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From Myth to Science: The Contribution of Mount Teide to the Advancement of Volcanology

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Abstract

This chapter outlines the progress of geological research into the origin and evolution of the Teide Volcanic Complex within the framework of Tenerife Island, the Canary Islands, and oceanic volcanism in general. Initially considered to relate to either the entrance to 'Hell' or to mythical Atlantis, for von Buch, von Humboldt, Lyell and the other great eighteenth and nineteenth century naturalists Teide eventually helped to shape a new, and at that time revolutionary concept; the origin of volcanic rocks from solidified magma. This school of thought slowly cast aside Neptunism and removed some of the last barriers for the development of modern Geology and Volcanology as the sciences we know today. Despite the volcanic nature of the Canaries having been already recognised by the twentieth century, modern geological understanding of the archipelago progressed most significantly with the advent of plate tectonics. While some authors still maintain a link between the Canaries and the Atlas tectonic regime (see also Chap. 2), geological research truly advanced in the Canaries through comparison with hotspot-derived archipelagos, particularly the Hawaiian Islands. This approach, initiated in the 1970s, provided a breakthrough in the understanding of Canary volcanism, demonstrating Tenerife and Teide to be one of the world's most interesting, complex and to many, one of the most iconic of oceanic volcanoes.

1.1 Introduction

European volcanoes such as Etna and Vesuvius have been constant references in Volcanology since Greek and Roman times. Detailed and accurate accounts, most notably the description by Pliny the Younger of the 79 A.D. eruption of Vesuvius that destroyed Pompeii and Herculaneum, laid the foundations of modern Volcanology. Volcanic terminology as common as

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"volcano" and "basalt" were first used in accounts penned by Pliny the Elder, as was "crater" by Aristotle. Etna and Vesuvius became historically relevant because of their frequent catastrophic eruptions that destroyed entire cities, such as Catania, in 1669, or Naples, in 1631, both causing many thousands of victims.

In contrast, the only aspect of interest of Mt. Teide until the eighteenth century was its exaggerated height (Figs. 1.1, 1.2). Teide was considered the highest mountain on Earth until Mont Blanc and the Andean volcanoes were measured and observed to be higher. It is interesting to note, however, that present-day Volcanology has reinstated Teide amongst the highest volcanic structures on the planet (only surpassed by Mauna Loa and Mauna Kea, on the island of Hawaii). If the base level is taken to be the ocean floor and not sea level, Mt Teide rises above 7,000 m (3,718 m a.s.l.).

While Vesuvius and Etna defined important catastrophic episodes in the history of Italy from Roman times to present, Teide volcano only posed a threat to the smaller population of aboriginal inhabitants on the island of Tenerife (the Guanches). The absence of explosive eruptions and victims since the colonisation of Tenerife at the end of the fifteenth century promoted the image of Teide as the main stable element in the landscape of the entire archipelago and as a prime cultural reference, even locally acquiring a protective role in folklore for example as "Father Teide". The eruptions on Tenerife in historical times have had a limited impact on the population and the economic infrastructure of the island, with the exception of the 1706 eruption which partially destroyed the town of Garachico and filled the harbour with lava (the main commercial port in Tenerife at the time). This eruption, however, was not directly related to Teide, its vent being located 17 km away on the NW rift zone.

The role played by the Canaries and Mt. Teide changed lastingly upon the arrival of well established naturalists such as Leopold von Buch, Charles Lyell, Alexander von Humboldt and Georg Hartung, among many others. During the eighteenth century, geology was at the centre of a long-lasting controversy between those who held the view that all rocks, including what we now see as volcanic rocks, were marine deposits formed by chemical precipitation in the ocean (Neptunists, after the god of the sea in Roman mythology) and those who believed that volcanic rocks resulted from the solidification of molten masses from the Earth's interior (Plutonists, after Pluto, Greek god of the underworld).

The former school, led by Abraham Gottlieb Werner (1750–1817), a renowned German professor of Geology (Fig. 1.3), and the latter by the Scot James Hutton (1726–1797), established a lively debate with strong religious overtones that lasted almost an entire century. The neptunistic theories rigorously adapted the teachings of the book of Genesis, contrasting the more "enlightened" ideas of the plutonists. The controversy contributed decisively to the development of Geology as a modern science and was based to quite an extent on the observations made in the Canaries by the now famous eighteenth century naturalists.

The relevant role of the Canaries and Mt. Teide in the resolution of crucial problems in Geology and Volcanology arose from the European continent, particularly from Germany, France and Scotland, due to the fact that the volcanic settings in those countries are much more difficult to interpret than Canarian volcanoes. Fervent neptunists and co-workers of the influential Professor Werner, such as von Buch and initially even von Humboldt himself, who had expressed numerous doubts, gradually became ardent defenders of plutonism after travelling to the Canaries, thereby irreversibly opening the door to the advancement of purely scientific Geology that was largely free from religious restrictions. To von Buch we owe the basic concept that minerals in lava are formed by magmatic crystallisation and to von Humboldt that volcanic alignments are due to tectonic activity at depth.

Regrettably, the essential role of the Canaries and Mt. Teide during this important stage in the development of modern Geology and

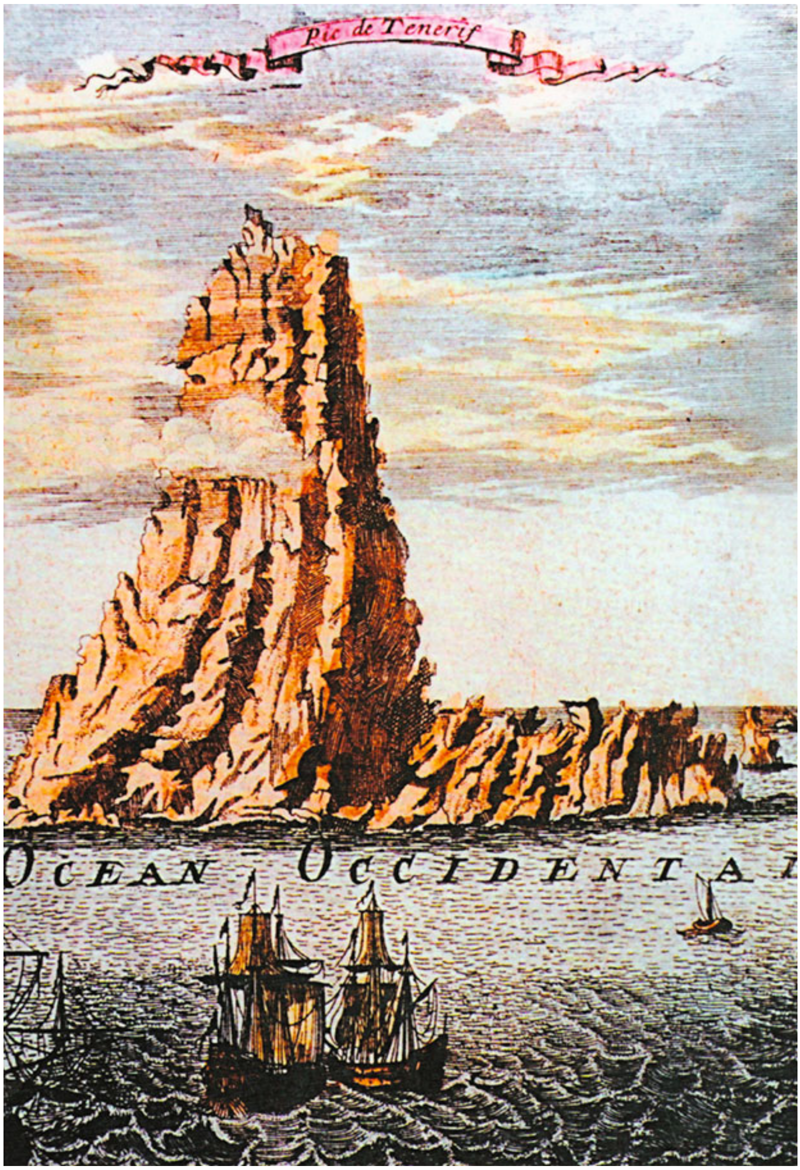


Fig. 1.1 The island of Tenerife and a towering Mount Teide in an engraving by Olfert Dapper in 1686

Volcanology did not continue. There were no research groups or centres in Spain or the Canary Islands at that time devoted to the discipline of Geology. Nonetheless the Canary Islands offered a privileged setting in which to study the Geology of oceanic islands, made possible by exceptional conditions: the absence of significant subsidence, allowing observation of all stages of evolution starting with the oldest formations. This is impossible in most similar archipelagos, where subsidence is a relevant factor causing the insular edifices to be submerged during relatively early stages of their evolution and the scant plant cover and low relative meteorisation rate of rocks and formations, being much lower in the Canaries because of the comparatively low rainfall. These favourable circumstances converted the Canaries, and Teide and the surrounding area in particular, into a world-renowned setting for the study of Volcanology, but this was not understood until the second half of the twentieth century.

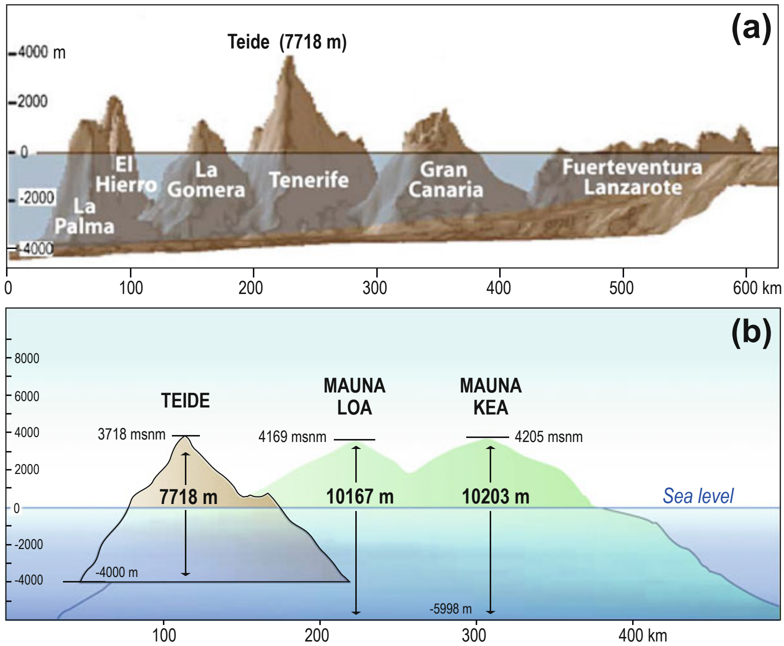


Fig. 1.2 **a** and **b**. Teide is by no means earth's highest mountain, as was generally accepted until Mont Blanc was measured (the first recorded ascent of Mont Blanc, 4,810 m, was in August 1786). However, besides having the highest elevation in the Canaries and Spain, it is the third highest volcanic feature on earth, with only Mauna Kea and Mauna Loa being higher

Fig. 1.3 Werner described the basalts of Stolpe (the birthplace of Leopold von Buch) as sediments without traces of melting. He interpreted the columnar features as desiccation cracks, like those found in drying mud

Establishment of the Hawaiian Volcano Observatory (HVO) by the U.S. Geological Survey at the beginning of the twentieth century is acknowledged as the key element in advancing the study of the Hawaiian Islands and leading to the development of modern Volcanology. Although an intense and continuous study of the Canaries began shortly thereafter, during the 1960s, there is a fundamental difference: while in Hawaii the above-mentioned

Observatory was a centre for the great majority of volcanological studies since 1912, a similar centre was never created in the Canaries, but research was led from Madrid, with the corresponding loss of efficiency and the dispersion of efforts, hindering the possibility that the Canary Islands could have become a similar world-famous setting for the development of Volcanology some 100 years ago.

This is exemplified in the development of volcanological terminology employed in the eighteenth and nineteenth centuries derived from Latin (volcano), Greek (crater, pyroclast, phonolite, etc.) and, to some degree Canarian Spanish (caldera, *malpaís*), but American English was the language used, coinciding with the creation of the Hawaiian Volcano Observatory, since the start of the twentieth century (hotspot, pillow lavas, surge, shield volcano, etc.) and especially Hawaiian terms (e.g., pāhoehoe and ‘a‘ā lavas) became internationally accepted.

1.2 Teide Volcano in Classical Mythology

There have been some references to Teide, mainly of a mythological nature, in the Classical Era. The best-known and most enduring legend involving the Canaries is the one related to Atlantis, narrated by the Greek philosopher Plato (427–347 BC) in his work Timaeus and Critias. According to this legend, a civilisation, the Atlantean, as advanced and powerful as the Egypt of the Pharaohs, disappeared overnight when the continent sank into the ocean. Only the highest peaks remained above water, to form the archipelagos of Macaronesia: Azores, Madeira, Cape Verde and the Canaries.

It is through Jean Baptiste Bory de Saint Vincent that this legend became scientifically significant in relatively modern times, when he related the Canaries to Atlantis during a visit to the archipelago, described in his work entitled *Essais sur les Îles Fortunées et l’Antique Atlantide* (Kunzli 1911). Acknowledged as a distinguished naturalist, Bory de Saint Vincent conferred scientific credibility on this legend, which was considered to be one of the possible theories of the origin of the Canaries until the mid-twentieth century. It was only when the Canaries were found to overlie oceanic crust, which moreover is more than 180 million years old, that any scientific basis ascribed to this attractive legend was radically dismantled.

However, reality exceeds even the most imaginative legends. Plato would probably have been stunned by a story involving an entire continent (Africa) moving several thousand kilometres away from America over more than 180 million years to form an ocean (the Atlantic) through which, more than 20 million years ago, the volcanic Canarian Archipelago was formed by a magmatic plume originating from the Earth’s interior at a depth of almost 3,000 km, and producing at its highest point, Teide, stretching vertically over 7,000 m from the ocean floor.

1.3 Mt. Teide in the Pre-Hispanic World

For the Pre-Hispanic population of Tenerife (the Guanches) Teide was the dwelling place of Guayota, an evil mythical creature, god of the deceased and identified with Hell (von Fritsch and Reiss 1868). The Guanches therefore envisioned Mt. Teide as a demonic spiritual force that brought death and destruction, quite the opposite of the image it adopted later in Hispanic Canarian folklore. The fear and superstition of the Guanches developed as they lived alongside the volcano and may have witnessed at least 6, possibly 8 of its eruptions, mostly around the base of the stratovolcano and on the NW Rift. On the other hand, they learnt how to take advantage of the resources provided by volcanism: the *cañadas* (flat, pumice-covered paths) for the seasonal migration of their goat herds; the volcanic rocks for building their huts, and the caves and volcanic tubes for occasional shelter. They were adept at mining the glassy volcanic obsidian, with which they skilfully fashioned cutting tools.

Similarly to most nomadic tribes, it is very possible that they used fire to clear the land of brush in order to make new pastures for their livestock, thus providing the source of several references to eruptions on Teide reported in ships' logs. As an example, the pre-historical age (1430 AD) for the volcanic cones nested in the La Orotava Valley comes from a Guanche oral tradition, reported by Humboldt on his journey to Tenerife in 1799. However, charcoal underlying lapilli from this eruption yielded a ^{14}C age of 29.090 ± 190 years BP, and the lavas, a ^{39}Ar/^{40}Ar age of 27.000 ± 5.900 ky (Carracedo et al. 2010). The Guanche tradition seems to fit better with the calibrated radiocarbon age of 590 ± 66 years BP, most probably related to a forest fire, obtained from charcoal underlying a pumice deposit mantling the Orotava Valley, probably from the Montaña Blanca eruption (Figs. 1.4, 1.5) (Carracedo et al. 2007).

Only a few Guanche words have survived, mostly in geographical and toponymical terms. The very name of Teide has its origin in the Guanche term *Echeide* (Hell). It is surprising, however, that this name was given to Teide and not to the island of La Palma, where volcanoes have been much more active during the Guanche period, causing several victims amongst the local population (Rodríguez Ruiz et al. 2002). Perhaps it was the continuous fumarolic activity at Teide's summit (with temporal emission of hot sulphurous gases forming a plume that may occasionally have been quite voluminous) that contributed to Teide being named after Hell, as eruptive activity on Teide's cone itself was limited to a single eruption during the Guanche Pre-Hispanic period (Carracedo et al. 2007).

1.4 References in the Fourteenth and Fifteenth Centuries

The first references to volcanic eruptions in Tenerife are limited to distant sightings by fifteenth century sailors, who used Teide as a natural landmark during their voyages across the

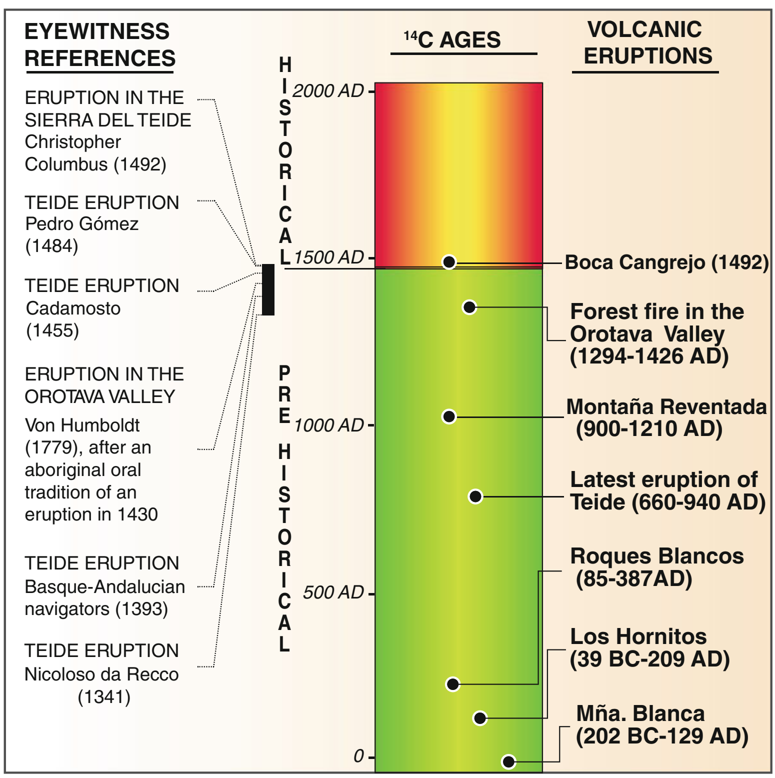


Fig. 1.4 Eyewitness references to supposed volcanic eruptions of Teide volcano (*left*) and actual geological events in the last 2000 years in Tenerife (of historical age or C^{-14} dated; *right*). The alleged date of the eruption in the Orotava Valley (1430 AD) coincides with an extensive forest fire in the valley dated at 1294–1426 AD (modified from (Carracedo et al. 2010)

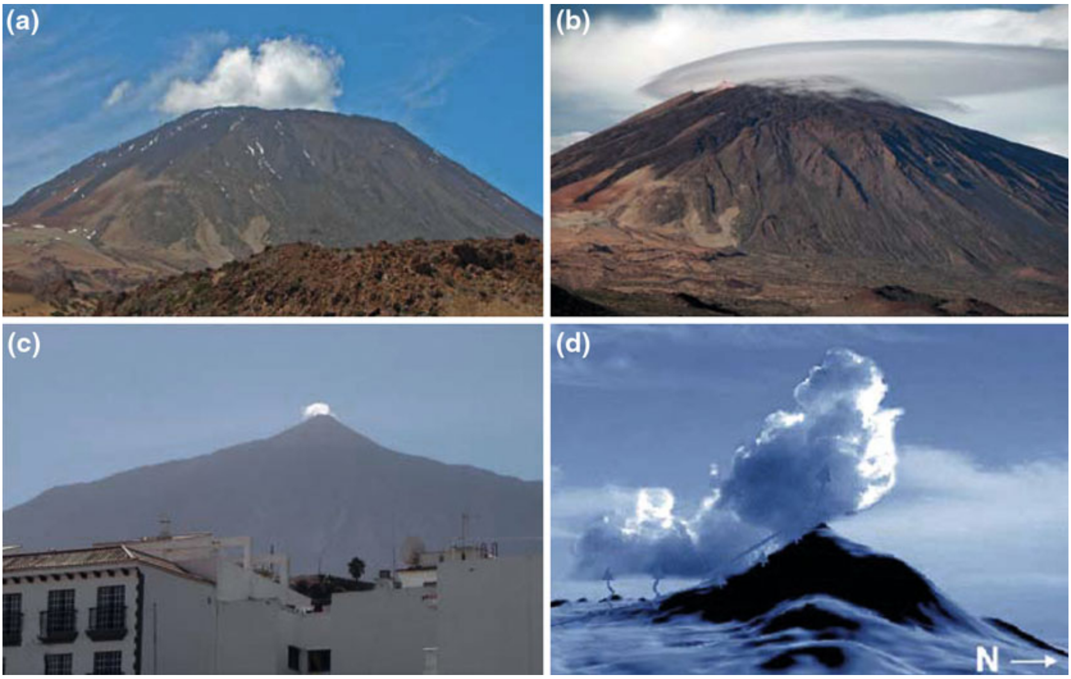


Fig. 1.5 **a**, **b**. Frequent spectacular 'plumes' in the summit area of Teide, locally known as 'Teide's headdress'. **c**. Small plume at the top of Teide in October 2004, initially interpreted as evidence of volcanic reactivation causing considerable alarm, later confirmed as a meteoric cloud (La nube que quiso ser protagonista. EL DÍA. Santa Cruz de Tenerife, 21-10-2004). **d**. Model of the formation of clouds at the summit of Teide volcano by local orographic convergence (Álvarez and Hernández 2006)

Atlantic because of its great height. Many of those references include descriptions of possible volcanic eruptions.

An account of a possible eruption of Teide contained in the ship's log kept by Nicoloso da Recco, copied by Boccaccio, was put forward by Santiago (1948) as indicating a Teide eruption: "*it must be remembered that, in 1341, the Italians, Castilians and other Spaniards who accompanied Recco observed that smoke issued from the Peak*" (Friedlander 1915).

However, the original source, the account by Giovanni Boccaccio ("About Canaria and other islands newly found in the ocean beyond Spain" 1341) clearly describes a well-known meteorological phenomenon, the so-called "Teide's headdress" (Fig. 1.2), a cloud that forms over the summit area due to an adiabatic process similar to the foehn effect: "*They found an island at which they did not wish to disembark because a certain wonder occurred there. A mountain is said to exist there, which, according to their calculations, is thirty miles high, or even more… at whose summit there is a mast the size of a ship's, from which hangs a large lateen sail, taut as a shield, that swollen with the wind extends over a large area, only to appear to decrease little by little, as in ships, to rise again at once, always in this same manner.*"

It is quite surprising that this accurate description of an atmospheric feature—clouds at the summit of Teide volcano that formed by local orographic convergence—has been interpreted as eruptions of Teide even in very recent scientific articles, using this feature to assess the probability of the eruptive hazard of the volcano. It is equally surprising that the development of one of these clouds over Teide on October 20, 2004 was believed to signal the onset of an eruption and caused great alarm among the residents of the island. Scientific and technical personnel continued relating this cloud to an eruptive column, asserting that this phenomenon was related to an increase in seismic activity observed at the time.

Another description of a possible eruption dates from 1393, the original source being the accounts of Andalusian and Basque seamen included in the chronicles of King Henry III, quoted for the first time in 1839 by Webb and Berthelot (Hausen 1955). That account states that "*on coming closer to the island they saw flames and smoke issuing from the highlands, whereupon they did not dare to disembark and sailed away from what they then began to call Hell Island*". Since the last Teide eruption has been dated at a much earlier date (eighth century), this putative eruption does not fit into the history of the volcano, and probably reflects a meteoric phenomenon.

A further reference to a possible eruption of Teide is that of Ca'da Mosto (*Il libro de la prima navegazione per l'Oceano alle terre de Negre de la Basse Etiopia*, 1455), citing "*Tenerife, the most populated of the islands and one of the highest on Earth…and in clear weather a mountain can be seen from a great distance burning continually in the centre of the island*". The radiometric ages obtained do not allow any leeway for a known eruption of Teide in that period (Fig. 1.4), thus these seafarers were most probably describing fumarolic activity at the peak, forest fires or the spectacular meteorological phenomena above Teide.

1.5 References to Teide Volcano at the Dawn of Science: The Renaissance and Baroque Periods (Sixteenth and Seventeenth centuries)

Rather than studying Teide as an active volcano, a task that would be approached centuries later, during the pre-scientific period in which the magical vision of the mountain was maintained, the most important issue was identifying its position and altitude (for navigational purposes).

Teide was surrounded by a mystical aura and believed to be the highest mountain on Earth until the altitude of Mont Blanc was measured. It was said that the sun seemed to be closer when viewed from the peak of Teide and that the heat was irresistible. In fact, Teide is a mountain that is relatively easy to climb (the custom nowadays is for all Canarians to climb the volcano on foot at least once, but there is also access by cable car). Back then, it seemed an extraordinary challenge, however. It is therefore not surprising that the main objective of the early scientists visiting the Canaries was to make the ascent to the Peak of Teide (Fig. 1.6).

If we examine the altitudes assigned to Teide until the latter part of the seventeenth century (see Fig. 1.1) one notes that they are expressed in miles and even leagues (about 3 miles), while the more suitable method of measuring in toises (190 cm approx.) or fathoms (90 cm approx.) was only introduced in the late seventeenth century.

In 1631, an eruption of Vesuvius that generated "torrens cineris" or torrents of ash—known today as pyroclastic flows—caused more than 4,000 victims. Shortly thereafter, in 1669, Mt. Etna erupted catastrophically, devastating one third of the area of Catania. Those catastrophic events prompted the study of volcanoes. At that time, the newly explored Andean volcanoes were the subject of continual reports, with even greater altitudes and with yet more frequent eruptions.

The scenario was prepared for the crucial visits and observations of the great naturalists of the eighteenth century—von Buch, von Humboldt, Lyell—fully exploiting the possibilities afforded by the industrial and cultural revolution at that time for exploration and scientific progress.

In the mid-seventeenth century, the scientific revolution (Galileo, Descartes, Newton, etc.) established the firm basis of a fundamental tool, the application of scientific method, in contrast with prevailing religious beliefs. Teide would no longer have strong magical connotations and would instead slowly transform to the theme of research it has become today.

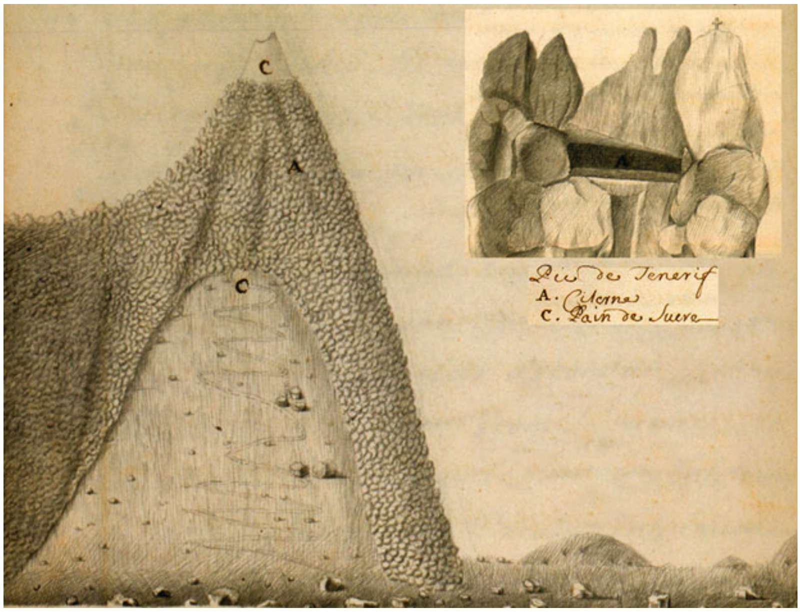


Fig. 1.6 Drawing by Louis Feuillée of the "Pic de Tenerife" (Teide Volcano) and the summit cone (Pain de Sucre or Sugar Loaf, Pan de Azúcar in Spanish) (Feuillée 1724). The path to climb the volcano and a natural reservoir (holding melting ice) are shown as facilities for the ascent

1.6 The Contribution of the Great Eighteenth and Nineteenth Century Naturalists

The main objectives early in this epoch were the ascent of Teide and measuring its altitude. The exact height was crucial for ships to calculate their position by means of simple trigonometric approximations (Figs. 1.7, 1.8, 1.9).

The Royal Academy of Sciences of Paris commissioned the astronomer Louis Feuillée in 1724 to set the precise position of the first meridian (on the island of El Hierro) and the altitude of Teide (see Fig. 1.7). Feuillée's measurement (2193 toises or 4,274 m) was considered incorrect and remained unpublished. In 1776, Jean Charles Borda, sent by the Royal Academy of Sciences of France to Tenerife with the same objective, obtained a value of 1905 toises (3,713 m), very close to the true elevation of 3,718 m (Borda 1776). Even Alexander von Humboldt, who arrived in Tenerife in 1779, was unable to improve Borda's work, which remained the best measurement of Teide's altitude until 1851 (Fig. 1.10).

However, the importance of Humboldt's visit to Tenerife was not only related to the accurate assessment of Teide's altitude, but to his geological and volcanological observations. Despite the fact that von Humboldt was a former student of Abraham Gottlieb Werner, the founder of the school of Neptunism, he completely changed his

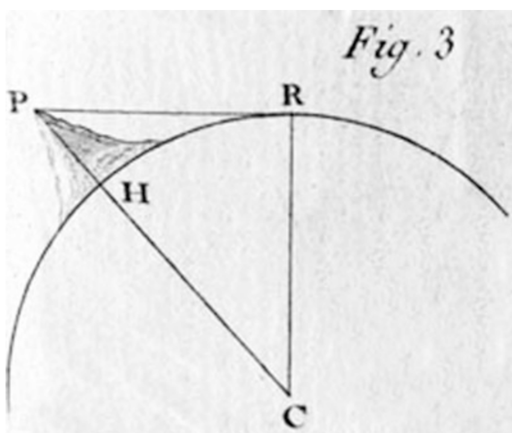


Fig. 1.7 The exact elevation of Teide was important to determine the position of ships by trigonometric calculations (d'Eveux Claret de Fleurieu 1773)

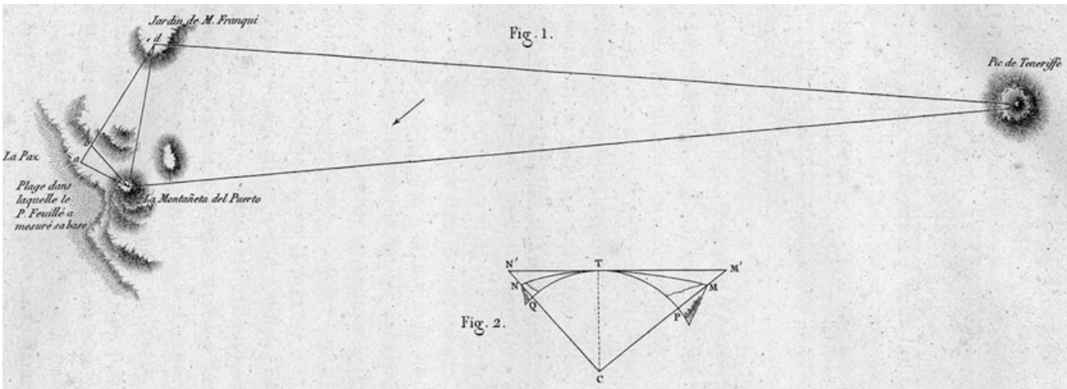


Fig. 1.8 Measurement by triangulation of the altitude of Teide volcano made by Borda in 1776 (Preiswerk 1909)

Fig. 1.9 Painting from the epoch of the measurement of Teide's elevation. Here, a view at the summit of Montaña Taoro (Montañeta del Puerto in the drawing of Fig. 1.8), one of the stations used in the triangulation

ideas after travelling to Tenerife and observing the island's volcanism, particularly Teide volcano and the recent eruptive vents and flows around the stratocone. His former idea that the German basalts were formed through chemical precipitation, crystallisation and deposition in the sea could not resist confrontation with Tenerife and Teide's volcanism, and he eagerly admitted that these rocks were formed by volcanoes. On this journey, he became a qualified and enthusiastic promoter of Plutonism and modern Geology, and of Teide volcano itself, through his prolific scientific writings and lectures (Preiswerk 1909).

Giovanni Bocaccio	1341	30 miles	
Alvise Ca'da Mosto	1455	60 Italian miles	
André Thevet	1555	18 marine leagues	
Thomas Herbert	1624	15 miles	
Bernhardus Varenius	1650	4 miles and 5 furlongs	
Edward Barlow	1668	27 miles	
Allain manesson Mallet	1683	15 miles	
Robert Challe	1690	2730 toises	5320 m
Louis Feuillée	1724	2193 toises	4274 m
Manuel Hernández	1742	2658 toises	5180 m
John Cross	1742	2408 toises	4693 m
Thomas Astley	1744	2,25 miles	4162 m
Michel Adanson	1794	2052 toises	3999 m
Jean Charles Borda	1776	1095 toises	3713 m
Alexander von Humboldt	1799		3736 m
Charles Phillipe de Kerhallet	1851		3715 m
Charles Piazzi Smyth	1856		3717 m
Parque Nacional del Teide	1954		3718 m

Fig. 1.10 Recorded elevation of Teide volcano through history

Leopold von Buch, also a former student of Abraham Gottlieb Werner and an ardent neptunist, visited Tenerife in 1815 following Humboldt's advice. He also was soon persuaded of the volcanic origin of Teide and the surrounding Las Cañadas Caldera; contradicting Werner, he admitted that volcanism is one of the main processes on Earth. However, after taking this

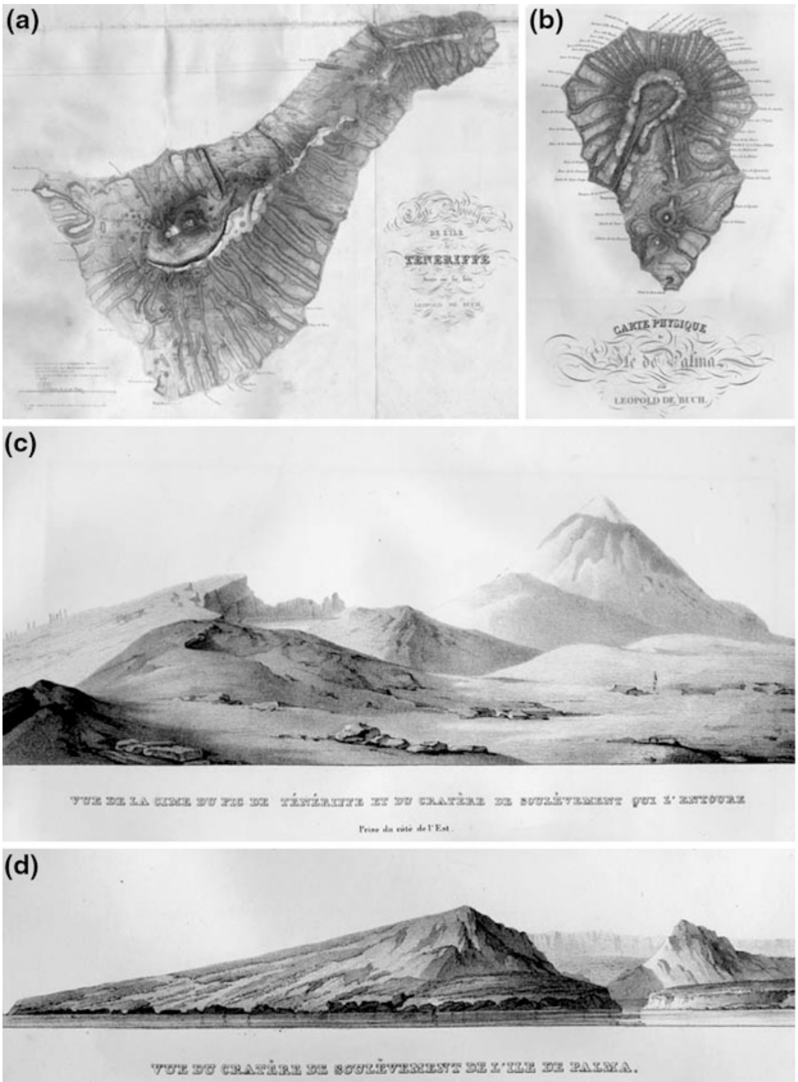


Fig. 1.11 To Leopold von Buch, Tenerife and La Palma were the prototypical examples of uplifted craters (or "craters of elevation", to distinguish them from eruption craters). The islands had been thrust upwards and then collapsed at their centres to form an uplifted crater or "caldera", a term that he took from La Palma. In this theory, that surprisingly had immediate success, the island was not the result of lava accumulation but "emerged ready-made from the interior of the earth". **a** Map of the island of Tenerife by Leopold von Buch (Jeremine 1930). **b** Map of the island of La Palma by Leopold von Buch (Jeremine 1930). **c** The Pic de Tenerife (Mt. Teide) and the encircling "uplifted crater" (the Caldera de Las Cañadas) viewed from the east in a drawing by Leopold von Buch (Jeremine 1930). **d** View from the west of the "uplifted crater" of La Palma in a drawing by Leopold von Buch (Jeremine 1930)

crucial step forward, von Buch took one step backwards with his theory of Craters of Elevation (*Erhebungscrater*), interpreting the Caldera de Las Cañadas and the Caldera de Taburiente (La Palma) as prototypical examples (Dittler and Kohler 1927) (Fig. 1.11a–d).

The Craters of Elevation theory was definitively abandoned when Charles Lyell, a student of James Hutton (the founder of Plutonism), arrived in the Canaries in 1853 to prove that the islands were formed by accumulation of successive eruptions, and that their calderas were not caused by uplift, but by collapse and erosion.

These great eighteenth and nineteenth century naturalists provided a crucial scientific basis for the development of modern Geology and Volcanology, and many of their ideas are still accepted today. Humboldt expressed concepts that only recently have been accepted by many geoscientists in the Canary Islands. While many of these present day geoscientists still relate seismicity inside the island's edifices to major oceanic fractures, von Humboldt claimed in 1800 that "*large destructive earthquakes have no direct connection with volcanic activities, which are the cause only of small local shocks…*", precisely the current distinction between tectonic earthquakes and local seismicity related to volcanism. It was von Humboldt's idea that "*Very high volcanoes have fewer eruptions than those of low altitude, because it is more difficult for lava to ascend them*", a clear explanation of the physical filter imposed on summit eruptions (particularly the heavier basanitic and basaltic magmas) in stratocones such as Mount Teide when magmas reach a critical height, favouring the eruption of lighter, phonolitic ones and eventual focus of vents on the volcano's periphery.

A lost opportunity was the frustrated visit of Charles Darwin to Tenerife. Inspired after reading Alexander von Humboldt's account of his ascent of El Teide, Darwin arrived in Tenerife in 1831 as the expedition naturalist aboard the HMS Beagle. However, as Darwin reports "*After heaving to during the night we came in sight of Tenerife at daybreak… The peak or sugar loaf has just shown itself above the clouds. It towers in the sky twice as high as I should have dreamed of looking for it. Oh misery, misery, we were just preparing to drop our anchor within half a mile of Santa Cruz when a boat came alongside bringing with it our death-warrant. The consul declared we must perform a rigorous quarantine of 12 days. Matters were soon decided by the Captain ordering all sail to be set and make a course for the Cape Verde Islands… And we have left perhaps one of the most interesting places in the world, just at the moment when we were near enough for every object to create, without satisfying, our utmost curiosity*". The reason to prevent Darwin from going ashore was the cholera outbreak in England in 1831. No doubt Darwin's visit could have made a great difference in the progress of Volcanology!

A significant advancement in the geological knowledge of Tenerife and Teide Volcano came with the work in the second half of the nineteenth century of the German geologists Fritsch, Hartung and Reiss (von Fritsch 1867). The first geological map of Tenerife was compiled by W. Reiss, already depicting the main volcano-stratigraphic units of the island, many aspects of which are still valid today (Fig. 1.12).

The main effort in the last decades of the nineteenth century and the first part of the twentieth was addressed to finding a solution for the origin of the Caldera de Las Cañadas and the Orotava and Güímar Valleys, once von Buch's earlier "Craters of Elevation" theory was abandoned. To Fritsch and Reiss, the two morphological depressions forming the Las Cañadas Caldera—divided by the Roques de García large spur—are the headwalls of two main drainage

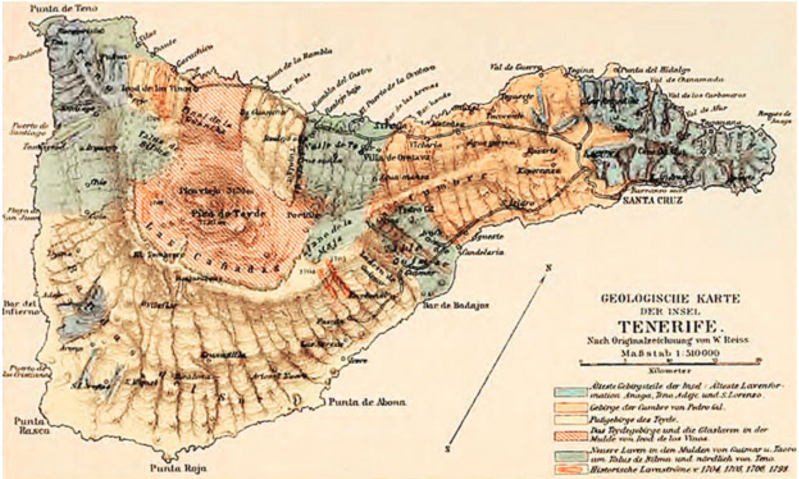


Fig. 1.12 The first geological map of Tenerife (von Fritsch 1867). The main volcano-stratigraphic units of the island are clearly defined: *in blue*, the oldest lavas (the Miocene Shields); *orange*, the Cumbre de Pedro Gil (the NE rift zone); *yellow*, the flanks of Teide (the Las Cañadas volcano); red stripes, Teide lavas filling the Caldera de Las Cañadas and the Icod Valley; *green*, recent lavas; *red*, historic eruptions (Meyer 1896)

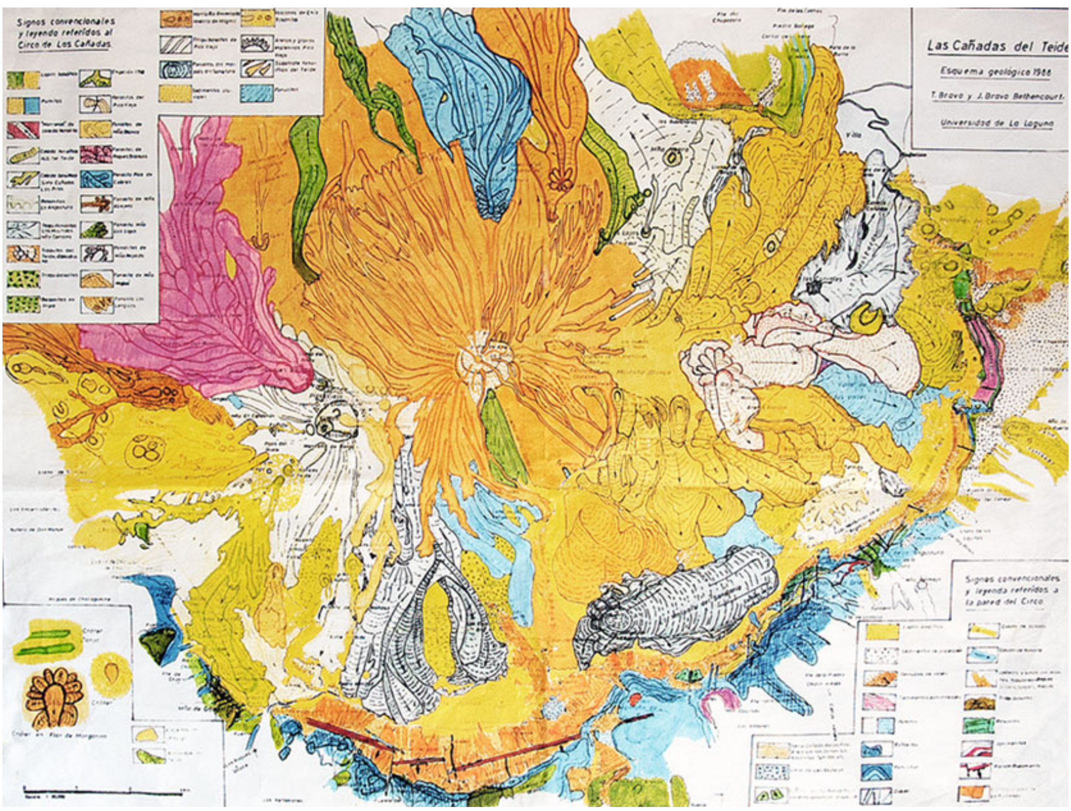


Fig. 1.13 Geological sketch map by Bravo-Bethencourt and Bravo (1989); from (Araña and Coello 1989)

systems, the Las Cañadas Caldera being an erosive feature similar to the Taburiente Caldera in La Palma, as proposed by Lyell in 1835 (von Fritsch and Reiss 1868). In contrast, Gagel (1910) postulated an explosive origin, similar to the Krakatau 1883 eruption, whereas Friedlander suggested a collapse caldera, similar to the Somma-Vesuvius complex (Friedlander 1915). Several models combining erosion, explosion and vertical collapse were proposed in the following years (Hausen 1955).

The valleys of La Orotava and Güímar were explained by von Fritsch, Hartung and Reiss as "*intercolline Räume*", valleys formed by lava accumulation at both sides of the depression (von Fritsch 1867).

1.7 Mount Teide in the Framework of Modern Volcanology: The Twentieth and Twenty-first Centuries

Research on Teide Volcano and the Las Cañadas Caldera during the first half of the twentieth century was mainly focused on petrological studies, prompted by the Chinyero eruption in 1909 (Preiswerk 1909; Kunzli 1911; Dittler and Kohler 1927; Jeremine 1930; Smulikowski 1937).

The Symposium of the *International Association of Volcanology and Chemistry of the Earth's Interior* (IAVCEI) hosted in Tenerife in 1968, fostered the geological study of the Canary Islands, particularly Tenerife and Teide Volcano,

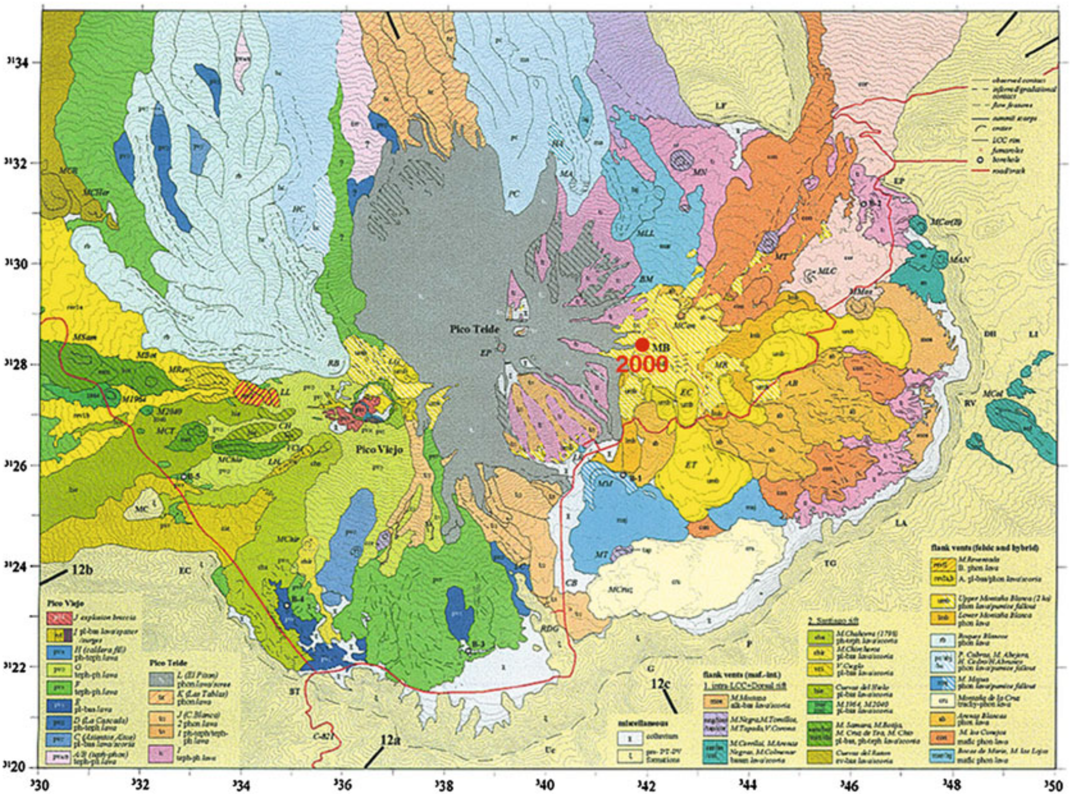


Fig. 1.14 Geological map of the Teide volcanic complex (Ablay and Martí 2000). This map is restricted to the Teide-Pico Viejo stratocones and vents, and the proximal edges of the NW and NE rift zones. Only one radiometric age is provided, which dates the 2 ky eruption of Montaña Blanca (Ablay and Marti 2000)

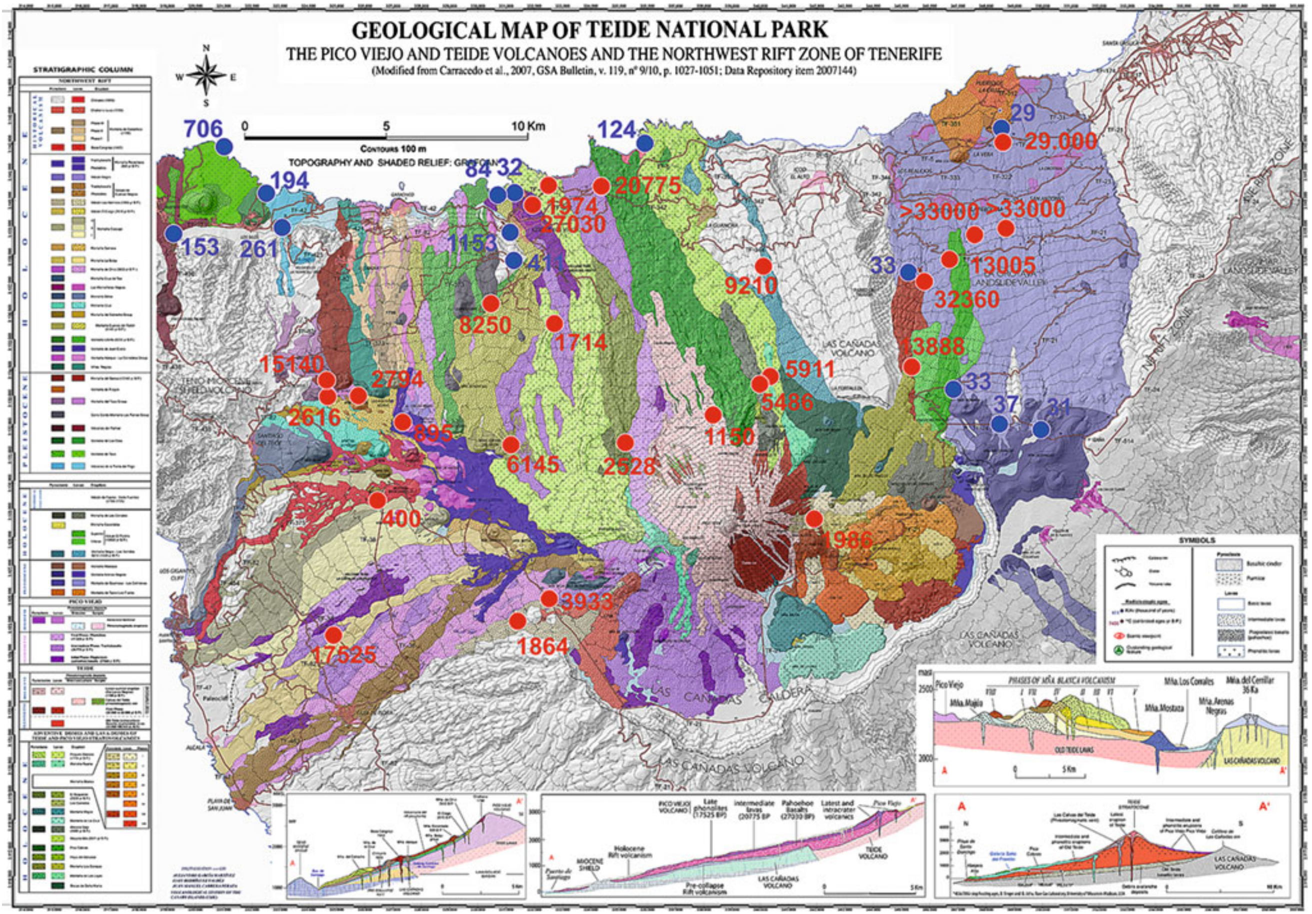


Fig. 1.15 Geological map of the Teide volcanic complex (Carracedo et al. 2007). This map includes the Teide and Pico Viejo stratocones, their vents, and the NW and NE rift zones. The map shows the ^{14}C and new K/Ar ages, on which the reconstruction of the structural and eruptive evolution of the volcanic complex was based. Ages shown in red are ^{14}C in years; in *blue*, K/Ar in ky (modified from Carracedo et al. 2007)

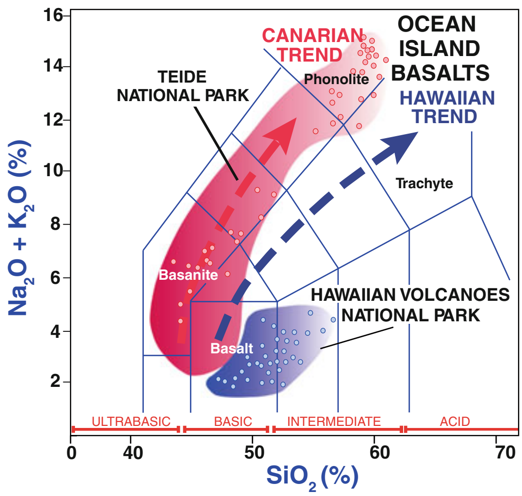


Fig. 1.16 Magmatic series of the Teide volcanic complex and the Mauna Loa and Mauna Kea volcanoes, forming respectively the Teide and Hawaii National Parks. In contrast to the basic magmas of the latter, the eruptions of Teide National Park include more evolved rocks (phonolites, trachytes). Combined, both sites represent the entire series on a large scale, with their corresponding eruptive mechanisms, volcanic features and landforms, justifying both Parks being included in the UNESCO World Heritage list (analytical data from Clague 1987; Rodríguez-Badiola et al. 2006)

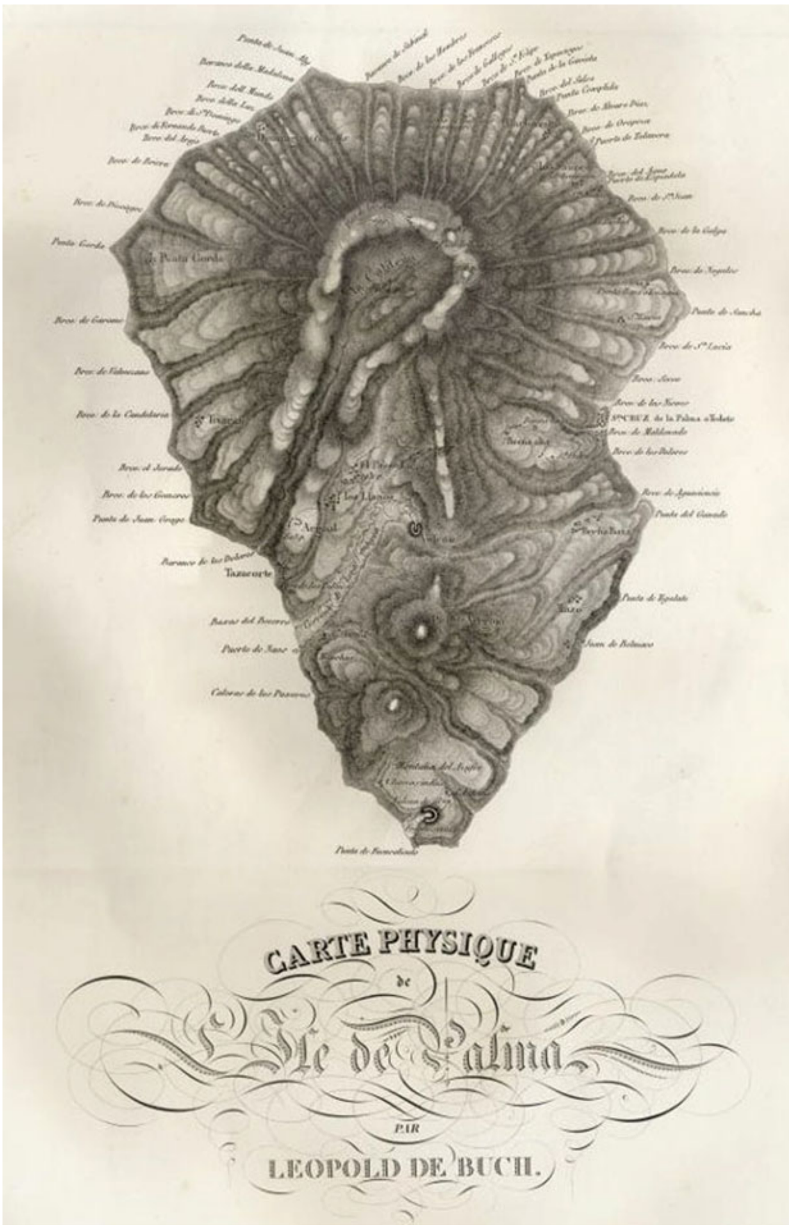
since then a research objective of global interest. Research efforts were directed to the study of the older (>200 ky) pre-caldera Las Cañadas Volcano (Fúster et al. 1968; Ridley 1970; Araña 1971; Booth 1973; Wolff 1985, 1987; Martí et al. 1994; Bryan et al. 1998, 2000, 2002; Edgar et al. 2002; Huertas et al. 2002; Pittari et al. 2005; Bryan 2006; Edgar et al. 2007) and the genesis of Las Cañadas Caldera (Navarro Latorre and Coello 1989; Watts and Masson 1995; Martí et al. 1997; Ancochea et al. 1999; Cantagrel et al. 1999; Marti and Gudmundsson 2000).

However, since 1968, limited progress was made on the reconstruction of the latest (post-caldera) volcanic phase of Tenerife (Fúster et al. 1968). Research was restricted to a revision of the early work and mapping (Navarro Latorre and Coello 1989), although recently petrological and geochemical aspects have improved considerably (von Fritsch 1867; Ablay et al. 1998; Ablay and Marti 2000; Wiesmaier et al. 2011), as well as the analysis of potential hazards of the volcano (Araña et al. 2000; Márquez et al. 2008; Martí et al. 2008).

Particularly surprising is the almost total lack of geochronological information in many recent papers, since dating was restricted to a single age for the Montaña Blanca lava dome at the base of Teide (Ablay et al. 1995). Several authors (Araña et al. 2000) even stated that dating the Teide volcanic complex was unfeasible, due to the impossibility of applying K/Ar and $^{40}Ar/^{39}Ar$ techniques to this period and the absence of suitable organic material (charcoal) for radiocarbon dating. Eventually this proved possible nevertheless, and a set of 54 new ages provided for the first time precise age constraints of the recent eruptive history of Teide Volcano and its associated volcanism (Carracedo et al. 2003, 2007). These new geochronological data form a framework on which to base the understanding of the structural and volcanic evolution of the Teide volcanic complex, and establish a realistic assessment of eruptive history and potential hazards.

Besides the geological maps of the Teide volcanic complex (Figs. 1.13, 1.14, 1.15) other newly developed resources facilitate the study of this geological area. Very accurate topographic maps (1:5000 and 1:10000) with shaded relief DTMs, 1:1000 and 1:500 orthophotographs and other thematic maps can be downloaded from http://visor.grafcan.es/visorweb/.

Teide National Park was inscribed on UNESCO's World Heritage List in 2007 (http://whc.unesco.org/en/list/1258) recognised for its natural beauty and its importance in providing



evidence of the geological processes that underpin the evolution of oceanic islands, complementing those of existing volcanic properties on the World Heritage List, such as the Hawaii Volcanoes National Park (Carracedo 2008).

The contrasting magmatic series of Hawaii and Teide National Parks is probably the basic argument to demonstrate how exceptional Mt. Teide is and how the Teide National Park complements the only listed volcanic National Park in an intraplate island, the Hawaiian Volcanoes National Park (Fig. 1.16). The magmas of Mauna Loa and Kilauea volcanoes located within the Hawaii Volcanoes National Park correspond to the less evolved "basalts" of the magmatic evolutionary series of intraplate islands. In contrast, the eruptions of Teide National Park span the entire series, including the more evolved rocks (phonolites, trachytes). Combined, both sites represent the entire series on a large scale, with their corresponding eruptive mechanisms, volcanic features and landforms, justifying both Parks to be registered

in the UNESCO World Heritage List (in 1987 and 2007, respectively).

The Teide area is a major setting for international research with a long history of influence on Geology and geomorphology, which, as we have seen goes back to the works of von Humboldt, von Buch and Lyell, and which made Mount Teide a significant site in the evolution of Volcanology as a science. Access within the Park is restricted these days, with visitors confined to marked paths and roads. Permission is required for collecting rocks and accessing Teide's summit.

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