MANTLE PLUMES: VOLCANIC HISTORY, GEOLOGICAL FEATURES AND VOLCANIC HAZARDS: THE CANARY ISLANDS, SPAIN

PLUMAS MANTÉLICAS: HISTORIA VOLCÁNICA, CARACTERÍSTICAS GEOLÓGICAS Y RIESGOS VOLCÁNICOS: LAS ISLAS CANARIAS, ESPAÑA

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Abstract

Numerous seamounts and submarine volcanoes and three chains of volcanic oceanic islands –including he Canarian Archipelago– cluster in the East Atlantic region. The Canaries, located close to the African coast and the tectonic Atlas system, have for a long time been considered to be different in their genesis and evolution from intraplate, plume-generated volcanic oceanic islands. This methodological approach produced significant uncertainties in the understanding of important geological features –stratigraphic units, geochemical variation trends, structural features, etc.– currently observed and explained in volcanic oceanic islands. However, mantle plume activity explains as well most of the main geological features of the Canaries. Clear similarities with intraplate volcanic oceanic islands such as the Hawaiian archipelago help in understanding the volcanic history and stratigraphy, the chemical composition and evolution of magmas and the generation of important geomorphological and structural features such as rift zones and caldera-type gravitational collapses. The relationship with a mantle plume explains the type of the predominant eruptive mechanisms and the concentration of active volcanism and volcanic hazards in the western edge of the archipelago, in accordance with the progression of the plume.

Key words: Volcanic oceanic islands, genetic models, structural features, recent volcanism, eruptive hazards.

Resumen

Numerosos volcanes submarinos y tres archipiélagos de islas volcánicas oceánicas –incluyendo las Islas Canarias– se extienden por el Atlántico oriental. Las Canarias, situadas próximas a la costa de África y al sistema téctónico del Atlas, han sido consideradas durante mucho tiempo como diferentes del resto de islas volcánicas oceánicas originadas por la actividad de un punto caliente mantélico. Este enfoque metodológico introdujo ambigüedades significativas en la definición de las principales unidades volcanoestratigráficas de las islas, así como en la comprensión de aspectos relevantes como las pautas de evolución geoquímica de los magmas, la formación de los principales rasgos estructurales –rifts, estructuras de colapso gravitatorio–, etc. La actividad de una pluma del manto en la formación de las Canarias explica, sin embargo, estos aspectos geológicos principales, así como los tipos de mecanismo eruptivo dominante y la concentración en el extremo occidental del archipiélago de las zonas con mayor actividad volcánica reciente y riesgo eruptivo, en concordancia con la progresión del punto caliente.

Palabras clave: Islas volcánicas oceánicas, modelos genéticos, rasgos estructurales, volcanismo reciente, riesgo volcánico.

Introduction

Submarine volcanoes are much more abundant than volcanic oceanic islands. More than 1 million < 100 m high seamounts have been observed, while volcanic oceanic islands just a few thousand. In fact, island-volcanoes can be considered as successful seamounts, in which volcanic activity persists for a very long time, building a volcano sufficiently high to emerge. Since the elastic oceanic crust flexes to compensate the increasing load and the volcano subsides as it grows, the total elevation may exceed 10 km before final emergence above sea level.

In intraplate settings, this long, sustained period of volcanic activity is provided by stationary mantle plumes or *hotspots.* Their surface expression is, generally, linear chains of seamounts and of island-volcanoes. This simple model is characteristic of fast spreading plates; however, it is frequently more complex in slow or quasi-stationary ocean basins. Since the plates cool with age and their thickness (T) increases with time ($Z=9.4t^{1/2}$ *Km*), the plate vulnerability

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–the possibility that a mantle plume will penetrate the lithosphere– accordingly decreases with time. However, the velocity of the plate is also a relevant factor, since the heating of the overlying plate will be less effective in a fast-drifting plume. The expression of the plate vulnerability ($V= K/lu^{1/2}$, where l is the thickness of the plate and u its drift speed) indicates that a plume has the same opportunity to produce island volcanoes in a very old, 40 Km thick plate drifting 1 cm/yr as in a young, 10 Km thick plate drifting at the very fast rate of 16 cm/yr (Gass, 1978).

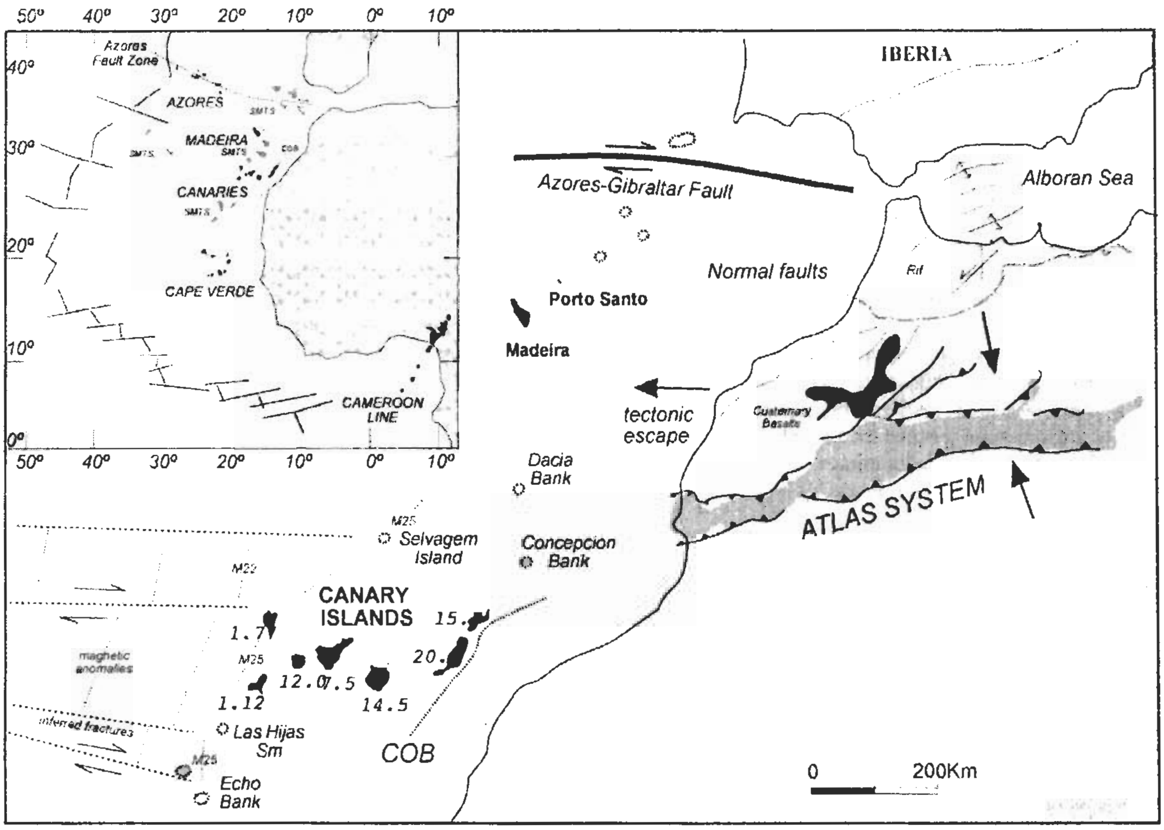


Figure 1: Geographic and geodynamic framework of the NW African continental margin volcanic groups (Modified from Carracedo *et al.* 1998).

Finally, the *fertility* of the plume is also crucial. If the overlying crust is small it will solidify attempting to penetrate the lithosphere. Only if the plume produces large volumes at high rates, it will succeed in producing island volcanoes.

Intraplate seamounts and island volcanoes occur in three different tectonic settings: intraplate, MORs and island arcs. In intraplate settings they are associated to hot spots, as discussed. Only a few seamounts are assumed to be of non-plume origin. These are related to extensional fractures and form solitary edifices instead of the linear discrete chains typical of intraplate plumes (Schmidt and Schmincke, 2000).

The above considerations are relevant to try to understand the genesis and evolution of the Canary Islands, a part of the volcanic archipelagos and many seamounts distributed throughout the eastern Atlantic (Fig. 1). These important topics, as well as the volcanic and tectonic history, structure, petrology and geochemical evolution and related volcanic hazards are considerably better understood for three main reasons:

1. *A methodological change in the study of the geology of the Canaries*, considering the archipelago to be similar to the other volcanic oceanic islands and not a "particular" geological scenario. The proximity of the African continent and the tectonic Atlas system suggested for a long time a peculiar, non-plume genesis and evolution for the Canaries. Differences were established between the eastern and western Canaries (although the latter have only been suf-

ficiently studied in the last decade), the former supposedly developed on continental or "transitional" crust. This prevented the application of the wealth of geological information gathered in oceanic volcanic islands –most especially in the Hawaiian Islands. In the other hand, despite being a most favourable scenario for geological investigatios (outcropping formations > 20 Ma, including the seamount stages, abundant unaltered rocks, scant vegetation, the possibility of direct observation of the deep structures of the volcanoes by means of many water tunnels or "galerías", etc.), the insufficiently known Canary Islands failed to play a more significant role in the general study of volcanic oceanic islands.

2. *The intense study of the western Canaries.* These younger islands, in a juvenile stage of shield building and with well preserved and perceivable geological features, nevertheless provided crucial information for the understanding of the geological characteristics of the Archipelago, significantly biased by the fact that the geological study of the Canaries was focussed in the older, intensely eroded eastern islands.

3. *The investigation* and *mapping* by high-resolution side-scan sonar systems *of the ocean floor surrounding the Canaries.*

Geological and geodynamic framework, genesis and evolution of the Canarian Islands

The Canary Islands developed in a geodynamic setting characterised by an old (Jurassic) oceanic lithosphere close to a passive continental margin, in a very slow-moving tectonic plate (the African plate). The absolute easterly motion of the African plate in the region of the Canaries may be as low as 0.9 cm/yr (about 2.4° in latitude and 5° in longitude).

A potentially very important difference between the Canaries and most other oceanic island groups is that the Canaries are located adjacent to a region of intense active deformation, comprising the Atlas Mountains and other provinces of

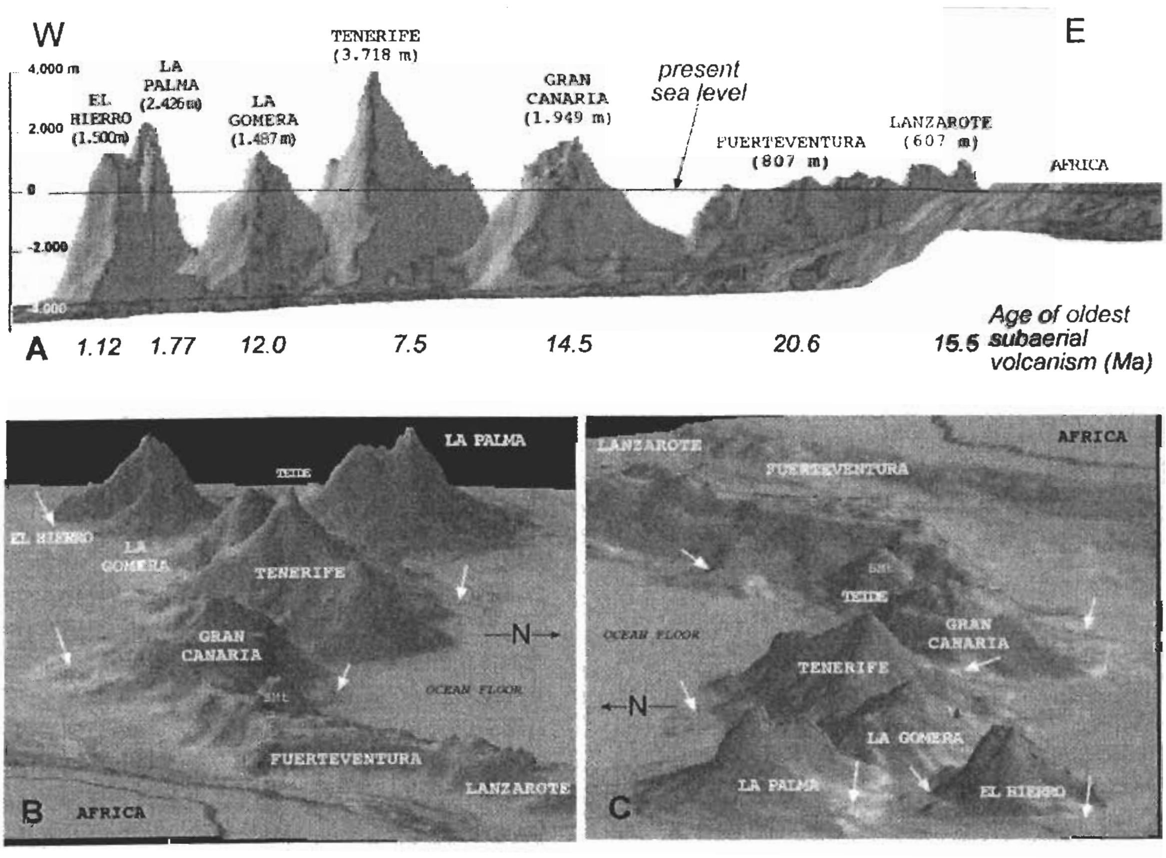


Figure 2: A) Shaded relief cross section (E-W) of the Canaries showing the subaerial/submarine volumes of the island edifices and the corresponding oldest age of the subaerial volcanism for each island (from Carracedo, 1999). B) Shaded relief view of the Canaries from the east. C) Idem from the west. Arrows indicate debris avalanche deposits from giant landslides (Modified from Carracedo *et al.*, 1998).

the Alpine orogenic belt (Fig. 1). However, clear geological or geophysical evidence for any tectonic association with the African tectonism has not been found in the area of the archipelago. Conversely, seismic, magnetic and geological studies carried out off the coast of Morocco (Dillon and Sougy, 1974) concluded that the Anti-Atlas feature abruptly terminates at the coast, without any evidence of an offshore continuation. Vink *et al.* (1984) considered strength differences between continents and oceans and reached the conclusion that continents are always weaker. Steckler and ten Brink (1986) and ten Brink (1991) analysed the total integrated strength of continental and oceanic lithosphere. Applying their conclusions to the African margin in the Atlas region it is evident that the > 150Ma old oceanic lithosphere is considerably stronger than the continent, precluding any fracture propagation from the Atlas towards the Canaries.

The continental-oceanic boundary to the west of the Fuerteventura-Lanzarote line (Fig. 1) is characterised by the presence of a 10-km thick layer of sediments. The lower load and conductivity of this formation are generally associated with a significant weakness of the lithosphere (Vink *et al.*, 1984), providing a favourable pathway for the magma.

The Canarian island chain

Three different groups of islands can be recognised by examining the volume and aspect ratio of the islands with their relative ages (Fig. 2 A): 1) The islands of Lanzarote, Fuerteventura, Gran Canaria and La Gomera, clearly older islands whose subaerial edifices have largely been mass-wasted by erosion; 2) Tenerife, the highest and most voluminous, probably at the peak of volcanic construction; and 3) La Palma and El Hierro, still in a very juvenile stage of growth.

The shaded-relief images shown in Fig. 2 B and C, which give an "empty ocean" view of the Canarian chain, clearly show that the elevation and emerged volume of the islands increase as their age decreases, in a westward (oceanward) trend.

Another interesting feature of the Canarian island chain is the fact that the islands of La Palma and El Hierro are growing simultaneously and form a N-S trending dual line of island volcanoes, perpendicular to the general trend of the archipelago (Fig. 2 B and C).

Dual-line volcanoes, such as the Kea and Loa trends in the Hawaiian Islands, have been associated with changes in tectonic-plate motion, resulting in the location of a volcanic load off the hotspot axis. Compressive stresses related to the off-axis volcano block the formation of the next island and split the single line of volcanoes into a dual line of alternating positions of volcanoes (Hieronymus and Bercovici, 1999).

Genetic models of the Canary Islands

Some non-plume models relate the formation of the Canaries with the African tectonism (Anguita and Hernán, 1975). However, in the absence of an asthenospheric anomaly these models are questionable since they are unable to account for the production of magma required to build the Canary Islands by lithospheric extension or by the rising of blocks and decompression melting of the asthenosphere beneath them (McKenzie and Bickle, 1988). Anguita and Hernán (2000) recently revised their early model, finally assuming a mantle plume in the genesis of the Canaries.

The activity of a mantle plume on a slow motion plate explains many of the main geological features of the Canaries. The progressive increase in age of the islands eastwards is concordant with the postulated hotspot pathway. Geological and structural features characteristic of intraplate plume-derived island groups –such as branched rift zones and two-stage volcanic construction of the islands (shield and post-erosional stages)– are readily observed in the Canaries.

Analysis of isotopic variations with distance and time in the Canaries has provided evidence for a mantle plume origin. Hoernle *et al.* (1991) reported isotopic systematics of lavas from Gran Canaria that appear to have a plume-like composition, with high $^{238}U/^{204}Pb$. According to these authors, the plume was located to the west of Gran Canaria during the Pliocene-Recent epochs. Hoernle and Schmincke (1993) analysed major and trace elements in the island of Gran Canaria, concluding that mafic magmas were probably formed by decompression melting in an upwelling column of asthenospheric material.

On the other hand, in the Canaries, neither the archipelago, nor the islands and their volcanic centres and rifts follow the postulated extension of the Atlas fault to the Canaries. In fact, the islands of Fuerteventura-Lanzarote are parallel to the continental margin, whereas the remaining islands of the archipelago follow a general E-W trend, with the above-mentioned dual line of La Palma and El Hierro configuring an N-S trend. Rifts in the western islands are radial and do not relate to the Atlas trend (Carracedo, 1994).

Rihm *et al.* (1998) demonstrated the presence of a group of apparently young seamounts (Las Hijas Smt.) located 70 km southeast of El Hierro. Their dyke and rift orientations are similar to those of the Canaries. Their location is consistent with the age-progression trend of volcanism in the Canarian Archipelago and the average spacing of these islands –obviously detached in time and space from the Atlas tectonism– is concurrent with the westward migration of the mantle plume that built the Canarian archipelago.

The heterogeneity of the magmatic and structural evolution of the Canaries, when compared with the Hawaiian Islands, may be related to major differences in plume source composition, dimensions and dynamics.

Age of the Canarian volcanism

Extensive geochronological studies have been carried out in the Canary Islands and more than 450 radiometric (K/Ar and $^{40}Ar/^{39}Ar$) ages from volcanics of the different islands have been published. At least 105 of these ages, from volcanics of the islands of La Palma and El Hierro, have been obtained with stringent requirements: sampling from well-controlled stratigraphic sections, using only microcrystalline groundmass, replicated analyses, combined use of K/Ar and $^{40}Ar/^{39}Ar$ methods and systematic comparison of the palaeomagnetic polarities of the samples with the currently accepted geomagnetic reversal timescales (Guillou *et al.* 1996, 1998, 2001).

A plot of the published radiometric ages from the Canaries (Fig. 3 A) shows three groups of islands: 1) Lanzarote, Fuerteventura and Gran Canaria, with subaerial volcanism 14.5 Ma or older and two main stages of volcanic growth separated by long periods of repose (erosional gap in the figure); 2) La Gomera, with subaerial volcanism not older than 12 Ma and only the pre-erosional gap stage of growth; and 3) Tenerife, La Palma and El Hierro, with subaerial volcanism younger than ~ 2 Ma and only the juvenile shield-stage of growth.

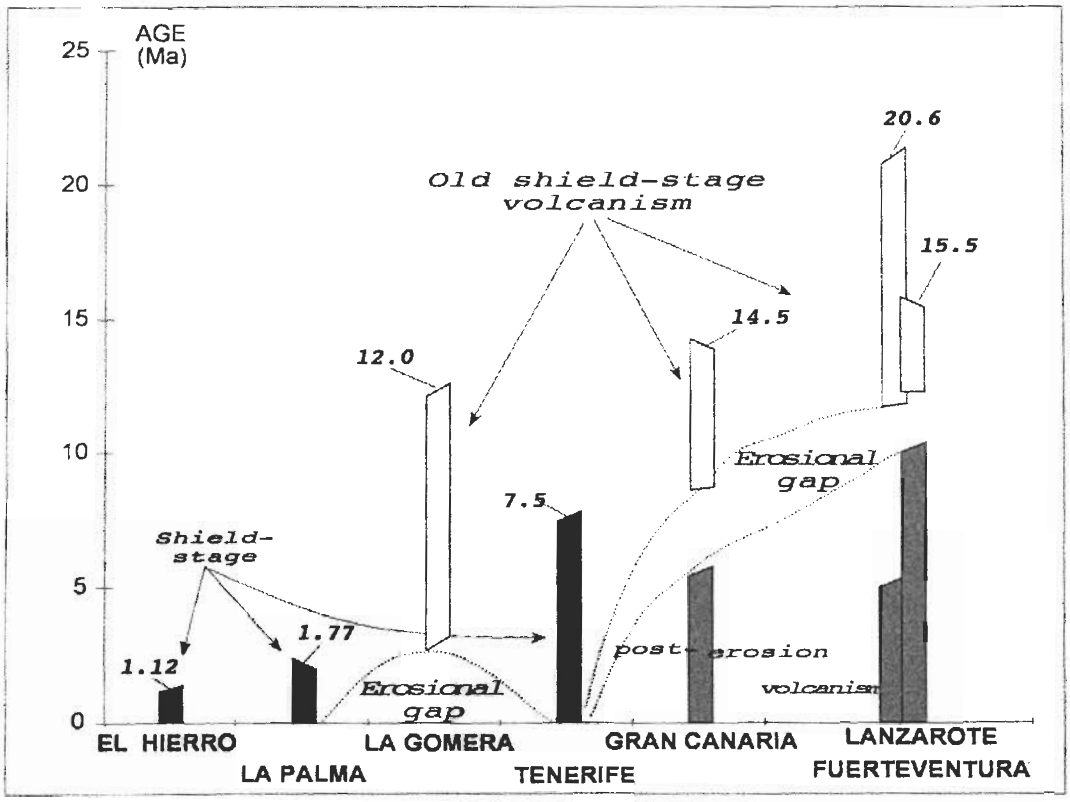
An interruption in the volcanic activity (i.e., erosional gap) of individual islands is a common feature of hotspot oceanic island groups. This feature was used in the Hawaiian Islands to separate two main volcano-stratigraphic units: the *shield stage* and the *post-erosional* or *rejuvenated stage* (Clague and Dalrymple, 1987; Walker, 1990). The application to the Canaries of this distinction (Carracedo *et al.* 1998; Carracedo, 1999) solves many of the problems raised by the use of the term "Series" in the volcano-stratigraphy of the islands. This terminology was used in the first comprehensive and modern compilation of the geology of the islands of Fuerteventura, Lanzarote, Gran Canaria and Tenerife carried out by Fúster *et al.* (1968 a-d). This term conformed to the stratigraphic code in use at the time, but not to the currently accepted code (NACSN, 1983), which restricts the use of "Series" to geological units formed during the same time-span and with synchronous boundaries. The use of terms such as "Old" and "Recent" Series led to considerable confusion, since the "Old" Series of La Palma or El Hierro are considerably younger than the "Recent" Series of Fuerteventura, Lanzarote or Gran Canaria.

This confusion is avoided when the concept of shield-stage and post-erosional or rejuvenation volcanism is applied to the Canaries, which can then be separated accordingly (Fig. 3 B).

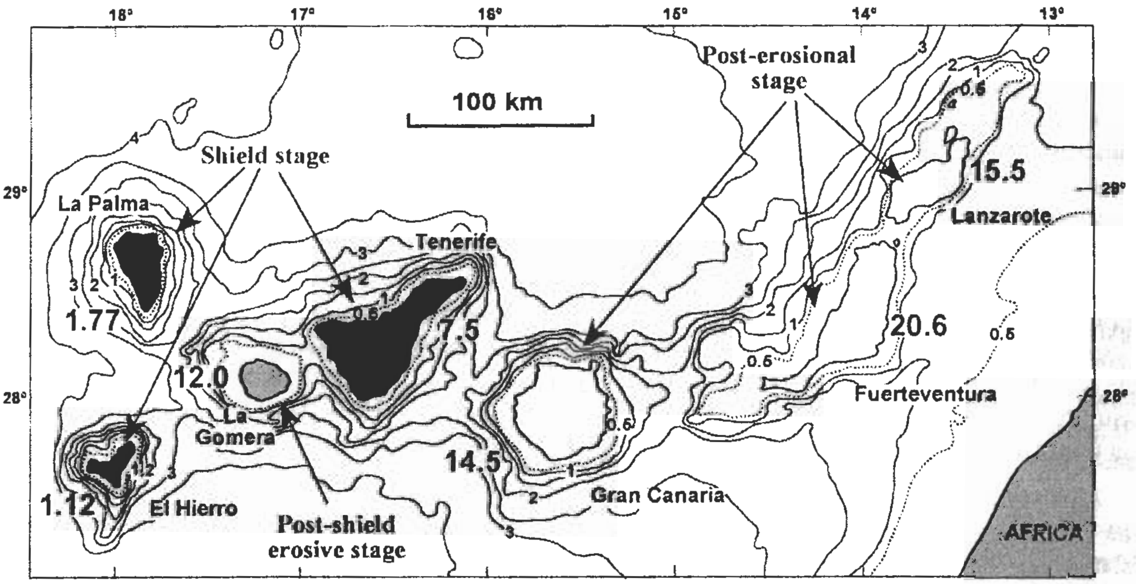
Another important stratigraphic unit of the Canarian islands that should be revised is the "basal complex" (Bravo, 1964). This unit outcrops in the islands of Fuerteventura, La Gomera and La Palma, consistently separated from the subaerial volcanism by a major unconformity. The "basal complex" combines variably deformed and uplifted sequences of submarine sediments and volcanic rocks (mainly pillow basalts), dyke swarms and plutonic intrusions.

Studies of the "basal complex" outcropping in the Caldera de Taburiente in La Palma (Staudigel and Schmincke, 1984) demonstrated that the "basal complex" represents the seamount stage of the growth of these islands and, as anticipated in the Hawaiian group, in oceanic islands in general. Similar conclusions had been reached for the "basal complex" of Fuerteventura (Stillman, 1987).

Detailed geological mapping inside the Caldera de Taburiente (Carracedo *et al.*, 2001) reassigned to younger subaerial stratigraphic units many of the formations previously inclu-



A



B

Figure 3: Published K/Ar ages from lavas of the Canary Islands. The presence of a gap in the eruptive activity allows the separation of two main stratigraphic units: Shield stage and post-erosional-stage volcanism. (modified from Carracedo, 1999).

ded in the "Basal Complex". When these units were excluded, the former "Basal Complex" consists only of the submarine volcanics and associated intrusions of the seamount described by Staudigel and Schmincke (1984). The term "Basal Complex" should be discarded and replaced by the general term "seamount" or "submarine volcanic edifice".

Subsidence history of the Canary Islands

An important difference between the Canaries and other oceanic island groups such as the Hawaiian Islands is the absence of comparative subsidence in the former (Schmincke *et al.*, 1997; Carracedo *et al.*, 1998; Carracedo, 1999).

Individual islands in the Hawaiian group subside and eventually become seamounts in 6-7 Ma. Conversely, subsidence is not significant in the Canaries (and the Cape Verde), a feature possibly related to the different geodynamic settings.

The lack of significant vertical movements of the islands in the post-seamount stages becomes evident from the observation of the position of contemporary sea levels, in the form of marine abrasion platforms, littoral and beach sedimentary deposits, coastal volcanic deposits (hyaloclastite-pillow lava deltas and Surtseyan tuff rings), and erosional palaeocliffs, widespread in the Canary Islands. These features consistently occur close to present sea level, within the range of eustatic sea level changes (Meco and Staerns, 1981; Carracedo, 1999).

Near-horizontal seismic reflectors observed in the volcanic apron of Gran Canaria (Funck, 1998) show this island to be stable at least since the late stages of shield-building, ~ 14 Ma ago. These reflectors reach the south flank of Tenerife, where they interbed with the volcanic aprons, providing evidence of the stability of this island during its entire volcanic history.

The Canaries apparently remain emergent for long periods of time, even exceeding 25 Ma, until completely mass-wasted through gravitational collapses, relatively frequent in the juvenile stages of growth, and erosion.

Magma production rates and eruptive frequency

Despite the many features that the Canaries share with the Hawaiian Islands, they differ greatly in important aspects related to magma evolution and production rates, and eruptive frequency. When compared with Canarian volcanoes, the Hawaiian shields involve much greater volumes and higher frequency of eruptions (Walker, 1990). The total volume of erupted magma and production rates are difficult or impossible to evaluate in the Canaries, in spite of the quality and amount of available age data, especially for the western islands.

Despite these uncertainties, Schmincke (1982) computed several estimations of the total volume of the islands in the Canarian archipelago, including the products of submarine and subaerial volcanism, intrusions and sedimentary materials, but did not consider materials removed by mass-wasting and by gravitational collapses. He obtained a range of estimated volumes of islands remarkably similar to that of many shields in the Hawaiian Islands (~ 20 x 10^3 km^3). This may imply that volumes of ~20 x 10^3 km^3 are optimum values for the maximum growth of volcanic oceanic islands in general.

The eruptive histories of the islands of El Hierro (Guillou *et al.*, 1996) and La Palma (Guillou *et al.*, 1998; Carracedo *et al.*, 1999*a,b*; Guillou *et al.*, 2001) are probably the best-constrained geochronologically of any of the Canary Islands. The uncomplicated development of these islands, which are still in their juvenile stage of shield growth, together with the abundant and accurate K/Ar ages and magnetic stratigraphy allows the closest possible approach to the reconstruction of the entire emerged volcanic history of any of the Canaries. Average magma supply rates during the entire history of El Hierro and La Palma are of the order of 0.1-0.4 km^3/ka (the highest values when the volume removed by lateral collapses is considered), whereas in the island of Hawaii these values have been estimated to be 20 km^3/ka (Moore and Clague, 1992).

Eruptive frequency and volume in the Canaries vary considerably, as observed for the historical eruptions (the last 500 years). The 1730-1736 eruption of Lanzarote is the largest to occur in the archipelago in this period, involving an eruptive volume as much as an order of magnitude larger than any other from historical eruptions at other Canarian islands (Carracedo *et al.*, 1992). However, the previous eruption in Lanzarote may be that of the Corona Volcano, dated at 53 Ka (Guillou, unpublished age). In the same period, as many as 100-1000 smaller eruptions may have taken place in the shield-building stage islands of El Hierro, La Palma and Tenerife.

Main structural features

The western and eastern Canaries show clear differences in structure and other important volcanic characteristics. The western islands display frequent, small-volume eruptions, high aspect ratio island edifices, well-defined, multi-branched, long-lasting rifts and frequent massive flank collapses. Conversely, in the eastern islands, volcanism is scarce and scattered, the islands have low aspect ratios and rifts and giant landslides seem to be absent.

Early interpretations related these apparently contrasting structural features in the Canaries to different geological and geophysical characteristics between the "eastern Canaries", possibly underlain by continental crust and the "western Canaries", resting on oceanic crust (Dash and Boshard, 1969). However, subsequent studies have clearly determined the presence of Mesozoic oceanic crust beneath the entire Canarian archipelago (Schmincke *et al.,* 1998). These structural differences may reflect, instead, the different stages of evolution –and erosion– of the islands (Carracedo *et al.,* 1998; Carracedo, 1999).

The form, structure and landscape of the Canaries are characterised by four main features: 1) shield volcanoes, such as the Garafía-Taburiente in La Palma; 2) stratovolcanoes, such as the Roque Nublo in Gran Canaria or the Teide Volcano in Tenerife; 3) rift zones, locally known as "dorsals", such as the Cumbre Vieja volcano in La Palma; and 4) collapse structures: vertical collapse calderas such as the Caldera de Tejeda in Gran Canaria, and gravitational collapse scarps and embayments such as the Caldera de Taburiente in La Palma or the Caldera de Las Cañadas in Tenerife.

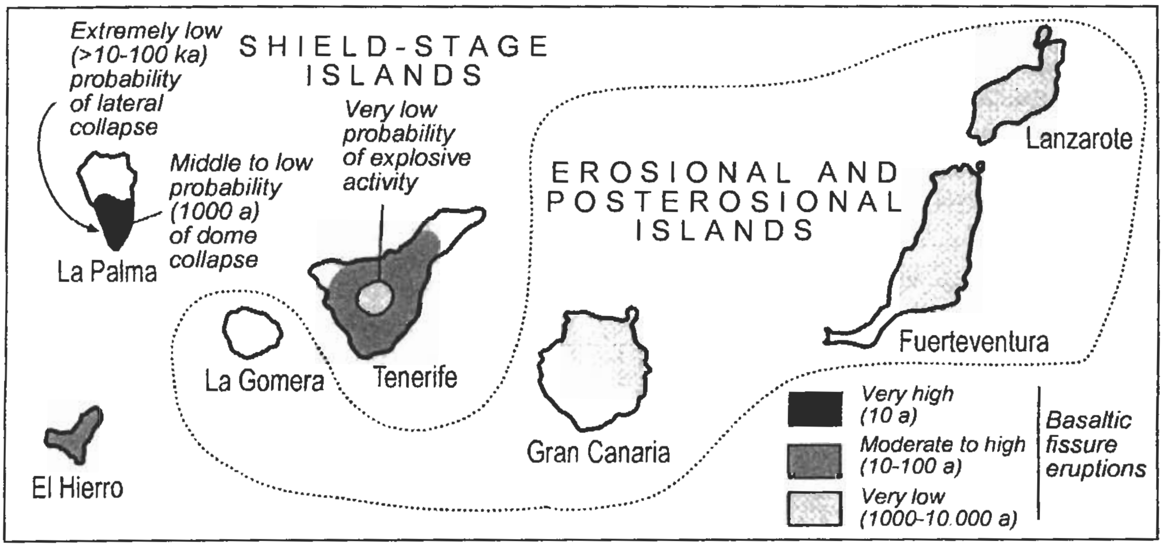


Figure 4: Schematic volcanic hazards in the Canaries.

Chemical composition and evolution

Magmas erupted in intraplate island volcanoes are interpreted as derived from mantle plumes. The chemical composition of lavas covers a wide chemical and isotopic variation, according to the depth of the mantle source and the degree of melting. The characteristic chemical evolution of oceanic island volcanoes (e.g.: the Hawaiian Islands) is dominated by tholeiitic basalts during the shield-building stage, when > 95% of the islands are formed. Magma supply rates during the shield-building stage are commonly so high as to prevent shallow magma chambers from undergoing progressive fractional crystallization, except in the post-shield stages (capping and rejuvenation stages of Walker, 1990), where alkalic/transitional basalts to trachytes are produced, as well as SiO_2 udersaturated lavas (basanites, nephelinites).

Tholeiite basalts are exceptional in the Canaries, as verified in the 1730 eruption of Lanzarote (Carracedo *et al.,* 1992, Carracedo and Rodríguez Badiola, 1991). Canarian volcanoes are characterised by moderate magma supply rates, except in the initial phases of the shield-building stages. These rates are just adequate to maintain shallow magma chambers where fractional crystallization occurs and felsic lavas are produced, in the form of intrusives (domes and lava-domes) and as large stratovolcanoes in the central islands of Tenerife and Gran Canaria (Pérez Torrado, 2000; Pérez Torrado *et al.*, 1995). The production of large volumes of felsic magmas in these stratovolcanoes gave way to explosive eruptions with emission of ignimbrites and plinian falls.

Recent and historical volcanism and volcanic hazards in the Canaries

Holocene volcanic eruptions have occurred in the entire Canarian group with the exception of La Gomera. However, the intensity of Holocene volcanism is not constant throughout the archipelago. Eruptive frequencies, extension and volumes during this period show significant differences in the archipelago, with the shield-stage islands having values at least 10-100 times greater than those for the post-erosional islands (Fig. 4). During the Holocene, 10-100 eruptions have been identified in La Palma (Carracedo *et al.*, 1999a; Guillou *et al.*, 2001), El Hierro (Guillou *et al.*, 1996) and Tenerife (Fúster *et al.* 1968d), whereas < 10 eruptions took place in Gran Canaria (Fúster *et al.*, 1968c; ITGE, 1992), Fuerteventura (Fúster *et al.*, 1968b) and Lanzarote (Fúster *et al.*, 1968a; Carracedo *et al.*, 1992). The occurrence of a relatively very long and voluminous eruption in Lanzarote (1730-1736) has prompted the erroneous idea of similar levels of volcanic activity along the entire Canarian chain. However, this idea is inconsistent with the fact that, prior to the 1730 eruption, the only eruptions of note are those of the Corona Volcano and Los Helechos volcanic group, dated at 53 and 72 ka, respectively (Guillou, unpublished ages).

The main volcanic hazards in the Canary Islands are shown in Fig. 4. The historical eruptions in the Canaries are basaltic fissure eruptions. However, the Jedey or Tahuya eruption (1585, La Palma) produced basalts and juvenile phonolites, and tholeiitic lavas were produced in the 1730 eruption of Lanzarote (Carracedo and Rodríguez Badiola, 1991; Carracedo *et al.*, 1992). Average eruption duration varies from 8 days to more than 6 years, but is typically 1 to 3 months. Volumes range from 0.2 to ~700 x 10^6 m^3, and most commonly 10-40 x 10^6 m^3. The area covered by lavas during an eruption varies from 0.2 to 150 x 10^6 m^2, with values most frequently between 3 and 10 x 10^6 m^2. All historical eruptions showed mainly seismic precursors, from >1 year to only a few hours prior to eruption onset.

Volcanic hazards are of a relatively low magnitude in the Canary Islands. The most likely hazards are related to basaltic fissure eruptions in the shield-stage islands, particularly in the Cumbre Vieja volcano, in south La Palma.

Although El Hierro is the geologically youngest island of the Canaries most of the recent eruptions have occurred in La Palma. At least 10 eruptive events occurred in that island in the last 2,500 yr, compared with only one eruption in El Hierro in the same period (Mña. Chamuscada, ^{14}C age of 2500 ± 70 yr B.P., Guillou *et al.*, 1996). The higher eruptive frequency and, consequently, higher volcanic hazard in La Palma may be related to the apparent alternating (on-off) of the main volcanic activity between these islands (Carracedo *et al.*, 1999a), in which only La Palma has had important eruptive activity during the Holocene.

Recent felsic, explosive volcanism is limited to the Teide-Pico Viejo volcanic complex, in Tenerife. However, according to Barberi (1989), the occurrence of several basaltic eruptions adventive to this complex suggests that its magmatic chamber is very reduced in size or inactive, an observation in agreement with the lack of explosive eruptions parallel to these basaltic events.

Several giant lateral collapses have occurred in the Canaries, as mentioned earlier. However, all the fast-growing, unstable volcanoes have already undergone lateral collapses and restored stable configurations. Only the Cumbre Vieja volcano in La Palma may be progressing towards an increasingly unstable configuration. Although this volcano may evolve in the geological future towards a more stable shape –changing configuration, being buttressed by another volcano, becoming extinct before collapsing or undergoing an aborted flank failure–, the possibility of a future giant collapse cannot be totally discarded. However, the Garafía and Cumbre Nueva volcanoes developed for 570 and 640 ka, respectively, before collapsing (Carracedo *et al.*, 1999*a,b*; Guillou *et al.*, 2001), and the age of the Cumbre Vieja volcano is only ~120 ka. The lack of seismicity or ground deformation (Moss and

McGuire. 1999), however, clearly shows that this volcano is presently stable.

Historical eruptions have happened when the islands had a low population or, later, in places with very few inhabitants. Only the 1706 eruption of Garachico, the anomalous long 1730 eruption of Lanzarote and the most recent eruptions of La Palma (1949 and 1971) posed any significant threat to the people and the economy of the region. Notwithstanding, the spectacular increase in the Canary Islands population (1.8 million inhabitants and 10-11 million visitors annually) has accordingly increased the risks.

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