first day with the Q-LavHA code, assuming a minimum thickness of 5 m for lava flows and an average thickness of 12 m. Map 3 shows a comparison of the two previous ones, zoning the coincident areas, the overestimated ones (where the actual lava field did not flood in the simulated area) and the underestimated ones (where the actual lava field flooded an area that had not been estimated in the simulation). The percentages of each area are 68%, 8% and 24%, respectively, which values this type of scientific tool.

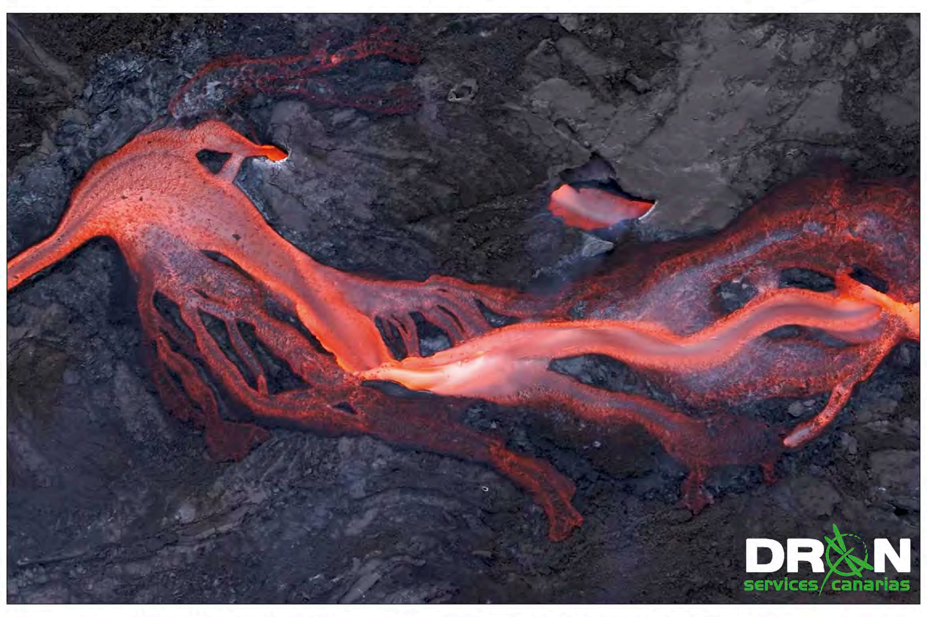






Fissure eruption: four active vents at the same time (October 25th, 2021)

Southern lava delta (*isla baja* on La Palma) at its maximum growth (November 14th, 2021)

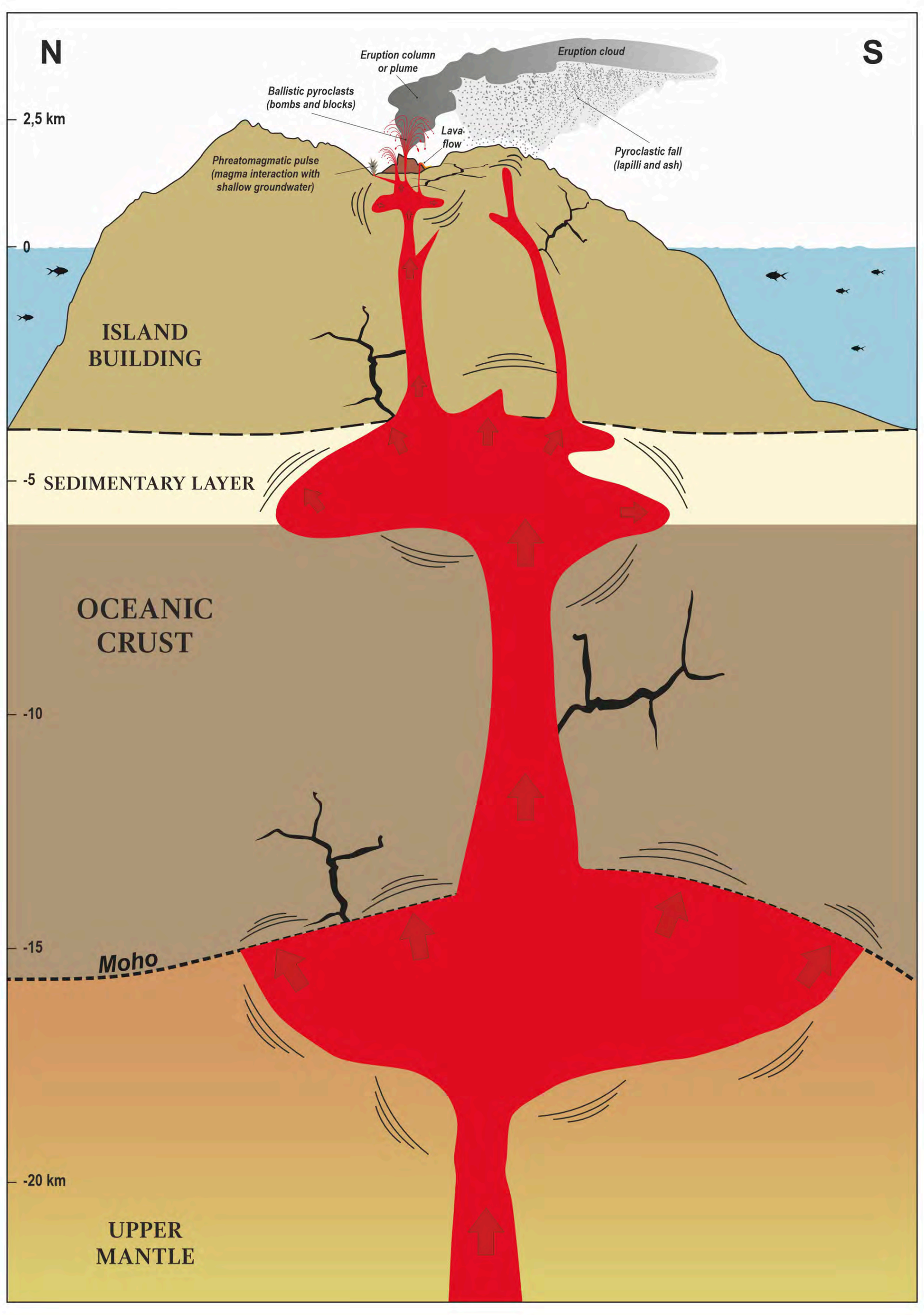


Lava flows: channels, overflows and tubes (November 15th, 2021)

Erratic block, the size of a house, broken off from the cone carried by a lava flow (November 13th, 2021)

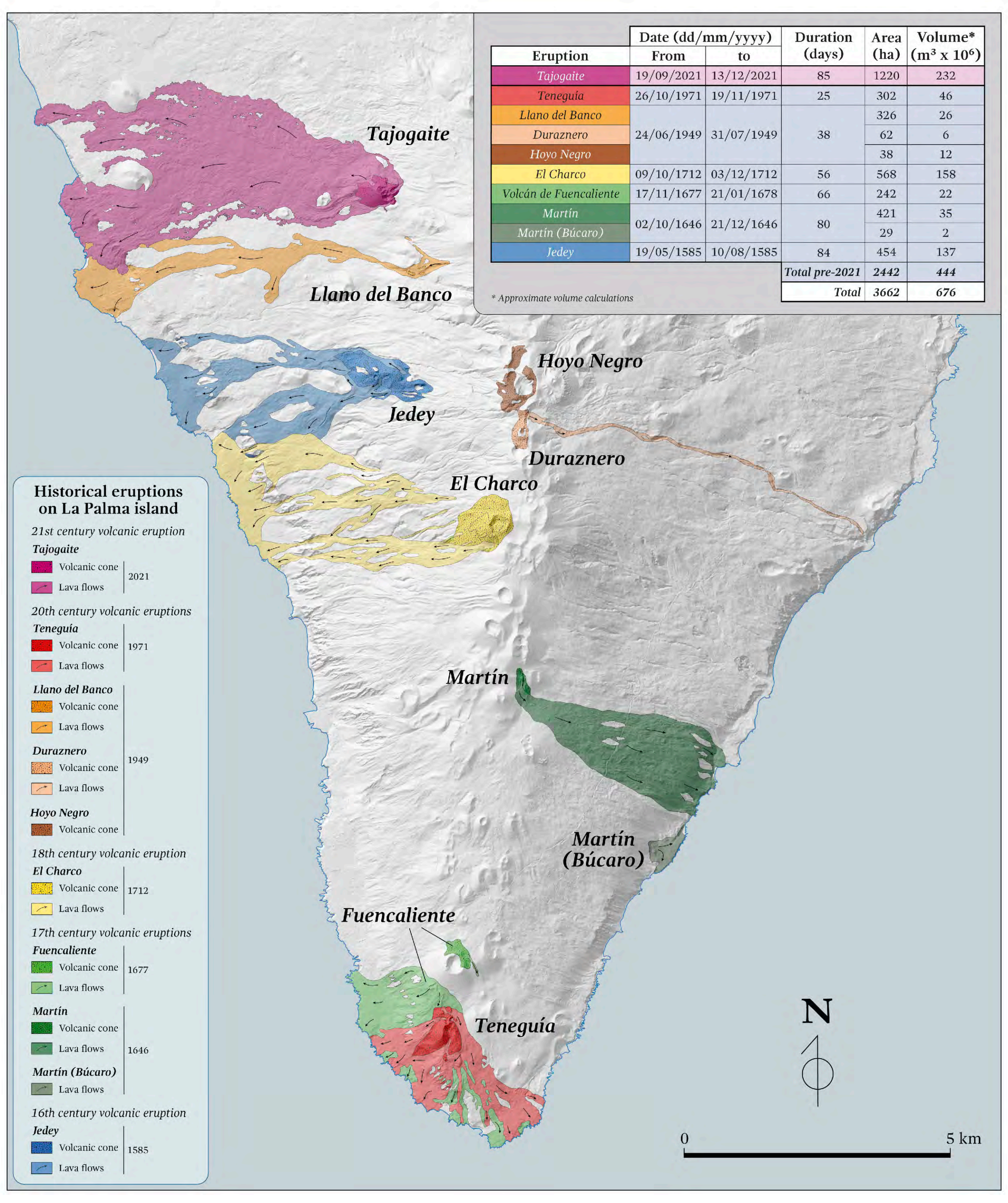
Interpretive model

The seismic data and the geochemical composition of the emitted materials revealed that this eruption has fed from two magmatic reservoirs: a deeper one located near the contact of the mantle with the oceanic crust and from which the basanitic magma would come and another shallower, probably at the base of the insular building, from which the tephrites ascended.



Historical eruptions on La Palma

From the 16th to the 20th century, there is evidence of six eruptions on the island of La Palma, almost half of all those documented for the entire Canary Islands. The eruption of the Tajogaite volcano in 2021 has been the longest and has emitted a volume of magma and covered a surface area equivalent to half the sum of the six previous historical eruptions, which gives an idea of its magnitude.



Eruption	Date (dd/mm/yyyy) From	to	Duration (days)	Area (ha)	Volume* (m³ x 10⁶)
Tajogaite	19/09/2021	13/12/2021	85	1220	232
Teneguía	26/10/1971	19/11/1971	25	302	46
Llano del Banco	24/06/1949	31/07/1949	38	326	26
Duraznero				62	6
Hoyo Negro				38	12
El Charco	09/10/1712	03/12/1712	56	568	158
Volcán de Fuencaliente	17/11/1677	21/01/1678	66	242	22
Martín	02/10/1646	21/12/1646	80	421	35
Martín (Búcaro)				29	2
Jedey	19/05/1585	10/08/1585	84	454	137
			Total pre-2021	*2442*	*444*
			Total	*3662*	*676*

* Approximate volume calculations

Eruption data

DURATION (85 days and 8 hours)	• From: 19-09-2021 14:11 (UTC) • To: 13-12-2021 22:21 (UTC)
ERUPTIVE TYPOLOGY	• Fissure eruption with predominantly strombolian mechanism and some phreatomagmatic pulses (magma interaction with shallow groundwater) • Volcanic explosivity index: 3 (in a scale from 0 to 8)
COMPOSITION OF THE MATERIALS ERUPTED (lavas and pyroclasts)	• Tephrites (somewhat differentiated magmas) at the beginning of the eruption • Basanites (more primitive magmas) from the end of September • Main minerals: olivine, clinopyroxene, magnetite, plagioclase and amphibole (only in tephrites)
CONE	• Area ≈ 32.7 ha • Volume: ≥ 28 million m^3 • Maximum height above previous surface ≈ 200 m • Number of craters: 6 • Average base length: 700 m
ERUPTION COLUMN	• Most frequent height: 3500 m above sea level (asl) • Maximum height: 8500 m asl • Maximum range of ballistic pyroclasts (bombs and blocks): 1.5 km • Pyroclastic fall volume (lapilli and ash): > 20 million m^3 • SO_2 emitted: 2 million tons (the emission of this gas from thermal power plants in Spain in the year 2021 was estimated between 5,000 and 40,000 tons)
LAVA FLOWS	• Covered subaerial area: ≈ 1187 ha • Surface reclaimed from the sea: ≈ 48 ha (≈ 43 ha south lava delta y ≈ 5 ha north lava delta) • Covered submarine area associated with lava deltas: > 21 ha • Subaerial volume: ≈ 187 millones m^3 • Submarine volume: ≥ 7 million m^3 (lava deltas and seaward extension) • Subaerial maximum travel: ≥ 6.5 km • Submarine maximum travel: ≥ 1.1 km • Average thickness: 12 m • Maximum thickness: 70 m • Maximum temperature measured: 1140 °C • Typology: mostly a'ā (*malpaís* in the Canaries) and minor pāhoehoe (*lavas cordadas* in the Canaries)
GEOPHYSICS	• Seismic events detected prior to the eruption (between September 11 and 19, 2021): ≥ 6700 • Seismic events detected during the eruption: > 10000 • Cumulative released seismic energy: 6.3×10^{13} joules (equivalent to about 175 million MWh, the electricity consumption of Spain in 8 months) • Maximum vertical deformation (terrain uplift): 33 cm
IMPACT	• Buildings destroyed by lava flows: ≥ 2900 • Buildings affected by pyroclastic fall deposits: > 200 • Crop surface destroyed by lava flows: ≈ 370 ha • Crop surface affected by pyroclastic fall deposits: ≈ 624 ha • Kilometers of roads affected: 73.8 • Canceled flights on the island: > 500 • Evacuated people: ≈ 7000

SIZE OF PYROCLASTS
• Bombs (rounded shapes) and blocks (angled shapes): > 64 mm • Lapilli (*picón*, *rofe* or *zahorra* in the Canary Islands): between 2 and 64 mm • Ash (*arena volcánica* in the Canary Islands): < 2 mm

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