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## CANARY ISLANDS, BIOLOGY

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The Canary Islands have an area of 7447 km<sup>2</sup> and are located close to the northwestern Saharan coast (~28° N latitude and 16° W longitude). They are composed of seven volcanic islands and a few islets. Several environmental factors contribute to the ecological peculiarities of these islands including the heavy influence of the cold Oceanic Canary current and the northeastern trade winds, the altitude (the highest mountain of Spain, Peak Teide [3718 m], is located on Tenerife [Fig. 1]), the occasional dry winds from the Western Sahara, the high elevation anti-trade dry winds from tropical latitudes, and a topography highly dissected by volcanoes, steep cliffs, caves, and deep gorges and gullies. The archipelago has never been connected to the mainland; however, during the last ice age, Lanzarote and Fuerteventura collectively formed one large island. Quaternary sea-level changes have also influenced the biogeography of the archipelago. It is likely that several “sea mountains” located between the Canaries and Madeira/the mainland were exposed during glacial periods and served as stepping stones for dispersal of faunal and floral elements. Fossil beaches



**FIGURE 1** Located in Parque Nacional Cañadas del Teide (Tenerife Island), Peak Teide (3718 m) is the highest mountain of Spain. Photograph by J. J. Bacallado.

located a few meters above the coastline provide further evidence for a changing topography caused by fluctuations in sea level.

### BIOGEOGRAPHY AND ECOLOGY

The Canary Islands and four additional volcanic archipelagoes (i.e., the Azores, Madeira, the Selvagens, and Cape Verde) form the Macaronesian Islands. There has been a long debate on whether these archipelagoes should be considered a distinct biogeographical unit. Macaronesia as a biogeographical entity is supported by the many plant genera and species that are endemic to more than one archipelago. In addition, several evolutionary lineages (clades) with considerable numbers of species are shared across some of these archipelagoes. Opponents of a single biogeographical unit contend that major bioclimatological differences among the archipelagoes support the Canary Islands and Madeira floras belonging to the Mediterranean region, whereas the floras of the Azores and Cape Verde are part of the Medio-European and Sudano-Zambesian regions, respectively.

The Canarian biota has been the focus of several phytosociological and bioclimatological studies, and five major terrestrial ecosystems, or life zones, can be recognized. The coastal thicket—low elevation arid woodland (*Kleinio-Euphorbietea canariensis*) is present in all the islands at low altitude (0 to 400 m on southern slopes, and a predominant coastal distribution on northern slopes [Fig. 2]). This zone is devoid of large trees and is mostly filled with small shrubs and perennial plants with succulent leaves and stems (e.g., *Euphorbia* spp., *Kleinia neriifolia*, *Ceropegia* spp., *Aeonium* spp., *Plocama pendula*) or coriaceous leaves (e.g., *Rubia fruticosa*, *Cneorum pulverulentum*, *Echium* spp.). Annual rainfall in this zone is below 250 mm.



**FIGURE 2** The coastal thicket, low-elevation arid woodland (*Kleinio-Euphorbietea canariensis*) on northern slopes of Teno (Tenerife Island). Foreground: large plant of *Euphorbia canariensis*. Photograph by J. J. Bacallado.

Dry sclerophyllous forests (*Rhamno crenulatae–Oleetea cerasiformis*) occur between 400 and 600 m (on southern slopes) and between coastal areas and 600 m (on northern slopes) on all islands. This plant community receives an average annual rainfall of 400 mm and has strong floristic links to the Mediterranean Thermophile forests, with those on northern slopes being floristically richer than those on southern slopes. Indicator plants for this ecosystem include trees such as *Olea europaea* subsp. *guanchica*, *Dracaena draco*, *Juniperus turbinata* subsp. *canariensis*, *Pistacia atlantica*, *Visnea mocanera*, *Phoenix canariensis* and small shrubs such as *Cheirolophus* spp., *Crambe* spp., *Echium* spp., *Rhamnus crenulata*, and *Sideritis* spp.

The humid evergreen forests (*Pruno hixa–Lauretea novocanariensis*) are restricted to those slopes of the islands that face the northeast trade winds and are

located between 600 and 1200 m. These forests, known as “laurel forests” because they are characterized by several tree species (i.e., *Apollonias barbujana*, *Laurus novocanariensis*, *Ocotea foetens*, and *Persea indica*) in the plant family Lauraceae, are usually cloud covered (average annual rainfall 800–1000 mm), with moisture levels enhanced by the extensive condensation of moisture on leaves, a phenomenon locally known as *lluvia horizontal* (“horizontal rain”). The humid evergreen forests are not found on the most easterly islands of Fuerteventura and Lanzarote, although some small pockets were likely present in Fuerteventura prior to the arrival of European settlers.

The fourth life zone is the Canary pine forest (*Chamaecytiso–Pinetea canariensis* alliance *Cisto–Pinion canariensis*). The only species of pine present in the islands, the endemic *Pinus canariensis* is the representative plant element of this zone. This vegetation type is also absent in Lanzarote and Fuerteventura, and has few small natural pockets on the island of La Gomera. This forest occupies northern (1200–2000 m) and southern (600–2300 m) slopes (average rainfall 200–800 mm). A transitional zone, known locally as Fayal-breza (*Andryalo–Ericetalia arboreae*), occurs between the laurel and pine forests. Two trees, “brezo” (*Erica arborea*) and “faya” (*Morella faya*) are the predominant plant species of this zone.

Finally, a fifth life zone is a high-elevation dry woodland (*Chamaecytiso–Pinetea canariensis* alliance *Spartocytisium supranubium*) and is confined to slopes over 2000 m on La Palma and Tenerife (average annual precipitation 400 mm, most as snow). During winter, frosts are common. Currently, this vegetation type has the shrubs *Adenocarpus viscosus* (on La Palma) and *Spartocytisium supranubium* (on Tenerife) as dominant species, and several endemic species such as *Echium wildpretii* (Fig. 3). However, in the past, this was an open forest where the “cedro canario” tree (Canary Island juniper, *Juniperus cedrus*) was an important species. This species was almost driven to extinction because it was extensively used for timber. Today, the Canary Island juniper is almost a memory on these islands and is mostly relegated to inaccessible landscapes on La Palma.

The humid evergreen forest has the highest number of endemic plants, invertebrates, and vertebrates. However, the two ecosystems with the lowest plant species diversity, the coastal thicket, low-elevation arid woodland and the dry, high-elevation open woodland, also possess an endemic flora/fauna adapted to their ecological peculiarities. For instance the endemic beetle *Lepromoris*



**FIGURE 3** Plant of *Echium wildpretii*. (Boraginaceae) growing on the high-elevation dry woodland (*Chamecytiso-Pinetea canariensis* alliance *Spartocytision supranubii*) of Tenerife Island, at Parque Nacional Cañadas del Teide. Photograph by J. J. Bacallado.

*gibba* feeds exclusively on succulent species of *Euphorbia* restricted to the coastal thicket. Likewise, the praying mantis *Pseudoyersinia teydeana* is only found on high-elevation ecosystems of Tenerife. Concerning vertebrates, the coastal ecosystem has an endemic mammal (the Canarian shrew, *Crocidura canariensis*) restricted to Fuerteventura and Lanzarote, and an endemic bird (the Canary Islands stonechat, *Saxicola dacotiae*) confined to Fuerteventura. There are no endemic vertebrates in the dry, high-elevation woodland, although both the “pinzon azul del Teide” (Teide blue chaffinch, *Fringilla teydea*) and the “murciélago orejudo” (long-eared bat, *Plecotus teneriffae*) are found in this ecosystem and in the pine forest.

#### TERRESTRIAL BIODIVERSITY: PLANTS

The Canary Islands house a veritable treasure trove of botanical diversity with over 1300 species of native vascular plants found in approximately 102 families and 712 genera. It is estimated that there are over 600 endemic species of seed plants, comprising 40% of the native flora. At least 22 genera of seed plants are endemic to the Canaries, with seven belonging to the family Asteraceae. In addition, 15 genera are endemic to the Canaries and at least one of the other Macaronesian archipelagoes. The four genera with the highest number of endemic spe-

cies are *Aeonium* (26 spp.), *Sideritis* (24 spp.), *Echium* (23 spp.), and the Macaronesian genus *Argyranthemum* (Asteraceae, 19 spp.).

Tenerife is the largest island and has the highest number of endemic species (144 spp.). However, the second largest island, Fuerteventura, which is relatively low and has little rainfall, has only 13 endemic species. Approximately 60 of the native plant species are shared exclusively by the Canaries and at least one of the other Macaronesian archipelagoes, and are not known to occur on the continent. Most of the plant families occurring in the Mediterranean basin are also present in the Canary Islands; however, there are some notable exceptions. The family Fagaceae does not currently have any native species on the islands, despite oaks being one of the most important components of the Mediterranean ecosystems. However, recent paleobotanical data suggest that oaks were part of the natural vegetation of Tenerife until they started declining around 2000 years ago. Likewise, the Ternstroemiaceae is not present in the Mediterranean basin but has one representative in the Canaries and Madeira.

Molecular and biogeographical data reveal that the vast majority of the closest continental relatives of the Canarian plants are found in the Mediterranean region. However there are exceptions, with some Canarian endemics having their closest relatives in southern and eastern Africa (e.g., *Canarina canariensis*, *Ceropegia* spp., *Cicer canariensis*, *Parolinia* spp., *Solanum vesperilio*, and *S. lidii*). Traditionally, a great proportion of the Canarian flora has been considered to belong to ancient lineages that became extinct on the continent following major global climatic changes after the Tertiary. Phylogenetic studies suggest that most of the endemics seem to have arrived and diversified on the islands relatively recently. It is estimated that over 156 independent dispersal events from the mainland have produced the current endemic flora of the archipelago. Based on the available molecular data, a few of the Canarian endemics appear to belong to early evolutionary branches, among them *Bosea yervamora*, *Limonium dendroides*, and the endemic genus *Navaea*.

Many of the endemic groups (e.g., the *Bencomia* alliance, the *Dendrosonchus* alliance, *Argyranthemum* spp., *Echium* spp.), follow a pattern found in other oceanic islands, as they tend to be arborescent and/or to exhibit woodiness as their main growth form. In most cases, these shifts appear to have originated on the Canarian archipelago following dispersal and speciation; the continental ancestral forms of these species appear to have been herbaceous.

Concerning non-vascular plants, approximately only 5% of the non-vascular native flora is endemic to the Canary Islands. There are 1634 native species of fungi (107 endemics), over 1294 of lichens (26 endemics), and 464 of mosses and liverworts (ten endemics).

Some of the endemic species have a broad ethnobotanical use. Two endemic legumes, tagasaste (*Chamaecytisus proliferus* subsp. *palmensis*) and gacia (*Teline stenopetala* var. *stenopetala*), and one endemic buckwheat (*Rumex lunaria*) are cultivated as fodder crops in several regions of the islands. The sap of the endemic palm *Phoenix canariensis* is commonly used to make a syrup on the island of La Gomera. In addition, other endemic/native species are highly valued for timber (i.e., *Pinus canariensis*, *Tamarix canariensis*, *Apollonias barbujana*).

#### TERRESTRIAL BIODIVERSITY: INVERTEBRATES

There are approximately 7608 species of terrestrial invertebrates in the archipelago, 95% of which are arthropods. The vast majority of them are insects (~77 endemic genera, 5953 native species [Fig. 4A]), and over 40% of the native species are endemic to the archipelago. However, most of the endemic genera have fewer than two species. Indeed the genus with the highest number of endemic species, the weevil *Laparocerus* (102 endemic species), is native to Morocco and the Macaronesian Islands. Gastropods are also important. They include over 241 native species, and 88.8% of them are endemic. Six mollusc genera are endemic to the Canaries. The snail Canarian genus *Hemicycla* has 76 species and is the second most species-rich genus of invertebrates in the archipelago. The Arachnida (pseudo-scorpions, spiders, and mites) are represented by approximately 800 native species, half of which are endemic. Twelve of the genera in the Arachnida are endemic. With over 43 species, the non-endemic genus of spiders *Dysdera* has the highest number of endemics.

Tenerife harbors the highest number of invertebrate endemic genera and of endemic species of beetles. Recently, DNA data have been used to reconstruct the origin and evolution of certain groups of Canarian insects. Most of these studies suggest a recent (Quaternary) origin for these organisms, although it has been suggested that species from the lowlands are older than those occurring at higher elevations, particularly on the humid evergreen forest and pine forest.

Some of the endemic insects display features that are common on other oceanic islands and have lost their dispersal ability. For instance the grasshopper, *Calliphona konigi*, the aforementioned praying mantis *Pseudoyersinia*



FIGURE 4 Representative fauna of the Canary Islands. (A) *Vanessa vulcanica*, a relatively common endemic butterfly of Madeira and the Canary Islands. (B) *Gallotia galloti* subsp. *gallotii*, a lizard endemic to Tenerife Island. (C) *Fringilla teydea* subsp. *teydea*, a finch endemic to Tenerife Island. Photographs by J. J. Bacallado.

*teydeana*, and endemic species of the beetle genera *Paradromius* and *Brosicus* are either wingless or their wings are poorly developed and non-functional.

The islands have an extensive cave system, which is mostly composed of volcanic tubes. This underground environment has one of the most peculiar ecosystems of the Canary Islands, with a highly endemic invertebrate fauna and with roosting sites for bats. This fauna was relatively unknown until 1980, when the first endemic invertebrate (*Callartida anophthalma*, Heteroptera) was

discovered in a cave system of El Hierro. Approximately 168 endemic invertebrate species thrive in this ecosystem; 124 of them are terrestrial, and the rest occur in aquatic environments. The vast majority of these invertebrates are insects (~80%), and 27% of them are spiders. A great proportion of these species are blind, lack any body pigmentation, and have large legs and antennae.

#### TERRESTRIAL BIODIVERSITY: VERTEBRATES

The Canary Islands have a poor vertebrate fauna without native amphibians or freshwater fishes. There are a total of 91 native vertebrate species: 69 of them are birds, 13 are reptiles, and nine are mammals. Endemicity at species levels is 23%. There is one endemic genus, the giant lizard *Gallotia* (six species [Fig. 4C]). The rest of the reptile species are endemic and belong to the gecko genus *Tarentola* (four species) and the skink genus *Chalcides* (three species). Eight of the mammal species are bats; the other native mammal is the aforementioned Canarian shrew, *Crocodyra canariensis*. Only one of the species of bats, *Plecotus teneriffae*, is endemic to the archipelago. Concerning birds, there are two endemic pigeons (*Columba bollii*, *Columba junoniae*), one endemic finch (*Fringilla teydea* [Fig. 4B]), one endemic stonechat (*Saxicola dacotiae*), and one endemic leaf warbler (*Phylloscopus canariensis*).

All of the endemic vertebrates are linked to the Mediterranean and European fauna. Molecular data suggest that *Gallotia* belongs to an ancient lineage that diverged in the Tertiary. These endemic reptiles exhibit gigantism and are the largest species of the family Lacertidae. Fossil records provide additional evidence for gigantism and other island syndrome features found in the endemic vertebrates. There are Late Tertiary–Early Quaternary fossils of giant terrestrial tortoises assigned to the genus *Geochelone*, and Holocene fossils of giant rats (two species belonging to the endemic genus *Canariomys*). In addition, there are fossils from a poorly known giant flightless bird from Lanzarote (approximately 6 million years old). Other extinct flightless birds include a passerine (*Emberiza alcoveri*) and a finch (*Carduelis triasi*); it is believed that these two species became extinct relatively recently.

#### MARINE BIODIVERSITY

The oceanic current systems that occur in the Canaries and the proximity of the archipelago to the Western Sahara coast are the most important environmental factors that influence the marine ecosystems of the archipelago. These factors promote limited isolation between the Canarian organisms and those occurring along the mainland coasts. Therefore, it is not surprising to find

low levels of endemicity within the marine groups. The cold oceanic current of the Canaries provides a dispersal avenue for marine organisms from Europe, North Africa, and tropical and subtropical regions of the New World. The northeastern trade winds also have a major influence, and they are major contributors for coastal upwelling from the African coasts. This upwelling reaches a peak during the summer season when nutrient-rich and low-salinity waters move from the bottom of the sea to the surface.

Because of the strong influence of the Canary current and the trade winds, most of the marine biota of the Canaries is not linked to the one found in the tropical waters of Africa. Therefore, the majority of the marine organisms are biogeographically linked to the Atlantic–Mediterranean regions and to the subtropical/tropical waters of the western Atlantic.

The Canarian marine flora has approximately 700 species (including over 23 species of blue-green algae and three species of flowering plants). Approximately 16 of the algal species are endemic to the Canarian archipelago. The majority of the native flora (~391 species) are red algae (Rhodophyta). Over 30% of the native species are also found in tropical and subtropical areas, and several of these species have a disjunct distribution with neotropical areas. The island with the highest number of species is Tenerife (476 spp.). In contrast, the western islands of La Palma and El Hierro have a poor flora with 196 and 189 species, respectively.

The Canary Island marine environments have a rich vertebrate fauna that includes 730 native species of fish. Only three fish species are regarded as endemic; however, it is likely that they have a broader distribution outside the Canarian marine boundaries, as they occur in deep waters. In the last 20 years, there has been an increase in the number of records of tropical and subtropical fishes, perhaps associated with current trends toward a warmer climate and also with the movement of vessels, as the Canarian ports are among the most active ones in this region of the Atlantic.

Most of the native marine fish fauna belongs to groups with a wide tropical and/or Atlantic distribution or occurring in warm and temperate regions of the western Atlantic; only 17 of the fish species found in the Canaries are restricted to the Macaronesian region. Indeed, only 6% of the fish fauna is linked to that of the tropical coasts of West Africa.

The islands are also rich in marine reptiles and mammals. Four species of marine turtles occur on the islands, but only the leatherback turtle (*Dermochelys coriacea*) has been reported to nest on the islands. Twenty-eight

cetacean species are known to occur in the archipelago. Most of these species are migrants, although at least three species (i.e., short-finned pilot whales [*Globicephala macrorhynchus*], sperm whales [*Physeter macrocephalus*], and bottlenose dolphins [*Tursiops truncatus*]) form permanent colonies in the archipelago waters.

There are over 2831 species of invertebrates in the marine environments; approximately 1180 of them (42%) are molluscs, and 1100 are arthropods (38%). However, very few of these are endemic to the Canaries.

### CONSERVATION BIOLOGY

Since the arrival of the first pre-Hispanic population to the islands (~2500 years ago), the Canarian biota has been extensively modified. It is believed that the pre-Hispanic inhabitants drove to extinction the endemic species of giant rats, at least one species of the giant lizards (*Gallotia goliath*), and two endemic birds, the Canarian quail (*Coturnix gomerae*) and the shearwater (*Puffinus olsoni*). Early settlers introduced goats, dogs, and pigs.

Shortly after the arrival of the first Europeans, land was heavily cleared for both urban and agricultural development. Sugarcane was the main cash crop of the islands during the fifteenth and sixteenth centuries. The need for charcoal and building materials for the sugarcane industry had a very negative effect on the dry and humid evergreen forests, and these ecosystems suffered a severe reduction in size during this period. In addition, the forests were severely exploited for timber, pitch, and torch poles. More recently, the coastal zones have been the main focus of human development. Coastal and low-elevation ecosystems have been the subject of recent and intensive urban/tourism development and road construction. There is no doubt that the flora and fauna of these areas should have the most immediate priority for conservation.

Two species of plants are considered recently extinct in the wild: *Solanum nava* from the evergreen forests of Tenerife and Gran Canaria, and *Kunkelliella psilotoclada* from the dry sclerophyllous forests of western Tenerife. The Gomera endemic *Viola plantaginea* has not been found since it was described in the nineteenth century. Likewise, the recently discovered *Helianthemum cirae* A. Santos, ined. from the Caldera de Taburiente National Park (La Palma) has not been found since 1992. Only one plant of *H. cirae* was originally found in the wild on an area that is heavily grazed. Since the arrival of the Europeans, at least three endemic/native species of vertebrates have vanished from the islands. Native populations of the

red kite (*Milvus milvus*) and the Mediterranean monk seal (*Monachus monachus*) have totally disappeared. The endemic oystercatcher, *Haematopus meadewaldoi*, a shorebird restricted to the eastern islands of Lanzarote and Fuerteventura, was last recorded in 1913 and is believed to have gone extinct in the 1940s.

Two non-native game mammals are currently widespread in two national parks—the Barbary sheep (*Ammotragus lervia*) in Caldera de Taburiente National Park and the European mouflon (*Ovis gmelini*) in the Cañadas del Teide National Park (Tenerife). Other introduced mammals include goats, domestic cats, European rabbits, black and brown rats, house mice, the Barbary ground squirrel, two species of shrew (*Crocidura russula* and *Suncus etruscus*), and the Algerian hedgehog (*Atelerix algirus*). There is ample evidence that all of the introduced species have had a detrimental effect on the native flora and fauna. For instance, the recently discovered and critically endangered giant lizard of La Gomera (*Gallotia gomerae*) has been driven to the verge of extinction by feral cats. Likewise, it is well known that introduced rats are the main predators on eggs of the two endemic species of pigeon and that ungulates modify the landscape severely through grazing.

Among vascular plants, it is estimated that over 400 species introduced by humans (approximately 32% of the flora) are currently established and naturalized in the Canarian ecosystems. Among them, the grass *Pennisetum setaceum* represents one of the most immediate threats to the native vegetation of the lowlands. Other “aggressive” invasive plants occurring at low elevation include the prickly pear (*Opuntia* spp., particularly *O. dillenii* and *O. maxima*) and the American aloe (*Agave* spp., particularly *Agave americana*). At higher elevations, the neotropical sunflowers *Ageratina adenophora* and *A. riparia*, and the spiderwort *Tradescantia fluminensis*, are major concerns in the evergreen forests. The California poppy, *Eschscholzia californica*, covers large areas of the open dry pine forests.

Approximately 45% of the Canarian land mass is officially protected in four national parks and 141 regional reserves/parks. The national parks of Cañadas del Teide and of Garajonay belong to the UNESCO World Heritage network. In addition, there are four UNESCO biosphere reserves in La Palma, Gran Canaria, El Hierro, and Lanzarote. There are also three marine reserves, and they cover the northern Lanzarote coasts and its offshore islets, the southeastern sector of El Hierro, and the southwestern coast of La Palma. These reserves aim to develop a sustainable management plan for the local fisheries.

## SEE ALSO THE FOLLOWING ARTICLES

Azores / Canary Islands, Geology / Cape Verde Islands / Caves as Islands / Fossil Birds / Madeira

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# CANARY ISLANDS, GEOLOGY

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The Canary Islands, located between 100 and 500 km from the coast of northwestern Africa (Morocco), consist of seven major volcanic islands forming a rough west-southwest to east-northeast trending archipelago. Together with the Selvagen Islands and a group of seven major seamount complexes (some of which were former

Canary Islands) to the northeast, they form the Canary volcanic province. Volcanism in this ~800-km-long and ~400-km-wide volcanic belt (located at 33–27° N and 18–12° W) decreases in age from the northeast (Lars Seamount, 68 million years) to the southwest (Hierro Island, 1 million years) and is interpreted to represent the Canary hotspot track (Fig. 1). The Canary volcanic province is located on Jurassic ocean crust (~150 million years old beneath the western part of the province to ~180 million years old beneath the eastern part of the province), and contains some of the oldest ocean crust preserved in ocean basins.

## GEOLOGICAL OVERVIEW OF THE EVOLUTION OF THE ISLANDS

The morphology of the Canary volcanic province show systematic changes from southwest to northeast, reflecting an increase in age (Figs. 1 and 2) and a change in evolutionary stage. As the volcanoes age, they originally go through a constructive phase of evolution in which growth of the edifice through volcanic activity outpaces its

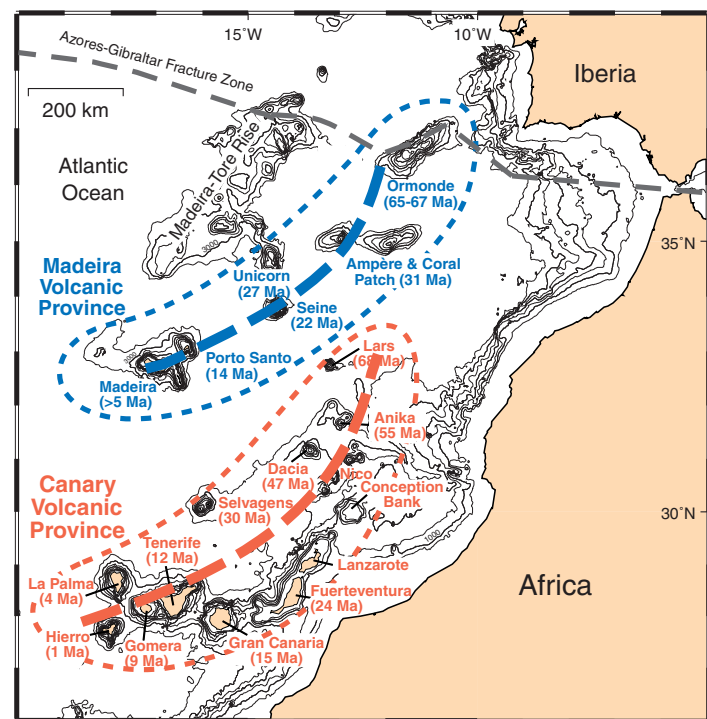


FIGURE 1 Bathymetric map showing the Canary (red) and Madeira (blue) volcanic provinces, including islands and associated seamounts, in the eastern central North Atlantic. Thick dashed lines mark centers of possible hotspot tracks. For clarity, only depth contours above 3500 m are shown. Bathymetric data from Smith and Sandwell (1997); ages and location of the Azores-Gibraltar fracture zone from Geldmacher et al. (2005) and Guillou et al. (1996).