# Temporal evolution of Diego Hernández formation (Las Cañadas, Tenerife) and confirmation of the age of the caldera using the $^{40}Ar/^{39}Ar$ method

JOSEP M. MITJAVILA[1] AND IGOR M. VILLA[2]

*Istituto di Geocronologia e Geochimica Isotopica. Via Maffi 36.56127 PISA, Italy.*
*Present addresses:* [1] *Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964 USA.*
[2] *Isotopengeologie. Universität Bern, Erlachstrasse 9A, 3012 Bern, Switzerland*

**Abstract:** The Cañadas caldera in Tenerife is one of the main structures of this island. Three main successive phases of caldera formation (I, II, III) are separated by periods of constructive activity. The easternmost section of the caldera (Diego Hernández wall) corresponds to the youngest preceding Caldera III deposits that fill a former valley on the E side of the pre-caldera III edifice. These deposits were dated with the K/Ar method, giving a maximum age of 0.179 ± 0.011 Ma for the Caldera III. The possible presence of excess Ar ($Ar_{xs}$) common in other Diego Hernández rocks, has been investigated using the $^{40}Ar/^{39}Ar$ technique. We obtained a plateau age of 0.183 ± 0.004 Ma and a isochron age of 0.179 ± 0.09 no distinguishable from the K/Ar age. The Diego Hernández Formation was built up in two stages separated by a gap. The first one took place after the formation of the paleovalley around 0.7 to 0.5 Ma BP. The second one occurred between 0,27 and 0.18 Ma. Afterwards, the Caldera III formed and the Teide-Pico Viejo volcanoes began their activity until the present.

**Key words:** $^{40}Ar/^{39}Ar$ age, K/Ar age, Diego Hernández Formation, Cañadas Caldera, Tenerife.

**Resumen:** La Caldera de las Cañadas en Tenerife es una de las estructuras más importantes de la isla. En ella es posible diferenciar tres importantes fases de formación (I, II, III) separadas por períodos de actividad constructiva. La sección de pared más oriental de la Caldera (Cañada de Diego Hernández) corresponde a los depósitos más jóvenes afectados por la tercera fase de formación, los cuales rellenan un paleovalle excavado en la ladera E del edificio precaldera (edificio Cañadas). Estos depósitos han sido datados con el método K/Ar. Los resultados obtenidos dan una edad de 0,179 ± 0,011 Ma para la tercera fase de formación de la Caldera. La posible presencia de Ar en exceso ha sido investigada usando el método $^{40}Ar/^{39}Ar$. En el presente trabajo, con el método $^{40}Ar/^{39}Ar$, hemos obtenido una edad plateau de 0,183 ± 0,004 Ma y una edad mediante el uso de la isocrona de 0,179 ± 0,009 Ma, estratigráficamente indiferenciable de la edad K/Ar. La formación Diego Hernández se formó en dos etapas separadas por un gap. La primera tuvo lugar después de la formación del paleovalle hace unos 0,7 Ma. La segunda ocurrió entre 0,27 y 0,18 Ma. Después se originó la tercera Caldera y los estratovolcanes Teide y Pico Viejo empezaron su actividad, en el lado Norte de la Caldera, hasta la actualidad.

**Palabras Clave:** Edad $^{40}Ar/^{39}Ar$, Edad K/Ar, Formación Diego Hernández, Caldera de las Cañadas, Tenerife.

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The Cañadas Caldera is an elliptical depression of 12 × 17 km located in the central part of Tenerife Island (fig. 1). Its detailed geology is described elsewhere (Fuster *et al.,* 1968; Ridley, 1970a; Ridley, 1970b; Araña, 1971; Fuster *et al.,* 1980; Araña and Coello, 1989). Martí *et al.,* (1992) describe the existence of at least 3 collapse structures (hereafter I, II, III). Each collapse follows the discontinuous construction of an edifice lasting about 0.5 Ma. Araña (1971), Mitjavila (1990) and Martí *et al.,* (1990) proposed that Diego Hernández Formation corresponds to the youngest pre-caldera III deposits. Thus, the correct dating of the rocks of Diego Hernández, mainly the correct dating of the last deposit, is a very important point for the knowledge of the evolution of the Tenerife volcanic system.

From the last pre-caldera III deposit five ages were obtained using K/Ar method, giving a weighted average of 0.179 ± 0.011 Ma (Mitjavila, 1990). To corroborate that age, due to the possibility that it contained excess Ar (hereafter $Ar_{xs}$) like many other Diego Hernández samples, we consider necessary to measure that important sample using the $^{40}Ar/^{39}Ar$ method. The $^{40}Ar/^{39}Ar$ method has the capacity to discriminate ideal mineral geochronometers from others affected by $Ar_{xs}$ (see Lanphere and Dalrymple, 1976).

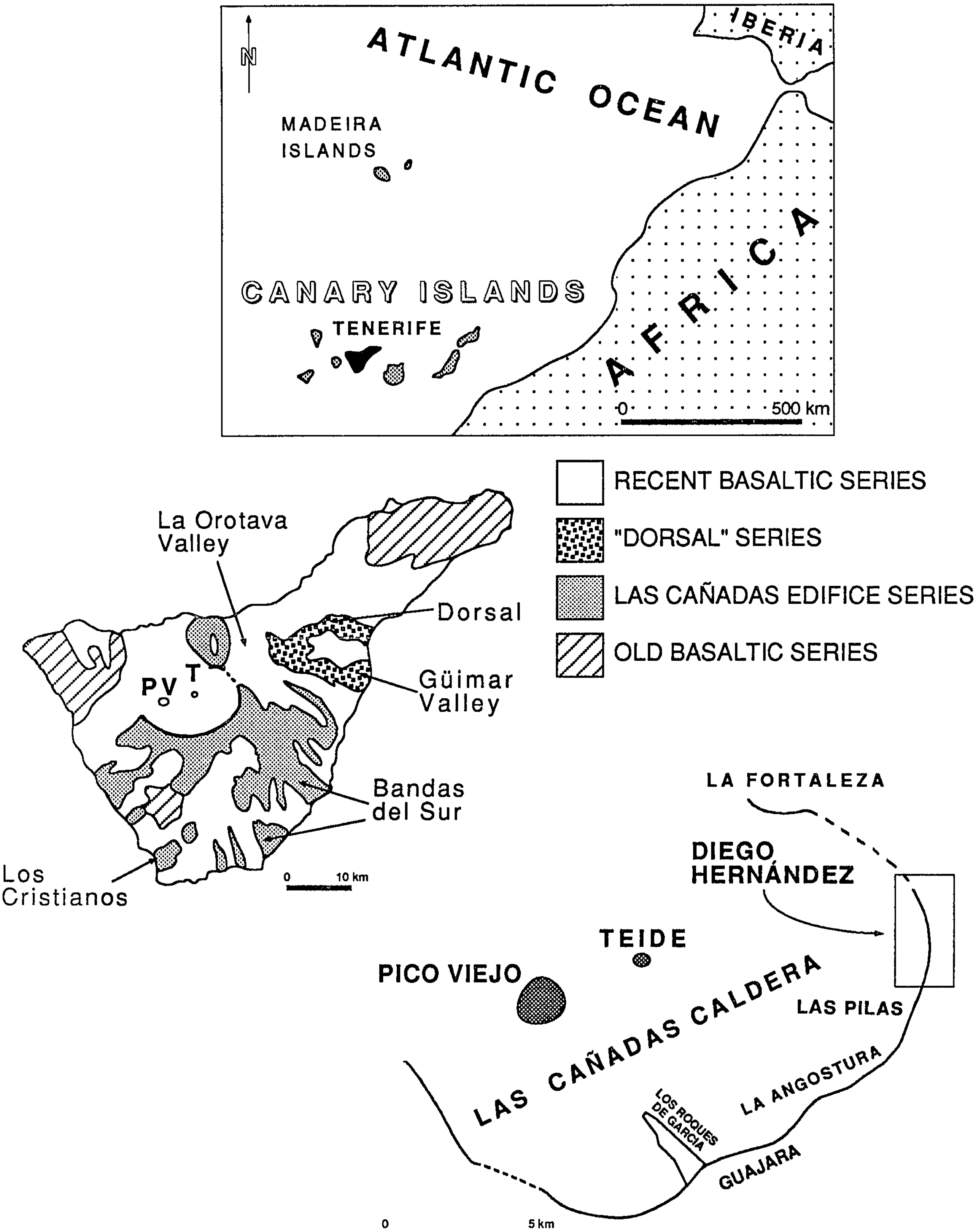


Fig. 1: Situation of Cañada de Diego Hernández and other locations cited in the text and geological squetch map of Tenerife Island.

## Previous Works

Previous studies with radiometric ages in Tenerife Island are not numerous. One of the first is by Abdel-Monem *et al.*, (1972). They already pointed out the existence of $Ar_{xs}$ in some rocks from Güimar Valley. They also give an approximate age for the Caldera formation: 0.2 Ma., based on two samples. One of the samples gives an apparent age of 0.189 ± 0.08 Ma. (after correction using the constants of Steiger and Jäeger, (1977). The other has very low content of radiogenic Ar that approaches the sensitivity limits of the mass spectrometer (Abdel-Monem *et* *al.*, 1972), thus they gave to this second sample an «age» less than 0.2 Ma. One difficulty when using these data is the impossibility to know from where these young samples were taken because by the descriptions given in the paper they seem to be from the Ucanca Formation that is dated from 1.14 ± 0.05 to 1.39 ± 0.04 (Ancochea *et al.*, 1990) or 1.18 ± 0.07 Ma to 1.54 ± 0.26 Ma (Martí *et al.*, 1992).

Other published Caldera ages are found in papers by Booth (1973) and Wolff and Storey (1984). Both use $^{14}C$ ages obtained by Shotton and Williams (1971) of 32000 years and 28500 years, respectively. The former authors dated an ignimbrite deposit overlying the Granadilla series in Los Cristianos area. Booth (1973) considers this ignimbrite as a part of the same eruption than Granadilla series. He thought that the age obtained was the age of the Caldera, but more recent stratigraphic review (Alonso, 1989) and a chronological studies (Ancochea *et al.*, 1990) of the Bandas del Sur area, as well as field recognition (new outcrops) by Araña (personal com.) demonstrate that the age of 32000 years is probably that of the recent phonolitic Caldera del Rey tuff ring volcano near Los Cristianos. The second age is from a plinian fall on the N side of the Island. This deposit was correlated by mineralogy to another fall of the Fasnia Formation in the Bandas del Sur area (Wolff, personal com.) but Ancochea *et al.*, (1990) convincingly argued that this age is too recent.

Cantagrel (1988) divides the evolution of Cañadas complex in 3 distinct volcanic episodes, giving an age of 0.3 Ma as the maximum age for the last caldera formation phase. Ancochea *et al.*, (1989) using the same data than Cantagrel (1988) give a maximum age for the caldera around 0.6 Ma. In a later and reviewed paper, Ancochea *et al.* (1990) give an age of 0.13 ± 0.02 to 0.174 ± 0.013 Ma for last episode of Caldera formation using their own data as well as datum after Martí *et al.* (1990). They also dated two lava flows from Diego Hernández wall at 0.72 ± 0.13 and 0.54 ± 0.06 Ma. In the same paper, Ancochea *et al.* (1990) give some clues for the correct chronological situation of other main structures outside the Caldera, such as Güimar and Orotava valleys. Martí *et al.* (1990) and Mitjavila (1990) have dated Diego Hernández Formation and Martí *et al.* (1992) outline other radiometric ages of the rest of the volcanic Formations of the Caldera wall. In this last paper, they pointed out the existence of at least three Caldera collapses seoarated by quiescence and constructive periods of approximately 0.5 Ma.

## K/Ar and $^{40}Ar/^{39}Ar$ ages

Table 1 is a compilation of some ages from literature for the Diego Hernández and preceding Formations, and our $^{40}Ar/^{39}Ar$ results. The complete details and analytical techniques are described in each of the papers cited. It can be clearly seen that K/Ar ages of some samples are older than their stratigraphic age. This is especially true for the basaltic rocks and mixing products analyzed in the papers cited in Table 1. It is therefore straightforward that basalts contain excess Ar, so that their K/Ar ages have no geological meaning. Therefore, in Table 1 we only included ages from evolved rocks or K-feldspars separates, except for units where these were unavailable (printed in italics).

Table 1: Ages obtained for the pre-Diego Hernández and Diego Hernández Formation rocks. All ages are from K-feldspars except where only «Basaltic ages» are available. The basalts, at least for samples DH-40 and DH-42, show $Ar_{xs}$ (see discussion on the text) for this reason the results are printed in italics. The $^{40}Ar/^{39}Ar$ ages (both: the «plateau» and the isochron ages) are printed in bold. Other information included is the weighted average age for the last pre-caldera III deposit, as well as the errors and stratigraphic information. The dashed thick line separates non-successive events or Formations. The references indicated in the last column are as follows: 1 = Mitjavila (1990) and/or Martí *et al.* (1990); 2 = Ancochea *et al.* (1990); 3 = Martí *et al.* (1992); 4 = Araña *et al.* (1989).

| MARTÍ *et al.* (1990) | | THIS WORK & MARTÍ *et al.* (1992) | | EVENT OR DEPOSIT | METHOD | SAMPLE NUMBER | FRACTION DATED | APARENT AGE (Ma) | ±1 σ | REFERENCE |
|---|---|---|---|---|---|---|---|---|---|---|
| SECOND CYCLE | | DIEGO HERNÁNDEZ FORMATION (3rt Cycle) | SECOND EPISODE | Topmost Bandas del Sur dep. | K-Ar | T.26.A | K-Feldspar | 0.130 | 0.020 | 2 |
| | | | | Last Pre-Caldera III deposit | " | F-11 | " | 0.170 | 0.008 | 1 |
| | | | | " | " | F-11/1 | " | 0.199 / 0.179 | 0.009 | 1 |
| | IV-5 | | | " | " | DH-76/1H | " | 0.173 / ± | 0.031 | 1 |
| | IV-5 | | | " | " | DH-76/5 | " | 0.176 / 0.011 | 0.035 | 1 |
| | IV-5 | | | " | " | DH-76/1 | " | 0.178 | 0.020 | 1 |
| | IV-5 | | | " | **Ar-Ar Plat.** | **DH-76/1** | " | **0.183** | **0.004** | This work |
| | IV-5 | | | " | **Ar-Ar Isoc.** | **DH-76/1** | " | **0.179** | **0.009** | " |
| | IV-2 | | | Towards the top | K-Ar | DH-58 | " | 0.225 | 0.026 | 1 |
| | II-2 | | | Towards the base | " | DH-23B | " | 0.266 | 0.017 | 1 |
| FIRST CYCLE | I-5* | | FIRST EPISODE | Topmost Lava flow | " | *DH-40* | *WR (Basalt)* | *2.01* | *0.16* | 1 |
| | I-5* | | | " | " | *DH-42* | *GM (Basalt)* | *1.59* | *0.10* | 1 |
| | I-3 | | | Middle Lava flow | " | *T.2.CH* | *(Basalt)* | *0.54* | *0.06* | 2 |
| | | GUAJARA FM. (2nd Cycle) | PRE-DIEGO HERNÁNDEZ FM. | Topmost la Angostura Wall | " | PA3 | K-Feldspar | 0.712 | 0.041 | 3 |
| | | | | Topmost las Pilas Wall | " | AD32 | " | 0.850 | 0.012 | 4 |
| | | DORSAL SERIES | | Genesis of the Paleovalley | " | *T.20.A* | *(Trachybasalt)* | *0.56* | *0.03* | 2 |
| | | | | " | " | *T.48.F* | *(Basalt)* | *0.78* | *0.18* | 2 |

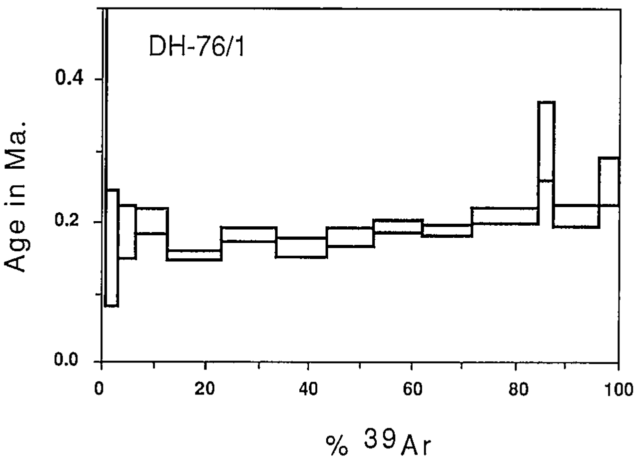


Fig. 2: Age spectrum of coarse feldspar (4 mm ≥ ø ≥ 1 mm) from the sample DH-76/1. The first step (0.7 % of the total gas) plots off-scale; the «plateau» age (0.183 ± 0.004 Ma) is calculated on steps 6-10, which contain 50 % of the released gas.

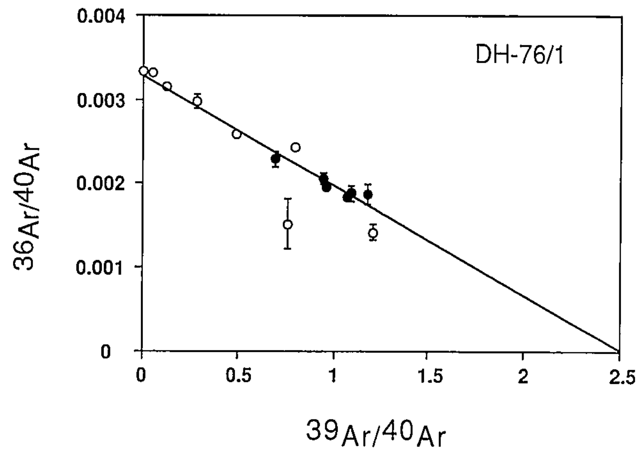


Fig. 3: Isochron diagram, of DH-76/1. The isochron is calculated from the filled circles and has intercepts corresponding to t = 0.179 ± 0.009 Ma, and $^{40}Ar/^{36}Ar$ = 301 ± 24.

Using the traditional K/Ar method, on the samples DH-76/1, DH-76/5, DH-76/1H, F-11 and F-11/1, all from the last pre-caldera III deposit, we obtained a weighted average age of 0.179 ± 0.011 Ma (Table 1). One of these, sample DH-76/1, which gives a K/Ar age of 0.178 ± 0.020 Ma, was analyzed with the $^{40}Ar/^{39}Ar$ method. Figures 2 and 3 shows the obtained results. There is no important concentration of $Ar_{XS}$. The five steps from sixth to tenth, which account for more than 50 % released gas, define a «plateau» that corresponds to an age of 0.183 ± 0.004 Ma, which is statistically indistinguishable from the K/Ar age. The isochron diagram (fig. 3) shows that the line through the 7 filled circles (steps 3, 4, 6 to 10) corresponds to an age of 0.179 ± 0.09 Ma with atmospheric trapped Ar ($^{40}Ar/^{36}Ar$ = 301±24) and statistically satisfactory dispersion (MSWD = 0.86).

## Discussion

With the K/Ar ages confirmed by $^{40}Ar/^{39}Ar$, we are able to draw a picture of the evolution of the Diego Hernández Formation. Previously, Mitjavila (1990) and Martí *et al.* (1990) divided the Formation in four sequences (I, II, III, IV) subdivided in units (1, 2, 3, ...). They grouped the sequences in two cycles, corresponding the first cycle to sequence I and the second cycle to sequences II, III, and IV (Table 1). Instead, we prefer to divide the Formation in two main episodes, equivalent to their cycles but without further division in sequences, because with the ages obtained, the evolution of the Diego Hernández Formation is much better explained (see Table 1).

The first Diego Hernández episode, from which ages only from basalts but not from evolved rocks are available, has to be younger than the topmost Guajara Formation. The topmost of this Formation in Las Pilas wall shows an age of 0.85 ± 0.012 Ma (Araña *et al.,* 1989) and in La Angostura wall an age of 0.712 ± 0.041 Ma (Martí *et at.,* 1992). The upper part of Las Pilas constitutes the South wall of the paleovalley within which the Diego Hernández materials were deposited. This paleovalley is related with the genesis of the Orotava valley and both are younger than the Güimar valley (Navarro and Coello, 1989; Ancochea *et al.,* 1990). These later authors give a maximum age of 0.78 ± 0.18 Ma and minimum of 0.56 ± 0.03 Ma for the formation of Orotava valley and consequently for the Diego Hernández paleovalley. After Ancochea *et al.,* (1990) the age of 0.78 ± 0.18 Ma is the most recent age obtained from a flow in the scarp of La Orotava valley and the 0.56 ± 0.03 Ma is the age of a lava flow covering the morphological scarp of La Orotava valley. These ages agree with the topmost Guajara Formation ages, already seen. Thus, the first episode can be constrained to have occurred between 0.78 ± 0.18 Ma and earlier than 0.266 + 0.017 Ma (age from the base of the second episode). We can consider that an age for this first episode could be approximately around the age obtained by Ancochea *et al.* (1990) for a basaltic lava flow, which is 0.54 ± 0.06 Ma old. This basaltic lava flow could contain some $Ar_{XS}$, but this point is not demonstrable with the available data. Our duplicate age of another basaltic lava flow stratigraphically higher than the Ancochea *et al.* (1990) sample, gave the ages of 2.01 ± 0.16 and 1.59 + 0.1 Ma. (Table 1) (Mitjavila, 1990; Martí *et al.,* 1990), clearly affected by $Ar_{XS}$ which was very inhomogeneous distributed in the rock.

After the first episode a gap in the deposition of volcanic material occurs, at least in the Diego Hernández valley. This interruption is evidenced by angular unconformities, paleoreliefs and reworked and epiclastic deposits. We suggest that during this gap in the E, the active eruptive vents were displaced to the N (La Fortaleza zone, see fig. 1) originating La Fortaleza Member, which is a succession of several units of welded rocks of peralkaline phonolitic composition, that spreads to the N covering parts of the Tigaiga Massif. This suggestion is based mainly on one geochronological datum (= 0.37 ± 0.07 Ma) Ancochea *et al.,* (1990) rather than on lithological characteristics because no similar rocks are found in Diego Hernández wall.

The second episode began close to 0.266 ± 0.017 Ma and ended 0.179 ± 0.009 to 0.183 ± 0.004 Ma ago. During this time, 150 to 160 m of phonolitic pyroclastic materials and 25 to 35 m of interbedded basaltic lava flows and strombolian fall deposits were deposited in the Diego Hernández zone. Notice that the outcropping section on the wall corresponds to a former proximal and channeled area. Thus, some deposits appear thicker here than they are in distal facies. On the other hand plinian pumice fall deposits here are scarce and very thin while in distant facies they can be 5 to 10 m thick. With these premises it is difficult to correlate the similar and probably related top deposits from Bandas del Sur series and the dispersed plinian falls from Arafo area in the Güimar valley (fig. 1), with the Diego Hernández Formation. Moreover, we can neither calculate the erupted volume nor the emission rate.

The age of the topmost Diego Hernández deposit is also the maximum age of the Caldera III, which is close to the 0.189 Ma (after correction) proposed by Abdel-Monem *et al.* (1972) and the 0.130 - 0.174 suggested by Ancochea *et al.* (1990).

After the third Caldera formed the stratovolcanoes Teide and Pico Viejo began their activity initiating a new volcanic cycle that is active until the present. Considering the volume of 150 $km^3$ for the Teide-Pico Viejo complex (Ancochea *et al.*, (1989) and the age of the Caldera III, the eruption rate is approximately of 1 $km^3$/ka.

## Conclusions

Despite the presence of $Ar_{XS}$ in basalts, the K-feldspars from white phonolites in the last pre-caldera deposit appear to contain none as demonstrated by the $^{40}Ar/^{39}Ar$ measurement. The same measurement also corroborates our previous K/Ar date on the same deposit. Thus, Diego Hernández ended its activity 0.179 to 0.183 Ma ago. Afterwards, the formation of Caldera III and the build-up of the Teide-Pico Viejo complex occurred.

As the formation mechanism of the Cañadas Caldera is still debated, it would be important to demonstrate the presence of distal deposits coeval with Diego Hernández, despite the difficulties inherent in facies changes. Therefore further geochronological work has to be done in the Bandas del Sur area and to the E of the Caldera (Güimar valley) to find correlation levels between these areas and Diego Hernández Formation to allow us to calculate the volume of the erupted materials.

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