

## THE 1677 ERUPTION OF LA PALMA, CANARY ISLANDS

J. C. Carracedo \* \*\*, S. Day \*\*, H. Guillou \*\*\* and E. Rodríguez Badiola \*\*\*\*

### ABSTRACT

The 1677 volcanic eruption, located close to the town of Fuencaliente at the south end of La Palma, has been associated with the large volcanic cone of San Antonio, an emission centre showing relatively high energy phreatomagmatic phases. However, detailed geological mapping and a reinterpretation of available eye-witness accounts clearly prove the San Antonio emission centre to be a preexisting volcano related to an eruption that occurred several thousands years earlier. The 1677 eruption, or Volcán de Fuencaliente is a low magnitude eruption composed of a small strombolian vent and a cluster of aligned spatter vents. About  $75-125 \times 10^6 \text{ m}^3$  of lavas from these spatter vents covered an area of  $4.5 \times 10^6 \text{ m}^2$  and formed a wide coastal platform with  $1.6 \times 10^6 \text{ m}^2$  of new land gained from the sea. This modest magnitude eruption is in better accord with the negligible damage caused to the area reported in the contemporary accounts. This revision of the 1677 eruption and its magnitude is relevant for the precise reconstruction of the recent volcanism of La Palma and the correct definition of volcanic hazards in the island.

**Key words:** *Volcanism, historic eruptions, eruptive processes, La Palma, Canary Islands.*

### RESUMEN

La erupción de 1677, localizada cerca de la población de Fuencaliente en el S de la isla de La Palma, ha sido asociada hasta ahora con el cono volcánico denominado San Antonio. Este centro de emisión presenta fases eruptivas de energía relativamente elevada. El estudio geológico de detalle de esta erupción y la reinterpretación de los relatos de la época indican que el volcán San Antonio es, en realidad, un aparato volcánico preexistente, relacionado con algún episodio eruptivo de varios miles de años de antigüedad. La verdadera erupción de 1677 o Volcán de Fuencaliente, es de baja magnitud y está formada por pequeños centros eruptivos estrombolianos y conos alineados de escorias. El volumen de lavas emitidas es de unos  $75-125 \times 10^6 \text{ m}^3$  y cubre una extensión de aproximadamente  $4,5 \times 10^6 \text{ m}^2$ , de los cuales  $1,6 \times 10^6 \text{ m}^2$  son terrenos ganados al mar. Esta erupción originó escasos daños en la zona, como se recoge en los relatos contemporáneos. La revisión de la erupción de 1677 es importante para el conocimiento del volcanismo reciente de La Palma y para la correcta definición del riesgo volcánico en la isla.

**Palabras clave:** *Volcanismo, erupciones históricas, mecanismos eruptivos, La Palma, Islas Canarias.*

### Introduction

Twelve volcanic eruptions have occurred in the Canarian archipelago since the Spanish colonisation in the xvth. century. Surprisingly, this important aspect of the history of the island is, in general, poorly known. There are few eye-witness accounts of the eruptive events and those available are often

second and even third-hand translations of the originals.

Moreover, the accounts were generally chronicled by priests and military personnel with no previous experience in volcanic phenomena. The terms coined on the spot to describe the different materials or phenomena were very inaccurate and related to biblical or military concepts.

\* Volcanological Station of the Canary Islands. CSIC. La Laguna. Tenerife, Canary Islands, Spain.

\*\* Cheltenham and Gloucester College of Higher Education. Cheltenham, UK.

\*\*\* Centre des Faibles Radioactivités. CEA-CNRS. Gif sur Yvette, France.

\*\*\*\* Museo Nacional de Ciencias Naturales. CSIC. Madrid, Spain.

With few exceptions, the main concerns of the ecclesiastic and administrative authorities were the effects on life and property, mainly farmland and livestock. This explains why the number and extent of the accounts correlate with the importance, in terms of damage to property, of the eruptions. Those eruptions located in remote places and which did not cause significant damage are so poorly acknowledged that they are often misquoted, incorrectly located or mistaken for other events (Carracedo *et al.*, 1992; Carracedo and Rodríguez Badiola, 1991; Hernández-Pacheco and Valls, 1982).

However, the eye-witness accounts and near-primary sources are usually consistent with the geology, and, when correctly interpreted, are a fundamental instrument for the reconstruction of the different eruptive events. A common practice in the historical reconstruction of these eruptions has been to interpret the accounts without checking them against a detailed volcanological study of the eruptions: most lack even a specific geological map. Therefore, basic errors have often been introduced and widely accepted. Nevertheless, the information that can be gathered from geological field observations of the erupted products is generally more reliable and detailed than these accounts and allows much clearer interpretation of the historic accounts. Previous examples of this approach are the studies on the 1585 eruption in La Palma (Hernández-Pacheco and Valls, 1982) and the 1730 eruption of Lanzarote (Carracedo and Rodríguez Badiola, 1991; Carracedo *et al.*, 1992).

The 1677 eruption of La Palma clearly exemplifies these problems. In this work we will report geological evidence that completely revises aspects of the eruption as fundamental as the nature and location of its emission centres and the eruptive mechanisms involved.

As in the case of the 1585 and 1730 eruptions, this enhances the importance of detailed geological work on the historical eruptions, as a necessary step in their correct and precise reconstruction. Only through these reconstructions will it be possible to gain an understanding of the behavioural patterns of the recent volcanism and arrive at a correct definition and management of volcanic hazards in the archipelago.

### **Geological and structural setting and characteristics of historic eruptions in La Palma**

Six (1585, 1646, 1677, 1712, 1949 and 1971) out of the twelve historic eruptions that have been

recorded in the Canarian archipelago occurred on the Cumbre Vieja volcano, which forms the southern part of the island of La Palma. This volcano is presently the most active in the whole of the archipelago (Carracedo, 1994, 1996), probably as a result of its location close to the present-day position of the Canarian hotspot (Carracedo and Day, 1995). Mapping presently in progress (Carracedo, Day and Guillou, 1996) has shown that historic and sub-historic activity on the Cumbre Vieja is concentrated along the main N-S ridge of the volcano, but with significant eruptions also having taken place on the western flank of the volcano, from elongated fissures which run downslope in an east-west direction.

Eruptions of the Cumbre Vieja volcano are dominated by basaltic lavas and strombolian pyroclastic deposits, but include violent phreatomagmatic explosions and in some cases the emplacement of phonolitic domes. Many of the eruptions, most notably those of 1585, 1712 and 1949, were from multiple vents. In the case of the 1949 eruption, the vents were spread over a distance of about 4 km (Bonelli Rubio, 1950; Day *et al.*, 1996). In these eruptions a systematic progression is evident from the mapped distribution of the eruption products: gas-rich, strombolian and phreatomagmatic explosive eruptions took place at the vents furthest up the slopes of the volcano whilst relatively quiet emissions of lava dominated activity at the lower vents. We show below that a similar pattern is evident in the 1677 eruption.

### **The 1677 eruption**

The 1677 eruption, known as the San Antonio eruption, is generally described in previous works (Machado, 1965; Hernández Pacheco and Valls, 1982; Romero, 1991) as being composed of a large volcanic cone (known as the San Antonio Volcano) with phreatomagmatic deposits and its voluminous lava flows reaching the sea and forming an extensive coastal platform. This volcanic group is located close to the town of Fuencaliente, the name of which alludes to a famous thermal and medicinal spa located at the coast, that was destroyed during the 1677 eruption.

In fact, the 1677 eruption involved only two volcanic elements: A) a relatively modest size strombolian vent located at the northern part of the large cone, partly perched at the crater rim, and B) a group of spatter vents on the SW slope of the San Antonio volcano, the actual vents of the aforementioned lava flows.

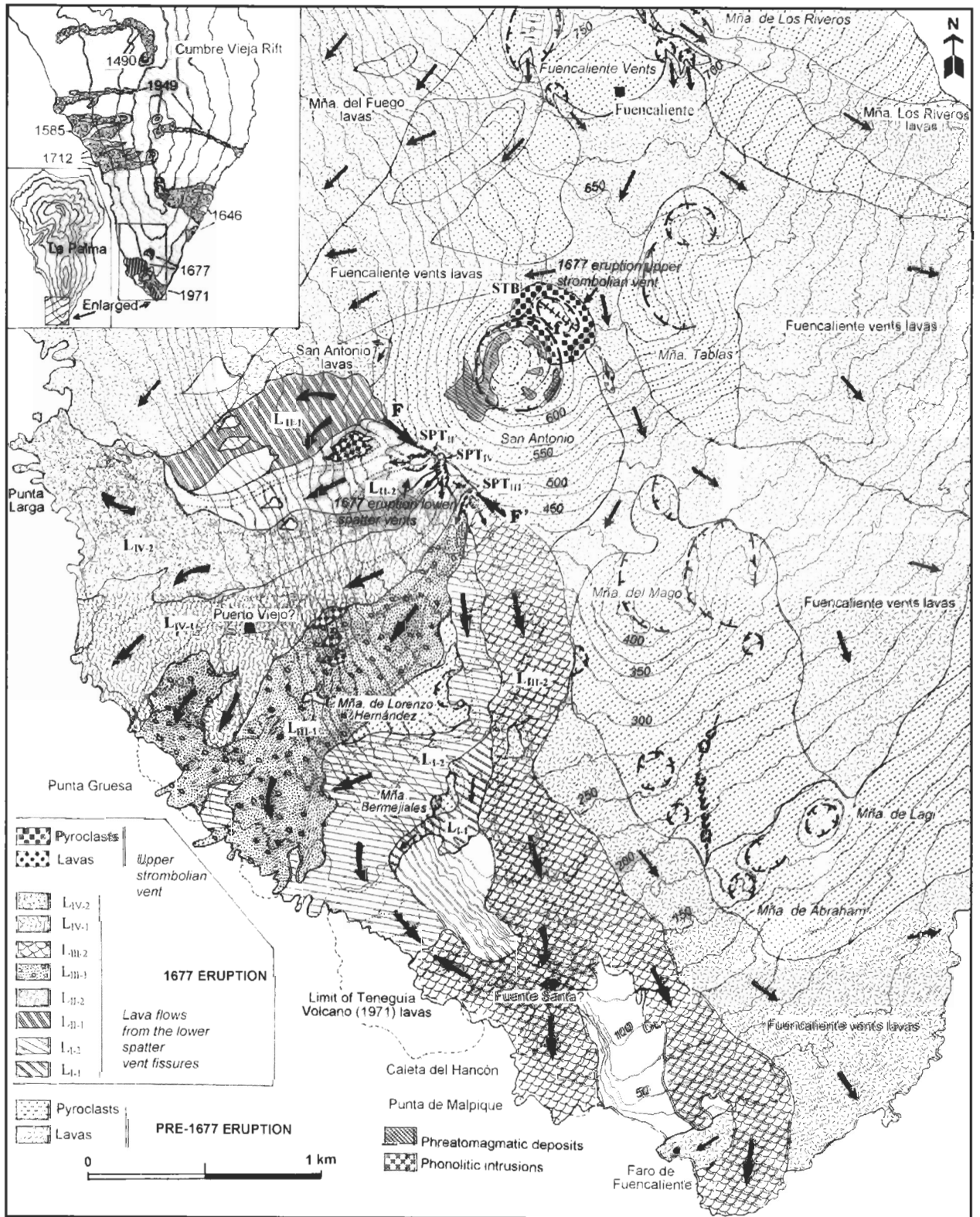


Fig. 1.—Geological map of the 1677 eruption.

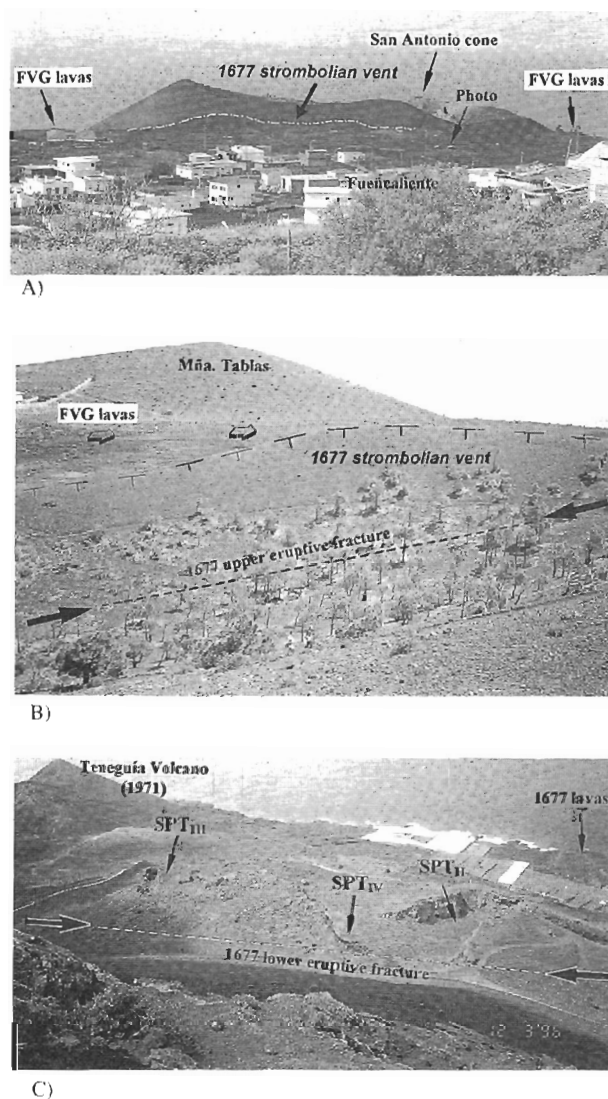


Fig. 2.—A. General view from Fuencaliente of the San Antonio Volcano (far end) and the 1677 upper strombolian vent. The *Photo* refers to the location of the photography of fig. 5A. B. View of the 1677 upper strombolian vent from the crater rim of the San Antonio Volcano. Note the Fuencaliente volcanic group lavas encircling the San Antonio and Mña. Tablas old volcanic cones. C. View of the clusters of spatter vents of the 1677 eruption located at the base of San Antonio Volcano.

### The San Antonio cone

Supposedly the main vent of the 1677 eruption, this is a large cone (560 m high and 1200 m wide, with a crater 400 m wide and 105 m deep) with clear phreatomagmatic features in its last stage of construction, including a relatively phreatomagmatic surge deposit up to 5 m thick.

As shown in figure 1, lavas from vents located further up in the rift, near the town of Fuencaliente (the Fuencaliente volcanic group or FVG), circum-

vent this cone at the west and flow between the San Antonio and Las Tablas volcanic cones at the eastern flank (fig. 2A).

The FVG lavas overlie a flow issuing from a lateral vent at the lower (southern) part of the San Antonio vent (see enlarged area B in fig. 3). They can be clearly observed flowing on top of the San Antonio cone in the track from Las Indias to the Teneguía Volcano (white arrow in fig. 4A), at the SW flank of the San Antonio cone. The whole is topped by flows from the Mña. del Fuego vents located higher at the rift and dated at 3.3 ka (Carracedo, Guillou and Day, in prep.), the San Antonio eruption being older.

This evidence clearly relates the San Antonio cone, that underlies most of the emission vents of the southern end of the Cumbre Vieja rift, to one of the older eruptions in this part of La Palma and very clearly not to the 1677 eruption.

The phreatomagmatic deposits present at the rim of the crater show base-surge deposits indicating relatively high energy episodes in this eruption (fig. 4A and B). However, these deposits have not been found covering the circumventing lavas, under those pyroclastic deposits which unambiguously belong to the 1677 eruption (see enlarged area A in fig. 3 and fig. 5A). This also excludes the San Antonio cone as belonging to the 1677 eruption.

These geological observations show that the 1677 eruption involved only, as mentioned above, a relatively small strombolian vent, perched on the northern rim of the San Antonio cone, and a group of spatter vents and lava flows at its base. This relatively low magnitude eruption of 1677 caused a correspondingly low level of damage. As quoted in the contemporary accounts, the main effect on the town of Fuencaliente, 1 km from the upper 1677 vent (fig. 2A), was the collapse of the church tower, in all probability due to earthquakes related to the eruption, and the burial of the Fuente Santa thermal spring. The revision of the eruption magnitude and style is in better agreement, as well, with the scant interest shown by the contemporary inhabitants, as evidenced by the limited extent and precision of the accounts, than would be a relatively large phreatomagmatic event, the effects of which on the area would have been far more destructive and hence more widely recorded.

An interesting issue arising from these discoveries is the name currently used to denominate the 1677 eruption as the San Antonio eruption or volcano. The volcanic eruptions in La Palma were sometimes named after the saint on whose feast-day they occurred, such as the San Juan volcano (1949). However, the date of the onset of the 1677 eruption

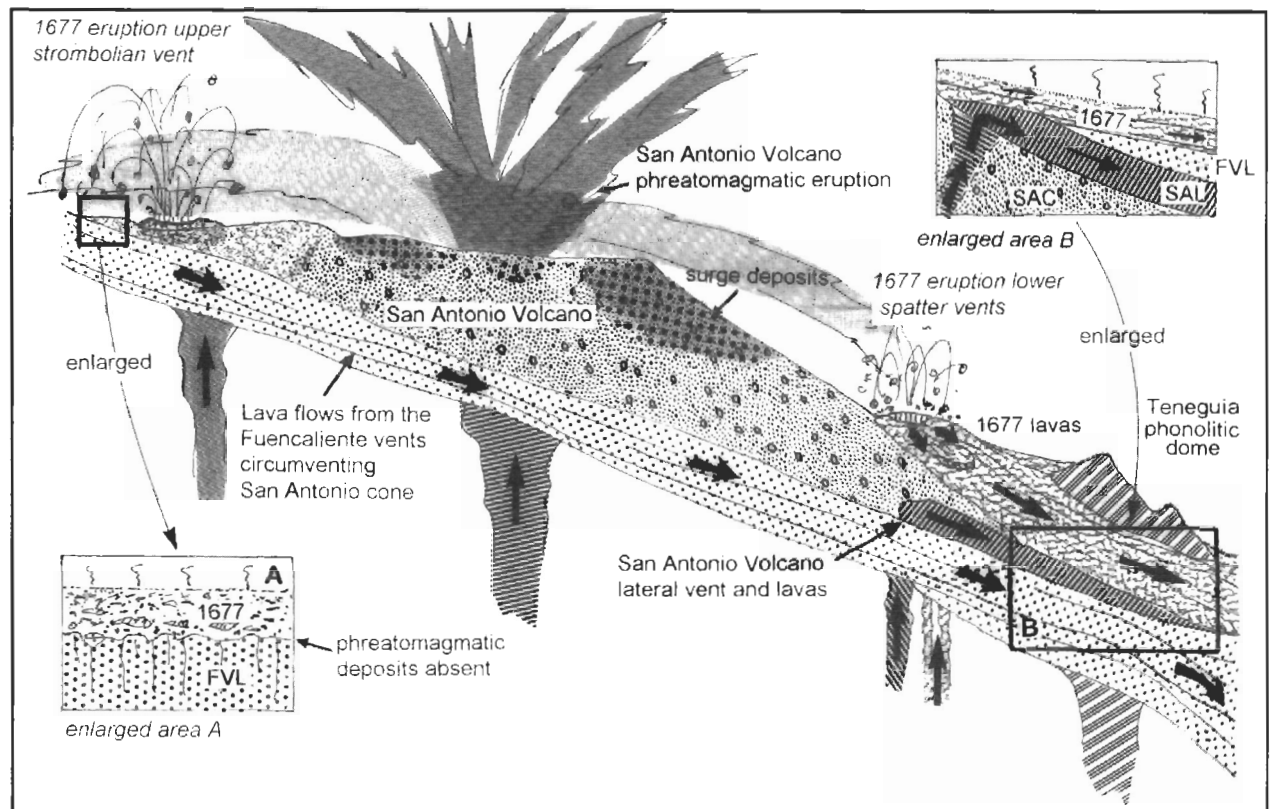


Fig. 3.—Schematic drawing showing the main stratigraphic and volcanological evidences excluding the San Antonio Volcano as a part of the 1677 eruption. FVL: Fuencaliente volcanic group lavas. SAC: San Antonio cone. SAL: San Antonio lavas.

does not coincide with the feast-day of Saint Anthony (San Antonio). On the other hand, the toponym San Antonio appears graphed close to the Fuente Santa emplacement and to the actual position of the present San Antonio volcano in a map elaborated by Torriani in 1586 to describe the location of the 1585 eruption (Torriani, 1592). This toponym was currently used in the area and may have been used to name the 1677 volcano. The small proportions and dispersion of the 1677 eruption vents may have imposed the use of a well-known geographic term to name the new eruptive episode.

We suggest using the name San Antonio, utilized presently to designate the 1677 eruption, as the toponym of the large old cone. The 1677 eruptive episode should be denominated *1677 eruption* or *Volcán de Fuencaliente*.

#### *The lower spatter cone lineaments*

As we will see later when discussing the eye-witness accounts, the eruption began, after several days of seismic activity in the area, with the formation of

a fissure at the base of the SW slope of the old San Antonio cone, named in the accounts *Mña. de Los Corrales* or *Mña. de Las Cabras*.

We have attempted to reconstruct the succession of eruptive events by defining the stratigraphic relations of the successive lava flows and the correlative vents, and comparing the geological information available with the contemporary accounts. However, this task has been hindered by the fact that a part of the 1677 lavas and vents has been covered by the lava flows and lapilli of the latter stages of the eruption and by the products of the nearby 1971 eruption. At the coast, the 1677 lavas are covered by extensive banana plantations. Aerial photographs taken before the 1971 eruption greatly helped in the mapping and stratigraphic correlation of the successive 1677 events.

*1st. eruptive event.* The initial spatter cone alignment (SPT<sub>1</sub> in figs. 1 and 6), cited in the accounts as a fissure that progressed towards the base of the San Antonio cone, was completely covered by the progression of the eruption. Fluid lavas (L<sub>1-1</sub> fig. 6) emitted at these vents flowed to the SE (towards the Fuente Santa) and



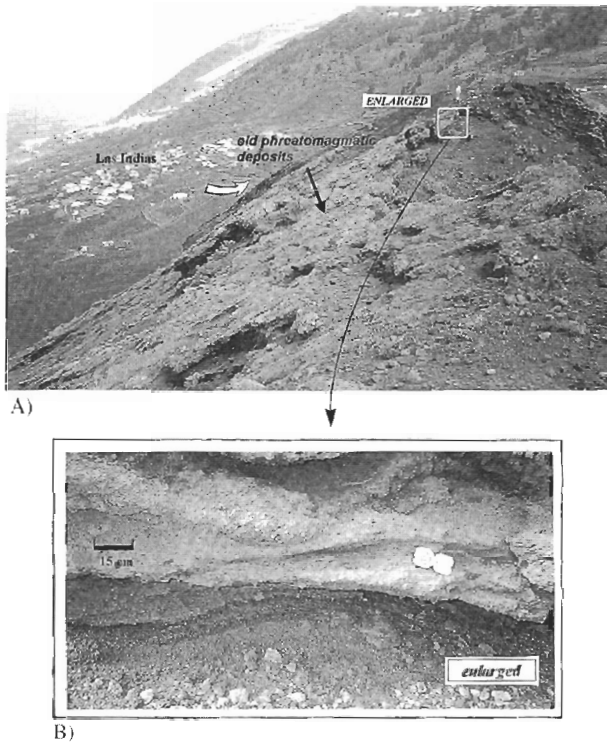


Fig. 4.—A. Phreatomagmatic deposits perched at the southwestern flank of the San Antonio Volcano. B. Close view of base-surge phreatomagmatic bedding in the rim of San Antonio Volcano.

stopped at the edge of the cliff. Another lava flow from the same vents ( $L_{1-2}$ ) changed direction to the south, and cascaded down the cliff towards the coast.

**2nd. eruptive event.** Another alignment of vents conforming a wide fissure ( $SPT_{II}$  in figs. 2C and 6) is located at the western edge of the lower eruptive fracture ( $FF'$  in fig. 1), close to the Roque Teneguía phonolitic plug. Lavas from these new vents ( $L_{II-1}$  and  $L_{II-2}$ ) flow down the cliff and reach the sea, conforming a wide coastal lava platform.

**3rd. eruptive event.** This vent alignment ( $SP_{TIII}$ ) is located at the SE edge of the lower eruptive fracture ( $FF'$ ). Lavas from this eruptive fissure flow downslope, separating into two flows, one progressing SW and down the cliff to the sea ( $L_{III-1}$ ), the other ( $L_{III-2}$ ) towards the S and the SE.

Apparently, the S trending branch flow of  $L_{III-2}$  was responsible for the destruction of the aforementioned Fuente Santa.

**4th. eruptive event.** This eruptive fissure ( $SPT_{IV}$ ) is located at the centre of the main eruptive fracture  $FF'$ , between  $SPT_{II}$  and  $SPT_{III}$ . Lava flows ( $L_{IV}$ ) from these last vents flow down the cliff to the W and SW, widening the coastal platform to its present extent.

### The upper strombolian vent

The other main feature of the 1677 eruption is a cinder cone of modest dimensions (400 x 260 m and 30 m high) located at the northern slope of the old San Antonio cone (see fig. 2A).

According to the accounts, this vent opened after several days of intense local seismic activity and after the formation of fractures that emitted hot gases (mainly hot air, with minor magmatic gases smelling of sulphur) and water vapour.

The crater is elongated (fig. 2B), with the axis parallel to the main fracture at the lower group of spatter vents.

The SW edge of this vent is perched on top of the crater rim of the old San Antonio cone (fig. 5B and C). Gravitational instability, probably increased by seismicity during the 1677 eruption, favoured the collapse of the perched part of the 1677 vent inside the San Antonio crater, restoring the rim circumference. The crater of the San Antonio volcano was probably much deeper, as is usually the case with phreatomagmatic vents in the Cumbre Vieja rift. The supplementary depth could have accommodated the pyroclastics fallen inside the crater during the 1677 eruption, as well as the collapse of the perched portion of the strombolian cone. All these products, and probably pieces of the old cone crater wall collapsed during intense seisms, partially filled the crater to its present depth (fig. 5C).

The visual effect of a continuous crater rim and the fresh 1677 lapilli covering the slopes of the cone may explain why the old San Antonio volcano has been confounded until now with the main vent of the 1677 eruption.

This vent is not breached and did not produce lava flows, with the exception of a small flow downslope of agglutinated spatters. Therefore, the 1677 eruption followed the general pattern of historic eruptions in La Palma: emission of lavas in the lower vents and explosive emission of pyroclastics in the vents above.

The depression existing between the northern flank of the 1677 upper vent and the town of Fuen-caliente was filled with magmatic gases during the eruption. Accumulation of  $CO_2$  may be responsible for the death of a peasant and numerous cattle, rabbits and birds, quoted in the accounts.

Three consecutive explosions, that flashed very high into the sky, developing into large balloons of fire, are said to have occurred after an especially intense seism. This phenomenon may point to a violent clearing of the eruptive conduit, obstructed by the partial collapse of the crater walls. A similar event was witnessed in the 1971 eruption.

### The 1677 eruption in the contemporary accounts

Some contemporary accounts of the 1677 eruption may have been lost and some of those preserved are only copies of the originals.

There are four main accounts affording data of interest for the reconstruction and description of the eruption:

1. *Relaciones (Accounts)* written by the priest Juan Pinto de Guisla of the 1646 (Martín Volcano) and 1677 eruptions. A copy of this account has been published by L. Buch (1825). A French translation in 1836 (Buch, 1836) of this first edition has been widely used. However, we have used a copy of the original, which was found and transcribed in 1806 by Lorenzo Rodríguez (1987).

2. *Gazeta del Ayuntamiento de La Palma (Gazette of the La Palma Town Council)*, diary of the development of the eruption from Nov. 13 to Nov. 26, 1677, kept by an anonymous local authority on 2 December 1677 (Anónimo, 1677). A French translation of this account by Webb and Berthelot (1839) has been widely known. A copy of the original has been recently published (Lorenzo Rodríguez, 1987).

3. Copy (the original lost) of the *Cartas (Letters)* sent by the chief bailiff of the Spanish Inquisition in La Palma, Antonio Pinto de Guisla, to the bishop B. García Ximénez on 29 November; 6 and 24 December 1677; 17 and 27 January 1678 (Anónimo, 1678).

4. Copy of a *Carta* dated 30 November 1677 from the vicar Melchor Brier to the Bishop (Archive of the Bishop García Ximénez, APLCLL, volume Q).

A clear indication that the San Antonio cone (Mña. del Corral in the account) occurred earlier than the 1677 eruption is the description of how the townspeople climbed to the top of Mña. del Corral (or San Antonio) to observe the newly opened lower vents (this same vantage point was used again by watchers during the 1971 eruption) and the fortunate circumstance that, after these people had left, a large vent opened in the mountain which «had it caught them unawares would have engulfed them in a voracious fire». This clearly refers to the old cone, with the lower spatter vents opening at its south base, and the upper strombolian vent starting at its higher, northern flank.

The accounts describe in some detail the progress of the eruption until 26 November. According to the Gazette, that day a lava flow (apparently, the S-trending branch flow of LIII/2) destroyed the Fuente Santa. Since this medicinal spa was one of the main economic resources of the area (and of La Palma),



A)



B)



C)

Fig. 5.—A. Pyroclastics (lapilli, bombs and scoria) from the 1677 eruption resting on the lavas of the Fuencaliente volcanic group. Note the absence of the phreatomagmatic deposits of the San Antonio volcano, less than 200 m away. These phreatomagmatic deposits should appear intercalated in the case of the San Antonio volcano being related to the 1677 eruption. B. Close view of the 1677 strombolian eruption pyroclastics resting on the old San Antonio volcano phreatomagmatic deposits. C. View of the interior of the crater of the San Antonio volcano. The collapse of the southern flank of the 1677 strombolian cone, perched on the rim of San Antonio volcano, and probably parts of the intensely fractured crater walls, have filled the crater to its present depth.

being visited by the infirm from Europe and even America, it is understandable that once the spa was destroyed the administration lost interest in the progress of the eruption, most of the accounts ending at that point.

Figure 7 shows a cartoon with the reconstruction of the eruption progression and its main events according to these accounts.

A few sentences in different letters give very scant indications of the advance of the eruption after the 26 November. On December 10, 1677, the upper vent apparently continued emitting lapilli, as well as the lower vents lava flows. The deaths of a shepherd and cattle were recounted that month.

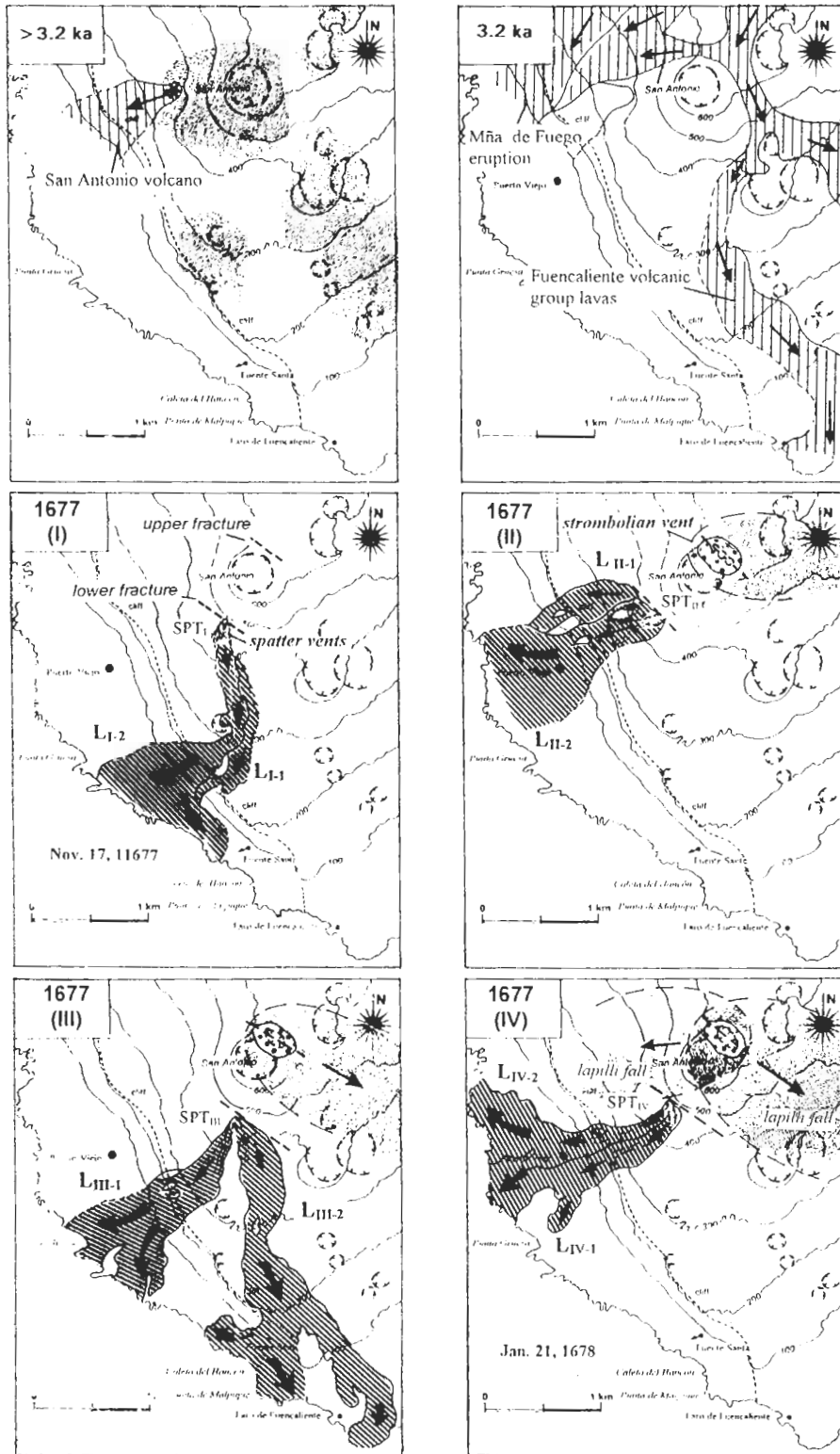


Fig. 6.—Reconstruction of the successive events of the 1677 eruption from field observations and the analysis of the aerial photographs made before the products of the 1971 Teneguia volcano partially covered this area.



The eruption is reported to have ceased, apparently abruptly, on 21 January 1678.

### Volcano-tectonic features of the 1677 eruption

The two main emission centres which were actually active during the 1677 eruption lie on a NE-SW trending line through the older San Antonio cone but are themselves elongated along NW-SE trending axes. Furthermore, both trends are oblique to the N-S trending volcanic rift or fissure swarm which has dominated volcanic activity in the southern subaerial part of the Cumbre Vieja throughout its history (Day, Carracedo and Guillou, 1996). Although NW-SE and NE-SW trending volcanic rift zones occur in the northern part of the Cumbre Vieja, these trends are not otherwise evident in the Fuencaliente area. It appears more likely that the very steep topography in the vicinity of the San Antonio cone distorted the local stress field during the eruption. McGuire and Pullen (1989) show that feeder dykes may become deflected to run down the slope of the local surface in areas of steep topography. Given the steep SW to W-facing steep slopes in the vicinity of the 1677 vents this topographic control provides an explanation for the overall NE-SW trend of the 1677 emission vents.

The existence of a NE-SW dyke beneath, and connecting, the two 1677 vents is further supported by the pattern of Strombolian activity at the upper vent and lava emission at the lower. This pattern is a ubiquitous feature of other historic and sub-historic, multi-vent eruptions on the island where gas-rich magma at the top of the feeder dyke is erupted with a Strombolian type of activity whilst more degassed magma flowing along the lower parts of the feeder dyke is erupted as lava from vents further downslope [see, for example, Bonelli Rubio (1950) on the 1949 eruption]. These multivalent eruptions are also characterised by simultaneous, linked changes in activity at separate vents (S. J. Day, mapping in progress). Simultaneous changes of this type are interpreted as reflecting increased magma supply rates in some cases, but more often can be attributed to magma drawdown in the feeder dyke. An event of this latter type may have occurred at the end of the second period of eruptive activity in 1677, when the end of lava emission from the lower vents around November 23rd. was accompanied by violent explosions at the upper vent, perhaps caused by entry of a limited amount of groundwater into the feeding fissure as magma drainback occurred at the end of this period of the eruption.

The NW-SE elongation of the upper and lower emission vents (*FF'* and *f* in fig. 1) appears to have

been established at the start of the eruption with the development of surface fractures with this trend some days before eruption of magma began (three days in the case of the lower vent; five days in the case of the upper vent). The contemporary accounts describe the opening of the fractures to a width «difficult to jump» in the space of a few minutes, and in association with strong earthquakes. Subsequently, hot gases were emitted, suggesting the presence of magma close beneath the surface, but as noted above no actual magma eruption took place for a few days. This indicates that the NW-SE trending fractures initially formed as «dry», unpressurised fractures. We suggest, therefore, that their formation was due to bulging of the steep SW-facing slopes around the old San Antonio cone as magma emplacement took place at depth, and consequent incipient slope instability manifested as NW-SE trending cracks running across the steep slope (Day and Carracedo, 1995). Subsequent «passive» magma upwelling then exploited these cracks as a convenient route to the surface.

One of the main concerns of the inhabitants of Fuencaliente during the 1677 eruption was the possibility of another fracture, parallel to those already opened, developing uphill and destroying the town. It is interesting to note that this concern, that implies an intuitive understanding of the tectonic framework of the eruptions in this part of La Palma, was also manifested during the 1971 Teneguía eruption.

### Quantitative parameters of the eruption

The eruption lasted 65 days, from 17 November 1677 until 21 January 1678. In some accounts the onset of the eruption is quoted as 13 November, but from this date until 17 November the only events quoted were strong seismic activity and the opening of fractures without any juvenile magma emission. The first output of magma, and therefore the actual beginning of the eruption, is located at sunset on 17 November. The relatively modest volume of pyroclastics and lavas suggests an intermittent eruptive process, with periods of reduced activity.

The surface covered by the 1677 lavas can be estimated at about  $4.5 \times 10^6 \text{ m}^2$ , of which  $1.6 \times 10^6 \text{ m}^2$  was new land gained from the sea. The small cinder cones of Mña. de Lorenzo Hernández and Mña. Bermijales, as well as the Roque Teneguía and other phonolitic plugs (see fig. 1) were not completely covered by the lavas, suggesting a relatively thin lava covering of the slopes and the cliff, that we can estimate at 10-15 m. However, the accumulation of lavas on the coastal platform may

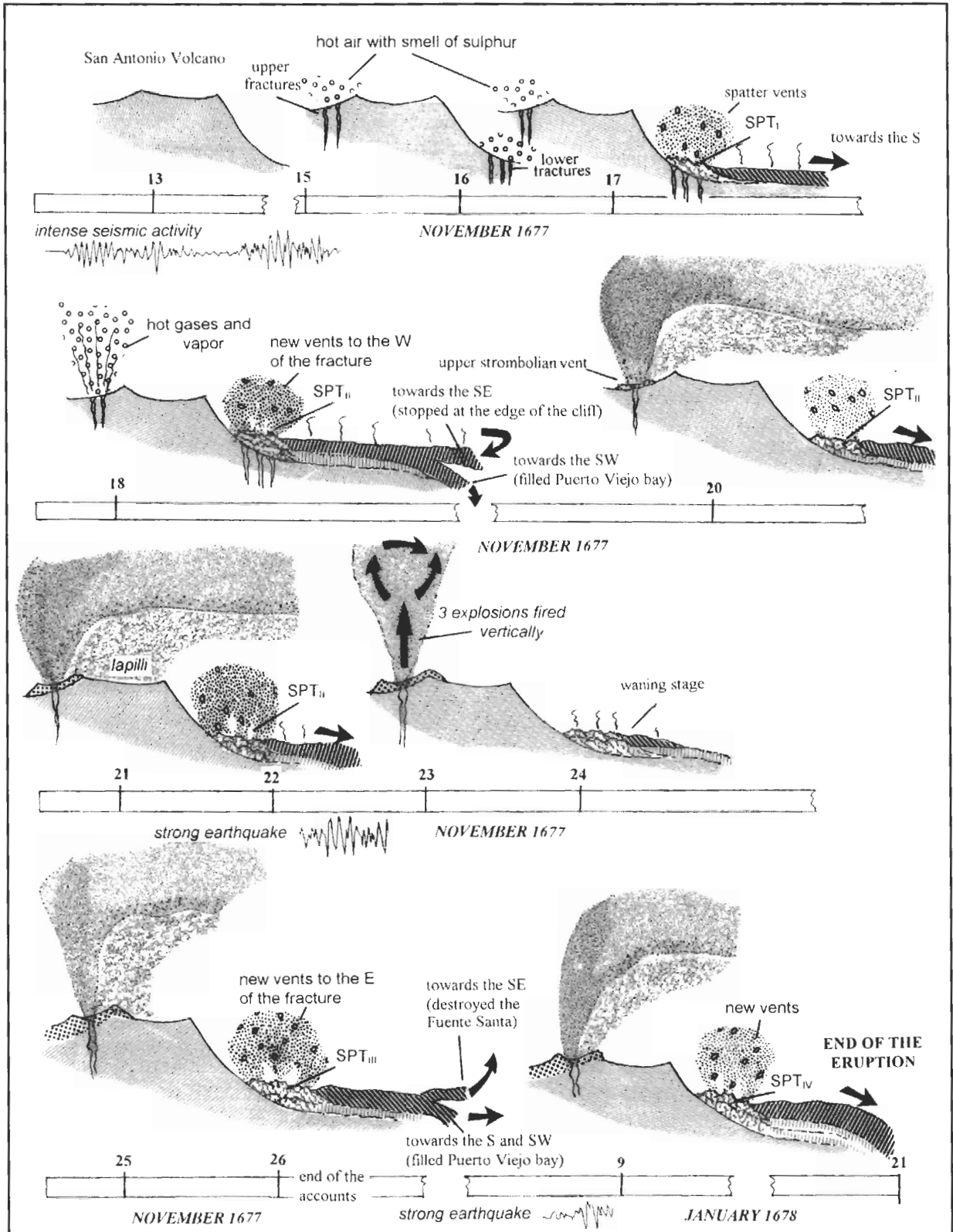


Fig. 7.—Cartoon depicting the progression of the 1677 eruption and the time occurrence of its main events and features as reported in the *Gazette*, an eye-witness account with a diary of the initial weeks of the eruption.

have reached 30-50 m. The total volume of lavas emitted in this eruption can be estimated therefore at about 76 to 122 x 10<sup>6</sup> m<sup>3</sup>.

An estimation of the velocity of the flows at a certain stage of the eruption is quoted in the accounts, which describes an experiment carried out by a contemporary using marks to measure the displacement of the flows. The estimation of about 20 m in half an hour (~ 0.01 m s<sup>-1</sup>) is surprisingly similar to the values reported from lavas from Kilauea and Mt. Etna (Kilburn *et al.*, 1995).

## Conclusions

Descriptions in eye-witness accounts and near-primary sources of the historic eruptions in the Canary Islands are usually consistent with the geology that can be assembled from detailed geological observations and mapping. The geological work is an essential step for the correct interpretation of these accounts and, consequently, for the precise reconstruction of the recent volcanism of the island, a necessary requisite in the definition and management of volcanic hazards.

Contrarily to the current idea, the 1677 eruption was a low magnitude episode, involving a small strombolian vent located above the old San Antonio volcano and a group of spatter vents at the base of the southern flank of this old volcanic cone.

The large, partially phreatomagmatic San Antonio volcano, is a relatively high energy event. Although considered to be the main vent of the 1677 eruption, it is in fact an old emission centre with a minimum age probably exceeding 10 ka.

The modest magnitude of this eruption, once the phreatomagmatic explosive eruption that built the old San Antonio cone is excluded, is in better agreement with the negligible damage caused to the area, and, accordingly, to the scanty and scarcely detailed contemporary accounts.

The location of the eruptive fissures active in the 1677 eruption, and their individual orientations, indicates the importance of local gravitational stresses in controlling their formation. Fracturing associated with the 1677 eruption suggests that incipient slope instability developed in the early part of the eruption.

In both 1677, and in the later 1971 eruption of Volcán Teneguía, the principal concern of the inhabitants of Fuencaliente was that another fracture, parallel to those already opened, might develop further uphill; eruption of scoria and lava might then destroy the town. Fuencaliente is the only town on La Palma which lies directly on the main rift zone of the volcano and the future occurrence of an

eruption in or close to Fuencaliente represents a serious volcanic hazard.

Our studies also indicate two additional potential hazards in this part of the island: 1) phreatomagmatic explosions, such as that which affected the prehistoric San Antonio volcano, which could devastate areas up to 1 to 2 km from the eruptive vent through the development of small-scale volcanic surges; and 2) relatively small-scale slope collapses in the immediate vicinity of eruptive vents.

## ACKNOWLEDGEMENTS

This work was supported by the Spanish DGICYT Research Project PB92-0119. We greatly appreciate and acknowledge the help of Dn. Pedro Nolasco Pérez, mayor of the town of Fuencaliente, who provided old manuscripts, drawings and copies of eye-witness accounts related to the eruption of 1677 that greatly improved this work.

## References

- Anonimo (1677). *Gazeta del Ayuntamiento de La Palma*, 2 de diciembre de 1677. Copia del original que se encuentra en el archivo del Marqués de Guisla Guiselin por Lorenzo Rodríguez, *Noticias para la historia de La Palma*.
- Anonimo (1678). *Edictos, Cartas, Instrucciones que se han despachado a los beneficiados e parrocos en todo este obispado desde principios del año 66 (1666) en adelante*. Arch. Parroq. La Concepción, La Laguna, Arch. B. García Ximénez, libro Q.
- Bonelli Rubio, J. M. (1950). *Contribución al estudio de la erupción del Nambroque o San Juan (isla de La Palma)*, Inst. Geog. y Catastral, Madrid.
- Buch, L. von (1825). *Physicalische beschreibung der Kanarischen Inseln*, Berlin.
- Buch, L. von (1836). *Description Physique des Iles Canaries*, Levrault Ed., Paris.
- Carracedo, J. C. (1994). The Canary Islands: an example of structural control on the growth of large oceanic island volcanoes. *J. Volcanol. and Geotherm. Res.*, 60, 225-242.
- Carracedo, J. C. (1996). A simple model for the genesis of large gravitational landslide hazards in the Canary Islands. In: W. McGuire, J. Neuberg and A. Jones (eds.), *Volcano Instability on the Earth and Terrestrial Planets*, Geol. Soc. London Spec. Public., 125-135.
- Carracedo, J. C., and Day, S. J. (1995). Contrasting origin and evolution of the eastern and western Canarian Islands. *XXI IUGG General Assembl.*, Boulder, USA.
- Carracedo, J. C., and Rodríguez Badiola, E. (1991). *Lanzarote: la erupción volcánica de 1730*, Cabildo Insular de Lanzarote, Las Palmas de Gran Canaria.
- Carracedo, J. C., Rodríguez Badiola, E., and Soler, V. (1992). The 1730-36 eruption of Lanzarote, Canary Islands: a long, high magnitude basaltic fissure eruption. *J. Volcanol. and Geotherm. Res.*, 53, 239-250.
- Day, S., and Carracedo, J. C. (1995). The structure and mechanism of asymmetric rift flank collapses in the Canary Islands. *XXI IUGG General Assembl.*, Boulder, USA.

- Day, S. J., Carracedo, J. C., and Guillou, H. (1996). Reconfiguration of the Cumbre Vieja volcano, La Palma: advance warning of a giant landslide? Abst. vol., *Applied Geoscience Conference, Geol. Soc. London*, Warwick, 9.
- Hernández-Pacheco, A., and Valls, M. C. (1982). The historic eruptions of La Palma island (Canaries Archipelago). *Revista Universidade Dos Acores*, 3, 83-94.
- Kilburn, C. R. J., Pinkerton, H., and Wilson, L. (1995). Forecasting the behaviour of lava flows. In: McGuire, Kilburn and Murray (eds.), *Monitoring Active Volcanoes*, UCL Press, London.
- Lorenzo Rodríguez, J. B. (1987). *Noticias para la historia de La Palma*, Inst. Estudios Canarios, tomo I, Cabildo Insular, La Palma, Tenerife.
- McGuire, W. J., and Pullen, A. D. (1989). Location and orientation of eruptive fissures and feeder-dykes at Mount Etna; influence of gravitational and regional tectonic stress regimes. *J. Volcanol. and Geotherm. Res.*, 38, 325-344.
- Romero, C. (1991). *Las manifestaciones volcánicas históricas del Archipiélago Canario*, 2 vols., Consejería Política Territorial, Santa Cruz de Tenerife.
- Torriani, L. (1592). *Descripcion e historia del reino de las Islas Canarias*, original published in 1940 by Wölfel. Translation of the original by A. Cioranescu in 1978, Editorial Goya (with the map of the 1585 eruption in La Palma made by Torriani).
- Webb, B., and Berthelot, S. (1839). *Histoire Naturelle des Iles Canaries*, 2 vols., Paris.

Recibido el 9 de mayo de 1996.  
Aceptado el 14 de junio de 1996.