# 2 Geological and Geodynamic Context of the Teide Volcanic Complex

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**Abstract**

Long-lived and lively debates commenced in the Canaries several decades ago regarding geological evidence that potentially helps to clarify important features and processes of ocean island volcanism. This included the true nature of the crust underlying the islands, the ultimate cause for the existence of the magmatism in the archipelago, and how large-scale morphological features that shape the islands, such as rift zones and giant landslide scars, have actually formed. The Canaries, once considered to be remnants of an older and larger sunken landmass, are now firmly integrated into the general framework of ocean island volcanism, thus gaining from the abundant geological information published in this field, and in return, providing volcanological data of global significance for ocean islands elsewhere.

## 2.1 Introduction

As volcanoes develop, they initially go through a constructive phase of evolution in which growth of the edifice through volcanic activity outpaces destruction through mass wasting (Hoernle and Carracedo 2009). During the destructive phase of evolution, mass wasting and erosion exceed volcanic growth and island volcanoes decrease in size until they are eroded to sea level. In this context, Teide Volcano currently represents the peak of development of Canarian volcanoes, the western islands not having yet attained this stage, and the eastern ones being already beyond it.

## 2.2 The Canary Volcanic Province

Tenerife lies, in time and space, at the centre of the Canary archipelago, the emerged islands forming a 490 km-long chain that increases in age towards the African continent (Fig. 2.1). However, to understand the genesis and evolution of this archipelago we have to take into consideration not only the presently emerged islands (Neocanaries) but the older islands, already submerged (Palaeocanaries). As the African plate moves over the magma source, it cools and subsides, and the older volcanoes of the chain sink beneath sea level forming

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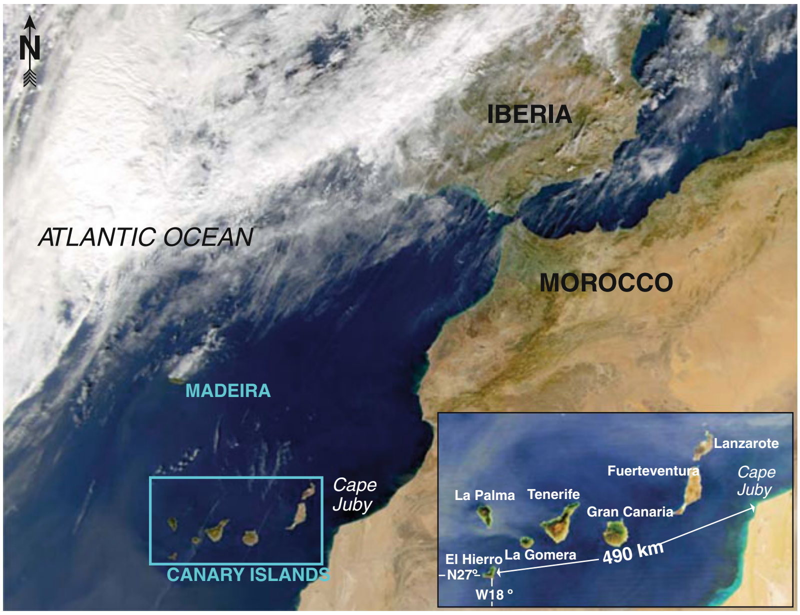



**Fig. 2.1** Image (NASA) showing the Canary Islands, in the central east Atlantic off the African coast

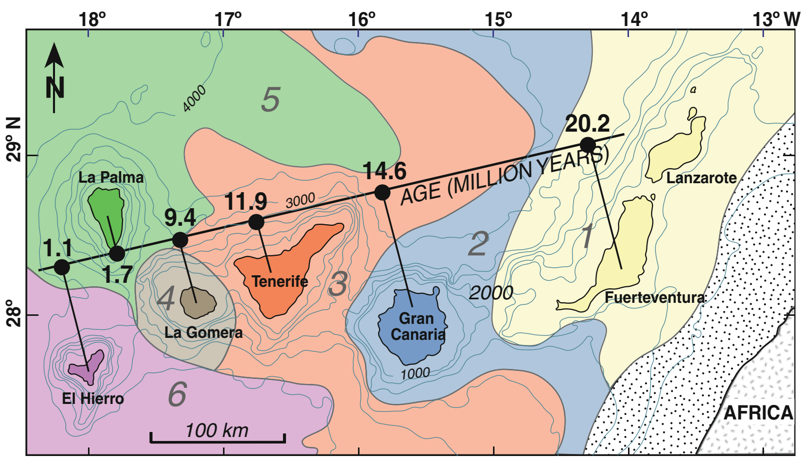



**Fig. 2.2** Constant W–E aging of the Canary Islands, consistent with the progressive overlap oceanwards of the islands' aprons (in respective colours), starting at Fuerteventura-Lanzarote. Ages from Guillou et al. (2004). Aprons from Urgeles et al. (1998)

seamounts. Therefore, from a geological point of view, it is crucial to take into account the entire chain of islands and seamounts, summarised as the Canary Volcanic Province (CVP).

The west to east aging of the Canaries is very well documented from abundant radiometric age determinations and from marine geophysical data, indicating that the ages of the oldest rocks of the different islands consistently increase from west to east, whereas their aprons consistently overlap in the opposite direction (Fig. 2.2).

Evidence for age progressive volcanism in the submerged, northern part of the CVP (Fig. 2.3) comes from radiometric dating of seamounts (Geldmacher et al. 2001, 2005). As quoted by these authors, additional evidence for age progressive volcanism in the Palaeocanaries is proven by a widespread and time-transgressive seismic layer, interpreted to reflect volcanic ashes from the Canary hotspot (Holik et al. 1991), present in oceanic sediments marking the Cretaceous/Tertiary boundary near Lars

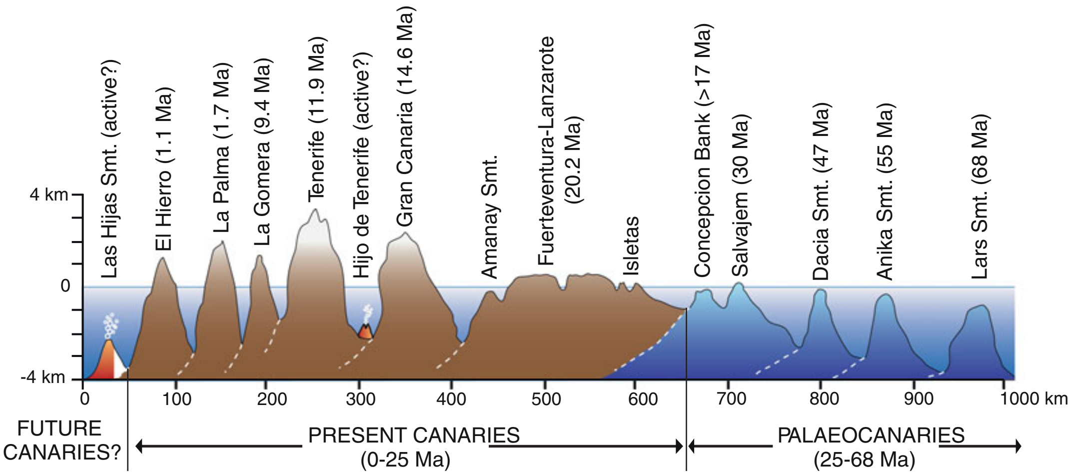



**Fig. 2.3** Schematic diagram showing the age progressive chain of islands and seamounts that forms the Canary Volcanic Province (ages from Geldmacher et al. 2001; Guillou et al. 2004)

seamount, but getting younger towards the Canary Islands.

The CVP and the Madeira Volcanic Province (MVP) show some interesting common features. Both volcanic lineations follow parallel curved trends (Geldmacher et al. 2001), suggesting that the islands formed roughly at the same average rate and in the same direction over the last 70 My (Fig. 2.4).

## 2.3 Genetic Models for the Canaries

Different hypotheses have been published to account for the origin and structural evolution of the Canary Islands. However, two models have been the subject of a lively debate since 1975. Anguita and Hernan (1975) attributed the Canarian magmatism to a propagating fracture from the Atlas mountains, a model based upon structures that cut through the lithosphere to be the cause of, and the control for, the location of the Canary volcanism. Alternatively, Carracedo (1975) postulated an upwelling mantle plume (cf. Morgan 1971), a feature largely independent of the lithosphere.

Although volcanic chains can be formed in relation to transform faults or propagating fracture zones (e.g., Azores), it is not easy to explain how large volcanic chains such as the Canary Islands can be generated within the context of decompression fracturing (McKenzie and Bickle 1988; White and McKenzie 1989). Furthermore, the lithosphere around the Canaries is among the oldest (Jurassic) and thickest on Earth, and therefore lithospheric faults would be problematic to account for the large volumes of magma required to develop the Canary and Madeira Volcanic Provinces. Stress-induced magmatism, reactivation of pre-existing fracture zones (Favela and Anderson 2000) or propagating fractures (Anguita and Hernan 1975), may channel the magma inside the lithosphere and control the geographic arrangement of island volcanoes. However, hotspot trails intersecting fracture zones (e.g., Azores) generally do not show a systematic age progression as is evident in the Canary archipelago (Guillou et al. 2004).

Although local seismicity has been detected around the Canaries, no evidence has been found to prove the existence of any major fault connecting the Atlas mountains with the Canaries in any detailed geophysical studies of the area (Martínez and Buitrago 2002) or in the Atlantic around the Canarian archipelago (Watts 1994; Funck et al. 1996; Watts et al. 1997; Urgeles et al. 1998; Krastel et al. 2001; Krastel and Schmincke 2002). Features interpreted to be crustal fractures that predated and facilitated the

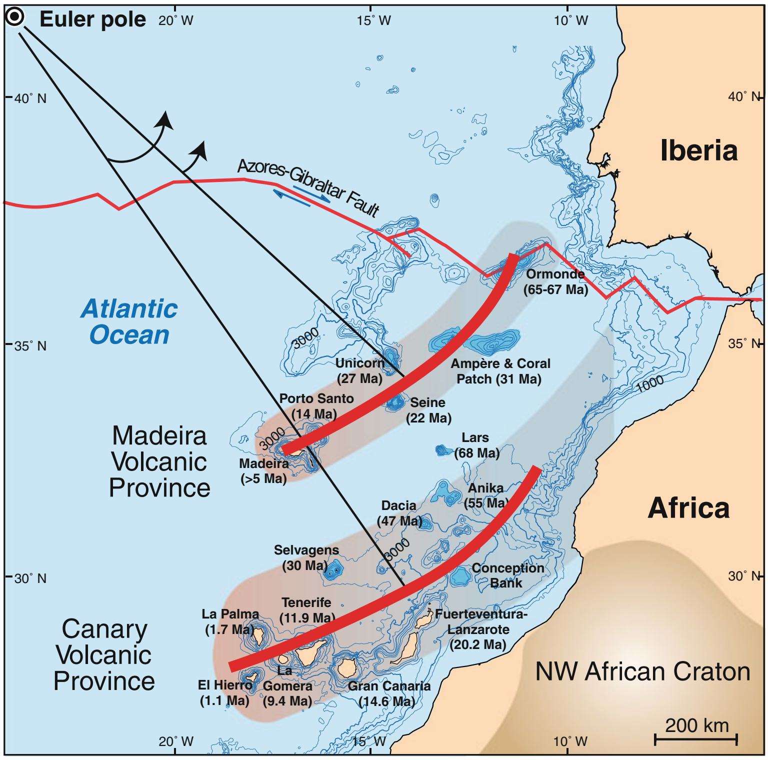



**Fig. 2.4** Bathymetric map showing the Canary and Madeira Volcanic Provinces, consisting of islands and associated seamounts, in the central east Atlantic. Both volcanic lineations follow parallel curved trends, suggesting that the islands formed roughly at the same average rate and followed the same course over the last 60 Ma (modified from Geldmacher et al. 2005)

formation of the Canaries, supporting their fracture-related origin (Geyer and Marti 2010), proved to be artifacts associated with ship tracks created during multi-beam data acquisition (Carracedo et al. 2011a).

Conversely, Canary and Madeira Volcanic Provinces age progression and curved synchronous tracks, clearly different from the E–W orientation of fractures or transform zones in the East Atlantic (Geldmacher et al. 2005), can be better explained in the context of a hotspot model (Carracedo et al. 1998).

Several features of the CVP, however, are not easily explained within the context of the classical mantle plume model, particularly the exceptionally long period of volcanic activity of islands in the CVP (e.g., at least 23 My for Fuerteventura). Geldmacher and coworkers (2005) proposed interaction of a Canary plume with edge-driven convection at the margin of the African craton (Fig. 2.5), consistent with further observations by Gurenko et al. (2006).

## 2.4 Hot Spot Dynamics and Plant Radiation

Macaronesia is a biogeographical region based on the existence of many common elements of flora and fauna. Recent phylogenetic analyses provided evidence of close similarities between species of the Macaronesian flora and the Iberian and Moroccan populations—particularly laurel forest communities, considered to be relicts of the Paleotropical Tethyan flora, which suggests a common origin.

The wet and warm climate in Southern Europe and North Africa during the Paleogene was conditioned by the influence of the warm east-to-west circum-equatorial global marine current, ensuring high temperatures and monsoon summer rains (Uriarte 2003). These conditions changed dramatically, and the tropical flora became extinguished on these continents as a result of the climatic deterioration

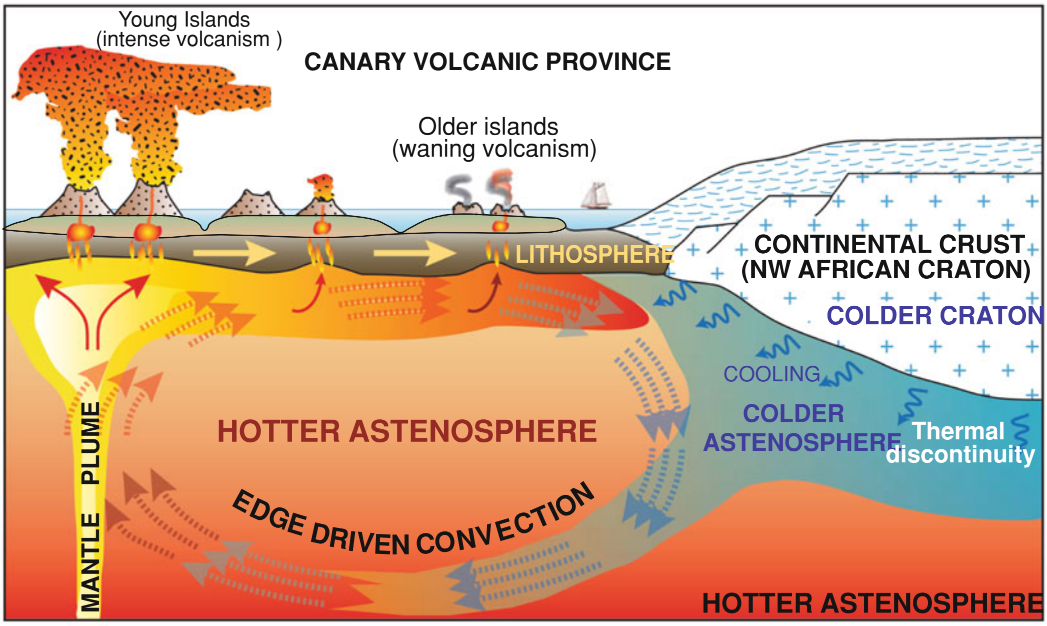



**Fig. 2.5** Hotspot or mantle plume model that can adequately explain the linear younging direction along a NE–SW oriented path for the Canary Islands (Carracedo et al. 1998). The conventional hot spot model cannot readily explain the long history of the Canary Islands and the occurrence of historic volcanism in Lanzarote. However, a coherent explanation may be interaction of small-scale upper mantle convection at the edge of the African craton with the Canary mantle plume (modified from Carracedo 1999; Geldmacher et al. 2005)

triggered by the arrival of the glaciations at about 3.2 My (Meco et al. 2006) and the onset of the Canarian marine current. The Iberian and Moroccan regions became a late refugium for these populations until the late Pliocene.

However, the presence of palaeo-endemic floral elements in the laurel forests of contemporary Macaronesia is difficult to explain because of the age differences and the excessive distances from paleotropical sources for the ocean-crossing dispersal abilities of species.

A new approach, linking radiation of paleotropical flora to the Macaronesian archipelagos and the hot spot model has been proposed by (Fernandez-Palacios et al. 2011), suggesting that large and high islands may have been continuously available in the region for as long as 60 million years (Geldmacher et al. 2005), functioning both as stepping stones and as repositories of paleoendemic forms and crucibles for neoendemic radiations of plant and animal groups. In turn, this model (Fig. 2.6) represents additional, non-geological evidence that is consistent with a hot spot origin for the Macaronesian archipelagos.

## 2.5 Absence of Significant Subsidence as a Crucial Feature in the Canaries

Possibly one of the most relevant differences in the geological evolution of the Hawaiian and the Canarian archipelagos is the absence of high-rates of subsidence characteristic of the majority of mantle plume-related islands in the Canaries. While ocean islands generally rapidly subside below sea level to become guyots, the Canaries remain above sea level for very long periods (e.g., Fuerteventura >23 My; Fig. 2.7). Had the Canaries experienced a subsidence history similar to that of the Hawaiian archipelago, only La Palma and El Hierro would still be above sea level.

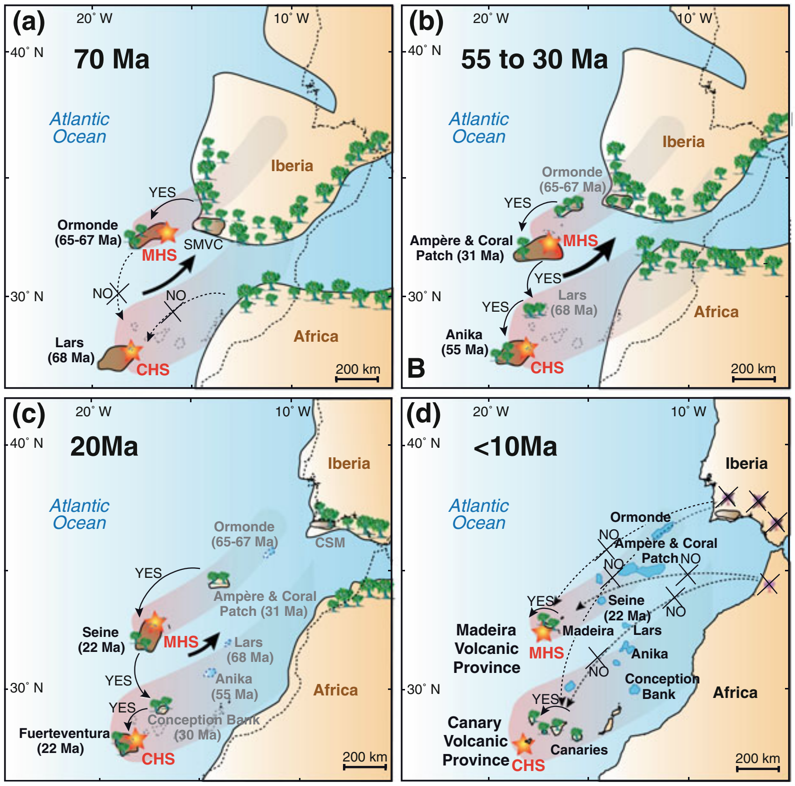



**Fig. 2.6** Large islands with high altitudes may have been continuously available in the region for as long as 60 million years (Geldmacher et al. 2005), serving both as stepping stones and as repositories of paleoendemic forms and crucibles of neoendemic radiations of plant and animal groups. This model may represent additional, non-geological evidence in favour of a hot spot origin for the Macaronesian archipelagos. *MHS* Madeira hot spot; *CHS* Canary hot spot; *SMVC* Sierra Monchique volcanic complex (modified from Fernandez-Palacios et al. 2011)

Therefore, this particular feature of the Canarian archipelago, possibly related to the characteristics of the oceanic crust in this area of the NE Atlantic (very old and rigid Jurassic crust), accounts for the existence of Tenerife and Teide Volcano (Fig. 2.8), unfeasible in a scenario of high-rate subsidence as on Hawaii.

## 2.6 Teide Volcano and the Evolution of the Canaries

The identical source and genetic processes recorded on the islands of the Canarian archipelago in a hot spot context may account for their similarities. However, significant differences between the islands are evident in their volume, elevation, morphology and igneous rock types from W to E, reflecting the increase in age and progression in evolutionary stage.

In contrast with the Hawaiian and most oceanic islands, where subsidence plays a major role, the Canaries show remarkable long-term island stability. Mass wasting and erosion, eventually outpacing volcanic growth, to reduce the size of the islands until they are eroded to sea level, requires periods of time that can exceed 20 My (e.g., Fuerteventura).

The age-dependent ratio of subaerial to submarine volume in the Canary Islands increases from the youngest western to the oldest eastern islands. However, the increase is not constant but shows a maximum in the central island of Tenerife, reflecting that the western islands have not yet attained the mature stage, while the eastern islands are already in an advanced phase of erosive decay (Fig. 2.9).

Therefore, although Gran Canaria, and probably Fuerteventura, also had central differentiated volcanic complexes (e.g., Roque Nublo Volcano), they have been dismantled by erosion

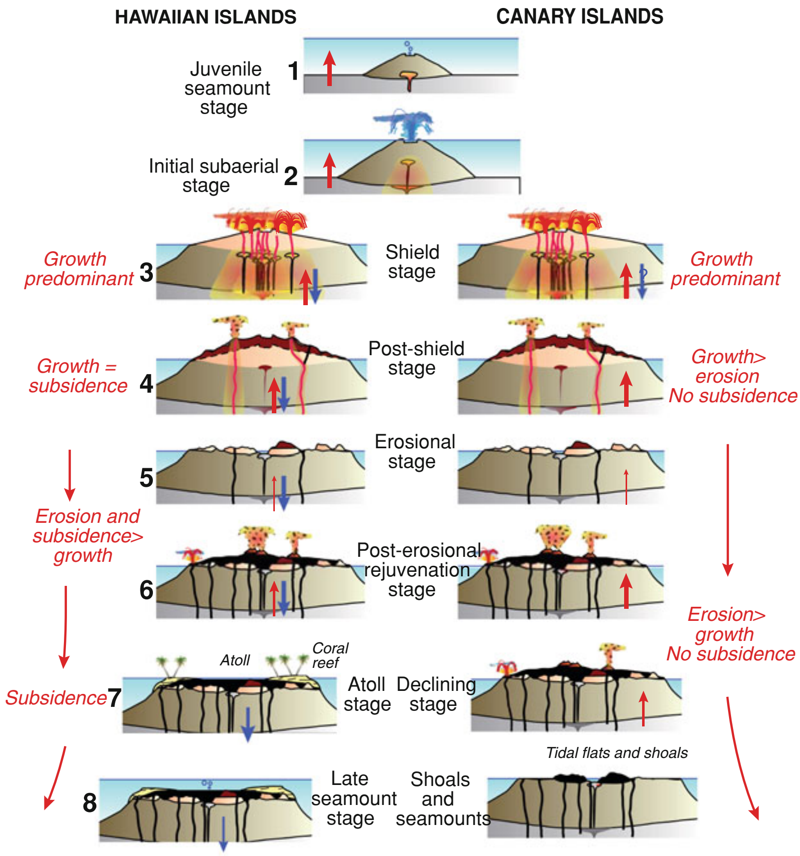



**Fig. 2.7** Schematic diagram illustrating significant differences in the evolution of the Hawaiian and the Canary oceanic archipelagos. The former (*left*) typify the life history of oceanic island chains derived from very active and fertile mantle plumes on relatively flexible, fast-moving plates. These islands grow very fast and subside very rapidly into seamounts (the oldest emerged island of the Hawaiian archipelago formed about 6 My ago). In contrast, the Canaries originate from a less active hot spot that penetrates a slow moving old plate, and are composed of long-lived islands with slow growth rates. The main difference is the lack of significant subsidence in the Canaries, with islands remaining emerged until mass-wasted by erosion (modified from Walker 1990; Carracedo et al. 1998)

(Pérez-Torrado et al. 1995; Stillman 1999; Troll et al. 2002). Likewise, the western islands may develop similar central volcanoes in the geological future, but at this stage of evolution of the Canarian archipelago only Tenerife, representing the present evolutionary peak in the development of the Canaries, appears to meet the conditions for an active felsic central complex such as Teide Volcano.

A simplified synthesis of the evolution of the Canary Islands is shown in Fig. 2.10. About 2 My ago a significant change occurred in the sequential development of the islands. The consistent construct of the Canarian archipelago as a single-line chain split after La Gomera into a dual-line configuration. While the onset of each successive island started once the previous one was in decay, La Palma and El Hierro, still in an early stage of shield growth, are being constructed simultaneously. This duality may account for the remarkably slower progress of island construction in the new dual-line configuration compared to the single-line configuration, with an interval of more than 8 My between the onset of La Gomera and that of La Palma and El Hierro.

**Fig. 2.8** The 3,718 m high Teide Volcano, nested inside the Las Cañadas Caldera, caps the centre of the island of Tenerife, and forms a part of the latest phase of volcanic construction on the island

## 2.7 Tenerife Before the Construction of the Teide Volcanic Complex

The Geology of Tenerife has been extensively studied (e.g., Hausen 1955; Fúster et al. 1968; Ridley 1970, 1971; Abdel-Monem et al. 1971; Carracedo 1975, 1979; Schmincke 1982; Wolff 1983, 1987; Ancochea et al. 1990, 1999; Watts and Masson 1995; Bryan et al. 1998, 2002; Thirlwall et al. 2000; Wolff et al. 2000; Edgar et al. 2002; Walter and Schmincke 2002; Guillou et al. 2004; Pittari et al. 2005; Walter et al. 2005; Bryan 2006; Pittari et al. 2006; Carracedo et al. 2007, 2011a; Longpré et al. 2009).

Three main shield volcanoes form the oldest part of the island with compositions ranging from undifferentiated to evolved magmas (basanites to phonolites).

### 2.7.1 Shield Stage

Fúster et al. (1968) described Tenerife as a large shield volcano mantled by subsequent volcanism, with the core outcropping in the south of the island (Roque del Conde massif), and at the NW and NE edges (Teno and Anaga volcanoes). This idea was supported by later observations through water tunnels excavated for groundwater mining (Navarro 1974; Carracedo 1975, 1979).

In a different approach, Ancochea and co-workers (1990) described the island of Tenerife as integrated by three old massifs located at the three corners of the island, representing independent island edifices, each with its own volcanic history (Fig. 2.11a). Most recently, Guillou et al. (2004) proposed, on the basis of observations from *galerías* and stratigraphic, isotopic, and paleomagnetic data, that a large Miocene shield not only forms the central part of Tenerife, but also extends towards the Anaga massif (Fig. 2.11b, c), underlying the NE Rift Zone and the Anaga volcano (Carracedo et al. 2007, 2011b).

In both models, the eruptive history of Tenerife is consistent with the evolutionary pattern of oceanic islands. It is characterised by the growth of three main shield volcanoes and a period of eruptive quiescence followed by post-erosive rejuvenation volcanism, mainly at the centre of the island.

The first of these old shield volcanoes developed at the central part of Tenerife (the Central Shield, Fig. 2.12a). Erosion and plausibly northbound massive landslides mass wasted the northern, windward flank of the shield, which only outcrops at present in the southwest, leeward flank of the island, and close to the Anaga massif. This geological formation, the oldest outcropping in the island, has been dated by radioisotopic methods ($^{40}Ar$ / $^{39}Ar$ and K–Ar) between 11.6 and 8.9 million years (Guillou et al. 2004).

About 6 My ago Teno volcano grew attached to the western flank of the Central Shield (Fig. 2.12b), which was probably already in eruptive quiescence at that point. The Teno shield developed in a relatively short period, from ca. 6.11 to about 5.15 My (Guillou et al. 2004; Longpré et al. 2009).

Finally, the shield-building stage of Tenerife was completed with the construction of the

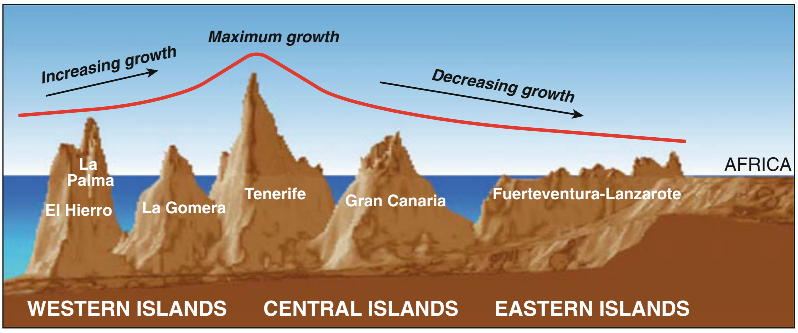



**Fig. 2.9** Computer-generated cross section of the Canary Islands, showing age versus height. At present, Tenerife represents the peak of evolutionary development in the Canarian archipelago (Carracedo et al. 1998)

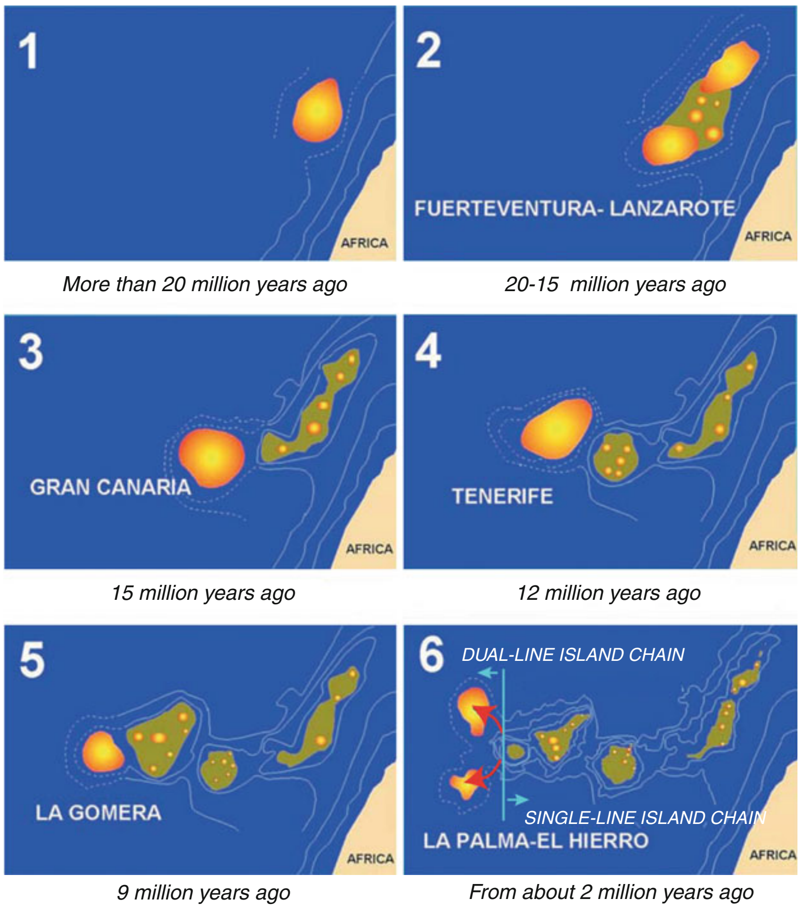



**Fig. 2.10** Sequential surfacing of the Canary Islands. An important feature of the Canary Islands is the lack of significant subsidence compared to other hotspot archipelagos, such as the Hawaiian Islands. If the subsidence rate in the Canary Islands were similar to that of the Hawaiian Islands, only La Palma and El Hierro would still exist as islands (modified from Carracedo 1999)

Anaga shield on the opposite side of the island, at the end of the northeast prolongation of the Central Shield (Fig. 2.12c). The Anaga volcano development took place in the interval from about 4.89 to 3.95 My (Guillou et al. 2004; Walter et al. 2005).

The main constructive activity in Tenerife ended about 3.5 My ago with the completion of

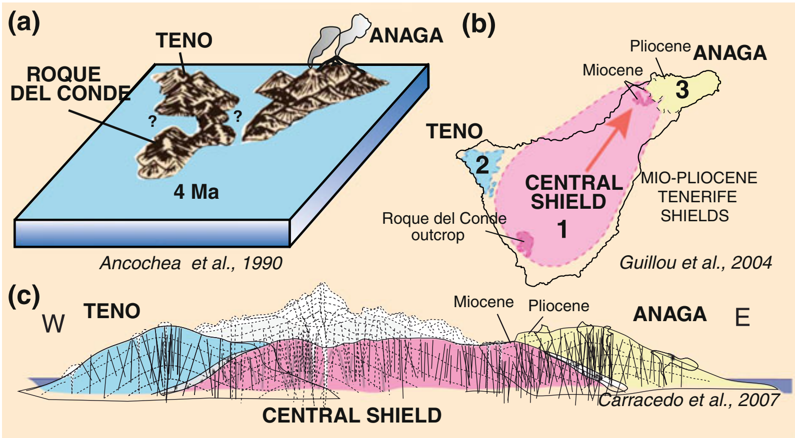
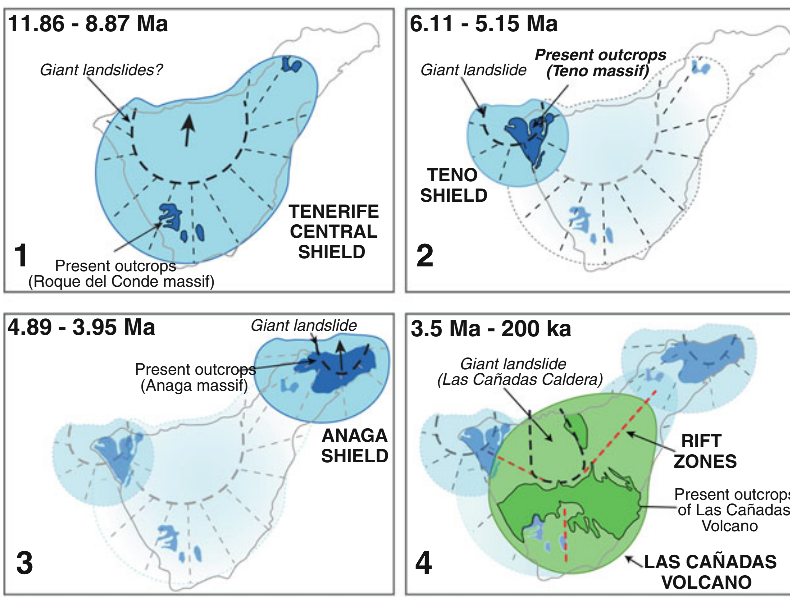



**Fig. 2.11** **a** Ancochea and coworkers (Ancochea et al. 1990) described the island of Tenerife as the integration of three old massifs located at the three corners of the island, representing independent edifices, each with its own volcanic history. **b** An alternative idea proposed by Guillou et al. (2004) of the extension of the Central Miocene shield towards the Anaga massif underlying the NE rift zone and the Anaga volcano. **c** Cross-section showing the relative spatial arrangement of Tenerife shield volcanoes (Carracedo et al. 2007)

**Fig. 2.12** Successive stages and associated main geological features in the development of Tenerife shield volcanoes and the posterosional rejuvenation central composite Las Cañadas Volcano




the three large shield volcanoes that, combined, form the bulk (90 %) of the present volume of the island. The main phase of activity of the Central Shield volcano ceased about 9 million years ago, entering a long (5.5 My) interval of volcanic repose and erosion (erosive gap), coinciding with the main phases of construction of the Teno and Anaga shields.

### 2.7.2 The Rejuvenation Stage of Tenerife: Las Cañadas Volcano

Renewed volcanic activity at the centre of the island formed Las Cañadas Volcano (Fig. 2.12d), from about 3.5 My ago (Ancochea et al. 1990, 1999; Huertas et al. 2002).

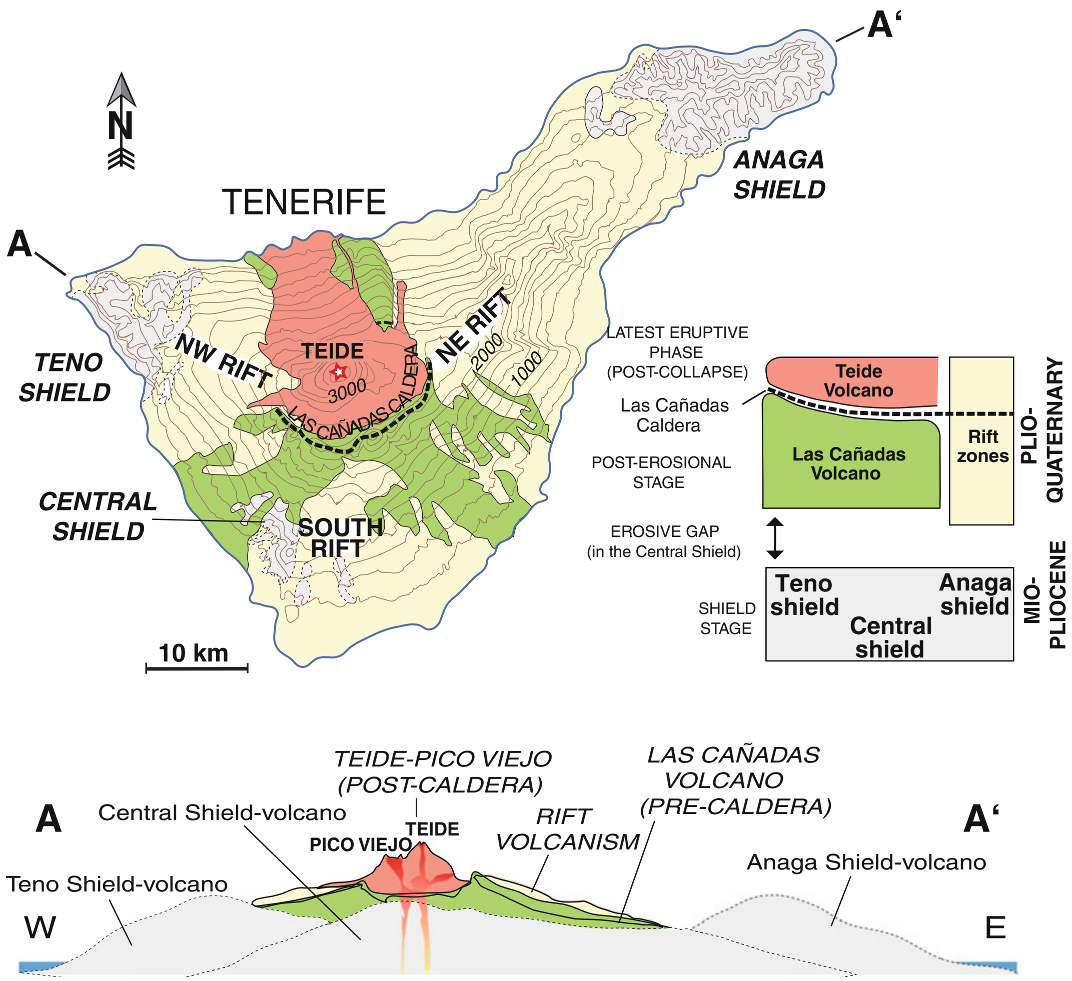



**Fig. 2.13** Simplified geological map and cross-section of the post-erosional rejuvenation volcanism of Tenerife, the coeval central felsic Las Cañadas Volcano and the basaltic rift zones

This is the most visible stage of the volcanism of Tenerife, since the main part of the Teide Volcanic Complex (TVC) represents the latest stage of growth of Las Cañadas Volcano (LCV). The coeval activity in the last 3 My of the rift zones (Chaps. 4, 5) and LCV, the latter with abundant central felsic volcanism and the former with predominant fissural basaltic eruptions, cover most of the island's surface, blanketing the outcrops of the shield volcanoes already described (Fig. 2.13).

The LCV has been extensively studied (e.g., Booth 1973; Wolff 1983, 1987; Martí et al. 1990, 1994; Bryan et al. 1998; Ancochea et al. 1999; Cantagrel et al. 1999; Edgar et al. 2002, 2007; Huertas et al. 2002; Brown et al. 2003; Brown and Branney 2004; Pittari et al. 2005, 2006).

According to Ancochea et al. (1999), the LCV developed in three successive phases separated by large scale flank collapses (Fig. 2.14). Phase 1 was predominantly effusive and basaltic, but in phases 2 and 3 eruptions were more differentiated (trachybasalts and phonolites) and more explosive. In these phases, plinian episodes erupted pyroclastic falls and pyroclastic

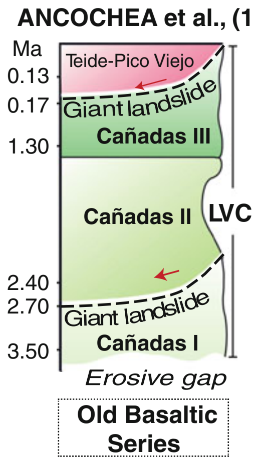



**Fig. 2.14** Stratigraphic model for the Cañadas Edifice (modified from Ancochea et al. 1999)

flows, which were predominantly directed by dominant winds to cover the southern flank of the island. Martí et al. (1997) proposed three main basaltic-to-phonolitic cycles of development for the Las Cañadas Volcano, each cycle initiated with mafic or intermediate eruptions that then evolved towards phonolitic products.

This succession of events seems to point to the simultaneous existence and interaction of rift zones and the felsic Las Cañadas Volcano. The former are probably responsible for the basaltic (fissural) eruptions and the successive flank collapses mentioned by these authors. In this context, the development of Las Cañadas Caldera and the TVC could represent the pinnacle of this latest of cycles.

It is therefore possible that several cycles with similar characteristics occurred before the TVC developed. However, these cycles took place in a posterosional island, where rift zones should be expected to have considerably lower energy than the rifts on ocean-island volcanoes in their mainstage of development (e.g., La Palma, El Hierro, Mauna Loa, and Kilauea). Therefore, the most probable future scenario is that their intensity will likely decline, although this does not imply that the TVC will be the last cycle of its kind to take place on the island of Tenerife.

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