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The Quaternary pyroclastic succession of southeast Tenerife, Canary Islands: explosive eruptions, related caldera subsidence, and sector collapse

R. J. BROWN*, T. L. BARRY†, M. J. BRANNEY*¶, M. S. PRINGLE‡ & S. E. BRYAN§

*Geology Department, University of Leicester, University Road, Leicester LE1 7RH, UK
†University of Cardiff (BAS/NIGL), Cardiff, Wales CF1 3YE, UK
‡SUERC/NSS Argon Facility, Scottish Enterprise Technology Park, Rankine Ave., East Kilbride G75 0QF, UK
§Department of Earth Sciences, University of Queensland, St Lucia, Queensland 4072, Australia

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Abstract – A much-revised Quaternary stratigraphy is presented for ignimbrites and pumice fall deposits of the Bandas del Sur, in southern Tenerife. New $^{40}Ar/^{39}Ar$ data obtained for the Arico, Granadilla, Fasnia, Poris, La Caleta and Abrigo formations are presented, allowing correlation with previously dated offshore marine ashfall layers and volcaniclastic sediments. We also provide a minimum age of 287 ± 7 ka for a major sector collapse event at the Güimar valley. The Bandas del Sur succession includes more than seven widespread ignimbrite sheets that have similar characteristics, including widespread basal Plinian layers, predominantly phonolite composition, ignimbrites with similar extensive geographic distributions, thin condensed veneers with abundant diffuse bedding and complex lateral and vertical grading patterns, lateral gradations into localized massive facies within palaeo-wadis, and widespread lithic breccia layers that probably record caldera-forming eruptions. Each ignimbrite sheet records substantial bypassing of pyroclastic material into the ocean. The succession indicates that Las Cañadas volcano underwent a series of major explosive eruptions, each starting with a Plinian phase followed by emplacement of ignimbrites and thin ash layers, some of co-ignimbrite origin. Several of the ignimbrite sheets are compositionally zoned and contain subordinate mafic pumices and banded pumices indicative of magma mingling immediately prior to eruption. Because passage of each pyroclastic density current was characterized by phases of non-deposition and erosion, the entire course of each eruption is incompletely recorded at any one location, accounting for some previously perceived differences between the units. Because each current passed into the ocean, estimating eruption volumes is virtually impossible. Nevertheless, the consistent widespread distributions and the presence of lithic breccias within most of the ignimbrite sheets suggest that at least seven caldera collapse eruptions are recorded in the Bandas del Sur succession and probably formed a complex, nested collapse structure. Detailed field relationships show that extensive ignimbrite sheets (e.g. the Arico, Poris and La Caleta formations) relate to previously unrecognized caldera collapse events. We envisage that the evolution of the nested Las Cañadas caldera is more complex than previously thought and involved a protracted history of successive ignimbrite-related caldera collapse events, and large sector collapse events, interspersed with edifice-building phases.

Keywords: ignimbrite, Tenerife, explosive eruptions, phreatomagmatism, Quaternary, volcanism.

1. Introduction

Previous studies of the well-exposed pyroclastic apron of southern Tenerife, known as the Bandas del Sur, catalogued numerous ignimbrites and fall deposits (e.g. Bryan, Martí & Cas, 1998) interpreted as the deposits of the most recent cycles in volcanic activity from Las Cañadas volcano (Bryan, Martí & Cas, 1998). Each protracted (e.g. ~300 ka) cycle was thought to be characterized by increasing explosivity and each was inferred to end with a climactic caldera-forming eruption. Quiescent periods were marked by widespread lava effusion. The data presented here reduce the overall number of Quaternary explosive eruptions recorded in the Bandas del Sur, and show that several of them were larger than hitherto appreciated. An interesting new pattern of Quaternary volcanic activity, with repeated explosive caldera collapse eruptions, is revealed, opening new insights into Tenerife's caldera subsidence and sector collapse history.

¶ Author for correspondence: mjb26@le.ac.uk

2. Geological setting of the Las Cañadas volcano

The island of Tenerife in the northeast Atlantic has undergone subaerial volcanism since Late Miocene times. Deeply eroded, emergent basaltic shield volcanoes ('Old Basaltic Series' 12 Ma to 3.3 Ma) have been partly buried by a prominent central shield volcano

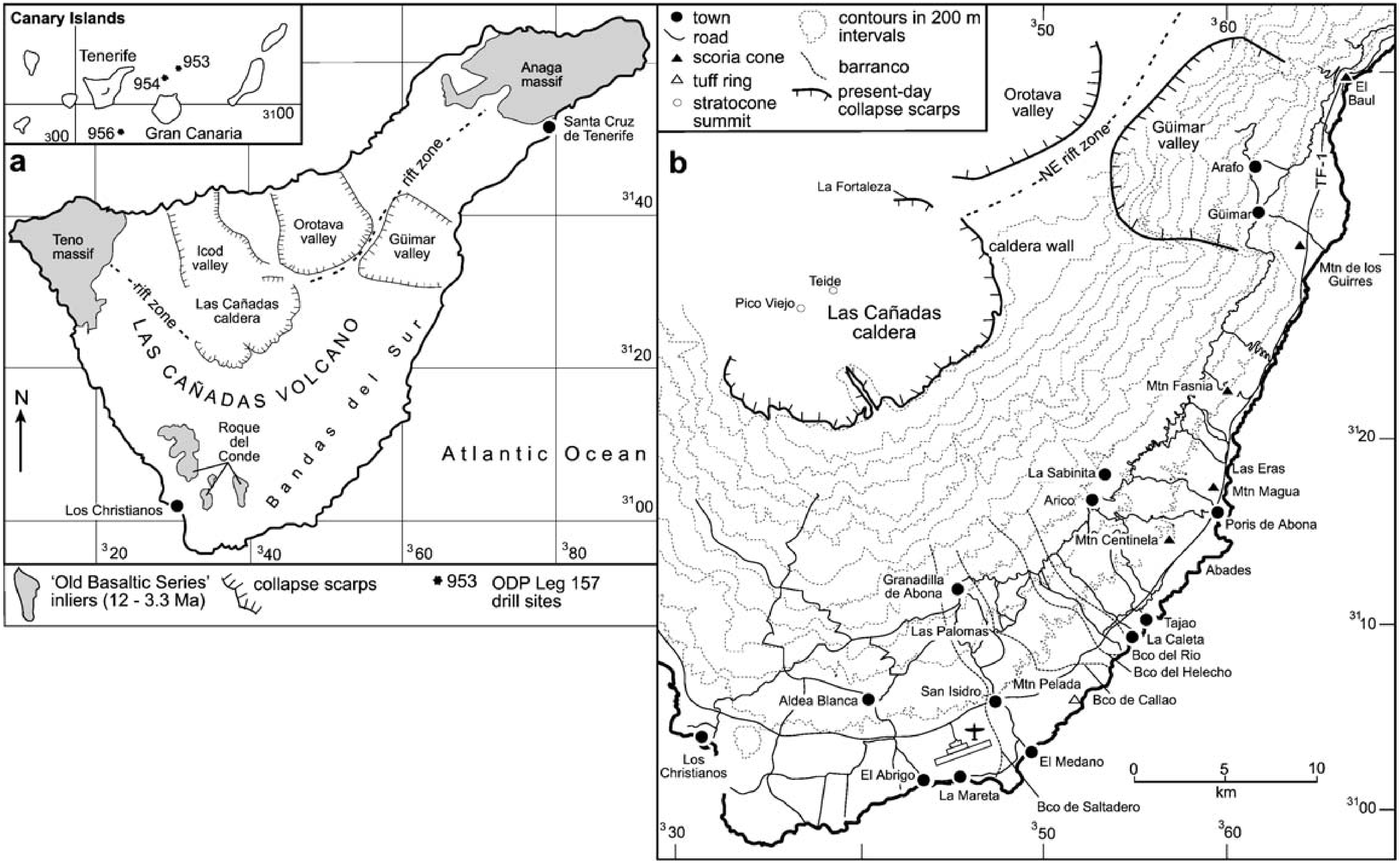

Figure 1. (a) Map of Tenerife showing the location of Las Cañadas volcano, the nested Las Cañadas caldera, three major sector collapse scars (the Güimar, Icod and Orotava valleys), and the Bandas del Sur, which is the location of the Quaternary pyroclastic succession described in this paper. The inset shows the location of the Canary Islands and the offshore drill sites (ODP Leg 157) where deposits from Las Cañadas are reported. (b) Detail of the Bandas del Sur showing locations referred to in the text. The numbered grid comprises 10 km intervals of the UTM Grid, zone 28. 'Bco' = Barranco; 'Mtn' = Montaña.

called Las Cañadas (Araña, 1971). The early eruptions (> 2 Ma) of Las Cañadas volcano were basaltic and effusion-dominated, whereas many of the later ones (3 Ma to 0.179 Ma) were more evolved and explosive (Ancochea *et al*. 1999). During its growth, Las Cañadas volcano underwent several large gravitational sector collapse events, leaving prominent lateral collapse scars (the Güimar, Icod and La Orotava valleys: Navarro & Coello, 1989; Ancochea *et al*. 1990). It has also developed a large (16 × 9 km) summit depression, known as the Las Cañadas caldera (Fig. 1), which has had a complicated evolution involving multiple caldera collapse events, as well as lateral collapses (flank failures; see Martí, Mitjavila & Araña, 1994, and Ancochea *et al*. 1999). In this work the term 'caldera' is used exclusively for a topographic depression caused by predominantly vertical subsidence into a subvolcanic magma chamber in response to magma withdrawal. Some calderas have a protracted history involving multiple collapse events, and their rims may be modified by inward-directed or outward-directed lateral (sector) collapse events. Intracaldera ignimbrites related to Las Cañadas caldera collapse have not been recorded and may lie buried beneath the post-caldera stratovolcanoes of Teide and Pico Viejo (Fig. 1). However, the outflow sheets (extracaldera pyroclastic deposits) are well exposed both in the caldera wall (Ancochea *et al*. 1990) and in an extensive pyroclastic apron on the volcano's southeast coastal flanks (Fig. 1). Submarine fallout tephra from Las Cañadas is recorded as far as 150 km ENE of the caldera (Rodehorst, Schmincke & Sumita, 1998).

2.a. The Quaternary succession in the Bandas del Sur

The Quaternary succession on the southeastern coastal flanks of Las Cañadas comprises mostly phonolitic ignimbrites and pumice fall deposits intercalated with flank-erupted scoria cones, impersistent basalt and phonolite lavas, epiclastic sandstones and conglomerates (Bryan, Martí & Cas, 1998; Fig. 2). Sedimentary lenses and numerous orange to brown palaeosols record quiescent periods between major explosive eruptions (Fig. 2). Some contain abundant Quaternary flora and fauna. Therefore, continued resolution of the onshore Bandas del Sur pyroclastic stratigraphy will complement the offshore record (e.g. Rodehorst, Schmincke & Sumita, 1998) to provide a temporal framework for understanding how eruption styles varied though time, and to explore possible relationships with Quaternary climate change and sea-level changes around the ocean island volcano.

The Bandas del Sur succession overlies basalts of the earlier, dominantly effusive phase of the volcano (Bryan, Martí & Cas, 1998). The cumulative thickness of the succession exceeds 300 m, but at individual locations it rarely exceeds 50 m because many eruption units are incomplete, condensed and patchily preserved as discontinuous lenses, so that no complete vertical succession of thick units occurs in one place. We infer that this is because the southeastern flank of Las Cañadas acted repeatedly as a bypass surface rather than as a major clastic depocentre for pyroclastic density currents, lahars and ephemeral streams as they flowed into the Atlantic Ocean. The ignimbrites are best preserved on the more gentle coastal slopes, whereas lavas and pyroclastic fall deposits dominate the steeper, upper flanks. Isopach and isopleth reconstructions of many of the pumice fall deposits are limited by erosional removal and by fallout into the ocean. However, the available data indicate that the source vents lay somewhere within the Las Cañadas caldera (e.g. Bryan, Cas & Martí, 2000).

All of the ignimbrites in the Bandas del Sur, apart from the Arico ignimbrite (which is welded in parts; see Section 4.c), are non-welded and extensively indurated by zeolites (Hernandez *et al*. 1993). Several of the pyroclastic units are compositionally zoned and show vertical variations in the composition of juvenile and accidental components (pumice, scoria, lithic clasts and/or phenocryst assemblages: Wolff, 1985; Bryan, Martí & Cas, 1998; R. J. Brown, unpub. Ph.D. thesis, Univ. Leicester, 2001; Bryan, Martí & Leosson, 2002).

A number of pyroclastic units within the Bandas del Sur succession have been correlated with parts of the Guajara and Diego Hernández formations exposed in the cliffs of Las Cañadas caldera, on the basis of radiometric data and similarities in phenocrysts, pumice, lithic clast assemblage compositions and occurrences of banded pumices (Ancochea *et al*. 1990; Martí, Mitjavila & Araña, 1994; Bryan, Martí & Cas, 1998; Wolff, Grandy & Larson, 2000). The present study, however, focuses on the coastal succession in the Bandas del Sur between Aldea Blanca and Güimar (Fig. 1), where excellent exposures through the pyroclastic stratigraphy occur along barranco walls, numerous quarries and in road cuts.

3. Geochronology

A paucity of reliable published radiometric data from the Las Cañadas succession in the Bandas del Sur means that the precise ages of the major explosive eruptions remain unresolved. Hitherto, most of the dating has been by K–Ar (see Table 1). Generally, K–Ar dating is analytically less precise than $^{40}Ar/^{39}Ar$ dating; furthermore, errors associated with the analysis of xenocrysts are greater with K–Ar dating, and it is therefore less suitable for single crystal work. New $^{40}Ar/^{39}Ar$ data on sanidine crystals (< 1 mm) are presented for six units in the Bandas del Sur succession.

Sample selection and preparation. Sanidine crystals were hand-picked from fresh pumice lapilli in fall deposits to minimize errors from dating accidental

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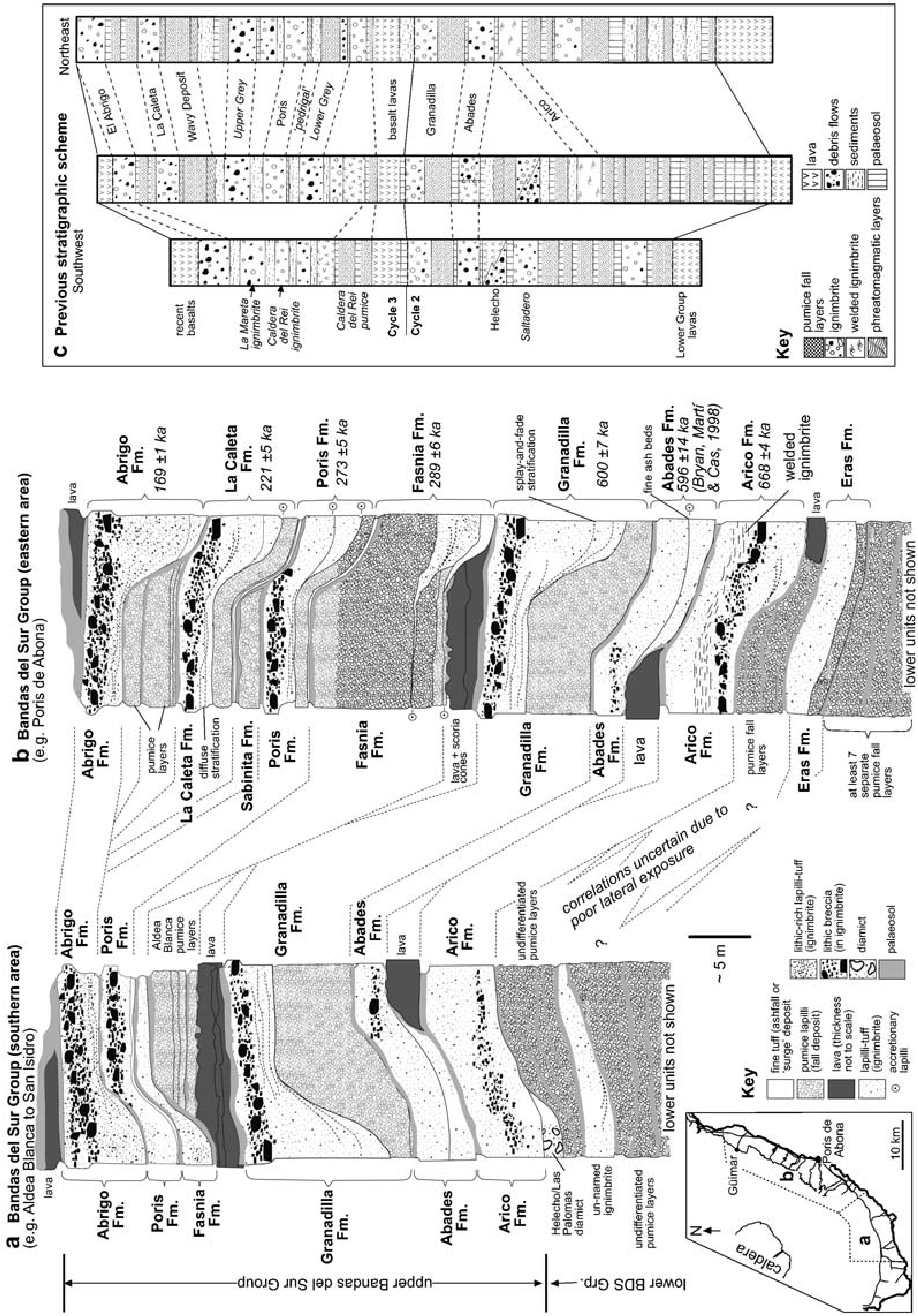

Figure 2. For legend see facing page.

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Table 1. Previous radiometric ages for pyroclastic units of the Bandas del Sur

Unit	Dating method	Age (ka)
[1]Abrigo ignimbrite	K/Ar	130 ± 20
[2]Poris ignimbrite	K/Ar	316 ± 10
[2]Abades ignimbrite	K/Ar	596 ± 14
[2]Granadilla ignimbrite	K/Ar	569 ± 14
[2]Granadilla ignimbrite	K/Ar	640 ± 10
[1]Arico ignimbrite	K/Ar	650 ± 30
[3]Arico ignimbrite	$^{40}Ar/^{39}Ar$	610 ± 90
[2]Saltadero ignimbrite	K/Ar	763 ± 13

[1] Ancochea *et al.* (1990).
[2] Bryan, Martí & Cas (1998).
[3] Huertas *et al.* (2002).

or xenocryst populations. For selected ignimbrites, sanidine crystals were taken from fresh, unaltered pumice lapilli. In the case of the La Caleta Formation (Fig. 2), pumice lapilli were altered and crystals were picked direct from the ignimbrite matrix. Sample sites are detailed in Table 4. The sanidine crystals were crushed to ∼1 mm grainsize, cleaned in 7 % dilute HF in an ultrasonic bath for 5 to 10 minutes, rinsed 3 times in distilled H_2O and then cleaned in distilled H_2O in an ultrasonic bath for 20 minutes.

Crystal samples were wrapped in Al foil packets, sealed in a 10 mm internal diameter quartz vial and irradiated at CLICIT facility of the Oregon State University TRIGA reactor. To monitor the irradiation flux parameter (J), packets of USGS standard sanidine 85G003, aged 27.92 Ma, were interspersed at least every 10 mm between the Tenerife samples. Values for J were known to better than 0.3 % at any given position within the vial (see Table 4). Where possible, single sanidine crystals were step-heated to total fusion using a 30W CO_2 laser at the Scottish Universities Research and Reactor Centre. Where crystals were considered too small (< 0.6 mm), multiple crystals were fused together for analysis (see Table 4). Weighted mean ages were calculated from incremental age determinations where each increment is weighted by the inverse of its variance, so that poor-quality data cannot have a disproportionate affect on the age result. Results are discussed below and presented in Table 2, with isochron ages for comparison. All ages are quoted with errors at the 1σ confidence level.

4. A revised Quaternary pyroclastic stratigraphy in the Bandas del Sur

Despite several recent studies of the pyroclastic deposits of the Bandas del Sur (Paradas & Fernández, 1984; Wolff & Storey, 1984; Wolff, 1985; Alonso, Araña & Martí, 1988; Bryan, Cas & Martí, 1998, 2000), the overall stratigraphy is not yet resolved. The succession between El Abrigo and Poris de Abona was first described by Bryan, Martí & Cas (1998), who defined the ‘Bandas del Sur Formation’ and 11 pyroclastic members within it (see Fig. 2c).

We present an extended and revised lithostratigraphy (Fig. 2) that has resulted from tracing the units laterally in the field, from detailed correlation, particularly of pyroclastic fall layers, and from new $^{40}Ar/^{39}Ar$ data. For convenience, the status of the Bandas del Sur succession has been elevated from a formation to a group. This is because it comprises a large number of distinctive individually mappable units, designated herein as formations, which can themselves be readily subdivided into members and beds. The change gives the succession the same status as the ‘Upper Group’ of the Cañadas caldera wall succession, with which it broadly correlates (Martí, Mitjavila & Araña, 1994), and will facilitate more detailed subdivision of the succession in the future. To avoid confusion, the original names of former members are retained where possible (see Fig. 2) in accordance with conventional stratigraphic procedure (see Holland, Audley-Charles & Bassett, 1978; North American Committee on Stratigraphic Nomenclature, 1983) so that, for example, the former ‘Abades Member’ of Bryan, Martí & Cas (1998) is now the Abades Formation. In the revised scheme, each formation typically records a major explosive eruption and is bounded by soils that record intervening periods of repose, whereas the members generally record a distinctive phase of an eruption (e.g. a pyroclastic fall or pyroclastic flow event). Several units (e.g. lavas, and some pyroclastic and sedimentary layers) within the Bandas del Sur Group remain without formal designation. The base of the group is not exposed in many sections and remains rather poorly defined; locally, for example, in the Güimar collapse structure, it rests upon older, mafic rocks from Las Cañadas volcano, but elsewhere it unconformably overlies deeply incised basaltic rocks of the ‘Old

Figure 2. A generalized stratigraphy of the upper part of the Bandas del Sur Group. Complex stratigraphic relations due to abundant erosional unconformities have been simplified to illustrate the succession on two vertical sections: (a) based on the area around San Isidro in the south, and (b) based on the area around Poris de Abona in the east. Pumice fall layers are shown approximately to scale, but maximum thicknesses of ignimbrites and lavas are not shown. Sedimentary units and numerous basaltic units are excluded for simplification. (c) Previous stratigraphic scheme modified from Bryan, Martí & Cas (1998), showing units formerly designated as the ‘Upper Grey’, ‘La Mareta’ and parts of the ‘Caldera del Rei’ that are now re-designated as part of the Poris Formation; the position in the southwest of the ‘Saltadero Member’ (of Bryan, Martí & Cas, 1998), now redesignated as part of the Arico Formation; and the Helecho deposit that was previously thought to be stratigraphically above the Saltadero and Arico ignimbrites. Fm. = Formation.

Table 2. Summary of new $^{40}Ar/^{39}Ar$ age data for pyroclastic units in southwest Tenerife

Formation	No. of analyses	Weighted mean age (ka)	MSWD	Isochron age (ka)	SUMS /(N-2)	$^{40}Ar/^{36}Ar$ intercept
Abrigo Formation	17 of 21	169 ± 1	1.09	168 ± 2	1.05	301.2 ± 4.6
La Caleta Formation	9 of 11	221 ± 5	1.80	230 ± 20	1.82	282.2 ± 18.6
Poris Formation:						
Member 9*	5 of 8	271 ± 6	0.42	265 ± 14	0.48	308.2 ± 30.4
Member 2	6 of 8	276 ± 9	0.90	247 ± 28	0.70	353.8 ± 57.5
Fasnia Formation	9 of 13	289 ± 6	2.42	287 ± 9	2.59	296.1 ± 7.00
Granadilla Formation	11 of 12	600 ± 7	1.75	598 ± 9	1.89	298.1 ± 10.2
Arico Formation	18 of 21	668 ± 4	1.49	668 ± 4	1.57	299.7 ± 8.1

Errors reported at 1 σ.
* This was the 'Upper Grey Member' of Bryan, Martí & Cas (1998).

Basaltic Series'. The top of the group is defined as the top of the uppermost extensive pyroclastic deposit, the Abrigo Formation (Fig. 2).

In summary, the main stratigraphic revisions (see Fig. 2) are as follows. (1) The Arico Formation includes the 'Arico ignimbrite' and the former 'Saltadero ignimbrite', which were previously regarded as unrelated deposits with different distributions. The Arico ignimbrite was previously considered to be of limited areal extent (Alonso, Araña & Martí, 1988), but is now traced over the entire length of the Bandas del Sur, as is the overlying Abades Formation. (2) The Poris Formation similarly has been traced the full length of the Bandas del Sur, and it includes units previously inferred to record unrelated eruptions, that is, the former 'Poris Member', 'Upper Grey Member', 'La Mareta Member', 'Caldera del Rei Ignimbrite Member' of Bryan, Martí & Cas (1998) and 'Pedrigal ignimbrite' of Bryan, Martí & Leosson (2002). (3) The La Caleta Formation comprises the former 'Wavy' and 'La Caleta' members of Bryan, Martí & Cas (1998), and is re-interpreted as recording a single, major explosive eruption. We outline the new lithostratigraphy below, in chronological order, referring to previous accounts where appropriate. This paper concerns the upper part of the Bandas del Sur succession, above and including the Arico Formation (cycles 2 and 3 of Bryan, Martí & Cas, 1998). We informally refer to this as the 'upper' Bandas del Sur Group. The stratigraphy of the 'lower' Bandas del Sur Group is less well resolved (see next Section).

4.a. The Eras Formation and the lower Bandas del Sur Group

The lower Bandas del Sur Group comprises more than 11 phonolite Plinian pumice fall deposits (Figs 2a, b, 3), exposed around Barranco de Callao, Poris de Abona and Las Eras (Fig. 1), more than 8 ignimbrites exposed in the south and east, and numerous lavas, sedimentary layers and palaeosols. Because their stratigraphy and correlations across the Bandas del Sur remain to be resolved they have not yet been formalized (see Fig. 2).

One of the most complete sections through lower Bandas del Sur pyroclastic deposits occurs around Las Eras (Fig. 3). Here, three pumice fall deposits occur between the Arico Formation and the underlying Eras Formation (see Fig. 2b), and a further six pumice fall deposits with intervening soils occur below the Eras Formation.

The Eras Formation (new name) comprises a phonolitic pumice fall deposit (Fig. 4a), overlain by a cream to pale green phonolite ignimbrite (Fig. 4b), up to 10 m thick, that is exposed between Poris de Abona and Las Eras (Fig. 1). The type section occurs on a small ridge 800 m west of the Las Eras autopista junction. At the type section the pumice fall layer is 1.8 m thick, non-graded and has a slightly finer-grained layer, 5 cm thick, 90 cm above the base. It overlies a soil developed on (unnamed) older pumice fall layers. The Eras ignimbrite is cream-coloured, lithic-poor, massive and locally diffuse-bedded pumiceous lapilli-tuff and contains abundant scattered blocks of pale green pumice (Fig. 4b). A distinctive feature is that the pumice lapilli are particularly abundant and commonly clast-supported. Phenocrysts include sanidine, plagioclase, biotite and haüyne. The formation is vertically zoned with the appearance of banded and mafic pumices approximately 8 cm above the base of the ignimbrite. The ignimbrite pinches out away from palaeovalleys, leaving only the pumice fall layer (Fig. 4a). At Poris de Abona (Fig. 1), the Eras Formation overlies basalt lava and has a soil at its top that is locally eroded out and overlain by alluvial volcaniclastic sediments, in turn overlain by a tephrite lava.

The Eras Formation records a chemically zoned Plinian eruption, which showered pumice over the eastern Bandas del Sur, and then generated a sustained pumice-rich pyroclastic density current that deposited a zoned ignimbrite sheet in the east. The extent of the density current(s) is not yet resolved.

At Barranco de Callao in the south, the lowest exposed part of the lower Bandas del Sur Group comprises two Plinian pumice fall layers, each with an upper soil overlain by a 6 m thick cream-coloured

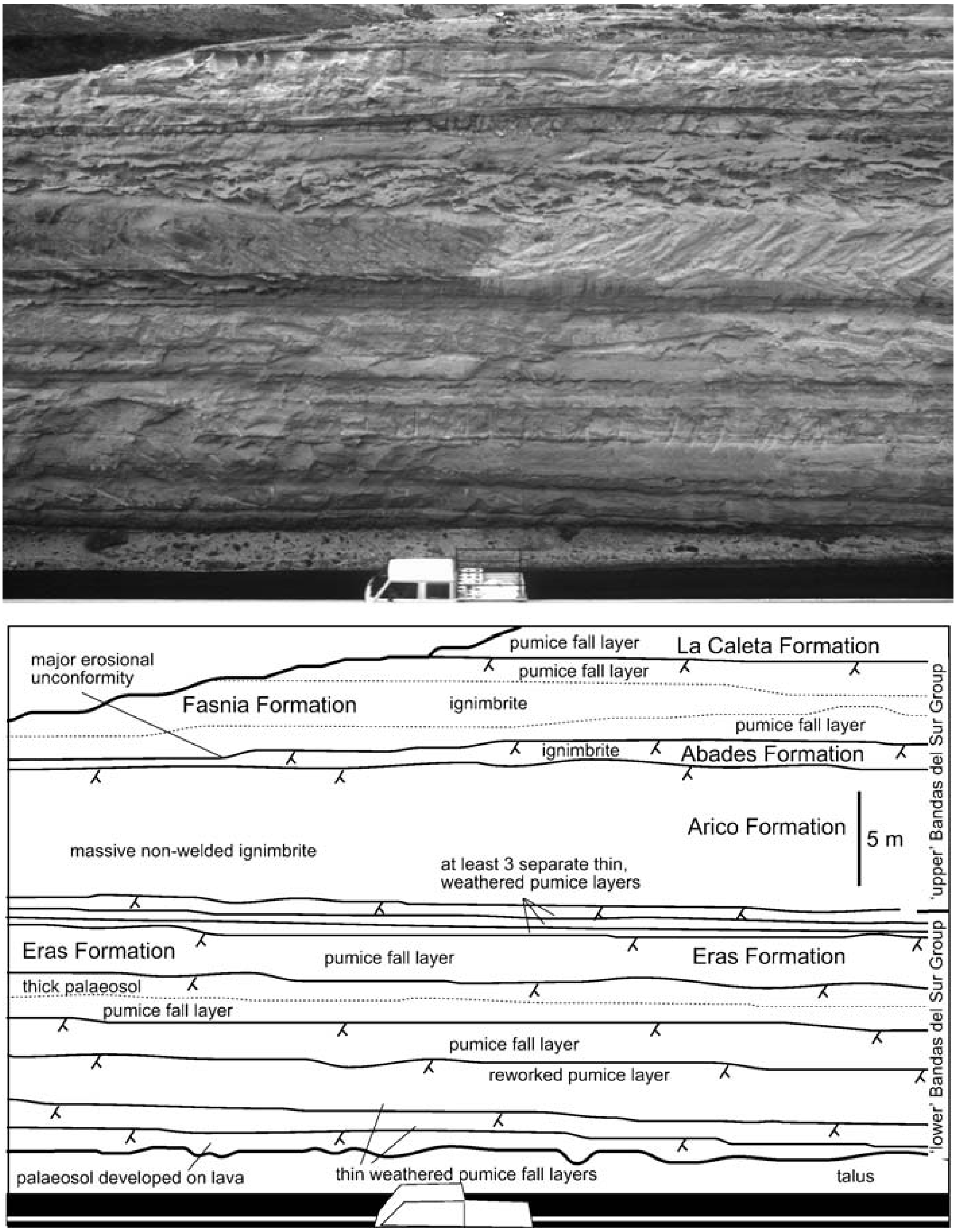

Figure 3. South-facing road cut through the middle part of the Bandas del Sur Group near Las Eras. The section comprises predominantly alternating pumice fall deposits and palaeosols (symbols), including at least eight separate pumice fall layers in the 'lower' Bandas del Sur Group. Named formations are marked. At least five separate pumice fall layers occur below the Eras Formation. Van is 4 m long.

phonolitic ignimbrite (Fig. 2a). The ignimbrite has a scoured base overlain by inverse-graded lapilli-tuff with diffuse bedding that passes up into massive lapilli-tuff. Diffuse bedding near the base of the ignimbrite passes laterally into massive lapilli-tuff via splay-and-fade stratification (Branney & Kokelaar, 2002). Most of the thickness of the ignimbrite contains abundant imbricated accidental lithic clasts, including mafic scoria. Overlying the ignimbrite are four (unnamed) phonolitic Plinian fall deposits, each with an intervening soil. These are overlain by the Arico ignimbrite (Fig. 2a).

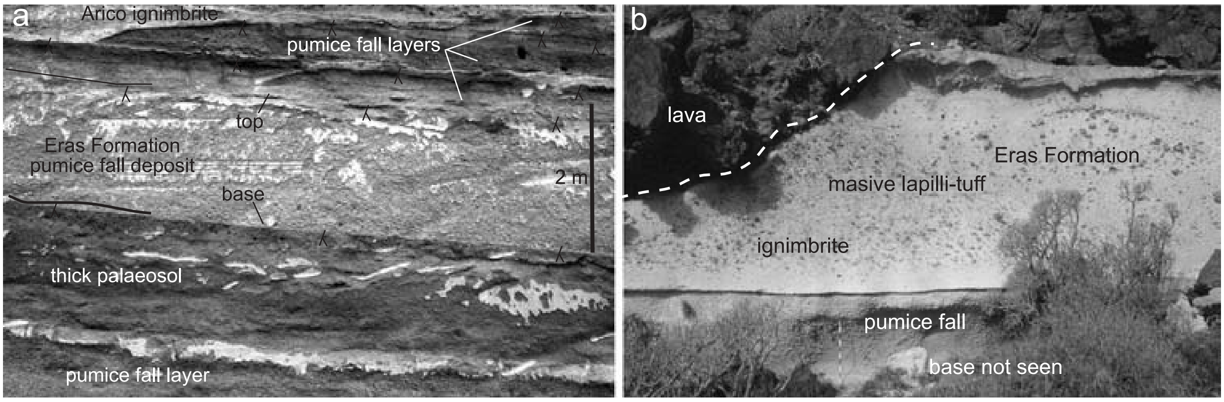

Figure 4. The Eras Formation. (a) The massive pumice fall deposit of the Eras Formation at Las Eras (Fig. 1) overlying a thick dark brown palaeosol developed in the top of an older, unnamed pumice fall deposit. At least three separate pumice fall deposits occur between the Eras and Arico formations. (b) The Eras ignimbrite at Poris de Abona (Fig. 1). Inverse-graded lapilli-tuff at base of ignimbrite sharply overlies the basal pumice fall deposit (base not seen) and passes up into massive lapilli-tuff, with abundant, sometimes framework-supported pumice lapilli and (pale green) pumice blocks. Thin pumice lenses occur in upper part of ignimbrite. The top of the formation is cut out by an erosion surface overlain by lava. Scale (bottom of photo, left of centre) is 1 m long.

4.b. The Helecho Formation

This formation is up to 25 m thick and comprises massive, very poorly sorted heterolithic diamicts with matrix-supported blocks up to 3 m in diameter in a fine-grained matrix (see Bryan, Martí & Cas, 1998). Its distribution is localized around Barranco del Helecho, La Caleta and San Isidro (Fig. 1). At the type locality, Barranco del Helecho (Fig. 1), it is overlain by a pumice fall layer and soil, and in turn overlain by the Abades Formation (see Section 4.d). However, its precise stratigraphic position remains uncertain because the basal contact is not observed. The Helecho Formation is described by Bryan, Martí & Cas (1998), who interpret it as the deposits of both cohesive debris flows and block-and-ash flows. A similar and possible correlative coarse diamict deposit ('the debris flow deposit of Las Palomas' of Bryan, Martí & Cas, 1998) is overlain by the Arico Formation around Las Palomas (Fig. 1). If it is equivalent to the Helecho Formation, then the formation must be older than the Arico Formation (Fig. 2a).

4.c. The Arico Formation

The Arico Formation comprises a distinctive layered pumice fall succession overlain by an extensive, vertically zoned, white, orange to dark-brown ignimbrite, the Arico ignimbrite, which is partly welded at some locations (Fig. 5). The pumice fall succession (Fig. 6a) has not previously been described. It comprises three layers: (1) the lowest is a layer of white fine pumiceous ash that drapes abundant plant moulds; (2) the second is a well-sorted layer of angular pumice granules; (3) the third and uppermost fall layer is of well-sorted angular coarse pumice lapilli. The pumice fall layers are preserved extensively around Poris and further west, but are commonly truncated by the erosional base of the Arico ignimbrite (Fig. 5). At Arico (Fig. 1), the fallout succession is up to 20 cm thick. The succession seen at the village of Arico (see Bryan, Martí & Cas, 1998) is incomplete and a thicker (30 m) and more complete succession occurs at Montaña Magua (see Fig. 5, log 5).

The Arico ignimbrite is characterized by abundant phenocrysts and lithic clasts, which both commonly show imbrication, and by the presence locally of dark-green to black, equant to oblate obsidian clasts (e.g. at Arico, Fig. 1). The phenocrysts include (in decreasing abundance) sanidine, biotite, magnetite, green pyroxene, hornblende, haüyne, sphene and apatite (Bryan, Martí & Leosson, 2002). Parts of the ignimbrite are described by Schmincke & Swanson (1967), Alonso, Araña & Martí (1988) and Bryan, Martí & Cas (1998). They reported that the ignimbrite is welded, and has a distribution restricted to a 9 km wide lobe around Arico (Alonso, Araña & Martí, 1988). However, recognition that the welded facies locally pass laterally into non-welded facies (e.g. at Magua; Figs 5, 6b) has led to the ignimbrite being traced much more extensively along the coast from the airport to northeast of Las Eras (Fig. 1). Its distribution is broadly similar to that of the other extensive ignimbrites of the Bandas del Sur Group. Where the ignimbrite is not welded it varies from white to orange, possibly thermal, colouration.

The Arico Formation is vertically zoned. All pumices within the basal fallout layers and the earliest-deposited parts of the ignimbrite are of white to very pale-green phonolite (Fig. 6a), and mafic pumices appear with increasing abundance up-section. In addition, the proportion of accidental lithic blocks and dark-green to black obsidian clasts first increases and then decreases markedly with height in the ignimbrite (Fig. 6c).

The Arico ignimbrite exhibits pronounced lateral and vertical facies changes from massive lapilli-tuff to

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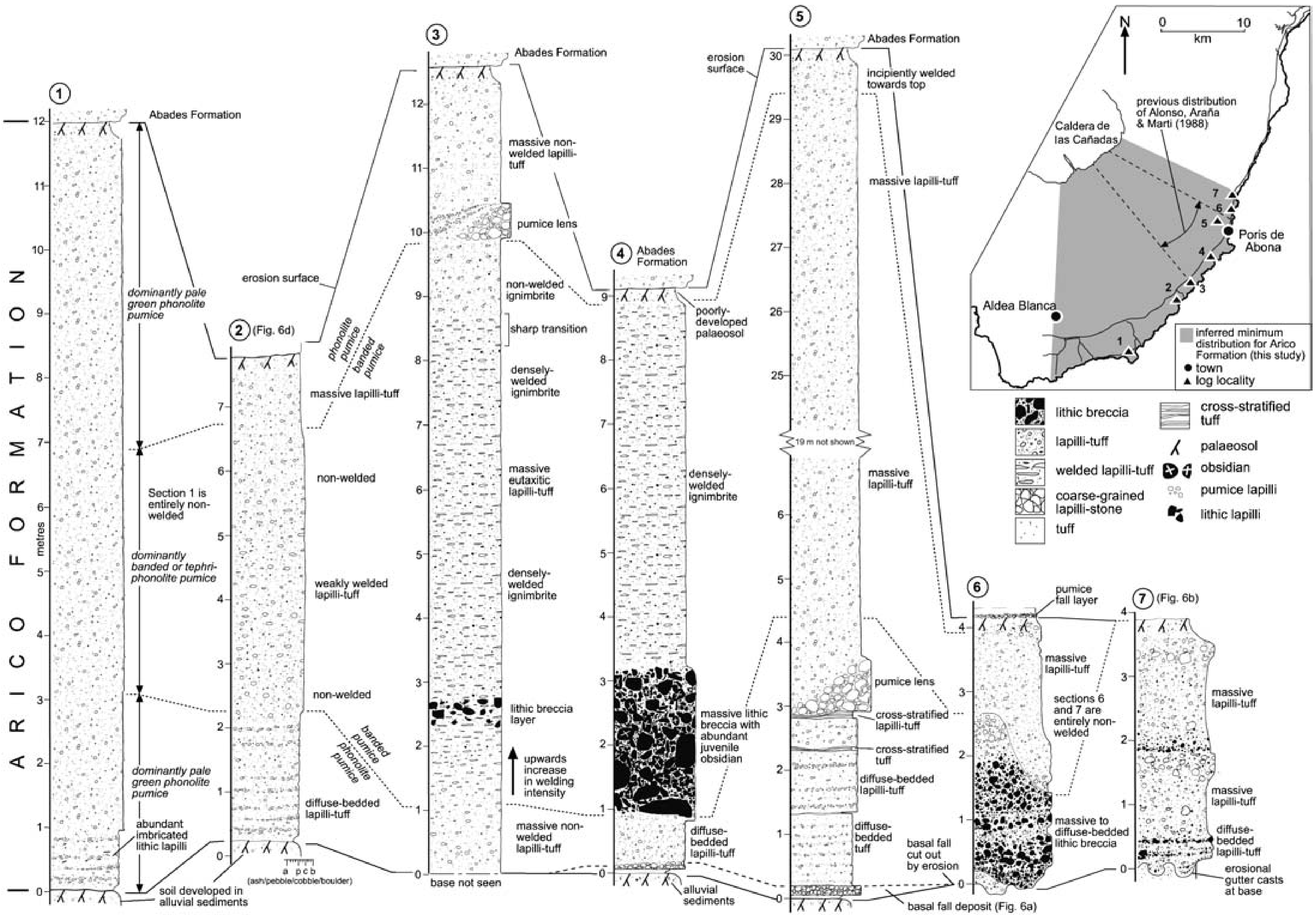

Figure 5. Representative logs through the Arico Formation illustrating lateral variations in depositional lithofacies and in welding intensity (see Fig. 6). The ignimbrite shows vertical compositional zonation, and the appearances and disappearances of banded pumice clasts, which include a mafic juvenile component, are indicated by dotted tie-lines.

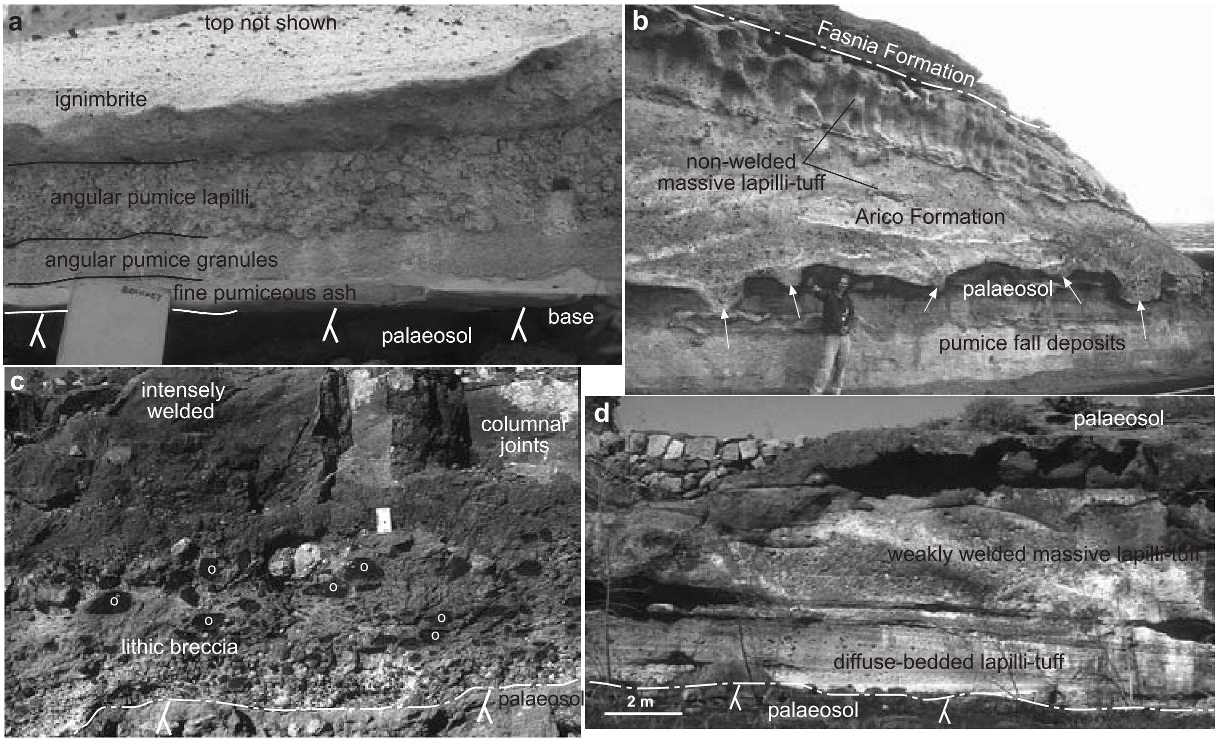

Figure 6. The Arico Formation. (a) Basal tripartite fall layers beneath the Arico ignimbrite at Montaña Magua (Fig. 1). The fall layers are locally cut out completely by the scour surface at the base of the ignimbrite. Notebook is 10 cm wide. Pyroclastic current flowed towards the viewer. (b) Basal gutter casts (arrowed) caused by vigorous erosion by the Arico pyroclastic density current at Las Eras (Fig. 1). The ignimbrite here is entirely non-welded. Pyroclastic current direction was towards the viewer. (c) Basal part of the Arico ignimbrite at Arico (Fig. 1). Cream-coloured, non-welded ignimbrite, 30 cm thick, with abundant pale green phonolite pumice and accidental lithic clasts passes up into lithic breccia, and then into columnar jointed eutaxitic lapilli-tuff ('o' refers to clasts of juvenile obsidian). Welding intensity increases upwards from the non-welded base. Notebook is 10 cm wide. (d) The Arico ignimbrite at Barranco del Rio (Fig. 1) showing non-welded, diffuse-bedded lapilli-tuff passing up into ~3 m of massive eutaxitic lapilli-tuff. Pyroclastic current moved from left to right.

diffuse-bedded lapilli-tuff with splay-and-fade stratification (see fig. 6.16A of Branney & Kokelaar, 2002). The ignimbrite includes locally impersistent layers and lenses of abundant large pumice clasts and lithic blocks, including well-developed lithic breccias up to 3 m thick, with abundant juvenile obsidian blocks and accidental lithic clasts (Fig. 6c). Two <20 cm thick layers of low-angle cross-stratified white ash occur intercalated with massive and diffuse-bedded lapilli-tuff layers within the lower part of the ignimbrite at one locality (see Fig. 5, log 5).

In places the Arico ignimbrite is partly welded (Fig. 6c, d). Fiamme and eutaxitic fabrics in the welded facies are oblate, indicating compactional flattening with no evidence for rheomorphism. Around Arico and Poris de Abona (Fig. 1), the intensity of welding increases upwards from non-welded at the base to intensely welded and locally vitrophyric eutaxitic lapilli-tuff, and then decreases to a non-welded, thermally oxidized top (see Figs 5, 6c, d). This welding profile varies laterally: the thickness of the lower non-welded zone varies from 10 cm to more than 4 m thick, and the entire thickness of the ignimbrite sheet is non-welded in the south (e.g. at Barranco de Saltadero; Fig. 1). Thus, the lateral variations in welding intensity are not simply a function of deposit thickness (see Fig. 5).

We report a new $^{40}Ar/^{39}Ar$ age of 668 ± 4 ka for the Arico Formation (Table 2). The precision improves on previous radiometric ages (see Table 1) and shows no evidence of xenocrystic contribution.

The Arico ignimbrite around El Médano (Fig. 1) has previously been called the 'Saltadero Ignimbrite Member' (Bryan, Martí & Cas, 1998), and outcrops at Barranco de Charcon have been recorded as the 'Stratified Ignimbrite of Barranco de Charcon' (Bryan, Cas & Martí, 1998). The ignimbrite at these locations occupies the same stratigraphic position, and has a similar phenocryst content, lithofacies associations and compositional zonation as the Arico ignimbrite elsewhere.

Interpretation. We infer that the Arico eruption had an initial waxing Plinian phase recorded by the upwards-coarsening pumice fallout succession. This culminated in sustained pyroclastic fountaining with a widespread, sustained pyroclastic density current. During this climactic phase, clast compositions, temperatures and chemistry of the pyroclastic density

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Table 3. Table listing the numerous features that are shared by successive ignimbrite sheets in the Bandas del Sur

Formation	Eras	Arico	Abades	Granadilla	Fasnia	Poris	La Caleta	Abrigo
Feature								
Basal plinian fall deposits	X	X	?	X	X	X	X	?
Extensive geographic dispersal	?	X	X	X	X	X	X	X
Predominantly phonolite composition	X	X	X	X	X	X	X	X
Banded pumice/magma mingling	X	X	X		X	X	X	X
Condensed sequences		X	X	?	X	X	X	?
Valley-fill and veneer ignimbrite	X	X	X	X	X	X	X	
Extensive lithic breccias		X		X	X	X	X	X
Lithofacies:								
massive	X	X	X	X	X	X	X	X
diffuse-bedded	X	X	X	X	X	X	X	X
diffuse-stratified	X	X	X	X	X	X	X	X
pumice lenses	X	X		X	X	X	X	X
Splay-and-fade stratification (*sensu* Branney & Kokelaar, 2002)		X		X	X	X	X	X
Internal erosion surfaces		X		X	X	X	X	
Compositional zoning	X	X	X	X	X	X	X	X
Lower parts of formation locally stripped by climactic-phase density currents		X		X	X	X		X

current(s) changed with time as a result of the changing nature and relative proportions of different types of pyroclastic components supplied to the pyroclastic current(s) with time. Basal scour surfaces (Fig. 6b) and the incomplete and condensed nature of the lower part of the Arico ignimbrite in many sections, such as around Arico (Fig. 6a), indicate that the waxing phase of the current(s) in many places was characterized by periods of non-deposition and erosion. Unequivocal flow-unit boundaries have not been found in the ignimbrite, and it probably largely represents the deposit of a single sustained current. However, two thin stratified layers at Montaña Magua (Fig. 5, log 5) represent tractional deposition from fully turbulent currents, and it is possible that there were short pauses during the initial stages of the current. The clasts of non-vesicular phonolite obsidian are interpreted as juvenile because some were sufficiently hot to flatten into fiamme, and because they locally grade texturally into green and white juvenile phonolite pumice. The obsidian may represent a phonolite intrusion or dome that was fragmented and entrained during the explosive eruption. The presence of Plinian fallout layers, the widespread distribution of the ignimbrite, and the association of diverse facies within the ignimbrite, including extensive diffuse-stratified veneers, splay-and-fade stratification, white pumiceous massive lapilli-tuff, stratified facies and lithic breccias (see Table 3) suggest that the eruption was broadly of a similar scale and style to other major explosive eruptions recorded in the Bandas del Sur Group. The substantial influxes of lithic blocks into the sustained current during the climactic phase of the eruption probably record caldera-collapse or another major erosional event. The widespread distribution of the Arico ignimbrite suggests that it was able to breach the southern and eastern walls of Las Cañadas caldera in a number of different places. This interpretation is in contrast to previous interpretations that suggested that the Arico eruption records a small localized dome-collapse eruption from a point source northeast of Arico, and that it that lacked a Plinian phase (Alonso, Araña & Martí, 1988).

4.d. The Abades Formation

The Abades Formation (Fig. 2a, b) comprises a non-welded phonolite ignimbrite, up to 10 m thick, with abundant pale cream pumice lapilli and ash and conspicuous scattered tephriphonolite black pumice lapilli and blocks, up to 60 cm. It is described in Bryan, Martí & Cas (1998), who cite Abades as the type area (Fig. 1) and describe it as compositionally zoned. No basal Plinian fallout layer has been recorded, although the base of the ignimbrite is commonly erosional. The ignimbrite varies from massive to diffuse-bedded, and contains two fine-grained massive to cross-stratified layers of fine ash of probable co-ignimbrite origin, in which small accretionary lapilli increase in abundance upwards. A K–Ar age of 596 ± 14 ka from alkali feldspar is reported (Bryan, Martí & Cas, 1998). This formation is now traced from El Médano in the south to Las Eras in the east.

4.e. The Granadilla Formation

The Granadilla Formation (‘Granadilla pumice and Granadilla ignimbrite’ of Booth, 1973; ‘Granadilla Member’ of Bryan, Cas & Martí, 2000) comprises a Plinian pumice fall deposit, ≤ 9 m thick, overlain by a widespread, non-welded phonolite ignimbrite, the ‘Granadilla ignimbrite’, ≤ 30 m thick (Fig. 2a, b). The formation is well described by Bryan, Martí & Cas (1998) and Bryan, Cas & Martí (2000), who cite a type area east of the town of Granadilla (Fig. 1). The formation exhibits reverse-to-normal cryptic

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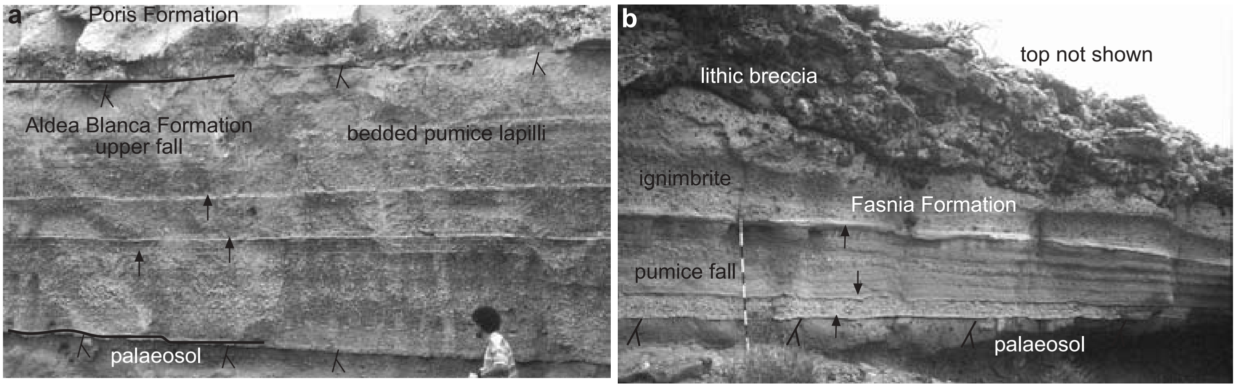

Figure 7. (a) The upper Aldea Blanca pumice fall deposit at Aldea Blanca (Fig. 1). Deposit exhibits diffuse bedding and intercalated thin fine ash beds (arrowed), abundant oxidized red lithic lapilli and banded and streaky pumice lapilli (not visible). (b) The Fasnia Formation at Las Eras (~ 15 km from source) comprises a bedded Plinian pumice fall deposit overlain by an ignimbrite comprising diffuse-bedded lapilli-tuff and lithic breccia. Note the erosional base of the ignimbrite, and the two thin layers of fine ash (arrowed) within the lower part of the pumice fall deposit. Metre-rule for scale.

compositional zonation (Bryan, Martí & Cas, 1998). The ignimbrite comprises massive, diffuse-bedded and locally stratified lapilli-tuff. It locally exhibits splay-and-fade stratification (*sensu* Branney & Kokelaar, 2002) and its base locally cuts deeply into the underlying fall deposit. In places, the pumiceous ignimbrite passes up into lithic breccias and/or block-bearing lithic-rich lapilli-tuff (Bryan, Martí & Cas, 1998). Conflicting K–Ar ages of 569 ± 14 ka and 640 ± 10 ka are recorded by Bryan, Martí & Cas (1998) from sanidine crystals in the ignimbrite. This may reflect the presence of xenocrysts and/or accidental crystals. We provide a new $^{40}Ar/^{39}Ar$ eruptive age of 600 ± 9 ka for the pumice fall deposit of the Granadilla Formation (see Table 2). This is based on individual analyses of 11 sanidine crystals.

4.f. The Aldea Blanca pumice fall deposits

Two pale grey phonolitic Plinian pumice fall layers, each with a soil developed on top, are exposed on a road-cut east of Aldea Blanca (Fig. 1). The lower fall layer overlies a soil developed variously on the Granadilla Formation and on post-Granadilla Formation scoria cones. The upper pumice fall layer is overlain by a soil, and variously by the Poris Formation, an ignimbrite of the Fasnia Formation ('un-named ignimbrite' of Bryan, Martí & Cas, 1998) and by the Abrigo Formation (Fig. 2). The fall deposits are also widely exposed in road cuts between the south coast and Granadilla (Fig. 1), where the thickest and coarsest sections are recorded. At Aldea Blanca, the lower fall layer is 1.65 m thick and the upper one is 2.7 m thick. Each has a distinctive internal stratigraphy based on vertical variations in the grainsize of pumice lapilli and changing proportions of abundant accidental lithic clasts, many of which are hydrothermally altered to a red colour (Fig. 7a). The former name 'caldera del Rei pumice fall deposits' (Bryan, Martí & Cas, 1998) was first coined by Paradas & Fernández (1984), who inferred an eruptive source at a nearby maar volcano called the 'Caldera del Rei', 3 km north of Los Christianos (Fig. 1). However, this provenance has not been substantiated, and preliminary isopach and isopleth data indicate a south-to-southwest dispersal from a source within Las Cañadas caldera. The fall deposits have not been recognized at Caldera del Rei and we have dropped the use of this name.

4.g. The Fasnia Formation

The Fasnia Formation comprises a succession of intercalated non-welded phonolitic ignimbrites, fine ash layers with accretionary lapilli and Plinian pumice fall deposits (see Fig. 2), which are thickly developed and well exposed around Fasnia (Fig. 1). The unit has previously been referred to as 'Unit J' (Walker, 1981) and as the 'Lower Grey Member' (Bryan, Martí & Cas, 1998), but it is renamed here after Fasnia, its type area. The Fasnia Formation extends across the Bandas del Sur from Aldea Blanca to northeast of Güimar (Fig. 1) and is reported in the caldera wall (Wolff, Grandy & Larson, 2000) and on the north side of Tenerife (J. A. Wolff, unpub. Ph.D. thesis, Univ. London, 1983; Martí, Mitjavila & Araña, 1994). It is the oldest recognized pyroclastic formation exposed in the sediment fill sequence on the floor of the Güimar sector collapse scar. We have determined an $^{40}Ar/^{39}Ar$ age of 289 ± 6 ka (Table 2), which is the first published eruptive age for the Fasnia Formation.

The Plinian pumice fall layers in the Fasnia Formation reach 8 m thick (at Fasnia), and exhibit a characteristic internal stratigraphy of bedding and grading picked out by vertical variations in the size of pumice lapilli and the proportion of accidental lithic clasts (Fig. 7b), which are abundant in some layers (see Bryan, Martí & Cas, 1998). Most pumice is white phonolite, but subordinate banded mafic pumice clasts

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also occur. At least two lithic-rich ignimbrites occur in the formation, each locally exceeding 10 m thick. They include massive, stratified and diffuse-bedded pumiceous lapilli-tuff and lithic-rich lapilli-tuff, layers and lenses of lithic breccia (Fig. 7b) and pumice-rich lenses. Each passes laterally into a thin layer of low-angle cross-stratified tuff, which in turn passes laterally into an erosion surface that locally cuts down into subjacent Fasnia fall layers and older deposits. Each of these erosion surfaces is directly overlain by, and draped by, succeeding Fasnia pumice fall layers. The lower ignimbrite is well exposed around Tajao (Fig. 1) while the upper ignimbrite is more widely distributed, for example, between Güimar and Aldea Blanca (Fig. 1). Thin layers of fine ash containing accretionary lapilli locally overlie each of the ignimbrites, and occur locally at the base of the formation, where they drape abundant vegetation moulds.

Interpretation. The Fasnia Formation records a major explosive eruption from Las Cañadas caldera that devastated the southeast sector of Tenerife and possibly most of the island. Plinian pumice blanketed eastern Tenerife with a dispersal axis near Fasnia where the fall layers are thickest. Destructive pyroclastic flows swept across the south and east flanks of the volcano, causing widespread erosion and depositing an extensive thin veneer of ignimbrite and co-ignimbrite ash fall deposits. The currents varied laterally from traction-based to granular fluid-based (*sensu* Branney & Kokelaar, 2002), respectively depositing cross-stratified and massive ignimbrite. Local valley-fills are composed of predominantly massive ignimbrite. Near-source erosion or rockfall during a climactic caldera-forming phase of the eruption caused large influxes of lithic blocks into the pyroclastic density currents, recorded as widespread lithic breccias. Much of the pyroclastic material bypassed subaerial flanks and was transported into the ocean.

4.h. The Poris Formation

The Poris Formation ('Poris Member' of Bryan, Martí & Cas, 1998) is a distinctive creamy-white phonolitic compound ignimbrite sheet in the upper part of the Bandas del Sur Group. It is exposed discontinuously for over 60 km between the villages of Aldea Blanca and El Baul (Fig. 1). It comprises ignimbrites and intercalated pumice fall and ashfall layers and is subdivided into 11 members (R. J. Brown, unpub. Ph.D. thesis, Univ. Leicester, 2001), the recognition of which has facilitated the widespread correlation. Member 1 comprises eight pumice and ashfall layers exposed between Aldea Blanca and Fasnia (Figs 8, 9a). The uppermost layer (layer H) has a Plinian dispersal and is up to 130 cm thick (Fig. 8). Members 2 to 4 are extensive thin ignimbrite veneers with diffuse stratification, splay-and-fade stratification and accretionary lapilli-bearing ash layers (Fig. 10). Member 5 is a Plinian pumice fall layer. Members 6 and 7 are comprised of variously massive and cross-stratified ignimbrites (Figs 9c, 10). Member 8 is a massive lithic breccia and lithic-rich lapilli-tuff (Figs 9b, 10), and Member 9 comprises diffuse-bedded to massive ignimbrite. Member 10 is a thin mafic pumice fall deposit of limited extent, while Member 11 comprises volcaniclastic sandstones that record sedimentation influenced by the Poris eruption. It is dominantly phonolitic, but exhibits vertical compositional zonation with the appearance of banded tephriphonolite pumices in Member 8 and mafic pumices in Member 10. It is bounded by soils and/or erosion surfaces and is interpreted to represent a single explosive eruption followed by post-eruption sedimentation and soilification. The formation is described in more detail elsewhere (R. J. Brown, unpub. Ph.D. thesis, Univ. Leicester, 2001).

We provide a new $^{40}Ar/^{39}Ar$ age of 273 ± 5 ka for the Poris eruption (Table 2). This is based on analyses of 11 sanidine crystals collected from pumice clasts in members 1 and 8. A previous K–Ar age obtained from sanidine crystals picked from ignimbrite matrix (316 ± 10 ka: Bryan, Martí & Cas, 1998) may have suffered incomplete argon extraction or inclusion of xenocryst or accidental crystal populations.

The lithic breccia of Member 8 has previously been described as the 'Upper Grey Member' (Bryan, Martí & Cas, 1998) and interpreted as the deposit of a separate, younger eruption (see inset of Fig. 2c). However, a reappraisal of the field relations led to the identification of five criteria that show that Member 8 represents a lithic-rich facies of the Poris ignimbrite. (1) The lithic breccia (Member 8) has a distribution closely similar to that of the underlying parts of the Poris ignimbrite (Member 7; Fig. 10). (2) Its base is locally gradational into the underlying parts of the ignimbrite, that is, there is inverse coarse tail grading of lithic clasts from Member 7 into the base of Member 8, with a common ignimbrite matrix. (3) Spectacular load structures occur at the base of the lithic breccias at many locations (Fig. 9b). Some load structures exhibit sheared ignimbrite flame structures of massive lapilli-tuff into lithic breccia, and some exhibit isolated lithic blocks that have sunk individually from the lithic breccia down to as much as 1.5 m through the underlying massive lapilli-tuff. These structures indicate that the underlying parts of the Poris ignimbrite were still extremely loose and uncompacted when the lithic breccias were emplaced. (4) There is no evidence for a time-break at the base of the lithic-rich part of the ignimbrite: no ash-fall layers, no evidence for fluvial erosion, or reworking and no evidence for pedogenesis is seen at the contact. (5) The lithic breccias locally pass upwards into typical creamy-white pumiceous and fine-grained massive lapilli-tuff lithofacies that is characteristic of the Poris ignimbrite (e.g. Member 9 at Montaña Magua; Fig. 10, logs 2 and 4).

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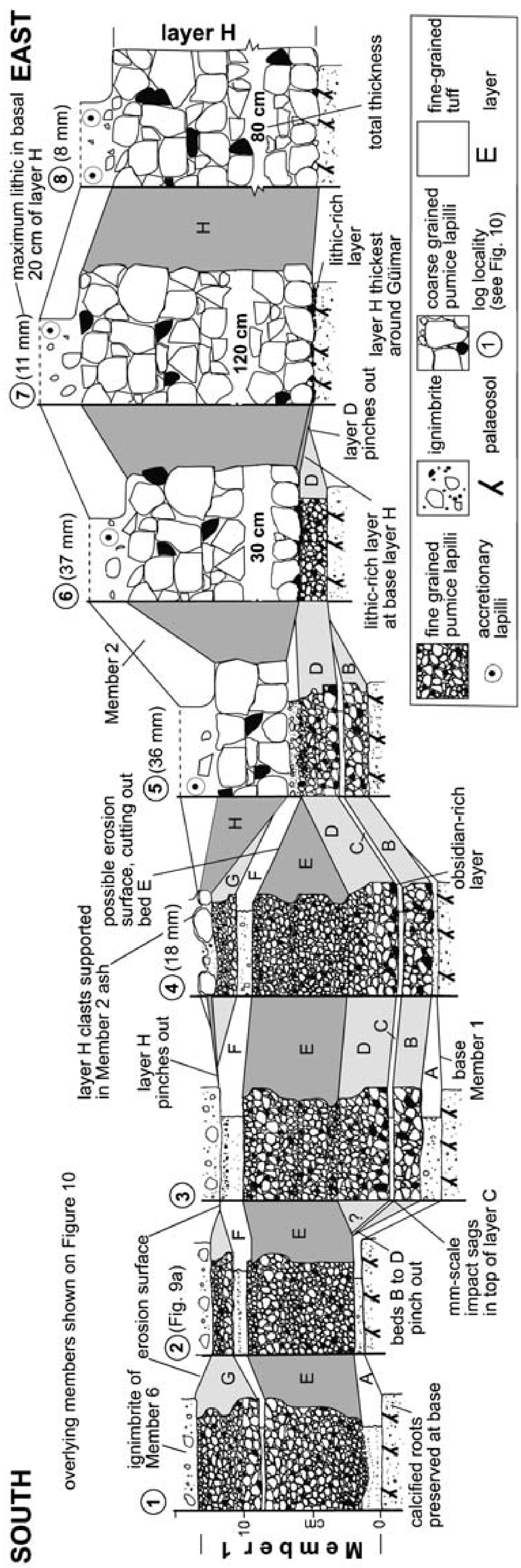

The interpretation that Member 8 records part of the Poris eruption is corroborated by our new $^{40}Ar/^{39}Ar$ data. Sanidine crystals collected from members 1 and 8 were treated as two separate groups and yielded $^{40}Ar/^{39}Ar$ of 276 ± 9 ka and 271 ± 6 ka respectively (Table 2). These are not statistically distinguishable, and our best estimate for the eruption age of the Poris Formation is the weighted mean of the two members, 273 ± 5 ka (mean square weighted deviance = 0.21).

Other parts of the Poris Formation exposed in the western Bandas del Sur have also previously been interpreted as recording different eruptions (the 'La Mareta Ignimbrite Member' and the 'Caldera del Rei Ignimbrite Member' of Bryan, Martí & Cas, 1998; Fig. 2c) based on apparent differences in pumice composition and phenocryst assemblages (Bryan, Martí & Cas, 1998, p. 616, table 1). However, members 1, 7, 8 and 9 have been traced from the type area at Poris into this southern region (Fig. 10), and two of these (members 8 and 9) contain conspicuous dense banded tephriphonolite/phonolite pumices. This establishes that all of the above-named units are part of the Poris ignimbrite. The apparent contrasting pumice and crystal assemblages are simply facets of the overall compositional zonation of the Poris Formation, which had hitherto not been fully understood.

Exposures of the Poris Formation between Poris de Abona and Abades (Fig. 1) have previously been informally described as the 'Pedrigal ignimbrite' (S. E. Bryan, unpub. Ph.D. thesis, Univ. Monash, 1998). We have traced members 8 and 9 of the Poris Formation into this ignimbrite and therefore consider the Pedrigal ignimbrite to be part of the Poris Formation. The Montaña Pelada tuff ring (Fig. 1), northeast of El Médano, is partly infilled by a previously undescribed phonolitic ignimbrite, which is now recognized as part of the Poris Formation. The ignimbrite overlies soils developed in Plinian fall deposits. The ignimbrite contains numerous palagonitized lapilli-tuff blocks eroded from the upstream side of the ring by the Poris pyroclastic density currents. We can therefore establish a minimum age of 273 ± 5 ka for the Montaña Pelada tuff ring.

Interpretation. Our new work shows that the Poris eruption was considerably larger than previously considered. It comprises a succession of Plinian pumice fall layers, ashfall layers and ignimbrites emplaced during a sustained, compositionally zoned explosive eruption. A widespread layer of lithic breccia records a major

Figure 8. Selected graphic logs through Member 1 of the Poris Formation, illustrating the correlations used to tie together the Poris ignimbrite sheet across the Bandas del Sur. Note contrasting distributions of layers A–G, and more easterly dispersal of layer H. Overlap between members 1 and 2 occurs around Poris de Abona (log 5). For locations of logged sections see inset of Figure 10.

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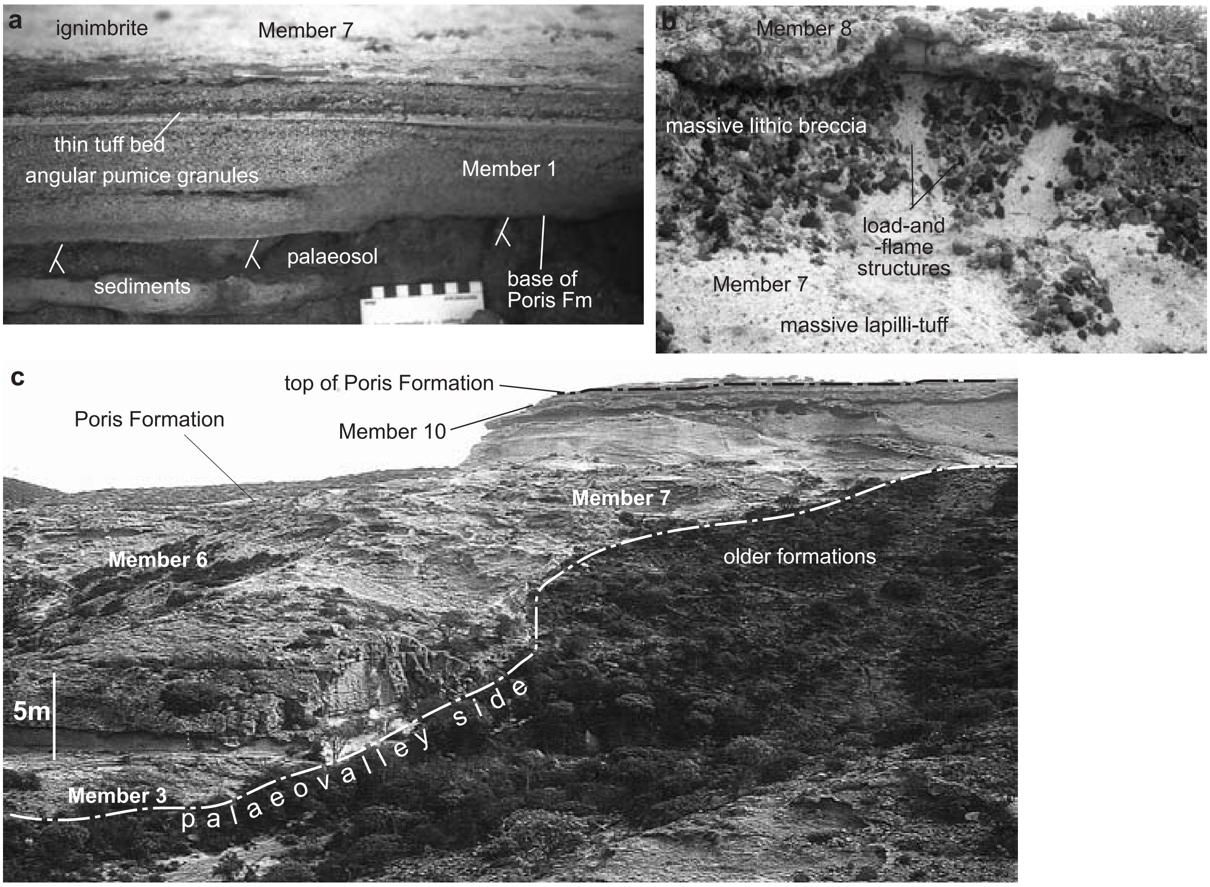

Figure 9. The Poris Formation. (a) Basal fall deposits (Member 1) comprising thin diffuse-bedded pumice falls, with interbedded laminae of fine ash (at La Mareta; Fig. 1). At this location, fall layers are disconformably overlain by massive lapilli-tuff of Member 7 (see Fig. 10, log 1). Scale in 1 cm divisions. (b) Lithic breccia of Member 8 at Tajao (Fig. 1). Soft-state load-and-flame structures are common along this contact, and indicate that Member 8 was emplaced while Member 7 was still loose and uncompacted. Field of view is ~ 4 m. (c) Valley-fill ignimbrite of members 3, 6 and 7 occupy a palaeovalley seen in cross-section at Montaña Magua (Fig. 1).

influx of accidental lithic clasts at the climax of the eruption. The sharp, erosional base of the lithic breccia at many locations records extensive erosion as the competence of the widely dispersed pyroclastic density current waxed. This waxing is recorded at some locations by inverse grading of lithic clasts, and there is no evidence that the erosion surface represents an eruptive hiatus. The volume of the Poris eruption is not known because most of the pyroclastic material entered the ocean.

4.i. The Sabinita Formation

The Sabinita Formation (new name) is a distinctive phonolitic pumice fall deposit named after its type area, the village of La Sabinita (see Fig. 1). It directly overlies the soil at the top of the Poris Formation in central to northeast parts of the Bandas del Sur (Poris de Abona to the Güimar valley). It is a massive, generally non-graded Plinian fall deposit, up to 2 m thick (e.g. at La Sabinita), and comprises very well-sorted, angular phonolite pumice lapilli with subordinate lithic lapilli (Fig. 11a). A distinctive feature is the presence of large pumice lapilli surrounded by smaller pumice lapilli, giving it a 'bimodal' grainsize appearance. A palaeosol, ≤ 40 cm thick, is developed at its top, and this is overlain by the basal fine tuff layers of the La Caleta Formation (see next section). Locally, pre-La Caleta Formation erosion has removed part or all of the Sabinita Formation, which is then preserved only as thin soilified remnants (e.g. at Güimar, Fig. 1).

4.j. The La Caleta Formation

The phonolitic La Caleta Formation, named after La Caleta (Fig. 1), its type area, consists of a basal fallout sequence overlain by ignimbrites (Fig. 11b, c). It includes the former 'Wavy deposit' and the 'La Caleta Member' of Bryan, Martí & Cas (1998). The basal fallout sequence comprises fine ash layers and a well-sorted, typically massive and non-graded Plinian pumice fall layer, up to 3 m thick (at Fasnia; Figs 1, 11b). Around Tajao (Fig. 1), the lower part of the fallout sequence is characterized by topography-draping parallel-laminated fine-grained pumiceous ash that coarsens to thin-bedded fine pumice lapilli towards Fasnia (Fig. 1). Convex-upward, periclinal 'hummocks'

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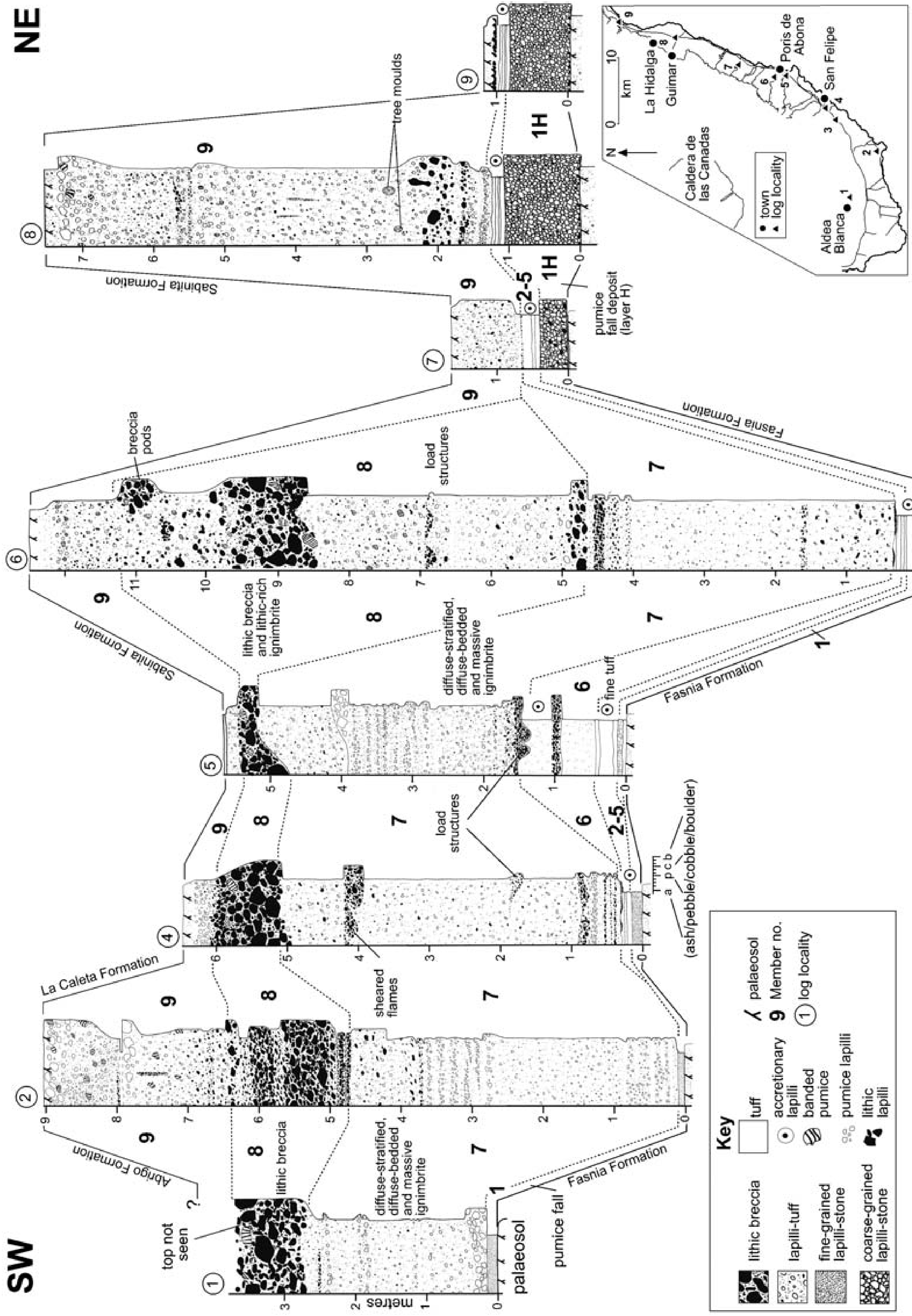

Figure 10. For legend see facing page.

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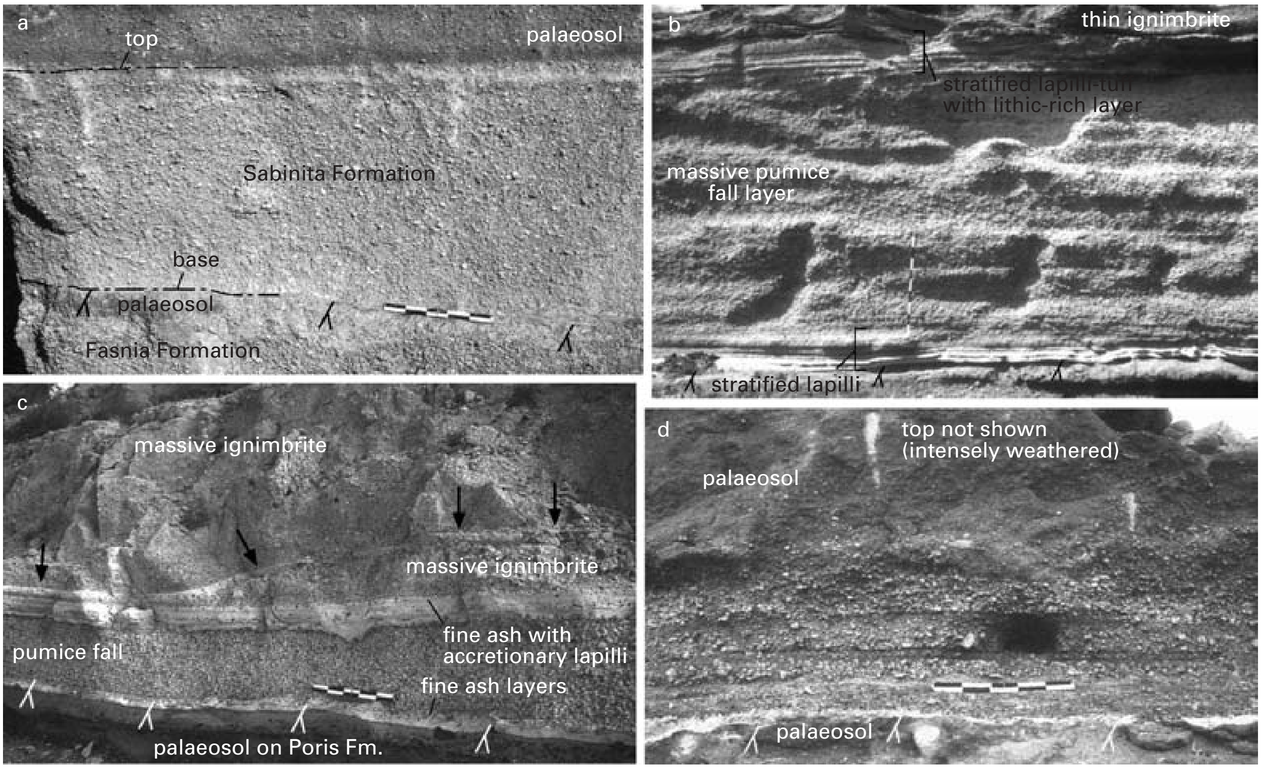

Figure 11. Deposits in the upper Bandas del Sur Group. (a) The massive pumice fall deposit of the Sabinita Formation at Las Eras (Fig. 1). Note evenly scattered larger pumice lapilli. (b) The basal Plinian fall deposit of the La Caleta Formation at Las Eras (Fig. 1), reaches 3 m thick, it comprises a lower stratified pumice lapilli and ash layer overlain by a thick, massive pumice lapilli layer, in turn overlain by an upper stratified layer containing thin layers of fine ash with diffuse-bedding and rich in lithic lapilli. (c) La Caleta Formation at Tajao (Fig. 1). 5 cm of parallel laminated fine ash overlies a palaeosol developed in the underlying Poris Formation, and is overlain by ~ 50 cm of Plinian pumice fall lapilli. This is overlain by a thin lenticular ignimbrite flow-unit draped by a fine ash layer, and buried by thick massive lapilli-tuff. (d) A distinctive (unnamed) pumice fall deposit that overlies the La Caleta Formation (see Fig. 2b), lower parts exhibit diffuse bedding defined by grainsize and lithic-rich layers (Las Eras quarry; Fig. 1). Scale shows 10 cm divisions.

occur in this laminated fine ash, some with soft-sediment deformation at their centres. Vegetation moulds can be seen on the underside of some of these hummocks. Accretionary lapilli occur within fine ash at the top of the pumice fall deposit (e.g. at Las Eras and Fasnia, Fig. 1).

The overlying phonolitic ignimbrites reach a total thickness of ~ 16 m and comprise massive, bedded and diffuse-stratified lithofacies. Fine ash and accretionary lapilli layers (LC-A of Bryan, Martí & Cas, 1998) drape several small, topographically confined ignimbrites (e.g. Tajao; Fig. 1). A block and boulder-bearing lithic breccia horizon occurs towards the top of the ignimbrite, and banded pumices occur throughout (see Bryan, Martí & Cas, 1998). An ^{40}Ar/^{39}Ar age of 221 ± 5 ka for the La Caleta Formation has been obtained in this study (Table 2).

Interpretation. The La Caleta eruption was similar to many other ignimbrite-forming eruptions on Tenerife. It commenced with a Plinian phase, with a dispersal axis centred over Fasnia. Previous interpretations of the ash hummocks have included ‘surge bedforms’ (Martí *et al*. 1995) or water-escape structures (Bryan, Martí & Cas, 1998), but their occurrence at the base of ashfall deposits, their morphology and association with ash and rootlet moulds in the palaeosol suggest that they formed by the blanketing of shrubs by fallout tephra. Subsequent rotting of the shrubs left empty moulds. The spacing of the moulds is similar to that of present day xerophytic plants in the Bandas del Sur such as spurge (*Euphorbia obtusifolia* and *E. woodii*). Similar structures probably created by the blanketing of shrubs (now rotted away) by moist ash are also locally found at the base of the Arico, Fasnia and Poris formations.

Figure 10. Graphic summary logs through the phonolitic Poris Formation showing the lateral continuity of the major widespread ignimbrite units (members 7–9). Note abundant diffuse bedding and stratification, and the widespread lithic breccias, features common to many ignimbrites in the Bandas del Sur Group. Banded pumice first appears in Member 8. See inset map for locations of logged sections.

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Table 4. Ar/Ar laser-fusion analytical data of Sanidine from Tenerife

Analysis no. (a)	No. of crystals	^{40}Ar/^{39}Ar (b)	^{37}Ar/^{39}Ar (b)	^{36}Ar/^{39}Ar (b)	^{40}Ar s.d. (%)	^{39}Ar s.d. (%)	^{37}Ar s.d. (%)	^{36}Ar s.d. (%)	^{40}ArR (mol)	^{40}ArR (c)	^{40}ArK (c)	^{39}ArCa (c)	^{36}ArCa (c)	K/Ca	^{39}Ar (%)	Age (ka)	(d)	± s.d. (ka)
Abrigo Formation ignimbrite [GR ^{3}582 ^{31}181]						J = 0.0001292 ± 0.0000006					Exp. no. tn2l0182.IHD			Total gas age =		173.4	±	1.3
fs17	1	0.8006	0.02302	0.000364	0.18	0.14	4.85	20.71	3.60E-16	86.7	0.11	0.00	1.67	21.3	5.1	161.4	±	5.0
fs21	1	1.112	0.07074	0.001429	0.21	0.17	1.37	3.93	3.90E-16	62.5	0.08	0.00	1.31	6.9	5.6	161.8	±	3.8
fs10	1	0.7852	0.02056	0.00024	0.56	0.12	3.72	28.86	2.90E-16	91.0	0.11	0.00	2.26	23.8	4.1	166.7	±	4.7
fs15	1	0.9675	0.06229	0.000864	0.17	0.16	1.5	5.1	4.90E-16	74.0	0.09	0.00	1.90	7.9	6.8	166.9	±	3.0
fs5	1	1.2646	0.02694	0.001861	0.24	0.17	8.35	2.41	2.40E-16	56.6	0.07	0.00	0.38	18.2	3.3	166.9	±	3.1
fs11	1	0.8687	0.018672	0.000517	0.51	0.27	4.7	26.82	1.60E-16	82.5	0.10	0.00	0.95	26.2	2.3	167.0	±	9.3
fs9	1	1.0625	0.02317	0.001159	0.12	0.14	5.56	5.31	4.10E-16	67.9	0.08	0.00	0.53	21.2	5.6	167.9	±	4.2
fs20	1	0.83	0.02423	0.000372	0.23	0.2	4.51	21.31	2.80E-16	86.9	0.10	0.00	1.72	20.2	3.8	167.9	±	5.3
fs13	1	0.8696	0.04579	0.000511	0.19	0.15	3.11	12.73	3.60E-16	82.9	0.10	0.00	2.36	10.7	5.0	168.0	±	4.3
fs19	1	0.856	0.02256	0.000458	0.25	0.1	3.98	18.49	2.60E-16	84.3	0.10	0.00	1.30	21.7	3.5	168.0	±	5.7
fs8	1	0.7427	0.014399	0.00007	0.3	0.16	7.56	93.15	4.20E-16	97.3	0.12	0.00	5.45	34.0	5.8	168.3	±	4.2
fs18	1	0.9701	0.02394	0.000837	0.24	0.23	5.9	10.46	2.70E-16	74.6	0.09	0.00	0.75	20.5	3.7	168.5	±	5.9
fs14	1	0.7842	0.02173	0.000198	0.15	0.12	2.07	22.9	5.20E-16	92.7	0.11	0.00	2.90	22.6	7.1	169.1	±	3.0
fs6	1	2.566	0.07766	0.006228	0.13	0.16	3.01	1.6	2.90E-16	28.5	0.03	0.01	0.33	6.3	4.0	170.3	±	6.9
fs4	1	1.2003	0.02564	0.001581	0.16	0.16	2.18	1.27	5.20E-16	61.2	0.07	0.00	0.43	19.1	7.0	171.1	±	1.5
fs16	1	1.1706	0.02527	0.001396	0.14	0.12	3.29	3.75	4.30E-16	64.9	0.07	0.00	0.48	19.4	5.6	176.9	±	3.6
fs7	1	1.0342	0.02299	0.000914	0.24	0.18	4.84	8.09	2.40E-16	74.0	0.08	0.00	0.66	21.3	3.1	178.1	±	5.0
fs3[e]	1	5.385	0.15821	0.015677	0.15	0.26	1.9	0.42	2.80E-16	14.2	0.02	0.01	0.27	3.1	3.6	178.1	±	6.6
fs2[e]	1	0.921	0.02493	0.00048	0.19	0.14	3.09	7.96	3.90E-16	84.7	0.09	0.00	1.37	19.7	5.0	181.8	±	2.6
fs12[e]	1	1.8174	0.02246	0.003372	0.14	0.16	4.85	2.64	2.70E-16	45.2	0.05	0.00	0.18	21.8	3.3	191.6	±	6.1
fs1[e]	1	2.078	0.0314	0.003905	0.12	0.12	4.1	1.08	6.40E-16	44.5	0.04	0.00	0.21	15.6	6.9	215.6	±	3.0
La Caleta Formation ignimbrite [GR ^{3}556 ^{31}102]						J = 0.0000875 ± 0.0000003					Exp. no. tb0l5171.IHD			Total gas age =		385.4	±	8.3
tf9	4	3.836	0.1614	0.009861	0.31	0.46	9.1	6.2	2.05E-16	24.3	0.02	0.01	0.43	3.0	7.0	147.5	±	27.9
tf4	1	2.894	0.1983	0.005790	0.65	0.31	6.8	13.7	3.20E-16	41.4	0.03	0.01	0.90	2.5	8.5	188.9	±	35.8
tf10	4	5.069	0.4146	0.012607	0.32	0.30	4.0	2.7	3.95E-16	27.1	0.02	0.03	0.87	1.2	9.2	216.8	±	15.7
tf12	9	2.927	0.1621	0.005292	0.43	0.67	8.8	13.9	2.45E-16	47.0	0.03	0.01	0.81	3.0	5.7	217.0	±	33.2
tf1	1	3.412	0.0890	0.006850	0.22	0.28	2.5	1.8	1.40E-15	40.8	0.03	0.01	0.34	5.5	31.8	219.8	±	5.8
tf2	1	2.580	0.1401	0.004015	0.44	0.23	6.2	7.6	5.50E-16	54.4	0.03	0.01	0.92	3.5	12.6	221.4	±	13.8
tf6	1	2.907	0.0075	0.004949	0.93	0.25	482	31.2	2.10E-16	49.7	0.03	0.00	0.04	65.2	4.7	227.9	±	70.1
tf5	1	2.669	0.1352	0.004142	0.92	0.44	11.3	24.3	2.80E-16	54.5	0.03	0.01	0.86	3.6	6.1	229.6	±	45.5
tf3	1	2.819	0.1505	0.003052	0.60	0.21	9.2	28.3	4.25E-16	68.4	0.03	0.01	1.30	3.3	7.1	304.2	±	38.7
tf7	1	2.870	0.0403	0.003078	0.51	0.38	81.6	39.1	2.05E-16	68.4	0.03	0.00	0.35	12.2	3.3	309.7	±	54.4
tf11[e]	5	30.730	0.4917	0.010964	0.16	0.71	4.0	16.9	3.40E-15	89.6	0.00	0.03	1.18	1.0	4.0	4342.0	±	90.0

Table 4. (*Cont.*)

Analysis no. (a)	No. of crystals	^{40}Ar/^{39}Ar (b)	^{37}Ar/^{39}Ar (b)	^{36}Ar/^{39}Ar (b)	^{40}Ar s.d. (%)	^{39}Ar s.d. (%)	^{37}Ar s.d. (%)	^{36}Ar s.d. (%)	^{40}ArR (mol)	^{40}ArR (c)	^{40}ArK (c)	^{39}ArCa (c)	^{36}ArCa (c)	K/Ca	^{39}Ar (%)	Age (ka)	(d)	± s.d. (ka)
La Caleta Formation pumice fall deposit [GR ^{3}556 ^{31}102]						J = 0.0000881 ± 0.0000003					Exp. no. tb0l5196.IHD			Total gas age =		259.5	±	16.3
tf1	1	2.578	0.1460	0.003754	0.38	0.24	5.5	13.4	2.55E-16	57.4	0.03	0.01	1.03	3.4	42.1	234.9	±	22.8
tf2	2	3.808	0.1806	0.007629	0.37	0.59	10.1	7.7	1.40E-16	41.1	0.02	0.01	0.62	2.7	22.0	248.8	±	27.2
tf3	2	3.823	0.1525	0.006753	0.22	0.41	8.8	9.4	2.20E-16	48.1	0.02	0.01	0.60	3.2	29.3	292.2	±	29.0
fs4	3	9.625	0.5811	0.026230	0.44	0.85	10.9	10.0	5.00E-17	19.9	0.01	0.04	0.58	0.8	6.7	305.1	±	120.0
Poris Formation ignimbrite (Member 8) [GR ^{3}578 ^{31}178]						J = 0.0000888 ± 0.0000003					Exp. no. tb0l5194.IHD			Total gas age =		898.0	±	6.8
tf5	1	2.672	0.0456	0.003400	0.17	0.21	9.8	5.7	6.50E-16	62.5	0.03	0.00	0.35	10.7	20.1	267.4	±	9.0
tf4	1	2.646	0.0065	0.003296	0.23	0.40	111	13.8	3.50E-16	63.2	0.03	0.00	0.05	75.6	11.2	267.7	±	21.0
tf3	1	1.978	0.0009	0.001013	0.26	0.28	586	21.0	4.90E-16	84.8	0.04	0.00	0.02	538.0	15.5	268.8	±	9.8
tf2	1	3.428	0.0110	0.005562	0.53	0.67	955	9.6	2.20E-16	52.0	0.03	0.00	0.05	44.4	6.6	285.5	±	25.0
tf6	4	2.607	0.0265	0.002560	0.14	0.27	23.6	20.6	3.95E-16	71.0	0.03	0.00	0.27	18.5	11.3	296.7	±	24.2
tf1[e]	1	4.512	0.0042	0.008486	0.15	0.21	100	3.8	6.50E-16	44.4	0.02	0.00	0.01	115.4	17.1	321.0	±	14.8
tf7[e]	5	16.732	0.1376	0.012496	0.15	0.31	6.3	2.2	3.10E-15	78.0	0.01	0.01	0.29	3.6	12.6	2090.0	±	15.0
tf8[e]	12	52.770	0.3497	0.027450	0.07	0.35	7.0	2.9	4.75E-15	84.7	0.00	0.02	0.34	1.4	5.6	7145.0	±	47.0
Poris Formation pumice fall deposit (Member 1H) [GR ^{3}578 ^{31}178]						J = 0.0000893 ± 0.0000003					Exp. no. tb0l5195.IHD			Total gas age =		4284.0	±	21.0
tf1	1	2.707	0.0085	0.002926	0.46	0.28	481	16.4	2.95E-16	68.1	0.03	0.00	0.08	58.0	12.1	296.7	±	22.3
tf2	1	2.353	0.0292	0.002623	0.27	0.25	22.1	12.8	3.70E-16	67.1	0.04	0.00	0.29	16.8	17.5	254.3	±	15.5
tf5	4	2.440	0.0005	0.002476	0.84	0.29	2197	16.6	2.95E-16	70.0	0.04	0.00	0.01	1012.0	13.0	274.9	±	19.3
tf6	5	2.481	0.0144	0.002510	0.32	0.25	59.2	15.7	3.50E-16	70.1	0.03	0.00	0.15	34.1	15.1	280.0	±	18.3
tf8	9	3.656	0.0146	0.006467	0.53	0.54	116.2	9.4	1.90E-16	47.7	0.02	0.00	0.06	33.6	8.2	280.8	±	28.5
tf4	2	3.311	0.0125	0.004502	0.18	0.28	78.3	16.3	3.30E-16	59.8	0.03	0.00	0.07	39.1	12.6	319.0	±	33.9
tf7[e]	9	123.420	0.2586	0.094980	0.06	0.35	4.6	1.1	1.45E-14	77.3	0.00	0.02	0.07	1.9	11.5	15302.0	±	85.0
tf3[e]	2	181.870	0.3893	0.132360	0.09	0.34	3.9	0.7	1.90E-14	78.5	0.00	0.03	0.08	1.3	10.0	22862.0	±	113.0
Fasnia Formation pumice fall deposit [GR ^{3}578 ^{31}178]						J = 0.0000903 ± 0.0000003					Exp. no. tb0l5169.IHD			Total gas age =		354.7	±	4.6
tf5	1	2.386	0.0113	0.003296	0.35	0.67	100.0	18.1	2.85E-16	59.2	0.04	0.00	0.09	43.5	3.3	229.7	±	27.9
tf12	5	2.129	0.0660	0.002038	0.45	0.33	11.6	26.2	5.50E-16	71.9	0.04	0.00	0.85	7.4	5.7	249.2	±	24.8
tf1	5	2.070	0.0071	0.001744	0.31	0.43	83.6	18.0	8.50E-16	75.1	0.04	0.00	0.11	69.2	8.7	253.0	±	14.7
tf11	1	2.141	0.0321	0.001913	0.48	0.30	24.0	20.3	6.00E-16	73.7	0.04	0.00	0.44	15.3	6.1	256.8	±	18.2
tf8	1	14.066	0.2233	0.042200	0.15	0.47	6.2	2.1	3.35E-16	11.5	0.01	0.02	0.14	2.2	3.4	262.7	±	44.7
tf7	1	2.203	0.0935	0.001731	0.60	0.43	14.8	76.5	3.20E-16	77.1	0.04	0.01	1.43	5.2	3.1	276.4	±	60.9
tf14	5	2.294	0.0558	0.001750	0.54	0.27	11.6	22.3	8.00E-16	77.6	0.04	0.00	0.84	8.8	7.1	289.7	±	18.2
tf4	1	5.714	0.0110	0.013234	0.12	0.20	35.1	1.5	1.85E-15	31.6	0.02	0.00	0.02	44.6	16.6	293.7	±	9.6
tf3	1	2.043	0.0131	0.000699	0.20	0.15	19.5	18.7	2.00E-15	89.9	0.04	0.00	0.49	37.4	17.7	299.0	±	6.1
tf2	15	2.689	0.0273	0.001656	0.18	0.19	8.4	6.3	2.55E-15	81.8	0.03	0.00	0.43	18.0	19.0	358.3	±	4.9
tf13[e]	5	4.570	0.1701	0.002040	0.23	0.43	6.1	20.2	1.25E-15	87.1	0.02	0.01	2.20	2.9	5.0	648.1	±	19.1
tf9[e]	1	8.463	0.1250	0.004410	0.29	0.47	9.9	12.3	1.70E-15	84.7	0.01	0.01	0.75	3.9	3.8	1167.2	±	26.2
tf6[e]	1	23.000	0.1980	0.037670	0.42	1.10	42.5	8.6	3.95E-16	51.7	0.00	0.01	0.14	2.5	0.5	1935.4	±	157.6

Table 4. (*Cont.*)

Analysis no. (a)	No. of crystals	^{40}Ar/^{39}Ar (b)	^{37}Ar/^{39}Ar (b)	^{36}Ar/^{39}Ar (b)	^{40}Ar s.d. (%)	^{39}Ar s.d. (%)	^{37}Ar s.d. (%)	^{36}Ar s.d. (%)	^{40}ArR (mol)	^{40}ArR (c)	^{40}ArK (c)	^{39}ArCa (c)	^{36}ArCa (c)	K/Ca	^{39}Ar (%)	Age (ka)	(d)	± s.d. (ka)
Granadilla Formation ignimbrite [GR ^{3}489 ^{31}111]						J = 0.0000896 ± 0.0000003					Exp. no. tb0l5170.IHD			Total gas age = 613.6			±	5.3
tf5	1	4.745	0.0640	0.003984	0.34	0.34	12.3	10.7	1.30E-15	75.3	0.02	0.00	0.42	7.7	6.1	577.2	±	20.0
tf9	5	7.011	0.0250	0.011587	0.15	0.46	26.0	2.9	1.50E-15	51.2	0.01	0.00	0.06	19.6	7.1	579.9	±	16.8
tf2	1	4.574	0.0431	0.003271	0.32	0.28	14.2	12.7	1.65E-15	78.9	0.02	0.00	0.35	11.4	7.7	583.1	±	19.4
tf7	4	5.806	0.0348	0.007321	0.12	0.28	12.6	3.3	2.25E-15	62.8	0.01	0.00	0.13	14.1	10.5	589.2	±	11.6
tf12	12	5.734	0.0377	0.006989	0.27	0.26	14.5	3.9	2.05E-15	64.0	0.01	0.00	0.14	13.0	9.4	593.1	±	13.0
tf4	1	6.966	0.1098	0.011171	0.21	0.46	8.9	5.7	1.25E-15	52.7	0.01	0.01	0.26	4.5	5.8	593.6	±	30.2
tf8	4	4.275	0.0351	0.001978	0.16	0.36	14.4	16.6	2.20E-15	86.4	0.02	0.00	0.47	13.9	10.1	596.6	±	15.4
tf11	1	4.743	0.0431	0.003045	0.15	0.29	16.0	9.8	1.95E-15	81.1	0.02	0.00	0.37	11.4	8.7	621.7	±	14.0
tf10	5	4.520	0.0449	0.001805	0.21	0.33	11.2	28.1	1.80E-15	88.3	0.02	0.00	0.66	10.9	7.7	644.6	±	23.5
tf3	1	4.615	0.0440	0.002121	0.38	0.27	20.0	25.6	1.25E-15	86.5	0.02	0.00	0.55	11.1	5.4	644.8	±	25.3
tf6	1	10.684	0.0770	0.022490	0.12	0.41	10.0	2.6	1.40E-15	37.8	0.01	0.01	0.09	6.4	5.9	653.4	±	27.9
tf1[e]	1	4.862	0.0309	0.002648	0.29	0.22	9.4	5.8	3.80E-15	83.9	0.02	0.00	0.31	15.9	15.8	659.5	±	7.7
Arico Formation ignimbrite [GR ^{3}543 ^{31}098]						J = 0.0001292 ± 0.0000006					Exp. no. tn2l0035.IHD			Total gas age = 670.9			±	3.8
fs7	1	3.161	0.02957	0.001316	0.23	0.36	2.03	14.3	5.10E-16	87.7	0.03	0.00	0.59	16.6	2.8	646.3	±	13.0
fs17	1	2.989	0.06537	0.00066	0.23	0.14	1.4	29.98	5.10E-16	93.6	0.03	0.00	2.62	7.5	2.7	652.0	±	13.1
fs9	1	3.659	0.0557	0.002854	0.12	0.11	0.77	2.64	1.40E-15	77.0	0.02	0.00	0.52	8.8	7.4	656.8	±	5.3
fs14	1	3.052	0.07218	0.0008	0.13	0.09	0.69	10.3	9.60E-16	92.4	0.03	0.00	2.38	6.8	5.1	657.4	±	5.6
fs15	1	3.244	0.02726	0.001409	0.1	0.11	2.05	11.45	1.00E-15	87.2	0.03	0.00	0.51	18.0	5.5	658.9	±	10.9
fs1	1	4.496	0.04873	0.005588	0.24	0.25	1.95	3.22	5.50E-16	63.3	0.02	0.00	0.23	10.1	2.9	663.6	±	12.7
fs10	1	3.019	0.05836	0.000549	0.31	0.2	1.73	32.63	4.90E-16	94.8	0.03	0.00	2.81	8.4	2.5	666.6	±	12.0
fs16	1	3.015	0.05778	0.000529	0.26	0.22	0.57	41.85	6.10E-16	94.9	0.03	0.00	2.88	8.5	3.2	666.9	±	14.7
fs6	1	3.074	0.0397	0.000719	0.36	0.34	2.79	35.66	3.70E-16	93.2	0.03	0.00	1.46	12.3	1.9	667.2	±	17.4
fs18	1	3.592	0.03996	0.002466	0.09	0.12	1.96	1.15	1.30E-15	79.8	0.02	0.00	0.43	12.3	6.6	667.7	±	2.3
fs20	1	3.032	0.05989	0.000574	0.16	0.18	1.77	8.64	1.50E-15	94.5	0.03	0.00	2.76	8.2	7.7	667.7	±	3.7
fs11	1	3.171	0.08714	0.001037	0.13	0.19	1.13	12.42	8.50E-16	90.5	0.03	0.01	2.22	5.6	4.4	668.8	±	8.7
fs19	1	3.305	0.05603	0.001442	0.13	0.15	2.27	2.14	1.70E-15	87.2	0.03	0.00	1.03	8.8	8.6	671.5	±	2.6
fs12	1	3.248	0.04426	0.001201	0.11	0.14	0.82	9.08	1.10E-15	89.2	0.03	0.00	0.97	11.1	5.5	674.8	±	7.4
fs5	1	3.191	0.03616	0.001	0.26	0.34	2.86	17.35	6.70E-16	90.8	0.03	0.00	0.95	13.6	3.5	675.3	±	12.0
fs21[e]	1	3.447	0.03506	0.001848	0.07	0.07	3.34	0.68	1.90E-15	84.2	0.02	0.00	0.50	14.0	10.0	676.2	±	1.2
fs2	1	3.17	0.0594	0.000886	0.16	0.09	0.86	9.14	1.40E-15	91.9	0.03	0.00	1.77	8.3	7.4	678.4	±	5.5
fs13	1	4.14	0.07129	0.004032	0.14	0.19	0.78	4.55	6.40E-16	71.3	0.02	0.00	0.47	6.9	3.2	687.9	±	12.6
fs4	1	3.352	0.03033	0.001265	0.2	0.5	2.6	17.25	6.20E-16	88.9	0.03	0.00	0.63	16.2	3.1	694.3	±	15.2
fs8[e]	1	3.239	0.02481	0.000808	0.15	0.21	2.13	15.82	8.30E-16	92.7	0.03	0.00	0.81	19.8	4.2	699.3	±	8.8
fs3[e]	1	3.116	0.0637	0.000297	0.33	0.52	1.54	131.93	4.00E-16	97.3	0.03	0.00	5.66	7.7	2.0	706.7	±	25.3

(a) Analyses labeled either individual total fusion analyses (tf#) or crystal previously degassed at *c.* 700 °C for *c.* 60 sec (fs#).
(b) Corrected for 37Ar and 39Ar decay, half-lives 35.1 days and 259 years, respectively.
(c) Radiogenic (R), calcium-derived (Ca), and potassium-derived (K) argon, respectively (percent).
(d) Ages calculated relative to 85G003 TCR at 27.92 Ma with le = 0.581*10-10/a and lb = 4.692*10-10/a; all errors reported as standard deviation of analytical precision.
(e) Probable xenocryst(s) present; analysis not used in best mean weighted age for sample.

4.k. Pumice fall units

At least two Plinian or sub-Plinian pumice fall layers overlie the palaeosol that is developed on the La Caleta Formation. The lower layer is up to 2 m thick and has a distinctive stratified basal part, ≤ 30 cm thick, defined by lithic lapilli horizons, overlain by a massive division of pumice lapilli, topped by a soil (Fig. 11d). The upper layer is massive and unremarkable, and has a soil developed in its top. Both fall layers are exposed in road cuts near Las Eras and Montaña Magua (Fig. 1). The upper layer is unconformably overlain by the Abrigo Formation.

4.l. Abrigo Formation

The Abrigo Formation comprises a pale grey, variably lithic-rich ignimbrite, up to 20 m thick, which crops out across the southern and central Bandas del Sur from Los Christianos to Fasnia (Fig. 1). It is dominated by massive, diffuse-bedded and stratified lapilli-tuff lithofacies. Pumice-rich lithofacies are common, and thin intercalated ash layers with sparse accretionary lapilli occur around La Mareta (Fig. 1). The uppermost bed comprises a matrix-supported pebble- to boulder-bearing lithic breccia (see Bryan, Cas & Martí, 1998). It is named after the town of El Abrigo (Fig. 1), near to the type section of Bryan, Martí & Cas (1998), and is the youngest widespread phonolitic pyroclastic deposit in the Bandas del Sur Group (Fig. 2), with a new $^{40}Ar/^{39}Ar$ age of 169 ± 1 ka obtained during this study (Table 2). An inferred correlative proximal lithic breccia at the top of the eastern caldera wall yielded a weighted K/Ar age of 179 ± 11 ka (Martí, Mitjavila & Araña, 1994). No associated Plinian pumice fall deposit has yet been found, but the base of the ignimbrite is widely erosive. The top of the deposit is not preserved.

5. Discussion

5.a. Age of the Güimar lateral collapse event

The Güimar valley (Fig. 1) is a steep-sided depression some 9 km wide formed by major gravitational sector collapse of eastern flanks of the Cañadas volcano (Navarro & Coello, 1989) probably generating tsunamis. The lateral collapse post-dates the youngest lava in the collapse scarps, with a K–Ar age of 830 ka (Ancochea *et al*. 1990), but hitherto no minimum age has been determined. Previous inferences were based on ages of lavas covering the sector collapse scarps of La Orotava valley on the north side of the island (Fig. 1), which was assumed to have formed around the same time (Ancochea *et al*. 1990). The Fasnia Formation is the oldest pyroclastic formation so far recognized within the Güimar valley, and our new date (289 ± 6 ka) provides a minimum age for the Güimar sector collapse event. However, sediments underlie the Fasnia Formation at Güimar and we cannot exclude the possibility that the sector collapse occurred considerably earlier.

5.b. Eruption style

Our new work in the Bandas del Sur shows that Las Cañadas volcano underwent a rather consistent series of major explosive eruptions. At least seven widespread ignimbrite sheets were emplaced, which all have similar extensive geographic distributions and share many characteristics (Table 3). Most of the large eruptions began with a Plinian phase and then produced ignimbrites and thin ash layers, some of co-ignimbrite origin. Each ignimbrite sheet comprises widespread, condensed, thin veneers of ignimbrite that exhibit diffuse-stratified and bedded facies, complex laterally variable vertical grading patterns, pumice lenses, splay-and-fade stratification (Branney & Kokelaar, 2002), and basal and internal erosion surfaces. Several are compositionally zoned and contain subordinate mafic (tephriphonolite) pumices and banded pumices, which suggest magma mingling occurred during, or immediately prior to, each eruption. In each formation, the ignimbrite veneers locally grade laterally into more restricted valley-fills (predominantly of pumiceous massive lapilli-tuff facies) within small palaeo-wadis.

Sustained passage of each major pyroclastic density current was characterized by phases of non-deposition and erosion, so that for each formation, the record of the entire course of the eruption is incomplete at most sections. This accounts for some of the previously perceived differences between successive ignimbrite sheets: some such differences are simply artefacts of the non-representative and incomplete nature of the first sections to have been described. Tracing the ignimbrites around the Bandas del Sur during the present study revealed the lateral variations and thus more complete eruption histories (e.g. for the Poris and Arico eruptions). Many of the ignimbrites contain thin, laterally persistent, probably co-ignimbrite fine ash and accretionary lapilli layers that drape topographically-confined ignimbrite (e.g. in the Abades, Fasnia, Poris, La Caleta and Abrigo formations). Some of these ash layers may record pauses in the passage of pyroclastic density currents, that is, they mark flow-unit boundaries. Because the bulk of the material carried by each pyroclastic density current is inferred to have passed into the ocean, eruption volume estimates based on onshore deposits could be underestimates by orders of magnitude. Therefore, the relative sizes of major eruptions cannot be discerned. However, the consistent widespread distributions of the ignimbrites, their similarity, and the presence of extensive lithic breccias recording climactic phases of emplacement suggest as many as seven separate caldera collapse eruptions occurred, and that each collapse event occurred sometime after the onset of widespread pyroclastic density currents, and after a significant amount of magma had already been evacuated. We propose, therefore, that the Las Cañadas caldera is considerably more complex than has previously been appreciated, and that it is probably a nested caldera structure with a protracted subsidence history. In addition, the Bandas del Sur Group includes numerous Plinian or sub-Plinian pumice fall layers for which ignimbrites have not yet been recorded (Fig. 2b, c).

5.c. Offshore correlations

The new $^{40}Ar/^{39}Ar$ data permit tentative correlation of Tenerife's onshore pyroclastic formations with previously dated offshore fallout tephra and volcaniclastic sand layers sampled during ODP leg 157 (drill sites 953, 954 and 956; see Fig. 1, inset), which have been related to Las Cañadas volcano (Rodehorst, Schmincke & Sumita, 1998). Sixty-eight trachyte to phonolite ashfall layers, with a combined thickness of ~ 250 cm, were recovered from the offshore sites, and range in age from 0.3 to 0.8 Ma (Rodehorst, Schmincke & Sumita, 1998). A fine-grained vitric ashfall layer (157-953-A, 5H-1, 56–57 cm) with an eruptive age of 610 ± 20 ka (Bogaard, 1998) may represent distal Plinian or co-ignimbrite fallout of the Granadilla eruption (600 ± 9 ka; Table 2). A well-sorted, pumice- and feldspar-rich, ashfall layer (sample 157-953-A-2H-5, 147–150 cm) 4 cm thick, 150 km ENE of Tenerife has a near-identical age (273 ± 6 ka; Bogaard, 1998) to the Poris Formation (273 ± 5 ka; Table 2), and is consistent with a broadly easterly dispersal direction as inferred for the later Plinian deposits of the Poris Formation (R. J. Brown, unpub. Ph.D. thesis, Univ. Leicester, 2001). The phenocrysts in this layer are similar to those in the Poris Formation, but the formation on land is crystal-poor and the correlation requires some crystal enrichment processes, such as removal of fine ash by winnowing in the umbrella cloud or water column. Two volcaniclastic sand layers (157-953A-2H-4, 77–79 cm and 157-956-3H-2, 81–87 cm) have ages of 247 ± 2 ka and 244 ± 6 ka respectively (Bogaard, 1998). These lie between our new ages for the Poris and La Caleta formations (respectively 273 ± 5 ka and 221 ± 5 ka) and one may correlate with the Sabinita Formation. Further dating of the onshore deposits is needed along with trace element geochemistry to strengthen these correlations.

5.d. The genesis of Las Cañadas caldera

Two contrasting models have been proposed to account for the genesis of Las Cañadas caldera and the present caldera wall: (1) repeated sector collapse of the northwest flank of Las Cañadas volcano (Navarro & Coello, 1989; Ancochea *et al*. 1990, 1999); and (2) three major caldera collapse events, each occurring at the end of a 100–500 ka explosive phonolitic 'cycle'. The 'cycles' relate respectively to the Ucanca, Guajara and Diego Hernández formations in the caldera wall (Martí, Mitjavila & Araña, 1994; Martí *et al*. 1997; Martí & Gudmundsson, 2000). Martí, Mitjavila & Araña (1994) inferred a three-stage, northeasterly migration of the three successive caldera collapse locations, citing outcrop patterns in the caldera wall and an inferred tripartite structure of the caldera as evidence. Gravity and seismic studies have revealed the presence of low-density material to a depth of 2–3 km in the northern part of Las Cañadas caldera (Camacho, Vieira & De Toro, 1991; Watts *et al*. 1997; Ablay & Kearey, 2000), which is consistent with an origin by caldera collapse events and repeated caldera infill.

Ancochea *et al*. (1990; 1999) and Cantagrel *et al*. (1999) both dispute the genesis of Las Cañadas by caldera collapse, and instead propose that it formed during the repeated growth and destruction of several large shield volcanoes or stratocones (Cañadas Edifices I, II and III of Ancochea *et al*. 1999) by northwards-directed flank failures. However, whilst the Icod and Orotava collapse scars testify to the occurrence of large-scale flank failure on Tenerife (see Ablay & Hürlimann, 2000; Watts & Masson, 1995, 2001), the genesis of Las Cañadas caldera solely by lateral collapse is difficult to reconcile with the present morphology of the caldera wall, which has an eastward-facing inflection at its west side and a south-facing scarp at La Fortaleza on its north side. It resembles a breached ellipse rather than a typical sector-collapse horseshoe. Geological evidence (e.g. mantling relationships of welded rocks and dyke intrusion patterns) presented by Martí, Mitjavila & Araña (1994) is also indicative of true caldera collapse. Martí, Mitjavila & Araña (1994) estimated that individual phonolitic pyroclastic deposits in the Bandas del Sur Group had erupted volumes of 5–40 km^3, with a total erupted volume of > 130 km^3 (dense-rock equivalent), which was similar to their inferred volume of the three original calderas (that is, prior to infill by Teide-Pico Viejo lavas). However, with possible concealed intracaldera ignimbrites, large volumes of pyroclastic fallout into the Atlantic (Bryan, Martí & Cas, 1998), and the evidence in the Bandas del Sur that large pyroclastic density currents bypassed the flanks to deposit in the ocean with relatively little onshore deposition, the volume estimates for the Bandas del Sur Group must be regarded as extremely conservative. Similar magnitude eruptions at other volcanoes frequently result in caldera collapse (e.g. Smith, 1979; Scott *et al.* 1996) and it is doubtful that Las Cañadas could erupt > 130 km^3 of material explosively without experiencing caldera subsidence (Martí, Mitjavila & Araña, 1994).

A cyclic pattern has been proposed (Bryan, Martí & Cas, 1998), in which individual eruptions increased in size towards the top of each of three explosive 'cycles', each culminating in caldera collapse. However, our re-evaluation of the stratigraphy provides little positive

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support within the Bandas del Sur succession for the existence of these cycles. It is not yet possible to determine the relative sizes of the major eruptions, required to invoke an increase in eruptive volume during each cycle. The similar distributions of the formations do not support a northeasterly migration of successive pyroclastic units in the Bandas del Sur as reported by J. J. Alonso (unpub. Ph.D. thesis, Univ. La Laguna, 1989) that would correspond to the more obvious northeasterly migration of caldera wall deposits (Martí, Mitjavila & Araña, 1994). The eruption dates cluster in two groups, 160–280 ka and 600–670 ka, but more age data are required before the significance of such clustering becomes apparent. In addition to the two, as yet undated, Aldea Blanca Plinian events, significant explosive activity seems to have occurred during the repose periods separating the proposed explosive cycles of Martí, Mitjavila & Araña (1994). This is recorded offshore by biostratigraphic and $^{40}Ar/^{39}Ar$ dating of submarine tephra-fall layers and volcaniclastic layers in boreholes 80–150 km SW–ENE of Las Cañadas caldera (Rodehorst, Schmincke & Sumita, 1998; Bogaard, 1998; see Fig. 1). The apparent absence of equivalent pyroclastic deposits onshore may reflect incomplete subaerial preservation (Rodehorst, Schmincke & Sumita, 1998; see also Fretzdorff *et al*. 2001), concealment by younger units and/or as yet incomplete dating. For example, early sector collapse events at Icod might have funnelled pyroclastic density currents into the ocean to the north, leaving no visible record. Many of the major eruptions recorded by the extensive lithic breccia-bearing ignimbrite sheets may have involved caldera collapse. Whilst it is likely that the duration of repose periods between major eruptions varied, the present stratigraphic, chronological and volumetric resolution remains insufficient to substantiate any long-lived cyclicity (*c*. 100–500 ka) within Las Cañadas volcano. More dating and tighter stratigraphic controls on the pyroclastic succession from Las Cañadas caldera are needed to define the exact nature of any cyclicity. We agree with Martí, Mitjavila & Araña (1994) that the Cañadas caldera is nested, but we propose that instead of a three-fold caldera collapse, Las Cañadas caldera has undergone numerous caldera collapse events.

The sector collapse and caldera collapse models for the origin of Las Cañadas depression are not mutually exclusive, and it seems likely that successive edifice-building phases were interspersed with both caldera-collapse and sector-collapse events. However, the ages of the various sector-collapse events, which may themselves have multiple origins, are as yet insufficiently constrained to establish a temporal link with the caldera-collapse events, as recently proposed by Martí *et al.* (1997). The broad similarity of numerous pyroclastic units beneath the Arico Formation with those above, suggests that this style of eruption history extended back beyond 1 Ma. We propose that Las Cañadas caldera is a considerably more complex nested structure than has previously been appreciated, with a protracted history of subsidence and infill.

Future explosive eruptions at Las Cañadas caldera, of similar volumes to those represented in the Bandas del Sur Group, would devastate large parts of the island. Flank failure, for example, of the Teide-Pico Viejo stratocone or other steep slopes of the Las Cañadas edifice (e.g. on the south side around Fasnia, Fig. 1; and on the north, at La Fortaleza, Fig. 1), could also occur during such an eruption (see Hürlimann, Martí & Ledesma, 2000). Much more work is needed to establish a comprehensive pyroclastic stratigraphy on which to base future dating programmes and the subsequent unravelling of Las Cañadas' fascinating volcanic history.

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